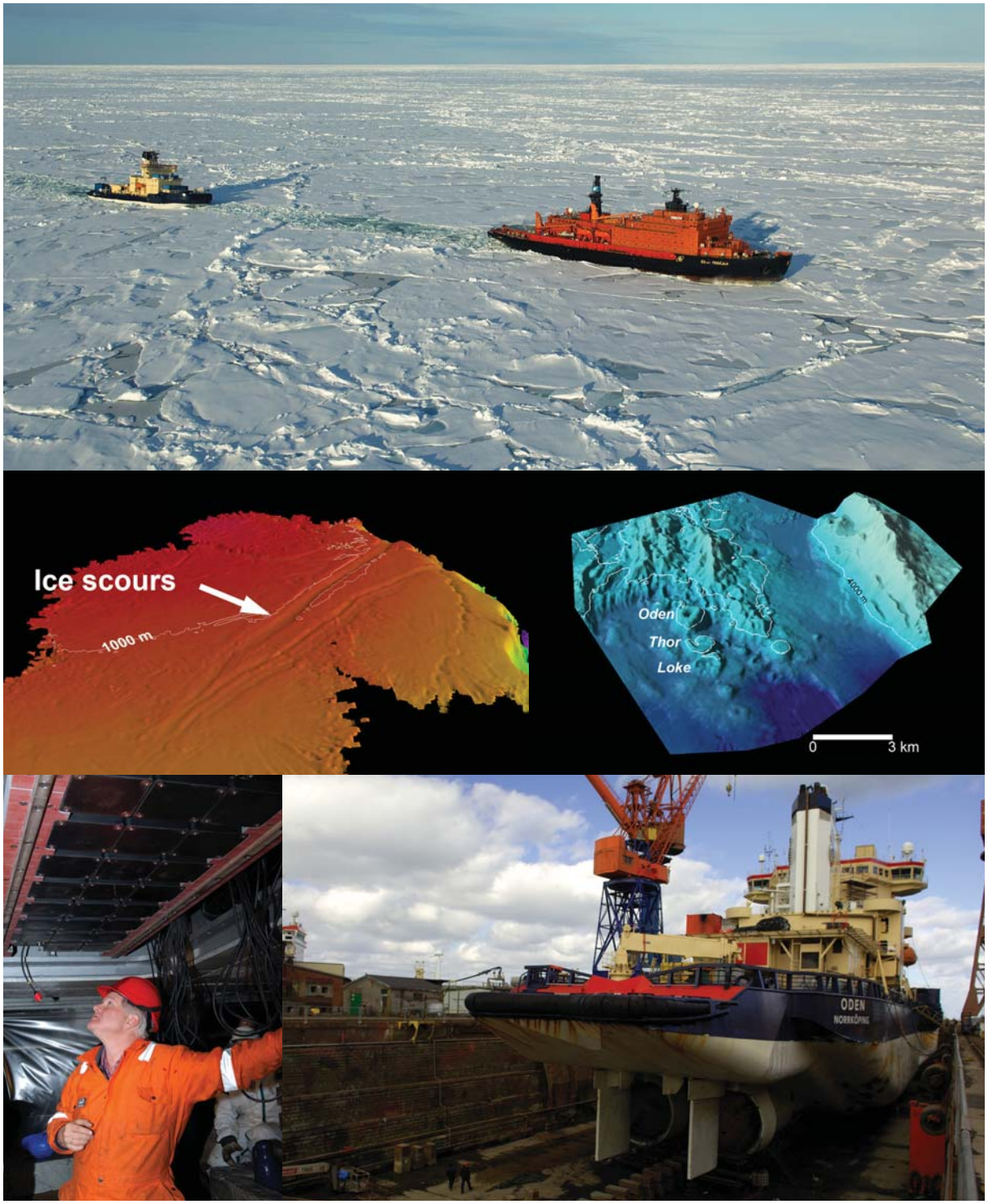

2007 REPORT

A Hull Mounted Multibeam Sonar and Subbottom Profiler on the Icebreaker Oden

Martin Jakobsson, Jan Backman, Leif Anderson, Göran Björk

Content

A Hull Mounted Multibeam Sonar and Subbottom Profiler on the Icebreaker Oden

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SWEDISH SUMMARY

Utforskningen av världshaven har under de senaste decennierna genomgått en revolutionerande utveckling med tillkomsten av det så kallade multibeamekolodet. Till skillnad mot traditionella ekolod, som bara mäter vattendjupet rakt under fartyget, mäter multibeamekolodet över ett stort område utifrån fartygets båda sidor genom att det sänder ut flera riktade akustiska signaler. Därigenom fås en 3D-bild av havsbottnen. Multibeamekolodet har bidragit till djupkartor som ökat vår förståelse av oceanografiska och geologiska processer, samt möjliggjort att vi kan placera oceanografiska, geologiska och biologiska provtagningsstationer där vi med stor detaljskärpa faktiskt vet hur havsbottnen ser ut. Om multibeamekolodet kompletteras med ett penetrerande sedimentekolod får vi också information om strukturen av de översta cirka hundra meterna av sedimentlagren; en helt nödvändig information för sedimentprovtagning till klimat- och miljöstudier. Under våren 2007 installerades av norska Kongsberg ett multibeam och penetrerande sedimentekolod i isbrytaren *Oden*. Projektet finansierades av Knut och Alice Wallenbergs stiftelse (KAW), Vetenskapsrådet (VR) och Sjöfartsverket. Installationen genomfördes i Öresundvarvets torrdocka i Landskrona och innebär att *Oden* nu är en av endast tre isbrytare utrustade med multibeamekolod som kan operera i de centrala delarna av Norra Ishavet. *Oden* är just nu världens

bäst utrustade isbrytare för geofysisk havsbottenkartering i de istäckta delarna av polarområdena. Under sommaren 2007 organiserade Polarforskningssekretariatet två expeditioner med *Oden* till den Arktiska oceanen: Arctic Gakkel Vents Expedition (AGAVE) och Lomonosov Ridge off Greenland (LOMROG). De multibeamdata som insamlades under dessa två expeditioner har redan bidragit till en rad genombrytande forskningsresultat. Under AGAVE karterades nybildade vulkaner på 4000 m vattendjup i den submarina spridningsryggen Gakkelryggen där havsbottnen delar på sig och ny jordskorpa ständigt bildas. *Odens* mätningar ger de hittills mest detaljerade akustiska bilderna av Gakkelryggen och bidrar till förståelsen om de processer som bygger upp vår jord. En modell baserad på multibeammätningarna av de nybildade vulkanerna har framtagits för Smithsonian Institution, paraplyorganisation för 19 muséer och 9 forskningscentra i USA (www.si.edu). Helt outforskade områden norr om Grönland undersöktes under LOMROG-expeditionen med hjälp av *Odens* nya multibeam och sedimentekolod. Spår av enorma isberg, som nått ner och skrapat havsbotten på mer än 1000 meters vattendjup, upptäcktes i de detaljrika bilderna multibeammätningarna gav. Dessa isberg är från de tidigare istidsperioderna och insamlade mätdata kommer att kunna hjälpa oss att rekonstruera Arktis istidshistoria. Alla djupdata som samlades in under AGAVE och LOMROG har redan fått bidra till projektet ”International Bathymetric Chart of the Arctic Ocean (IBCAO)” vars syfte är att ställa samman den mest kompletta helhetsbilden av Arktiska oceanens havsbotten. Ett flertal tidigare oupptäckta så kallade ”Seamounts” (undervattenberg) kartlades under LOMROG och kommer att föreslås namn till den UNESCO-knutna namnkommittén SCUFN (Sub-Committee on Undersea Feature Names).

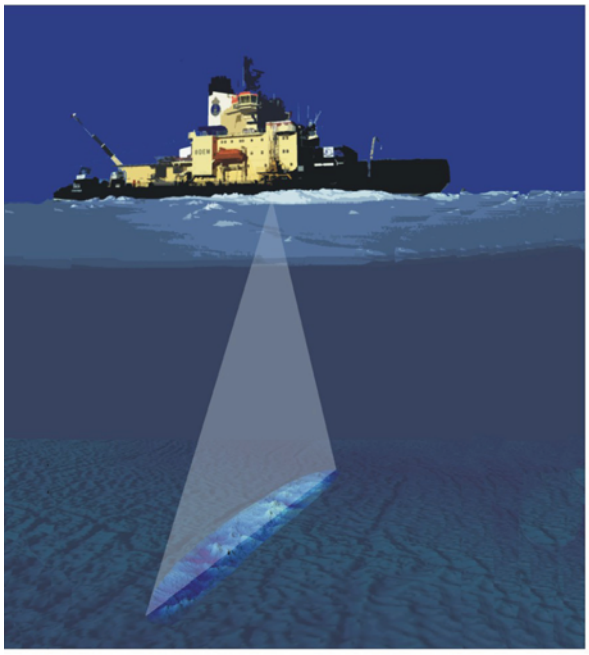
INTRODUCTION AND BACKGROUND

The perennial sea ice cover of the central Arctic Ocean has efficiently prevented systematic seafloor mapping using surface vessels. Only the most powerful icebreakers can operate in these areas and among them, only the German *R/V Polarstern* and the American *USCGC Healy* have been equipped with the latest technology for mapping the seafloor; the multibeam sonar. For the very same reasons, the majority of the areas of the Southern Ocean surrounding the Antarctic continent remain uncharted. The Swedish icebreaker *Oden*, built in 1988, has more and more become a dedicated research vessel due to the icebreaker’s splendid capability as a scientific platform with the capacity of operating in the most difficult Arctic and Antarctic sea ice conditions. Beginning with the *Arctic Ocean 1991* expedition, the Swedish Polar Research Secretariat (SPRS) has organized several Arctic Ocean expeditions based on *Oden* as the scientific platform. This concept is currently being expanded to include expeditions to the Southern Ocean and within the next five years it appears likely that we will see *Oden* operating both in the Arctic and around the Antarctic on a yearly basis.

The development of the multibeam bathymetric sonar represents a major

breakthrough in geophysical ocean mapping. The technology involves the use of many simultaneous acoustic beams to cover and map a large fan-shaped area of the ocean floor in contrast to a conventional single-beam echo sounder, which draws only a single narrow profile of the seafloor topography directly under the ship (Figure 1). The multibeam is capable of generating 3D-portrayals of the seafloor that shows its morphological characteristics at very high resolution. Multibeam surveys around the world are currently contributing to a new revolution regarding our understanding of seafloor processes.

In 2004, a group was formed with the purpose of carrying out a feasibility study regarding an installation of a hull mounted multibeam and subbottom profiler system on the *Oden*. This group consisted of Mats Andersson, Head of Ship Management at the Swedish Maritime Administration (SMA), Ulf Hedman, logistics manager of SPRS, and Martin Jakobsson, Royal Swedish Academy of Sciences Research Fellow at Stockholm University. In turn, they contracted Veden Engineering to evaluate if a multibeam installation technically could be performed while still maintaining the present icebreaking, maneuver and structural capabilities of *Oden* and to estimate the installation costs concerning the required hull modifications to be done in dry-dock. The documentation provided by Veden Engineering was subsequently issued to Det Norske Veritas for approval of the Classification Society for the vessel. Since the assembled study group and the report from Veden Engineering concluded that a multibeam installation was feasible and that it significantly would enhance *Oden's* capabilities as a research vessel but would not impoverish its icebreaking performance, financing for the equipment was applied for and awarded through research grants to Stockholm University and Gothenburg University from Knut and Alice Wallenberg Foundation (KAW) and the Swedish Research Council (VR). SMA agreed to finance



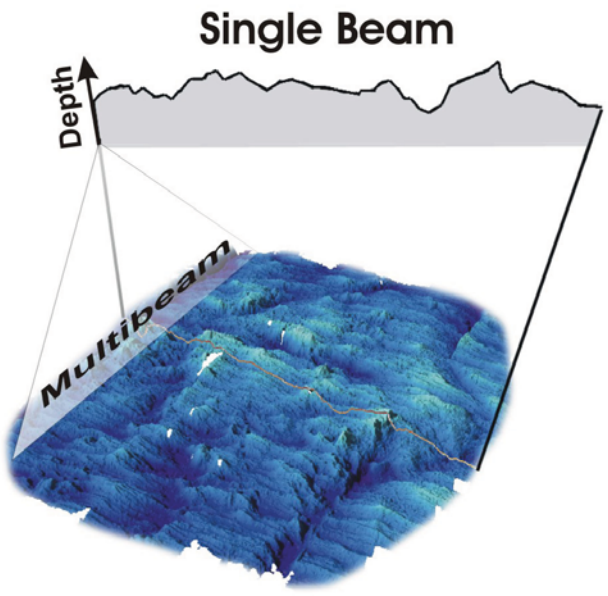


Figure 1 (From the original KAW proposal). The concept of a multibeam sonar. A fan-shaped area of the ocean floor is continuously mapped. A multibeam system provides a high-resolution 3D-portrayal of the seafloor that unravels its true morphological characteristics. A conventional echo sounder provides a 2D bathymetric profile along the path of the ship from a single beam (right).

and manage the installation, which subsequently was undertaken during the spring of 2007 in the dry-dock of Öresundsvarvet in Landskrona, southern Sweden.

During the summer of 2007 two expeditions with *Oden* were organized by SPRS: Arctic Gakkel Vents Expedition (AGAVE) and Lomonosov Ridge off Greenland (LOMROG). During these two expeditions the multibeam and subbottom profiler collected data that provided the basis for new scientific discoveries. Moreover, unknown areas of the Arctic seafloor were mapped for the first time. This report describes the installation of the multibeam and subbottom profiler and highlights some of the first results from the AGAVE and LOMROG expeditions.

MULTIBEAM SYSTEM AND INSTALLATION

After evaluation of tenders it was decided that the Norwegian company Kongsberg Maritime were to deliver and install their well proven deepwater multibeam system with an integrated subbottom profiler. The first of Kongsberg's deep water systems EM12 was released in 1990 and for *Oden* the latest model in this series, EM122, was offered. Compared to the precursor of EM122, called EM120, the new system featured enhanced mapping resolution and increased area coverage of the seafloor underneath the ship while still using the same acoustic transmitters and receivers mounted in the icebreaker's hull. In addition, acoustic characterization of the water column has been included as a standard feature in EM122. When it was time for installation during the spring of 2007, however, Kongsberg had not been able to finish critical software components for their new hardware dealing with the significantly more demanding signal processing of EM122. Therefore, the fallback was to install the EM120 model and later upgrade to EM122. This upgrade will be implemented by Kongsberg during the spring of 2008 and is further described below.

An EM120 (1°x1°) multibeam echo sounder with the integrated subbottom profiler SBP120 (3°x3°) was installed while *Oden* was placed in dry-dock between April 17 and May 15 at Öresundsvarvet in Landskrona. Table 1 lists the main technical specifications of the installed EM120 and SBP120 as well as the specifications of the EM122. Figure 2 shows a schematic illustration of the *Oden* multibeam components.

Multibeam systems require precise information of the sound velocity in the water column for depth calibration. Therefore, a Conductivity Temperature Depth (CTD) probe from Sea-Bird Electronics (Model SBE 9 plus) was included in the multibeam system setup on *Oden*. In addition, sound velocity is directly measured regularly using probe mounted in *Oden's* sea water chest located just aft of the multibeam receive transducer array.

EM120 (1°)
Depth range: 20 to 11000 m
Swath width: up to 6 times water depth
Beam width: 1°x1°
Beams: 191 covering a sector up to 150°
Frequency: 12 kHz

SBP120 (3°)
Frequency range: 3-7 kHz, chirp
Vertical resolution: 0.35 ms
Horizontal resolution: 3°x3°
Integrated with EM120 by using the same receiving transducer array

Table 1. Multibeam and subbottom profiler technical specifications.

The EM120 12 kHz multibeam echo sounder is designed to perform seabed mapping – bathymetry and seabed imagery- to full ocean depth with an explicit resolution, coverage and accuracy. During the spring of 2008, Kongsberg Maritime will upgrade the EM120 *Oden* installation to the new EM122. This system upgrade does not involve new hull installations of the transmitting or receiving arrays, but new signal processing capabilities that will enhance the system's performance. EM122 will be capable of handling 288 simultaneous beams and multi pinging implying improved resolution. The signal to noise ration will be improved through the use of FM (Frequency Modulated) chirps.

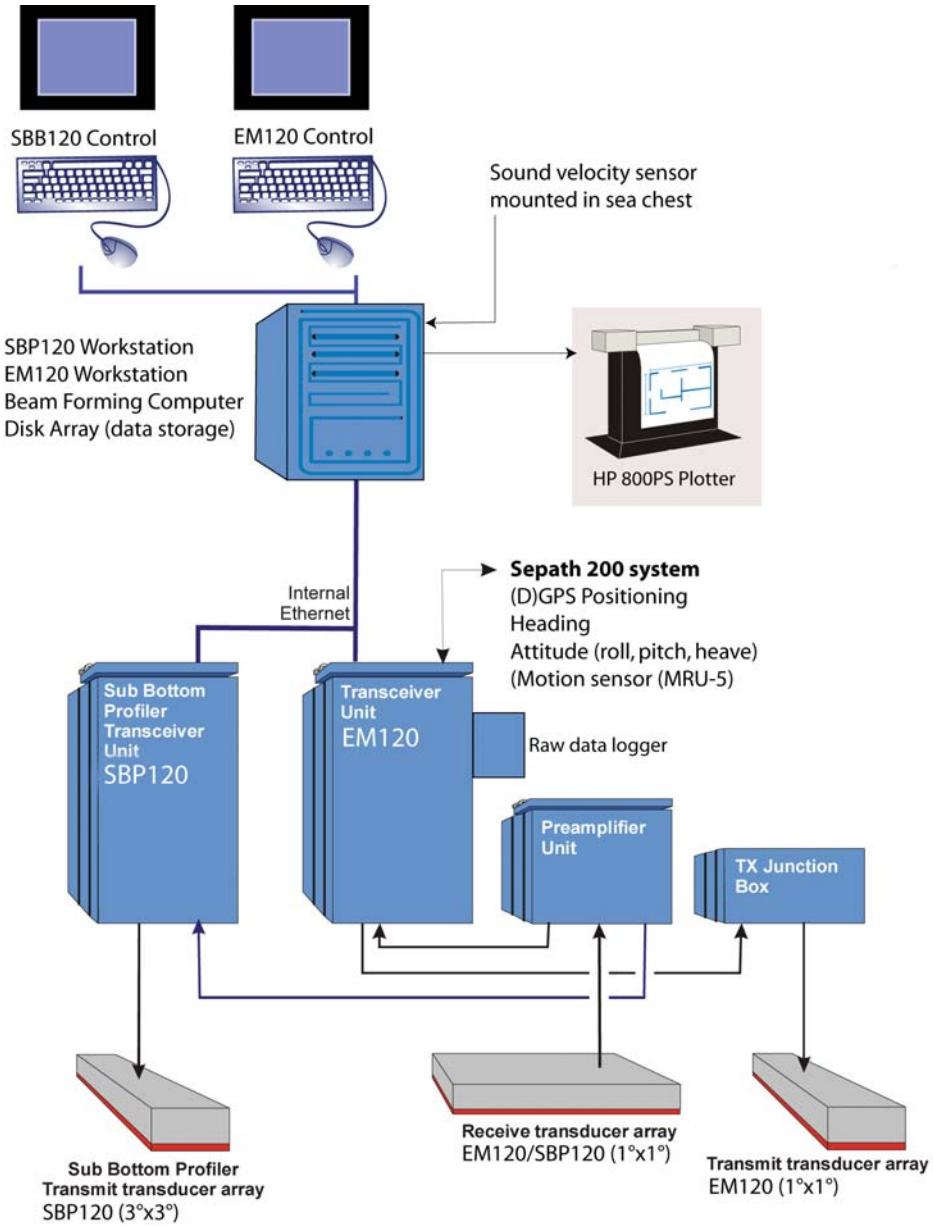


Figure 2. Schematic illustration of the EM120/SBP120 system installed on the Oden. The drawings is a modified version of Kongsberg's original.

Photo 1. Icebreaker Oden placed in dry-dock at Öresundsvarvet in Landskrona. The photo shows the stern of the icebreaker and its two large (4x8 m) rudders.

Photo 2. The constructed steel frame for the combined receiver transducer array (RX-unit) for both EM120 and SBP120. This frame was mounted in the hull of icebreaker Oden together with one frame for the EM120 transmitter and one for the SBP120 transmitter (TX-units).

Photo 3. The first cut in Oden's hull for the installation of the receiving acoustic array (RX-unit).

Photo 4. The acoustic transmitters and receivers of the multibeam and sub-bottom profiling system is placed in Oden's large "ice knife", which is seen in this photo. This feature diverts the broken ice to each side of the ice-breaker hull. This means that underneath the ice knife there should be less crushed ice passing than on each side of it.

Photos 5 and 6. (Left) A portion of the SBP120 transmitting array (SBP TX-unit). This 8 m long and 1 meter wide array is mounted along ship. (Right) The 8 m long and 1 m wide EM120 transmitting array, which is mounted next to the SBP transmitting array.

Photo 7. The 8 m long and 1 m wide receiving array mounted across the ship's hull.

Photo 8. Both the multibeam and subbottom profiler TX-units are covered by ice protection windows made of polyurethane plastic reinforced by imbedded titanium rods. The polyurethane later proved to have been hardened in insufficient conditions resulting in delaminating between the plastic and the titanium. These windows will be replaced by Kongsberg during the spring of 2008. The receiving array is protected by a pure titanium plate.

Photo 9. The transceiver and preamplifier units for EM120 and SBP120. These were installed above the engine room on a specially constructed platform.

Photos 10-11. The multibeam operator station located on the bridge of Oden. This space was specially constructed as an extension of the bridge.

SEA ACCEPTANCE TEST

The Sea Acceptance Test (SAT) for the EM120 and SBP120 installation was performed off the islands Vesterålen and Kvalöya, northwestern Norway. Multibeam bathymetry and subbottom profiles were acquired outside of the Norwegian territorial waters from the approximately 200 m deep continental shelf, the steep continental slope and from the 1000-2000 m deep seafloor commencing at the foot of the continental slope (Figures 3-5). The SAT survey followed Kongsberg's standard procedure for system calibration and the technical details are reported in a separate document. The acquired data were post-processed using the software Caris HIPS and Fledermaus by the participants from Stockholm University. All participants involved with the multibeam operation are listed in Table 1.

In summary, the SAT survey revealed that the multibeam system suffered from a depth offset at about 45-50° out from nadir (the center beam directly underneath the ship). This depth offset was on the order of 1-2 % of the water depth (Figures 6-7). It was later found by Kongsberg engineers that the offset problem was caused by a time delay inherited from the system electronics. Several circuit boards were replaced after the SAT survey, which resulted in that the offset was reduced. Apart from the offset problem, the EM120 and SBP120 installation was found be of high quality. In particular, the extraordinary precise measurements of the multibeam system's reference points (linking the transducers, motion reference unit and GPS antenna with a common coordinate system) carried out by Metria and the Swedish Maritime Administration implied that practically no calibration of the system regarding roll, pitch and heave bias was required.

Table 1. SAT Survey participants involved with the multibeam operation.

Name	Affiliation
Björn Eriksson	Dept. of Geology and Geochemistry, Stockholm University, Sweden
Dale Chayes	Lamont-Doherty Earth Observatory, Columbia University, USA
Per Frejvall	Swedish Polar Research Secretariat, Sweden
Benjamin Hell	Dept. of Geology and Geochemistry, Stockholm University, Sweden
Martin Jakobsson	Dept. of Geology and Geochemistry, Stockholm University, Sweden
Bengt Liljebladh	Earth Science Centre, Gothenburg University, Sweden
Axel Meiton	Swedish Polar Research Secretariat, Sweden
Christian Smith	Kongsberg Maritime, Norway
Ronald Sutherland	Kongsberg Maritime, UK
Tom Weber	Center for Coastal and Ocean Mapping, University of New Hampshire, USA

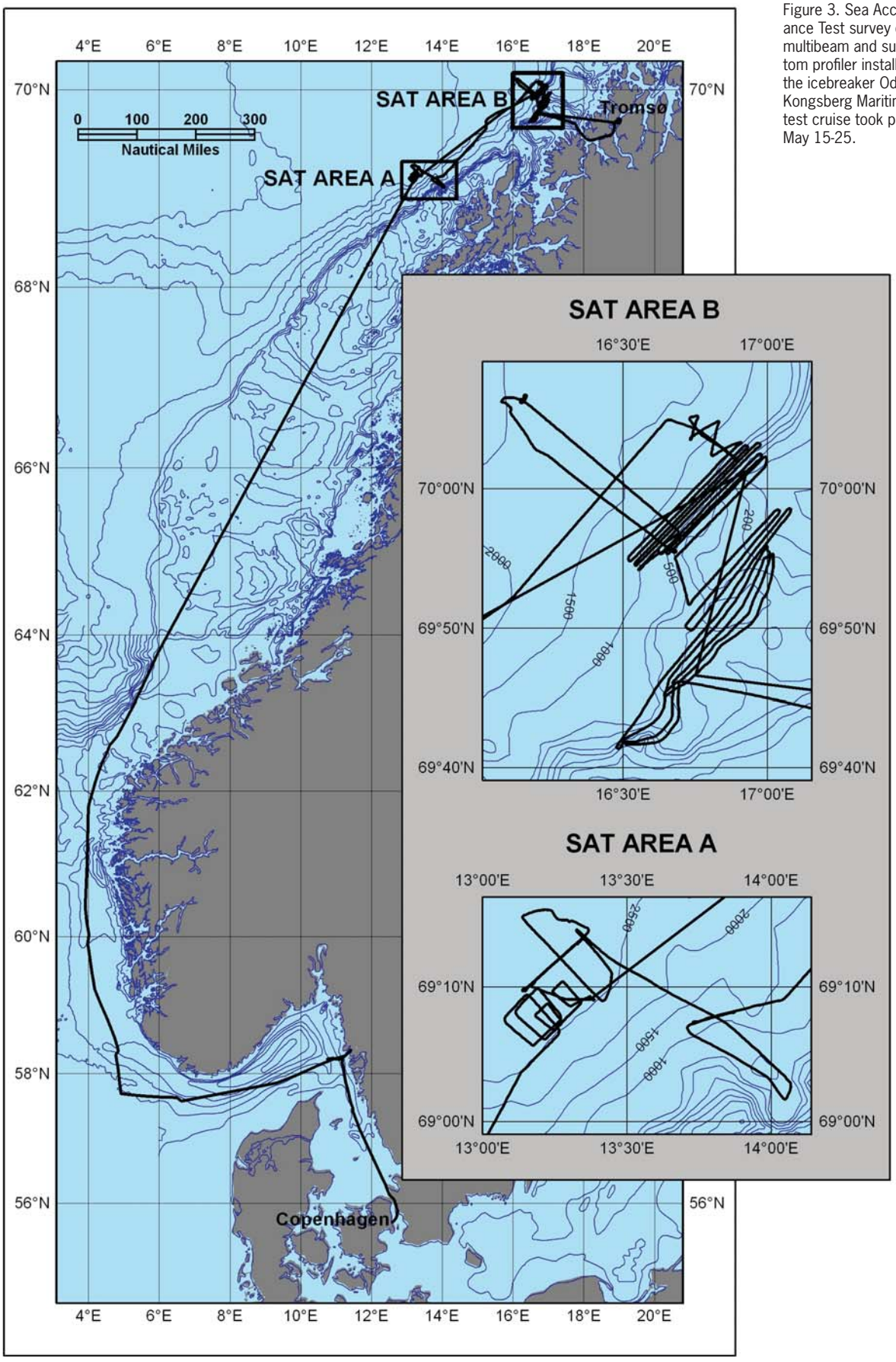


Figure 3. Sea Acceptance Test survey of the multibeam and subbottom profiler installed on the icebreaker Oden by Kongsberg Maritime. This test cruise took place May 15-25.

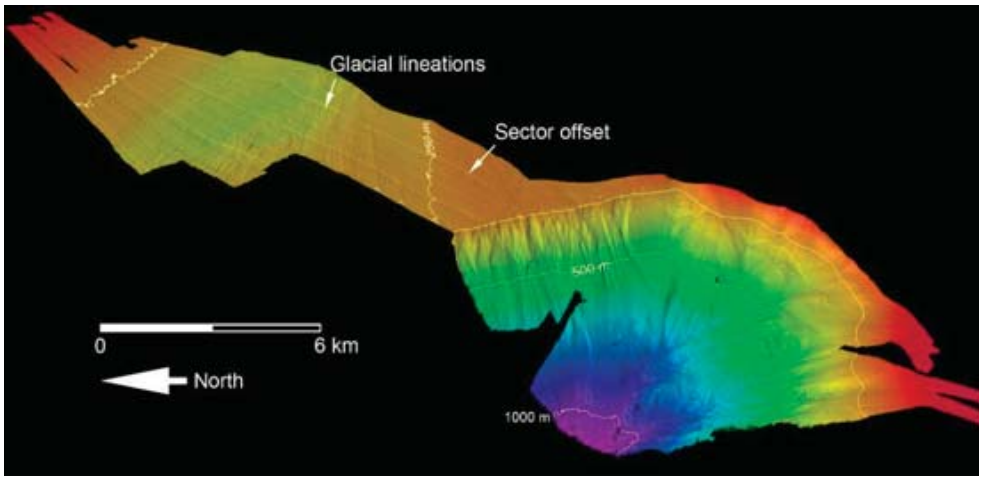


Figure 4. Multibeam data from the Oden SAT survey outside of Kvalöya Island, northwestern Norway. The image shows the southern portion of SAT AREA B shown in figure 2. Glacial lineations are clearly seen on the shallow shelf. The survey revealed that the EM120 had a problem with a depth offset in the 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.

Mapping Results

The collected multibeam bathymetry shows the true morphology of the spectacular canyons in the surveyed area and "glacial lineations" molded by previous glaciations into the shallow continental shelf (Figures 4 and 5). The so called glacial lineations are preserved traces in the seafloor from the Scandinavian Ice Sheet. During past ice ages the large Scandinavian Ice Sheet at times covered most of Scandinavia, for example during the Last Glacial Maximum at about 20 000 years ago. This ice sheet extended out at several places of the Norwegian continental margin in the form of fast flowing ice streams. Such ice streams typically create glacial lineations while interacting with the seafloor they move over. Our multibeam data show that the mapped lineations on the shelf off Kvalöya Island typically have widths >100 m and a relief >5 m. Similar glacial lineations are for example found around the Antarctic continent [*Dowdeswell, et al.*, 2006], in several other multibeam mapped areas of the Norwegian-Svalbard

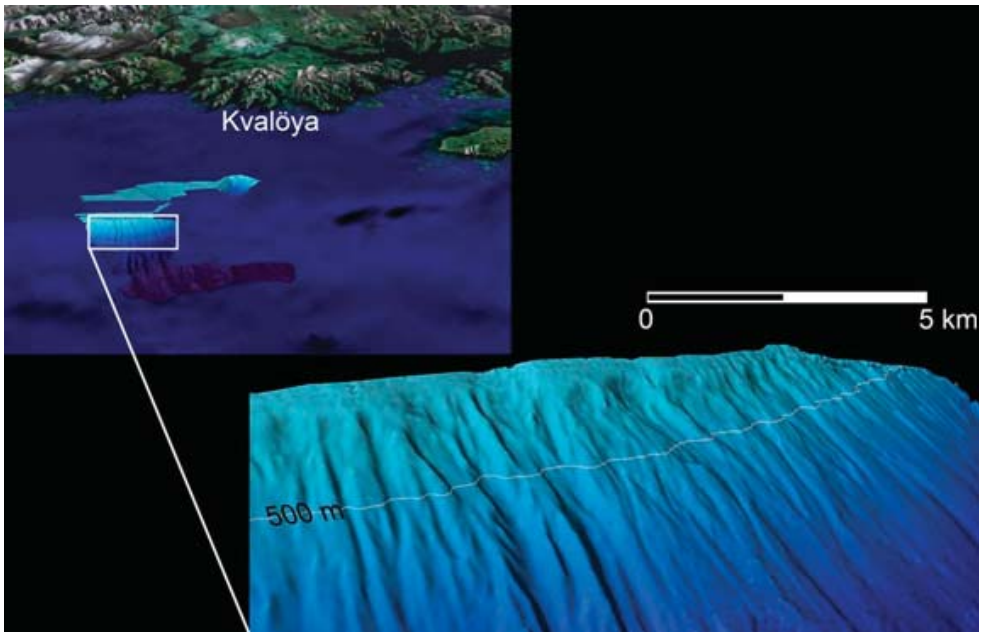


Figure 5. Multibeam data collected in SAT AREA B (Figure 3). The zoomed in area shows how multibeam reveals the characteristics of the continental slope.

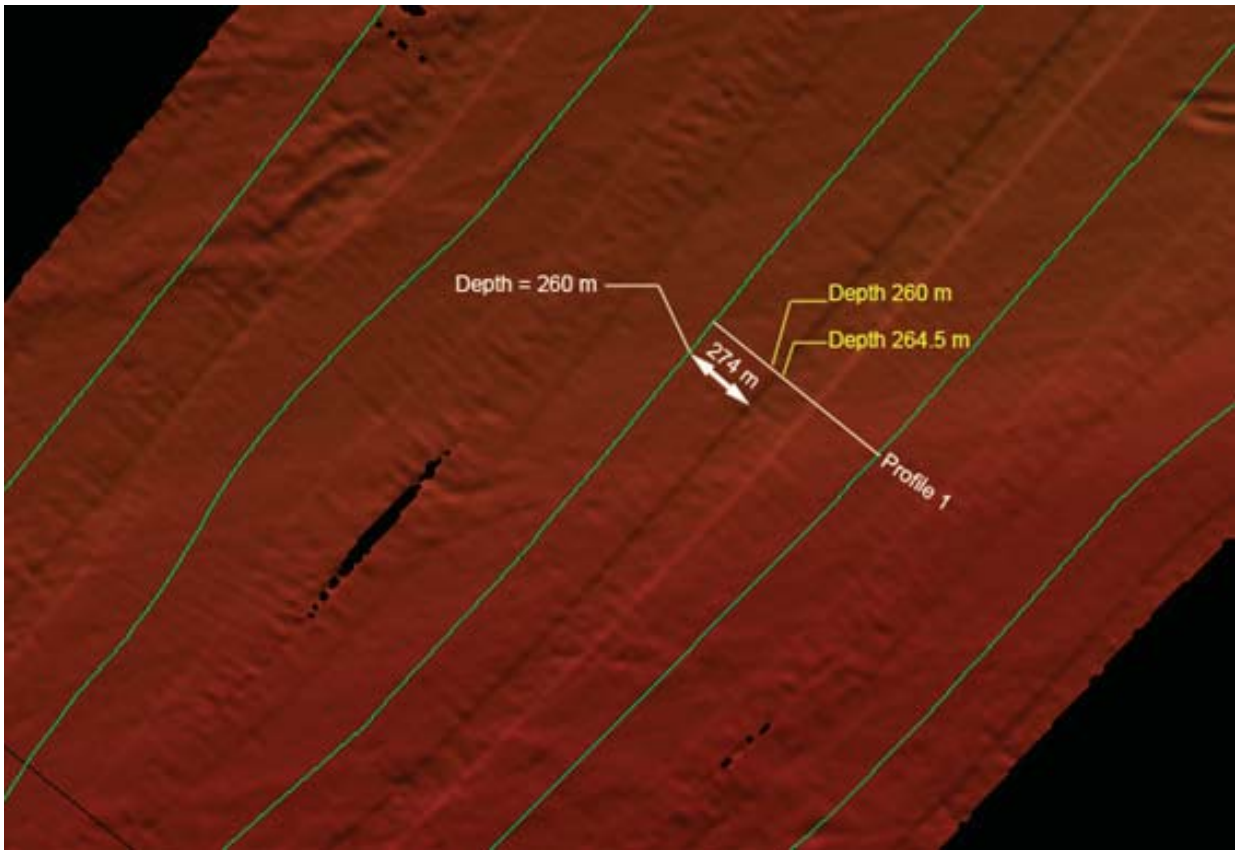


Figure 6. EM120 bathymetry from the shallow shelf off Kvalöya Island. Data was gridded at 15x15 m pixels. Profile 1 is shown in figure 7. The offset (1-2 % of the water depth) is clearly seen at about 45-50° out from nadir on the port side. Kongsberg engineers found that this problem was caused by a slight time delay inherited from the system electronics. Several circuit boards were replaced after the SAT survey, which resulted in that the offset was reduced.

continental margin [*Ottesen, et al.*, 2005], and in the Arctic Ocean [*Jakobsson, et al.*, 2005].

The raw multibeam data was continuously logged during the survey using an installed "raw data logger". This data also includes the entire water column. Tom Weber from the Center for Coastal and Ocean Mapping, University of New Hampshire, worked on processing this raw data during the cruise and showed that the data hold a great potential for physical oceanographic work involving mapping of water masses (Figure 8).

UPGRADE TO EM122 AND REPLACEMENT OF ICE PROTECTION WINDOWS

Kongsberg are currently performing the final tests on the new EM122 system. We have scheduled to install the new required electronics and software for EM122 on the *Oden* during the spring of 2008. This installation will be followed by a short test cruise off Svalbard on June 23-28.

As mentioned in the caption of Photo 8, the polyurethane plastic of the ice protection windows were hardened under insufficient conditions resulting in delaminating between the polyurethane and the titanium. *Oden* will be placed in dry-dock in Landskrona during the spring of 2008 in order to replace these windows. The new version of the protection windows has been manufactured by Kongsberg with support from Bodycote CSM in Linköping, Sweden. The test cruise and dry-docking is financed by the Swedish Maritime Administration and the production and installation of the new ice protection windows falls under the multibeam system warranty issued by Kongsberg.

EXPEDITIONS 2007
Arctic Gakkel Vents (AGAVE)

After the multibeam SAT survey and a following test cruise with *Oden* involving setup of heavy equipment on the aft-deck, the National Science Foundation (NSF) financed and Swedish Polar Research Secretariat operated Arctic Gakkel Vents (AGAVE) expedition, that started July 1 from Longyearbyen, Svalbard (Figure 9). Their main target was to study hydrothermal vents in the approximately 4000-5000 m deep axial valley of the Gakkel Ridge; the Arctic spreading ridge where the seafloor grows and form new ocean crust at a rate of approximately 1 cm/year. A hydrothermal vent is a local opening (fracture or crack) in the seafloor where geothermally heated water exits. These vents are commonly

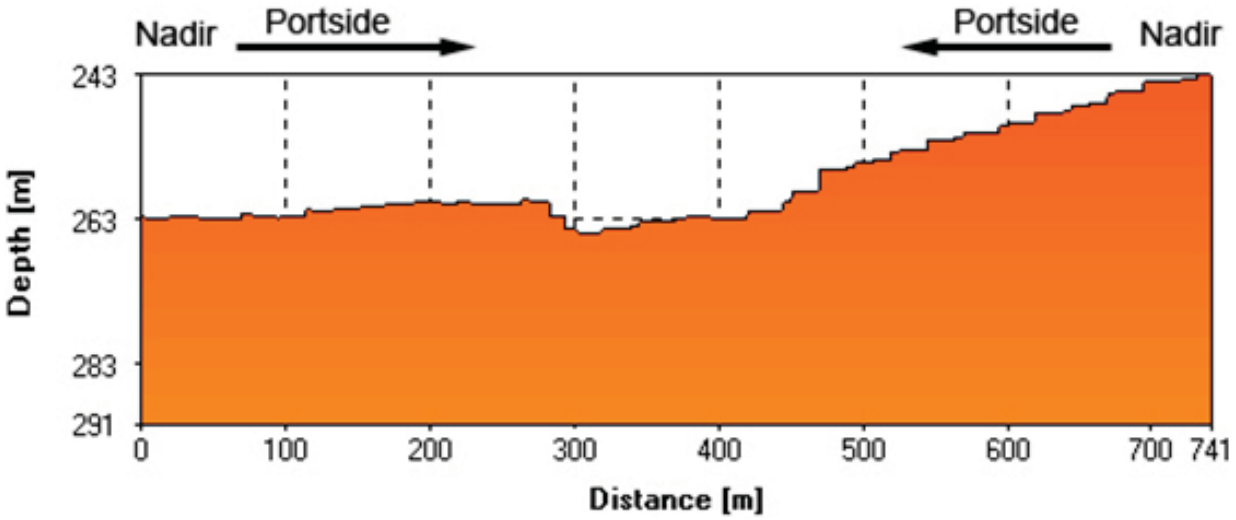


Figure 7. Profile between two adjacent survey tracks clearly showing the depth offset along the swath. The profile location is shown in figure 1.

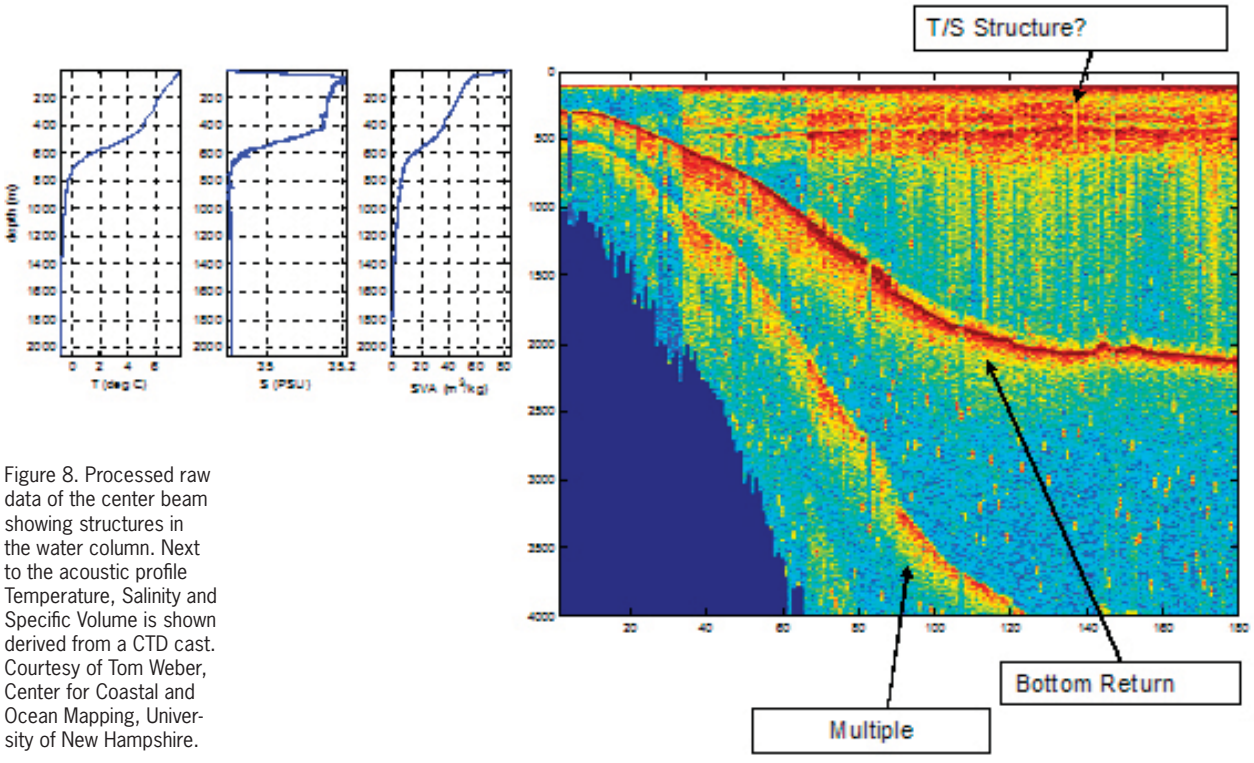


Figure 8. Processed raw data of the center beam showing structures in the water column. Next to the acoustic profile Temperature, Salinity and Specific Volume is shown derived from a CTD cast. Courtesy of Tom Weber, Center for Coastal and Ocean Mapping, University of New Hampshire.

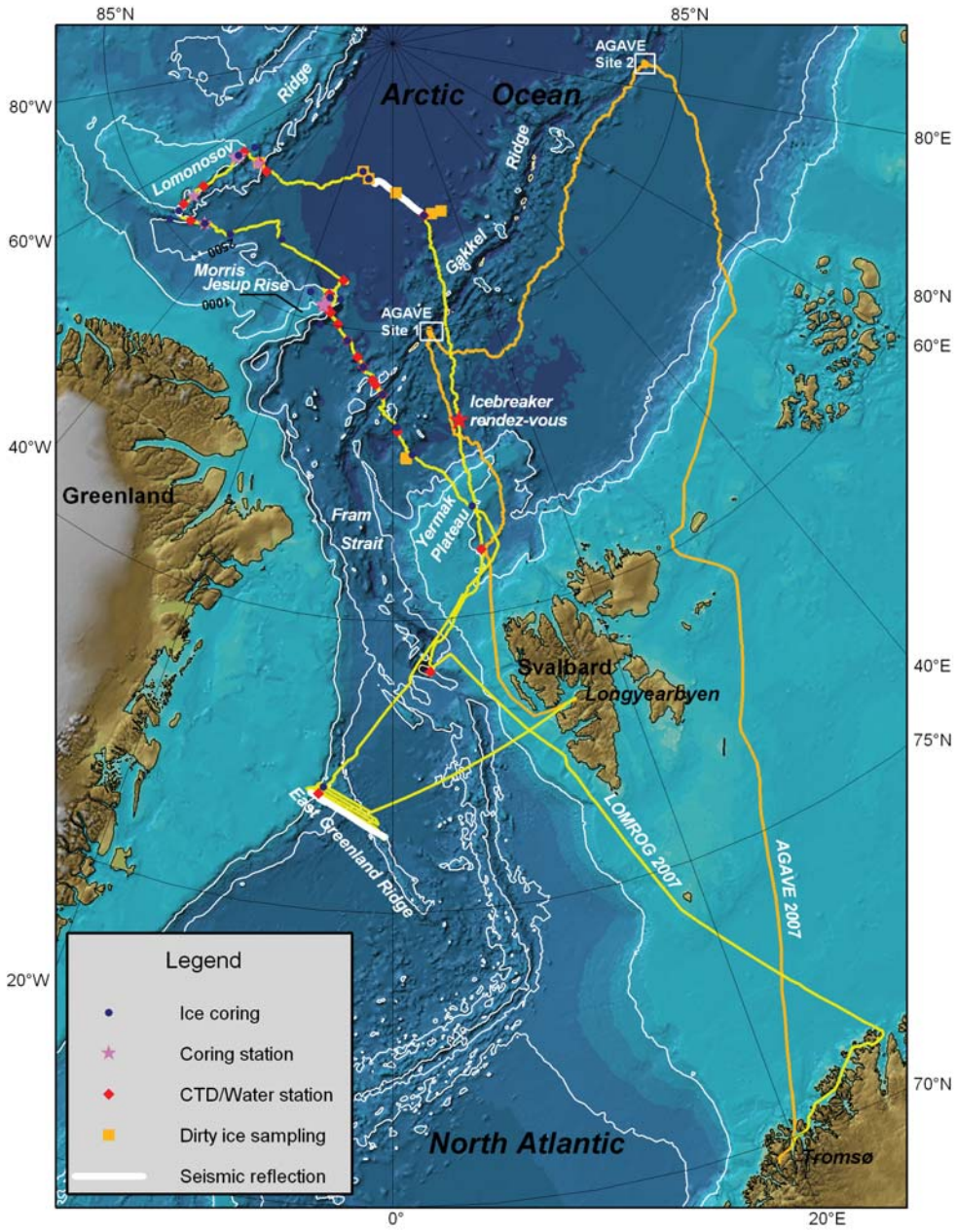


Figure 9. Map showing the track of the two Arctic Ocean cruises with Oden in 2007: AGAVE and LOMROG.

found in volcanic active regions such as ocean spreading zones. To study the Gakkel Ridge axial valley in detail the AGAVE scientist had brought the two Autonomously Operated Vehicles (AUV) *Puma* and *Jaguar*, both designed at the Woods Hole Oceanographic Institution (USA). An AUV is a robotic underwater vehicle designed to move about by itself without a cable connecting it back to the "mother ship". In addition, the Remotely Operated Vehicle (ROV) called CAMPER (CAMera samPlER) was brought along. This vehicle is not autonomous and instead steered through a cable. With these equipments they possessed the tools for a detailed study of the seafloor, although all this relied heavily on *Oden's* new multibeam to first map the bottom topography of the areas to be studied.

Björn Eriksson from Stockholm University and Christian Smith from Kongsberg were included in the

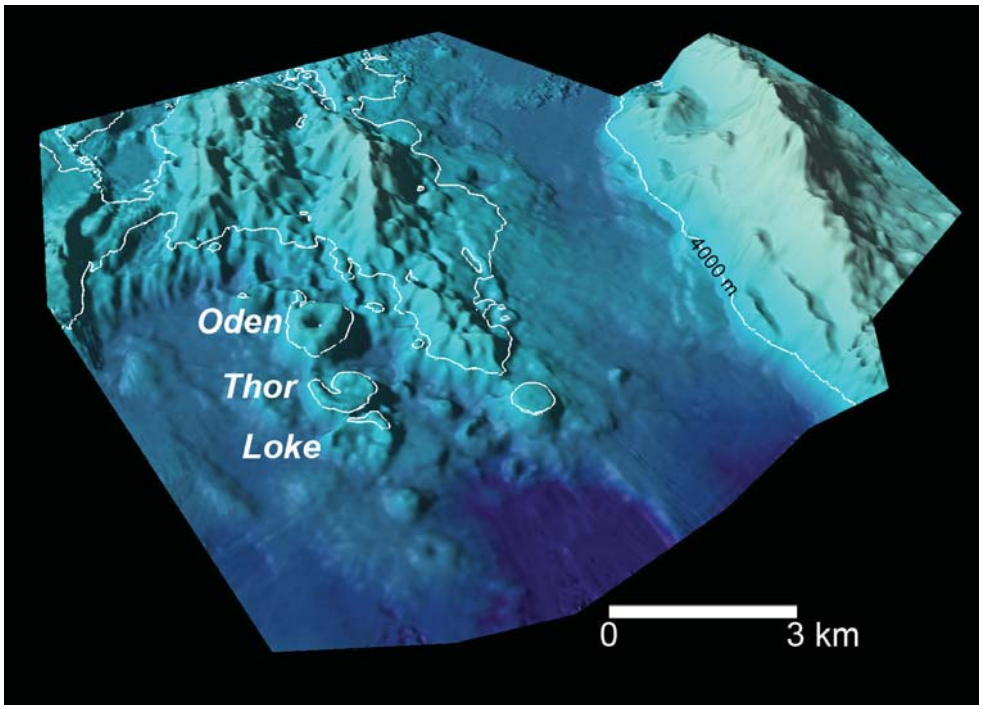


Figure 10. Bathymetric image of Site 2 investigated during the AGAVE cruise (Figure 9). Several small volcanoes were discovered from the multibeam mapping and from the three named Oden, Thor and Loke fresh lava flows were viewed in the photos and films acquired with the ROV CAMPER [Sohn, et al., Submitted].

AGAVE expedition to operate the multibeam and subbottom profiler. Since the selected two study areas of the Gakkel Ridge axial valley only were a few tens of kilometers across, *Oden* could cross over these areas with the multibeam several times. Therefore, an unprecedented high resolution multibeam mapping could be carried out. In fact, the data could be gridded at a resolution of 15-20 m in 4000 m water depth. With a 1°×1° deep water multibeam system, such as the EM120 on *Oden*, one can normally expect to achieve a resolution not greater than systems so called footprint; the area of the seafloor each beam average the depth over. In 4000 m water depth the footprint is approximately 70 m for a 1°×1° multibeam.

In Site 2 of their studied areas, at about 85°20'E 85°38'N, small volcanoes were mapped with the *Oden* multibeam (Figures 9 and 10). These were not discovered by previous mapping carried out in the area by US icebreaker *USCGC Healy* and German *R/V Polarstern* during the Arctic Mid Ocean Ridge Expedition (AMORE) 2001 because the size of the volcanoes were too small to be resolved using the multibeam systems on these two ships to perform conventional mapping, i.e. passing the area only once with the multibeam. In 1999 a major earthquake swarm was located to this area of the Gakkel Ridge and it was suggested that the cause was a volcanic eruption on the seafloor [*Edwards, et al.*, 2001]. Indeed AGAVE scientist found fresh lava flows from three small volcanoes they named *Oden*, *Thor* and *Loke* (Figure 10). The *Oden* multibeam data collected during AGAVE show to-date the most detailed bathymetric image of the deep axial valley of the Gakkel Ridge. The scientific discoveries including the multibeam data from the AGAVE cruise have now been summarized in an article recently submitted to the journal Nature [*Sohn, et al.*, Submitted].

Bathymetric model at the Smithsonian Institution in Washington

Our knowledge of the shape of the seafloor depends on the level of details the applied mapping techniques will provide us with. The deep oceans beyond the ice covered regions have been possible to broadly map at a horizontal resolution of 20-25 km using satellites simply because the sea surface bulges up and down mimicking the seafloor topography, and the sea surface height can be mapped from space [*Smith and Sandwell*, 1997]. To get a more detailed and precise image of the seafloor we need to use echo sounders of which the latest technology is the multibeam. The results from the AGAVE expedition inspired scientists and curators at the Smithsonian Institution to illustrate how the seafloor looks like in the deeper parts of the Gakkel Ridge axial valley and how our knowledge of the Arctic Ocean seafloor simply is a function on how well it has been mapped. To do this a digital bathymetric model of the Gakkel Ridge was assembled by Martin Jakobsson, Stockholm University. The model is based on three data sets, all with different resolutions. The first dataset is the International Bathymetric Chart of the Arctic Ocean (IBCAO), which is an international project that having worked continuously, since 1999, on improving the bathymetric portrayal of the Arctic Ocean by assembling all available data to a single database. The horizontal resolution of the latest IBCAO version is 2 km [*Jakobsson, et al.*, submitted]. The second dataset is comprised of the multibeam mapping done by US *USCGC Healy* and German *R/V Polarstern* during the AMORE expedition in 2001 [*Michael, et al.*, 2003]. These data have a horizontal resolution of approximately 100 m. The third data set consists of the new *Oden* multibeam images acquired during AGAVE 2007. Figure 11 illustrates the concept for the model, which currently is being produced.

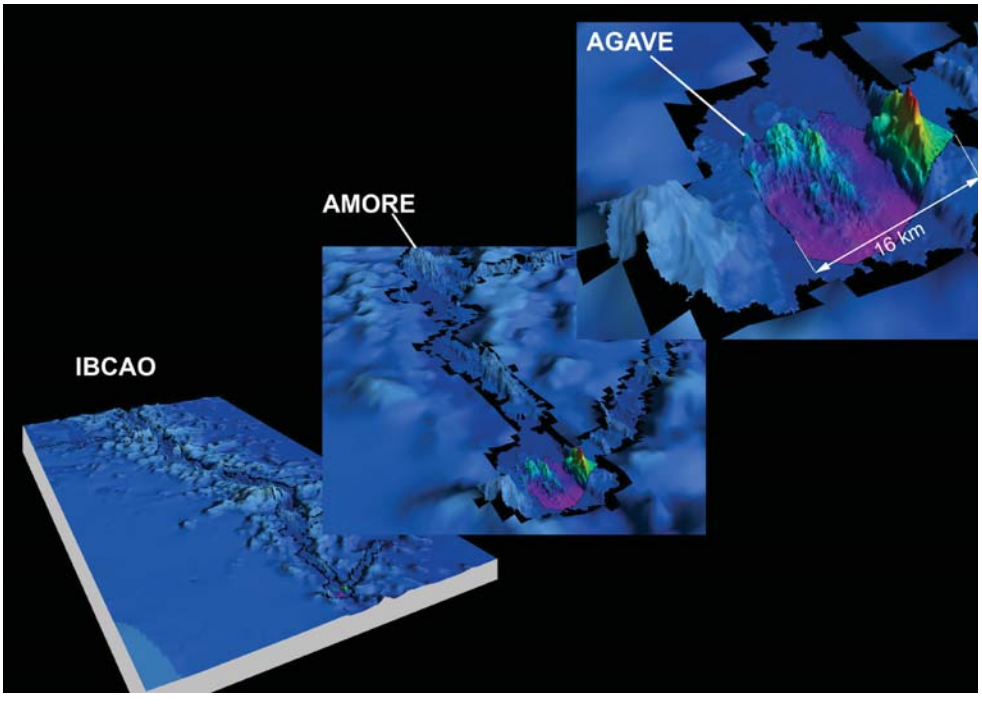


Figure 11. The concept for the bathymetric model currently being produced for the Smithsonian Institution (see text for further explanations).

Photos 12-13. The beginning of a model of the Gakkel Ridge manufactured by Bradley Samuels, Situ Studio, New York.

Lomonosov Ridge off Greenland (LOMROG)

This expedition in 2007 was mainly focused on investigating the submarine Lomonosov Ridge north of Greenland's northern continental margin (Figure 9). This part of the Arctic is virtually unexplored as difficult sea ice conditions have made it inaccessible for most surface vessels. Swedish icebreaker *Oden* supported by the new Russian nuclear icebreaker *50 Let Pobedy* (Photo 14) became the first surface vessels to reach the southern most tip of the Lomonosov Ridge off Greenland. In this area, LOMROG carried out multibeam mapping, subbottom and seismic reflection profiling, gravity measurements, geological coring, oceanographic station work, sea ice thickness measurements and sampling of the sediment laden sea ice. In addition, scientific work was done on the Morris Jesup Rise and East Greenland Ridge as well as along a transect across the western Fram Strait. It should be noted that in the LOMROG area north of Greenland, severe sea ice conditions were encountered with 10/10 ice cover (100%) and sometimes 4 m thick multiyear ice floes while the rest of the Arctic Ocean experienced the smallest sea ice cover since systematic satellite measurements began 28 years ago (National Snow and Ice data Center: http://nsidc.org/).

The LOMROG expedition was organized by the Swedish Polar Research Secretariat as 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 Arctic Ocean as well as for Denmark's Continental Shelf Project under the United Nations Convention on the Law of the Sea (UNCLOS) Article 76. A major reason for targeting the ice-infested area north of Greenland was that this region likely holds answers to key questions regarding the glacial history of the Arctic Ocean, such as whether or not immense ice shelves existed in the Arctic Ocean during past glacial periods. To test the hypothesis of a huge Arctic Ocean ice shelf, LOMROG multibeam-mapped the areas of the Lomonosov Ridge north of Greenland and the Morris Jesup Rise. The oceanographic component of LOMROG investigated the pathways of the Atlantic water and deep water between the Eurasian

Basin and Canadian Basin. Such a pathway may exist between the Lomonosov Ridge and the Northern Greenland shelf. This work is an extension of the collaboration between Stockholm University and Gothenburg University from 2005 when multibeam mapping was carried out from *USCGC Healy* and we found an overflow of deep water across the central part of the Lomonosov Ridge [*Björk, et al.*, 2007].

Glacial erosion was indeed mapped with the multibeam and subbottom profiling system at water depths shallower than approximately 800 m. Sediment cores retrieved from the glacially scoured sea floor on the Lomonosov Ridge contained diamicton, sediment transported and reworked by glacial ice, thus confirming the multibeam data. The multibeam data from the Morris Jesup Rise showed large iceberg scours 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 12). These data were collected using a completely new multibeam survey technique we named "pirouette surveying". The technique involved *Oden* stopping and turning around in a half circle whenever an open to semi-open lead in the pack ice was encountered while acquiring multibeam data (Figure 13). The idea was to cover a 360° sector around the ship equal to the multibeam swath width, which commonly was between 3-4 times the water depths, although sometimes we achieved a swath up to 5 times the water depth. Occasionally the ship was rotated 360° to increase the resolution of the mapped area underneath the ship. After one "pirouette" was completed, *Oden* broke ice using its full capacity to the end of the multibeam swath coverage, where a new pirouette was carried out. It is clear that this technique relies on *Oden´s* unique turning capability and it implies that we can collect multibeam data in practically all sea ice conditions as long as an opening can be made large enough for the icebreaker to spin around.

On the Yermak Plateau multibeam data was collected along a previous survey track by *USCGC Healy* from the HOTRAX 2005 expedition. 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 is a more modern and higher resolution system (Figure 14).

Photo 14. The Russian new nuclear icebreaker 50 Let Pobedy (50 Years of Victory) supporting Oden while working in the extreme sea ice conditions north of Greenland.

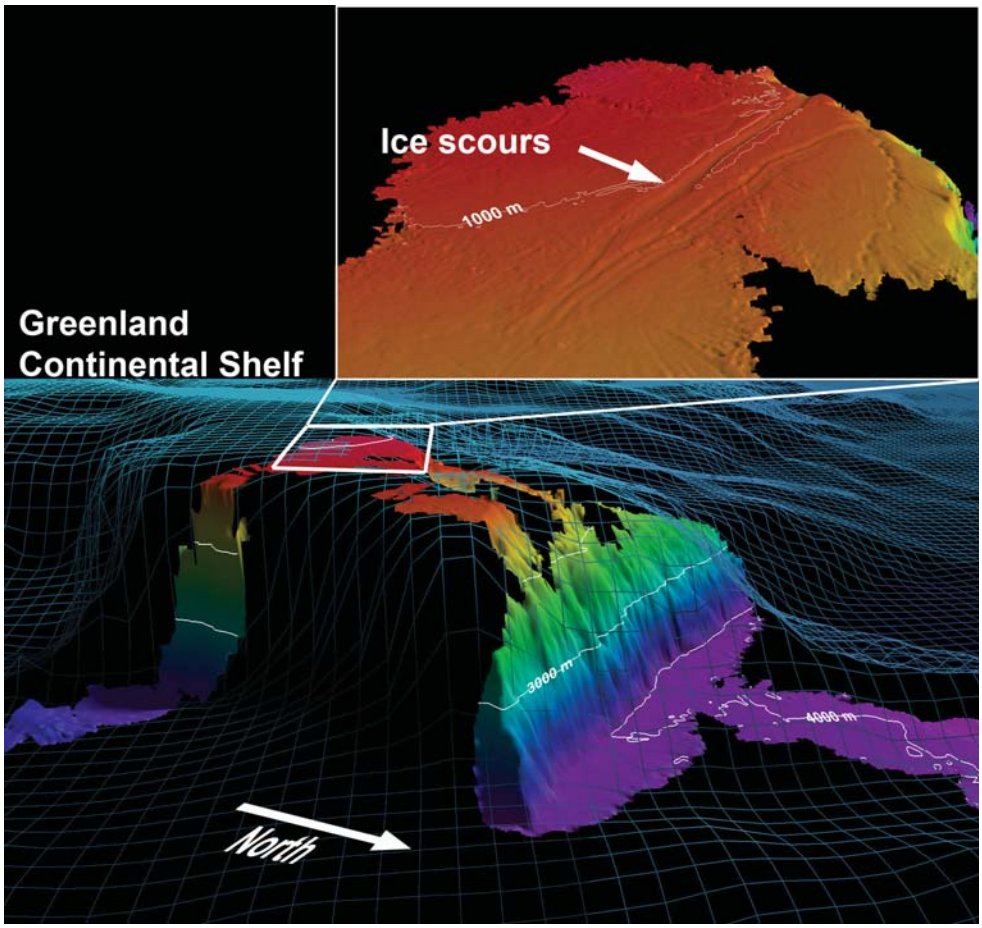


Figure 12. Multibeam data collected from the Morris Jesup Rise using the "pirouette technique" (see Figure 13). The large iceberg scours are from previous ice ages. The arrow points on one of the deepest mapped ice berg scours in the Arctic Ocean. Sediment cores were retrieved from the ice scours in 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.

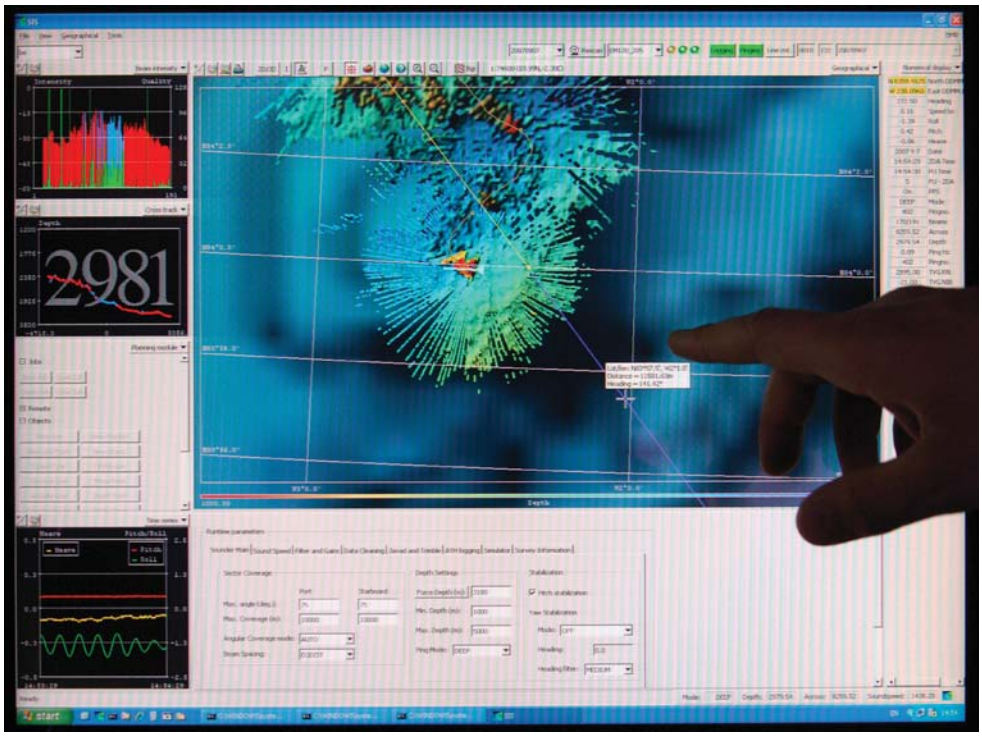


Figure 13. The computer screen of the EM120 multibeam acquisition system SIS (Seafloor Information System) by Kongsberg. The photo of the screen was taken during "pirouette surveying" of the slope of the Morris Jesup Rise.

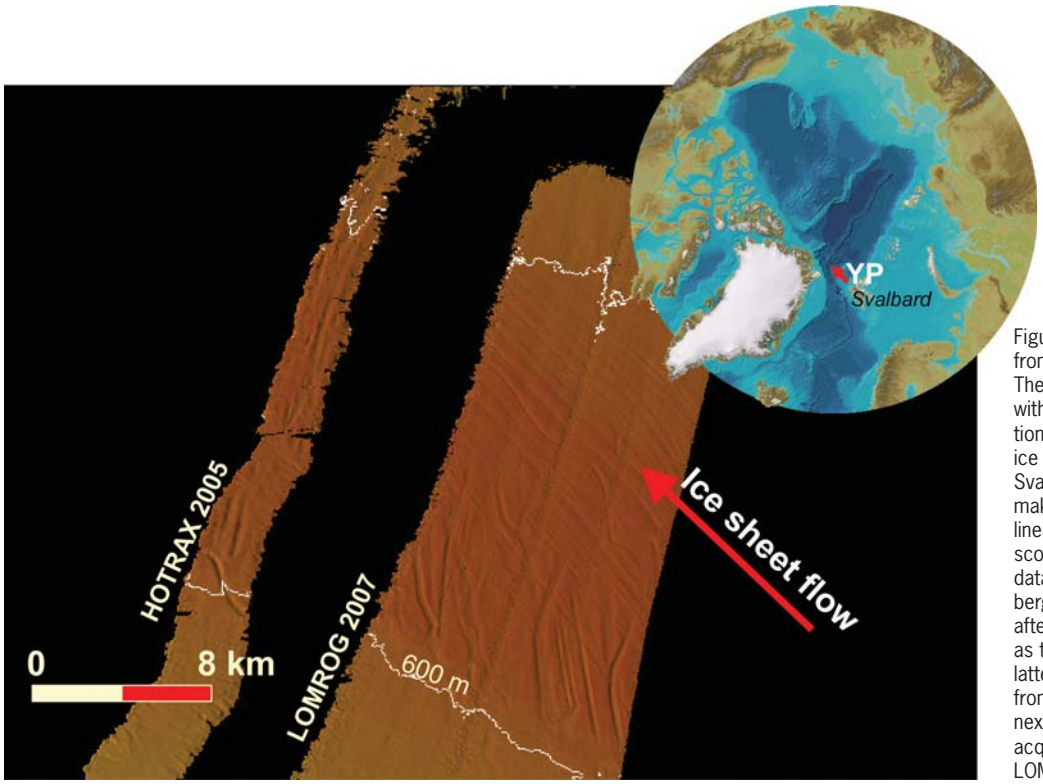


Figure 14. Multibeam data from the Yermak Plateau. The red arrow is lined up with the glacial lineations generated from an ice sheet advance from Svalbard out over the Yermak Plateau. Across the lineations some iceberg scours can be seen. The data show that the iceberg scours were created after the glacial 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.

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 15).

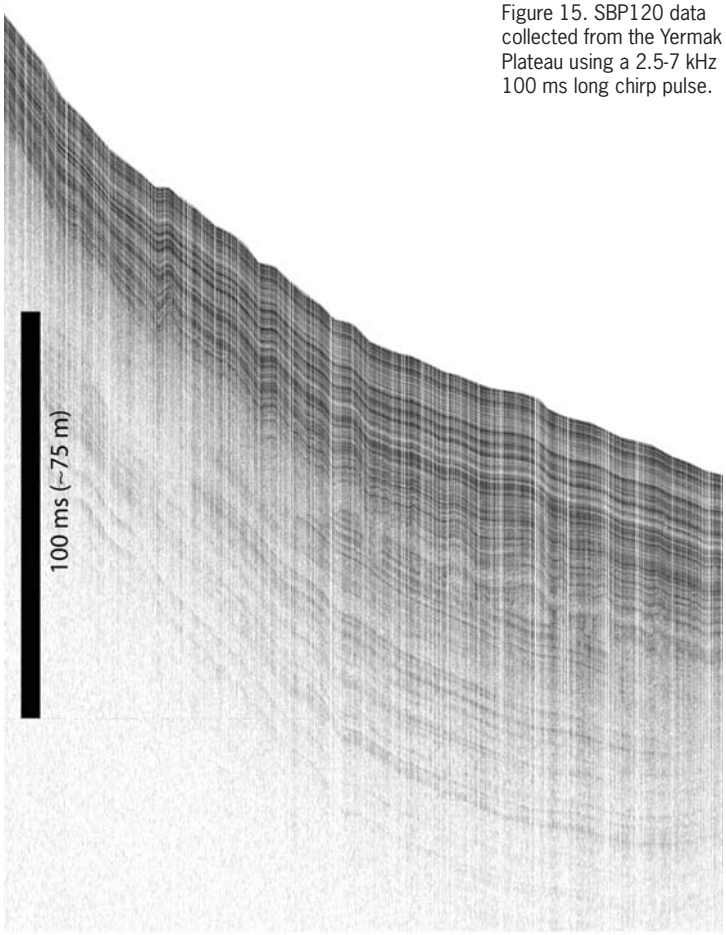


Figure 15. SBP120 data collected from the Yermak Plateau using a 2.5-7 kHz 100 ms long chirp pulse.

Southern Ocean

The US National Science Foundation (NSF) contracted *Oden* in 2007 to carry out the annual break-in of

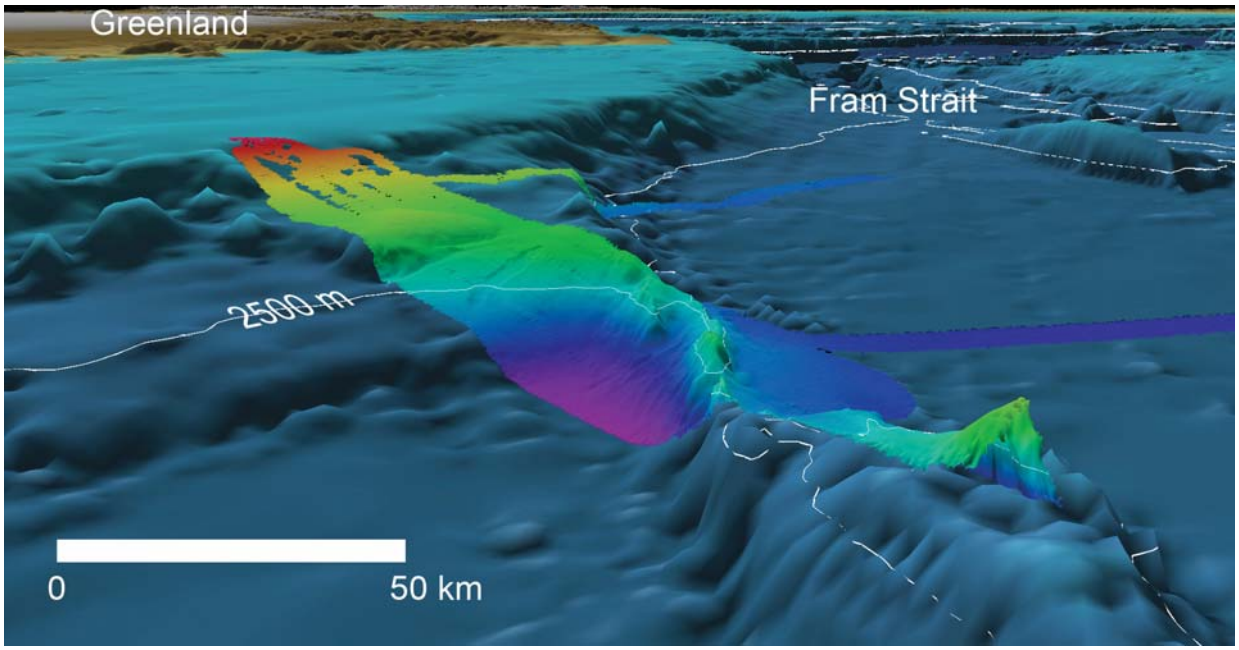


Figure 16. Multibeam bathymetry collected from the East Greenland Ridge during the LOMROG 2007 cruise. These data are a part of the Danish Continental Shelf Program (http://a76.dk/lang_uk/main.html)

the McMurdo Ship Channel in the Ross Sea, Antarctica. This created an opportunity for the Swedish Polar Research Secretariat (SPRS) and the Swedish Research council (VR) to organize a case-of-opportunity research expedition in collaboration with NSF Office of Polar Programs (OPP). Scientific work could make use of the transit from South America to the Ross Sea. Further research plans are currently being developed for the austral summer 2008/09 as NSF has decided to continue use the *Oden* for the McMurdo break-in.

Naturally, our goal is that the multibeam should be operated continuously during these Antarctic expeditions since the Southern Ocean is as poorly mapped as the Arctic Ocean. We have established collaboration with the International Bathymetric Chart of the Southern Ocean (IBCSO) in order to make sure that all data we collect will end up, once processed, in their database to contribute towards a better regional portrayal of the Southern Ocean seafloor. This is of benefit for practically all marine research around Antarctica.

During the 2007/08 cruise with the *Oden*, the multibeam was operated during the Atlantic transit from Sweden to South America by Mats Wisen from the Swedish Maritime Administration (SMA) and from South America to Antarctica by Axel Meiton from SPRS. These data have just arrived to Stockholm University and we will initiate a student project for a Candidate exam involving multibeam processing and analysis. Once the data have been processed these will be distributed to all researches that took part in the pertinent *Oden* Southern Ocean cruise.

It is clear that in order to collect high quality data, the bare minimum of two multibeam/CTD operators are required as data acquisition is a 24-hour operation. Thus, we are currently working towards a sustainable solution on how to staff *Oden* with qualified multibeam and CTD operators during all cruises as well as on how to provide multibeam data processing services for scientist

that do not posses, or have any training in the use of, the required processing tools but are in need of the bathymetry for their research.

IBCAO

The International Bathymetric Chart of the Arctic Ocean (IBCAO) is an international project endorsed by the International Arctic Scientific Committee (IASC), the International Hydrographic Commission (IHO), and the Intergovernmental Oceanographic Commission (IOC). The purpose of the project is to assemble all available bathymetric data north of 64°N into one coherent database and from this database, produce the most up-to-date Digital Bathymetric Models (DBM) and maps of the Arctic Ocean.

A new version of IBCAO (Version 2.0) has been worked on during the past years. There is a significant improvement compared to earlier releases of IBCAO. For example, the new version contains information from most recent multibeam cruises, in particular cruises with *USCGC Healy* and *R/V Polarstern* and now also *Oden*. A scientific article describing the new IBCAO has recently been submitted to Geophysical Research Letters [*Jakobsson, et al.*, in press]. The new DBMs as well graphics and maps of the Arctic Ocean will soon be available for free public download from the official IBCAO web page (www.ibcao.org)

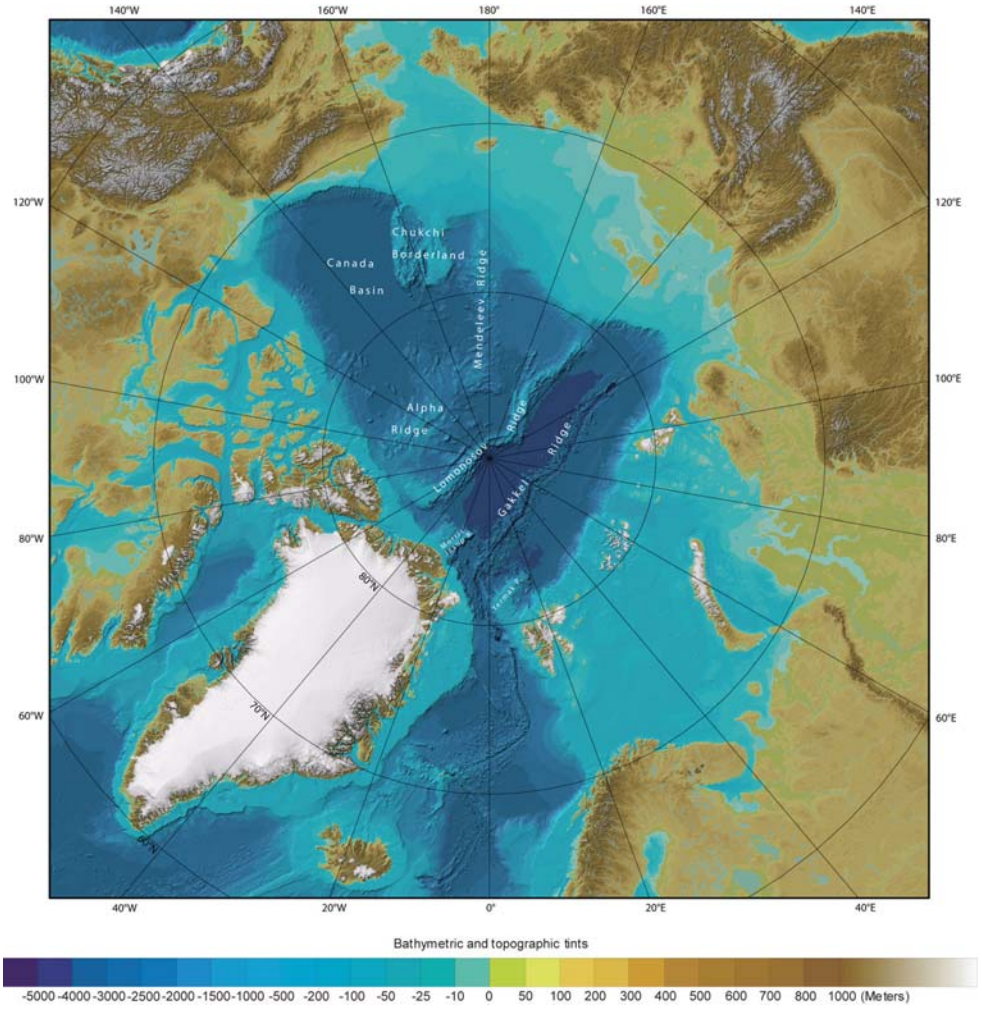


Figure 17. Version 2.0 of the International Bathymetric Chart of the Arctic Ocean (IBCAO). This version has made use of all the data collected during the Arctic cruises with Oden in 2007 [Jakobsson, et al., submitted].

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