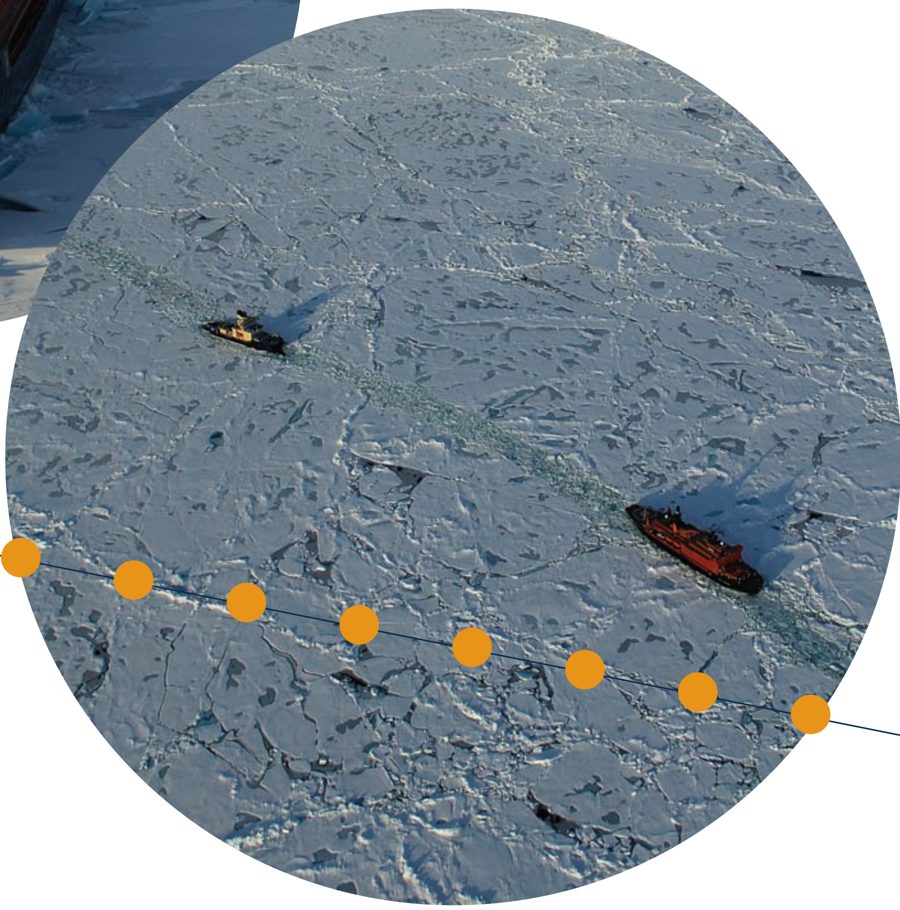
# Lomonosov Ridge off Greenland 2007 (LOMROG)

## Cruise Report

Martin Jakobsson, Christian Marcussen
and LOMROG Scientific Party



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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE AND ENERGY

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# Lomonosov Ridge off Greenland 2007 (LOMROG)


## Summary

The Lomonosov Ridge off Greenland was the primary focus for the LOMROG expedition. This part of the Arctic is virtually unexplored as difficult sea ice conditions have made it inaccessible for surface vessels. With Swedish icebreaker Oden supported by new Russian nuclear icebreaker 50 Let Pobedy (50 Years of Victory), LOMROG managed to reach the southern most tip of the Lomonosov Ridge off Greenland to carry out multibeam mapping, subbottom and seismic reflection profiling, gravity measurements, geological coring and oceanographic station work. The LOMROG expedition is a Swedish/ Danish collaboration project with participating scientists also from Canada, Finland, and USA. The data collection was made for the purpose of studying paleoceanography/ oceanography, glacial history and the tectonic evolution of the of the Arctic Ocean as well as for Denmark's Continental Shelf Project under the United Nations Convention on the Law of the Sea Article 76. One of the reasons for targeting the ice-infested area north of Greenland was that it likely holds answers to key questions regarding the glacial history of the Arctic Ocean, such as whether immense ice shelves existed in the Arctic Ocean during past glacial periods. To test the hypothesis of a huge Arctic Ocean ice shelf, LOMROG mapped the areas of the Lomonosov Ridge north of Greenland and Morris Jesup Rise using the new EM120 multibeam bathymetry and SBP120 subbottom profiling system installed on the Oden during the

spring of 2007. Extensive erosion of the seabed was mapped down to water depths of approximately 800 m on the Southern Lomonosov Ridge and sediment cores were retrieved from the eroded areas. Shipboard preliminary analyses of this geophysical mapping data and acquired sediment cores suggest that the seabed erosion is due to either grounding of icebergs or an ice shelf, or combination of both. In addition, the multibeam data from the Morris Jesup Rise revealed large iceberg scours down to a water depth of approximately 1050 m.
The oceanographic component of LOMROG investigated the pathways of the Atlantic water and deep water. Water masses originating from the Canadian Basin side, which have crossed the Lomonosov Ridge at about 88°30'N 154°E, were found following the slope along the southern Lomonosov Ridge slope on the Amundsen Basin side. The primary objective of the Danish part of LOMROG was to collect bathymetric, seismic and gravimetric data in the Amundsen Basin and along the Lomonosov Ridge in order to acquire the necessary data according to Article 76 in UNCLOS. Despite severe ice conditions bathymetric multibeam data covering the continental slope in various places, 135 km seismic data in Amundsen Basin, 15 km on the Lomonosov Ridge and 165 km off North East Greenland were obtained. Gravity data were acquired along the ships track using gravimeter on board Oden and on the ice. Ice cores were retrieved at 28 stations in order to study the role of the sea ice in the transport of $CO_2$ from the atmosphere to the ocean. During LOMROG valuable experience was gained both in relation to the use of the newly developed seismic equipment and how to operate under severe ice conditions in the area north of Greenland using two icebreakers. A new multibeam survey technique was developed that made it possible for Oden alone to collect high-quality data in 10/10 ice conditions. This technique involves that Oden is spun around 180° in a "pirouette" while acquiring multibeam data in a sector 360° around the ship equal to the multibeam swath width. After one "pirouette" was done, the icebreaker broke ice using its full capacity to the end of the coverage, where a new pirouette was carried out.

Photo 1. Swedish icebreaker Oden and the new Russian icebreaker "50 Let Pobedy" in the hard ice conditions on the Lomonosov Ridge north of Greenland. (Photo Martin Jakobsson).

## Introduction and background

The Lomonosov Ridge off Greenland (LOMROG) project was designed to study the virtually unexplored area of the submarine Lomonosov Ridge ca 350 km north of Greenland (Figure 1). The project idea was initiated by Martin Jakobsson and Christian Marcussen during the IV-ICAM (International Conference on Arctic Margins) in Halifax, Canada, 2003. The ice conditions north of Greenland are well known to be the toughest in the Arctic Ocean and the expedition strategy was to reach the southern Lomonosov Ridge by entering the ridge at about 87-88°N and work along its crest towards the south. No research from surface vessels had previously been carried out in this part of the Arctic Ocean. The interest in this ice-infested area stems from a range of scientific questions and the fact that Denmark needs to acquire geophysical data from this region in order to put forward a claim for an "extended continental margin" under United Nations Convention on the Law of the Sea (UNCLOS) Article 76. The LOMROG project's main scientific components were to study the Arctic Ocean:

1. Paleoceanography
2. Glacial history
3. Oceanography
4. Tectonic evolution

In addition to these main components, a range of subprojects were added including studies of the role of sea ice in the transport of $CO_2$ from the atmosphere to the ocean, distribution of mercury in the atmosphere and ocean, and the Arctic Ocean gravity field.

The Swedish Polar Research Secretariat (SPRS) was contacted with the expedition plans and a proposal including the scientific objectives was submitted to the Swedish Research Council (VR) and funded in 2005. Simultaneously, the LOMROG expedition was included in the budget for the Danish Continental shelf Project. Furthermore, the cruise was incorporated as a component in the Arctic Palaeoclimate and its Extremes (APEX) research network program endorsed by the ICSU/WMO Joint Committee for the International Polar Year 2007-2008 (IPY) as a formal IPY activity.

SPRS initiated the logistical work in early 2006 of organizing LOMROG as a Swedish/Danish collaboration project with participating scientists also from Canada, Finland, and USA. The Swedish icebreaker Oden was decided to be the main research platform and in order to acquire reflection seismic profiles in the expected hard 10/10 ice conditions north of Greenland, it was suggested already at an early stage that one of the Russian nuclear icebreakers should be contracted for support. After negotiations with the Murmansk Shipping Company, the new largest Russian nuclear icebreaker "50 Let Pobedy" (50 Years of Victory) was contracted by SPRS and financed by the Danish continental shelf project.

During the spring of 2007, Oden went through a major upgrade through the installation of a multibeam bathymetric sonar (Kongsberg EM120) and chirp subbottom profiler (Kongsberg SBP120). The sonar was financed by the Knut and Alice Wallenberg foundation and VR and the installation, which took place April 17 to May 15 in the Landskrona dry-dock located in southern Sweden, was financed by the Swedish Maritime Administration (SMA). These instruments were together with the seismic equipment developed by the Danish Continental Shelf Project key to the planned LOMROG operations.

A successful Sea Acceptance Test (SAT) of the sonar installation was carried out between May 15 and 25 off the coast of northwestern Norway (Figures 2 and 3). During this period, the handling of the seismic equipment, which had been designed to tow in heavy ice conditions behind the Oden, was also tested.

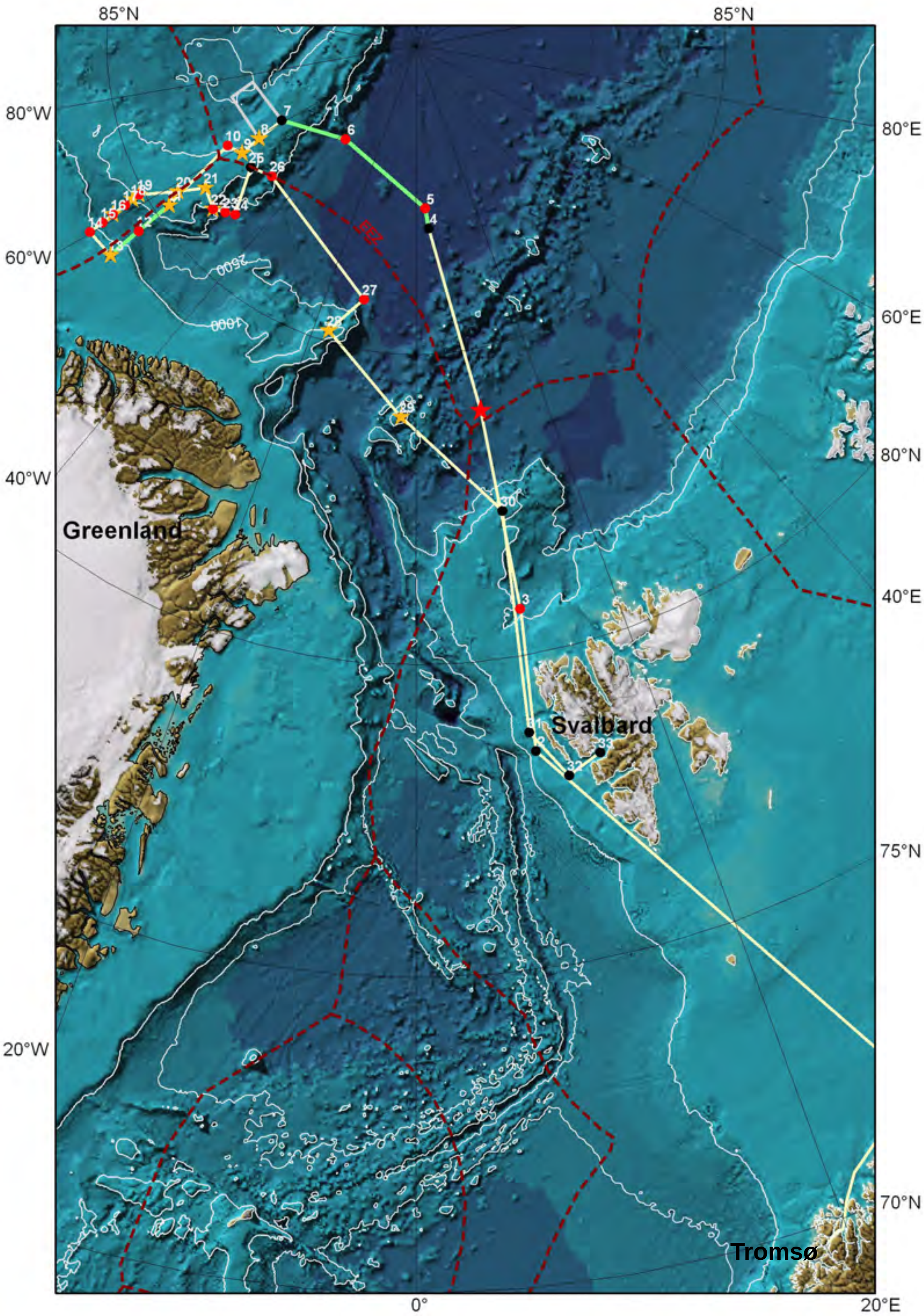



Figure 1. Initial LOMROG cruise plan. The red star shows the proposed rendezvous position between Swedish icebreaker Oden and Russian nuclear icebreaker "50 Let Pobedy" (50 Years of Victory). Red dots indicate planned CTD stations, orange stars coring stations, and the green bold lines are planned reflection seismic profiles. The expedition started in Tromsø August 11, 2007 and ended in Longyearbyen, Svalbard, September 16. The final real cruise track is shown in Figure 6.

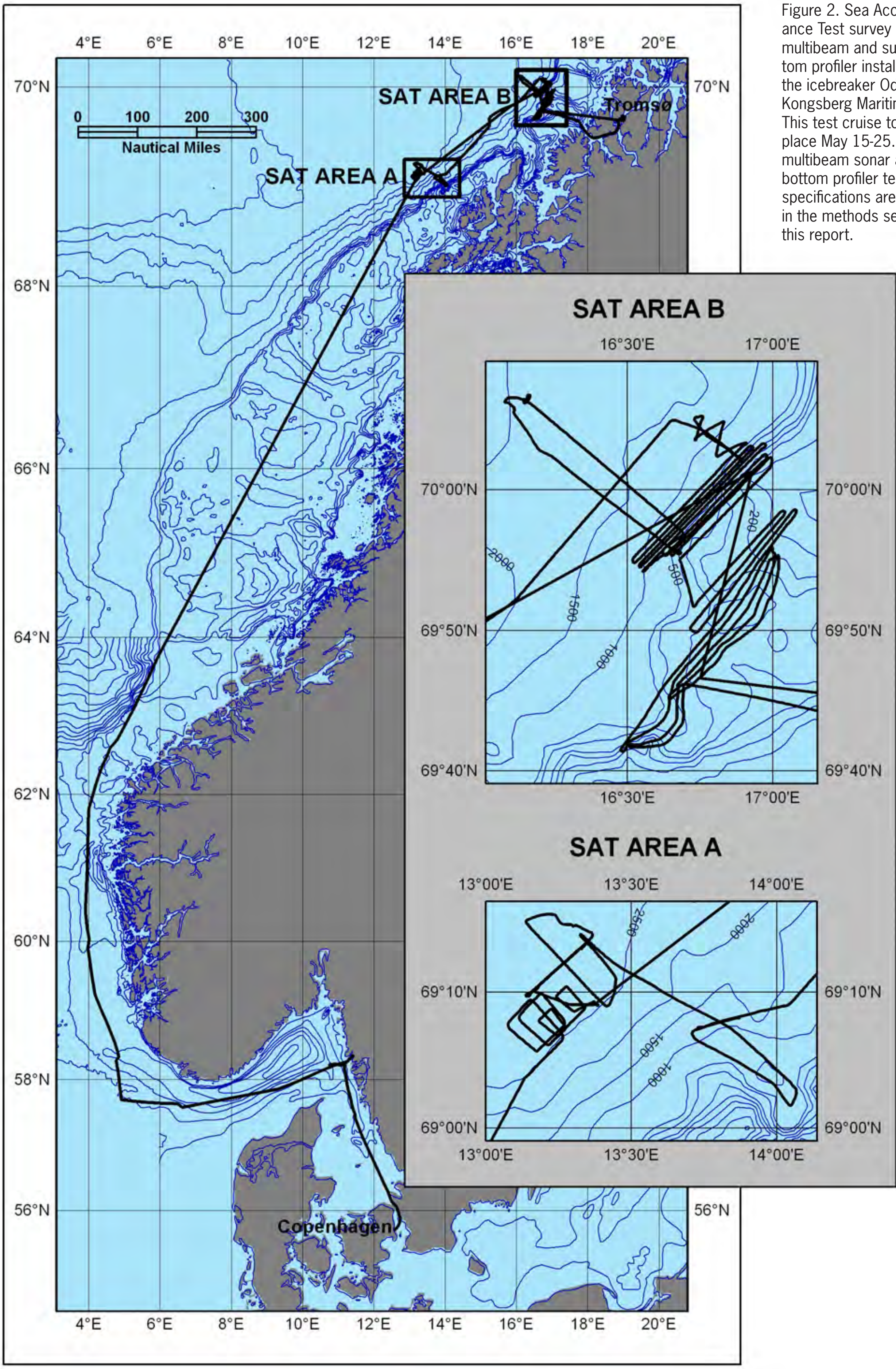



Figure 2. Sea Acceptance Test survey of the multibeam and subbottom profiler installed on the icebreaker Oden by Kongsberg Maritime. This test cruise took place May 15-25. The multibeam sonar and subbottom profiler technical specifications are listed in the methods section of this report.

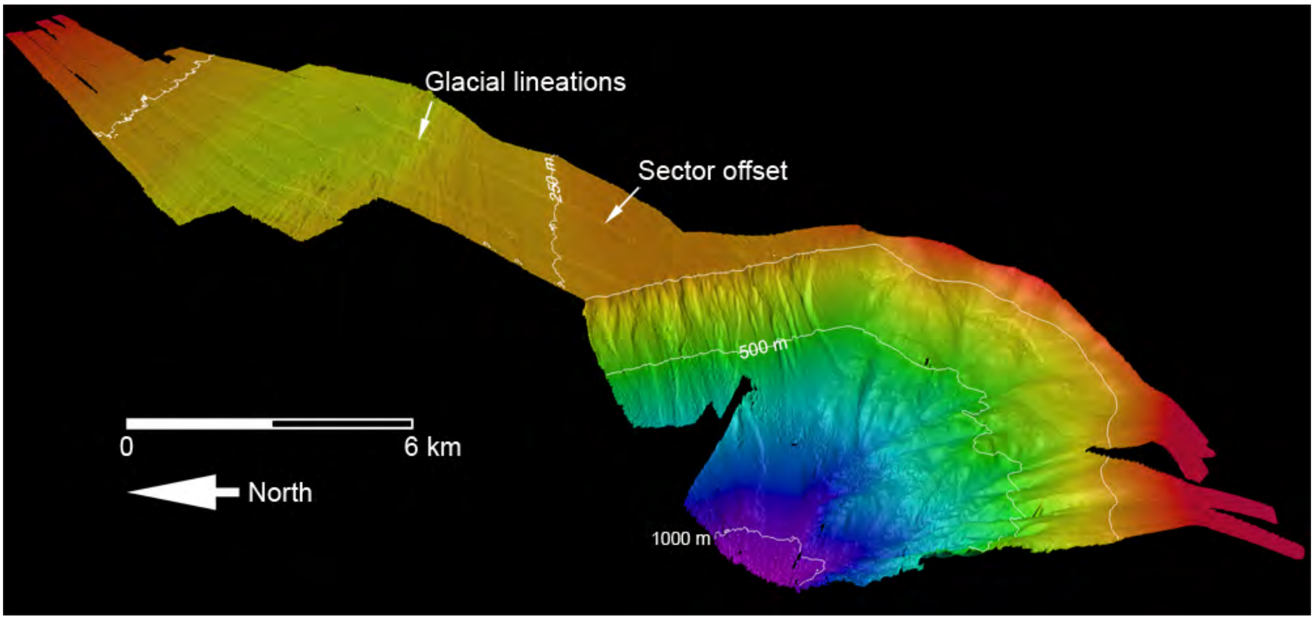



Figure 3. Multibeam data from the Oden SAT survey outside of Lofoten Island, northwestern Norway. The image shows the southern portion of SAT AREA B shown in figure 2. Glacial lineations are clearly seen on the shallow shelf. The survey revealed that the EM120 had a problem with a depth offset in the outer sector along the multibeam swath. This offset occurred at about 45-50° out from nadir and amounted to approximately 1-2 % of the water depth. This problem was corrected by Kongsberg before the LOMROG expedition.

### *Paleoceanography and glacial history*

Previous expeditions to the Lomonosov Ridge with Oden in 1996 and the US nuclear submarine Hawkbill in 1999 demonstrated the occurrence of glacier ice grounding down to 1000 m present water depth at about 87°N (Siberian side) on the ridge crest (Jakobsson, 1999; Polyak et al., 2001). If this ice grounding resulted from a much debated, but supposedly coherent and large floating ice shelf (Mercer, 1970), the Lomonosov Ridge north of Greenland must also be scoured. To test the hypothesis of a huge Arctic Ocean ice shelf, one of LOMROG's key goals was to map the areas north of Greenland using Oden's newly installed multibeam and subbottom profiler. Data from these two instruments combined should make it possible to address the type, frequency and directions of ice erosion/ scouring activity as well as their age relationships. Glacial seafloor features from previous glaciations should be covered by sediments and retrieving this stratigraphy atop the glacial morphology should make it possible to date the events that caused them. Therefore, in addition to take long sediment cores for paleoceanographic studies, LOMROG had the potentially glacially scoured areas of the Lomonosov Ridge as a target for sediment coring. The Morris Jesup Rise, protruding from the northeastern Greenland continental margin, was the other main target area for the LOMROG expedition for the same scientific reason as the southern part of the Lomonosov Ridge off northwestern Greenland. Furthermore, both these areas are of great interest for the Danish continental shelf project (see below), making it possible to combine the Swedish and Danish interest and outline the LOMROG cruise plan (Figure 1).

### *Oceanography*

The oceanographic component of LOMROG focuses on constraining and understanding the pathways of the Atlantic water and deep water across the Lomonosov Ridge between the Eurasian Basin and Canadian Basin and through the western Fram Strait. A deep water pathway may exist between the Lomonosov Ridge and the Northern Greenland shelf and, thus, the knowledge of the shape of the seafloor in this area is also of interest for the oceanography. The LOMROG oceanography is an extension of the 2005 scientific program when oceanographic station work was carried out from the Oden and multibeam mapping from USCGC Healy during the Healy-Oden Trans-Arctic expedition (HOTRAX). The data from HOTRAX showed that water overflow from the Makarov Basin (part of the Canadian Basin) to the Amundsen Basin (part of the Eurasian Basin) takes place across a 1870 m deep sill in the central Lomonosov Ridge at about 88° 25'N, 150°E (Björk et al., 2007). This water appears to follow the Lomonosov Ridge slope southwards towards Greenland and, thus, one question is if it can be traced on the southern most tip of the ridge and how the circulation continues from this point and onwards.

### *Tectonic evolution*

A key to the tectonic evolution of the Arctic Basin, in particular the pre-Gakkel Ridge spreading, is the nature and history of the Lomonosov Ridge. Based on the first continuous bathymetric profile across Lomonosov Ridge, Dietz and Shumway (1961) suggested that the ridge is a fault block rather than a volcanic construction. This theory was later developed and it was suggested that the ridge was a continental sliver which had rifted off the outer continental shelf of Eurasia between northern Svalbard and Severnaya Zemlya during the Late Paleocene to Holocene propagation of the Mid-Atlantic Ridge into the Arctic Ocean (Vogt et al., 1979). The unmapped connection to the Greenland/Canadian continental margin may play a crucial role in understanding the tectonic history of the Arctic Basin, in particular the first opening of the Eurasian Basin. This part of LOMROG primarily represents collaboration between Stockholm University and GEUS. In combination with the Danish Continental Shelf Project, a seismic reflection profile was planned across the apparent gap between the northern Greenland margin and the Lomonosov Ridge (Figure 1).

### *Denmark's continental shelf project*

Following Denmark's ratification in 2004 of the United Nations Convention on the Law of the Sea (UNCLOS from 1982), Denmark, Greenland and the Faroe Islands have a period of maximum 10 years to make claims beyond the current Exclusive Economic Zone (EEZ), which is defined by 200 nautical miles (NM) from a country's baseline. Article 76 of UNCLOS is the key to future jurisdiction over resources on and below the seabed beyond 200 NM. There are five potential areas for extended Article 76 claims off Greenland and the Faroe Islands; one of them in the Arctic Ocean north of Greenland. 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. The most critical issue is to be able to demonstrate a natural prolongation of the submerged land territory based on geological and geomorphological factors, and later to document claims in detail by using the various formulas and constraint lines of Article 76 (Commission on the Limits of the Continental Shelf (CLCS) 1999). For construction of these lines it is necessary to define the location of the foot of the continental slope and the 2500 m depth contour, and to know the sediment thickness beyond the foot of the slope. The foot of the continental slope is defined as the point of maximum change of gradient at the base of the continental slope. LOMROG is the first of a series of three planned cruises in the Arctic Ocean that GEUS anticipate to carry out. The purpose is to begin collecting the multibeam data across the edges of the Lomonosov Ridge and the Northern Morris Jesup Rise to determine the foot of slope essential to a possible submission to CLCS along with seismic data crucial both to the tectonic understanding the Lomonosov Ridge and its connection to Greenland and for knowledge and documentation of sediment thickness in the Amundsen Basin.

## Ice conditions and ship operations

The sea ice conditions during the Arctic summer of 2007 were in general the lightest we have witnessed since systematic satellite monitoring begun 30 years ago (Comiso et al., 2008). The minimum extent, that is total area covered by any type of sea ice including open water between flows, was reached in September 14-16 when approximately 4.1 × $10^6$ $km^2$ was covered by sea ice. This is a decline of 24% compared to the earlier record low in 2005 (Comiso et al., 2008) (Figure 4). However, in the LOMROG operational area north of Greenland and in the Western part of the Fram Strait, difficult sea ice conditions were encountered with some flows thicker than 4 m and abundant large pressure ridges. In fact, it was speculated during the LOMROG cruise that the light conditions in the rest of the Arctic Ocean may have resulted in a more movable pack ice in turn leading to locally heavier ice conditions North of Greenland in 2007 compared to summers with generally larger sea ice extents in the Arctic Ocean. The reason for this speculation is that the general sea ice drift patterns have a tendency to push the ice over to this part of the Arctic Ocean. Figure 5 shows the ice concentration in the Arctic Ocean in August 25 when LOMROG operated on the southern part of the Lomonosov Ridge. From this map it is evident that there were practically no open areas North of Greenland during LOMROG. Between August 13 and September 16 regular stops where made to sample sea ice by drilling, measuring thickness, freeboard height and snow cover, as well as snow and ice density. The drilling program was an ad-hoc research programme taking advantage of gravity measurement activities and the sea ice coring and sampling research programme of the Greenland Nature Institute. The results are reported on in this cruise report and provide a ground truth to the observations made by satellite.

The two icebreakers Oden and 50 Let Pobedy operated together from the rendezvous August 17 until August 31. The standard means of operation consisted of that 50 Let Pobedy broke ice in front of Oden who followed in the wake (see Photo 1). The convoy could generally move forward with several knots in difficult ice conditions, but when the ice pressure was moderate. During the period of hard ice pressure encountered in the Lomonosov Ridge area there were, however, frequent occasions when Oden got stuck due to the large amount of crushed up ice that directly clogged the wake behind the nuclear ice breaker 50 Let Pobedy. This heavy “slush” was occasionally very difficult for Oden to handle as it was pushed in front due to the form of the icebreaker’s bow. The slush also caused poor multibeam data quality as it was drawn beneath the hull of Oden to cover the multibeam transducers. During the day of August 25 we were informed that one of the propellers of 50 Let Pobedy had been damaged and, therefore, she was forced to depart earlier than originally planned. The consequence from this was that the original plan of transecting to the Northern Greenland’s continental shelf from the Southern tip of the Lomonosov Ridge had to be aborted. Instead LOMROG targeted the next planned survey area, the Morris Jesup Rise (Figure 1). The two icebreakers separated August 31. The cooperation with the Russian icebreaker had been excellent. The ice conditions north of Greenland had been so difficult that a one ship operation would not have been possible.

The sea ice thickness and coverage (near 10/10) in the Morris Jesup Rise area were not much different compared to what was encountered on the Southern Lomonosov Ridge, although there were significantly less abundant large pressure ridges. The single ship operation lead to the invention of a new multibeam survey technique, referred to as “pirouette surveying”, which is described in this cruise report in the multibeam bathymetry chapter.

Figure 4. Minimum median sea ice in 2007 compared to 2005. The maps are based on microwave measurements from satellites (National Snow and Ice Data Center).

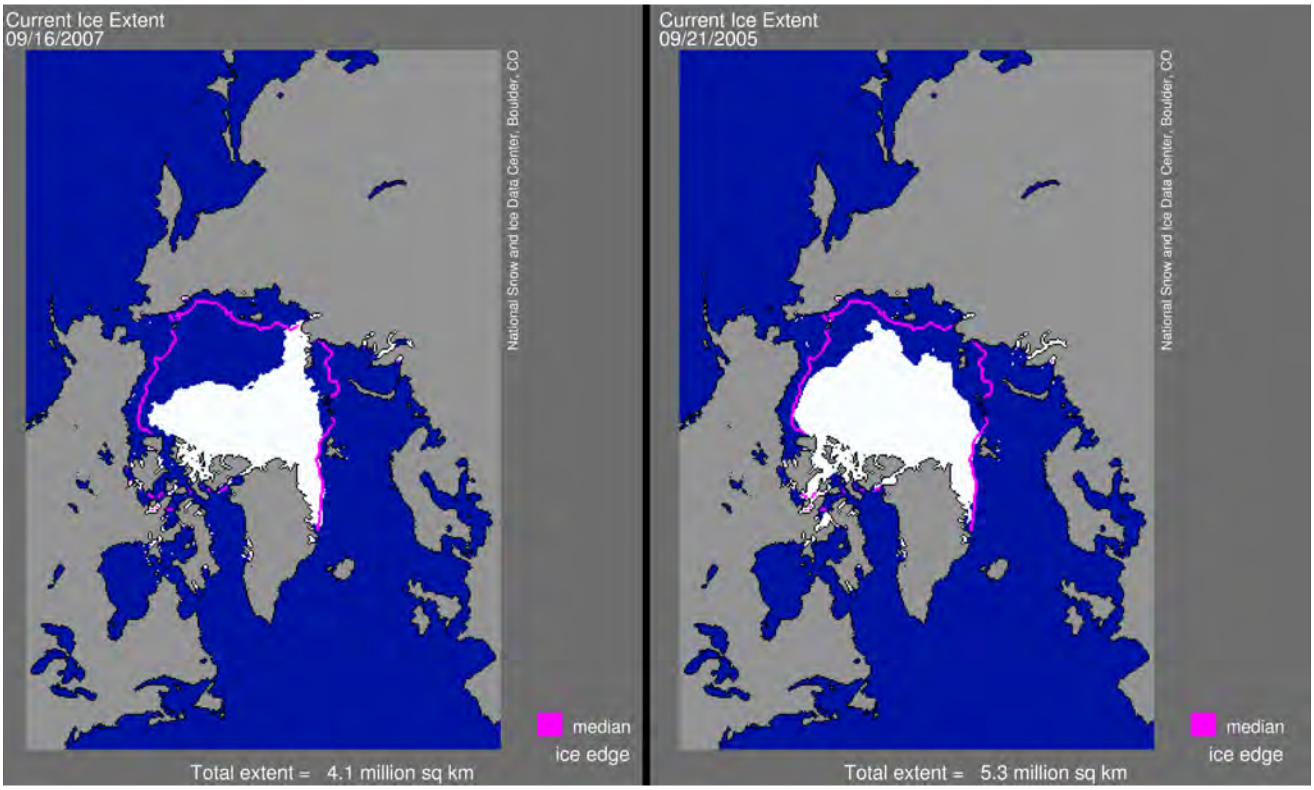
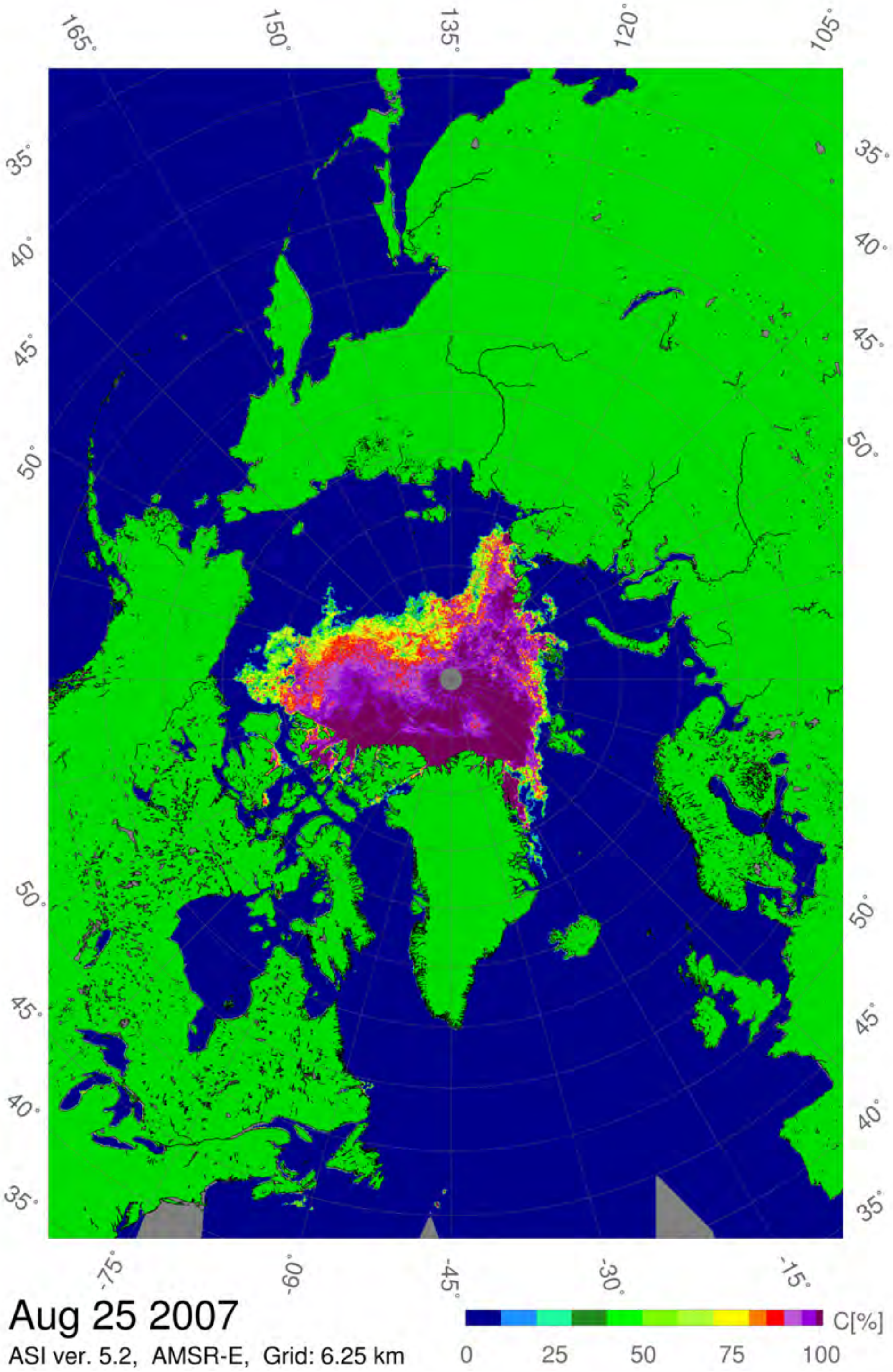


Figure 5. Sea ice concentration derived from remote sensing using the AMSR-E 89 GHz channels (Spreen et al., 2008).



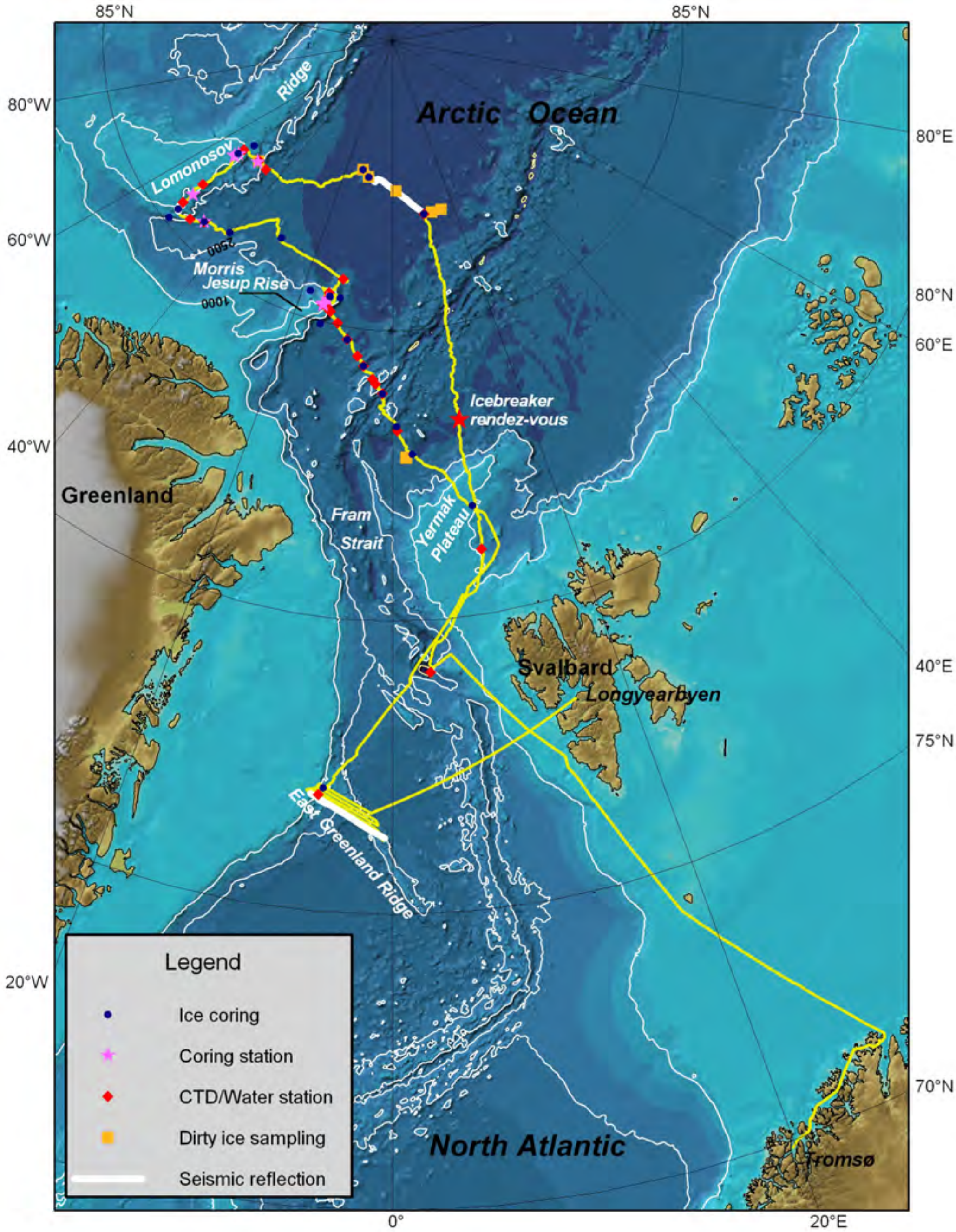



Figure 6. LOMROG cruise track, station work and seismic profiling. Detailed maps showing station numbers etc are included in this report in the subchapters.

## Participants

Table 1 lists the participants of the LOMROG 2007 expedition. In addition, there area several scientists working on the LOMROG data that not took part in the expedition. These are not listed in Table 1.

Table 1. LOMROG participants.

| Marine geology and paleoceanography project | | | |
|---|---|---|---|
| Scientist/PI | Jakobsson, Martin | Stockholm University | Sweden |
| Scientist | Darby, Dennis | Old Dominion University | USA |
| Technician | Eriksson, Björn | Stockholm University | Sweden |
| Scientist | Hanslik, Daniella | Stockholm University | Sweden |
| Scientist | Hell, Benjamin | Stockholm University | Sweden |
| Technician | Karasti, Markus | Stockholm University | Sweden |

| | | | |
|---|---|---|---|
| Scientist | Löwemark, Ludvig | Stockholm University | Sweden |
| Scientist | Polyak, Leonid | Byrd Polar Research Centre | USA |
| Scientist | Sellén, Emma | Stockholm University | Sweden |
| Scientist | Wallin, Åsa | Stockholm University | Sweden |
| **Denmark's continental shelf project** | | | |
| Scientist/PI | Marcussen, Christian | Geological Survey of Denmark and Greenland (GEUS) | Denmark |
| Scientist | Anthony, Dennis | Royal Danish Administration of Navigation and Hydrography | Denmark |
| Scientist | Dahl-Jensen, Trine | Geological Survey of Denmark and Greenland (GEUS) | Denmark |
| Scientist | Forsberg, René | Danish National Space Center | Denmark |
| Scientist | Funck, Thomas | Geological Survey of Denmark and Greenland (GEUS) | Denmark |
| Scientist | Janzen, Timothy | Canadian Hydrographic Services | Canada |
| Scientist | Lykke-Anderssen, Holger | University of Aarhus | Denmark |
| Scientist | Ramløv, Hans | Roskilde University | Denmark |
| Scientist | Rödel, Lars-Georg | University of Aarhus | Denmark |
| Scientist | Sølvsten, Morten | Royal Danish Administration of Navigation and Hydrography | Denmark |
| Scientist | Trinhammer, Per | University of Aarhus | Denmark |
| Scientist | Vankilde-Pedersen, Thomas | Geological Survey of Denmark and Greenland (GEUS) | Denmark |
| **Oceanography project** | | | |
| Scientist/PI | Andersson, Leif | University of Gothenburg | Sweden |
| Scientist/PI | Björk, Göran | University of Gothenburg | Sweden |
| Scientist | Eriksson, Patrick | Finnish Institute of Marine Research | Finland |
| Scientist | Gårdfeldt, Katarina | Chalmers/University of Gothenburg | Sweden |
| Scientist | Hjalmarsson, Sofia | University of Gothenburg | Sweden |
| Scientist | Jutterström, Sara | University of Gothenburg | Sweden |
| Scientist | Olsson, Anders | University of Gothenburg | Sweden |
| Scientist | Nilsson, Johanna | University of Gothenburg | Sweden |
| Scientist | Zemlyak, Frank | Bedford Institute of Oceanography | Canada |
| **Logistics and media** | | | |
| Exp. Mgt. | Karlqvist. Anders | Swedish Polar Research Secretariat | Sweden |
| Exp. Mgt. | Rickberg, Sofia | Swedish Polar Research Secretariat | Sweden |
| Media | Andrea Helminen, Suvi | STV | Denmark |
| Media | Sorento, Kenneth | STV | Denmark |
| MD | Ekblad, Krister | Swedish Polar Research Secretariat | Sweden |
| IT-man | Frejvall, Per | Swedish Polar Research Secretariat | Sweden |
| Pilot | Akse, Geir | Swedish Polar Research Secretariat | Sweden |
| Pilot | Mäki, Thomas | Swedish Polar Research Secretariat | Sweden |
| Hkp-Mek | Reskow, Mart | Swedish Polar Research Secretariat | Sweden |
| Teacher | Sjöö, Carin | Fyrisskolan, Uppsala | Sweden |
| **Icebreaker crew** | | | |
| Master | Årnell, Tomas | Oden Crew | Sweden |
| Ch. Officer | Andersson, Erik | Oden Crew | Sweden |
| 2:nd Officer | Wisén, Mats | Oden Crew | Sweden |
| 2:nd Officer | Wahlberg, Kenneth | Oden Crew | Sweden |
| Bosun | Hansson, Mats | Oden Crew | Sweden |
| Able Seaman | Sjöbom, Einar | Oden Crew | Sweden |

| | | | |
|---|---|---|---|
| Able Seaman | Hansson, Lars-Åke | Oden Crew | Sweden |
| Able Seaman | Nilsson, Jan | Oden Crew | Sweden |
| Ch. Engineer | Skantze, Dan | Oden Crew | Sweden |
| 1:st Engineer | Hillberg, Markus | Oden Crew | Sweden |
| 2:nd Engineer | Rundqvist, Jörgen | Oden Crew | Sweden |
| 2:nd Engineer | Hahne, Martin | Oden Crew | Sweden |
| Oiler | Bladh, Per | Oden Crew | Sweden |
| Oiler | Pettersson, Olof | Oden Crew | Sweden |
| Oiler | Leth, Aron | Oden Crew | Sweden |
| Ch. Cook | Andersson, Lars | Oden Crew | Sweden |
| Messman | Romero, Hilda | Oden Crew | Sweden |
| Messman | Wahlqvist, Christina | Oden Crew | Sweden |
| Cook | Sundström, Sandra | Oden Crew | Sweden |
| Fitter | Lundberg, Stellan | Oden Crew | Sweden |
| 2:nd Officer | Nilsson, Stigbjörn | Oden Crew | Sweden |

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## Scientific Methods

### *Multibeam bathymetry*

During the cruise, bathymetric mapping with a multibeam echo sounder was performed continuously. The LOMROG expedition multibeam mapped three main target areas: the Lomonosov Ridge, the Morris Jesup Rise and the East Greenland Ridge (Figure 6). In addition, the Yermak Plateau was surveyed along some dedicated transect lines with limited lengths. During transits between the main survey areas and station work, bathymetric data was collected. The data quality was highly dependant on the ice conditions and if Oden was following in 50 Let Pobedy's wake or not (see results). The multibeam and subbottom data acquisition was monitored around the clock during four hour shift by two watchmen at each shift (Table 2).

#### *Equipment*

Icebreaker Oden is equipped with a Kongsberg EM120 1°x1° multibeam echo sounder (serial number 205) including raw data logger (Figure 7). The EM120 multibeam can perform seabed mapping to full ocean depth (11 000 m). The nominal sonar frequency is 12 kHz with an angular coverage sector of up to 150 degrees and 191 beams per ping. Due to the

Table 2. Multibeam watch standing.

| | |
|---|---|
| Team 1 (0-4 & 12-16) | |
| **Morten Sølvsten** | **Royal Danish Administration of Navigation and Hydrography** |
| **Björn Eriksson** | **Stockholm University** |
| Team 2 (4-8 & 16-22) | |
| **Tim Janzen** | **Canadian Hydrographic Services** |
| **Benjamin Hell** | **Stockholm University** |
| Team 3 (8-12 & 20-24) | |
| **Dennis Anthony** | **Royal Danish Administration of Navigation and Hydrography** |
| **Emma Séllen** | **Stockholm University** |
| **Leonid Polyak** | **Byrd Polar Research Centre** |
| **Ludvig Löwenmark** | **Stockholm University** |

ice protection of the transceivers, the useable angular coverage is reduced down to approx. 2 × 65°; the width of the useable mapping data is typically three-four times the water depth (during the LOMROG cruise factors of 0.5…7 times water depth were achieved). The transmit fan is split in several individual sectors with independent active steering according to vessel roll, pitch and yaw. This places all soundings on a "best fit" to a line perpendicular to the survey line, thus ensuring a uniform sampling of the bottom and possible 100% coverage. The EM120 transducers are linear arrays in a Mills cross configuration with separate units for transmit and receive.

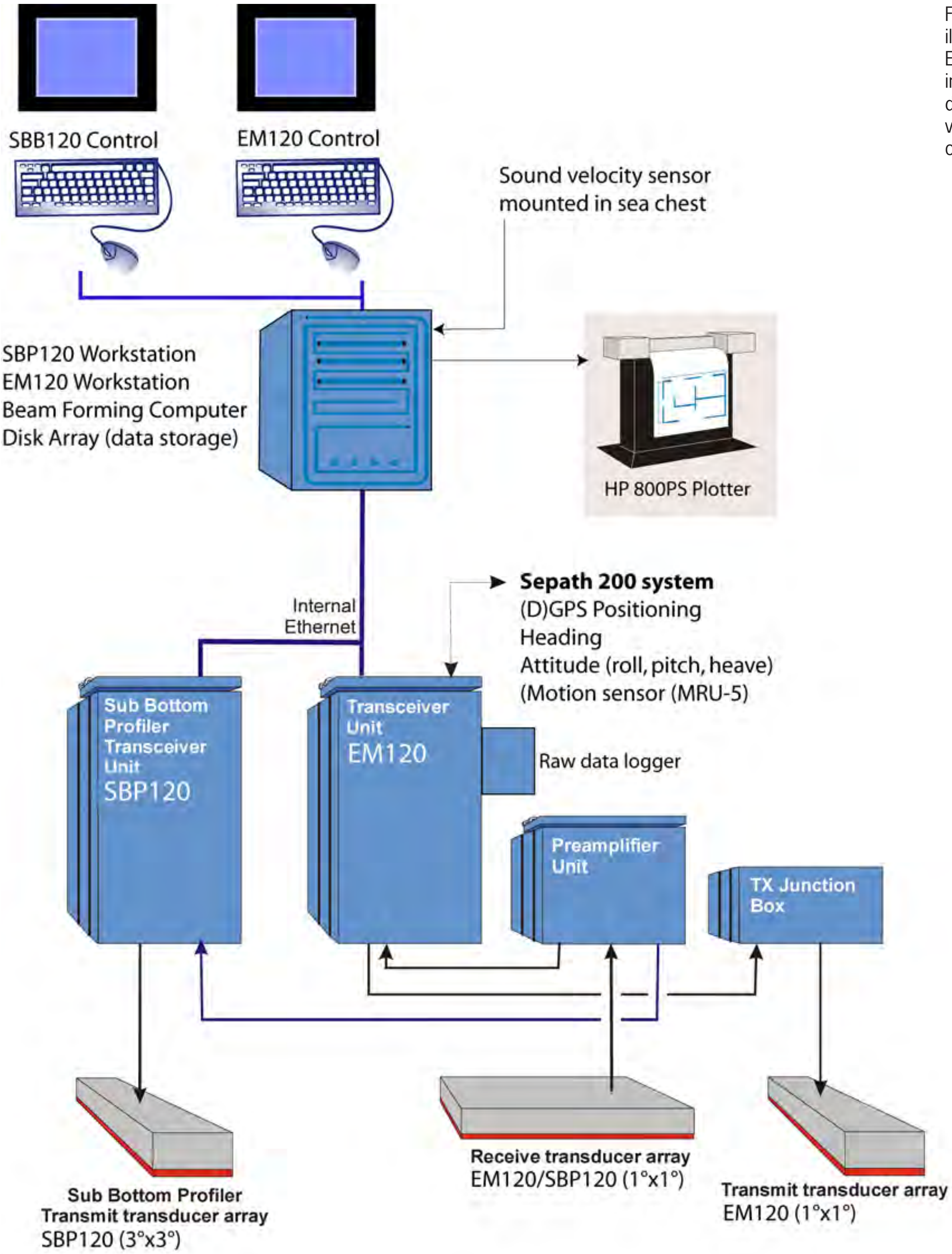



Figure 7. Schematic illustration of the EM120/SBP120 system installed on the Oden. The drawings are modified versions of Kongsberg's original.

Photos 2-4. (Top left) A portion of the SBP120 transmitting array (SBP TX-unit). This 8 m long and 1 meter wide array is mounted along ship. (Top right) The 8 m long and 1 m wide EM120 transmitting array, which is mounted next to the SBP transmitting array. (Middle) Both the TX-units are covered by ice protection windows made of plastic reinforced by titanium rods. The receiving array is protected by a pure titanium plate. (Bottom) The 8 m long and 1 m wide receiving array mounted across the ship.

The Raw Data Logger is a device for recording and displaying raw data from the multibeam echo sounder system. The main purpose is to log the samples throughout the water column for all the 128 receiver staves. Sample data is sent from the Transceiver Unit at up to 12000 samples per second. The data rate is up to 6.1 Mbytes per second.

A Seatex Seapath 200 (serial number 4000) motion sensor is used for roll, pitch and heave compensation of the

Multibeam echo sounder. The Seapath 200 is also use to provide heading and position information.

*System settings*

The following system settings were usually used for EM120 multibeam surveys in the ice:

*(Runtime Parameters - Sounder Main)*

**Max. angle:** 2x10…2x75deg, depending on data and seafloor detection quality

**Max coverage:** depending on water depth, usually higher than angular limit

**Angular coverage mode:** AUTO (MANUAL results in less beams being used)

**Beam spacing:** EQDIST

**Ping mode:** Depending on water depth, using AUTO during ice breaking can result in the wrong mode being used because of bad bottom detection.

**Pitch stabilization:** On

**Heading filter:** MEDIUM

*Runtime Parameters - Sound Speed*

**Sound speed profile:** .asvp file from CTD

**Abs. coeff. files, salinity:** Automatically computed from SVP

**Abs. coeff. files, CTD:** D:\sisdata\common\svp_abscoeff\default

**Sound speed at transducer:** Sound velocity probe not used. Source: PROFILE.

*Runtime Parameters - Filter and Gains*

**Spike Filter Strength:** OFF

**Range Gate:** NORMAL

**Slope, Aeration, Sector Tracking, Interference:** All off

**Absorption Coefficient Source:** Salinity, 35ppt

**Normal incidence sector:** 6°

*Runtime Parameters - Filter and Gains*

**Real Time Data Cleaning:** None

*Javad and Trimble: Off*

*ATH Logging: Off*

*Sound velocity correction*

During the whole cruise regular CTD casts were done as part of the oceanography program. This program is described in further details under its own section. In total, 27 CTD casts were carried out, but not all were used for sound velocity correction of the multibeam echo sounding data as some were located spatially very close.

The data was read from the sensors, depth was calculated from pressure and salinity and upcast and downcast measurements were merged. Then the CTD data in Seabird .cnv format was read, sound velocity was calculated from temperature, salinity and depth and the sound velocity profiles were saved in Simrad .asvp format. The sound speed formula used is Coppens (1981, taken from the Simrad EM120 Operators Manual). A 12000 m value of 1681.37m/s (CTDs 001-025) or 1666.81 (CTD 026 onwards) was added to the sound velocity profiles (the echo sounder operating software requires all profiles to extend to 12000m depth) and the profile was thinned out by means of the SIS sound velocity editor (thinning factor 0.1) prior to loading it into the EM120 operating software SIS. Generally the most recent or closest sound velocity profile available was used. However, in some cases deeper sound velocity profiles from a nearby CTD cast were used instead of more recent, closer by but shallower ones.

Throughout the cruise, no sound velocity profile related data problems were encountered (such as systematically too shallow or too deep values of the outer beam soundings). This might be due to the fact that often no cross-lines were run, though. Nevertheless, the sound velocity profiles did not vary very much within oceanographic regimes. The greatest variations observed were between the Amundsen Basin west of the Gakkel Ridge, the Nansen Basin east of the Gakkel ridge and shelf regions north of Norway and around Svalbard. Generally variations of more than 1 m/s only between different CTD casts occurred only in the uppermost 700 m.

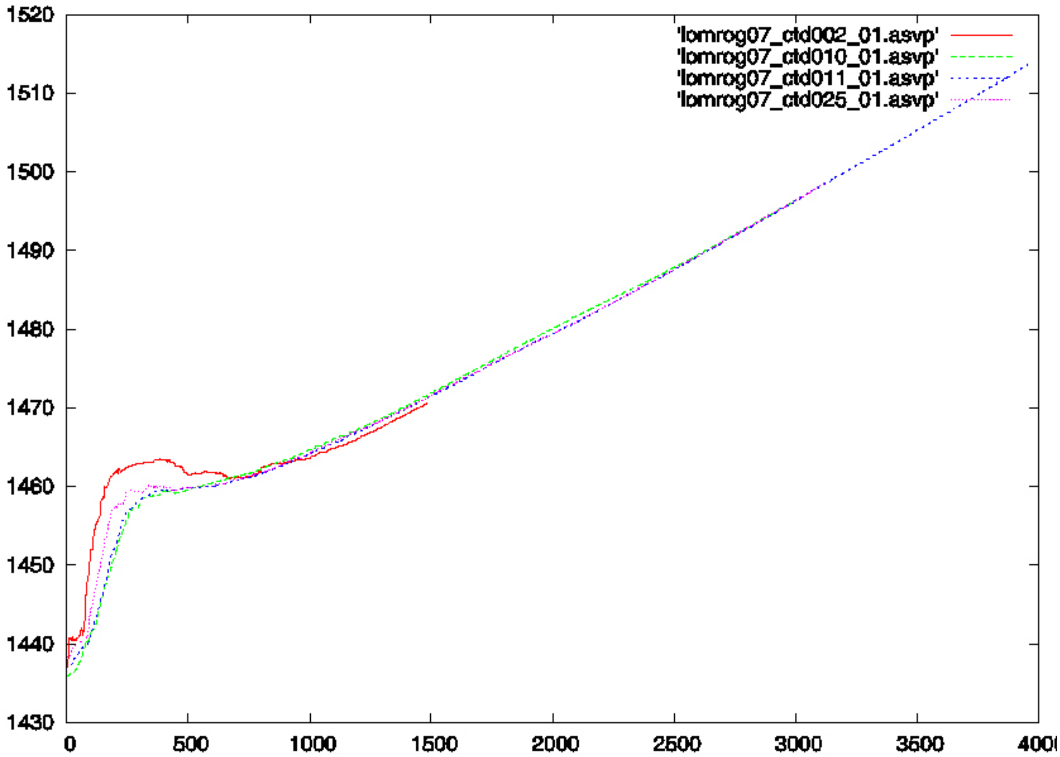



Figure 8. Typical sound velocity profiles; selected profiles show generally the largest differences encountered.

*Real time sound velocity measurements at the transducer depth*

Icebreaker *Oden* is equipped with a real-time sound velocity probe by Applied Micro System LDT for providing up-to-date sound speed values near the transducers needed for beam forming. This real time probe is situated within the sea-water intake in the ship's hull. Depending on re-circulation of water in the sea-water intake and probably other factors, the sound velocity reading can fluctuate within a range of up to several meters per second (usually some +-0.3m/s). Because the surface values of the sound velocity profiles were very reliably close to the real-time-reading average, the real time probe values were virtually never used during Multibeam mapping.

At almost every CTD cast, the CTD was stopped at the transducer's depth (both during downcast and upcast) and the sound velocity derived from temperature, salinity and depth (8 m) was compared to the real time probe's measurement at the same time. On average, the real time probe value was systematically 0.1 m/s too high (Table 3). This must be considered a very low discrepancy and the reason for the difference hard to point our. However, it should be noted that the temperature in the seawater intake most probably not exactly is the same as in the ocean at the same depth.

| RTP Depth % m | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | CTD | | | | RTP | Differ-ence | Notes |
| CTD station | up down | Date | Time | Salinity σ / ppt | Temp. T / °C | Sound Speed c / m/s | Sound Speed c / m/s | CTD-RTP m/s | |
| Average | | | | 31.88 | -1.71 | | | -0.1 | |
| lomrog07_004 | down | 22-08-07 | 22:12 | 30.7415 | -1.6353 | 1435.8 | 1435.8 | 0 | |
| | up | 23-08-07 | 00:48 | 30.737 | -1.644 | 1435.75 | | – | No RTP reading done, extract from MB data |
| lomrog07_005 | down | 23-08-07 | 05:45 | 30.374 | -1.622 | 1435.37 | 1435.4 | -0.03 | |
| | up | 23-08-07 | 07:19 | 30.442 | -1.622 | 1435.46 | 1435.5 | -0.04 | |
| lomrog07_006 | down | 23-08-07 | - | 30.5253 | -1.623 | 1435.57 | 1435.7 | -0.13 | No salinity reading, taken from CTD |
| | up | 23-08-07 | - | 30.5253 | -1.623 | 1435.57 | 1435.7 | -0.13 | No salinity reading, taken from CTD |
| lomrog07_007 | down | 25-08-07 | 18:23 | 31.09 | -1.671 | 1436.1 | 1436.3 | -0.2 | |
| | up | 25-08-07 | 19:30 | 31.0459 | -1.667 | 1436.06 | 1436.2 | -0.14 | |
| lomrog07_008 | down | 26-08-07 | 12:52 | 31.249 | -1.675 | 1436.3 | 1436.4 | -0.1 | |
| | up | 27-08-07 | 14:10 | 31.247 | -1.675 | 1436.3 | 1436.4 | -0.1 | |
| lomrog07_009 | down | 28-08-07 | 00:10 | 31.0256 | -1.6685 | 1436.03 | 1436 | 0.03 | |
| | up | 28-08-07 | 02:10 | 31.0457 | -1.6647 | 1436.07 | 1436.2 | -0.13 | |
| lomrog07_010 | down | 28-08-07 | 09:26 | 30.99 | -1.661 | 1436.01 | 1436.1 | -0.09 | |
| | up | 28-08-07 | 11:30 | 31.015 | -1.667 | 1436.02 | 1436.1 | -0.08 | |
| lomrog07_011 | down | 31-08-07 | 06:03 | 32.008 | -1.716 | 1437.13 | 1437.3 | -0.17 | |
| | up | 31-08-07 | 09:05 | 32.013 | -1.711 | 1437.16 | 1437.3 | -0.14 | |
| lomrog07_012 | down | 01-09-07 | 08:33 | 31.92 | -1.709 | 1437.04 | 1437.1 | -0.06 | |
| | up | 01-09-07 | 10:52 | 31.933 | -1.711 | 1437.05 | 1437.1 | -0.05 | |
| lomrog07_013 | down | 01-09-07 | 13:20 | 32.06 | -1.718 | 1437.19 | 1437.3 | -0.11 | |
| | up | 01-09-07 | 15:05 | 32.073 | -1.721 | 1437.19 | 1437.3 | -0.11 | |
| lomrog07_014 | down | 01-09-07 | 18:38 | 31.968 | -1.716 | 1437.08 | 1437.2 | -0.12 | |
| | up | 01-09-07 | 18:38 | 31.971 | -1.713 | 1437.09 | 1437.2 | -0.11 | |
| lomrog07_015 | down | 03-09-07 | 11:25 | 31.935 | -1.715 | 1437.04 | 1437.3 | -0.26 | |
| | up | 03-09-07 | 12:24 | 32.005 | -1.711 | 1437.15 | 1437.3 | -0.15 | |
| lomrog07_016 | down | 04-09-07 | 15:15 | 32.42 | -1.737 | 1437.59 | 1437.6 | -0.01 | |
| | up | 04-09-07 | 16:24 | 32.481 | -1.736 | 1437.68 | 1437.6 | 0.08 | |
| lomrog07_017 | down | | | | | FALSE | | – | RTP: 1437.7 |
| | up | | | | | FALSE | | – | |
| lomrog07_018 | down | | | | | FALSE | | – | |
| | up | 05-09-07 | 01:10 | 32.49 | -1.745 | 1437.64 | 1437.5 | 0.14 | |
| lomrog07_019 | down | 05-09-07 | 07:16 | 32.835 | -1.768 | 1438 | 1438 | 0 | |
| | up | 05-09-07 | 10:15 | 32.73 | -1.756 | 1437.92 | 1438 | -0.08 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| lom-rog07_020 | down | 05-09-07 | 18:22 | 32.88 | -1.765 | 1438.08 | 1438.2 | -0.12 | |
| | up | | | | | FALSE | | – | |
| lom-rog07_021 | down | 06-09-07 | 05:40 | 33.04 | -1.77 | 1438.27 | 1438.4 | -0.13 | |
| | up | 06-09-07 | 08:40 | 32.94 | -1.767 | 1438.15 | 1438.3 | -0.15 | |
| lom-rog07_022 | down | 06-09-07 | 15:25 | 32.987 | -1.783 | 1438.14 | 1438.3 | -0.16 | |
| | up | 06-09-07 | 18:29 | 32.982 | -1.782 | 1438.13 | 1438.3 | -0.17 | |
| lom-rog07_023 | down | 07-09-07 | 00:56 | 33.043 | -1.785 | 1438.2 | 1438.4 | -0.2 | |
| | up | 07-09-07 | 03:17 | 33.082 | -1.781 | 1438.27 | 1438.3 | -0.03 | |
| lom-rog07_024 | down | 07-09-07 | 09:50 | 33.12 | -1.776 | 1438.35 | 1438.6 | -0.25 | |
| | up | 07-09-07 | 11:58 | 33.168 | -1.78 | 1438.4 | 1438.5 | -0.1 | |
| lom-rog07_025 | down | 07-09-07 | 18:03 | 33.204 | -1.792 | 1438.39 | 1438.6 | -0.21 | RTP reading 12min later |
| | up | | | | | FALSE | | – | |
| lom-rog07_026 | down | 12-09-07 | 09:50 | 30.855 | -1.647 | 1435.9 | | – | No RTP reading done, extract from MB data |
| | up | 12-09-07 | | 30.94 | -1.63 | 1436.1 | | – | No good RTP reading |
| lom-rog07_027 | down | | | | | FALSE | | – | |
| | up | | | | | FALSE | | – | |

Table 3. Comparison between CTD surface reading and the real time velocity probe mounted in Oden's sea water intake.

As a less time consuming alternative to CTD casts, some expendable pressure-temperature sensors (XPT, "Sippican") where planned to be taken on the cruise. Due to software driver problems, no XPT casts were carried out, though.

*Ship board processing*

All data were immediately processed onboard using the software Caris HIPS. In general, the processing consisted of a first application of the "Cube" algorithm followed by manual inspection and editing using the area based editor in Caris. So called "Field Sheets", which is defined map sheets in Caris, were constructed along the LOMROG survey track (Figure 9). Once the multibeam data were processed, grids were generated for the Field Sheets on a polar stereographic projection with the true scale at 75ºN. These multibeam grids were subsequently visualized using the software Fledermaus and brought into Intergraph's GIS Geomedia Professional for final map making.

### *Chirp sonar profiling*

*Equipment*

Icebreaker Oden is equipped with a Kongsberg SBP120 3° subbottom profiler (Figure 7). The SBP120 subbottom profiler is an extension to the EM120 multibeam echo sounder. The primary application of the SBP120 is the imaging of the topmost sediment layers under the sea floor. The SBP120 uses an extra transmit transducer unit, whereas one broadband receiver transducer of the EM120 multibeam echo sounder is used for both the EM120 and the SBP120 systems. A frequency splitter directly after the receiver staves divides the 12 kHz multibeam signal from the lower frequency (2.5 to 7 kHz) chirp sonar signal.

The normal transmit waveform is a chirp signal (which is an FM pulse

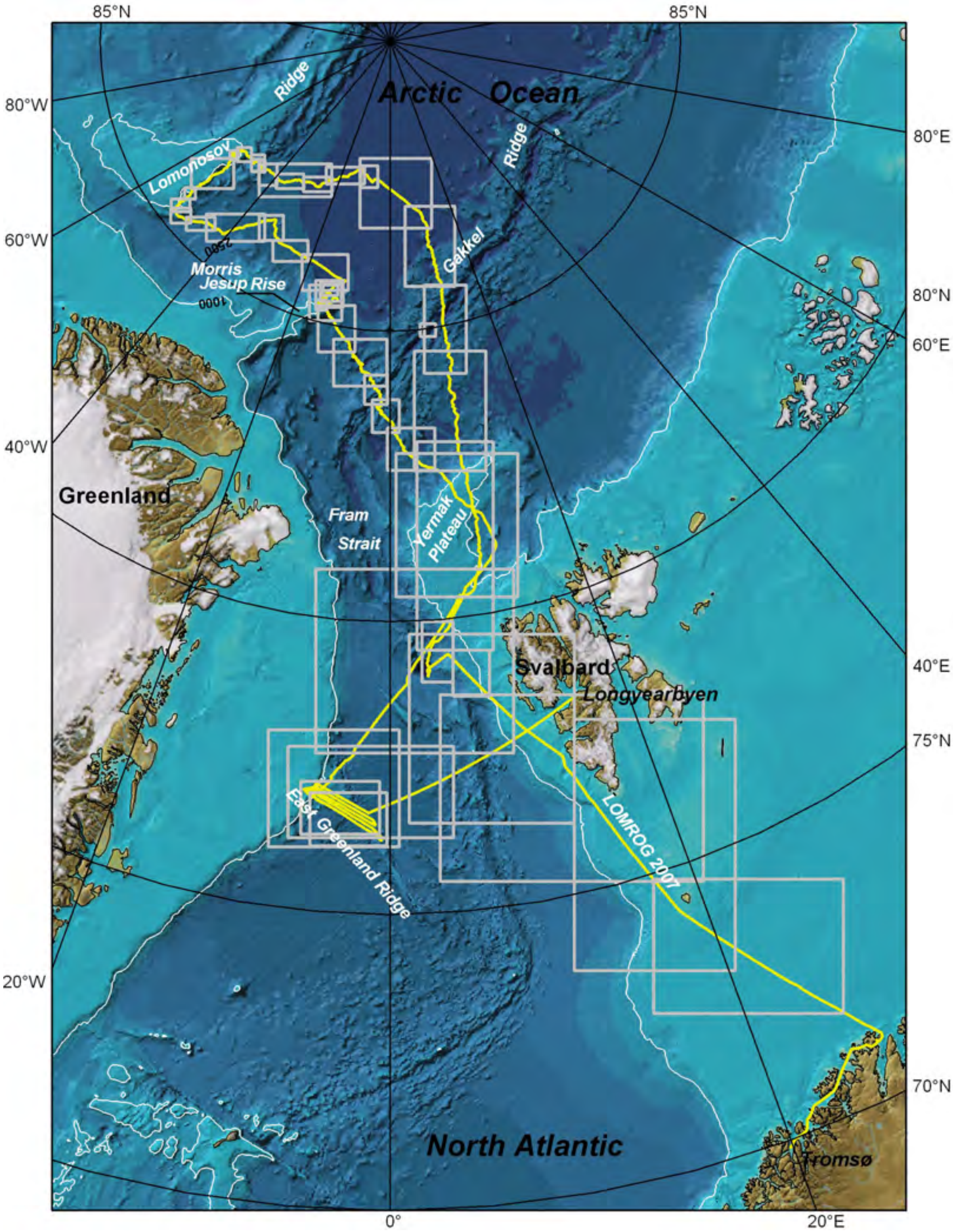



Figure 9. Defined "Field Sheets" in Caris HIPS.

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.

*System settings*

The following system settings were usually used for SBP120 chirp sonar profiling in the ice. They are a good starting point for experimenting with different settings.

**Transmit mode:** Normal (usually) or Burst (there might be issues with PU when switching between the two).
**Synchronization:** Fixed rate
**Ping interval:** Various, depending on water depth and survey speed mostly (max. a few pings per footprint). If the set value is too low concerning the TWT at present water depth (acquisition delay + acquisition window length + chirp pulse length), the system will choose the minimal value for this parameter combination itself. Increased ping interval to 20…30s for station work etc (stationary ship or ice drifting).
**Acquisition delay:** depending on water depth, seafloor reflection preferably in upper 80 ms of collected data
**Acquisition window:** 200ms, in steep terrain when it is hard to follow the seafloor reflection manually 300ms or in extreme cases even more might help the operator
**Pulse form:** Hyperbolic chirp up (best trade-off of energy/penetration and resolution)
**Sweep frequencies:** 2500…7000Hz
**Pulse shape:** 15% (Simrad recommendation, 0% actually will not result in a non-tapered signal, but in an almost-not-documented slight tapering due to physical and electronics restrictions).
**Pulse length:** 100ms (seems to be a good trade-off between energy/penetration and resolution).
**Source power:** 0dB
**Beam width Tx/Rx:** 3° ("focused" is not narrower than 3°, which is the physical limit of the transducers)
**Number of beams:** Various, depending on geology. When going along-slope the off-center beams often contain better information than the center beam. Otherwise nobody has really experimented with multi beam sediment echo sounding yet (or advanced processing of this kind of data)
**Beam spacing:** Usually 3°. In order to obtain a different "swath width" the beam number was varied.
**Calculate delay from depth:** Not working properly, should be off
**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

*Ship board processing*

Ship board processing of the acquired SBP120 chirp sonar data was not routinely carried out during the LOMROG cruise. However, selected lines were processed using the three software 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 is not reported here.

### Single beam bathymetry from sea ice

*Equipment*

Bathymetry information should have been collected in addition to the multibeam acquisition along tracks nearby the ship using a single beam portable echo sounder by Reson (Table 4). The idea was to do the data collection in conjunction with the gravity program. However, this bathymetry program failed due to a malfunctioning echo sounder (see Results).

The single beam trough ice bathymetry and gravity team consisted of Rene Forsberg (Danish National Space Center), Timothy Janzen (Canadian Hydrographic Service, CHS) and Morten Sølvsten (Royal Danish Administration of Navigation and Hydrography, RDANH). In addition, Dennis Anthony from RDANH should have been trained to carry single beam measurements from the sea ice.

The general plan was to follow Oden's track using the helicopters, land where possible to acquire bathymetric soundings where the multibeam could not reach. The procedure was to acquire a depth measurement where ice conditions allowed the helicopter to land close to small open water areas as this was expected to give the best result concerning the bathymetric measurement. If no open water could be found, the team was prepared for another well known method – measuring through the ice using thin layer food grade gear oil.

Depths were planned to be acquired at a sound speed in water of 1500m/sec and hence corrected afterwards based on CTD casts made from Oden. The whole process was under ideal conditions expected to take 5 to 10 minutes per site.

| | |
|---|---|
| 1 | Reson NS420DS modified Echo sounder |
| 1 | – Reson TC2135 15Khz transducer |
| 1 | – Reson TC2144 24Khz transducer |

Table 4. Single beam portable echo sounder components.

### *Sediment coring*

*Equipment*

The Stockholm University piston/gravity corer was used to take all cores during the LOMROG expedition. This corer was constructed by M. Jakobsson for the Arctic Ocean 96 expedition with icebreaker Oden in consultation with Jim Broda from Woods Hole oceanographic institution. Its length can be adjusted in 3 m long barrel sections with an outer diameter of 108 mm. The maximum core length is probably not more than 15 m (5 sections) and the standard size is 12 m. Cores close to 12 m has successfully been retrieved so far with this corer. The barrels are coupled to each other using 400 mm long couplings that fit outside the barrel and which are fixed using M16 insect screws. Specially manufactured polycarbonate transparent liners are used with an inner/outer diameter of 80/88 mm. The core head weight can be modified in increments of 68 kg; the most common weight used for piston coring during LOMROG was 1360 kg (20 weights) and 1088 kg (16 weights) for gravity coring. Maximum core head weight is 1428 kg. The standard piston core release arm is designed so that a trigger weight of 1/10 of the main core head weight should be used. In other words, if the core head led weights amounts to 1360 kg, the trigger weight should be 136 kg. The change from piston core mode to gravity core mode is made by taking out the piston and mounting a special lifting top including a flapper valve.

For the LOMROG expedition, a new core handling system was designed in order to be able to launch the corer using the A-frame on the aft deck (Photos 6-7). This handling system consisted of a cradle and a rail in which the cradle was gliding. The system proved to work excellently and the launching times were sometimes only around 10-15 min which is a significant reduction compared to previous expeditions. The coring winch consisted of a renovated winch provided by SPRS that originally had been installed on the icebreaker Ymer for the "Ymer 80" expedition. This winch was equipped with a non-rotation free 16 mm wire. In order to compensate for a possible rotation problem during core launch and retrieval, a large swivel was used. This winch setup including the non-rotation free wire caused numerous problems for the coring operation (see result section).

*Core curation*

Before coring, the liners were marked with a straight lengthwise line for orientation, upwards pointing arrows and a core ID on every 150 cm section. The core ID denotes cruise, year, core type and core number:
LOMROG07-PC-XX for piston core;
LOMROG07-TC-XX for trigger core;
LOMROG07-GC-XX for gravity core
Each 150 cm section was marked with letters to identify the position in the core. The bottom section was marked DOWN in the lower part and A in the upper part. The next section was marked A in the lower part and B in the upper part etc. (DOWN-A, A-B, B-C, C-D etc.).

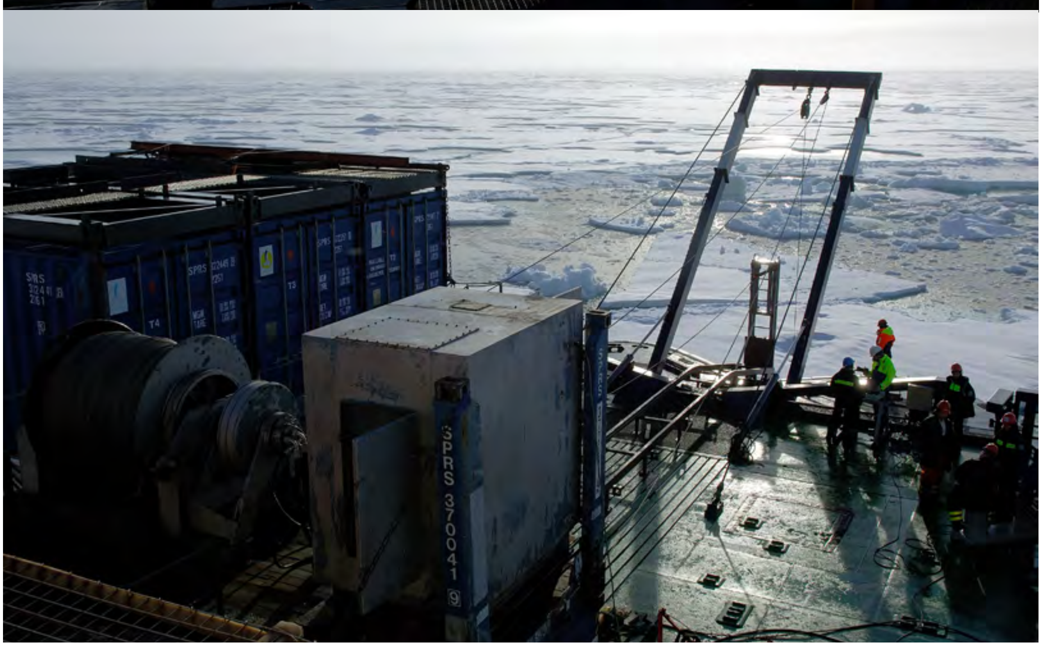
After being cut, the 150 cm sections were renumbered from the top and downward, with the top section as section 1. Styrofoam was inserted where there were gaps in the core. The core sections were then stored upright in room temperature. After at least 12 hours, the sections were logged with a Geotek Multi Sensor Core Logger (MSCL). The core sections were then split with a circular saw in two halves along the orientation line. A 0.20 cm plastic trimmer cord was used to split the sediment. The halves were scraped across the width of the core half with a large spatula to create a smooth surface, plastic depth markers inserted and a measuring tape put on along the length of the core halves. One half was denoted ARCHIVE, the other half WORKING. The WORKING half was scanned using a color line scan camera imaging system Geotek (Geoscan III), and after that described. An overview photograph of all the WORKING sections in a core was made. Finally, the ARCHIVE and WORKING halves were stored in D-tubes at 5°C in a refrigerator container.

### *Multi Sensor Core Logging*

*Physical properties and magnetic susceptibility*

The Geotek #39 Multi-Sensor Core Logger (MSCL) from Stockholm University was installed in the main laboratory located on the foredeck of the *Oden* (Photo 8). The MSCL was mounted for whole cores and equipped with sensor systems to measure gamma density, core diameter, p-waves, magnetic susceptibility, temperature and a line scan camera for core imaging.

The gamma attenuation was measured using a $^{137}$Cs 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.


Photos 5-7. (Top) The mechanical counter of wire that is being out hauled from the coring winch. This counter caused problems for the coring operations for two reasons: 1) the accuracy was not good enough in order to judge when the corer hit the seafloor at a certain depth. This forced us to out haul an excess of wire when taking gravity cores. 2) The location of the counter was far from the winch operations. (Middle) The corer docked in the launching cradle. (Middle and bottom photo) Coring setup on the aft-deck of Oden. The coring winch is at the left corner of the photo. The rail in which the coring cradle glides is seen mounted on the aft-deck. This launching system was constructed for the LOMROG expedition.

The MSCL was calibrated before use, and a calibration piece was logged initially in all cores. The sampling interval was 1 cm, and all sections were logged with the orientation line facing upwards. The raw measurements were logged and post-processed using the Geotek MSCL 7.6 software.

The raw data was processed using the following parameters:
*Sediment thickness:* outer liner diameter 8.8 cm, liner thickness 0.35 cm;
*P-wave velocity:* p wave off set from calibration (PTO=27.45);
*Temperature:* 20°C;
*Salinity:* 0 ppt;
*Depth:* 0 m;
*Gamma density:* constants obtained after calibration (A=-0.00004, B=-0.0608, C=9.7066), no adjustment for density, A=1; B=0;
*Butt error distance:* 0.2 cm.

All sections were logged, except LOMROG07-PC-07 section 2 and section 4, because they were mistakenly already split. After section 1, as a substitute, an empty liner was logged with the same length as section 2. The logging was finished after section 3.
LOMROG07-GC-10 was re-logged to estimate the reproducibility.

*Color line scan camera*
The working halves of the split cores were scanned using a Geoscan III 2048 color line scan camera with a Nikon AF Nikkor 50 mm 1:1.8 D objective and Geotek Imaging 2.4 software. The system collects a section image in a continuous movement with a vertical and horizontal resolution of 100 ppcm. Calibration was done before each core was scanned and/or when the system was switched on. The calibration was made according to the manual. Imaging speed was approximately 5 min per 1.5 m core section. The image files were saved in the Windows bitmap format.

Due to an offset between the zero point of the stepper motor and the camera scanning of the top ~0.5 cm of each core could only be obtained by sticking a piece of tape on the end cap to trigger the line acquisition.

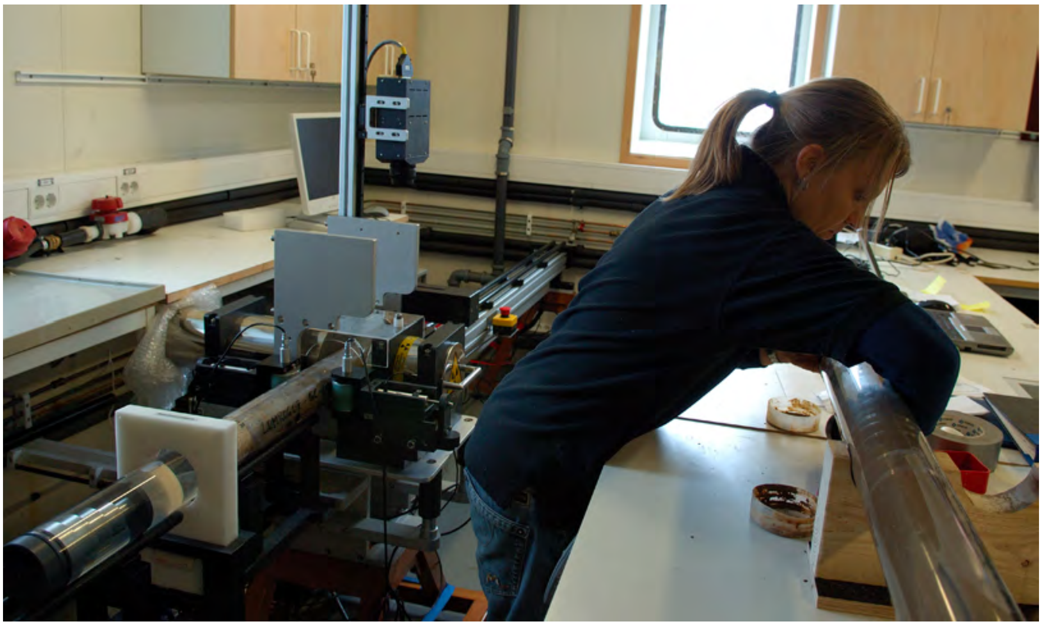


Photo 8. Multi Sensor Core Logger installed in the main lab located on the foredeck of the Oden.

### *Sediment description*

After multi-sensor core logging, all cores were split, described, line-scanned, and photographed. Altogether approximately 30 m of core material were examined. Lithological description was based on sediment color (Munsell Color Chart), texture, and structures. Hydrochloric acid (10%) was used on small amounts of material removed from the cores to confirm calcareous material such as fossil tests and calcareous ice-rafted debris (IRD). Where obvious in the cores, microfossils and diagenic features were sampled and examined under a binocular microscope. The sediment stratigraphy and descriptions of the cores were drawn using the software Strater.

### *Dirty sea ice observations*

*Observations and sampling protocol*

Observations on encounters with dirty ice are rarely recorded by icebreaker expeditions in the Arctic Ocean. During LOMROG, the three officers driving the *Oden* were instructed on the identification of sediment-laden ice as opposed to ice with algae. A spreadsheet was left near the drivers post for them to record date, time, latitude, and longitude of any encounters. In addition, the helicopter pilots were likewise instructed to note the coordinates of any dirty ice encountered during flights. However, spotting dirty ice was not the main focus of the pilots or the drivers and, thus, some encounters were probably never noted. Snow cover plays a major role in spotting dirty ice and by the 26$^{th}$ of August, there was sufficient snow cover, about 10-15 cm, that spotting dirty ice became nearly impossible. Once *Oden* was in the pack ice on August 15$^{th}$, dirty ice was observed and recorded through the 26$^{th}$. Not all observed dirty ice could be sampled. Sampling was only possible when we could be transported to the pack ice, usually by helicopter so as not to impede the schedule of the expedition. Still several excellent amounts of dirty ice were sampled from the 18$^{th}$ to the 23$^{rd}$ of August (Figure 6). When possible, replicate samples were collected from the same dirty ice floe. All samples were collected using a large stainless steel ice scoop that was cleaned between each sample. Starting on September 7, 2007 icebergs were encountered and at least 10 were often in sight at one time, sometimes on the 8$^{th}$ there were more than 20 within 6 nm. Two icebergs were sampled on the 9$^{th}$ using the same methods as for sea ice.

*Sample Processing*

All samples consisted of ice with sediment ranging in total volume from 1 to 8 liters. They were placed in bags initially when sampled but transferred to clean buckets in the lab onboard *Oden* and allowed to melt. Buckets were covered with plastic to prevent contamination and each numbered with the station and sample number. Once melted, the sediment settled-out (rarely with the aid of table salt) and most of the melted ice was siphoned off using a small vacuum pump. The remaining melt water was filtered through 0.45 µm Millipore filter and either an in-line or conventional vacuum filtration device. After about four or five of these filters were clogged with fine sediment, the remainder was filtered through coffee filters. Millipore filters were collected for sites LOMROG07-DICE-01, 02, and 05. Two samples from site LOMROG07-DICE-04 (04B and C) were left to partly dry and transferred to plastic bags with out any filtration.

### *CTD and water sampling*

*Data acquisition*

CTD cast were done at 27 stations covering parts of the western Eurasian Basin and one cast at the East Greenland continental margin (Figure 6).  Water was collected at 26 of these stations; the East Greenland continental margin was the station where no water was sampled. Water was collected using a 24-bottle rosette sampler equipped with 7.5 liter Niskin type bottles and a CTD (Sea Bird 911+). When brought back onboard the rosette was moved into a heated double container as quickly as possible to avoid freezing the samples. Water samples were immediately drawn for the individual parameters to be determined in the following order; CFCs, oxygen, mercury, dissolved inorganic carbon/pH/total alkalinity, nutrients, oxygen-18, and salinity.  Number of samples analyzed for the different constituents are given in Table 5.

Photos 9-10. The CTD/ rosette sampler is on its way back from the water (left) and Sara Jutterstöm is collecting water for the determination of DIC (right).

*Ship board processing*

The CTD data were processed through the standard Sea-Bird software routines (data conversion, cell thermal mass, filter, loop edit, derive and bin average). The final data is averaged in 1 dbar bins. Salinities were also determined in each Niskin bottle using an Autosal lab-salinometer. The temperature in the clean room, inside the laboratory at fore deck, had strong fluctuations and gave not ideal conditions for the salinity analyses but was nevertheless manageable. The final bottle salinity data should have a good quality with accuracy of ±0.001 psu. The bottle salinities were then compared with the CTD bottle file data in order to check the accuracy of the CTD system. The comparison with bottle data showed an offset of about -0.0044 psu between the CTD and Autosal salinities meaning that the CTD sensor gave too low values. The final CTD data were corrected by determining an average salinity offset using bottles with salinity > 34.8 psu and excluding outliers outside 1 SDA. One sample was then identified (Stn. 20, 4000 dbar) having identical offset as the average offset. The Autosal conductivity for this sample was determined for the same temperature and pressure when the bottle was tripped (P=4000 dbar, T=-0.6708 oC). The Autosal conductivity divided by the CTD conductivity gives then a slope correction of 1.000119 which has been used to post-process the data according to Sea-Bird recommendations.

Water for chemical analysis were drawn from water samplers directly after the rosette was brought on board and analyzed within hours of sampling. The precisions given below were computed as standard deviations of duplicate analyses. Samples for CFCs were drawn from the bottles on the rosette with glass syringes, which were kept under cold water until analysis (within a few hours). They were measured by purge-and-trap extraction and pre-concentration, gas chromatographic separation on a capillary column, and electron capture detection calibrated against a standard gas mixture. The precision was in the order of 1 % and the accuracy was about 0.02 pmol kg-1. Oxygen was determined using automatic Winkler titration system, precision ~1 µmol kg-1. Total dissolved inorganic carbon (DIC) was determined by a coulometric titration method having a precision of ~1 µmol kg-1, with the accuracy set by calibration against certified reference materials (CRM), supplied by A. Dickson, Scripps Institution of Oceanography (USA). Total alkalinity (TA) was determined by potentiometric titration, precision ~1 µmol kg-1, (Haraldsson et al., 1997), with the accuracy set the same way as for DIC. The determination of pH was performed by the use of a diode-array spectrophotometer using a sulphonephtalein dye, m-cresol purple, as indicator (Clayton and Byrne, 1993; Lee and Millero, 1995), and measured in a 1 cm flowcell thermostated to 15 oC (pH15). The precision and accuracy for the pH15 measurements were ±0.0005 and ±0.002 pH units, respectively. pH in situ was calculated from TA, pH15 and in situ temperature by using the CO2-system program by Lewis and Wallace (1998). For these calculations the carbon dioxide constants of Roy et al. (1993; 1994) were applied, and the pH was on the total hydrogen ion scale. The nutrients (phosphate, nitrate, and silicate) were determined using a SMARTCHEM auto-analyzer applying standard analytical protocol giving a precision near 1% at full scale. Salinity samples collected from the rosette were analyzed onboard using a Guildline 8400 salinometer, with an accuracy of 0.003.

### ***Mercury in Arctic seawater and air***

*Sampling and analytical procedure of total mercury (Hgtot) and monomethylmercury (MMHg) in water*

Aiming an assessment of input and accumulation of mercury (Hg) in Arctic marine waters about 200 samples for determination of total mercury (Hgtot) and monomethylmercury (MMHg) were taken at ~20 stations along the LOMROG expedition route. The mercury sampling was designed as profile measurements at the CTD water stations sites and the content of mercury in the samples will be further studied in combination with data on movements of water masses.

| Station | Latitude | Longitude | Bottom depth | CFC | Oxygen | Mercury | DIC | pH | TA | Nutrients | O-18 | Salinity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 79.121 | 3.411 | 5160 | 3 | 3 | 3 | 0 | 3 | 0 | 0 | 0 | 0 |
| 2 | 81.113 | 9.854 | 1573 | 15 | 15 | 10 | 13 | 15 | 14 | 15 | 0 | 15 |
| 3 | 86.968 | 10.168 | 4338 | 23 | 23 | 12 | 22 | 23 | 23 | 23 | 10 | 23 |
| 4 | 86.883 | -44.628 | 3444 | 23 | 23 | 12 | 23 | 23 | 23 | 23 | 10 | 23 |
| 5 | 86.899 | -48.236 | 1807 | 18 | 18 | 6 | 18 | 4 | 18 | 18 | 10 | 18 |
| 6 | 86.816 | -53.826 | 967 | 16 | 16 | 4 | 16 | 16 | 16 | 16 | 10 | 16 |
| 7 | 85.892 | -52.919 | 749 | 21 | 21 | 8 | 21 | 21 | 21 | 21 | 15 | 18 |
| 8 | 85.432 | -52.383 | 1189 | 22 | 22 | 8 | 21 | 22 | 22 | 22 | 12 | 19 |
| 9 | 85.345 | -48.708 | 2433 | 19 | 19 | 12 | 19 | 19 | 19 | 19 | 8 | 19 |
| 10 | 85.493 | -46.189 | 3005 | 0 | 0 | 10 | | | 14 | 20 | 0 | |
| 11 | 85.803 | -11.723 | 3985 | 24 | 24 | 12 | 24 | 24 | 24 | 24 | 12 | 23 |
| 12 | 85.519 | -14.178 | 3061 | 21 | 21 | 12 | 21 | 21 | 21 | | 12 | 21 |
| 13 | 85.479 | -13.865 | 2113 | 23 | 23 | 8 | 23 | 23 | 23 | 23 | ? | 23 |
| 14 | 85.410 | -14.303 | 1340 | 19 | 19 | 0 | 19 | 19 | 19 | 19 | 10 | 19 |
| 15 | 85.294 | -14.936 | 1004 | 17 | 17 | 0 | 17 | 17 | 17 | 17 | 10 | 17 |
| 16 | 85.269 | -13.875 | 1074 | 20 | 20 | 10 | 20 | 20 | 20 | 19 | 12 | 19 |
| 17 | 85.212 | -13.173 | 2473 | 22 | 22 | 12 | 22 | 22 | 22 | 22 | 12 | 20 |
| 18 | 85.211 | -12.997 | 3360 | 23 | 24 | 12 | 24 | 24 | 24 | 24 | 12 | 21 |
| 19 | 85.041 | -11.106 | 3890 | 24 | 24 | 0 | 24 | 24 | 24 | | 12 | 24 |
| 20 | 84.790 | -8.703 | 3989 | 24 | 24 | 0 | 24 | 23 | 24 | | 11 | 24 |
| 21 | 84.531 | -6.399 | 4081 | 24 | 24 | 12 | 24 | 24 | 24 | 24 | 12 | 24 |
| 22 | 84.369 | -5.196 | 3915 | 24 | 24 | 0 | 24 | 24 | 23 | 24 | 12 | 24 |
| 23 | 84.154 | -3.431 | 3003 | 22 | 22 | 0 | 22 | 22 | 22 | 22 | 12 | 22 |
| 24 | 84.074 | -2.929 | 2616 | 21 | 21 | 11 | 21 | 21 | 21 | 21 | 12 | 21 |
| 25 | 83.911 | -1.682 | 3139 | 23 | 24 | 0 | 24 | 24 | 24 | 24 | 12 | 24 |
| 26 | | | | | | 8 | | | | | | |

Table 5. Station numbers with positions and bottom depth, and number of data per individual constituent and station.

For each sample 125 ml sea water was collected in acid washed Teflon bottles. In order to avoid losses of volatile fractions of Hg species 250 µdm3 conc. H2SO4 was added to each bottle immediately after sampling. The samples were stored in a freezer (about -18 oC) and will be further analyzed in laboratory after the cruise. Hgtot is analyzed after treating the samples with an oxidizing agent (e.g. BrCl or H2O2). The oxidized mercury is then reduced to Hg0 by SnCl2 and collected on a sampling gold-trap by purge and trap technique. The sampling gold-trap is transferred to an analytical line and heated to about 500 oC whereas the mercury is thermally released from the trap and transferred via a stream of argon gas to a fluorescence detector. Determination of MMHg content in the samples will be conducted after derivatisation by an ethylating agent using the gas chromatography CVAFS technique as described in Lee et al., 1994.

### *Measurements of Total Gaseous Mercury (TGM) in air*

Along the LOMROG track continuous measurements of total gaseous mercury in air were carried out. A portable mercury analyzer (LUMEX Mercury Analyzer RA-915+) was placed in a heated (20 $^{o}$C) container

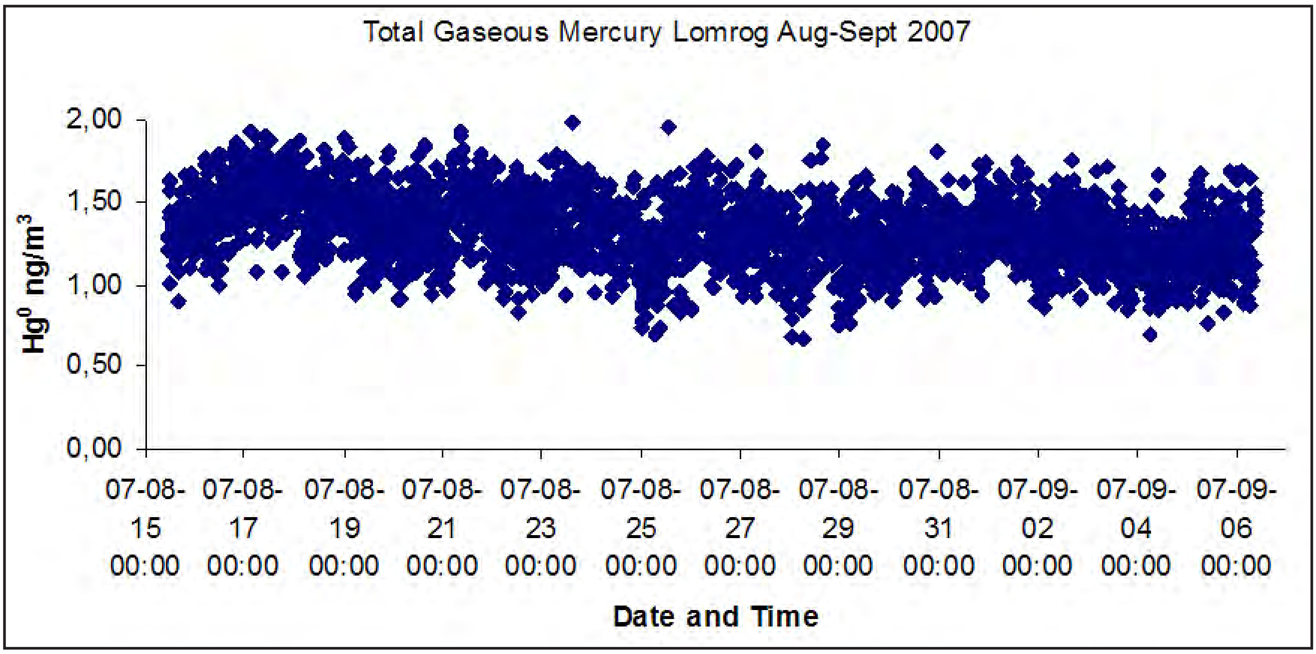



Figure 10. Total Gaseous Mercury (TGM) measured in air at 20 m above sea level during the LOMROG expedition.

and connected to an inlet of the sample air pumped from about 20m above sea level. Figure 10 presents data from parts of the expedition i.e. 22 days, August15 to September 6. The average concentration of TGM during this period was 1.3 ± 0.2 ng m-3. The data will be further analyzed with respect to some ambient parameters e.g. wind conditions and sea ice coverage.

### *Reflection Seismic*

*Equipment design and constraints*

The strategy for handling of air guns and the streamer in the ice was based - to a large extent - on experience gained by other workers on previous cruises in the Arctic Ocean. The two prime concerns were to minimize the risk for ice induced physical damage of the equipment towed in the water behind the icebreaker and to reduce the risk for having the streamer forced up towards the ice by the turbulent and forceful propeller wash. It was found that the only reasonable way to achieve these goals would be to increase the tow depth to calm waters below the propeller wash. This depth was unknown. Therefore, the tow system was constructed to allow for large flexibility in towing depth.

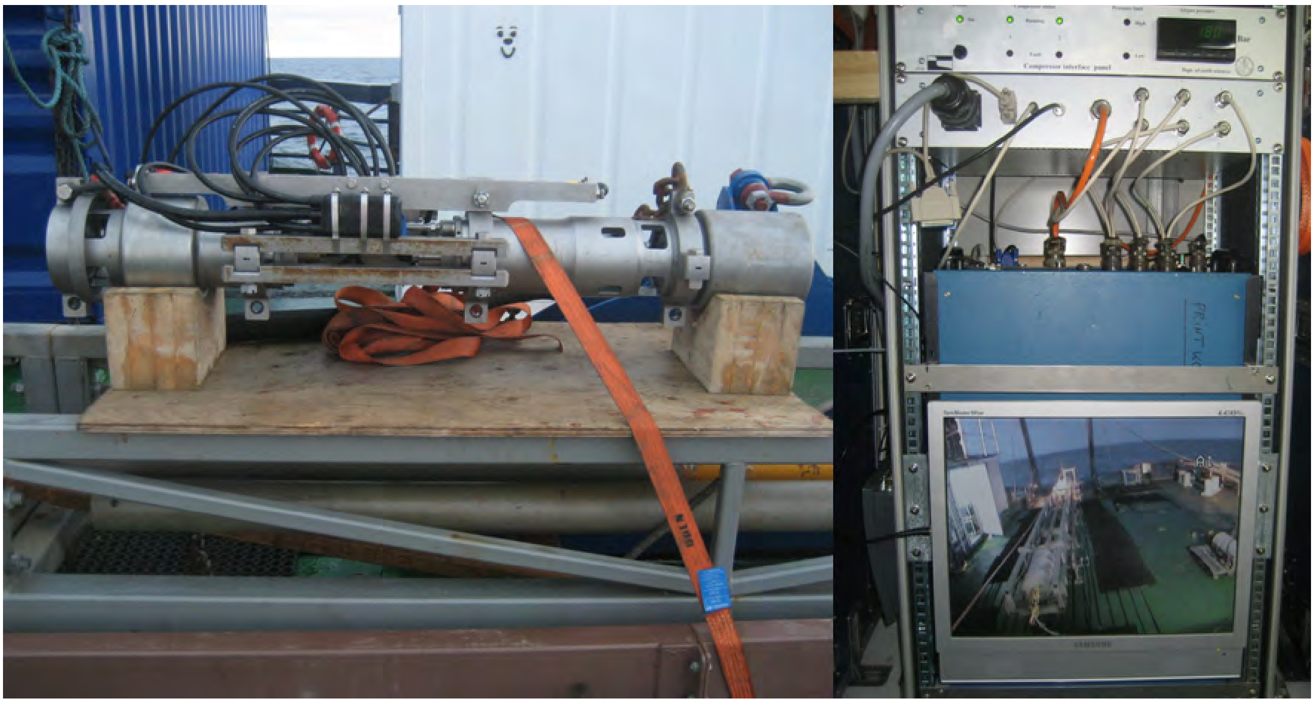
During data acquisition it was found that it was possible to keep the air-guns and the streamer in approximately the same depth and that the streamer was unaffected by the propeller wash at a depth of approximately 20 m. The choice of 20 m as tow depth has negative consequences - related to the ghost effect - for the data quality. The amplitudes of certain frequency components of the seismic signal will be attenuated due to interference between the outgoing signal from the air guns and the signal reflected from the water-ice/ice-atmosphere boundaries 20 m above the air guns and interference between the incoming signals to the receivers in the streamer and the reflected signals from the water-ice/ice-atmosphere boundaries 20 m above the streamer.

Theoretically, at 20 m depth the ghost phenomenon produces attenuation of signal amplitudes around the frequencies 37.5, 75 and 112.5 Hz (and higher frequencies with intervals of 37.5 Hz). Frequency bands applied in the preliminary processing of data onboard the icebreaker indicated that the reflections contain frequencies from lowest values at 10-20 Hz to highest values at 100 Hz. Thus, it may be concluded that the choice of 20 m as the tow depth most likely has a negative effect on the seismic signal, resulting in a reduction of the resolution in the seismic profiles. In the following a brief overview of the reflection seismic equipment used onboard *Oden* is given.

### *Seismic source*

As seismic source a 605 cu.in. linear airgun cluster array was used consisting of two Sercel guns; one G-gun and one GI-gun. The guns were fired at 200 bar and the pressurized air was produced by 2 Hamworthy 70mm Series Air Compressors. A gun trigger unit, TGS-8, was triggered by NaviPac (see below) every 25 m and triggering the guns (Photos 11-12). Communication to and from the airguns (trigger signal, depth transducer, near field hydrophone) was taking place through the umbilical cable also including hoses for the air supply. The umbilical cable was handled using a hydraulic winch. A wire winch was used for handling of the airgun cluster. Furthermore the wire winch was also used for deployment and recovery of the gravity and piston core sampling equipment.

A hydrophone was placed at each G-gun to measure and synchronize (in the TGS-8 trigger unit) the mechanical firing delay of the shots. The two G-guns were fired simultaneously, while the I-gun (injector) was fired using a delay with the purpose of reducing the collapse of the air bubble and thereby the bubble pulse. The optimum delay is depending on the gun tow depth and the P/B ratio was measured to be highest at a delay of 65 msec. Later during the survey it turned out that there was actually no firing delay of the injector due to



Photos 11-12. Sercel 605 cu.in. linear airgun cluster and TGS-8 gun trigger unit with aft deck monitor screen.


Photos 13-14. Geometrics GeoEel streamer and the streamer power supply unit SPSU.

a software failure in the TGS-8 gun controller. Nevertheless the P/B ratio was generally observed to be better than 30.

Also a depth transducer was mounted on the gun array in order to monitor the tow depth of the array. The transducer values were updated after each shot and monitored and recorded on the TGS-8 PC from where they were extracted as text documents.

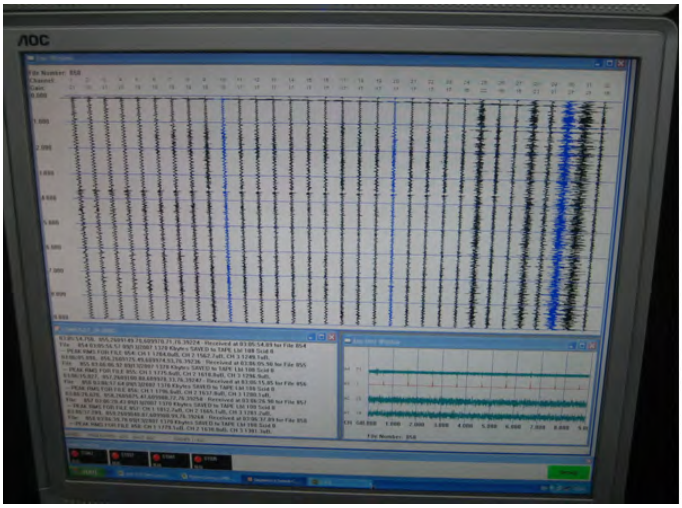
### *Streamer*

The streamer was a digital 48 channel Geometrics GeoEel streamer with one 50 m stretch section and 6 live sections and a total active length of 300 m (Photo 13). There were 8 Benthos GeoPoint hydrophones in each channel. Power supply to the streamer and all data communication from the streamer took place through the umbilical cable. In the front of each live section were a depth transducer and an A/D module and in the front of the stretch section was a Repeater module for transmitting the signals through the lead-in cable of the streamer. A streamer power supply unit, SPSU, provided power to the A/D modules, trigger interface and Ethernet connection to the streamer. A hydraulic winch was used for handling the streamer.

### *Acquisition system*

Data were recorded in SEG-D (8058 rev. 1) on a PC running the seismic controller Geometrics GeoEel software CNT-2. The controller was connected to the SPSU via Ethernet and receiving the digitized signals from the streamer as well as auxiliary channels 1-4. On Aux. ch. 1 and 2 data from two sonobuoy radio receivers was recorded (see also sonobuoy report in section 7) and on Aux. ch. 3 the PPS pulse from the GPS. Aux. ch. 4 was idle. Data were recorded simultaneously on LTO-2 tapes with a capacity of 200 Gb and on a RAID 250 Gb hard disk.

The navigation software NaviPac (see below) sends an event trigger every 25 m and a string to Comm. 1 on the CNT-2 PC. The string contains Time, Event, Position (x, y), Depth, and is transferred to the SEG-D external header on tape and hard disk. The CNT-2 PC could not recognize this string if it was send at the same time as the event trigger. It was therefore necessary to add a delay between the event trigger and the actual trigger signal send out from the gun PC



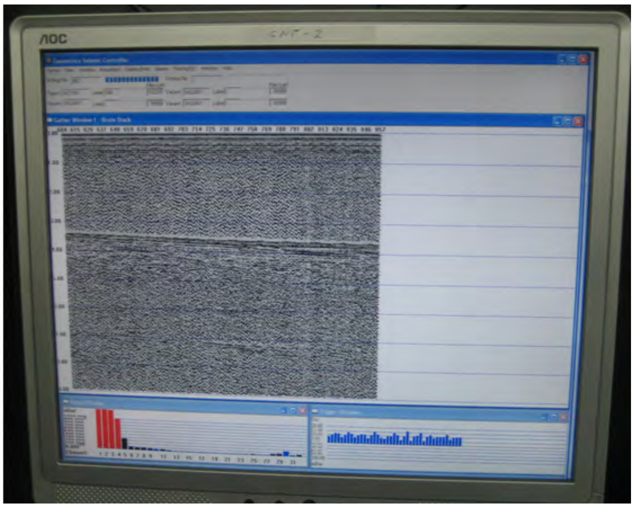


Photo 15-16. Seismic controller display facilities, shot gather window to the left and brute stack window to the right.

(TGS-8). It turned out that a delay of 1100msec in the gun PC was necessary to secure correspondence between event nos. and file nos.

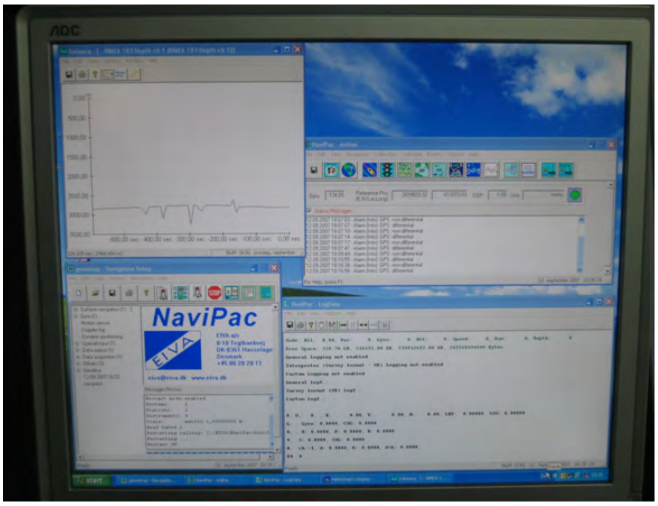
The seismic controller provided the following display facilities during survey (see also Photos 15-16):

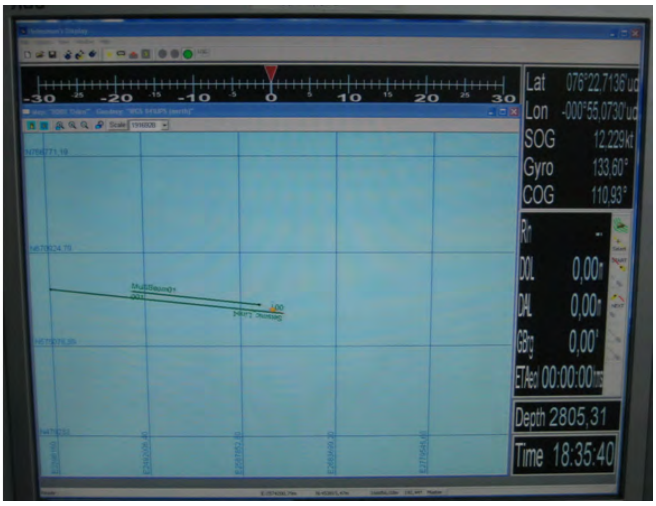
- A shot gather window where various display settings could be changed on the fly as appropriate.
- A real-time brute stack window where various processing and display parameters could be changed on the fly as necessary.
- A noise window showing noise values in µbar from all 48 channels as a "snapshot" calculated between shots.
- A trigger window showing the time interval between shots and the energy of a specified hydrophone (in this set-up channel 1).
- A streamer depth window displaying the depth from each depth transducer module.

During survey the CNT-2 software generated a log file named Lomrog07_linenumber.0000 with the following format:

- First line is read from the serial input from the NaviPac software described below (not all numbers are readable in the log file, but all data are stored in the SEG-D header). The format of the string is: Time HH:MM:SS (UTC),

Photos 17-18. NaviPac setup window and NaviPac Helmsman's display for survey control.



Event no, X pos, Y pos (UPS, WGS 84, LC 605 gun array Position), Depth (from the ships data)<CR> <LF>
- Second line is File no., exact CNT-2 trigger time, size in Kbyte and Reel no.

Furthermore data from the streamer depth transducers was stored in a text file and the real-time brute stack in an internal file-format. These files were named Lomrog07_linenumber.0000.depth and Lomrog07_linenumber.0000.gather1, respectively. When a line was finished the brute stack was converted to SEG-Y format and imported to the seismic interpretation software Kingdom Suite for printing on an Epson A1 printer.

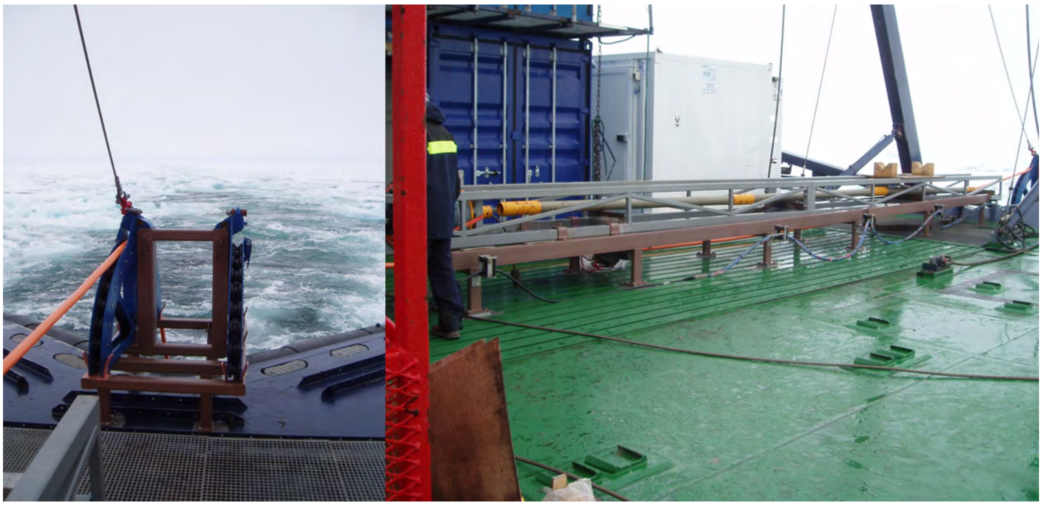
*Navigation and positioning system*
A separate Thales DG16 GPS was used for positioning of the reflection seismic equipment together with the navigation and data logging software NaviPac from EIVA A/S. The GPS has inbuilt beacon and WAAS receivers for differential corrections. The survey area in the Arctic Ocean was however outside the coverage area of both systems and the GPS was used without differential corrections. NaviPac received antenna coordinates from the GPS, water depth below transducer (8 m.b.s.l.) from the center beam of the ships Kongsberg EM120 multibeam echo sounder and gyro course from the ships Furuno gyro. Outputs from NaviPac were trigger signal to the TGS-8 and event trigger and data string to the CNT-2 controller. Run lines (survey lines) were generated in the so called Helmsman's display part of NaviPac and the survey is controlled from this display (Photos 17-18). The possibility of distributing run line data to a Helmsman's display on the bridge running in slave mode was not used.

*Container and equipment setup on Oden*
Several containers were used for the reflection seismic operation. The winch container with the three winches for the umbilical, streamer and gun array wire, respectively, was placed across-ship on the central part of the afterdeck (Photos 19-22). To the starboard the compressor container was placed. Also to the starboard a gun workshop and streamer container was placed and on top of these containers two containers with storage space were available.

At the very aft a frame for the streamer and umbilical sheave was mounted. Wheels mounted along the rail for the coring equipment were used during deployment of the streamer (Photos 22-23). After deploying the streamer was connected to the umbilical and removed from the streamer sheave and the airgun cluster was deployed. After deploying of the airguns using the wire winch and the A-frame (operated by the ship crew) the umbilical sheave was mounted in the frame. This setup with only one cable from the ship into the sea consisting of a heavy duty umbilical was designed to protect the seismic equipment as much as possible from ice impact and to facilitate a large depth for both airguns and streamer.

Cables were connecting the umbilical winch and the registration container placed on the port aft side of deck 4 (Photo 24). Here the navigation software (NaviPac) and multichannel acquisition system (Geometrics CNT-2, SPSU, TGS-8, Winradio) were installed and operated.

Photos 19-22. On top the winch container and workshop container with storage containers above. Below interior of compressor and workshop container.



Photos 22-23. Frame for streamer and umbilical sheave on the very aft and wheels for streamer along the rail for coring equipment.

Photos 24-25. Registration container on deck 4 and interior of the container.

| | |
|---|---|
| **Source** | 1 Sercel G and 1 Sercel GI gun |
| Chamber volume | 605 cu.inch (250 + 250 + 105) |
| Fire pressure | 200 bar (3000 psi) |
| Mechanical delay | 16 ms |
| Planned tow depth | 20 m |
| | |
| **Streamer** | Geometrics GeoEel |
| Length of tow cable | 43 m |
| Length of stretch section | 50 m |
| No. of active sections | 6 / 5 / 4 / 3 |
| Length of active sections | 300 / 250 / 200 / 150 m |
| No. of groups in each section | 8 |
| Total no. of groups | 48 / 40 / 32 / 24 |
| 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 (500 Hz) |
| Gain setting | 6 dB |
| No. of recording channels | 48 / 40 / 32 / 24 |
| No. of auxiliary channels | 4 |
| Shot spacing | 25 m |
| Record length | Variable between 8.5 and 11 |

Table 6: Summary of acquisition parameters

*Ship board processing*

Onboard processing was carried out on a ProMAX system running on a laptop computer with an external hard disk and LINUX as operating system. Below a status of processing done onboard is given with recommendations of further processing. The processing presented is not final.

*Shot numbering and record numbers, navigation, shot time (for sonobuoys) and geometry*

The navigation system NaviPac produces event numbers each time a trigger is sent to the Geometrics system. This number is not unique to the seismic lines, as the numbers restart from a lower number on occasion (new runline, re-start of system etc). The record numbers from Geometrics are used as field files identification number (ffid) and as the unique identifier. The tie between NaviPac and the Geometrics data logging system is not completely unique. On some occasions a navigation string is not sent to the data logging, and on some occasions a wrong string is sent (i.e. the previous one). Thus care must be taken when assigning geometry to the seismic data. The sonobuoy data were recorded both on an auxiliary channel and on a stand-alone data logger.

In order to extract records from the stand-alone recording, accurate shot times are needed. The data acquired are not on an absolutely straight line, but surprisingly close. A test with true crooked line processing will be carried out later.

*Noise*

The data acquired are very noisy. Oden is built for icebreaking and the noise from the ice itself and the cavitation noise is high. A series of tests for noise elimination was carried out consisting of editing (extraordinary noisy shots and traces were marked and eliminated, shots with an additional triggered shot edited to eliminate the extra trigger); an FK-filter to eliminate noise from Oden propagating with water velocity, a time and space variant band pass filter designed to eliminate unwanted noise as well as enhancing the primary data; and a shot-mix where each channel from three neighboring shots are mixed with a weighting factor of 1-2-1 between shots.

Figure 11 (below) shows the noise level (in µbar) on both raw and processed data. The level after processing (approximately 10 µbar) is acceptable considering the conditions under which the data were acquired.

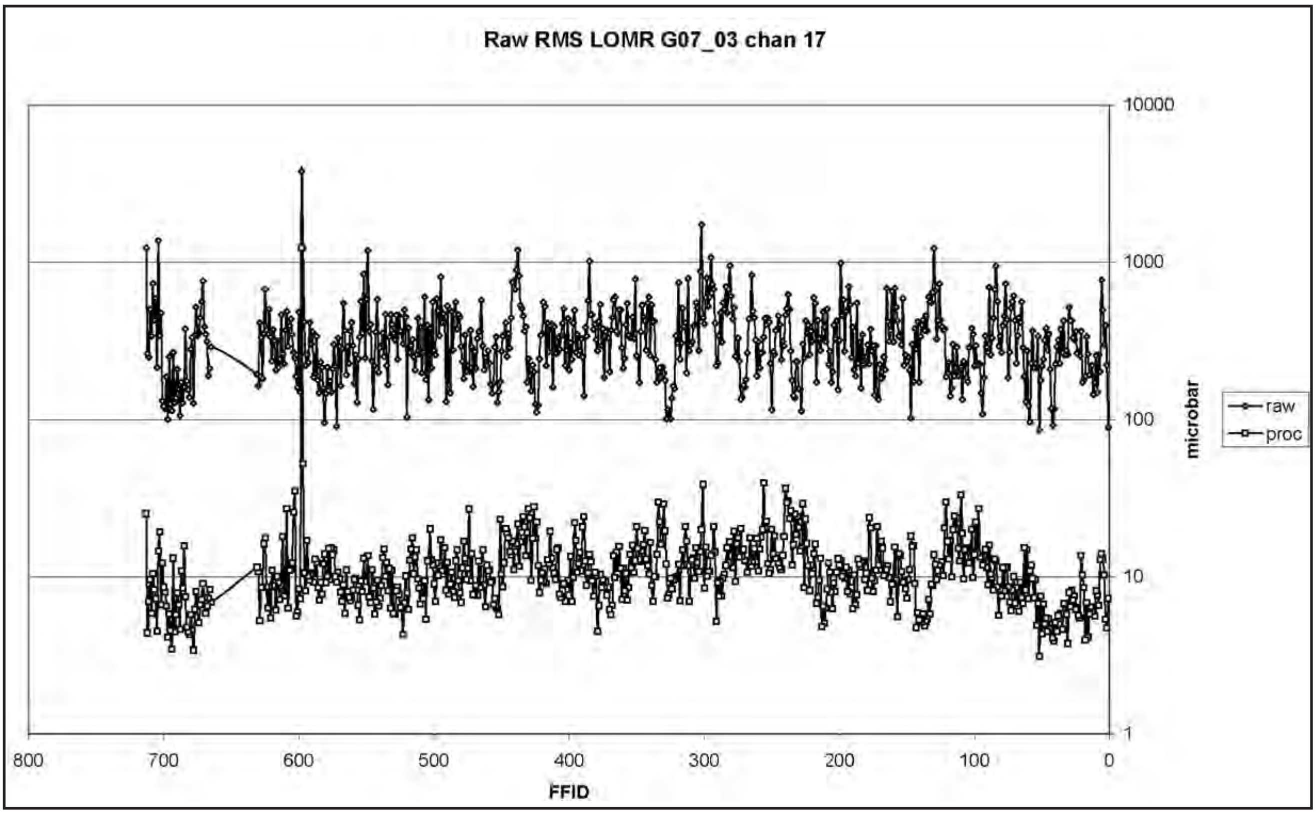
*Statics*

Gun delay: -16 ms (to be applied before normal move-out (NMO)). Datum static: streamer nominal 25 m, gun nominal 20 m, average 22.5 m. With a water velocity of 1440 m/s, the static correction is +31 ms (to be applied after NMO).

*Streamer statics (see Fig. 12)*

The speed of the ship during the data acquisition was very variable; from over 5 knots to standstill. When Oden was stuck in ice, the streamer sank; streamer sections furthest behind the ship sank deepest. This resulted in

Figure 11a. Shows the noise level in µbar on both raw and processed data from channel 17. The noise level after processing (approx. 10 µbar) is acceptable considering the conditions under which the data were acquired.



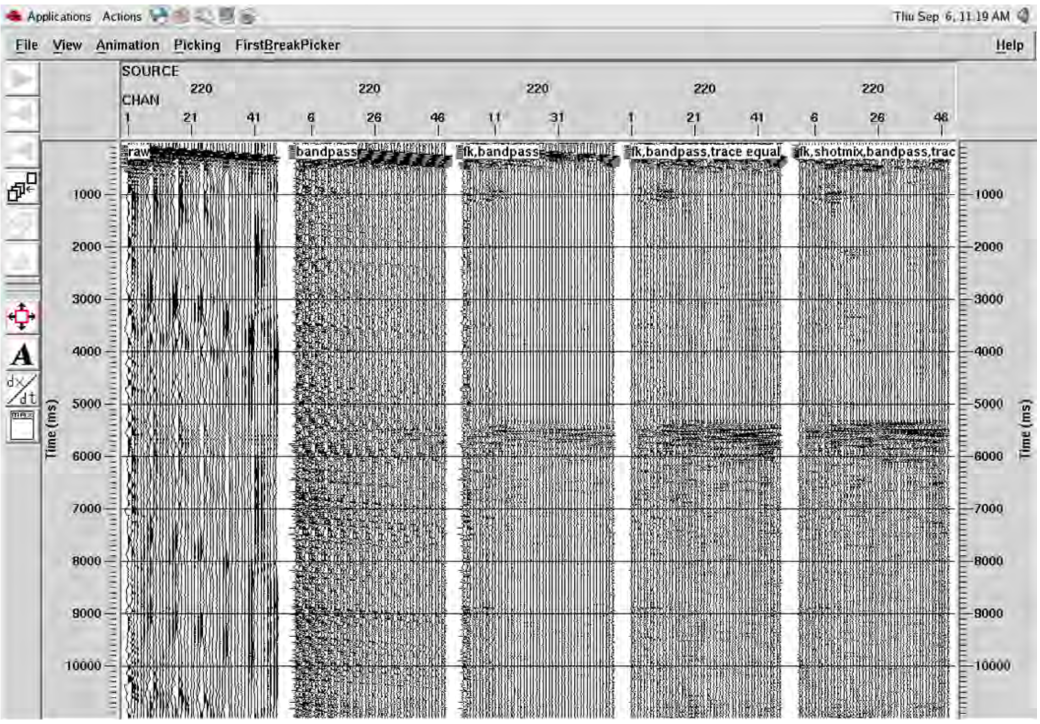


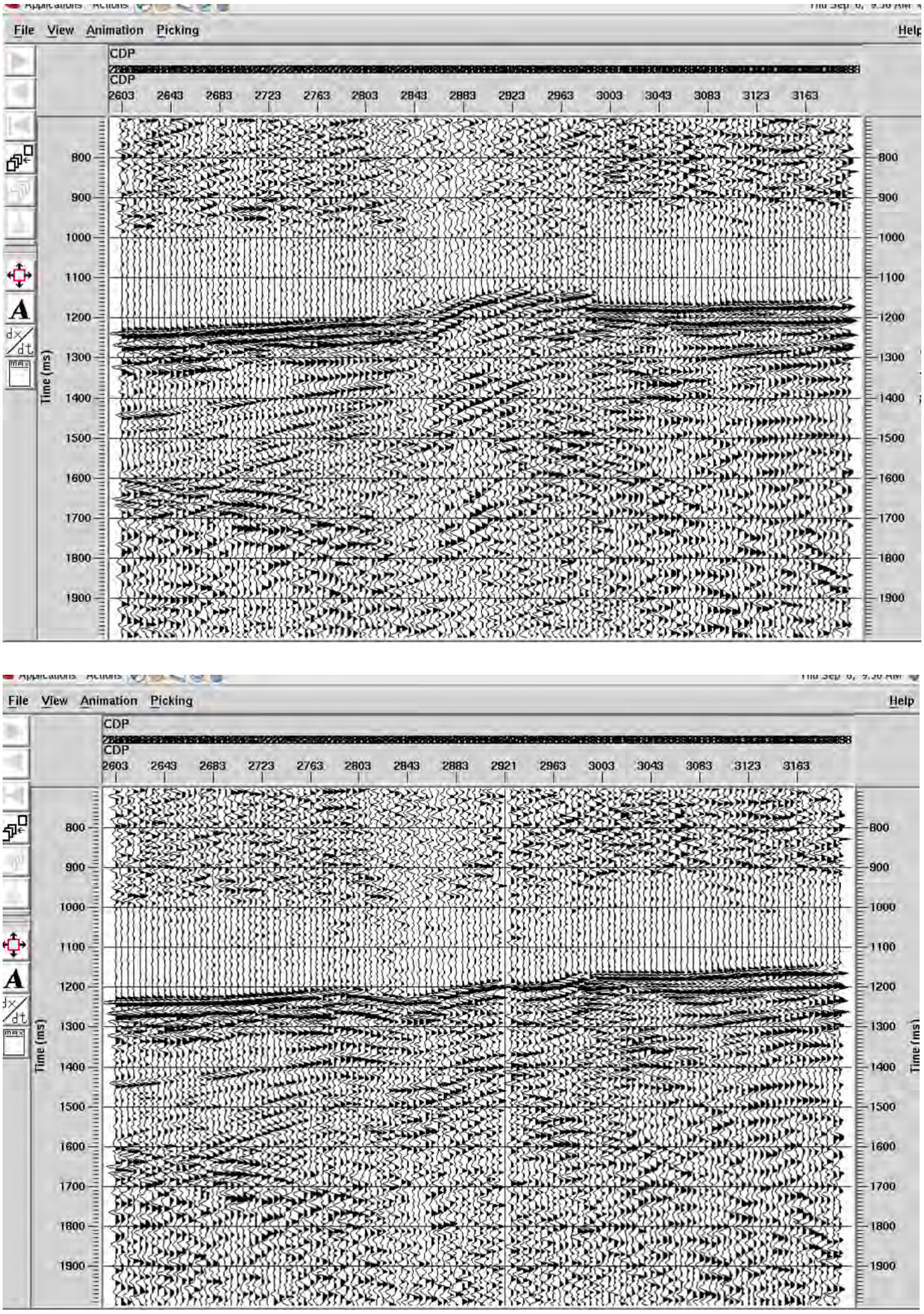

Figure 11b. The panels show steps of noise elimination (from left): raw data, bandpass filter applied, FK-filter added, trace equalization added, shot mix added.

early arrivals on the deepest parts of the streamer. The sections of the stack when Oden was stationary are very noisy and incoherent. Additional noise was created when Oden used full engine power to push forward through the ice. On LOMROG07-3 (see Results), the streamer depth was recorded for each shot, but as only one depth sensor reading was updated every shot, a full update was at intervals of 6 shots. In addition, all values over 70.32 m were recorded as 70.32 m. On LOMROG07-1, the streamer depth was only updated at large intervals.

For LOMROG07-3 the streamer depths recorded were interpolated both between shots and along the streamer to give a receiver depth at each channel for each shot. When the recorded depth was >70 m, the previous values were used to extrapolate. These depth values were applied as a streamer static, reducing the streamer depth to a nominal 20 m. Traces with depths >55 m were eliminated from the stack, which improved the stack in the noisy sections. This procedure is not possible for lines LOMROG07-1 and 4 as only few streamer depths were recorded on these lines.
However, in the noisy sections it would be possible to a) perform an NMO b) pick the seabed reflection c) correct it to the same value as the near traces across each shot (provided the seabed is flat, a very good assumption for this line). This would have the same effect as the static correction described above but a test for automatic picking of the seabed reflection indicates that many of the picks have to be edited manually.

*Velocities*
The small maximum offset (344 m) means that the differential moveout on the traces is very small. Even the seabed reflection has a moveout of only 5 ms for LOMROG07-1 in the abyssal plain and 30 ms for the shallower seabed on the Lomonosov Ridge. Thus virtually no velocity

Figure 12a and b. a) Part of LOMROG07-3 with no streamer static applied b) with streamer static applied.




information is contained in the data. For the stacks made during on-board processing "common-sense" velocities were chosen. For final stacking and particularly for migration and depth conversion the velocities from the sonobuoys will be used and correlated along picked horizons on the data (see sonobuoy report).

*Stacking*

The data were stacked following trace editing, streamer static correction (only LOMROG07-3), shot-mix and NMO correction. After stack the data were band pass filtered and an automatic gain control (AGC) with a window length of 500 ms was applied.

*Migration and depth conversion*
Not attempted on board.

*Tests for acquisition parameters (see Figure 13)*
When acquiring data in such a hazardous environment as the pack ice with ice concentrations of 10/10, the seismic equipment towed behind Oden is prone to be damaged. The streamer length used for LOMROG07-1 and 3 was six sections of 50 m length each; in total 300 m active streamer. Based on the data acquired with this streamer it was attempted to evaluate how the data quality is affected by the streamer length. In Figure 13 a section of LOMROG07-1 (see Results for line information) is stacked using only part of the streamer ranging from only one section (1-fold) to all six sections (6-fold). Otherwise processing was identical, although all data had undergone FK-filtering with all six

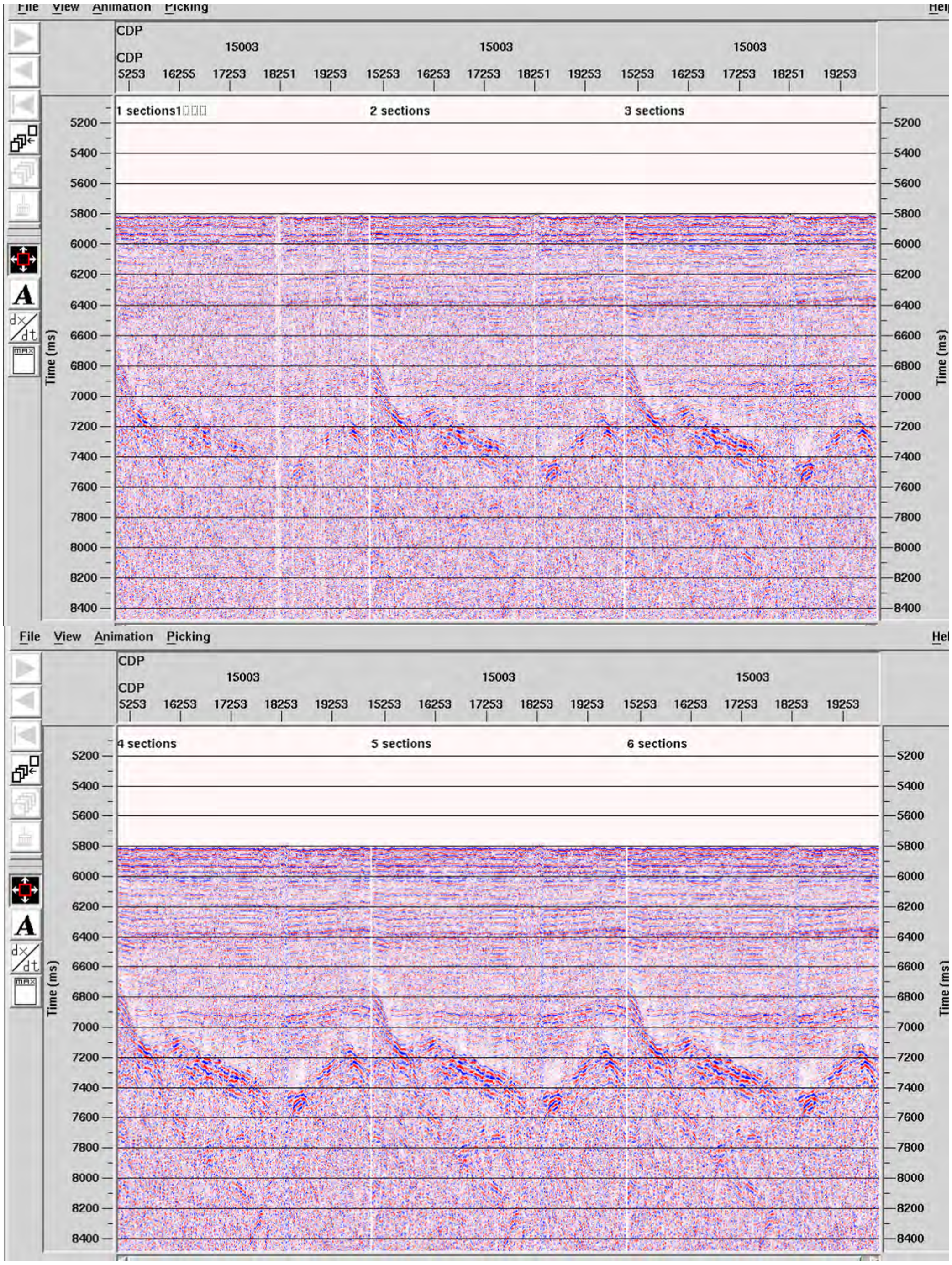



Figure 13a and b. The top panel has one, two and three sections; the bottom panel four, five and six sections (complete streamer). There are only slight differences in data quality when using 4, 5 or 6 sections.

sections. Visual inspection of the test panels suggests that a streamer shortened to four sections will provide data with only slightly reduced quality.

### Sonobuoy

*Equipment*

During the reflection seismic data acquisition of the LOMROG 2007 expedition, a Geometrics streamer with a maximum active length of 300 m was used for recording. A longer streamer was not manageable in the ice-infested Arctic waters and as consequence; velocity information from the sedimentary units is very limited. However, sediment velocities are important for the documentation of the sediment thickness of the extended continental shelf, if the 1-%-sediment-thickness formula (Gardiner line) is to be applied. Therefore, sonobuoys were deployed to record the seismic signals at larger offsets.

The sonobuoys of type AN/SSQ-53D(2) from ULTRA Electronics recorded the shots from the reflection seismic experiment with a nominal shot spacing of 25 m. The seismic source was a G-GI gun cluster consisting of two G guns with a volume of 250 cubic inches each and a GI-gun with a volume of 105 cubic inches. The total volume of the array was 605 cubic inches (9.9 L); the air pressure was 3000 psi (200 bar). Nominal towing depth of the gun system was 20 m.

### Gravity measurements

*Equipment*

During all of the LOMROG cruise measurements of the gravity acceleration has been done by the Danish National Space Center. Changes in the earths gravity field is due to changes in depth and the geological composition of the subsurface. Gravity increase generally towards the poles due to the flattening and rotation of the earth, and removal of this effect yields gravity anomalies. These anomalies are small – at the level of a millionth of g – corresponding to the conventional gravity unit mGal (1 mGal = 0.00001 m/s2). Gravity measurement is extensively used in geophysical exploration, as well as for precise geodetic measurement with satellites and navigation. The main purpose of the LOMROG gravity measurements was to support the interpretation of seismic data, and to provide detailed in-situ data as a reference for planned airborne gravity surveys between Greenland and the North Pole in 2008.

Gravity has been measured with a marine gravimeter of type Ultrasys Lacoste and Romberg (Serial no. S-38). The instrument is in principle an ultra precise spring balance with a proof mass, mounted on a gyro stabilized platform, which is kept in balance by a complicated feedback system. The gravimeter was mounted in the machine room close to the center of mass of Oden (Photo 26). The system records data every 10 sec, which after processing and reference measurements in the harbors of Tromsø and Svalbard yields gravity at an accuracy of approx. 1 mgal and 2-500 m resolution, depending on the speed of Oden and ice conditions.

As a complement to the marine gravity data, measurements with land gravimeters have been made by helicopter operations in profiles across

Photos 26-27. (Left) L&R gravimeter S-38 mounted in machine room. (Right) Swedish Icebreaker Oden.

the flanks of the Lomonosov Ridge and the Morris Jesup Rise. These operations have been less extensive than originally planned due to the malfunction of the portable echo sounder equipment, and the limited operating range of the helicopter (max 20 NM range from ship due to safety).

*Reference gravity measurements*

The marine gravity measurements have been tied to the international absolute reference system through base ties at Tromsø and Longyearbyen, Svalbard. Reference gravity values have been provided by Statens Kartverk, Norway. Photo 28-29 show ties in Tromsø, and Table 7 the used gravity reference values. The pier in Tromsø was tied to the SK stations “Tromsø S” and “Tromsø Q” twice using land gravimeter G-867, and similarly the pier in Svalbard was tied to two reference points in Longyearbyen airport (due to airport reconstruction Longyear P has been lost, but location is approximately correct). The tie adjustment showed an error of 0.05 mGal. It was found that the “Tromsø S” point (formerly the police station stairs, now the art museum) had been modified.

Photos 28-29. Left: G867 at Tromsø S point (old police station); right: Gravimeter at Brevika quay, next to Oden

Table 7. Marine gravity reference stations.

| Site | *Lat* | *Lon* | *g (mgal) pier level* | *Base reading* | *Time JD* |
|---|---|---|---|---|---|
| Tromsø S (old police station) | 69 38.89 | 18 57.67 | 982552.53 | - | - |
| Tromsø Q (Tromsø museum) | 69 38.09 | 18 54.84 | 982551.45 | - | - |
| Tromsø pier (Brevika), 2.40 m a.s.l. | 69 40.77 | 18 59.77 | 982555.72 | 9750.0 | 223.91 |
| Honningsvåg, bunker pier | 70 59.27 | 25 56.13 | 982668.05 | 9867.6 | 224.83 |
| Longyearbyen P (SAS office) | 78 14.80 | 15 29.80 | 982962.99 | - | - |
| Longyearbyen Hangar | 78 14.81 | 15 29.48 | 982963.02 | - | - |
| Longyearbyen (Bykaia), 2.75 m a.s.l. | 78 13.77 | 15 36.10 | 982964.71 | 10159.7 | 260.31 |


Photos 30-31. Left: Ice drilling with a Kovacs Auger; right: An ice measurement off-ship seen from Oden.

However, ties between Tromsø S and Q showed gravity change was less than 0.1 mGal. Original values have therefore been retained in Table 8. An additional base reading and land gravimeter tie (from Tromsø) was made to the Honningsvåg pier. Pier g-values were reduced to sea-level prior to the marine processing by applying a gradient of 0.26 mGal/m (corresponding to free-air gradient minus quay half-plate effect).

*Geodetic GPS measurements*

During the entire cruise a Javad geodetic receiver collected dual-frequency GPS at 5 sec interval from a location on top of container 11 near the front of the ship. The measurements were back up to the ship navigation system, but also allow – upon use of precise orbit and clock information from the international GPS service – to compute the position of the ship to an absolute accuracy of 10-20 cm. This gives independent information on the geoid and the ocean dynamic topography. The measurements were tied to sea-level at two ice stops (Aug 25 and Sep 9) using a 2nd Javad receiver. The GPS measurements will be processed at a later stage, and used i.e. to improve the reference for satellite measurements of sea-ice thickness, as well as derive improved methods

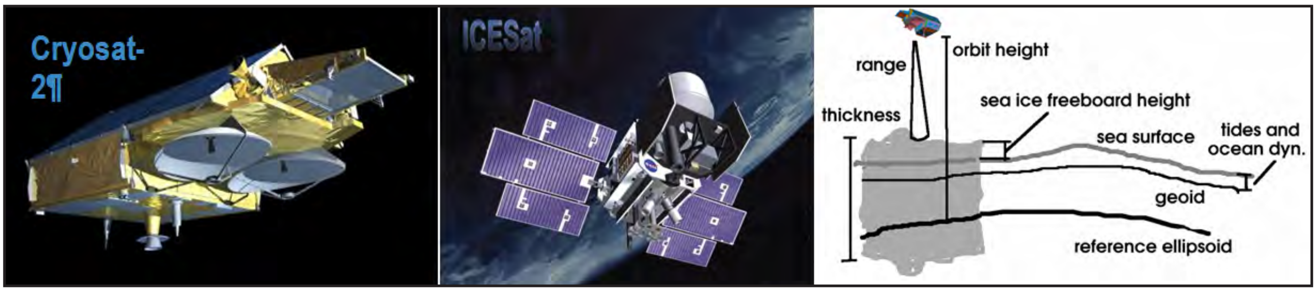



Figure 14. Satellite measurement of the sea ice thickness in the Arctic Ocean is the primary aim of CryoSat, and has also been successfully demonstrated by ICESat. The freeboard height measurement from space is accurate to few cm. The geoid (ideal height of the ocean surface) is determined from gravity measurements.

for more accurate marine gravity processing in the ice (taking into account the full 3-D motion of the ship during ice stops).

### *Sea ice thickness*

*Equipment and Data acquisition*

Between August 13 - Sept. 16 a number of daily stops where made to sample sea ice by drilling, measuring thickness, freeboard height and snow cover, as well as snow and ice density. The drilling program was an ad-hoc research programme taking advantage of gravity measurement activities and the sea-ice coring and sampling research programme of the Greenland Nature Institute (carried out by Hans Ramløv, RUC).

The purpose of the sea ice drilling programme, apart from general information on the ice thickness, was to provide systematic sampling of freeboard to thickness ratios. Freeboard height, i.e. the height of the ice surface above the sea-level (Figure 14), is the only way sea-ice thickness can presently be measured from space. Current satellite missions with sea ice thickness measurement as primary or main objectives is NASA's ICESat mission (launched 2003, measuring by laser to the top of the snow), and ESA's CryoSat (failed at launch 2005, to be relaunched 2009), measuring sea-ice thickness by radar measurement to the snow-ice interface.

In spite of many decades of intensive ice drilling from drifting ice stations, icebreaker cruises etc., systematic sampling of freeboard to thickness ratios ("k-factors") in the Arctic Ocean has been sporadic, and climatological modeling has usually been the main source of this information for space applications. In situ data, such as the summer-period data collected during LOMROG, and recent spring time activities in connection with EU and ESA projects (e.g., the Damocles IPY project and ESA CryoSat field validation activities north of Greenland) are important for validation of these climatological models.

### *Sea ice chemistry*

*Equipment and Data acquisition*

Different types of sea ice were collected using a 7 cm KOVACS ice core drill fitted with a battery driven hand drill. 10 cm pieces from the top, middle and bottom of the ice core were cut out and transferred to plastic containers. Before collecting the 10 cm pieces the temperature along the core was measured at 10 cm intervals.

The physical parameters air temperature, snow depth, snow temperature (5 cm intervals), ice surface temperature, ice density, total ice salinity (melted ice core) were measured at each drill hole and ice core piece. Density of the core pieces was determined from top, middle and bottom, where possible, by measuring and weighing of the core piece.

Preparation of ice cores for measurements of $TCO_2$, total alkalinity (TA), salinity and Chlorophyll a were carried out. The collected core pieces were taken to the laboratory and cleaved. One half was transferred to a gas proof plastic bag ("Würgler bag") and sealed. The ice was melted in the bag and the melt water is transferred to gas tight containers and preserved with $HgCl_2$, which were brought to the laboratory in Nuuk (Greenland) where the final measurements are to be done.

The other half was melted; some melt water was transferred to a plastic vial for the measurement of salinity and the rest was filtered through a glass filter and the filter was thereafter frozen for the later determination of the chlorophyll a content of the filtrate (i.e. the ice). In addition to the ice cores water samples from 10 m depth were acquired from the CTD which was operated from one of the Swedish groups participating on the expedition.

## Results

### *Multibeam bathymetry*

*Surveying in the ice*

Under ice-free conditions the multibeam data quality was good. Oden is characterized by rather slow and steady movements, which can easily be compensated for by means of the motion sensor. Therefore the data from Barents and Greenland Sea showed good quality. Nevertheless, when reaching the ice edge and going into pack ice, the data quality decreased significantly as is the case for all icebreakers equipped with multibeam. Breaking ice had several negative effects on the multibeam system's performance:

- The multibeam transmitting and receiving array are installed in Oden's "ice knife". This ice knife is designed to divert the crushed up ice to the sides preventing a lot of ice from gliding underneath the hull. Despite this, it appears like some pieces rather frequently passes in front of the multibeam transducers causing signal loss.
- In heavy ice conditions (10/10 ice) Oden's flushing system is needed, which flushes large amounts of water onto the ice in front of the ship. Depending on how the icebreaker is moving, a lot of air bubbles may come in under the ship causing signal problems. If possible, this system should not be used while acquiring data.
- In very heavy ice conditions (10/10 ice cover, large pressure ridges and floes as thick as 4 m) as we encountered on the Lomonosov Ridge north of Greenland, Oden requires assistance in order to not only fight the ice. Only Russian nuclear icebreakers with 75 000 horse powers are capable to break through ice this hard at some knots. While we followed in the wake of the assisting Russian icebreaker 50 Let Pobedy very poor data quality was achieved. This was due to the enormous amounts of broken ice, air bubbles and ice slush that end up in the wake behind 50 Let Pobedy.
- A technique involving that Oden was spun around 180° in a "pirouette" while acquiring multibeam data, was invented and used where the ice conditions were hard, but some small open ponds were found. This technique proved very efficient and was used first in the Morris Jesup area. The idea was to cover a sector 360° around the ship equal to the multibeam swath width. After one "pirouette" was done, the Oden broke ice using its full capacity to the end of the coverage, where a new pirouette was carried out.
- In hard ice condition during transit between work areas where there was no time to have the multibeam acquisition in mind and break ice as gentle as possible, it was discovered that if the swath width was limited to 2x10° data could be acquired with higher success.
- When Oden surveys in open leads, with more or less no waves, very good multibeam data quality can be achieved.


Photo 32. "Pirouette survey". This technique (further described in the text) proved very efficient and was used first in the Morris Jesup area. The idea was to cover a sector 360° around the ship equal to the multibeam swath width. After one "pirouette" was done, the Oden broke ice using its full capacity to the end of the coverage, where a new pirouette was carried out.

Good quality data at 12 knots in flat water was achieved in long leads in the Gakkel Ridge area during transits between CTD stations.

- In thinner ice (~1 m) like we experienced in areas of the Fram Strait and over the East Greenland Ridge, relatively good multibeam data could be acquired while breaking ice.

*Experienced technical problems*

- Setting max and min coverage to a value does not narrow the swath down to that value necessarily. Often the swath stays broader.
- System locks on depths close to the set maximum depth
- System locks on depths above the set minimum depth (often 2000…2600m in "Deep" mode)
- Angular coverage mode "MANUAL" results in only 1/3 to 1/2 of all possible beams being used.
- "Devil's horns" or "Erik's horns": Horn-like, very reliable, false detections at the edge between phase and amplitude detection sectors of the swath. A beam steering calibration file fixing this problem was provided by Kongsberg during the expedition. This fix was not applied to the PU software, though, because during the installation and sea acceptance test program manual fine-tuning of similar setting files for the beam steering was carried out by the Kongsberg engineers on board. There might be the possibility to overwrite these (custom) settings.

During survey in heavy ice the MB-system crashed regularly and had to be restarted. The reason for this is assumed to be due to the very strong vibrations which regularly occurred during ice breaking, and which is assumed to have a negative effect on the electronics and multibeam and survey computers. These were not mounted in shock absorbing racks. During survey while drifting or transit in moderate ice conditions, the system seldom crashed.

*Acquired Data*

Figure 15 shows an overview of the multibeam coverage after shipboard processing during the LOMROG cruise. From this map it is evident that the hard ice conditions in the southern Lomonosov Ridge area severely affected the multibeam mapping. However, the pirouette surveying technique, which first was invented when Oden had to operate alone on the Morris Jesup Rise, made it possible to collect data in pretty much any ice conditions.

Glacial erosion was mapped with the multibeam in water depths shallower than approximately 800 m on the Lomonosov Ridge and on the Morris Jesup Rise large iceberg scours were discovered down to a water depth of approximately 1050 m, among them also the deepest and most spectacular iceberg scours so far found in the Arctic Ocean (Figure 16). These data from the Morris Jesup Rise were collected using the pirouette surveying technique (Photo 32). On the Yermak Plateau multibeam data was collected along a previous survey track by USCGC Healy from the HOTRAX 2005 expedition (Figure 17). The EM120 data provides a far more detailed view of the seafloor morphology and also a wider swath compared to Healy's Seabeam 2112, although it should be noted that the EM120 installed on the Oden is a more modern and higher resolution system. The East Greenland Ridge was systematically mapped and only portions of the survey area were covered by sea ice allowing surveying along predefined tracklines (Figure 18).

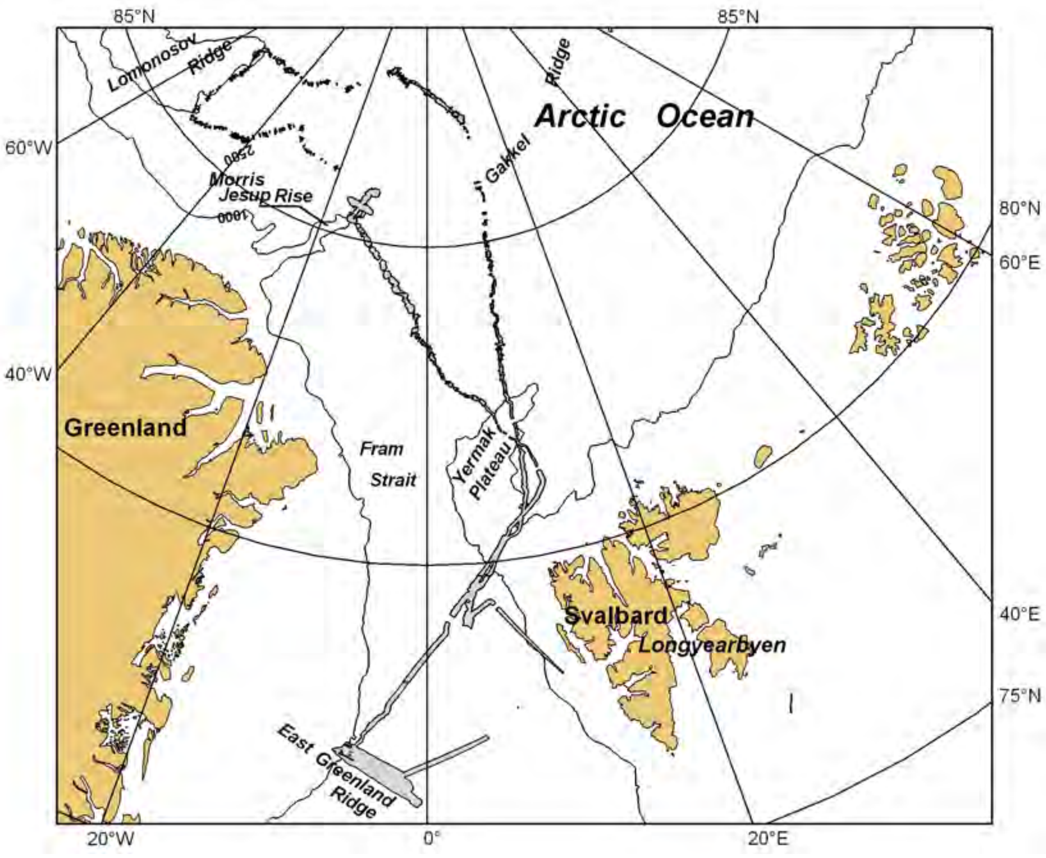



Figure 15. Coverage of the multibeam mapping data processed during LOMROG. Note that the data acquired during transit south of approximately 76°N were not processed onboard.

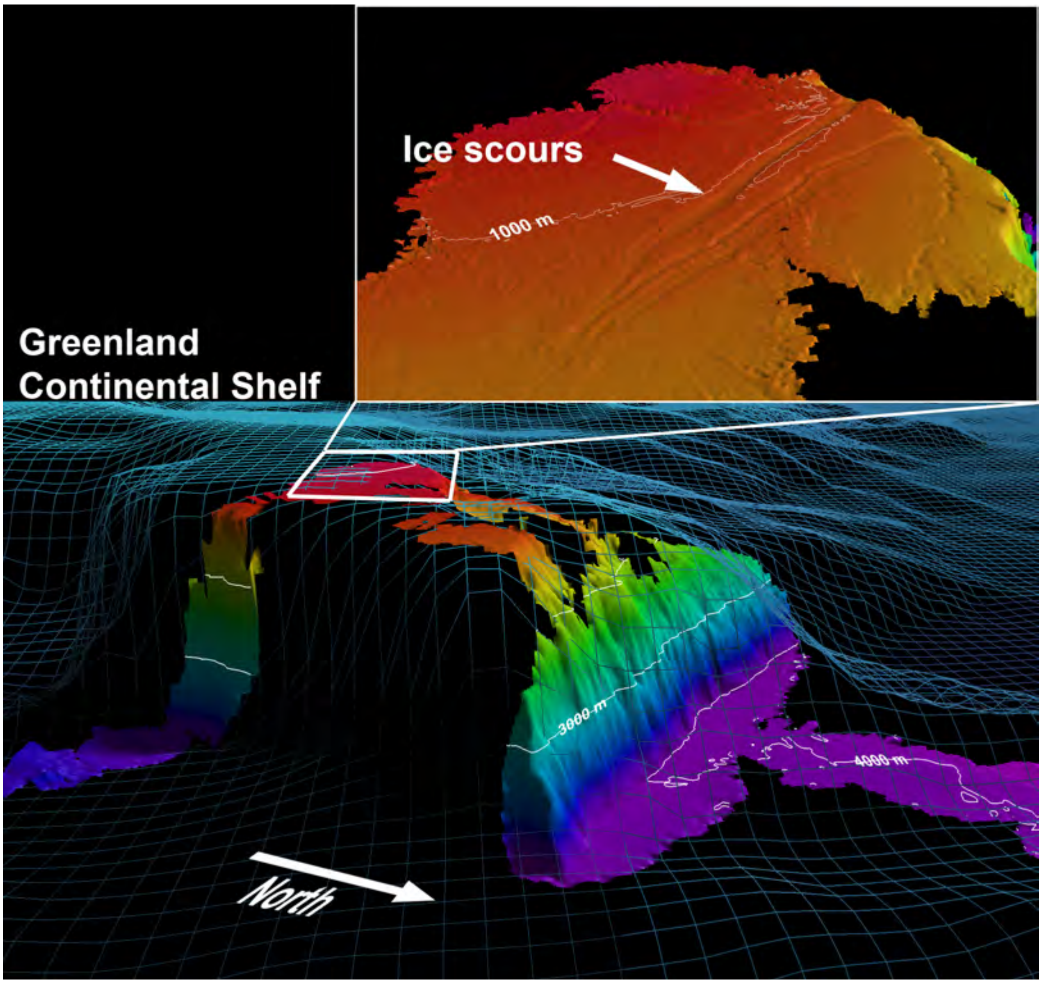



Figure 16. Multibeam data collected from the Morris Jesup Rise using the "pirouette technique" (see Photo 32). The large iceberg scours are from previous ice ages. The arrow points on one of the deepest mapped ice berg scours in the Arctic Ocean. Sediment cores were retrieved from the ice scours in order to investigate how much sediments have been accumulated since the scours were formed. This will allow dating of the ice scouring event(s). The foot of the Morris Jesup Rise was successfully mapped with the multibeam for the Danish Continental Shelf project. The background mesh shows the bathymetry of the International Bathymetric Chart of the Arctic Ocean (IBCAO) Version 1.0. It is clearly seen how much more detail the new multibeam data reveals. In the new IBCAO version 2.0, all the LOMROG bathymetry is included.

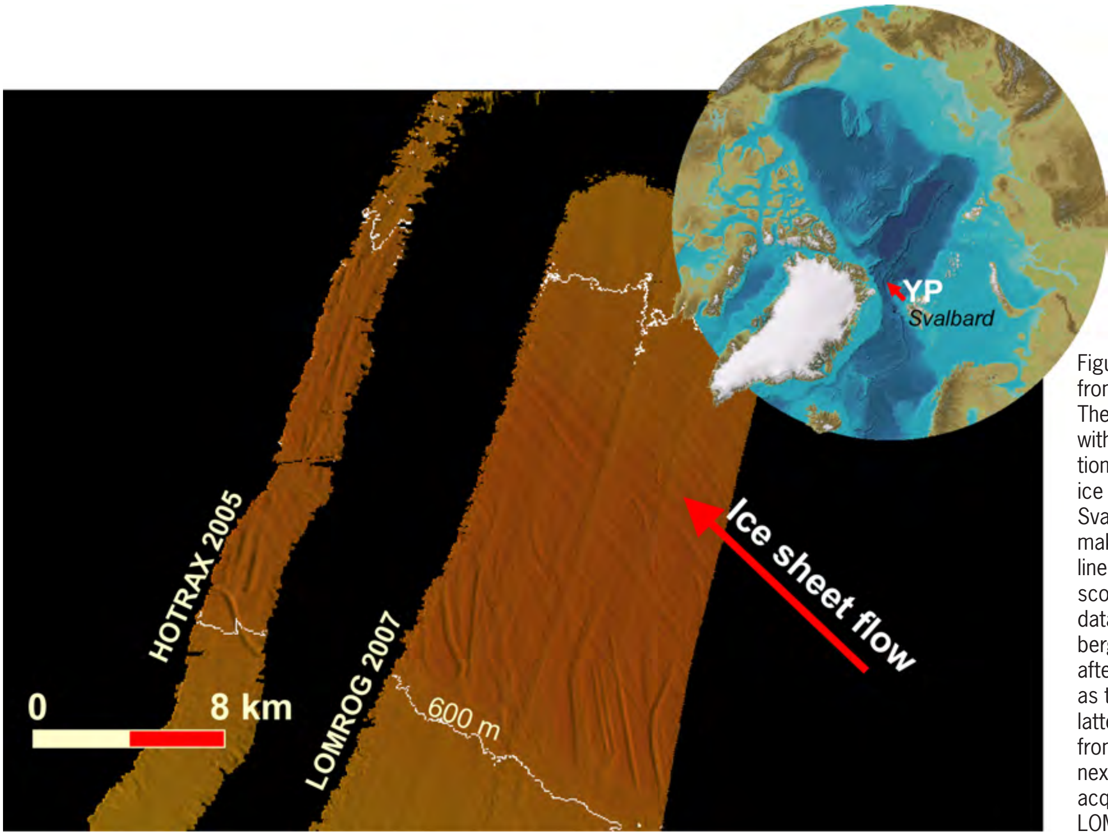



Figure 17. Multibeam data from the Yermak Plateau. The red arrow is lined up with the glacial lineations generated from an ice sheet advance from Svalbard out over the Yermak Plateau. Across the lineations some iceberg scours can be seen. The data show that the iceberg scours were created after the glacial lineations as they cut trough the latter. The narrower swath from USCGC Healy runs next to the two swaths acquired with Oden during LOMROG 2007.

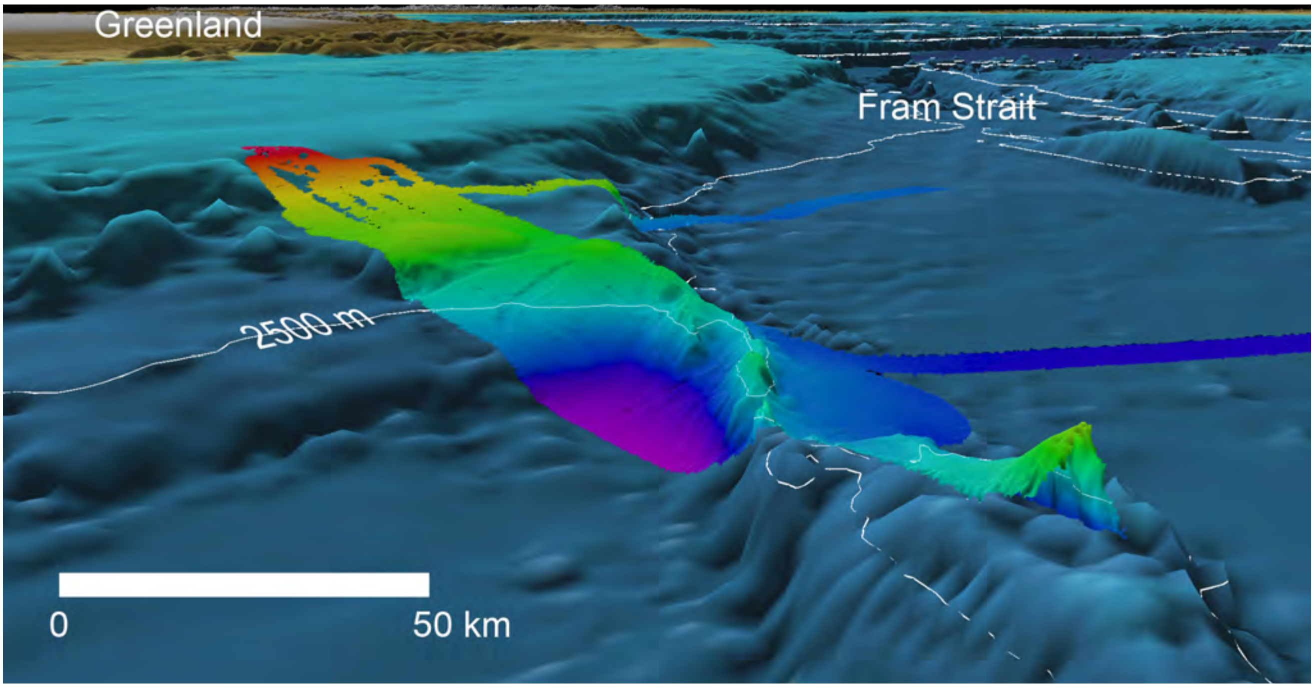



Figure 18. Multibeam bathymetry collected from the East Greenland Ridge during the LOMROG 2007 cruise. The multibeam bathymetry is here shown overlaid on the new IBCAO version 2.0, which has made use of these data in this area.

### *Chirp sonar profiling*

The SBP120 subbottom profiler provided high-resolution records with a penetration up to nearly 100 m in clays throughout the cruise when the ice conditions were moderate; 1.5 m thickness and occasional open leads. In difficult ice conditions where we had to use the pirouette survey technique, the subbottom profiler is more difficult to use as this type of geophysical data should be recorded along strait track lines. In any case, the subbottom information was essential for the selection of sediment coring sites during the entire LOMROG cruise. The acquired records made it possible to locate undisturbed sections optimal for obtaining cores for paleoclimate research (Figure 19).

### *Single beam bathymetry from sea ice*

The single beam echo sounder was first tested on the ice close to Oden using the ship's 220V power without success. However, a second test from the ship was successful and the team was ready for a new trial out on the sea ice. A pair of car batteries was brought along as a power supply and the team set out for data acquisition with the helicopter. The echo sounder did not perform while out on the ice, and it was discovered that the batteries did not deliver the required voltage. In order to find more problems in addition to the power supply, the echo sounder was opened and analyzed by Per Trinhammer and Morten Sølvsten. Two circuits had burned and Reson (John Gyrud) was contacted to get the manufacturers opinion on making shortcuts on these circuits. After further testing the circuits close to the shortcuts, it burned again. Several days later and additional shortcuts, the receiver amplifier did not respond to signals at all. In total only three soundings were obtained using the single beam echo sounder (Table 8 and 9).

The single beam echo sounder failed and will be repaired after return to Denmark and a full error report should be included as part of the

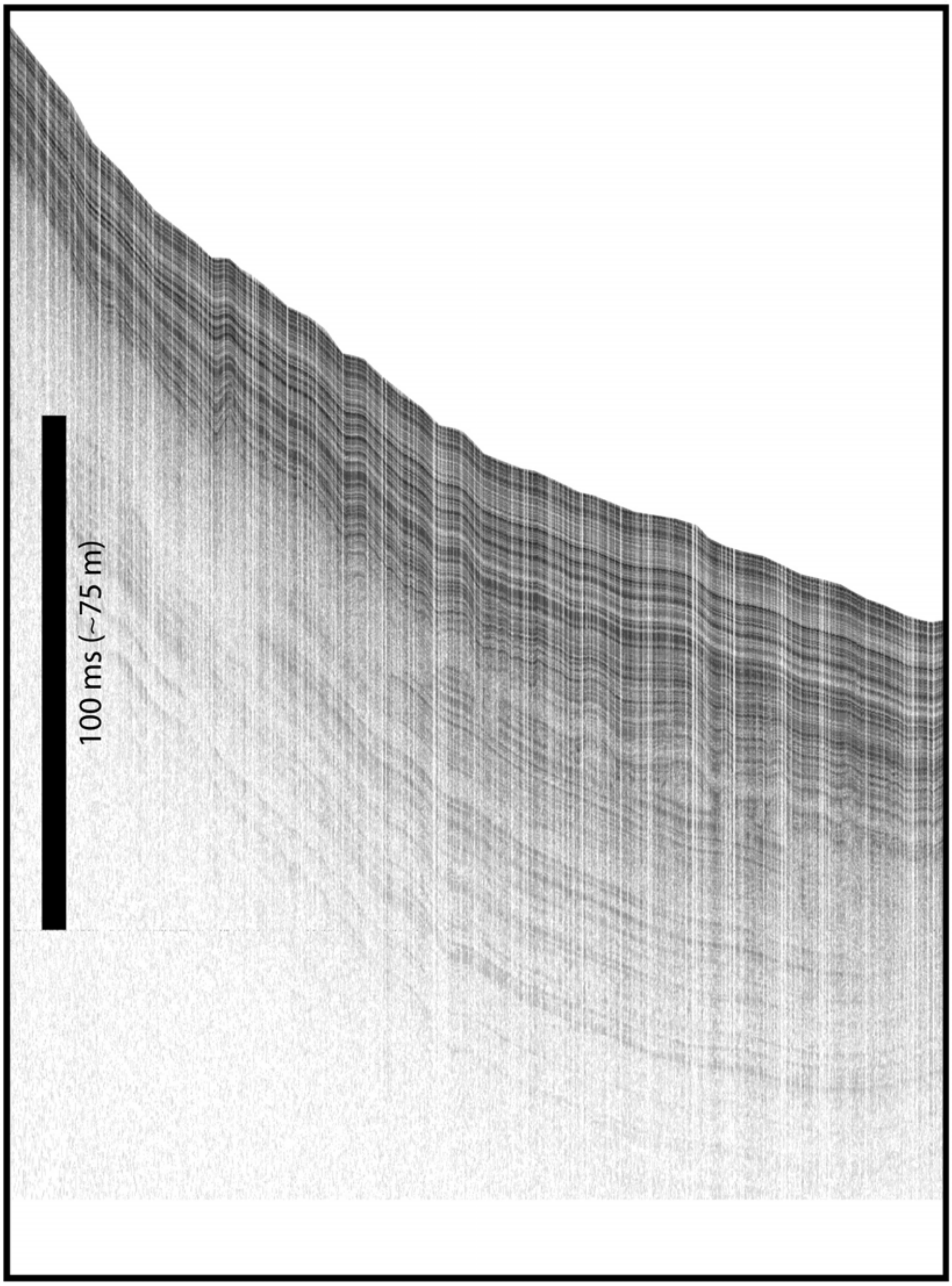



Figure 19. SBP120 data collected from the Yermak Plateau using a 2.5-7 kHz 100 ms long chirp pulse.

Table 8. Single beam bathymetric readings from the sea ice.

Bathymetry Positions - LOMROG 2007

Notes: WGS84 - GPS positioning (non corrected, hand held units)
Depths have been measured through water column
Depths are collected at a fix speed of sound set to 1500 m/sec and corrected by average speed of sound calculated from CTD casts

| Stat. Name | Latitude North | Longitude West | Meas-ured Depth (m) | TX Off-set | Corrected Depth (m) | Draft | Time (UTC) | Date | Avg. SVL m/sec | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| B11 | 86 45.7515 | 048 06.2438 | 2128 | 2 | 2080.3 | 2.0 | 15:22 | 23/08/2007 | 1465 | NS420DS -15 KHz |
| B12 | 86 46.1884 | 047 14.9881 | 1574 | 2 | 1536.1 | 3.0 | 16:54 | 23/08/2007 | 1461 | NS420DS -15 KHz |
| 84 | 85 17.3927 | 051 56.6915 | 1229.0 | 3.0 | 1196.6 | 2.0 | 14:10 | 25/08/2007 | 1458.0 | NS420DS -24 KHz |

Table 9. Used CTD profiles for sound velocity correction of the depth data.

| Location Name | SVL file Used |
|---|---|
| **B11** | **200708230536_lomrog07_ctd005_01_coppens.asvp.xls** |
| **B12** | **200708230536_lomrog07_ctd005_01_coppens.asvp.xls** |
| **84** | **200708251816_lomrog07_ctd007_01_coppens.asvp.xls** |

repair. For the next Arctic Ocean expedition, it is recommended that at least one full set of spare parts should be brought along. It should be considered to purchase an additional complete portable echo sounder similar to the ones CHS use as they probably are the most experienced regarding single beam sounding from sea ice. The set helicopter range of 20 nautical miles from Oden (decided for security reasons) is a bit too short to achieve good coverage away from Oden's track.

### *Sediment coring*

Altogether 4 piston cores and 6 gravity cores were retrieved from the Lomonosov Ridge and Morris Jesup Rise. No cores were taken from the Yermak Plateau or the East Greenland Ridge as the priorities in these areas were on geophysical mapping. Table 10 lists the cores and their recovery and Figure 20 shows their locations. The longest core of 6 m was retrieved from the Morris Jesup Rise. It should be noted that most of the short cores were taken from the ice eroded areas where sediment compaction is an issue. The new piston/gravity core launching system proved to work very well and significantly reduced the time to take a sediment core compared to previous coring expeditions with the Oden. The main logistical problems we experienced with the coring were related to the old coring winch, which on several occasions broke down and had to be repaired.

During sectioning of core LOMROG07-PC-07, the lower end-cap of section 1 came off and the lowermost 50-70 cm of sediment slid out on deck. A piece of sediment, ca 20 cm, was put back into section 1. The rest of the sediment was put in a 33 cm split liner, which became section 2. Section 4 was mistakenly split before multi sensor core-logging could be performed.

### *Multi Sensor Core Logging*

The high-quality multi sensor core logs acquired onboard provide a tool for an initial stratigraphic correlation between the different coring sites. The low number of outliers, and the generally smooth rather than spiky records in magnetic susceptibility, P-wave velocity, and gamma density suggest that the obtained data are of high quality and not significantly affected by the shaking caused by ice-breaking. This is further corroborated by the reproducibility test performed on core LOMROG07-GC-10, which was first measured under shaky conditions during a phase of intense ice breaking, and subsequently remeasured under calm conditions when the ship was lying still for CTD sampling (Figure 21). Gamma density and magnetic susceptibility values are for all practical purposes identical while P-wave values show a slight offset, potentially attributable to differences in ambient temperature, and a number of smaller spikes in the first measurement, likely due to ice-induced shaking of the multisensor corelogger.

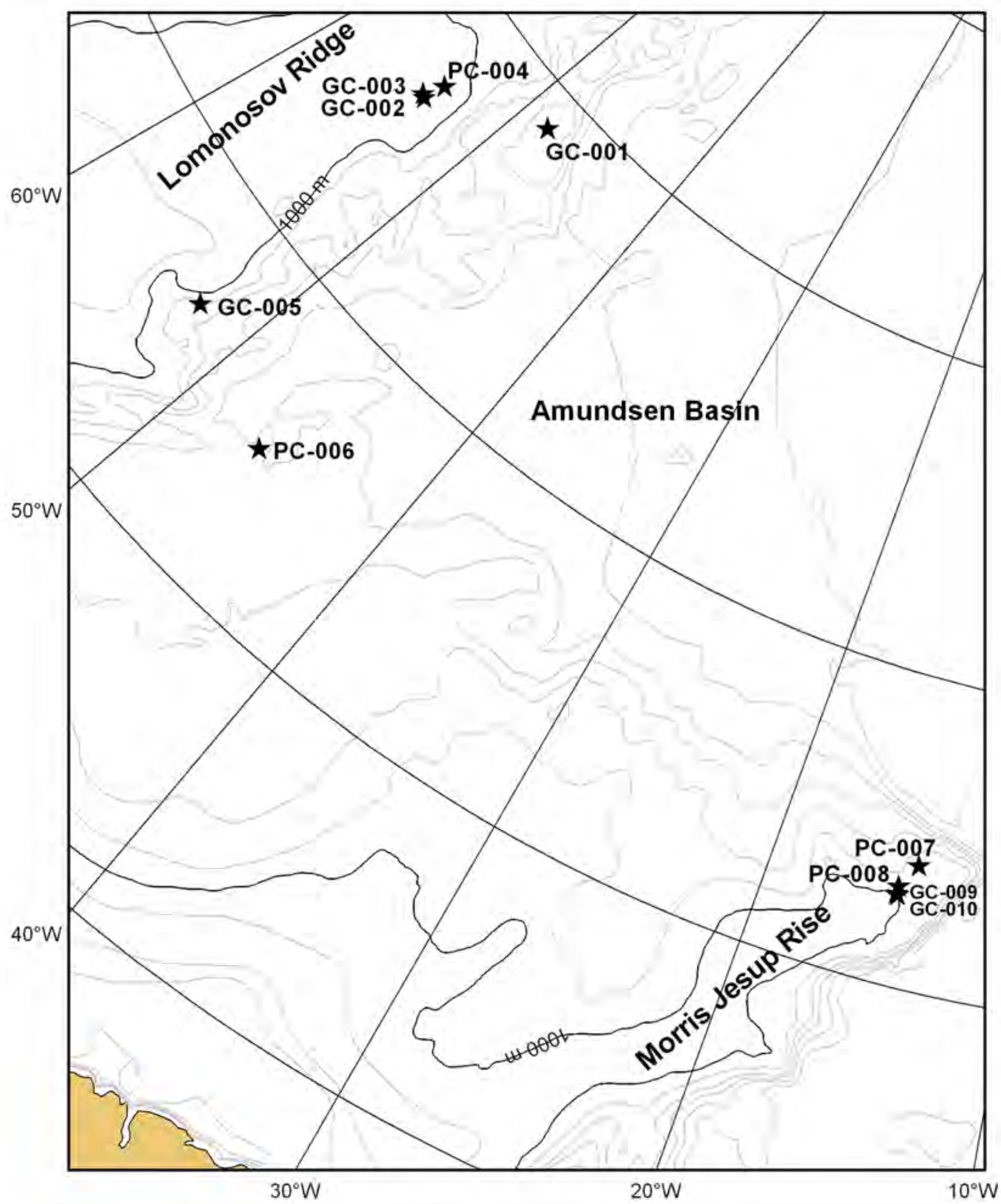



Figure 20. Sediment cores taken during the LOMROG expedition. The 1000 m depth curve is shown in black. Gray lines are depth curves with 500 m increments.

The gamma density measurements on the first three cores show generally smooth records with only solitary peaks (Figure 22). In contrast, the later cores show considerably stronger variability. Especially LOMROG07-GC-05, LOMROG07-PC-06, and LOMROG07-PC-07 display several pronounced peaks and troughs that allow a tentative correlation.

P-wave velocities generally vary between 1500 and 1600 m/s (Figure 23). Larger deviations from these values are found in uppermost part of cores GC-02 and GC-03, and in the lower parts of cores PC-08 and GC-09. The three cores GC-05, PC-06, and PC-07 show a typical pattern of values stepwise jumping between 1500 and 1600. It is interesting to note that these are also the cores displaying the largest amplitude in gamma density and magnetic susceptibility changes. As in gamma density, the magnetic susceptibility display only small variations in the first three cores and considerably larger amplitude in the other cores (Figure 24).

| Station | Coring date | Core head weight (kg) | Trigger weight (kg) | Gravity Piston | Recovery (m) | Penetration (m) | Trigger line scope (m) | Rigged core length (m) | Latitude | Longitude | Water Depth (m) | Time in water | Time out of water | Time on bottom | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOMROG07-GC-001 | 23-Aug-07 | 1088 | | GC | 1.47 | 6 | | 6 | 86.15233 N | 48.1523 W | 1573 | 10:50 | 11:53 | 11:23 | Lomonosov Ridge high in the slope from Amundsen Basin |
| LOMROG07-GC-003 | 24-Aug-07 | 1088 | | GC | 1.98 | 4.5 | | 6 | 86.62783 N | 54.959 W | 721 | 10:49 | 11:15 | 11:02 | Lomonosov Ridge near top |
| LOMROG07-GC-002 | 24-Aug-07 | 1088 | | GC | 2.43 | 4 | | 6 | 86.63183 N | 54.1512 W | 723 | 08:44 | 09:11 | 08:56 | Lomonosov Ridge near top |
| LOMROG07-PC-004 | 24-Aug-07 | 1360 | 140 | PC | 5.49 | 8 | 3.5 | 9 | 86.70117 N | 53.7672 W | 811 | 17:17 | 17:48 | 17:36 | Lomonosov Ridge crest, below ice erosion |
| LOMROG07-GC-005 | 26-Aug-07 | 1088 | | GC | 2.85 | 5 | | 6 | 85.65383 N | 52.4543 W | 1440 | 06:48 | 07:46 | 07:19 | Lomonosov Ridge slope towards Amundsen Basin |
| LOMROG07-PC-06 | 28-Aug-07 | 1360 | 140 | PC | 4.18 | 7 | 3.5 | 9 | 85.49333 N | 46.27333 W | 3009 | 14:34 | 16:50 | 15:45 | South East spur of Lomonosov Ridge |
| LOMROG07-PC-07 | 01-Sep-07 | 1360 | 140 | PC | 4.68 | 9.5 | 3.5 | 9 | 85.39967 N | 14.282 W | 1252 | 20:52 | 21:39 | 21:16 | Location: up on plateau, NE Morris Jesup rise. Close to slope. Section 2 splitted directly without logging |
| LOMROG07-PC-08 | 02-Sep-07 | 1360 | 140 | PC | 6.03 | 9 | 5 | 9 | 85.31983 N | 14.8575 W | 1038 | 21:42 | 22:20 | 22:01 | Location: up on plateau, NE Morris Jesup rise. Liners were assembled by fasing edges and taping carefully |
| LOMROG07-GC-09 | 03-Sep-07 | 1088 | | GC | 2.34 | 6 | | 6 | 85.2945 N | 14.8922 W | 1016 | 10:08 | 10:48 | 10:27 | Location: up on plateau, NE Morris Jesup rise. Taken in glacial scour |
| LOMROG07-GC-10 | 03-Sep-07 | 1088 | | GC | 2.58 | 6 | | 6 | 85.29312 N | 14.8146 W | 1017 | 16:54 | 17:56 | 17:36 | Location: up on plateau, NE Morris Jesup rise. Taken in glacial scour |

Table 10. Gravity and piston cores retrieved during the LOMROG expedition from the Lomonosov Ridge and Morris Jesup Rise

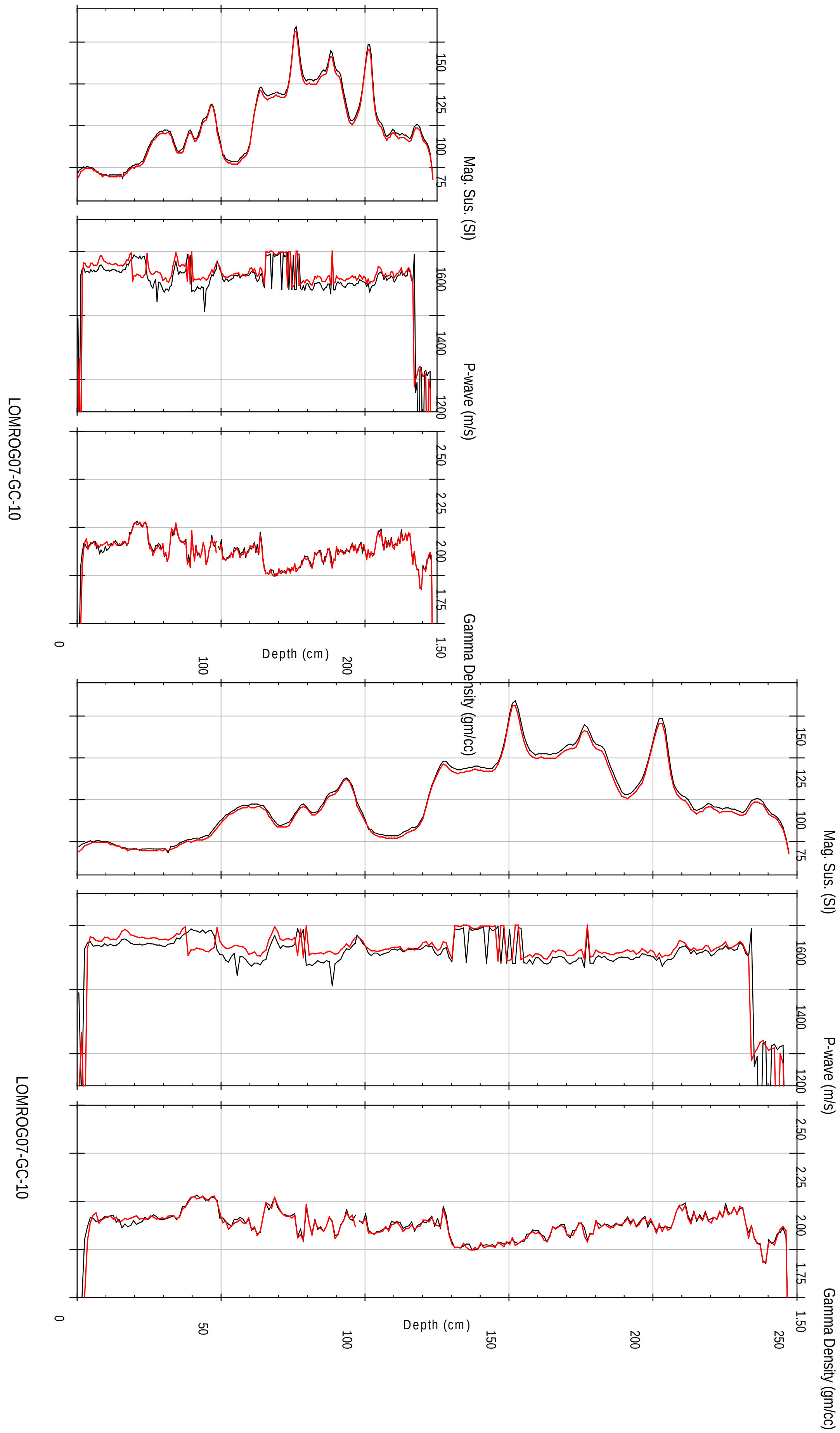
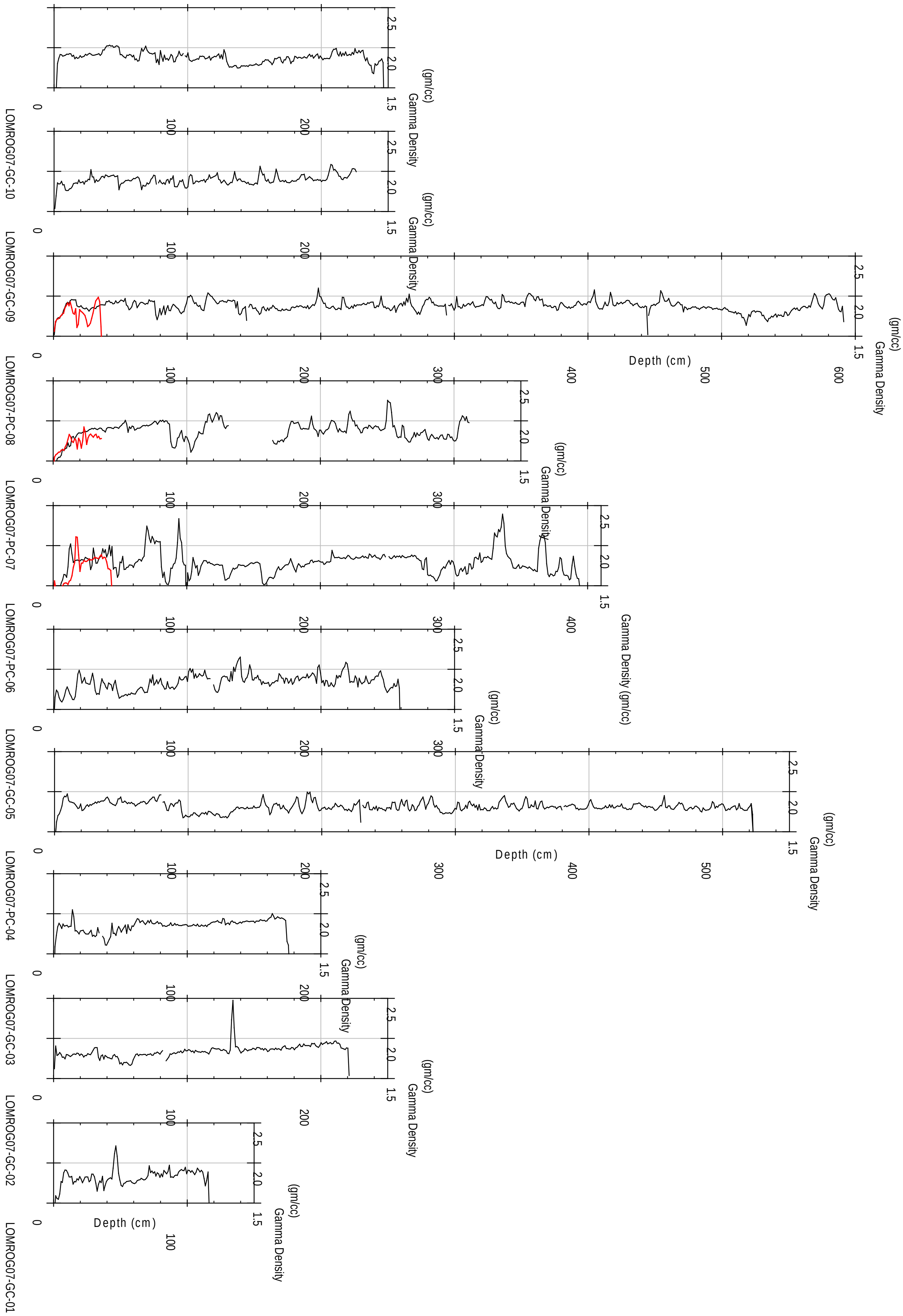



Figure 21. Reproducibility test performed on core LOMROG07-GC-10. The core was first measured under shaky conditions (black line) during a phase of intense ice breaking, and subsequently remeasured under calm conditions when the ship was lying still for CTD sampling (red line).

Figure 22. Gamma bulk density of the LOMROG cores.



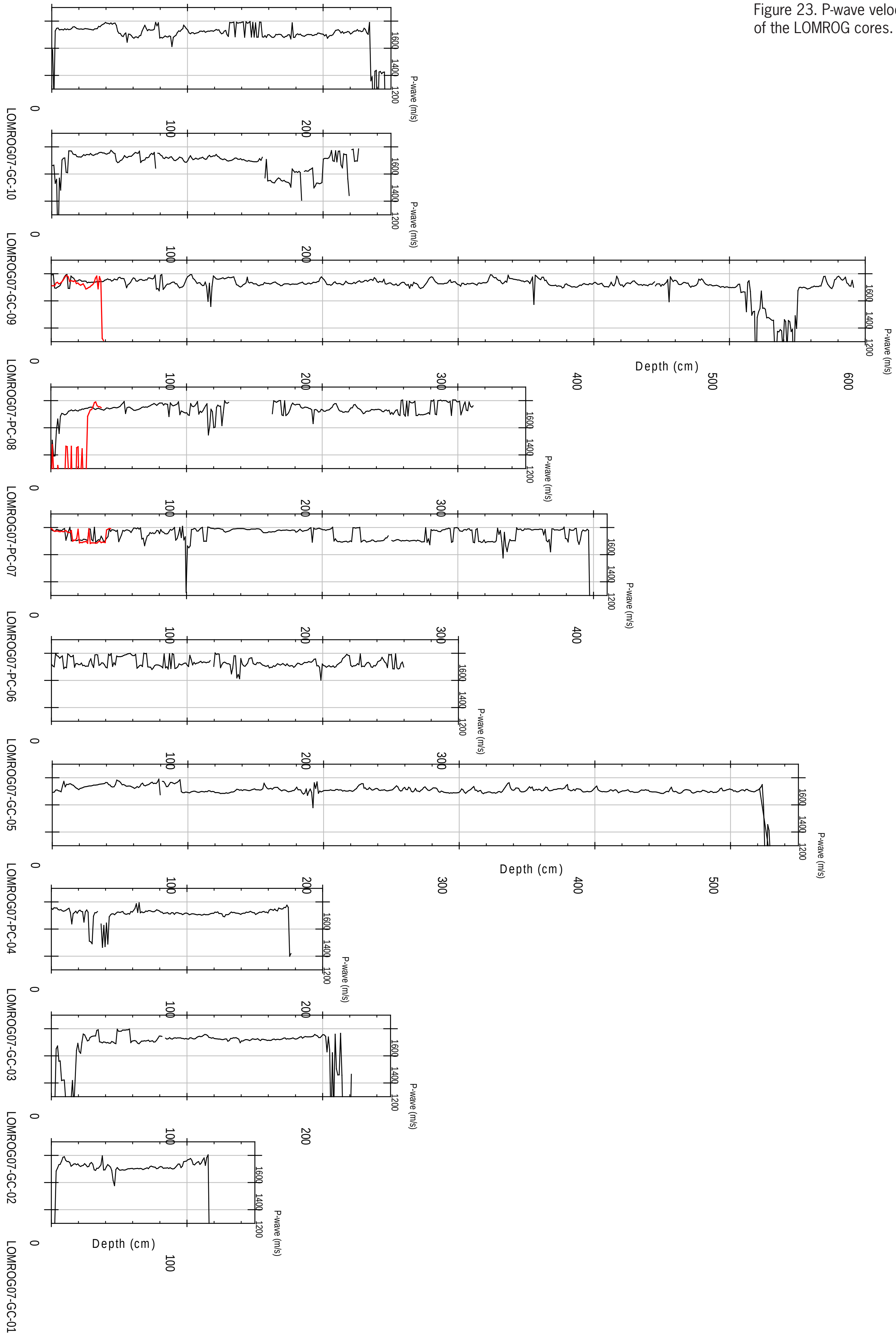
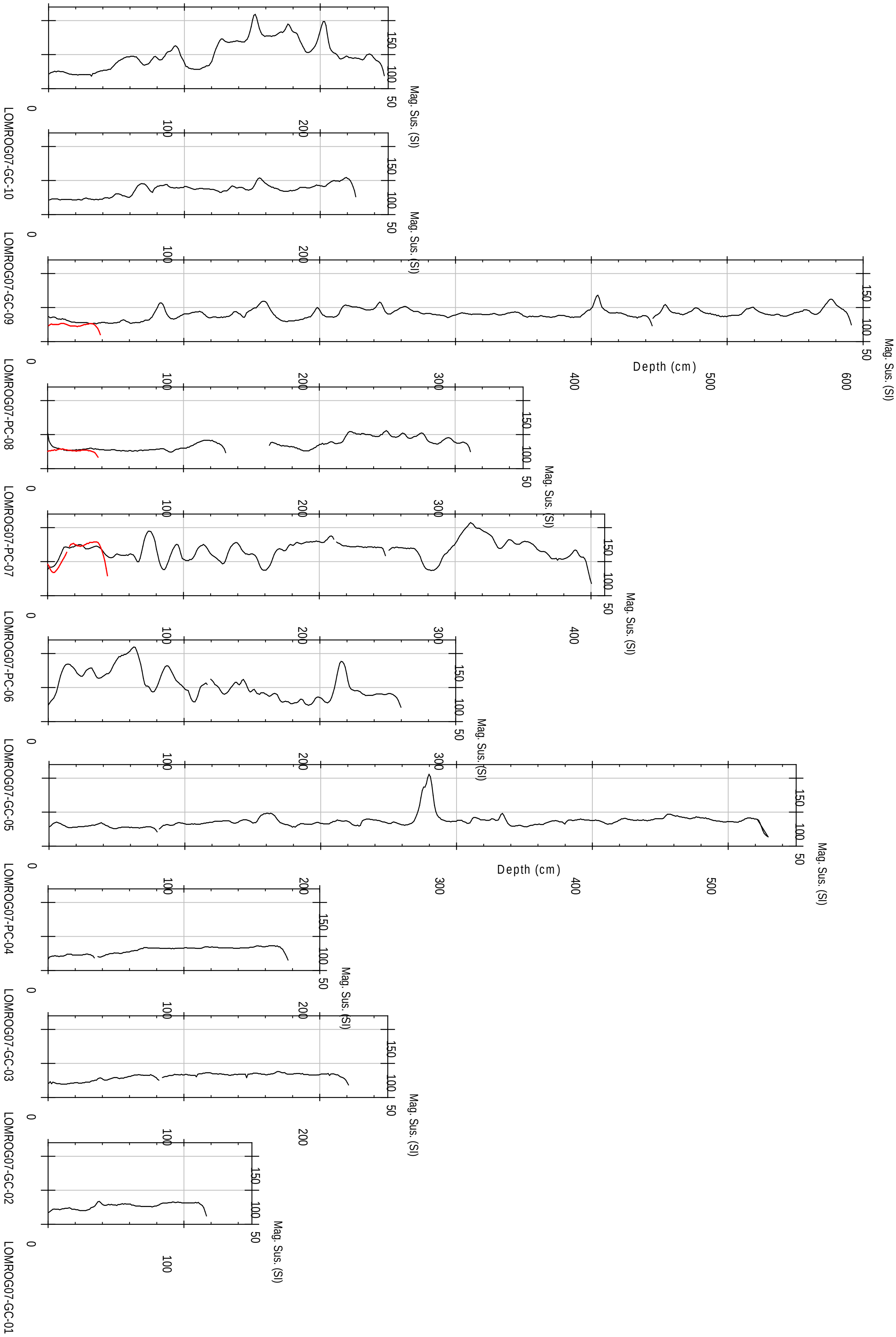



Figure 23. P-wave velocity of the LOMROG cores.

Figure 24. Magnetic susceptibility velocity of the LOMROG cores.



### *Lithology*

Described sediments are mostly composed of silty to slightly sandy muds with variable amounts of IRD, scattered or concentrated in layers, and lenses/layers of sandy muds or muddy sands. Appendix I shows the lithology of all cores. The size of IRD is mostly on a scale of millimeters to a few centimeters, but in some cases reaches >10 cm. The colors of sediment are predominantly in the brown hues (10YR, sometime 7.5YR or 2.5Y). Interlamination of brown to dark brown with lighter colored yellowish (grayish, olive) brown sedimentary intervals on decimeter to centimeter scale is characteristic for the LOMROG cores as elsewhere in the central Arctic Ocean. Sediments are typically bioturbated to some extent, resulting in characteristic sediment mottling. Dark aggregates of Fe-Mn micronodules occur at certain stratigraphic levels. On some occasions, notably on the Morris Jessup Rise, layers of concentrated calcareous biogenic debris occur such as bryozoans, sponge spicules, and other types of attached benthic fauna.

### *Dirty sea ice*

All observations of dirty ice from the bridge or from helicopter are listed in Table 11 and the sampled locations are plotted in Figure 25. The first five sample sites were collected using the helicopter. D. Darby collected the first four samples, helicopter pilot, G. Akse, collected samples at the next site and M. Jakobsson collected the sixth sample from a broken ice slab alongside Oden using the aft crane and personnel cage. Assisting in sampling were G. Akse (sites LOMROG07-DICE-01 & 2), K. Gårdfeldt (site 3), D. Hanslik (site 4), and C. Sjö (site 5). Assisting D. Darby at the two icebergs were M. Jakobsson, G. Akse, and A. Karlqvist. The approximate volume of mud collected at each site is listed in Table 13.

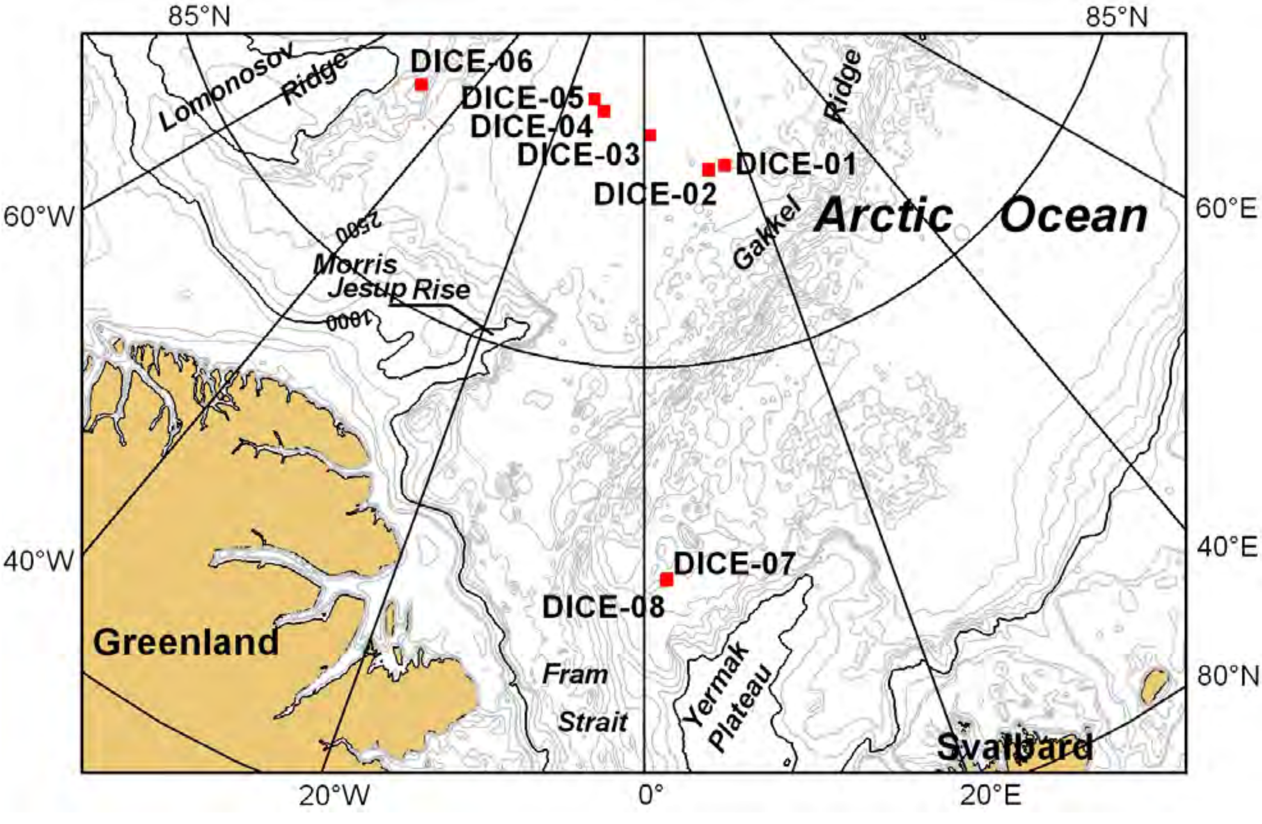



Figure 25. Locations of dirty ice samples.

Table 11. Observations of encounters with dirty ice and samples collected (shaded gray).

| Date | Time (UTC) | Latitude | Longitude | Distance from last observation (Km) | Avg. NH/Hr | Comments |
|---|---|---|---|---|---|---|
| 8/16/2007 | 6:00 | 82° 9.64' | 9° 52.22'E | | | First dirty ice since entering ice pack |
| 8/17/2007 | 10:00 | 82° 15.76' | 9° 47.87'E | 6.13 | 1.53 | Continuous patches for 2 hours |
| 8/17/2007 | 7:00 | 83° 03' | 9° 34.0'E | 47.27 | 5.25 | 1-1.5m ice thickness |
| 8/18/2007 | 0:10 | 84° 16.9' | 10° 24.8'E | 74.11 | 14.34 | |
| 8/18/2007 | 2:00 | 84° 31.8' | 10° 39.7'E | 14.97 | 8.15 | |
| 8/18/2007 | 6:15 | 85° 13.0' | 10° 57.7'E | 41.25 | 9.71 | |
| 8/18/2007 | 7:41 | 85° 28.3' | 11° 23.7'E | 15.43 | 10.76 | Start of large discontinuous patchy dirty ice |
| 8/18/2007 | 7:45 | 85° 27.5' | 11° 22.9'E | 0.81 | 12.04 | End of dirty ice patch-one floe is 170mX80m; Mostly 1 m thick ice with occasional 2m; patchy but ever present algae |
| 8/18/2007 | 9:45 | 85° 48.0' | 11° 30.7'E | 20.51 | 10.26 | |
| 8/18/2007 | 10:05 | 85° 50.232' | 11° 20.17'E | 2.36 | 7.87 | |
| 8/18/2007 | 11:00 | 85° 58.823' | 16° 0.716'E | near TARA | | LOMROG-07-DICE-1; small floe with mud pellets dispersed in ice |
| 8/18/2007 | 11:20 | 85° 58.403' | 12° 41.503'E | near TARA | | LOMROG-07-DICE-2; Concentration of mud in cryogenic holes/old melt pond |
| 8/18/2007 | 12:25 | 86° 0.02' | 11° 25.39'E | 9.80 | 4.20 | Small patches of low conc. Dirty ice for last 2.5 hours |
| 8/18/2007 | 12:58 | 86° 3.8' | 11° 19.3'E | 3.78 | 7.14 | Mostly first year ice <1m (0.8-1.4m), very small patches of dirty ice; By 15:00 Hr more multi-yr ice still mostly 1st yr. |
| 8/19/2007 | 6:06 | 87° 6.7' | 7° 39.1'E | 64.24 | 3.78 | |
| 8/19/2007 | 6:28 | 87° 7.7' | 7° 19.8'E | 1.39 | 3.76 | |
| 8/19/2007 | 8:31 | 87° 0.09' | 6° 52.9'E | 7.73 | 3.76 | Highly concentrated dirty ice |
| 8/19/2007 | 13:35 | 87° 23.8' | 1° 24.0'E | 28.63 | 5.73 | Nearly continuous patches until 20:00 |
| 8/19/2007 | 14:30 | 87° 24.385' | 1° 6.674'E | | | LOMROG-07-DICE-3A&B+ziplock bag at 3B; 10 m apart; part of extensive swath of dirty ice |
| 8/19/2007 | 20:00 | 87° 10.0' | 6° 32.7'W | 26.45 | 4.07 | Exited heavy concentration of patchy dirty ice |
| 8/19/2007 | 23:40 | 87° 36.2' | 6° 7.3'W | 26.19 | 7.14 | |
| 8/20/2007 | 9:30 | 87° 33.43' | 7° 3.085'W | 3.62 | | First coring station |
| 8/20/2007 | 10:30 | 87° 33.9' | 7° 45.1'W | 1.85 | 1.85 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 8/20/2007 | 13:35:00 AM | 87° 37.2’ | 9° 0.8’W | 4.58 | 1.53 | |
| 8/20/2007 | 13:35:00 AM | 87° 37.2’ | 9° 0.8’W | | | LOMROG-07-DICE-4A, B, C, D/E; very large floe of dirty ice (>0.5km), +many small floes nearby; Bryozoans, mollusks (large clam 2cm), & seaweed. |
| 8/21/2007 | 5:30 | 87° 44.4’ | 12°30’W | 11.11 | | Very concentrated dirty ice until next entry; stopped for engine leak |
| 8/21/2007 | 5:55 | 87° 44.2’ | 12°47’W | 0.69 | | |
| 8/21/2007 | 8:20 | 87° 43.9’ | 13°9.08’W | 1.53 | 0.67 | |
| 8/21/2007 | 11:30 | 87° 43.33’ | 13° 4.3’W | 2.27 | 0.76 | Still lots of dirty ice around; stopped to reassemble engine |
| 8/21/2007 | 14:55 | 87° 43.3’ | 13° 7.6W | | | LOMROG-07-DICE-5A&B; A: scattered mud in ice; B: conc. on surface about 2-3cm thick; pressure ridge |
| 8/22/2007 | 3:05 | 87° 11.63’ | 26° 34.7’W | 47.71 | | |
| 8/22/2007 | 8:15 | 87° 8.48’ | 32° 54.22’W | 63.07 | 12.13 | Light snow might be hiding more dirty ice; lots of algae in wake |
| 8/22/2007 | 14:15:00 AM | 87°55.2’ | 38° 36.0’W | 53.10 | 8.85 | |
| 8/23/2007 | 4:10 | 86°55.8’ | 47° 19.1’W | 46.34 | 3.31 | |
| 8/23/2007 | 7:00 | 86° 53.75’ | 48° 12.3’W | 66.54 | | LOMROG-07-DICE-6; collected by M. Jakobsson in crane age along side starboard aft. |
| 8/23/2007 | 15:40 | 86°50.6’ | 51° 10.0’W | 13.58 | 1.57 | |
| 8/23/2007 | 16:50 | 86°51.31’ | 52° 48.4’W | 15.24 | 13.03 | Small patches of low conc. Dirty ice; extensive pressure ridges |
| 8/24/2007 | 3:00 | 86° 40.6’ | 54° 14.4’W | 5.46 | 4.66 | |
| 8/24/2007 | 13:00:00 AM | 86° 38.718’ | 54° 30.17’W | 12.62 | 1.26 | Very dark small patch |
| 8/24/2007 | 15:00 | 86° 40.8’ | 54° 12.2’W | 11.51 | 5.76 | |
| 8/25/2007 | 1:00 | 86° 31.4’ | 53° 2.1’W | 7.58 | 3.79 | |
| 8/25/2007 | 9:30 | 86° 11.94’ | 52° 46.46’W | 29.34 | 3.45 | No dirty ice, extensive ridging; 1.5-3m ice |
| 8/28/2007 | 13:50 | 85° 29.2 | 44° 28.8 | 71.55 | 8.42 | Spotted during helicopter reconnaissance |
| 8/28/2007 | 13:56 | 85° 29.7 | 44° 12.8 | 56.17 | 6.61 | Spotted during helicopter reconnaissance |
| 8/28/2007 | 13:57 | 85° 28.4 | 43° 24.2 | 5.16 | 0.61 | Spotted during helicopter reconnaissance |
| 8/30/2007 | 14:00 | 86° 7.1 | 30° 53.1 | 69.16 | 8.14 | |
| | | | | | | |
| | | | Avg. Distance | 24.77 | 5.88 | |
| | | | Std. Dev. | 24.22 | 3.85 | |

Table 12. Iceberg observations and sampling.

| Date | Time (UTC) | Latitude | Longitude | Distance from last observation (Km) | Comments |
|---|---|---|---|---|---|
| 9/7/2007 | 13:30 | 84° 2.7 | 0° 22.5W | | Small bergs <7m high, <50m long |
| 9/8/2007 | 17:00 | 83° 22.0 | 0° 20.2E | 40.68 | Moderate size berg with visible sediment some over 1 km in length (visual estimate from ship >5 NM away) |
| 9/8/2007 | 21:45 | 83° 16.8 | 0° 41.0E | 5.75 | 10-20 small bergs within 5nm |
| 9/9/2007 | 20:30 | 82° 48.97 | 1°52.946E | 29.17 | LOMROG-07-DICE-7 iceberg 0.5km long by 30 m high surface pellets from last summers melt. |
| 9/9/2007 | 20:45 | 82° 47.916 | 1° 47.883E | 1.22 | LOMROG-07-DICE-8 iceberg 0.2km long by 11 m high surface pellets from last summers melt |

Table 13. Visually estimated volume of mud collected at each site.

| Approx. volume of each sampled dirty ice floe | | | | | | |
|---|---|---|---|---|---|---|
| | Visually Estimated Mud | | Replicates | | | |
| Sample Number | Volume (cc) | | Volume (cc) | | | |
| LOMROG-07-DICE-1 | 6 | | | | | |
| LOMROG-07-DICE-2 | 20 | | | | | |
| LOMROG-07-DICE-3 | 9 | | | | | |
| LOMROG-07-DICE-4 | 1,100 | | A=~20 | B=~10 | C=~15 | D&E=~1,000 |
| LOMROG-07-DICE-5 | 1,350 | | A=~150 | B=~1,200 | | |
| LOMROG-07-DICE-6 | 2 | | | | | |
| LOMROG-07-DICE-7 | 3 | | | | | |
| LOMROG-07-DICE-8 | 3 | | | | | |

### *CTD and water sampling*

The locations of all CTD and water sampling stations are shown in Figure 26. The observations at the Amundsen Basin slope of the Lomonosov Ridge (Stn 4, 9 and 10) show a clear signal of Canadian Basin Deep Water (CBDW) at around 2000 m with similar characteristics to a station (Stn. 41) in the vicinity of the 1870 m deep channel in the central Lomonosov Ridge at about 88° 25'N, 150°E found during the Beringian/Hotrax 2005 expedition (Björk et al., 2007) (see also Figure 27 for some selected station data). A vertically broad CBDW signal was also clearly visible at the flanks of the Morris Jessup plateau (Stn. 12, 17, 18 and 19).

A more vertically narrow and weaker signal was observed over the western Amundsen Basin (Stn. 3, 21-25). The observations during LOMROG infer that the major inflow of CBDW to the Amundsen Basin indeed occurs at the central Lomonosov Ridge channel and that the flow continues along the slope of the ridge towards Greenland. The further circulation follows the Greenland continental slope towards southeast to the Morris Jessup plateau where eventually some of the flow leaves the continental slope, becomes interleaved, and can be identified as a weak salinity maximum over the central Amundsen Basin.

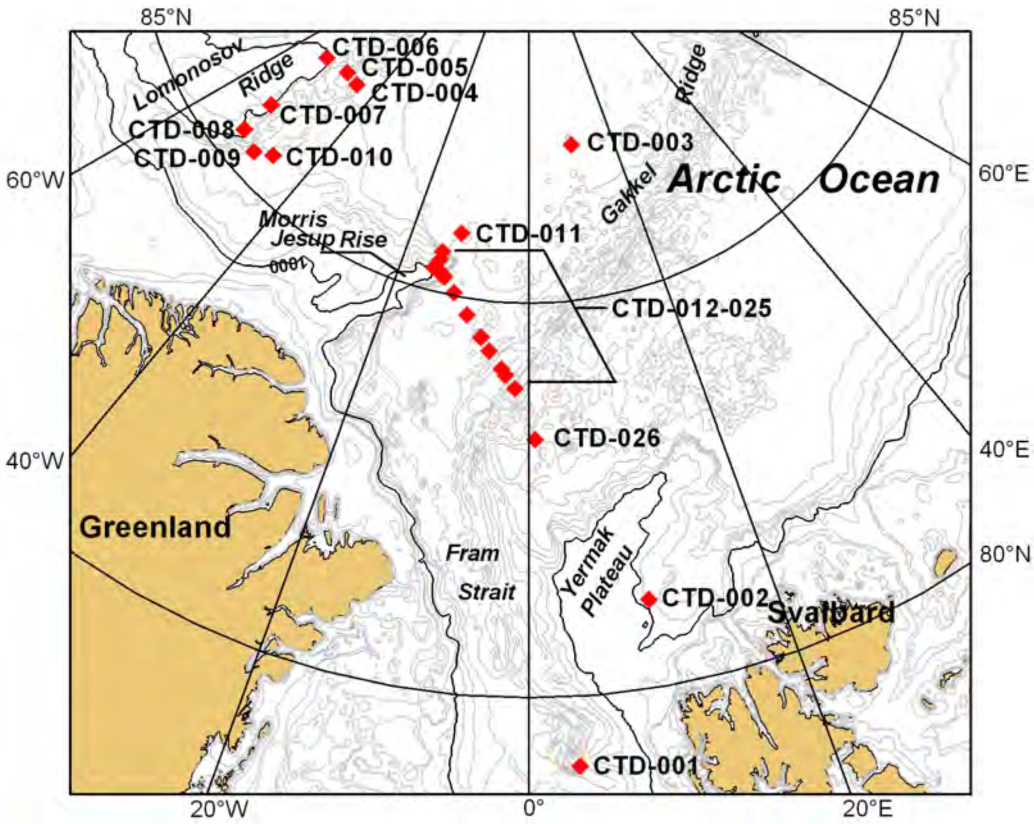



Figure 26. CTD and water sampling stations.

## *Reflection Seismic*

After passing Svalbard on August 15th a deployment test was performed with the seismic equipment while we were still in relatively ice-free waters. The deployment of the streamer and guns went very well, but we had some trouble getting the umbilical sheave into its position in the frame. A first attempt was performed with only 10 m tow length of the umbilical cable and the guns immediately behind the vessel. Increasing the tow length of the umbilical cable to 40 m was, however, enough to pull the sheave into the right angle and get it into the frame.

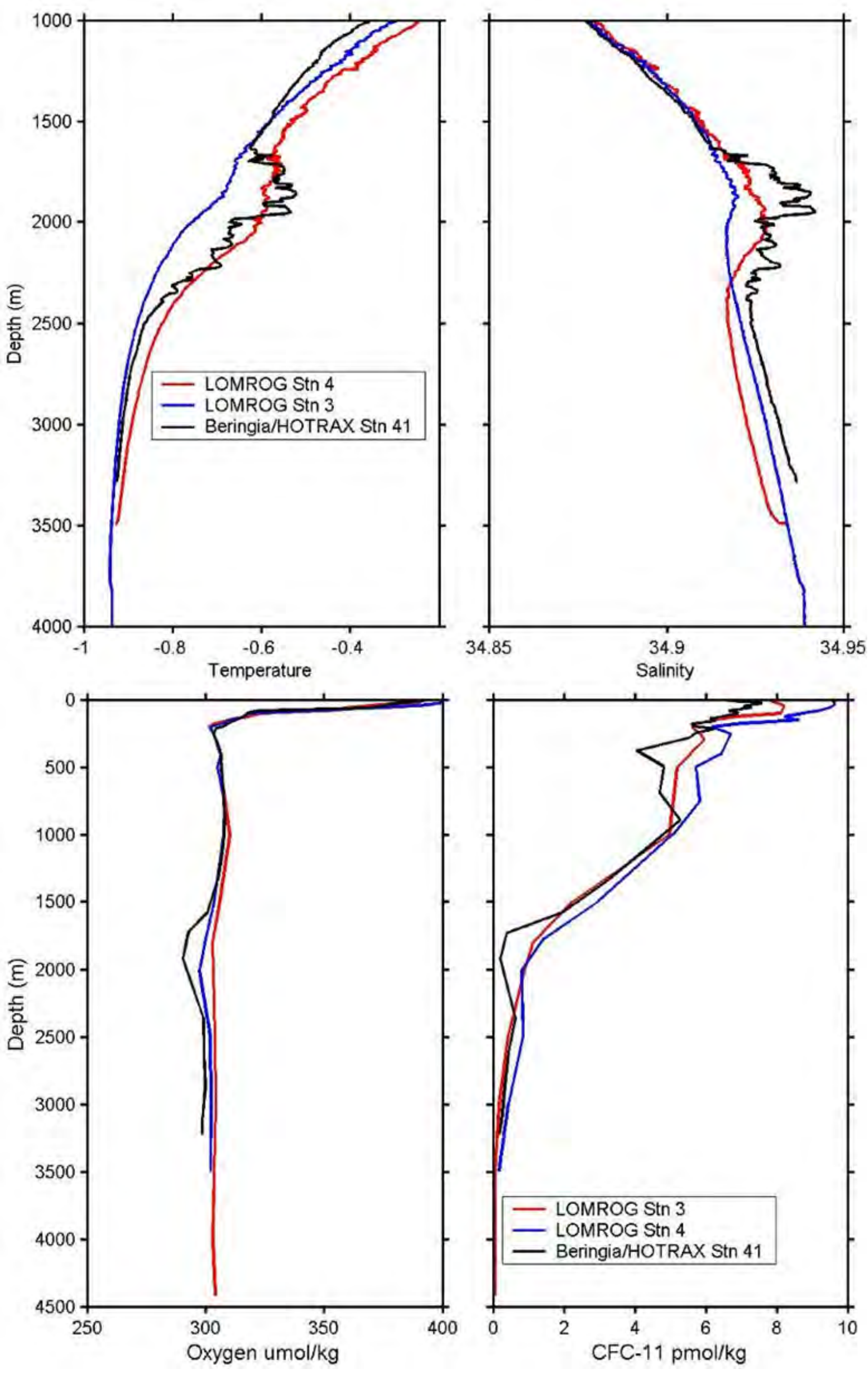
After deployment, a successful function test of the complete seismic acquisition system was carried out firing the guns at low pressure. The observed tow-depth of the guns at a survey speed around 4 knots was more or less as expected/planned in approx. 20 m. The tow-depth of particularly the far sections of the streamer was somewhat deeper, i.e. from 30-40 m, while the front sections were more or less located in approx. 20 m as expected/planned. It was therefore decided to balance streamer section 3-6 with additional silicone oil. Also all “loose parts” on the airgun array were checked and tightened and secured as necessary.

During survey a line overview log has been maintained. Below is a short description of the essential actions during the reflection seismic survey. In Table 14 a summary of the line overview log is given.

Line Lomrog07_01

The reflection seismic data acquisition was started on line Lomrog07_01 on August 19th around 01:30. We found an area were Oden following 50 Let Pobedy was able to create 100-200 m

Figure 27. Temperature and salinity data showing the structure of the CBDW signal seen as a temperature and salinity maximum at around 2000 m depth. The CBDW water is also less ventilated ("older") which is seen in the oxygen and CFC-11 signals. The Beringia/Hotrax station 41 station is from the central Lomonosov Ridge, LOMROG Stn 4 is further towards Greenland at the Amundsen Basin flank of the ridge, and LOMROG Stn 3 is from the central Amundsen Basin.




open water behind the ship providing reasonable conditions for deploying the seismic equipment. Launching the streamer and umbilical went fine, but similar to the function test we had problems getting the umbilical sheave into the frame, even with 40 m tow-length of the umbilical. Low vessel speed may have caused reduced pull from the airguns in the water and thereby not helping getting the sheave in the right angle. It took some work

Photos 33-34. Mounting the umbilical sheave in the frame and concentrated winch operator.

with the wires in and out on the winch and the A-frame to get the sheave in place (Photos 33-34).

The general ice conditions were far from favorable with relatively thick ice and large areas with pressure ridges. After only 6 km of data acquisition 50 let Pobedy was stuck in the ice for a few minutes. It could be observed on the depth transducer readings from both airguns and streamer that they were sinking in the water column. It also appeared, however, that both airguns and streamer was in relatively safe conditions being washed away from the vessel by the propellers. During the following 24 hours, the umbilical was caught a number of times by large blocks of ice coming into the wash of the ship, causing or nearly causing the guns (and a few times also the streamer) to be lifted out of the water. Furthermore Oden was stuck in the ice several times. When Oden was stuck 50 let Pobedy usually made a large turn and sailed along our port side to break the ice around Oden (Photos 35-36). At around 01:30 on August 20th Oden

Photos 35-36. 50 let Pobedy sailing along Oden to break the ice and 50 let Pobedy sailing backwards to "pick up Oden".

experienced problems with a main engine and as the ice conditions were very difficult it was decided to make a stop for maintenance also leaving 50 let Pobedy time for regularly maintenance. The seismic equipment was recovered and the airguns needed repair of a near field hydrophone and a hose collector-box, while the streamer was in good shape.

During the past 24 hours data acquisition had been terminated three times and restarted on line Lomrog07_01A, Lomrog07_Per and Lomrog07_01E, respectively. First time it was because of loosing the gun trigger signal, next because of breakdown caused by attempt to change record length on the fly, and thirdly because of GeoEel software problems, see also Summary of line overview log in Table 14 below.

Line Lomrog07_02
After some hours Oden finished repairing the engine for the time being and we steamed westwards for about 9 km trying to find better ice conditions. At around 13:00 on August 20th we deployed the seismic equipment again for recording line Lomrog07_02. Because of the ice conditions the ice-free water behind Oden was very limited. Based on the experience from the times we had been stuck in the ice, we decided to launch the equipment while lying still and keeping the nose up against the ice and using the wash from the propeller to push the streamer and the guns backwards away from Oden (Photos 37-38). This worked very well and the only problems were once again getting the sheave into its position in the frame. Also this time it took some work with the wires in and out on the winch and the A-frame to get the sheave in place.

In the following 12 hours the umbilical was again often caught by large blocks of ice causing or nearly causing the guns to be lifted out of the water and Oden was stuck in the ice many times. 50 let Pobedy sometimes turned and sailed along our port side and sometimes went backwards to "pick us up".
Around 01:00 on August 21st the streamer got caught in the ice and all communication to the streamer was lost. We recovered the equipment and the guns were intact, while only the stretch section and 1 out of 6 active streamer sections were recovered. A helicopter search was performed to try to find the remaining streamer sections, but without success. After the loss of the 5 streamer sections it was decided to move towards southwest to the area for the next seismic line and hope for more favorable ice conditions there.

Line Lomrog07_03
Around 16:00 on August 26th we started acquisition of line Lomrog07_03. The equipment was deployed lying still in the ice using the wash from the propeller to push the streamer and the guns backwards away from Oden. Getting the sheave into the frame was more successful this time using a robust handmade steel pipe as lever when tilting the sheave in the right angle (Photos 37-38). For the next 7 hours the umbilical was caught by large ice blocks very often and Oden was also stuck in the ice often. Around 23:00 we lost communication to the streamer again and recovered all the equipment. Both the guns and all streamer sections were recovered

Photos 37-38. Space of ice-free water available for deployment of equipment and mounting umbilical sheave in frame using handmade lever.

this time, but 2 live streamer sections were damaged. They had been caught in the ice and were both punctured and one had broken wires inside. The damaged sections were removed and 1 additional section mounted.

Around 01:00 on August 27th the equipment was deployed again while lying still, this time with 5 active sections. For the next 3 hours Oden was stuck in the ice most of the time and the umbilical were caught by large ice blocks 3 times. The third time communication to the streamer was lost and the equipment was recovered. However, only the airguns were brought onboard while the stretch section and 6 live sections had been lost. Parts of the streamer could be observed at two different places in the ice and several attempts were made from the helicopter to pull the streamer up from the ice (Photos 39-41). After trying for some time without success it was decided to let 50 let Pobedy try to break the ice around the streamer while the helicopter was pulling. After trying this for a while also unsuccessful it was decided to let 50 let Pobedy try a rescue operation on its own. They lowered a person down on the ice with the crane to tie a rope in the streamer. Then they moved slowly forward to break the ice around the streamer and tried to recover it while gliding back. By repeating this operation for some time they succeeded in recovering the stretch section, 2 live sections and 2 A/D converters. The equipment was however heavily damaged and it will take thorough testing to verify which parts eventually can be used again.

Line Lomrog07_04

Later it was decided to acquire a seismic line in an area off Northeast Greenland and on September 12th we reached the starting point for line Lomrog07_04. Around 19:00 the equipment was deployed. Three new streamer sections had been supplemented with a repaired fourth section. Prior to deployment the streamer had been tested thoroughly on deck, but unfortunately had a failure after deployment. After recovery and some hours of fault-finding it turned out that the A/D converter on section 2 had to be replaced. Around 00:30 on September 13th we started acquisition of line Lomrog07_04 in ice-free waters.


Photos 39-41. On top, attempt to recover lost streamer sections with helicopter and by a combination of 50 let Pobedy and helicopter. To the right 50 let Pobedy streamer rescue operation.

During the acquisition we entered into ice filled waters (8/10), but nothing causing problems for Oden or the seismic equipment. Data acquisition was, however, during the following 24 hours terminated two times and subsequently restarted on lines Lomrog07_04A and _04B, respectively. First because of a broken air hose in the airgun array and secondly because of an unrecoverable fault in streamer section 4 which was then removed. Around 01:15 on September 14th line Lomrog07_04B was terminated as planned at end of line (EOL).

### *Sonobuoy*

A total of 17 sonobuoys were deployed along the four reflection seismic lines (Figure 28 and Table 15). The hydrophone depth of the buoys was set to 30 m and after an operating life of eight hours; the buoys destroyed themselves and sank to the seafloor. The hydrophone signals of the buoys were radioed back to the ship, where the signals were received by a VHF base station antenna (model MD HB-G3/HS) that was connected to a sonobuoy receiving system (Winradio WR-2902e). The antenna was mounted on the railing above the bridge at a height of 25.3 m.
The signals from the receiver where recorded on the auxiliary channels of the reflection seismic acquisition system. This has the disadvantage that the recording length is tied to the one used for the reflection seismic data acquisition, which is not sufficient to record all relevant phases at larger shot-receiver distances. In order to be independent of this record length, sonobuoy data were also recorded continuously on a Taurus seismometer (manufactured by Nanometrics) starting with line 3.
Normally, sonobuoys are launched pneumatically or by cartridge-actuated devices. Such a launcher shoots the buoys some 100 m sideways of the

| Line | Record length (sec) | Duration (hours) | No. of shots | Shots per hour | No. of times being stuck in the ice have been reported and no. per hour | No. of times parts of the equipment is registered to be out of the water | No. of times mis-trigging because of survey speed have been reported |
|---|---|---|---|---|---|---|---|
| LOMROG07_01 | 11 | 4 | 497 | 124 | 5 / 1.3 | 2 | 2 |
| Comments | Guns not shooting on first c. 50 shots<br>Line terminated because of loosing trigger signal | | | | | | |
| LOMROG07_01A | 11 / 9 | 14.5 | 2823 | 195 | 9 / 0.6 | 2 | 2 |
| Comments | Shot 3233-3472 only 9 s record time<br>NaviPac resetting event numbers, after event 3329 comes event 137<br>Line terminated because of breakdown caused by new attempt to change record length on the fly | | | | | | |
| LOMROG07_Per | 9.5 | 0.25 | 48 | 192 | 0 / 0 | 1 | 0 |
| Comments | Problems with GeoEel software, testing old version of GeoEel software<br>Restarting shot numbers from 1<br>Line terminated because of problems also with old version of software | | | | | | |
| LOMROG07_01E | 9.5 | 4.5 | 466 | 104 | 6 /1.3 | 0 | 0 |
| Comments | Restarting system with the latest version of GeoEel software again<br>Resetting streamer modules at the end of the line<br>Line terminated because Oden need to perform engine maintenance | | | | | | |
| LOMROG07_02 | 9.5 | 12 | 904 | 75 | 16 / 1.3 | 2 | 2 |
| Comments | 1 hour break in shooting while 50 let Pobedy runs a “navigation route” in the ice<br>Line terminated due to loss of streamer | | | | | | |
| LOMROG07_03 | 8.5 | 7 | 631 | 90 | 10 / 1.4 | 12 | 0 |
| Comments | Line terminated due to failure of 2 streamer sections | | | | | | |
| LOMROG07_03A | 8.5 | 3 | 49 | 16 | Mostly stuck | 3 | 0 |
| Comments | Only 5 streamer sections, 44 channels<br>Line terminated due to loss of streamer | | | | | | |
| LOMROG07_04 | 9.5 | 16 | 5265 | 329 | 0 | 0 | 0 |
| Comments | Only 4 sections, 36 channels<br>Line terminated because of broken air hose in airgun array | | | | | | |
| LOMROG07_04A | 9.5 | 1.75 | 464 | 265 | 0 | 0 | 0 |
| Comments | Only 4 sections, 36 channels<br>Line terminated because of failure in last streamer section | | | | | | |
| LOMROG07_04B | 9.5 | 3.25 | 972 | 299 | 0 | 0 | 0 |
| Comments | Only 3 sections, 28 channels<br>Line terminated as planned at EOL | | | | | | |

Table 14. Summary of line overview log.

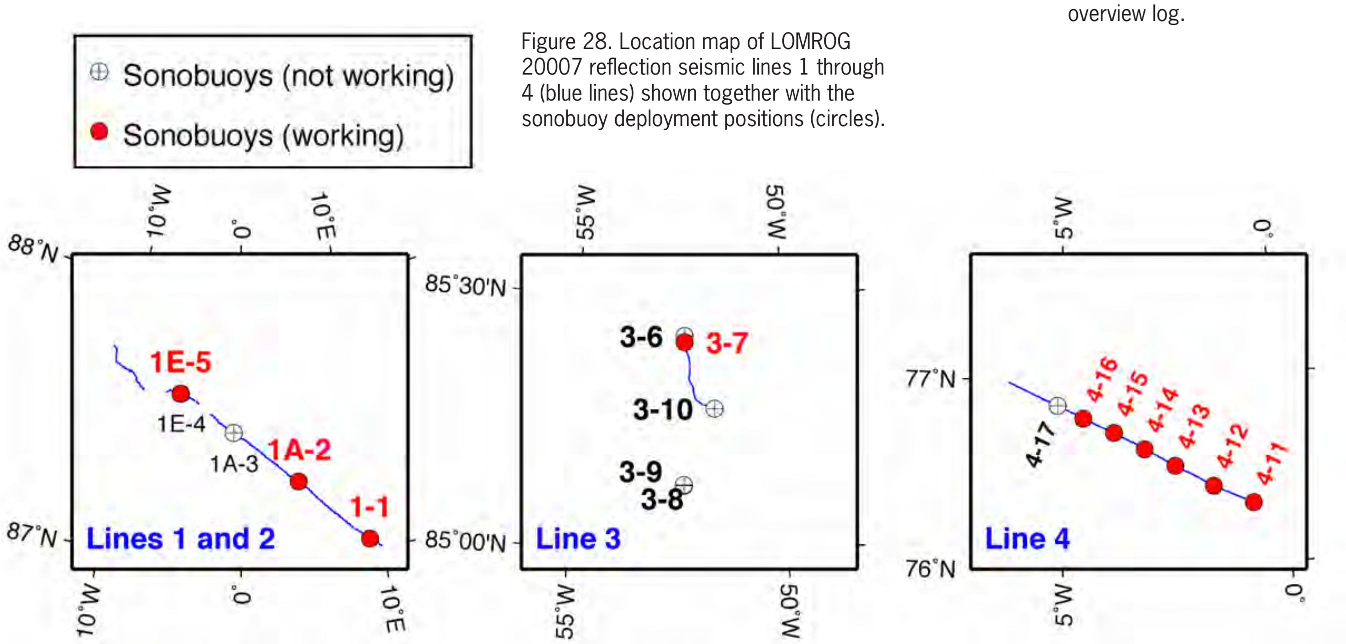



Figure 28. Location map of LOMROG 20007 reflection seismic lines 1 through 4 (blue lines) shown together with the sonobuoy deployment positions (circles).

Table 15. Sonobuoy deployment times and positions.

| Station | Date and Time | (UTC) | Longitude | Latitude | Remarks |
|---|---|---|---|---|---|
| 1-1 | 19 AUG 2007 | 03:05 | 9°12.238'E | 87°02.197'N | |
| 1A-2 | 19 AUG 2007 | 10:14 | 4°26.768'E | 87°16.524'N | |
| 1A-3 | 19 AUG 2007 | 16:05 | 0°33.889'W | 87°27.698'N | No signal. |
| 1E-4 | 19 AUG 2007 | 22:12 | 5°13.885'W | 87°35.720'N | Did not surface. |
| 1E-5 | 19 AUG 2007 | 22:31 | 5°17.261'W | 87°35.671'N | |
| 3-6 | 26 AUG 2007 | 15:40 | 52°23.150'W | 85°25.267'N | Did not surface. |
| 3-7 | 26 AUG 2007 | 16:04 | 52°23.100'W | 85°24.492'N | |
| 3-8 | 26 AUG 2007 | 20:52 | 52°22.704'W | 85°07.615'N | Deployed by helicopter. Did not surface. |
| 3-9 | 26 AUG 2007 | 20:59 | 52°22.592'W | 85°07.666'N | Deployed by helicopter. Did not surface. |
| 3-10 | 27 AUG 2007 | 00:51 | 51°39.500'W | 85°16.690'N | Did not surface. |
| 4-11 | 13 SEPT 2007 | 01:00 | 0°44.382'W | 76°19.406'N | Ice-free water. |
| 4-12 | 13 SEPT 2007 | 04:02 | 1°36.447'W | 76°25.442'N | Ice-free water. |
| 4-13 | 13 SEPT 2007 | 07:08 | 2°27.170'W | 76°32.380'N | Ice-free water. |
| 4-14 | 13 SEPT 2007 | 09:38 | 3°08.113'W | 76°37.972'N | Ice-free water. |
| 4-15 | 13 SEPT 2007 | 12:11 | 3°49.806'W | 76°43.276'N | Ice-free water. |
| 4-16 | 13 SEPT 2007 | 14:34 | 4°31.300'W | 76°48.100'N | Light ice. |
| 4-17 | 13 SEPT 2007 | 18:47 | 5°07.352'W | 76°52.017'N | Did not surface. 3/10 to 5/10 ice. |

ship in order to avoid entanglement of the buoy with the seismic gear towed behind the ship. However, this deployment procedure could not be followed due to the dense ice around the ship. For lines 1 through 3, the only available ice-free area was behind the ship, where the wash from the propellers kept a 50 to 100 m long channel open before the ice was closing again. Hence, the sonobuoys were deployed from the lowermost afterdeck of the ship (Photo 42). Deployment from the afterdeck had a high failure rate in 10 tenths ice cover (55 %). On portions of line 4 with no ice cover, buoys were thrown into the water from the port side of the afterdeck.

The main reason for the failure of the sonobuoys was probably that the ice closed behind the ship in the minute it takes for the sonobuoy to descend to the operating depth of 30 m and to resurface afterwards. Heavy wash from the ship's propellers may accelerate the movement of the sonobuoy away from the ship and under the ice. Even when the buoy surfaces again, it will still be in the area where individual ice blocks are exposed to substantial movements before the wash and ice eventually calm down some 200 m behind the ship. During this phase, the sonobuoy is exposed to the risk of being crushed in the ice. In addition, water temperatures between –2°C and –1°C may have contributed to some failures, since the manufacturer specifies the operating temperature to be between 0°C and 35°C.

On line 3, two sonobuoys were deployed by helicopter some 20 km ahead of the ship in an open water pool. This was done in an effort to reduce the failure rate and to increase the range of the radio signals from the sonobuoys by avoiding tilted ice blocks that can shield the transmission of the signals. The helicopter was flying at the centre of the 200-m-wide pool at an altitude of 5 m and the sonobuoys were dropped in the water through the rear door. Prior to deployment, the parachute of the sonobuoy was removed because the pilots did not feel comfortable with it and were concerned that the rotor blades might catch the parachute. Both sonobuoys did not surface after deployment.

Photo 42. Sonobuoy deployment from the afterdeck of the Oden.

Out of the 17 sonobuoy deployments, ten instruments transmitted useful data back to the ship. The range of the VHF signals of the sonobuoys is determined by the line of sight. For the given antenna height, the maximum range is 21 km in calm seas. This maximum range was not obtained for all sonobuoys and in particular in heavy ice the range was as little as 4 km. The reduced range is attributed to ice that is obstructing the line of sight; in particular if the sonobuoy is hidden beneath an ice block. In addition, it is also possible that the loss of the radio signal is related to the premature end of the lifetime of the buoy. This means essentially that the ice damaged either the hydrophone or the entire buoy.

One of the fundamental problems of using sonobuoys is that they are free to drift with the prevailing ocean currents. For the proper analysis of the data, the exact distance between the sonobuoy and individual airgun shots has to be determined. In order to calculate the distance from the known shot position to the unknown sonobuoy position, the traveltime of the direct wave (Fig. 29) can be used if the velocity structure in the water column is known. During the LOMROG experiment, CTD measurements were carried out by the shipboard's oceanographers from which velocity-depth profiles were calculated. For the sonobuoy drift correction, the closest water velocity measurement was used.

Initial data processing and modeling was carried out on the vessel. It was possible to obtain velocity models of the sedimentary column for all stations, even for sonobuoys with a reduced range. These velocity models will guide the final processing of the reflection seismic data and will help to convert the sediment thickness from two-way traveltime to depth, as required to make a claim to extend the continental shelf under the United Nations Convention on the Law of the Sea (UNCLOS).

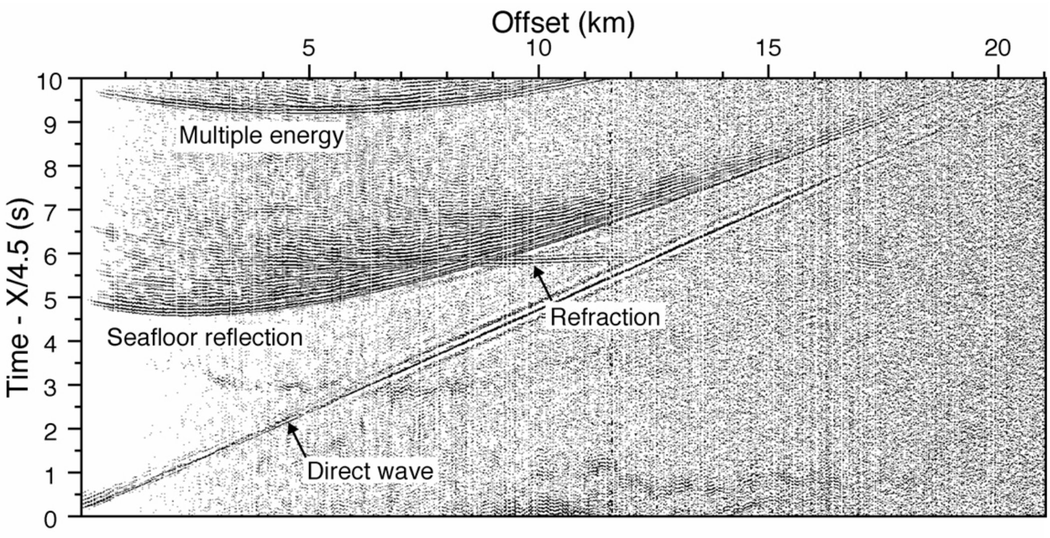



Figure 29. Example of a sonobuoy record section from the LOMROG experiment. Horizontal scale is the distance between the sonobuoy and the airgun shot; vertical scale is the traveltime displayed with a reduction velocity of 4.5 km/s. Data are bandpass-filtered from 5 to 24 Hz and a correction for the drift of the sonobuoy is applied.

Figure 29 shows an example of a sonobuoy record from the LOMROG experiment. The direct wave and the seafloor reflection can be easily correlated up to offsets of 20 km. Later reflections can be seen between 5 and 7 s reduced traveltime and these phases can be used to determine the velocities within the sediments. In addition, at offsets >9 km, some refracted seismic energy can be recognized up to offsets of 18 km, where the signal becomes too weak to be recognized in the noise. These refractions provide additional information on the velocity structure of the underlying basement. Although not strictly necessary for the main objective of the seismic program, the extra information about the crustal structure can help to interpret the reflection seismic data in a broader context. In experiments with an interest in the crustal structure, the usage of a different seismic source is recommended. The source should be more low-frequent than the present G-GI gun cluster. For an initial test, it might be worthwhile to use a single gun with a volume of around 600 cubic inches, compared to the maximum chamber size of 250 cubic inches in the G-GI gun cluster. This could be a reasonable compromise between the resolution requirements of the reflection seismic data and the need for slightly larger ranges in the refraction/sonobuoy part of the experiment.

### *Gravity measurements*

Marine gravity measurements were done during the entire cruise. The track plot of the cruise is shown in Figure 30 along with gravity anomalies from the Arctic Gravity Project, an ongoing international effort to combine all available airborne, surface, submarine and satellite gravity data. Gravimeter data were collected at 10 sec interval, and processed using the DNSC marine software “eotvos”, which incorporates Eötvös corrections from the ship GPS navigation (logged at 5 sec), outlier and spike detection, and a zero-phase filtering scheme. Some minor data gaps occurred at a small part of the cruise due to some serial communications problems, but most were sufficiently short (few min) to allow interpolation. The only major data loss was a 1 hr segment south of the Gakkel Ridge (site B, cf. Fig. 31), giving a data gap of approx 20 km.

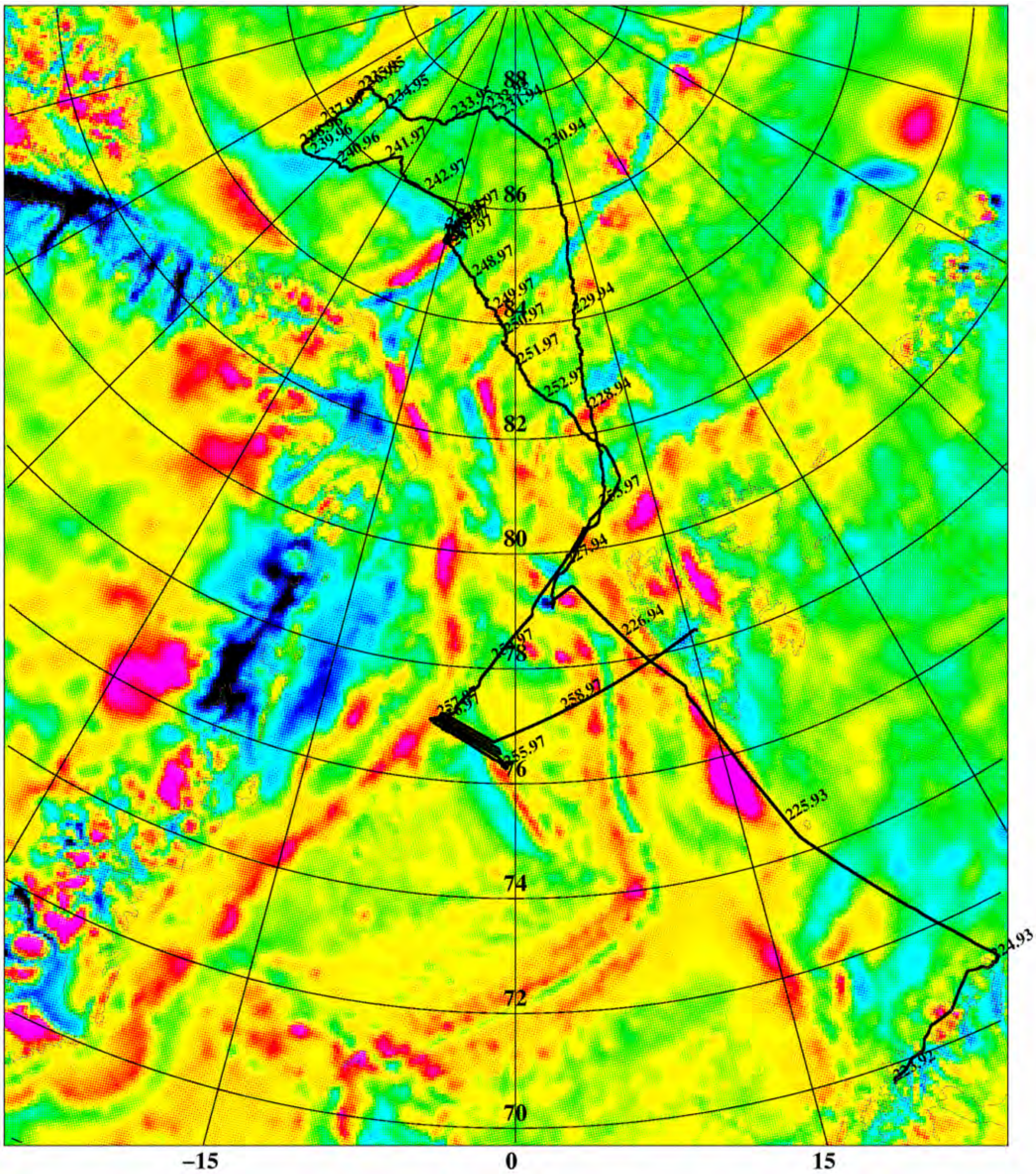
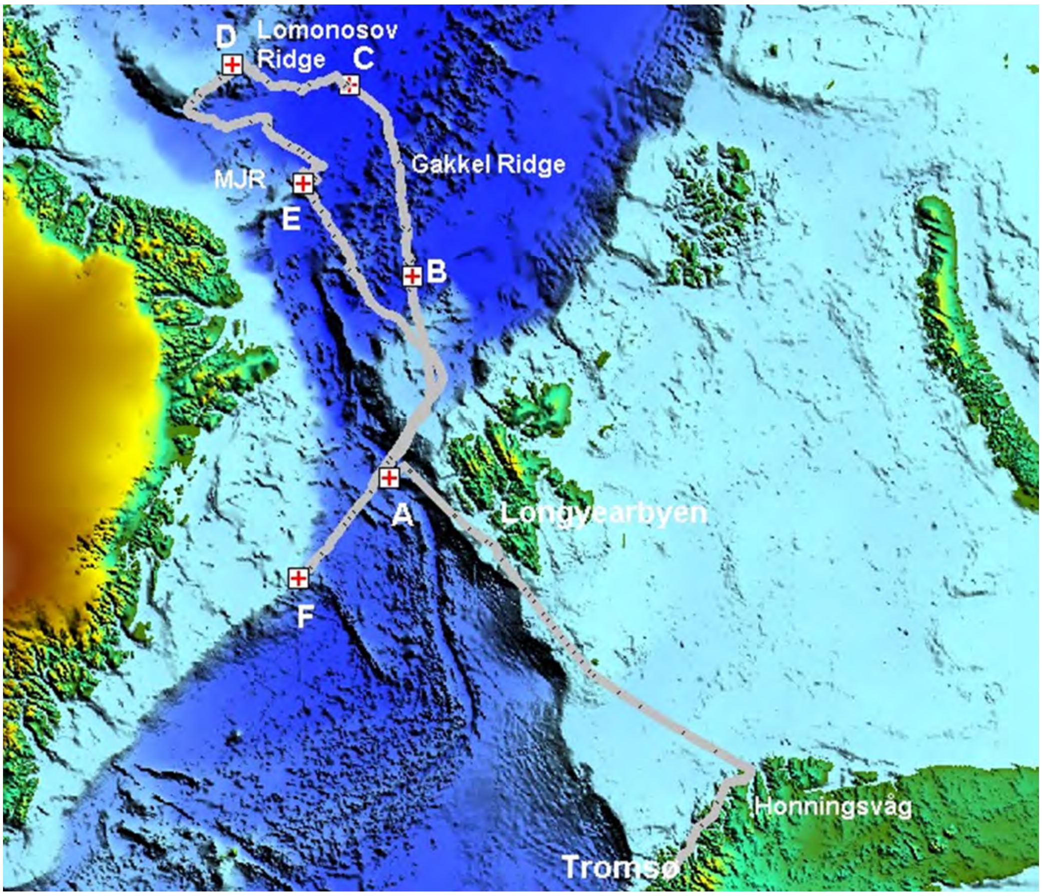



Figure 30. Marine gravity of the LOMROG cruise, status Sep 15. Numbers along track are Julian Day epochs. Background plot are gravity anomalies (mgal) of the Arctic Gravity Project (version Jan 2006, NGA/DNSC). Due to the irregular movements in the ice, with frequent stops and a very irregular track path, gravity data collected in the ice was somewhat noisier than data collected in open water. A filtering of 7x60 sec (RC) was used in the ice, opposed to the conventional 5x60 sec for marine gravity, corresponding to a resolution around 1 km for most of the cruise. Estimated errors of the free-air gravity anomalies are around 1 mgal. Drift of the S38 during the 5-week cruise was only 0.1 mGal, which is an extremely low number. Data were processed in "legs", using CTD or coring stops to download and reset the gravimeter. The legs are shown in Figure 4 and Table 2.

| Leg # | Data start | | Data stop | | Comments |
|---|---|---|---|---|---|
| | Date - JD | UTC | Date - JD | UTC | |
| 1: Tromsø – A (Malloy Deep) | 11/8 - 223 | 2054 | 15/8 - 227 | 0805 | Marine filtering |
| 2: A – B (Nansen Basin) | 15/8 - 227 | 0908 | 17/8 - 229 | 1743 | Ice filtering |
| 3: B – C (Amundsen Basin) | 17/8 - 229 | 1900 | 19/8 - 231 | 2218 | Do |
| 4: C – D (Lomonosov Ridge) | 19/8 - 231 | 2226 | 24/8 - 236 | 0948 | Do |
| 5: D – E (Morris Jesup Rise) | 24/8 - 236 | 0956 | 3/9 - 246 | 1634 | Do |
| 6: E – F (East Greenland Ridge) | 3/9 - 246 | 1650 | 12/9 - 255 | 0935 | Marine filtering |
| 7: F – Longyearbyen | 12/9 - 255 | 0945 | 16/9 - 259 | 2121 | Do |

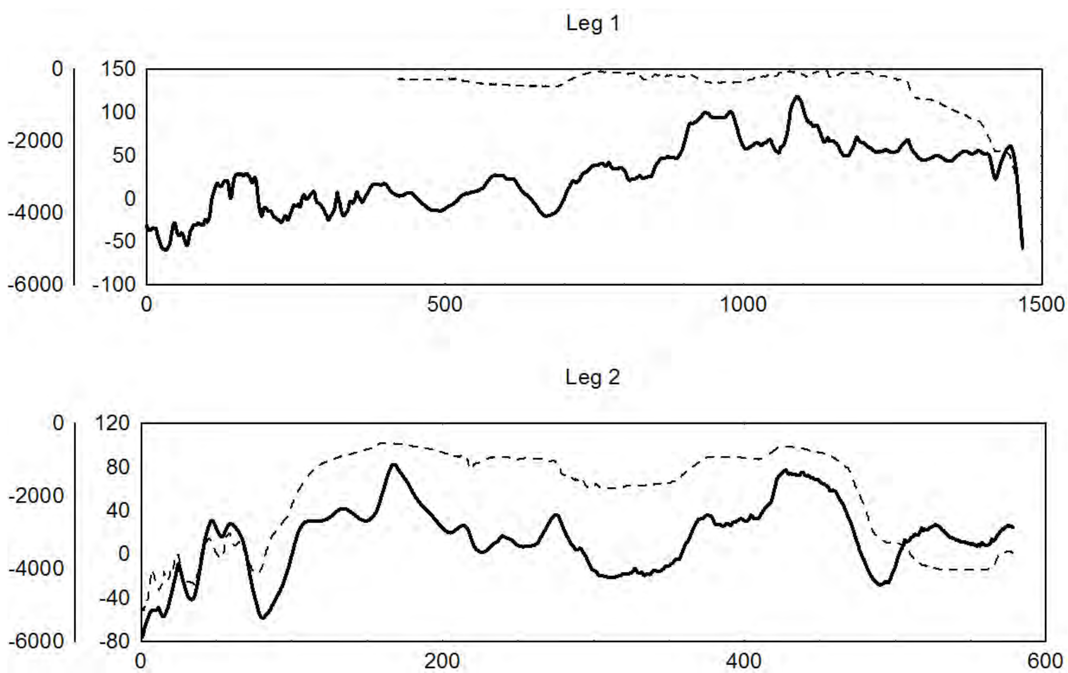
Table 16. Overview of Lacoste and Romberg marine gravimetry

Figure 31. Processing legs of the LOMROG gravity measurements. Background is the IBCAO bathymetry.




Bouguer anomalies (gravity anomalies with bathymetric effects subtracted) have not yet been computed due to insufficient availability of depth data. Figure 32 shows the processed gravity data with an overlay of available multibeam bathymetry as of Sep 15, cf. Figure 33.

Fig 32a. Gravity anomalies mGal along the legs. X-coordinates are distance along irregular track in km. Bathymetry is shown as dotted line with a separate depth scale at far left. The correlation of gravity and bathymetry is obvious, but significant geological anomalies are also seen, most visible on the shelf (Leg 1).



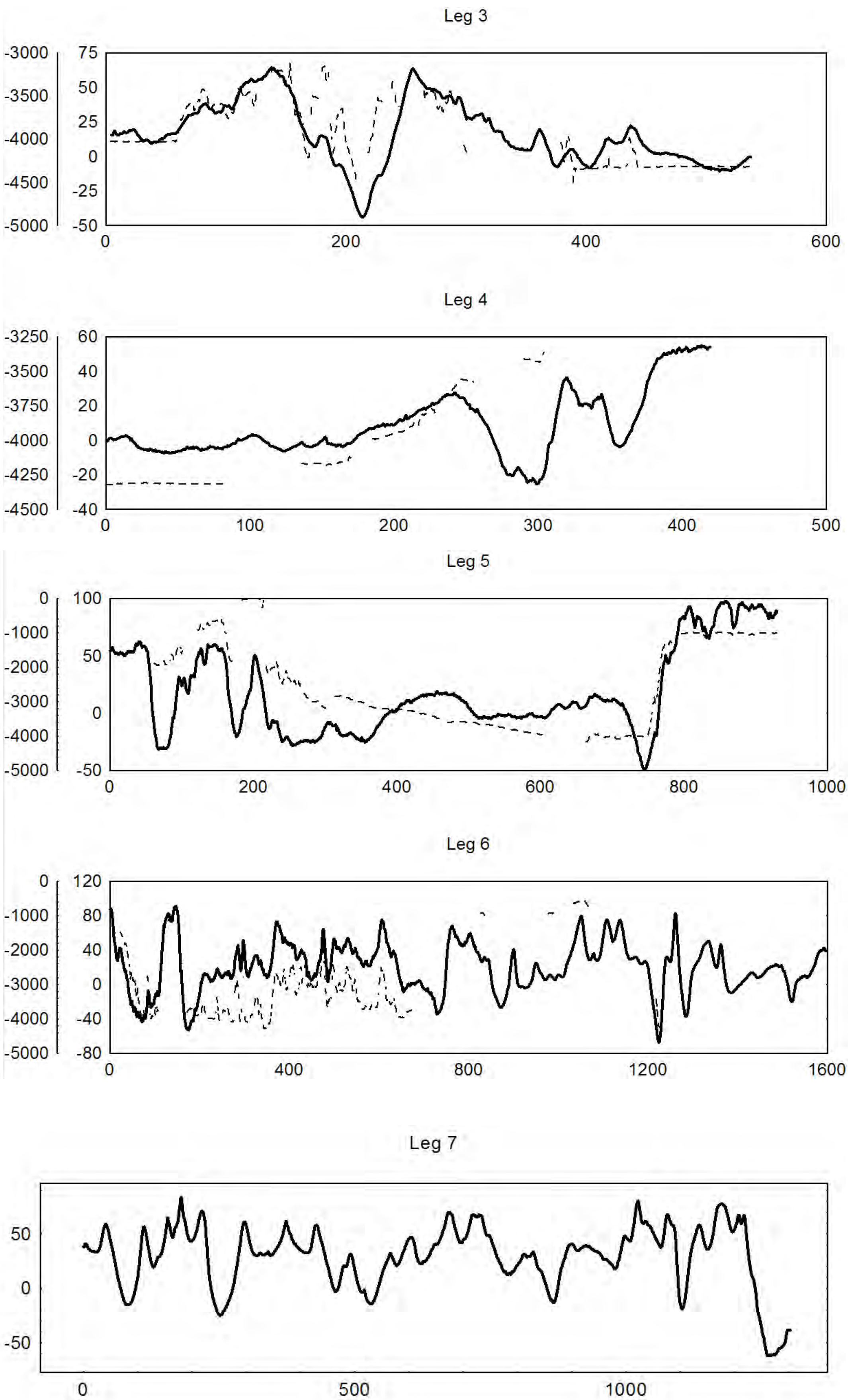
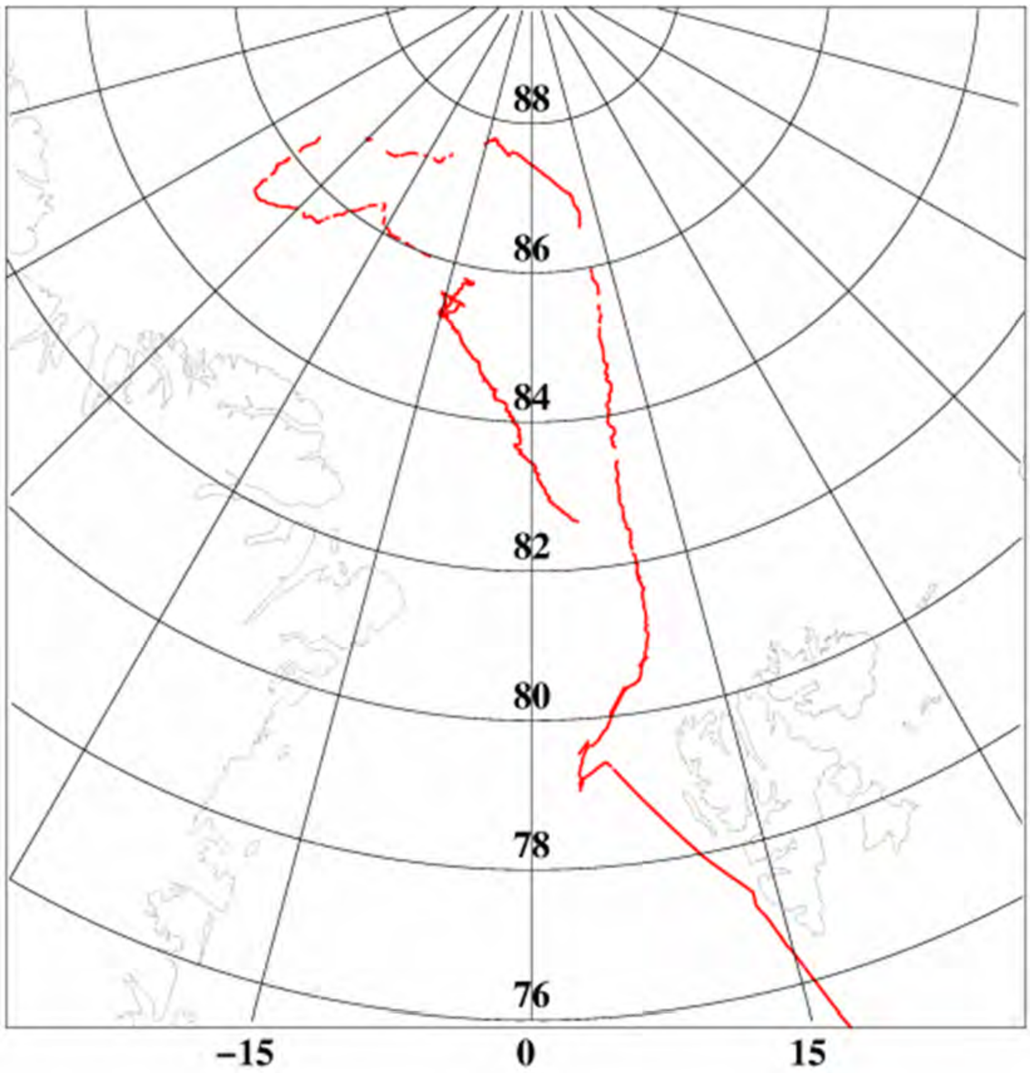



Figure 32b. Gravity anomalies mGal, continued (no depths available on Leg 7 at time of writing).

Figure 33. Available multi-beam data for Bouguer gravity processing, as of Sep 15.




*Helicopter gravity program*

The helicopter gravity program was originally intended to be a joint gravity/bathymetry operation, which would provide profiles of data across the Oden track. For gravity, the use of measured depths would make it possible to compute Bouguer anomalies, and thus separate bathymetric and non-bathymetric gravity signals, e.g. as an aid in estimation of sediment thickness. Due to an echo sounder malfunction, only 3 depth measurements were collected. The gravity program was therefore restricted to the margins of the Lomonosov Ridge and Morris Jesup Rise, where gravity anomaly variations are most rapid, and gravity would help to estimate bathymetry.

The land gravimeter G867, operated in ice-damped mode, was used for the off-ship gravity program, and 85 points were measured on 6 flight profiles at 5 km spacing, see Figures 34 and 35. Measurement times on the profiles were on average 6 minutes/point, including the helicopter transit between points. The estimated relative accuracy of the measurements is 0.2 mGal. The offship gravity measurements were checked for drift and tares relative to the ship gravimeter by occasional readings on the ice close to the Oden. The drift of the land gravimeter are thus controlled by the marine gravimeter, which is controlled by the land ties. The overall drift of the G867 during

Photo 43-44.

the cruise was 1.6 mGal, which is quite satisfactory considering the rough handling during ice surveys.

An example of the detailed gravity mapping on Morris Jesup Rise is shown in Figure 35, incorporating both helicopter and Oden measurements, as well as earlier American airborne measurements of lower accuracy and resolution.

The gravity measurements clearly indicate that the bathymetry on the eastern side is smoother than indicated by the current bathymetry models. Work is planned for joint inversion of gravimetry and bathymetry in the region together with Stockholm University.

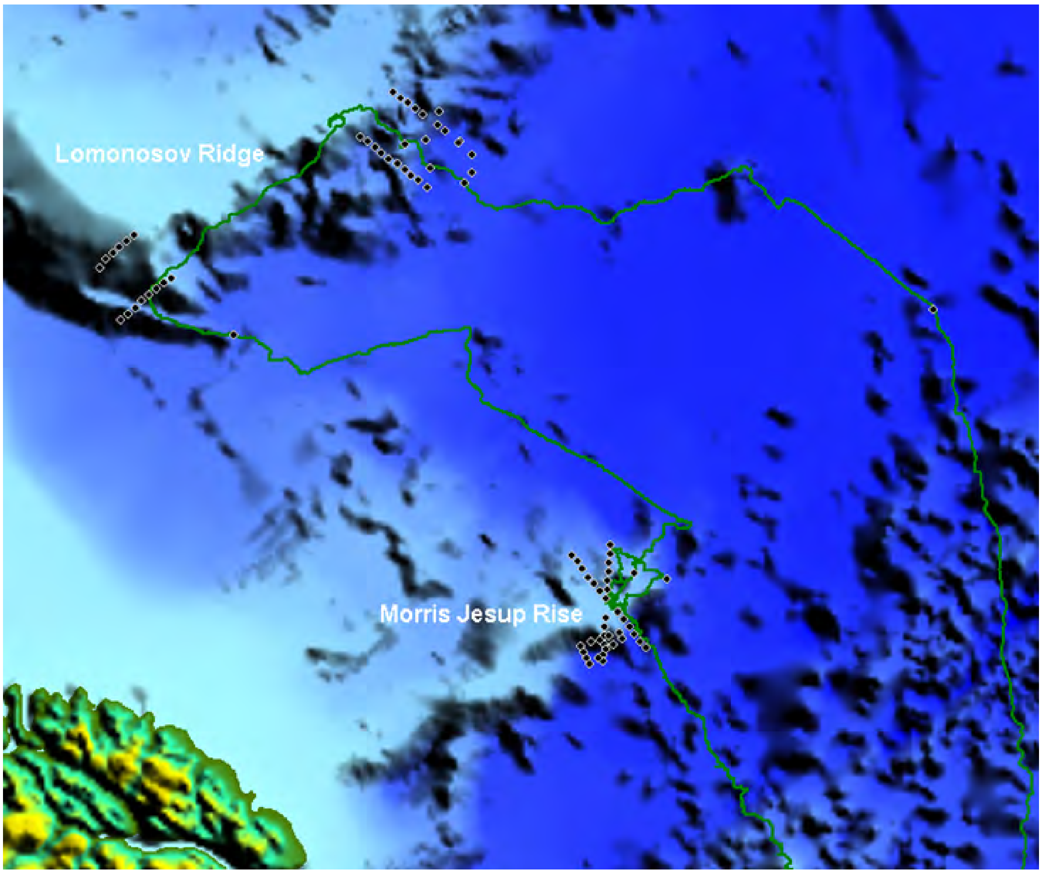
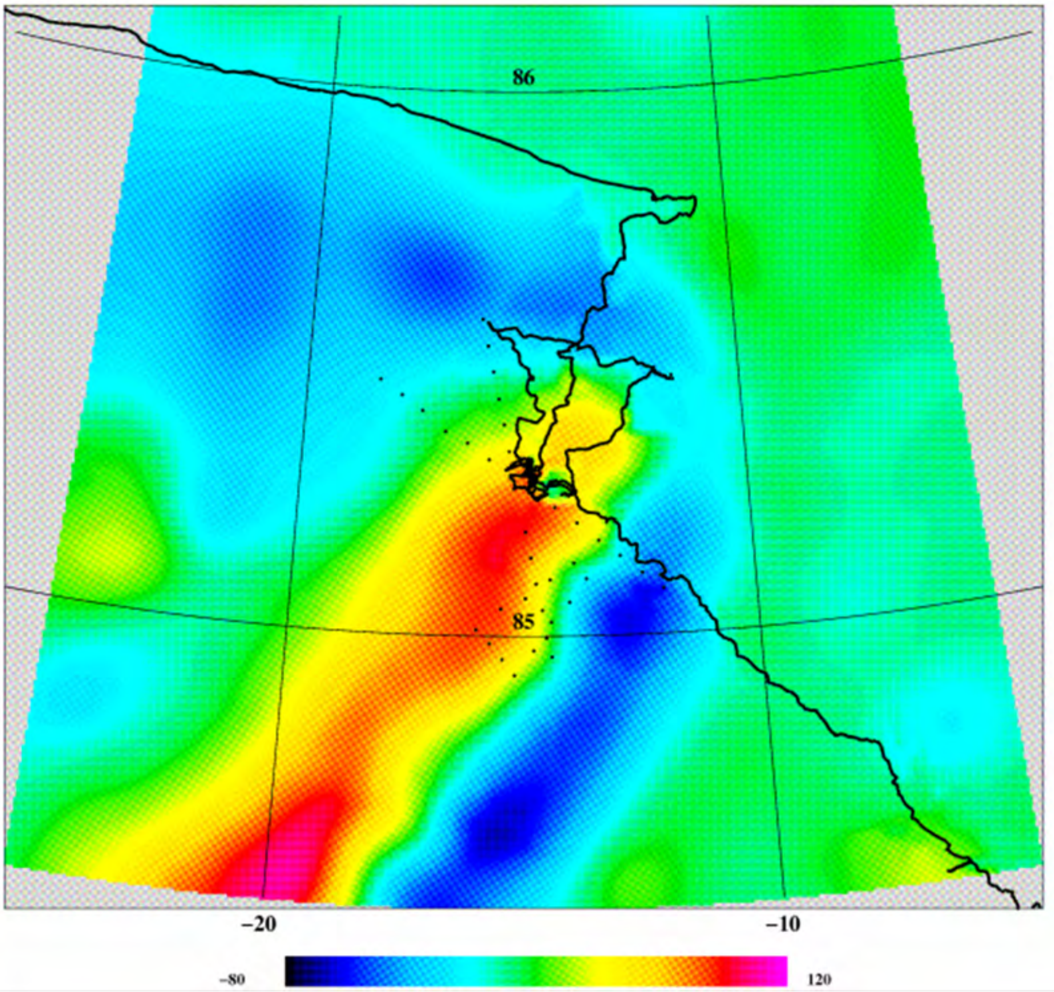



Figure 34. Location of the off-ship helicopter gravity profiles. Greenland at lower left.

Figure 35. Gravity anomalies on Morris Jesup Rise. Scale -80 to 120 mGal.




*Experiences and conclusions*
Oden provided an excellent platform for marine gravity measurements, and measurements in the ice were superior to data from many other icebreakers or even submarines, in spite of the irregular navigation with frequent course and speed changes. The used S-38 gravimeter proved stable and reliable with only small drift. The collected gravimetry data will be useful both in connection with the Danish UNCLOS project, as well as an important new data contribution to the Arctic Gravity Project.

The helicopter measurements were swift and efficient, but limited by both range of helicopter, weather (white-out conditions frequent) and the daily routine of the ship. However, with a functioning echo sounder and longer operations ranges this could be an efficient way to collect relevant additional geophysical data on future cruises.

### *Ice drilling and freeboard measurements*

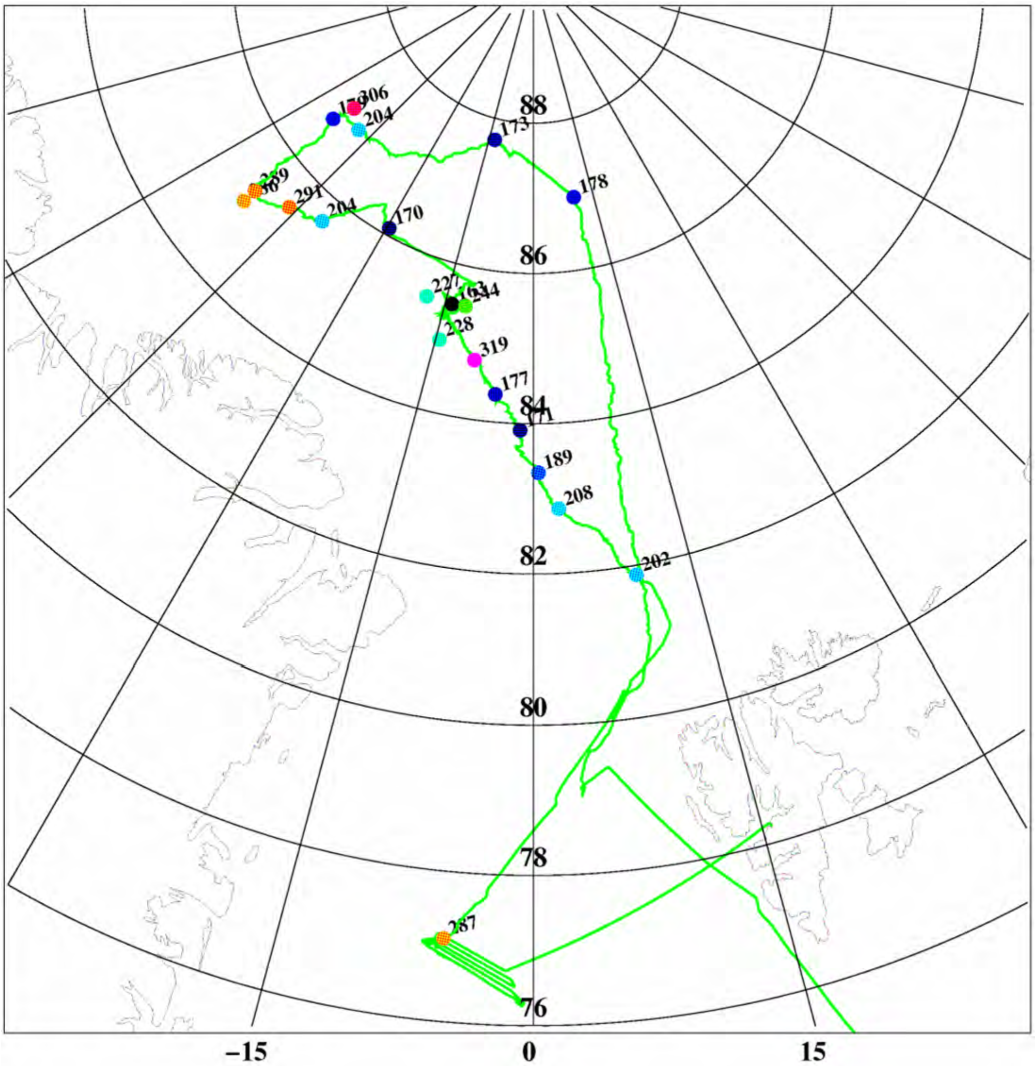
Ice thickness was measured on large floes, somewhat randomly selected, on a near-daily basis. Access to the floes was mainly by helicopter, and in a few cases by crane off the Oden. On each floe a number of holes were drilled by a Kovacs auger, driven by a power drill, and the ice thickness, ice freeboard height and snow thickness measured at each site. In the beginning of the cruise melt pools on the sea ice were widespread, and hindered mobility on the floes. Time did not allow sampling in the melt pools. On many sites sea ice and snow density was measured as well. The ice density was measured by weighing core samples of the Greenland Nature Institute programme, and snow density by sampling a representative mix of new and corn snow. Generally snow depth was quite small. Table 17 below summarizes the sites and average data, and Figure 36 shows the locations sampled.

It is apparent from Table 11 and Figure 36 that the thickness vary dependent on the selected floes, but it is also apparent that the thicker ice is found in the Lomonosov Ridge area. In some cases, floes sampled were clearly refrozen floes of very varying thickness. With the random selection of floes, many types of ice were sampled, as also reflected in the large range of k-factors and sea ice density etc. It should be pointed out that the measurements were generally at the level parts of large floes; no drillings of ice ridges were done. In some regions, notably towards the southern end of the Lomonosov Ridge, pressure ridges and deformed ice were widespread (Photo 47), and leads nearly absent, so the average thickness will be significantly larger than inferred from the drilling. An overall average ice thickness for the different regions is thus difficult to estimate reliably from this kind of sampling, but he thickest ice on the southern Lomonosov Ridge was clearly well above 3 m in average thickness.

| Day | Floe position | Ice thickness (cm) | | | | Free-board height | Mean snow depth | Aver. k-fact. (snow) | Ice density $g/cm^3$ | Snow density $g/cm^3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | # holes Drilled | Mean | Min | Max | | | | | |
| 18 | 86 58.13 10 07.48 | 12 | 178 | 164 | 258 | 17 | 11 | 5.6 | 0.91 | |
| 21 | 87 43.26 -13 07.20 | 6 | 173 | 162 | 202 | 16 | 14 | 6.3 | 0.82 | |
| 23a | 87 00.29 -52 58.19 | 3 | 306 | 238 | 405 | 24 | 18 | 9.1 | 0.82 | |
| 23b | 86 52.27 -48 06.86 | 3 | 204 | 182 | 240 | 13 | 13 | 8.7 | 0.88 | |
| 24 | 86 41.91 -53 59.38 | 5 | 179 | 152 | 231 | 12 | 15 | 6.2 | 0.84 | |
| 26a | 85 17.45 -51 57.12 | 3 | 289 | 255 | 332 | 32 | 14 | 7.3 | 0.84 | |
| 26b | 85 05.31 -51 47.20 | 3 | 286 | 255 | 327 | 22 | 16 | 9.0 | 0.83 | |
| 28 | 85 29.55 -46 12.42 | 4 | 291 | 203 | 369 | 26 | 14 | 6.3 | | 0.31 |
| 29 | 85 39.51 -40 25.02 | 4 | 204 | 180 | 228 | 22 | 11 | 4.5 | 0.91 | 0.21 |
| 30 | 86 05.76 -29 30.39 | 4 | 170 | 149 | 184 | 15 | 15 | 6.8 | 0.83 | 0.28 |
| 1 | 85 27.72 -13 51.62 | 4 | 163 | 150 | 192 | 12 | 15 | 4.4 | 0.79 | 0.26 |
| 2 | 85 27.94 -18 19.08 | 2 | 227 | 224 | 229 | 32 | 13 | 4.6 | 0.90 | |
| 3 | 84 57.71 -14 24.43 | 4 | 228 | 145 | 305 | 23 | 19 | 9.8 | 0.89 | 0.20 |
| 4 | 85 28.38 -11 34.44 | 4 | 244 | 155 | 372 | 18 | 15 | 7.5 | 0.93 | 0.21 |
| 5 | 84 47.23 -8 42.01 | 2 | 319 | 290 | 347 | 28 | 31 | 9.0 | 0.93 | |
| 6 | 84 22.14 -5 11.24 | 5 | 177 | 153 | 199 | 11 | 19 | 5.2 | 0.94 | |
| 7 | 83 54.65 -1 42.46 | 3 | 171 | 160 | 182 | 14 | 20 | 5.8 | 0.84 | |
| 8 | 83 20.81 0 34.06 | 4 | 189 | 147 | 262 | 14 | 22 | 7.6 | 0.91 | |
| 9 | 82 51.76 2 40.72 | 4 | 208 | 172 | 274 | 19 | 11 | 7.9 | 0.91 | |
| 10 | 81 52.41 9 41.49 | 4 | 202 | 146 | 286 | 21 | 10 | 5.6 | 0.89 | 0.35 |
| 14 | 77 06.34 -5 20.45 | 3 | 287 | 191 | 452 | 85 | 8 | 7.7 | 0.89 | 0.28 |

Table 17. LOMROG average ice drilling results. Unit: cm. k-factor includes snow (laser freeboard ratio).

Figure 36. Average sea-ice thickness for the ice floes drilled during LOMROG. Average thicknesses are shown in cm.




Photos 46-47. Left: measuring freeboard in drill hole; right: thick deformed ice in the Lomonosov area (Aug 28).

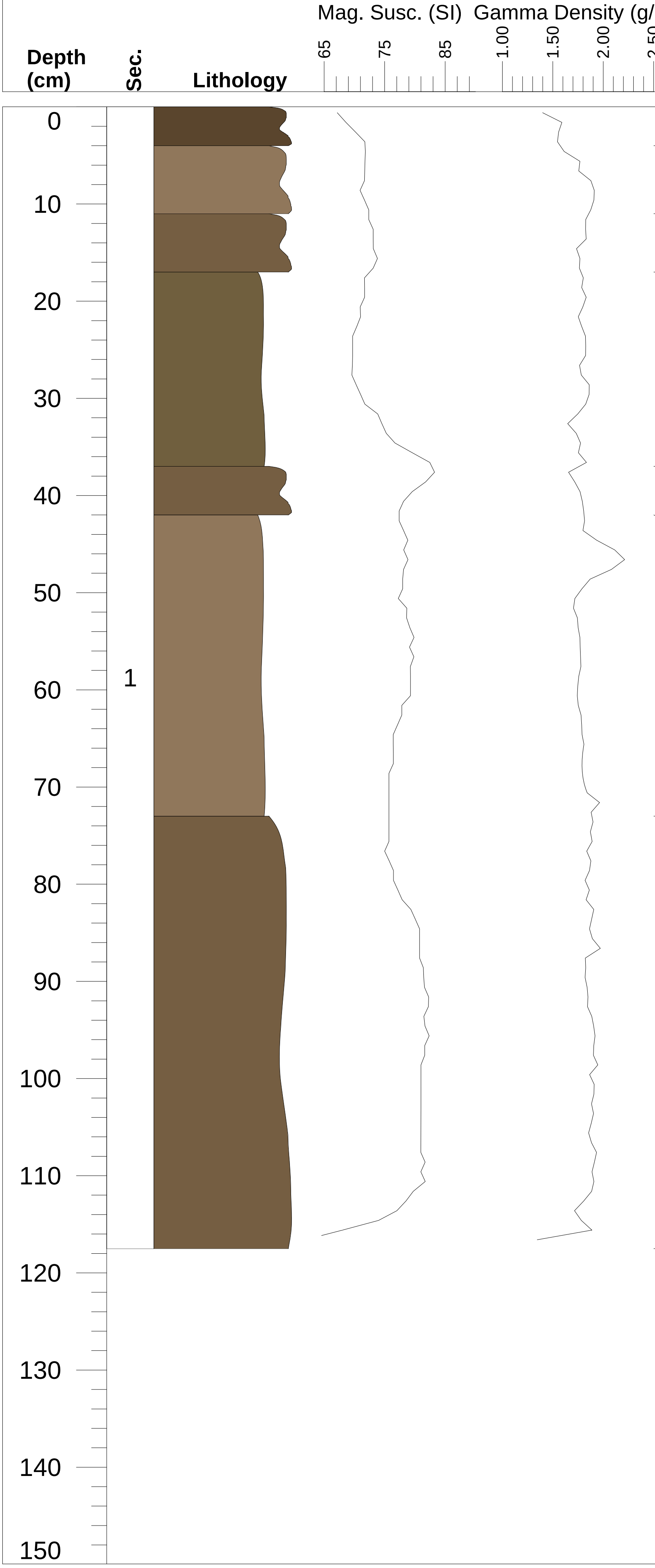
The thickness and various k-factor data collected will be merged with data from earlier (spring) airborne laser campaigns, submarine and in-situ measurements from a number of recent projects (EU SITHOS, GreenICE and Damocles; ESA CryoVex projects), as well as compared to satellite measurements from ICESat.

## Appendix I: Core Description

# LOMROG07-GC-01

Position: 86°52.35'N, 48°09.14'W    Depth (m): 1573

Date Acquired: 8/23/2007    Described by: Leonid Polyak




**Description**

Dark brown, soft, slightly sandy mud with some IRD; contact clear, slightly uneven, probably bioturbated.

Brown to grayish brown (10YR5/3 to 5/2) sandy mud, with some lighter colored streaks; contact-gradational transition by a slight change of color

Brown to dark brown to dark grayish brown (10YR4/3 to 4/2), slightly sandy mud; contact uneven, probably bioturbated.

Olive brown to light olive brown (2.5Y5/3-below 31 cm) mud with unevenly distributed IRD and mud clumps; below 31 cm-mostly lighter colored, very soft, fine mud; patches of brown sediment as in unit above to ~22 cm; contact even; indistinct lamination near the contact

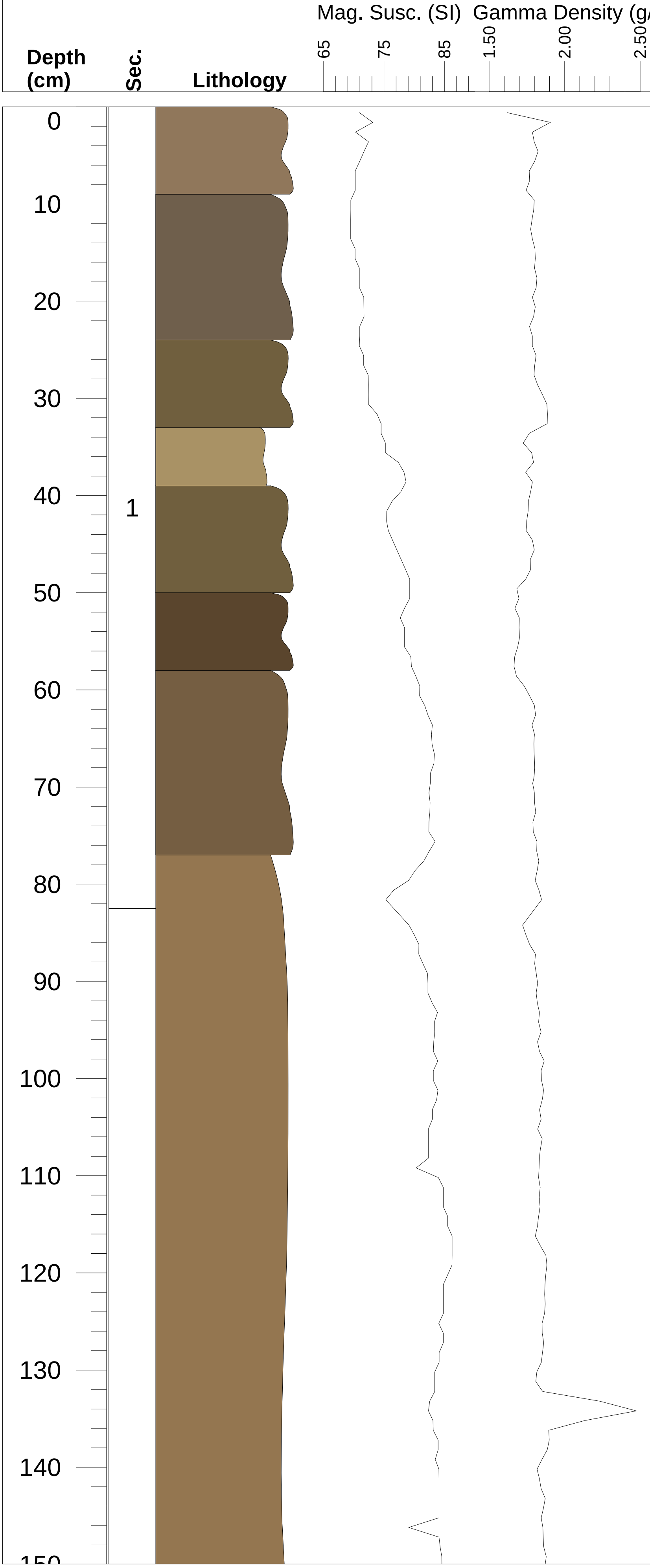
Brown to dark brown grayish brown (10YR4/3 to 4/2), slightly sandy mud with some whitish granules; contact uneven, probably bioturbated

Brown (10YR5/3 to 5/2) mud with unevenly distributed sand and IRD; upper part to ~48-52 cm (oblique contact) is darker colored (transitional in color from unit above) and has numerous IRD up to 2 cm in diameter; lower part is lighter colored and some whitish granules, notably along the oblique lamina at 63-68 cm and along the lower contact (the latter includes IRD to 1 cm in diameter probably carbonates); contact oblique (69-77cm), distinct

Predominantly brown, but somewhat mottled, slightly sandy mud with seemingly irregular patches of lighter and darker colored sediment

# LOMROG07-GC-02

Position: 86°37.94'N, 54°11.63'W
Depth (m): 724
Date Acquired: 8/24/2007
Described by: Leonid Polyak




**Description**

Brown, sandy mud with lighter colored hard sediment (hard ground or IRD) on top of 2-3 cm; gradual transition to the next unit by slight change in color

Dark grayish brown to brown (10YR4/2 to 5/3), sandy mud, mottled (bioturbation); contact even, by color

Olive brown to dark grayish brown (2.5Y4/3 to 4/2), sandy mud, indistinctly laminated; 24-26 cm appears less sandy; separated from the rest of the unit by a very dark lamina with a lighter lamina underneath; contact very distinct, mostly even

Light yellowish brown to olive yellow (2.5Y6/4 to 6/5), very soft mud with clumps of semi-hard sediment (carbonaceous IRD?); gradual transition to unit below

Olive brown slightly sandy mud with mottles of overlying sediment-probably a transitional unit between units above and below; gradual transition

Dark brown (10YR3/3 to 4/3), slightly sandy mud, somewhat mottled; contact strongly bioturbated

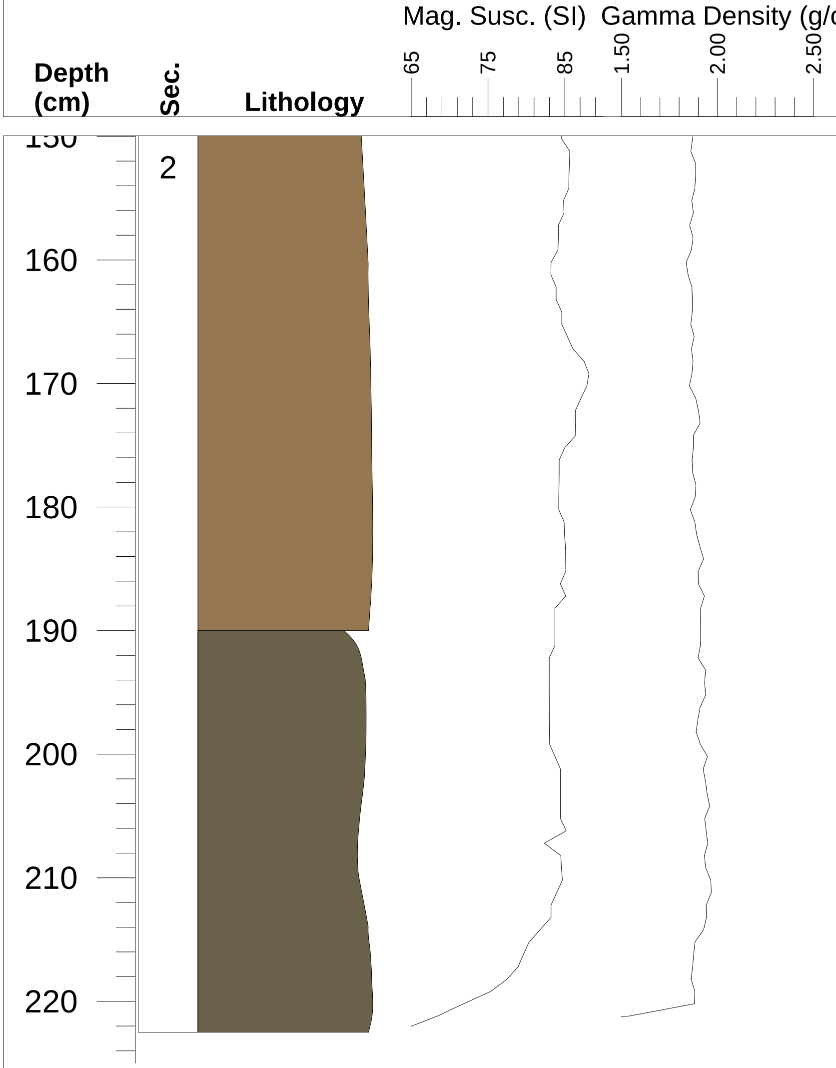
Brown to olive brown (10YR4/3 to 2.5Y4/3), slightly sandy mud with streaks and indistinct laminae of darker and lighter sediment;74-77 cm are more olive brown, indistintly laminated; contact uneven

Yellowish brown, slightly sandy mud (as a background), with laminae and irregular patches of dark brown (10YR3/3), slightly sandy mud, notably at 77-78 cm, 84.5-87 cm, 88-97 cm (side patch), 100-109 cm (side patch), 109-112.5 cm, 114-116 cm, 153-155 cm, 178-182 cm, 185-190 cm; dispersed dropstones, notably a 7-cm, well rounded sandstone at 133-139 cm; contact even

# LOMROG07-GC-02

Position: 86°37.94'N, 54°11.63'W    Depth (m): 724

Date Acquired: 8/24/2007    Described by: Leonid Polyak



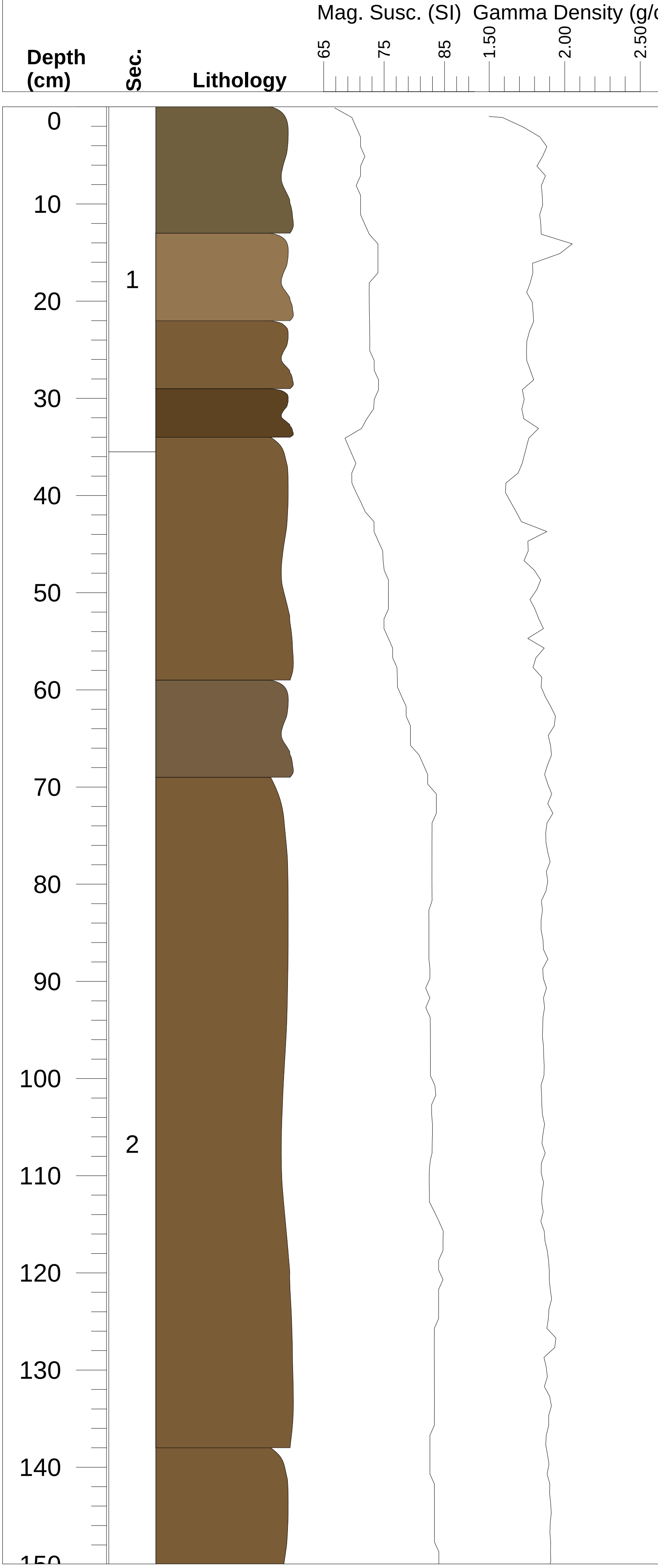

**Description**

Stiff, olive gray sandy mud with coarser granules; darker sediment (5Y3/2) at 198-200 cm and below 215 cm

# LOMROG07-GC-03

Position: 86°37.67'N, 53°57.54'W Depth (m): 721

Date Acquired: 8/24/2007 Described by: Leonid Polyak




**Description**

Olive brown to brown (2.5Y4/3 to 10YR4/3), slightly sandy mud, mottled with patches of dark brown (10YR3/3) mud; overall slightly lighter below 8 cm; contact uneven, accentuated by IRD below

Yellowish brown to light yellowish brown (10YR5/4 to 6/4), sandy mud with abundant IRD, probably carbonates; contact uneven, probably bioturbated

Dark yellowish brown to brown (10YR4/4 to 4/3), sandy mud, mottled; possibly a transitional unit between those above and below; gradational transition

Dark yellowish brown to dark brown (10YR3/4 to 3/3), sandy mud, less mottled than above but with some light colored streaks; a sandy lamina at 33 cm; contact slightly uneven, oblique (33-34 cm)

Interlamination of darker and lighter colored, overall dark yellowish brown (10YR4/4 to 3/4), sandy mud; no darker laminae below 56 cm; contact indistinct, by the appearance of more solid color

Brown to dark yellowish brown (10YR4/3 to 4/4), very sandy mud, with a large lens of muddy sand on one side of the core; with IRD, including a large stone in the archival half; contact subtle, by a slight change in color and sand content

Dark yellowish brown to brown (10YR4/4 to 4/3), slightly sandy mud with some amount of IRD (large stone at 118-120 cm in the archival half); gradual transition by the appearance of dark layers

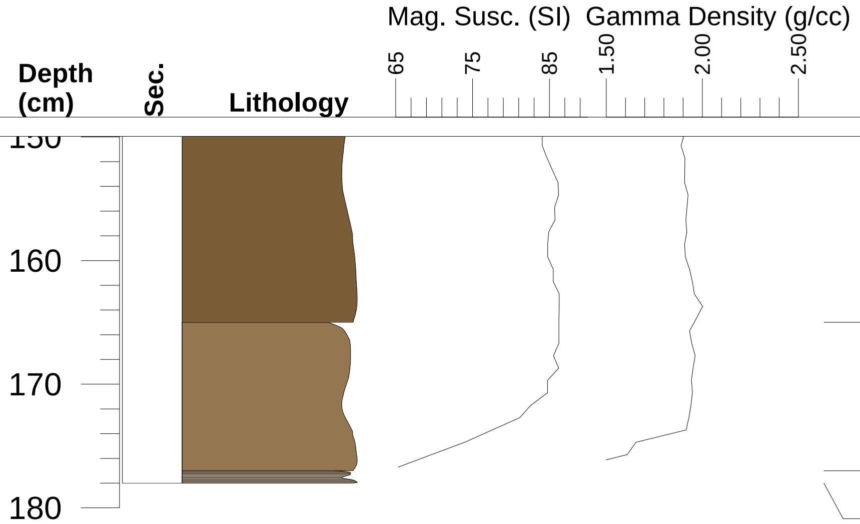
# LOMROG07-GC-03

Position: 86°37.67'N, 53°57.54'W

Depth (m): 721

Date Acquired: 8/24/2007

Described by: Leonid Polyak




**Description**

Dark yellowish brown, slightly sandy mud, similar to that above, but with darker layers (10YR3/4), notably at 140-141 cm, 146.5-147.5 cm, and 150-151.5 cm; mottles of lighter colored sediment near the bottom

Yellowish brown, slightly sandy mud with irregular laminae and patches of darker sediment (10YR3/3); contact relatively even

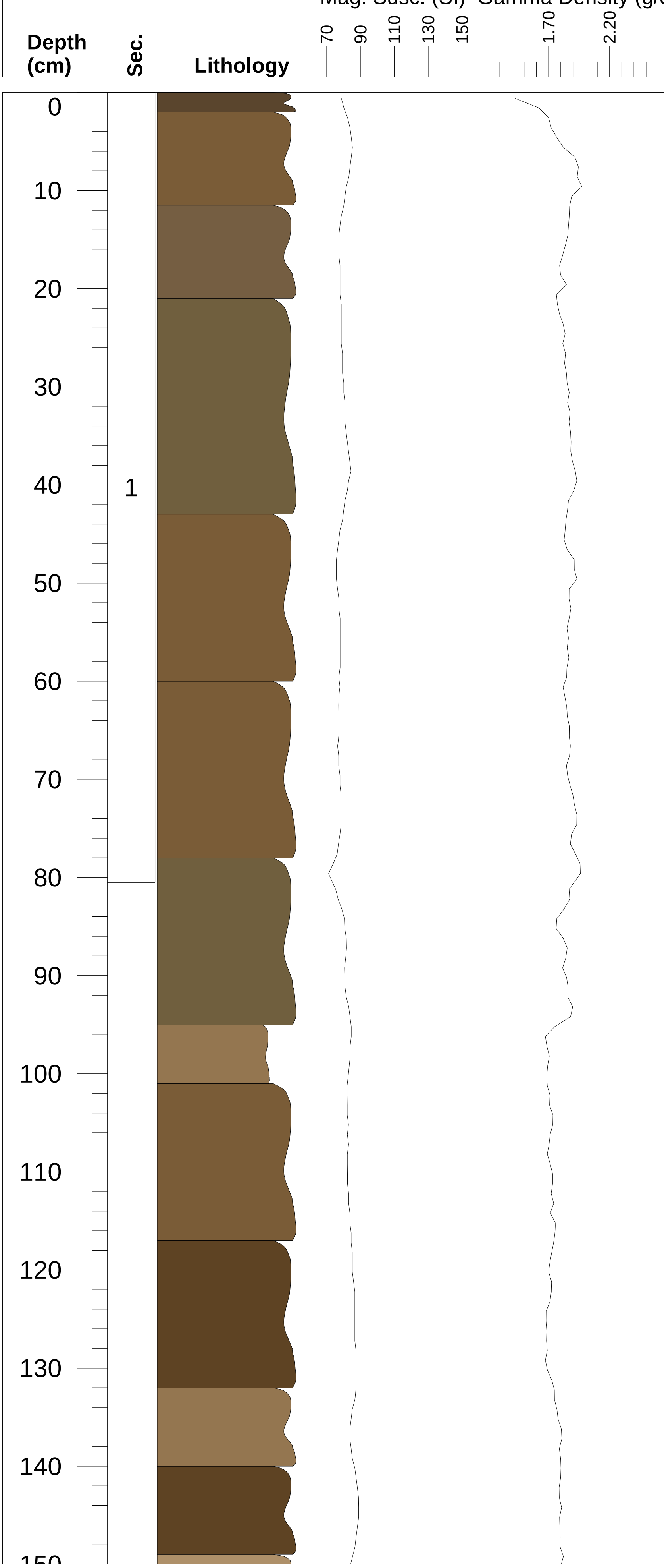
Dark grayish brown to dark olive gray (2.5Y4/2 to 5Y3/2), sandy, very cohesive mud; more sediment in the core cutter

# LOMROG07-PC-04

Position: 86°42.07'N, 53°46.03'W  Depth (m): 810

Date Acquired: 8/24/2007  Described by: Leonid Polyak

| Depth (cm) | Sec. | Lithology | Mag. Susc. (SI) | Gamma Density (g/cc) | Description |
|---|---|---|---|---|---|




Dark brown, soft, slightly sandy mud; contact uneven, probably bioturbated

Dark yellowish brown, sandy mud with sandy lenses to ~8cm; lighter colored near the bottom; contact uneven, with small mottles

Brown, slightly sandy mud, with some lighter colored streaks; a darker lamina at the bottom; contact uneven

Olive brown to dark yellowish brown (2.5Y4/3 to 10YR4/4), slightly sandy mud with mottles and indistinct laminae of darker sediment: contact subtle, by a slight change in color

Dark yellowish brown, slightly sandy mud, with a watery, sandy layer (lens?) at 56.5-58.5 cm; contact subtle, by a slight change in color

Dark yellowish brown to olive brown (10YR4/4 to 2.5Y4/3), slightly sandy mud, with indistinct, more olive-colored mottles, especially below 64 cm; contact slightly uneven

Olive brown, sandy mud with IRD; contact even, distinct

Yellowish brown, very soft mud; contact slightly uneven

Dark yellowish brown, slightly sandy mud, lighter and darker mottles; gradual transition

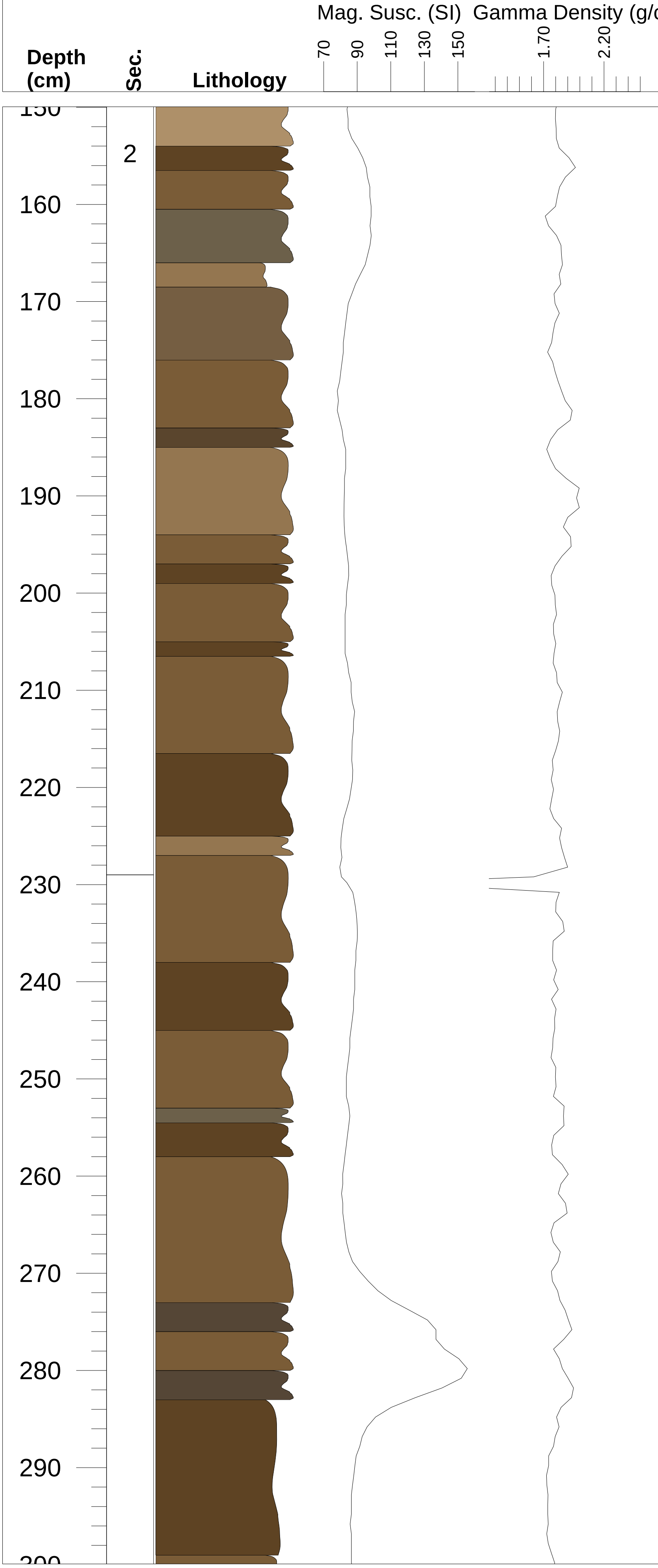
Dark yellowish brown, slightly sandy mud, somewhat darker and less mottled than above; color grades to dark brown (10YR3/3); contact uneven, probably bioturbated

Yellowish brown, sandy mud with admixture of lighter colored sediment, probably detrital carbonates; gradual transition

Dark yellowish brown, slightly sandy mud, somewhat mottled, contact uneven, probably bioturbated

# LOMROG07-PC-04

Position: 86°42.07'N, 53°46.03'W
Depth (m): 810
Date Acquired: 8/24/2007
Described by: Leonid Polyak




**Description**

Light yellowish brown, sandy mud with numerous whitish granules, probably detrital carbonates; contact even, distinct

Yellowish brown, slightly sandy mud with a sandy lamina at 155-156 cm (oblique); darker colored at the bottom; contact slightly uneven but distinct

Dark yellowish, sandy mud; more sandy towards the bottom; contact even, distinct

Olive brown, sandy mud with gray mud clumps; contact clear, slightly uneven

Yellowish brown, soft mud; contact slightly uneven

Brown to dark yellowish brown, slightly sandy mud, mottled; contact uneven, probably bioturbated

Dark yellowish brown, slightly sandy mud somewhat mottled; contact uneven

A patch of dark brown, slightly sandy mud; unevenly distributed on top of lumpy IRD layer; contact uneven

Yellowish brown, sandy mud with abundant IRD, probably detrital carbonate; contact strongly uneven, oblique (192-196 cm)

Dark yellowish brown, slightly sandy, somewhat mottled mud; contact uneven, probably bioturbated

Dark yellowish brown, sandy mud with streaks of lighter and darker color; contact uneven, subtle, by a slight change in color

Dark yellowish brown, slightly sandy, mottled mud; gradual transition by a slight change in color

Dark yellowish brown, slightly sandy mud; contact slightly uneven

Dark yellowish brown, slightly sandy mud; slightly mottled; contact slightly uneven

Dark yellowish brown, slightly sandy mud; mottled; contact uneven

Yellowish brown, sandy mud with whitish granules; probably detrital carbonate; contact slightly uneven

Dark yellowish brown, slightly sandy mud, with numerous mottles (ichnotraces) 2-3mm wide below 229 cm; gradual transition

Sediment similar to that above, but with numerous darker mottles

Lighter colored sediment with few mottles; contact slightly uneven

Olive brown to dark yellowish brown sandy mud; relatively even contact

Dark yellowish brown, slightly sandy, mottled mud; contact uneven

Predominantly lighter colored (10YR4/4 to 5/4), less mottled mud, somewhat darker and sandier to 264 cm and at 266-268 cm; uneven contact

Very dark grayish brown, sandy mud; contact uneven; dropstone at 276 cm

Dark yellowish brown mud; contact uneven

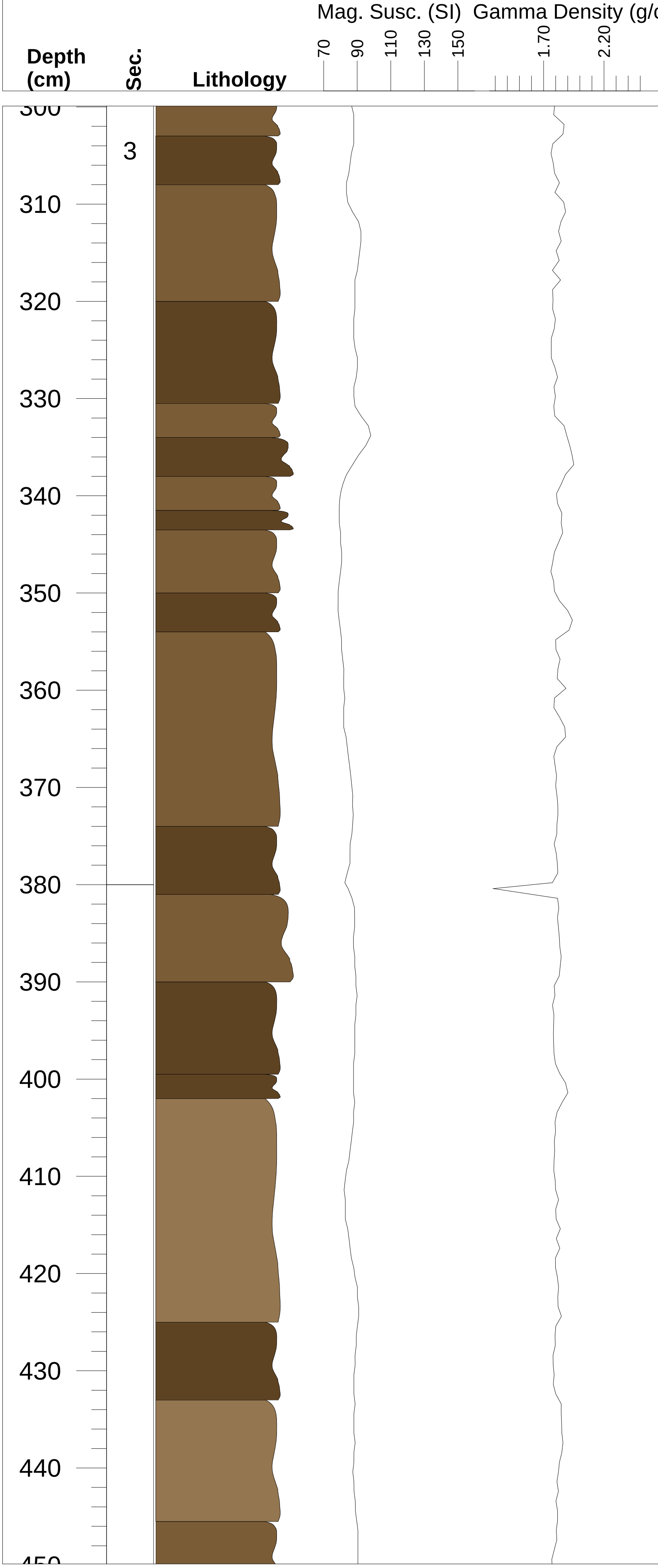
Sandy mud layer, same as at 273-376 cm; relatively even contact, with a lighter colored lamina at the bottom

Strongly mottled silty mud with 1-mm dark speckles, probably Mn-micronodules; contact strongly uneven, bioturbated

# LOMROG07-PC-04

Position: 86°42.07'N, 53°46.03'W | Depth (m): 810

Date Acquired: 8/24/2007 | Described by: Leonid Polyak




**Description**

Slightly mottled silty mud, gradual transition by a slight darkening in color

Mottled silty mud, contact uneven

Silty mud (10YR4/4 to 5/4); very slightly mottled; contact uneven

Mottled silty mud, contact uneven

Slightly mottled silty mud, contact slightly uneven

Massive sandy mud; contact even

Slightly mottled silty mud; contact uneven, subtle

Silty mud (10YR3/4 to 4/4); slightly mottled

Slightly mottled silty mud (10YR4/4 to 5/4)

Sandy mud (10YR3/4 to 4/4); mostly massive with some IRD; contact almost even

Silty mud (10YR4/4 to 5/4); somewhat mottled; more mottling at 365-368 cm; contact uneven

Strongly mottled silty mud; contact uneven

Silty mud (10YR4/4 to 5/4); small mottling; contact uneven

Mottled silty mud, contact slightly uneven

Slightly mottled sandy mud with IRD or sand lenses; contact very conspicuous even

Silty mud (10YR5/4 to 4/4) with various degree of mottling; more brown mottling and dark speckles to 409 cm; somewhat darker colored at 411.5-413 and 415-417cm; contact strongly uneven

Strongly mottled silty mud, contact uneven

Silty mud (10YR5/4 to 4/4), slightly mottled; contact subtle

Silty mud (10YR4/4 to 3/4); more brownish below 450 cm; contact uneven

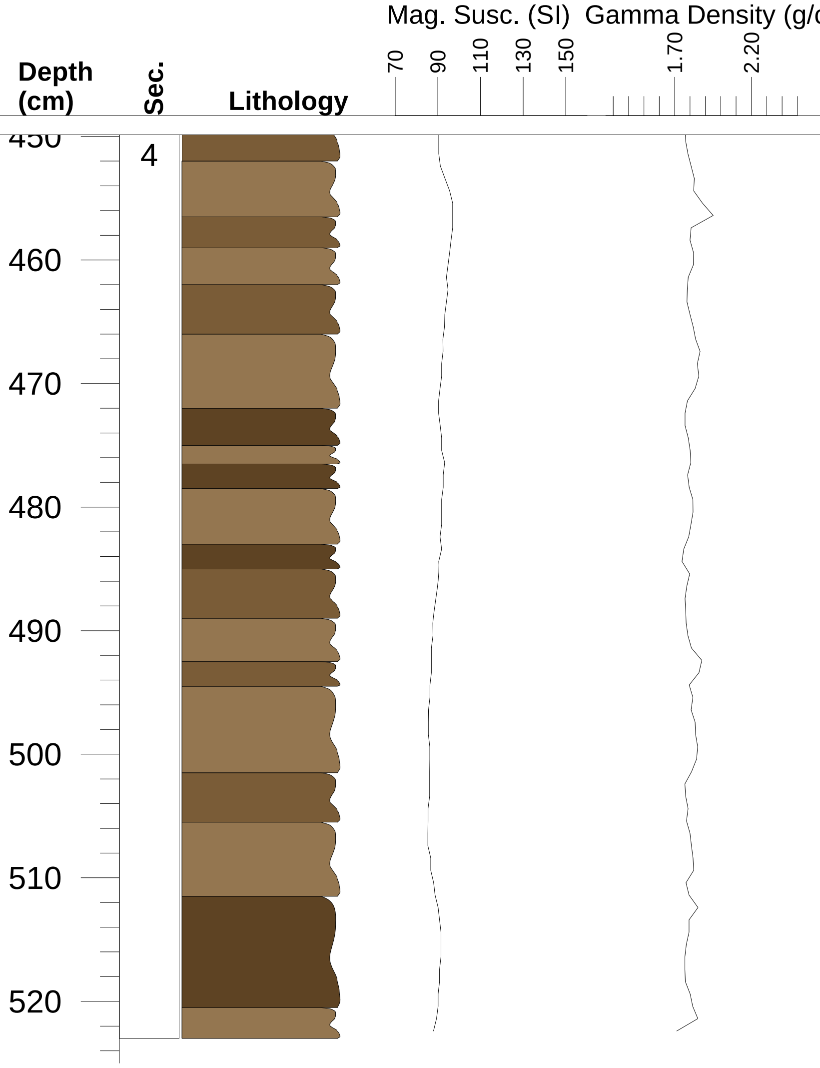
# LOMROG07-PC-04

Position: 86°42.07'N, 53°46.03'W

Depth (m): 810

Date Acquired: 8/24/2007

Described by: Leonid Polyak




**Description**

Slightly mottled silty mud; a sandy lamina at the bottom (or concentration of Mn oxides)

Silty mud (10YR4/4 to 3/4); somewhat mottled; contact strongly uneven

Silty mud

Silty mud (10YR4/4 to 3/4)

Very slightly mottled, silty mud; contact almost even

Silty mud, more intense brown color than brown (dark) units above

Slightly mottled silty mud; contact uneven

Strongly mottled silty mud; contact uneven

Slightly mottled silty mud; contact uneven

Slightly mottled silty mud; gradual transition

Mottled silty mud; contact uneven

Slightly mottled silty mud; contact uneven

Slightly mottled silty mud; contact uneven

Very slightly mottled, silty mud; contact slightly uneven

Silty mud; mostly 10YR4/4, but with a layer of lighter (yellowish), somewhat sandy mud at 503-504 cm; contact uneven

Slightly mottled silty mud; contact slightly uneven

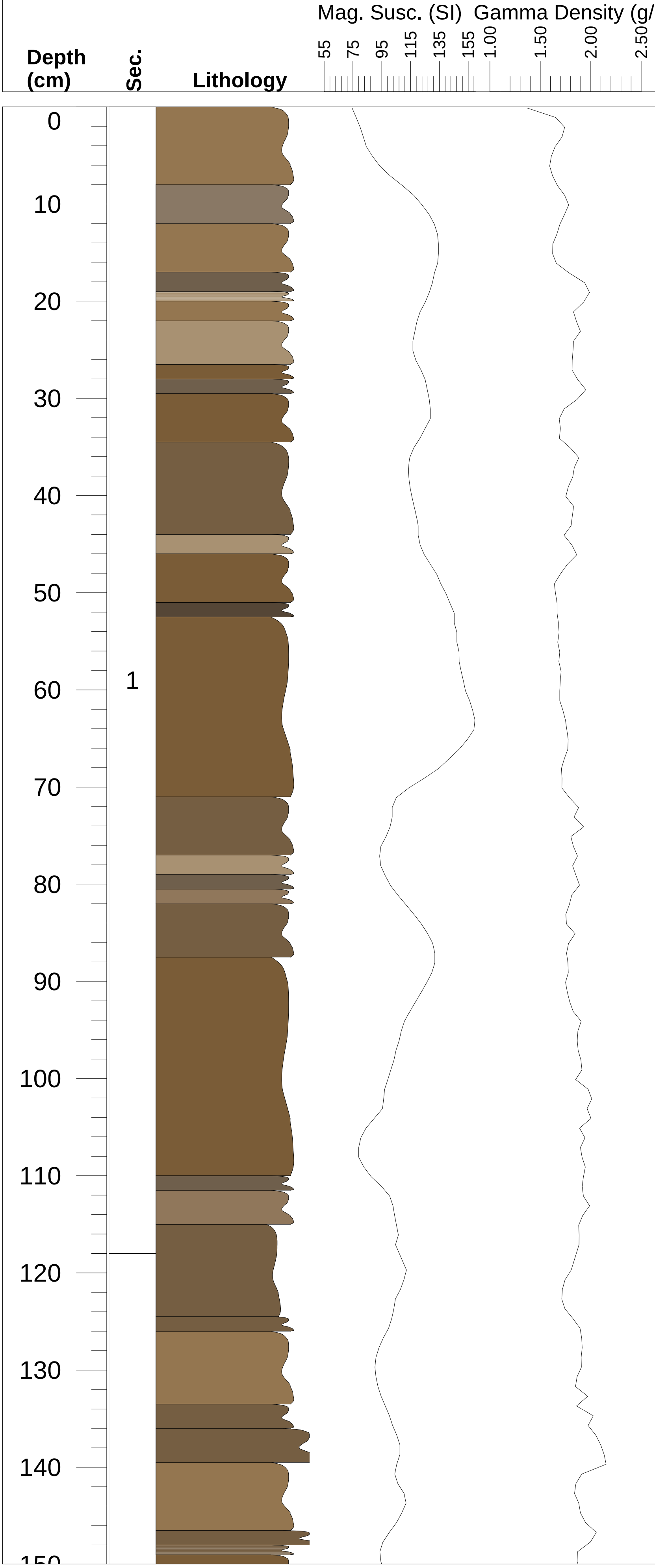
Silty mud (10YR3/4 to 4/4); strongly bioturbated (mottled); contact uneven

Silty mud; slightly mottled

# LOMROG07-GC-05

Position: 85°39.23'N, 52°27.26'W  Depth (m): 1320

Date Acquired: 8/26/2007  Described by: Leonid Polyak




**Description**

Yellowish brown to brown (10YR5/4 to 4/3), slightly sandy mud, with indistinct dark brown laminae at 0-1 cm and 4.5-5.5 cm; contact slightly uneven

Grayish brown to brown (10YR5/2 to 5/3), slightly sandy mud; contact indistinct, by slight change in color

Yellowish brown to brown (10YR5/4 to 5/3), slightly sandy to sandy mud (more sandy near the bottom); contact even

Dark grayish brown, sandy mud, with more yellowish brown color near the bottom; contact not very distinct

Pale brown to light brownish gray (10YR6/3 to 6/2), sandy mud; contact slightly uneven

Yellowish brown to brown (10YR5/4 to 5/3), slightly sandy mud; contact distinct, slightly uneven

Pale brown to light brownish gray (10YR6/3 to 6/2), sandy mud, probably detrital carbonate; contact distinct, fairly even

Dark yellowish brown to brown (10YR4/4 to 4/3), sandy mud; contact slightly uneven

Dark grayish brown (10YR4/2 to 2.5Y4/2), sandy mud with IRD; contact slightly uneven

Dark yellowish brown, sandy mud; contact slightly uneven

Brown to dark yellowish brown (10YR4/3 to 4/4), sandy mud, with darker brown, indistinct laminae; IRD; uneven contact

Pale brown to very pale brown (10YR6/3 to 7/3), sandy mud, probably detrital carbonates; contact very uneven; somewhat oblique

Dark yellowish brown, sandy mud, with some mottling; contact uneven, probably bioturbated

Very dark grayish brown, slightly sandy mud, somewhat mottled; contact uneven, bioturbated

Dark yellowish brown, slightly sandy mud, with distinct dark brown laminae, notably at 58-59 cm, 60-64 cm, 66.5-67.5 cm, and ~69 cm; contact indistinct, by a slightly change in color

Brown to dark grayish brown (10YR4/3 to 4/2), sandy mud with darker colored mottles or indistinct laminae; contact somewhat uneven

Pale brown to brown (10YR6/3 to 5/3), sandy mud, probably detrital carbonate; slightly uneven contact

Dark grayish brown, sandy mud; contact uneven

Brown to grayish brown (10YR5/3 to 5/2), sandy mud; contact subtle

Brown to dark yellowish brown (10YR4/3 to 4/4), slightly sandy mud, with darker colored (dark grayish brown) mottling; a sand lamina between 85-86 cm; contact subtle, by a slight change in color

Dark yellowish brown to brown (10YR4/4 to 4/3 to 5/4), variably sandy mud, with some mottling and indistinct laminae; dark-colored clumps below 105 cm; a distinct yellow, sandy clump between 109-110 cm; contact slightly uneven

Dark grayish brown to dark brown (10YR4/2 to 3/3), slightly sandy mud; contact slightly uneven

Brown to yellowish brown (10yR5/3 to 5/4), slightly sandy mud; a darker colored, more sandy lamina between 112-113 cm; contact somewhat uneven

Brown to dark yellowish brown (10YR4/3 to 4/4), silty mud; more brownish between 115-118.5 cm and 121-122.5 cm; contact almost even, by a slight change in color and sand content

124.5-136 cm composite, interlamination of sandy muds with somewhat different colors. 124.5-126 cm brown, contact somewhat uneven

Background yellowish brown (10YR5/4 to 4/4), with darker (10YR4/2 to 4/3) layers at ~127 cm, 129-130 cm, and~133 cm; contact slightly uneven

Brown; lighter colored at 135-136 cm; contact somewhat uneven.

Brown, muddy sand with IRD; a ~3cm dropstone penetrates into the underlying unit; contact somewhat uneven

Yellowish brown (10YR5/4 to 6/4), slightly sandy mud, with darker colored mottles of 2-3 mm in diameter; contact slightly uneven

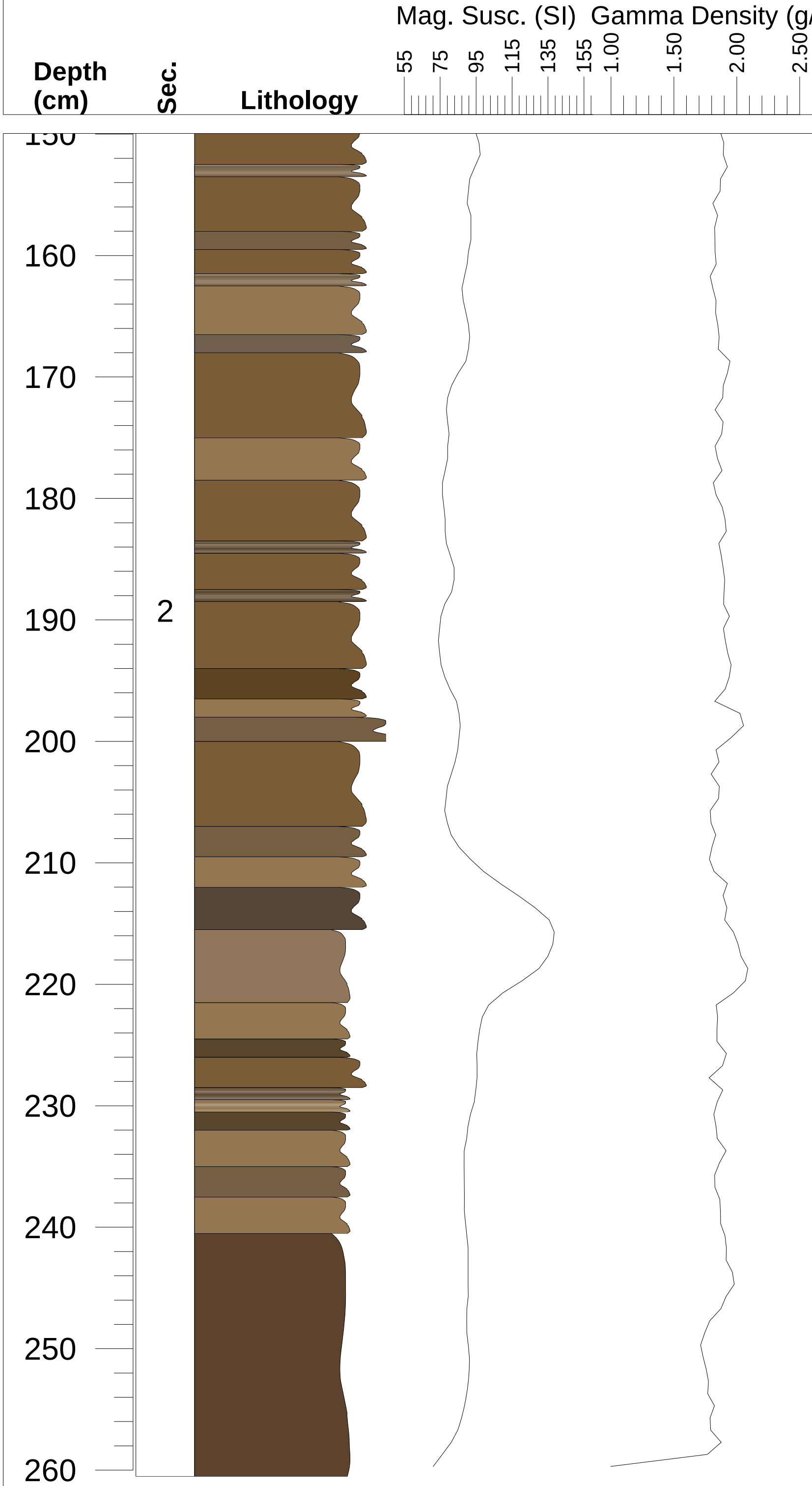
Brown, muddy sand; contact slightly uneven

Interlamination of sandy muds with darker and lighter colors, some

# LOMROG07-GC-05

Position: 85°39.23'N, 52°27.26'W Depth (m): 1320

Date Acquired: 8/26/2007 Described by: Leonid Polyak




**Description**

Interlamination of sandy muds with darker and lighter colors; some mottling and mud clumps (148-215.5 cm) 148-149 cm: Brown, uneven, subtle contact

Somewhat mottled, with clumps; subtle contact

Slightly more brownish; subtle contact

Dark yellowish brown to yellowish brown (10YR4/4 to 5/4); contact subtle, slightly uneven

More brown; contact uneven

More yellowish brown; contact uneven, subtle

More brown; contact uneven, subtle

Yellowish brown (10YR5/4 to 4/4), with darker clumps; contact subtle, uneven

Dark grayish brown; contact distinct, slightly uneven

Dark yellowish brown, slightly darker below 173 cm; diffuse dark laminae around 170 cm; dark clumps below; contact slightly uneven

Yellowish brown, slightly grayish, with dark clumps; a dark lamina at the bottom; contact slightly uneven

Some darker clumps; contact diffuse, uneven

Dark brown; relatively distinct, slightly uneven contact

Dark yellowish brown, slightly grayish, with darker clumps; contact slightly uneven

Dark brown, slightly grayish; contact distinct, slightly uneven

Dark yellowish brown, slightly grayish, lighter colored below 193 cm; contact distinct, slightly uneven

Dark yellowish brown, darker than above, somewhat mottled; contact distinct, slightly uneven

Yellowish brown; contact distinct

Brown, muddy sand; lighter colored on top; with darker lenses; contact slightly uneven

10YR4/4 to 5/4, somewhat mottled, with some intervals more brownish (indistinct); contact diffuse, uneven

10YR4/3 to 4/4, brown to dark yellowish brown; contact somewhat uneven

Yellowish brown (10YR5/4 to 4/4); contact distinct, uneven

Dark brown to brown, somewhat grayish, slightly mottled; contact distinct, uneven

Brown to light brown (7.5YR5/3 to 6/3), silty mud with some IRD; contact somewhat uneven; a red speckle (iron oxide?) between 216-217 cm ("salmon colored" unit?)

Interlamination of brown and yellowish brown, mostly silty muds with some darker clumps (221.5-240.5 cm). 221.5-224.5 cm: Yellowish brown (10YR5/4 to 4/4), with some more brownish mottles, especially between 222-223 cm; contact diffuse, somewhat uneven

Brown to dark brown (10YR3/3 to 4/3), strongly mottled, contact uneven

Dark yellowish brown, slightly sandy mud; contact somewhat uneven

Brown to dark brown; contact distinct, uneven

Yellowish brown; contact distinct, uneven

Brown to dark brown; contact diffuse, uneven

Yellowish brown to dark yellowish brown, with some darker clumps; contact distinct, slightly uneven

Brown, somewhat mottled; contact strongly uneven

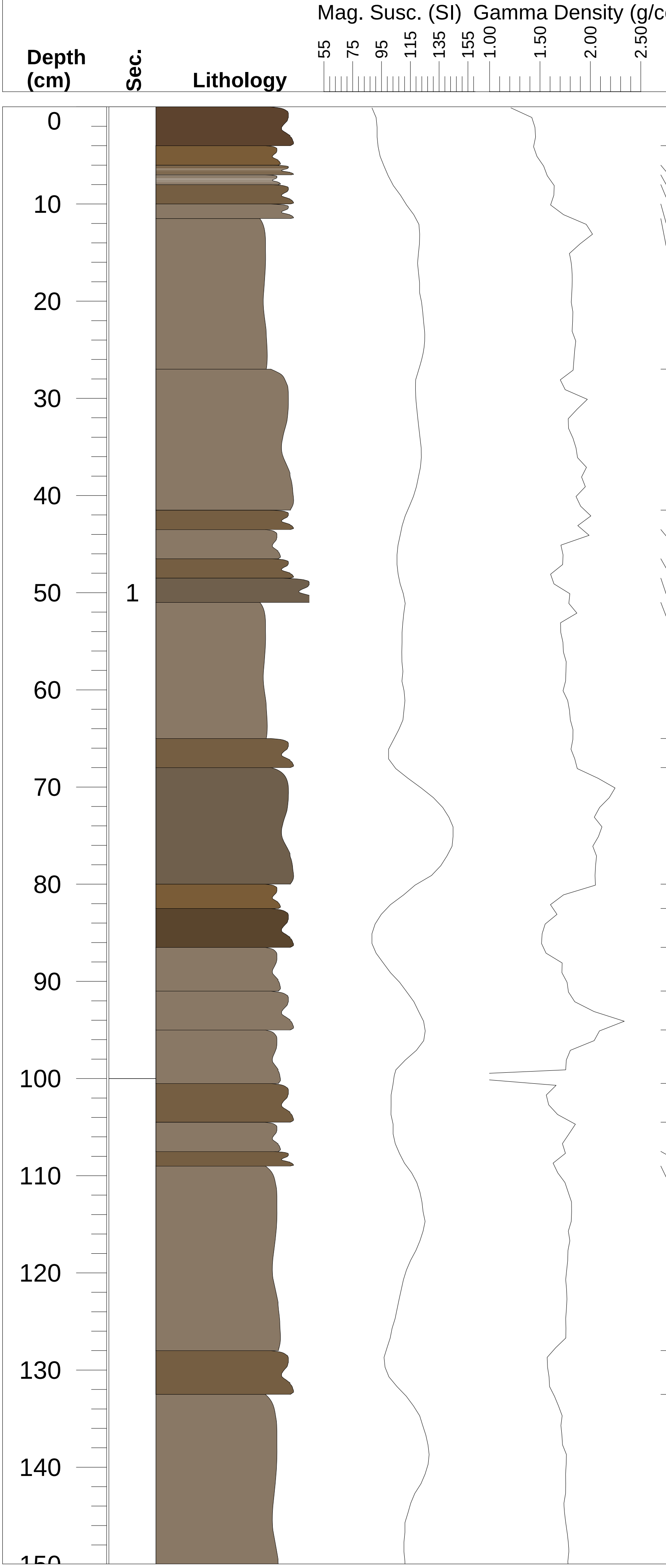
Yellowish brown to dark yellowish brown, with darker mottles; contact slightly uneven

Mostly dark brown (7.5YR3/3 to 10YR3/3), silty mud; some intervals are slightly lighter colored; some subtle mottling

# LOMROG07-PC-06

Position: 85°29.6'N, 46°16.4'W    Depth (m): 3007

Date Acquired: 8/28/2007    Described by: Leonid Polyak




**Description**

Dark brown, slightly sandy, very soft mud; contact strong bioturbated

Dark yellowish brown, silty, very soft mud with fine brown laminae; contact even

Brown, slightly sandy, very soft mud; contact uneven

Grayish brown, silty mud with fine brown laminae; contact uneven

Brown to dark brown, slightly sandy mud with some darker mottling; contact uneven

Grayish brown, very sandy mud with coarse clasts; contact relatively even

Grayish brown, fine-grained mud, lighter colored (10YR6/3) to ~16 cm; come light color mottling below; contact relatively even

Grayish brown to more yellowish, indistinctly laminated mud, with intense yellowish brown laminae at 27-27.5 cm and 34.5-35 cm; sandy mud with IRD at 29-30 cm and 35-36 cm; contact somewhat uneven

Brown to dark yellowish brown (10YR4/3 to 3/4), slightly sandy mud with IRD; contact uneven

Grayish brown, very soft, silty mud with fine brown laminae to 45 cm; contact slightly uneven

Brown to yellowish brown (10YR4/3 to 3/4), slightly sandy mud; contact mostly even

Dark grayish brown, muddy sand; contact mostly even

Grayish brown, soft, fine grained mud with indistinct lighter colored laminae; yellowish brown laminae to 53 cm; brown, somewhat sandy laminae below 58 cm; contact distinct, mostly even

Brown to dark grayish brown sandy mud with IRD; contact uneven.

Dark grayish brown to dark gray (10YR4/2 to 4/1), sandy mud; reddish small clumps (5YR4/3) and coarse clasts dispersed between 71.5-74.5 cm; contact slightly uneven

Dark yellowish brown, silty mud; contact somewhat uneven

Dark brown, slightly sandy mud; contact uneven

Grayish brown, silty mud with brown, slightly sandy laminae; dark grayish brown to 88 cm; contact relatively even

Similar in color, but much more sandy mud with IRD; contact indistinct, somewhat uneven

Similar in color, more fine-grained mud, with brown laminae, notably at 96.5-97 cm and 98-98.5 cm; contact uneven

Brown (10YR4/3 to 4/4), soft, slightly sandy mud with a lens of sandier sediment at 103 cm; contact somewhat uneven, gradual

Grayish brown, soft, silty mud with some mottling and a laminae of more brownish sediment at ~106 cm; contact distinct, uneven

Brown (10YR4/3 to 4/4), slightly sandy mud, darker at the top; contact uneven, gradual

Grayish brown, soft, silty mud with some indistinct mottles and laminae of brownish color to 119 cm, notably at 114-115 cm; more grayish laminae below 119 cm; some fine brown laminae at 127.5-128.5 cm; contact distinct, slightly uneven

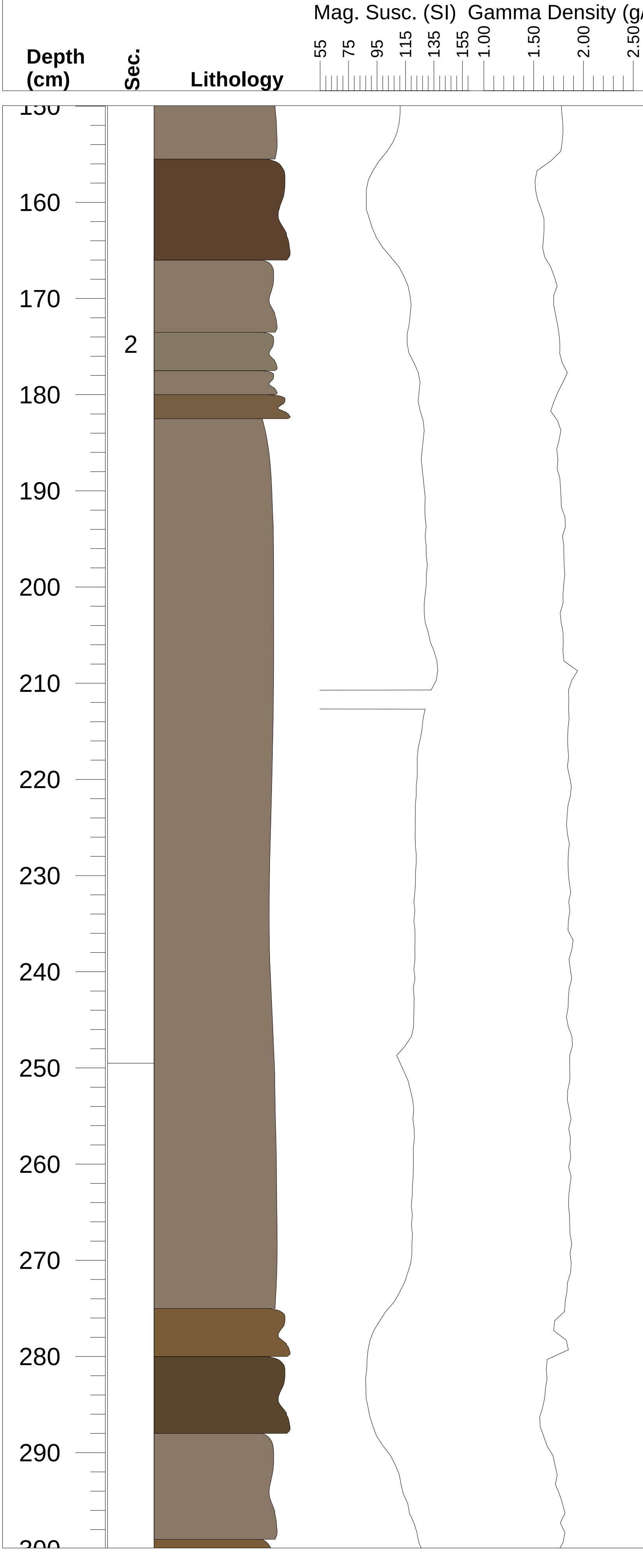
Brown to dark brown (10YR4/3 to 3/3), slightly sandy mud; contact uneven, gradual

Grayish brown, silty mud with patches of brown sediment to 142 cm; more grayish below; contact distinct, mostly even

# LOMROG07-PC-06

Position: 85°29.6'N, 46°16.4'W  Depth (m): 3007

Date Acquired: 8/28/2007  Described by: Leonid Polyak




**Description**

Dark brown (7.5YR3/3 to 10YR3/3), slightly sandy mud; slightly more dark grayish below ~162 cm; patches of lighter grayish sediment near the bottom; contact uneven, somewhat gradual

Grayish brown, silty mud with numerous mottles of dark brown sediment; contact subtle, uneven

Grayish brown (more grayish than above and below), fine-grained mud with indistinct lamination; some coarse clasts near the bottom; contact distinct, mostly even

Grayish brown, silty mud; contact slightly uneven

Brown (10YR4/3 to 4/4), slightly sandy mud; contact uneven, somewhat gradual

Grayish brown, mostly fine-grained mud; indistinct brownish mottling to ~202 cm; a brownish band at 184-186 cm; color more grayish below 212 cm; several sandy laminae, notably at 208.5 cm, 236.5 cm, 237.5 cm, 259 cm, and 270.5 cm; contact distinct, mostly even

Dark yellowish brown to brown (10YR4/4 to 4/3), somewhat sandy mud; a dark gray, indistinct lamina (more sandy?) at 278-279 cm; contact uneven, gradual

Dark brown, very slightly sandy mud with mottles of lighter colored sediment; contact uneven, somewhat gradual

Grayish brown, silty mud with patches of dark brown color; contact distinct, slightly uneven

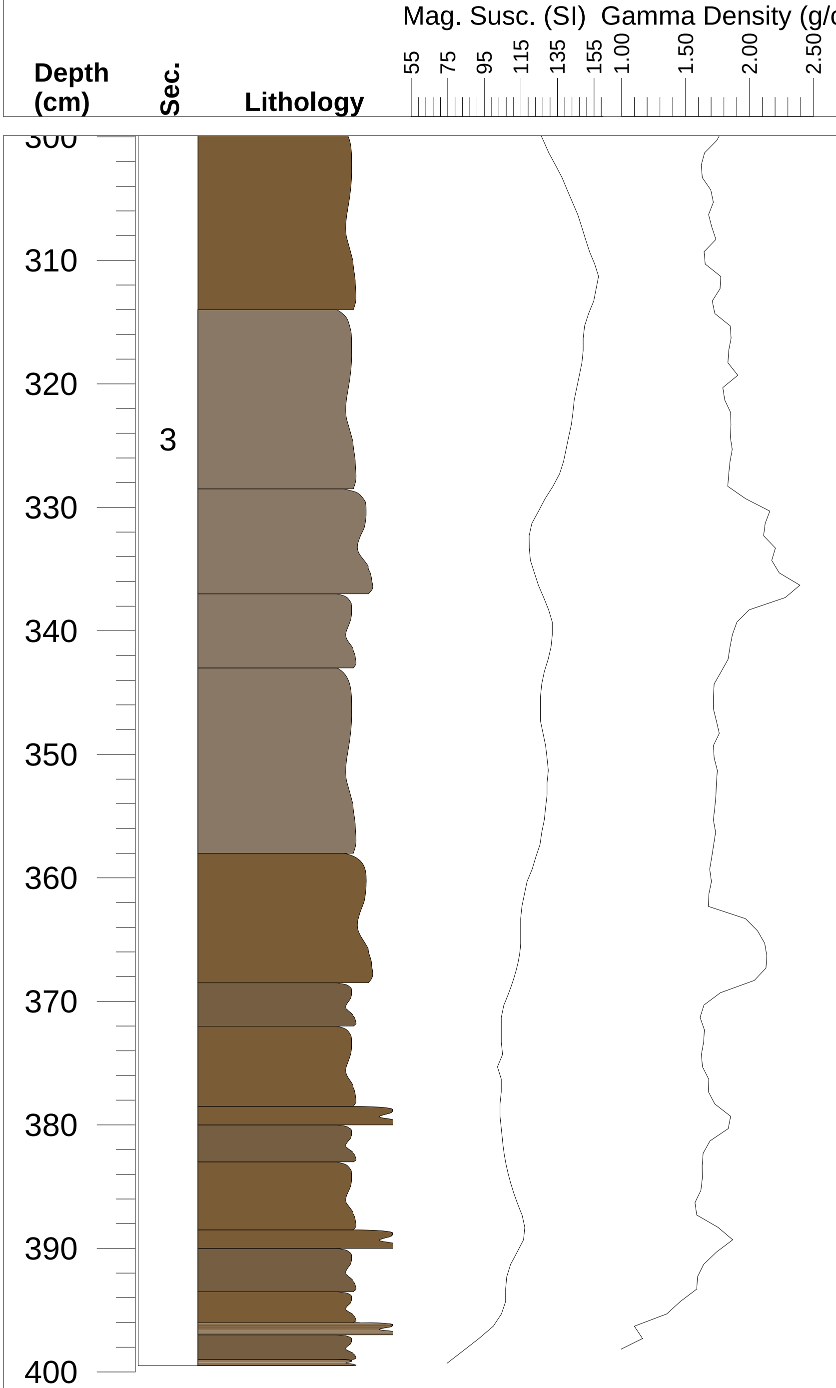
# LOMROG07-PC-06

Position: 85°29.6'N, 46°16.4'W

Depth (m): 3007

Date Acquired: 8/28/2007

Described by: Leonid Polyak




**Description**

Interlamination of dark yellowish brown (predominant color), brown and grayish laminae; mostly fine-grained but with some sandy laminae, notably at 304.5 cm; contact distinct, mostly even

Grayish brown, silty mud with some brownish laminae between 316-320 cm; a few dark-colored patches; contact uneven

Grayish brown to brown (10YR5/2 to 5/3), very sandy mud with abundant IRD; contact uneven

Grayish brown, fine-grained mud; contact strongly uneven, oblique

Grayish brown to brown (10YR5/2 to 5/3), silty mud with darker colored mottles; a dark grayish brown band with indistinct contacts on top; contact uneven

Dark yellowish brown to brown (10YR4/4 to 4/3), slightly sandy mud with IRD; a 7 cm dropstone; contact disturbed

Brown (10YR4/3 to 3/3), mostly silty mud, somewhat mottled; contact uneven, somewhat gradual

Dark yellowish brown, silty mud, indistinctly mottled; contact distinct, slightly uneven

Dark yellowish brown, muddy sand layer; contact distinct, mostly even

Brown (10YR4/3 to 3/3), mostly silty mud, somewhat mottled; contact uneven, somewhat gradual

Dark yellowish brown, silty mud, indistinctly mottled; contact distinct, slightly uneven

Dark yellowish brown, muddy sand layer; contact distinct, mostly even

Brown (10YR4/3 to 3/3), mostly silty mud, somewhat mottled; contact uneven, somewhat gradual

Dark yellowish brown, silty mud, indistinctly mottled; contact distinct, slightly uneven

Dark yellowish brown, muddy sand layer; contact distinct, mostly even

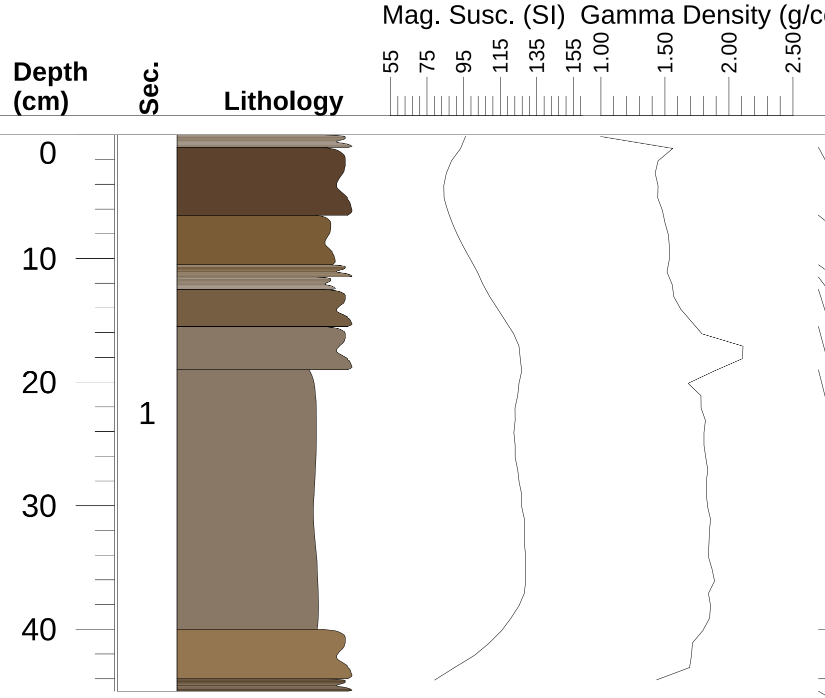
Brown (10YR4/3 to 3/3), mostly silty mud, somewhat mottled; contact uneven, somewhat gradual

Dark yellowish brown, silty mud, indistinctly mottled; contact distinct, slightly uneven

# LOMROG07-TC-06

Position: 85°29.6'N, 46°16.4'W Depth (m): 3007

Date Acquired: 8/28/2007 Described by: Leonid Polyak



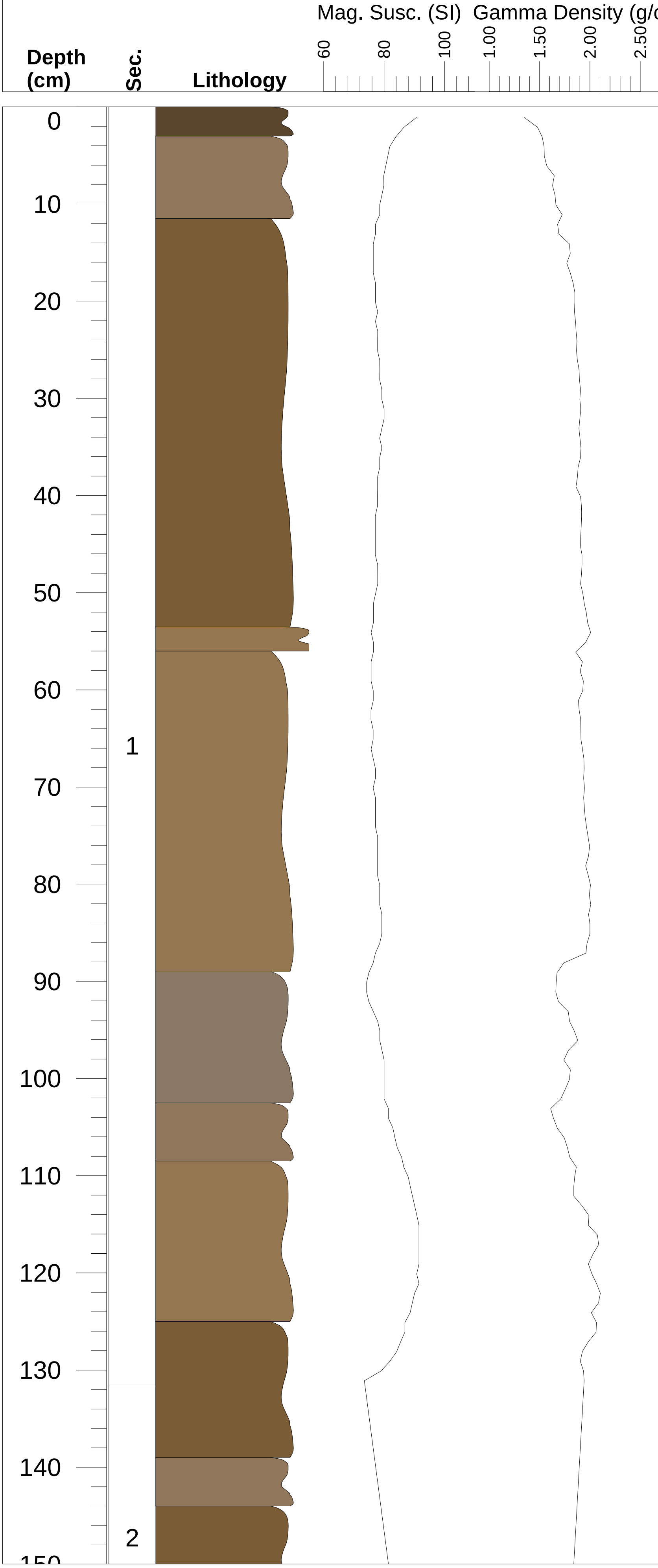

**Description**

| Description |
|---|
| Grayish brown, slightly sandy, very soft, watery mud; distinct, slightly uneven contact |
| Dark brown, slightly sandy, very soft mud; contact strongly bioturbated |
| Dark yellowish brown (10YR4/4 to 4/6), silty, very soft mud, with fine brownish (more sandy?) laminae; mostly even contact |
| Brown, slightly sandy, very soft mud; even contact |
| Grayish brown, silty mud with fine brown laminae; very soft; contact even |
| Brown to dark brown (10YR4/3 to 3/3), slightly sandy mud with some darker mottling; contact somewhat uneven |
| Grayish brown, very sandy mud with coarse clasts; some lighter and darker indistinct laminae; contact even |
| Grayish brown, fine-grained mud, with lighter-colored mottling; indistinct lamination below 35 cm; contact distinct, slightly uneven, oblique |
| Similar sediment, but more yellowish and sandy; especially at the top; contact distinct, oblique due to coring disturbance |
| Dark brown, slightly sandy mud with grayish, fine laminae |

# LOMROG07-PC-07

Position: 85°23.98'N, 014°16.92'W    Depth (m): 1252

Date Acquired: 9/1/2007    Described by: Leonid Polyak




**Description**

Brown to dark brown, variable sandy mud; contact uneven, oblique

Brown (10YR5/3 to 5/4), variably sandy mud; contact even

Dark yellowish brown to brown (10YR4/4 to 4/3), variably sandy mud with mud clumps between ~15-20 cm; darker mottles below; the bottom ~3 cm are more grayish

Yellowish brown to brown (10YR5/4 to 5/3), muddy sand; gradual transition to less sandy sediment below

Yellowish brown, variably sandy mud; more sandy next to top; somewhat darker color below ~80 cm

Grayish brown, soft, slightly sandy mud with small, indistinct; color slightly yellowish below ~96 cm; a darker colored lamina at the bottom; gradual transition

A similar sediment with more brown color (10YR5/3 to 6/3); a darker lamina at the bottom; gradual transition

Yellowish brown (10YR5/4 to 5/3), sandy mud, grading to muddy sand below ~103 cm; contact distinct, slightly uneven

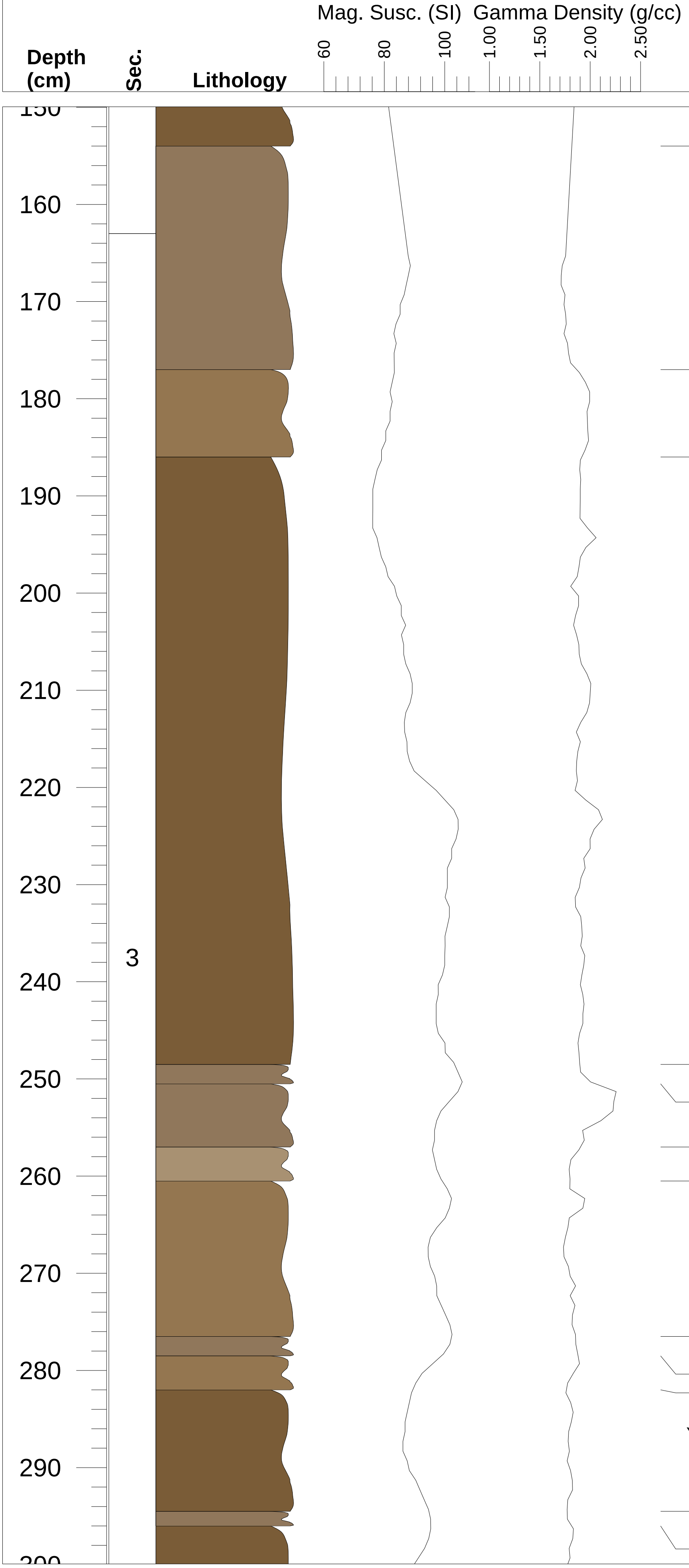
Dark yellowish brown, slightly sandy, slightly mottled; contact somewhat uneven

Brown to yellowish brown (10YR5/3 to 5/4), soft, somewhat sandy mud with IRD; contact uneven, gradual

Dark yellowish brown, sandy mud with indistinct mottling; more brownish near the bottom; contact uneven

# LOMROG07-PC-07

Position: 85°23.98'N, 014°16.92'W
Depth (m): 1252
Date Acquired: 9/1/2007
Described by: Leonid Polyak


**Description**

Brown to yellowish brown (10YR5/3 to 5/4), sandy mud, soft; contact indistinct by increase of sand content

Yellowish to dark yellowish brown (10YR5/4 to 4/4), very sandy mud with some mud clumps; contact subtle

Dark yellowish brown, sandy mud with some indistinct mottling; lighter colored grayish laminae between 198-206 cm; very sandy, lighter colored layers at ~208 cm and between 220-223 cm; sediment more sandy between ~225-232 cm; contact distinct, uneven

Brown to pale brown (10YR5/3 to 6/3), somewhat sandy mud; contact subtle, by a slight change in color

Brown to yellowish brown (10YR5/3 to 5/4), sandy mud woth IRD; contact uneven

Pale brown, somewhat sandy mud; contact subtle, uneven

Yellowish to dark yellowish brown (10YR5/4 to 4/4), sandy mud; more sandy between 270-273 cm; darker colored below; contact uneven

Brown to pale brown (10YR5/3 to 6/3) ,somewhat sandy mud; contact uneven

Dark yellowish brown, slightly mottled mud; contact slightly uneven

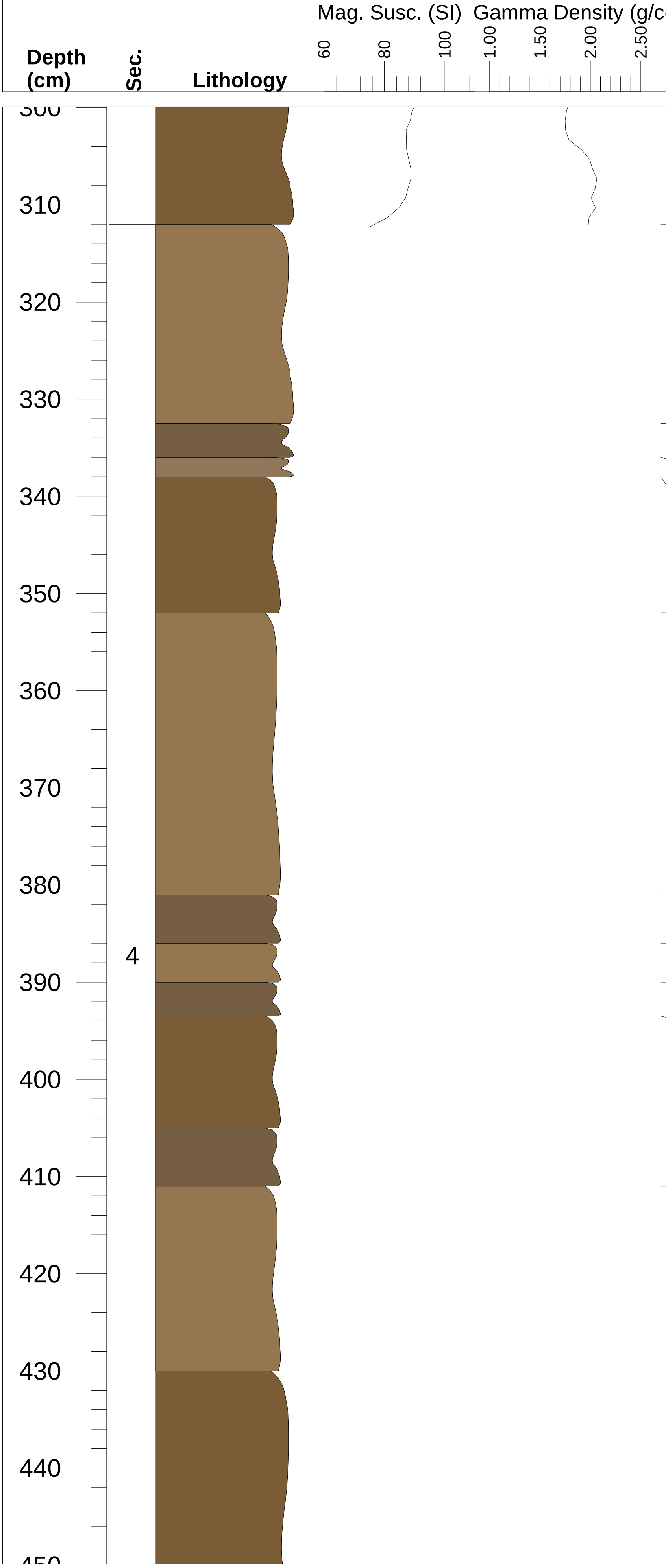
Yellowish brown, slightly sandy mud with somewhat variable color: intervals of darker and lighter color, some more brownish; sediment is more sandy below 291 cm; contact uneven

Brown to pale brown (10YR5/3 to 6/3), slightly sandy mud; contact uneven

# LOMROG07-PC-07

Position: 85°23.98'N, 014°16.92'W    Depth (m): 1252

Date Acquired: 9/1/2007    Described by: Leonid Polyak


**Description**

Dark yellowish brown sandy mud; ends at the section end (suspicious)

Yellowish brown, slightly sandy mud with more brownish sediment at 312-314 cm, 316-317 cm, and 319-321 cm; indistinct, fine lamination near the bottom; gradual transition

Brown to dark brown (10YR4/3 to 3/3), slightly sandy mud; contact somewhat uneven, gradual

Brown to pale brown (10YR5/3 to 6/3), slightly sandy mud; contact distinct, slightly uneven

Dark yellowish brown to brown (10YR4/4 to 4/3), mostly silty mud with darker mottling; intervals 338-343 cm and 348-352 cm are more brownish; contact distinct

Yellowish brown, mostly silty mud, possibly more sandy near the top; a larger dropstone at 374-380 cm; contact uneven

Brown to dark brown (10YR4/3 to 3/3), silty, mottled mud; contact uneven, somewhat gradational

Yellowish brown to grayish silty mud; contact uneven

Brown to dark brown, silty, indistinctly laminated mud; contact uneven

Dark yellowish brown, silty mud, with darker mottling; gradual transition

Brown to dark yellowish brown (10YR4/3 to 4/4), silty mottled mud; gradual transition

Yellowish brown, silty, mottled mud, more brownish near the top; contact distinct

Dark yellowish brown, sandy mud to muddy sand; notably, sand layers at 430-434 cm, 441-443 cm, 449-451 cm, and below 459 cm

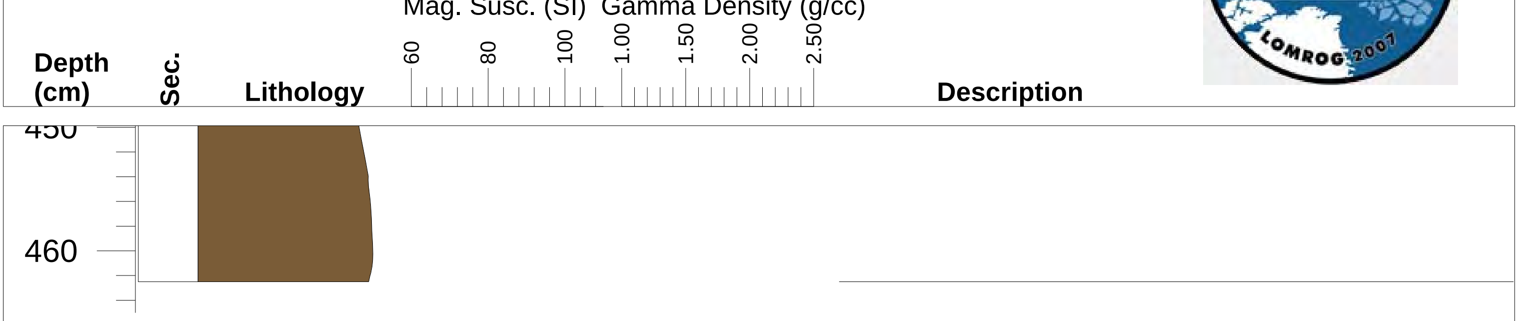
# LOMROG07-PC-07

Position: 85°23.98'N, 014°16.92'W

Date Acquired: 9/1/2007

Depth (m): 1252

Described by: Leonid Polyak



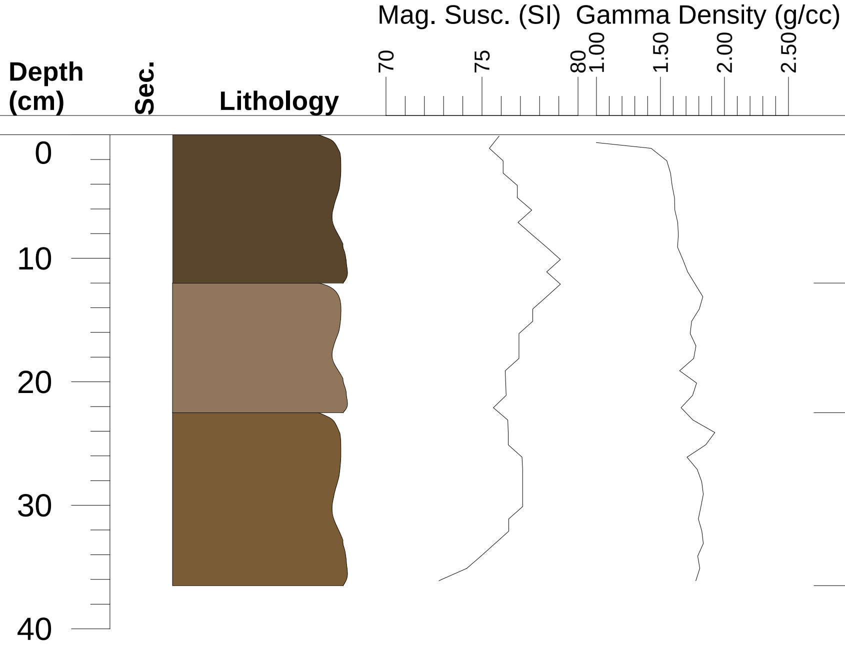
# LOMROG07-TC-07

Position: 85°23.98'N, 014°16.92'W

Depth (m): 1252

Date Acquired: 9/1/2007

Described by: Leonid Polyak




**Description**

Brown to dark brown, variably sandy mud; somewhat more dark grayish near the bottom (below ~10 cm); a layer of biogenic lag (bryozoans, sponge spicules, worme tubes, benthic forams) at ~4.5-5.5 cm; contact uneven

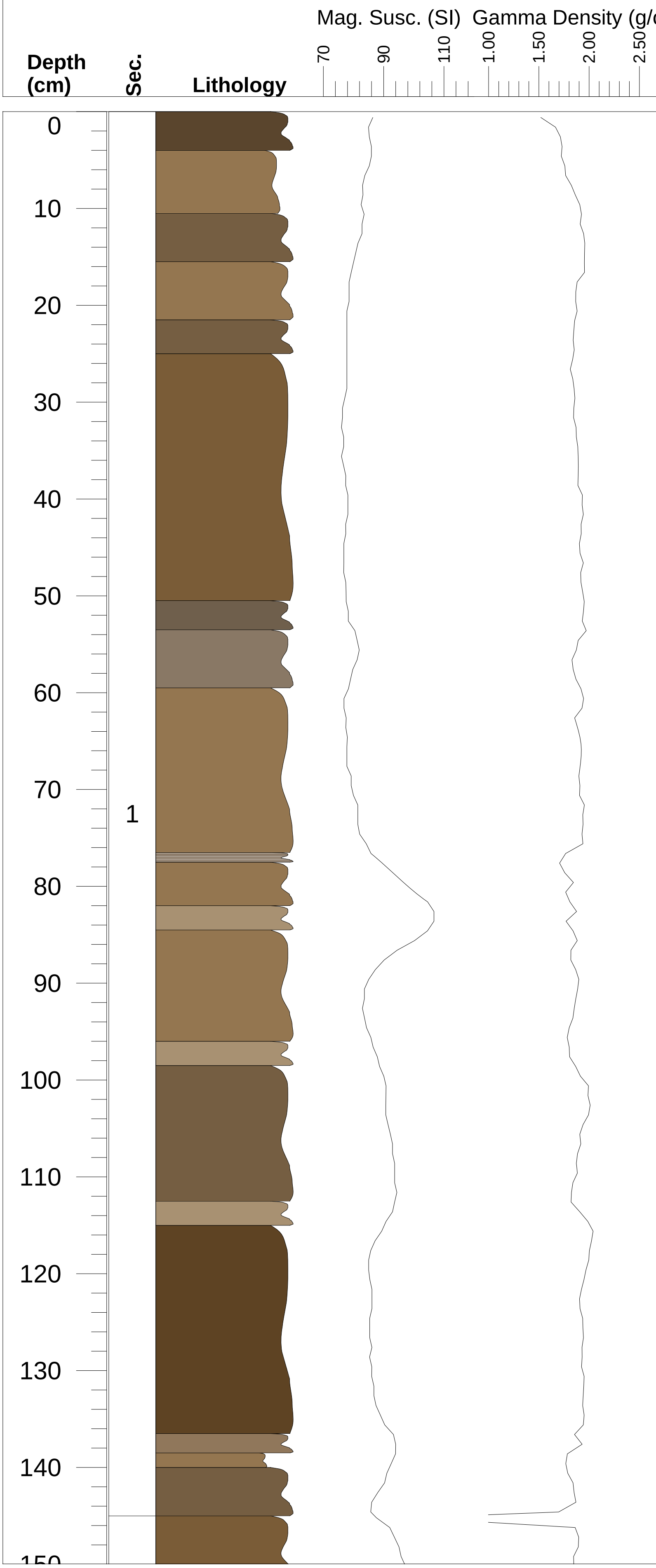
Brown to yellowish brown (10YR5/3 to 5/4), variably sandy mud; brownish, indistinct laminae between 16-19 cm; contact mostly even

Dark yellowish brown to brown (10YR4/4 to 4/3), sandy mud, with abundant mud clumps below 31 cm ('cottage cheese' structure)

# LOMROG07-PC-08

Position: 85°19.19'N, 014°51.45'W    Depth (m): 1038

Date Acquired: 9/2/2007    Described by: Leonid Polyak



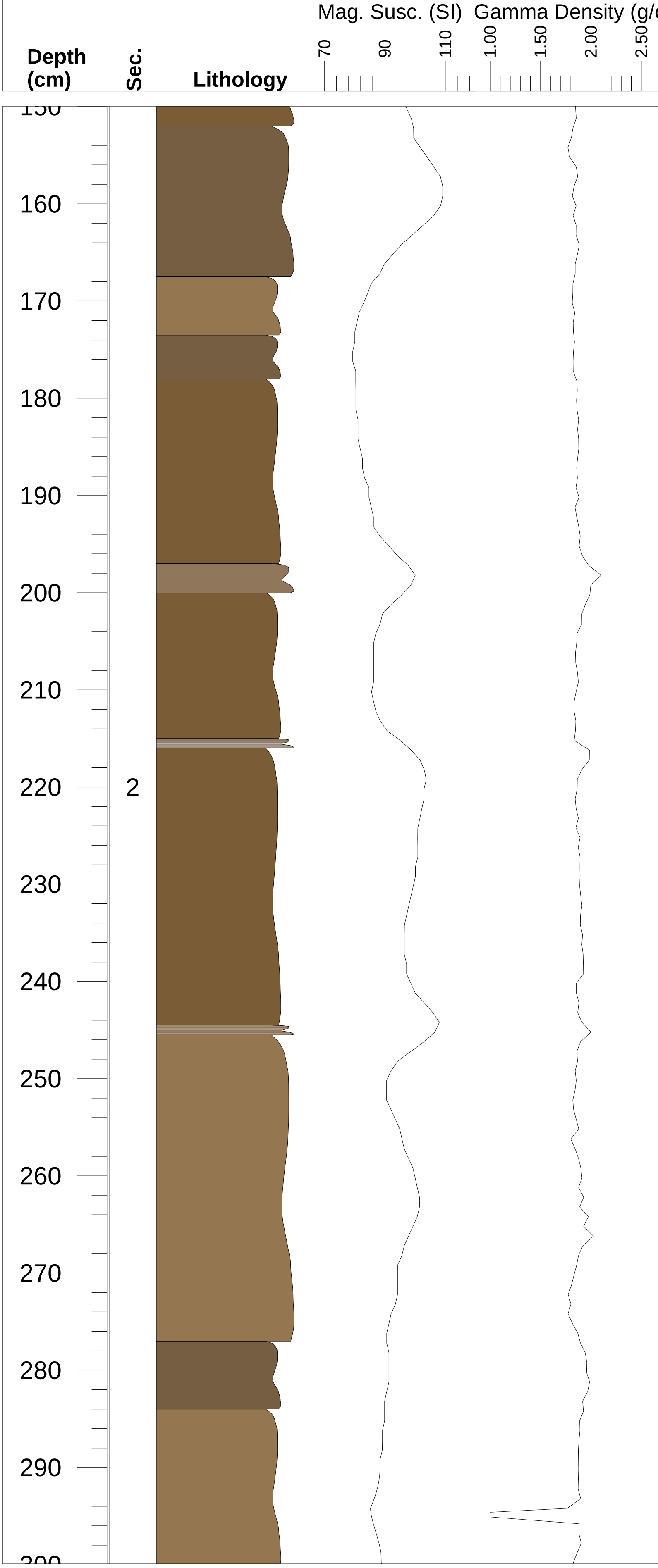

**Description**

- Brown to dark brown (10YR3/3 to 4/3), soft, slightly sandy mud; contact somewhat uneven
- Yellowish brown to brown (10YR5/4 to 4/3), silty to slightly sandy mud, more brownish between 5.5-7.5 cm; contact uneven, indistinct
- Brown to dark yellowish brown, slightly sandy mud; contact indistinct, uneven
- Yellowish brown, slightly sandy mud; contact distinct, slightly uneven
- Brown to dark yellowish brown (10YR4/3 to 4/4), slightly sandy to silty mud; mottled with a distinct brown lamina on top
- Dark yellowish brown, slightly sandy mud, mottled between 25-40 cm and 44-47 cm; a lighter colored lamina at the bottom; contact slightly uneven
- Dark grayish brown, sandy mud to fine sand; contact distinct, mostly uneven
- Grayish brown to brown (10YR5/2 to 5/3), soft, sandy mud; more grayish to 55 cm, more brownish below; contact subtle, slightly unclear
- Dark yellowish brown, slightly sandy to silty mud, mottled, more brownish between 65-70 cm; contact distinct, slightly uneven
- Grayish brown, soft, slightly sandy mud; gradational transition
- Yellowish brown, slightly sandy mud; gradational transition
- Pale brown, slightly sandy mud; probably detrital carbonate; contact distinct, slightly uneven
- Yellowish brown, slightly sandy mud; gradational transition
- Pale brown, slightly sandy mud; contact uneven
- Brown, strongly mottled, slightly sandy mud; contact uneven
- Pale brown, sandy mud; probably detrital carbonate; contact distinct, slightly uneven
- Dark yellowish brown, very sandy mud, with a few indistinct, brown laminae between 120-126 cm; distinct, slightly uneven contact
- Brown, soft, slightly sandy mud, with IRD; contact slightly uneven
- Yellowish brown, soft mud; contact somewhat uneven, gradational
- Brown to yellowish brown, mottled, slightly sandy mud; contact coincides with section break (suspicious)
- Yellowish brown, sandy mud; contact slightly uneven

# LOMROG07-PC-08

Position: 85°19.19'N, 014°51.45'W    Depth (m): 1038

Date Acquired: 9/2/2007    Described by: Leonid Polyak




**Description**

Brown to yellowish brown, slightly sandy mud, indistinctly mottled or laminated; contact uneven

Yellowish brown, silty mud; contact slightly uneven

Brown to yellowish brown, silty mud, indistinctly mottled or laminated; contact slightly uneven

Yellowish brown, silty mud, somewhat mottled; contact slightly uneven

Brown, sandy mud with IRD; contact disturbed

Yellowish brown, silty mud; a lighter colored layer at 206-208 cm; a brown lamina at 211-212 cm; contact distinct, slightly uneven

Grayish brown, slightly sandy mud; contact gradational

Yellowish brown, silty mud, slightly lighter colored near the top; with brown laminae or mottles, notably at 224 cm, 230 cm, 235 cm and near the bottom; contact distinct, slightly uneven, accentuated by a fine sand lamina

Brown to pale brown (10YR5/3 to 6/3), slightly sandy mud; contact gradational

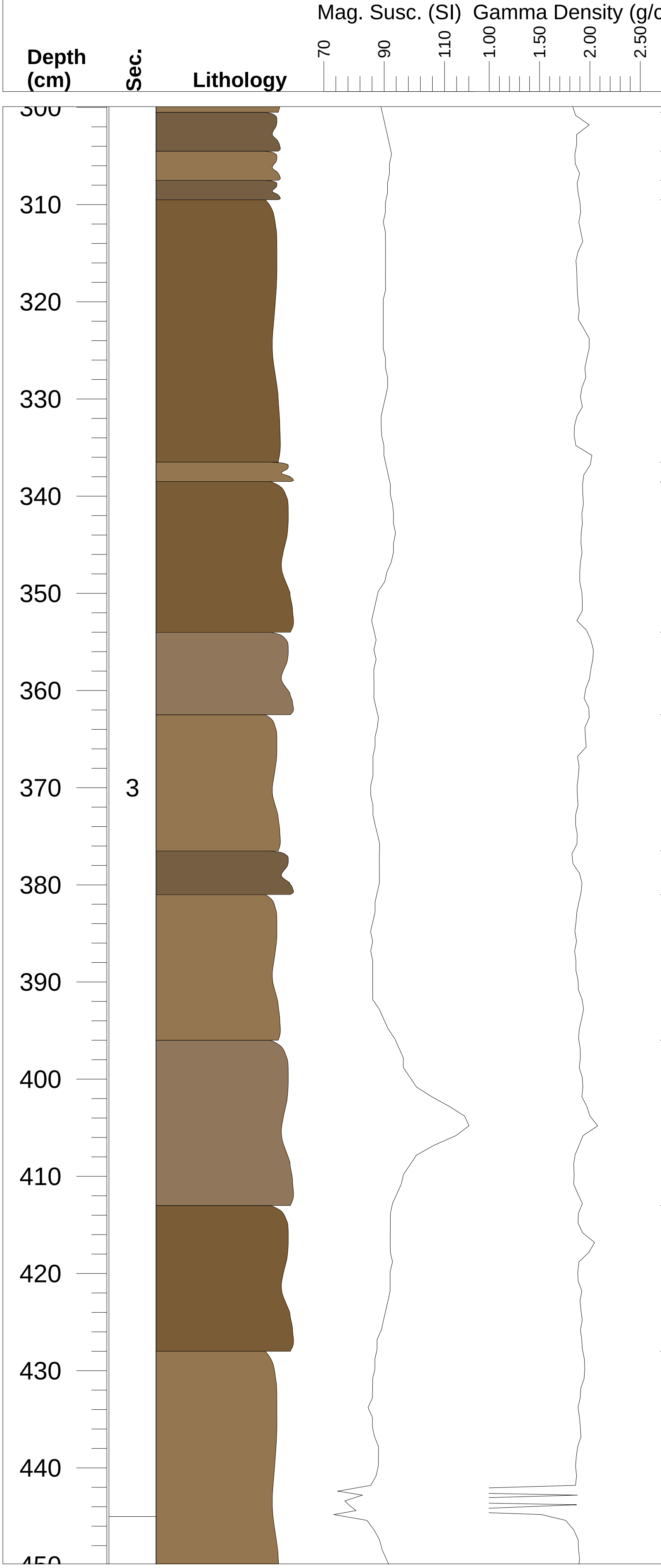
Yellowish brown to brown, slightly sandy mud with IRD, mottled, more lighter colored to ~250 cm; with indistinct brown layers between 250-270 cm and especially pronounced at 273.5-274.5 cm; whitish speckles in the bottom ~2 cm (detrital carbonate?); contact uneven

Brown to yellowish brown, somewhat mottled, silty mud; contact uneven somewhat gradational

Yellowish brown, silty mud; contact uneven

# LOMROG07-PC-08

Position: 85°19.19'N, 014°51.45'W
Depth (m): 1038
Date Acquired: 9/2/2007
Described by: Leonid Polyak




**Description**

Brown, silty mud with indistinct mottling/laminae; contact uneven, indistinct

Yellowish brown, silty mud; contact uneven, indistinct

Brown, silty mud with indistinct mottling; contact uneven, indistinct

Dark yellowish brown, silty mud with some dark brown mottles, notably at ~312 cm; a sandy layer at 324-325 cm; contact strongly uneven

Yellowish brown to pale brown (10YR5/4 to 6/3), sandy mud; contact uneven

Dark yellowish brown, slightly sandy mud

Brown to yellowish brown, slightly sandy mud; darker colored patch at 360-361 cm; lighter colored near the top; contact uneven

Yellowish brown, relatively light colored, silty mud; the upper ~1 cm, especially light colored; contact somewhat uneven

Brown, silty mud with indistinct mottling; contact uneven

Yellowish brown, silty mud; below ~390 cm-interlamination with sediment below (brown sandy mud); gradual transition

Brown, sandy mud with IRD; a lighter colored (10YR5/3 to 4/3) lamina at 405-406 cm; gradual transition

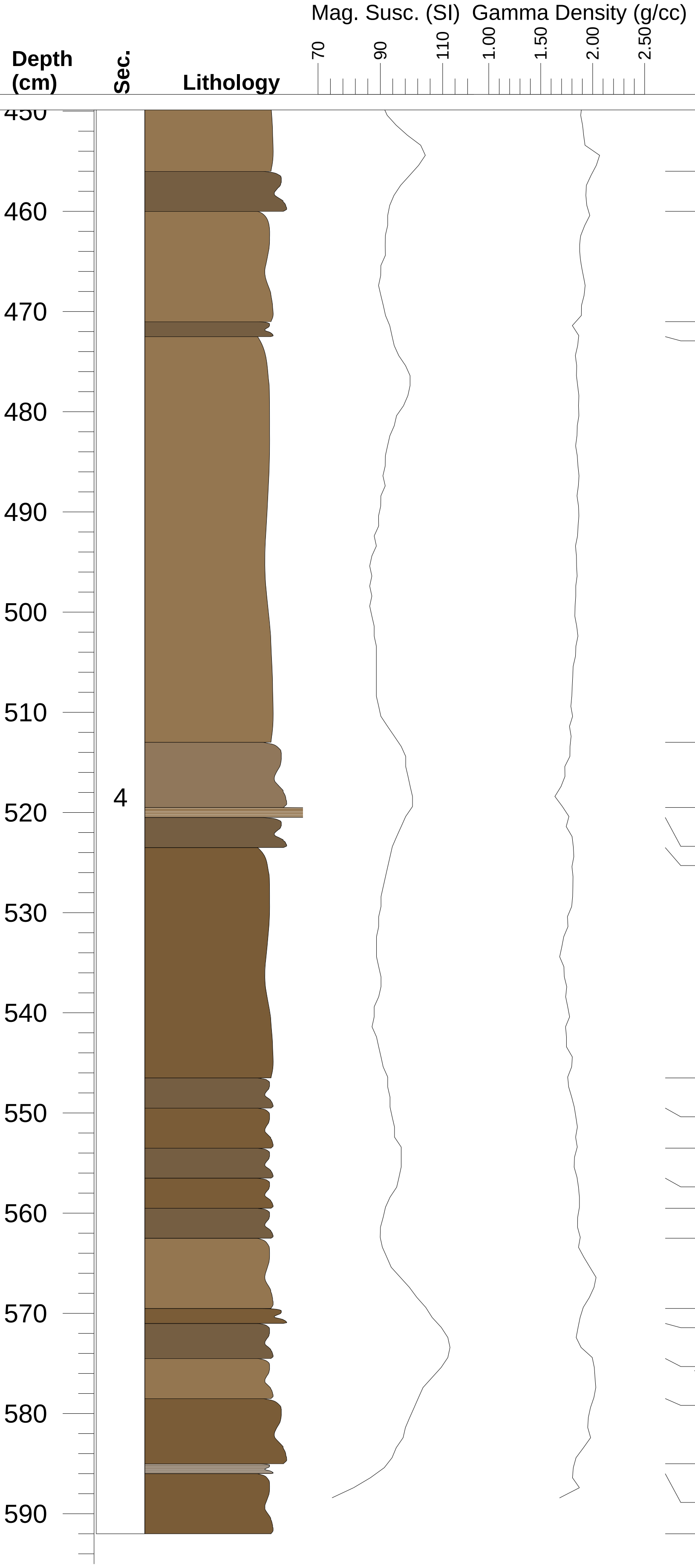
Dark yellowish brown, slightly sandy mud, mottled; contact slightly uneven

Yellowish brown, relatively light colored, silty mud; with some IRD; a brownish sandy layer at the bottom; contact slightly uneven

# LOMROG07-PC-08

Position: 85°19.19'N, 014°51.45'W Depth (m): 1038

Date Acquired: 9/2/2007 Described by: Leonid Polyak




**Description**

Brown to dark yellowish brown, slightly sandy mud; contact indistinct

Yellowish brown, relatively light colored, silty mud with some mottling below 467 cm; contact uneven

Brown, silty mud layer; contact slightly uneven

Yellowish brown, mostly silty mud with some sandy intervals; 476-483 cm slightly more brownish with IRD; 488-492 cm-also more brownish; 502-504 cm-sandy; contact slightly uneven

Brown, slightly sandy mud with some IRD; contact slightly uneven

Yellowish brown, relatively light colored, silty mud; contact slightly uneven

Brown, slightly sandy mud; gradational transition

Dark yellowish brown to lighter colored (10YR4/4 to 5/4), silty mud; grading into lighter color down-core; distinctly mottled below 542 cm; contact slightly uneven

Brown to dark yellowish brown, silty mottled mud; contact slightly uneven

Dark yellowish brown, silty, mottled mud; gradual transitions

Brown to dark yellowish brown, silty mud, mottled; contact slightly uneven

Dark yellowish brown, silty mud, mottled; gradual transition

Brown, silty mud, mottled; contact uneven

Yellowish brown, relatively light colored, silty mud; contact slightly uneven

Dark yellowish brown , sandy mud; contact slightly uneven

Brown to dark yellowish brown, mottled, silty mud; gradual transition

Yellowish brown, relatively light-colored, silty mud; contact slightly uneven

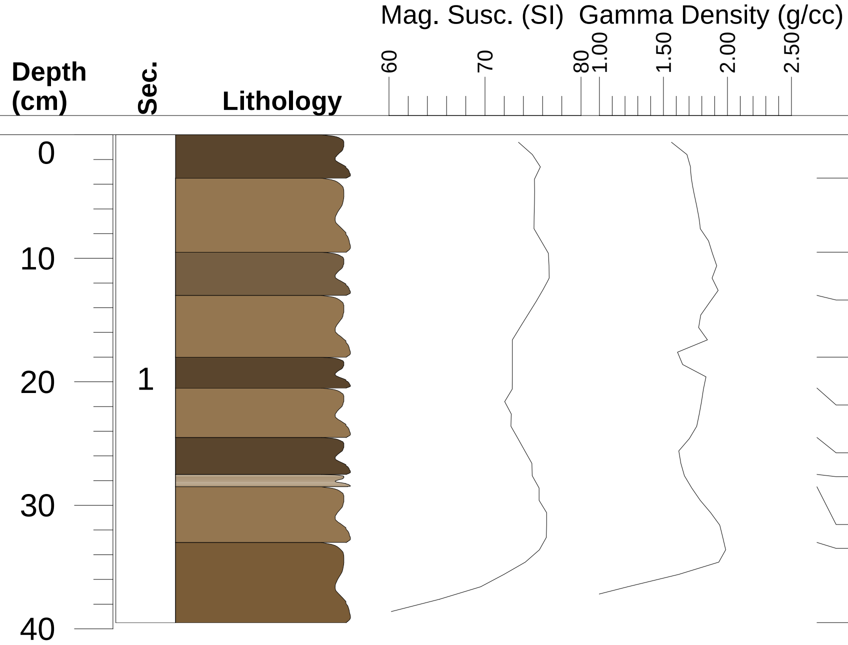
Dark yellowish brown, slightly sandy mud; brown lamina at the bottom; contact distinct, slightly uneven

Grayish brown, light colored, silty mud layer; contact slightly uneven

Dark yellowish brown, silty mud; mottled

# LOMROG07-TC-08

Position: 85°19.19'N, 014°51.45'W
Depth (m): 1038
Date Acquired: 9/2/2007
Described by: Leonid Polyak




**Description**

Dark brown, slightly sandy mud; contact distinct, somewhat uneven

Yellowish brown, slightly sandy mud, more brownish between 5.5-7 cm; contact somewhat uneven, gradual

Brown, sandy mud with indistinct mottling; contact somewhat uneven, gradual

Yellowish brown, sandy mud with sand lenses near the top; contact uneven

Uneven mixture of brown and yellowish brown, somewhat sandy mud (mottling? lamination?); contact somewhat uneven

Yellowish brown, somewhat sandy mud, with a yellowish lamina (lense?) at 22-23 cm; contact uneven

Brown to dark brown, slightly sandy mud; contact uneven

Pale brown to brown (10YR6/3 to 5/3), sandy mud with darker mottles (clumps?); contact uneven

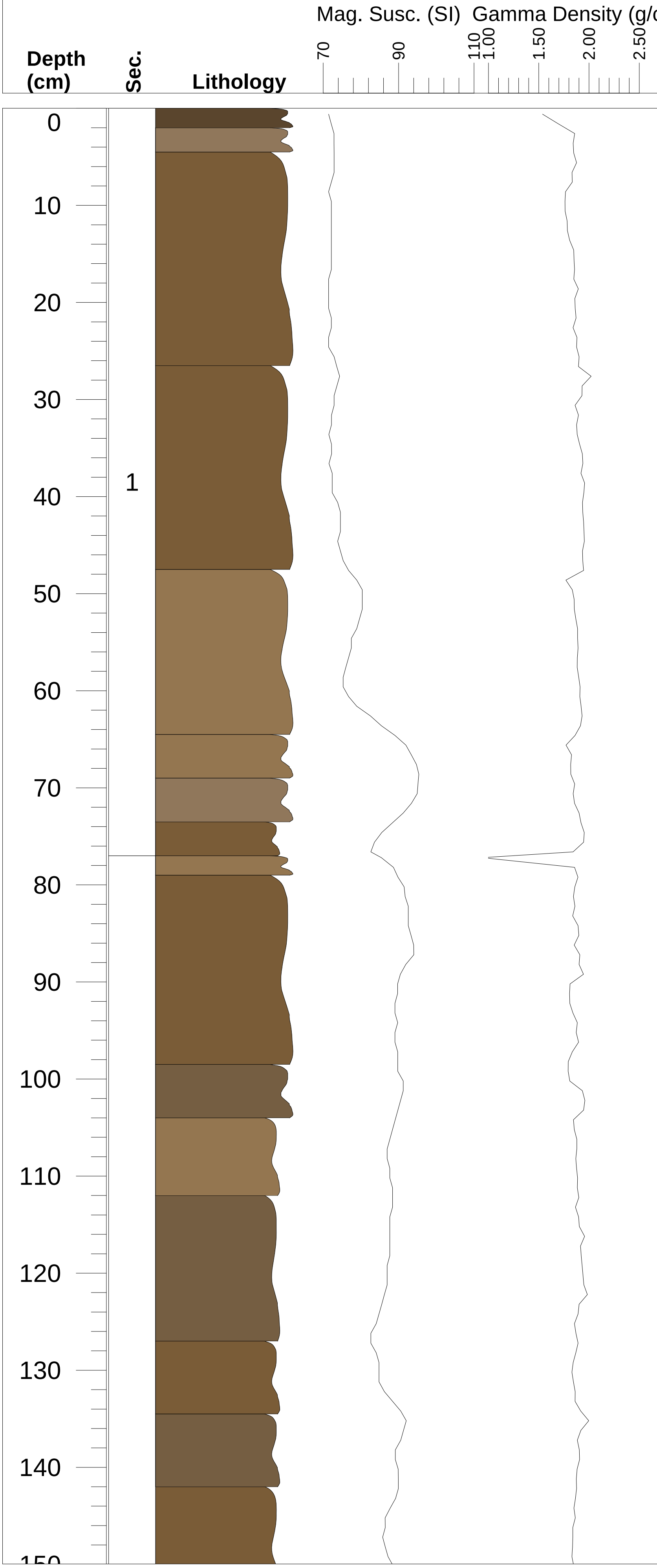
Yellowish brown, sandy mud; contact somewhat uneven

Dark yellowish brown to brown (10YR4/4 to 4/3), sandy mud; more brownish above ~36 cm

# LOMROG07-GC-09

Position: 85°17.67'N, 014°53.53'W Depth (m): 1016

Date Acquired: 9/3/2007 Described by: Leonid Polyak




**Description**

Dark brown, slightly sandy, soft mud; a Scaphopode picked at the bottom of the unit; contact uneven, oblique (0.5-3.5 cm)

Brown to pale brown, lumpy sandy mud; contact uneven, oblique (3.5-5.5 cm)

Mostly dark yellowish brown, variably colored, slightly sandy to silty mud; more brownish to 7 cm; increasingly grayish below ~20 cm, with brownish laminae at 21-22 cm and 23-24 cm; dark grayish brown (10YR4/2) below 24 cm; contact distinct, mostly even

Variably colored unit (sandy mud) gradually changing color from light yellowish brown above 29.5 cm to dark grayish brown below 42 cm; dark mottles/speckles especially below 40 cm; contact distinct, even

Variably colored unit (sandy mud), similar to above, but overall slightly lighter colored; grayish brown (10YR5/2) at the top, yellowish brown at most of the unit, slightly more grayish below 59 cm; contact slightly uneven, oblique

Strongly yellowish brown, slightly sandy, soft mud; contact slightly uneven

Brown to grayish brown, mottled, slightly sandy mud; light colored (detrital carbonate?) mottles at the bottom; contact uneven

Dark yellowish brown, silty mud; slightly mottled; contact coincides with section break

Yellowish brown, soft, slightly sandy mud, light colored

Dark yellowish brown, slightly sandy to silty mud; more brownish between 84-89 cm and below 95 cm; gradual transition

Brown to dark yellowish brown, slightly sandy and mottled mud; contact uneven

Yellowish brown, silty mud; brownish layer at 109-110 cm; contact strongly uneven, oblique

Brown to dark yellowish brown, very slightly sandy mud; contact slightly uneven

Interlamination from 127-226 cm of more brownish (10YR4/3) to yellowish brown (10YR4/4 to 5/4), mostly silty mud with some sandy intervals; 127-134.5 cm Yellowish brown silty mud

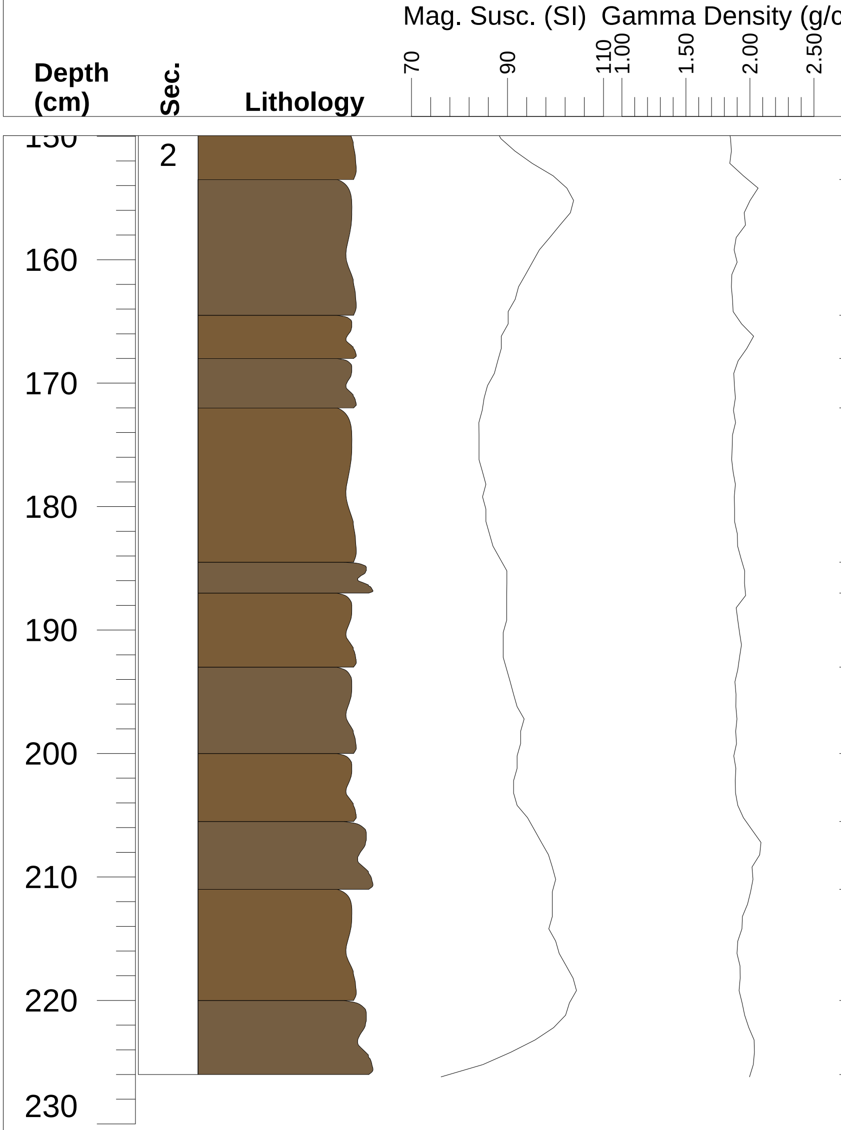
Brown, silty mud; sandy lamina on top; contact uneven

Yellowish brown silty mud

# LOMROG07-GC-09

Position: 85°17.67'N, 014°53.53'W    Depth (m): 1016

Date Acquired: 9/3/2007    Described by: Leonid Polyak




**Description**

Brown, silty mud; sandy layer at 154-156 cm; contact uneven, with patches of same sediment below

Yellowish brown silty mud

Brown, silty mud; uneven, gradual contact

Yellowish brown silty mud

Brown, sandy mud with relatively distinct contacts

Yellowish brown silty mud

A few brownish laminae within this, mostly yellowish brown interval, silty mud

Yellowish brown silty mud

Brown, sandy mud with IRD; relatively distinct contacts

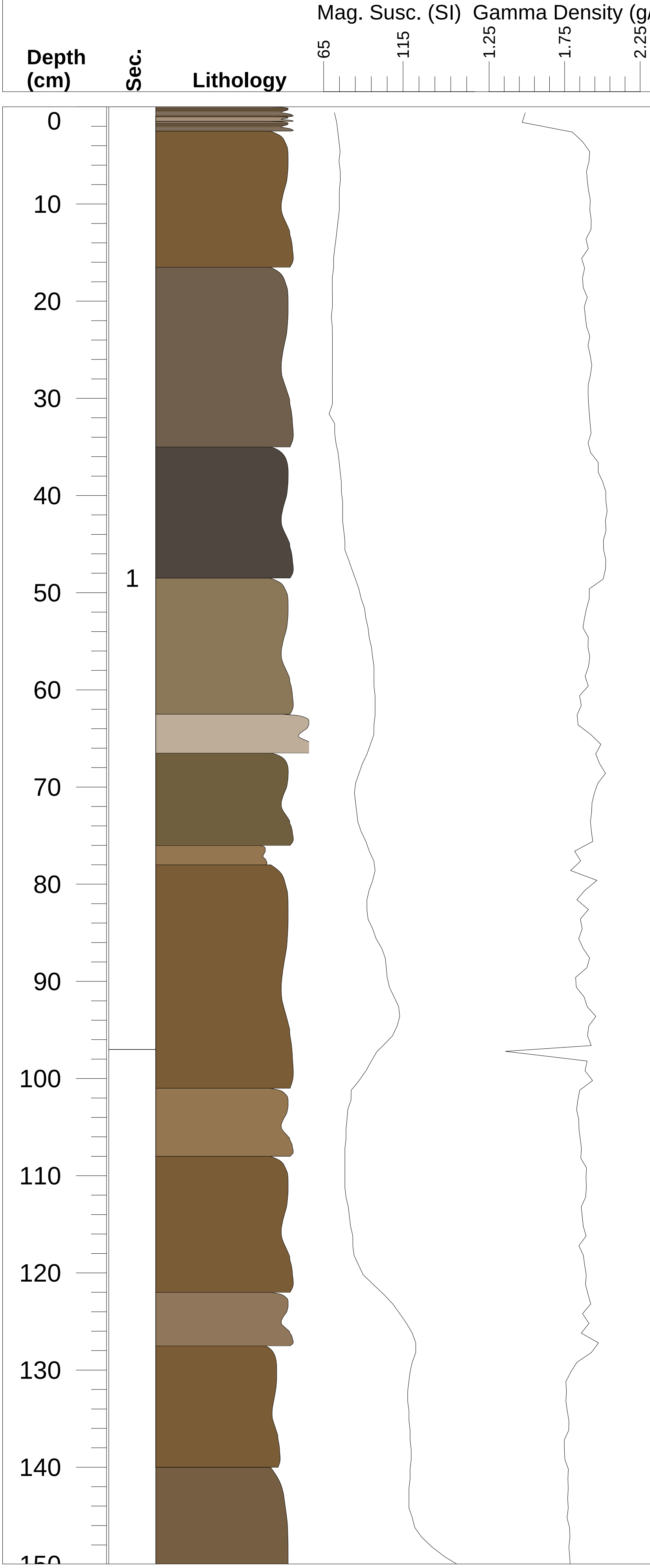
Yellowish brown silty mud

Brown, slightly sandy, mottled mud

# LOMROG07-GC-10

Position: 85°17.587'N, 014°48.874'W  Depth (m): 1017

Date Acquired: 9/3/2007  Described by: Leonid Polyak




**Description**

Dark brown, slightly sandy mud; contact uneven, oblique

Brown to pale brown (10YR5/3 to 6/3), sandy mud (with detrital carbonates?); contact uneven, oblique

Dark brown, slightly sandy mud; contact slightly uneven

Mostly dark yellowish brown, slightly sandy mud with indistinct lamination, more lighter colored and grayish to 6 cm; distinct sandy laminae at 14.5 cm and at the bottom; contact by the sandy lamina, otherwise gradual transition

Mostly dark grayish brown, slightly sandy mud, grading from more yellowish color at the top to strongly dark grayish with small mud clumps evident below ~28 cm; contact slightly uneven, somewhat gradual

Very dark gray, sandy (fine sand) mud; contact distinct, mostly even, with a lighter colored lamina

Light olive brown, slightly sandy mud, with some IRD; contact uneven

Light gray, very coarse lumpy sediment-obviously detrital carbonate; contact uneven, oblique (66-67 cm)

Olive brown, sandy mud (fine sand), contact distinct, mostly even

Yellowish brown, soft mud; contact slightly uneven

Dark yellowish brown to brown (10YR4/4 to 4/3), slightly sandy to sandy mud especially sandy between 88-95 cm; strongly mottled; gradual transition

Yellowish brown to brown (10YR5/4 to 5/3), slightly sandy mud; contact distinct, slightly uneven

Dark yellowish brown to grayish brown (10YR4/2), slightly sandy mud with grayish mud clumps, especially below 116 cm; contact distinct, mostly even

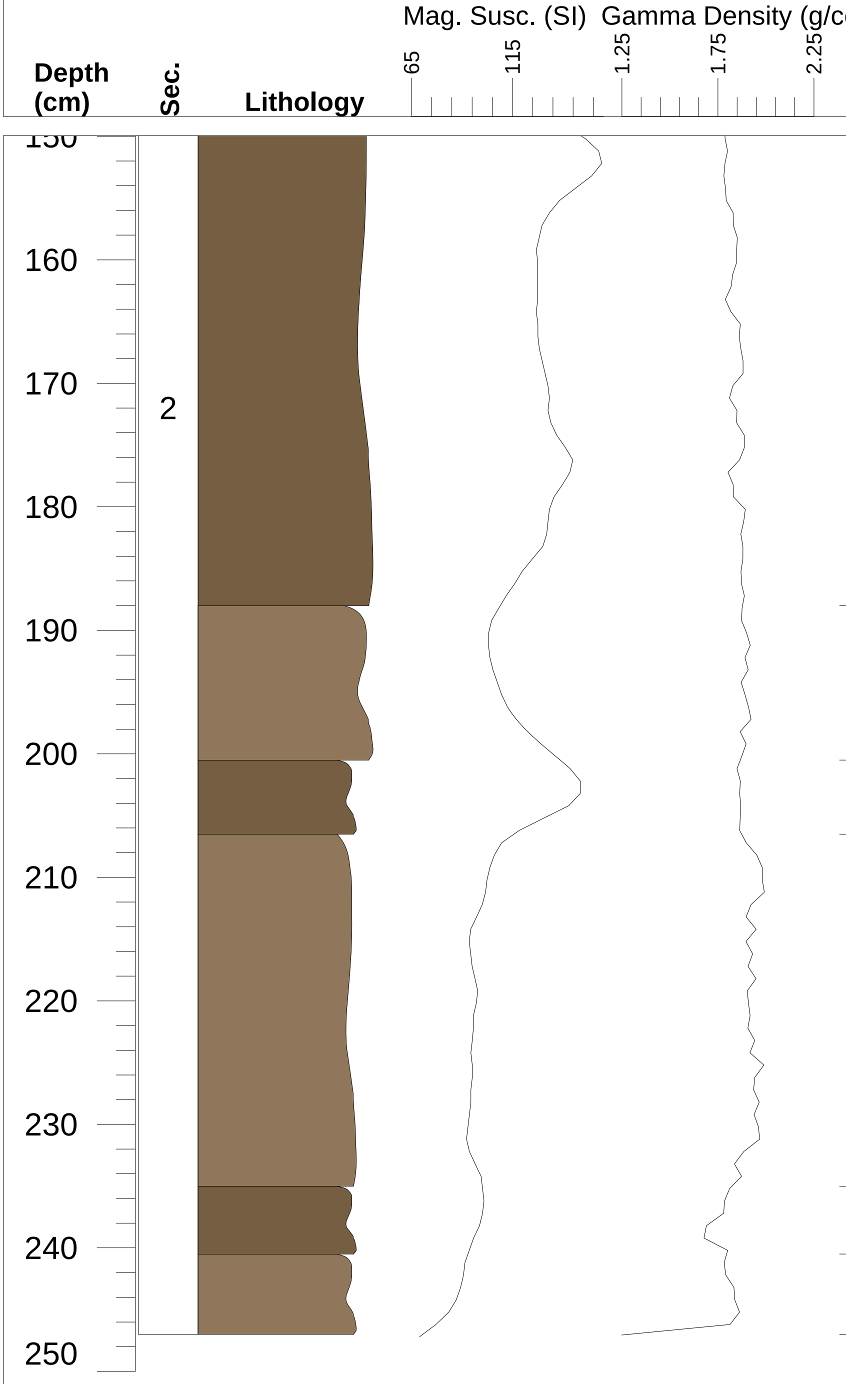
Brown to pale brown (10YR5/3 to 6/3), soft mud with some sand and IRD; more sandy and slightly lighter colored below 125 cm; contact distinct, uneven

Dark yellowish brown, silty mud with faint indistinct lamination; gradual transition

# LOMROG07-GC-10

Position: 85°17.587'N, 014°48.874'W    Depth (m): 1017

Date Acquired: 9/3/2007    Described by: Leonid Polyak




**Description**

Unevenly colored, mostly brown to dark yellowish brown (10YR4/3 to 4/4), silty to slightly sandy mud; 140-151 cm-indistinct interlamination of dark yellowish brown and brown; below-more intensely brown bands and patches, somewhat irregular; distinct, oblique brown bands at 169-173 cm, 176-180 cm, and 181-184 cm; contact slightly uneven, gradual

Interlamination of lighter to darker to brown (10YR4/3) laminae up to ~5 mm thick; darker brown laminae below~194 cm; gradual transition

More solid brown, silty mud; gradual transition

Relatively light brown to yellowish or grayish brown (10YR5/4 to 5/2), silty mud with indistinct fine brown lamination and several distinct brown (10YR4/3) bands at 213.5-214.5 cm, 220.5-221.5 cm, 228-229 cm, 230-231 cm, and ~232 cm; gradual transition

More solid brown, silty mud with a lighter colored lamina at 237-238 cm; contact relatively distinct, uneven

Lighter colored brown, silty mud with darker colored laminae at ~243 cm and 245.5 cm

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Lomonosov Ridge off Greenland 2007 (LOMROG)

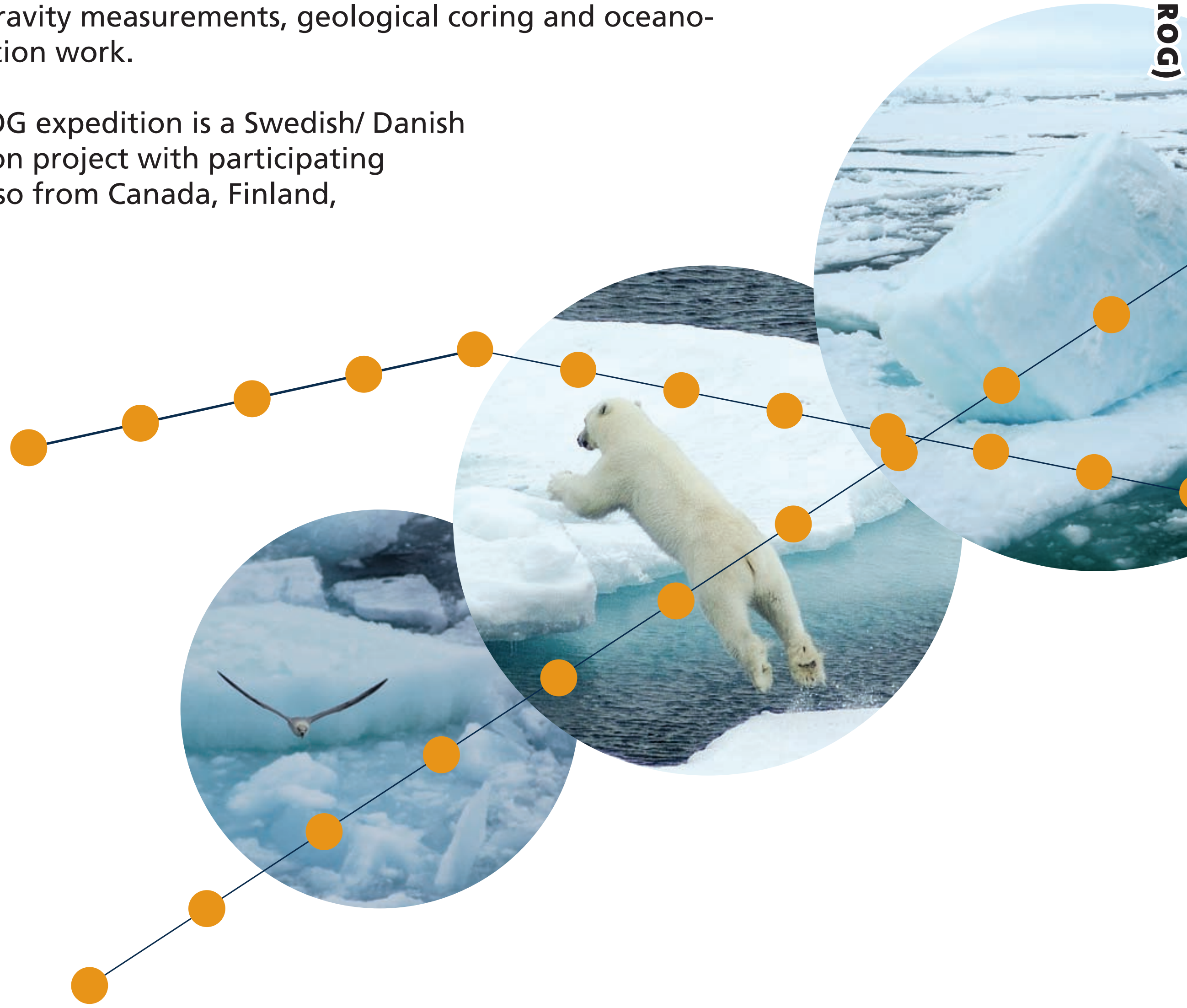
**About the LOMROG project:**

The Lomonosov Ridge off Greenland was the primary focus for the LOMROG expedition.

This part of the Arctic is virtually unexplored as difficult sea ice conditions have made it inaccessible for surface vessels.

With Swedish icebreaker *Oden* supported by new Russian nuclear icebreaker *50 Let Pobedy* (50 Years of Victory), LOMROG managed to reach the southern most tip of the Lomonosov Ridge off Greenland to carry out multibeam mapping, subbottom and seismic reflection profiling, gravity measurements, geological coring and oceanographic station work.

The LOMROG expedition is a Swedish/ Danish collaboration project with participating scientists also from Canada, Finland, and USA.



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