CHALLENGES OF COLLECTING DATA FOR ARTICLE 76 IN ICE COVERED WATERS OF THE ARCTIC

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Abstract

Meeting the requirements of Article 76 in ice covered waters of the Arctic poses unique challenges. In addition to the issue of determining baseline points around ice shelves, these challenges include obtaining continuous bathymetric and seismic profiles. The existing data in the Arctic Ocean, particularly on the North American side is very sparse and much is the result of data collected for site-specific projects rather than systematic mapping efforts. The costs and uncertainty of successful data collection is very much impacted by the remoteness of the Arctic areas and short operational survey seasons. If a vessel breaks down or survey equipment fails or is lost, it is probable that the 6- 8 week annual survey season will be over before a replacement can be outfitted and positioned to the survey area. Data collection is also complicated by weather and ice conditions which have been more variable and less predictable in recent years. Another risk is the capability and availability of survey platforms and equipment that can operate in different ice conditions. This paper examines these challenges from the perspective of the Arctic and the Canadian and Danish efforts to collect data to support submission to the Commission on the Limits of the Continental Shelf

1. Introduction

Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS) is a relatively short Article, defining the juridical continental shelf and setting out the process to determine the outer limits of the juridical continental shelf over which coastal states enjoy sovereign rights.

A number of papers interpreting Article 76 were published in the years between conclusion of the Convention in 1982, its coming into force in 1994 and the May 1999 adoption of the definitive Scientific and Technical Guidelines of the Commission on the Limits of the Continental Shelf (CLCS 1999).

In the Scientific and Technical Guidelines each requirement of Article 76 is expanded upon in considerable detail addressing data collection, primary and supplementary data, documentation, analysis, etc to assist the coastal states in interpreting and applying the provisions of Article 76 consistently.

However, in the 100 pages of the Guidelines, only two references are made to the application of Article 76 in ice-covered waters.

> *4.2.3. However, bathymetric information derived from seismic reflection and interferometric side-scan sonar measurements may be considered as the primary source in a submission for the purpose of delineating the 2,500 m isobath in special cases such as in ice-covered areas. The Commission may pay particular attention to the calibration and corrections applied to these data.*

and

> *8.2.19. Modelling based on a combination of gravity and magnetic data may also give an estimated depth-to-top of the basement in areas with thick sediment piles and no interbedded lava or intrusions. The range of error from this method is very large relative to the seismic methods. The error in the determination of the depth-to-top of the basement depends upon the quality of the magnetic data, the densities and susceptibilities used in the calculations and the relative position of the Moho. However, in areas with ice cover or very deep basements, modelling of a combination of a heterogeneous gravity and a magnetic data set may be a valuable supplement to a sparse seismic database used in the mapping of the top of the basement.*

The Guidelines do address minimum data coverage, advising to allow for deviations of profiles to ensure the minimum of a point on the outer limit every 60 M is met. This is particularly relevant in the Arctic where ice cover impacts the ability of vessels to reach specific points and often dictates the path followed to arrive at a specific point.

> *8.2.20. Article 76, paragraph 7, states that "the coastal State shall delineate the outer limits of its continental shelf ... by straight lines not exceeding 60 nautical miles in length, connecting fixed points ..." This requirement must be combined with the requirement of paragraph 4 (a) (i) that the sediment thickness at each of the fixed points shall be at least 1 per cent of the shortest distance to the foot of the slope.*
>
> *8.2.21. The above requirement means that the minimum requirement is a data coverage that documents the required sediment thickness at fixed points at a spacing of maximum 60 M. In principle, the survey must be designed to prove the continuity of the sediments from each selected fixed point to the foot of the slope (see sect. 8.5). One way to achieve the implied minimum standard is to select a series of well documented geophysical profiles from the foot of the slope to their intersection with the claimed delineation line at a spacing of less than 60 M. The seismic lines therefore need to be a maximum of 60 M apart when planning a seismic survey for the purpose of delineating the outer limit of the continental shelf. However, this does not allow for any deviations in the straight-line segments. Thus, a closer line spacing may be considered in order to give more flexibility. The allowed deviation increases with a closer line spacing according to the approximate formula:*
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> *Line spacing in nautical miles = Cosine max. angle of deviation from orthogonal * 60 M*

8.2.22. The 60 M maximum spacing requirement allows coastal States to bridge natural indentations in the sediment thickness rather than following the sometimes meandering path of the precisely measured feature. This may also permit a less detailed sampling over the margin, with a possible reduction of the costs involved in the collection and interpretation of the data. However, it is evident that such a formal minimum data coverage could miss some important details of the morphology of the outer limit of the continental margin, and the resulting 1 per cent line could only be a rough approximation of the true geological limit. Coastal States that suspect that such an approximation will be to their disadvantage will benefit from executing more comprehensive and detailed surveys. In general, the data coverage should reflect the complexity of the outer margin.

Other than as noted above there are no special considerations given in Article 76 or in the Scientific and Technical Guidelines of the CLCS for data collection in ice-covered waters.

At the third biennial conference of the Advisory Body on Law of the Sea (ABLOS) - addressing difficult issues in the Law of the Sea, a paper was presented on the difficulties of determining the edge of the land mass and territorial Sea baselines, where the land / sea interface was covered in permanent ice (Harsson *et al.* 2003).

2. Challenges to meet requirements in UNCLOS article 76 in the ice-covered waters of the Arctic

2.1 Remoteness

The North American side of the Arctic Ocean is a long way from ports, fuel, suppliers and other infrastructure. Transit time for an icebreaker from Halifax or Montreal is in the two week range depending on ice conditions. In the eastern Arctic, all fuel and cargo comes in once a year in August, much of it via Nanisivik, the only deep water port in the eastern Arctic. Nanisivik is 500 M from the Arctic Ocean, 200 M from Resolute, 450 M from Eureka and 600 M from Alert (Fig. 1). Alert is a Canadian Forces Station and is supplied totally by air with the majority of fuel and cargo coming in via the US Air Force Base in Thule Greenland, 350 M to the south of Alert. Cargo and fuel can be barged ashore at Resolute and Eureka. There are gravel runways at Resolute, Eureka, Alert and Station Nord that can take cargo planes most of the year.

In Canada supplies and passengers come via Yellowknife or Ottawa on commercial flights that operate daily to Iqaluit, 900 M south of Resolute, with connections to Resolute several days a week or via chartered aircraft. A chartered C-130 Hercules from Yellowknife to Resolute costs in the $150,000 range and can carry a cargo of 100 drums of fuel (20,500 Litres). All movement of gear and people north of Resolute is by charter aircraft.

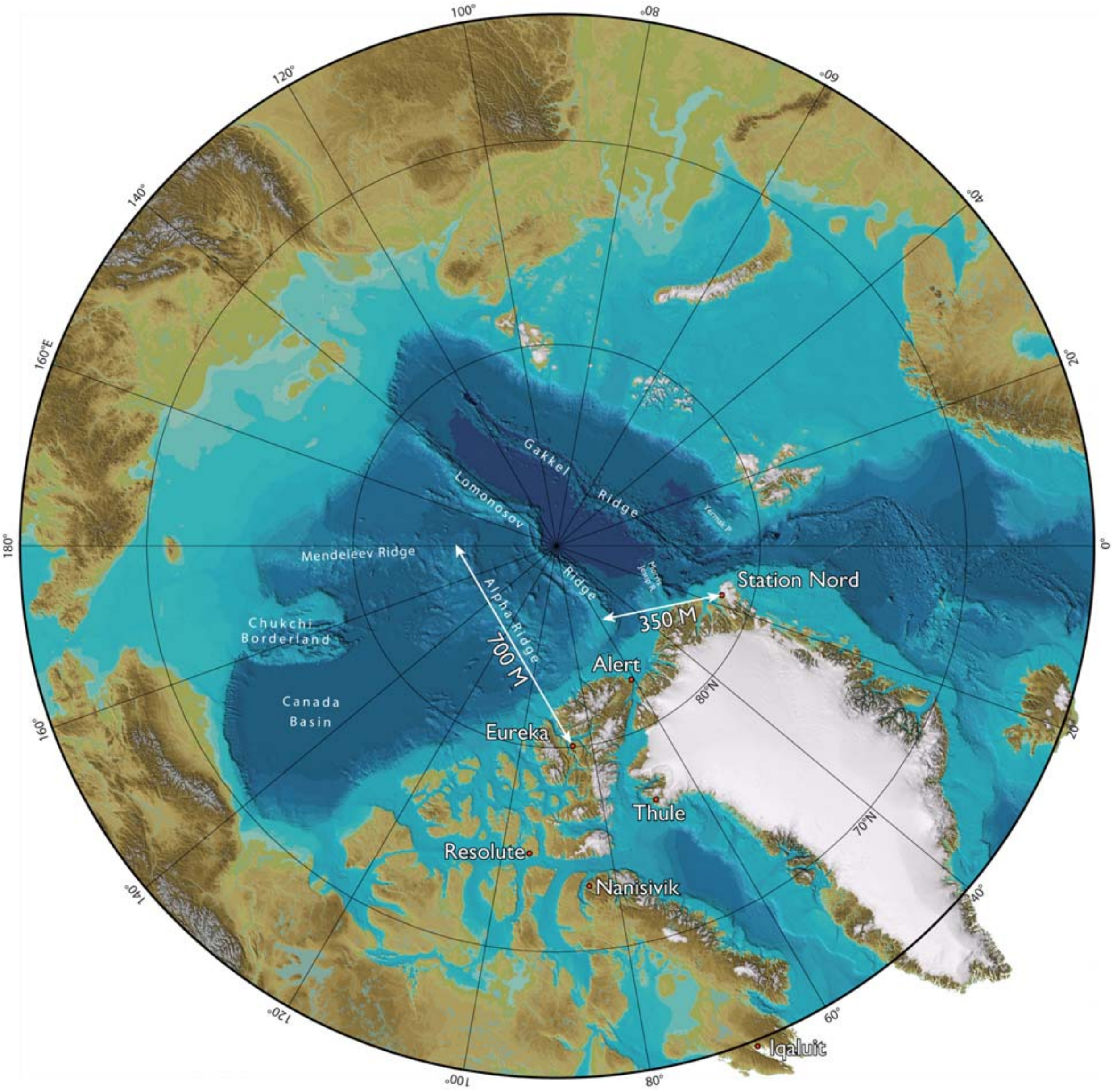

Figure 1: *Long distances in the Canadian and Greenland Arctic make logistics difficult and very expensive.*
(IBCAO Version 2.23 http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/ibcaoversion2.html)

From a Danish perspective, Station Nord is 650 M from Thule and 350 M from Lomonosov Ridge, so the Canadian bases are much closer to this area of interest. Transporting equipment and people from Copenhagen to Nord or Alert is logistically challenging and time consuming. Denmark does not have an Arctic class icebreaker and must charter. The start point for the transit of a chartered icebreaker to the area north of Greenland is normally Tromsø in northern Norway (loading of heavy equipment) and Longyearbyen on Svalbard (personnel) with a transit time to the area north of Greenland of several days depending on ice conditions.

While there is local infrastructure such as accommodations and electricity at Resolute, the Environment Canada weather station at Eureka, at Canadian Forces Station Alert and at Station Nord, all this infrastructure needs to be brought north for work on the Arctic Ocean. This remoteness means that fuel and accommodations and generators must be shipped north a year in advance of a winter operation and then flown to an ice-camp or must be flown to Alert and Station Nord. While the endurance of icebreakers depends on the fuel required to break different ice conditions, Canadian icebreakers normally operate on a 5 or 6 week cycle while in the Arctic and can refuel from barges near shore in the western Arctic. However, the vessels must carry all the gear and spares needed for a 6 week survey out of touch with land and re-supply possibilities. The Swedish Icebreaker *Oden* used in the Danish project has an endurance of 100 days and Russian nuclear icebreakers do not need "refuelling" for several years.

If something fails during a winter operation it is possible to have spare equipment flown up from the south, a helicopter replaced within 2 weeks, etc. If an icebreaker equipped for survey work breaks down during a 6 week survey, the work area normally will be well beyond the range of the vessel's helicopter to bring is spare parts or experts. It is unlikely that a replacement vessel could be found, outfitted and positioned to the Arctic before the 6-8 week survey window for the year closes.

The challenge of the remoteness is further complicated by the traditional weather conditions (temperature, months of darkness, flying conditions) as well as traditional ice conditions with yearly variations thrown in.

2.2 Weather

There are two traditional operating windows for surveying on the Arctic Ocean. On-ice operations in March and April when the weather is normally cold and clear and icebreaker operations in August and September when ice melt is at its maximum.

Operational considerations also include the temperature. Thirty year average temperatures for Canadian Forces Station Alert, the most northerly permanently inhabited site in Canada (82°20'N), ranges from +3.3°C in July to -33.4°C in February with average temperatures above freezing only in June, July and August. The average daily minimum ranges from +0.1°C in July to -36.1°C in March.

The Arctic night where the sun does not rise between late October and late February also imposes constraints in available time windows for survey activity. There is sufficient daylight by the second week of March to carry out on-ice survey work using helicopters. There is a strong correlation between hours of sunlight, temperature and precipitation. For example, the amount of snowfall in May is double that in March (Environment Canada website 2008). Past experience in this area is that warming temperatures in May (average -11.8°C versus average -24.4°C in April and -32.4°C in March) leads to ice crystals and ice fog that severely limit flying operations on the ice. This situation of poor flying weather for on-ice operations continues through the summer months when the sun never sets, so the operational window for efficient on-ice surveys is at maximum early March to early May.

In the western Arctic where ice condition are lighter and the ice breaks up each summer, the winter weather at Sachs Harbour (72°N, 126°W) is similar to Alert. The thirty year average temperatures ranges from +6.8°C in July to -29.3°C in January with average temperatures above freezing only in June, July and August. The average daily minimum ranges from +3.3°C in July to -32.9°C in January. Temperatures climb sharply to an average of -10.8°C in May, so the winter survey window is similar to that of higher latitudes.

There is a second weather window in August and September when survey work can be carried out from icebreakers. By August the annual ice melt is underway, peaking in late August or early September. At 72°N the sun sets for the first time on August 13 and by September 25 there is 12 hours between sunrise and sunset, reducing to 9 hours by October 10. Average daily maximum temperatures in September are +0.6°C while average minimums -4.1°C. At higher latitudes the hours of daylight decrease more quickly, for example at 82°N there is 12 hours daylight on September 25 but only 5.7 hours on October 10.

Daylight is essential to select routes through multiyear ice and to recover gear caught in ice. Darkness usually means stopping the vessel each night and the gear is brought on board and redeployed after it is daylight. Manoeuvring to overlap with the end of line on the previous day can take several hours. Below freezing temperatures also causes the seismic gear to freeze up when it is on deck and airguns to freeze when first deployed into the water. Thus the efficiency of the operation decreases in proportion with decreasing daylight and temperatures, therefore, the survey window for the icebreaker operation is August and September.

2.3 Ice Conditions

While climate variations has seen the permanent Arctic ice cap shrink on given years the concentration of ice north of Canada and Greenland continues to be very heavy, and at times heavier at minimum extent (Fig. 2).

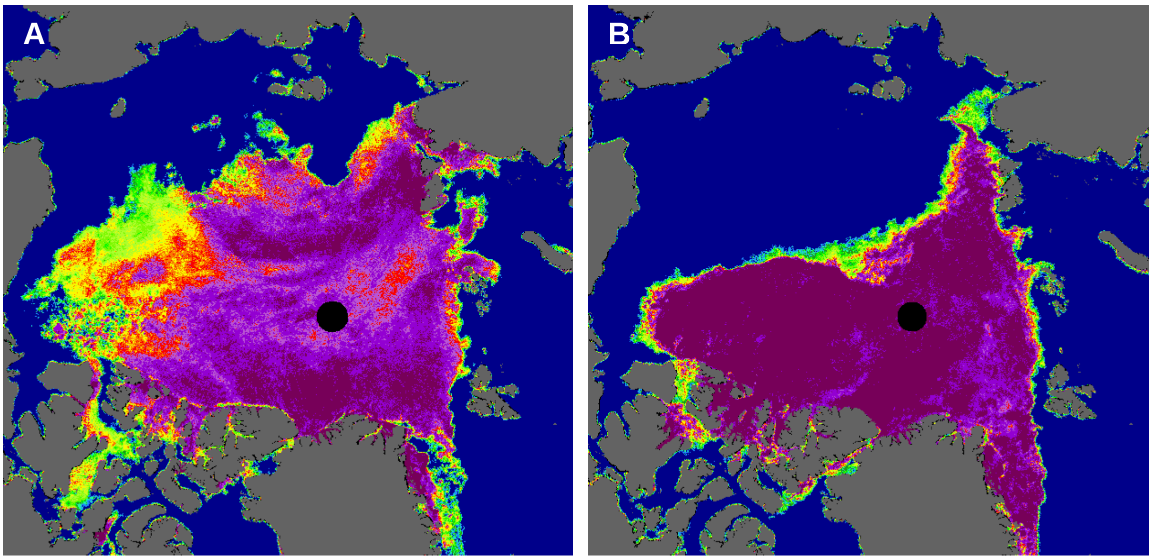

Figure 2: *Sea ice coverage in the Arctic Ocean.* ***A*** *– August 1, 2007* ***B*** *– September 30, 2007. Arctic sea ice reached its lowest annual extent–the absolute minimum–on September 15, 2007. Dark colours indicate heavy ice conditions. (Map source: AMSR Sea Ice Maps, IUP University of Bremen, http://www.iup.uni-bremen.de:8084/amsr/amsre.html).*

The variability of summer ice conditions has also affected winter survey operations. There are few large pans of multi-year ice available for ice-camps and the increased motion of the ice has led to many small pans of ice, large pressure ridges as well as frozen and open leads of various ages. These areas of relatively thin ice are very susceptible to wind which causes further rafting of ice or the opening of new leads during the winter period. Unstable rafted ice is not a good recipe for safely establishing and removing large winter ice-camps.

3. Existing Data

The traditional view of the Arctic Ocean is of a permanent ice cap covering much of the ocean. This ice cover has prevented traditional marine surveying and mapping techniques from being used. This same ice cover has spawned opportunities for non-conventional data collection techniques such as the use of ice-camps and through-ice techniques and data collected by submarines. In recent years space and airborne gravity and magnetic data have also identified general features of the seabed. This collage of data sets represents decades of work with data of different accuracies depending on the instrumentation available and used at a given time. However, there remain large areas that are sparsely surveyed and areas in the ice-covered waters where surface vessels have never been able to operate (Fig. 1).

The area of the Arctic Ocean immediately north of the Canadian archipelago and Greenland is one such area where ice concentration is very heavy and existing survey data too sparse to meet the requirements for UNCLOS for foot of slope and 2500 metre depth contour depiction. The existing seismic data in the offshore areas is even sparser.

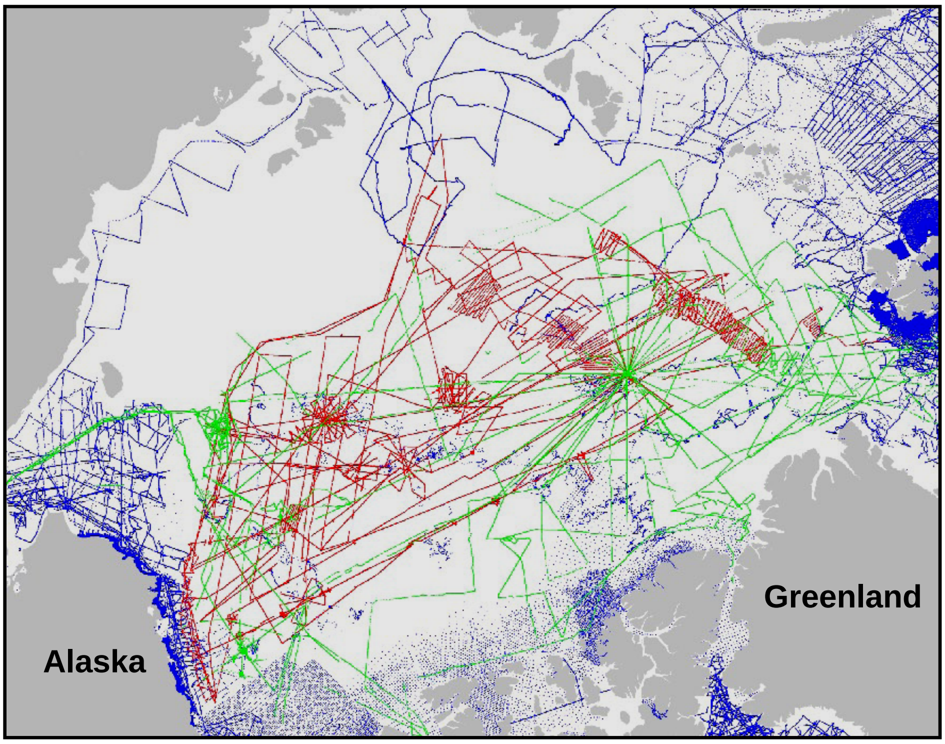

Figure 3: *Existing bathymetric data coverage (blue: spot soundings; green: US & UK nuclear submarines (1958–1992); red: SCICEX nuclear submarine (1993–1999) – EB-IBCAO, March 2000).*

4. Operational Strategies

Desktop studies were used to indicate which formulae will maximize Canada and Denmark's continental shelf in the Arctic and forms the basis of the data collection strategy. In general, the sediment thickness formula (Gardiner line) and the 350 M from the Territorial Sea baselines constraint formula will maximize the continental shelf in the western Arctic. Determining that Alpha and Lomonosov Ridges are natural prolongation of the continental shelf and form submarine elevations is key to planning data collection in this area using the 2500 metre depth contour combined with the 350 M as constraint formula. Sparse seismic data in the Amundsen Basin north of Greenland indicate that the sediment thickness formula will be used in this area.

The existing bathymetry in the foot of slope and 2500 metre depth contour areas is not sufficiently dense to meet the requirements for an outer limit point every 60 M. The knowledge of sediment thickness in the Canada Basin is rudimentary at best. While there have been a number of scientific expeditions to portions of Lomonosov Ridge (e.g. the Arctic Coring Expedition (ACEX) in 2004 – IODP website 2008) there is less existing knowledge concerning Alpha Ridge.

An ideal data collection plan in the Canadian part of the Arctic Ocean was laid out with 50 M line spacing (to allow for deviation in ice) then discussed with Canadian Coast Guard (Fig. 4). Their advice was that data collection from conventionally powered Arctic icebreakers will be very difficult north of 80ºN in the area immediately north of the Canadian archipelago. Past experience with Russian nuclear powered icebreakers has been that ability to operate in the ice conditions of the Lincoln Sea ice-pack is not guaranteed and in past attempts only a few hours of seismic data could be collected.

In the area north of Greenland a two stage plan has been developed with the first stage being acquisition of on-ice bathymetric and seismic data for the test of appurtenance and the second to acquire the necessary bathymetric data along the flank of the Lomonosov Ridge (foot of slope and 2500 m depth contour) and sediment thickness data using reflection seismic methods in the relevant parts of the Amundsen Basin.

Therefore, plans were developed to collect bathymetric and seismic profiles in the western Arctic and north of Greenland using icebreakers and to collect bathymetric profiles and test of appurtenance seismic profiles using on-ice techniques between the Amundsen and Canada Basins.

The on-ice test of appurtenance surveys will be refraction seismic surveys in specific areas of interest such as the North American ends of Alpha and Lomonosov Ridges. The on-ice bathymetric surveys will be profiles of sounding approximately 50 M apart as well as strategically placed profiles to connect to existing data. Sounding will be collected along each profile at sampling or "ping" rates that vary from 10 km to 2 km, with the denser sampling in the foot of the slope area.

The on-ice techniques will be continued westward until the icebreaker surveys are met.

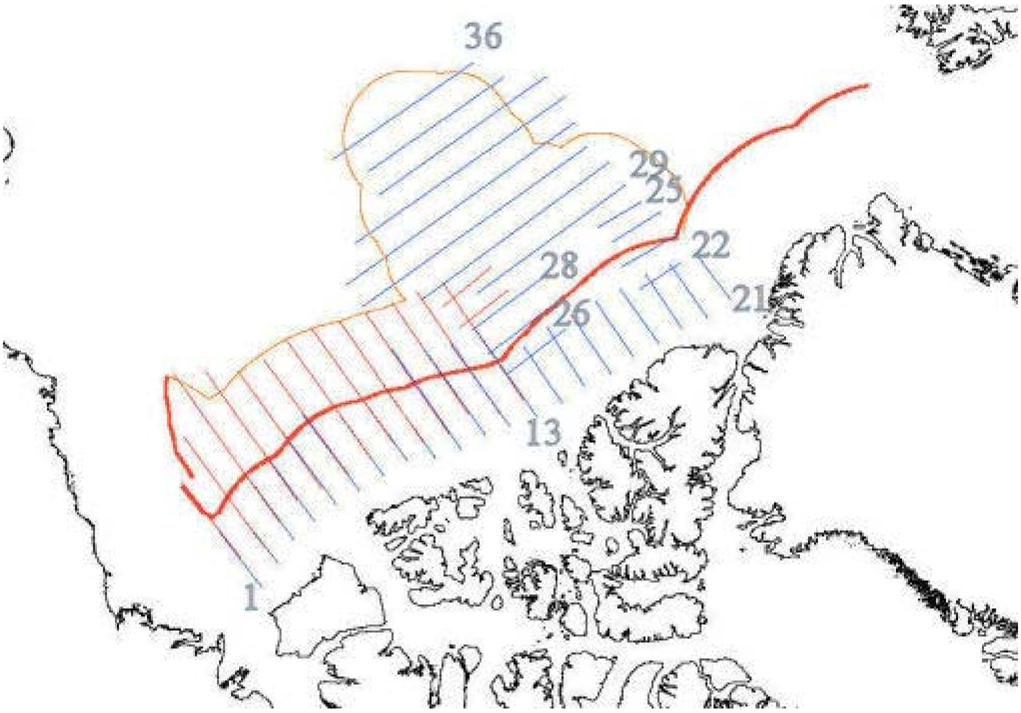

__Figure 4:__ Ideal survey lines at 50 M for the Canadian part of the Arctic Ocean (Straight red lines are seismic profiles; Blue lines are bathymetric profiles; bold red line is the 200 M EEZ; the thin orange line is the maximum outer limit as set by constraint formulae).

5. Logistic Challenges

Commercial hydrographic survey and seismic vessels are not typically icebreakers. Multi beam echo sounder systems that are protected from ice and towing commercial seismic gear in ice covered waters is not the norm for these survey companies. Only a few Polar Class icebreakers are available capable of operating in these parts of the Arctic Ocean.

Specialized seismic gear, strengthened to survive in broken ice behind an icebreaker is required. Ideally the survey vessel must be capable of operating in 10/10 ice 3 to 5 metres thick and able to tow the seismic gear at 3–4 knots. This slow towing speed and inability to reverse without hauling in the seismic gear precludes using speed and momentum to break ice while surveying. It was concluded that an escort icebreaker is essential in ice conditions greater than 6/10 coverage.

Hydrographic and seismic surveys from ice camps have not been conducted in the Canadian Arctic for more than a decade. Camp equipment, survey equipment and expertise have all aged and in many cases are no longer available. It was recognized that existing government scientific resources needed to be supplemented by partnering and contracting needed expertise. In order to share costs and assemble the necessary experienced staff, cooperation between Canada and Greenland was established. This has proved to be mutually beneficial for the past 3 years and will be continued in the following years.

The effort to establish an ice camp to accommodate 35–40 people, as well as the fuel (800–1000 barrels) for 3 to 5 helicopters, a de Havilland Twin Otter on skis and the infrastructure (electricity, showers, toilets, kitchen, communications) is significant. Ice camps also require a runway on the ice to bring in camp gear, supplies and fuel. While the Twin Otter aircraft on skis can land and take off from a 230 metres airstrip, their payload of 1100 Kg, make them uneconomical and inefficient for establishing a large camp. Larger aircraft require longer runways and more fuel (Fig. 5).

Aircraft	Speed (knots)	Fuel/Hour (L)	Range with load (M)	Cargo (Kg)	Airstrip (m)	Cost / Hour + Fuel ($)
Twin Otter	140	450	500	1100	230	1200
DC-3 Turbo	200	600	1200	2500	1100	3100
Buffalo	230	925	600	5500-7700	1100-1300	4800
C-130 Hercules	320	3000	1250	16000	1600	11000

Figure 5: *Aircraft Specifications*

Given the distances from the Canada and Greenland coasts (700M), reaching the outer limits of the survey area using aircraft and ice camps will be a major challenge. If a sufficiently long runway could be found, part of each load of fuel delivered would be needed for the aircraft to return to land. Depending on ice conditions in a given year, icebreakers may be able to collect the necessary bathymetry at the outer edge of Alpha Ridge.

A strategy has been developed to maximize the use of existing data wherever possible and supplement with additional data collection. In addition to icebreaker surveys in the western Arctic and on-ice measurement in the eastern Arctic, non-traditional survey approaches are being considered. These include under-ice data collection using submarines and Underwater Vehicles (UUV) as well as airborne gravity and magnetic surveys to support the seismic data regarding sediment thickness and continuity.

The class of submarine used by the USA for SCICEX has been decommissioned and the submarines currently in use have not been equipped for science. If a decision was made by the USA today to equip these submarines to collect bathymetry for UNCLOS, it is unlikely that the necessary engineering studies and modifications could be completed in time for data collection useful for the Canadian and Danish submissions to be collected. A proposal to utilize modular UUV's that could operate to 5000 metres and be moved by ski planes and deployed from small ice-camps is being explored for bathymetric surveys in areas difficult to reach by icebreaker or on-ice techniques. In theory, the UUV operation can be conducted from smaller ice-camps and be less susceptible to weather conditions, but do bring other challenges and risks.

6. Operational Experiences

6.1 Western Arctic

Canada commenced work in the western Arctic in 2005 with a trial on the *CCGS Amundsen* which is equipped with a SIMRAD EM 300 Multi Beam Echo Sounder system. This trial had two objectives, determining if the vessel could reach the 2500 metre depth contour in the Beaufort Sea and secondly to determine the performance of that multi beam system. While the vessel reached the 2500 metre depth contour with difficulty, it was determined that useful multi beam sounding data could not be collected from the *CCGS Amundsen* while the vessel was breaking ice.

The University of New Hampshire and the National Atmospheric and Oceanic Administration (NOAA) in the USA have been collecting multi beam bathymetry in the western Arctic for a number of years using the *USCGC Healy* which is equipped with a SeaBeam system. They have experienced similar results to the *CCGS Amundsen* when breaking ice and have developed a ratcheting technique of ramming, reversing through the ice rubble and then accelerating in the same track. During that period of acceleration useful multi beam data is obtained (Mayer 2004).

In 2006 a second trail was conducted with the larger icebreaker, the *CCGS Louis S. St-Laurent* to test the ships 12 KHz Knudsen single beam echo sounder and a new ice-strengthened seismic system. The latter trials were conducted on an opportunity basis during an oceanographic cruise and the results used to improve the system for a dedicated seismic survey in 2007.

Those modifications included adding an A-Frame to the vessel for seismic gear deployment and a new digital streamer. Because of the remoteness of the area spare airgun arrays and spare streamers were major additions. A new digital processor enhanced the radar images to distinguish between ice and open water and assisted in avoiding large heavy ice flows. The radar worked well until the new ice formed and was covered with snow, then new and old ice were no longer distinguishable.

One navigation objective was to avoid heavy ice because the vessel was towing seismic gear at a speed of 3–4 knots and did not have the momentum to break ice. The option of ramming and backing was problematic because the gear had to be hauled in before reversing. Breaking lines also introduced the added challenge of back tracking to overlap the seismic line while the ice flows continued to be in motion. At times small gaps in coverage occurred when ice prevented a return to the end of line point. To comply with environmental assessment provisions, seismic operations were also stopped when within 1 Km of marine mammals. The air guns were shut down as the vessel continued past the mammal and the guns re-started when a safe distance was reached.

Ice conditions in 2007 were relatively light at the outer ends of the lines (near the 350 M constraint line) and heavier as the lines approached the shelf (Fig. 6). The ability to follow planned lines was directly correlated with ice conditions. Where the ice was relatively light the lines could be followed with few variations. Where ice conditions were heavy the lines follow whatever circuitous route the icebreaker could find through the ice and continue to proceed in the generally intended direction. The lighter ice conditions at the outer ends of the lines meant that required spacing could be achieved in the area of the outer limits of the continental shelf.

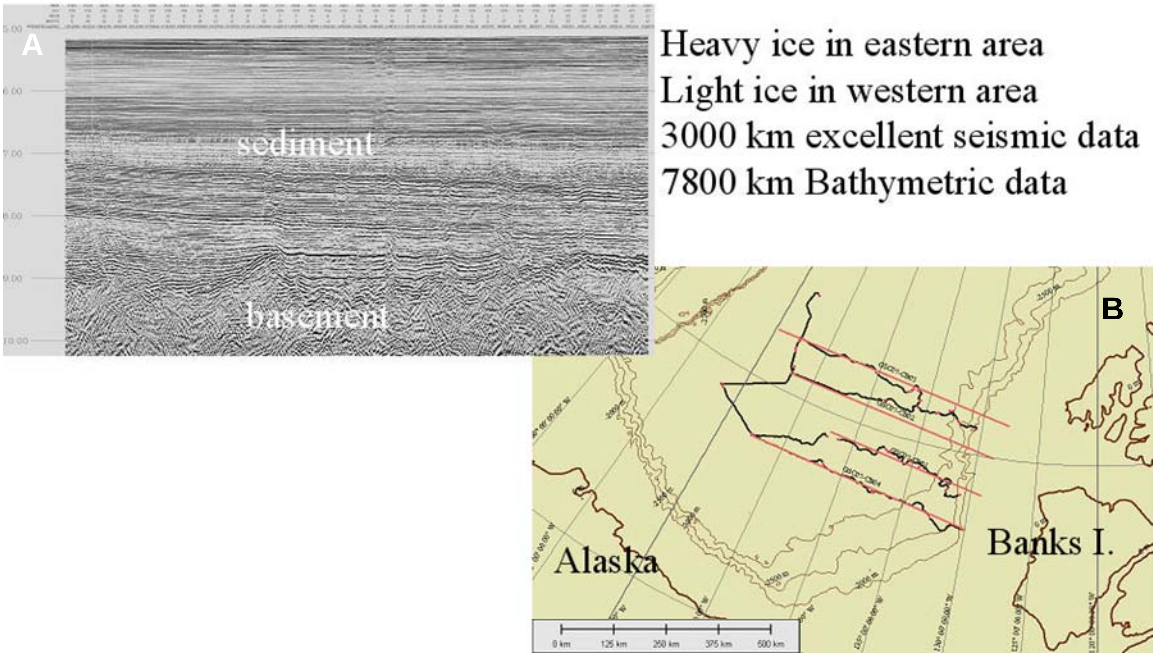

Figure 6: *2007 seismic lines.* ***A*** *– Data example* ***B*** *– A total of 3000 Km of seismic data (planned – red, achieved – black) was collected as well as 7800 Km of single beam sounding (collected on all transits, manoeuvring, etc.). Several conclusions were reached:*

1. *The survey had to start earlier than September 1 because by early October freezing temperatures were impacting the seismic gear, new ice was forming, and the ever increasing darkness impacted the ability of the ship to navigate around heavy ice resulting in longer and longer down-time each day.*
2. *An escort icebreaker was required for the survey to proceed north of 77°N.*
3. *The new compressor was a weak link and a spare compressor was needed for 2008.*
4. *The digital streamer provided excellent data.*

In 2008 the planned seismic coverage includes connecting to certain existing seismic lines in the western Arctic and rendezvousing with the *USCGC Healy* in early September and running a two ship operation for the month of September. The *CCGS Louis S. St-Laurent* will operate alone from August 21 until the rendezvous with the *USCGC Healy* approximately September 8. The general plan is to run lines 50 M apart but there are several options for which lines will be run first, depending on ice conditions.

6.2 Eastern Arctic

The work commenced in March 2006 with a joint Canada–Denmark survey based from CFS Alert. The primary objective was the **L**omonosov **R**idge **T**est of **A**ppurtenance (LORITA) which was an on-ice refraction seismic experiment using explosive charges as sound source and 100 Taurus seismometers which were set out on the ice as recording devices (Fig. 7). It entailed 3 helicopters and a twin otter aircraft and a Canadian–Danish Team of approximately 30 people. Timing was important and weather played havoc with deployments and retrievals.

Figure 7: *LORITA refraction seismic experiment spring 2006.* ***A*** *– Each seismic line required drilling 11 holes approximately 20 Km apart.* ***B*** *– Suspending either 350 Kg or 175 Kg of Pentolite explosives 100 metres below the ice at each hole.* ***C*** *– Setting out up to 100 seismometers at intervals of 1.5–2 Km and firing the charges.* ***D*** *– Collecting all the instruments and then downloading the data (Photos: Christian Marcussen and Ron Verrall).*

Despite losing 65–70% of the time to bad weather, the primary objective of mapping the crustal structure from the Lomonosov Ridge to the Canadian–Greenland shelf was achieved (Fig. 8). Only two instruments and their data were lost. However, the secondary objective of collecting bathymetry and gravity data at each instrument location and across the trough south of Lomonosov Ridge was not achieved due to the weather.

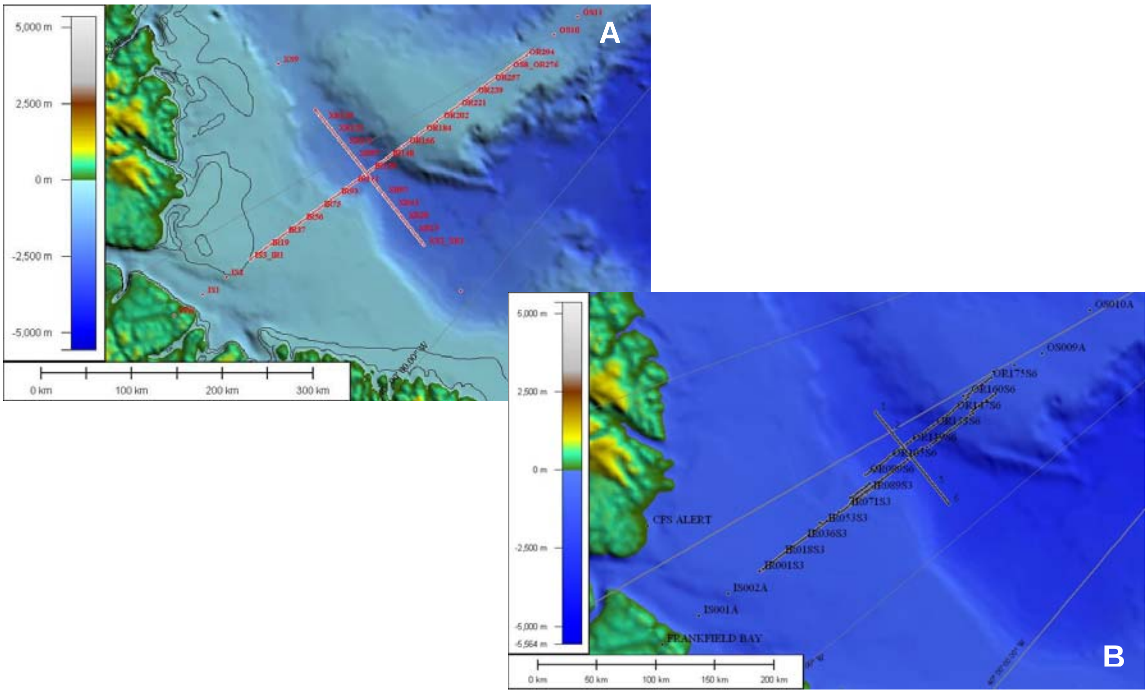

Figure 8: *LORITA refraction seismic experiment spring 2006.* ***A*** *– Planned and* ***B*** *– achieved lines, offset in N–S line due to ice drift during a bad weather period with no data acquisition.*

A March 2007 bathymetric survey to complete the LORITA sounding met with worse weather than in 2006. The ice for 100 M off the shore north of Alert was continually in motion, emptying ice through Nares Strait between Ellesmere Island and Greenland (Fig. 9). It was difficult to find ice flows 300 metres in length for twin otters to land with fuel caches. In one three-day period a fuel cache drifted 50 M. The open water caused summer-like flying conditions of ice crystals and ice fog despite normal winter temperatures and over 95% of the time was lost. Little of the bathymetric objective was achieved.

Figure 9: ***A*** *– Satellite image off Alert (March 2007) showing drainage of sea ice in the Lincoln Sea trough the Nares Strait.* ***B*** *– Helicopters with no horizon in spring of 2007.*

In 2007 the Swedish / Danish LOMROG cruise (Swedish Polar Research Secretariat 2007) using the Swedish icebreaker *Oden* and the Russian nuclear icebreaker *50 let Pobedy* took place with Canadian participation. The planned survey was focused on

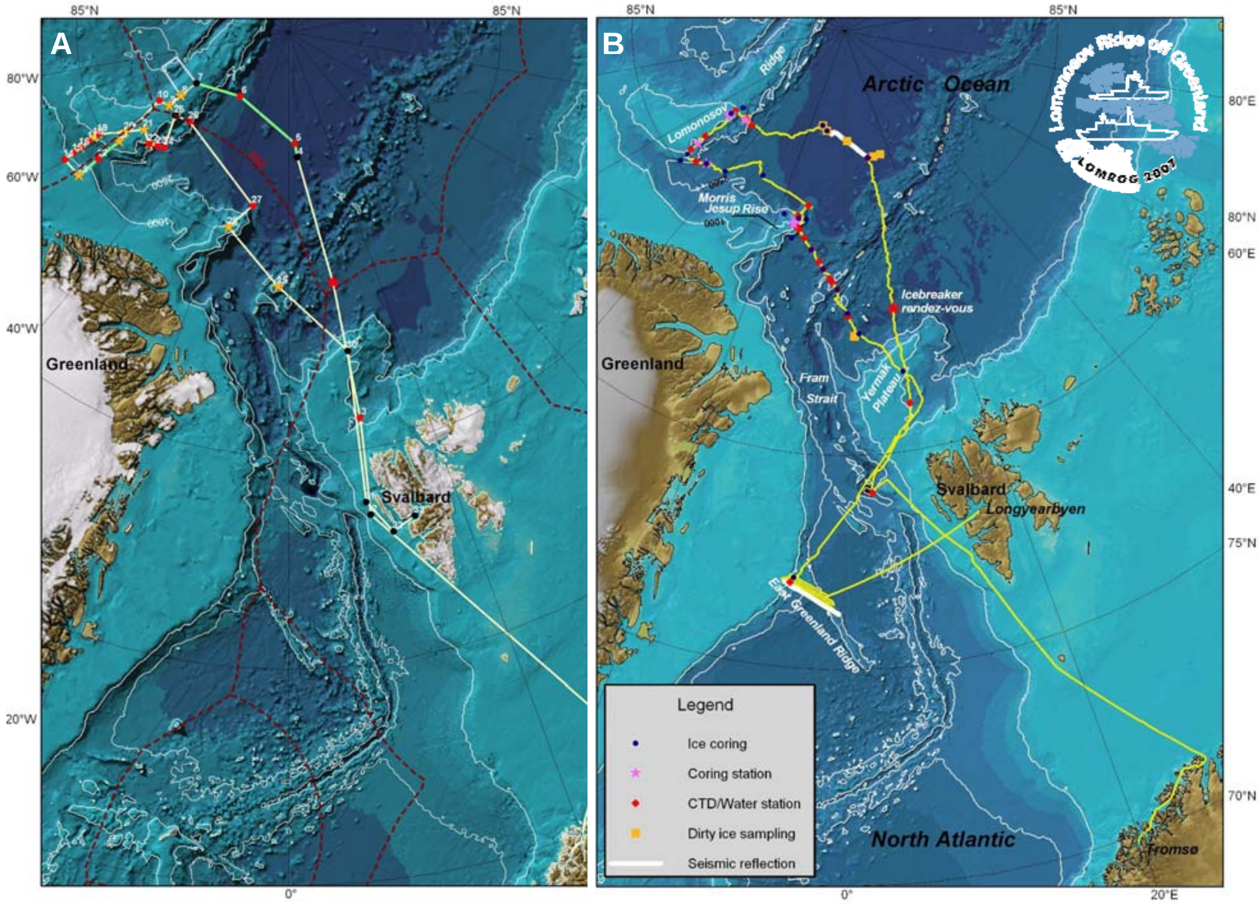

Figure 10: *LOMROG Cruise2007.* ***A*** *– Planned route (black dot: coring stations; red dot: CTD and water sampling station; red star: icebreaker rendezvous; white line: multi beam; green line: reflection seismic).* ***B*** *– Sailed route. Gravity data were acquired along the sailed route. Heavy ice conditions prevented access to the Lincoln Sea. The southern part of the Lomonosov Ridge has never before been visited by surface ships.*

data acquisition in the Amundsen Basin and the eastern side of the Lomonosov Ridge. However the cruise also included two bathymetric lines on the western side of Lomonosov Ridge and to survey a seismic line along Lomonosov Ridge (Fig. 10). Oden was equipped with a multi beam bathymetric sonar (Kongsberg EM120) and chirp subbottom profiler (Kongsberg SBP120). Seismic equipment designed for use in heavy ice was also used during the LOMROG cruise.

The amount of aeration and the broken ice in the water made it difficult for the multi beam echo sounder system on the ODEN to detect and track bottom. The practice developed was to stop every 15 minutes to confirm that they were tracking bottom, The ODEN did collect spectacular multi beam data by doing slow pirouettes in areas where ice conditions allowed for a pirouette (Fig. 11).

Close to and on the Lomonosov Ridge the multiyear sea ice was 10/10 coverage, 3 to 5 metres thick with pressure ridges to 6 metre and the ice was under compression. *Oden* was frequently stuck in the track made by the *50 let Pobedy* despite being able to use all 24000 HP and the nuclear breaker with 75000 HP would have to return and free the *Oden*.

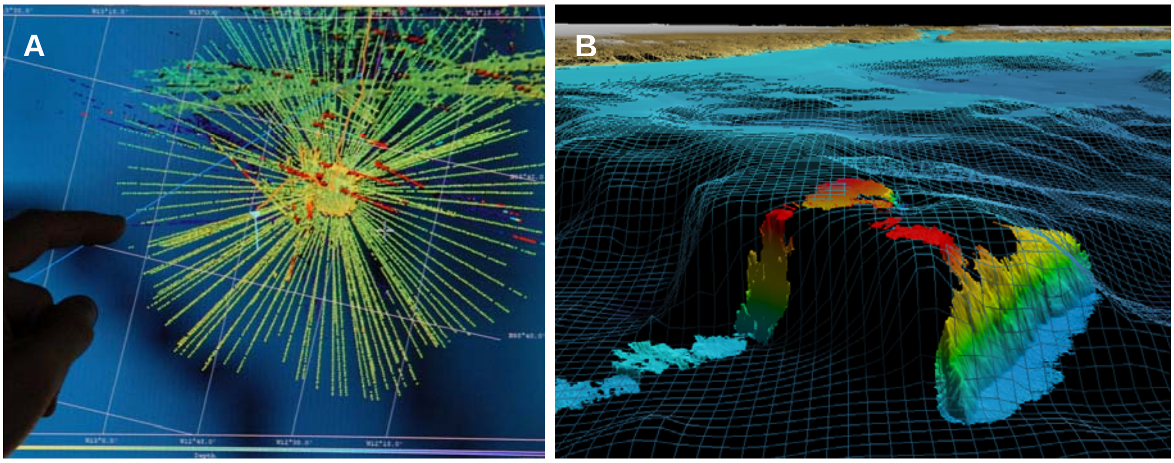

Figure 11: ***A*** *– Data acquisition window of Oden's EM120 multi beam system showing how bathymetric data was collected in a 360° sector around the ship, referred to as "pirouette surveying". This method worked well in hard ice conditions where the heavy ice breaking otherwise significantly disturbed the data acquisition (Photo: Martin Jakobsson).*
B *– 3D-view of the multi beam mapped Morris Jesup Rise north of Greenland (see Fig. 11 for general location). The International Bathymetric Chart of the Arctic Ocean (IBCAO) grid model is shown (blue grid) as a comparison to the new detailed multi beam bathymetry (Map courtesy Martin Jakobsson).*

Figure 12: *Seismic equipment developed for acquisition of seismic data in heavy ice conditions within the Danish Continental Shelf Project. In order 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 propeller wash the tow depth was increased to calm waters below 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. ***A*** *– Seismic source (Sercel 605 cu in. linear air gun cluster),* ***B*** *– Geometrics GeoEel digital streamer,* ***C*** *– Winch container for streamer and umbilical,* ***D*** *– Inside view of recording container (Photos: Thomas Vangkilde-Pedersen).*

In the Amundsen Basin east of the Lomonosov Ridge a 130 km long seismic line was acquired in the course of two days in heavy ice conditions (Fig. 12). A significant amount of the seismic streamer was damaged or lost in the broken ice despite towing airguns and streamer 20 metres below the surface (Fig. 13). The *Oden* and *50 Let Pobedy* did not get into the Canadian area of the Lincoln Sea to carry out the bathymetric surveys due to the heavy ice and moved to other objectives north and northeast of Greenland (Fig. 10).

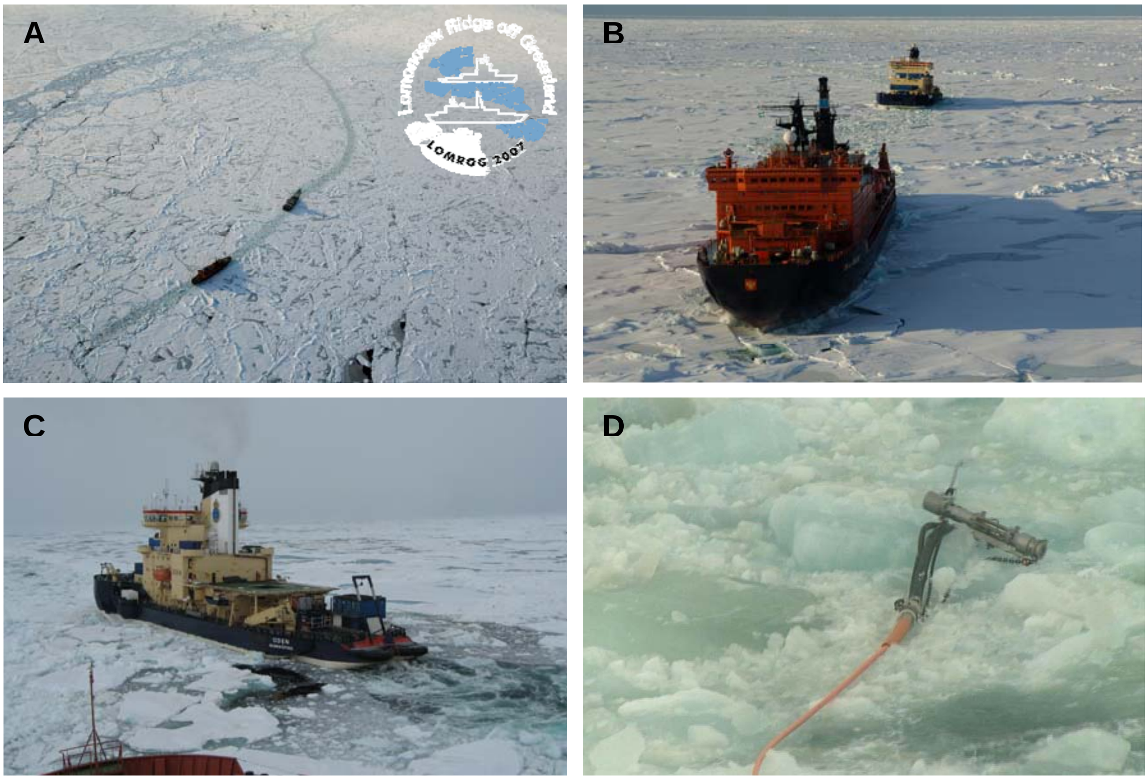

Figure 13: *Two -vessel seismic operations during LOMROG in 2008.* ***A*** *and* ***B*** *– 50 let Pobedy and Oden trailing behind in severe ice conditions in the Lomonosov Ridge area,* ***C*** *– Oden stuck in ice during seismic data acquisition,* ***D*** *– Umbilical, airgun and streamer dragged along on the sea ice surface (Photos: Martin Jakobsson and Kenneth Sorento).*

In March–April 2008 the **A**lpha **R**idge **T**est of **A**ppurtenance (ARTA) project was staged out of the Environment Canada weather Station at Eureka. This refraction seismic survey was a repeat of the LORITA experiment using the same instrument and procedures. A plan to establish a large hydrographic camp 100 M offshore had to be abandoned due to ice conditions (Fig. 14). It was not possible to find an ice flow 1000 metres long for a runway and satellite imagery showed large open leads extending through the surveys area. A small 3-person seismic reflection camp was established 100 M offshore, however, the main camp was established on shore-fast ice near the mouth of Nansen Sound and the survey area adjusted to what was achievable from that location (Fig. 15). The seismic instruments were housed at Eureka and flown to the ice for deployments and returned to Eureka to download data and replace batteries for the next deployment.

A B

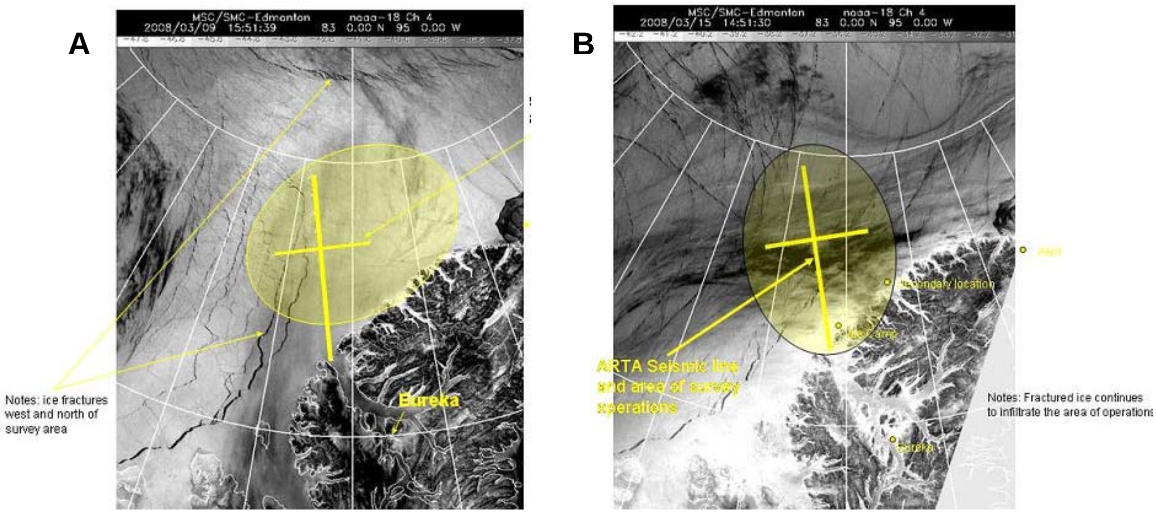

Figure 14: *Planned and revised area of ARTA survey. Satellite image showing sea ice conditions on **A** – March 9, 2008 and **B** – March 15, 2008.*

Near the end of the ARTA project an experiment to collect longer seismic lines beyond the range of the helicopter was conducted using seismic instruments propelled from a Canadian Forces Aurora aircraft. These instruments were designed to penetrate the ice sufficiently to remain upright and transmit data back to the aircraft. Ice conditions (pressure ridges, open water, leads with thin ice) made deployment at points, where the instruments would function, a challenge and precluded using predefined positions. The results of the data recorded are still being analyzed.

Weather conditions in March 2008 were actually colder than normal with -52C temperatures experienced during camp set up as the team struggled to clear a runway and erect insulated tents for accommodation and working space. At this temperature things that are normally flexible (grease, hoses, fuel lines, drive belts) either freeze solid or become brittle and break like glass.

The ice was severely rafted and consisted of many small pans of mostly first and second year ice. Because the ice was relatively thin it was in motion, impacted by the wind and was constantly piling up or being broken apart into new leads. This impacted where helicopters could safely land and open leads did create ice fog that at times impacted progress. As the survey approached the end of April more time was being lost than worked due to bad weather and survey operations were terminated on April 30.

Figure 15: *ARTA project spring 2008 – Photo of landfast ice and camp with 900 meter ice runway at entrance of Nansen Sound.*

Both the seismic and bathymetric programs completed their revised objectives for the season (Fig. 16) but the camp removal was delayed for nearly three weeks because the Buffalo aircraft chartered to remove the camp had mechanical problems. The area covered in a $7 million survey with good weather versus the total area provides an idea of the magnitude of the task.

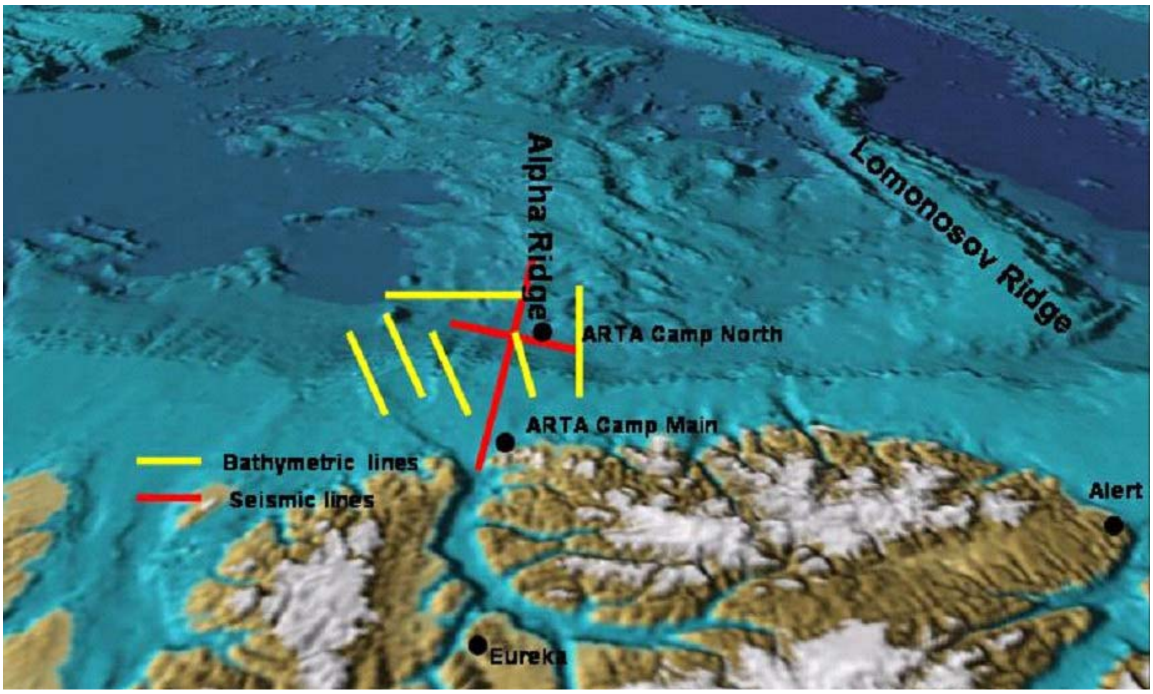

Figure 16: *Final coverage achieved on ARTA.*

7. Future plans

In the eastern Arctic the plans for 2009 include a spring (March–April) bathymetric survey from shore-fast ice near Ward Hunt Island on northern Ellesmere, a joint Canadian–Danish survey out of CFS Alert to complete the LORITA bathymetry, flying a Danish–Canadian airborne gravity survey from Station Nord, Alert and Eureka and a return in August–September with the *Oden* to the area around the North Pole as a Danish–Swedish–Canadian cooperation.

Longer term plans include working west from the ARTA project area from camps on or near the shore collecting bathymetric profiles for foot of slope and possibly deploying UUV to collect bathymetry from small offshore ice-camps as well as further cruises with the *Oden* supported by a Russian nuclear icebreaker in the Amundsen Basin.

In the western Arctic longer term plans for 2009 and beyond are to continue to work north with icebreakers in a two ship operation.

8. Conclusions

A number of factors impact the level of difficulty in acquiring the required data in the Arctic. There factors introduce risks that are not predictable and difficult to mitigate because they vary from year to year and area to area. The remoteness of the Arctic Ocean, short survey seasons and severe and unpredictable weather and ice conditions all contribute to the uncertainty. A number of observations, challenges and conclusions are listed below.

- The logistic challenges posed by the remoteness of the survey area are significant, costly and there is a very real risk of losing a season due to logistics.
- A season is at most 4 months per year if both winter and summer surveys are conducted.
- Distances from terrestrial staging bases to the outer edges of Alpha Ridge pose a major logistic challenge in an area not normally frequented by icebreakers.
- Icebreakers can collect good seismic data in relatively light ice conditions and employing a philosophy of avoiding heavy ice and following a circuitous route. Straighter routes can be followed in two-icebreaker operations.
- Collecting seismic from icebreakers in 10/10 ice even with an escort icebreaker is difficult and the risk of losing the seismic gear high, especially when ice is under compression.
- Collecting multi beam bathymetry while breaking ice or following an escort icebreaker is difficult and data quality suffers.
- The unpredictable and changing ice conditions pose a risk to establishing ice-camps in ideal or even acceptable locations and achieving a planned objective in a specific winter season.
- Long used on-ice refraction seismic survey techniques, while labour intensive and susceptible to weather, do work for test of appurtenance.
- It is also possible to collect bathymetric profiles using proven on-ice techniques.
- Due to the difficulty of collecting data, there is little opportunity to collect redundant coverage in ice covered waters
- Use of new technology such as UUV offers possibilities to mitigate weather conditions for bathymetry but the risks of loss is relatively high

- Airborne gravity and magnetics can be collected to complement existing technology.
- There is cooperation between all Arctic coastal states at the scientific level.

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10. Links

Canadian Continental Shelf Project: http://www.international.gc.ca/continental/index.aspx

Danish Continental Shelf Project: http://a76.dk

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