DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/106

Lomonosov Ridge off Greenland 2009 (LOMROG II) – Cruise Report

Christian Marcussen and the LOMROG II Scientific Party

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

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List of Contents

Summary

The LOMROG II cruise in 2009 was organized as a joint Danish-Swedish-Canadian cruise. Furthermore a Russian hydrographer participated in the cruise. The primary objective of the Danish and the Canadian part of LOMROG II was to collect bathymetric, seismic and gravimetric data along the flanks of the Lomonosov Ridge and in the Amundsen Basin in order to acquire the necessary data to document an Extended Continental Shelf beyond 200 nautical miles according to Article 76 in UNCLOS. The Swedish part of the cruise, consisting of two science projects, was organized by the Swedish Polar Research Secretariat.

Bathymetric data were acquired using the "pirouette method" developed during LOMROG I in 2007. Further bathymetric data were collected using the ships helicopter along 11 profiles. Despite severe ice conditions, multibeam bathymetric data were collected along six crossings of the Lomonosov Ridge whereas gravity data were acquired along the ships track using the gravimeter on board *Oden* and from the ice using a portable gravimeter as spot measurements. During the cruise a total of 380 km reflection seismic data were collected and 38 sonobuoys were deployed, hereof 30 successful deployments. Seismic data could only be acquired because the ice was not under compression and by breaking a lead twice before seismic data acquisition could commence.

With the main emphasis on collection of bathymetric data, the LOMROG II cruise was very successful in achieving its goals as planned; however more data could have been acquired if a lead icebreaker had been available. The presence of a lead icebreaker could have reduced time needed for transit and icebreaking by up to two weeks, which could have been used to complete acquisition of bathymetric data along the Lomonosov Ridge.

Through the Swedish Polar Research Secretariat, two Swedish science projects (sediment coring and plankton ecology) were integrated in cruise. During LOMROG II, cooperation and synergy between these two projects and the Danish science projects on board *Oden* was developed. As examples, the Danish Oceanography project provided facilities (portable CTD) to take water samples and plankton samples on ice CTD stations and the coring project provided samples for the Bacteria project. Water from the CTD casts was also shared between various projects. The helicopter supported very efficiently all these activities.

To better understand how the Arctic has responded to past climatic changes, detailed records of environmental changes from different parts of the Arctic are needed. The sediment coring project acquired 8 piston cores and one gravity core resulting in a total sediment recovery of 47.62 m. Geographically three cores were taken on the crest of the Lomonosov Ridge, one in the Makarov Basin, three in the intra-basin, and two on the continental rise on the Amundsen Basin–side of the Lomonosov Ridge.

The oceanography project sampled a total 16 unique ship stations and 20 ice-borne stations. Where time permitted, ship stations include both a deep cast and a shallow cast for additional collection of water samples. Water was also collected at the ice-borne stations.

The plankton ecology project investigated the vertical distribution of meso-zooplankton by multiple opening-closing net hauls from *Oden* and ice borne stations reached by helicopter. In total 29 stations along the cruise track were sampled in the Nansen, Amundsen and the Makarov basins and across the Gakkel and Lomonosov Ridges.

The microbial respiration project tried to establish how large a role microbial respiration plays in determining the concentration of CO_2 within both first-year and multi-year sea ice, and thus influencing the exchange of CO_2 between sea ice and the atmosphere. Ice cores were retrieved from both first year and multiyear ice floes at a total of 14 ice stations.

Environmental samples including water, zooplankton, sediment, and sea ice were collected and shared with the project for bacteria isolation and community studies. Water samples were taken from various depths using a CTD rosette equipped with 7 l sampling bottles. Live zooplankton was collected from the water using plankton nets. Sediment samples were obtained using a piston sediment corer. Sea ice cores from pack ice were obtained with an ice core driller. A total of 31 samples were collected.

For the project "DNA of the Polar Seas" the objective to get a minimum of four deep sea water samples from the Arctic Ocean was met. A total of 18 stations were sampled: 13 from the ship, 5 on the ice including various depths at the same station. A total of 25 samples were obtained, including 3 snow and 2 ice core samples. The deepest samples were taken at 4300 meters.

A Swedish poet, a Swedish teacher and a media team from Denmark also participated in the cruise.

On August 22, 2009 at 21:04 (UTC) Oden reached the North Pole - the 6th time Oden reached the North Pole and the third time on its own. Photo: Adam Jeppesen.

1. Introduction

By Christian Marcussen, Geological Survey of Denmark and Greenland

The area north of Greenland is one of three potential areas off Greenland for extension of the continental shelf beyond 200 nautical miles according to the United Nations Convention on the Law of the Sea (UNCLOS), article 76 (Marcussen et al. 2004, Marcussen & Heinesen 2010). The technical data needed for a submission to the Commission on the Limits of the Continental Shelf (CLCS) include geodetic, bathymetric, geophysical and geological data. Acquisition of the necessary data poses substantial logistical problems due to the ice conditions in the area north of Greenland.

Data acquisition in the area north of Greenland started in 2006 with the Danish-Canadian LORITA expedition (Jackson & Dahl-Jensen 2010), during which refraction seismic data from the shelf area north of Greenland and Ellesmere Island to the Lomonosov Ridge were collected. The LOMROG I cruise with *Oden* and *50 let Pobedy* collected bathymetric and seismic data in 2007 (Jakobsson et al. 2008). In spring of 2009, bathymetric and gravimetric data were collected from the sea ice in cooperation with Canada, using helicopters in an area north of Greenland covering the southern part of the Lomonosov Ridge. Furthermore, aero-geophysical data were acquired on either side of the Lomonosov Ridge. More information on the Danish Continental Shelf Project is available on www.a76.dk.

The LOMROG II cruise was organized in cooperation with the Swedish Polar Research Secretariat and the Canadian Continental Shelf Project. The Canadian Project paid for five days of ship time, whereas the remaining costs were split between Denmark (80%) and Sweden (20%).

The main objectives of the LORMOG II cruise were

UNCLOS related:

1. Acquisition of bathymetric data on both flanks of the Lomonosov Ridge supported by CTD casts from both *Oden* and the sea ice
2. Acquisition of seismic data in the Amundsen and Makarov basins
3. Acquisition of gravity data along *Oden*'s track

Add-on science:

4. Swedish research projects:
    - Sediment Coring
    - Plankton Ecology
5. Research projects from Denmark, Greenland and the USA:
    - Oceanography
    - Microbial Respiration in Arctic Sea Ice DNA
    - Bacterial Communities and Bioactive Bacteria in Arctic Marine Environments
    - DNA of the Polar Seas

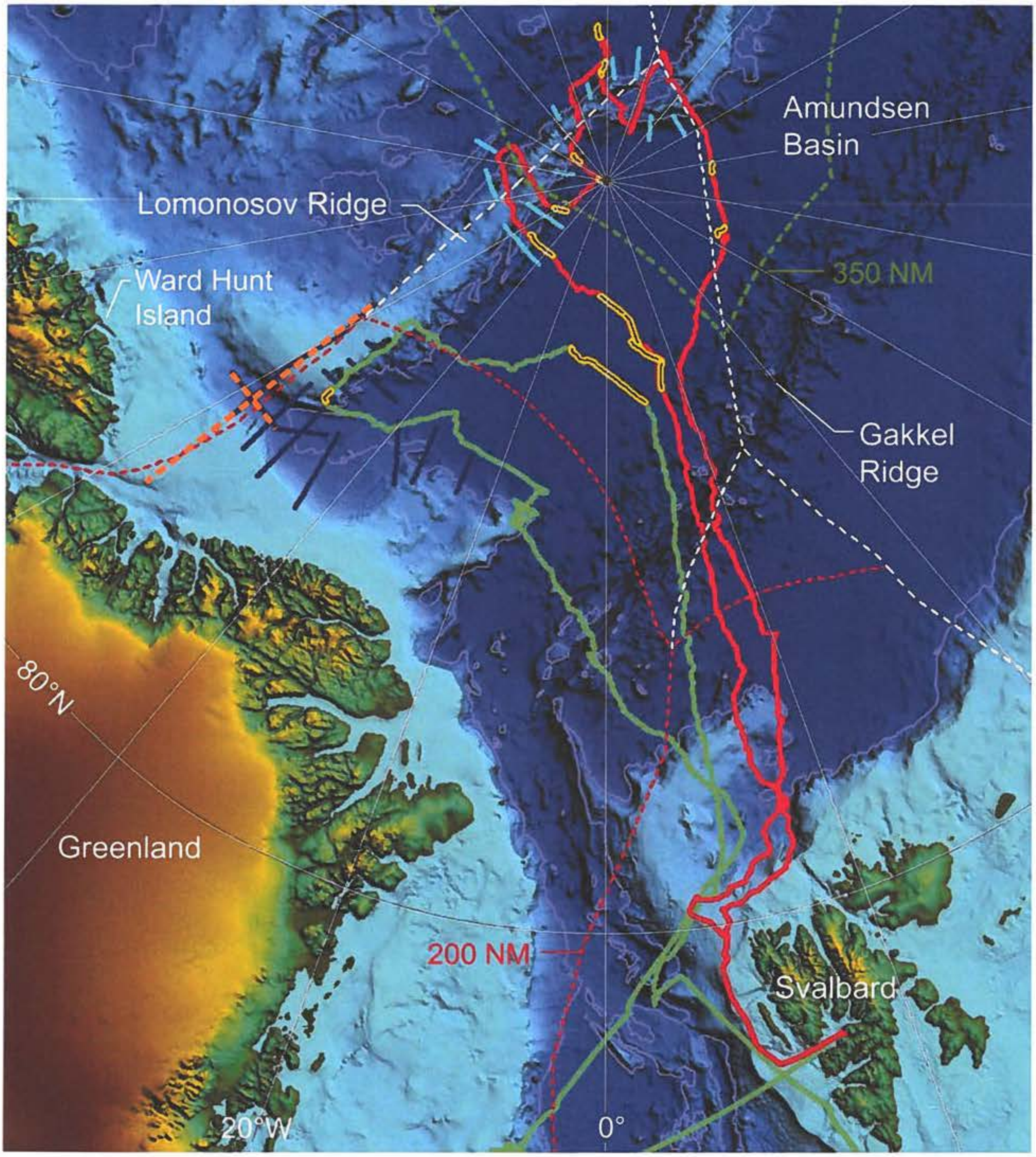

Figure 1. *LOMROG II ship track and Denmark's Article 76 field work north of Greenland from 2006 to 2009. Orange stippled line: LORITA refraction seismic lines (2006); green line – LOMROG I ship track (2007); red line – LOMROG II ship track (2009), dark blue lines – bathymetric profiles acquired by helicopter during spring of 2009; light blue lines – bathymetric profiles acquired by helicopter from Oden during LOMROG II in 2009; yellow lines – seismic lines acquired during LOMROG I and II (2007 and 2009); white stippled lines – unofficial median lines.*

In 2009 *Oden* operated without a lead icebreaker in the Arctic Ocean. For this reason, areas with extreme ice conditions close to Greenland were avoided. The LOMROG II cruise started on July 31 in Longyearbyen, Svalbard, where it also ended on September 10.

References:

Jackson, H.R., Dahl-Jensen, T. & the LORITA working group 2010: Sedimentary and crustal structure from the Ellesmere Island and Greenland continental shelves onto the Lomonosov Ridge, Arctic Ocean. Geophysical Journal International **182**, 11-35.

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2. Weather and Ice Conditions during LOMROG II

By Peter Löfwenberg & Margareta Osin-Pärnebjörk - Sweden; Leif Toudal Pedersen & Steffen M. Olsen - Danish Meteorological Institute

2.1 Weather

During the expedition, weather observations were made manually every six hours. These were sent to the global weather community via email. Weather data (temperature, relative humidity, air pressure, sea surface temperature, wind - relative to the ship and true wind -, surface analysis of wind and pressure, satellite images) were available on *Oden*'s internal network until the ship arrived in Longyearbyen. After the expedition weather data can be retrieved via Swedish Polar Research Secretariat.

The expedition started from Longyearbyen in fair weather but the fog appeared as expected during the first night. Fog or stratus clouds then dominated until the beginning of the science measurements on August 4, when there were two days with a lot of sun shine. After that, fog and low stratus again dominated. The temperature dropped from +7°C in Longyearbyen to around ±0°C at the ice edge. Further north the temperature remained almost constant close to 0°C for two thirds of the expedition. From the 19^{th} of August the temperature was mainly between 0 and -5°C. From the last of August, even lower temperatures were observed (down to -8°C). Fog occurred approximately in every third observation, low stratus clouds every second observation. Precipitation was not measured but a total of approximately 5 mm fell during the expedition, most of the time as drizzle or very light snow fall. The largest amount came in a few hours of rain.

The weather did not stop any science measurements but delayed helicopter operations on a few occasions.

2.2 Ice Conditions

The Arctic sea ice conditions during the summer of 2009 have been in general light. At the summer minimum in mid-September, the total ice extent was among the three lowest on record (with 2007 and 2008 being the other two). However, most of the reduction in the ice area took place in the part of the Arctic Ocean facing Russia and Alaska (Figure 2). In the part of the Arctic Ocean where the LOMROG II cruise was conducted, the ice situation was not particularly easy.

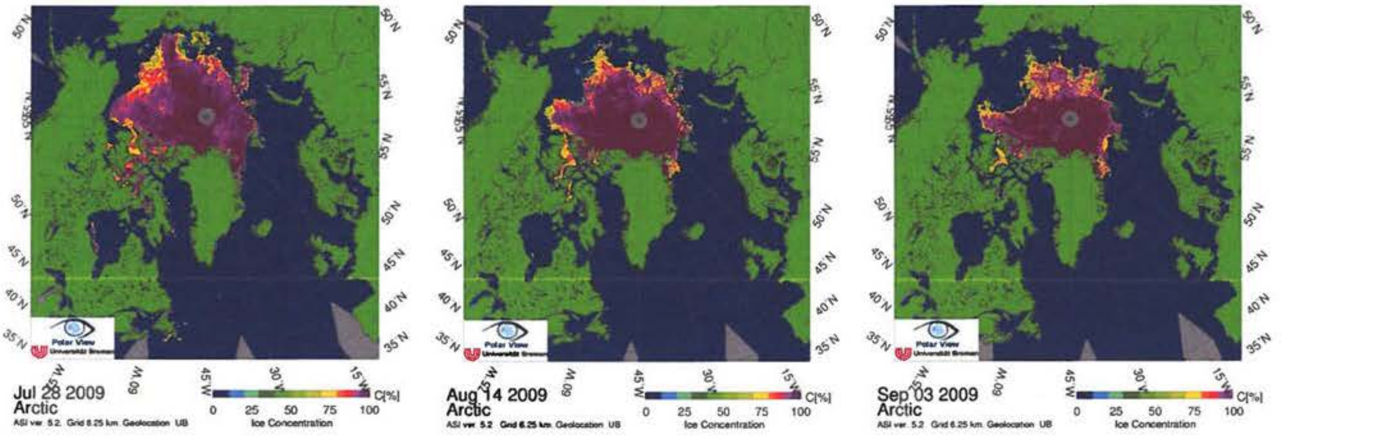

Figure 2. *Polar View ice concentration overviews on July 28, August 14 and September 3, 2009. Ice conditions in the area north of Greenland/Svalbard is not reduced substantially, but rather stable during this period.*

Ice information during the cruise was obtained from the Danish Meteorological Institute, the Norwegian Meteorological Institute, the Danish Technical University and University of Bremen.

Dedicated RADARSAT images were received during the transit voyages between Svalbard and the area of investigation. As an example, a RADARSAT image from July 30 (Fig. 3) showed a heavily ridged area around 82°30'N 10°E which was avoided by planning the cruise track to the east of it.

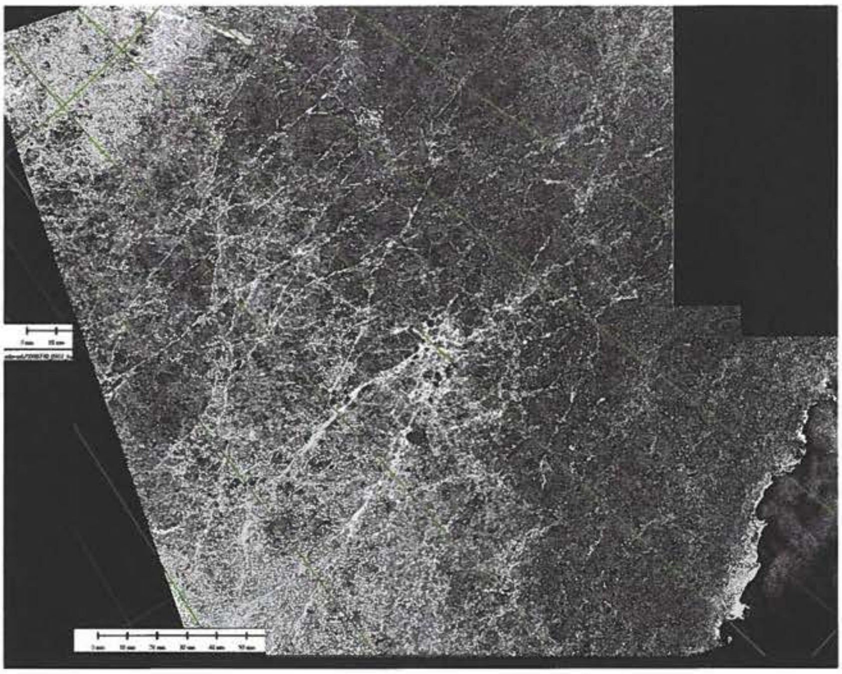

Figure 3. *RADARSAT image 20090730 07:00 UTC. Near the center of the image the heavily ridged area is seen. The out-bound cruise track was put to the east of this area.*

The transit between the ice edge at 80°45'N 15°E and the operation area was characterized by a substantial amount of multi-year (MY) ice mixed with varying concentrations of first-year (FY) ice. Many floes encountered carried substantial amounts of sediments and a large fraction of the ice surface was covered by melt-ponds (Figure 4). Air temperatures were generally just around the freezing point and leads and small areas of open water could be identified by helicopter ice reconnaissance flights.

The sediment loaded ice is likely to originate from the Siberian shelf areas where sediments suspended in rivers are frozen into the ice. This also confirms the general ice drift pattern where ice in this area often originates from the Laptev Sea.

Figure 4. *Dirty ice (left) and substantial melt-ponding (right) were characteristic features of the ice encountered on the outbound journey.*

Subsequent RADARSAT and ENVISAT SAR images showed very little detail due to melt ponds nearly completely covering the sea ice and were therefore discarded as a substantial help for navigation. Only a limited number of SAR scenes were received during the operations in the Central Arctic Ocean for this reason.

In the central Arctic the ice generally consisted of a mixture of 1-2 m thick first-year and 3 m thick multi-year ice floes and our first crossing of the Amundsen Basin as well as most of the operations over the Lomonosov Ridge were in quite difficult ice conditions with a substantial fraction of multi-year ice and pressure ridges. During the final passage through the Amundsen Basin however, ice conditions were substantially lighter. This might be associated with the area of FY-ice that was transported across the North Pole area during February to May (see figure 5). The spring transport is likely to have continued during summer but as the ice gets closer to Greenland, compression is also likely to occur.

For the home-bound journey we again received RADARSAT and ENVISAT images from DMI, and these images helped identify areas of easier ice for navigation (Figure 6). However, during the last 3 days through the ice, easterly winds compacted the ice substantially (Figure 7) and made advancement very difficult since very few openings were encountered. Air temperatures below -5°C meant that the openings encountered were already refrozen and therefore much harder to press into during icebreaking. The many melt ponds encountered on the outward journey were also refrozen at this stage.

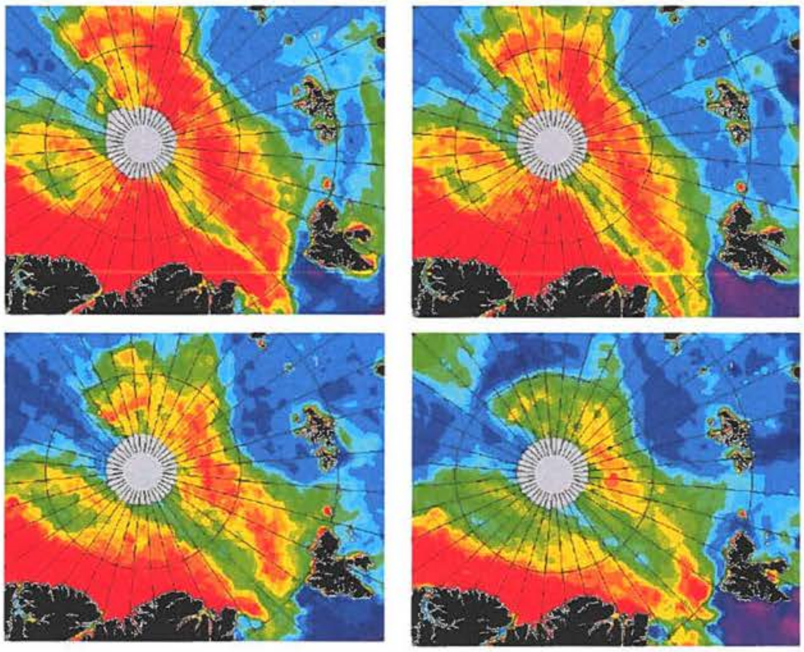

Figure 5. *Distribution of MY-ice (red) and FY-ice (blue) and mixtures (green-yellow) The 4 images above show conditions on March 1, April 1, May 1 and June 1. The June image is less useful since the MY/FY ice distinction is blurred by melting snow. In particular the red patch NW of Svalbard is a snow signature and not MY-ice.*

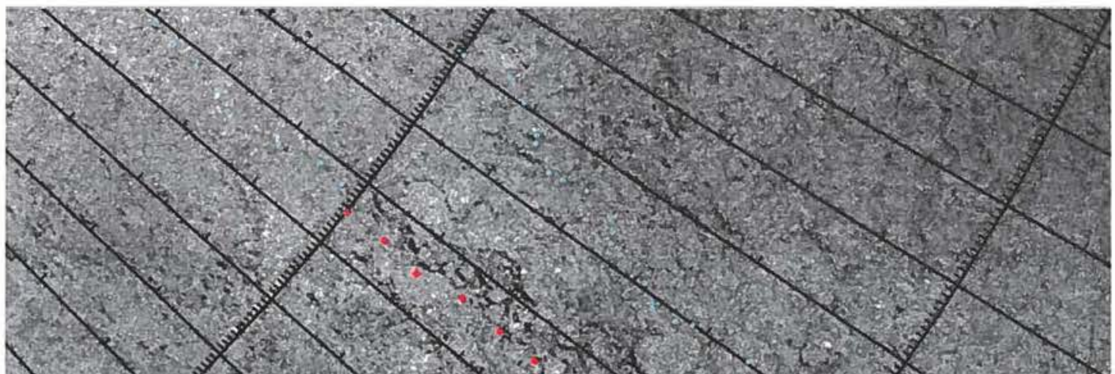

Figure 6. *Subsection of RADARSAT image from August 30 with hourly Oden positions overlain. The red dots show the homebound journey and the very rapid progress through the area with many open leads. In less than 13 hours we covered 1 degree of latitude (86 to 85N) during this period. Note that the red dots are more and more displaced to the west of the open water area in the radar image. This is due to the fact that the ice drifts towards the west between the radar image acquisition and the Oden passage. Helicopter reconnaissance is again very important for accurate guidance of the ship in the ice.*

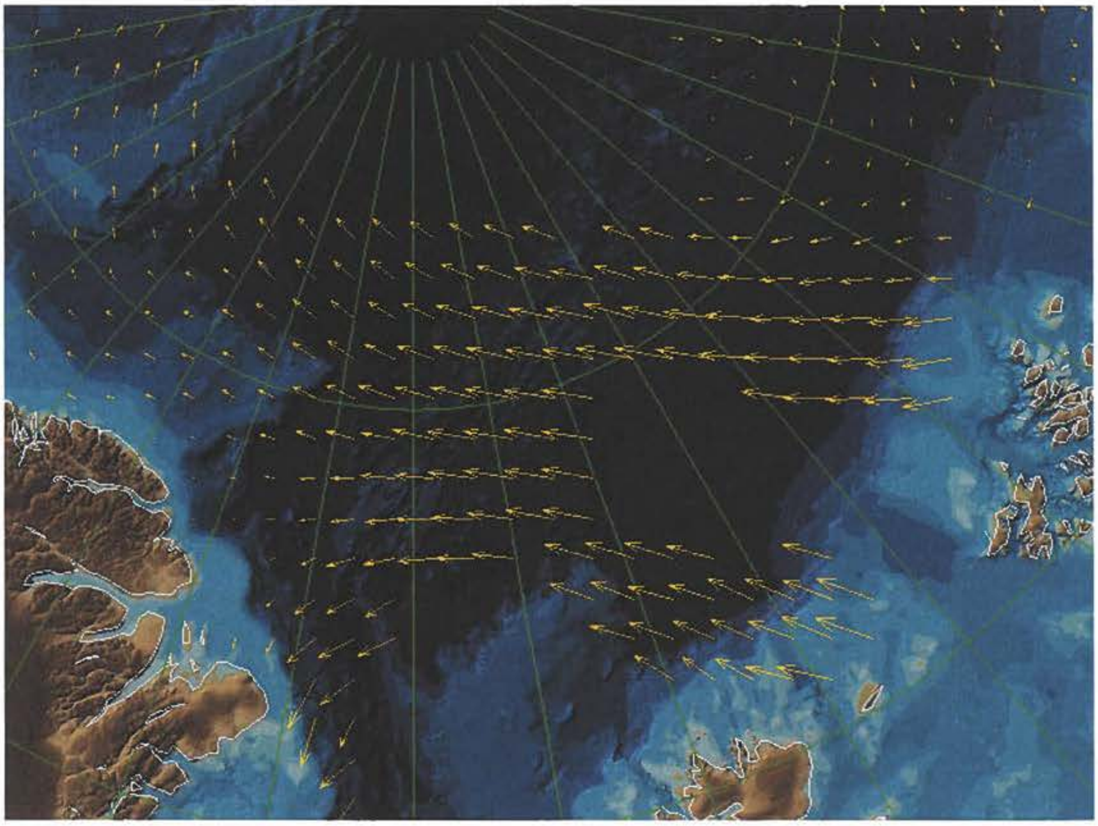

Figure 7. *Ice drift pattern between September 2 and September 3, 2009 showing the effect of the easterly winds that compacted the ice substantially in the area between 85N and Svalbard.*

3. Multibeam Bathymetry Echo Sounding

By Benjamin Hell - Stockholm University, Uni Bull - Danish Maritime Safety Administration, Michael Lamplugh - Canadian Hydrographic Survey and Yra Firsov - VNIIOkeangeologia, St. Petersburg, Russia

3.1 Equipment

3.1.1 Hardware - Kongsberg EM122 Multibeam Echo Sounder

The Swedish Icebreaker *Oden* is equipped with a permanently mounted Kongsberg EM122 1°x1° 12 kHz multibeam echo sounder (MBES) as well as a Kongsberg SBP120 chirp sonar (sub bottom profiler, SBP). The initial installation was carried out in spring 2007, when a Kongsberg EM120 MBES (serial number 205) was installed. This unit was the predecessor of the next generation EM122; with both models utilizing the same transducers. In the spring of 2008, the MBES was upgraded to the current EM122 model (serial number 110) by exchanging the transceiver electronics. It should also be noted that the original ice protection of the hull-mounted transducers has been upgraded twice. The first time was in the spring of 2008 and most recently in the spring of 2009.

The Kongsberg EM122 is a MBES system featuring a nominal frequency around 12 kHz, which is capable of sounding measurements at the full ocean depth of up to 12 km. In the 1°x1° configuration installed on *Oden* both the transmit (Tx) and receive (Rx) transducers dimensions are about. 8 m by 1 m. They are separate linear transducers installed in a Mill's cross configuration (Tx in alongship direction) in the ship's hull underneath the ice knife, about 8.1m below the water line and 15cm inside the hull surface. For ice protection, 12cm thick polyurethane elements reinforced with titanium rods are mounted flush in the hull, leaving a few centimetres (water filled) space between their inside and the transducer elements. The Rx transducer (with ice protection) is further covered with an additional titanium plate (see Figure 8 and 9).

Figure 8. *EM122 Rx transducer during with titanium plate covering ice protection elements*

Figure 9. *EM122 Tx transducer during installation, with some of the ice protection elements fitted.*

The EM122 MBES provides for a lateral coverage of up to 2x75° under optimal circumstances for installation on regular survey vessels. Initially, it was anticipated that the ice protection would limit the lateral coverage to 2x65° however; the observations made during this expedition suggest that this performance is not to be expected. The current configuration (with existing ice protection) limits the effective coverage to (at best) 2x55° (corresponding to ca. 2.9 times the water depth). However, this performance is only achievable under very favourable conditions such as when drifting with the ice. Furthermore, the generally high background noise level of the ship and the effects of ice and air bubbles underneath the ship's hull limit the lateral coverage even more during "high noise" operations such as heavy ice breaking or fast open water transits.

The EM122 configuration on the *Oden* has a minimum beam width of 1° in both alongship and athwarthship directions. The beams are transmitted in 3-9 distinct sectors (depending on the water depth), which are distinguished by frequency (11.5 kHz-13 kHz). Each sector is individually compensated for vessel roll, and can be compensated for yaw and pitch (these last two options however, were not used during this expedition). The system also has a number of different sounding modes. With the "Equiangle" and "In-Between" modes there is a maximum of 288 bottom detections per swath, however there is a higher density mode (HD-Equidistant) that is capable of increasing the sounding sampling per beam, which makes up to 432 bottom detections possible per swath (this last mode was used for all of the science program work). On the transit back to Longyearbyen the in-between mode was selected to investigate whether that mode might yield better results while in transit through ice. The EM122 also allows for a frequency modulated (FM) chirp-like signal to be used in the deeper sounding modes (enabled for this expedition) and provides the ability to collect the water column information for all beams. The separate water column files (*.wcd) were logged at all times during LOMROG II. These files have the same naming convention as the sounding files (*.all) but with a different extension, as noted above.

All of the raw files were organized by UTC day. UTC time was used for all sounding data collection. If a logged line starts before midnight but ends after the start of the next day it is stored in the day the line started. The convention used to number the lines was as follows:

LineNumber_yyyymmdd_hhmmss_Oden.all (and .wcd)

Where:

LineNumber – the number of the line. The system was set to increment the line each hour, but it was often earlier due to survey requirements.

Yyyymmdd – yyyy is four digit year; mm is two digit month and dd is two digit date

hhmmss – the time using 24 hour clock (UTC)

e.g. 2025_20090830_195325_Oden.all and 2025_20090830_195325_Oden.wcd

In order to make the tracking and backing-up of data as easy as possible we adopted the following convention in assigning line numbers: Starting with line number 0001 we logged data from Longyearbyen to the work area. Once we were on-site we start to number the lines according to the "leg" we were doing over the Lomonosov Ridge (LR). So the first leg was comprised of the "1000" series of numbers. At this time we also started keeping hand-written log sheets.

The second leg over the LR was the 2000 series etc. In all, there were six distinct crossing of the LR. Once we had completed the last of the seismic lines at waypoint #21 we started the 7000 line series; which is the transit back to Longyearbyen.

3.1.2 Calibration

The MBES transducer offsets were last calibrated in a patch test between 19 May 2007 and 24 May 2007 by Christian Smith (Kongsberg Maritime). Calibrations of the transmitted energy of the different swath sectors in order to achieve an even distribution of backscatter energy over the entire swath (so-called backscatter calibration) was done by Christian Smith (echo sounder mode "**Deep**" and "**Shallow single swath**", 04 June 2009) and Benjamin Hell (echo sounder modes "**Deep single swath**", "**Deep dual swath 2**" and "**Very Deep single swath**", 09 August 2009).

3.1.2.1 Kongsberg Seapath 200 Motion Sensor

The Seapath 200 provides a real-time heading, attitude, position and velocity solution by integrating the best signal characteristics of two technologies, Inertial Measurement Units (IMUs) and the Global Positioning System (GPS). The Seapath utilizes the SeaTex MRU5 inertial sensor and two GPS carrier phase receivers as raw data providers. It is critical to have good motion sensor, gyro and GPS data in order to achieve optimal surveying capability. The Seapath replaces three sensors; gyro compass heading reference, the motion sensor for roll, pitch and heave and GPS for positioning and velocity determination. By using one instrument to provide this critical data, potential timing and synchronization problems are virtually eliminated.

There were very few issues with this system's performance. Very occasionally a "red" error message appeared on the SIS display, indicating a missed data package but that immediately cleared after acknowledging the message. When the North Pole was within a few hundred meters of our position the Seapath displayed "Invalid" for quality of **Heading** and "Reduced quality" for **Pos/Vel**, **Heave**, and **Roll/Pitch**.

3.1.3 Acquisition Software

The Seafloor Information System (SIS) is the software that controls the multibeam system and logs the data. Version 3.6.2 was installed in June 2009 before the SAT (Sea Acceptance Tests) was conducted 13-17 July 2009.

This latest version of the software is much more stable than what was available in 2008. In fact most of the LOMROG II survey was stored and displayed in the same project (previously this would have been impossible). The real-time gridding of the seafloor imagery was also very stable and worked flawlessly. There does however seem to be an issue with the display in the geographic window when sounding in the proximity of the North Pole (see Figure 10)

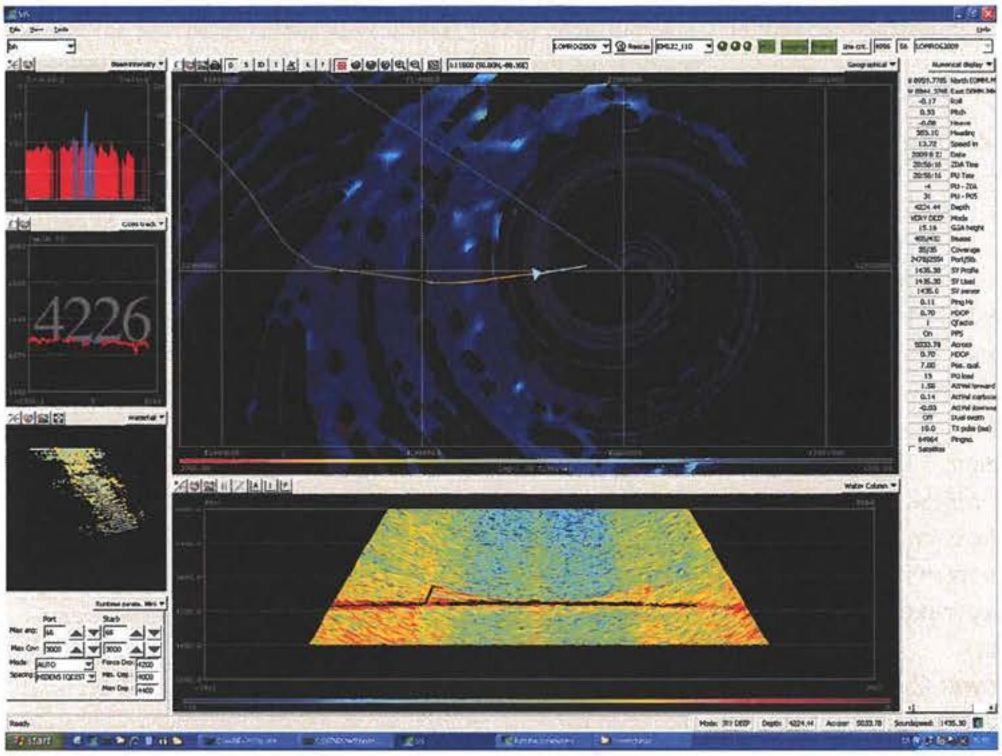

Figure 10. *SIS screen grab when ODEN is within 50meters of North Pole. Note: Swaths are not 90 degrees to ships head but are displayed as converging on the pole.*

3.2 System Settings: Working Set of Parameters for SIS

3.2.1 Runtime Parameters

3.2.1.1 Sounder Main

Angular coverage mode:	Auto (and adjust Min/Max coverage)
Max/Min angle:	65°
Beam spacing:	HIDENS EQUDIST
Min/Max depth:	As close around the seafloor as necessary and possible
Dual Swath mode:	Dynamic (only effective in Very Shallow to Deep modes)
Ping Mode:	Auto, (If Manual used then very large swath width (meters) & beam angles specified)
FM enable:	on
Pitch stabilization:	off
Yaw Stabilization:	off
Heading Filter:	Medium

3.2.1.2 Sound Speed

Sound speed at transducer:	The surface sound speed was taken from the profile for the majority of the survey operations. However if the sensor was used, the following settings were used
Sensor Offset:	-0.1
Filter:	60

3.2.1.3 Filters and Gains

Spike filter strength:	Strong (has positive impact on swath width!)
Range gate:	Normal (and Small on the Abyssal Plain)
Penetration filter strength:	Strong
Slope:	On
Aeration:	On
Sector tracking:	On
Interference:	Off
Angle from nadir:	6°
Absorption coeff. source:	Profile
Salinity:	35
Tx power level:	Max
Startup ramp:	0

3.2.1.4 Data Cleaning

None

3.2.2 Externally Set Parameters

3.2.2.1 Logging

Enable EA logging:	1 *(this could probably be changed to 0)*
Log error estimate:	0 *(would this be interesting to log?)*
SVP change makes new line:	0 *(this should probably be changed to 1)*
Water column disk *(allows this data to be logged in a separate directory)*:	leave empty (same as .all)
Eiva compatible datagram:	0
Enable raw data logger:	0
Pinging hotkey:	F10
New line hotkey:	F5
Logging hotkey:	F2
Save all depths in grid:	0
Indicate SeaBec use:	0
Data cleaning method:	1 (Grid Engine)
Line counter interval:	3600 (one new line every hour)

3.3 Sound Speed Control

A copy of each CTD cast made was obtained every time a new cast was collected from the ship (and where applicable, from the helicopter). The data was copied to a common directory on the ship's RAID set. It was then accessed by the multibeam team and converted to depth and sound velocity pairs (max 1000 lines). The SIS software requires the profile to be extended to 12 km so that was done at the same time.

It should be noted that overall, the profiles were very stable and changed little over the duration of the survey. There were, however, some differences between the Amundsen and Makarov Basins: The closest in location on that side of the ridge was used if a new profile was not available after crossing over the Lomonosov Ridge. For the most part, the sound speed from the profile was used for sound speed at the transducer rather than the output from the Td sensor. This was due to some instability in these readings, likely due to working in heavy ice conditions.

3.4 Depth Modes Used

Below is a list of modes and the suggested depth range that they are designed to support. It should be noted that the Ping mode used can be forced, which was done.

- Very shallow: 10-100 m
- Shallow: 50-600 m
- Medium: 300-1400 m
- Deep: 800-9000 m
- Very deep: 6000-12000 m

It should be noted that all of the data collection on this expedition was made in the **Very Deep** mode with some short periods of collection in the **Deep** mode when we came up on a Ridge (under 2000 m). It was only when the Deep mode was selected that the Dynamic swath capability would become effective and the system would attempt to send and receive two swaths with each ping. This mode was not used very often. It appears that with this installation and the ice protection currently in place, there needs to be a significant pulse transmitted in order to get a usable return. Since the deepest water encountered was less than 4500m we should have only been using Deep Mode, but that was not possible.

3.5 Known Problems with the MBES System

3.5.1 Echo Sounder Limitations

- Prone to Erik's horns
- Limited lateral coverage (specifically in this installation with the ice shields)
- Some outer beam wiggling remaining
- In dual swath mode (at least in the deep mode) the backscatter data shows strange stripes in sectors 2, 3, 7 and 8 (even when filtering away either of the swaths as described in the backscatter calibration documentation).
- The spike filtering setting has an impact on the achievable swath width (Fig. 11): Setting spike filtering to *strong* increases the swath width compared to lower spike filtering settings.

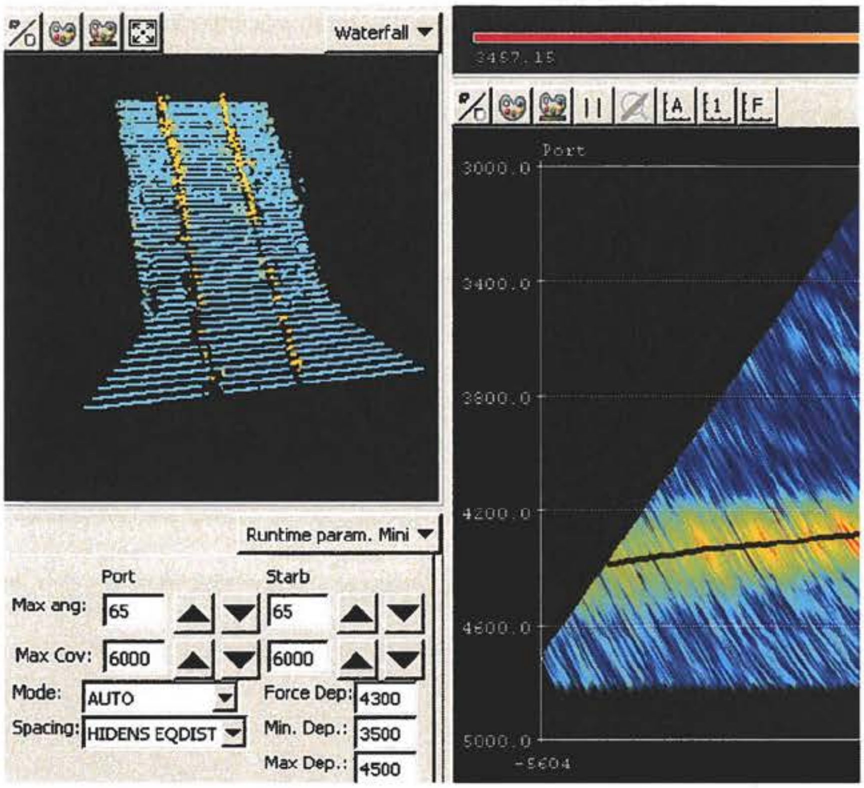

Figure 11. *Spike filtering settings have an influence on the swath width achieved. While drifting at low speed over a flat sea floor, setting the spike filtering to strong resulted in the swath width slowly being increased over the following pings.*

3.5.2 Software Bugs

- When working in projection mode, COG - LON = DTK (Desired Track) (western LON negative). This means that the DTK must be corrected for latitude in order to work with the auto pilot. This bug affects the Helmsman displays and the COG arrow in the geographical window. How to reproduce this bug: Set geographic window to projection. Plan line at some high longitude. The Helmsman DTK will then show the line course offset by the longitude.
- Probably related to the previous bug: The ship heading arrow points in the wrong direction when working in a projection with True North not equal Map North. In Polar Stereographic it is offset by the value of the present longitude. Switching the graticule to projection is a workaround, but then it is not possible to extract lat/long positions from the map using the measuring tool. Sometimes this workaround does not work.
- Depth scale of water column display does not match the depth scale in the cross track display. Is the water column data SVP (Sound Velocity Profile) corrected? It would be very useful to have a function for "locking" the digitizing of the sea floor

from within the water column display, as it is often possible to "see" the seafloor and it appears that no bottom detections are logged.

- SIS sometimes displays approximately twice (or something else entirely) the vessel's speed in the numerical display. Three thousand knots was in fact, observed while at the North Pole. It should be noted that the Seapath display for speed is quite stable. (see Figure 12; Screen capture)
- The display of detections in the *Cross track/Beam intensity*, *Water column* and *Geographical* windows is not always synchronized.
- Weird things happening to the SIS data gridding (and display) when getting closer than a couple of nautical miles to the pole. (see Figure 3: screen capture)

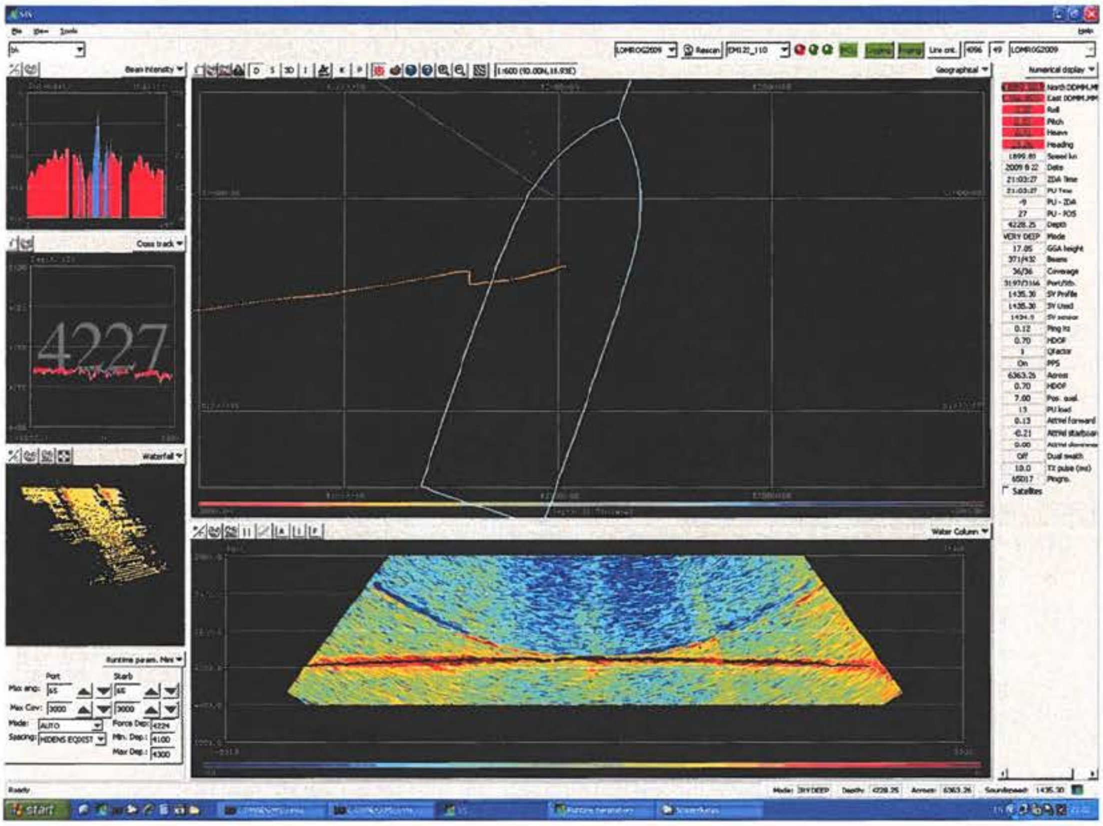

Figure 12. ***Oden at the North Pole. Note pole is now on the foredeck and the Numerical Display is giving an error warning. Also, the vessel speed is not 1899.83 knots.***

3.6 Personnel

MBES measurements were carried out continuously during the entire expedition, with a team of six working according to the following watch scheme:

Time	Name	Affiliation	Log sheet initials
0-4 and 12-16	Benjamin Hell	Stockholm University, Sweden	BH
	Yra Firsov	VNIIOkeangeologia, St. Petersburg, Russia	YF
4-8 and 16-20	Uni Bull	Danish Maritime Safety Administration	UB
	Rasmus Pedersen	GEUS, student from University of Copenhagen	RP
8-12 and 20-24	Michael Lamplugh	Canadian Hydrographic Service Bedford Institute of Oceanography, Halifax, Canada	ML
	Jonas Johansen	GEUS, student from University of Copenhagen	JJ

The watch times are ship time (Swedish) and two hours ahead of UTC, which was used as data time. For the transit back south to Longyearbyen after Sep 1, the watch scheme was changed to the following:

Time	Name	Affiliation	Log sheet initials
00:00-06:00	Yra Firsov	VNIIOkeangeologia, St. Petersburg, Russia	YF
6-8 & 14-16:30	Esben Villumsen	GEUS, student from University of Aarhus	EV
8-10 & 16:30-19	Rasmus Pedersen	GEUS, student from University of Copenhagen	RP
10-12 & 19-21:30	Anja Gunvald	GEUS, student from University of Aarhus	AG
12-14 & 21:30-24	Jonas Johansen	GEUS, student from University of Copenhagen	JJ

Figure 13. *MultiBeam Team at the North Pole. Kneeling: Rasmus Pedersen & Jonas Johansen Standing: left to right; Yra Firsov, Mike Lamplugh, Benjamin Hell and Uni Bull*

3.7 Ship Board Data Processing

All ship board processing of echo sounding data was carried out using Caris HIPS and SIPS (version 6.1, SP2). For additional visualization of bathymetry data gridded in Caris HIPS, IVS 3D Fledermaus (versions 6 and 7) was used. During the cruise an inventory of all collected data was built in an Intergraph GeoMedia Professional (version 6.1) geographical information system.

3.7.1 Caris HIPS and SIPS Data Processing

Data conversion: The echo sounder data in ALL format were converted into Caris HDCS data using the Caris HIPS and SIPS conversion wizard. Some data filtering was carried out by setting a depth gate during the conversion.

Apply tide: Zero tide was applied to all data.

Compute TPE: The total propagated error was computed. Both surface sound speed and sound speed profile were assumed to be within ±2 m/s, all other values set to zero (see below for VCF (CARIS's, Vessel Config File) settings).

Merge: The data were merged (this process assigns geographic positions to all soundings and reduces them for tide and any other specified corrections such as new sound velocity profile).

Create field sheet: Temporary field sheets for the survey areas were created in Universal Polar Stereographic projection (North). The spatial extent of the field sheets was typically a few days data collection and would be bounded within one field sheet.

Data cleaning and gridding: Manual data cleaning was performed. In case of some transit data, the swath editor and then the subset editor after data was merged were used. Temporary data grids were created using CUBE gridding. The grid resolution used was typically 100 m, but at shallow depths (< 1000 m) gridding was performed at 50m resolution. The data cleaning and gridding was often an iterative process since decisions about the quality of single soundings can be difficult given the overall poor data quality, especially during ice breaking.

Quality control, final field sheets and bathymetry grids: Towards the end of the cruise, the main target areas were split into a set of non-overlapping (abutting) field sheets for quality control and the production of final data grids.

North Pole: It would appear that CARIS HIPS has a problem displaying the swaths properly at the North Pole. At the time of writing, further investigation is required.

3.8 Summary

During LOMROG II 2009 IB *ODEN* travelled a total of 3402 nautical miles. Multibeam data was acquired during this entire journey.

Eight field sheets were created over the Lomonosov Ridge (Fig. 14) and nine field sheets were created for the transit to/from Longyearbyen (Fig. 15).

It should be noted that the bathymetric data acquired during the LOMROG II cruise will be incorporated in the IBCAO database.

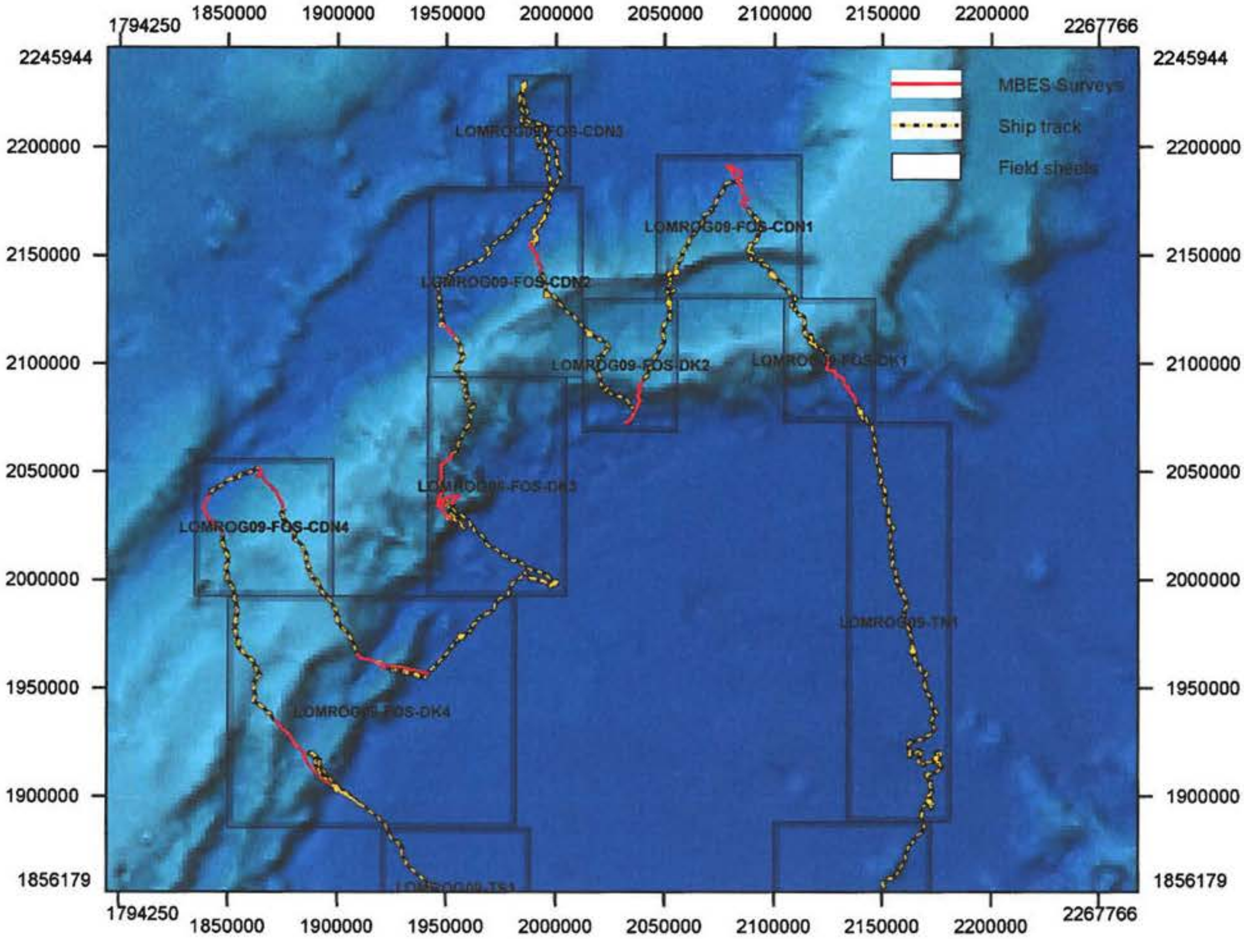

Figure 14. *Detailed map showing the eight field sheets created over the Lomonosov Ridge.*

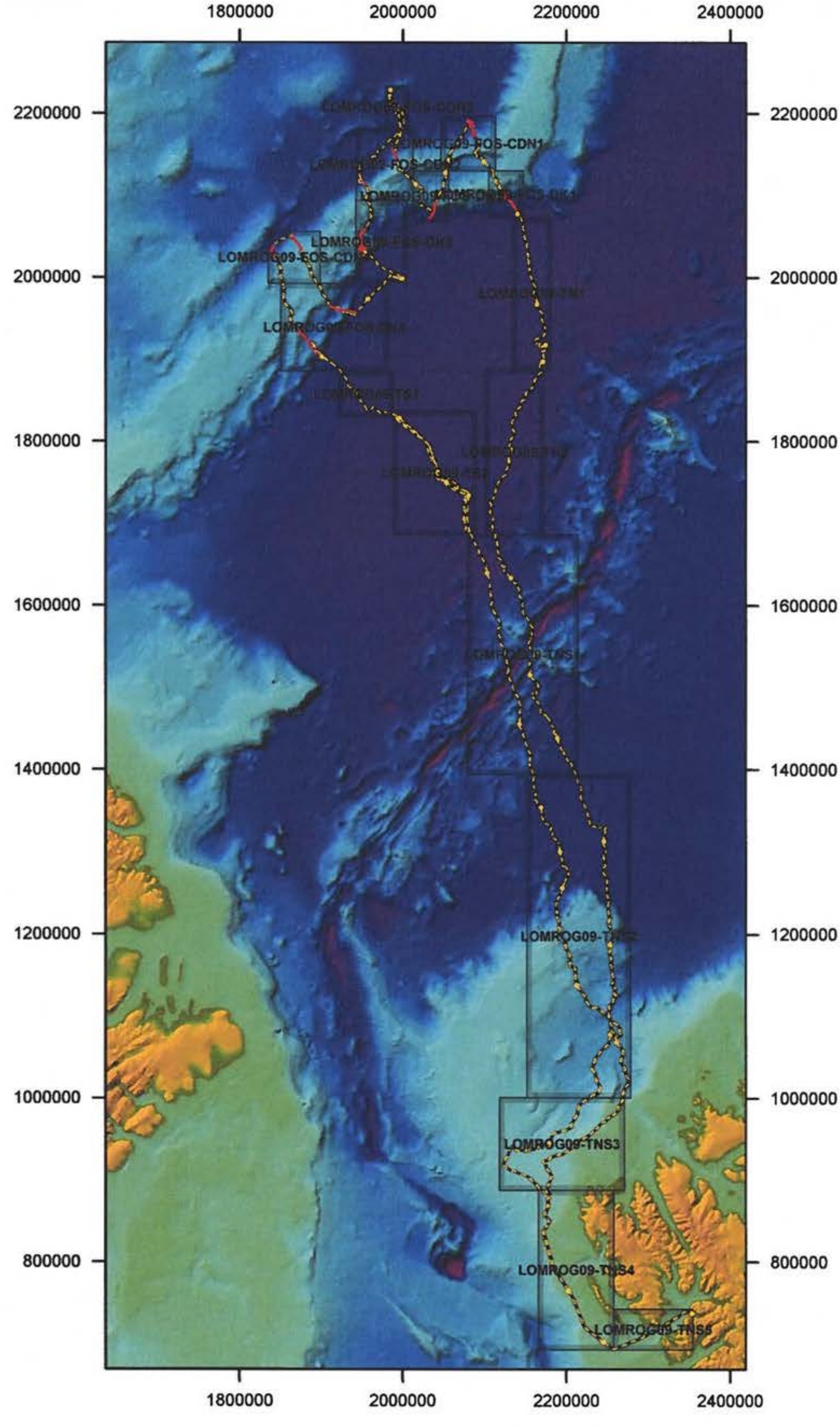

Figure 15. *Regional map showing all field sheets created during the LOMROG II cruise.*

4. Chirp sonar profiling

By Benjamin Hell - Stockholm University

4.1 Equipment

Icebreaker *Oden* is equipped with a Kongsberg SBP120 3°x3° subbottom profiler primarily used for the acoustic imaging of the topmost sediment layers underneath the sea floor with a frequency range of 2.5 kHz to 7 kHz. The SBP120 subbottom profiler is an add-on to the EM122 multibeam echo sounder installed. It uses an extra transmit transducer unit, whereas one single broadband receiver transducer is used for both the EM122 multibeam echo sounder and the SBP120 systems. A frequency splitter directly after the receiver staves, separates the ~12 kHz multibeam signal from the lower frequency (2.5...7 kHz) chirp sonar signal.

The normal transmit waveform is a chirp signal (which is an FM pulse where the frequency is swept linearly or hyperbolically). The outer limits for the start and stop frequencies of the chirp are 2.5 kHz and 7 kHz, providing a maximum vertical resolution of approximately 0.3 milliseconds. In addition to linear chirps, the system offers CW pulses, hyperbolic chirps and Ricker pulses. The system is capable of providing beam opening angles down to 3°, and up to 11 beams in a transect across the ship's keel direction with a spacing of usually 3°. The system is fully compensated for roll, pitch and heave movements of the ship by means of the Seatex Seapath 200 motion sensor used for the Multibeam echo sounder.

4.1.1 System settings

At most times the SBP120 chirp sonar was run with the following system settings:

Transmit mode:	Normal
Synchronization:	Fixed rate
Ping interval:	Usually 10 s. For station work when drifting with the ice in some cases the ping interval was increased to 60s.
Acquisition delay:	depending on water depth, seafloor reflection preferably in upper 100ms of collected data.
Acquisition window:	300 ms
Pulse form:	Hyperbolic chirp up (this pulse provides the best trade-off between energy/penetration and resolution).
Sweep frequencies:	2500...7000 Hz
Pulse shape:	5% tapering
Pulse length:	100 ms (this is a relatively long signal, which provides the energy needed to record more than noise in ice breaking situations).
Source power:	-1 dB (0 dB can harm the electronics)

Beam width Tx/Rx: 3° ("Normal")

Number of beams: Usually 5. When going along-slope the off-center beams often contain better information than the center beam.

Beam spacing: 3°

Calculate delay from depth: As this functionality is still not working properly in all but the very best echo sounding conditions, it should not be used.

Automatic slope correction: Off, heavily relies on very good Multibeam data, which never is the case in ice.

Slope along/across: Usually 0.0° but can be changed when going along/across steep slopes (> 3°) constantly.

Slope quality: Parameter read from Multibeam data stream, do not set or change.

4.2 Ship board processing

Ship board processing of the acquired SBP120 chirp sonar data was not routinely carried out during the LOMROG II 2009 cruise. However, selected lines were processed using the three software packages Sioseis (http://sioseis.ucsd.edu/), Seismic Unix (http://www.cwp.mines.edu/cwpcodes/) and ProMAX by Landmark. As no standard processing scheme was setup, the details of the signal processing are not reported here.

5. Reflection Seismic Survey

By Holger Lykke-Andersen & Per Trinhammer, Department of Earth Sciences, University of Aarhus and Thomas Funck, John Hopper & Christian Marcussen, Geological Survey of Denmark and Greenland

5.1 Introduction

Acquisition of seismic data in the Amundsen and Makarov basins on both sides of the Lomonosov Ridge was the second priority of the cruise (Figure 1). A comprehensive Seismic Acquisition Report has been prepared separately (Lykke-Andersen et al. 2011). Below a short account on some of the experiences gained during the LOMROG II cruise regarding acquisition of seismic data in ice filled waters is given.

5.2 Seismic Equipment

In order to work successfully in the harsh environmental conditions in the Arctic, the seismic equipment had to be modified considerably. These modifications were made in cooperation with the Department of Earth Sciences at the University of Aarhus, based on previous experience with data acquisition in ice-filled waters (Jakobsson et al., 2008, Marcussen et al. 2008):

- The streamer is considerably shorter than in open water. For the LOMROG II cruise, a 250-m-long streamer was used. There are many advantages to using a short streamer in the Arctic. Seismic streamers are designed to maintain a constant depth in the water only while the ship is in motion. If the ship's speed falls below 2 knots, the streamer will sink. Below 300m, the electronics in the streamer will be crushed by the water pressure. With a 250-m-long streamer, deployment and recovery of the streamer was possible while the ship was stopped, which significantly decreases the risk of damage.
- The seismic source is considerably smaller and therefore also more compact than for open water surveys. This simplifies deployment and recovery in the event that equipment has to be brought on board quickly, for example when the ship becomes stuck in ice and has to reverse to free itself.
- The streamer and guns are towed at a depth of approximately 20 m, which is more than twice as deep as in normal surveys. This is below the wash from the ship's propellers, which can be a source of considerable noise, especially when extra power is needed to break ice in order to keep the ship moving forward. At the same time, a towing depth of 20 m helps to prevent the equipment from coming in contact with ice, which can cause damage(e.g., the streamer can get pinched in the ice).

- The airguns and the streamer are connected with only one cable to the ship (the "umbilical"). This minimizes the risk of damage by ice and serves to simplify deployment and recovery of the gear so that it can be done quickly.
- The seismic signals are recorded as the time it takes for energy to return to the surface from a subsurface reflector. In order to apply the 1%- sediment-thickness formula (Gardiner line – United Nations Convention on the Law of the Sea, Article 76), it is necessary to convert the travel time to thickness. For this conversion it is necessary to know the seismic velocity within the sedimentary column. Therefore, sonobuoys were deployed along the seismic lines to record the seismic signals at larger offsets, from which velocities can be obtained. These can detect the seismic signals up to 25 km away from the ship. The buoys transmit the signals back to *Oden*, where the data are recorded. The only challenge is to deploy the buoys in the wake of *Oden* without having them destroyed by ice. To decrease the failure rate a new deployment technique was developed, where a 10-m-long rope was attached to the parachute of the buoy in order to prevent the buoy to surface beneath the ice. This technique increased the success rate of the sonobuoys considerably (to 100 %).

5.3 Operational Experience Gained During LOMROG II

Oden's normal mode of operation under heavy ice conditions is to break ice at as high a speed as possible. If the ship gets stuck in the ice, it would normally back and ram as many times as necessary to pass the obstacle. However, neither high speed nor backing and ramming are possible with seismic gear deployed behind the ship:

Figure 16. *Oden collecting seismic data along a prepared track.*

- High speed would create an unacceptable noise level behind the ship. In addition, the seismic gear is not designed to withstand a high speed.
- As the ship travels faster, the towed gear gets pulled toward the surface, risking damage by ice.
- *Oden* cannot back due to the risk of getting the seismic gear tangled in the propellers.

To meet the above limitations there are different options:

1. In easier ice conditions, where *Oden* can break ice continuously at 3 to 4knots, seismic data of reasonable data quality can be acquired. However, long continuous profiles are often not possible since ice conditions change rapidly and evaluation of ice conditions from the helicopter is not always easy or accurate. This is a particular challenge for this project since UNCLOS requires data to be collected at a certain density. The ice conditions often prevent *Oden* from being able to acquire data where needed.
2. A second option is to have *Oden* break a 25 nautical mile long lead or track along a pre-planned line, going back along the same lead to make it wider, and finally to acquire the seismic data while passing through the lead a third time (Figure 16). This option, which was suggested by the captain and the first mate of *Oden*, has some obvious advantages. Data can most likely be acquired along pre-planned lines since ice conditions can be evaluated during the first pass and changing ice conditions can be evaluated during the second pass. Data quality is better since *Oden* does not need full engine power on the third pass and can keep a more steady speed. In addition, the risk of losing or damaging the seismic gear is reduced considerably. However, data acquisition is more time consuming when employing this method.
3. A third option is to use two icebreakers. A lead icebreaker - as powerful as possible - breaks a lead along a pre-planned line, possibly several times in order to prepare as wide a lead as possible. *Oden* trails behind acquiring seismic data. Using two icebreakers will of course increase the cost for the operations considerably. However, this is partly balanced by a faster and better data acquisition as well as having the option to collect data along lines that are longer than 25 nautical miles. A Russian nuclear icebreaker - *50 let Pobedy* - was used for this purpose during the LOMROG I cruise in 2007. Under very severe ice conditions with sea ice under compression, this option also has limitations.

5.4 Acquisition and Processing Parameters

Source	1 Sercel G and 1 Sercel GI gun
Chamber volume	605 cu.inch (250 + 250 + 105)
Fire pressure	180 bar (2600 psi)
Mechanical delay	16 ms
Nominal tow depth	20 m
Streamer	Geometrics GeoEel
Length of tow cable	43 m
Length of vibration section	50 m
No. of active sections	4/5
Length of active sections	200 / 250 m
No. of groups in each section	8
Total no. of groups	32 / 40
Group interval	6.25 m
No. of hydrophones in each group	8
Depth sensor	In each section
Nominal tow depth	20 m
Acquisition system	Geometrics GeoEel controller
Sample rate	1 ms
Low-cut filter	Out
High-cut filter	Anti-alias (405 Hz)
Gain setting	0 dB
No. of recording channels	32/40
No. of auxiliary channels	4
Shot spacing	12 s
Record length	11 s

Table 1. *Summary of acquisition parameters*

A standard shipboard processing sequence was developed using the onboard ProMax software:

1. SEG-D read with trace dc bias removal
2. Bandpass filter
3. User defined spectral shaping filter
4. Spike and noise burst editing
5. Shot gather f-k filter and resample to 2ms
6. Geometry assignment, including gun and cable statics
7. Trace equalization
8. Trace mixing on shot gathers

9. Midpoint sort and stack
10. Final geometry and amplitude recovery
11. Post-stack constant velocity migrations
12. Seafloor mute
13. SEG-Y output
14. grd conversion and plot

The *User defined spectral shaping filter* proved to be very efficient in addressing some of the inherent noise problems of the seismic data recorded. Overall, the data quality is surprisingly good given the difficult acquisition environment. On all lines collected, the basement arrivals are clear. Although in some of the deeper basins with thicker sediments, signal penetration is clearly becoming an issue. In addition, within the Amundsen Basin, the uniformity of the reflectivity pattern in the sediments is obvious on all profiles. Thus, despite the lack of long profiles, establishing stratigraphic correlations in such a uniform depositional environment should not be a major issue (Fig. 17).

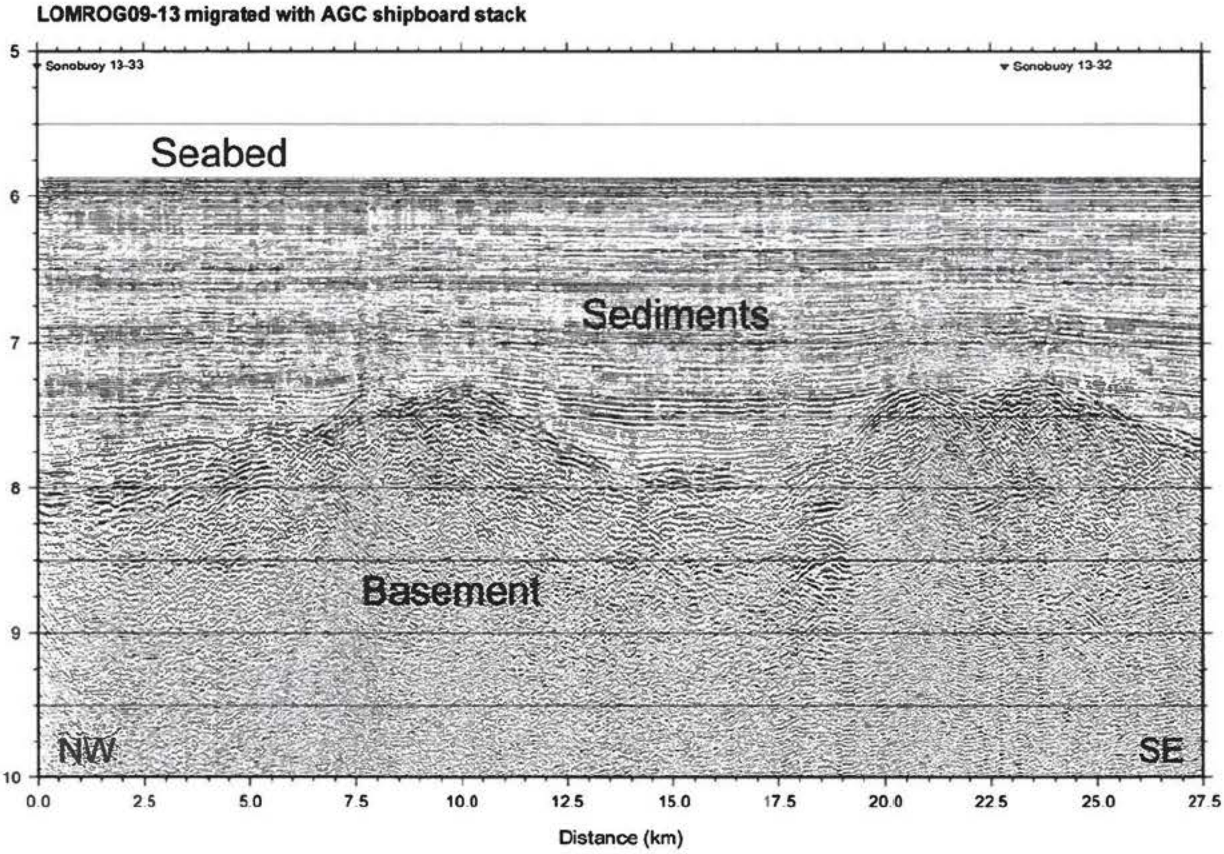

Figure 17. *Seismic line acquired in the Amundsen Basin showing the overall good data quality.*

5.5 Results

During the LOMROG II cruise a total of 380 km of seismic data were acquired, mostly by *Oden* preparing a track prior to acquisition (option 2 as described above). 38 sonobuoys were deployed, hereof 30 successful deployments.

This year, none of the seismic gear was lost in the ice as happened during the LOMROG I cruise and in many other Arctic seismic experiments. Only one section of the streamer was damaged by the ice. In general, the data quality is better than that obtained during LOMROG I in 2007.

5.6 References

Lykke-Andersen, H., Funck, T., Hopper, J.R., Trinhammer, P., Marcussen, C., Gunvald, A.K. & Jørgensen, E.V. 2010: Seismic Acquisition Report – LOMROG II in 2009, Danmarks og Grønlands Geologiske Undersøgelse Rapport 2010/53, 73 pp + 5 appendices.

6. Single Beam Bathymetry from Sea Ice

By Uni Bull - Danish Maritime Safety Administration & Henriette Skourup - National Space Institute

Spot sounding of bathymetric information has been collected to supplement the multibeam data acquisition. The approach taken was to combine the bathymetric data acquisition along with the gravity programme.

6.1 Field Procedure

The acquisition team was deployed by the ship's helicopter to pre-planned positions well outside of *Oden*'s multibeam coverage. The lines were typically planned to be approximately 15 nautical miles distance from the ship's track. With a 5 km interval between soundings, a number of profiles on both flanks of the Lomonosov Ridge were made. These profiles were made parallel to the ship's track and/or perpendicular to the expected depth contour. The positions were chosen such that the depths acquired would include both the 2500m contour and the FOS (Foot of Slope) contour. At all sounding positions gravity measurements were also acquired.

Figure 18. *Helicopter setup with Navisound 420-DS and GETAC ruggedized notebook.*

The equipment used was the same as used (with good results) by this team during the LOMBAG-expedition out of Ward Hunt Ice Camp in April 2009. A modified Reson Navi-Sound 420-DS echo sounder (serial no. 97037) was mounted in a flight case and put in the helicopter (Figure 18). The echo sounder was controlled by a GETAC M220-5C21 ruggedized notebook using the Reson NaviSound Control Center software (which also logged the digital data). The echo sounder's paper trace was enabled and annotated as a back-up/supplement to the digital data. The echo sounder used an Airmar M175 (12 kHz-C) transducer that had been fitted with handles. Positioning was done by connecting a battery powered handheld Thales Mobile Mapper stand-alone GPS-receiver to the echo sounder. The helicopter provided 28 V DC to the echo sounder. The GETAC-notebook was running on batteries. An ice-dampened Lacoste & Romberg land gravimeter (serial no. G932) was used for the gravity measurements. This setup proved its durability during the LOMBAG 2009 expedition in temperatures down to minus 40°C.

Figure 19. *Airmar 12 kHz transducer being lowered into a melt pond.*

Bathymetry was acquired at a fixed average sound speed of 1500 m/s and post-processing corrected the field values using the appropriate average sound speed at the given depth based on CTD-casts made from *Oden*. Also, the readings were corrected for a faster travel time through ice where applicable. A zero tide value was used (as was done with all of the multi-beam data). Hand written notes were also made in the field. This documentation will be used as quality control and include position, time and registered depth.

The initial plan was to find "good sounding ice" based on the experience gathered during the LOMBAG-expedition. "Good sounding ice" would be primarily first year ice with a distinct and relatively flat surface with only a small amount of snow on top. Bio-degradable gear oil or food oil poured onto the ice would create a usable medium for sound transmission between the transducer and the ice.

It quickly proved impossible to find such ice conditions in the high Arctic. The transition between snow and ice were generally very indistinct (probably due to partial melting and refreezing of the snow and ice during the summer) and it was impossible to get the needed contact between the Airmar-transducer and the ice. Instead small melt ponds were used. The thin layer of ice was broken and (when required) a considerable amount of slush ice was removed from the bottom of the melt pond. Then the Airmar-transducer could be lowered into the water. This method improved signal-to-noise ratio substantially, compared to the oil-on-ice-procedure.

Figure 20. *Airmar 12 kHz transducer in direct contact with seawater.*

As the expedition progressed, more and more open or newly re-frozen leads were used, thereby providing the team with near normal sounding conditions as the transducer could be lowered into the sea water directly. The evolution of this sounding program created a need for innovation in methods to suspend the transducer (see Figs 19 to 21).

Figure 21. *Airmar 12 kHz transducer in direct contact with seawater.*

6.2 Results

During the LOMROG II expedition a total of 96 successful soundings were made ranging from 1382 m to 4304 m. The soundings were completed as eleven lines/profiles (Fig. 22). Five profiles on the Danish-Asian side of the Lomonosov Ridge, five profiles on the Canadian-Asian side of the Lomonosov Ridge and one profile on Marvin Spur.

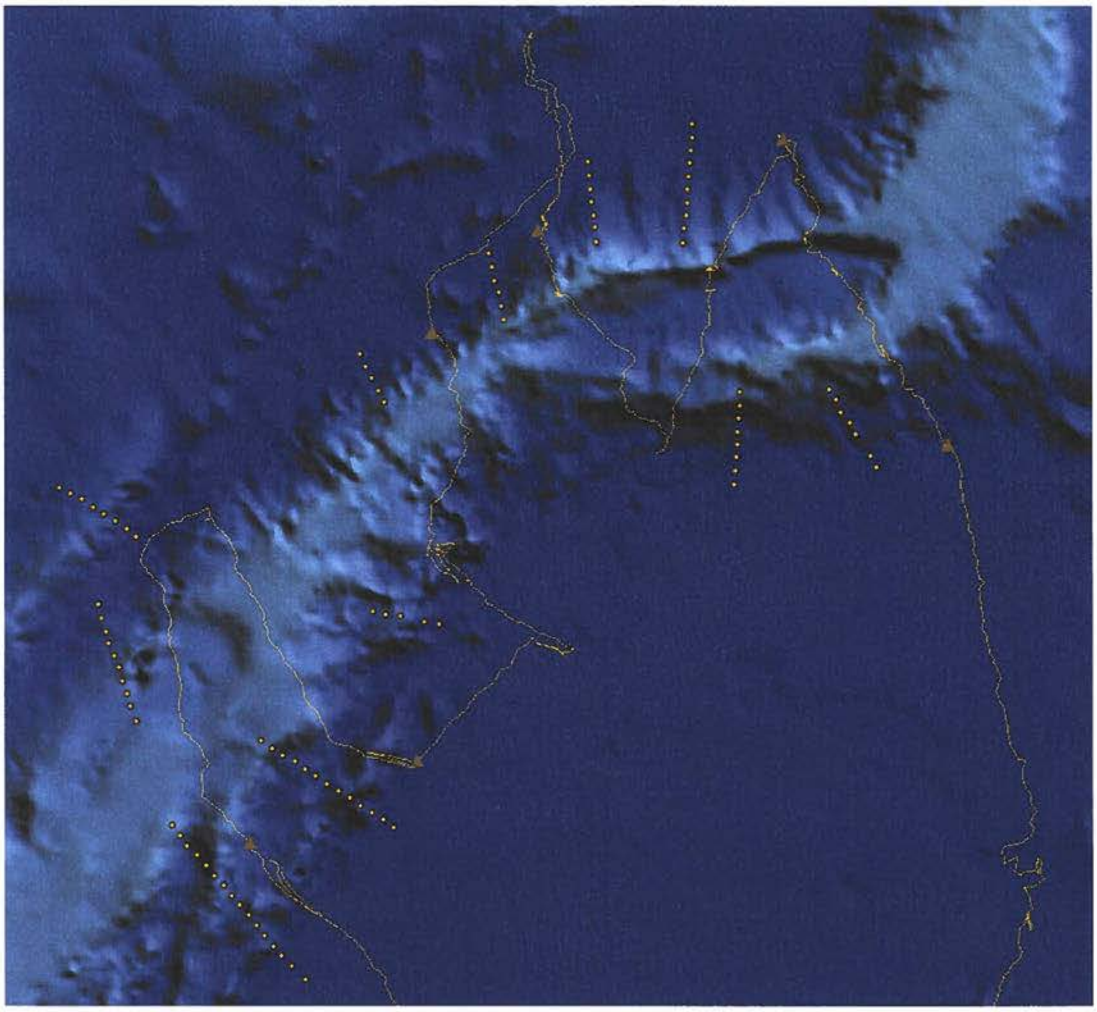

Figure 22. *Overview of completed single-beam soundings (yellow dots) with ship's track and CTD-positions.*

7. Gravity Measurements during LOMROG II

By Henriette Skourup - National Space Institute

7.1 Introduction

Ocean gravity data reflects the bathymetry and the density distribution of the oceanic crust and mantle. Low gravity values are related to low densities, submarine canyons, and trenches at the bottom of the sea. High gravity values are related to high densities, sea mounts, and ocean ridges. Gravity increases generally towards the poles due to the flattening and rotation of the earth. After removal of this last effect gravity anomalies can be identified. Variations in gravity anomalies are expressed in mGal (1 mGal = 10^{-5} m/s^2), and a 1mGal change in gravity corresponds roughly to 7 m bathymetry in the "free air anomalies".

Therefore, coincident measurements of gravity and depth makes it possible to compute Bouguer anomalies, and thus separate bathymetric and non-bathymetric signals, e.g. as an aid in estimation of sediment thickness.

During the LOMROG II cruise the gravity acceleration has been measured by staff from the National Space Institute (DTU Space). Coincident high resolution observations of the bathymetry obtained from multi- and single beam sounders (see section MB & section SB) gives the unique opportunity to support the interpretation of seismic data from the gravity readings. Further, the data can be used to improve existing gravity models of the Arctic Ocean, i.e. (ArcGP) the Arctic Gravity Project

7.2 Equipment

A marine gravimeter, an Ultrasys LaCoste and Romberg (serial no.: S-38) was installed in the engine room near the center-of-mass of the ship (the same location as during LOMROG I) to minimize the effect of the ship's movement (Figure 23). The instrument is in principle an ultra-precise spring balance with a "proof mass", which is mounted on a gyro stabilized platform. Leveling is maintained by a complicated feedback mechanism. The accuracy of the marine gravimeter is about 1 mGal with 200-500 m horizontal resolution in the final map. This variation is dependent on ice conditions and the speed of the *Oden*.

Figure 23. *Marine Gravimeter S-38 mounted in the engine room.*

To complement the marine gravity measurements, the helicopter was used to make measurements on the ice. For this phase of the program two LaCoste and Romberg relative gravimeters were used. G-867 owned by DTU Space and G-932 kindly provided by the Geodetic Survey Division, Natural Resources Canada (NRCan) (Figure 24). Both gravimeters have the option to operate in an ice-dampened mode. The estimated relative accuracy of the measurements is 0.2 mGal.

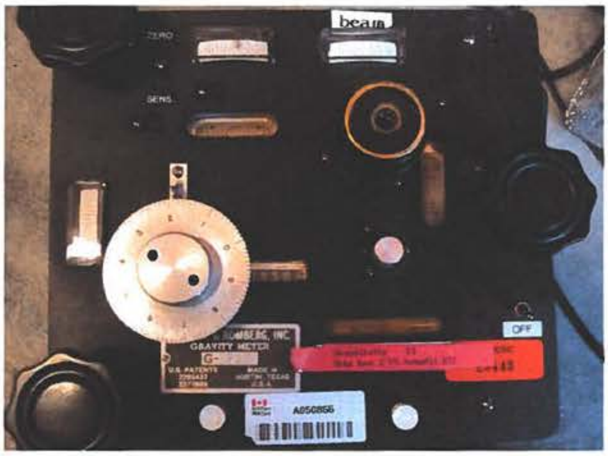

Figure 24. *LaCoste and Romberg land gravimeter*

Figure 25. *Gravity measurements on the ice. Photo: Adam Jeppesen.*

7.3 Measurements

The marine gravimeter operated in "marine mode" during the entire cruise and logged data every 10 seconds along *Oden*'s track (yellow line in Figure 26).

In addition, a total of 122 gravity readings were measured on the ice by use of helicopter, see Figure 26 for locations. Each measurement takes 5-10 minutes under ideal conditions. The Canadian gravimeter G-932 was used for most of the measurements, as the G-867 had a loose connection, which made it unreliable. At latitudes higher than 88 30' N and relative shallow waters less than 1,900 m, e.g. on the Lomonosov Ridge, the gravimeter (G-932) went out of scale (maximum range 7,000) making readings impossible. This occurred at 8 locations.

Of the 122 gravity measurements 97 were measured along 10 lines parallel to the ship track across the Lomonosov Ridge and one line over Marvin Spur to map the flank of the ridge systems and the foot-of-slope. The distance between successive measurements along a line is 5km. At each location the depth was measured using a single beam sounder (see chapter 6 of this report). The other 25 readings were done along *Oden*'s route, whenever time and flying conditions permitted activities on the ice (depth measurements were not taken at these locations).

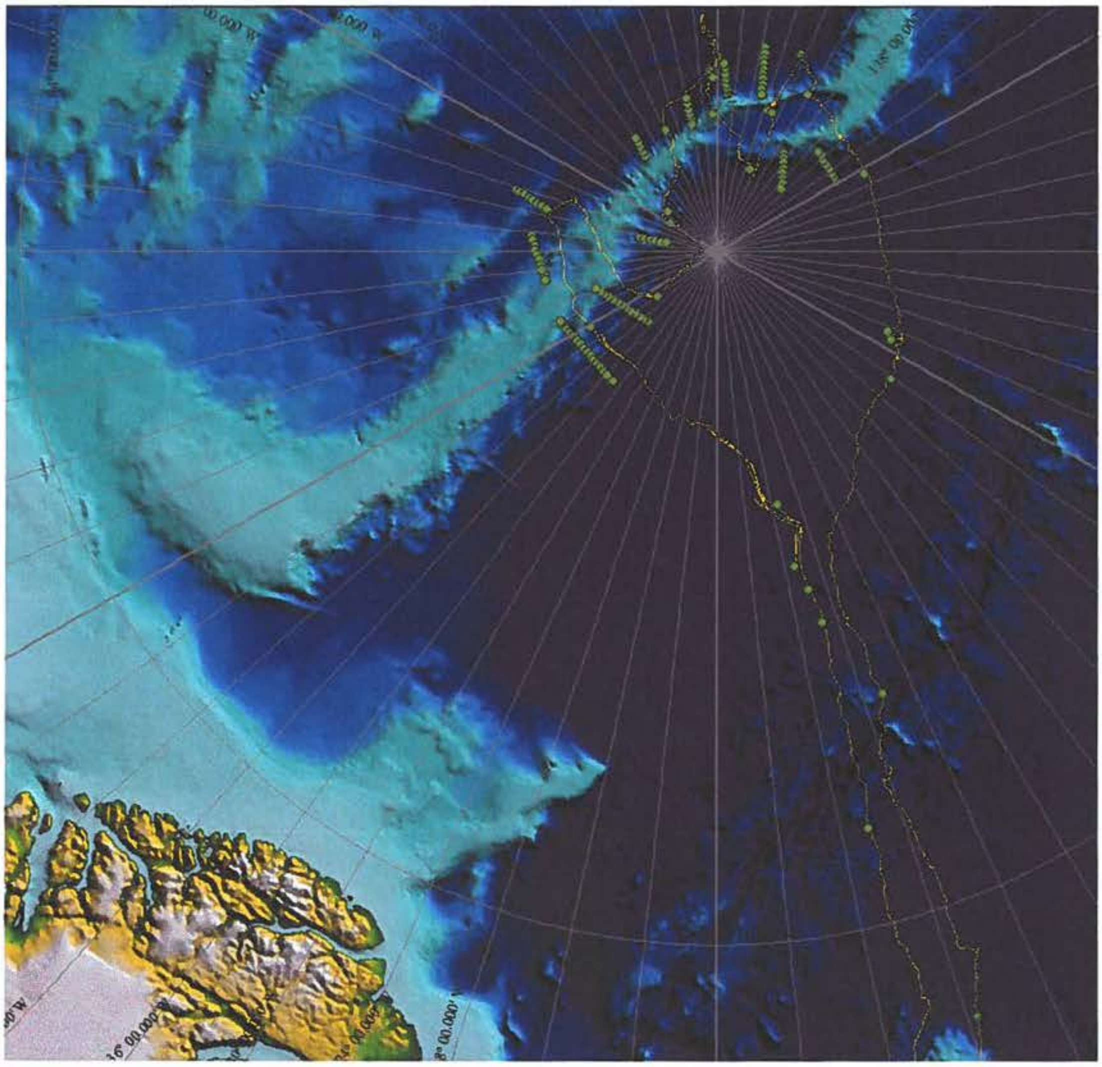

Figure 26. *Plot of gravity measurements (green dots, Oden's track line shown in orange.*

7.4 Ties

The gravity readings of both the marine- and the land gravimeter need to be tied to the International absolute reference system. Such gravity references are to be found in Longyearbyen, but unfortunately *Oden* was not able to dock at the beginning of the cruise. However, this was the case at the end of the cruise, where measurements were obtained at two locations; Longyearbyen hangar and the pier (Bykaia) next to Oden. The gravity value at the pier was calculated from the absolute reference station in the hangar using least square adjustment and subsequently reduced to sea level (more information in Skourup & Strykowski 2011).

The land gravimeters used for measurements on the ice, were checked for drift and tares relative to the marine gravimeter by occasional readings on the ice close to the *Oden* (9 locations). The drift of the land gravimeter are thus controlled by the marine gravimeter, which in turn, is controlled by the land ties.

7.5 Processing

At time of writing, it was not possible to process the gravity data, as there are no reference values available. The processing will be done as soon as possible after the expedition (see Skourup & Strykowski 2011). GPS positions of *Oden* were logged every 5 seconds and as a backup a high precision dual frequency geodetic GPS (Javad) was mounted on top of a container near the front of the ship logging every 10 seconds.

Once the gravity values are calculated, the gravity changes related to changes in bathymetry can be removed by using coincident data obtained from the single- and multi beam soundings. The remaining gravity signal originates from the different geological compositions below the sea bed, and is left for later interpretation to support the seismic work.

7.6 Reference

Skourup, H. & Strykowski, G. 2011: LOMROG II: Arctic gravity survey 2009 – Final Report. National Space Institute (DTU Space), Technical University of Denmark, 23pp.

8. Sediment Coring

By Ludvig Löwemark, Åsa Wallin, Markus Karasti, Matti Karlström, and Benjamin Hell, Stockholm University

8.1 Methods

8.1.1 Piston and Gravity Sediment Coring

Piston and gravity cores during LOMROG II were retrieved with the Stockholm University coring system. The barrel length can be adjusted in 3m increments by adding 3 m-long barrel segments that are coupled using 400 mm long couplings secured with 4 M16 bolts on each side. The outer barrel diameter is 108 mm and the inner diameter of the transparent plastic liner is about 80mm. Wall thickness of the plastic liner is about 3.5 mm. The advantage of using transparent plastic liners is that they allow a preliminary inspection of the cored sediment directly after retrieval.

Figure 27. *The coring team during LOMROG II consisted of Ludvig Löwemark, Markus Karasti, Matti Karlström, and Åsa Wallin from Sweden and Jonas Zilmer Johansen from Denmark. Axel Meiton, Per Trinhammer, Lars-Georg Rödel and the Oden Crew helped with the winches.*

Piston cores were taken using a core weight of 1360 kg (20 weights) and a trigger weight of 136 kg (1 large and 4 small weights). Gravity cores were taken using 1088 kg (16 weights). Switching between piston and gravity coring was made by exchanging the coring heads, one prepared for piston coring and one for gravity coring. To prevent the piston core from accidental triggering during launches, the arm on the release mechanism was secured with a pressure release that activates the system once the water depth exceeds 400 m.

The new core handling system introduced for the LOMROG I expedition in 2007 (Jakobsson et al., 2008) had been modified to minimize interference with the ships maneuvering system (Figure 28). The outer/lower part of the core cradle had been made retractable, which allowed the lower part of the core cradle to be lifted out of the water after the core had been launched. This has the benefit of allowing the ship to use its propellers to keep the area behind the ship ice free during coring. Before this modification, the thrust of the propellers caused the cradle to move and tilt during coring operation with risk for injuries and disturbances of the coring itself. The winch used was the same as the one used during LOMROG I in 2007, but it had been completely renovated by SPRS, and a tension meter and a distance meter had been installed to allow better control of the coring.

Figure 28. *The new, retractable cradle for the piston and gravity core.*

Figure 29. *The barrel of the piston core is filled with water to prevent the water pressure from pushing the piston up into the coring device while lowering it into the sea.*

Figure 30. *The piston core release mechanism with pressure release mounted before launch).*

8.1.2 Core Curation

Liners were marked lengthwise to help orient the cores after retrieval, and to guide core splitting. Every 150 cm, the liners were marked with a line to indicate section breaks, and each section was marked with core ID, e.g. LOMROG09-PC-01, where PC denotes a piston core, GC a gravity core, and TC a trigger weight core. Each section was also marked with arrows indicating up, and breaks between core sections were marked from base to top according to the following scheme to allow safe identification: DOWN-A, A-B, B-C etc.

Figure 31. *Åsa Wallin is placing the measuring tape on one of the core sections.*

Directly after retrieval, the cores were divided into 150 cm sections and top and base of each section were sealed with end-caps. In the case of gaps in the sediment, these were filled out with styrofoam to prevent movement of the sediment in the liner. Core sections were brought to the sedimentology lab and allowed to acclimatize at room temperature for at least 12 hours before being logged on the Geotek Multi Sensor Core Logger (MSCL). The core liners were then cut lengthwise with a circular saw, and split into two halves with a 1mm fishing line. The core halves were cleaned, the surface smoothed, and tape with cm-markings was placed on the side of the liner for a depth scale (Figure 31). Core halves were separated into working and archive halves. The working half was used for core description, while the archive halves were used for an overview photograph of the complete core, and a line scan photograph of each section using the MSCL RGB-camera. From some of the working halves sediment slabs for X-ray radiography were taken following standard procedures (Löwemark et al., 2004). Plastic boxes (H=6 mm, L=90 mm and W=60 mm) were pushed into the sediment and cut out with a 0.7 mm fishing line. The boxes were placed in airtight bags and stored for later X-ray imaging. Finally archive and working halves were covered with plastic foil, sealed with plastic tubing, placed in D-tubes and stored in the refrigerator container at 5°C.

For one core, LOMROG09-PC-09, subsamples for microbial studies were taken by Jeff Bowman and Matthias Wietz at 150 cm intervals (Figure 32). Syringes 10 mm in diameter with cut-off nozzles were pushed into the sediment and taken to their lab for further analysis.

Figure 32. *Jeff Bowman and Matthias Wietz subsampling core LOMROG09-PC-08 for microbes.*

8.1.3 The Geotek Multi Sensor Core Logger

The Geotek Multi Sensor Core Logger (MSCL) was installed in the main lab on foredeck of *Oden* (Figure 33) and set up for whole core measurements (see table 2). The MSCL was mounted for whole cores and equipped with sensor systems to measure gamma density, core diameter, p-wave velocity, magnetic susceptibility, temperature and a line scan camera for core imaging. The gamma attenuation was measured using a 137Cs gamma source with 5 mm collimator and a count time of 15 seconds. A Bartington loop sensor with 100 mm diameter was used for measuring the magnetic susceptibility with the settings zero before core: 10 cm; SI units; sampling time 1 second; sample cycle 1. A standard platinum resistance thermometer probe was placed in a block of Styrofoam to register the room temperature.

Figure 33. *The Geotek Multi Sensor Core Logger mounted in the sediment lab.*

The MSCL was calibrated before the measurements started and before each core the calibration was logged as a quality control measure. All cores were logged with the orientation line facing upwards. The raw measurements were logged and post processed using the Geotek MSCL 7.6 software.

Sediment liner outer diameter	87 mm
Liner thickness	35 mm
P-wave velocity offset	PTO = 21.73
Temperature	20°
Salinity	0 ppt
Depth	0 m
Gamma density constant after calibration	A =-0.00006, B = 0.0478, C = 9.5616
Butt error distance	2 mm

Table 2. *Geotek Multi Sensor Core Logger parameters used during LOMROG II.*

8.1.4 Sediment Description

The split cores were described. Color and lithological changes were noted on a log sheet and subsequently put into the core description using the Strater software package. Special attention was paid to diagenetic features and disturbances caused by the coring itself.

8.1.5 MSCL Color Line Scan Camera

The working halves were scanned using the Geoscan III 2048 color line scan camera and a Nikor 50mm 1:1.8 D objective. The system has a resolution of 100ppcm and was calibrated before the cores were scanned.

8.2 Results

8.2.1 Sediment Coring

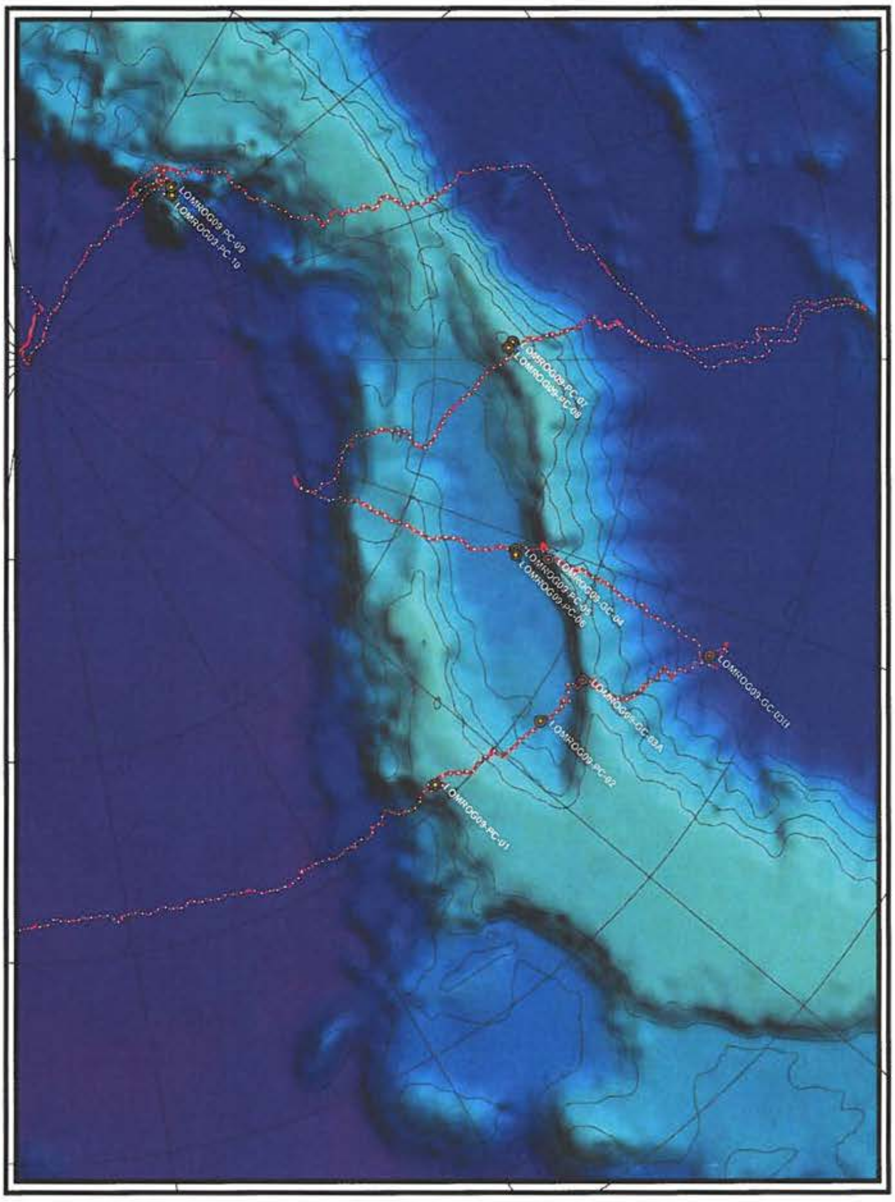

Figure 34. *Map showing the position of the cores taken during LOMROG II.*

During LOMROG II, 8 piston cores and one gravity core were retrieved (Table 3), resulting in a total sediment recovery of 47.62 m. Geographically, three cores were taken on the crest of the Lomonosov Ridge, one in the Makarov Basin, three in the intra-basin, and two on the continental rise on the Amundsen Basin–side of the Lomonosov Ridge (Figure 34). Two gravity coring attempts in the channels connecting the intra-basin with the Makarov basin resulted in empty cores except for a few pebbles. The first of these gravity coring attempts was labelled LOMROG09-GC-03. This core number was then reused in the subsequent gravity coring station in the Makarov Basin. To avoid confusion they are referred to as LOMROG09-GC-03A and LOMROG09-GC-03B, respectively. In order to eliminate this kind of labelling problem it was decided that any future empty cores should keep their core numbers and be declared as empty cores in core lists. Consequently, core LOMROG09-GC-04 is empty and the next full core is LOMROG09-PC-05.

Core	Location	Latitude N	Longitude	Water Depth (m)	No. of sections	Barrel length (cm)	Trigger (cm)	Date
LOMROG09-PC-01	Lomonosov Ridge top	88° 32' 43.8"	133° 29' 38" E	1244	4	498	0	20090812
LOMROG09-PC-02	Lomonosov Ridge intra-basin	88° 27' 01.4"	144° 36' 44" E	2534	2	178	76	20090813
LOMROG09-GC-03A	Lomonosov intra-basin channel	88° 25' 06.8"	149° 49' 24" E	1965	0	0		20090813
LOMROG09-GC-03B	Makarov Basin	88° 09' 51.6"	156° 21' 44" E	3814	2	263		20090814
LOMROG09-GC-04	Lomonosov intra-basin channel	88° 37' 30"	158° 47' 13" E	1689	0	0		20090814
LOMROG09-PC-05	Lomonosov Ridge intra-basin	88° 42' 27.2"	158° 30' 55" E	2679	5	605	6	20090815
LOMROG09-PC-06	Lomonosov Ridge intra-basin	88° 42' 12.4"	157° 58' 58" E	2684	4	528	25	20090815
LOMROG09-PC-07	Lomonosov Ridge top	88° 48' 21.8"	177° 56' 03" W	1244	4	453	13	20090817
LOMROG09-PC-08	Lomonosov Ridge top	88° 49' 00"	178° 35' 00" W	1082	4	596	16	20090817
LOMROG09-PC-09	Amundsen Basin side of Lomonosov Ridge	89° 26' 50.5"	128° 54' 22" W	3477	5	686.5	34	20090821
LOMROG09-PC-10	Amundsen Basin side of Lomonosov Ridge	89° 27' 41.1"	130° 23' 20" W	3429	6	765	20	20090821

Table 3. *Piston and gravity cores retrieved during LOMROG II.*

8.2.2 Coring Equipment

The winch used for coring had been completely renovated since LOMROG I in 2007. Despite this, several problems were encountered. First, the wire had not been spooled under tension, resulting in a very loose packing of the wire on the drum. To solve this we had to use valuable ship time to lower a weight of 700 kg down to 4000 m and then spool it in again. During this operation several problems with the winch were discovered.

First, it was not possible to start the winch in a smooth manner. Starts were abrupt and at close to full speed. Furthermore, it was not possible to use high speed when spooling in the wire, the heavy weight caused the winch to slowly loose wire rather than spool it in. Yet another problem was the uneven spooling of the wire on the drum. Apparently this was in part due to the fact that a wire of the wrong thickness had been used. This caused the wire guide to spool the wire in an uneven manner often resulting in the wire getting caught between earlier whorls. The tension meter installed in the block proved very useful during piston coring as the abrupt decrease in tension clearly signalled when the piston core was released.

In contrast, the wire length indicator broke down after 3 meters, and we had to rely on the bronze wheel placed on the side of the winch. As the winch was placed on top of another container, this meant that one person had to stand on the second floor at the back of the aft deck and hand-signal the depths to the person controlling the winch. This was both awkward and potentially dangerous as the person in charge of the winch did not have direct control of the wire length. This problem was temporarily solved by Axel Meiton, who rigged a webcam next to the bronze wheel that could then be viewed remotely on a notebook on the aft deck.

8.2.3 Cradle Problems

In addition to the problems caused by the unsteady winch, significant problems and dangers arose from the new retractable cradle. During assembly and disassembly, the hex-bolts holding the barrel sections together could not be reached with the Allan keys because of the close structure of the cradle, as compared to the open construction of the original cradle. The core barrel was also bent because the new retractable part of the cradle lies higher than the old part. This put strong tension on the hex-bolts and also made it extremely difficult to attach the hex-bolts connecting the different sections during assembly.

Figure 35. *The core barrel in the new cradle had to be straightened with straps to allow aligning the core segments.*

These problems were overcome by lifting the core barrel from the floor of the cradle with straps (Figure 35). However, the constant raising and lowering of the barrel was time consuming and increased the risk of injuries.

As a general remark, the fact that 3 winches, one crane and the A-frame need to be operated simultaneously during launch makes the launching process prone to errors that could increase the risk of accidents, especially when the coring crew is tired after longer periods of coring.

8.2.4 Multi Sensor Core Logging

All cores were logged at room temperature except LOMROG09-PC-08 which was logged cold as it was to be split and sampled for microbes directly after logging. It was judged that the living microbial fauna could change dramatically if the core was allowed to reach room temperature before sampling. The record of LOMROG09-PC-08 does not differ markedly from its sibling core LOMROG09-PC-07 taken at approximately the same position, indicating that MSCL measurements performed at 6°C are comparable to those obtained at room temperature. Generally, the MSCL measurements are of the highest quality with low numbers of outliers. Especially in the gamma density, certain features could be correlated over some distance between several of the cores (Figure 36).

8.2.4.1 P-wave Velocities

P-wave velocities are typically 1300 to 1450 m/s and often display abrupt jumps between higher and lower levels. Nearby cores often show large similarities in the general pattern allowing a correlation between the cores. This is particularly obvious in the cores LOMROG09-PC-05 and LOMROG09-PC-06 from the intra-basin where similarities in the peak pattern allow a peak-by-peak correlation of the entire cores.

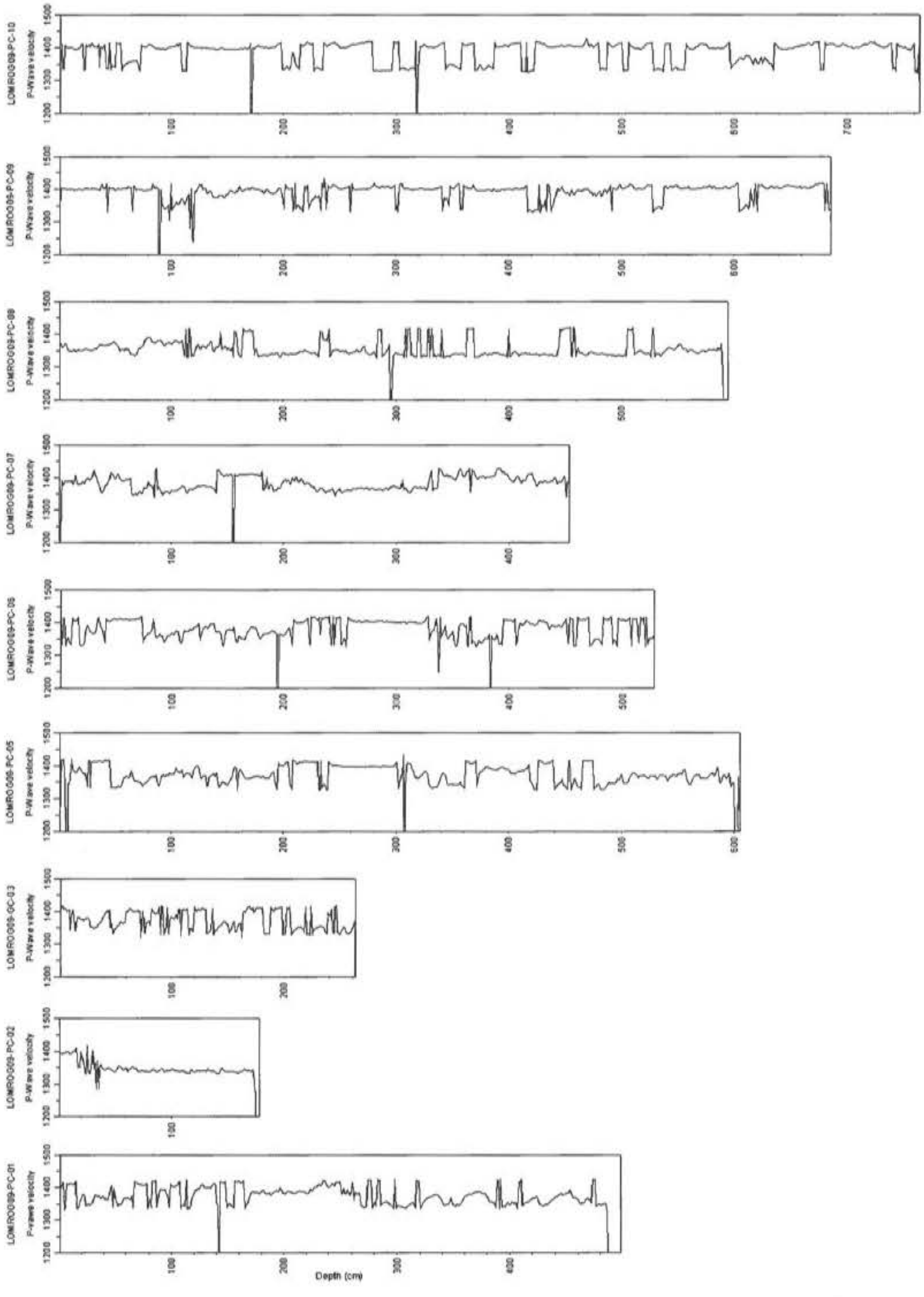

Figure 36. *Compilation of P-wave velocities for the 9 cores obtained during LOMROG II.*

8.2.4.2 Gamma Densities

Gamma densities mostly vary between 1.5 and just below 2 gm/cc (Figure 37). Similar to the P-wave velocities, variations in gamma densities can also be used to correlate between cores. Again LOMROG09-PC-05 and LOMROG09-PC-06 are so similar that they can be correlated peak by peak for their entire length. Interestingly, LOMROG09-PC-09 from the rise on the Amundsen Basin-side of the Lomonosov Ridge display large similarities with the two cores from the intra-basin, while LOMROG09-PC-10 shows few similarities although taken at practically the same position.

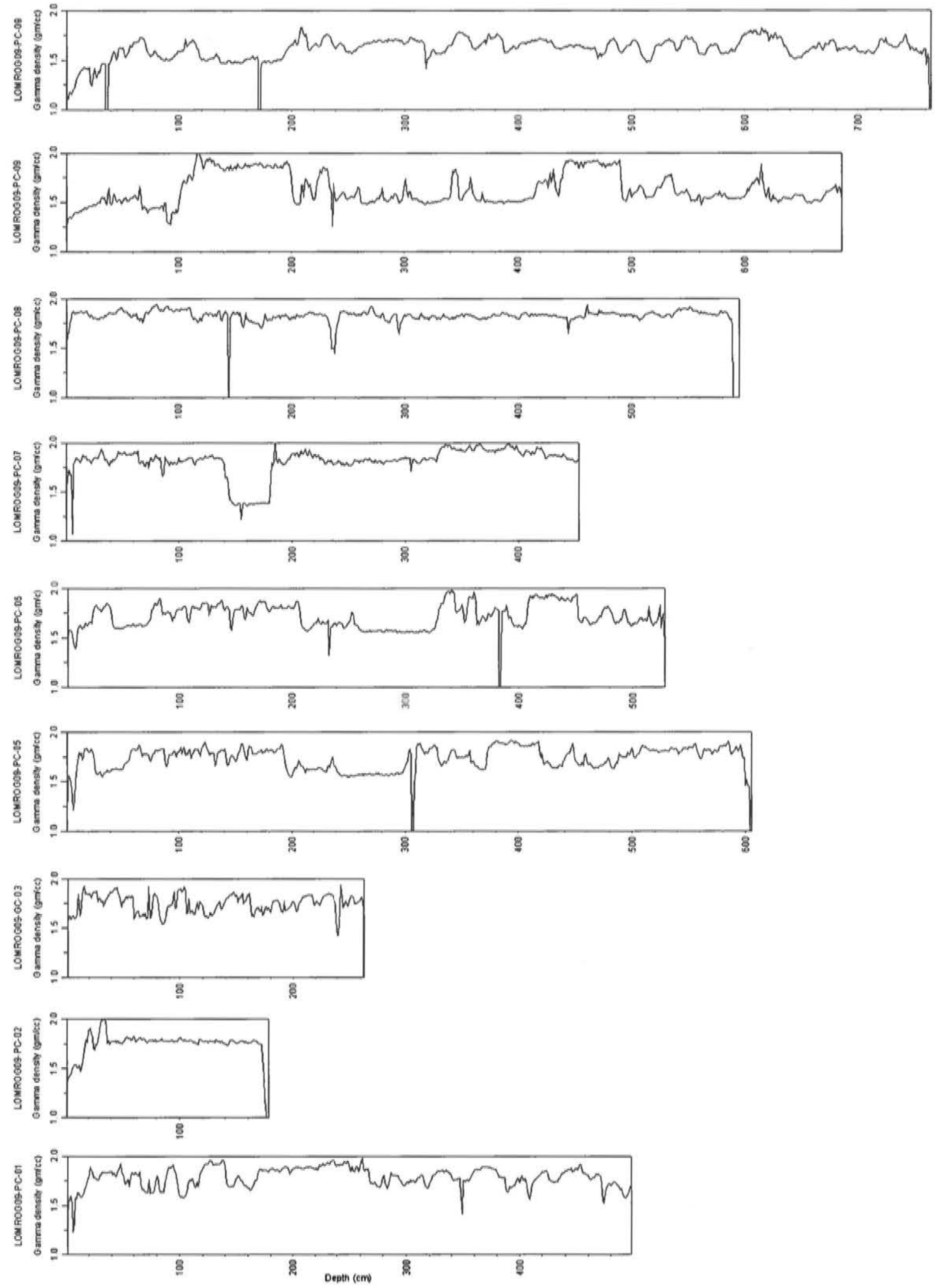

Figure 37. *Compilation of gamma densities for the 9 cores obtained during LOMROG II.*

8.2.4.3 Magnetic Susceptibilities

Magnetic susceptibilities vary from minima around 15 to maxima around 30 with a few peaks reaching up to almost 60 (Figure 38). Similarities in magnetic susceptibility between the cores are considerably less pronounced compared to P-wave velocity and gamma density. As before, largest similarities are found between LOMROG09-PC-09 and LOMROG09-PC-10.

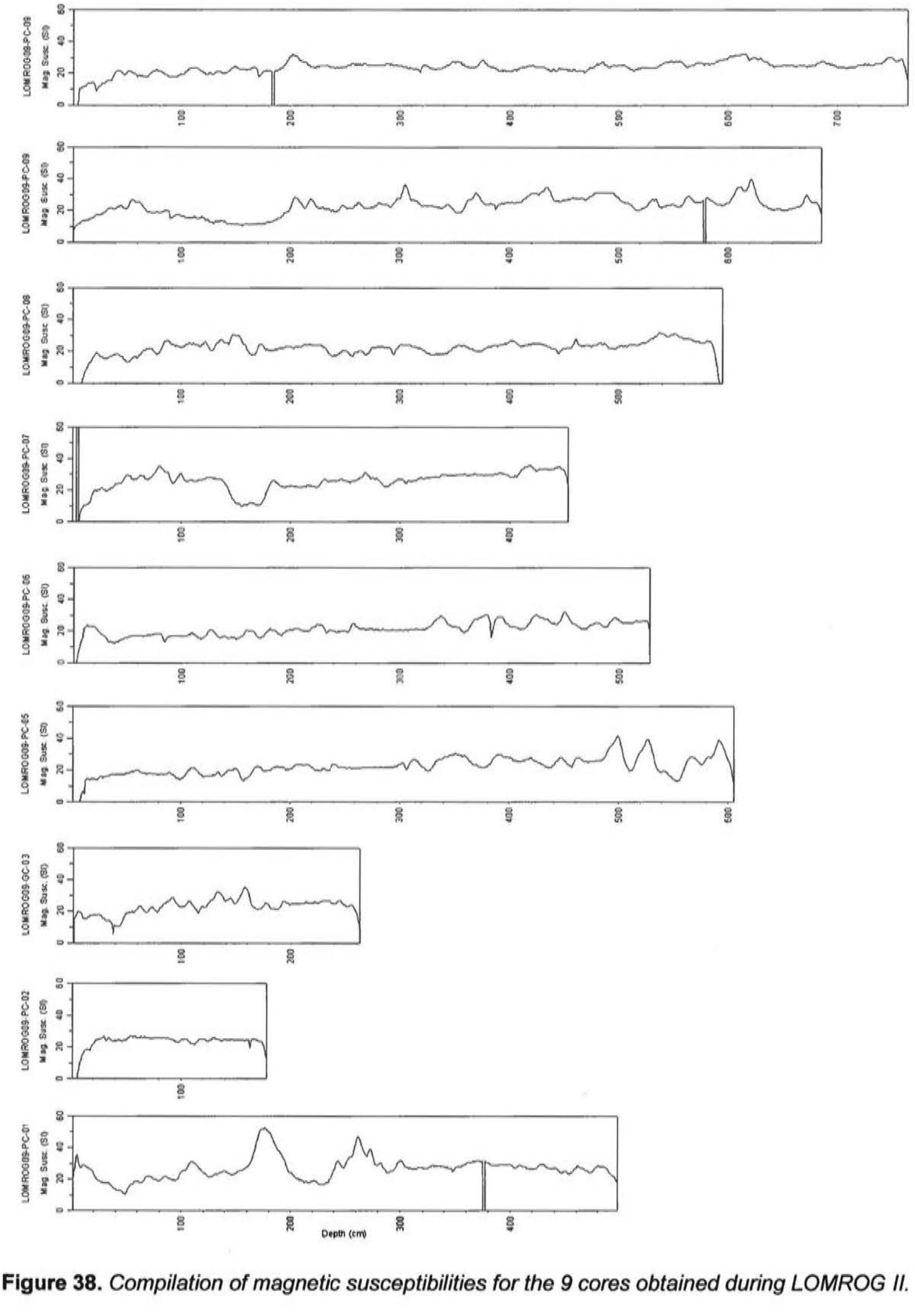

Figure 38. *Compilation of magnetic susceptibilities for the 9 cores obtained during LOMROG II.*

8.2.5 Lithology

The obtained cores all consist of brownish greyish silty mud with sandy intervals. Several of the sandy layers have sharp base boundaries indicating erosional events. Occasional ice rafted pebbles were observed in several of the cores. Typically, a sediment sequence would consist of lighter olive grey brown background sediments with a number of intercalated dark brown or grey layers. These layers vary in thickness from subcentimeter to several tens of cm. In the uppermost first or second meter many of the cores contained a distinct grey layer with a sharp base boundary and gradual transition into brownish sediments in the top. This grey layer is characteristic for sediments from the central Lomonosov Ridge as well as from many other parts of the Eurasian basin (Spielhagen et al., 2004) and our working hypothesis at the moment is that this layer is related to the catastrophic draining of a huge ice-dammed lake on the Siberian hinterland. Detailed core descriptions for each core as well as rationale for the choice of coring positions are given in the appendix III.

8.3 References

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9. Dredging

By Christian Marcussen, Geological Survey of Denmark and Greenland

On August 15, 2009 an attempt was made to dredge on the Eurasian flank of the Lomonosov Ridge. The purpose of this attempt was to get *in situ* samples of older strata of the Lomonosov Ridge. Experience gathered by the US icebreaker *Healy* showed that the slope of a dredging site should at least have an inclination of 25 degrees. A box dredge from Marinetechnik Kawohl was used for this experiment (Figure 40).

Based on previous acquired multibeam data a locality was chosen. Ice conditions were however so difficult that *Oden* could not break a lead in the optimum direction (Figure 39). The procedure for dredging with *Oden* was as follows:

- First *Oden* breaks a lead along the preplanned track twice taking into account drift of the ice and the topography of the seabed.
- Then the dregde was lowered to the seabed and *Oden* moved a distance of 1 nautical mile away from the dregde.
- The dregde was then pulled in by the coring winch while carefully monitoring the tension on the wire. However, it soon turned out that the tension on the wire to the dregde was quite low indicating that little was dredged from the seabed.

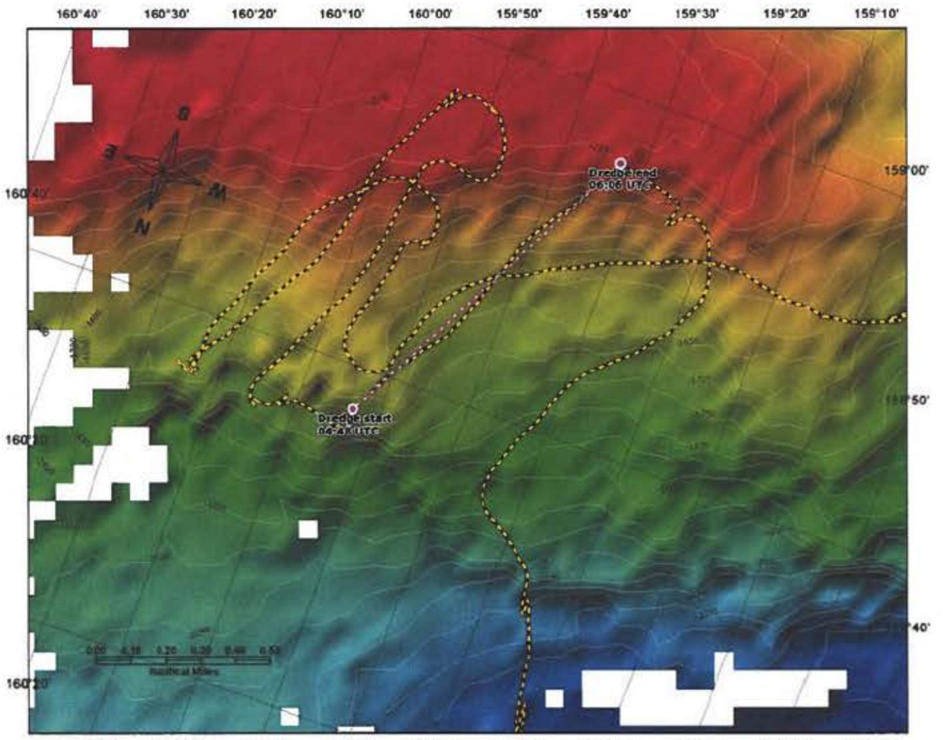

***Figure 39.** Map showing Oden's course during the attempt to dredge the Lomonosov Ridge. Oden course is not perpendicular to the steepest part of the flank of the ridge.*

After recovering the dredge only a small stone was found – probably a *drop stone*. This experiment showed that dredging is possible from *Oden*. However, it requires careful planning and manageable ice conditions. A map of potential dredging sites, where the slope has inclinations higher than 25 degrees, is shown in Figure 41.

Figure 40. *Box Dredge from Marinetechnik Kawohl used under the dredging attempt.*

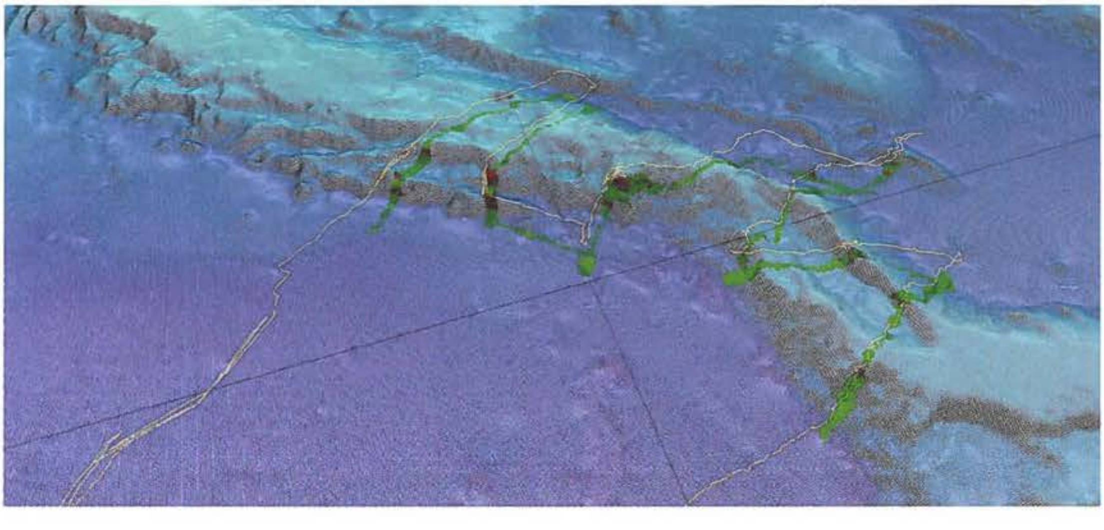

Figure 41. *Map showing areas (in red) with slopes larger than 25 degrees, which could constitute potential dredging sites for future cruises. Map based on LOMROG II multibeam data and IBCAO 2.23.*

10. Oceanography

By Steffen M. Olsen and Leif Toudahl Pedersen - Danish Meteorological Institute (DMI)

10.1 Introduction

The oceanographic component of LOMROG II is an integrated part of the overall cruise theme. Knowledge of variations in water mass distribution along the cruise track is required for calibration of multibeam sonar mapping of the seafloor bathymetry. The primary purpose of the oceanographic work is thus to supply representative, near real time vertical profiles of sound velocity derived from CTD measurements of temperature, salinity and pressure as a function of depth. Data are collected either from the ship during stations or at ice borne 'satellite' stations reached by helicopter, typically ahead of *Oden* along the planned cruise track. Helicopter CTD data acquisition has shown to be feasible and efficient, reaching the required depth of two kilometres within a three hour operation and saving valuable ship station time. The acquired data is of superior quality in comparison with data collected by expendable probes and potentially of similar cost.

In addition, a number of add-on science projects to the continental shelf project depend on oceanographic CTD measurements and the simultaneously collection of water samples, a synergy which has been developed during the cruise to make optimal use of resources.

The oceanographic data acquired will further contribute to the understanding of Atlantic water circulation in the Amundsen Basin and will yield an updated view of the state of the polar mixed layer and halocline structure by including several passages across the upper ocean frontal structure aligned with the Lomonosov Ridge. Stations were also planned in the central region of deep exchange across the Ridge as identified by the HOTRAX expedition in 2005, presumably of Canadian Basin deep water from the Makarov Basin towards the Amundsen Basin. LOMROG I oceanographic data acquired closer to Greenland indirectly confirmed the existence of such exchange. LOMROG II data will potentially document the persistence of this exchange, in part by collecting data in the actual channels of exchange, which is a region that is also of interest to the paleoceanographic science team on board *Oden*.

10.2 CTD Data

Measurements of water mass distribution along the cruise track include both ship borne and ice borne CTD station work with different instrumentation. In total, 16 unique ship stations and 20 ice-borne stations were completed (Table 4 and 5, Figure 43). Where time permitted, ship stations include both a deep cast and a shallow cast for additional collection of water samples.

Figure 42. *Ice station setup. The SBE19plusV2 CTD (center) has just been pulled out of a lead in the sea ice. The mobile winch (blue) holds 2000m synthetic rope and is powered by a generator. A Niskin type bottle for water sampling lies in the snow. The winch is configured in boom* assembly for *working over the ice edge and the wire counter hangs over the open water. In the background Kajsa Tönnesen, University of Gothenburg, is packing up her plankton nets with help from the helicopter pilot.*

Station work started during the transit track with relatively coarse spacing but was intensified in the study area along the Lomonosov Ridge including the intra-basin of the Ridge. Ship borne stations made use of the on board CTD rosette system owned by the University of Gothenburg and consisting of a 24-bottle rosette sampler equipped with 7.5l Niskin type bottles, an SBE9*plus* CTD with an SBE11*plus* Deck Unit. Due to a malfunction, the sensor package of this CTD was changed after the first test station during the transit and the new set used throughout the rest of the cruise. Ice stations were reached by helicopter, where we made use of a SBE19*plus*V2 pumped SEACAT in profiling mode in combination with a portable winch with 2000m non-conductive line (Figure 42). Limited water was collected using just a single 2.5 or 4 l Niskin bottle by drop-messenger triggering. The portable system was supplied for the cruise by the Danish Meteorological Institute (DMI).

Station ID	Date	Longitude	Latitude	Cast	Discrete sampling (m): N(utrients),C(hlorophyl),								Integrated sampling (m):					
lomrog2		cast start	cast start	(m)	M(icroplankton), I(sotopic composition), B(acteria)								P(lankton), B(iomass)					
ctd					*10*	*20*	*40*	*60*	*100*	*150*	*200*	*300*	*0-100*	*0-50*	*50-100*	*100-150*	*150-200*	*200-250*
00101#	0802	016°41.50'E	81°56.45'N	2627	N/C/M/I/B	N/C/M/I	N/C	N/C/M/I	N/C/M/I	N/C/I	N/C/M/I	N/C/I		B	B	B	B	B
00201	0808	059°41.61'E	88°12.84'N	4355														
00202	0809	059°07.94'E	88°11.95'N	300	N/C/M/I/B	N/C/M/I/B	N/C/I/B	N/C/M/I/B	N/C/M/I/B	N/C/I/B	N/C/M/I/B	N/C/B						
00301	0809	065°35.02'E	88°16.15'N	4362														
00401	0811	117°57.32'E	88°33.35'N	4291	N/C/M/I/B	N/C/M/I	N/C/I	N/C/M/I/B	N/C/M/I	N/C/I	N/C/M/I	N/C/B	P	B	B	B	B	B
00501	0812	133°16.07'E	88°32.92'N	1231	N/C/M/I/B	I	N/C/I	N/C/M/I/B	N/C/M/I	N/C/I	N/C/M/I	N/C/B	P	B	B	B	B	B
00601	0813	150°09.63'E	88°24.65'N	1860	N/C/M	N/C/M	N/C	N/C/M	N/C/M	N/C	N/C/M	N/C	P/B	B	B	B	B	B
00701	0814	157°07.39'E	88°08.80'N	3904	N/C/M/I/B	N/C/M/I	N/C/I	N/C/M/I/B	N/C/M/I	N/C/I	N/C/M/I	N/C/B	P/B	B	B	B	B	B
00801	0815	158°53.42'E	88°42.66'N	2674														
00802	0815	158°18.56'E	88°42.32'N	300	N/C/M/B	N/C/M	N/C	N/C/M/B	N/C/M	N/C	N/C/M	N/C/B	P	B	B	B	B	B
00901	0817	178°02.71'W	88°48.49'N	1156	N/C/M	N/C/M	N/C	N/C/M	N/C/M	N/C	N/C/M	N/C	P	B	B	B	B	B
001001	0817	175°38.15'W	88°35.81'N	3929														
01002	0818	176°06.43'W	88°35.70'N	300	N/C/M/B	N/C/M	N/C	N/C/M/B	N/C/M	N/C	N/C/M	N/C/B	P	B	B	B	B	B
01101	0820	156°16.45'W	88°50.69'N	3888	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	P	B	B	B	B	B
01201	0821	129°20.37'W	88°27.13'N	2000														
01202	0821	130°49.00'W	89°27.95'N	3485	N/C/M/I	N/C/M/I	N/C/I	N/C/M/I/B	N/C/M/I	N/C/I	N/C/M/I	N/C/I	P	B	B	B	B	B
01301	0822	123°02.56'W	89°35.45'N	305	C	C	C	C	C	C	C	C		B	B	B	B	B
01401*	0824	053°24.01'W	89°21.25'N	4135	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C	P	B	B	B	B	B
01501	0826	058°27.28'W	88°43.74'N	2847														
01502	0826	058°40.31'W	88°43.76'N	300	N/C/M/I	N/C/M/I	N/C/I	N/C/M/I	N/C/M/I	N/C/I	N/C/M/I	N/C	P	B	B	B	B	B
01601	0831	015°56.25'E	86°39.78'N	4375	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C	P	B	B	B	B	B

Table 4. *Ship borne CTD station list*

#Malfunction of sensors caused loss of data in intervals during downcast, sensor package replaced.

**No downcast available.*

Station ID	Date	Longitude	Latitude	Cast	Discrete sampling (m): N(utrients),C(hlorophyl),						Integrated sampling:		
lomrog2				(m)	M(icroplankton), I(sotopic composition), B(acteria)						P(lankton), B(iomass)		
heli_ctd					*10*	*20*	*40*	*60*	*100*	*200*	*0-100*	*0-50*	*50-100*
00101	0804	019°11.38'E	83°59.55'N	1600									
00201	0805	017°36.57'E	85°03.77'N	1805	N/C/M/I	N/C/M/I		N/C/M	N/C/M/I	N/C/M/I			
00301	0806	020°24.97'E	85°52.60'N	1908	N/C/M/I	N/C/M/I		N/C/M/I	N/C/M/I	N/C/M/I	P	B	B
00401	0807	020°31.74'E	87°11.79'N	1955	N/C/M/I	N/C/M/I		N/C/M/I	N/C/M/I	N/C/M/I	P	B	B
00501	0809	071°50.06'E	88°25.34'N	1927	N/C/M/I	N/C/M/I		N/C/M/I	N/C/M/I	N/C/M/I	B		
00601	0811	099°55.50'E	88°36.10'N	1906	N/C/M/I	N/C/M/I		N/C/M/I	N/C/M/I	N/C/M/I	P	B	B
00701	0813	151°44.46'E	88°20.49'N	1939	N/C/M/I	N/C/M/I		N/C/M/I	N/C/M/I		B		
00801	0815	158°43.18'E	88°37.62'N	1604									
00901	0817	174°28.41'E	88°43.23'N	1955									
01001	0819	175°26.80'W	87°35.18'N	1984	N/C/M/I	N/C/M/I		N/C/M/I	N/C/M/I	N/C/M/I	P/B		
01101	0821	129°20.37'W	89°27.13'N	2000									
01201	0821	127°56.87'W	89°23.78'N	2010	C	C		C	C	C	P/B	B	B
01301	0822	140°06.83'W	89°36.00'N	2010									
01401	0823	097°09.31'W	89°48.15'N	2007	C	C		C	C	C	P/B	B	B
01501	0825	110°09.21'W	88°42.87'N	2002	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	P/B	B	B
01601	0826	081°30.80'W	88°42.44'N	1627	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	P/B	B	B
01701	0827	020°57.28'W	88°41.03'N	1884	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	P/B		
01801	0829	010°05.22'E	87°53.44'N	1958	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	P/B	B	B
01901	0830	015°56.93'E	87°24.12'N	76									
02001	0830	014°16.83'E	87°09.18'N	2009	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I		P	B	B
02101	0901	014°55.34'E	84°58.95'N	2000	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	N/C/I	P/B	B	B

Table 5. *Ice borne CTD station list*

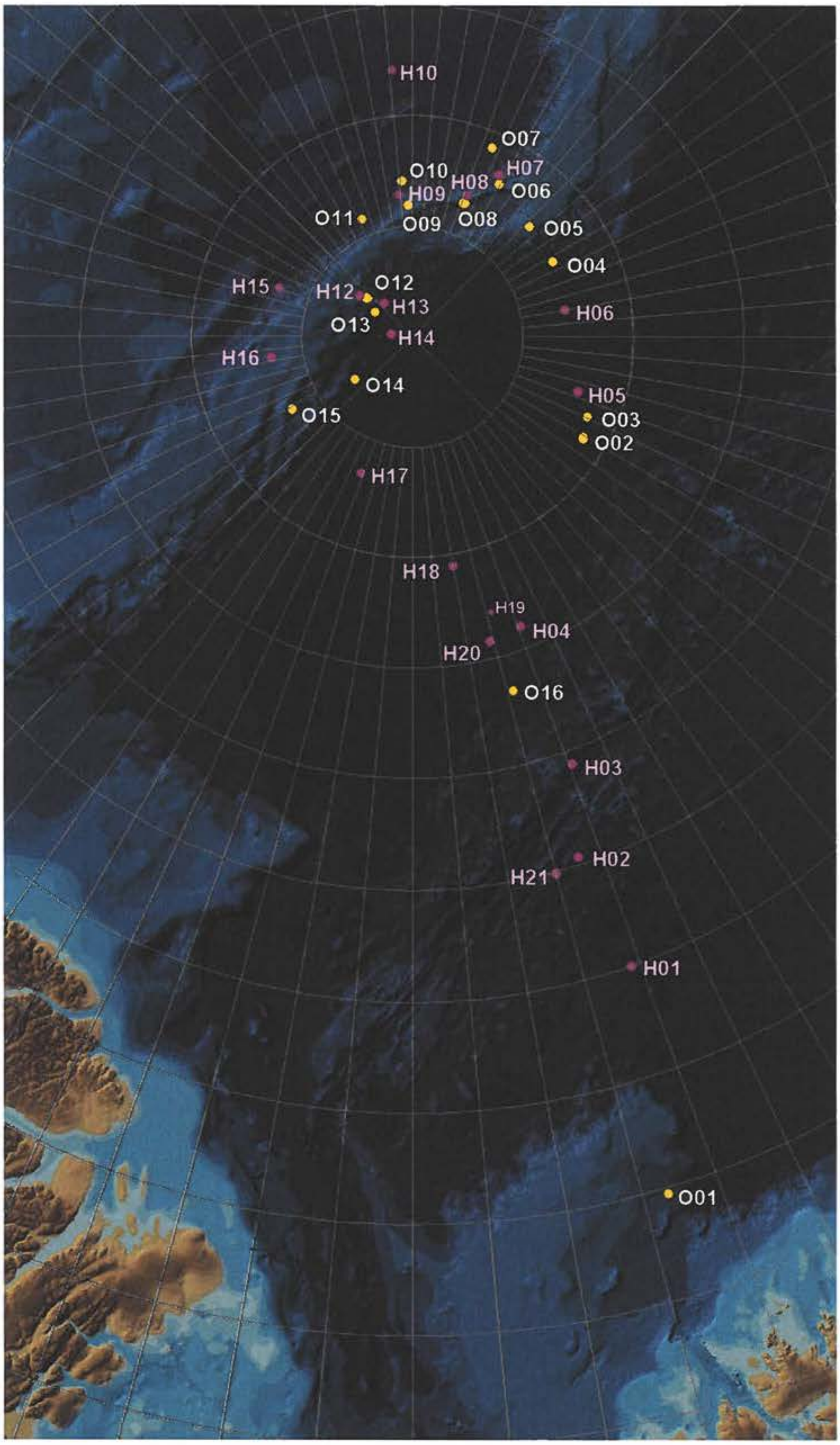

Figure 43. *Station map including ship- (yellow) and ice-borne stations reached by helicopter (purple). Positions of stations can be found in Table 4 and 5.*

10.3 Calibration of Sensors

In order to achieve a consistent dataset, processing of the SBE9*plus* and SBE19*plus*V2 data has been performed in parallel, including the same steps but with some modifications related to the difference in sampling frequency of the instruments, accuracy and sensor specifications. The final dataset was intercalibrated between the systems and the accuracy of the data was checked and corrected against bottle salinity readings.

At one mid cruise station, the SBE19*plus*V2 system was mounted in the ship borne rosette system during a 2000m cast for direct comparison of sensor performance against the SBE9*plus* unit. After correcting for offsets in deck pressure readings of both units, the known drift history of the SBE9*plus* was extrapolated yielding an offset correction of -0.0002°C. Comparison of profiles suggested the SBE19*plus*V2 readings of temperature should be adjusted with an offset correction of 0.0015°C. The result from this one-cast alignment of the two temperature profiles has been used in the post processing of all cruise data except for the temperature readings from the first station (lomrog2_00101). This cast used a different sensor package and the correction is not applicable. For pressure readings, the cast with dual systems did, however, also highlight differences in pressure readings exceeding 1db at depth. This difference cannot be accounted for here, but are found to be within the specified uncertainty of the sensors.

One sample was selected for on board bottle salinity reference measurements for each of both ice borne and ship stations. Close to fifty individual samples have been measured on board yielding satisfactory statistics for performing corrections. Additional bottle readings will be available post cruise from about 140 upper ocean oxygen-18 samples (see Table 4 and 5). On board bottle salinities were measured using an Autosal Guildline 8410 portable lab salinometer with a nominal precision of 0.003 psu (practical salinity units). Reference readings are primarily but not exclusively based on deep samples representing in general the weekly stratified abyssal water column. The mean error between CTD salinity and bottle salinities could be estimated at a precision of 0.001 psu, disregarding obvious outliers, and revealed a small difference of 0.0015 psu for the SBE9*plus* unit and a more significant mean error of -0.0281 psu for the for the SBE19*plus*V2 unit. These numbers fit nearly perfectly with an offset of 0.0030 psu identified from the mid cruise dual system cast comparing the units. For the first test station with the SBE9*plus* only two bottle salinity readings were available but consistently showed a difference of 0.009 psu but obviously associated with higher uncertainty. For all three conductivity sensors in use, the identified difference from bottle readings has been accounted for by calculating a representative slope correction from conductivity readings and used in the post processing.

10.4 Data Processing

After calibration, raw data are converted to pressure, in situ temperature and conductivity and pressure readings are initially high pass filtered twice in order to smooth high frequency data and to obtain a uniform descent history of the cast. The applied cut-off period for the SBE9*plus* and SBE19*plus*V2 is 0.15 and 1.0 seconds, respectively. Inherent misalignment time delay in sensor responses and transit time delay in the pumped plumbing line are corrected by advancing conductivity 0.073 sec relative to pressure for the SBE9*plus* and temperature relative to pressure by 0.5 sec for the SBE19*plus*V2. By this alignment, measurements refer to the same parcel of water and the procedure eliminated artificial spikes in the calculated salinity which is dependent on temperature, pressure and conductivity. A recursive filter was then applied to remove cell thermal mass effects from the measured conductivity according to the specifications for the individual sensors of the two CTD systems. This correction of salinity is significant in the upper layers with steep temperature gradients, but otherwise negligible. The last modification of the data removes scans with slow descent rate or reversals in pressure. Post processed data is averaged into 1m bins and includes a number of derived parameters: potential temperature, salinity, density, sigma theta, depth, descent rate and sound velocity.

10.5 Additional Data

Water samples were also drawn for post cruise analysis of the oxygen-18 content of surface water along the cruise track. The 8 sampling depths are given in Table 4 for ship borne stations extending from the surface to the upper part of the Atlantic Layer. These depths are also used for the sampling of nutrients and chlorophyll by the plankton project. A subset of these standard depths has also been sampled from ice borne stations (Table 5), where the shallowest of the samples were collected by hand line. Combined, these data will serve to decompose the freshwater content of the polar surface mixed layer and halocline into Pacific, riverine and sea ice melt water fractions. This in turn yields information on the formation-, state- and evolution of the arctic halocline that shields the sea-ice from the warmth of the Atlantic Layer water.

At a number of ship borne CTD stations, the rosette was equipped with a single self-contained 300 kHz downward looking Acoustic Doppler Current Profiler (ADCP) supplied for the cruise by DMI. The vertical range scanned by the ADCP is found to be limited because of the few acoustic scatters in the Arctic Ocean. Furthermore, the proximity of the magnetic pole makes use of ADCPs' in the region problematic and the raw individual bin data stored will await post cruise processing for current shear at DMI.

10.6 Results

The combined set of ship and ice borne hydrographic stations recovered are generally much larger in spacing compared to classical hydrographic mapping of boundary currents, frontal structures and baroclinic flow cores. The net is characterized as an aerial survey which yields insight into the evolution of the polar mixed layer, halocline structure and heat content in the Atlantic layer likely affected by climate change. However, a number of key stations for the deep water routes of the Arctic Ocean have also been reached and nearly all stations in the survey reach into the deep water masses of the Arctic below the intermediate Atlantic layer.

Through flow of Canadian Basin deep water (CBDW) from the Makarov Basin to the Amundsen Basin has been documented by direct measurement in the two deepest channels across the Lomonosov Ridge into the intra basin of the Ridge. A bottom layer with CBDW properties is observed in both channels with a thickness of about 200m and with signatures of a strong current shear above this layer. CBDW is found below 1700m in the intra-basin to depths of about 2200m. A strong signal of a CBDW flow core is seen on the flanks of the Ridge towards Greenland whereas CBDW is not present upstream of the intra-basin which suggest an organized flow core aligned with the topography towards Greenland.

However, a surprisingly undiluted CBDW signal is also observed at stations in the interior Amundsen basin near the Nansen-Gakkel Ridge. This may likely be the imprint of isolated lenses with anomalous water mass properties rather than the signature of baroclinic flow cores. Large variations at depth between nearby casts in the eastern Amundsen Basin supports the hypothesis of eddies playing a dominant role in forming the hydrography of the region and contribute significantly to water mass transport to the interior of the basin.

11. Plankton Ecology

By Kajsa Tönnesson - University of Gothenburg, Sweden and Rasmus Swalethorp - National Environmental Research Institute, University of Aarhus, Denmark

11.1 Introduction

The effect of environmental changes on the biological pelagic system in the central Arctic Ocean is difficult to estimate due to limited data. The central Arctic Ocean is characterized by the most extreme seasonal light regime of all marine systems (Auel and Hagen 2002). The primary production, which is mainly composed of ice algae and pelagic phytoplankton, forms the base of the food web, thus supporting organisms at higher trophic levels. The amount and distribution of phytoplankton is therefore likely to affect the behaviour and distribution of zooplankton. Herbivorous zooplanktons are the primary grazers on the phytoplankton biomass (Figure 44). Previous investigations of the central Arctic Ocean have found that two *Calanus* (*C. glacialis* and *C. hyperboreus*) and one *Metridia* species (*M. longa*) account for a substantial part of the zooplankton biomass (Mumm 1993; Kosobokova and Hirche 2000; Auel and Hagen 2002). The *Calanus* species, in particular, with high energy content in the form of lipids (Swalethorp et al. 2009), are important prey items for larger carnivorous zooplankton, fish larvae, fish, birds and whales (Falk-Petersen et al. 2007; Laidre et al. 2007).

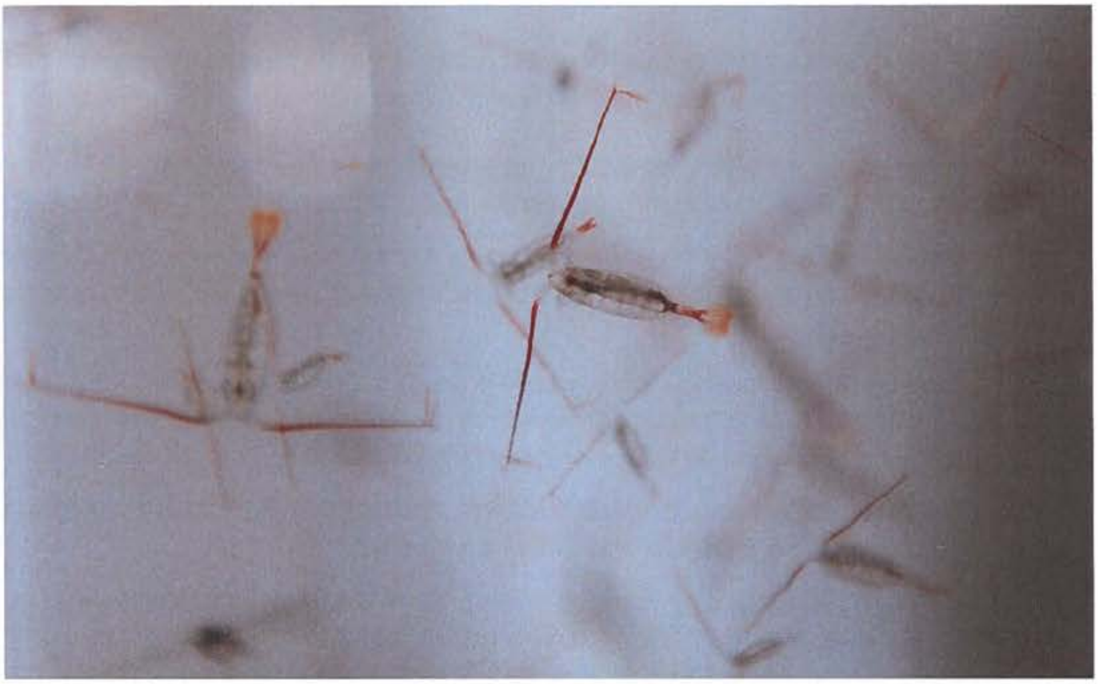

Figure 44. *Sample of copepods from at plankton net (0-100 m) with an adult Calanus hyperboreus female in the front. Photo: Martin Ramsgård.*

Carnivorous zooplankton might have a substantial impact on prey communities. The large carnivorous copepod *Pareuchaeta* is common in the central Arctic Ocean (Mumm 1993; Kosobokova and Hirche 2000; Auel and Hagen 2002) and could play an important role in the predation on small copepods.

Zooplankton, both herbivores and carnivores, modify the prey community by grazing and predation. Zooplankton will also have an impact on the benthic-pelagic coupling through sedimentation of organic aggregates. The trophic structure of the heterotrophic community is important to determine what fraction of the primary production is exported from the surface to the deep ocean and the sediment. One of the main mechanisms is the vertical flux of zooplankton fecal pellets. Due to their high sinking speeds, large particles are not consumed or remineralised in the water column as readily as small, suspended particles. Therefore, these organisms may represent an important mechanism coupling the pelagic system with the benthic community. Apart from fuelling the benthos, part of the organic material is buried. Thus this fecal pellet flux also acts as a carbon sink from the atmosphere to the deep sea sediments.

The primary focus of most previous studies has been to describe the mesozooplankton species composition, abundance and vertical distribution in relation to different water masses and basins or with a temporal resolution to describe seasonal changes. Investigations including phytoplankton, protozooplankton, mesozooplankton and the predatory interaction between or within them are however scarce. The relative importance of the different components of the Arctic zooplankton community for grazing, predation and sedimentation is not very well investigated. Data on how these trophic interactions responds to environmental change is also required for better understanding the dynamics of Arctic pelagic ecosystems.

During the cruise sampling of plankton was carried out in the Nansen, Amundsen and Makarov basins, on transects across the Gakkel and Lomonosov Ridges. The aims were:

1. To describe the structure, distribution and biomass of phytoplankton, protozooplankton and mesozooplankton in the surface water (0-250 m).
2. To determine the grazing pressure and fecal pellet production of the most dominant copepods (*C. glacialis*, *C. hyperboreus* and *M. longa)* as well as the whole copepod community.
3. To examine specific predator prey relationships, through analyses of fatty acids and stable isotopes used as trophic markers in *C. glacialis*, *C. hyperboreus* and *M. longa* as well as in their possible food sources (phytoplankton and protozooplankton).
4. To determine the grazing, diet and predation pressure by carnivorous zooplankton (*Pareuchaeta* sp., *Sagitta* spp. and *Eukrohnia hamata*).
5. To measure the composition and content of different lipid classes, carbon and nitrogen in *Metridia longa*. The composition of different lipid classes is associated with different physiological processes, and thus provides some insight into the lifecycle of this poorly studied species.

11.2 Net sampling

The vertical distribution of mesozooplankton was investigated by multiple opening-closing net hauls from *Oden* and ice borne stations reached by helicopter. In total, 29 stations along the cruise track were sampled in the Nansen, Amundsen and the Makarov basins and across the Gakkel and Lomonosov Ridges (14 times from the ship and 15 times from the ice borne stations, Table 1 and 2). Stratified samples were collected in 0-50, 50-100, 100-150, 150-200 and 200-250 m depths intervals from the ship (MultiNet, mesh size 45 µm, Figure 45) and 0-50 and 50-100 m from the ice borne stations (WP-2 net with closing device, mesh size 45 µm, Figure 43). All samples were preserved in a 4% formalaldehyde/seawater solution and will be analysed for abundance, biomass and species composition after the cruise.

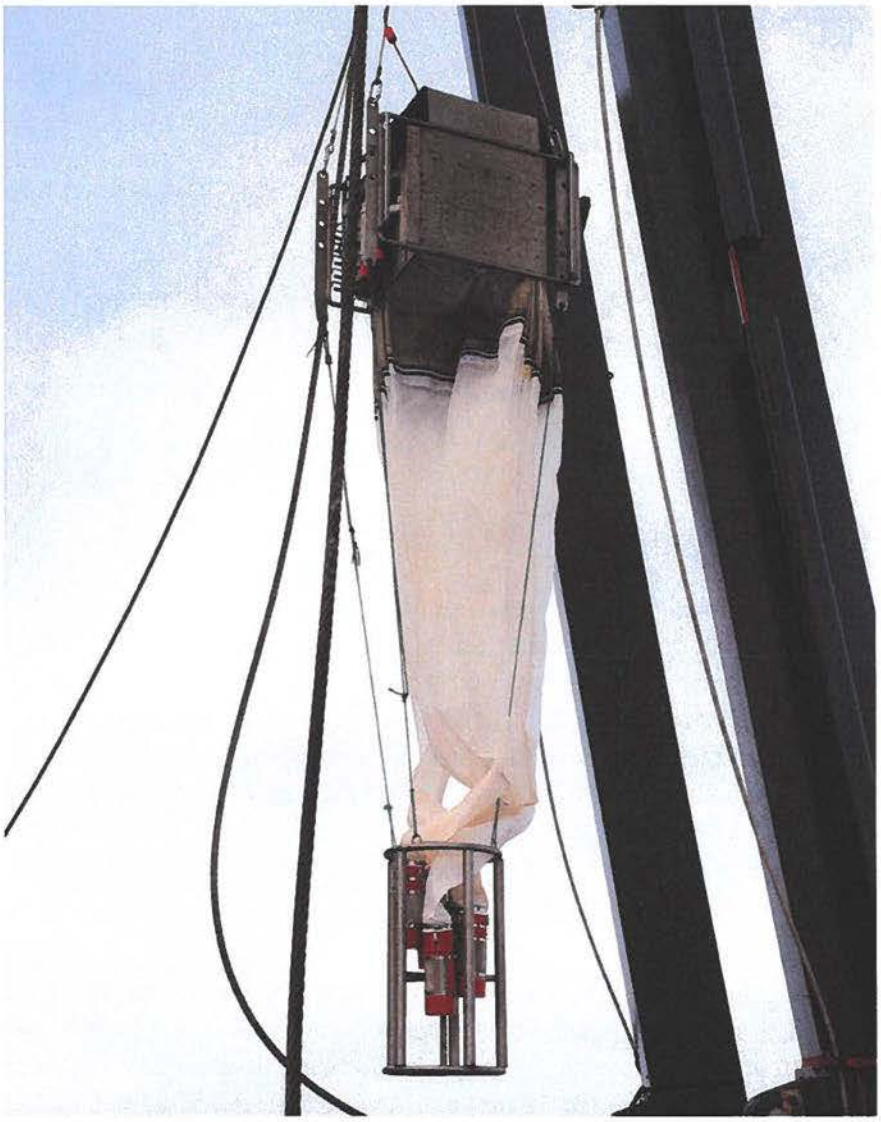

Figure 45. *Hydrobios MultiNet hanging from the A-frame at the aft-deck. The MultiNet is used for sampling mesozooplankton from five different depth intervals in the water column. Photo: Daniella Gredin.*

Figure 46. *Rasmus Swalethorp taking mesozooplankton biomass samples from the ice using a WP-2 net (45µm mesh size).*

11.3 Water sampling

From the ship, water was collected from eight depths (10, 20, 40, 60, 100, 150, 200 and 300 m) using a 24-bottle rosette sampler equipped with 7.5 liter Niskin type bottles (15 stations, Table 4). A subsample of these depths has also been sampled from ice borne stations with a 4 liter (sometimes 2.5 liter) Niskin type bottle (Table 5, Figures 47 and 48). Water was collected for nutrients, protozooplankton (dinoflagellates and ciliates) and chlorophyll. In addition, at 5 stations (Table 6) suspended fecal pellets were collected at 3 depths (20, 40 and 100 m) and water from the surface (10 m and 20 m) collected for fatty acids and isotopic analyses of its phyto- and protozooplankton content.

The samples for inorganic nutrients (phosphate, nitrate, nitrite, ammonia, and silicate) were collected directly from the water sampler and immediately frozen (-18°C) for post cruise analyses. Samples for protozooplankton were taken at 5 depths at 18 stations and preserved with 2% acidified Lugol's solution for analyses after the cruise. Water samples were taken at 30 stations for chlorophyll *a* measurements. Water (500 – 1500 ml) was filtered onto filters (GF/F, 10 µm and 50 µm) which were then extracted in 5 ml 96% ethanol for 24 hours and kept frozen for post cruise fluorometrical analyses.

Figure 47. *Rasmus Swalethorp taking water samples from different depths using a 4 l Niskin type bottle.*

Figure 48. *Kajsa Tönnesson and Steffen M. Olsen taking water samples using the generator powered CTD winch. In the front, the helicopter pilot Christian Schager watches out for Polar bears.*

11.4 Incubations

To understand how organic material and nutrients are channelled through the food web, it is important to quantify the rates (production, grazing, predation and sedimentation). Quantitative information on feeding rates is particularly important since they represent the major transfers of biomass within ecosystems. The methods to quantify grazing (predation) of zooplankton are numerous and during the LOMROG II cruise, several methods (gut fluorescence, gut content analyses and pellet production) have been used. Most methods have strengths and weaknesses. The choice of which method to use depends on the type of zooplankton and the ingested food (herbivory, omnivory and carnivory). The combination of several methods will give us important information on different aspects of food and feeding. Though some methods are more laborious than others (e.g. analyses of stomach contents) they are important since they can give information about food selection and prey-size preferences (or limitations).

Animals for experiments (Table 6) were obtained from the upper 100 m using a WP-2 net with a 450 µm mesh size. For the *in situ* growth experiments a net with a 45 µm mesh size was used. The content of the cod-end was then transferred to a thermo box and brought to the main laboratory on the fore-deck. Following experiments were conducted: Fecal pellet production, *In situ* pellet production, *In situ* growth rate experiments and Gut evacuation experiments. Water used in incubations was tapped from the seawater system (pumped from 10 m depth) located in the main lab onboard *Oden*. Animals for chemical analyses (carbon, nitrogen, isotopes, lipids and fatty acids) were collected from the same net hauls.

Figure 49. *A refrigerator used to store incubations at in situ temperatures (-1 to -1.7°C). In the top Pareuchaeta sp., Calanus glacialis and C. hyperboreus are stored individually in 620 ml bottles.*

11.4.1 Pellets Production Experiments

Pellets (egested material) are the part of the food that has not been absorbed by the digestive system of the animal. For copepods, which have pellets covered by a membrane, collection of fecal pellets is possible. Moreover, the number of pellets must show a clear relationship with feeding intensity and be independent of the type of food. To quantify ingestion, information about the pellet production rate and the relation between egested pellets and ingested food or absorption efficiency is needed.

Figure 50. *Kajsa Tönnesson sorts copepods for experiments.*

11.4.2 Pellet Production and Feeding Rates for Three Dominating Copepods

We conducted fecal production experiments for three of the most dominant copepods (*Calanus hyperboreus*, *C. glacialis* and *Metridia longa*) on several stations during the cruise (25 stations with *C. hyperboreus* and *C. glacialis*, and 17 stations with *M. longa*). *C. hyperboreus and C. glacialis* females were individually transferred to 620 ml polycarbonate bottles containing 100 µm filtered seawater (Figure 48). *M. longa* females were transferred to 650 ml fecatrons (with false 400 µm mesh bottom). The bottles/fecatrons were then incubated for 24 h at *in situ* temperature (approximately -1 to -1.7°C, Figure 49). After incubation the females length was measured and fecal pellets produced were counted and measured.

11.4.3 *In situ* Fecal Pellet Production

The fecal pellet production of the copepod community was measured through short time incubations conducted at 5 stations (Table 6). On deck subsamples of the cod-end were immediately distributed into 5 fecatrons (PVC tubes with 400 µm false mesh bottom) filled with filtered sea water (Figures 51 and 52). The copepods were incubated for 1-2 hours, and then both copepods and fecal pellets produced were preserved in acidic Lugol's solution. At 5 stations, water samples for the quantification of suspended fecal pellets were collected at 3 depths (20, 40 and 100 m). The water samples were concentrated on a 20 µm sieve, fixed in 2 % acidic Lugol's solution for post cruise analyses.

Figure 51. *Five 1.5 l fecatrons used to measure the fecal pellet production of the whole copepod community.*

11.4.4 Feeding Rates for *Pareuchaeta sp.*

Feeding rates for *Pareuchaeta* sp. were measured indirectly by estimating pellet production since experimental studies have shown a linear relationship between food intake and number of pellets defecated. Within 1 hour of collection, individual *Pareuchaeta* sp. females or copepodites were transferred by pipette into 620 ml polycarbonate bottles filled with 64 µm filtered seawater. The bottles were incubated at 72 hours at in situ temperature (-1 to -1.7°C). At the end of the incubations, the content was gently poured through a 50 µm sieve to collect animals and fecal pellets. The length of females or copepodites and the dimensions of the pellets were measured using a dissection microscope.

11.4.5 Gut Evacuation Experiment

A gut evacuation experiment with *Pareuchaeta* sp. was performed at one station in the Amundsen basin (Table 6). Within 1 hour of collection, 10 females were gently transferred with a pipette to three fecatrons (10 females per fecatron), each standing in a beaker containing 64 µm filtered seawater. The beakers were then incubated in a refrigerator close to *in situ* surface temperature (-1 to -1.7°C) for 72 hours (until complete gut evacuation was reached). Every 30 to 120 min, the fecatrons were transferred to new beakers, and the beaker content gently poured through a 50 µm sieve to collect the pellets.

The gut evacuation rate will be determined by a regression between the number of pellets remaining in the guts of the 10 animals in each fecatron against time. To our knowledge, this is the first report on fecal pellet production and gut evacuations rates for *Pareuchaeta* sp. in this area. Predation impact can be calculated based on the feeding rate, *Pareuchaeta* sp. abundance, prey abundance and prey production. Complementary studies to show possible selectivity will be performed through gut content analyses after the cruise.

11.4.6 *In situ* Growth Experiments

In situ growth rate experiments with young stages of copepods (copepodites) were conducted at five stations during the cruise (Table 6). Within a few hours of collection a fraction (160 -200 µm) of the copepod community was transferred into cans filled with 64 µm filtered seawater. Four replicate cans were then incubated for six days at *in situ* temperature (-1 to -1.7°C). At the end of the incubations, the content was gently poured through a 64 µm sieve to collect all animals. The samples were preserved in a 4% formalaldehyde/seawater solution for post cruise analysis.

11.5 Gut Analyses

11.5.1 Gut Fluorescence

The principle of the gut fluorescence method is that pigments of ingested algae can be quantitatively recovered (i.e. extracting pigments from algae in an organic solvent) from the animal. This gives a measurement of the amount of gut content, and knowing the turnover rate of the gut contents, the ingestion rate can be calculated. The main weakness of the method is the uncertainty about pigments destruction and its restriction to phytoplankton prey. Gut fluorescence was measured on females of *Calanus glacialis* and *C. hyperboreus* at 15 stations (Table 6).

After the collection, a sub-sample of copepods was immediately concentrated on a piece of 450 µm plankton net and frozen (-50°C). The samples were then stored in the freezer (-18°C) for further handling and analyses after the cruise. The rest of the cod end was poured into a tray and *C. hyperboreus* was gently collected and transferred into vials containing 5 ml 96 % ethanol (2 per vial) extracted for 24 hours and frozen (-18°C) for post cruise analyses. After the cruise frozen *C. glacialis* will also be transferred into vials with 96% ethanol (5 per vial). All samples will be analyzed for pigment (chlorophyll *a*) as described above.

Figure 52. *Kajsa Tönnesson takes down fecatron incubations carried out on the ice. She filters the copepods and their fecal pellets onto a 20µm filter and conserves them for later analyses.*

11.5.2 Gut Analyses

The diets of the chaetognaths (arrow worms), e.g. *Sagitta* spp. and *Eukrohnia hamata*, will be determined in the biomass samples collected from 29 stations along the cruise track (Table 4 and 5). To estimate the stomach content, each chaetognath will be dissected under microscope, and prey organism will be identified to species level and stage. Analyses of stomach contents of field sampled zooplankton are a common method for estimating ingestion rate of carnivorous zooplankton. Prey composition and production will be used to estimate predation pressure and selectivity.

11.5.3 Carbon, Lipids, Fatty Acids and Isotopic Analyses

At 22 stations different stages of *Paraeuchaeta* sp. were collected for dry weight and carbon measurements. Within 1-3 hours of collection, copepodites and adults were measured, washed in 0.7µm filtered seawater placed in pre-weighted tin capsules and frozen (–80°C) for post cruise analyses. Adult *Metridia longa* females were collected at 4 stations for dry weight, carbon and nitrogen measurements. The copepods were stored in filtered seawater for about 24 hours at *in situ* temperature in order for them to empty their gut. They were then washed in 0.7µm filtered seawater, placed in pre-weighted tin capsules and stored frozen (-80°C) for post cruise analyses. Carbon and nitrogen analyses are to be performed on a CHNS Elemental Analyser (EA 1110 CHNS CE instruments).

Additional *M. longa* females were put into glass tubes (4-5 per glass) and stored frozen (-80°C). Post cruise the amount of polar (phospholipid) and different non-polar lipid classes (triacylglycerol, wax esters, sterols) are to be determined through extraction in chloroform/methanol (2:1 vol.) followed by spectrophotometrical (polar) and HPLC (Dionex HPLC system, P680 pump, Gina 50 autosampler with a Alltech MKIII Evaporative Light-Scattering Detector) analysis (non-polar). Adult females of *Calanus glacialis*, *C. hyperboreus* and *M. longa* were collected at 5 stations for determination of their fatty acid and isotopic composition. The females were pre-stored in filtered seawater for approximately 24 hours, washed and placed individually in pre-weighed tin capsules (isotopic) and glass tubes (1 *C. hyperboreus*, 3 *C. glacialis* or 4-5 *M. Longa*) following the same procedure as for *M. longa* collected for carbon, nitrogen and lipid classes. The phyto- and protozooplankton from approximately 100 l of seawater collected at 10-20m was divided into three size fractions (0.7-20µm, 20-50µm, 50-90µm), filtered down onto combusted GF/F filters and stored frozen (-80°C) in tin foil or glass tubes.

Post cruise, the composition of different carbon and nitrogen isotopes and different fatty acids will be measured in the three copepod species and in the different size fractions of their possible food source. These profiles will them be compared to determine the predator-prey relationship.

11.6 References

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Station ID	Fecatron	*In situ*	Gut	*C. glacialis*	*C. hyperboreus*	*M. longa*	*Pareuchaeta* spp.	*Pareuchaeta* spp.	*In situ*
	incubation	pellet	fluorescence	FP	FP	FP	FP	gut evacuration rate	growth rate
Lomrog2_00101									
Lomrog2_heli_00201									
Lomrog2_heli_00301				X	X	X	X		
Lomrog2_heli_00401				X	X	X	X		
Lomrog2_00202			X	X	X	X	X	X	
Lomrog2_heli_00501							X		X
Lomrog2_heli_00601			X	X	X	X	X		
Lomrog2_00401		X		X	X				
Lomrog2_00501			X	X	X	X	X		
Lomrog2_00601				X	X				
Lomrog2_heli_00701									
Lomrog2_00701				X	X	X	X		
Lomrog2_00802	X		X	X	X	X	X		
Lomrog2_00901	X	X	X	X	X	X	X		X
Lomrog2_01002				X	X				
Lomrog2_heli_01001			X	X	X	X	X		
Lomrog2_01101	X	X	X	X	X		X		X
Lomrog2_01202			X	X	X	X	X		
Lomrog2_heli_01201			X	X	X		X		
Lomrog2_01301									
Lomrog2_heli_01401			X	X	X	X	X		
Lomrog2_01401	X	X		X	X		X		
Lomrog2_heli_01501				X	X	X	X		
Lomrog2_heli_01601			X	X	X		X		
Lomrog2_01502				X	X	X	X		
Lomrog2_heli_01701			X	X	X	X			X
Lomrog2_heli_01801			X	X	X	X	X		
Lomrog2_heli_02001			X	X	X		X		X
Lomrog2_01601	X	X	X	X	X	X	X		
Lomrog2_heli_02101				X	X	X	X		

Table 6. *List of experiments and in situ measurements conducted at different stations. Stations sorted by date. FP stands for fecal pellet production.*

12. Microbial Respiration in Arctic Sea Ice

By Jeff S. Bowman – University of Washington School of Oceanography, Seattle, USA

12.1 Methods

Our project seeks to establish how large a role microbial respiration plays in determining the concentration of CO_2 within both first-year and multi-year sea ice, and thus influencing the exchange of CO_2 between sea ice and the atmosphere. Ice cores were retrieved from both first year and multiyear ice floes at a total of 14 ice stations (a 15^{th} ice station was dedicated to sampling features of the ice surface). Ice flow locations and a short description are given in Table 7.

Station ID	Date	Latitude	Longitude	CO_2 (ppm)	Comments
LOMROG09-Ice1	3-Aug-09	83.01258N	18.85367E	395.6	Multiyear ice
LOMROG09-Ice2	4-Aug-09	84.46333N	19.45667E	383.6	Multiyear ice
LOMROG09-Ice3	8-Aug-09	88.25067N	53.62550E	382.8	Multiyear ice
LOMROG09-Ice4	10-Aug-09	88.37566N	65.72520E	384.6	Multiyear ice
LOMROG09-Ice5	12-Aug-09	88.53008N	134.83075E	381.1	Multiyear ice
LOMROG09-Ice6	14-Aug-09	88.15280N	156.97520E	376.8	Multiyear ice
LOMROG09-Ice7	16-Aug-09	89.22831N	157.97850E	380.9	Multiyear ice
LOMROG09-Ice8	18-Aug-09	88.49328N	178.40850W	374.5	First year ice
LOMROG09-Ice9	19-Aug-09	88.42214N	177.28860W	388.5	First year ice
LOMROG09-Ice10	21-Aug-09	89.47536N	128.51161W	383.5	With DNA of the Polar Seas, multiyear ice
LOMROG09-Ice11	23-Aug-09	89.88600N	95.59417W	-	Multiyear ice
LOMROG09-Ice12	26-Aug-09	88.70621N	69.74980W	392.6	With DNA of the Polar Seas, multiyear ice
LOMROG09-Ice13	29-Aug-09	87.74353N	13.51784E	-	First year ice
LOMROG09-Ice14	31-Aug-09	86.08367N	15.64067E	386.6	Multiyear ice
LOMROG09-Ice15	2-Sep-09	84.84218N	14.66989E	-	Surface feature sampling only

Table 7. *Sampling locations*

Figure 53. *Ice coring procedure. A hand powered KOVACS ice corer was used to create a hole for in situ measurements of CO_2 flux and to obtain samples for biological analysis. To prevent contamination cores were placed in a trench cleared of snow. Before bagging for transport the exterior of each core section was shaved away with an ethanol sterilized saw. Photo: Matthias Wietz.*

To measure the flux of CO_2 *in situ,* a hand powered 9 cm KOVACS ice core drill was used to create a 0.5 m deep hole (Figure 53). A GMP343 diffusion model infrared CO_2 probe (Vaisala, Finland) with an air tight rubber gasket was inserted into the hole (Figure 54). The CO_2 probe was controlled onsite by a laptop running the PuTTy terminal application. Care was taken to insure a tight seal between the gasket and the surrounding ice. The concentration of CO_2 within the headspace between the ice freeboard and the probe was monitored during the duration of the station visit on one minute intervals using a 30 second averaging filter. With this filter noise was reduced to ± 1 ppm.

To determine the physical characteristics of the sea ice, an ice core was removed and drilled along its length at regular intervals. The interior temperature was measured through the drill holes by a thermocouple. A second core, handled aseptically, was obtained for biological analysis. These analyses include cell count (DAPI), aerobically active cell count (CTC), community fingerprint (T-RFLP or ARISA), chlorophyll content, particulate and dissolved organic carbon and $\delta^{13}C$ values, and measurement of dissolved and particulate extracellular polysaccharide substances (EPS). A third core was obtained for incubation experiments. On site, a 140 cm "average" of this core (representative sections of the top, middle, and bottom of the core totaling 140 cm) was placed in a dark airtight ABS plastic incubation chamber which was immediately capped with the CO_2 probe and gasket. Five 10 cm sections of this core were retained for additional incubation experiments. An atmospheric air sample was obtained at each site for carbon stable isotope analysis in a combusted, Teflon capped glass vial which had been previously flushed with CO_2 free artificial air.

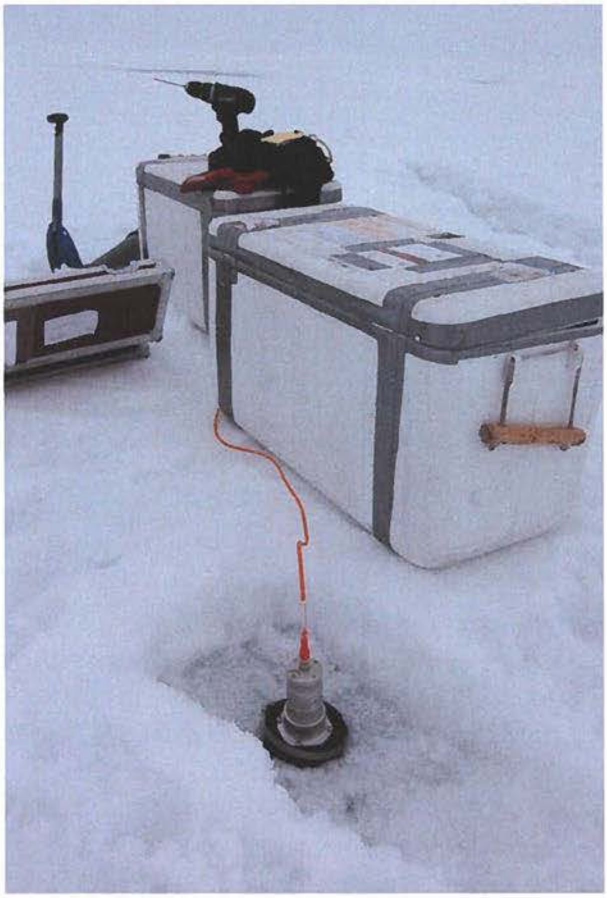

Figure 54. *In situ measurement of CO_2 flux. A rubber gasket was used to create an airtight seal between the GMP343 probe and ice. The probe was left in place for the duration of each ice station, which varied between 1 and 3 hours.*

On return to *Oden,* the ice core incubation chamber was placed in a refrigerator held at 1˚C. Ice prepared at -80˚C was used to lower the temperature to 0˚C or slightly cooler. The concentration of CO_2 in the headspace of the incubation chamber was monitored over approximately 44 hours using a 5 minute sampling interval and a 30 second averaging filter. Additional 10 cm sections from the third core were placed in gastight Tedlar bags (Analytical Specialties, USA) along with a combusted glass vial and Teflon cap (Figure 55).

The atmosphere was removed from the bags with a vacuum pump and the bags were re-inflated with CO_2 free artificial air. After several days of dark incubation at -1.5˚C the glass vials were capped without unsealing the bags. Values for $\delta^{13}C$ of CO_2 produced during the incubation period will be determined by GC-IRMS to evaluate respiratory activity. Sections (approximately 20 cm in length) designated for filtration from the second core were melted into 1 l of 0.2 µm sterile filtered artificial seawater (ASW). This melting procedure maintained the salinity at around 20 psu (approximate salinity of brine channels within

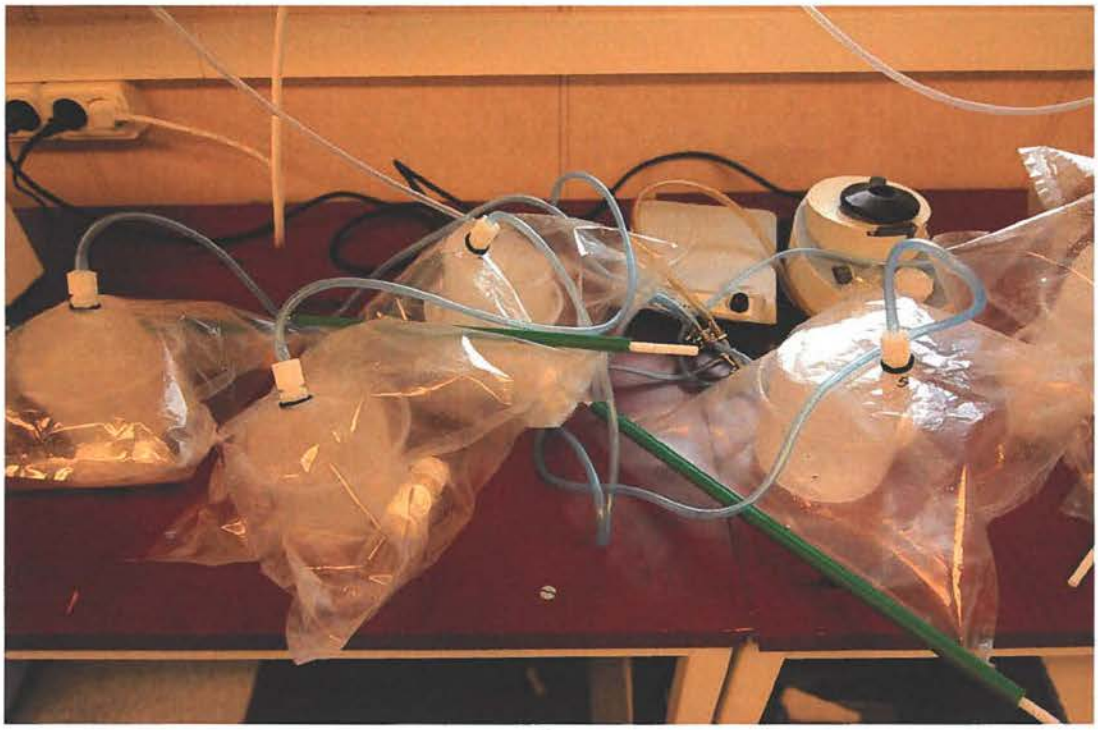

Figure 55. *Use of gastight bags to measure $\delta^{13}C$ of CO_2 released from sea ice. The glass vial and Teflon cap can be seen inside each Tedlar bag. The silicone tubing running from each bag connects to a manifold which controls the flow of artificial air during bag inflation.*

the ice, see Appendix IV) through the melting process. Once melted the total volume of ASW and sample was determined, and measured quantities of the melt solution were filtered for each analysis (Table 8). All analyses will be conducted at the University of Washington's School of Oceanography, Seattle, USA except for the stable isotope analysis. This analysis will be conducted at the Stable Isotope Lab of the Department of Earth and Space Sciences, University of Washington.

In addition to the sampling described above, two sets of cores were recovered for environmental genomics in collaboration with the LOMROG II project DNA of the Polar Seas (see locations in Table 7). These cores were handled aseptically, with an additional measure of care given to preventing contamination. Core sections were removed from the ethanol sterilized core barrel onto autoclaved aluminum foil. The outer portion of the ice core was removed with an ethanol sterilized saw blade and the core sections were immediately packaged in double, sterile bags in an ethanol sterilized cooler. The core sections were melted into 0.2 µm sterile filtered ASW before further processing.

Analysis	Volume	Filter type	Notes
Cell count (DAPI)	40 ml	NA	Fixed with formaldehyde to 2% final concentration.
Aerobically active cell count (CTC)	100 ml	0.2 µm black polycarbonate, 47 mm	Concentrated on filter, resuspended in ASW for CTC incubation. Fixed with formaldehyde to 2% final concentration.
DNA	500 ml	0.2 µm nitrocellulose, 47 mm	Washed through with SET buffer.
Chlorophyll	200 ml	combusted GFF, 25 mm	
EPS	50 ml	0.45 µm polycarbonate, 25 mm	Filtrate captured for dissolved EPS.
$\delta^{13}C$	200 ml	combusted GFF, 25 mm	Filtrate captured for dissolved carbon.

Table 8. *Procedures for biological analysis*

12.2 Results

Physical characteristics of the recovered ice cores are shown in Appendix IV.1. A "slush layer" was noticed in most of the cores recovered, occurring at approximately 1 m intervals in longer cores (Figure 56). The locations of these layers (origin uncertain) are shown in the Appendix. Preliminary *in situ* CO_2 measurements are shown in Appendix IV.2. The signal from these measurements was highly variable, with no obvious correlation to ice depth or type (first year or multiyear). As additional biological parameters become available we hope to gain some understanding of the mechanisms shaping these signals. Preliminary results from the core incubations are shown in Appendix IV.3. As with the *in situ* measurements, there was a wide variation in signal. In all cases however, the sea ice was initially undersaturated in CO_2 and readily absorbed CO_2 from the incubation chamber head space. After equilibrium was reached an increase in CO_2 concentration within the headspace (hypothesized to be the result of microbial respiration) was apparent in all incubations except for LOMROG09-Ice13. The timing and strength of this increase varied widely between cores.

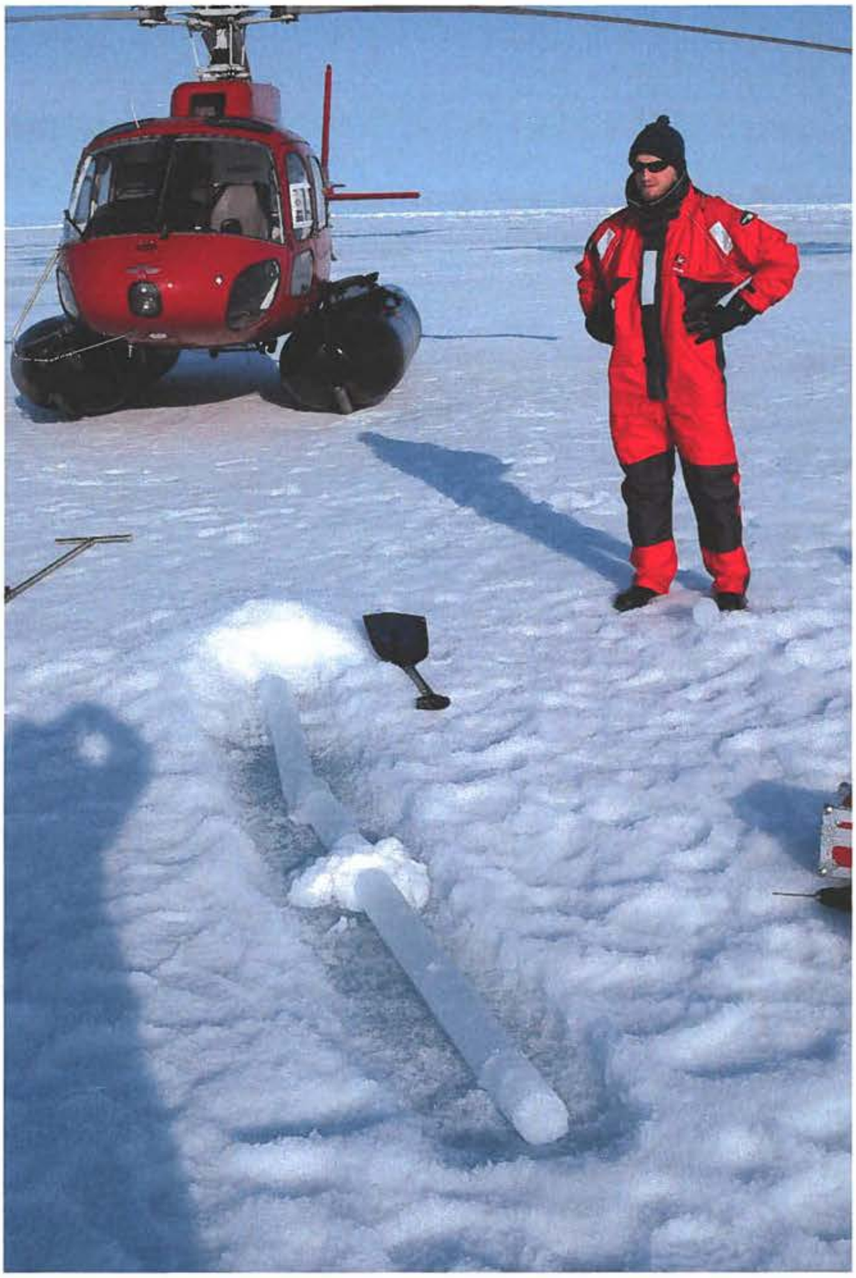

Figure 56. *Slush layer within multiyear ice core. This photo from LOMROG09-Ice2 clearly shows the slush layer located between 110 cm and 150 cm. Total length of the core pictured is 285 cm.*

13. Bacterial Communities and Bioactive Bacteria in Arctic Marine Environments

By Matthias Wietz - Technical University of Denmark - National Institute of Aquatic Resources (DTU Aqua)

13.1 Introduction

Microorganisms represent the main form of biomass in the marine environment. The diversity, activity and ecological importance of marine microbes have therefore become key research subjects over the previous years, greatly enhancing our knowledge on the structure and function of marine microbial communities. Current research on the physiological capacities of marine bacteria yields insights into bacterial interactions and their ecological role in biogeochemical and nutrient cycling. Increasingly, the marine environment and its inhabiting microbes are also regarded as a source of novel chemical compounds with a potential value in biotechnology.

The present study addresses the investigation of marine bacterial communities in largely unexplored North polar habitats, as well as the isolation of *bioactive bacteria* from these locations. The term bioactive bacteria refers to marine bacterial strains that produce antibiotic substances inhibiting or killing other (disease-causing) microorganisms. Finding of novel bioactive bacteria would be of great value for the pharmaceutical sector as well as for food and aquaculture industries, who share an increasing need for novel antibiotics needed to combat multidrug-resistant pathogens. The marine environment is becoming a focus in the search for such antibacterial compounds (Jensen & Fenichal, 2000; Gram et al., 2009), and polar habitats such as sea ice have been suggested as a potential source (Thomas & Dieckmann, 2002). Although 90% of the Earth's oceanic waters have a temperature of 5°C or less, relatively few scientific studies have investigated polar waters for biotechnologically relevant bacteria. This expedition was thus a unique opportunity to obtain unknown strains that produce bioactive compounds at low temperatures. The isolation of Arctic bioactive bacteria was complemented by bacterial diversity studies on bacterial communities collected from Arctic waters and sea ice. Their investigation by molecular fingerprinting techniques will yield valuable insights into the structure of bacterial communities and the microbial ecology in Arctic marine environments. The samples collected during LOMROG II represent a valuable complement to the collection of bioactive bacteria and marine bacterial communities that our group established during the global Galathea-3 expedition.

13.2 Scientific Methods

Some scientific methods (see the section *11.2. and 11.3* for a detailed description) could not be performed during the expedition, mainly due to work safety but also for scientific reasons:

1. Growing of bacteria on solid agar medium, including the determination of total viable counts, was not an option aboard *Oden* since very sterile conditions must be achieved during this work. This is only possible in a bacteriological lab.
2. The "replica-plating" technique (see below) needed to identify the bioactive strains from the raw environmental isolate was also not an option, since this would have involved the growing of pathogenic bacterial strains aboard the ship.
3. The molecular characterization of bacterial communities in water and sea ice is preferably done in a bacteriological lab, since various harmful chemicals are involved. Furthermore, planned molecular experiments require a fluorescence microscope. Installation of such equipment was however impossible, since the performance and durability of the microscope would have been adversely affected by ship movements and vibrations.

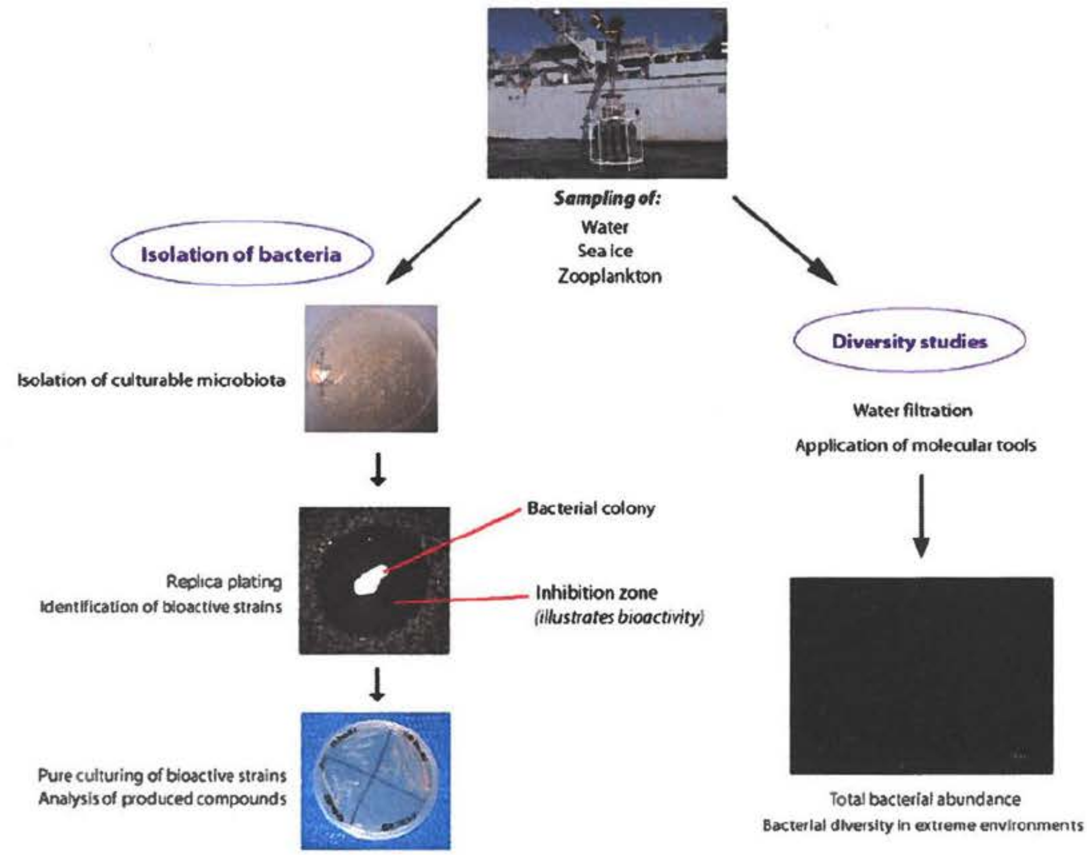

Figure 57. *Overview of the experimental approach.*

For the above reasons, raw environmental samples were preserved instead for later analysis at the home institution. Bacterial samples were transferred to a protective freeze-storage solution at –80°C. By this means, most bacteria are kept in a dormant state, from which they can be revived later. Detailed studies on the isolates will be performed with revived bacteria under controlled and sterile laboratory conditions at the home institution. Likewise, sampled bacterial communities were preserved at –80°C after being captured on membrane filters.

As indicated above, the scientific work is divided into a ship-based part, focusing on the collection and preparation of various samples for subsequent analyses, and a DTU-based part focusing on the detailed characterization of obtained samples. An overview of the experimental approach is given in Figure 57.

13.3 Scientific Work on Board

13.3.1 Collection of Raw Environmental Samples

Environmental samples including water, zooplankton, sediment, and sea ice (Table 9) were collected by standard procedures (see relevant sections in this report for a detailed description of sampling procedures) and kindly shared with the present project for bacteria isolation and community studies. Water samples were taken from various depths using a CTD rosette equipped with 7 l sampling bottles (performed by Steffen M. Olsen and Leif Toudal Pedersen). Live zooplankton was collected from the water using plankton nets (performed by Kajsa Tönnesson and Rasmus Swalethorp). Sediment samples were obtained using a piston sediment corer (performed by Ludwig Löwemark, Åsa Wallin and Markus Karasti). Sea ice cores from pack ice were obtained with an ice core driller (performed by Jeff Bowman and Matthias Wietz).

13.3.2 Preparation of Raw Samples for Isolation of Bacteria

Water

Per sample, triplicate subsamples (0.75 or 1 ml each) were mixed with freeze-storage solution (60% glycerol in sterile MilliQ water) and frozen at –80°C. For selected samples, an additional subsample was transferred to a liquid bacterial growth medium (50% Marine Broth) in closed tubes and incubated at 20°C.

Sea ice

On the coring site, drilled ice cores (first-, second-, or multiyear ice) were cut into 20 cm subsections, which were scraped from the outside to remove attached snow and contaminating material. Sections were transported back to *Oden* inside sterile plastic bags while kept on ice. Aboard *Oden* sections were melted in an equal volume of sterile-filtered artificial seawater (47 psu), with melting preferably done at 4°C. From selected sections from the upper, middle and bottom parts of a core, triplicate sub samples (0.75 or 1 ml each) were mixed with freeze-storage solution (60% glycerol in sterile MilliQ water) and frozen at –80°C. For selected samples, an additional subsample was transferred to a liquid bacterial growth medium (50% Marine Broth) in closed tubes and incubated at 20°C.

Zooplankton

Larger zooplankton (e.g., snails, ctenophores) were rinsed with sterile seawater and swabbed using sterile cotton swabs. Swabs were transferred to 4 ml of sterile-filtered seawater and vortexed vigorously to remove bacteria from the cotton to the water. Triplicate subsamples of this homogenate (0.75 or 1 ml each) were mixed with freeze-storage solution (60% glycerol in sterile MilliQ water) and frozen at –80°C. Smaller zooplankton (e.g. copepods) were rinsed with sterile seawater and ground mechanically using a sterile mortal and pestle within 4 ml of sterile-filtered seawater. Triplicate subsamples of this homogenate (0.75 or 1 ml each) were mixed with freeze-storage solution (60% glycerol in sterile MilliQ water) and frozen at –80°C. For selected samples, an additional subsample was transferred to liquid bacterial growth medium (50% Marine Broth) in closed tubes and incubated at 20°C.

Sediment

Approx. 3 ml of sediment were extracted from an opened core using a sterile 10 ml syringe. The resulting sample consisted of a sediment piece of ~ 3 cm length and 1 cm diameter, of which only the middle cm within the syringe was used while the upper and bottom sections were discarded. Sediment pieces were transferred to freeze-storage solution, vortexed vigorously and frozen at –80°C.

13.3.3 Filtration of Water and Melted Sea Ice for Bacterial Community Analyses

Raw water and melted sea ice samples (Table 9) were vacuum-filtrated onto polycarbonate membrane filters (diameters of 25 and 47 mm) with 5 µm (for capture of particle-associated bacteria) and subsequently 0.2 µm pore size (for capture of free-living bacteria). Samples were treated differently according to the molecular tools to be subsequently applied. Filters for CARD-FISH were fixed with 2% paraformaldehyde and frozen at –80°C. Filters for DNA extraction were directly frozen at –80°C.

Station	Position	Source	Sample description	Analysis	
				Isolation	Diversity
LOMROG09-BAC01	81.94083 N	Water	CTD (10 m depth)	x	x
	16.69166 E				
LOMROG09-BAC02	83.01258 N	Ice core	Multiyear, upper section (0-20 cm)	x	x
	18.85367 E				
LOMROG09-BAC03	84.46333 N	Ice core	Multiyear, upper section (0-20 cm)	x	x
	19.45667 E		Lower section (180-200 cm)	x	x
LOMROG09-BAC04	85.87666 N	Zooplankton	Copepods (*Calanus hyperboreus*)	x	
	20.46566 E	Ice algae	Pieces of chain-forming diatoms	x	
LOMROG09-BAC05	87.19650 N	Zooplankton	Snail (*Clione* sp.)	x	
	20.52900 E		Arrow worm (*Eukrohnia hamata*)	x	
			Copepods (*Calanus glacialis*)	x	
LOMROG09-BAC06	88.19916 N	Zooplankton	Ctenophore (*Mnemiopsis* sp.)	x	
	59.13233 E		Ctenophore (*Beroe* sp.)	x	
LOMROG09-BAC07	88.19916 N	Water	CTD (10 m depth)	x	x
	59.13233 E				
LOMROG09-BAC08	88.25067 N	Ice core	Multiyear, middle section (150-170 cm)	x	x
	53.62550 E				
LOMROG09-BAC09	88.37566 N	Ice core	Second-year, upper section (0-17 cm)	x	x
	65.72520 E				
LOMROG09-BAC10	88.55883 N	Water	CTD (10, 60 and 300 m depth)	x	x
	117.87066 E				
LOMROG09-BAC11	88.56533 N	Water	CTD (10, 60 and 300 m depth)	x	x
	133.26783 E				
LOMROG09-BAC12	88.54866 N	Zooplankton	Ctenophore (probably *Beroe* sp.)	x	
	133.26783 W				
LOMROG09-BAC13	88.53008 N	Ice core	Multiyear, bottom section (410-430 cm)	x	x
	134.83075 E				
LOMROG09-BAC14	88.14666 N	Water	CTD (10, 60 and 300 m depth)	x	x
	157.12316 E				
LOMROG09-BAC15	89.22831 N	Melt water	Salinity: 0 psu	x	x
	157.97850 E	Ice	Multiyear, bottom section (385-405 cm)	x	x
		Snow		x	x
LOMROG09-BAC16	88.29400 N	Sediment	Various strata	x	
	178.45000 W				
LOMROG09-BAC17	88.49328 N	Ice	First-year, bottom section (120-140 cm)	x	
	178.40850 W				
LOMROG09-BAC18	88.42214 N	Melt water	Salinity: 4 psu	x	x

Table 9. *Samples collected during LOMROG II and planned subsequent analyses at the home institution (isolation of bioactive bacteria and/or diversity studies).*

Station	Position	Source	Sample description	Analysis	
	177.2886 W				
LOMROG09-BAC19	88.42214 N	Ice	First-year, bottom section (110-128 cm)	x	X
	177.28860 W				
LOMROG09-BAC20	88.84483 N	Zooplankton	Amphipods (*Termisto* sp.)	x	
	156.27416 W		Copepods (*Pareuchaeta* sp.)	x	
LOMROG09-BAC21	89.47536 N	Meltwater	Salinity: 0 psu	x	X
	128.51161 W				
LOMROG09-BAC22	89.16770 N	Water	CTD (10 and 60 m depth)	x	X
	130.29400 W				
LOMROG09-BAC23	89.47536 N	Snow	from ice surface	x	X
	128.51161 W	Meltwater	Salinity: 0 psu	x	X
		Ice	Multiyear, upper section (0-20 cm)	x	
			Middle section (140-160 cm)	x	
			Bottom section (280-300 cm)	x	X
LOMROG09-BAC24	89.88600 N	Meltwater	Salinity: 2-3 psu	x	
	95.59417 W	Snow	from ice surface	x	X
		Ice core	Multiyear, upper section (0-20 cm)	x	
			Middle section (70-90 cm)	x	
			Slush layer (100-130 cm)	x	X
			Bottom section (220-240 cm)	x	X
LOMROG09-BAC25	89.35416 N	Deep water	CTD (4134 m depth)	x	X
	53.40016 W				
LOMROG09-BAC26	88.72933 N	Water	CTD (10 and 60 m)	x	X
	58.67183 W				
LOMROG09-BAC27	88.70621 N	Ice core	Multiyear, slush layer (80-110 cm)	x	X
	69.74980 W		Bottom section (330-350 cm)	x	X
LOMROG09-BAC28	88.68383 N	Zooplankton	Copepods (*Calanus hyperboreus*)		X
	20.95466 W				
LOMROG09-BAC29	86.08367 N	Ice core	Multiyear, bottom section (340-360 cm)	x	X
	15.64067 E	Dirty ice		x	
LOMROG09-BAC30	86.66300 N	Deep water	CTD (4375 m depth)	x	X
	15.93750 E				
LOMROG09-BAC31	84.84218 N	Frost flowers	from pond surface	x	
	14.66989 E				

Table 9. (cont.) *Samples collected during LOMROG II and planned subsequent analyses at the home institution (isolation of bioactive bacteria and/or diversity studies).*

13.4 Follow-up Work at the Home Institution (DTU Aqua)

The detailed analysis at DTU Aqua will consist of individual steps addressing the (i) isolation of bacteria from environmental samples, (ii) screening of obtained isolates for bioactivity, and (iii) taxonomic, physiological and chemical characterization of selected isolates. Supporting culture-independent studies using molecular techniques will characterize the composition of bacteria communities at selected sites from where bioactive isolates were obtained.

13.4.1 Isolation of Bacteria

Revival and isolation of bacteria from cryopreserved raw samples will be done using a selection of bacterial growth media. Raw samples will be thawed from –80°C and streaked on various agar mixtures adjusted to the nutrient requirements of different bacterial groups. Our strategy will target different groups known to harbour strains producing potent antimicrobials:

1. Heterotrophic bacteria including the groups most commonly isolated during Galathea 3 will be isolated using general marine bacterial growth medium at various temperatures.
2. Marine actinobacteria will be isolated using actinobacteria-specific medium. This bacterial group is regarded as a promising source of novel bioactive metabolites (Bull & Stach, 2007) and already recognized as producers of potent antibiotics (e.g. streptomycin).
3. Oligotrophic and psychrophilic bacteria will be isolated using specific, low-nutrient media at low temperatures. There has been little work done on the bioactivity of such extremophilic bacteria, which suggests an increased chance that novel bacteria including bioactive strains will be isolated from the LOMROG II samples.

13.4.2 Bioactivity Testing

From the raw isolates containing a multitude of different bacteria, those strains producing bioactive compounds will be identified by using the *replica-plating* technique. This includes the transfer of bacterial biomass from selected agar plates onto plates containing either *Vibrio anguillarum* (fish pathogen) or *Staphylococcus aureus* (human pathogen). Bioactive strains will show their activity by killing the target pathogen, which can be detected by the naked eye on replica plates by the formation of inhibition zones (Figure 57). Bioactive strains will be pure-cultured from the raw isolate to enable in-depth studies of their taxonomic identity, physiological properties and metabolite profile. Chemical analyses will investigate bacterial culture extracts by HPLC and mass spectroscopy to identify compounds that are responsible for the bioactivity.

13.4.3 Bacterial Diversity Studies

Bacterial abundance and diversity in Arctic marine environments will be screened by molecular tools. Total cell numbers will be determined using DNA stains that label bacterial cells with a fluorescent compound, which can be detected by fluorescence microscopy. More detailed insights into the composition of bacterial communities will be achieved by techniques such as CARD-FISH, enabling the detection, identification, and quantification of bacteria in environmental samples. The technique involves the application of small molecules (probes) which bind to certain structures within bacterial cells. We will apply different probes that are specific for certain "target" bacteria of interest. Since the probes are labeled with an enzyme, addition of the enzyme's substrate (labeled with a fluorescent compound) will lead to a deposition of fluorescent substrate inside those cells that have bound the probe. Fluorescence microscopy can then be used to detect those cells, which will emit a bright light.

Additional staining of the sample with a general fluorescent DNA stain will label all other bacteria in the sample that have not bound the probe with a different color. Counting the fractions of differently colored bacteria will enable a quantification of the cell fraction that has bound the probe. Such insights are valuable for microbial ecology studies addressing the distribution of marine bacteria, interactions with other microorganisms, and potential ecological implications. We will apply probes that are specific to (i) higher bacterial groups commonly found in marine waters; (ii) microbes specialized to the Arctic environment, and (iii) groups harboring bioactive bacteria. This analysis will provide insight into the structure and ecology of highly adapted bacterial communities thriving in extreme polar environments.

13.5 Results and Outlook

Since the cultivation of live bacteria as well as molecular studies aboard *Oden* were not an option, no results are so far reportable. Revival and screening of obtained bacteria will be performed within 2-3 months after the expedition. These tests will indicate the number of bioactive strains obtained, and allow a rating of their bioactivity. Within the next half year, more detailed experiments will follow addressing the physiology, taxonomic identity and chemistry of obtained strains.

The most bioactive strains will be implemented in an ongoing multidisciplinary research project at DTU Aqua and other Danish universities focusing on bioactive bacteria from the World's Oceans. This project is based on samples from the Galathea 3 expedition, and the bioactive strains obtained during LOMROG II will represent a valuable complement to our global library of bioactive microbes which so far lacks strains from the high Arctic Ocean.

13.6 References

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14. DNA of the Polar Seas

By Jens Blom & Nikolaj Blom - Center for Biological Sequence Analysis (CBS), Technical University of Denmark (DTU) (NB currently at Novozymes)

14.1 Introduction

The overall goal of the project "DNA of the Polar Seas" is to compare and establish a baseline for the genetic repertoire of microbial communities of various polar region environments: the deepest and coldest parts of the oceans, snow samples and sea ice cores. The latter two sample types are the results of recent discussions with other research groups, both in Denmark (E. Willerslev, snow samples) and during the actual LOMROG II cruise (J.Bowman, University of Washington, Seattle, Microbial Respiration in Sea Ice & Sea Ice Core Metagenomes, see chapter 11).

Only about 1% of microbial species from environmental samples can be grown under standard laboratory conditions, thereby leaving the remaining 99% unexplored. However, this fraction can be examined by analyzing the DNA – the genome content – instead of the living organisms, a scientific approach known as environmental genomics or metagenomics.

This approach requires a relatively high amount of DNA to be acquired directly from the sample. To increase the total amount of DNA per sample and because microbial cell count decreases with an increase in depth, large volumes of water, in particular from the deep parts, are needed. Often, more than 100 liters were sampled from the deepest parts (4000+ m).

To capture the microorganisms from the marine, snow or ice samples, the main procedure consists of a series of filtration steps. The resulting filters are re-suspended in buffer and stored at -80 C onboard *Oden* until the end of the cruise. From the captured microorganisms, the entire pool of DNA is extracted and sequenced using state-of-the-art high-throughput sequencing technology (454 or Solexa). The following bioinformatics analysis then allows for the identification of novel biochemical pathways, genes and enzymes that are presumed to function under high pressure, high salinity or low temperature. These findings can be correlated with the environmental and climatic parameters and also point to novel enzymes that may have use in technical industries, *e.g.* as cold-active fat-digesting enzymes for washing detergents or energy-saving catalysts for a number of industrial processes.

Already a number of samples taken during the Danish Galathea 3 marine expedition (2006-2007) have been analyzed using various sequence-based methods. A phylogenetic analysis (based on 16S-rRNA gene sequencing) has revealed surprising differences and similarities between microbial communities from various locations and depths. The opportunity for this project to obtain true Arctic samples as part of the LOMROG II cruise represented a unique chance to enable a more complete data set which would truly show the differences and similarities between Arctic and Antarctic marine microbial environments as well as highlighting the impact of aging of cold abyssal water masses in the Arctic on the community.

14.2 Scientific Methods

For sea water sampling, the CTD-coupled water sampler rosette of 24 Niskin-type 7.5 liter bottles was used. As far as possible, water was drawn aseptically (discarding the first 100 ml) using pvc tubes into sterile plastic bags (up to 5 bottles, 35 liters, were combined in a single bag), which were enclosed in a 70 liters hard plastic box, closed off and stored temporarily until further processing in the main laboratory. A total of 28 to 168 liters of sea water was processed at each sea water/CTD sample station.

Snow samples were collected by helicopter excursions on the sea ice, where a clean and milliQ-rinsed snow shovel was used to fill a 10 liter (rinsed) bucket, which was then emptied into sterile plastic bags, ~ 30 liters of snow in each. Two bags of 30 liters were then enclosed in a 70 liter closed plastic box for further transportation. A total of 120 liters of snow was collected each time. This was allowed to melt in the lab for 24-36 hours before filtration.

Ice core samples were collected in collaboration with Jeff Bowman and the project "Microbial physiology of sea ice" using a 9-cm Kovacs ice corer. Between 5 meters and 9 meters of combined, total ice cores (2-3) were collected at each station. They were cut into pieces of 20-30 cm and stored in sterile plastic bags (triple layered due to the high risk of rupture by the sharp ice). Once in the laboratory, a specified volume of artificial sea water of defined salinity was added to the melting cores to ensure an acceptable final salinity. After complete melting (4-5 days) the melt water was filtered using the standard procedure.

Filtration of sea water or melt water from snow or ice cores was performed using the same procedure. Each bag of water was processed individually through the serial filtration setup. Before each new sample type, the prefilter setup was rinsed by pumping 1 liter of sterile milliQ water through the system. After the prefilter had been installed in the filter holder, the first 0,5 liter of sample water was pumped through and discarded before the outlet tube was connected to the final cartridge filter (see Figure 58).

After filtration of all bags from the same environment (*e.g.* same depth) the 142 mm membrane prefilter (2,0 um) and the 0,2 um cartridge filter were stored. In a few cases, mainly working on snow samples, the prefilter clogged several times due to soot particles, and had to be changed (up to four times). From the prefilter, a small piece (ca. 5x5 mm) was cut out and stored in a 1 ml 3% Glutaraldehyde solution in a cryotube for further electron microscopy. The rest of the prefilter was stored in 10 ml RNAlater buffer solution in a 10 ml Falcon tube for further DNA extraction. The 0,2 um cartridge (final) filter was drained and closed off with parafilm, then overlaid with 30 ml of sterile Tris-EDTA-Sucrose buffer using a syringe. The glutaraldehyde samples were kept at +4 °C refrigeration, while the RNAlater and Tris-EDTA-Sucrose samples were initially frozen at -20 °C , then transferred to -80 °C storage.

Figure 58. *Filtration setup in Oden main lab. Water sample is pumped via tube at right through prefilter and final filters on tripods.*

14.3 Results

The objective of getting a minimum of four deep sea water samples from the Arctic Ocean was met. A total of 18 stations were sampled: 13 from the ship, 5 on the ice (see Table 10). Including various depths at the same station, a total of 25 samples were obtained, including 3 snow and 2 ice core samples. The deepest samples were taken at 4300 meters, comparable to the deepest sample previously taken near Antarctica in the Southern Ocean at 4200 meters. In contrast to the relatively young Antarctic bottom water (AABW), the water mass from the Makarov basin represents a much older environment, which may have an impact on the microbial communities present.

The stations in the Arctic Ocean were distributed along the cruise track and span water masses from both the Nansen and Amundsen basins, from the Makarov basin, and from the intra-basin of the Lomonosov Ridge, thus representing a wide diversity of marine environments encountered.

In general, three types of water masses were sampled (see Figure 59): 1) Arctic Ocean Deep water from depths between 2000 and 4300 meters with salinities above 34.9 psu and temperatures ranging from -0,2 to -0,7°C; 2) warmer Atlantic Layer water masses from 300 to 350 meters with salinities below 34.9 psu and temperatures ranging from 0,8 to 1,2°C and; 3) upper ocean water from 50 meters with variable salinity between 30 and 34 psu and temperatures between -1,8 and -1,4°C, largely representing a deeper remnant winter mixed layer below the upper, thin and fresh summer ice melt layer.

These three sample sets represent water with variable recirculation timescales, where the upper ocean water samples are modified annually by wintertime convection, whereas the Atlantic layer is renewed on timescales of years to a decade, depending on location and linked to the different recirculating cells of the Atlantic layer in the Arctic Ocean. The time scale to associate with each sample will be closely linked to the temperature, with older water having colder temperatures. Arctic Ocean deep water renewal is not well quantified, but is multi-decadal for the Amundsen and Nansen Basins and most likely multi-centennial to millennial for the Canadian Basin deep water, which was sampled here in the Makarov Basin. The difference in time-scale indicating when the water has been exposed to the surface and modified by air-sea exchanges may have an impact on microbial communities and will be studied further. In this respect the samples from the Makarov Basin have aged significantly more than any sample collected in the abyss of the Southern Ocean.

Table 10. *Summary of sample data for the project "DNA of the Polar Sea", showing project ID, cruise-CTD-ID, date, position, sample type, total depth, sample depth, sample volume, sample temperature and sample salinity.*

Project ID *LOMROG09-*	CruiseID *lomrog2_ctd*	Date	Latitude	Longitude	Sample type	Total depth (m)	Sample depth (m)	Volume (liter)	Temp (deg C)	Salinity (PSU)
PDNA-20	00101	20090802	81°56.45'N	016°41.50'E	CTD-DEEP	2691	2500	77	-0.780	34.921
PDNA-22	00201	20090808	88°12.84'N	059°41.61'E	CTD-DEEP	4460	4300	105	-0.638	34.941
-	-	-	-	-	CTD-MEDIUM	-	350	28	1.170	34.859
-	-	-	-	-	CTD-SURFACE	-	50	28	-1.802	33.515
PDNA-23	00301	20090809	88°16.15'N	065°35.02'E	CTD-DEEP	4457	4300	168	-0.638	34.941
PDNA-25	00501	20090812	88°32.92'N	133°16.07'E	CTD-MEDIUM	1258	300	70	1.068	34.848
PDNA-26	00601	20090813	88°24.65'N	150°09.63'E	CTD-SURFACE	1198	50	105	-1.544	32.596
PDNA-27	00701	20090814	88°08.80'N	157°07.39'E	CTD-DEEP	3912	3850	112	-0.272	34.953
PDNA-28	00801	20090815	88°42.66'N	158°53.42'E	CTD-DEEP	2725	2630	112	-0.678	34.921
-	-	-	-	-	CTD-SURFACE	-	50	49	-1.507	32.565
PDNA-29	00901	20090817	88°48.49'N	178°02.71'W	CTD-MEDIUM	1181	300	42	0.878	34.837
PDNA-30	01001	20090817	88°35.81'N	175°38.15'W	CTD-DEEP	3934	3885	112	-0.268	34.953
-	-	-	-	-	CTD-MEDIUM	-	300	28	0.873	34.838
-	-	-	-	-	CTD-SURFACE	-	50	28	-1.481	32.018
PDNA-31	01101	20090820	88°50.69'N	156°16.45'W	CTD-MEDIUM	3898	300	42	0.978	34.845
PDNA-32	01201	20090821	88°27.13'N	129°20.37'W	CTD-DEEP	n.m.	2000	84	-0.494	34.931
-	-	-	-	-	CTD-SURFACE	n.m.	50	84	-1.484	31.783
PDNA-34	01301	20090822	89°35.45'N	123°02.56'W	CTD-MEDIUM	n.m.	300	112	1.208	34.844
PDNA-36	01501	20090826	88°43.74'N	058°27.28'W	CTD-DEEP	2863	2800	140	-0.739	34.926
-	-	-	-	-	CTD-SURFACE	-	50	28	-1.486	30.915
PDNA-33ice	n.a.	20090821	89°27.12'N	129°19.70'W	Ice cores	n.a.	0	49	n.m.	n.m.
PDNA-35ice	n.a.	20090826	88°42.00'N	069°45.00'W	Ice cores	n.a.	0	68	n.m.	n.m.
PDNA-21S	n.a.	20090805	85°15.00'N	018°18.00'W	Snow	n.a.	0	44	n.m.	n.m.
PDNA-24S	n.a.	20090811	88°35.05'N	099°45.20'W	Snow	n.a.	0	48	n.m.	n.m.
PDNA-37S	n.a.	20090830	87°27.48'N	016°13.61'W	Snow	n.a.	0	XXX	n.m.	n.m.

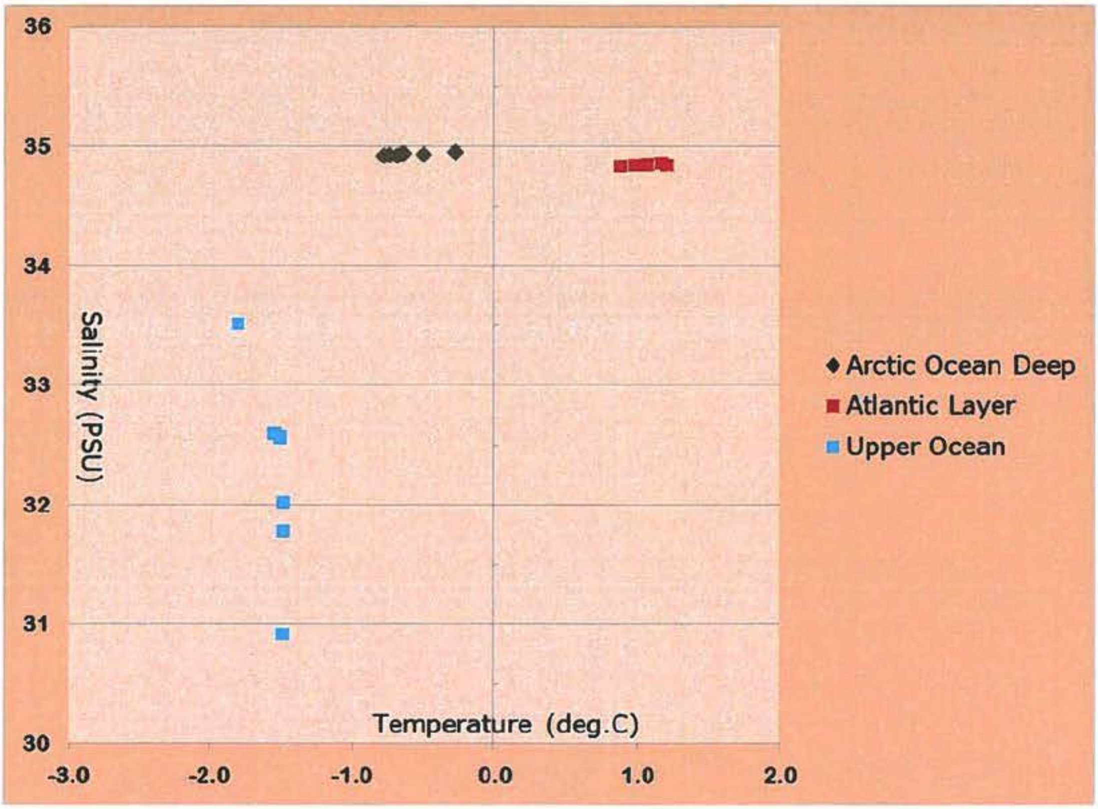


Figure 59. *Salinity (PSU) vs. Temperature (deg C) for the three main water types sampled.*

The critical issue of getting enough microbial biomass, especially from the deepest samples cannot be evaluated before additional lab tests have been done back at the DTU lab. However, with sample volumes up to 168 liters, the chances are high that enough microbial DNA can be extracted from the filters. In general, a volume between 28 and 168 liters of water was filtered for each depth sampled.

Overall, the number of samples obtained and the technical procedures fully met with and even surpassed our expectations for this cruise. Future detailed studies of the DNA of the microbial communities in Arctic sea water, snow or ice, will reveal if new biological processes can be identified and whether or not they are unique to these environments.

15. Art and Media Projects

15.1 Adam Jeppesen - Photography

During the voyage, documentation of the landscape and life on board *Oden* was carried out by the Danish artist, Adam Jeppesen, using photography and video. The work is part of a larger expedition entitled North by Southwest – a land/sea based journey from the North Pole to the South Pole, resulting in the exhibition "Headlines" at the National Museum of Photography in Copenhagen as well as the exhibition, "On Sleepwalking" at Galleri Image in Århus (more information on www.adamjeppesen.com).

The majority of the work was done while onboard *Oden*, but images were also shot on the ice whenever possible. The main focus was to document the ice edge, the geographical North Pole and the scientific work being carried out on the ice. In addition, emphasis was put on capturing the expansive scale of the high arctic landscape.

15.1.1 Equipment

For the highest possible resolution, a Deardorff 8 x 10" field camera with a Fujinon prime lens was used. Both color and black & white film was exposed. For color, the film stock used was Velvia and Provia 100 – both will be developed employing E-6 process. The black & white film stock used was Ilford FP4. This film will be developed using a reversal process, turning the negatives into positives. For light metering a Minolta IV light reader was used.

Fig. 60. *Equipment and work conditions for the Photography project.*

Due to the size of the individual sheets of film (8 x 10 "/20.32 x 25.4 cm) the detail of the printed images exceeds any other available format. This is important, as the final pieces will range to a maximum size of 180 x 220 cm. The video part of the project was shot on a Panasonic 102A mini dvd camera.

15.1.2 Results

A total of 74 color and 25 black & white sheets were exposed. Of these approximately 70% were used while onboard *Oden*, while the remaining sheets were exposed on the ice, documenting the landscape and scientific work being carried out.

The development of the film will be done in Copenhagen and Düsseldorf after having disembarked in Longyearbyen. Several images from the cruise will be on display during the exhibition "On Sleepwalking", at Gallery *Image*, in Århus, October 9th – November 15th 2009. A larger exhibition covering the North by Southwest expedition will open at The National Museum of Photography in Copenhagen in the fall of 2011. Work will also be presented through the artist representing galleries in Copenhagen and Köln (Peter Lav Gallery, Copenhagen and Kudlek van der Grinten, Köln).

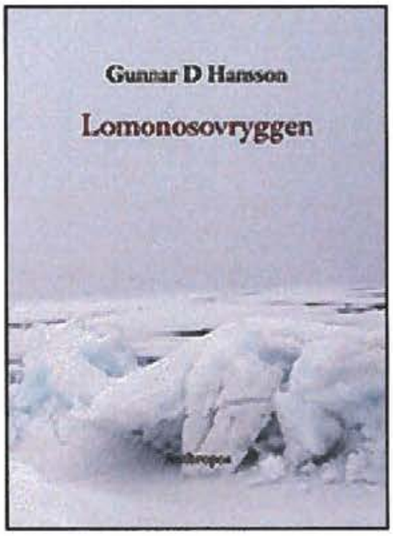
Fig. 61. *Black and white photography illustrating ice conditions during LOMROG II*

In addition to photography, video was used to document the landscape, making use of moving images to illustrate the slow, but distinct changes in travelling from the open sea to the ice edge and further into the thick multiyear ice. This material will be edited and presented as an installation giving the viewer a look into the world and transformations of the high arctic. A venue for the installation has not been decided yet.

15.2 Gunnar D Hansson - Poems

"Through the Northern Sea of Ice and just passing the North Pole deep under the Sea Ice stretches the Lomonosov Ridge. The ridge is named after the great Russian scientist and poet Michail Lomonosov. During six weeks of late summer in 2009 Gunnar D Hansson participated in an expedition with the icebreaker *Oden*. The expedition's main task was to map the geological formations of the Lomonosov Ridge. During the cruise a collection of poems called *Lomonosovryggen* came about as Hansson eleventh collection of poems.

In the book older times speculative perceptions of the Arctic meet modern days scientific and climate-political issues. The book contains a discussion of the conditions for literature, about the arctic sublima and tries to formulate an arctic poetry. Gunnar D Hansson's latest publications are *Senecaprogramme* (2004) and *Lyckans berså* (2008)." (from the cover of the book, translated from Swedish).



Gunnar D Hansson 2009: *Lomonosovryggen*. Anthropos, Stockholm, 174pp. ISBN 978-91-85722-31-0

15.3 Martin Ramsgård - Media

During the LOMROG II cruise, the media group has mainly produced footage for television as well as many photos. In all, about fifteen hours of video were produced and approximately 500 photos were taken.

The work of the media group on LOMROG II was influenced by the fact that we did not have any obligations beforehand. However we made some agreements during the cruise and have therefore produced some news stories for Denmark's Radios (DR) news programme and some scientific stories for DR2. A story on the Plankton Project to TV2FYN has also been prepared. Before the cruise, we also had contacts with several newspapers in Denmark and the popular scientific magazine *Illustreret Videnskab* for which we likely will write some articles. But here as well, no agreements were settled before the cruise.

The material collected during LOMROG II is comprehensive enough to produce several TV programs on the scientific work undertaken during the cruise. Themes could include mapping of the Lomonosov Ridge, the piston coring, the microbial life within the ice and the condition of the polar ice. There have been talks with the DR2 program *Viden om*, but no deals are settled so far. We are confident, however, that the material we have gathered is so interesting and unique that stories on the broad scientific work during the LOMROG II expedition will be made.

16. Acknowledgements

The many results obtained during the LOMROG II cruise could not have been achieved without the excellent cooperation between the crew of *Oden*, the helicopter crew and the science party. The cooperation between the different science groups made it possible to exploit the resources on board *Oden* and provided by the helicopter in a very efficient manner.

All members of *Oden*'s crew, the helicopter crew and the scientific party are thanked for their large commitment for making this cruise so successful.

17. Appendices and Enclosures

17.1 Appendix I: List of Participants

List of Participants

Photographer	Adam Jeppesen	Media team
Scientist	Anja Kinnberg Gunwald	GEUS/ University of Århus
Logistics Coo	Axel Meiton	Swedish Polar Research Secretariat
Fitter	Baldomero Cortizas	*Oden* crew
Scientist	Benjamin Hell	Stockholm University
Chief Scientist	Christian Marcussen	GEUS
Hkp. Pilot	Christian Schager	Kallax Flyg
2:nd Officer	Mats Wisén	*Oden* crew
Ch. Engineer	Dahn Joelsson	*Oden* crew
2:nd Engineer	Daniel Ernhill	*Oden* crew
2:nd Engineer	Daniel Jönsson	*Oden* crew
Information Coo	Daniella Gredin	Swedish Polar Research Secretariat
Able Seaman	Einar Sjöbom	*Oden* crew
Master	Erik Andersson	*Oden* crew
Scientist	Esben Jørgensen	GEUS/ University of Århus
Poet	Gunnar Hansson	
Scientist	Henriette Skourup	DTU Space
Scientist	Holger Lykke-Andersen	University Århus
2:nd Officer	Ivan Öström	*Oden* crew
Able Seaman	Jan Nilsson	*Oden* crew
Scientist	Jeff Bowman	University of Washington
Scientist	Jens Blom	DTU CBS
Scientist	John Hopper	GEUS
Scientist	Jonas Johansen	GEUS/Copenhagen University
Oiler	Jonas Lindén	*Oden* crew
1.st Engineer	Jörgen Rundqvist	*Oden* crew
El. Engineer	Jörn Johansson	*Oden* crew
Scientist	Kajsa Tönneson	University of Gothenburg
Ch. Cook	Lars Andersson	*Oden* crew
Scientist	Lars Rödel	GEUS
Oiler	Leif Andersson	*Oden* crew
Scientist	Leif Toudal Pedersen	Danish Meteorological Institute
Scientist	Ludwig Löwemark	Stockholm University
Meteorologist	Margareta Osin-Pärnebjörk	
Journalist	Martin Ramsgård	Media team
Scientist	Markus Karasti	Stockholm University
Bosun	Mats Hansson	*Oden* crew
Scientist	Matthias Wietz	DTU Aqua
Teacher	Matti Karlström	

Able Seaman	Mattias Karlsson	*Oden* crew
Scientist	Mike Lamplugh	Canadian Hydrographic Service
Scientist	Nikolaj Blom	DTU CBS
Hkp. Mek	Nils Eriksson	Kallax Flyg
Scientist	Per Trinhammer	University of Aarhus
Meteorologist	Peter Löfwenberg	
Cook	Ranjit Roy	*Oden* crew
Scientist	Rasmus Pedersen	GEUS/Copenhagen University
Scientist	Rasmus Swalethorp	NERI, University of Århus
MD	Rickard Ånell	*Oden* crew
2:nd Officer	Stefan Söderholm	*Oden* crew
Scientist	Steffen M. Olsen	Danish Meteorological Institute
Hkp. Pilot	Sven Stenvall	Kallax Flyg
Scientist	Thomas Funck	GEUS
Oiler	Thomas Johansson	*Oden* crew
Ch. Officer	Thomas Strömsnäs	*Oden* crew
Messman	Tina Hansson	*Oden* crew
Scientist	Uni Bull	Danish Maritime Safety Administration
Scientist	Yra Firsov	*VNIIOkeangeologia, St. Petersburg, Russia*
Scientist	Åsa Wallin	Stockholm University

17.2 Appendix II: Multibeam Acquisition: TPE (Total Propagated Error) Background Information

The convention for the Cartesian coordinate system for the EM122 is as follows:

X = Positive Forward
Y = Positive Starboard
Z = Positive Down

The convention for the Cartesian coordinate system for CARIS HIPS/SIPS is as follows:

X = Positive Starboard
Y = Positive Forward
Z = Positive Up

The settings in the rest of this section are just a documentation of the values that were entered into the system during LOMROG II. A quick examination of these values shows inconsistencies with these numbers. There is not an obvious way to enter the ship's physical draught (which was 8.1 meters at the start of the trip). As some of the 4,500 tons of fuel is used, the draft will decrease significantly. It is reported that the range in draught values due to fuel usage is 6.7 to 8.7 meters.

It also appears that the X & Y values of the MRU to Transducer in the HIPS VCF file have been transposed. This will not affect any sounding positions unless a different sound velocity is re-applied in HIPS.

SIS Installation Settings:

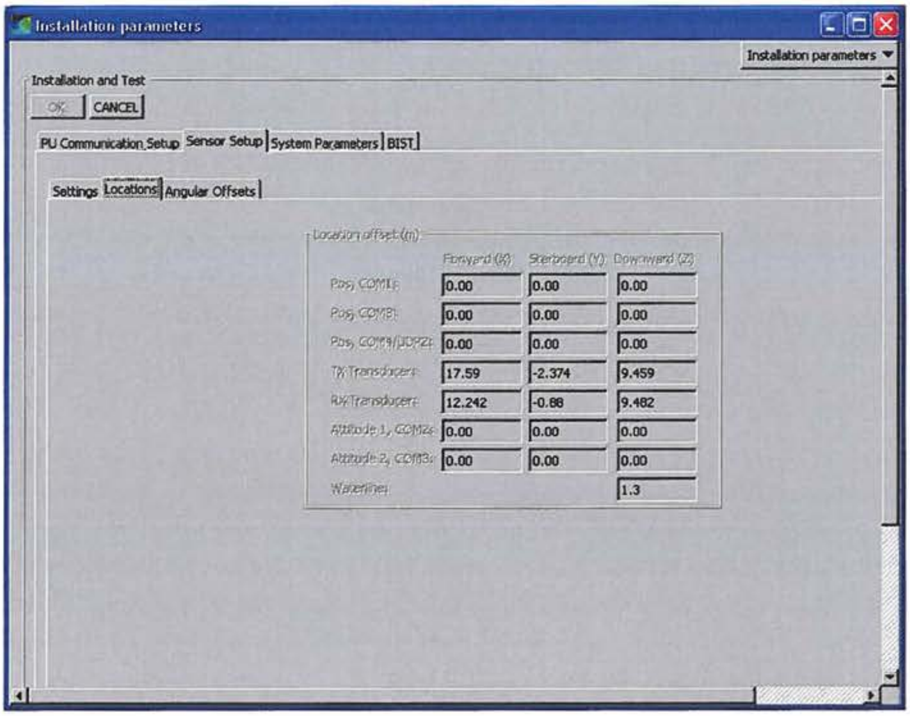


Figure 1. *Installation parameters: Locations*

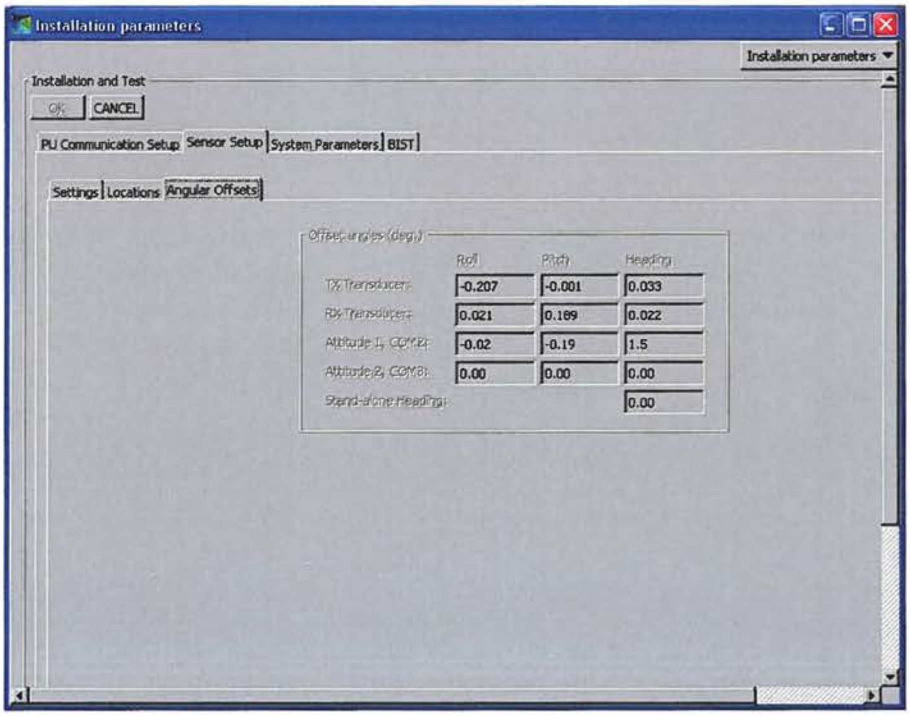


Figure 2. *Installation parameters: Angular Offset*

SeaPath settings extracted from Configuration Report:

Vessel

Geometry

Vessel dimensions:

Length: 107.00 Width: 30.00 Height: 30.00 [m]

Center Of Gravity (CG) location:

CG-X: -60.00 CG-Y: 0.00 CG-Z: 8.00 [m]

Description

Vessel data:

Type: Ice Breaker Owner: Sjøfartsverket

Name: *Oden* Country of origin: Sweden

Sensor

GPS Geometry

Antenna Lever Arm

From CG to antenna #1:

X: 3.973 Y: -3.050 Z: -33.152 [m]

GPS Antenna Configuration

Baseline length: 2.500[m] Heading offset: -1.68[deg] Height difference: 0.099[m]

Attitude Processing

Max pitch and roll angles: 15.00

Max average pitch and roll angles: 7.00

MRU Geometry

MRU Lever Arm

From CG to MRU:

X: 0.000 Y: 0.000 Z: 0.000 [m]

MRU Mounting Angles:

Roll: -179.77 Pitch: -0.15 Yaw: 0.30 [deg]

==================================

CARIS/HIPS 6.1

From the VCF (Vessel Configuration File), settings for TPE:

Time Stamp: 2007-140 01:00

Comments Estimated after installation

Offsets

Motion sensing unit to the transducer 1

X Head 1 17.590

Y Head 1 -2.370
Z Head 1 -9.460
Motion sensing unit to the transducer 2
X Head 2 0.000
Y Head 2 0.000
Z Head 2 0.000
Navigation antenna to the transducer 1
X Head 1 14.860
Y Head 1 -1.500
Z Head 1 -42.600
Navigation antenna to the transducer 2
X Head 2 0.000
Y Head 2 0.000
Z Head 2 0.000

Roll offset of transducer number 1 0.000
Roll offset of transducer number 2 0.000

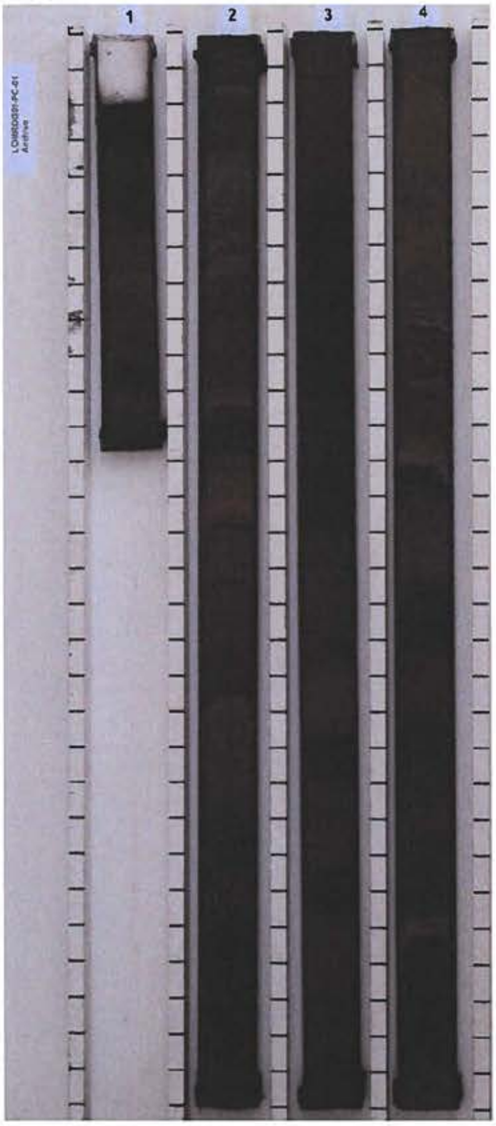
Heave Error: 0.050 or 0.100" of heave amplitude.
Measurement errors: 0.000
Motion sensing unit alignment errors
Gyro:0.000 Pitch:0.000 Roll:0.000
Gyro measurement error: 0.020
Roll measurement error: 0.020
Pitch measurement error: 0.020
Navigation measurement error: 10.000
Transducer timing error: 0.000
Navigation timing error: 0.000
Gyro timing error: 0.000
Heave timing error: 0.000
PitchTimingStdDev: 0.000
Roll timing error: 0.000
Sound Velocity speed measurement error: 0.000
Surface sound speed measurement error: 0.000
Tide measurement error: 0.000
Tide zoning error: 0.000
Speed over ground measurement error: 0.000
Dynamic loading measurement error: 0.500
Static draft measurement error: 0.000
Delta draft measurement error: 0.500
StDev Comment:
=================================

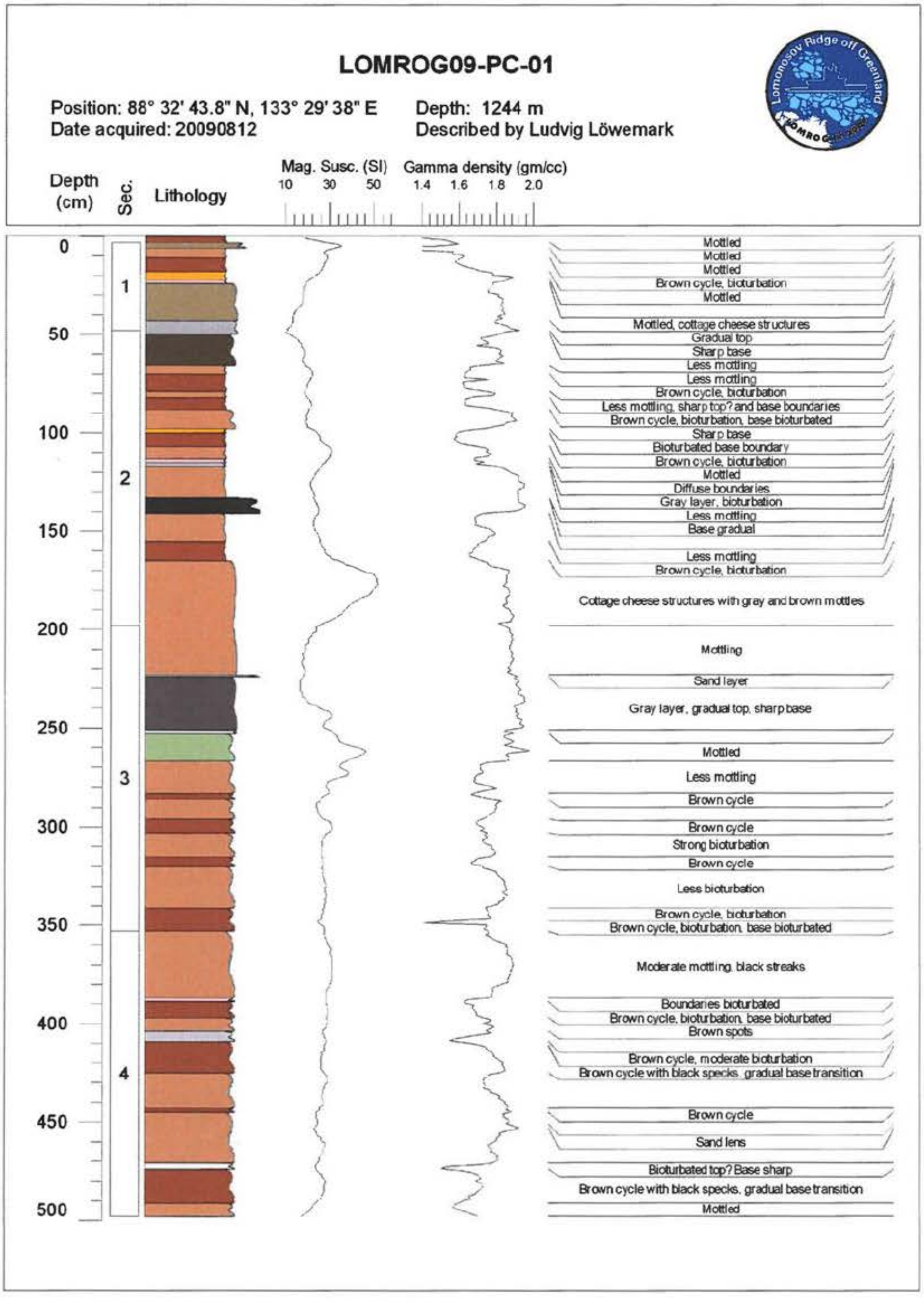
17.3 Appendix III: Core Descriptions

LOMROG09-PC-01

The core was taken on the crest of the Lomonosov Ridge on the Amundsen Basin side of the intra-basin. The coring point was situated in a flat area where sub-bottom profiler data indicated undisturbed, horizontally layered sediments. The core was taken to provide a paleoceanographic record that can be used to connect records on the Siberian side of the ridge with records obtained from the Greenland side of the ridge.

The core consists of a typical sequence of yellowish olive grey brown sediments with intercalated cycles of brown sediment and two distinct grey layers separated by a sharp boundary. The presence of two grey layers, both positioned in similar positions relative to surrounding brown cycles could be an indication that there has been a partial doubling of the cored sequence. The phenomenon of doubled sequences is well known from piston coring and is caused by the rebound of the wire after it has been released by the trigger weight.



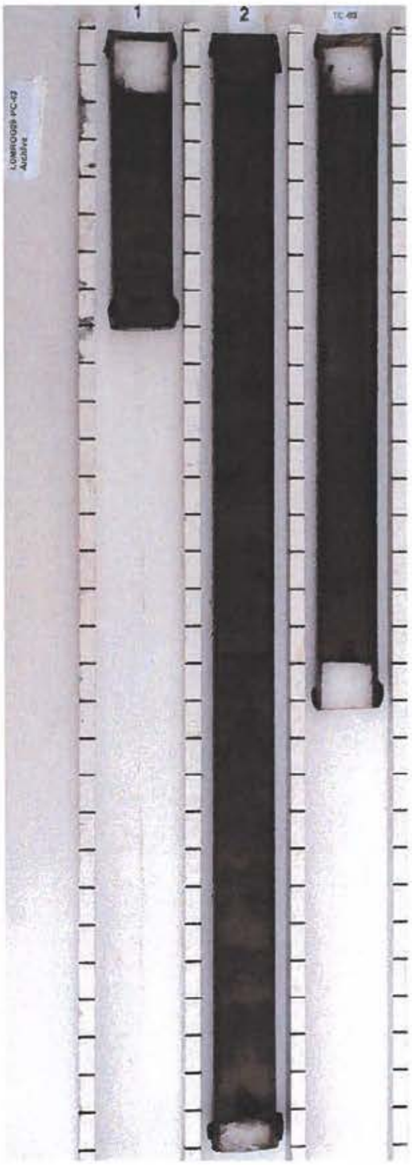


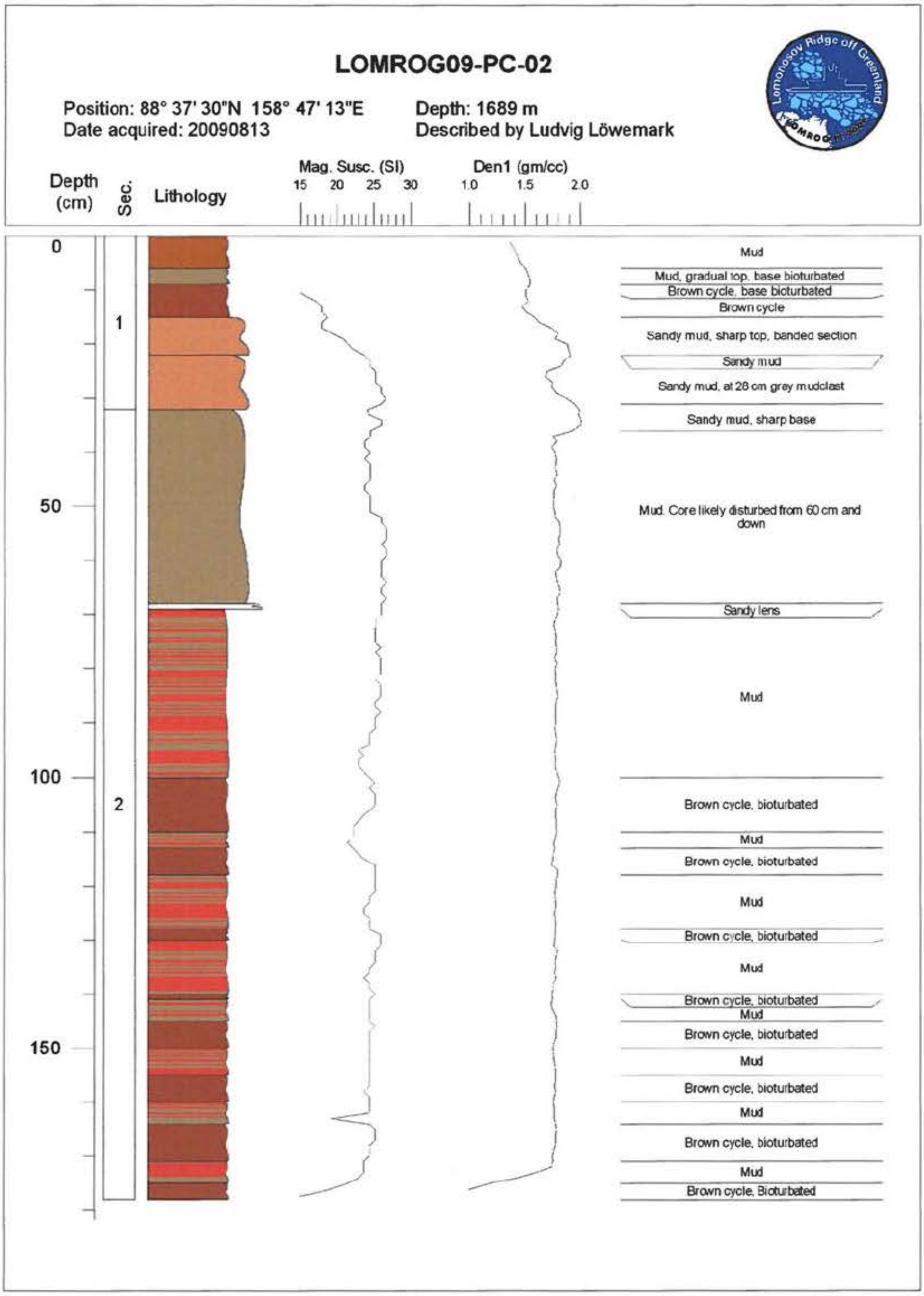
LOMROG09-PC-01
Position: 88° 32' 43.8" N, 133° 29' 38" E
Date acquired: 20090812
Depth: 1244 m
Described by Ludvig Löwemark
Depth (cm)
Sec.
Lithology
Mag. Susc. (SI)
10 30 50
Gamma density (gm/cc)
1.4 1.6 1.8 2.0
0
50
100
150
200
250
300
350
400
450
500
1
2
3
4
Mottled
Mottled
Mottled
Brown cycle, bioturbation
Mottled
Mottled, cottage cheese structures
Gradual top
Sharp base
Less mottling
Less mottling
Brown cycle, bioturbation
Less mottling, sharp top? and base boundaries
Brown cycle, bioturbation, base bioturbated
Sharp base
Bioturbated base boundary
Brown cycle, bioturbation
Mottled
Diffuse boundaries
Gray layer, bioturbation
Less mottling
Base gradual
Less mottling
Brown cycle, bioturbation
Cottage cheese structures with gray and brown mottles
Mottling
Sand layer
Gray layer, gradual top, sharp base
Mottled
Less mottling
Brown cycle
Brown cycle
Strong bioturbation
Brown cycle
Less bioturbation
Brown cycle, bioturbation
Brown cycle, bioturbation, base bioturbated
Moderate mottling, black streaks
Boundaries bioturbated
Brown cycle, bioturbation, base bioturbated
Brown spots
Brown cycle, moderate bioturbation
Brown cycle with black specks, gradual base transition
Brown cycle
Sand lens
Bioturbated top? Base sharp
Brown cycle with black specks, gradual base transition
Mottled

LOMROG 09-PC-02

The core was taken in the Siberian side of the intra-basin in order to obtain a high-resolution record that can be compared to core HLY0503-18 taken nearby during the HOTRAX expedition in 2005.

The core consists of a number of brown cycles superimposed on a sequence of alternating lighter and darker olive grey brown layers. The lower part of the core shows signs of core disturbance and sediment flow, likely caused by the suction of the piston during coring.




LOMROG09-PC-02
Position: 88° 37' 30"N 158° 47' 13"E
Date acquired: 20090813
Depth: 1689 m
Described by Ludvig Löwemark
Depth (cm)
Sec.
Lithology
Mag. Susc. (SI)
15 20 25 30
Den1 (gm/cc)
1.0 1.5 2.0
0
50
100
150
1
2
Mud
Mud, gradual top, base bioturbated
Brown cycle, base bioturbated
Brown cycle
Sandy mud, sharp top, banded section
Sandy mud
Sandy mud, at 28 cm grey mudclast
Sandy mud, sharp base
Mud. Core likely disturbed from 60 cm and down
Sandy lens
Mud
Brown cycle, bioturbated
Mud
Brown cycle, bioturbated
Mud
Brown cycle, bioturbated
Mud
Brown cycle, bioturbated
Mud
Brown cycle, bioturbated
Mud
Brown cycle, bioturbated
Mud
Brown cycle, bioturbated
Mud
Brown cycle, Bioturbated

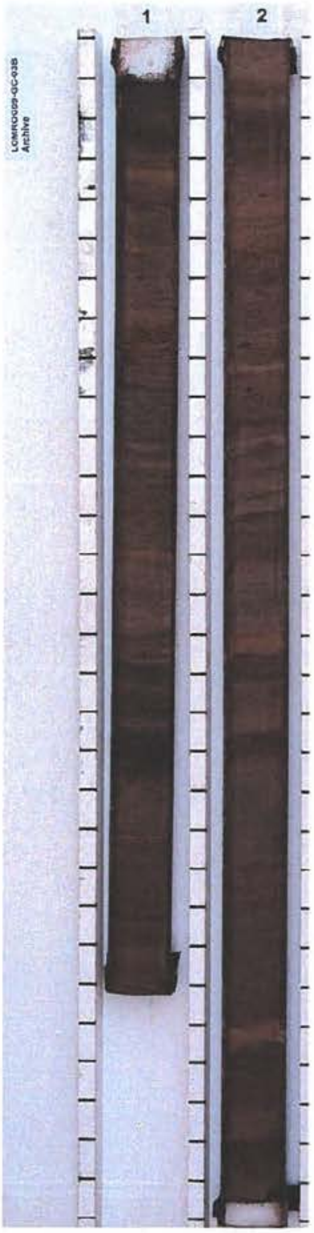
LOMROG 09-GC-03A (Failed gravity coring attempt on the Lomonosov Ridge)

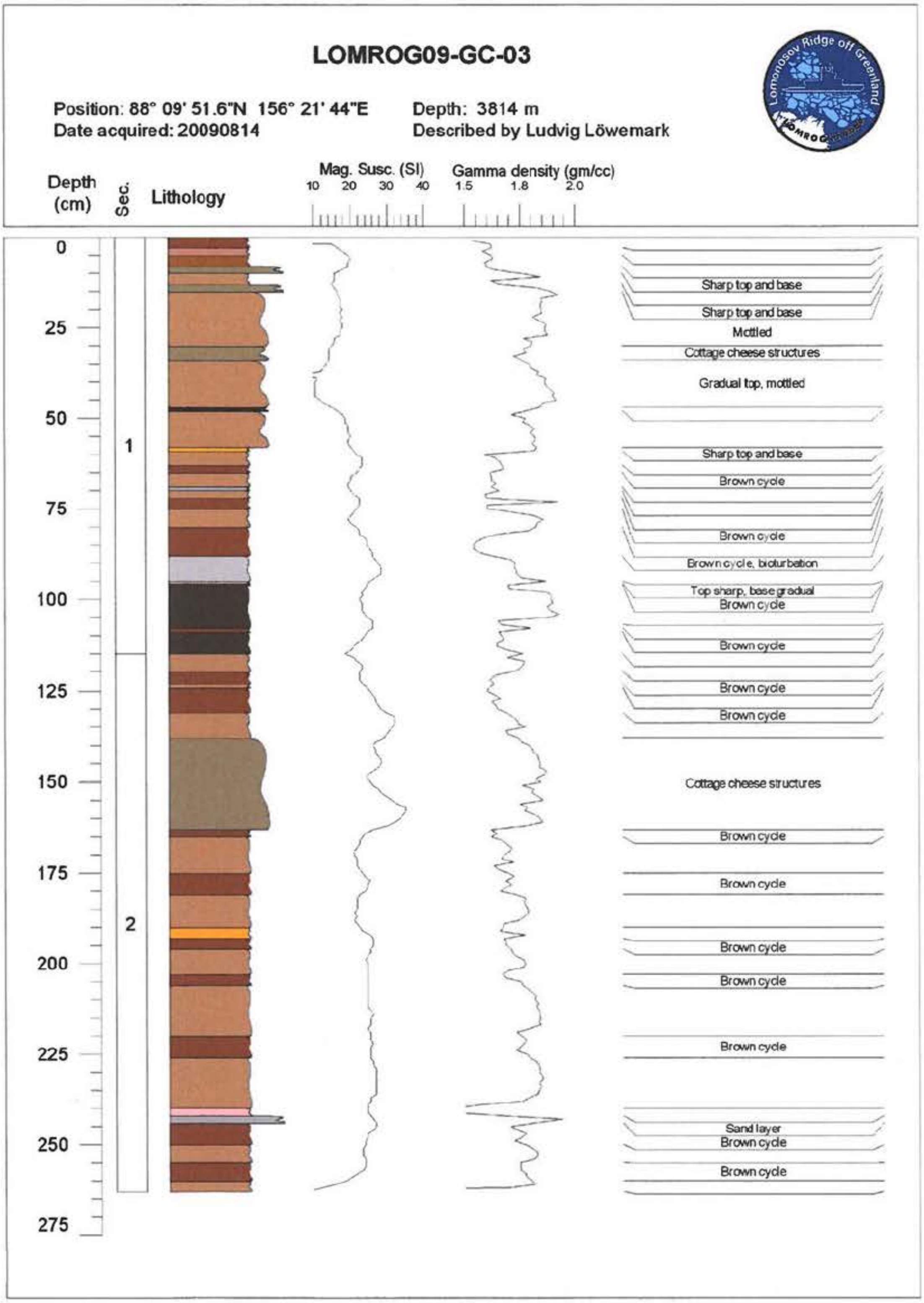
An attempt was made to core the sediment in the deepest channel connecting the Intra-basin with the Makarov Basin. The channel has a sill depth of 1870 m (Björk et al., 2007) and the core was taken in the mouth of the channel on the Intra-basin side of the ridge. It was hypothesized that the sediment at this position would hold a record of variations in intensity of the exchange between the Makarov and Intra-basin waters. Unfortunately, although mud on the outside of the corer indicated a penetration of more than 5 m, the core was empty except for an approx. 4 cm large pebble.

LOMROG 09-GC-03B

The core was taken in the Makarov Basin southeast of the Siberian end of the Intra-basin. The core is hoped to provide a link between the Eurasian Basin and the Canadian Basin sedimentary regimes.

The core consists of a number of brown cycles superimposed on the general sequence of olive grey brown sediment.




LOMROG09-GC-03
Position: 88° 09' 51.6"N 156° 21' 44"E
Date acquired: 20090814
Depth: 3814 m
Described by Ludvig Löwemark
Lomonosov Ridge off Greenland
LOMROG
Depth (cm)
Sec.
Lithology
Mag. Susc. (SI)
10 20 30 40
Gamma density (gm/cc)
1.5 1.8 2.0
0
25
50
75
100
125
150
175
200
225
250
275
1
2
Sharp top and base
Sharp top and base
Mottled
Cottage cheese structures
Gradual top, mottled
Sharp top and base
Brown cycle
Brown cycle
Brown cycle, bioturbation
Top sharp, base gradual
Brown cycle
Brown cycle
Brown cycle
Brown cycle
Cottage cheese structures
Brown cycle
Brown cycle
Brown cycle
Brown cycle
Brown cycle
Sand layer
Brown cycle
Brown cycle

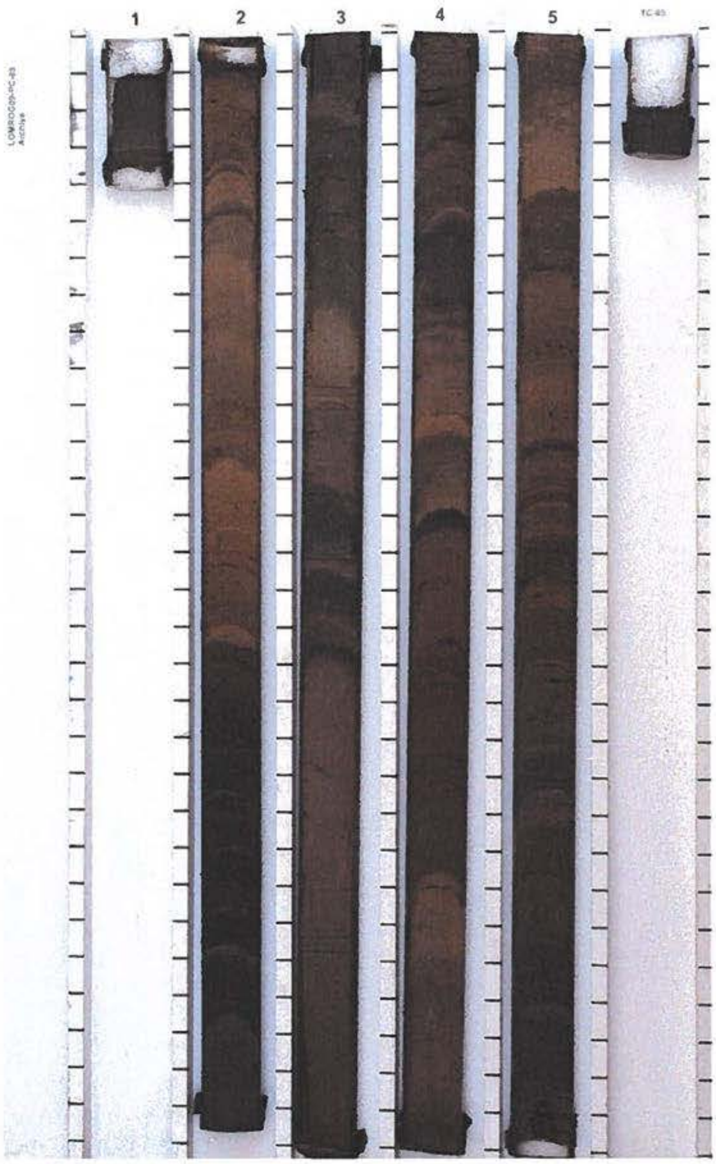
LOMROG 09-GC-04 (Failed gravity coring attempt on the Lomonosov Ridge)

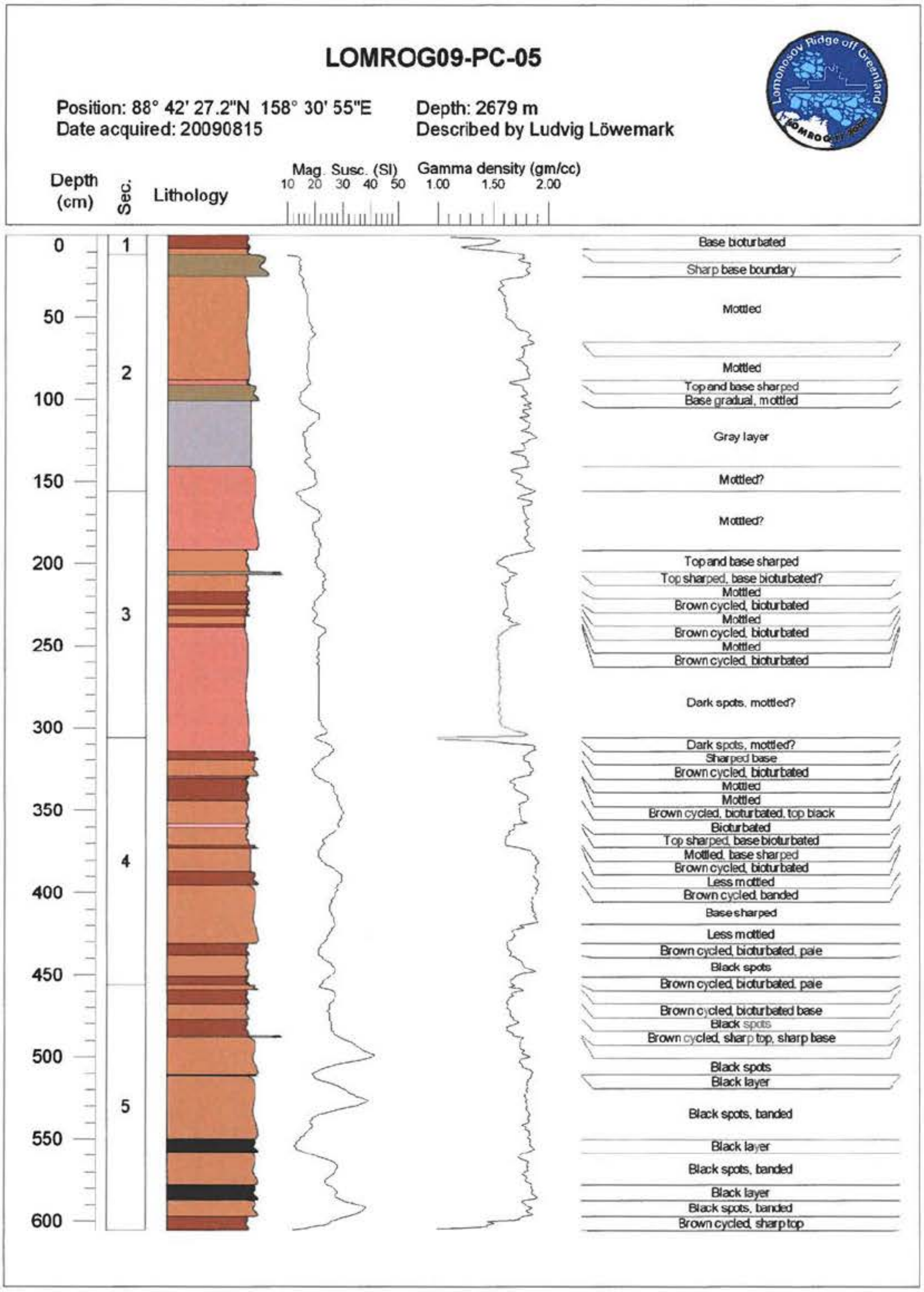
This coring was placed on the saddle of the second deepest channel between the Makarov Basin and the Intra-basin. Following the previously outlined hypothesis, it was hoped that this site would render a record of the exchange between the two basins. However, the core was empty except for a few sand grains, although the mud on the outside indicated penetration to around 4 m.

LOMROG 09-PC-05

The core was taken in the Lomonosov Ridge intra-basin in anticipation that we should obtain a high resolution record of paleoclimatic and paleoceanographic events that can be compared to the record derived from core HLY0503-18 taken during the HOTRAX-expedition 2005.

The core contains a typical sequence of brown cycles intercalated in an olive grey brown background sediment, and a pronounced grey layer.

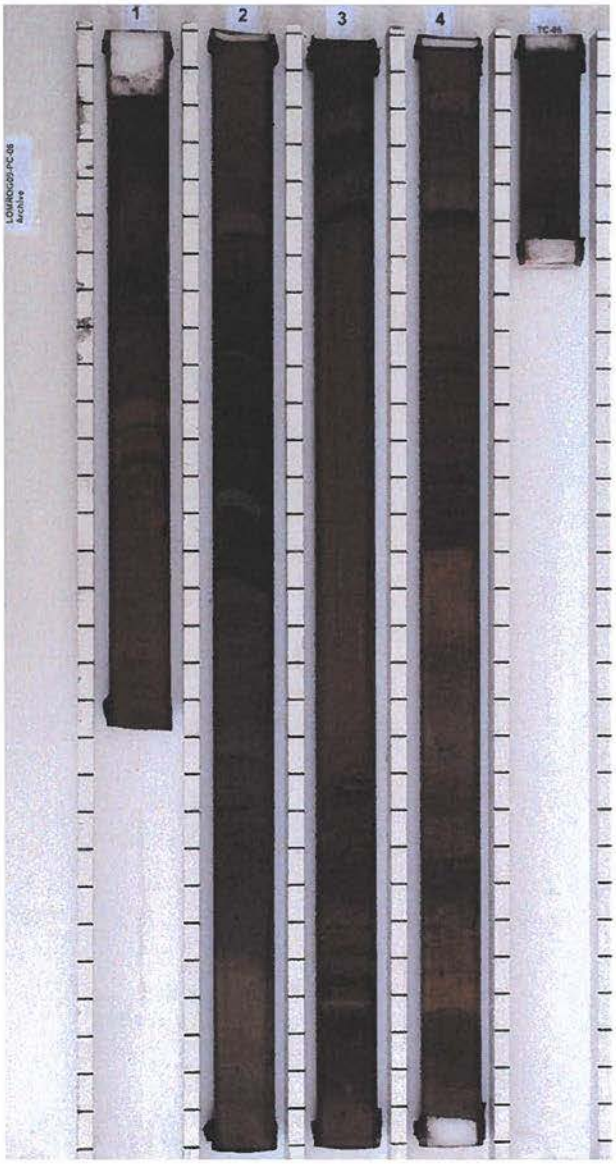



LOMROG09-PC-05
Position: 88° 42' 27.2"N 158° 30' 55"E
Date acquired: 20090815
Depth: 2679 m
Described by Ludvig Löwemark
Lomonosov Ridge off Greenland
Depth (cm)
Sec.
Lithology
Mag. Susc. (SI)
10 20 30 40 50
Gamma density (gm/cc)
1.00 1.50 2.00
0
50
100
150
200
250
300
350
400
450
500
550
600
1
2
3
4
5
Base bioturbated
Sharp base boundary
Mottled
Mottled
Top and base sharped
Base gradual, mottled
Gray layer
Mottled?
Mottled?
Top and base sharped
Top sharped, base bioturbated?
Mottled
Brown cycled, bioturbated
Mottled
Brown cycled, bioturbated
Mottled
Brown cycled, bioturbated
Dark spots, mottled?
Dark spots, mottled?
Sharped base
Brown cycled, bioturbated
Mottled
Mottled
Brown cycled, bioturbated, top black
Bioturbated
Top sharped, base bioturbated
Mottled, base sharped
Brown cycled, bioturbated
Less mottled
Brown cycled, banded
Base sharped
Less mottled
Brown cycled, bioturbated, pale
Black spots
Brown cycled, bioturbated, pale
Brown cycled, bioturbated base
Black spots
Brown cycled, sharp top, sharp base
Black spots
Black layer
Black spots, banded
Black layer
Black spots, banded
Black layer
Black spots, banded
Brown cycled, sharp top

LOMROG 09-PC-06

The core was taken in the Lomonosov Ridge intra-basin in anticipation that we should obtain a high resolution record of paleoclimatic and paleoceanographic that can be compared to the record derived from core HLY0503-18 taken during the HOTRAX-expedition 2005.

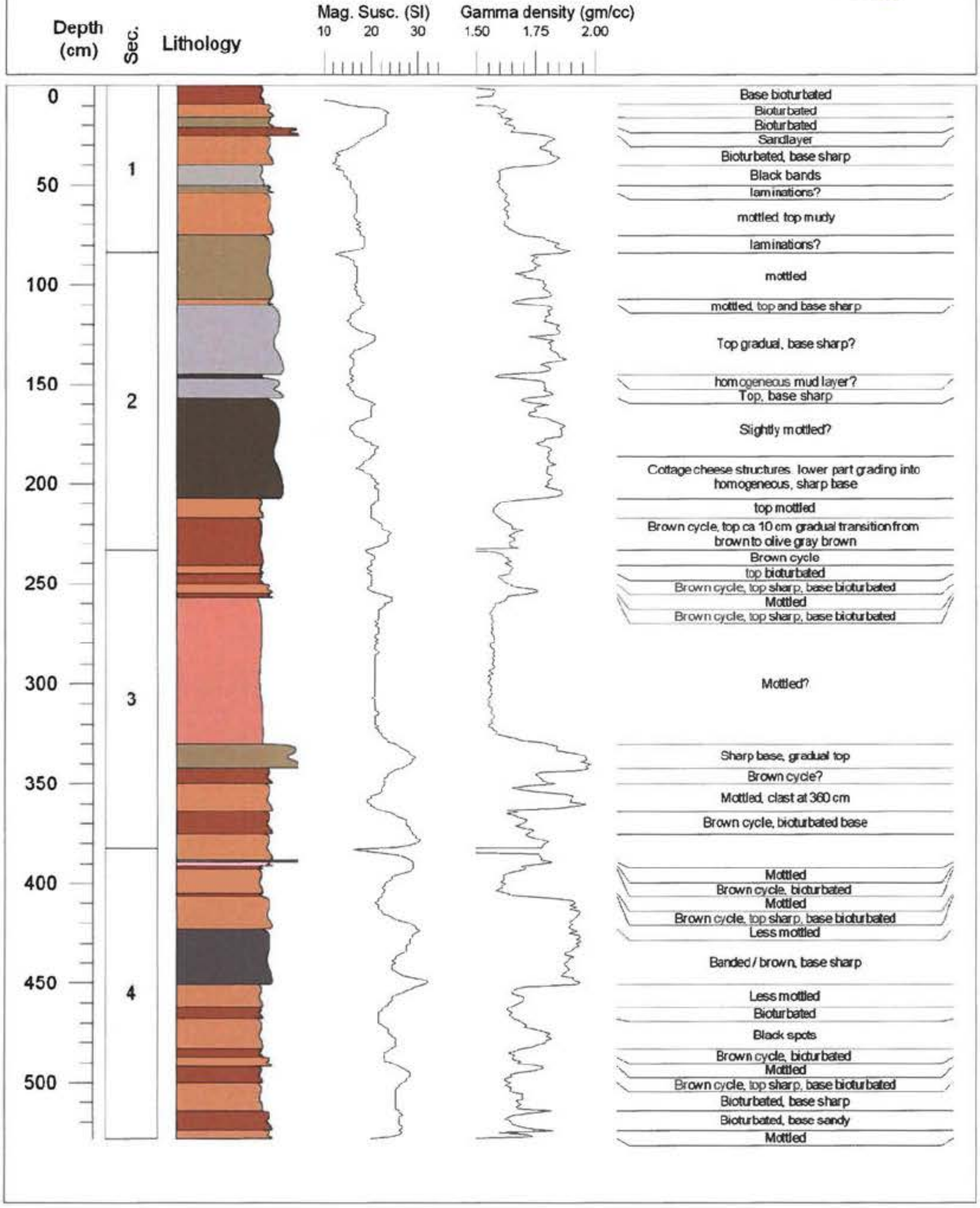
The core is almost identical to LOMROG09-PC-05 and contains a typical sequence of brown cycles intercalated in a olive grey brown background sediment, and a well pronounced grey layer.



LOMROG09-PC-06

Position: 88° 42' 12.4"N 157° 58' 58"E
Date acquired: 20090815

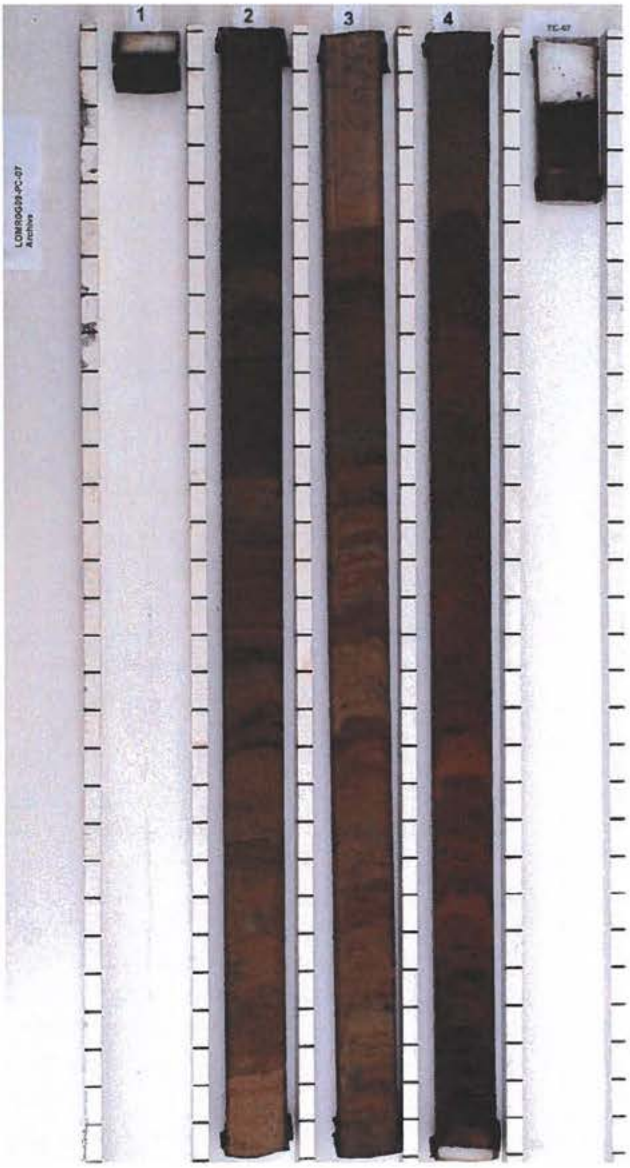
Depth: 2684 m
Described by Ludvig Löwemark

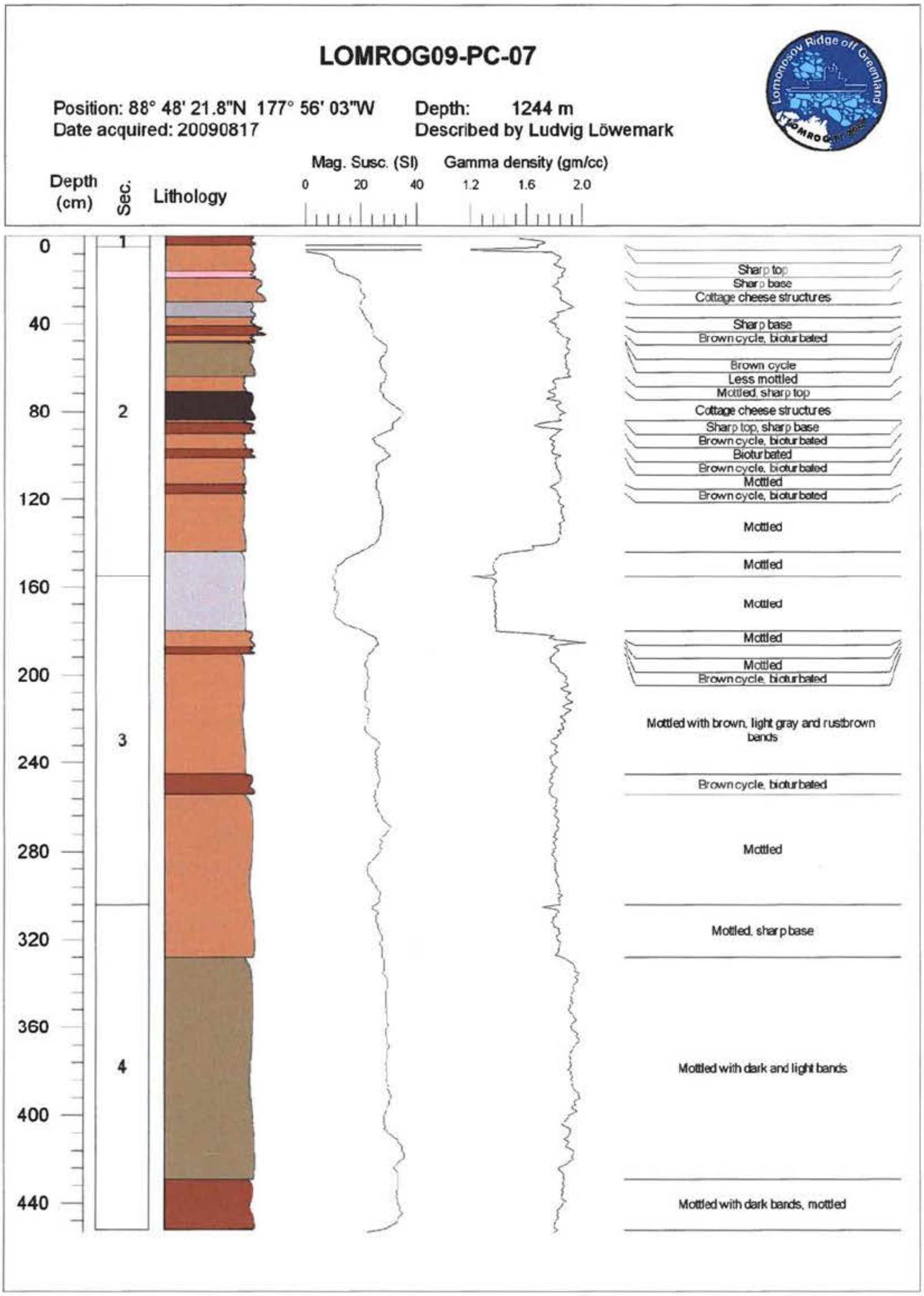


LOMROG 09-PC-07

LOMROG09-PC-07 was taken to obtain an undisturbed paleoceanographic record that would allow records from the Siberian side of the Lomonosov Ridge to be correlated to records from the Greenland side of the ridge. Because this core location is situated close to the Makarov Basin, it will potentially allow a correlation between the Eurasian and Canadian sedimentation regimes.

The core consists of a sequence of brown cycles intercalated in a light grey brown background sediment. However, in contrast to most cores on the Lomonosov Ridge crest, this core doesn't contain a clearly visible grey layer. Only a thin and bleak greyish layer can be observed at around 50 cm.

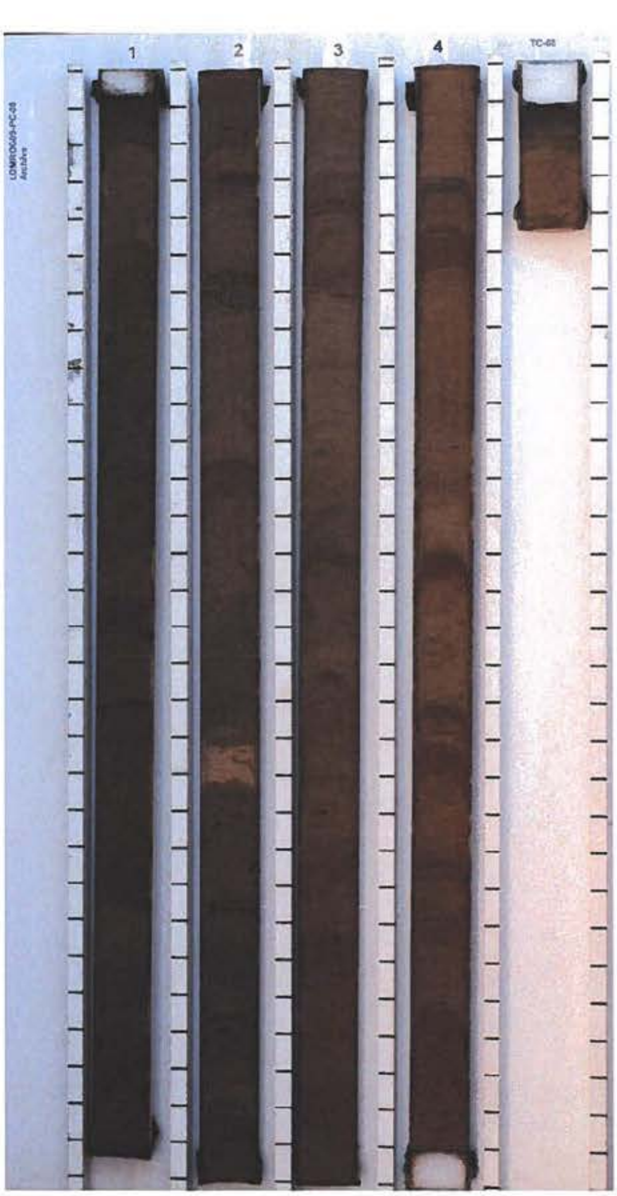


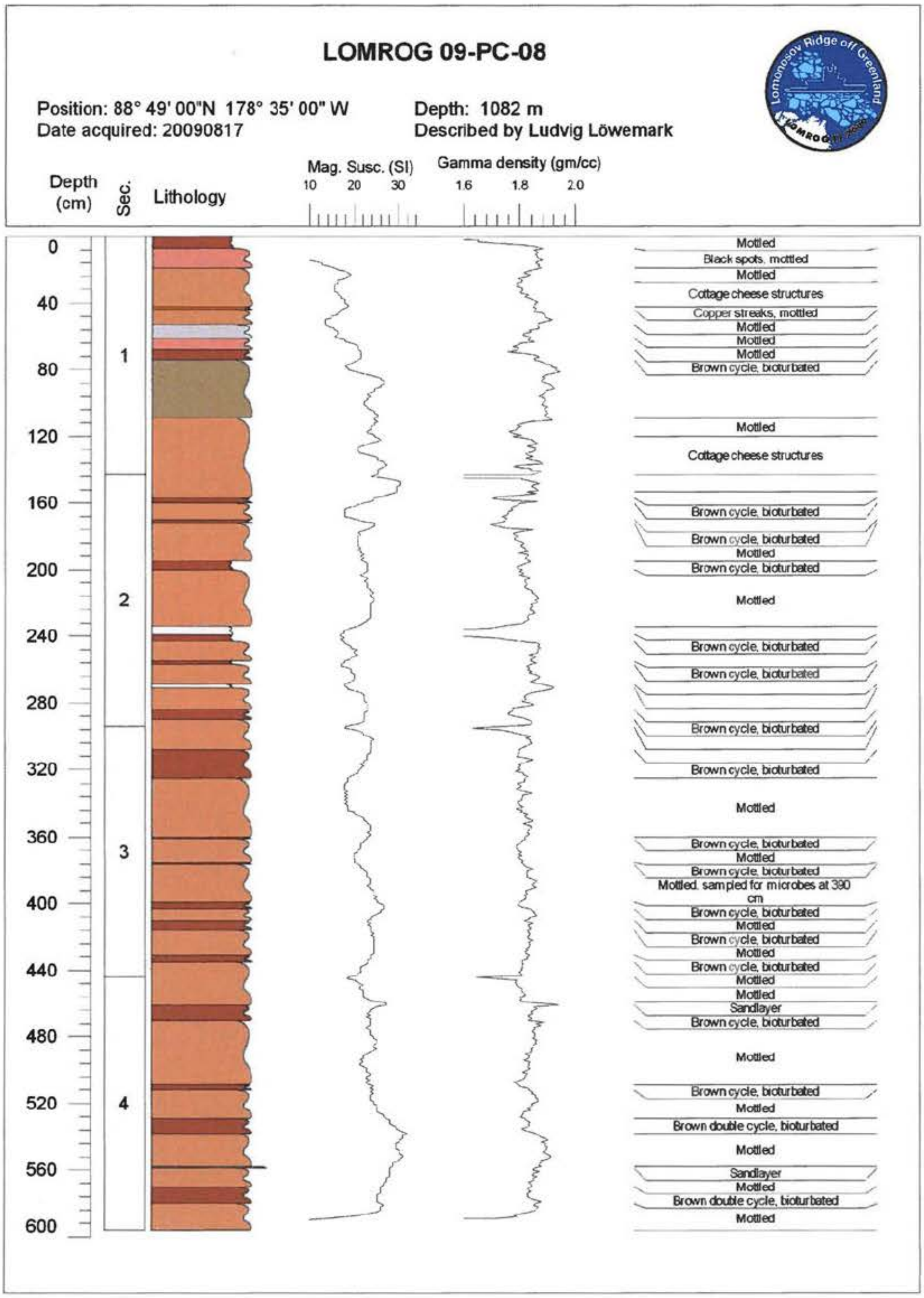

LOMROG09-PC-07
Position: 88° 48' 21.8"N 177° 56' 03"W
Date acquired: 20090817
Depth: 1244 m
Described by Ludvig Löwemark
Lomonosov Ridge off Greenland
LOMROG
Depth (cm)
Sec.
Lithology
Mag. Susc. (SI)
0
20
40
Gamma density (gm/cc)
1.2
1.6
2.0
0
40
80
120
160
200
240
280
320
360
400
440
1
2
3
4
Sharp top
Sharp base
Cottage cheese structures
Sharp base
Brown cycle, bioturbated
Brown cycle
Less mottled
Mottled, sharp top
Cottage cheese structures
Sharp top, sharp base
Brown cycle, bioturbated
Bioturbated
Brown cycle, bioturbated
Mottled
Brown cycle, bioturbated
Mottled
Mottled
Mottled
Mottled
Mottled
Brown cycle, bioturbated
Mottled with brown, light gray and rustbrown bands
Brown cycle, bioturbated
Mottled
Mottled, sharp base
Mottled with dark and light bands
Mottled with dark bands, mottled

LOMROG 09-PC-08

Like LOMROG09-PC-07, LOMROG09-PC-08 was taken to obtain an undisturbed paleoceanographic record that would allow records from the Siberian side of the Lomonosov Ridge to be correlated to records from the Greenland side of the ridge. Because this core location is situated close to the Makarov Basin, it will potentially allow a correlation between the Eurasian and Canadian sedimentation regimes.

Core LOMROG09-PC-08 is very similar to LOMROG09-PC-07. The core consists of a sequence of brown cycles intercalated in a light grey brown background sediment. However, in contrast to most cores on the Lomonosov Ridge crest, this core doesn't contain a clearly visible grey layer. Only a thin and bleak greyish layer can be observed at around 50 cm, similar to core LOMROG09-PC-07.

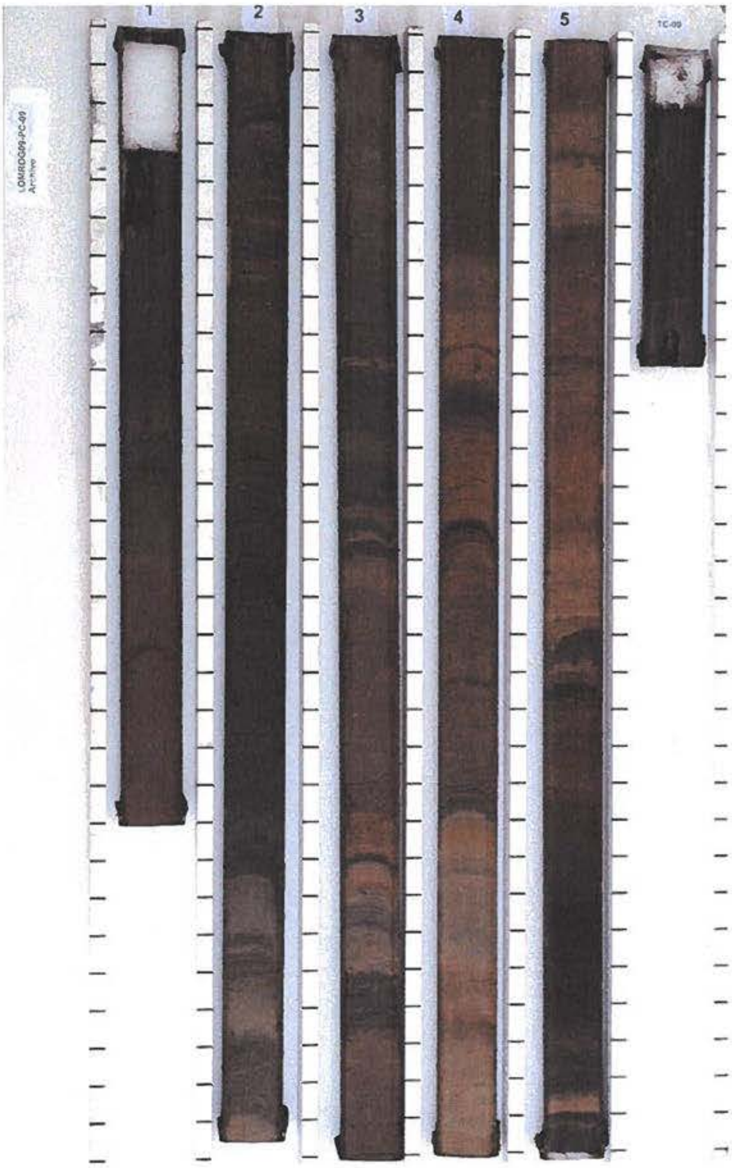


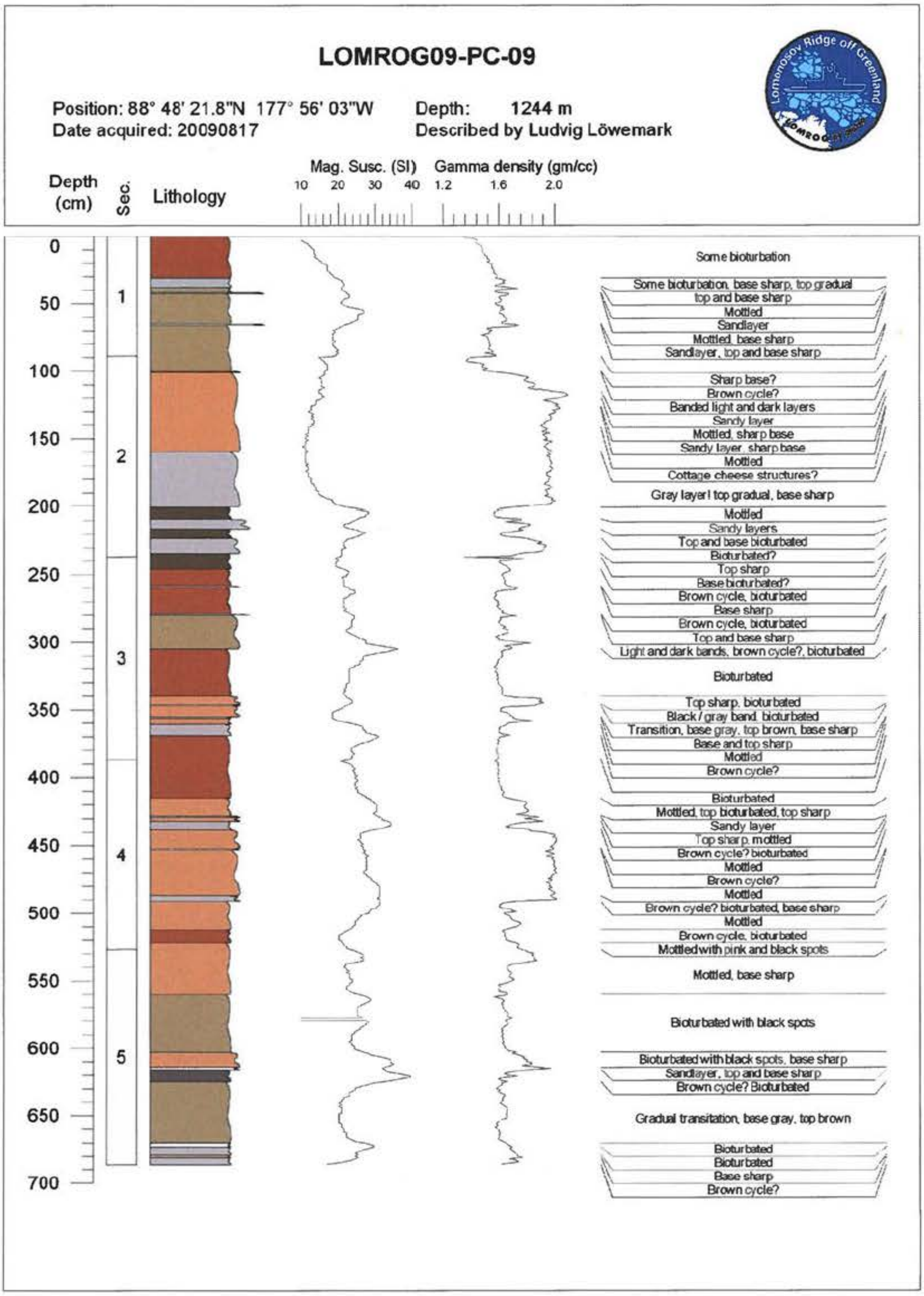

LOMROG 09-PC-08
Position: 88° 49' 00"N 178° 35' 00" W
Date acquired: 20090817
Depth: 1082 m
Described by Ludvig Löwemark
Lomonosov Ridge off Greenland
Depth (cm)
Sec.
Lithology
Mag. Susc. (SI)
10 20 30
Gamma density (gm/cc)
1.6 1.8 2.0
0
40
80
120
160
200
240
280
320
360
400
440
480
520
560
600
1
2
3
4
Mottled
Black spots, mottled
Mottled
Cottage cheese structures
Copper streaks, mottled
Mottled
Mottled
Mottled
Brown cycle, bioturbated
Mottled
Cottage cheese structures
Brown cycle, bioturbated
Brown cycle, bioturbated
Mottled
Brown cycle, bioturbated
Mottled
Brown cycle, bioturbated
Brown cycle, bioturbated
Brown cycle, bioturbated
Brown cycle, bioturbated
Mottled
Brown cycle, bioturbated
Mottled
Brown cycle, bioturbated
Mottled, sampled for microbes at 390 cm
Brown cycle, bioturbated
Mottled
Brown cycle, bioturbated
Mottled
Brown cycle, bioturbated
Mottled
Mottled
Sandlayer
Brown cycle, bioturbated
Mottled
Brown cycle, bioturbated
Mottled
Brown double cycle, bioturbated
Mottled
Sandlayer
Mottled
Brown double cycle, bioturbated
Mottled

LOMROG09-PC-09

The core was taken on a spur protruding northward into the Amundsen Basin from the Lomonosov Ridge in order to obtain a record of variations in the Makarov Basin deep water that flows into the Amundsen Basin through the intra-basin.

The core consists of a sequence of brown cycles intercalated in the otherwise generally dark grey brown background sediment. The core also contains a distinct grey layer and consequently displays a typical central Arctic Ocean sequence.



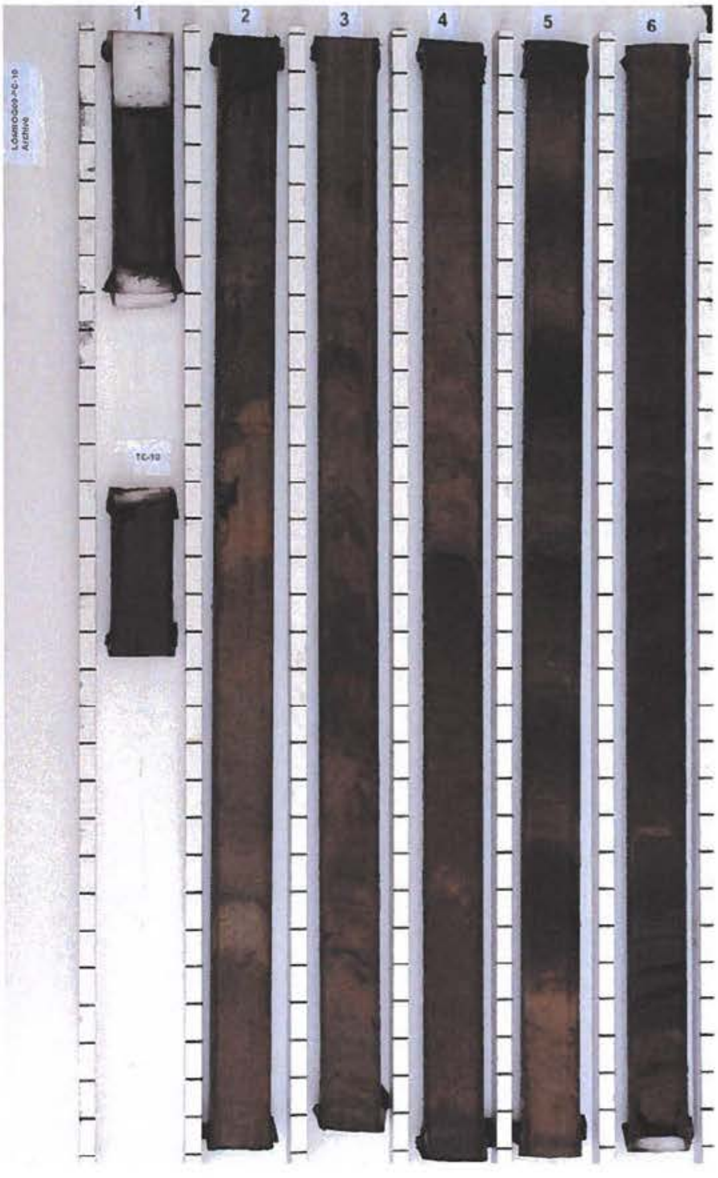


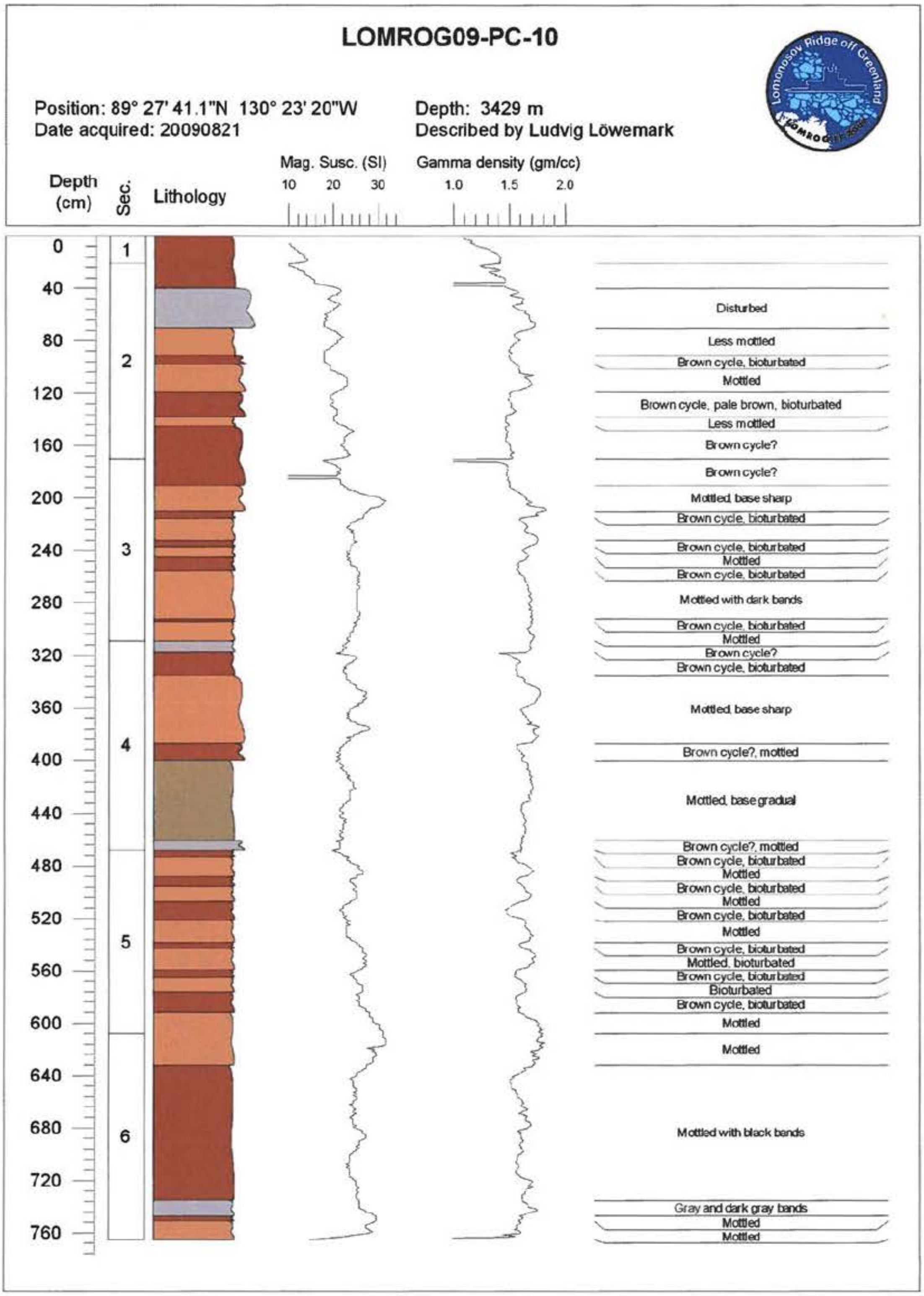
LOMROG09-PC-09
Position: 88° 48' 21.8"N 177° 56' 03"W
Date acquired: 20090817
Depth: 1244 m
Described by Ludvig Löwemark
Lomonosov Ridge off Greenland
LOMROG
Depth (cm)
Sec.
Lithology
Mag. Susc. (SI)
10 20 30 40
Gamma density (gm/cc)
1.2 1.6 2.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
1
2
3
4
5
Some bioturbation
Some bioturbation, base sharp, top gradual
top and base sharp
Mottled
Sandlayer
Mottled, base sharp
Sandlayer, top and base sharp
Sharp base?
Brown cycle?
Banded light and dark layers
Sandy layer
Mottled, sharp base
Sandy layer, sharp base
Mottled
Cottage cheese structures?
Gray layer! top gradual, base sharp
Mottled
Sandy layers
Top and base bioturbated
Bioturbated?
Top sharp
Base bioturbated?
Brown cycle, bioturbated
Base sharp
Brown cycle, bioturbated
Top and base sharp
Light and dark bands, brown cycle?, bioturbated
Bioturbated
Top sharp, bioturbated
Black / gray band, bioturbated
Transition, base gray, top brown, base sharp
Base and top sharp
Mottled
Brown cycle?
Bioturbated
Mottled, top bioturbated, top sharp
Sandy layer
Top sharp, mottled
Brown cycle? bioturbated
Mottled
Brown cycle?
Mottled
Brown cycle? bioturbated, base sharp
Mottled
Brown cycle, bioturbated
Mottled with pink and black spots
Mottled, base sharp
Bioturbated with black spots
Bioturbated with black spots, base sharp
Sandlayer, top and base sharp
Brown cycle? Bioturbated
Gradual transitation, base gray, top brown
Bioturbated
Bioturbated
Base sharp
Brown cycle?

LOMROG09-PC-10

The core was taken next to LOMROG09-PC-09 on the same spur protruding northward into the Amundsen Basin from the Lomonosov Ridge in order to obtain a record of variations in the Makarov Basin deep water that flows into the Amundsen Basin through the intra-basin.

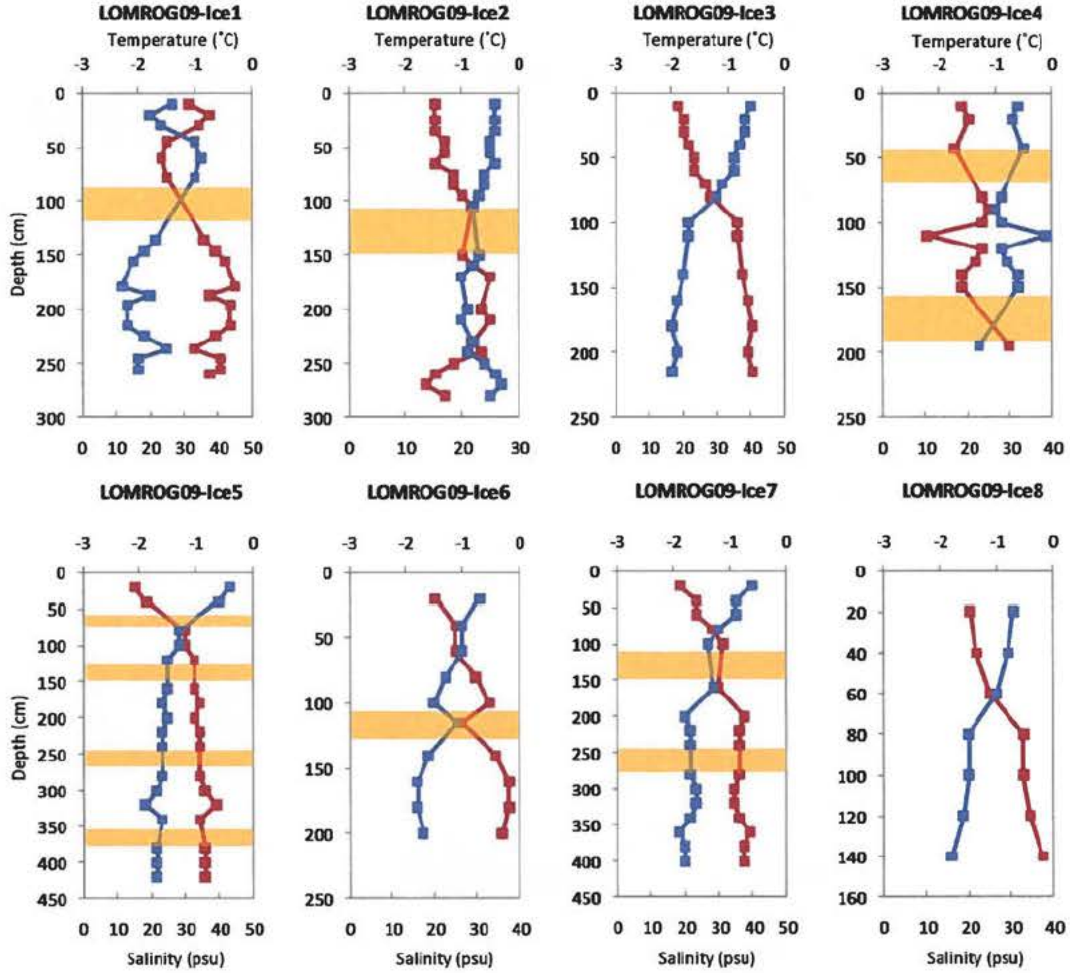
Like LOMROG09-PC-09, the core consists of a sequence of brown cycles intercalated in the otherwise generally dark grey brown background sediment. The core also contains a grey layer, although much less distinct than in LOMROG09-PC-09.



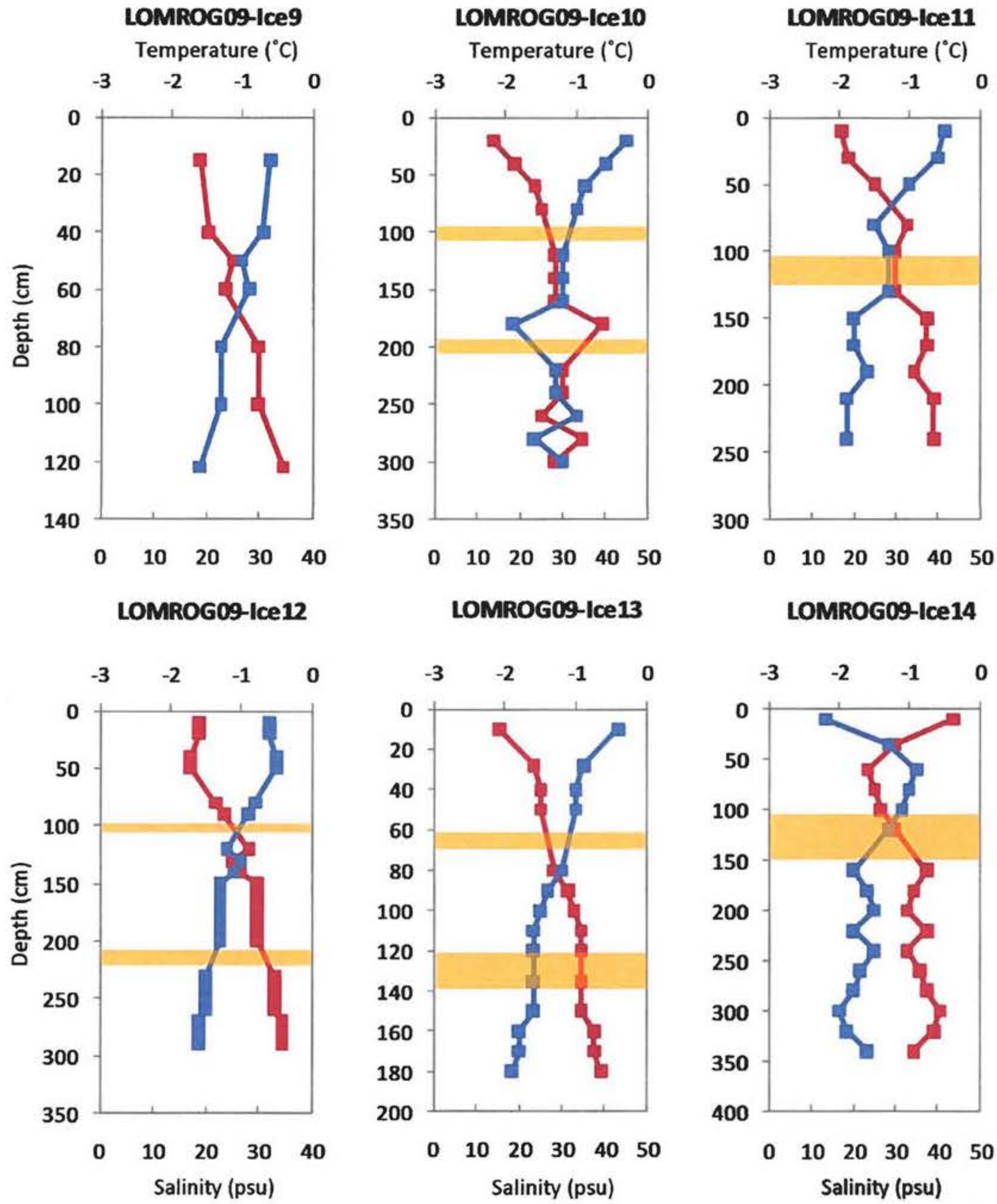


LOMROG09-PC-10
Position: 89° 27' 41.1"N 130° 23' 20"W
Date acquired: 20090821
Depth: 3429 m
Described by Ludvig Löwemark
Lomonosov Ridge off Greenland
Depth (cm)
Sec.
Lithology
Mag. Susc. (SI)
10 20 30
Gamma density (gm/cc)
1.0 1.5 2.0
0
40
80
120
160
200
240
280
320
360
400
440
480
520
560
600
640
680
720
760
1
2
3
4
5
6
Disturbed
Less mottled
Brown cycle, bioturbated
Mottled
Brown cycle, pale brown, bioturbated
Less mottled
Brown cycle?
Brown cycle?
Mottled, base sharp
Brown cycle, bioturbated
Brown cycle, bioturbated
Mottled
Brown cycle, bioturbated
Mottled with dark bands
Brown cycle, bioturbated
Mottled
Brown cycle?
Brown cycle, bioturbated
Mottled, base sharp
Brown cycle?, mottled
Mottled, base gradual
Brown cycle?, mottled
Brown cycle, bioturbated
Mottled
Brown cycle, bioturbated
Mottled
Brown cycle, bioturbated
Mottled
Brown cycle, bioturbated
Mottled, bioturbated
Brown cycle, bioturbated
Bioturbated
Brown cycle, bioturbated
Mottled
Mottled
Mottled with black bands
Gray and dark gray bands
Mottled
Mottled

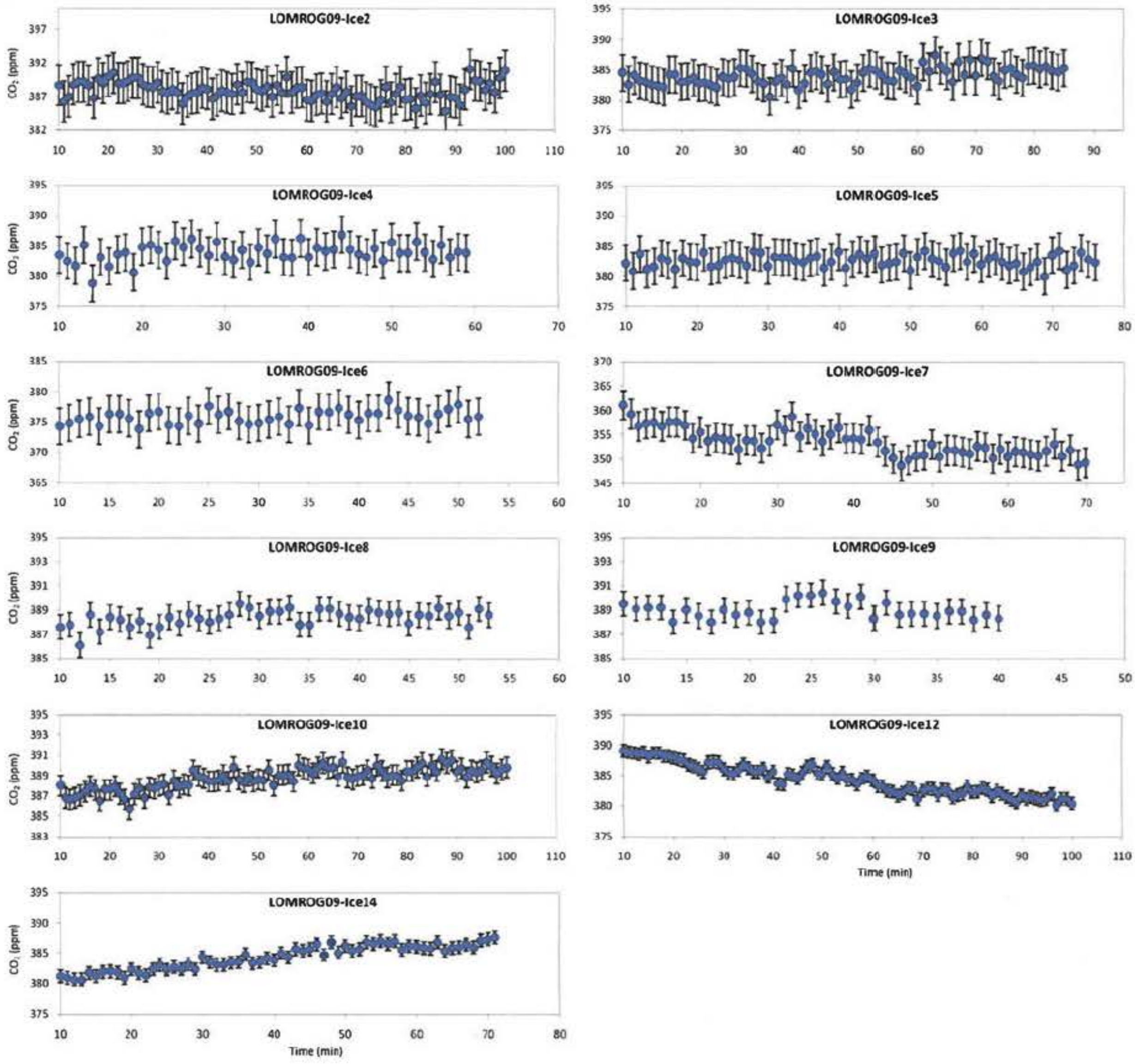
17.4 Appendix IV: Microbial Respiration in Arctic Sea Ice



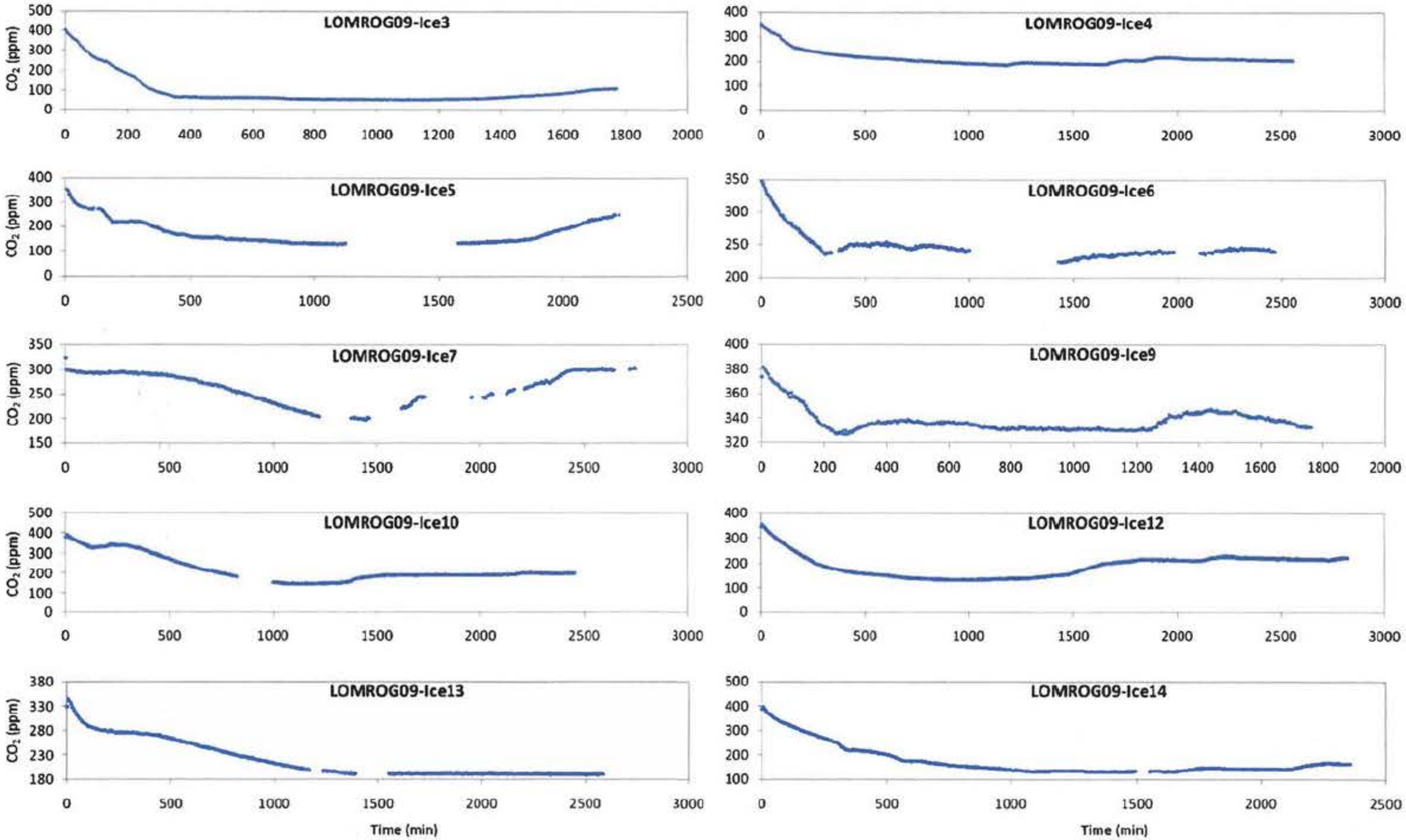
Appendix IV.1. *Environmental conditions (temperature and salinity) for brine channels within the ice of a representative core from each ice station are shown. Temperature was measured directly, salinity was determined from an empirically established relationship between temperature and salinity within ice. Locations of slush layers within each core are indicated by the yellow bands.*



Appendix IV.1. (cont.) *Environmental conditions (temperature and salinity) for brine channels within the ice of a representative core from each ice station are shown. Temperature was measured directly, salinity was determined from an empirically established relationship between temperature and salinity within ice. Locations of slush layers within each core are indicated by the yellow bands.*



Appendix IV.2. *In situ CO_2 flux measurements are shown. The first 10 minutes of each measurement was discarded, since this time was characterized by a rapid shift in concentration as the headspace reached equilibrium with the ice. Note that LOMROG09-Ice2 through LOMROG09-Ice8 used a 10 second averaging filter resulting in a greater error of ± 3 ppm. LOMROG09-Ice1, LOMROG09-Ice11, and LOMROG09-Ice13 not reported due to technical problems.*



Appendix IV.3. *Whole core incubations are shown. LOMROG09-Ice1, LOMROG09-Ice2, and LOMROG09-Ice8 are not shown due to technical problems with data collection.*