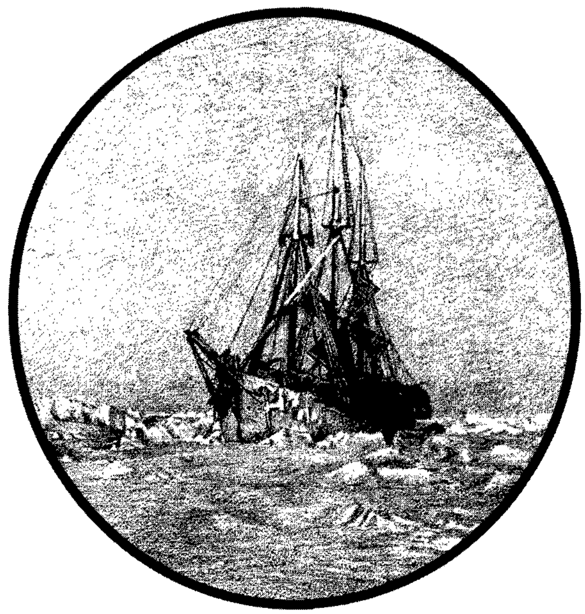
NANSEN ARCTIC DRILLING

IMPLEMENTATION PLAN

FRONT COVER:

The research vessel *Polarstern* in the central Arctic Ocean on her way to the North Pole during the ARCTIC '91 expedition. Photo courtesy of H. Kassens.

AN IMPLEMENTATION PLAN FOR THE NANSEN ARCTIC DRILLING PROGRAM



MAY 1997

A scientific drilling strategy to investigate the environmental dynamics and lithospheric evolution of the Arctic Ocean. Commemorating the pioneering work of Arctic explorer Fridtjof Nansen during the *Fram* expedition, 1893-1896.

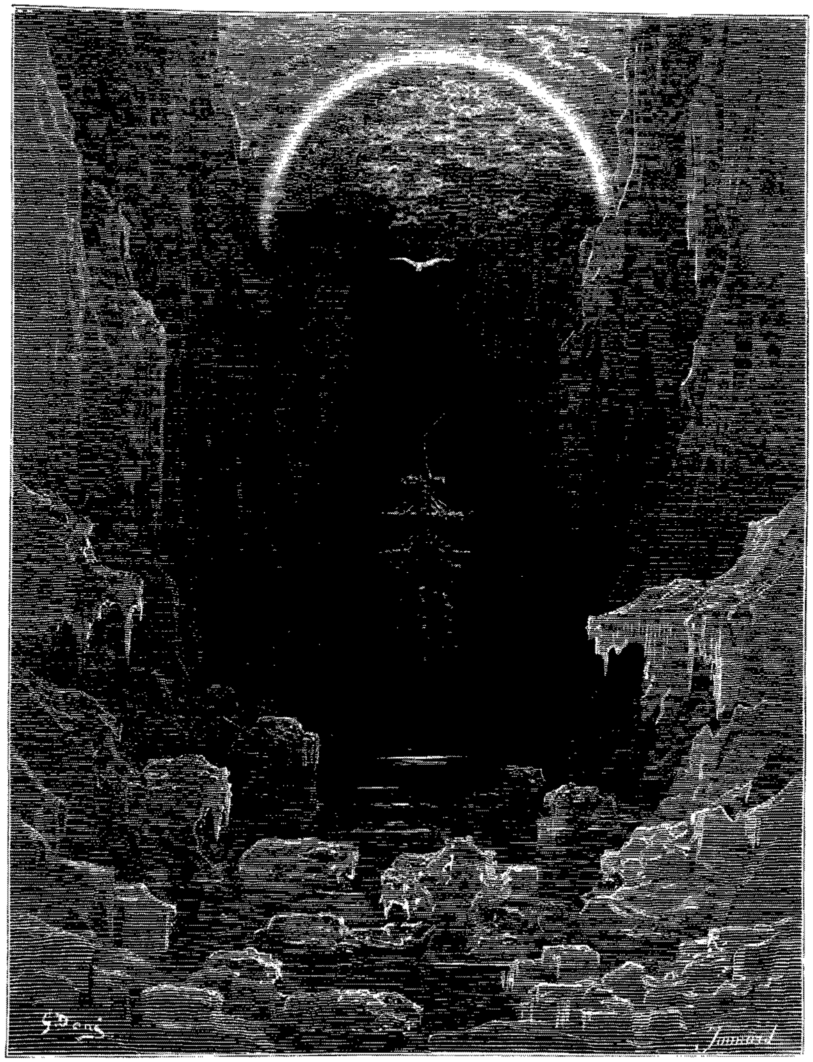


Illustration by G. Dore for "The Rime of the Ancient Mariner" by S.T. Coleridge.

THE ICE WAS HERE, THE ICE WAS WAS THERE,
THE ICE WAS ALL AROUND.

EXECUTIVE SUMMARY

The Nansen Arctic Drilling Program (NAD) is an international group of scientists and institutions working together to develop a coordinated research initiative to address the geologic and paleoclimatic history of the Arctic Ocean. NAD has two major research themes. The first is the role of the Arctic in global environmental change on both short (decadal) and long (millenial) time scales. The second is lithospheric evolution, with targets including many of the unstudied features of the Arctic basin. The two themes are linked because structural features affect oceanic circulation, especially through the gateways connecting the Arctic Ocean to the world ocean.

A number of global models (climate, plate tectonic, and ocean circulation) are hampered by the lack of information from the Arctic Ocean. Long sediment and rock cores from the Arctic seafloor will reveal the role of the Arctic in Earth's history. Attaining this goal requires teamwork. This document, the *NAD Implementation Plan*, outlines a staged program consisting of projects tied to specific locations to address these themes. The program concentrates first on the Quaternary sedimentary record which is the most logistically feasible goal. The second stage of the program, as NAD technologies and experience improve, will delve deeper into the Arctic to obtain upper Mesozoic and Cenozoic sediments and rocks which record paleoenvironmental, tectonic, and lithospheric evolution.

Drilling strategies to achieve NAD's scientific goals focus on continental shelves (e.g., the Laptev Sea) and on topographic highs (e.g., the Lomonosov Ridge). The shelf sites will yield sedimentary sequences for high-resolution studies of the Quaternary. To study the long-term paleoceanography of the central Arctic, an icebreaker-based Giant Piston Coring (GPC) program and an Arctic-oriented program similar to the International Marine Global Past Changes Study (IMAGES) are recommended first, to be followed by a drilling program. Where appropriate (e.g., eroded seafloors), offset drilling is proposed as a means to extend the paleorecords obtained with piston cores.

In this endeavor, NAD will benefit greatly by continued close association with the international Ocean Drilling Program (ODP) which has recovered deep cores from more accessible portions of the world's oceans. An active and operational program will require funding at a level estimated to be between 3 and 4 million U.S. dollars per year. Funding may be based on 'contribution units', on a project basis or some combination thereof.

CONTENTS

Figure 1: Map of the Arctic Ocean.

INTRODUCTION

WHAT IS NAD?

The Nansen Arctic Drilling Program (NAD) is an international coalition of scientists and research institutions seeking to explore the geologic history and structure of the Earth beneath the Arctic Ocean via scientific ocean drilling. A small group of scientists and government officials first met in 1989 at the International Geological Congress. Discussion beyond this meeting led to the establishment of NAD, which is named after the visionary Norwegian scientist and humanitarian, Fridtjof Nansen, who studied the Arctic over a century ago during the famous *Fram* expedition across the central Arctic. NAD is led by an Executive Committee composed of scientists from institutions actively involved in Arctic research. Working with the Executive Committee is a Science Committee, comprised of Arctic researchers, and a Technical Committee, comprised of scientists and engineers with Arctic expertise.

Nations with scientists participating in NAD include Canada, Denmark, Finland, France, Germany, Iceland, Japan, Norway, The Netherlands, Russia, Sweden, the United Kingdom, and the U.S.A. The involvement of additional scientists, organizations, and nations is encouraged. NAD maintains a formal secretariat at Joint Oceanographic Institutions in Washington, D.C. as a focus for program communications. The NAD Secretariat is funded by contributions from government agencies and scientific institutions. Its functions include producing a semiannual newsletter, *The Nansen Icebreaker*; maintaining an international mailing list with over 900 scientists; and distributing documents such as the *NAD Science Plan* (*Polarforschung*, 1992, 61, 1-102) and a report on available Russian technology for Arctic drilling.

A NAD Workshop gathered geoscientists and engineers in St. Petersburg, Russia from October 14 to 15, 1996 to develop a stepwise strategy for achieving scientific drilling in the Arctic Ocean. The workshop, hosted by the Russian Arctic and Antarctic Research Institute (AARI), was partially supported by the U.S. National Science Foundation (NSF). The sixty-eight workshop participants represented most of the Arctic nations (Appendix I). Based on workshop discussions, the *NAD Science Plan*, and input from scientists unable to attend the workshop, this document—the *NAD Implementation Plan*—was created. Many thanks are due to workshop hosts and attendees, supportive government agencies, and all other contributing scientists.

BACKGROUND

The international Ocean Drilling Program (ODP) has sampled all of the world's oceans except the Arctic and nearshore areas of Antarctica. Subsequently, the ODP core collection has proven invaluable in identifying paleoenvironmental trends and oceanographic processes. Likewise, Arctic marine cores would provide data revealing regional climate variations and constraining the tectonic evolution of the Arctic's enigmatic Amerasia Basin. The U.S. National Academy of Science, recognizing the value of such cores, endorsed Arctic scientific drilling in their 1991 report "Opportunities and Priorities in Arctic Geoscience."

The gap in scientific drilling, and our geologic knowledge of the Arctic, is the result of several factors. First, existing scientific drilling platforms are not ice capable and, second, site survey techniques used to identify drilling sites in icebound seas have only recently become available. NAD is seeking creative solutions to the first problem by exploring a range of platform options which are suitable for Arctic conditions. The second problem, of obtaining seismic data in an ice-covered ocean, has been solved by the inception of the Submarine Ice Experiment (SCICEX) which has access to the Arctic ocean by working beneath the ice.

Based on our current knowledge from terrestrial data and fragmentary marine data, the Arctic's climate evolved stepwise in response to global changes associated with Cenozoic cooling. There is evidence for regional warmth and climatic connections across North America and Asia's Ural Mountain area during the Cretaceous. A stable system existed with an isolated, perhaps, but fully marine Arctic basin. A regional transition in the Paleogene/Neogene (40 to 15 Ma) marks the beginning of global cooling. At this time, glacial ice was restricted to Antarctica. The timing and duration of the transition are unknown. Existing ODP cores provide clues. The oldest ice-rafted debris (IRD) on the Voring Plateau, in the Norwegian Sea, is dated at about 11 Ma. This debris may mark the first arrival of Northern Hemisphere glaciers at the sea. The most important climatic transitions occurred in the Miocene and Pliocene, especially at 2.6 Ma when synchronous bipolar climatic records begin for reasons which are not understood. The most recent stage of a modern bipolar glacial Earth, with approximate 100 k.y. cycles and over 100 m eustatic sea-level variation, began during the Pleistocene about 0.9 Ma. Documenting the paleoenvironmental history of Earth is necessary for scientifically sound understanding of Pleistocene glaciations. Arctic terrestrial data contain large gaps so long cores from the seafloor are necessary to complete this story.

The Arctic Ocean sediments may also hold clues to the individual histories of the circum-Arctic ice sheets. In places, such as Greenland, old ice sheets remain (from before 130 ka); while in other locales, such as Baffin Island, Novaya Zemlya, ice sheets have formed more recently (since 10 ka). Glacial ice sheets on the Eurasian mainland vanished completely after the last glacial maximum. Rapid climate change occurred across the Arctic within the past 10 k.y. Changes appear to have been non-synchronous in the region. Even more recently, during the last 50 years, glacier termini have rapidly retreated in parts of the Arctic and sub-Arctic while in other areas there has been little change or even a re-advance (as in Western Scandinavia).

The Eurasia Basin and the Amerasia Basin are the Arctic Ocean's two primary deep basins. The Cenozoic history of the Eurasia Basin, which includes the Nansen and Amundsen/Fram sub-basins, is relatively well understood. Magnetic anomalies indicate that the Eurasian and North American plates began rifting at the Arctic Mid-Ocean Ridge about 60 Ma. This rifting separated the Lomonosov Ridge from the Barents Sea continental shelf. The Amerasia Basin, which includes the Canada and Makarov sub-basins, is older than the Eurasia Basin and rifting there dates from the late Mesozoic with possible late Cenozoic extension. Reconstructing the Amerasia Basin is difficult and a number of competing hypotheses exist. The Alpha-Mendeleyev Ridge, a feature on the scale of the Alps, is of unknown origin but a key to any reconstruction model. Subsequently, samples are required to constrain and further develop the geologic hypotheses.

SCIENTIFIC THEMES

NAD has two general scientific themes. The first is environmental dynamics which includes the climatic and paleoceanographic history of the Arctic region, and the second is the lithospheric evolution of the Arctic basin. Specific objectives for the first NAD theme call for understanding: decadal- to millennial-scale climate variability which can be related to other records of global climate change; the evolution of the Arctic sea-ice cover, permafrost, and water masses; the history of circum-Arctic ice sheets; the evolution and adaptation of the biota to shifts in environment; the forcing processes which cause the rapid climatic shifts as recorded in ice cores; and the relationship among the marine, terrestrial, and ice-core paleoenvironmental records.

Beginning in the late Neogene and during the Quaternary, the world ocean and atmosphere mutually adjusted to their present condition. A global "conveyor belt" of oceanic circulation developed, driven by salt import and surface cooling which generated bottom water, and the Arctic Ocean became ice covered. Sea-ice cover is linked to the global climate system through albedo feedback and bottom-water circulation. Environmental coupling between the Arctic and lower latitudes is recognized via the influence of the combined sea-ice/bottom-water system and a glacial-eustatic linkage. The Arctic Ocean is rimmed by the Earth's most extensive continental shelves which are sensitive to sea-level fluctuations. Several very large rivers deliver a massive flux of fresh water. Variation of river flow may influence ice formation and the ocean's retention of solar energy. Therefore, elucidating the history of ice cover in the Arctic and relating it to other paleoclimatic records will help establish the extent of Arctic influence on lower-latitude climate.

Many Arctic ridges and plateaus are unsampled and of unknown composition and origin inspiring NAD's second scientific theme: lithospheric evolution. Until the lithospheric evolution of the Arctic is understood, we can only speculate about the tectonic history of the surrounding continental margins and their resources. Therefore, the high-priority objectives of the second NAD theme include understanding: the rifting processes that created the Lomonosov Ridge; the possible existence of a large igneous province (LIP) of Cretaceous age which includes the Alpha-Mendeleyev Ridge; active, slow-spreading ridge processes represented by the Arctic Mid-Ocean Ridge; and the structural character of the Arctic Ocean's marginal plateaus. The environmental dynamics theme is linked to the lithospheric evolution theme by the oceanic gateways. These gateways, controlled by tectonics (Fram Strait) and sea level (Bering Strait), connect the Arctic to the world ocean impacting oceanic circulation and subsequently climate.

To explore these scientific themes, NAD first proposes to sample high-sedimentation-rate sections on the Arctic continental shelves and slopes to study the last two glacial/interglacial cycles. Longer-range NAD plans include establishing a Giant Piston Core (GPC) program to obtain cores for studying Arctic climate both in the Quaternary and prior to the late Neogene development of glacial conditions in the Northern Hemisphere. This strategy strives to link NAD objectives with funded programs for late Quaternary climate research such as the European Science Foundation's (ESF) Polar North Atlantic Margins Programme (PONAM) and the U.S. NSF's Earth System History Program. Finally, to meet its other scientific goals, NAD plans to obtain long cores recording late Mesozoic to middle Cenozoic paleoceanography as well as basement core material to study the Arctic's lithospheric dynamics and structural evolution.

SCIENCE ISSUES

EXPLORING the Arctic Ocean with a drilling program in order to develop truly global models cuts across scientific disciplines because the Arctic is tectonically and climatically coupled to the surrounding continents and linked to the Pacific and Atlantic oceans. Understanding the causes of past variations in natural processes is accepted as essential to evaluating modern changes. This is especially true in the complex Arctic region where many questions remain regarding environmental dynamics and lithospheric evolution as well as their effect on the global environment.

The Arctic basin receives three significant chemical and thermally distinctive inputs: Atlantic, Pacific, and river waters. There are good reasons to believe (sea level change, deglaciation, and opening of the Fram Strait) that these three fluxes and the relative proportions of ice/liquid/vapor have varied dramatically over the last few million years and that the signals caused by these variations are preserved in the seafloor sediments which await our sampling.

Major sedimentary cycles have been identified in North Atlantic deep-sea core records (Milankovitch cycles, Heinrich/Bond events, and Dansgaard/Oeschger events). Investigation at similar resolutions and time scales in the Arctic Ocean may lead to a better understanding of climatic variability and associated processes. To what degree are high- and low-latitude records related? Do Arctic climates lead or lag those of the lower latitudes? Is the Arctic record more sensitive to rapid events than the North Atlantic? Documenting the scale of climatic changes in the Arctic Ocean will also better define the processes and prospects for past and future rapid climatic change. Knowledge of the Arctic's paleoenvironment and the composition of the sedimentary rock sequences are also relevant for natural resource assessments including exploration for hydrocarbons.

The lithospheric evolution or tectonic development of the Arctic basin is intimately linked to the development of the adjacent ocean basins, margins and continents. Understanding the geometry of past and present plate boundaries in the Arctic would complete the model of late Mesozoic and Cenozoic Northern Hemisphere plate motions. Determining the composition and history of the major ridges—Lomonosov, Alpha-Mendeleyev—are crucial to this effort. An understanding of the marginal plateaus—Chukchi, Yermak, and Morris Jessup—is also necessary to complete the picture.

The two major NAD scientific themes outlined above, environmental dynamics and lithospheric evolution, are part of a larger Earth system. This is emphasized in the Arctic where tectonic processes have influenced oceanic circulation and, subsequently, climate, via the opening of Arctic Ocean gateways and the development of major structures such as the Lomonosov Ridge.

ENVIRONMENTAL DYNAMICS

What is the role of the Arctic in global change?

Paleoceanographic data have shown that the Arctic Ocean is linked to the global climatic system. Does the Arctic drive global change? If so, when and how did it attain this role? And in turn, what drives the Arctic? Rapid changes have occurred in the Arctic during episodes of global climatic variation as latitudinal gradients and transfers of mass and heat are altered. However, contemporary spatial and temporal variations in the Arctic are not understood. Long-term studies using the geologic and paleoceanographic records are essential to establishing a history of the temporal variability of Arctic processes since the onset of the cooling and glaciation of the Northern Hemisphere. Potential drilling sites on the continental shelves of the Laptev, Kara and Chukchi seas have been identified to initially address primary scientific issues.

Four major scientific issues can be identified:

1) **Onset and variability of perennial sea-ice cover and its impact on ocean circulation and the heat budget.**
The parameters of sea-ice cover are poorly understood but its influence, which may be dramatic, is manifested through: changes in albedo; water-column stability, and bottom-water formation; ocean/atmosphere heat and evaporative exchange; and bio-productivity and carbon sinks. The issue raises several questions. When did 'perennial' sea-ice cover develop? Were sea ice and continental ice sheets related? Did an open sea (free of sea ice) and lowered sea level assist ice-sheet growth? Did the development of the sea ice amplify polar cooling through restricted ocean heat transfer? To answer such questions, it is time to expand upon the tantalizing data from the short low-resolution Arctic cores currently available, by obtaining high-resolution data and long cores.

2) **Relationship among Northern Hemisphere glacial cycles, global sea level and Arctic Ocean sea-ice cover.**
The continental shelves have not been static. Global sea level which affects shallow shelves is linked to Northern Hemisphere glaciation; and the role of sea ice in controlling precipitation levels requires further definition. The history of sea-level fluctuations, including their magnitude, is valuable for determining the economic and environmental impacts of rising sea level on low-lying oceanic islands and coastal regions. Low sea level also influences Arctic oceanography dramatically by, eliminating the Pacific Ocean's flux into the basin, increasing sediment supply, and perhaps causing basin stagnation.

3) Permafrost and gas hydrate dynamics.
Permafrost and gas hydrate formation and stability play an important role in late Cenozoic and modern environmental change across the Arctic continental margins. Both are susceptible to climatic changes as well as marine regressions and transgressions, ice regime and thermal regime. Permafrost, or its relict, is likely to be found beneath the wide, shallow continental shelves of Eurasia where it might be exploited as an indicator of past climatic conditions. Of global importance, is the potential release of greenhouse gases, primarily methane, as a result of degradation of permafrost and the subsequent escape of underlying gas hydrates.

4) Evolution of polar biota.
Polar marine faunas are less species diverse than tropical faunas, and many polar species have long geologic records. Arctic organisms must be adapted to subfreezing temperatures, the dark polar winter, and a seasonal food supply. These conditions favor life histories which include a winter resting stage and rapid summer growth and breeding. Biotic successions may help unravel Arctic paleoclimatic history by reflecting the environmental changes to which they responded. Of prime importance will be filling the gap in our knowledge of the Arctic's Eocene-Miocene environmental history and its associated biota during a hypothesized time of growing climate instability.

LITHOSPHERIC EVOLUTION

What is the nature of the major structural features of the Arctic Ocean basin and how did they evolve?

During the last several decades what we have learned about the global oceans has given context to what we understand about the continents. The Arctic's Amerasia Basin is the last "holdout" to global plate tectonic evolution. This late Mesozoic ocean is ringed by continents and mountain ranges with their own complicated tectonic histories. Without the context provided by the tectonic history of the Arctic and its sub-basins, continental tectonic provinces remain local abstractions. Major structures in the Arctic Oceanrepresent unique aspects of global lithospheric dynamics. Several specific structures and issues to be considered are:

1) Lomonosov Ridge and lithospheric rheology during the rifting process.
Rifts are associated with thermal weakening of the lithosphere and early tectonic deformation over a zone whose width depends on lithosphere rheology. The localized deformation on the continental side of the pre-Cenozoic continent-ocean

crustal boundary is the predicted consequence of the contrast in lithospheric strength across the boundary. The Lomonosov Ridge may be a sliver of continental crust rifted apart from the Barents Sea shelf by propagation of the Arctic Mid-Ocean Ridge (AMOR) at approximately 60 Ma. Although the long narrow form of the ridge is surprising, Baja California provides an analog. A series of perched half-grabens seem to segment the ridge and may reflect reactivation of preexisting structures parallel to the Barents Sea continental margin. Cretaceous rocks are probably obtainable beneath the eroded Tertiary section which in places is quite thin. These rocks would expand our knowledge of the Mesozoic history of northern Eurasia. The internal structure of the Lomonosov Ridge is being mapped using seismic reflection data collected by the vessels *Polarstern* and *Oden* and using gravity anomaly data from the Submarine Ice Experiment program (SCICEX).

2) **Origin and nature of the Alpha-Mendeleyev Ridge.**
Large igneous provinces (LIPs) are accumulations of mafic rocks formed by processes distinct from those associated with plate movements. At times in the past, particularly during the Cretaceous, the mantle flux associated with the emplacement of LIPs, may have exceeded that associated with the global mid-ocean ridge system. Therefore, LIP emplacement is an important factor in determining global geochemical cycles.

One model suggests that the Alpha-Mendeleyev Ridge, a lithospheric feature stretching across the Arctic Ocean basin, may represent a Cretaceous LIP. The principal data supporting this model come from seismic refraction studies which indicate a crust approximately 40 km thick with a structure similar to that of other oceanic LIPs. Supporting evidence for the emplacement of a LIP in the Arctic during the Cretaceous can also be found in the terrestrial record of continental flood-basalt volcanism observed on Axel Heiberg Island. However, our knowledge of the Alpha-Mendeleyev Ridge remains limited because only a few cores are available. Based on these cores, a continental origin for parts of the Alpha Ridge must be considered. Fragments of alkali basalts were recovered from one dredge haul and metamorphosed continental rock fragments were found in seafloor sediments at another site. It also hypothesized, based on aeromagnetic data, that the Mendeleyev Ridge is a separate feature from Alpha Ridge.

Because of its large size and its importance to meaningful Arctic reconstructions, the Alpha-Mendeleyev Ridge should be sampled by NAD drilling. Information about the ridge is also essential to understanding the evolution of the Canada Basin, the foundation upon which later Cenozoic tectonic changes are imposed. Deep penetration of basement is not feasible at this ridge, but even samples from shallow penetrations would be valuable.

3) **The origin of marginal plateaus: Yermak Plateau and Morris Jessup Rise.**
Geophysical data suggest that the Morris Jessup Rise and the northern section of the Yermak Plateau are an oceanic LIP which once formed an Iceland-like massif. The

formation of the plateaus is probably related to the triple junction that existed north of Greenland in the early Oligocene. When Greenland ceased to move independently relative to North America, rifting separated Morris Jessup Rise and the Yermak Plateau.

4) **Origin and history of the Chukchi Borderland.**
There is a general belief among researchers that the Chukchi Borderland is of continental origin and the Amerasia Basin formed as Arctic Alaska rotated away from Arctic Canada during the Mesozoic. However, there is little geological or geophysical data from either the margins or the Canada Basin which can be used to test this hypothesis. Also, this simplistic model cannot explain either Alpha Ridge or the Chukchi Cap region. A prime target for scientific drilling would be the Chukchi Borderland which is comprised of three north-south trending ridges: Northwind Ridge, the Chukchi Cap and the Arlis Plateau. The USGS collected a series of seismic reflection profiles, as well as cores and dredges, in this region during the 1990s. Samples from the Northwind Ridge included late Paleozoic shallow-water marine carbonates and Mesozoic sediments resembling strata in the Sverdrup sedimentary basin of the Canadian Arctic Islands. Canadian investigators have also identified sites in the Beaufort Sea for which seismic data are available with the breakup unconformity lying about 500 m beneath younger sediments.

ARCTIC OCEAN GATEWAYS

What is the role of Arctic tectonic gateways in global change?

The complex bathymetry of the Arctic Ocean which is the product of regional tectonics has been shown to influence oceanographic circulation. Thus, a descriptive model of bathymetric evolution is necessary to develop a historical appreciation of basinal circulation.

The Arctic Ocean is connected to the world ocean by two major gateways: the deep Fram Strait into the North Atlantic Ocean and the shallow Bering Strait into the North Pacific Ocean. Previously, during the Cretaceous, the Arctic Ocean was connected to the Gulf of Mexico through a North American interior seaway and to the Tethys Sea through western Siberia. The Fram Strait probably opened during the middle to late Miocene, providing the Arctic Ocean's first deep water connection to the world ocean since the Cretaceous. The opening of the Bering Strait is poorly constrained to the middle Pliocene, about 3.5 Ma, and may have been as early as 4 Ma. In general, little is known about the Arctic Ocean gateways existing from the Cretaceous to the Miocene. The paleoceanographic record, especially biotic successions and affinities, will help delineate the existence and timing of these past oceanic connections. Thus, this information will help to determine the impact of regional tectonics on global climate.

The Arctic Ocean gateways are influenced by sea-level change as well as tectonic uplift and lateral motions of the continents. The extent of these connections impacted oceanic circulation which in turn influenced biotic patterns remains to be determined. If climatic effects on biota can be differentiated from tectonic effects, it will be possible to isolate a climatic and/or a tectonic event in the paleoceanographic record. Five issues that need to be addressed are:

1) Pre-Miocene biogeography of the Arctic Ocean, especially the Pacific gateway.
2) Pre-Miocene circulation pattern in the Arctic Ocean.
3) The impact of Fram Strait's opening on global climate.
4) Arctic gateway impacts on evolution and migration of biota.
5) Quaternary sea-level influences on the flux of Pacific water through the Bering Strait.

STRATEGIC DEVELOPMENT

TO ACHIEVE the scientific objectives discussed in the preceding section, the Nansen Arctic Drilling Program is focusing on the Arctic Ocean's continental shelves, slopes, and topographic highs. The deep basins are not feasible drilling sites at this time because of the combined challenges of thick turbidite accumulations, sea-ice drift, and expensive logistics.

The NAD strategy calls for progressing in a step-by-step manner and optimizing scientific returns from the outset. Initially, continental shelves and the ridges will be simultaneously targeted because each has advantages. The strongest signals of open ocean productivity will be found on some of the highs, whereas the shelf and slope sequences are most sensitive to sea-level changes and variations in fluvial discharges.

NAD drilling tactics are also based on the tradeoffs between the depth of penetration in the section and the type of bottom-hole sediments. Expanded and condensed sections each have distinctive uses. Shelf sequences tend to be expanded with high sedimentation rates. When well chosen, they may offer high-resolution, short-term sedimentary records for key time intervals.

Condensed sedimentary sections from basinal ridges may be more complete and cover longer time intervals for the same depth of penetration as a shelf section. On topographic highs or ridges, low sedimentation rates make the entire Cenozoic—and at least part of the Cretaceous—accessible to relatively shallow and therefore inexpensive drill cores. These sediments are likely to be continuous and datable by both microfossils and paleomagnetic reversal stratigraphy.

For Phase 1 of its program, NAD proposes drilling sites on the Arctic continental margins and plateaus. The initial drilling target will be the Laptev Sea continental shelf which contains an expanded Pliocene to Holocene sedimentary sequence in an accessible location. Simultaneously, during Phase 1, a Giant Piston Core program (organized like an Arctic IMAGES-type program) is recommended for the ridges to initiate study of the long-term history of the central Arctic Ocean paleoenvironment. For Phase 2, a full-scale drilling program is proposed with sites on topographic highs in the central Arctic. Here, to extend the paleorecords and to reach basement, an offset drilling strategy is recommended.

All the drilling objectives discussed in the following section have high scientific merit. However, their sampling order may be in response to external catalysts such as vessels of opportunity, co-funding with other projects, or commercial ventures.

DRILLING TARGETS

ARCTIC CONTINENTAL MARGIN TARGETS

The circumpolar continental margins and their adjacent plateaus present opportunities for studying specific aspects of the Arctic's paleoenvironmental evolution. Besides containing a Cenozoic sedimentary record, these regions will also provide information on lithospheric evolution, primarily volcanism and possible fragmentation of the margins. Sediments from these areas record the following processes:

- decadal- to millenial-scale Arctic climate changes;
- fluxes of sediment, water and ice to and across the Arctic shelves;
- sea-level fluctuations and their effects;
- the glacial history of ice sheets and permafrost; and
- biotic evolution in the neritic zone.

These processes can be most effectively reconstructed using stratigraphic sections from areas with uninterrupted sediment accumulation throughout the Cenozoic. Where feasible, correlation with terrestrial stratigraphic sequences is desirable. NAD has identified drilling targets in the following areas: Laptev Sea, Barents and Kara seas, Yermak Plateau and Morris Jessup Rise, East Siberian and Chukchi seas, Chukchi Borderland, and Beaufort Sea. General descriptions, scientific objectives, available data, and drilling recommendations for these regions follow.

Laptev Sea

The Laptev Sea shelf is occupied by a Cenozoic-age rift system which extends from an active spreading center in the Eurasia Basin onto the continental margin. The spreading center is the Arctic Mid-Ocean Ridge (AMOR) which is also known as the Gakkel Ridge. It is one of a few global examples of the intersection of an active spreading center with a passive continental margin. The rift system consists of a central East Laptev Uplift and smaller horsts flanked by deep grabens. The total sediment thickness varies between 1 and 3 km on the uplifts and 5 and 8 km (or more) in the rifts.

Objectives
The primary goal of drilling in the Laptev Sea is to recover an upper Cenozoic section, as complete as possible and spanning approximately 4 million years from the Pliocene to Holocene, in order to obtain the best record possible of climatic oscillations. Sediments recording the last several hundred thousand years will receive particular attention.

Available data
Our current knowledge of the Laptev Sea continental margin is based on adjacent onshore geology and offshore multichannel seismic reflection data, collected primarily by Russian investigators over the past two decades and including recent German data. Drill sites (Appendix II) have been initially identified on the eastern part of the Laptev Sea shelf, where a detailed seismic stratigraphy has been developed. These data show that

the Bel'kov-Svyatoi Nos Rift is filled with upper Cenozoic sediments deposited at a very high rate which ranged between 0.4 and 0.5 m/ky for the last 8 thousand years.

The proposed drill sites are located within areas of degraded permafrost, as modeled from the present estimate of cryolithozone structure. Should relict permafrost be present, drilling will provide valuable data on its dynamic state. Year-round weather data and long-term satellite observations provide accurate information on sea-ice distribution. The southern edge of the Arctic drifting ice cover is found between 76°N and 80°N. In winter and spring, from November to June, the main part of the Laptev Sea is covered by shorefast ice. Shallow water depths (less than 50 m) prevent strong currents and significant ice displacements on this part of the continental shelf.

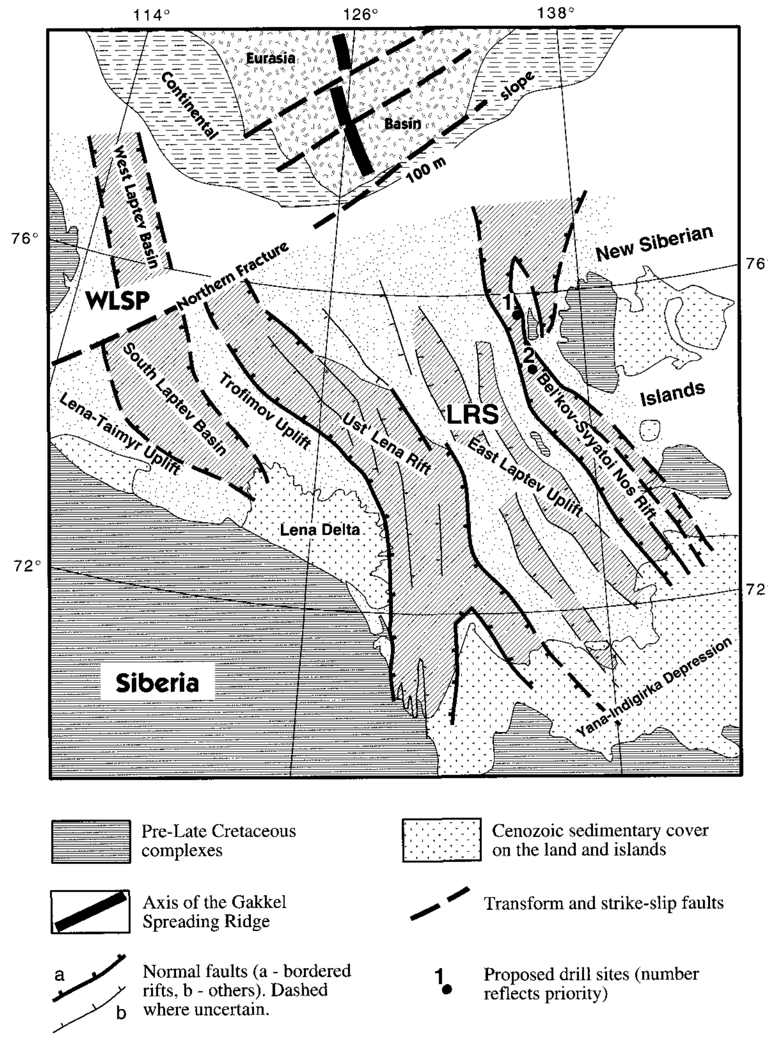


Figure 2. Proposed Laptev Sea drill sites. "LRS" represents the Laptev Rift System and "WLSP" represents the West Laptev Structural Province. Figure courtesy of B. Kim and S. Drachev.

Recommendations

It is envisioned that in 1997, a site selection meeting will be held to bring together all existing data, finalize site selection, and determine where additional site surveys are needed. In 1998, additional site surveys will be conducted and the data processed and interpreted. The target date for drilling is 1999. Scientific drilling in the Laptev Sea should be carried out by a moored vessel during the summer or a light drill rig operation from the shorefast ice during the spring.

Barents and Kara Seas

The Barents and Kara seas occupy the wide continental shelf north of Eurasia. The discharge of the Ob' and Yenisey rivers into the Kara Sea represents approximately 40% of the Arctic Ocean's riverine input. These river systems drain much of Eurasia and are affected by changes in climate from the steps of the Himalayan Mountains to the Arctic perimeter. Numerous sedimentary basins, within the Kara Sea and at its northern edge where troughs empty into the deep Eurasia Basin, should record changes in location and volume of freshwater input from the Ob' and Yenisey rivers, as well as the influx of Atlantic-derived water, and the movements of large Pleistocene ice sheets. Sedimentary sequences from the Barents and Kara shelf seas and the adjacent continental margin contain a rich history of climatic change. These largely untapped archives record fundamental changes in the hydrologic and ice balance in the Northern Hemisphere.

Objectives

The general purpose of drilling in the Barents and Kara seas is to gain insight on climatic change. Specific objectives are to determine the interaction among continental shelf glaciation, Eurasian river discharge, global sea-level changes, and North Atlantic thermohaline circulation into and along the margin of the Arctic's deep basins.

Available data

Seismic reflection data, boreholes, and coastal excavations indicate that Quaternary deposits in the Kara Sea are up to 200 m thick, although their stratigraphic continuity and age are not well understood. Thick lenses (tens of meters) of prodeltaic sediments have been identified up to 78°N, presumably marking the past extensions of the Ob' and Yenisey rivers. However, many sedimentary sequences in the Kara Sea have been truncated or disrupted by glaciotectonism and the development of subaerial permafrost and its subsequent melting. Continuous—and probably high-resolution—Holocene sequences (up to 15 m thick) occur near the entrances of the Ob' and Yenisey estuaries and in certain basins of the southern Kara Sea.

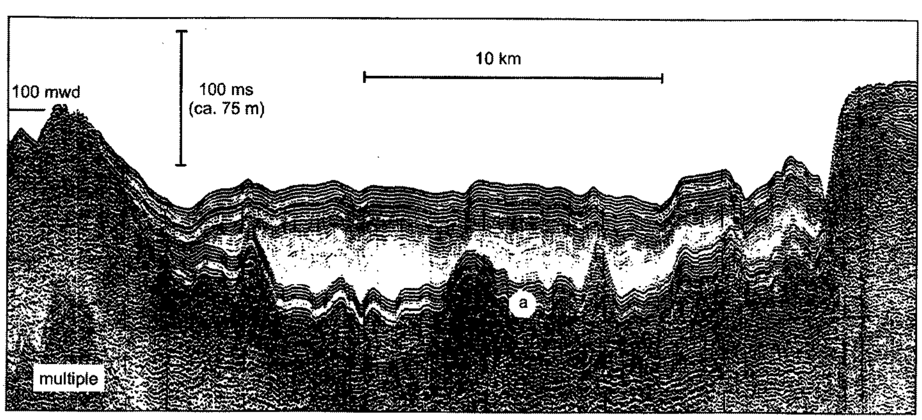


Figure 3: A sparker record from the Kara Sea south of the Voronin Trough. A 50 m thick accumulation of probable prodeltaic sediments overlies a high-relief surface (a), which was presumably modified by glacial activity. Data from the Marine Arctic Geological Expedition (MAGE), Murmansk, Russia. Figure courtesy of L. Polyak.

Expanded sequences of Quaternary sediments are expected to be found at the northern margin of the Barents and Kara Sea shelf in the fans of the Franz Victoria, Saint Anna and Voronin troughs, that empty from the shelf into the Eurasia Basin. The sedimentary sequences in these trough fans may record multiple incursions of voluminous ice sheets onto the continental shelf during the Pleistocene, as would be indicated by diamictons and debris-flow sequences. In turn, progradation of the Ob' and Yenisey rivers should be identifiable by using sedimentological characteristics and geochemical tracers. A wealth of seismic and acoustic survey data is available at a variety of Russian institutions and should be assimilated to focus future site surveys.

Recommendation
Much of the desired stratigraphic record can be obtained by piston coring and shallow drilling. Therefore, once specific sites are defined by site surveys, shallow drilling in selected sedimentary basins in the Kara Sea should be conducted as a first drilling phase in this region. The second drilling phase should target the fans of the Saint Anna and Voronin troughs.

Yermak Plateau and Morris Jessup Rise

The Yermak Plateau, north of Svalbard and the Fram Strait, is a prime location for paleoceanographic studies because of rapid Neogene sedimentation rates. The Morris Jessup Rise, located north of Greenland, is a marginal plateau like the Yermak Plateau. Sediments from these features contain a record of Arctic and Atlantic ocean exchange through the Fram Strait.

Objectives
The Yermak Plateau and the Morris Jessup Rise are ideally situated to study the surface and deep water-mass exchange through a major Arctic gateway, the Fram Strait, and the oceanographic effects of the onset of Northern Hemisphere glaciation. Sampling these sediments is crucial for understanding the influence of Fram Strait on the history of ocean circulation in the Northern Hemisphere. Specific scientific objectives for drilling in this region include determining the timing of the first outflow of Arctic Ocean water to the Atlantic, the affect of the subsidence history of the Yermak Plateau on water mass exchange, and the history of IRD sedimentation in the Arctic.

The ODP Ocean History Panel ranked drilling on the northern Yermak Plateau as a very high priority for ODP Leg 151. During the leg, excessive ice in the region confined drilling to the southern portion of the plateau. This was an excellent area for Pleistocene paleoceanography but lacked evidence for the onset of glaciation and pre-glacial oceanic circulation.

A secondary objective of drilling on both the northern Yermak Plateau and the Morris Jessup Rise is to identify the age and nature of its basement. Drilling would test the hypotheses of an igneous origin for the plateaus as related to a possible extension of the North Atlantic basaltic province which includes Iceland. The continental shelf of northeast Greenland also has geologic relevance because prior to the opening of the Fram Strait the Yermak Plateau was adjacent to it.

Available data

For the Yermak Plateau, ODP site survey data are available, as are a wealth of conventional multichannel data and some high-resolution seismic lines. In contrast, only very limited geophysical data are presently available for the Morris Jessup Rise and the northeast Greenland shelf.

Recommendation

The site YERM-1, at 81°05.5'N 7°E, is recommended for drilling. This proposed site is mature from a site-survey standpoint because it has already been approved by the ODP Site Survey Panel and by Norwegian authorities for the *JOIDES Resolution* to drill. The site requires drilling in a water depth of about 900 m and penetrating 680 m with modest ice thickness conditions. Therefore, a coring rig mounted on an icebreaker such as *Oden, Polarstern, Kapitan Dranitsyn,* or on a geotechnical drillship such as the *Bucentaur* would be well suited for this site. The combination of site-survey readiness, high scientific priority, modest ice cover, and proximity to ports makes this site ideal for the next deployment of an icebreaker-mounted drill rig. Site survey and additional data are needed to continue evaluating the suitability of Morris Jessup Rise and the northeast Greenland shelf for drilling.

East Siberian and Chukchi Seas

The East Siberian and Chukchi seas occupy the very broad continental shelf of the northeastern Asia. The geological and environmental history of this region is closely connected to evolution of the Amerasia deep-water basin, which is the oldest part of the Arctic Ocean. Moreover, it is uncertain whether or not it is a passive or sheared continental margin or some combination thereof.

Objectives

The primary purpose to drill these continental shelves is to establish the region's environmental history and its links to the evolution of the Amerasia Basin. Pliocene and Pleistocene sea level change had dramatic impacts on the region's shallow seas and circulation through the Bering Strait. Until further geophysical data from the East Siberia and Chukchi seas are available, more specific objectives cannot be defined.

Available data

Limited multichannel seismic reflection profiles for the East Siberian and Chukchi seas exist. Most of these profiles are owned by private industry and are currently inaccessible to the scientific community. However, a few profiles collected in the East Siberian Sea by Russian and German expeditions between 1989 and 1994 are available for use and suggest potential drill sites. These profiles show a large riftogenic basin, to the north of the New Siberian Islands, filled with a clastic sedimentary sequence 5 to 7 km thick. Based on the existing stratigraphy of the New Siberian Islands, these deposits are late Mesozoic and Cenozoic in age. The geologic history of this area is similar to the more thoroughly studied Yukon Basin, an upper Cenozoic terrestrial sequence, and Beaufort Shelf. The U.S. Geological Survey (USGS) has an extensive data base of geophysical data north of Bering Strait.

Recommendation
Alliances with industry should be explored to improve scientific access to existing seismic data from the region. This baseline data may allow more specific scientific objectives to emerge which may eventually lead to drilling targets to be identified.

Chukchi Borderland

The Chukchi Borderland is a separate feature from the continental shelf to the north of the Chukchi Sea and the Bering Strait. It includes the Northwind Ridge, the Chukchi Cap, and Arlis Plateau. The gateway region between the Arctic and Pacific oceans was not eroded by continental ice sheets during the last glaciation making it valuable for paleoceanographic studies. It also has been free of the isostatic effects of ice loading which complicates interpretations of paleoclimatic history of the Arctic-Atlantic ocean gateway region between Greenland and Svalbard. Furthermore, the Pacific gateway lies within the marginal ice zone and is not influenced by the transpolar drift.

Objective
The scientific objective of drilling in this region would be to evaluate the importance of the Pacific gateway in regulating the influx and efflux of cold-adapted biota to and from the Arctic Ocean in order to establish good geomorphological and chronological constraints. The nature and volume of these biota, in turn, will allow the primary forces regulating Arctic paleoproductivity, carbon flux and carbonate/opaline sediment deposition to be understood. A secondary and more challenging objective is to reach Mesozoic basement. Although it is assumed to be continental in nature, this has not been confirmed. This basement material would provide information about the breakup unconformity and bracket the time of continental breakup to form the Amerasia Basin.

Available data
A fair amount of geophysical data are available. However, these data need to be compiled and analyzed for possible drill locations.

Recommendation
Site surveys need to be conducted to carefully define drilling targets. However, the general strategy would be to drill a thick Neogene sequence on the Chukchi Borderland away from the influence of the Alaskan and Siberian landmasses.

Beaufort Sea

The Beaufort Sea is adjacent to Alaska and Canada at the mouth of the Mackenzie River. Sedimentation in the Beaufort-Mackenzie Basin continued from the Cretaceous-Tertiary into the late Neogene and Quaternary, and is punctuated by a major erosional period in the late Miocene. Quaternary sediments may be more than 1000 m in thick. They are composed principally of thick, interlayered regressive delta plain/delta front sands and thin transgressive fine-grained silts.

Objectives
The primary objective of drilling this region is to recover and examine a thick, high-resolution Holocene paleoenvironmental record from both the McKenzie River delta and the marine environment. Analyses would highlight changes in riverine input, any glacial sediment components, sea-level changes, impact of Bering Sea water, and the appearance of sea ice.

Available data
The general stratigraphic framework for the late Neogene to Quaternary sedimentary succession in the Beaufort Sea has been determined by correlating deep seismic reflection sections with sedimentological and biostratigraphic analyses of cuttings and geophysical logs from several exploration wells. However, only limited data is available for the upper few hundred meters of the sequence compared to moderate data available for greater depths. A 500 m deep core drilled by Gulf Canada in 1988 for engineering purposes continues to be analyzed.

Recommendation
Deep-core research to resolve the discrepancies emerging from the various data sets. A model should be established to explain the origin of 700 m of ice-bearing sediments beneath the Beaufort Shelf. Once the results of the deep core study are complete, the Beaufort Shelf should be discussed as a future drill site.

CENTRAL ARCTIC TARGETS

The topographic highs and ridges of the central Arctic Ocean basin—which encompasses the Amerasia and Eurasia basins—contain records of the environmental history and tectonic evolution of the Arctic region. Key scientific issues to be explored using drill cores from these features include:

- Mesozoic/Cenozoic Arctic climate changes;
- crustal affinities of the Alpha/Mendeleyev Ridge (oceanic or continental?);
- initiation and subsequent history of Arctic sea-ice cover; and
- biotic evolution and paleoproductivity.

Drilling sites will be identified where shallow offset drilling or a Giant Piston Coring (GPC) program may effectively determine basement characteristics and recover a record of sediment accumulation from the late Mesozoic through the Cenozoic. NAD has identified general targets on the Lomonosov, and Alpha-Mendeleyev ridges as well as a flat-topped seamount associated with the AMOR/Gakkel Ridge. General descriptions, scientific objectives, available data and drilling recommendations for these regions are expanded upon in the following section.

Lomonosov Ridge

The Lomonosov Ridge, which stretches across the Arctic Ocean from the Canadian continental margin to the Siberian margin, separates the Amerasia and Eurasia basins. The ridge is remarkable for its extensive length (1700 km) compared to its width (50-70 km). Water depths at its crest range from 500 to 1500 m. It is capped by a 500 m thick section, presumably hemipelagic, which unconformably overlies dipping sediments on its Alaska-facing slope. Older sediments appear to be rotated fault blocks below the central ridge and the Barents Sea facing slope. Elevated ridges, such as the Lomonosov, are isolated from turbidites and tend to preserve condensed sections of pelagic sediments, providing an opportunity to obtain a relatively long geologic record from more obtainable short cores.

Objectives

A primary objective for investigating the Lomonosov Ridge is to determine the nature of its basement and to understand the dynamics of the rifting process. Because the Lomonosov Ridge transects the Arctic Ocean, its condensed record of pelagic sedimentation which overlies the basement could be used to construct cross-basin paleoceanographic profiles. Therefore, additional objectives for obtaining long cores is to help document the initiation and history of Arctic sea-ice cover and glaciation; paleo-water mass characteristics; as well as biotic evolution and paleoproductivity.

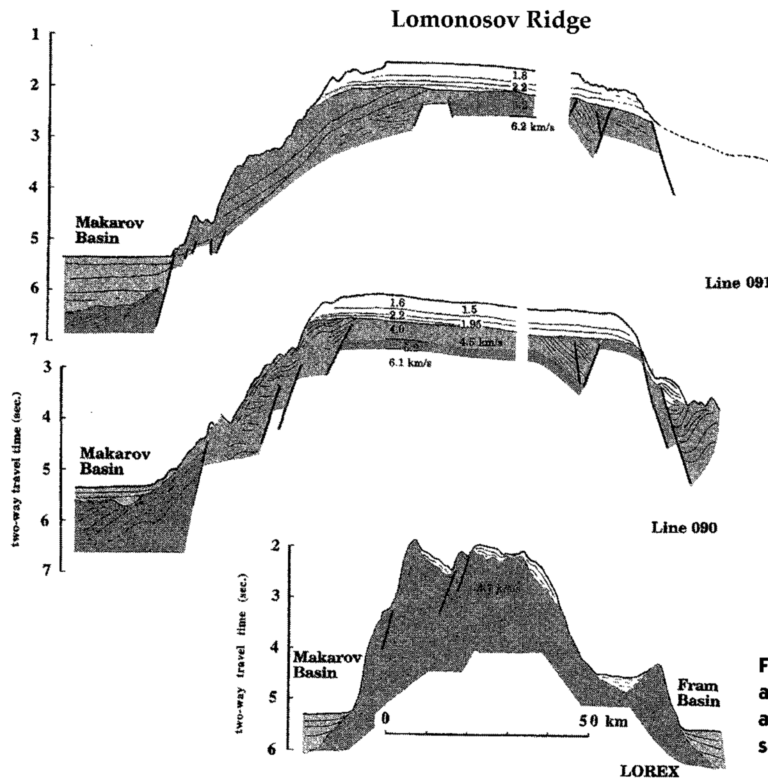


Figure 4. Seismic reflection profiles across the Lomonosov Ridge. Figure adapted from Polarforskningssekretariatet brochure *Arctic Ocean - 96.*

Available data

R/V *Polarstern* and *Oden* (1991 and 1996) collected five transects of multichannel seismic reflection measurements across the Lomonosov Ridge with along-track Parasound profiling (1991) and detailed CHIRP-sonar sub-bottom profiling (1996). Nearly 40 piston and kastenlot cores (up to 12 m long) were recovered from the ridge crest, mostly from candidate drill sites targeting the Cenozoic hemipelagic section above the regional unconformity. The uppermost sediments are a uniform 8 to 12 m thick drape. Sedimentological, micropaleontological, and geochemical studies of the cores indicate high-amplitude, short-term variations as well as long-term changes in sea-ice cover, oceanic circulation patterns, carbon flux, and glacial history (probably back to the Plio-Pleistocene).

Recommendation

First, existing data must be evaluated and specific sites selected. To achieve the paleoenvironmental objectives, a GPC program (analogous to an Arctic IMAGES program) combined with shallow drilling, as attempted from *Oden* in 1996, is recommended for Phase 1 exploration of the Lomonosov Ridge, followed by additional site surveys and deeper drilling with heavier equipment (Phase 2). Use of an offset drilling strategy would extend the paleorecord and sample basement.

Alpha-Mendeleyev Ridge

The Alpha-Mendeleyev Ridge (AMR) is a 450 km wide, irregular feature extending across the Amerasia Basin, separating the Canada Basin from the Makarov Basin. It rises over 2,700 m above the adjacent abyssal plain to water depths shallower than 1000 m. The complex horst and graben topography of potentially volcanic and possibly continental rocks is covered by 0.5 to 2 km of sediments. The magnetic anomaly pattern over the ridge is irregular but correlated with ridge topography. Only deeply weathered alkali basalt fragments from the basement of the Alpha Ridge are available and suggest it might be a LIP. The oldest sediment deposits recovered are slump deposits of Upper Cretaceous black, organic-rich mud and biosiliceous ooze. The Alpha and Mendeleyev ridges may be separate features with quite different origins; for instance, based on its magnetic signature, Mendeleyev Ridge appears to have continental affinities.

Objectives

The major scientific objectives of investigating the Alpha-Mendeleyev Ridge are to determine its origin, by recovering basement samples, and to unravel its Cenozoic history. Short cores recovered from ice island station T-3 over Alpha Ridge have provided the only Cretaceous to early Tertiary record from the Arctic Ocean. The range of bottom sediment ages may provide the means to construct a composite section for the Tertiary from multiple piston cores.

Available data

Alpha Ridge has been investigated by a number of methods, including: gravity and bathymetry from ice stations and submarines, crustal structure from seismic refraction and reflection data from ice stations, and both airborne gravity and magnetics from aircraft. A large number of sediment cores are available from the ridge, as are several dredge hauls from the Canadian ice station on the Ridge. Despite this apparent abundance of data, the origin of the ridge remains obscure.

Recommendation

The anticipated sidescan survey of selected features on the AMR by the U.S. Sturgeon-class submarine (1998 or 1999) via the SCICEX program is the logical first step in a project that will eventually lead to drilling. The survey should be followed by recovery of long cores whose locations are chosen to take advantage of the wide range of sediment ages that are exposed on AMR, especially in valleys or grabens. The information from existing short cores, future long cores, and the submarine survey which will collect backscatter, gravity and sub-bottom profiles can be used to select coring and drilling sites. The Alpha Triangle, from 86°N to 88°06'N and 98°W to 139°W is the most promising region, because it is here ice island station T-3 sampled older sediments. Drill sites will also be constrained by water depth. Other constraints are ice conditions near the more shallow Ellesmere Island side of the ridge, and safety concerns about gas hydrates associated with bottom simulating reflectors (BSR).

Arctic Mid-Ocean Ridge

The Arctic Mid-Ocean Ridge (AMOR), also known as the Gakkel Ridge, transects the Eurasia Basin separating the Amundsen and Nansen sub-basins. The AMOR is the slowest oceanic spreading ridge in the world, and global plate motion models predict a rate of 0.5 cm/year for the proximal portion of the ridge adjacent to the Laptev Sea shelf. The deep AMOR axis is at 5 km water depth near its intersection with the continental slope. A complex, blocky morphology characterizes the ridge's narrow zone of exposed oceanic crust which emerges from beneath the abyssal plain sediments.

Objectives

The primary scientific objective of studying the AMOR is to further understand the regional tectonics of the Eurasia Basin. Specifically, drilling into the continental slope to sample above the buried extension of the AMOR should reveal much about the interaction of magma with the overlying sedimentary section and provide information on the timing of the deformation of the Laptev Sea shelf by the extending ridge. A secondary objective to drill on the AMOR's flanks is to gather further data on Arctic paleoceanography.

Available data

The morphology of the AMOR is known from a few narrow-beam echo-sounder records collected by icebreakers and submarines. Multichannel seismic profiles were obtained in 1990 by the Marine Arctic Geological Expedition (MAGE) in the southernmost Eurasia Basin along the Laptev Sea continental slope. Our understanding of the AMOR and its basement morphology as a function of spreading rate should improve dramatically during the next few years with the addition of new data collected by the SCICEX program. In 1996, the USS *Pogy* collected new bathymetric and gravity profiles out to 40 nautical miles on either side of the ridge axis. For the 1997 cruise, the submarine will be outfitted with a SeaMARC type side-looking sonar. Tentative cruise plans call for the collection of backscatter and bathymetric coverage of the exposed basement supplemented by regional transects across the abyssal plain. Completion of this mapping effort will provide the information necessary to support a variety of other scientific programs.

Recommendation

Hard rock drilling challenges and the depth of the Eurasia Basin make it unlikely that the AMOR itself will be drilled in the near future. However, opportunities are offered by a large flat-topped seamount near the AMOR. This seamount may be an isolated sliver of continental crust capped by pelagic sediments. These sediments are isolated from clastic input and should also have an interesting paleoceanographic record.

SITE SURVEY AND DRILLING TECHNOLOGY

APPROACHES TO SITE SURVEYING

Conducting site surveys, using traditional methods, in the ice-infested waters of the Arctic Ocean requires different approaches for deep and shallow water. These approaches are discussed in the following section. However, the advent of submarines with a geophysical capability, such as in the Submarine Ice Experiment (SCICEX) program, introduces both new platforms and a new strategy for carrying out site surveys in ice. The SCICEX program is discussed in the Alliances section of this plan.

Shallow water

The first requirement for a single ship to successfully carry out shallow-water Arctic site surveys is ice-cover conditions which are light enough for the vessel to maintain a constant survey speed. Also, in order to attenuate multiples, collecting seismic multichannel data in shallow water requires a longer hydrophone cable than used for deep-water surveys. Maintaining good control on streamer depth requires depth-control devices attached to the cable. The quality of seismic data acquired using traditional ship operations by recent Russian and German expeditions in the Laptev Sea are quite acceptable.

Deep water

Deep-water seismic reflection surveys are invariably conducted in very heavy ice conditions (greater than 50% ice cover). Disruptions are likely because equipment under tow may catch on blocks of ice and be violently forced to the surface. Therefore, it is essential that the seismic source is towed as close to the ship as possible. This can be achieved by mounting the air guns below a depressor or heavy weight. The seismic streamer is more robust than the air guns and must be towed without depth control and tail buoy. The seismic noise level behind a single icebreaker at 200 m offset is around 5 microbar, which yields good quality seismic data. However, a single icebreaker will not be able to maintain constant survey speed and the streamer will sink while the vessel moves very slowly, resulting in varying delay of the surface ghost reflection and seismic pulse shape.

High-resolution sub-bottom sediment profiling is most efficiently done with hull-mounted systems. Arctic Ocean '96 demonstrated that towed systems can be used successfully if great care is taken.

APPROACHES TO SAMPLING

Shallow water

NAD currently has two options for drilling its proposed continental margin targets in shallow-water environments like the Laptev Sea where the goal is to obtain continuous cores from the uppermost 400 m of sediments. One option is to drill from shorefast ice during the winter using mobile and relatively inexpensive lightweight rigs. The second option is to drill from a jack-up or dynamically positioned vessel in summer. The experience of the Cape Roberts Project (Antarctica) will be valuable in selecting options.

Three possible platforms are: the drill vessel *Bavenit* (AMIGE, Murmansk, Russia); *Skate II* type jack-up for marine geotechnical investigations with supply vessels *Neftegaz* and *Anna Ahmatova* (ARKTIKMOR-NEFTEGAZRAZVEDKA-AMNGR, Murmansk, Russia); and the NEDRA Baikal-600 mobile unit (NEDRA, Yaroslavl, Russia). The first two platforms would drill during the ice-free summer season and the latter would work from shorefast ice in the early spring.

Deep water

Giant Piston Core Program
Core lengths of at least 30 meters and as long as 50 to 75 meters will be necessary to accomplish NAD scientific goals. These depths are within reach of a Giant Piston Core (GPC). NAD supports the initiation of a GPC program in order to begin sampling and taking advantage of light ice conditions as they occur in different parts of the Arctic. Potential sites for a GPC program could be identified in some of the key NAD target areas mentioned in this document. To accomplish this, existing icebreakers and research vessels must first be evaluated for installation of the GPC system. At present, only the R/V *Marion Dufresne* is capable of retrieving large diameter piston cores that exceed 50 m in length.

Drilling program
Ice thickness over the Lomonosov Ridge in the central Arctic Ocean is generally on the order of 3 m with the occasional presence of older, significantly larger, and harder floes. Drilling in drifting, heavy sea ice will require an icebreaker to clear a lead in front of an ice-strengthened drilling vessel. Maintaining site location over a period of several days is a

major operational constraint. The largest class of icebreakers will be needed to clear the way for sites chosen based on scientific objectives alone. A compromise between scientific priority and ice field challenges increases the number of suitable platforms. A dynamic- positioning system to maximize drilling time is highly desirable.

Figure 5. View of the drill rig on the *Bavenit*. Photo courtesy of M. Gelfgat.

Considering costs and the need to build experience in true Arctic Ocean drilling operations, NAD recommends a step-by-step approach beginning with a GPC program, if a suitable vessel is available for deep-water sites and shallow drilling on topographic highs. Our Arctic experience to date suggests that a single icebreaker can, under favorable ice and weather conditions, maintain position in 2 to 3 m thick drifting sea ice for periods sufficiently long enough for shallow drilling operations. The vessel must be equipped with a moon pool—including protection which extends the moon pool at least 5 m below the hull. This experience will help to refine optimum targets and define a cost-effective approach for the deeper targets.

It may be possible to use a special submersible drilling rig 6/4000 class (GNPP "SEVMORGEO", St. Petersburg, Russia) from on board a research vessel or icebreaker. This rig was purposely designed for geological prospecting in the ocean. It is a submarine rotary drilling rig for drilling along with rock core sampling up to 6 m deep when sea depth is up to 6 km (see Appendix III).

NAD WORKPLAN

Proposed timing for the NAD Scientific Agenda

	1993	1994	1995	1996	1997	1998	1999	2000
Yermak Plateau	X					X?		
Svalbard Margin		X				X?		
Lomonosov Ridge				X				X?
Alpha Mendeleyev site survey						X	X	
Alpha Mendeleyev drilling								X
Laptev Sea site survey					X	X		
Laptev Sea drilling							X	

NAD ORGANIZATION

The Nansen Arctic Drilling Program can benefit greatly from a close association with the international Ocean Drilling Program. The expertise and the organizational experience of the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) would be both difficult and very expensive for NAD to duplicate. A new JOIDES structure for scientific evaluation (implemented in 1997) suggests potential for the relationship between NAD and ODP to converge.

PARTICIPATION

The Nansen Arctic Drilling Program is open to any nation or organization with a viable community of researchers in marine geology and an interest in the geology of the Arctic region. It is estimated that an active and operational program will require funding at a level between 3 and 4 million U.S. dollars per year. Contributions to participate in NAD may take several paths. One approach is that the membership be subdivided into twenty "contribution units" at a level of US$150k to US$200k per contribution unit per year. Larger nations with greater interest in the program should be prepared to participate at the two- or three-unit level. The size of this contribution level is sufficiently small that there should not be a need for consortium structures. NAD will also consider "contributions in kind" as part of the membership participation. Contributions in kind could include, but not be limited to, providing: legal access, relevant data (e.g., earth science, oceanographic, hydrological, meteorological), intellectual resources, or local logistic support. Program-based funds are the strongly preferred option. However, for some contributors this level of commitment may not be possible, and for them, participation on a project-by-project basis would be most welcome. The table on page 28 shows estimates of possible funding allocation.

PROGRAM MANAGEMENT

The planning interval for the NAD Operational Phase will be ten years. This phase will be divided into two five-year periods with a review of progress at the end of the first five-year interval. It is expected that members will make a "commitment in principle" to the full ten-year program but it is understood that national research budgets for such an extended period cannot be predicted.

The organizational structure of NAD should follow the ODP model. One of the participant funding agencies would be the gathering point for funding contributions, probably the agency with the largest contribution. This agency in turn will undertake a contract with a program management organization. This organization will incorporate current secretariat functions with broad-scale NAD program coordination. It will provide newsletters, liaison among countries and funding agencies, and overall continuity for NAD in the future. It will also issue a Request for Proposal or an equivalent for a science operator. The NAD science operator will be responsible for the general operation of the drilling phases, and should be an institution with substantial experience in Arctic operations.

The establishment of a Nansen Arctic Panel or a Program Planning Group should be established in the JOIDES advisory structure. This panel would encourage proposals relevant to NAD drilling objectives from the international scientific community. Nansen Arctic Panel membership would be selected by the NAD Science and Executive committees, but in every other way the resulting Nansen Arctic Panel would form an integral part of the JOIDES structure.

- Site survey, pollution prevention and safety issues relevant to Nansen Arctic drilling would be handled by JOIDES Site Survey Panel and Pollution Prevention and Safety Panel (subject to their approval).
- NAD Science Committee drilling priorities would be divided into those ranked highly enough and logistically appropriate for drilling with the platform chartered by the NAD science operator or JOIDES.
- The ODP repositories and databases would be open to NAD cores and data, at cost.

LINKS WITH OTHER ORGANIZATIONS

NAD has established formal linkage with the Ocean Drilling Program (ODP), International Global Biosphere Program (IGBP) and Past Global Changes (PAGES), the Arctic Ocean Sciences Board (AOSB), the Arctic Paleo-River Discharge (APARD), Working Group VIII of the U.S./Russia bilateral agreement on the Environment, the bilateral Russian-German cooperation in the Arctic, and the International Arctic Science Committee (IASC). There are links also to major funded programs for late Quaternary climate research such as the European Science Foundation's Polar North Atlantic Margins Programme (PONAM) and the U.S. NSF's Earth System History Program. NAD has informal linkage with the International Continental Drilling Program (ICDP) and the Cape Roberts Project .

NAD is currently an ODP Liaison Group which is a means for ODP to communicate with national and international geoscience programs with interest in ocean drilling. This called for NAD to create an *Implementation Plan* so that a formal proposal can be created and submitted to ODP. This document is the response. NAD's scientific objectives are parallel to those in the ODP Long Range Plan.

Estimated NAD funding requirements projection

$M

	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08
Program Management	0.20	0.20	0.20	0.30	0.30	0.30	0.40	0.40	0.40	0.40
Vessel Charter	2.30	2.30	2.30	2.60	2.60	2.60	2.90	2.90	2.90	2.90
Science Operator	0.60	0.60	0.60	0.70	0.70	0.70	0.80	0.80	0.80	0.80
Science Support	0.10	0.10	0.10	0.15	0.15	0.15	0.20	0.20	0.20	0.20
TOTAL	$3.20	$3.20	$3.20	$3.75	$3.75	$3.75	$4.30	$4.30	$4.30	$4.30

NAD Program Management
A NAD Secretariat will continue, but will be incorporated into an overall program management organization. This organization will facilitate NAD communications (e.g., newsletters), serve as liaison among countries and funding agencies, and issue a Request for Proposals (RFPs) for the science operator.

Vessel Charter
Platform costs cover the drilling rig plus icebreaker escort costs if required.

Science Operator
The Science Operator is responsible for operation of the selected drillship and associated activities of cruise staffing, logistics, for engaging platforms, procuring supplies, providing logistic support and the general operational conduct of the program.

Science Support
Science support is to cover scientists' travel and incidental costs.

Estimated NAD funding contributions projection

$M

	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08
Lead Funder	0.75	0.75	0.75	1.00	1.00	1.00	1.10	1.10	1.10	1.10
4 Major Funders	1.00	1.00	1.00	1.20	1.20	1.20	1.40	1.40	1.40	1.40
3 Funders	0.45	0.45	0.45	0.60	0.60	0.60	0.75	0.75	0.75	0.75
3 Minor Funders	0.30	0.30	0.30	0.36	0.36	0.36	0.42	0.42	0.42	0.42
Project Contributions	0.70	0.70	0.70	0.59	0.59	0.59	0.63	0.63	0.63	0.63
TOTAL	$3.20	$3.20	$3.20	$3.75	$3.75	$3.75	$4.30	$4.30	$4.30	$4.30

In 1995, a proposal was submitted by NAD to the Ocean Drilling Program's Executive Committee through JOI (as the NAD Secretariat). This proposal aimed to provide NAD with an infrastructure of management, science advice and coordination, and a potential working system of repositories and databases, through access to those aspects of the ODP structure at cost. EXCOM responded to this proposal with the following statement:

EXCOM Consensus 95-2-12
EXCOM welcomes the proposal from the Nansen Arctic Drilling Program for close cooperative relationship with ODP, and the establishment of the NAD secretariat in JOI. EXCOM recognises that NAD addresses fundamental scientific problems in regions of the world, and requires facilities that are beyond ODP capability. The proposed framework for collaboration will be beneficial to both programs and to the overall advance of marine and polar science. Finalisation of the co-operative framework requires further discussion and agreement on the membership, status and the name of the "Arctic Panel" and confirmation the NAD will operate and abide by ODP sampling and curation protocols.

EXCOM responded to NAD's creation of this *Implementation Plan* with the following motion:

February 1997 EXCOM Motion 97-1-13
EXCOM recognizes the recent developments in NAD Science planning and their relevance to the ODP Long Range Plan. To further the collaborations between ODP and NAD, EXCOM extends an invitation to a representative of the Nansen Arctic Drilling program to present the NAD Science Implementation Plan to the next EXCOM meeting in June 1997 in Brest.

ALLIANCES

Since its initiation, the Nansen Arctic Drilling Program has promoted scientific sampling and drilling in the Arctic. Via coordination with other programs, some progress has already been made. Several scientific endeavors relevant to NAD are discussed in this section. The success of these activities demonstrates: the potential science yield from Arctic cores, the viability of a variety of platforms, and an increase of both international ambitions and logistical competence in Arctic operations.

INTERNATIONAL ARCTIC OCEAN EXPEDITION 1991

The first NAD-related sampling program was undertaken as part of the International Arctic Ocean Expedition 1991 (IAOE 91 or Arctic 91). Extensive coring was conducted from the *Polarstern* which was accompanied by the *Oden*. The vessels also carried out substantial seismic reflection profiling. A suite of coring devices was used at 54 stations, including a giant box corer, a multicorer, a giant piston corer, a kastencorer (gravity corer without piston), and a gravity corer. The cores, up to 12 m long, were also sampled for paleomagnetic studies and microfossil analyses (planktonic and benthic foraminifers, diatoms, ostracods and pollen). Shipboard biostratigraphic analyses used calcareous nannofossils.

An undisturbed upper Cenozoic sediment sequence, recovered from the Lomonosov Ridge during the expedition, provides clues for approaching Arctic Cenozoic paleoceanography. Magnetostratigraphic data and correlation of the variable fluxes of 10-Beryllium isotopes reveal, for the first time, a chronostratigraphic framework for Arctic cores which can be correlated to lower-latitude records. Ice rafted debris (IRD) of probable Eurasian origin was found during oxygen isotope stages 16, 12, 10 and—most importantly— 6. Planktonic foraminifers appeared during some of the recent interglaciations, but seem to have been adapted to life under sea ice for some time. The Lomonosov record suggests that for the past 4 m.y., the Arctic Ocean was—as it is today—covered by multi-year sea ice.

ARCTIC OCEAN 1996

Following up on the most promising results from Arctic '91, scientists on the Swedish icebreaker *Oden* carried out a research program on the Lomonosov Ridge in 1996. The principal target was a 500 m thick hemipelagic sequence on top of the ridge. Multichannel seismic reflection surveys and high-resolution CHIRP sonar sub-bottom sediment profiling were used to define locations for piston coring, hydrostatic coring and shallow drilling. A total of 31 piston cores were recovered, the longest being 11.3 m, and no drill cores were recovered.

Previous sampling efforts revealed that the target sediments were covered by an 8 to 12 m thick drape of younger deposits, and were thus barely accessible by conventional coring. *Oden* carried a modest wireline diamond drilling system (see back cover photo) to reach these deeper sediments. The drill's bottom assembly and riser were successfully set in 962 m water depth at 87°5'N, 145°E. The first two deployments were aborted and on the third attempt, drill string deployment began after continuity of the riser was established. An obstruction was encountered in the riser, and both the drill string and the riser had to be retrieved. A lack of time prevented further drilling attempts.

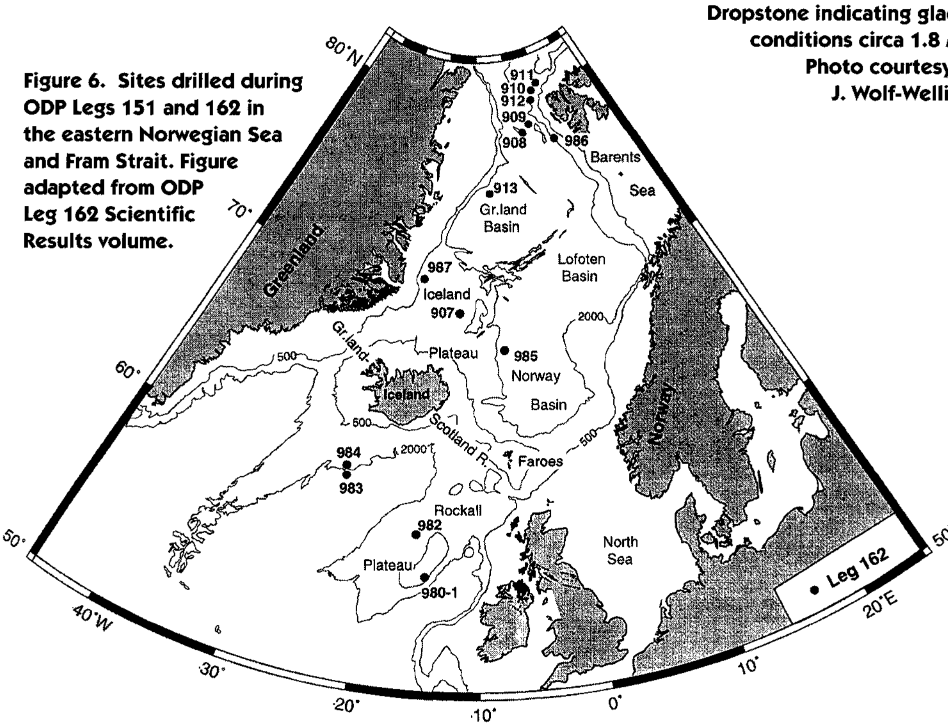


Figure 6. Sites drilled during ODP Legs 151 and 162 in the eastern Norwegian Sea and Fram Strait. Figure adapted from ODP Leg 162 Scientific Results volume.

Figure 7. ODP Leg 151, Site 907A, Core 4H, 38 mbsf. Dropstone indicating glacial conditions circa 1.8 Ma. Photo courtesy of J. Wolf-Welling.

OCEAN DRILLING PROGRAM ARCTIC GATEWAYS

ODP Legs 151 and 162

ODP Leg 151 drilled in the Fram Strait, the northern Greenland Sea, and on the Yermak Plateau to obtain, for the first time, long Arctic sediment sections. Seven sites were drilled yielding evidence of the transition of northern hemisphere deep-sea basins from temperate climate conditions (as in the Eocene and Oligocene) to glacial conditions (in the Pliocene and Pleistocene). Except for a few interruptions, the Leg 151 cores record the paleoceanographic history from the Eocene—when the Norwegian Sea was small and narrow—to the Quaternary. During the Eocene, southern surface water carried temperate to subtropical siliceous biota northward. Only during the late Oligocene and early Miocene did a cool to temperate water mass develop. The first evidence of marine ice was found in middle to late Miocene sediments. The influence of marine sea ice and the influx of glacial ice, first from Greenland and later from northwestern Europe, increased following the middle Miocene until it reached a threshold—approximately 3.5 to 4 Ma off southern Greenland and 3.2 Ma in Fram Strait and off northwestern Europe. These trends are interpreted as an increase in ice cap growth on either side of the Norwegian-Greenland Sea. Rapid glacial/interglacial oscillations are recorded in the Pliocene and Quaternary sediments. A temperate interval in the middle Pliocene, which can be correlated to the development of boreal forests in northeastern Greenland, appears to have interrupted IRD production.

At Site 910, approximately 80 km north of what is presently Svalbard, ODP encountered severe drilling problems while trying to penetrate an indurated layer of glaciogenic sediments. Later analyses showed that the section was clearly over-consolidated, but overlain by glacial-marine sediments younger than 0.6 Ma. Thus, the Svalbard ice may have extended far onto Yermak Plateau during early glaciations that may have been more extreme than later Quaternary glaciations. Likewise, in Alaska, earlier northern glaciations were very extensive.

The second ODP leg to investigate the Atlantic Arctic Gateway, Leg 162, was also of great interest to NAD. One of the objectives of Leg 162 was to document the late Neogene histories of the Greenland and Svalbard-Barents ice sheets. Drill sites were chosen to investigate the independent glacial histories of these two major circum-Arctic ice sheets. ODP Site 987, on the East Greenland margin, yielded a sediment sequence which suggests continuous glaciation on Greenland since the late Miocene, with increased glaciation during the Pliocene. Site 986 on the Svalbard margin indicates a younger age for the Svalbard-Barents ice sheet. An upper Pliocene through Quaternary section at Site 986 also indicates major glacial expansion to the shelf break during the Pleistocene. These results support a hypothesis, to be further tested by NAD, that the circum-Arctic ice sheets had separate histories during the late Neogene interval of polar cooling.

OTHER DEVELOPMENTS

Beaufort Sea Core

A 500 m engineering core from the depositional center of the Beaufort-Mackenzie Basin (late Neogene to Holocene in age) was drilled by Gulf Canada in 1988. The core is being analyzed at the Bedford Institute, Halifax, Nova Scotia to determine if the site warrants a dedicated science drilling project. NAD is following the progress of this project with keen interest.

To date, independent studies have been completed on the sedimentology, pore water geochemistry (salinity, isotopes to determine origin of pore waters), palynology, micropaleontology, macrofossils, in situ ice fabric, and velocities. Cyclic marine transgressive-regressive sediment sequences are recognized downcore, but sedimentological and stratigraphic interpretations differ as to whether six or eight cycles are preserved. The chronological control, which is poor, indicates that the entire sequence may be younger than 500 ka.

Future research will focus on resolving the discrepancies emerging from the various data sets and establish a model to explain the origin of 700 m of ice bound sediments beneath the Beaufort Shelf.

Laptev Sea System

In 1994, an ongoing, multi-disciplinary program titled the Laptev Sea System was initiated by German and Russian research institutions. The program's scientific objectives are to understand environmental processes (and their relationship to global change) for the Laptev Sea region including its watersheds and the adjacent Arctic seas. This program is funded by the Russian and German Ministries for Science and Technology and has included year-round expeditions to the Laptev Sea and to the Siberian hinterland, as well as workshops and the exchange of scientists. To date, the research has both defined and quantified the effect of fresh water and biogeochemical input from major rivers (including the Lena) on: the Arctic marine environment, faunal patterns, the interaction of Atlantic and Pacific marine fauna, ecosystem dynamics, and continental shelf sediment processes. This program is complementary to NAD's paleoceanographic objectives in the Arctic.

U.S. Science Ice Exercise (SCICEX)

The stability, silence, range and independence from surface conditions render a Sturgeon-class submarine a nearly ideal platform for geophysical measurements. Since 1993, the U.S. Navy has made a Sturgeon-class nuclear-powered submarine available for annual unclassified science cruises to the Arctic Ocean. Approximately 50,000 km of underway gravity anomaly and narrow-beam bottom sounder data have been collected, substantially expanding the unclassified data base for the Arctic Ocean. Three more cruises in 1997, 1998 and 1999 will complete the planned SCICEX program.

The data collected to date is the largest addition to the unclassified database since the heyday of the ice island stations, but the capability of the submarine has, so far, been under-utilized. Additional instrumentation is being funded by the U.S. National Science Foundation's (NSF) Office of Polar Programs which supported an initial engineering study in 1996 and has agreed to fund the fabrication and testing of a SeaMARC-type Sidescan Swath Bathymetric Sonar and a Data Acquisition and Quality Control System. In support of NSF's commitment, a private organization, the Palisades Geophysical Institute, is funding acquisition of a CHIRP, swept-frequency sub-bottom profiler. The transducers for these sonars will be mounted in a instrument "pod" attached to the keel of the submarine. This equipment will be ready for the 1998 SCICEX cruise.

The Ocean Drilling Program has relied extensively on geophysical survey data to define optimal drilling sites. The SCICEX program is the best opportunity to efficiently collect site survey data in the Arctic. The Ocean Data Equipment Corporation CHIRP sub-bottom profiler selected for this application, will penetrate the sediment column to at least 100 meters, with a resolution of approximately 30 cm. These data will be especially useful for siting long piston cores. Combined with the backscatter and bathymetry data, it should also be possible to identify eroded sections exposed on the sea floor, ideal for offset coring strategies, which make the most of the limited penetration of piston corers.

APPENDIX I

ATTENDEES

Nansen Arctic Drilling Program Implementation Plan Workshop
14-15 October 1996
Arctic and Antarctic Research Institute
St. Petersburg, Russia

Ludmila Andrianova, VNIIO, Russia
Nadezhda Alexeeva, St. Petersburg Administration, Russia
William Austin, Dept. of Geography, Univ. of Durham, UK
Anders Backman, Icebreaking Dept., Swedish Maritime Admin., Sweden
Henning Bauch, GEOMAR, Germany
Glenn Berger, Quaternary Sciences Center, Desert Research Inst., USA
Nikita Bogdanov, Lithosphere Institute, Russian Academy of Sciences, Russia
Vlidimir Bondarev, State Enterprize "AMIGE", Russia
Garrett Brass, Arctic Research Commission, USA
John Chesher, British Geological Survey, UK
Bernard Coakley, Lamont-Doherty Earth Observatory, Columbia Univ., USA
Sergei Drachev, Shirshov Inst. of Oceanology, Russia
Yuriy Egorov, State Enterprise "Sevmorgeo", Russia
David Falvey, Joint Oceanographic Institutions, USA
Benjamin Flower, Univ. of California, Santa Cruz, USA
Dieter Fütterer, Alfred Wegener Inst. for Polar and Marine Res., Germany
George Gamsakhourdia, Science & Technology Center "FUGRO-JAKES", Russia
Valery Gataullin, Oil and Gas Research Institute, Latvia
Michael Gelfgat, Aquatic Co. Ltd, Russia
Gabriel Ginsburg, VNIIO, Russia
Tatyana Gorokhova, Geographical Dept., St. Petersburg Univ., Russia
Garrik Grikurov, VNIIO, Russia
David Harwood, Dept. of Geology, Univ. of Nebraska-Lincoln, USA
Kay Heykendorf, BEO, Germany
Hans Hubberten, Alfred Wegener Inst. for Polar and Marine Res., Germany
Alexander Ivanov, St. Petersburg Administration, Russia
Vladimir Ivanov, VNIIO, Russia
Gennady Ivanov, VNIIO, Russia
Ruth Jackson, Geological Survey of Canada, Canada
Richard Jarrard, Dept. of Geology and Geophysics, Univ. of Utah, USA
Andrea Johnson, Joint Oceanographic Institutions, USA
G. Leonard Johnson, Univ. of Alaska, USA
Vyatcheslav Kochukov, State Science & Production Enterprise "NEDRA", Russia
Heidemarie Kassens, GEOMAR, Germany
Boris Kim, VNIIO, Russia

Yngve Kristoffersen, Inst. of Solid Earth Physics, Univ. of Bergen, Norway
Alexey Kryilov, VNIIO, Russia
Alexander Lisitsin, Institute of Oceanology, Russia
Boris Lopatin, VNIIO, Russia
Ron MacNab, Geological Survey of Canada, Canada
Yuri Matveev, SPSE "Sevmorgeo", Russia
Martin Melles, Alfred Wegener Inst. for Polar and Marine Res., Germany
Lev Merklin, Shirshov Institute of Oceanology, Russia
Peter Michael, Dept. of Geosciences, Univ. of Tulsa, USA
Yevgeny Musatov, VNIIO, Russia
Vladimir Nicolayev, Botanical Institute, Russia
Alexey Novikov, VNIIO, Russia
Lisa Osterman, Mary Washington College/US Geological Survey, USA
Gennadiy Parsadanov, Arctic and Antarctic Research Institute, Russia
Vladimir Pavlenko, Arctic Center, Russian Academy of Sciences, Russia
Lev Pevzner, State Science and Production Enterprise "NEDRA", Russia
Alexander Podrazhansky, J-SC "AKVATIKA", Russia
Ross Powell, Dept. of Geology, Northern Illinois University, USA
Leonid Polyak, Byrd Polar Research Center, USA
Lincoln Pratson, Inst. of Alpine Research, Univ. of Colorado, USA
Sergey Priamikov, Arctic and Antarctic Research Institute, Russia
Sergey Rokos, State Enterprize "AMIGE", Russia
Pavel Rekant, VNIIO, Russia
Norbert Roland, Federal Inst. for Geosciences and Natural Resources, Germany
Bettina Rohr, GEOMAR, Germany
Igor Semenenkov, Hydrometerological Institute, Russia
Alexander Simonov, Sevmorneftegeofizika, Russia
Valeriy Solovyev, VNIIO, Russia
Ruediger Stein, Alfred Wegener Inst. for Polar and Marine Res., Germany
Kari Strand, Inst. of Geosciences and Astronomy, University of Oulu, Finland
John Tarduno, Earth & Environmental Sciences, Univ. of Rochester, USA
Jörn Thiede, GEOMAR, Germany
Leonid Timokhov, Arctic and Antarctic Research Institute, Russia
Jacob Verhoef, Geological Survey of Canada, Canada
Mikhail Zaitsev, Arctic and Antarctic Research Institute, Russia

APPENDIX II

PROPOSED LAPTEV SEA DRILL SITES

1. Geographic locations (See Figure 2, page 13):
   DS-1: 75°44'N; 135°00'E
   DS-2: 75°05'N; 135°35'E

2. Scientific objectives:
   - Quaternary paleoceanography
   - offshore permafrost properties
   - detailed history of changes in sea ice for last two glacial/interglacial epochs
   - detailed history of organic carbon flux productivity and CO_2
   - age determination of the seismic stratigraphic units
   - history of river discharge and possible glacial icecaps

3. Water depth:
   - 30 m

4. Tectonic setting:
   - northern part of the Bel'kov-Svyatoi Nos Rift, Laptev Sea Rift System

5. Total sediment thickness:
   DS-1: 5.5 km
   DS-2: 4 km

6. Anticipated stratigraphy and nature of the sediments:
   - interbedded shallow-water marine and continental clays, silts, sands and gravels of late Pliocene to Holocene age

7. Permafrost conditions:
   - degraded (?) permafrost (separated lenses of frozen sediments)

8. Weather and ice conditions:
   - typically open water from July to late September
   - shorefast ice from November to May

APPENDIX III

RUSSIAN PLATFORM TECHNICAL DATA

Several Russian organizations have Arctic drilling technologies suitable for drilling the NAD marginal Arctic Ocean targets as well as drilling in shallow water. These capabilities are summarized below.

Russian capabilities also exist for reaching NAD's central Arctic targets and are discussed in the document: *Nansen Arctic Drilling, A technical report of the British Geological Survey visit to Russia.* This report was compiled by A.C. Skinner (Marine Geology and Operations Group, BGS) and published in April 1994. It is available from the NAD Secretariat.

AMIGE

Geotechnical drilling vessel: *Bavenit*
Anchoring positioning: up to 40 m depth
Dynamic positioning: 300 m and greater
Drilling rig specifications
- derrick: 35m; 60t
- heave compensation: about 3.5m
- power swivel: 625 daN.M; 40t
- mud pumps: 1170 1/min—24 Bar, 580 1/min—50 Bar

Personnel capacity:
- 50 AMIGE staff
- 20 scientific staff

ARKTIKMORNEFTEGAZRAZVEDKA (AMNGR)

Jack-up rig for marine geotechnical investigations: *SKATE II*
Operational water depth: 3-20 m
Drilling rig from NEDRA Baikal 600 unit
Neftegaz supply vessel to transport jack-up rig and equipment
Anna Ahmatova supply vessel with 150-person capacity for drilling crew & scientific staff

GNPP NEDRA

Mobile drilling complex located on a barge (MBK)
Derrick: 15.5m, 20t
Personnel capacity: 40 people, including 20 scientists.
Operational duration: 6 months.

Specifications
- Continuous coring system
- Aluminum drillstring and BAIKAL 2 coring system
- Borehole diameter: 212.7 mm
- Sample diameter: 56 mm
- Rotary core diameter: 80 mm
- Sample/core length: up to 6 m per run in plastic liner

Deep-Sea Submersible Drilling Rig GBU-6/4000

Technical data, Specifications and Components:
- Drilling depth: up to 6 km
- Water depth: up to 4000 m
- Drilling tool OD: 59 or 76 mm
- Drilling tool RPM: 270-400 or 800
- Rate of downward drill tool feed: 0.04 or 0.3 m/min.
- Torque: 120-140 NM
- Bit load - WOB: 4-8 kn.
- Flushing pump
  - pressure: up to 2 MPa
  - flow rate: 15 l/min.
- Maximum angle of drilling rig inclination (seafloor slope): 15°
- Dimensions (LxBxH): 2.5x2.0x7.0 m
- Weight: 3500 kg
- Power supply - storage battery
  - total capacity: 800 Ah
  - voltage: 24 V
- Remote control system monitors the following parameters:
  - rig angle inclination
  - electric current for each motor
  - storage battery voltage
  - drilling tool rotation speed
  - position of drilling tool (up and down);
  - drilling operations observation by monochrome TV camera
- The drilling rig control is provided by eight active command through cable.
- The research vessel *Professor Logachev* is equipped with a dynamic positioning system and a transit winch towing system:
  - lifting capacity: 16 tons
  - drum capacity for cable-rope KGP-1/150 (coaxial): 8000 m

Operator timing for the Laptev Sea Project

OPERATOR	AMIGE	AMNGR	NEDRA
Preparation time (platform & equipment)	2 months	2 months	2 months
Mobilization time	11 days	25 days	15 days
Potential operational days	32 days	30 days	100 days
Demobilization time	9 days	23 days	15 days
Working dates	July-Sept.	June-Oct.	Aug.-April
ESTIMATED COSTS FOR 30 WORKING DAYS (1-2 boreholes in US$ thousands)			
Mobilization	323.7	380.5	500.0
Performance	998.2	660.0	400.0
Demobilization	274.6	315.5	150.0
Total (US$ thousands)	1596.5	1356.0	1050.0

ACRONYMS & ABBREVIATIONS

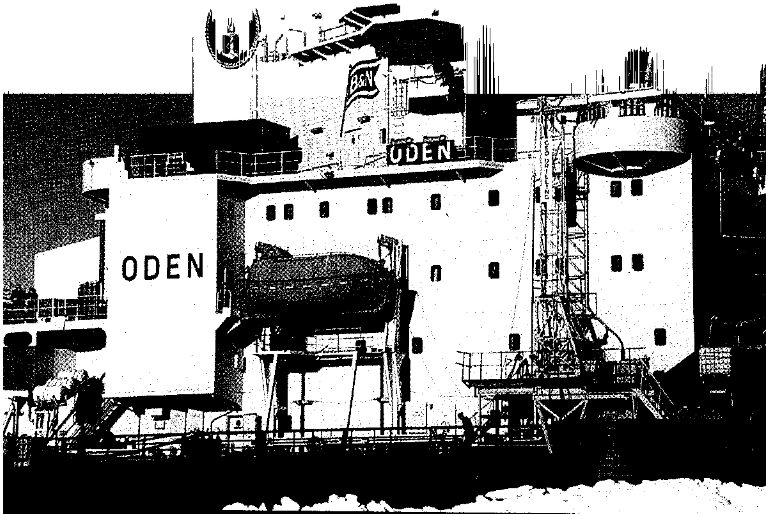
AARI	Arctic and Antarctic Research Institute, Russia
AMOR	Arctic Mid-Ocean Ridge (Gakkel Ridge)
ANTOSTRAT	Antarctic Ocean Stratification
AOSB	Arctic Ocean Science Board
APARD	Arctic Paleo-River Discharge
AWI	Alfred Wegener Research Institute for Polar and Marine Science, Germany
BGS	British Geological Survey
BSR	Bottom simulating reflector
CDP	Continuous depth profile
ESF	European Science Foundation
EXCOM	JOIDES Executive Committee
GEOMAR	Research Center for Marine Geoscience, Germany
GPC	Giant Piston Core
IAOE	International Arctic Ocean Expedition
IMAGES	International Marine Global Changes Study
IASC	International Arctic Science Committee
IRD	Ice rafted debris
JOI	Joint Oceanographic Institutes Inc.
JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
ka	kilo-anna or thousand years before present
k.y.	thousand years
LIP	Large igneous province
LDEO	Lamont Doherty Earth Observatory, U.S.
Ma	mega-anna or million years before present
MAGE	Marine Arctic Geological Expedition
MESH	Marine Aspects of Early Earth System History
m.y.	million years
NAD	Nansen Arctic Drilling Program
NSF	U.S. National Science Foundation
ODP	Ocean Drilling Program
PAGES	Past Global Changes Programme
PCOM	JOIDES Planning Committee
PONAM	Polar North Atlanic Margins Programme
SCICOM	JOIDES Science Committee
SCICEX	Submarine Ice Experiment
TEDCOM	JOIDES Technology and Engineering Development Committee
USGS	U.S. Geological Survey

BACK COVER:

Top: *ODEN* with rig for shallow drilling on the right. Photo courtesy of Y. Kristoffersen.

Middle: Arctic bathymetry image generated by the Environmental Research Institute of Michigan (ERIM) using the ETOPO-5 bathymetry data set distributed by the NOAA National Geophyscial Data Center.

Bottom: U.S.S. *Fargo* surfacing in Arctic ice pack. Photo courtesy of U.S. Navy.



DRILLING PROGRA

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