Scientific drilling in the Arctic Ocean and the site survey challenge: Tectonic, paleoceanographic and climatic evolution of the Polar Basin

JEODI Workshop, Copenhagen, Denmark, January, 2003

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EXCUTIVE SUMMARY

The Joint European Ocean Drilling Initiative (JEODI) was established in 2002 as a two year EU funded project to bring a distinctive European component to the new era of scientific ocean drilling. This Thematic Network brought together all the major European member states involved in scientific ocean drilling and JEODI has emphasized as one of the target areas: Arctic Science, with drilling of the almost unexplored Arctic Ocean.

The JEODI Workshop "Preparing for Scientific Ocean Drilling in the Arctic: The Site Survey Challenge" was held in Copenhagen, January 13-14, 2003, in order to discuss scientific drilling in the Arctic Ocean. The workshop was organised by Naja Mikkelsen, Yngve Kristoffersen, Jan Backman, Wilfried Jokat and Jørn Thiede and it brought together 50 Arctic scientists (Europe and Russia 39, US and Canada 11), managers, operators and specialists. The focus of the workshop was on the site survey challenge in the ice-covered waters of the Arctic Ocean. Acquisition of adequate marine geophysical site survey data is a necessary pre-requisite for planning and safely drilling and coring the Arctic's sediments and bedrock. The workshop was sponsored by the Joint European Ocean Drilling Initiative (JEODI under the EU 5th Framework Programme and by the Geological Survey of Denmark and Greenland. The printing of the workshop report was sponsored by JEODI and by the Nansen Arctic Drilling Programme (NAD).

The workshop recommends that:

- The scientific importance of Arctic deep-sea drilling for paleoceanographic, climatic and tectonic goals is well understood, but the lack of adequate site survey data hampers the development of mature drilling proposals. Potential drilling locations were discussed for all major ridges (Gakkel Ridge, Lomonosov Ridge, Alpha - Mendeleev Ridge) as well as for the continental margins and marginal plateaus. The workshop participants recommended a decadal program of dedicated expeditions to the central Arctic with the goal of completing site surveys for potential drill sites.
- At present it is difficult to develop mature drilling proposals aimed for targets in the central Arctic Ocean because adequate site survey data are by-and-large lacking; the exception being the Lomonosov Ridge. The situation is far better for the Arctic continental margin and marginal plateau areas. The workshop participants encouraged geophysical working groups on the Yermak Plateau, the Chukchi Plateau - Northwind Ridge and Laptev Sea continental margin to formulate and submit preliminary drilling proposals.
- Whereas scientific expeditions to the Arctic Ocean have been organized for the past 25 years on mostly an ad hoc basis, they have lacked long term, international well-coordinated planning procedures. To maximize the efficiency of costly site surveys, which often require two-ship operations, this process must change into a detailed and well-coordinated planning procedure where results may be reviewed at regular annual or biannual intervals. The Arctic Science Summit Week (ASSU) will provide a suitable venue for such reviewing.
- There is a need for a decadal site survey program in the Arctic Ocean
- The upcoming IPY in 2007-2008 offers a superb opportunity for operating a suite of expeditions to the central Arctic Ocean to conduct systematic site surveys e.g. over selected segments of the Alpha - Mendeleev Ridge Complex, employing suitable icebreakers from the USA, Canada, Russia, Sweden, Finland and Germany and since 2003 – China.

- Recognizing that Arctic Ocean geoscientific data relevant for site surveys are presently dispersed over many institutions and countries the workshop participants recommended the establishment of a data base to collect all data in a unified and easily accessible format.
- Site survey technology is under constant development; many of the available technologies have to be adopted for use in the ice-covered Arctic waters. The workshop participants recommended requesting from iSSP, iILP and iTAP the establishment of an IODP working group focusing on the development of site survey strategies for the Arctic Ocean
- Drilling technology for ice-covered deep-sea basins has yet to be tested. Proposals for drill ships, capable to operate in the central Arctic were discussed and the workshop participants encouraged further development of the plans.
- There is a major need for communication within the Arctic geoscientific community. The workshop participants recommended a follow-up workshop in two years time. The continuation of the communication can be organized by the existing NAD organization, which maintains a newsletter (The Nansen Icebreaker).

The workshop participants recommended publication of the workshop results.

> “ Mare incognitum, The Arctic Ocean, is despite its critical role in global climate evolution, the only ocean basin whose history is virtually unknown. Investigating the Arctic Ocean is certain to yield scientific and technological benefits to the Society.” (COMPLEX, 1999)

1. Scientific challenges of the Arctic Ocean

The most important geoscientific issues of the high Arctic Ocean may be grouped into the follow three major themes. These themes (Figure 1.1) are briefly discussed in the following chapter.

Theme 1: Birth of the Arctic Ocean Basin

- Tectonic evolution
- Arctic Ridges: case studies of global lithosphere processes

Theme 2 : Paleoceanography

- Physical and chemical changes of the watermass in the evolving deep Polar Basin
- Arctic gateways

Theme 3 : Arctic climate evolution

- Arctic environment during global warmth
- Cenozoic climate change
- Development of local and regional ice sheets
- History of Arctic sea ice
- Millennial scale climate changes

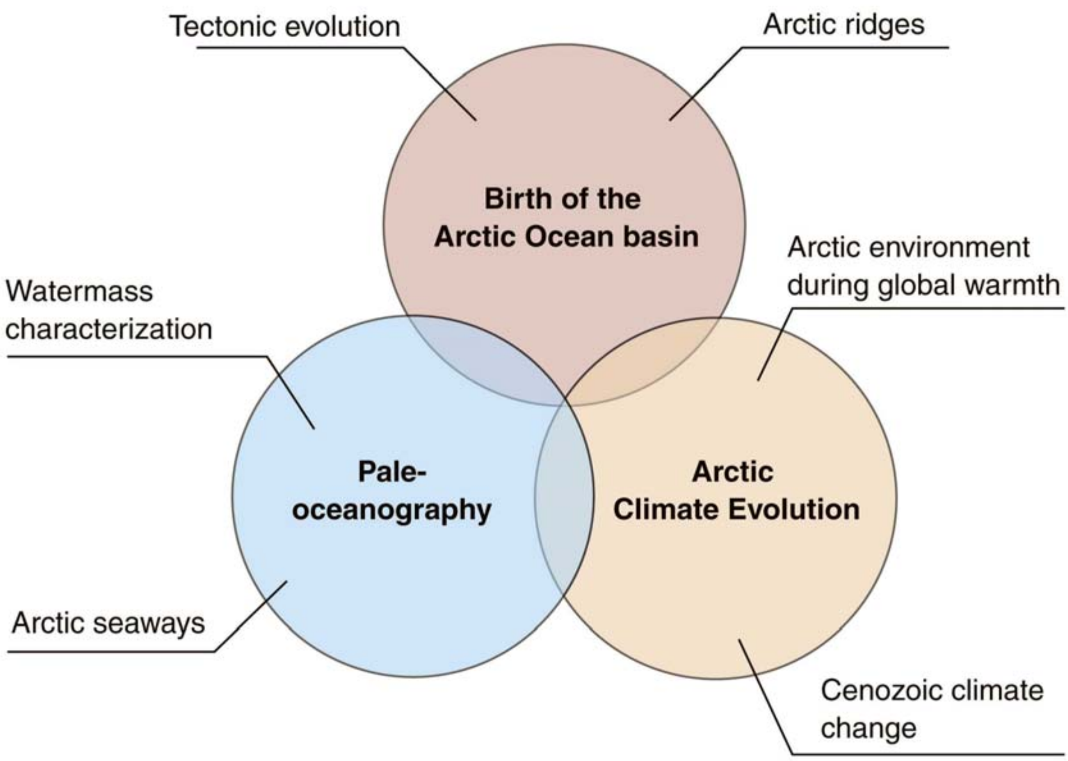


Fig. 1.1 Scientific challenges of the Arctic Ocean

Theme 1: Birth of the Arctic Ocean Basin

Tectonic evolution

Tectonic movements of crustal blocks have caused many changes in the high Arctic environments since Mesozoic times. The present deep basins of the Arctic Ocean may have formed in at least two stages (Fig. 1.2). We envision the Canada Basin evolved throughout the Late Jurassic/Early Cretaceous by rifting of Arctic Alaska and Chukota away from the Canadian craton (Grantz et al., 1998; Green et al., 1986). Alternatively, the Canada Basin may represent a part of the Pacific plate which extended into the Arctic in the Jurassic and later became cut off and isolated by microplate accretion (Churkin and Trexler, 1980). From the Late Paleocene and onwards the Eurasia Basin was created by extension of North Atlantic sea floor spreading into the Arctic region between Svalbard and Greenland. The deep Polar Basin was landlocked from its creation until the opening of the Fram Strait in the late Eocene/early Oligocene, when a deep connection was established to the Atlantic Ocean. Shallow epicontinental connections existed to the Atlantic via a western interior seaway in North America (Cenomanian-Early Mastrichtian) and during the Late Cretaceous through Eocene to Tethys via the Turgai Strait in western Siberia.

This first order evolutionary scenario is widely accepted, but is mainly drawn from geophysical and geological inferences and practically no “ground truth” represented by key geological samples. The Sverdrup Basin of the Canadian Arctic Islands and the Arctic Alaska Basin of northern Alaska, have similar tectonic histories and contain closely correlative and lithologically similar sedimentary sequences of Mississippian to Neocomian age (Grantz et.al., 1979; Embry, 1990). In the central Canada Basin, an extinct spreading center is inferred from a linear gravity low correlative with the symmetry axis of weak magnetic lineations (Vogt et al., 1982; Laxon and McAdoo, 1994). The evolution of the Eurasia Basin is better understood because of active sea floor spreading and better definition of magnetic lineations throughout the basin (Vogt et al., 1979).

All deep sub-basins of the Arctic Ocean have a thick cover of sediments, and their tectonic evolution may as a first step be deciphered from scientific drilling of the high-standing physiographic elements such as the Northwind Ridge, Chukchi Plateau, and the Lomonosov Ridge – all of which probably represent tectonic microplates of continental crust isolated by plate tectonic processes. Coring of bedrock on the plateaus and ridges will determine the Cenozoic, Mesozoic, and possibly Upper Paleozoic stratigraphy of these microplates and permit their correlation with each other and with their origin on the Arctic continental margin. Such ties would enable an improved plate tectonic reconstruction.

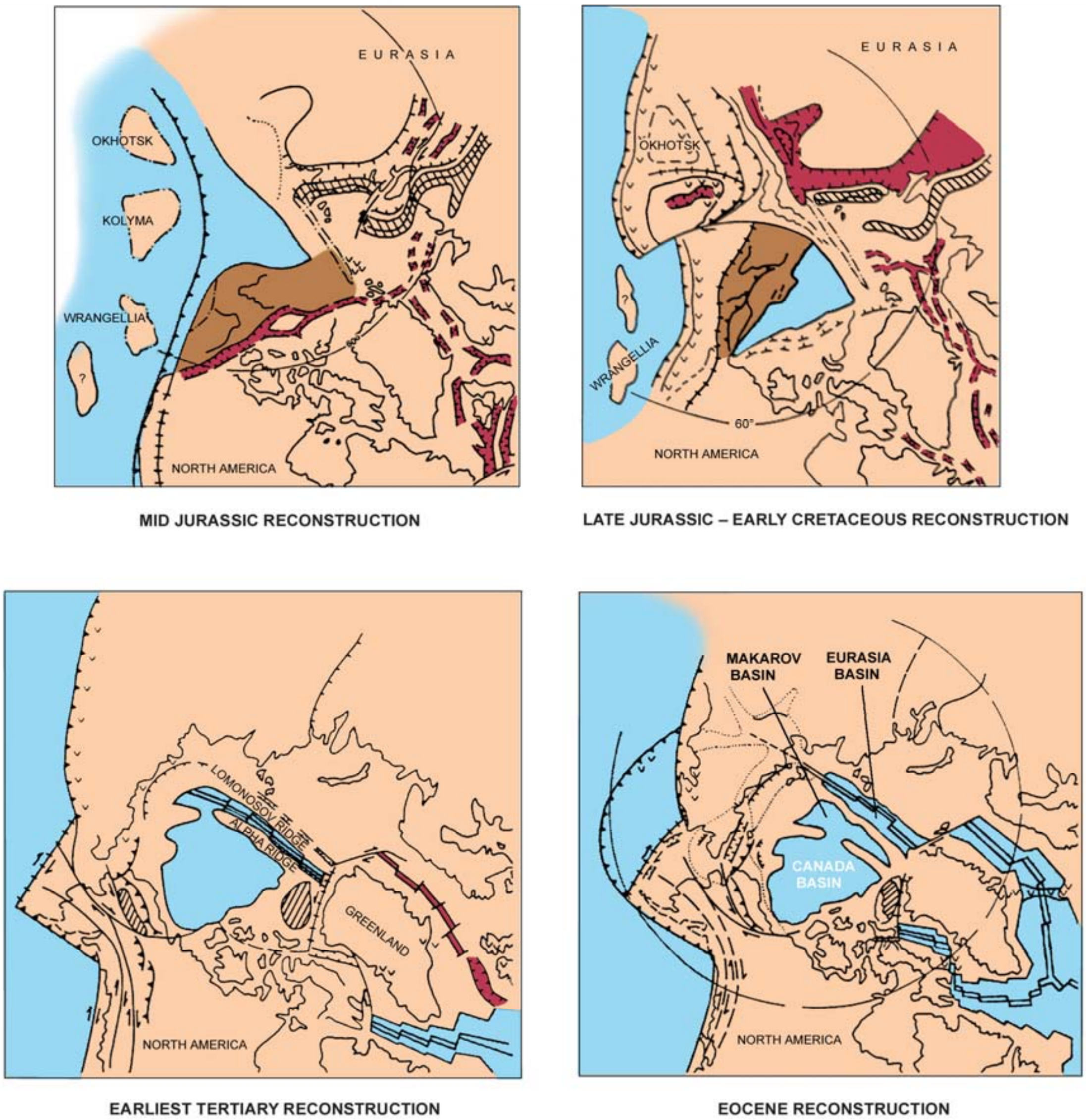


Figure 1.1. Outline of the tectonic evolution of the Arctic Ocean (after Green et al.,1986)

Arctic ridges: case studies of global lithosphere processes

Gakkel Ridge

Total opening rates decrease from 1.33 cm/yr at the western end of Gakkel Ridge to 0.63 cm/yr near the Laptev Shelf as defined by the Nuvel-1 global plate solution (DeMets et al., 1990), and make this spreading center the slowest of the mid-ocean ridge system on the planet. Co-linear seafloor spreading anomalies can be traced completely across the Eurasia Basin (Karasik 1968; Vogt et al.,1979). This implies that organized seafloor spreading is occurring even at extremely low spreading rates, although melt production should theoretically decrease dramatically or perhaps shut off (Sparks et al, 1993).

A more than 1000 km long segment of Gakkel Ridge was investigated by multibeam bathymetry and geological sampling during 2001 by icebreakers ”Polarstern” and ”Healy” in a dedicated geological survey effort (Michael et al., 2003; Jokat et al., 2003). This part of the Gakkel Ridge appears to contain three distinct magmatic-tectonic segments with a juxtaposition of tectonic and volcanic products and processes throughout. A central segment (3º E -11º E) displayed little bathymetric evidence of volcanism and dredging recovered subordinate basalt. The bathymetric and volcanic segmentation is linear and occurs in the absence of any ridge offsets, suggesting that magmatic segmentation may be controlled by mantle processes. Objectives for scientific drilling will be to obtain relatively fresh basement samples to establish the depth and extent of mantle-seawater chemical and thermal interaction on the ridge.

Alpha- and Mendeleev ridges

The Alpha-Mendeleev Ridge complex is a 2000 km long, 250 to 800 km wide, broad rugged structure which rises up to 2000 m above the adjacent abyssal plains (Fig. 1.3). The relation between the two ridges is uncertain, but they are both associated with large amplitude magnetic anomalies (>1000 nT) in contrast to the lower amplitudes over the abyssal plains (Vogt et al.,1982; Verhoef et al., 1996). Dredged rock samples include altered alkaline basalt (Van Wagoner and Robinson, 1985) and material recovered by piston coring exhibits MORB affinities (Muehe and Jokat, 1999; Jokat, 2003). The absence of earthquake activity, and heat flow less than the average for the Canada Basin (Langseth et al., 1990), together with the presence of Maastrichtian (65-70 Ma) fossils near the ridge crest (Clark, 1974), distinguishes the Alpha-Mendeleev Ridge complex from active mid-ocean ridges and require formation by the Late Cretaceous. The Alpha Ridge has a dimension, crustal thickness and crustal velocity structure (Fig. 1.3) which is strikingly similar to the large oceanic plateaus of the Pacific (Jackson et al., 1986). It may represent a large igneous province. The ridge is blanketed by more than 1 km thick undisturbed sediments (Hall, 1973, 1979; Jokat et al., 1999) which also include carbon-rich black muds (Clark et al., 1986). A major proportion of the organic material in the mud is apparently of terrestrial origin which may have been derived from a vegetative cover on islands when Alpha Ridge was emergent (Weber, 1990). Whether the black shales document anoxic conditions in isolated local basins or the depositional environment under an oxygen minimum in oceanic water masses remains an open question.

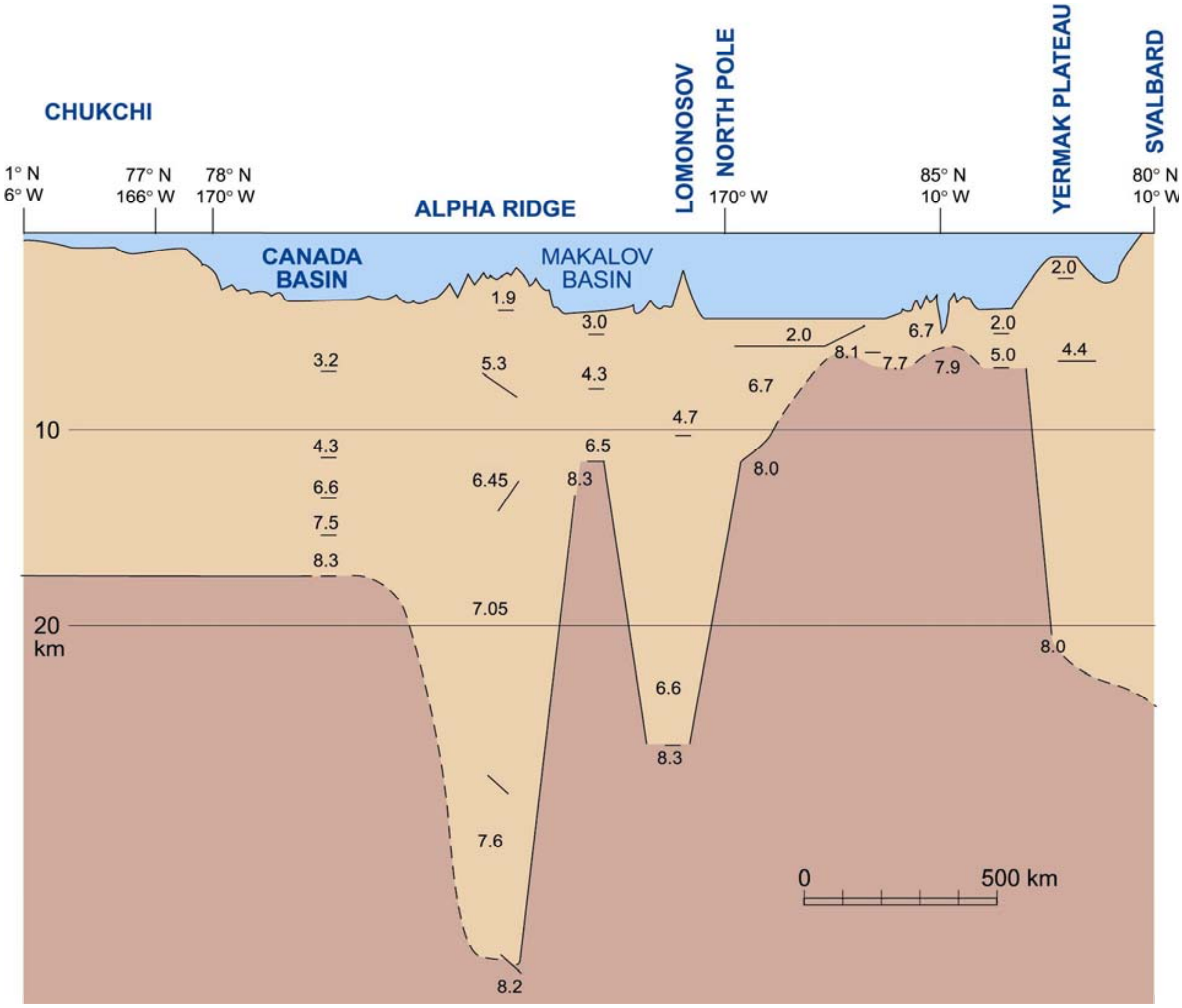


Figure 1.3. Summary of the seismic velocity structure of the crust of basins and ridges in the Arctic Ocean. (after Jackson and Johnson; 1985)

Scientific drilling and sampling of the sediment cover and basement rocks on the Alpha- and Mendeleev Ridges will capture the history of Cretaceous volcanism and similarly provide the history of the polar environment during the Cretacous i.e. the early “greenhouse” state of the planet.

Lomonosov Ridge

The Lomonosov Ridge is more than 1500 km long and less than 150 km wide. If proven to be a continental fragment (Jokat et al., 1992), it represents truly unique global information on the relative strength of continental and oceanic lithosphere. The olivine rheology of the oceanic lithosphere is estimated to be three times stronger than typical continental lithosphere which includes a 35 km thick continental crust of predominantly quartz/plagioclase rheology (Vink et al., 1984). Juxtaposed oceanic and continental lithosphere in a tensional stress field would be weakest landward of the continental shelf edge and the Lomonosov Ridge may have formed as a result of this mechanism. Scientific drilling of the sediments and the bedrock of the ridge would establish the nature of the crust, and the history of vertical motion in relation to plate kinematics. Additionally the sediments will reveal the Cenozoic climate history.

Theme 2: Paleoceanography

Physical and Chemical changes of the evolving Polar Basin

The Arctic Ocean has since its formation passed through different physical and chemical stages. These stages witness a transition of the Polar Basin from a stagnant and oxygen deficient ocean through a temperate upwelling basin into cold and ventilated ocean, which today has profound impact on the global ocean circulation. Only sporadic information is available form the early period of the Arctic Ocean. Four short sediment cores document the initial Mesozoic Arctic Ocean environment when the Amerasian basin was formed. The occurrence of black shales representing the earliest phase of the formation of the Polar Basin is considered to represent oxygen-deficient conditions in a closed basin about 80-85 million years ago (Clark et al., 1986). These oxygen deficient conditions were followed by conditions more typical of a temperate upwelling system some 80 –50 million years ago as witnessed by the presence of biogenic silicious oozes. The formation of the Eurasia basin around 56 millions years ago and the opening of the Fram Strait about 40 million years ago initiated a shift from an environment charaterized by abundant silica accumulation under estuarin conditions to a more ventilated environment which also permitted flow of deeper waters across the bathymetric sills (Thiede et al. 1990). A connection was established between the polar basin and the world oceans, and the cold and ventilated Arctic Ocean became part of the global ocean system.

Arctic gateways

The Arctic Ocean existed as a closed basin for nearly one hundred million years before a deep water connection to the North Atlantic was established through the Fram Strait. The first indication of an Arctic-Atlantic seaway is suggested by the occurrences in northern Alaska and Ellesmere Land of late Paleocene mollusks and ostracodes previously known only in northern Europe (Marincovich et al., 1990). Direct evidence on the evolution of the Fram Strait gateway is non-existent, except that sediments from Site 909 in the deep central part of the Fram Strait suggest no dramatic changes in bottom water activity during the Early Miocene through the Pliocene (Myhre, et al., 1995). Scientific drilling of a 2 km thick sediment drift deposited by inflowing Atlantic water along the northern flank of the Yermak Plateau would enable an understanding of the gateway evolution and provide a more rigorous reference for assessments of the contribution of the Arctic tele-connection on the global thermohaline circulation throughout the Cenozoic.

The Bering Strait separates North America from Eurasia. During the low-stands of the last ice age it was periodically exposed, cutting off the input of water from the northern Pacific Ocean and making the “peopling” of North America possible. Geophysical study of the history of the Strait could set the stage for a drilling proposal. Understanding the history of exposure of the Bering Strait would have important consequences for oceanography and archaeology.

Theme 3: Arctic Climate evolution

The Arctic environment during global warmth

Since the discovery in 1883, of tropical plants in Cenomanian fluvio-deltaic sediments from west Greenland, it has been apparent that the Late Cretaceous climate of the northerly high latitudes – at least during certain intervals – was far warmer than it is today (Nathorst, 1911). The description by Kemper (1987) of glendonites (pseudomorphs of the low-temperature hydrated form of calcium carbonate, ikaiite) in lower Valanginian and upper Aptian sediments from the Sverdrup Basin in Arctic Canada (70°-80º palaeolatitude), however, implies that Early Cretaceous seawater temperatures were at times close to freezing. Almost certainly these cooler temperatures record global changes because, in the case of the late Aptian at least, coeval glendonites are also know from the Southern Hemisphere, being found in the Eromanga Basin in Australia at a palaeolatitude of 65º (Frakes and Francis, 1988; De Lurio and Frakes, 1999). The implication of these isolated occurrences is that, even in a so-called 'greenhouse' period, the Arctic Cretaceous climate was not uniformly warm and equable but experienced considerable variation. Other palaeontological data support the general contention that the mid- to Late Cretaceous Arctic climate was generally rather mild: the presence of deciduous trees, and leaves with characteristic morphologies at 80° - 85° N (Parrish and Spicer, 1988; Herman and Spicer, 1996), the presence of crocodiles above 60º N (Markwick, 1998) and, most specifically, the discovery of champosaurs (warm-blooded reptiles) in the Turonian of the Sverdrup Basin at 72° N palaeolatitude (Tarduno et al., 1998; Huber, 1998).

Cretaceous material has been cored from three locations on the Alpha Ridge: the cores Fl-437 and Fl-533 taken during the drift of the ice-island T-3 (1963-1974) and Core 6 of the Canadian Expedition to Study the Alpha Ridge (CESAR) in 1983 (Fig. 4.2). One core (Fl-533) comprises organic-rich black mud whose TOC content rises to 15%, and the other contains two laminated siliceous ooze rich in diatoms, ebrideans and silicoflagellates. Integration of the various biostratigraphic indices from all three cores allows more than one interpretation: the organic-rich and siliceous sediments could be coeval or represent successive episodes of pelagic deposition. Both sediments can be interpreted as the product of fertile waters, probably under the influence of active upwelling centers that may have varied with respect to their nutrient concentrations and planktonic biota in time and space (Kitchell and Clark, 1982; Mudie et al., 1986; Dell'Agnese and Clark, 1994; Firth and Clark, 1998). Strong seasonality is implied by the laminated nature of the sediments, with layers rich in resting spores of diatoms alternating with layers rich in their vegetative cells. There are no dropstones in these sediments and thus no evidence for glacial activity.

The unlithified nature of the Cretaceous sediments of the Arctic makes them a unique resource for investigating the evolution of siliceous and organic-walled plankton, as well as elucidating palaeoceanographic and palaeotemperature change in the high latitudes during a 'greenhouse' period of the Earth's history. Given that the Arctic Ocean was connected to epicontinental seas across Asia and North America (Fig. 1.4), and given that the Western Interior seaway was locally characterized by reduced salinity (e.g. Wright, 1987; Cochran et al., 2003), the possibility also exists that the waters of the Cretaceous Arctic were less than fully marine at times in its history (Hay et al., 1993). Salinity stratification may have been a feature of this ocean throughout much of the Cretaceous.

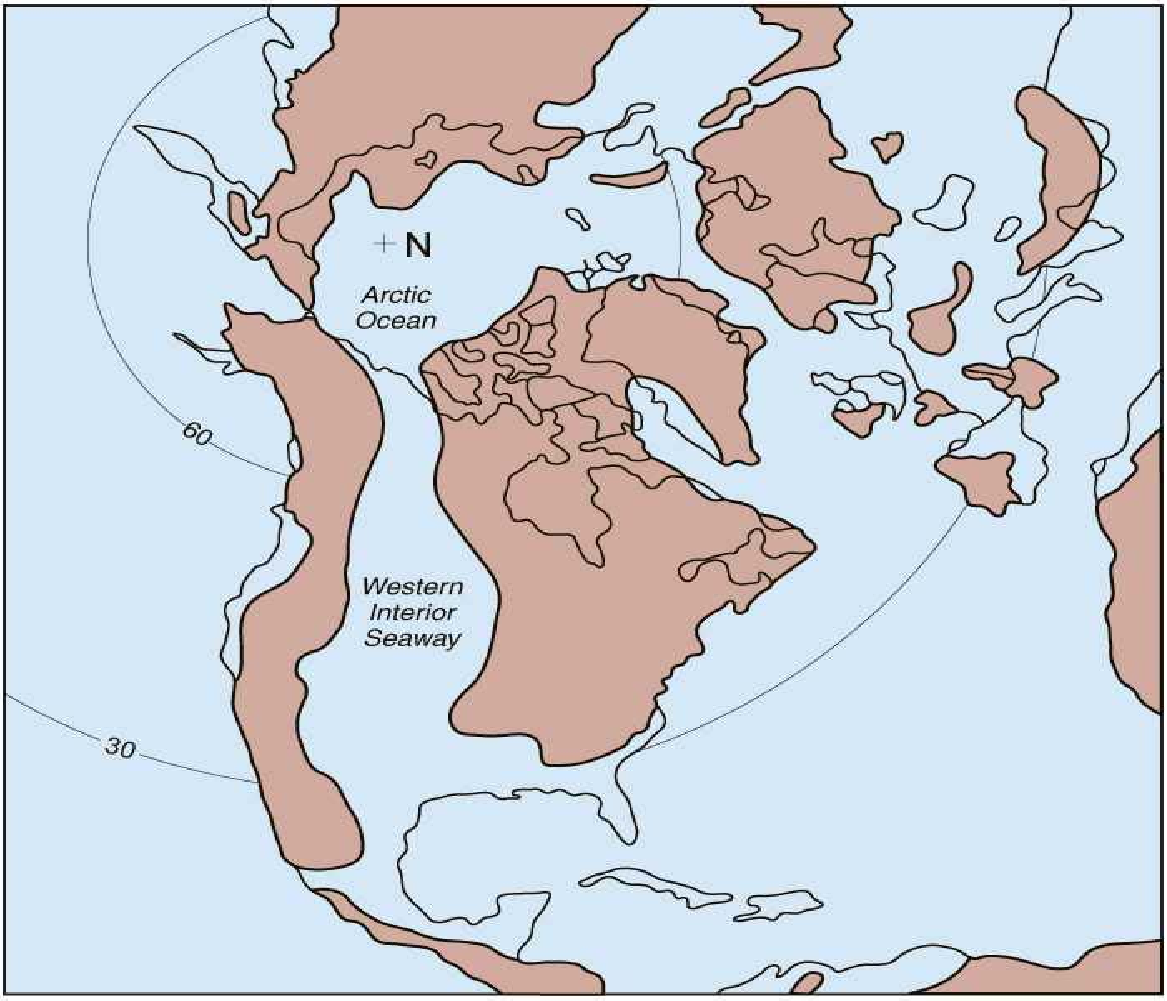


Figure 1.4. Polar view of the Arctic Ocean during the Late Cretaceous (Turonian) showing likely connections to epicontinental seas such as that of the Western Interior of North America. (After Hay et al., 1993)

Cenozoic climate change

A major element in the evolution of Cenozoic environments has been the transformation from warm Eocene oceans with low latitudinal and bathymetric thermal gradients into the more recent modes of circulation characterized by strong thermal gradients, oceanic fronts, cold deep oceans and cold high latitude surface waters. About 92% of all water in today's oceans is colder than ~10°C. In the Eocene, 50 million years ago, all water in the oceans was warmer than 10°C. Bottom temperatures during the early Eocene, the time of maximum Cenozoic warmth, were on the order of 12°C, and large-scale continental ice sheets did not exist because Earth's warm climate inhibited the growth of continental ice-sheets (Miller et al., 1987; Zachos et al., 2001).

The transition to today's world, with Antarctica covered by a continental ice-cap and seasonally variable but persistent sea-ice cover in the Arctic, is linked to both the change in climate that increased latitudinal gradients and to oceanographic changes that connected surface and deep-sea circulation between high and low latitude oceans. Thus, throughout the course of the

Cenozoic, the climate on Earth has changed from one extreme (Paleogene greenhouse lacking ice) to another (Neogene icehouse with bipolar glaciation).

It has long been recognized that our lack of knowledge about the role the Arctic played in the maintenance and development of these climatic extremes is a major gap in our ability to understand and model global environmental change (e.g., COMPLEX, 1999; IODP Science Plan, 2001).

Development of local and regional ice sheets

ODP Legs 151 and 162, as well as previous drilling legs, have revealed that there existed, probably in Greenland, ice sheets which calved into the ocean and delivered ice rafted detritus to the sea floor sediments from melting icebergs, as far back as the Middle/Late Miocene boundary about 12 Ma (Fronval and Jansen, 1996; Wolf-Welling et al., 1996). Marked phases of a more intense glaciation are recorded during the Late Miocene, but probably only reflecting Greenland glaciation. We have no information on the early developments of the Northern Hemisphere cryosphere from the circum-Arctic proper.

About 3 million years ago a marked phase of global cooling set in, leading to widespread expansion of ice sheets across the sub-Arctic regions in both Eurasia and North America 2.75 million years before present (Jansen et al., 2000; Kleiven et al., 2002). Before and at the inception of large scale glaciation around 3 million years ago, a relatively warm Arctic probably prevailed, with forests growing along the shores of the Arctic Ocean where tundra and permafrost now prevail (Funder et al., 1985; Kniess et al., 2002). During glacial phases, the northward heat transport to the Arctic was greatly diminished. Before this marked cooling, climates were only cold enough to sustain glaciers on Greenland, indicating that the ocean was warmer and sea-ice cover diminished compared to the present (Larsen et al., 1994; Fronval and Jansen, 1996). During most of the following time, the prevailing glacial situation indicates that perennial sea ice cover and cold conditions existed over the Arctic, however, less freshwater influx during glacials may have reduced surface ocean stratification and ice-free areas or polynyas may have prevailed. The sea level lowering also left major portions of the shelf areas above sea level, hence drastic changes in Arctic circulation must have occurred.

The next main change in the Arctic/Sub-Arctic climate system occurred approximately 1 million years ago. After this time, glacial episodes became longer, with a distinct 100.000 year cyclicity, and glaciation became more severe. However, the short milder interglacials became warmer than before, due to stronger inflow of warm Atlantic surface waters to the Nordic Seas (Berger and Jansen, 1994; Jansen et al., 2000). The long term effects of ice sheet erosion also changed the communication between the Arctic and the Sub-Arctic. Erosion deepened the Barents region, which changed from a land area to an epicontinental sea, thus creating a new path for water mass exchange with the Arctic during interglacials.

We need to know the boundary conditions which initiated the Northern Hemisphere Miocene glaciation; where and when did glaciers and ice sheets nucleate around the Arctic? There was a much later initiation of Eurasian Ice Sheets during the Late Pliocene, but information from Siberia and Arctic Canada is scarce. When the timing is clarified, we can understand more about possible triggering mechanisms, such as the closure of the Panama seaway, uplift of the Tibet Plateau, CO_2 -trends, or perhaps impacts from the hydrological cycle on the oceanic heat flux to the Arctic.

The Arctic ice sheets may have played a significant role in the transition to 100 kyr climatic cycles. The Mid-Pleistocene climate shift (41 ->100 kyr cycles) is characterized by increased presence of marine-based ice sheets. We need to clarify the extent of these in the circum-

Arctic, and whether the Arctic ice sheets always have been controlled by the obliquity/tilt cycle, or has axial precession also played a role?

History of sea ice

The climatic development of the Arctic and sub-Arctic has been characterized by three main system variables; a) changes in sea-ice cover, which have influenced albedo, air-sea exchange and freshwater budgets; b) changes in the ice sheet dimensions, which have influenced albedo and atmospheric flow. Also meltwater influx from diminishing ice sheets during deglacial phases have influenced ocean circulation; c) thermohaline ocean circulation, which has had a major impact on the northward heat flux to the region.

Lack of suitable material from the central Arctic prevents documentation of the long term history of the Arctic sea ice cover and ocean climate. We do not know when sea ice cover commenced, and much of its temporal and spatial variability is so far not documented. The evidence at hand is interpolated from drilling open water areas outside of the perennial ice pack, and detailed knowledge is only available for the last few glacial periods.

Many studies have implicated a strong positive feedback from the sea-ice cover as being the key mechanism whereby small changes in the solar insulation originating from changes in the orbital parameters lead to high amplitude climate responses (Imbrie et al., 1993; Koc and Jansen, 1994). Arctic Ocean processes and feedback may therefore have been pivotal in bringing the world into and out of the ice ages. Most of the comprehensive climate models predict almost complete disappearance of summer sea ice by the end of this century. Modeling of the response of the climate system to continued increased greenhouse gas levels indicates that sea ice cover disappears in all seasons in the next 175-200 years under current emission rates. If the sea-ice should disappear we are faced with a situation which has analogues in the past, from where important knowledge can be gained:

- What were the climatic boundary conditions when the sea ice cover commenced (atmospheric CO2 -levels, global and regional temperatures)?
- When did it occur (seasonally and perennially)?
- How variable has the sea-ice cover been under different climatic boundary conditions?

The Arctic sea-ice cover is to a large extent dependent on the low salinity surface layer and a strong halocline underlying this layer. The time of emergence of the halocline is unknown, and the processes that led to its inception are unknown. It is also unclear if the hydrological cycle is a part of the process that led to glaciations via capping the surface (albedo feedback) and/or reduced deep overturning.

Millennial scale climate changes

On top of the long term trends and orbital scale variability, there is ample evidence for high amplitude millennial to century scale climate variability in the high latitude regions of the Northern Hemisphere. These millennial scale events are recorded globally. High amplitude shifts in temperature and precipitation occurred with startling speed, with shifts in annual mean temperature on the order of 5-10°C happening over a decade or two (Dansgaard et al., 1993, Alley et al., 2003; Koc et al., 1993; Haflidason et al.,1995). These abrupt climate changes occurred repeatedly during glacials with a temporal spacing between 2000 and 1000 years. The last of these large scale climate events were the Younger Dryas cooling about 12,000 years ago, which was followed by two cold phases with less amplitude, the last of which happened about 8200 years ago. Coolings in the regions surrounding the Arctic were associated with widespread drought over Asia and Africa, as well as changes in the Pacific circulation. Mid-latitude regions were most affected, and the amplitudes of these climate shifts were reduced in the high Arctic.

Model experiments have reinforced the hypothesis that changes in the strength of the thermohaline ocean circulation (THC), which transports heat from low to high latitudes, is a key factor behind these climate changes (see review by Rahmstorf, 2002). The rapid climate shifts were accompanied by changes in the style of deep water formation in the Arctic/Sub-Arctic, and by concomitant changes in the northward protrusion of warm water towards the Arctic (Dokken and Jansen, 1999). Apparently the high amplitude climate shifts were caused by, or at least strongly amplified by, freshwater release from calving and melting of continental ice sheets in the circum-Arctic. But due to their global extent, it is still an open question whether their root cause lies in processes in the tropics or south of the Equator, or in processes in the circum-Arctic itself.

It is unclear when the millennial scale changes started to occur. We also do not know the degree to which these affected the Arctic proper, which may have been rather insensitive to changes. Only data from inside the Arctic Ocean can resolve this issue.

2. The present Arctic ocean environment

The presence of perennial sea ice in the Arctic Ocean is maintained by a strong vertical stratification in the upper 150 m of the water mass. Reduced vertical diffusion effectively insulates the underlying warm Atlantic layer from the surface. The sea ice cover in turn acts to maintain the ocean in a low-energy state by creating a high surface reflectance and limiting turbulent heat exchanges between the ocean and the atmosphere, thereby contributing to the polar heat sink (Nakamura and Oort, 1988). The deepest Arctic Ocean is, however, ventilated laterally from its shelves, thus circumventing the strong upper-ocean stratification in the interior ocean (Aagaard and Carmack, 1994).

Sea ice concentrations

The extent of sea ice cover varies with the annual cycle by a factor of two; a maximum extent in March and a minimum in September (Fig. 2.1). The microwave radiation from the ice penetrates most clouds as well as the polar night, and reliable coarse resolution overviews of the ice cover from satellite borne instruments have been available on a regular basis from 1978 and daily from 1987.

Figure 2.2 shows the ice cover at the beginning of September from 1997-2002. The largest variations during this period are seen in the Laptev and East Siberian Seas. First-year ice normally represents up to 40% of the Arctic Ocean ice cover, having a thickness that rarely exceeds 2 m (Barry et al., 1993). Away from the coastal regions, about 60% of the ice cover is ice which has survived one or more melt seasons. This multi-year ice is typically 3-5 meters thick. Linear stretches of open water, or areas of thin ice called “leads” are typically 10-1000 m wide. They are broadly correlated with large-scale wind fields and have similar space and time scales (Milnes and Barry, 1989).

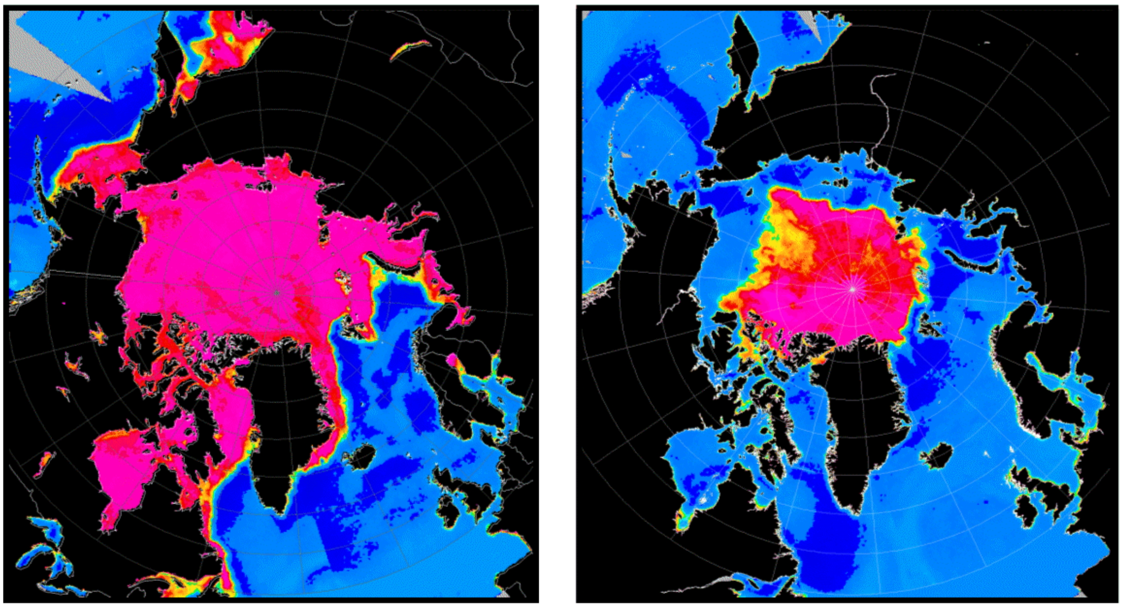


Fig. 2.1. Satellite microwave radiometer observations of the ice distribution in the Arctic in February 2002 (left) and September 2002 (right) Blue colours are ice free water; green-yellow-orange-red-purple corresponds to increasing concentration (areal coverage) of ice. Figures from: http://www.seaice.dk/DCRS/latest-ice.html

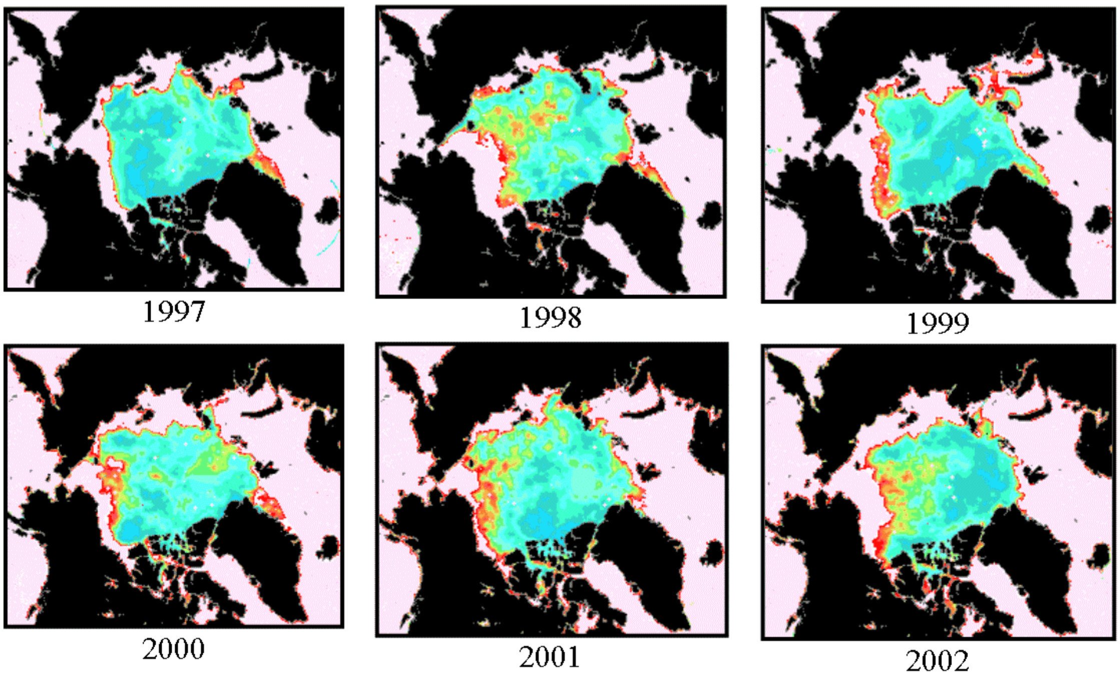


Fig. 2.2. Ice cover at the beginning of September. Blue is total ice cover, green-yellow-red corresponds to lower ice concentrations of ice and pink is ice free. From: http://polar.wwb.noaa.gov/seaice/Analysis.html

Ice dynamics and variability

The mean high in sea level pressure over the Arctic Ocean drives the sea ice motion in the anticyclonic Beaufort Gyre and the Transpolar Drift (Fig. 2.3). Sea-ice dynamics can be described by the momentum balance where the air and water stresses, the Coriolis force, and the ice interaction are the dominant terms (Hibler, 1986). Ice interaction can be large during the winter and near the coasts, but is considered a small term during the summer season and away from the coasts. On time-scales longer than a year the contributions from winds and ocean currents in driving sea ice motion are roughly equal, but the drift of sea ice on shorter time-scales (1 yr) follows the wind (Thorndike and Colony, 1982). On short timescales, the ice drifts with a speed of about 1% of, and about 5 degrees to the right of, the geostrophic winds (hypothetical wind above the friction layer where the pressure gradient balances the Coriolis force). About 70% of the day-to-day or monthly ice motion can be explained by the local geostrophic wind (Thorndike and Colony, 1982). During periods of decelerating wind, ice motion can become current driven, manifested both as skin drag and form drag on the underside of the ice. The ratio of ice “sail” height to “keel” depth may reach 1:5 for first year ice, making form drag in the oceanic boundary layer of equal or greater importance than skin drag (Smith and McLean, 1977).

Research based on synoptic observations of ice drift and surface pressure obtained by the International Arctic Data Buoy Program since 1979 have demonstrated that sea-ice motion follows an annual cycle and also that the mean motion correlates with the Arctic Oscillation (Thompson and Wallace, 1998; Rigor et al., 2002). The most striking feature of the annual cycle is the weakened ice drift north of Svalbard and the Barents- and Kara Seas during the summer, together with a major change in drift direction north of the New Siberian Islands (Fig. 2.3)

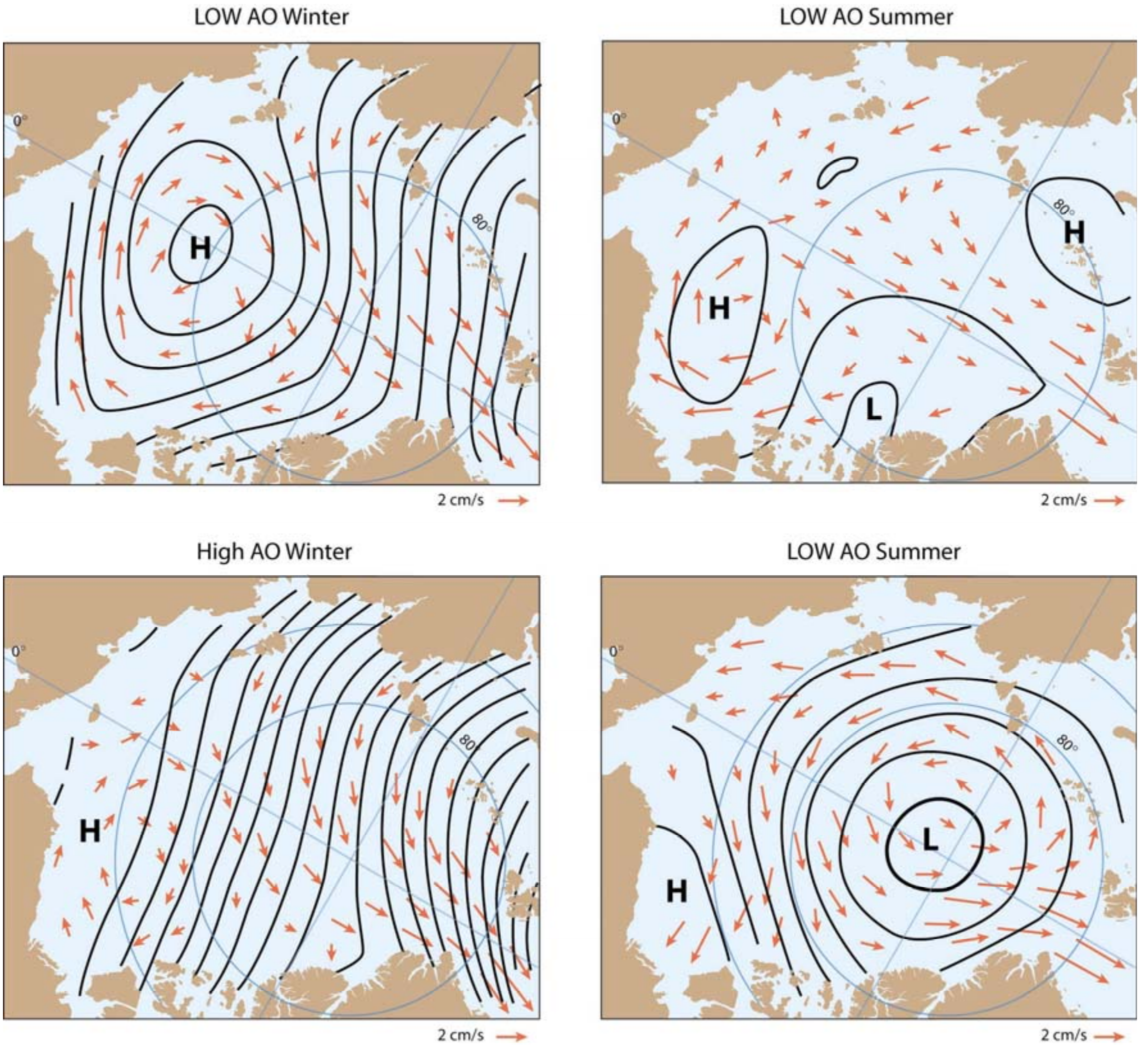


Fig. 2.3 Mean ice motion in the Arctic based on data from the International Arctic Data Buoy Program (http://iabp.apo.washington.edu/) since 1979 shown in relation to average atmospheric pressure at sea level. From Rigor et al. (2002)

The Arctic Oscillation (AO) can be interpreted as the surface signature of modulations of the strength of the polar vortex aloft related to an exchange of atmospheric mass between the Arctic Ocean and the surrounding zonal ring centered at 45°N (Proshutinsky and Johnson, 1997; Rigor et al., 2002). Figure 2.4 shows the variation of the AO-index over the last two decades. Ice drift velocities are generally slower during a high AO state (lower sealevel pressure over the Arctic and stronger westerlies at subpolar latitudes). The center of the Beaufort Gyre move several hundred kilometres closer to the Alaskan coast and the Transpolar Drift is shifted more towards Canada with concurrent increased advection of ice from the Laptev Sea into the Transpolar Drift (Fig. 2.5). On the average, it takes ice more than 6 years to drift from the Beaufort Sea to the Fram Strait and one year from the North Pole. During high AO years, ice drift from the Beaufort Sea to the Fram Strait takes more than a year longer, but ice travels faster from the North Pole to the Fram Strait. This condition leads to increased divergence of sea ice, which in turn promotes increased production of more thin sea-ice over the Eurasia Basin (Rigor et al., 2002).

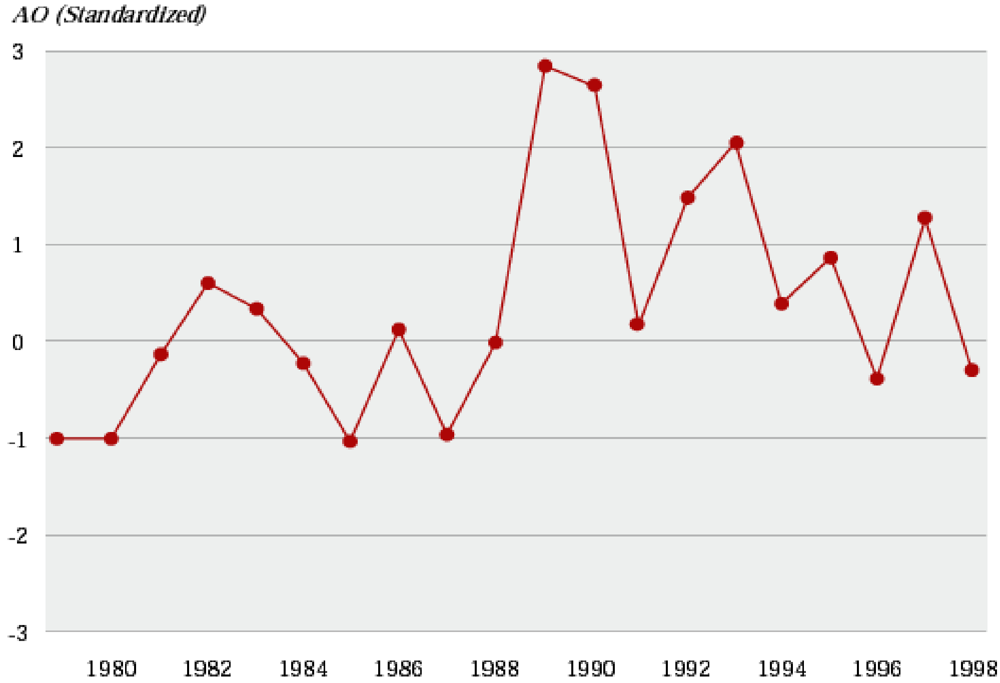


Fig. 2.4 Standardized monthly AO index (dots) and winter means of the monthly AO index (circles) for 1979-98. - From Rigor et al. (2002)

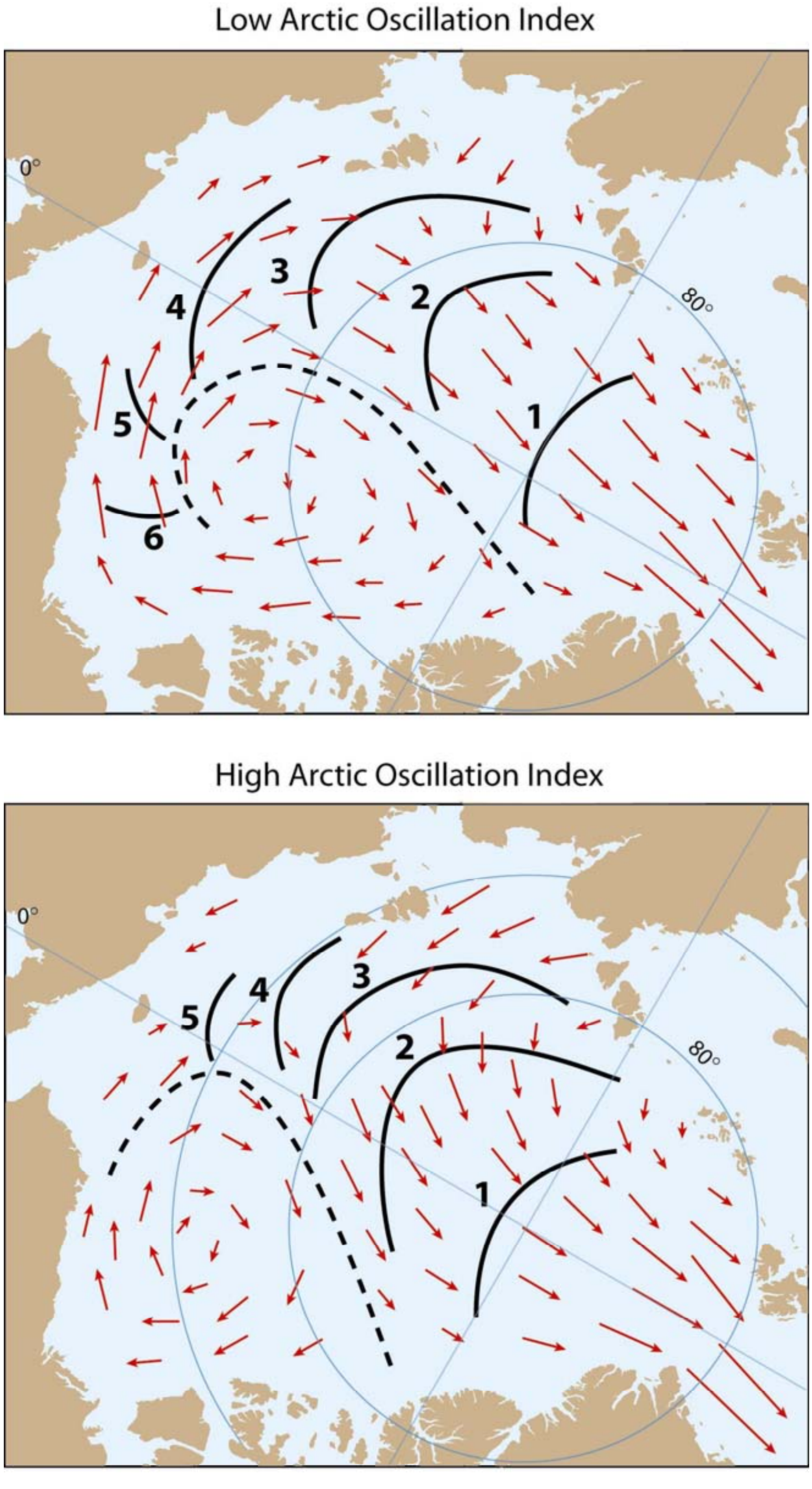


Fig. 2.5 Isochron maps showing the number of years required for a parcel of ice to exit from the Arctic through the Fram Strait. (a) Field during the low-index phase of the AO index and (b) field during high-index phase of AO. The dashed line delimits the area for which ice either recirculates in the Beaufort gyre or is advected through the Fram Strait. From Rigor et al. (2002)

Sea-ice thickness

The sea-ice thickness is determined by two main factors; firstly by a thermodynamic effect controlled by fluxes of radiative, sensible and latent heat in the adjacent atmosphere and oceanic boundary layers, and secondly by a dynamic effect from traction on the top and the underside of the ice. Wind traction on the ice surface and current traction on the underside of the ice causes mechanical compression and conversion from thin ice to thicker ice, as well as divergence and opening of new leads with generation of new ice. The annual cycle of freezing and melting begins with freezing of meltwater ponds on the ice and open-water leads as the air temperature starts to drop rapidly in late August (Fig. 2.6) About 80% of the annual snowfall (10-15 cm water equivalent) is deposited by early November (Untersteiner, 1990).The accretion of ice continues until May, slowly under thick ice and more rapidly under thin ice.

The onset of melting corresponds to a mean air temperature near –1.2° C (Doronin, 1970). Development of melt ponds at 85° N starts on the average about July 1, and the melt season continues until late August. The extent of ponds increases to about 25% of the surface area (locally up to 45%) by mid-July. Through the annual cycle, ice is added to the bottom and melted away at the top. The seasonal variation in ice draft due to melting and freezing processes is approximately 0.3 meter (Maykut and Untersteiner, 1971).

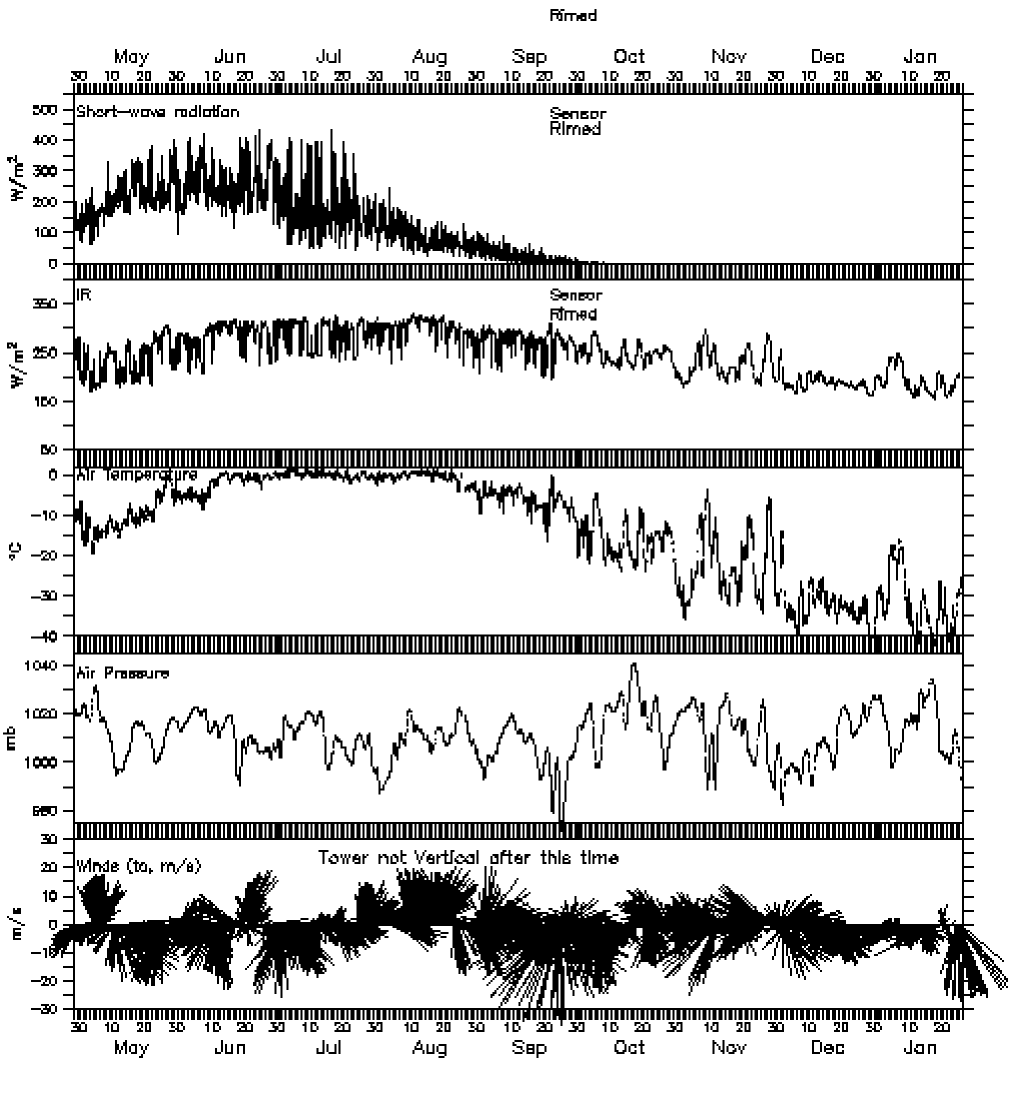


Fig. 2.6 Environmental conditions at the North Pole during 2003. From NOAA Arctic Theme Page http://www.arctic.noaa.gov/gallery_np_weatherdata.html

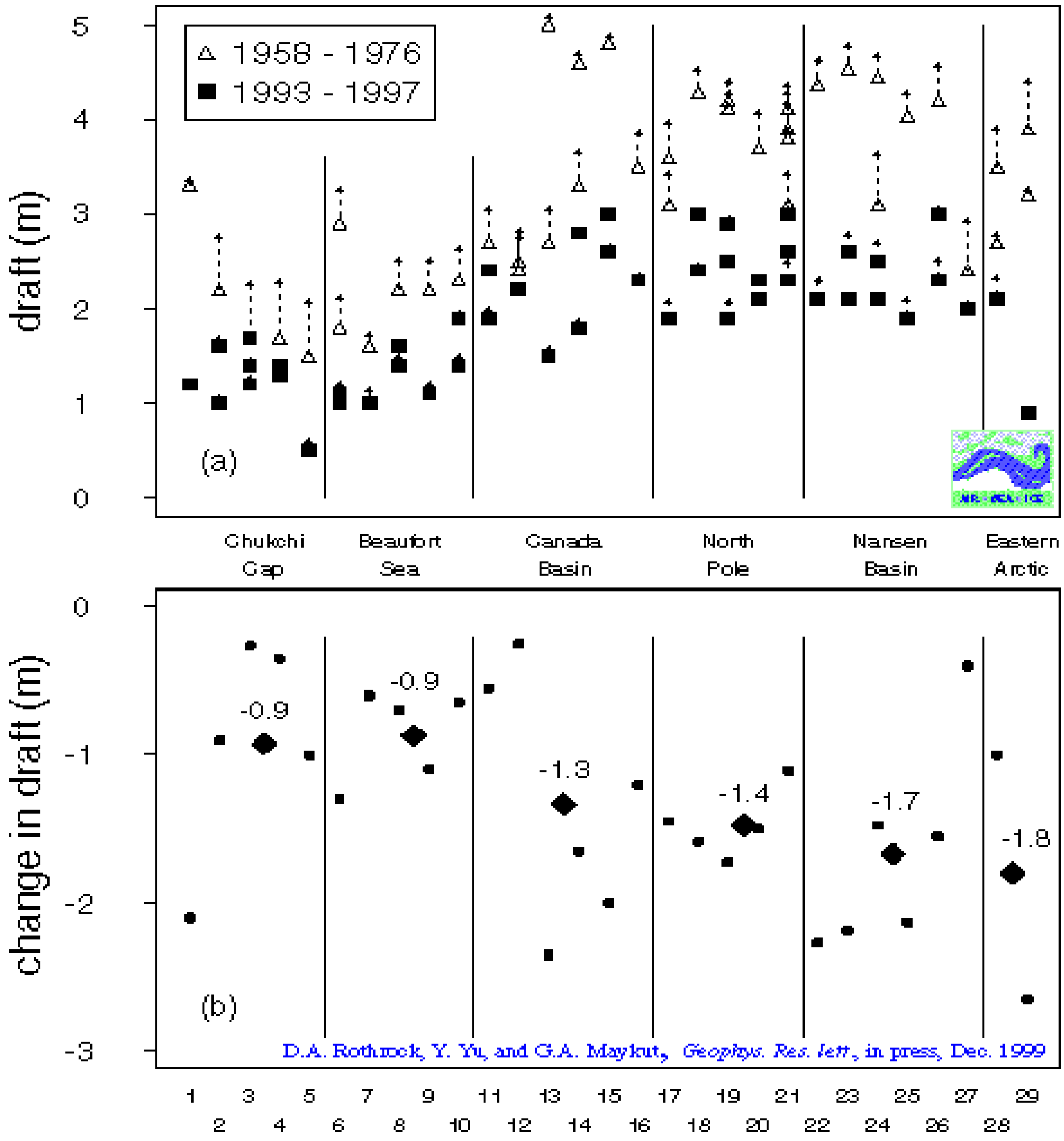


Figure 2.7 Mean ice drafts at crossings of early cruises with cruises in the 1990s. Early data (1958--1976) are shown by open triangles and those from the 1990s by solid squares, both seasonally adjusted to September 15. The small dots show the original data before the seasonal adjustment. The crossings are grouped into six regions separated by the solid lines and named appropriately. (b) Changes in mean draft at cruise crossings (dots) from the early data to the 1990s. The change in the mean draft for all crossings in each region is shown by a large diamond. The abscissa gives the number of each crossing . After Rothrock et al.(1999)

The mean ice-drafts in the different areas of the Arctic Ocean as summarized by Rothrock et al. (1999) are shown in Figure 2.7. The ice is generally < 2 meter thick in the central part of the Arctic Ocean and the Nansen Basin, but > 2 meters in the Beaufort Sea and over the Chukchi Cap. Visual observations of ice ridging taken during U.S. Navy Birdseye flights covering most of the Arctic Ocean have been compiled and published (Weeks et al., 1971). In broad terms, 0.5-2 ridges per kilometer characterize the ice surface. Pressure ridges have keel draft to sail height ratios of 3-4:1, with larger ratios for first year ice (Tucker, 1989). Keels are usually wider than sails and cluster around 50-150 meters with mean total widths around 70 meters

(Wadhams, 1994). The mean draft of pressure ridges exceeding a 9 m threshold is 10-12 m for most of the Arctic Ocean during summer. Their occurrence is 1-3/km.

Arctic Ocean weather

Summer cyclones and anticyclones in the Arctic, north of 65° N are generally more frequent, but weaker than their winter counterparts (Serreze et al., 1993). The increase in cyclonic activity occurs between April and June and is associated with an increase in the extent of low-level Arctic stratus clouds. Most cyclones follow a path along the periphery of the Arctic Ocean. The primary difference from winter is that cyclones are distributed more widely throughout the Arctic. The average surface pressure over the Arctic Ocean is positive, but during the summer low pressures frequently move into the central basin. The melting of the pack-ice in the summer leads to the formation of persistent fog and low clouds. The amount of cloud during July and August exceeds 90% and most of it is low-level stratiform clouds (70%) (Curry and Herman, 1985 ; Herman and Goody, 1976). Arctic stratus clouds tend to occur in well-defined layers of 300-500 m thickness. The optimum time window for marine summer operations in the Arctic Ocean is the period between the peak of the melt season in early August and the rapidly falling temperatures in early September.

3. Site survey requirements

The purpose of a site survey is to document that proposed drilling locations are suitable for the proposed science objectives and suitable for drilling operations. The International Ocean Drilling Program guide and requirements to site surveys are available at: http://www.ldeo.columbia.edu/databank/SSP.html

The mandate of the site survey panel as stated on the Site Survey Panel (SSP) website is to evaluate the available site survey data to ensure that:

- proposed sites can be adequately imaged from the supplied data
- sites selected based on the data can answer the scientific questions which have been posed
- sites are located where it is feasible for an IODP drilling platform to drill
- sufficient data to support both the science and the drilling operations have been supplied.

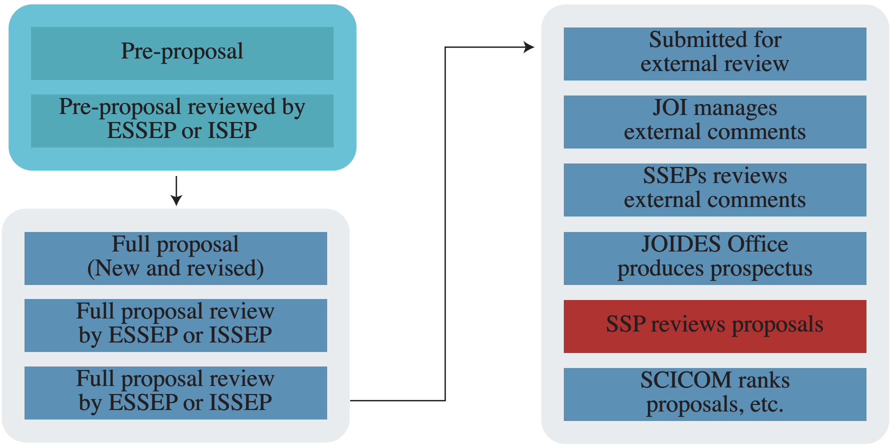
The major change from ODP to IODP will be the availability of multiple drilling platforms (riser, non-riser and 'mission specific platforms (MSP)'). This will enable the new program to drill targets which were outside the operational capabilities of the JOIDES Resolution. These new multi-platform operations also need a new structure in the proposal evaluation system, and major changes will be implemented during the transition from ODP to IODP.

The new recommendations for the site survey panel were formulated on the first meeting of the interim Site Survey Panel in February, 2002. The important difference between the old and the new proposal evaluation pathway is shown in Fig. 3.1. During the ODP phase, proposals reached the SSP at a very late stage. Within the IODP, the SSP will evaluate the proposals already at the pre-proposal stage. Specifically, the Site Survey Panel will:

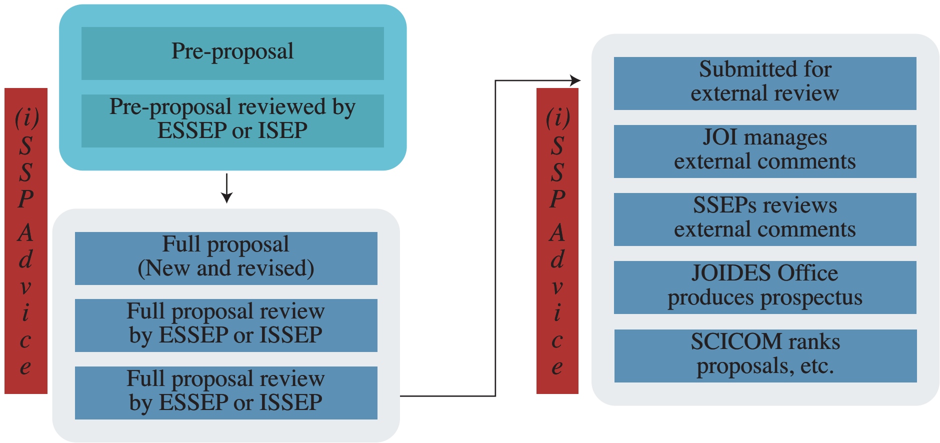
- provide guidelines and suggestions to the proponents who have been asked to submit full proposals
- review pre-proposal(s) especially regarding necessary site survey data types
- provide guidelines and suggestions , i.e. provide contact between proponents and research group(s) experienced in site survey data collection
- identify any potential natural or man-made hazards at the drill sites at an early stage so that the Pollution Prevention and Safety Panel may schedule a preview of the proposal at one of their meetings.

Currently relevant site survey data for the Arctic Ocean are dispersed over a variety of research institutions and countries. A network of institutions and relevant geophysical- and geological data holders with experience in site survey data acquisition from the Arctic Ocean should be established. This network should assemble and maintain a geophysical/geological database.

Another very important point could be the appointment of an IODP working group tasked with development of site survey strategies for the Arctic Ocean. The current iSSP (interim Site Survey Panel which will become the SSP in the new IODP) is currently developing, together with the iPPSP (interim Pollution Prevention and Safety Panel), a new target matrix system which will be adapted to the different drill targets as well as to the different drilling platforms. In addition to the advice from the proposal watchdogs, this matrix system will provide the proponents with the possibility to access a list of the data types needed for the site survey of their proposals via the internet. As soon as site survey data are available these data should be submitted to the site survey database. This requires close co-operation and contact between the SSP watchdog and proponents.



ODP Proposal Pathway *(Source: A Guide to the Ocea Drilling Program)*



Simplified Proposal Pathway in IODP showing
(i)SSP advice/guidance along every proposal step.

Fig. 3.1 Simplified pathways in the ODP and IODP drilling proposal handling

The Site Survey Panel has developed recommendations for eight major “Target Types” (Table 3.1). Data requirements have been developed for each target type. Generally a collection of geophysical and geological information is recommended for site characterization. Minimum requirements for sites on topographically elevated features are 3.5 kHz echosounder. However, in specific instances the Site Survey Panel will also require high-resolution or deep penetration seismic data, seismic velocity data, a grid of intersecting seismic lines, refraction data, swath bathymetry, side-looking sonar, photography or video imagery, results of rock sampling and information on water currents and ice conditions.

Data on Ice Conditions are for sites in high latitude areas

	Data type	Drilling environment (target type) A	B	C	D	E	F	G	H
1	High Resolution Seismic Reflection	X	Y, X*	Y, X*	X or 2	X*	Y, X*	Y, X*	X* or 6
2	Deep Penetration Seismic Reflection		X	X	X or 1	X*	Y, X*	Y, X*	Y or 5a
3	Seismic Velocity Determination	X*	X	X	X*	X*		X*	
4	Grid of Intersecting Seismic Profiles	Y, X*	X	X	Y, X*	Y, X*	Y*	Y, X*	
5a	Refraction (surface source)		Y, X*	Y, X*	Y, X*	Y, X*	Y, X*	Y, X*	Y or 2
5b	Refraction (near bottom source and receiver)						Y*		Y*
6	3.5 kHz	X	X	X	X	X	Y, X*	X	X* or 1
7	Swath Bathymetry	Y, X*	Y, X*	X	Y*	Y, X*	X	Y, X*	X
8a	Side-looking Sonar (shallow towed)	Y*	Y, X*	Y		Y*	Y	Y, X*	Y
8b	Side-looking Sonar (near-bottom towed)	Y, X*	Y, X*	Y, X*		Y*	Y, X*	Y, X*	Y, X*
9	Photography or Video			Y			X	Y, X*	X
10	Heat Flow		Y, X*	Y, X*		Y, T	Y		
11a	Magnetics		Y	Y	Y, X*	Y, X*	Y, X*	Y	X
11b	Gravity		Y	Y	Y*	Y*	Y*	Y	Y
12	Sediment Cores	X	Y, R	Y, R	R	R, T	X*	Y, X*, R	X*
13	Rock Sampling		Y	Y		Y, X*	X	Y, X*	X
14a	Water Current Data	X*	X*	X*			X*	X*	X*
14b	Ice Conditions	X*	X*	X*	X*	X*	X*	X*	X*
15	OBS Microseismicity						Y*		Y*
16	Navigation	X	X	X	X	X	X	X	X
17	Other	X*	X*	X*	X*	X*	X*	X*	X*

X = Required
X* = May be required for specific sites
Y = Recommended
Y* = May be recommended for specific sites
R = Required for re-entry sites
T = Required for high temperature environments

A = Paleo environment or Fan (APC/XCB)
B = Pasive Margin
C = Active Margin
D = Open Ocean Crust (>400 m sediment)
E = Open Ocean Crust (< 400 m sediment)
F = Bare Rock Drilling
G = Topographically Elevated Feature
H = Tectonic Window

Table 3.1 Recommendations for data to be included in “Target Types”.

4. Inventory of geoscientific data in the Arctic Ocean

Bathymetry

A new International Bathymetric Chart of the Arctic Ocean (Fig. 4.1) has been compiled and comprises historical and modern data sets that were previously unavailable (Jakobsson et al., 2000). It is a 2.5 x 2.5 km grid model which also encompass soundings from US and British navy nuclear submarine cruises between 1958-1988, echosoundings of cruises of the SCICEX program 1993-1999, and echosoundings from icebreakers and research vessels of Canada, Germany, Norway, Russia, Sweden and the United States. The map is available at: http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/

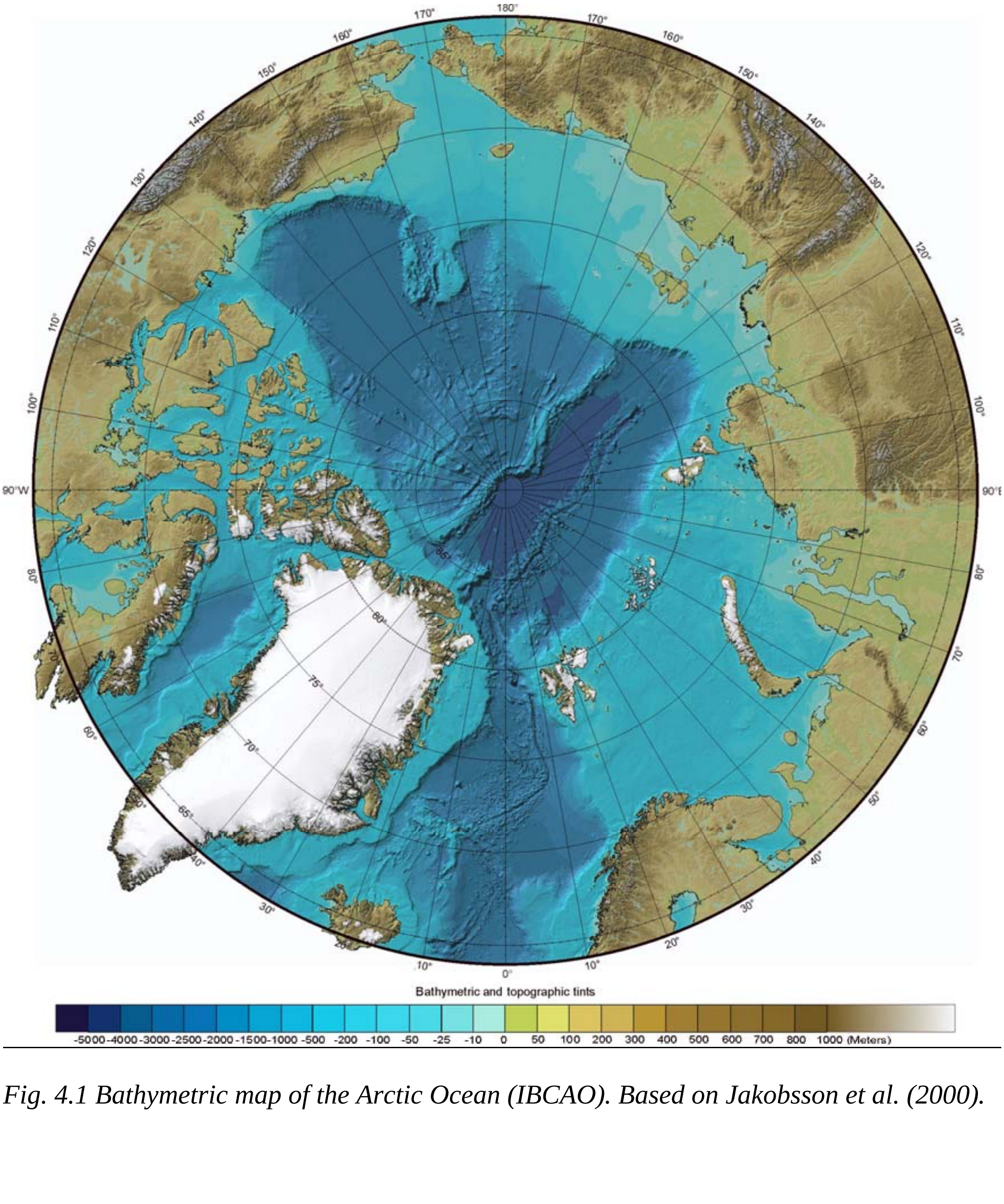


Fig. 4.1 Bathymetric map of the Arctic Ocean (IBCAO). Based on Jakobsson et al. (2000).

The use of multibeam swath mapping systems on icebreakers Polarstern and Healy represents a new era in charting the Polar Basin. A further breakthrough was the use of a multibeam system on the U.S.Navy nuclear submarine Hawkbill in 1999 where swath data was acquired at a speed of 16 knots. Presently, the western half of the Gakkel Ridge, a short segment of Lomonosov Ridge and part of Chukchi Plateau are mapped at a detail useful for geological process studies.

Seismic reflection

The geographical distribution of seismic reflection data from the Arctic Ocean is displayed in Figures 4.2 – 4.6 and the particulars of surveys and expeditions are tabulated in Table 4.1 and 4.2. In total some 20.000 km of seismic reflection data is available from the part of the Arctic Ocean covered by perennial sea ice. About 75% of this inventory has been collected from camps on sea ice or ice islands moving mainly in response to the surface wind field at an average rate of 3-5 km/day. The seismic data collected by Russian scientists from ice camps constitutes about

11.000 km and is the result of 3.940 seismic crew-days (Gramberg et al., 1991). It is noted that during almost 30 years of intermittent ice station operations, the inventory grew annually by about 500 km of new seismic lines compared to about 300 km since the introduction of modern icebreaker surveys.

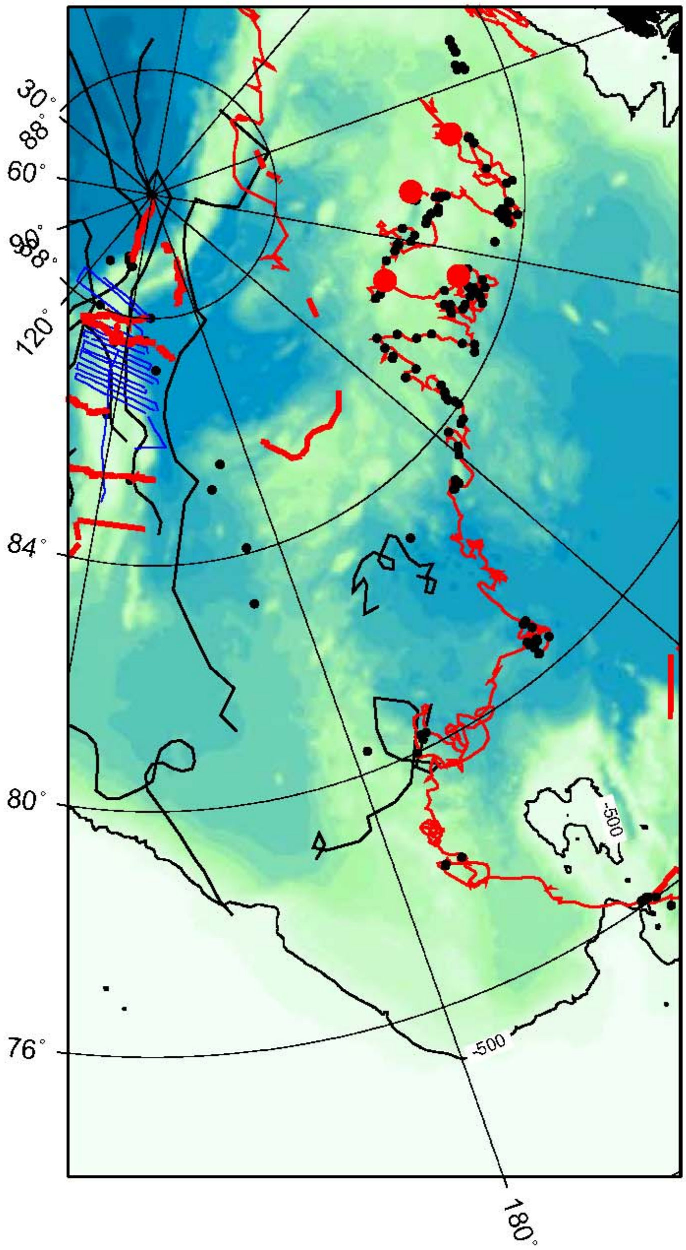
The data coverage is scattered and the total inventory is equivalent to about 3 months production by a single seismic vessel in the open ocean. Nevertheless, a feature like the Lomonosov Ridge is traversed by five ice stations, and has six seismic traverses by icebreakers, a fairly extensive coverage of swath bathymetry as well as high resolution chirp sonar. Also the wealth of data captured during the AMORE 2001 expedition makes 2/3 of Gakkel Ridge among the best surveyed spreading ridge segments in the world oceans.

Ice platform	Area	Year	Bathymetry	Seismic equipment	Recording volume	Penetration	Data
T-3	Canada Basin, Alpha Ridge	1962-1974	12 kHz	9 kJ sparker at 8 m 2 hydroph. 30 m apart	analogue	3.5 sec	4.000 km
NP-13	East Siberian Sea	1965		3-50 detonators fired in center of 1150 x 1150 m crossed array of 2 x 12 geophones	oscillograph		340 km
Arlis--II	Canada Basin	1963-1965	12 kHz	5 kJ sparker, single hydrophone	analog tape	1.0 sec.	
	Greenland Sea			0.45 kg primers at 10 min. interval 6 hrs/day		3.5 sec	
NP-21	Lomonosov Ridge	1973-1974		3-50 detonators fired in center of 1150 x 1150 m crossed array of 2 x 12 geophones	analog tape		476 km
NP-22	Mendeleev Ridge-Amundsen Basin	1974-1982		3-50 detonators fired in center of 1150 x 1150 m crossed array of 2 x 12 geophones	analog tape		3.400 km
NP-23	Makarov Basin - Lomonosov Ridge	1977-1978		3-50 detonators fired in center of 1150 x 1150 m crossed array of 2 x 12 geophones	analog tape		1280 km
NP-24	East Siberian Sea, Amundsen Basin	1979-1980		3-50 detonators fired in center of 1150 x 1150 m crossed array of 2 x 12 geophones	analog tape		1790 km
LOREX	Lomonosov Ridge	1979	3.5 kHz	10 inch? airgun, single hydrophone at 5 m	analog tape	1.2 sec	appr. 180 km
				1 and 10 kg explosives five times a day 24 seismometers 90 m spacing in cross	digital	Moho	200 stations
FRAM-I	Gakkel Ridge	1979	12 kHz	40 inch? airgun, single hydrophone	analog tape	2 sec.	
FRAM-III	Nansen Basin	1981	12 kHz	9 kJ sparker and single hydrophone	analog tape		200 km
FRAM-IV	Nansen Basin	1982	12 kHz	120 inch? airgun 10 m below the ice, 20 channel sonobuoy array, 100 m spacing, 50 m shot point distance	digital	2 sec	200 km
CESAR	Alpha Ridge	1983	3.5 kHz	40 inch? airgun, single hydrophone	analog tape		
NP-26	Mendeleev Ridge-Canada Basin	1983-1986		3-50 detonators fired in center of 1150 x 1150 m crossed array of 2 x 12 geophones	analog tape		1450 km
NP-28	Fram Strait	1987-1989		3-50 detonators fired in center of 1150 x 1150 m crossed array of 2 x 12 geophones	analog tape		1820 km
NP-31	Canada Basin-Northwind Ridge	1988-1989		3-50 detonators fired in center of 1150 x 1150 m crossed array of 2 x 12 geophones	analog tape		450 km
							Total 15.586 km

Table 4.1 Ice station seismic reflection surveys

Platform	Area	Year	Bathymetry	Seismic equipment	Recording	Penetration	Data volume	Sonobuoys
Polarstern	Lomonosov Ridge	1991	Hydrosweep	2x180 inch? airguns below 1 ton weight at 7 m	digital	+2 sec.	270 km	5
	Eurasia Basin			Tuned array, 8 guns 1440 inch?, 12 channel, 300 m long streamer, 183 m offset			1.200 km	12
Oden	Lomonosov Ridge	1996	12 kHz	2 x 80 inch? below depressor at 0-7 m depth, 8 channels, 200 m active length, 120 m offset	digital	+2 sec.	700 km	0
Polarstern	Alpha Ridge	1998	Hydrosweep	Tuned array, 8 guns 1440 inch? 32 channels, 200 m active length, 100 m offset	digital	+2 sec.	330 km	
	Lomonosov Ridge						920 km	
Polarstern	Gakkel Ridge	2001	Hydrosweep	Tuned array, 8 guns 1440 inch?, geohone array on ice	digital	Moho	0 km	18
	Nansen Basin			Tuned array, 8 guns 1440 inch?, 48 channels, 300 m active length	digital	+2 sec.		16
Oden	Amundsen Basin Lomonosov Ridge	2001	12 kHz	2x250 inch? G-guns below depressor at 0-7 m depth 8 channels, 200 m active length, 100 m offset	digital	+2 sec.	100 km	
	Nansen Basin	2001	12 kHz				700 km	55
Polar Star	Northwind Ridge Canada Basin	1988	12 kHz	195 inch? airgun suspended below a 1270 kg weight and towed up to 20 m below the sea surface. 2-channel hydophone streamer with 150 m active section	digital	+ 5 sec.	155 km	14
Polar Star	Northwind Ridge Northwind Basin	1992	12 kHz	674 inch? tuned array of 6 airguns suspended below a 1270 kg weight and towed as much as 20 m below sea surface. Dual-channel hydrophone streamer with 150 m active section	digital	6.5 sec.	500 km	36
Polar Star	Canada Basin, Northwind Ridge	1993	12 kHz	674 to 1303 inch? tuned array of 6 air guns suspended below a 1270 kg weight and towed as much as 20 m below sea surface. 2-channel hydrophone streamer with 150 m active section.	digital	6.5 sec.	1,900 km	28
							Total 6.675 km	

Table 4.2 Icebreaker seismic reflection surveys



Figur 4.2 Plot of seismic reflection data collected from Alpha Ridge and its vicinity: ice-breaker surveys (heavy red lines) , drifting ice stations (thin black lines, Russian; thin red lines, Canadian and U.S.), and SCICEX high resolution chirp sonar surveys (thin blue lines). The seismic data was acquired by "Polarstern" in 1991 and 1998, "Oden" in 1996, Arlis-II in 1964-65, CESAR in 1983, T3 in 1966-74 and by Russian icestations NP-13, NP-21, NP-22, NP-23, NP-24, NP-26 and NP-28.

Locations of sediment cores shown by black dots and red large dots represent cores which contained Cretaceous sediments. Sediment cores have been recovered by "Polarstern" in 1991 and 1998, "Oden" in 1996, "Polar Sea" in 1994, CESAR in 1983 and T3 in 1966-74.

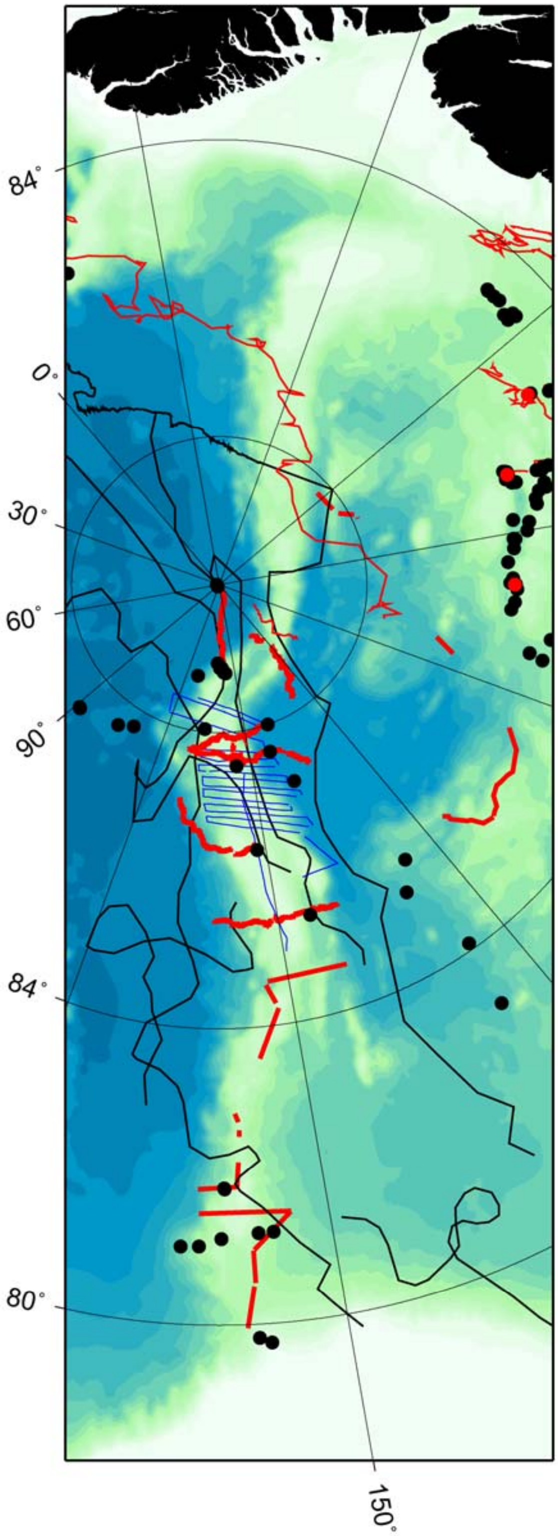


Fig. 4.3 Overview of seismic reflection data collected from Lomonosov Ridge and its vicinity: icebreaker surveys (heavy red lines) , drifting ice stations (thin black lines, Russian; thin red lines, Canadian and U.S.), and SCICEX high resolution chirp sonar and swath bathymetry surveys (thin blue lines). The seismic data was acquired by "Polarstern" in 1991 and 1998, "Oden" in 1996, Arlis-II in 1964-65, CESAR in 1983, LOREX in 1979, T3 in 1966-74 and by Russian icestations NP-13, NP-21, NP-22, NP-23, NP-24, NP-26 and NP-28.

Locations of sediment cores shown by black dots. Large red dots represent cores which contained Cretaceous sediments. Sediment cores have been recovered by ”Polarstern” in 1991, 1995 and 1998, ”Oden” in 1996, ”Polar Sea” in 1994, CESAR in 1983 and T3 in 1966-74.

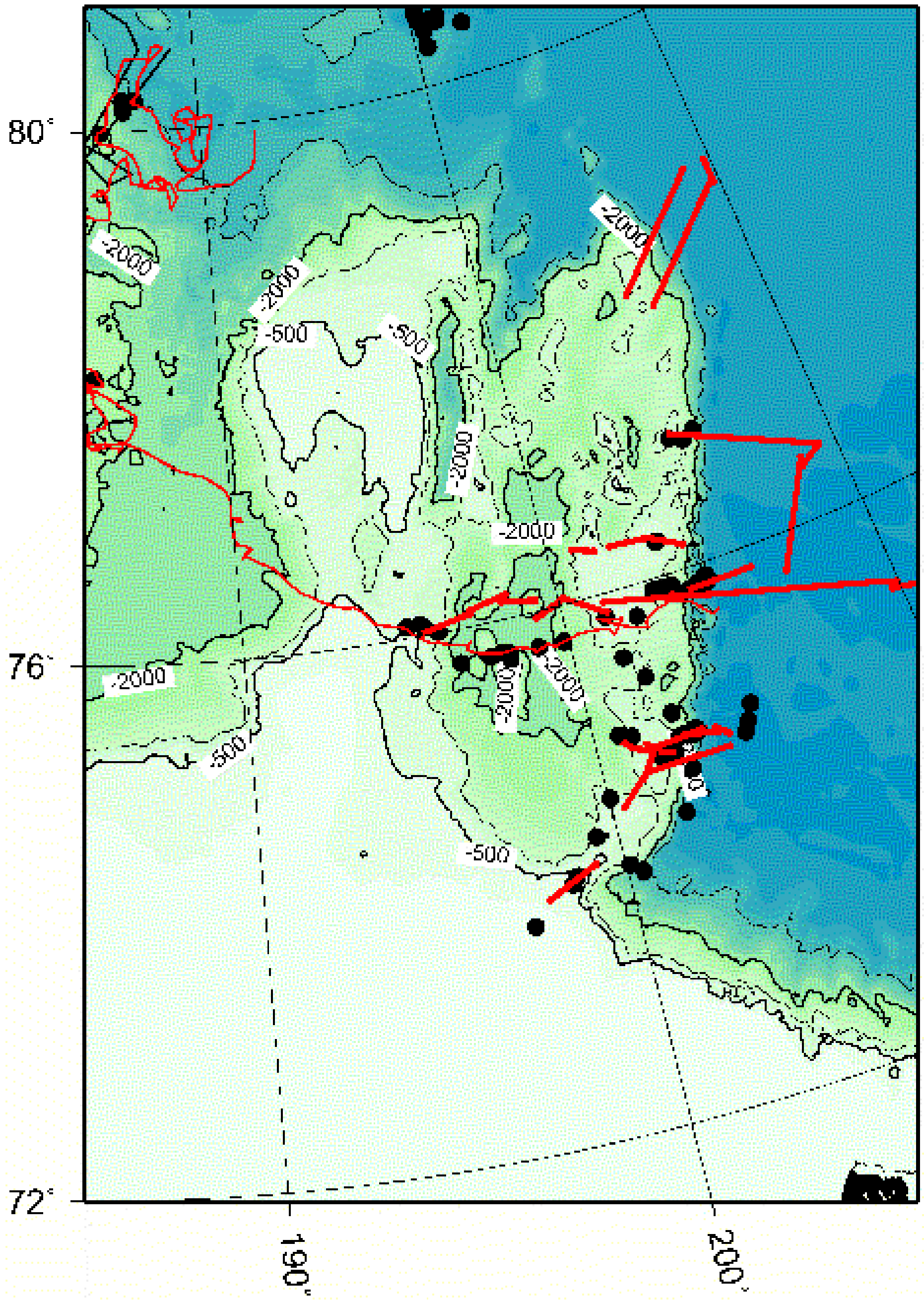


Fig. 4.4 Map of Chukchi Plateau and Northwind Ridge with seismic reflection data collected by icebreaker surveys (heavy red lines) and drifting ice stations (thin red lines, U.S; thin black lines, Russian). Seismic reflection surveys by A. Grantz with ”PolarStar” in 1988, 1992 and 1993, from T3 in 1966-69, and from Russian ice station NP-26 in 1983.

Location of sediment cores taken by A.Grantz in 1988, 1992, 1993, and 1994 and from ice station T3 are shown by black dots.

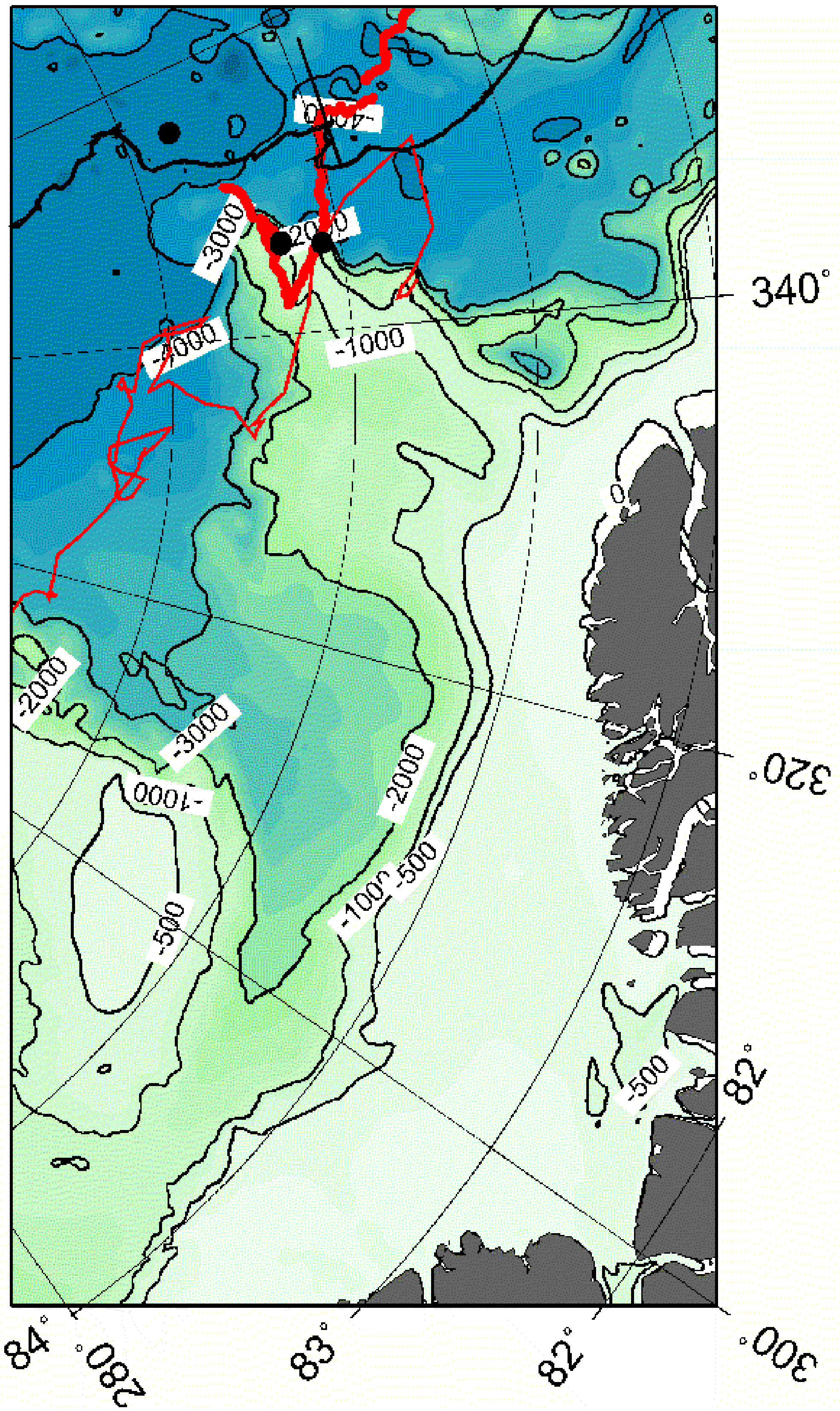


Fig. 4.5 Plot of seismic reflection data collected from Morris Jesup Rise and its vicinity by "Polarstern" (heavy red line) and drifting ice station Arlis II (thin red line) and Russian North Pole 28 (black line). Locations of sediment cores recovered by "Polarstern" in 1991 are indicated by black dots.

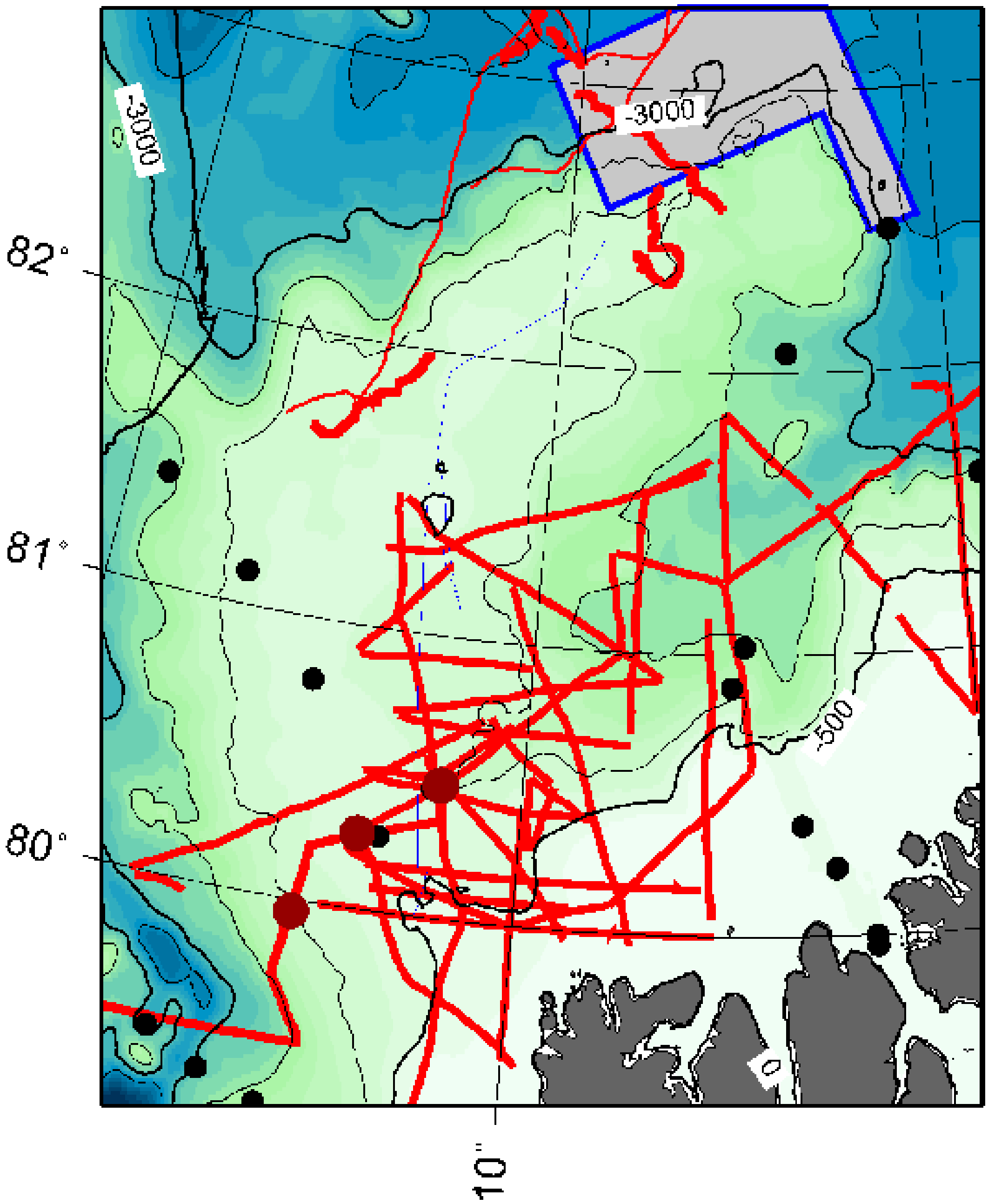


Fig. 4.6 Yermak Plateau. Overview of seismic reflection data collected from Yermak Plateau by vessels (heavy red lines) , and drifting ice stations (thin black lines, Russian; thin red lines, U.S.). A detailed SCICEX high resolution chirp sonar and swath bathymetry survey has been carried out within the framed area. The seismic data was acquired by University of Bergen in 1976, 1977 and 1979, with "Oden" in 2001, by the Norwegian Petroleum Directorate in 1990, by "Polarstern" in 1991, and from ice stations Fram-3 and Fram-4 and North Pole 28.

Locations of sediment cores recovered during the 1980 "Ymer" expedition are shown by black dots and ODP Sites 910-912 by large brown dots.

High resolution seismic reflection (> 1 kHz)

Low frequency echosounders (3.5 kHz) give sub-bottom penetration up to 100 m and are an invaluable guide for choice of sediment coring and shallow drilling locations. 3.5 kHz echo-sounders were used on the Canadian LOREX and CESAR expeditions while the 12 kHz beam commonly used on other expeditions is heavily attenuated below the water-sediment interface and rarely displays sub-bottom penetration, particularly in a turbidite environment. Modern research vessels such as “Polarstern” and “Healy” have seismic high resolution systems which provide sub-bottom penetration up to 50 m. The chirp sonar mounted on the the hull of U.S. Navy nuclear submarine “Hawkbill” (Fig. 4.7) had similar depth penetration, and represented a real break-through in terms of data coverage (Fig. 4.8).

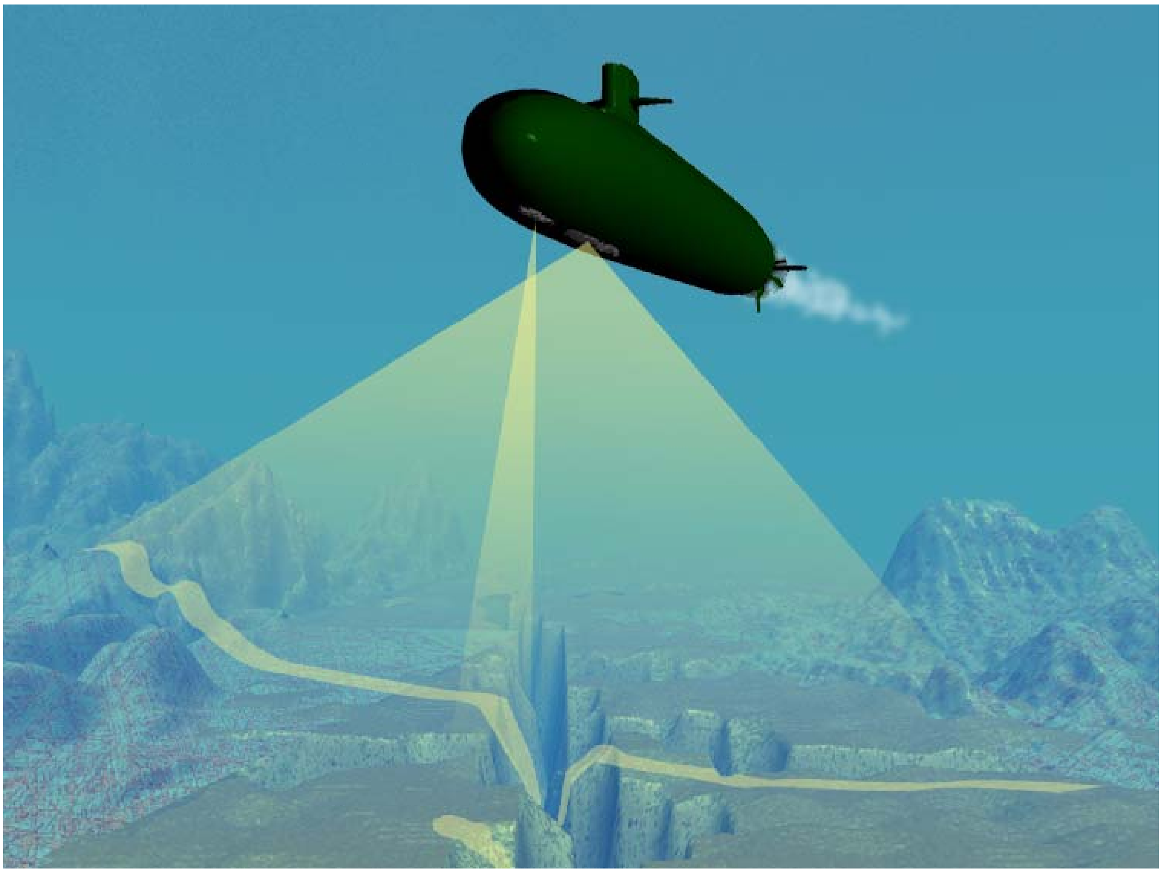


Fig. 4.7 The concept for seabed mapping and charaterization from a nuclear submarine platform as successfully carried out by U.S.N. Hawkbill in 1999 (Figure courtesy of Paul Bienhof).

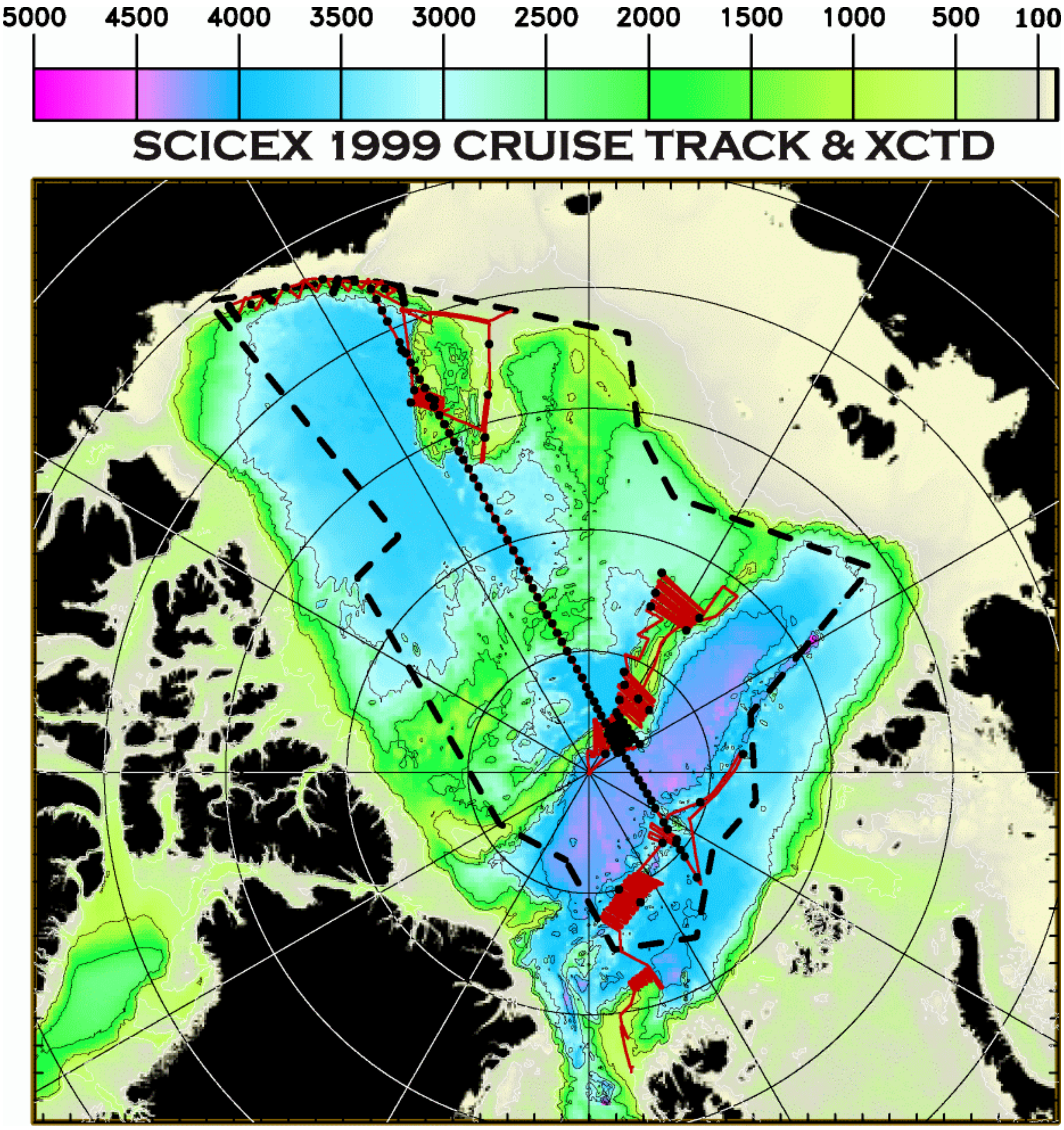


Fig. 4.8 SCICEX 1999 Cruise track with swath bathymetry and chirp sonar recording (red line). Black dots along the basin transect from Alaska towards Franz Josef Land indicate locations where expendable probes for sea water conductivity, temperature and depth (X CTD) were deployed. Approximate limit of 200 n.m. Exclusive Economic Zone indicated by dashed black line. Figure from : http://boreas.coas.oregonstate.edu/scicex/scicexmaps/

Seismic refraction

The locations of seismic refraction measurements in the Arctic Ocean are shown in Fig. 4.9. Most of these experiments were carried out with helicopter support from drifting ice stations (Fig. 4.10). The lines are mostly 50 to 100 km long with shot spacing rarely less than 5 km. The use of sonobuoys from icebreakers has made a vast improvement in spatial sampling out to a maximum of 30 km offset. Close to one hundred sonobuoy measurements have been made along traverses in the Nansen- and Amundsen Basins, while fifteen successful measurements have been obtained on Lomonosov Ridge and three on Alpha Ridge (Table 4.2). Seventy eight measurements have been carried out in the Canada Basin and over the Northwind Ridge.

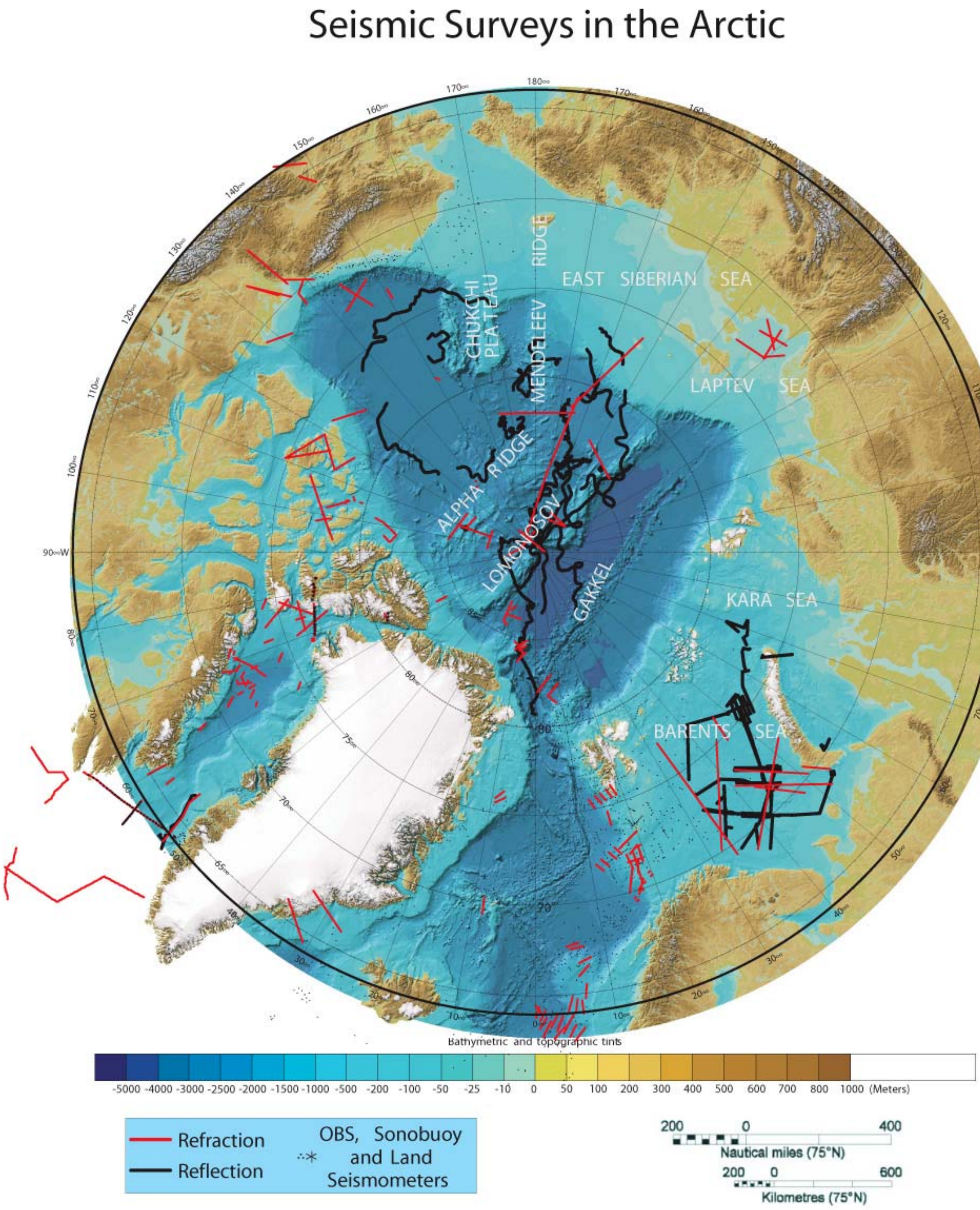


Fig. 4.9 Seismic refraction surveys and some reflection surveys in the Arctic (data compiled by R. Jackson)

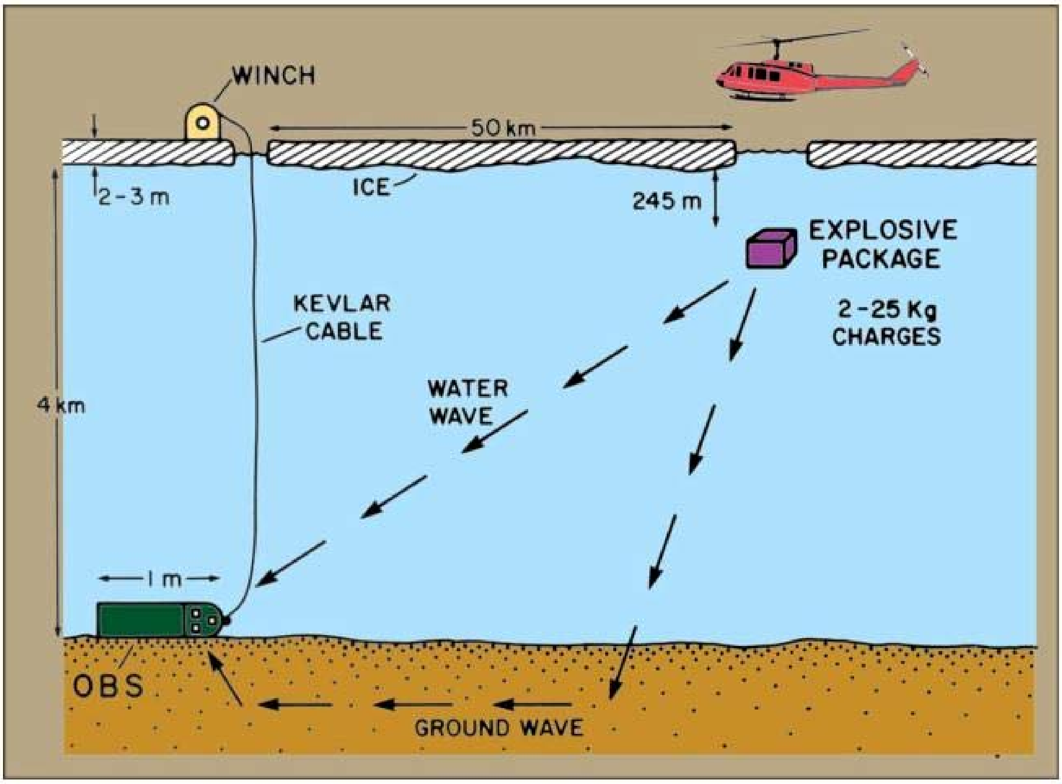


Fig. 4.10 Cartoon showing the procedure for seismic refraction experiment used by Jackson et al. (1982)

Heat flow

The compilation of marine heat flow data from the deep Arctic Ocean by Langseth et al. (1990) shows that a total of 444 successful measurements had been made. In addition, 21 new measurements were made along and off-axis on Gakkel Ridge during the AMORE 2001 expedition (Thiede et al., 2002).

Magnetics

Regional reconnaissance aeromagnetic mapping began in 1946 by Soviet agencies and in 1950 by the United States Navy. A joint compilation by scientists at VNIIOkeanologia and the US Naval Research Laboratory of Russian aeromagnetic surveys carried out between 1961 and 1992, and U.S. surveys between 1972 and 1998 provides the most comprehensive representation of the spatial anomalies in the residual magnetic field over the Arctic Ocean (Fig. 4.11). This follows a pioneering effort undertaken at the Geological Survey of Canada-Atlantic to create a coherent magnetic anomaly data base for the Arctic region (Macnab et al., 1989; Verhoef et al., 1996).

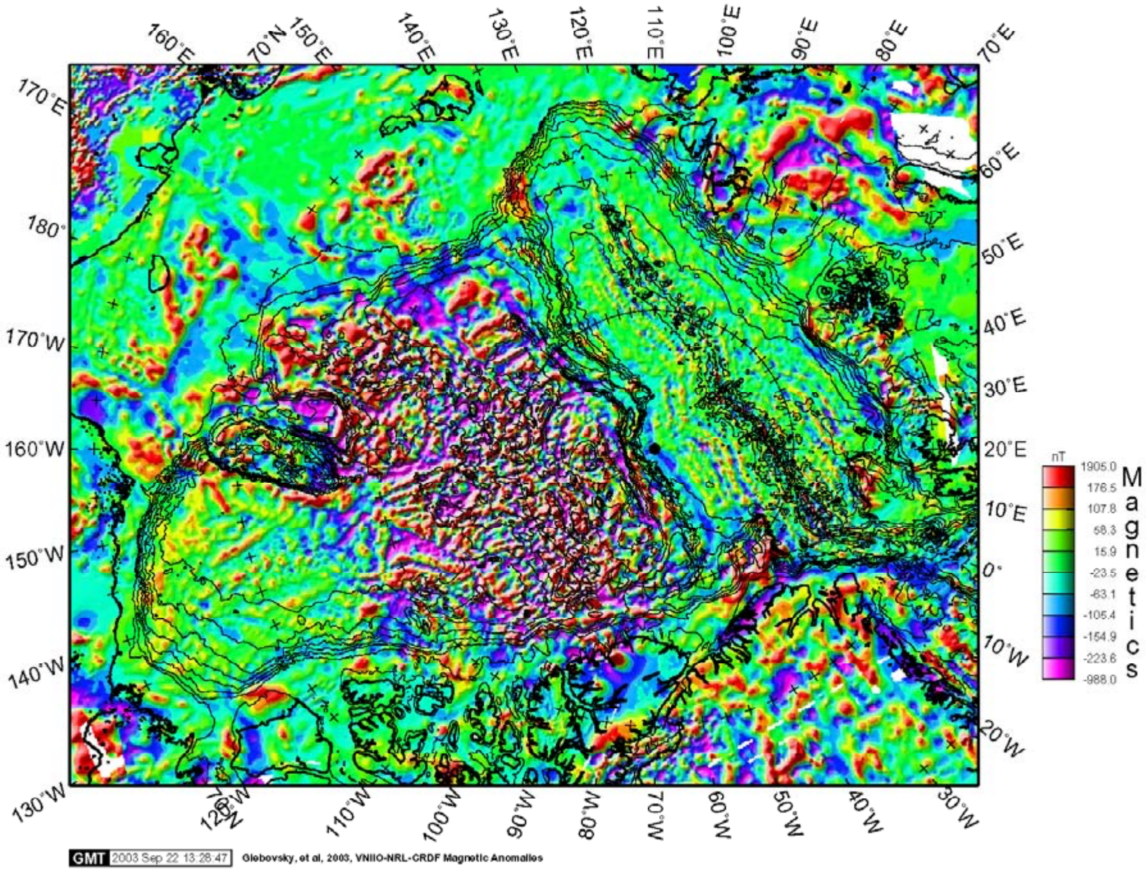


Fig. 4.11 Magnetic anomaly map of the Arctic Ocean with bathymetry superimposed. From Glebovsky et al. (2000).

Gravity

Nansen carried out the first five determinations of the earth‘s gravitational attraction in the Arctic Ocean by pendulum measurements during the drift of ”Fram” 1893-1896 across the Eurasia Basin. Readings of gravity by a damped land-gravimeter at ice camps has been part of the scientific program on all U.S. and Canadian ice stations. After 1979, the gravity data base was augmented by use of helicopters out to over a hundred kilometer away from the ice camp. Gravity have also been collected on Russian ice stations and during air craft landings on the ice.

Airborne gravity surveying using kinematic GPS techniques have revolutionized the methods of gravity data collection in the Arctic Ocean. The current database of airborne gravity is primarily the result of surveys by the US Naval Research Laboratory (Brozena and Salman, 1996), and more local campaigns around Greenland, Svalbard and Ellesmere Island by Scandinavian, German and Canadian groups. Systematic airborne surveys have also been carried out by Russian investigators. Gravity data have been collected from nuclear submarines on all the six SCICEX cruises since 1993. The Arctic Gravity Project is an international effort to compile the public domain free-air and Bouguer gravity data bases north of 64° N. The 5´x 5´ free-air gravity map is shown in Fig. 4.12.

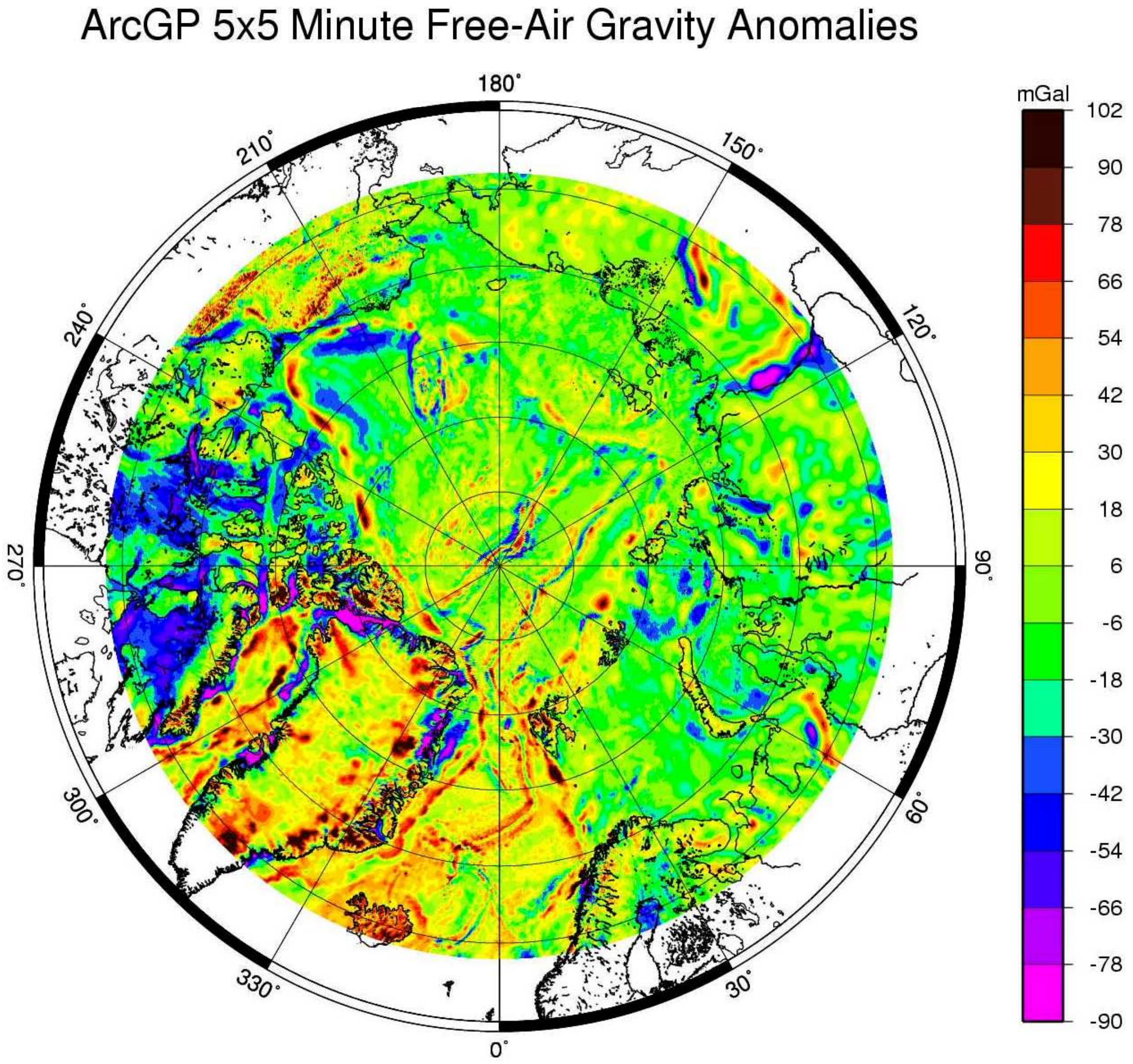


Fig. 4.12 Free Air gravity anomaly map of the Arctic. From http://www.nima.mil/GandG/agp/

Sediment cores

The scientist O.B. Bøggild, who was entrusted with examination of the first four mud samples ever recovered from the deep Polar Basin during Nansen‘s drift with ”Fram” published his results ....”in the hope that a tolerably clear idea thereby be obtained of the lithology of the bottom of the North Polar Sea ” (Bøggild, 1906). Today, over1000 sediment cores have been recovered by U.S and Canadian ice stations and 356 during expeditions with western ice breakers (Table 4.3). Unfortunately, we do not have numbers for the Russian effort which may have been larger. Logistics constrained the weight of coring equipment used on ice stations and the longest core taken from T-3 was 5.5 m, while the average length was 3-3.5 m (Minicucci and Clark, 1983; Clark et al., 1980). The weight of the 10 m long Ewing-Kullenberg piston corer used on T-3 was 550 kilos. Coring devices weighing 1.200 kilos or more used from ice-breakers have generally only yielded 5-8 m of recovered sediments, 12 cores are longer than 10 m. The longest core (16.92 m) was recovered from the Amundsen Basin by ”Polarstern” in 1991 using the long piston coring facility of Atlantic Geoscience Centre, Canada (Futterer et.al., 1992). Pre-Neogene sediments have accidentally been recovered in four cores from the central part of Alpha Ridge (Mudie et al., 1986; Clark, 1974), lower Mesozoic non-marine siltstone in one core from the flank of Lomonosov Ridge near the North Pole (Grantz et al., 2001). The only target oriented sediment coring effort in the Arctic Ocean known to data yielded late Paleozoic and Mesozoic rocks in a dozen cores from Northwind Ridge (Grantz et al., 1998).

Platform	Area	Year	Bathymetry	Coring equipment	Number of cores	Core length	Oldest sediment
T-3	Canada Basin, Alpha Ridge	1962-1974	12 kHz	Ewing-Kullenberg piston corer 10 m long, 75 mm diam. 550 kg	580	5.5 m	Upper Cretaceous
LOREX	Lomonosov Ridge	1979	3.5 kHz	Gravity corer, 2.4 m long, 67 mm diam., 118 kg	42	0.2 - 1.7 m	
FRAM-I	Gakkel Ridge	1979	12 kHz	Gravity corer 2.0 m long, 50 mm diam., 30 kg	8	0.07 - 0.95 m	Quaternary
Ymer	Nansen Basin	1980	12 kHz	Piston corer, 12 m long, 100 mm diam., 1,4 ton	45	< 8.9 m	Quaternary
FRAM-III	Nansen Basin	1981	12 kHz	Gravity corer	10	0.3 m	Quaternary
FRAM-IV	Nansen Basin	1982	12 kHz	Gravity corer, 3.o m long, 37 mm diam., 50 kg	7	0.5 m	
CESAR	Alpha Ridge	1983	3.5 kHz	Piston corer, 6-9 m long, 67 mm diam., 545 kg	16	0.2-1.7 m	Upper Cretaceous
Polar Star	Northwind Ridge	1988	12 kHz	Piston corer, 87 mm diameter cores, 1.3 ton weight stand	9	Up to 8.3 m	Upper Jurassic
	Canada Basin			Box corer, approx. 30 by 40 cm box	9	Up to 61 cm	Quatery
Polar Star	Eastern Alaskan	1989	12 kHz	Piston corer, 87 mm diameter cores, 1.3 ton weight stand	23	2.0 to 6.2 m	Eocene
	Beaufort Sea slope and rise			Box corer, approx. 30 by 40 cm box	9	0.61 cm	Quaternary
Polarstern	Nansen Basin	1987	Hydrosweep	Piston/gravity corer, 5.75 m long, 120 mm diam., 2 ton	63	5.7 m	
Polarstern	Eurasia Basin /	1991	Hydrosweep	Gravity corer, 10 m length, 120 mm diam., 1.5 ton	1	0.29 m	
	Lomonosov Ridge			Box corer, 12 m length, 300x300 mm square, 3.5 ton	14	1.58 - 9.76 m	
				Large piston corer, 21 m long, 105 mm diam., +3 ton	28	0.7 - 16.92 m	
Polar Star	Northwind Ridge	1992	12 kHz	Piston corer, 87 mm diameter cores, 1.3 ton weight stand	53	0.68 to 8.7 m	Paleozoic
	Northwind Basin			Box corer, approx. 30 by 40 cm box	17	Up to 61 cm	Quaternary
Polar Star	Northwind Ridge	1993	12 kHz	Piston corer, 87 mm diameter cores, 1.3 ton weight stand	23	0.88 to 8.19 m	Paleozoic
	Canada Basin			Box corer, approx. 30 by 40 cm box	21	8 to 48 cm	Quaternary
Polar Star	Chukchi	1994	12 kHz	Piston corer, 87 mm diameter cores, 1.3 ton weight stand	16	0.28 to 8.56 m	Middle Jurassic or Lower Cretaceous
	Eurasia Basin via North Pole			Box corer, approx. 30 by 40 cm box	18	31 to 53 cm	Quaternary
Oden	Lomonosov Ridge	1996	12 kHz	Piston corer, 88 mm core diam, 12 m long, 1 ton weight	24	0.46 - 9.0 m	Quaternary
				Selcore hydrostatic corer, 100 mm diam., 1 ton	3		
Polarstern	Alpha Ridge-	1998	Hydrosweep	Gravity corer, 12 m length, 120 mm diam., 1.5 ton	14	6.5 m	
	Lomonosov Ridge			Box corer, 12 m length, 300x300 mm square, 3.5 ton	1	7.5 m	
Polarstern	Gakkel Ridge Nansen Basin Amundsen Basin	2001	Hydrosweep	Gravity corer, 10 m length, 120 mm diam., 1.5 ton	10	0.69 - 6.6 m	
				Total number of cores: 1048			

Table 4.3 Sediment cores recovered by U.S. and Canadian ice stations and ice breakers.

5. Strategies for site surveys in the Arctic Ocean

Background

Site surveys are a prerequisite for any scientific drilling activity to test models for the geological history of the Arctic Ocean. We need the general geologic framework in place and a suite of geophysical and geological data to optimize the location of potential drill sites. Pre-defined geographical locations and planned survey patterns present a major challenge in the presence of 2-3 m thick sea ice often drifting at several hundred m/hr.

Characterization of a potential drill site requires the following types of data:

Seismic reflection measurements

The need to define a regional and local stratigraphic framework makes seismic reflection measurements (<500 Hz for sufficient penetration) a key element in site surveys. This can be carried out from drifting sea ice, or in single- or multi-ship icebreaker operations.

A sea ice platform for seismic data acquisition can exploit two important Arctic features;

1. the ambient noise in the water (Dyer, 1984) is well below the extrapolated curve of sea-state ”zero” noise level in the open ocean (Knudsen et al. ,1948).
2. the ice surface is well-suited for deployment of arrays.

Traditionally, a single hydrophone in the water or an array of surface seismometers summed into one trace have been used on drifting ice stations. Extended surface arrays have been used for isolated shots (Overton, 1984; Baggeroer and Duckworth, 1983), and in a single case (Fig. 5.1) for continuous multichannel seismic data acquisition (Kristoffersen and Husebye, 1985). The signal to noise ratio is well above that for seismic data acquired by icebreakers. Periods of bad data quality from ice stations in the past were most often due to radio interference and other man-made noise.

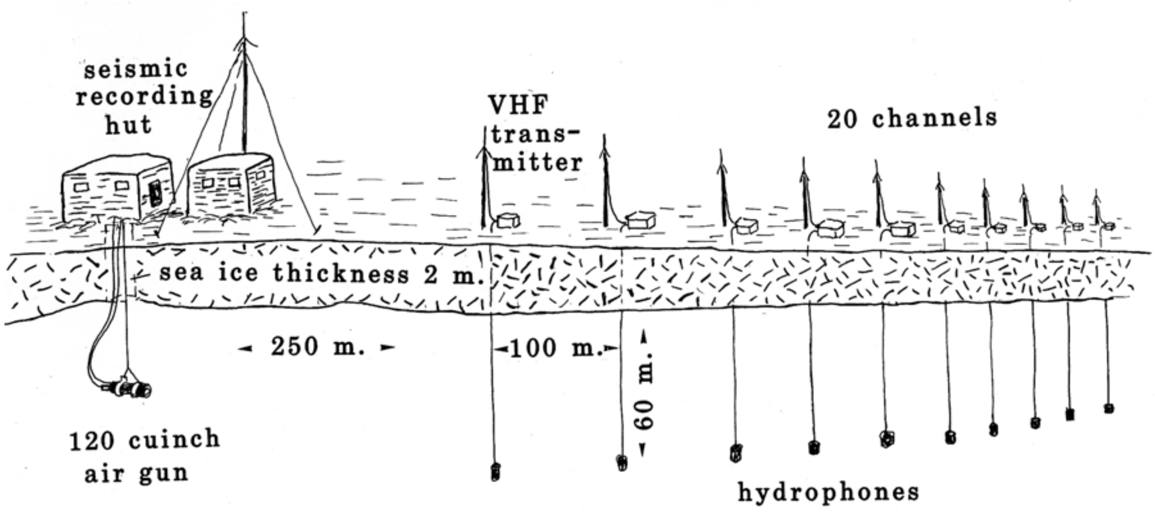


Fig. 5.1 Array of modified sonobuoys used for seismic multi-channel seismic reflection measurements on drifting sea ice. From Kristoffersen and Husebye (1985).

The ice surface moves as a coherent unit during the winter season and lends itself to deployment of large arrays. Optimal sun light and weather conditions limit use of sea ice as platform to the spring weather window (late March – early June). A seismic array may be disrupted by ice dynamics and dictate data transmission from array elements by radio (Kristoffersen and Husebye, 1985) rather than by surface cables (Baggeroer and Duckworth,1983) or a wireless digital local area network (WLAN). True 3-D seismic surveys in the Arctic Ocean can presently only be carried out by experiments on the ice surface. Such data sets would circumvent the problem of achieving a survey grid by a surface vessel and fully meet the SSP requirements. An infrastructure established every year in the vicinity of the North Pole for tourist operations (www.polarcircle.com/gb/site/barneo) may be exploited as an advanced base for independent science programs at a reasonable cost. In the future seismic 3-D surveys may be achieved using nuclear submarines.

Conventional 2D-marine multichannel seismic surveys are carried out by icebreakers in the Arctic Ocean (Jokat et al., 1995a). However, limitations with respect to control of source and cable depth as well as higher ambient noise level strongly influence data quality. In 7/10 – 9/10 of ice, most frequently encountered in the central Polar Basin, the wake behind the vessel is anywhere from a few meters to several hundred meters. Two icebreakers operating in tandem provide more continuous progress and leave a better wake. However, practical average survey speeds rarely exceed 3 knots (single vessel 2 knots) and diesel driven icebreakers are most often constrained to follow leads of opportunity.

It is essential that towed equipment enter the water as close to the stern as possible. Ice caught by towing lines may force either the source, the hydrophone cable or both to the surface and cause damage or ultimately loss of equipment. The equipment is towed with signal cables and air supply lines bundled in a heavy duty hose from deck level to the source depth (Fig. 5.2). Two different approaches guide the choice of source depth; in the ”survival mode” the source is towed deeper than the keel and propeller wash (+20 m), and in the ”suicide mode” the source is meant to fly at regular survey depth between 5 and 10 m. The surface ghost reflections which interfere with the primary source pulse will cause a highly undesirable notch in the source spectrum at 30 Hz and 60 Hz for a source as deep as +20 meter. A shallower source will, on the other hand, be violently tossed around in the propeller wash during ice breaking. Using two icebreakers in tandem allow operation of more elaborate sources such as a cluster of eight air guns (24 liter) suspended from a frame behind e.g. ”Polarstern” (Fig. 5.2, lower panel). The ice prohibits use of depth controlling birds on the hydrophone cable and in 7/10-9/10 of ice, the practical cable length is 200-300 meters. A moving icebreaker frequently looses momentum particularly during single ship operation (average every 200 m during the 2001 Lomonosov Ridge site survey expedition). In this situation, the hydrophone cable may sink unevenly and result in severe signal distortion between channels in a single shot.

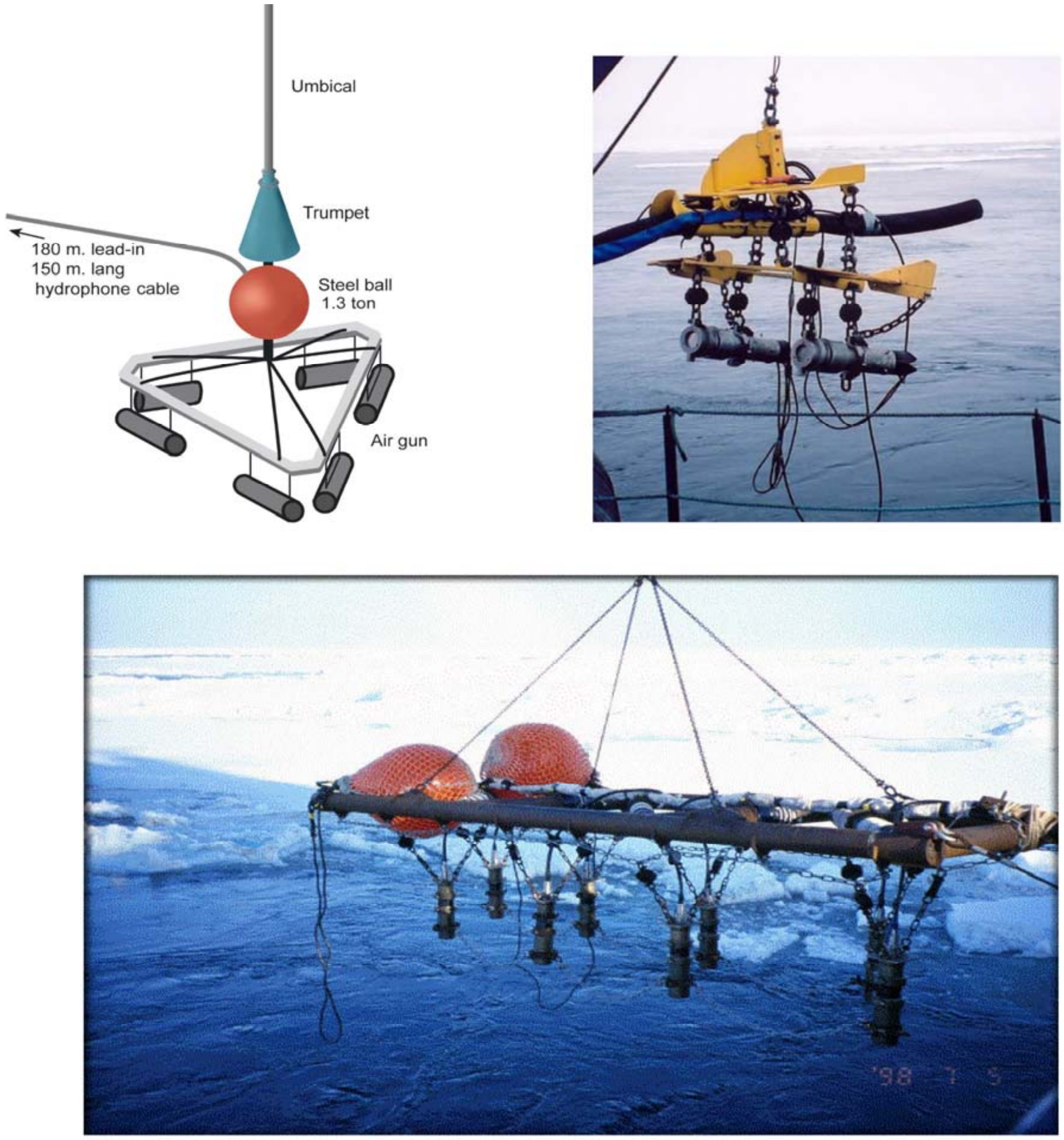


Fig. 5.2 Seismic source configurations used for seismic reflection measurements in the Arctic Ocean. Upper left: system used in single ship operation by Grantz et al. (1993); upper right; by Kristoffersen et al. (2001), and lower panel: air gun array used by Jokat et al. (1999) in a nuclear icebreaker assisted operation.

The energy in the hydrophone cable noise was in 1991 15-20 microbar (rms) for Polarstern operating alone and 5-10 microbars (rms) when the seismic data was acquired in the wake of another icebreaker (Jokat et al., 1995a). For comparison, open ocean surveys experience background noise levels <5 microbars.

Nevertheless, in spite of considerable problems such as low data fold, lack of source and streamer control as well as ambient noise levels 3-5 times higher than normal, the quality of seismic reflection data is surprisingly good and adequate for site characterization purposes. We note, that icebreakers are more flexible and collect the same amount of seismic data in an hour as would be acquired from an ice station in a day, but the data quality is likely to be lower and the cost is at least an order of magnitude larger.

Future seismic reflection surveys would be most efficiently carried out by a nuclear submarine if the technology became available. Presently, high resolution chirp sonar surveys (penetration < 50 meters) yield excellent quality data useful for targeting optimum sediment coring locations (Fig. 5.3).

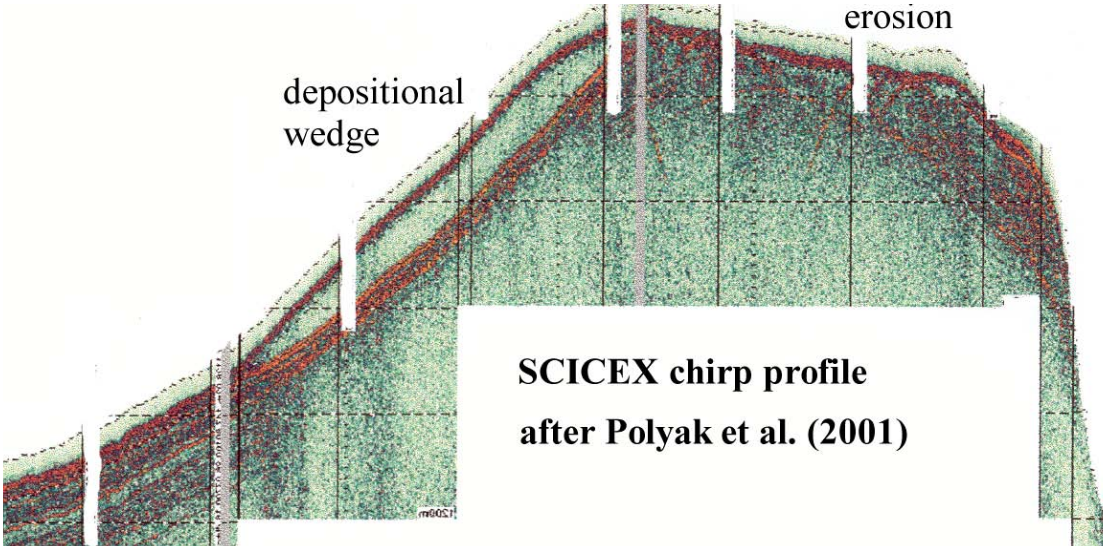


Fig. 5.3 Example of SCICEX chirp sonar profile across Lomonosov Ridge. Depth scale is 50 m between dashed horizontal lines. After Polyak et al. (2001).

Seismic refraction measurements

Spatial resolution is essential for meaningful investigations of crustal architecture. A moving ship is the most practical environment for providing a repetitive source at increasing offsets. The signals may be recorded by an array on the ice. This approach was successfully used by ”Polarstern” on the Gakkel Ridge during AMORE 2001 expedition (Thiede et.al., 2002).

Heat flow measurements

The temperature gradient in the sediments is measured by a 5-10 meter long lance with a series of outboard distributed thermistors. It is conveniently carried out from a research vessel, but may well be carried out from a small ice camp or by aircraft landings on the ice.

Gravity and magnetic measurements

Potential field measurements are most efficiently carried out by airborne surveys, and gravity also from submarines. The magnetic signature of basement may be variable, but gravity is particularly useful for tracking the extension of basement features progressively buried by sediments below the abyssal plain as well as lateral sub-basement density variations.

Sediment coring and dredging

The past efforts to obtain sediment cores from the deep polar basin show that <2 meters of sediments were recovered using equipment weighing <150 kg. Cores longer than 5 m required more than 1 ton, and heavy (+3 tons) coring devices were needed to obtain cores longer than 10 meters (Table 4.3). Modern research icebreakers facilitate use of heavy coring devices. What are most urgently needed are dedicated coring and dredging efforts at locations already known as having the potential for extended stratigraphy, such as the steep Eurasia Basin facing slopes of Lomonosov Ridge or slopes on the marginal plateaus as well as eroded areas and slopes of basement highs on the Alpha Ridge (Clark and Grantz, 2002).

Need for new technologies

The workshop suggested a number of highly desirable developments to advance geoscience in the high Arctic:

1. The most substantial progress would come from continuing science operations like SCI-CEX using nuclear submarines. A capability should be developed for seismic reflection measurements from this platform.
2. More robust towing arrangements for seismic surveys should be developed to allow for maximum icebreaker propulsion power while collecting useful data.
3. Sediment coring equipment with better penetration and recovery is needed in marine geology in general and for Arctic Ocean use in particular.
4. 3D-seismic data would greatly improve site characterization and experiments using drifting sea ice as platform should explore this.

6. Target areas

Alpha-Mendeleev Ridge

Primary science questions:

- Did the Cretaceous planet Earth warm and cool relatively uniformly across a range of latitudes, or were local factors dominant in governing temperature at specific locations?
- What was the Arctic environment during periods of extreme global warmth?
- Are Alpha- and Mendeleev ridges a result of Cretaceous plume activity or do they have different origins?

Existing geophysical and geological data

The limited geoscientific data available from the Alpha- and Mendeleev Ridges include ice station trajectories with seismic reflection measurements and a number of sediment cores (Fig. 4.2). Several short cores (< 3.5 meters) have captured piecewise stratigraphic representations of Mesozoic sediments which have documented a warm Mesozoic ocean and upwelling conditions, and proven immensely valuable data points in a latitudinal description of the global Cretaceous paleoenvironment. A two-ship expedition with the Russian nuclear icebreaker Arktika and RV Polarstern advanced to the flank of Alpha Ridge during the 1998 season and obtained 320 km of multichannel seismic data, three sonobuoys and recovered six sediment cores, 4.5 – 7.2 meters long (Jokat et al., 1999). A sample of altered tholeitic basalt was included at the base in one of the cores and a tentative date of 83 Ma has been obtained (Jokat, 2003).

Need for additional data

Alpha Ridge is the most difficult of the major submarine features of the Arctic Ocean to access by surface vessels. More seismic reflection measurements has highest priority in order to identify locations where an offset sediment sampling technique can be applied to obtain the best possible stratigraphic range including basement rocks.

Define drilling sites and prioritise

Mesozoic sediments can probably be obtained anywhere on Alpha-Mendeleev Ridge, and locations can be defined by seismic data from ice stations as well as from the “Polarstern” 1998 cruise. However, the limited data available render a discussion of drilling sites premature at this point.

Lomonosov Ridge

Primary science questions

- The Lomonosov Ridge represents the opportunity for a case study of lithosphere rheology. We need to establish:
  - the nature of the crustal framework
  - ridge history during rifting and formation of Eurasia Basin
- The significance of the ridge as a barrier for oceanic circulation.
  - establish history of water exchange through saddle points.
  - history of ridge interaction with deep draught ice
  - the evolution of the Late Cenozoic Arctic glaciation as documented in the conformable surface sediment cover.

Existing Geophysical and Geologic Data

The available seismic reflection data base include six transects of good quality seismic reflection data and five ice station tracks across the ridge crest (Fig. 4.3). The 1999 SCICEX cruise provided swath bathymetry, shallow penetration seismics (chirp sonar), and gravity at nominal 10 km line separation within the segments 83°-84° N and 86° 30‘ – 89° N. The 58 sediment cores recovered from Lomonosov Ridge have all captured upper Pleistocene and younger sediments with the notable exception of two cores raised from the steep Eurasia Basin slope of the ridge. Core 94-PC27 (1520 m. water depth) sampled Lower Jurassic and Lower Cretaceous nonmarine siltstone, while core 94-PC29 from a depth of 3010 m on the lower slope recovered weakly consolidated anoxic Neogene siltstone with an average TOC of 4.1wt% (Grantz et al., 2001).

Need for additional data

A sediment coring campaign, supported by seismic surveying of stratigraphic transects that appear promising based on available data, must have highest priority in a geoscience program on future expeditions. This include sampling transects up the steep Eurasia Basin flank of the ridge, and sampling the stratigraphic windows into the prograding slope section exposed by erosion in canyon walls on the Makarov Basin side.

Define drilling sites and priorities

Proposal 533 for scientific drilling on Lomonosov Ridge is highly ranked and has been approved by all iODP panels for drilling using a mission specific platform. Primary objectives are Cenozoic paleoceanography and the nature of the ridge framework and its tectonic history.

Gakkel Ridge

Primary science questions

Extremely slow spreading rates (13 mm – 5 mm/yr. full rate) on the Gakkel Ridge imply the lowest temperatures of magma extraction from the mantle and limits the depth region within which partial melts can form to the deeper parts of the melting column. This permits in principle the study of both nearly unmelted mantle and of basalts derived from extremely low temperatures of partial melting.

We want to:

- obtain relatively fresh basement samples from the sedimented central and eastern portion of the ridge
- establish the depth and extent of mantle-seawater chemical and thermal interaction on the ridge by obtaining relatively fresh basalt samples
- determine existence of unique vent biomass communities

Existing Geophysical and Geologic Data

The wide range of geological and geophysical investigations carried out during the 2001 AMORE expedition raised the state of knowledge of 2/3 of the Gakkel Ridge (3°-86° E) to the highest level among the spreading centers in the world oceans. Two seismic reflection transects at 70° E show a sediment filled rift valley (Jokat and Micksch, 2004) where the basalt lies some 7 km down, beneath 3-4 km of sediment.

Need for additional data

More geophysical data, particularly seismic refraction data is needed to establish the geophysical signatures of segmentation in melt production along the ridge, and to use this information to interpret the significance of the high amplitude magnetic anomaly zone over the flanks of the Gakkel Ridge (Feden et al., 1979).

Define drilling sites and priorities

Two preliminary drilling targets may the identified; one at the eastern end of the central area at 85° N, 94° E where the sediment infill may reach 500 m, and a second at 86° N, 50° E where the sediment cover is thinner.

Chukchi Plateau - Northwind Ridge

Primary science questions

Three major science issues can be addressed by drilling on Chukchi Plateau (the plateau) and Northwind Ridge (the ridge), which are microplates of continental crust isolated by plate tectonic processes in the oceanic Amerasia Basin of the Arctic Ocean

- Coring of the post-rift Hauterivian (mid-Lower Cretaceous to Quaternary) pelagic strata that overlie the plateau and ridge has the potential to provide a record of the paleoenvironment of the Northwind Ridge and Chukchi Plateau microplates and the Amerasia Basin for at least much of its history.
- Piston coring indicates that the mid-Pliocene to Quaternary glacial record is nearly complete on the crest of Northwind Ridge. Longer and larger volume cores therefore promise to provide important new insights into the history of sea ice development and glaciation in and around the Amerasia Basin during the ice ages.

Existing Geophysical and Geologic Data

Piston coring from the east face of Northwind Ridge (Grantz et al., 1998) has recovered either continental shelf or slope strata of all Phanerozoic systems except the Silurian and Devonian. Seismic reflection profiles show that these rocks extend beneath Northwind Ridge and at least the southeast part of Chukchi Plateau (Fig. 6.1). Reconstructions of the Chukchi Borderland, and the morphology of its high-standing physiographic elements strongly suggest that the entire Chukchi Plateau is underlain by such rocks. Several seismic reflection profiles (2 or 12 channel) cross all or part Northwind Ridge from 74.5° N to 78.1° N and the eastern part of Chukchi Plateau near 76° N (Fig. 4.4). At least the upper part of the ridge and plateau beneath all of these profiles is underlain by seismic reflections typical of sedimentary rocks.

Piston coring (Phillips and Grantz, 1997) has also shown that the crest of Northwind Ridge is underlain by an essentially complete section of mid-Pliocene to Holocene cyclical strata from which the complete history of sea ice and glaciation in the Amerasia Basin can be interpreted.

Need for additional geo-data

Intersecting crossing pairs of standard (low to medium frequency) and of high resolution seismic reflection profiles are needed at two prospective drill sites on both Northwind Ridge and Chukchi Plateau. In addition, pairs of crossing high-resolution profiles are required at least one intermediate prospective drill site on both the ridge and the plateau. Only two standard profiles may be required on Northwind Ridge if existing profiles are utilized. The profiles should cross at right angles and be at least 30 km long.

Proposed drill sites

Bedrock drill sites: Existing reflection profiles on Northwind Ridge suggest that the Cenozoic and Cretaceous section beneath the southern part of the ridge is significantly thicker than beneath the northern part. We therefore suggest a drill site on the ridge crest near 74.5° N to sample the thickest post-rift (Hauterivian to Cenozoic record) and a drill site on the ridge crest near lat. 77 ° or 78° N to sample the Mesozoic and upper Paleozoic pre-rift record. On the assumption that the situation on the Chukchi Plateau may be similar, we suggest that bedrock drill sites on the plateau be located near lat. 76.5° N and 78° N. If only one pair of sites can be drilled, we suggest Chukchi Plateau be given priority over Northwind Ridge because piston cores have already roughly defined the stratigraphy of the ridge.

Quaternary and Pliocene drill sites

These sites should include both of the proposed bedrock drilling sites on Northwind Ridge and Chukchi Plateau and an intermediate site about half way in between on both the ridge and the plateau. At least three sites are required on each ridge or plateau because piston cores from Northwind Ridge indicate that the thickness of the Late Pliocene and Quaternary deposits thins northwards. It will therefore be important to adequately define the thickness gradient and associated lateral changes in sedimentary character to achieve a full understanding of these deposits and the synglacial paleoenvironment of the Amerasia Basin. If a choice has to be made, drill sites on Chukchi Plateau should have priority over sites on Northwind Ridge because at least a piston core record of the mid-Pliocene to Quaternary stratigraphy and paleoclimate on Northwind Ridge already exists (Phillips and Grantz, 1997). However, continuously drilled large diameter core sections will probably significantly improve our understanding of the synglacial record on Northwind Ridge.

Possible pre-proposals for IODP

No IODP pre-proposals are contemplated because a proposal to acquire both seismic reflection and refraction data from Northwind Ridge and Chukchi Plateau, and bedrock piston cores from Chukchi Plateau, was submitted to the U.S. National Science Foundation by the Institute for Geophysics of the University of Texas in February, 2003.

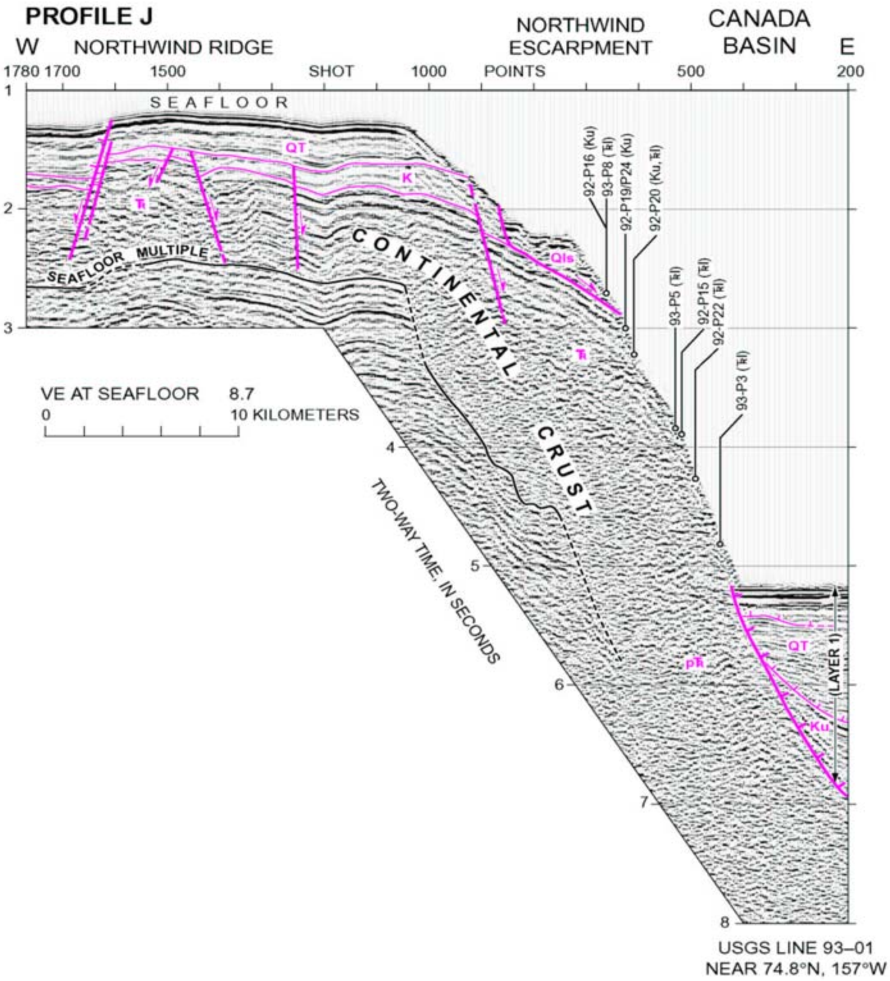


Fig. 6.1 . Seismic reflection profile 93-01 showing the structure and inferred stratigraphy and location of piston cores that sampled bedrock on the adjacent part of Northwind Escarpment. Qls-submarine slide; QT-Quaternary and Tertiary; K-Cretaceous; Tr-Triassic; pTr-pre-Triassic. (Figure courtesy of A. Grantz)

Yermak – and Morris Jesup Plateaus

Primary science questions

Yermak- and Morris Jesup Plateaus are conjugate features with respect to the Gakkel Ridge and are located at the gateway for water mass exchanges between the North Atlantic and a landlocked polar basin.

Sites in this area will be optimal for the following science issues:

- monitoring Atlantic inflow through the Cenozoic;
- definition of events when thick glacier ice was present in the Arctic Ocean.
- capture the signal of earliest glacial input to the Arctic Ocean
- document the paleoenvironment and timing of volcanic build-up of the plateaus.

Drilling a more than 2 km thick sediment drift along the north flank of Yermak Plateau (Jokat et al., 1995b) would yield an unprecedented Cenozoic record of inflow of Atlantic water which up until ca. 1 Ma. was concentrated through the gateway. Erosion of the sediment cover in the Barents- and Kara seas has subsequently facilitated flow through the Barents Sea (Dimakis et al., 1998). Drilling the north trending sedimentary wedge, deposited along the western perimeter of the the Yermak Plateau from erosion upstream by deep draft icebergs, would provide a log of the episodes where thick glacier ice exited the Arctic Ocean. A similar approach may be applied for similar not yet discovered features on Morris Jesup Rise. Morris Jesup Rise would lie in the exit path of thick glacier ice originating from discharge areas around the margins of the Amerasia Basin.

Existing geophysical and geological data

The northern flank of Yermak Plateau is covered by SCICEX swath bathymetry and side-scan sonar (Fig. 4.6), but only two seismic reflection traverses have defined the large sediment drift deposit. Sites 910-912 were drilled on the southern Yermak Plateau during Leg 151, but did not penetrate the entire glacial section at 505 mbsf. (Myhre et al., 1995). Several seismic reflection lines are available in the area south of 81° 30‘N which presented frequent open water conditions during good ice years in the late 1970’s. Piston and gravity cores on Yermak Plateau have only recovered upper Quaternary sediments.

The northern tip of Morris Jesup Rise was traversed by ice station Arlis-II in 1965 and had a short visit by Polarstern in 1991 with collection of seismic reflection data and a sediment core (Fig. 4.5). The over 7 m long core documents continuos sediment deposition at least since MIS 14 (Evans and Kaminski, 1998).

Need for additional data

Additional seismic reflection data across the sediment drift along the northern flank of Yermak Plateau are critical to formulation of a drilling proposal. The crestal region of the sediment drift show evidence of migration with exposure of deeper strata accessible by the conventional piston coring technique.

Our present almost complete lack of geophysical data from Morris Jesup Rise make it difficult to realize the scientific potential of the area (Fig. 4.5).

Shelf and upper slope (East): Laptev Sea, East Siberian Sea, Canadian/Alaska Arctic Margins

Primary science questions

The margins of the Arctic Ocean have the thinnest pack-ice and probably the shortest intervals of low productivity in the past. Therefore the continental slopes in certain areas are promising areas for high marine sedimentation rates and presence of biogenic proxies. Conditions exists for gas hydrates to occur associated with permafrost on circum-arctic continental shelves. Submergence of the arctic shelves during interglacials would have produced progressive warming of the shelf sediments with gas hydrate destabilization and methane release. We need information on the character, stability and possibly the resource potential of these deposits as well as their potential for instigating climate change.

Laptev Sea and East-Siberian Sea:

- obtain a record of the marine extent of former ice sheets in the area and the history of sea ice cover especially during glacial extremes.
- investigate thermal and hydrogeological processes that control methane release from destabilized permafrost-associated gas hydrate accumulations
- study the structural and tectonic processes associated with propagation of an oceanic spreading center into continental lithosphere
- study the intersection of the modern active Gakkel Ridge with the Laptev shelf and slope.

Canada/Alaska margins:

- obtain a record of the extent of former continental and marine based ice sheets in the area
- investigate the history of sea ice and paleooceanographic conditions that accompanied the cyclical alternation of glacial and interglacial environments in the Arctic Ocean
- investigate thermal and hydrogeological processes that control methane release from destabilized permafrost-associated gas hydrate accumulations
- investigate the history of the Bering Landbridge and the influx of Pacific waters through the Bering Strait.
- investigate the structural relationship between crustal blocks in the Northwind Ridge/Chukchi Borderland region.

Existing geophysical and geological data

Multichannel seismic reflection data have been obtained on the Laptev Shelf and upper slope by the Marine Geophysical Expedition (MAGE) of Murmansk (Sekretov, 2002), and on the East Siberian slope by Bundesanstalt und Rohstoffe (BGR), Hannover (Roeser at al., 1995) under the Russian-German Cooperation: Laptev Sea System. Sediment coring and Parasound profiling have been carried out by Polarstern (Kassens et. al., 1995) as well as shallow drilling on the shelf.

Need for additional data

Medium resolution seismic reflection data are needed to identify piston coring or shallow drilling targets in selected areas of the Canadian/Alaska margin. 1.) The Upper Cretaceous to Holocene pelagic and tuffaceous sedimentary cover (which is locally at least as thick as 1200 m) that overlies Alpha Ridge adjacent to the Canadian margin. 2.) The pelagic section of similar age inferred to overlie southern Northwind Ridge adjacent to the Chukchi Shelf. 3. Isolated knolls deeper than 700 or 800 m on the Canadian/Alaska continental slopes. 4.) The outer shelf and upper slope of the Mackenzie Delta system.

The numerous seismic reflection profiles and offshore wells that exist in this region will provide important guidance as to the existence and location of useful core and shallow drill sites in the offshore Mackenzie Delta.

Shelf and upper slope (West): Lincoln Sea, North Greenland margin, Fram Strait, Northern Barents Sea

Primary science questions

The continental slope of the Lincoln Sea and Northeast Greenland margins is the source area for a large submarine fan which extends along the base of the Lomonosov Ridge to the North Pole in the Amundsen Basin (Kristoffersen et al., 2004). In the Fram Strait, the inflow of Atlantic water through the gateway has left a legacy represented by a large sediment drift along the north slope of Yermak Plateau. Key science issues are:

- the earliest glaciation of northern Greenland;
- the history of Atlantic inflow to the Arctic Ocean
- the sea ice conditions north of Svalbard and the Barents-Kara margin through the Quaternary glacial cycles

Existing geophysical and geological data

The transpolar drift of sea ice is constrained by the northern landmasses on approach to the Fram Strait gateway. This leads to ice convergence and heavy sea ice conditions on the Lincoln Sea- and North Greenland shelf and continental slopes. So far prevented acquisition of any seismic reflection data in this region beyond the transit by ice station Arlis II in 1965 and a brief visit by Polarstern on the northern Morris Jesup Plateau in 1991 (Fig. 4.5). The availability of data in the Yermak Plateau area is described under section 6.5 above. Six seismic transects (1470 km) arcoss the margin north of Svalbard east of Yermak Plateau were acquired by Polarstern in 1999, and one by Oden in 2001. The stratigraphic section on the lower continental slope in this region appears to comprise several slump deposits.

Need for additional data

New data is definitely needed for the Lincoln Sea/ North Greenland sector of the Arctic Ocean. Particular effort should be to obtain data across the adjacent shallow region of the Lomonosov Ridge which holds a clue to the question about past occurrences of thick glacial ice in the Arctic Ocean.

Define drilling sites and prioritize

The highest priority for scientific drilling must be the large sediment drift/deposits along the north flank of Yermak Plateau.

7. Planned activities in the Arctic Ocean

Scientific drilling on the Lomonosov Ridge (IODP)

A proposal for scientific drilling on the Lomonosov Ridge was submitted to ODP in the spring of 1999. In June 2003, the interim Pollution Prevention and Safety Panel granted the final approval to drill a suite of the proposed sites to meet all the paleoceanographic and tectonic objectives put forward in the proposal.

The background was given by the work of an Arctic Detailed Planning Group (ADPG), established by JOIDES in 2000. The ADPG report formulated the scientific rationale and outlined the general scheme of such a coring operation to take place in the summer of 2004. This will be possible only with a coordinated effort involving a number of icebreakers to assist during the transit and the actual coring phase.

The single issue which will make the difference between failure and success is the ice condition. Maximum efforts will be devoted to understanding, foreseeing and possibly controlling the ice conditions. The fleet of vessels involved in the operation needs to meet a number of criteria consistent with the analysis of ice and weather conditions. The positioning capability of the coring platform is of utmost importance.

Denmark/Greenland: Activities in the area north of Greenland related to UNCLOS §76

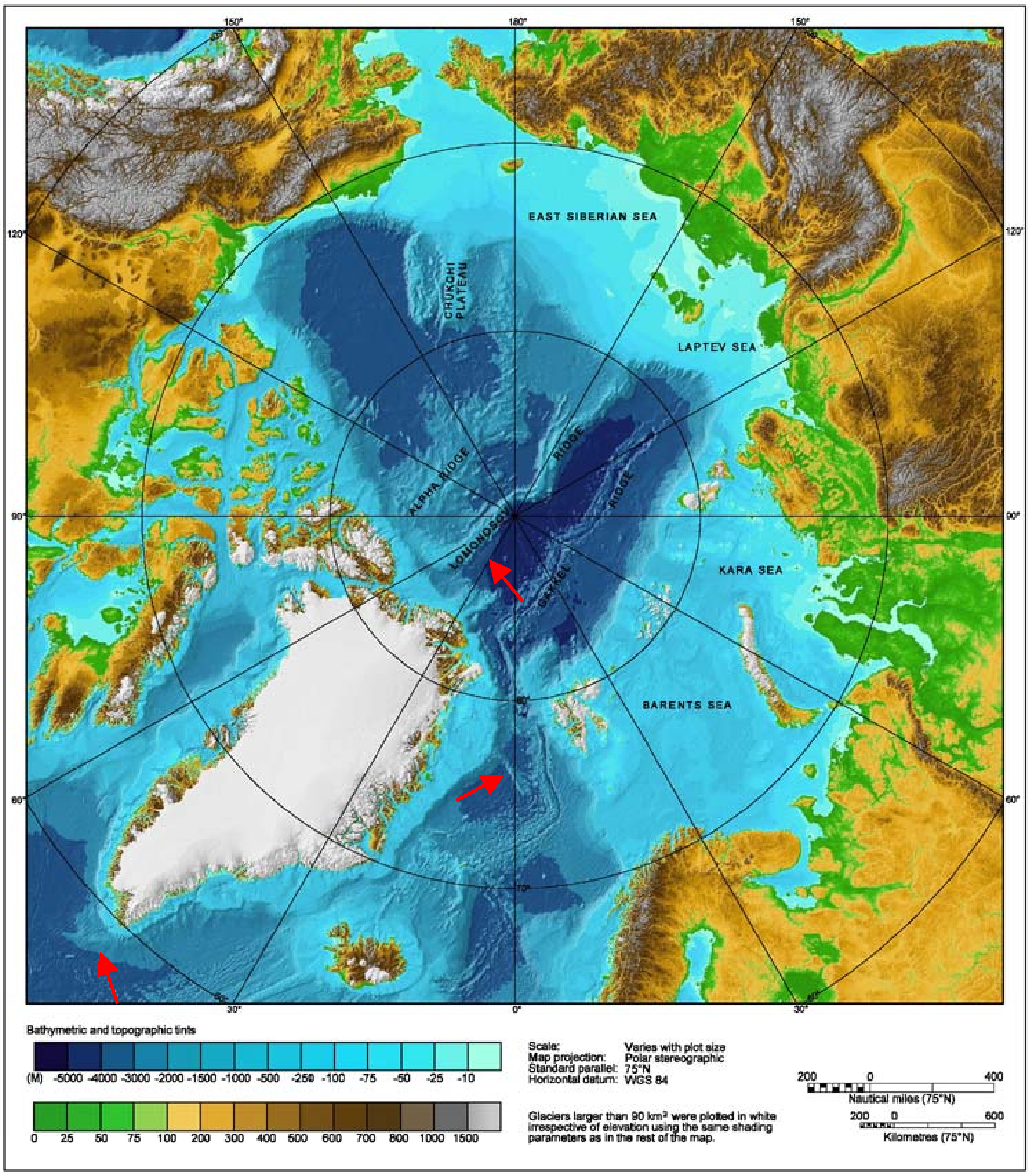


Fig. 7.1 Map showing areas of planned activities (red arrow) within the Danish / Greenlandic §76-project (from IBCAO, 2001)

It is expected that Denmark ratifies the United Nations Convention on the Law of the Sea (UNCLOS) during 2003. In this context Denmark has launched an UNCLOS §76 project, which is embedded within the Geological Survey of Denmark and Greenland (GEUS) in cooperation with other Danish, Faroese and Greenlandic organizations. The project will cover two areas around the Faroe Island and two areas off Greenland with a budget of 150 mill. DKK (approx. US$ 22 mill.) over 10 year for data acquisition, processing, documentation and preparation of submissions. The area north of Greenland in the Arctic Ocean will be covered by a separate project where funding has yet to be granted.

In 2002 seismic refraction and reflection data were acquired along the Greenland Ridge (GR) off North-East Greenland in cooperation with University of Bergen. The data is presently being processed and will hopefully shed some new light on the crustal structure in this area.

It is anticipated that new reflection seismic data will be acquired off South Greenland during the summer of 2003 to investigate the nature of the Eirik Ridge (ER) and the sediment thickness close to the extinct spreading between Labrador and Greenland.

A desktop study covering the area north of Greenland was completed in early 2003 with the following recommendations:

- Based on data in the public domain it is expected that Denmark / Greenland can extend the juridical continental shelf in the area north of Greenland beyond 200 nautical miles.
- The existing data coverage (bathymetry, geophysical and geological data) is very sparse and the physical conditions in the area are very difficult for data acquisition.
- A multi-phase programme has been proposed where the first step will include acquisition of bathymetric and refraction seismic data along the innermost parts of the Lomonosov Ridge (as seen from Greenland - LR). The next step will be to acquire bathymetric, refraction and refraction seismic data along the Lomonosov Ridge and in the Amundsen Basin.
- Due to the expected very high costs of the data acquisition programs Denmark / Greenland will try to establish cooperation with other circumpolar nations (especially Canada) in order to develop geological models of mutual interest.

Germany

Germany plans to concentrate the effort during the coming years in two regions in the Arctic Ocean with the following objectives:

Fram Strait -Yermak Plateau:

- geophysical studies to improve constraints on the opening of Fram Strait and definition of the main tectonic elements that form Yermak Plateau
- to establish a high-resolution stratigraphic framework (Tertiary-Quaternary)
- to study the short- and long-term variability in sea-ice cover, paleoproductivity, and paleoceanographic circulation patterns in relation to climate change
- to identify the sediment characteristics of slides, to study their frequency of occurence and their relationsship to climate change, and to quantify the sediment transfer from the shelf and upper slope to the deep-sea basin
- study the extent and history of Quaternary Eurasian ice sheets along the Kara Sea margin

Alpha-Mendeleev Ridge and continental margin of the East Siberian Sea :

- to investigate with geophysical and geological methods the shallow and deep structure of the crustal transition between Lomonosov Ridge and the Makarov Basin as well as the junction between the Mendeleev Ridge and the Eastern Siberian Shelf
- to establish a stratigraphic framework (Cretaceous-Tertiary-Quaternary) for the area.

- to study the controlling processes on long-term change in siliciclastic and biogenic fluxes during the transition from the Paleogene greenhouse world without sea ice to the Late Neogene icehouse condition.
- to study the short-term variability in terrigenous and organic-carbon supply in relation to Quaternary glacial/interglacial changes
- to study total sediment and organic-carbon budgets and their spatial and temporal variability in selected time slices from the Cretaceous to the Paleocene/Eocene to the Pleistocene/Holocene

Russia: Plans of future Russian earth science activities in the central Arctic Ocean

VNIIOkeangeologia in cooperation with PMGRE and other sister organizations are currently developing a proposal to the Ministry of Natural Resources of the Russian Federation for two Arctic expeditions which may take place in 2004 and 2005 or in subsequent years, depending on budget constraints.

The main objective of the proposed expeditions will be to investigate deep structure and nature of the crust in the zone of transition from the East Siberian Shelf to Lomonosov Ridge and Mendeleev Rise (Fig. 7.2). The studies will focus on two main research targets using a wide range of exploration technologies including imaging structure and composition of the entire crust by means of deep seismic sounding and gravity/magnetic observations, characterization of the upper crust and especially the sedimentary layers (including the uppermost sub-bottom sequences and bottom sediments) by seismic reflection and HRS studies, coring and bottom sampling guided by visual control (TV, photo, etc.).

Deep seismic sounding (DSS) profiles and other research activities are envisaged within the corridors shown in Figure7.2. The location of other relevant data already existing in the area and/or firmly planned for acquisition prior to the proposed expeditions are also indicated. The traverses are laid out in a crossed pattern to optimize identification of crustal boundaries.

The scientific objectives in each of the proposed areas should ideally be accomplished during one field season. The technology of DSS observations will be similar to that applied during the “Transarctic-2000” cruise when a research icebreaker was used as a base for helicopters and scientific groups working on sea ice. Investigations of the sedimentary layer will be given higher priority and be carried out more systematically than during “Transarctic-2000”.

The above-proposed activities are in good agreement with the objectives and goals of the several international and bilateral programs whose cooperative implementation in the harsh high Arctic environment has long been discussed by the earth science community. Such collaboration is presently receiving a new incentive in connection with IPY initiatives, and the Russian proposal is open for integration in any multinational effort that may jointly be undertaken by several countries.

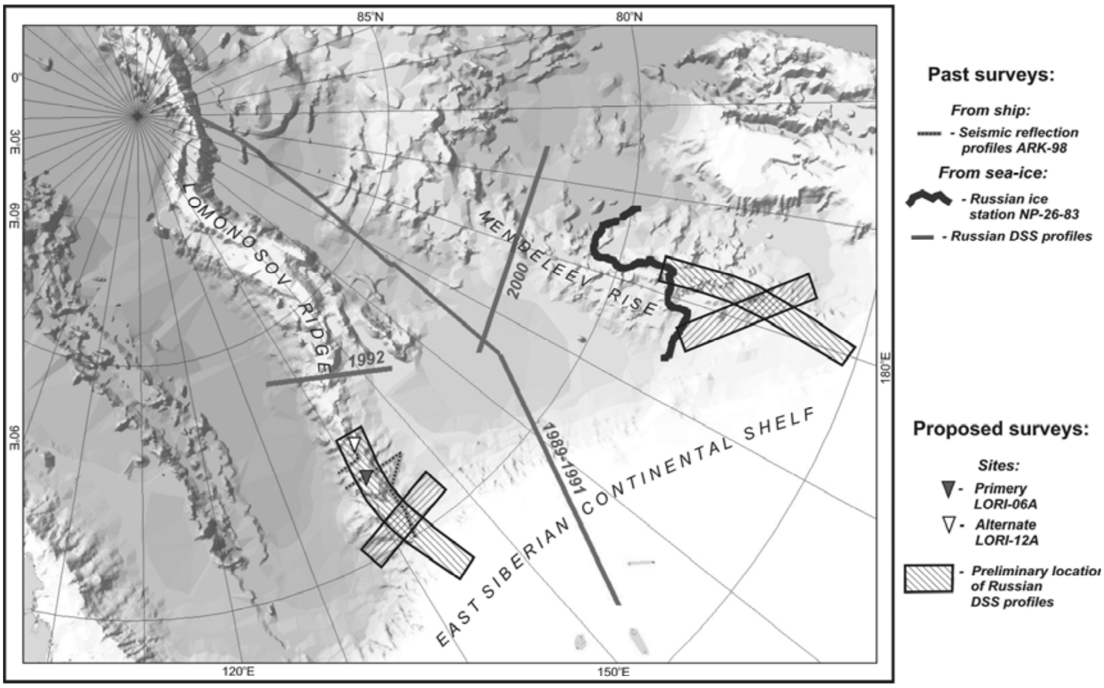


Fig. 7.2. Russian activities planned for the Arctic Ocean

Sweden: The ”Beringia 2005” expedition

The Swedish Polar Research Secretariat is organizing a research expedition to the Beringia-region in the summer of 2005 using the ice-breaker Oden as a platform. The secretariat would like to make “Beringia 2005” an international venture and to develop collaborative arrangements with arctic organisations operating in the region. The expedition will be divided into three legs of which the third one from mid August - end of September 2005 will be devoted exclusively to marine research along a transect from northern Alaska over the Polar Basin to Scandinavia. This leg will focus on: The role of the Arctic Ocean in the climate system including themes as water mass variability and circulation patterns, atmosphere-ocean interactions, geology and geophysics of the Arctic Ocean, biogeochemical cycles and land-shelf-basin interactions.

U.S.A.

A group of US, Swedish and Norwegian investigators is planning a cross-basin cruise on the US Coast Guard icebreaker Healy for the Summer of 2005 (Fig. 7.3).

The cruise will begin near Point Barrow, Alaska and sail across all the major ridges in the basin, collecting cores, multi-beam swath bathymetry and sidecan, sub-bottom profiler, multi-channel seismic reflection and gravity data. Proposals for this cruise, which will, in part, be conducted in tandem with the Swedish icebreaker Oden, were submitted to the US National Science Foundation in February, 2004 .

The future of dedicated, unclassified submarine science cruises

The greatest strength of the submarine for Arctic operations is the ability to efficiently collect a number of co-registered geophysical data sets from a single platform at high speed.

The final dedicated SCICEX cruise sailed from Pearl Harbor in mid-March 1999 (Fig. 4.8). While the SCICEX program continues at a low level, it still has life in the enthusiasm it has engendered in other countries and throughout the disciplines that study the Arctic Ocean. Denmark/Greenland Canada and Norway have extended invitations to SCICEX to operate in their Exclusive Economic Zones. These invitations have enlarged the SCICEX operational area by nearly 50%, permitting access to the entire northern edge of North America as well as areas that can never be reached by surface ships (e.g. the Lincoln Sea).

Renewed, dedicated submarine access to the Arctic is the most efficient way to map the Arctic seafloor and extend the oceanographic and cryological time series, to synoptically monitor the Arctic during what may be a dramatic period of climate change, particularly at high latitudes.

While the science community values the achievements of SCICEX and would welcome further dedicated cruises, the rapid decommissioning of the entire Sturgeon class has decimated the US submarine fleet, limiting its ability to service military missions. Even though the US Navy might welcome further SCICEX cruises, military demands for submarine time make it unlikely that any new, dedicated cruises will be planned for pure science missions. The most likely means to new, dedicated cruises is through the political process, which could allocate resources and direct deployment of submarines in service of US national needs.

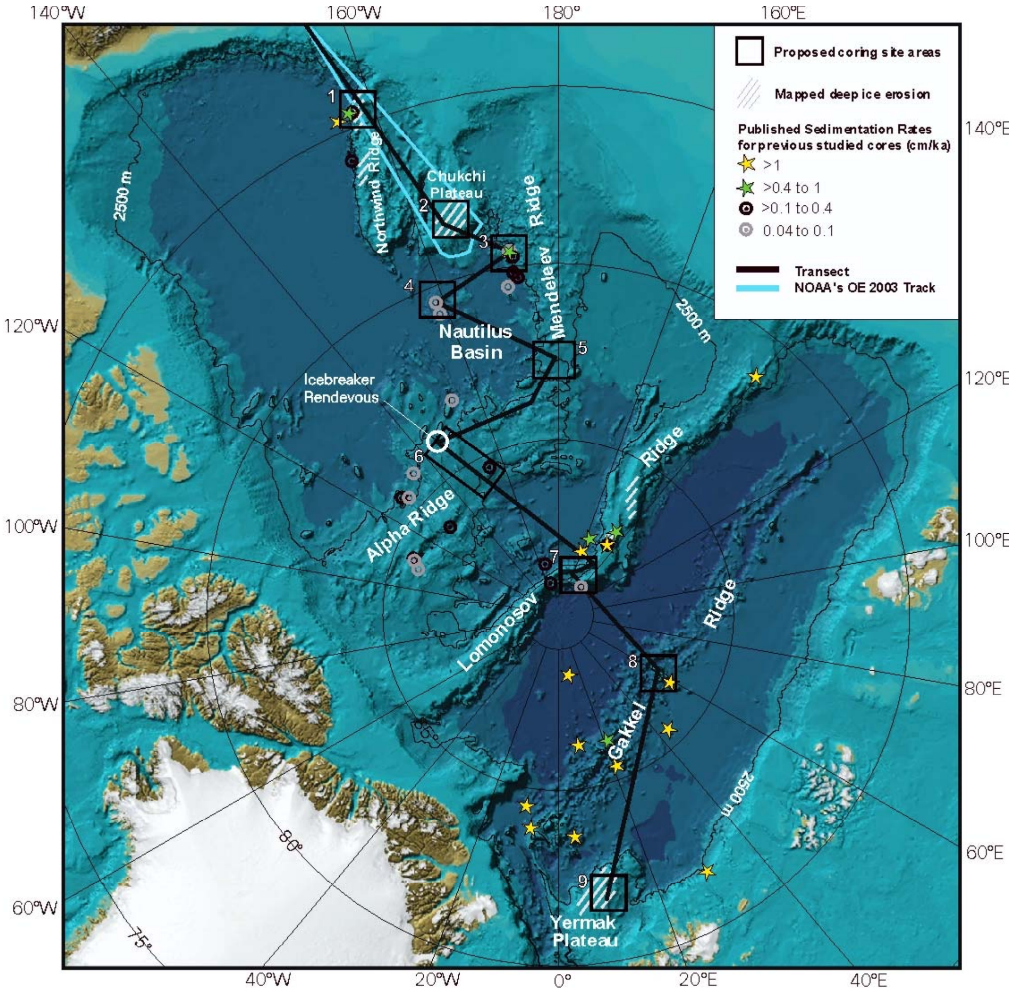


Fig 7.3   Proposed track for a cross-basin marine geophysical and geological cruise on the US Coast Guard icebreaker Healy for the Summer of 2005.

Aurora Borealis – A European research platform

European nations have a particular interest in understanding the Arctic environment with its potential for change because highly industrialized countries extend into high northern latitudes and Europe is under the steady influence of and in exchange with the Arctic environment. In addition considerable living and non-living resources are found in the Arctic Ocean, its deep-sea basins and their adjacent continental margins. Modern research vessels capable of penetrating into the central Arctic are few. A new state-of-the-art research icebreaker is therefore required to fulfil the needs of European polar research and to document multi-national European presence in the Arctic. This new icebreaker would be conceived as an optimized science platform from the keel up and will allow long, international and interdisciplinary expeditions into the central Arctic Ocean during all seasons of the year (Figs. 7.4 and 7.5).

In spite of the critical role of the Arctic Ocean in climate evolution, it is the only sub-basin of the world's oceans that has not been sampled by the drill ships of the Deep-Sea Drilling Project (DSDP) or the Ocean Drilling Program (ODP). Its long-term environmental history and tectonic structure are therefore poorly known. This lack of data represents one of the largest gaps of information in modern Earth Science, also relevant for the field of hydrocarbon exploration.

Therefore, the new research icebreaker AURORA BOREALIS should be equipped with drilling facilities to fulfill the needs of the IODP (Integrated Ocean Drilling Program, starting in 2003) for an "Alternate Platform" to drill in deep, permanently ice-covered ocean basins. The drilling equipment will only be used during the summer months and should be removable, potentially to be used and adapted to ICDP-projects. The icebreaker must also be powerful enough to keep station against the drifting sea-ice cover and will have to be equipped with dynamic positioning.

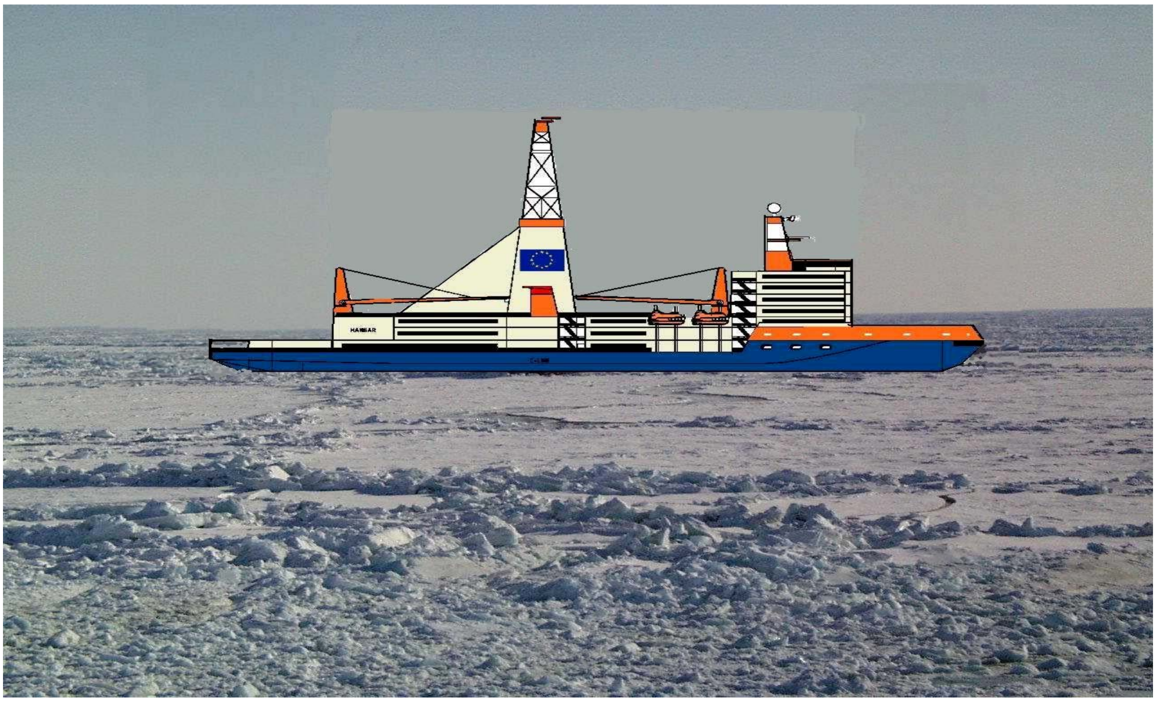


Fig. 7.4 Conceptual model of *AURORA BOREALIS in the Arctic Ocean*

AURORA BOREALIS will be a novel research icebreaker with no national or international competitor because of its drilling capability, its sophisticated modularized mobile laboratory systems allowing mission-specific laboratories, its moon pools for drilling and for the deployment of remotely operated vehicles (ROV) and autonomous underwater vehicles (AUV) for sub-ice surveys, its propulsion and dynamic positioning systems, and its capability for also investigating the high latitude ice-covered deep-sea basins during the more unfavorable seasons of the year.

An efficient use of the new research icebreaker requires the formation of a consortium of European countries and their polar research institutions. The construction of AURORA BOREALIS as a joint European research icebreaker would result in a considerable commitment of the participating nations to co-ordinate and expand their polar research programs in order to operate this expensive ship continuously and with the necessary efficiency. If AURORA BOREALIS is eventually established as a European research icebreaker for the Arctic, European polar research will be strengthened; Europe will contribute to meet the Arctic drilling challenge within IODP and retain its top position in Arctic research. However, in a long-term perspective the AURORA BOREALIS could also be used to address Antarctic research targets, both in its mode as a regular research vessel as well as a polar drill ship.

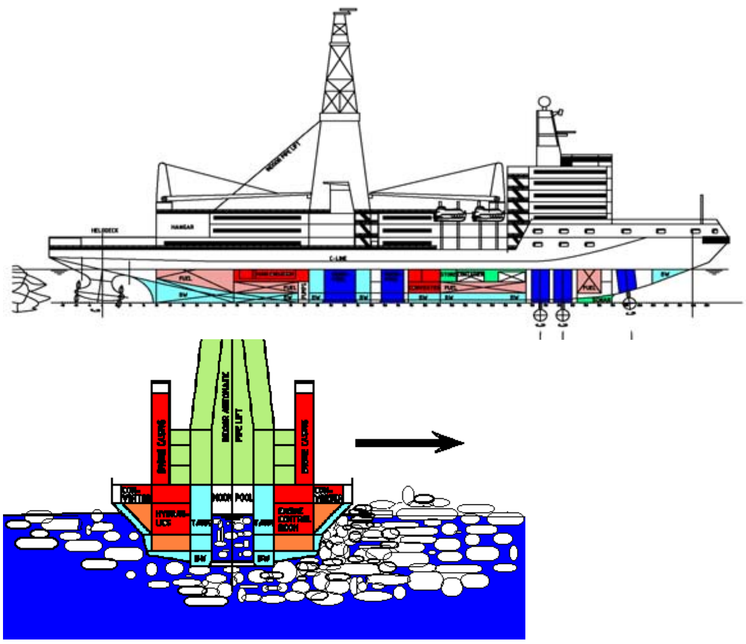


Fig. 7.5 AURORA BOREALIS Research Icebreaker Conceptual Design by HSVA

The principle questions that need to be addressed at a European Scale are:

- Should Europe have a coordinated polar research program in the Arctic (as well as in the Antarctic)?
- Should Europe have tools allowing us to do research in the most extreme environments and during the most extreme seasons?
- Is the time ripe for a large-scale international, interdisciplinary effort in the central Arctic?
- Is the topic of Arctic deep-sea drilling important enough to warrant the large-scale effort to establish a decadal drilling program (which also means large expenses for preparative work to permit to define drill sites)?

The AURORA BOREALIS project has been considered only from a European perspective because IODP expects the European IODP membership to contribute alternative drilling platforms and because we feel that the European participation in IODP warrants lead agency status. However, as the interest in the Arctic grows, one could imagine other potential contributors such as USA, Canada, Japan and China to cover part of the expenses. A design study is underway.

8. The interim Industry Liaison Panel (iILP)

Investigations of the tectonic and paleoenvironmental evolution of the Arctic Ocean by scientific drilling will be of considerable interest to the petroleum industry. The Industry Liaison Panel within the IODP (iILP) serves to promote synergies between the scientific community and industry.

A goal of iILP is to achieve 5 industry-linked proposals or proposals with significant industry input in IODP, either with highly-ranked status or in a schedule phase within 5 years. To achieve this the panel will maintain a short list of the most relevant proposals for industry, and proactively offer advice in improving them/adding industry-related objectives. The panel will further strive to increase industry support for IODP, for instance including representatives on DPG's.

The current iILP action plan include review proposals submitted to IODP for interest to industry and:

- identify data, analyses, etc that could apply
- suggest enhancements and advice for proposals
- identify areas of interest for joint industry/academic studies and coordination
- identify topics on list of industry interests
- conduct workshops for planning of new proposals
- make new proposals
- promote IODP and its benefits to industry
- liaise between industry and academia on IODP issues

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10. Contributors

The present report was compiled and edited by Yngve Kristoffersen and Naja Mikkelsen based on contributions, collective arctic experience and visions for the future expressed by more than fifty scientists from 8 European countries, Canada and the United States that attended a workshop under the Joint European Ocean Drilling Initiative, 13-14 January 2003 in Copenhagen.

Main written contributions:

Arctic Climate Evolution:	Hugh Jenkyns, University of Oxford, UK
	Eystein Jansen, University of Bergen, Norway
Sea ice concentrations and variability:	Leif Toudal, Denmark Technical University, Denmark
Inventory of seismic reflection data:	Arthur Grantz, US Geological Survey, USA
	Wilfried Jokat, AWI, Germany
	Bernard Coakley, Univ. of Alaska, USA
	Yngve Kristoffersen, University of Bergen, Norway
Seismic refraction data:	H. Ruth Jackson, Bedford Institute, Halifax, Canada
Magnetic data:	VNIIO-NRL-GRDF (Glebovsky et al. (2000)
Free-Air gravity data:	http://www.nima.mil/GandG/agp/
Sediment cores:	Arthur Grantz, USGS, US
Strategies for site surveys:	Arthur Grantz, USGS, US
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Alpha-Mendeleev Ridge:	Wilfried Jokat, AWI, Germany
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Chuckchi Plateau - Northwind Ridge:	Arthur Grantz, USGS, US
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Yermak- and Morris Jesup Plateaus:	Yngve Kristoffersen, University of Bergen, Norway
Shelf and upper slope Laptev Sea, East Siberian Sea:	Yngve Kristoffersen, University of Bergen, Norway
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Shelf and upper slope Lincoln Sea, North Greenland margin, Fram Strait, Northern Barents Sea:	Yngve Kristoffersen, University of Bergen, Norway
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USA:	Bernard Coakley, Univ. of Alaska, USA
The Interim Industry Liaison Panel:	John Hogg, EnCana Cooperation, Canada

11. Workshop program

<u>Monday, January 13, 2003</u>

Introduction and Key Note Lectures
Chair: Jørn Thiede

09.30 – 11.00	Registration and coffee
11.00 – 11.15	Welcome (N. Mikkelsen / J. Thiede)
11.15 – 12.15	Overview of Arctic Ocean Tectonic Evolution:
	- Amerasia Basin (A. Grantz)
	- Eurasia Basin (W. Jokat / Y. Kristoffersen)
12.15 – 12.30	Coffee break
12.30 – 13.30	Overview of Paleoceanography and Paleoclimate:
	- Mesozoic Developments (H. Jenkyns)
	- Cenozoic Developments (J. Thiede and J. Backman)
13.30 – 14.30	Lunch

Site Survey Matters
Chair: Naja Mikkelsen

14.30 - 15.00	Ice motion and variability (L. Toudal Petersen)
15.00 – 16.45	Site survey matters:
	- Site survey requirements and permissions (S. Neben)
	- Reality of site surveys under Arctic conditions:
	General considerations (A. Grantz)
	From ship (Y. Kristoffersen)
	- Safety requirements (M. Hovland)
	- IODP Industry Liaison Panel issues (J. Hogg)
	Discussion
16.45 – 17.00	Coffee break

Logistics and Technologies
Chair: Jan Backman

17.00 – 18.00	Logistics and new technologies:
	- Lomonsov Ridge Project (A. Karlqvist)
	- Aurora borealis (P. Egerton)
	- Geophysical data collected from submarines (B. Coakley)
	- Marine geophysics (Y. Kristoffersen)
	- Discussion
18.00 – 18.20	Overview of seismic data in the Arctic (W. Jokat/ R. Jackson)
18.20 – 18.30	Group Photo
18.30 – 19.30	Ice breaker party
20.00 -	Dinner

Tuesday, January 14, 2003

Regional Considerations

Chair: Yngve Kristoffersen

8.30 – 8.45	**Plenum**
	Setting the stage for the working groups (J. Thiede)
8.45 – 11.00	**Regional working Groups**
	- Alpha - Mendeleev Ridge
	- Lomonosov - Gakkel Ridge
	- Chukchi Plateau - Northwind Ridge
	- Yermak - Morris Jesup Plateau
	- Shelf and upper slopes (east) Laptev Sea, East Siberian Sea, Canadian/ Alaska Arctic Margins
	- Shelf and upper slopes (west) Fram Strait, Lincoln Sea, East Greenland margin, Northern Barents Sea, Bearing Landbridge
11.00 – 11.15	Coffee break
11.15 – 12.30	**Plenum**
	Presentation by working groups
12.30 – 13.30	Lunch

Future activities in the Arctic Ocean

Chair: Wilfried Jokat

Current / planned expeditions in the Arctic Ocean:

13.30	- Canada (K. Moran)
	- U.S.A. (K. Moran/L. Mayer)
	- Russia (N. Bogdanov)
	- Denmark / Greenland (C. Marcussen)
	- Sweden (D. Hedberg)
	- Germany (W. Jokat)
	Discussion
14.30 – 15.30	- Discussion of priorities
	- Strategies for site survey investigations
15.30 – 15.45	Coffee break
15.45 – 16.00	Wrap-up

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Fig 12.1 Group Photo of the workshop participants (Photo: J. Lautrup, GEUS)