**Integrated Ocean Drilling Program**
**Expedition 302 Scientific Prospectus**

# ACEX Arctic Coring Expedition
# Paleoceanographic and tectonic evolution of the central Arctic Ocean

**2004**

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# Paleoceanographic and tectonic evolution of the central Arctic Ocean


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## DISCLAIMER

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# ABSTRACT

Five drill sites are proposed on the ridge crest of the Lomonosov Ridge in the central Arctic Ocean. The sites are distributed between 88°N and 81°N in water depths ranging between 800 and 1415 m, and are all located in international waters. The ridge was rifted from the Kara/Barents Sea shelves during early Paleogene time and subsequently subsided to its present water depth. Since that time, sediments of biogenic, aeolian and ice-rafted origin have accumulated on the ridge crest. In our primary target area between 87°N and 88°N these sediments are about 450 m thick, indicating an average rate of sedimentation of ~10 m/my throughout the course of the Cenozoic. Sampling of these sediments would provide an unprecedented and unique opportunity to acquire a first-order knowledge about the paleoceanographic history of the central Arctic Ocean. Sampling of the underlying bedrock provides a similarly unique opportunity to decipher the tectonic history of the Lomonosov Ridge and the formation of the Eurasian Basin. The proposed program epitomizes both the spirit and the science of the new Integrated Ocean Drilling Program, calling upon the creative use of mission specific platforms and directly addressing a number of the key scientific questions raised in the IODP Initial Science Plan. Amongst scientific issues relating to "Environmental Change, Processes and Effects" are:

- The long-term (50 Ma) climate history of the central Arctic Ocean, and its role in Earth's transition from one extreme (Paleogene greenhouse) to another (Neogene icehouse).
- The shorter-term (Neogene) climate history, connecting the Neogene history of the Arctic Ocean to that of the North Atlantic Ocean at sub-millennial scale resolution.

Scientific issues relating to "Solid Earth Cycles and Geodynamics" are: the composition and origin of the pre-Cenozoic bedrock underlying the sediment drape; and the rifting and subsidence history of the Lomonosov Ridge. Five sites distributed over six degrees of latitude are proposed, partly with overlapping goals, which will make the drilling expedition less vulnerable to severe local ice conditions. The major goals of this proposal can be achieved by completing one site to 450 mbsf. Should ice conditions at this site be prohibited, a suite of sites from other areas along the ridge can be drilled to achieve the proposed science.


# INTRODUCTION

The Arctic Ocean and its marginal seas play a fundamental role in the global ocean/climate system. The dense, cold, bottom waters of most of the world's oceans, which originate in the Nordic seas, strongly influence global thermohaline circulation, driving world climate. The permanent Arctic sea-ice cover has a tremendous influence on the Earth's albedo and the distribution of fresh water. It varies both seasonally and over longer time periods and thus has a direct influence on global heat distribution and climate. While understanding the history of the Arctic Ocean is critical for climate, ocean-circulation or tectonic models that would be truly global, the logistical difficulties associated with the work in this remote and harsh region have prevented us from gathering the critical data needed to document the role of this key region in the development and maintenance of the global climate system.

Except for the Pleistocene, only isolated, discontinuous intervals of sediments representing Cenozoic time have been sampled by coring. Thus the Arctic Ocean, despite its critical role in global climate evolution, is the only ocean basin whose history is virtually unknown. The complex history of this basin, which receives surface water from the North Pacific, the North Atlantic and the various large rivers which drain northern Eurasia and North America, where water exists in all three phases year round, can only be studied by direct sampling of the sediments which record its history. The sediment sections preserved on the basinal highs have captured a record of the development of the Fram and Bering Straits, varying fluxes of fresh water into the basin, the development of the Arctic sea ice and the history of the high-latitude effects of the Cenozoic glaciation. This information is necessary to fully understand the climate of the Northern Hemisphere, providing a dataset that complements ice and sediment cores collected at lower latitudes.

Five primary sites are proposed (Figure **F1**) to recover a 450 m-thick sediment sequence and the upper 30 m of the underlying acoustic basement (bedrock) from the crest of the Lomonosov Ridge. The sediment sequence represents a unique archive of the past 50 million years of paleoenvironmental evolution in the central Arctic Ocean, whereas the transition into the acoustic basement and its uppermost parts represents a similarly unique archive of the early tectonic evolution of the Eurasian Basin.

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## GEOLOGICAL SETTING

Ever since Bruce Heezen and Maurice Ewing recognized, in their 1961 paper, that the mid-ocean rift system extended from the North Atlantic into the Arctic Ocean, it has been assumed that the Lomonosov Ridge was a continental fragment originally split off from the Eurasian continental margin. Aeromagnetic surveys of the Eurasian Basin have since mapped a remarkably clear pattern of magnetic lineations which can be interpreted in terms of seafloor spreading along the Gakkel Ridge since Chron C24 at ~53 Ma (Wilson, 1963; Vogt *et al.*, 1979; Kristoffersen, 1990a). If we compensate for that motion of the seafloor, the Lomonosov Ridge is indeed brought into juxtaposition with the Barents/Kara Sea margin in early Cenozoic reconstructions. Zircon-bearing bedrock samples from the Lomonosov Ridge at 88.9°N yield a latest Permian (~250 Ma) age (Grantz *et al.*, 2001). The only known source for c 250 Ma old zircons in the circum-Arctic is in the post-tectonic syenites of northern Taymyr Peninsula and nearby islands in the Kara Sea, lending support to the tectonic model in which the ridge is interpreted to be a continental sliver that separated from the Eurasian plate.

As the Lomonosov Ridge moved away from the Eurasian plate and subsided, sedimentation on top of this continental sliver began, and indeed has continued to the present, providing what may be a continuous stratigraphic sequence (Figures **F2**-**F3**). The elevation of the ridge above the surrounding abyssal plains (~3 km) indicates that sediments on top of the ridge have been isolated from turbidites and are likely of purely pelagic origin, chiefly biogenic, aeolian or ice-rafted.

Deep-penetration reflection seismic profiles were acquired from the Lomonosov Ridge on icebreaker-based expeditions in 1991, 1996, and 1998 (Jokat *et al.*, 1992; 1998; 1999; Kristoffersen, 1997a). The first deep-penetration seismic cross-lines from the Lomonosov Ridge were collected in 2001 (Yngve Kristoffersen, personal communication, and ODP Data Bank). The first high-resolution chirp profiles were collected in 1996 (Jakobsson, 1999). In 1999, the SCICEX program collected abundant high-resolution seismic chirp data, swath bathymetry and sidescan sonar backscatter data from a USN nuclear submarine (Pyle *et al.*, 1997), contributing many new exciting results (Polyak *et al.*, 2001; Edwards *et al.*, 2001) including a much improved bathymetric chart of the Arctic Ocean (Jakobsson *et al.*, 2000a; see also **www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html**).

High-resolution chirp sub-bottom profiler (Figure **F4**) and interferometric swath bathymetry and backscatter data collected over the Lomonosov Ridge from the USS Hawkbill in the Spring of 1999 have been provided to the site-survey data center at LDEO. The chirp data in Figure **F4** show the continuous drape of mantle-bedded pelagic sediments that are the primary target for this drilling program.

Two of the key seismic profiles (AWI-91090 and AWI-91091) were acquired across the Lomonosov Ridge in about 8/10 ice cover during the 1991 expedition (Jokat *et al.*, 1992). At 88°N in 1 km of water, the ridge is 80 km wide with a 450 m thick section of acoustically stratified sediments that cap the ridge above an unconformity (Figure **F3**). Below this unconformity, sediments are present in down-faulted asymmetric half-grabens. Seismic velocities from refraction experiments are typical for deep-sea sediments above the unconformity (1.5-2.2 km/s) and are >4 km/s below.

Several dozens of short cores (<10 m) of Pleistocene and Holocene age exist from the central parts of the Lomonosov Ridge, indicating average sedimentation rates of ~7-10 m/m.y. (e.g., Gard, 1993; Jakobsson *et al.*, 2000b; 2001). By assuming that the tectonic model of the onset of Cenozoic marine sedimentation on the ridge is approximately correct in terms of timing (50 Ma: Jokat *et al.*, 1992) and considering the total thickness of the section (450 m) above the unconformity, a rate of 7-10 m/m.y. is consistent with the average sedimentation rate of the entire section: 9 m/m.y.

Little information is available about pre-Pleistocene paleoenvironments in the central Arctic Ocean. Temperate marine conditions existed during the Late Cretaceous (Campanian- Maastrichtian) based on evidence provided by silicoflagellates and diatoms from three short T-3 and CESAR cores, all retrieved from the Alpha Ridge in the Amerasian Basin (Clark *et al.*, 1980; Bukry, 1981; Thiede *et al.*, 1990). One 3.64 m-long core (F1-422) containing mid- or late Eocene silicoflagellates also has been retrieved from the Alpha Ridge, providing the sole evidence for early Cenozoic marine conditions in the Arctic (Bukry, 1984). Thus, existing core material, at best, represents a few percent of the Cenozoic paleoceanographic history of the Arctic Ocean.

It is concluded that the 450 m-thick sediment sequence draping the crest of the Lomonosov Ridge between 87°N and 88°N (Figures **F2**-**F3**) contains a unique archive of climatic and paleoceanographic information, which is the key to unravelling the long-term (50 Ma) Cenozoic environmental history of the central Arctic Ocean.

# FROM GREENHOUSE TO ICEHOUSE: ARCTIC'S ROLE IN THE DEVELOPMENT OF CENOZOIC CLIMATIC EXTREMES AND RAPID CLIMATE CHANGE

## Cenozoic climatic extremes

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

The transition to today's world, Antarctica covered by a continental ice-cap and seasonally variable but persistent sea-ice cover in the Arctic, is linked to both the change in climate that increased latitudinal gradients and to oceanographic changes that connected surface and deep-sea circulation between high- and low-latitude oceans. Thus, throughout the course of the Cenozoic, the climate on Earth has changed from one extreme (Paleogene greenhouse lacking ice) to another (Neogene icehouse with bipolar glaciation).

It has long been recognized that our lack of knowledge about the role the Arctic played in the maintenance and development of these climatic extremes is a major gap in our ability to understand and model global environmental change (e.g., COSOD I, 1981; COSOD II, 1987; ODP Long Range Plan, 1996; COMPLEX, 1999; IODP Science Plan, 2001).

The recovery of a 450 m thick, continuous Cenozoic stratigraphic section, encompassing 50 My, from the central part of the Lomonosov Ridge would fill that gap and represent a fundamental step to a quantitative description of global change that incorporates the influence of the Arctic Ocean. Key among our climate objectives is to determine when the Arctic became ice-covered, and to study the variability of sea ice in terms of frequency, extent and magnitude. In this context, the Miocene uplift of the Himalayan-Tibetan region is of particular interest as it may have triggered enhanced flow of Siberian rivers and changed the fresh-water balance of the Arctic's surface waters, considered to be a key factor in the formation of Arctic sea-ice (Driscoll and Haug, 1998).

### Rapid climate change

Cenozoic sedimentation rates on the central parts of the Lomonosov Ridge are probably too low to allow ultra-high resolution (sub-annual to decadal) studies of climate change. Late Neogene and Pleistocene sediments on the huge and shallow Siberian shelves were deposited at rates which could permit ultra-high resolution, but problems pertaining to jurisdiction, hydrocarbons and permafrost indicate that higher-resolution sites must be located elsewhere. The sediment section draping the crest on the Lomonosov Ridge becomes progressively thicker when approaching the Siberian (Laptev Sea) margin (Jokat, 1999) and the Lena River. The total sediment thickness above the unconformity is two- to three-fold compared to that occurring on the central parts of the Lomonosov Ridge. The southernmost sites proposed (at ca. 81°N to 82°N and 800 m to 1400 m water depth) would avoid the jurisdiction, permafrost and hydrocarbon problems of the shelf environment but still permit sub-millennial scale resolution and studies of Arctic rapid climate change in the Pleistocene and Neogene.

These two topics, Earth's change from extreme warmth (lack of glaciation) to extreme cold (bipolar glaciation), and rapid climate change, are key elements in the IODP Science Plan. Scientific drilling in the Arctic is the only means available to collect the data necessary to decipher the history of the Arctic Ocean and to connect to the history of the Greenland ice sheet and the North Atlantic. This proposed drilling program would be the first controlled sampling of the Arctic seafloor, with the potential to provide much more detailed, continuous information than has come from short (<10 m), opportunistically sited cores. These data would open a new chapter in the study of Northern Hemisphere climatic behaviour.

## SCIENTIFIC OBJECTIVES

There are two major objectives: understanding the paleoceanographic history and the tectonic evolution of the central Arctic Ocean.

- The history of Arctic paleoceanography is so poorly known that we can look at the recovery of any material as a true exploration that will, by definition, increase our knowledge and understanding of this critical region.
- The tectonic objectives are focused on ridge evolution. If proven to be a continental fragment, it represents truly unique global information on the relative strength of continental and oceanic lithosphere

### Paleoceanographic objectives

There are a number of specific paleoceanographic objectives, questions that can be framed on results from lower latitudes, for which we believe there are testable hypotheses and that fully fit the scientific objectives outlined in the IODP Initial Science Plan; we offer some examples of these below.

#### *History of ice rafting*

Recent drilling in the Norwegian, Iceland, Irminger, and Greenland Seas has shown that the first coarse-grained ice-rafted material seems to appear earlier off southern Greenland than in the Fram Strait - Yermak Plateau region (Thiede and Myhre, 1996).

Does this trend continue into the central Arctic Ocean? Did the cooling and glacial inception occur earlier in the sub-Arctic than in the central Arctic or vice versa? These questions can be addressed only through sampling of central Arctic seafloor sediments. The presence or absence of ice-rafted material in a constrained stratigraphic context (see below) should directly address this issue.

### *Local versus regional ice-sheet development?*

Drilling results from the Fram Strait and Yermak Plateau regions have shown a series of middle and late Miocene pulses of ice rafting (14 Ma, 10.8-8.6 Ma, 7.2-6.8 Ma, 6.3-5.5 Ma, and continuing in sediments younger than 5 Ma.) (Thiede and Myhre, 1996). Do these represent local Svalbard ice expansion events or can the events also be observed in the central Arctic? The resolution of this issue has important ramifications on the climatic history of the Arctic. Again the presence or absence of ice-rafted material in a constrained stratigraphic context should provide the means to determining the answer to this question.

### *Density structure of Arctic Ocean surface waters, nature of North Atlantic conveyor and onset of Northern Hemisphere glaciation*

Aargard and Carmack (1994) proposed that the convective renewal rate and nature of large-scale North Atlantic/Nordic Seas circulation is dependent on the fresh-water supply from the Arctic Ocean. Driscoll and Haug (1998) also call upon changes in fresh-water input (from Siberian rivers) to facilitate ice formation and contribute to the onset of Northern Hemisphere glaciation. A decrease in fresh-water supply would move the present site of deep-water North Atlantic convection from the Greenland Sea into the central Arctic Ocean basins; this model implies a virtually ice-free Arctic Ocean. The contrast from ice-covered, well-stratified (oxygen-poor) Arctic Ocean waters to ice-free waters with free air-sea exchange (well oxygenated) will undoubtedly generate a recognizable signal in the sediments accumulating on the seafloor. A major change in river input should yield a strong sedimentological signal and deposit pollen and spores. These signals which can only be measured in the Arctic Basin should also be expressed in a number of other paleoceanographic proxies including, major and/or trace element geochemistry (i.e., MnO content), as well as in the isotopic composition of the calcareous benthic forams, if present.

### *Timing and consequences of the opening of the Bering Strait?*

Consistent with the model of Aargard and Carmack, Stigebrandt (1981) suggests that a decrease in fresh-water supply combined with a shut-off of Bering Strait inflow would result in the virtual loss of sea ice. Classically, the opening of the Bering Strait has been recognized by a dramatic change in the composition of shallow-water marine faunas (e.g., Marincovich, *et al.*, 1990) and in particular the influx of Pacific boreal molluscs to Iceland (Einarsson *et al.*, 1967). Ice-rafted debris should reveal when sea ice first formed in the Arctic Basin. Is the timing of this first permanent sea-ice cover coincident with the arrival of the Pacific boreal molluscs to Iceland?

### *Land-sea links: response of Arctic to Pliocene warm events*

Svend Funder and colleagues (1985) have demonstrated that northernmost Greenland was forested in the late Pliocene. Was this warm event local or regional? What was the Arctic Ocean doing at this time? Was biogenic carbonate preserved in the Arctic Basin at this time?

### *Development of deep Fram Strait and deep-water exchange between Arctic and GIN (Greenland, Iceland, Norway) seas/world ocean*

The Fram Strait represents the only deep-water connection between the Arctic and the world ocean. The timing of the formation of this passage is critical to the development of global circulation models. Several reconstructions exist (based mostly on tectonic arguments, e.g., Lawver, *et al.*, 1990, Eldholm *et al.*, 1990, Kristoffersen, 1990b) that place opening at times ranging from early Oligocene to late Miocene. What would the effect of the outflow of Arctic bottom waters have on the environment within the Arctic Basin?

### *History of biogenic sedimentation*

The four pre-Pleistocene cores from the Alpha Ridge (with ages of ~70 and ~35 Ma, respectively), all consist of black biosiliceous muds that indicate poorly ventilated bottom waters. Was the Arctic continuously biosiliceous and poorly stratified between 50 and 35 Ma? (Our drilling strategy will probably only take us back to the early Eocene). Plio-Pleistocene cores from Fram Strait and Yermak Plateau all contain biogenic carbonates. When did the transition from the dominance of biosiliceous sedimentation to carbonate-dominated sediments occur? Is this transition related to the strength of North Atlantic advection into the high latitudes?

## Stratigraphic control

Dating of Arctic Ocean sediments offers a classic problem in stratigraphy. When considering the general lack of information about the composition and microfossil contents of "pre-Pleistocene" sediments in the central Arctic, it appears pointless to speculate about the abundance and preservation of the various microfossil groups (e.g., foraminifers, nannofossils, radiolarians, diatoms, silicoflagellates), although spores, pollen, and dinoflagellates are likely to occur consistently. Magnetostratigraphy and various isotopic methods (e.g., Sr, U-Pb) in combination with biostratigraphy should ensure adequate chronological control. The use of ion microprobe techniques will allow in-situ analysis of element and isotope compositions of geological samples on a micrometer scale. Zircon, monazite and sphene are routinely analyzed for U-Pb ages >20 Ma using ion mass-spectrometry, where ages are determined on individual grains, making the technique well suited for sediment core material.

We must take into account the possibility that foraminiferal calcite may be largely lacking in the Lomonosov Ridge sediments, either due to carbonate dissolution or to paleoecological exclusion, thus preventing us from applying the conventional paleoceanographic proxy methods provided by stable isotope and trace element analysis of foram shells. Still, we consider that the wide array of existing analytical techniques in sedimentology, sediment physical properties, geochemistry, and paleontology, which can be applied to the Lomonosov Ridge sediments will yield adequate answers to our key questions. Available paleoceanographic proxy indicators include, for example, Plio-Pleistocene biogenic carbonate, dinoflagellates, pollen and spores, silicoflagellates, diatoms, O-isotopes in biogenic silica, fishapatite stable isotopes, etc. Spectral signatures of sediment color banding and provenance studies of IRD are also useful tools for deciphering the Arctic paleoenvironmental puzzle.

## Tectonic setting

The Lomonosov Ridge and the Eurasia Basin developed during the Late Cretaceous and Cenozoic, substantially expanding the Arctic Ocean basin and opening a deep-water connection to the North Atlantic. The Lomonosov Ridge has an asymmetric architecture expressed in its central part by strata prograding towards the Amerasian Basin. The topsets have been eroded away. The units are unconformably overlain by a several hundred metre thick drape of velocity <2 km/s (Jokat *et al.*, 1992). In contrast, the Eurasia Basin side of the ridge is a steep terrace of narrow fault blocks which accommodate more than 4 km of vertical relief relative to basement of the Amundsen Basin (Poselov *et al.*, 1998; Sorokin *et al.*, 1998).

The ridge structure changes character from a main block in the central narrow part to a more broadly faulted area towards the Laptev Sea (Jokat, 1998) as well as the Greenland and Canadian margin (Coakley and Cochran, 1998). The central narrow part of the Lomonosov Ridge near the North Pole exhibits a strong uneven reflection below about 600 m of sediments (Kristoffersen, 1998). These reflections resemble the acoustic image of basalt flows that also have been interpreted to cover basement on the margin north of Franz Josef Land and Kvitøya (Baturin, 1987), and may suggest a more-or-less continuous basalt province between Franz Josef Land and Ellesmere Island during Cretaceous time (Kristoffersen, 1998). Interpretation of the late Paleozoic and Mesozoic paleoenvironment of the northern margin suggests that the area to the north of Svalbard and Franz Josef Land was for the most part elevated to or above sea level from the Permian through Cretaceous, except for the Early Triassic and Late Jurassic (Doré, 1991). Present geological information of pre-Cenozoic rocks from the Lomonosov Ridge is limited to piston core recovery (Eurasian flank near 89°N; Grantz *et al.*, 1998; 2001) of monolithic rubble of indurated siltstone clasts containing reworked Devonian and Carboniferous spores, zircons of latest Permian age, and spores of a Jurassic and Cretaceous fern.

## Tectonic objectives

The Lomonosov Ridge is more than 1500 km long and less than 150 km wide. If proven to be a continental fragment, it represents truly unique global information on the relative strength of continental and oceanic lithosphere. The olivine rheology of the oceanic lithosphere is estimated to be three times stronger than typical continental lithosphere that includes a 35 km-thick continental crust of predominantly quartz/plagioclase rheology (Vink *et al.*, 1984). Juxtaposed oceanic and continental lithosphere in a tensional stress field would be weakest landward of the continental shelf edge (Lavier and Steckler, 1997; Steckler and ten Brink, 1986) and the Lomonosov Ridge may have formed as a result of this mechanism. The tectonic objectives for drilling on the Lomonosov Ridge are:

- To investigate the nature and origin of the Lomonosov Ridge by sampling the oldest rocks below the regional unconformity in order to establish the pre-Cenozoic environmental setting of the ridge.
- To study the history of rifting and the timing of tectonic events that affected the ridge.

# PRIORITY OF OBJECTIVES

The **first priority (I)** is the continuous recovery of a ~450 m thick sediment sequence from the crest of the Lomonosov Ridge between 87°N and 88°N. If we can achieve continuous sampling of the 450 m thick section in one of our key sites, the fundamental paleoceanographic objectives would be met. These sites are all located between 87°N and 88°N.

The **second priority (II)** is to sample the sites located near the Siberian margin, in order to recover a paleoceanographic Neogene sediments at higher, sub-millennial scale, resolution and to create a latitudinal transect spanning over ~6° of latitude in the Arctic Ocean. The **third priority (III)** is to sample the transition across the regional unconformity to establish the pre-Cenozoic environmental setting of the ridge, and to study the rifting and timing of tectonic events that affected the ridge.

# OPERATIONAL STRATEGIES

The operational plan includes strategies for transiting through ice to the drill sites and for maintaining station during drilling.

A fleet of icebreakers have been contracted to conduct this expedition. The fleet includes three vessels: a nuclear-powered icebreaker (*Sovetskiy Soyuz*) that will be the front line in ice breaking; a diesel-powered Icebreaker Polar-20 class (*Oden*) that will manage the broken ice to protect the drilling operation; and a diesel-powered Icebreaker ICE-10 class drilling vessel (*Vidar Viking*).

During icebreaking, the prime objective is to transit through a region with a minimum of fuel consumption, vessel damage, and time spent. The strategies, therefore, are ones of avoidance, lead following, and identifying ice environs that would result in minimal resistance. Vessels follow courses that may not be straight in order to minimize the energy and damage. This type of strategy will be followed while the vessels are in transit, but is in stark contrast to ice management strategies.

When on station, ice management requires direct engagement of difficult ice in order to ensure that ice does not impact the stationary, drilling platform, *Vidar Viking*. The *Sovietsky Soyuz* and *Oden* must follow the direction of ice approach to ensure that approaching ice is reduced to a tolerable level for the drilling vessel. The general strategy for ice management, while on station, will have the *Sovetskiy Soyuz* assigned to break ice first, up-drift of the ice flow. *Oden* will work within a close radius of the *Vidar Viking* to manage the ice and maintain a safe drilling zone.

# PROPOSED DRILL SITES

Successful drilling in the Arctic requires contingency planning. Sites are identified that span a large region of the Lomonosov Ridge to ensure that drilling can take place in one area should ice conditions preclude drilling operations in another. These areas are defined as the operational priority contingency areas (PCAs) within which the scientific priorities can be achieved. Because the PCAs are distributed over a 360 nm long and 40 nm wide corridor along the crest of the Lomonosov Ridge, they provide options should any single area have severe ice conditions. Severe ice conditions can occur within our study corridor, but during summer months, it is highly unlikely that more than one area would have severe conditions at any one time. Thus, the first site drilled will be in the PCA (Figure **F1**) that has suitable ice conditions to achieve the highest science priority possible and subsequent site selections will follow the same strategy.

There are five primary drill sites identified on the Lomonosov Ridge (Figure **F1**) to recover sequences that address our three priority objectives.

The first primary site (LORI-13A; Figures **F1**, **F2**, **F4**) is required to ensure recovery of a complete stratigraphic sediment record and to meet the highest priority paleoceanographic objective, a high-resolution long-term (50 Ma) climate history of the central Arctic Ocean; and the tectonic objective. It is proposed to drill and sample to a maximum penetration of 480 m to recover the complete hemipelagic sediment sequence (450 m) and 30 m of acoustic basement (bedrock). Because of the different objectives, it is proposed to drill three holes at this site, one APC/XCB/RCB hole to full penetration and two APC/XCB holes to recover multiple sections of the sediment sequence to ensure complete recovery for construction of a composite section (see Site Summary Forms). It is also proposed to wireline log the deepest hole at this site after completion of the coring. A similar strategy will be employed at all other cored sites.

| Site | Lat N | Lon E | Water Depth (m) | Seismic Line | Shot Point Range | Depth Below Seabed (m) |
|---|---|---|---|---|---|---|
| **Primary** | | | | | | |
| **LORI-13A** | 87° 39.5’ | 144° 37.8’ | 1070 | AWI-91091 | 1400-2100 | 500 |
| | | | | | 2100-2300 | 450 (drape only) |
| **LORI-06A** | 81° 28.5’ | 140° 50.7’ | 800 | AWI-98590 | 940-1350 | 650 |
| **LORI-04A** | 85° 23.3’ | 150° 20.6’ | 794 | Arctic-96015 | 150-275 | 200 |
| | | | | | 300-500 | 200 |
| | | | | | 500-650 | 375 |
| | | | | | 650-800 | 475 |
| **LORI-05A** | 83° 58.9’ | 147° 25.0’ | 890 | AWI-98565 | 500-1100 | 350 |
| | | | | | 1100-1600 | 400 |
| **LORI-10A** | 86° 24.9’ | 147° 15.6’ | 1132 | Arctic-96012 | 980-1180 | 400 |
| **Alternate** | | | | | | |
| **LORI-08A** | 87° 54.0’ | 138° 38.6’ | 1124 | AWI-91090 | 1800-3300 | 500 |
| **LORI-14A** | 87° 37.55’ | 147° 14.65’ | 1415 | UB-0105 | 240<br>Point location only | 400 |
| **LORI-12A** | 82° 04.3’ | 142° 02.6’ | 1392 | AWI-98580 | 150-350 | 720 |
| | | | | | 450-575 | 720 |
| | | | | | 625-840 | 720 |
| | | | | | 575-625 | 500 |

**Table T1.** ACEX – Summary of EPSP-approved (formerly PPSP) location SP ranges and depths. The approvals are based on the assumption that the seismic line width is 200 m, with the stated navigation as the center point.

Should drilling or coring result in unexpected problems at LORI-13A, two separate alternate sites have been approved: LORI-08A (Figures **F1** and **F3**) for completing the primary paleoceanographic objective (I), and LORI-14A (Figures **F1**, **F2** and **F4**) for completing the tectonic objective (III). It is proposed to drill and sample three APC/XCB holes to a maximum penetration of 450 m at LORI-08A to recover the hemipelagic sediment sequence. At LORI- 14A, it is proposed to drill and sample a single RCB hole to 200 mbsf to meet the tectonic objectives, where the transition between the oldest part of the hemipelagic sediment sequence and acoustic basement can be reached at a penetration depth of 176 m.

The second science priority is the recovery of a shorter-term climate history that will link the Neogene history of the Arctic Ocean to that of the North Atlantic Ocean at a sub-millennial scale resolution. For this objective, Site LORI-06A (Figures **F1** and **F5**) has an expanded Neogene sediment section and it is proposed to drill and sample three APC/XCB holes to EPSP approved depths. An alternate site to this one, Site

LORI-12A (Figures **F1** and **F5**) is located more than half a degree north so that it could be drilled, should the local ice conditions at LORI-06A be severe or if drilling difficulties are encountered. This site is interpreted to have an expanded Neogene sediment section, similar to the primary site.

Should the ice conditions prevent drilling at Site LORI-13A and its alternates, the primary paleoceanographic objectives can also be met by drilling either at Site LORI-10A (Figures **F1** and **F6**) or at Site LORI-05A (Figures **F1** and **F6**). At these sites the drilling strategy is identical and it is proposed to drill and sample three APC/XCB holes to EPSP-approved depths. One hole at each site will also be targeted for logging. The tectonic objective could be achieved within another priority contingency area at Site LORI-04A (Figures **F1** and **F7**) that is situated over a culmination of old sediments and/or basement below the regional unconformity within 200 m of the seafloor. Therefore, it is proposed to drill and sample a single RCB hole to EPSP-approved depths. Should drilling difficulties be encountered at any of these three primary sites, alternate sites can be drilled at any point within a limited range along the seismic line (see Site Summary Forms).

## CORING STRATEGY

The coring vessel is '*Vidar Viking*', an AHTS vessel with a polar ice class, full DP and a 2 m-diameter moonpool with under-hull ice protection via a retractable 'skirt'. The depth of protection requirement has been decided from data acquired from ice-stream modelling of the vessel hull during the design phase.

SeaCore, an offshore drilling contractor has been contracted to provide drilling services. A SeaCore modular drilling rig (R100 Model) structurally modified and equipped to operate in up to –20 degrees centigrade temperatures with top drive of sufficient lifting capacity installed for coring operations. Drilling tubulars are API standard with up to date thread and crack inspections and comprise 7" OD drillcollars and 5" API Range 2 drillpipe, both with 5 1/2" FH connections and a minimum 4" ID. The rig comes complete with pipe rack, pipe handling, power packs, mud tanks and all accessories and spares. Naturally degrading polymer mud will be used while drilling.

### Coring tools

BGS will supply a multi-function wireline suite of interchangeable coring tools for the expedition. Because these tools are new developments, ESO will additionally carry a proven suite of wireline coring tools (Appendix III). A variety of core bits will also be carried to allow coring in all anticipated formations including roller-cone core bits, PDC and natural diamond bits, and pilot bits with specially designed diamond crowns for hard-rock core recovery.

All inner barrels operate within the same outer core barrel. Thus it will be possible to sample soft to firm sediments and competent rock without tripping the drillstring, provided the main core bit lasts for the entire borehole length.

A modification of the ODP piston corer will be the main tool of use in soft to stiff formations. Due to derrick restrictions this is limited to a 4.5 m core length. Apart from the length of this tool all other dimensions are the same as the existing ODP

APC. There are additional inner-barrel tools should difficult or sandy formations be encountered. These include a push corer that can be rotated if required and can collect up to 4.5 m core length. For more competent formations an inner barrel system equivalent to the ODP XCB and RCB is used and can be variably adjusted to project or be part of the main drill bit. All of these systems are equipped with a non-return valve that seals overpressure borehole fluids from travelling up the drillstring ID and onto the drillfloor while the inner barrel is latched.

# SAMPLING AND MEASUREMENT STRATEGY

This Sampling and Measurements Plan for ACEX (Appendix 1) was prepared to meet the scientific objectives of IODP Proposal 533-Full3 following the recommendations of the Science Advisory Structure. This plan is the first for MSPs in scientific ocean drilling and incorporates some new approaches required due to the nature of MSPs where the science will be conducted offshore and onshore.

During the offshore component, three science activities will be conducted: (1) ephemeral properties (pore-water chemistry, microbiology, physical properties; gas analyses for safety purposes) will be measured and/or selected samples preserved; (2) core logging, supplemented with downhole logs for near real-time stratigraphic correlation; and (3) near real-time micropaleontology (and palynology) for biostratigraphic analyses. Cores will be sealed and stored in temperature-controlled containers for processing onshore. A subset of the full scientific party will participate during the offshore phase to complete this work.

The offshore science component is further divided into two parts: work conducted on *Vidar Viking* and on *Oden*. The primary scientific function on *Vidar Viking* is stratigraphic correlation to ensure that a complete sediment record is recovered at the prime sites. Also, measurements in support of drilling safety will be conducted. All core catcher material will be sampled on *Vidar Viking* and transferred to *Oden* primarily for micropaleontology (and palynology) and secondarily for sedimentology. After core intervals are confirmed to be duplicates (during stratigraphic correlation) from paired holes and on a selected basis, whole round intervals (5-10 cm lengths) will be sampled on the *Vidar Viking* for physical properties, pore-water chemistry and microbiology. Pore-water analyses will be conducted on both ships and microbiology sample preservation and analyses, physical property measurements, and organic chemistry analyses (for safety) will be conducted on *Oden*.

During the onshore component, the remaining scientific measurements and observations will be completed on the sealed cores requiring the entire scientific party (Appendix 1).

# DEFINITION OF ACEX EXPEDITION RESULTS (ER) DATA

ER data for ACEX includes:

- All data collected on *Vidar Viking* and *Oden* during the Expedition (Table **T2a**).
- All data derived from samples taken on *Vidar Viking* and *Oden* that are defined as minimum measurements by the Scientific Measurements Panel (SciMP)[1].
- Data needed to meet the scientific objectives of ACEX (Table **T2b**).

| Data Type | Location of Measurement |
|---|---|
| MSCL | *Vidar Viking* |
| Physical properties | *Oden* |
| Logging | *Vidar Viking* |
| Hydrocarbon monitoring | *Vidar Viking* and *Oden* |
| Carbonate content | *Oden* |
| Pore-water chemistry[4] | *Vidar Viking and Oden* |
| Biostratigraphy (cc only) | *Oden* |
| Seismic data | *Oden* |
| Geophysical survey data | Collected pre-expedition |

**Table T2a** Types of data collected offshore to be included in ER volume.

| Data Type | Location of Measurement |
|---|---|
| Physical properties[2] | Bremen |
| Visual core description | Bremen |
| Digital core photos | Bremen |
| MSCL[3] | Bremen |
| Paleomagnetic reversal stratigraphy | Scientist's labs; results to be delivered to Science Party 2 months after the start of the moratorium period |
| Geochemistry[5] | Bremen |
| Pore-water chemistry[4] | Bremen |

**Table T2b** Types of data collected onshore to be included in ER volume.

1 SCIMP is currently preparing the recommended IODP policy on minimum measurement requirements
2 Index properties, acoustic velocity, resistivity and thermal conductivity
3 For parameters not captured on the *Vidar Viking* or that require re-measurement
4 Typical constituents will include salinity, pH/alkalinity, ammonia, and chloride, but a final list will be determined by the science party
5 As discussed by Shipboard Scientific Party

# GEOPHYSICS

The EPSP approved the sites proposed and, as requested, approved a range of shotpoints where each site could be positioned to improve the ice contingency plans. The EPSP determined that it would not be necessary to acquire any additional cross-lines before drilling, and approved a 200 meter wide swath along the approved shot point intervals (Table **T1**). Further seismic lines will not therefore be collected for site-selection purposes. However, seismic equipment and an operational team will be on board *Oden*, and additional could be acquired for scientific purposes after the successful completion of sites.

# SAMPLE ALLOCATION COMMITTEE AND SAMPLING REQUESTS

At the time of the publication of this Scientific Prospectus, the IODP Sample, Data, and Obligations policy is not finalized but the interim IODP Sample, Data and Obligations Policy (**www.iodp.org/downloads/IODP_SD_Policy.pdf**) has been put in place. Access to data and core sampling during Expedition 302, or within the 1-year moratorium following the onshore part of the expedition, must be approved by the Sample Allocation Committee (SAC).

The SAC (composed of Co-Chief scientists, Staff Scientist, and ESO Curation Manager onshore or the curatorial representative onboard ship) will work with the Scientific Party to formulate a formal expedition-specific sampling plan for post-cruise sampling.

The SAC reviewed and made decisions on sample requests for the offshore component of the expedition, but deferred the onshore requests until after the offshore phase. The SAC agreed that this deferment is needed so that sample requests can be reviewed in the context of the known core recovery and lithology.

All sample frequencies and sizes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the expedition objectives. Some redundancy of measurement may be unavoidable, but minimizing the duplication of measurements among the Scientific Party (may include approved shore-based collaborators) will be a factor in evaluating sample requests.

The minimum permanent archive will consist of one half of each core taken from the deepest hole drilled at a site. As such, the archive halves of cores from additional holes drilled to equal or shallower depths that contain replicate copies of stratigraphic intervals constituting the minimum permanent archive, need not be designated as permanent archive, but can be, if so desired by the SAC. This may be required, for example, to fill gaps in recovery in the deepest hole. If not designated as permanent archive, they are "temporary archive". If a composite splice section is constructed and the sampling demand exceeds the working half, an alternative scenario may be required to make sure that all samples can be taken from the spliced section. In this case, the permanent archive will be defined from cores that are not part of the splice (e.g., from cores from different holes).

The Sample Allocation Committee comprises:

| | |
|---|---|
| Jan Backman | Co-chief |
| Kate Moran | Co-chief |
| Ursula Röhl | ESO Curation Manager (Alex Wülbers is the offshore representative) |
| Dan Evans | ESO Staff Scientist |

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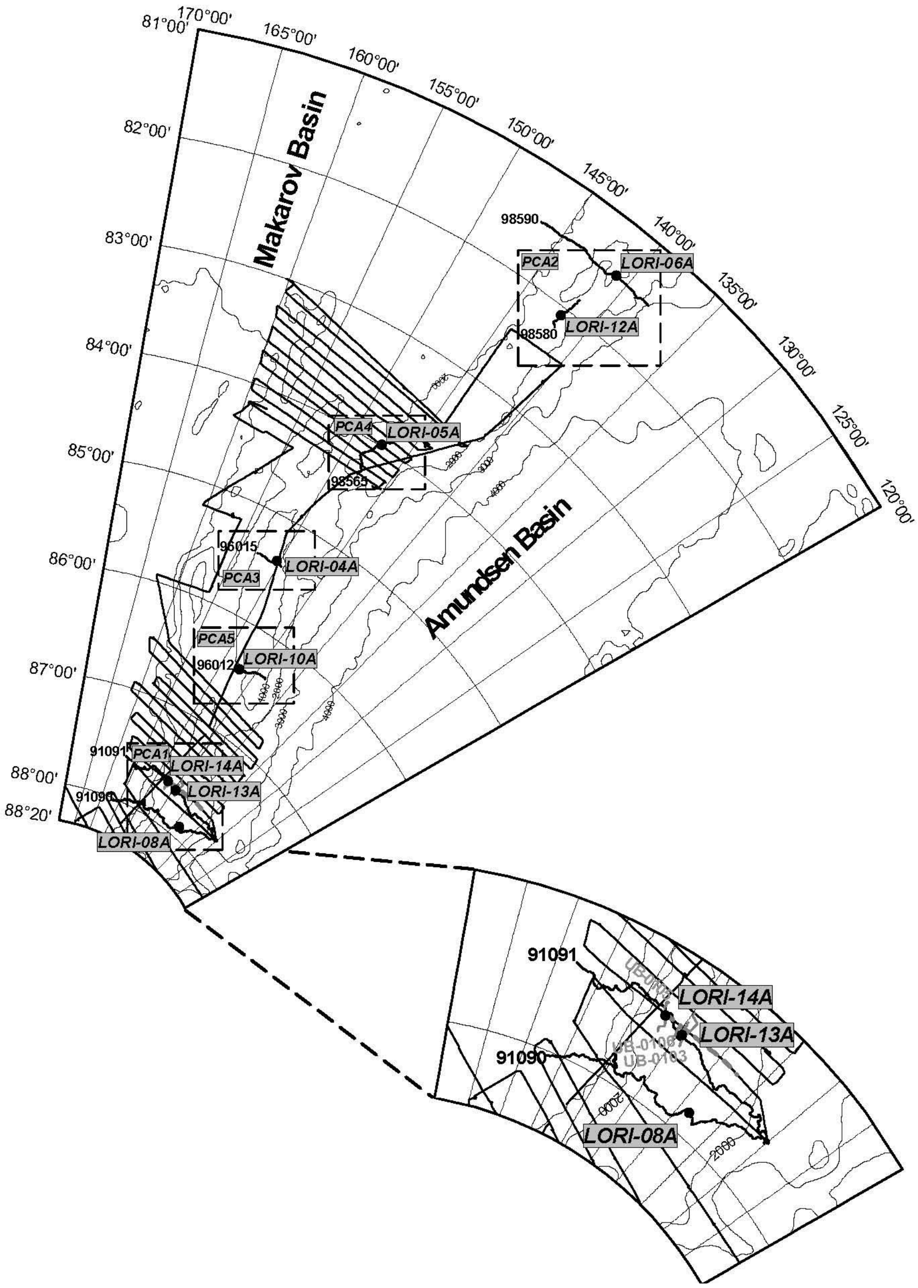



**Figure F1.** Primary (13, 6, 4, 5, 10) and alternate (8, 14, 12) LORI sites, reflection seismic profiles (icebreaker data: wiggly lines), and SCICEX chirp profiles (regular grid). PCA: Priority Contingency Areas. Thick gray stippled line in PCA1: Chirp profile shown in Figure F4.

# SITE SUMMARIES

## Proposed Site: LORI-13A

**Priority:** 1
**Position:** 87°39.45’N 144°37.80’E
**Water Depth:** 1070m
**Sediment Thickness:** 450m
**Target Depth:** 480m
**Approved Maximum Penetration:**

**Seismic Coverage:**
Deep Penetration
seismic reflection
Primary Line(s): UB 0103 airgun
Location of Site on line SP 246
Crossing Lines(s): AWI 91091

**Parasound Coverage:**
High resolution seismic reflection
Primary Line(s): AWI Parasound

**Objectives:**
1. Drill and sample the most complete stratigraphic pelagic sediment section to meet the paleoceanographic objectives for understanding the paleo Arctic Ocean circulation, its relationship with global climate, and changes in sediment flux to the basin.
2. Penetrate and sample acoustic basement to meet the tectonic objectives.

**Drilling Program:**
Drill and sample 2 APC/XCB holes to 450 mbsf and 1 APC/XCB/RCB hole to 480 mbsf.
Triple APC to refusal, XCB 30 m into basement and log.

**Downhole Logging Program:**
Ice conditions permitting, the aim is to log at least one hole. At a minimum, formation density, porosity, resistivity, velocity, and gamma-ray spectrum will be logged.

**Nature of Rock Anticipated:** Sediments: Silty clays, clays, siltstone, claystone
Basement: Continental crust rock: lithology is not known, but could range from volcanics to carboniferous rocks.

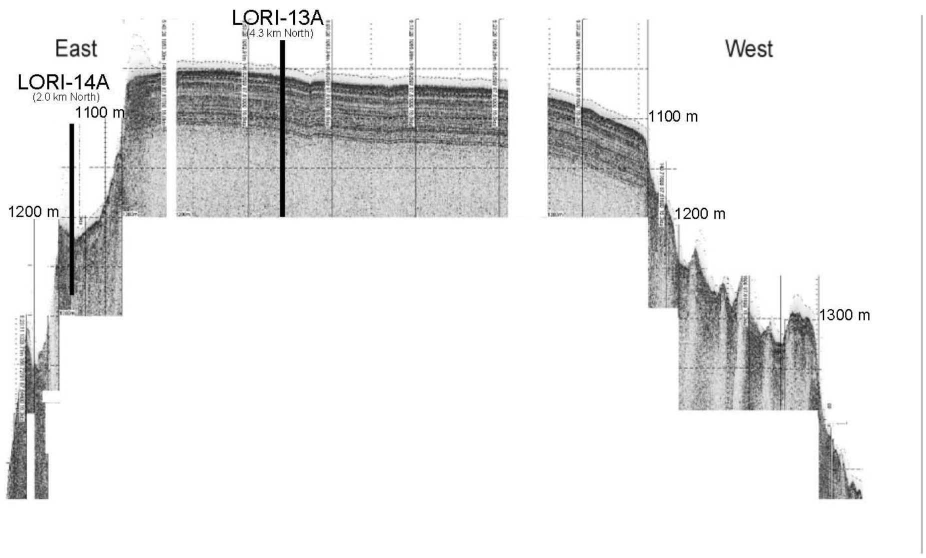



**Figure F4**. High resolution seismic profile (SCICEX chirp data) across the Lomonosov Ridge near Sites LORI-13A and LORI-14A. Geographic location is shown in Figure **F1** (thick gray stippled line).

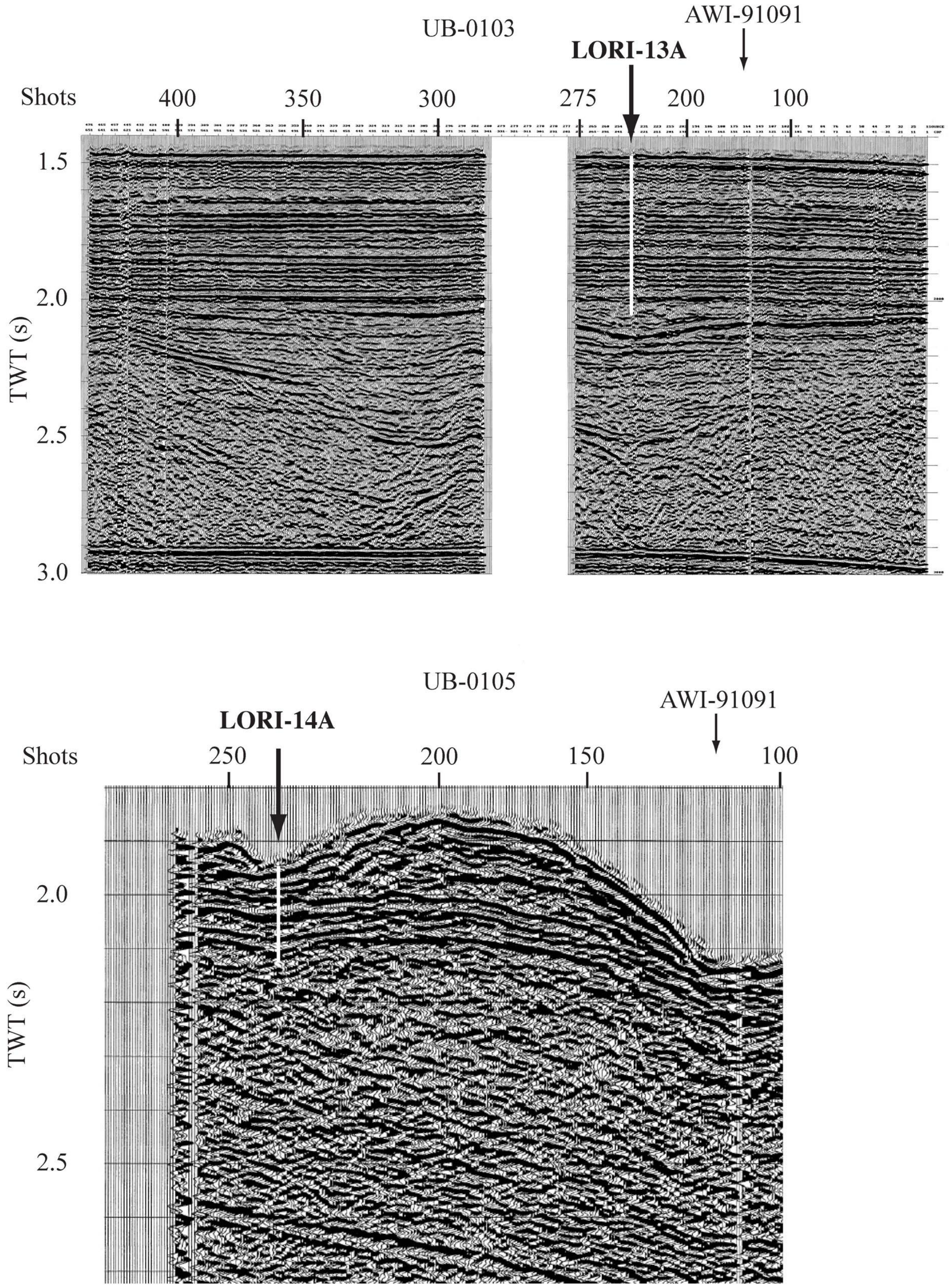



**Figure F2.** Primary paleoceanographic Site LORI-13A on seismic line UB-0103 (upper panel). Alternate tectonic Site LORI-14A on seismic line UB-0105 (lower panel). Crossline AWI-91091 marked. Geographic locations are shown in Figure F1.

## Proposed Site: LORI-08A alternate site to LORI-13A

**Priority:** ?1A
**Position: Deg:** 87 °53.9'N 138 ° 38.6'E
**Water Depth:** 1124m
**Sediment Thickness:** 450m
**Target Depth:** 450m
**Approved Maximum Penetration:**

**Seismic Coverage**
Deep Penetration
seismic reflection
Primary Line(s): AWI 91090 Airgun
Location of Site on line (SP or Time only): SP 2700

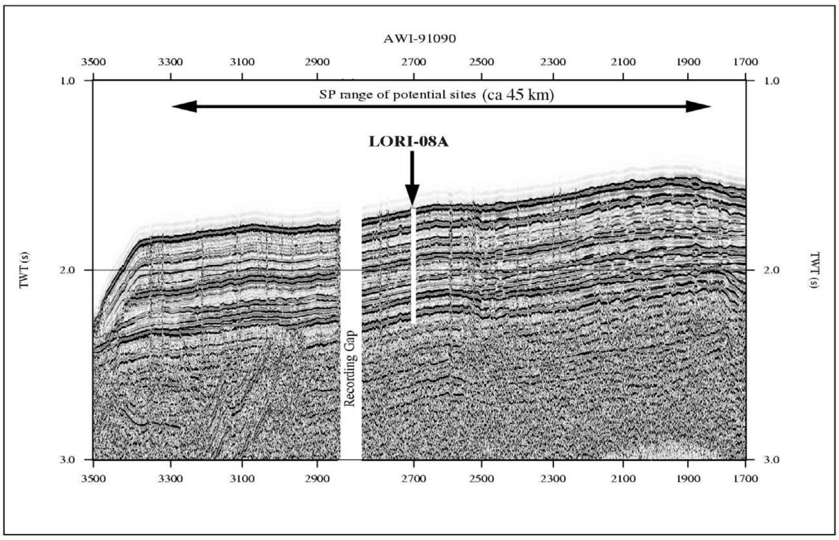
**Parasound Coverage:**
Primary Line(s): AWI Parasound
Location of Site on line (SP or Time only)

**Objectives:** Drill and sample a complete stratigraphic pelagic sediment section to meet paleoceanographic objectives for understanding the paleo Arctic Ocean circulation, it relationship with global climate, and changes in sediment flux to the basin.

**Drilling Program:** Drill and sample 3 APC/XCB holes to 450 mbsf and log.

**Downhole Logging Program:**
Ice conditions permitting, the aim is to log at least one hole. At a minimum, formation density, porosity, resistivity, velocity, and gamma-ray spectrum will be logged.

**Nature of Rock Anticipated:** Silty clays, clays, siltstone, claystone



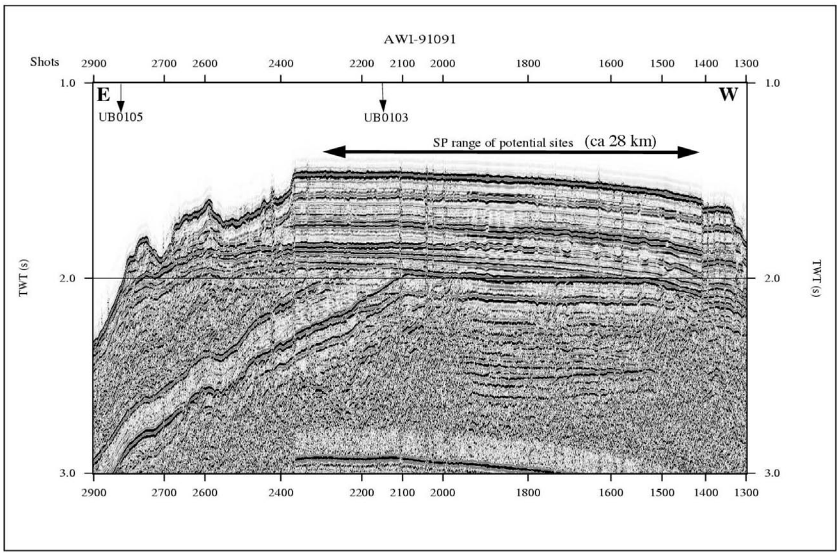




**Figure F3.** Reflection seismic cross-sections of Lomonosov Ridge along profiles AWI-91090(upper panel) and AW-91091 (lower panel). Shotpoint ranges of potential paleoceanographic sites are shown, e.g., Site LORI-08A. Geographic locations are shown in Figure **F1**. Vertical arrows show positions of seismic crosslines UB-0103 and UB-0105 (see Figure **F2**).

## Proposed Site: LORI-14A alternate site to LORI-13A

**Priority:** ?1B
**Position: Deg:** 87 °37.55'N 147 ° 14.65'E
**Water Depth:** 1415m
**Sediment Thickness:** 90m
**Target Depth:** 200m
**Approved Maximum Penetration:**

**Seismic Coverage**
Deep Penetration
seismic reflection
Primary Line(s): UB0105 Airgun
Location of Site on line (SP or Time only): SP 240
Crossing Lines: AWI 91091

**Parasound Coverage:**
Primary Line(s): AWI 9Parasound
Location of Site on line (SP or Time only)

**Objectives:**
Penetrate and sample acoustic basement to meet the tectonic objectives

**Drilling Program:**
Drill and sample a single RCB hole to 200 mbsf.

**Downhole Logging Program:**
Ice conditions permitting, the aim is to log at least one hole. At a minimum, formation density, porosity, resistivity, velocity, and gamma-ray spectrum will be logged.

**Nature of Rock Anticipated:** Silty clays, clays, siltstone, claystone. Continental crust rock: lithology is not known, but could range from volcanics to carboniferous rocks.

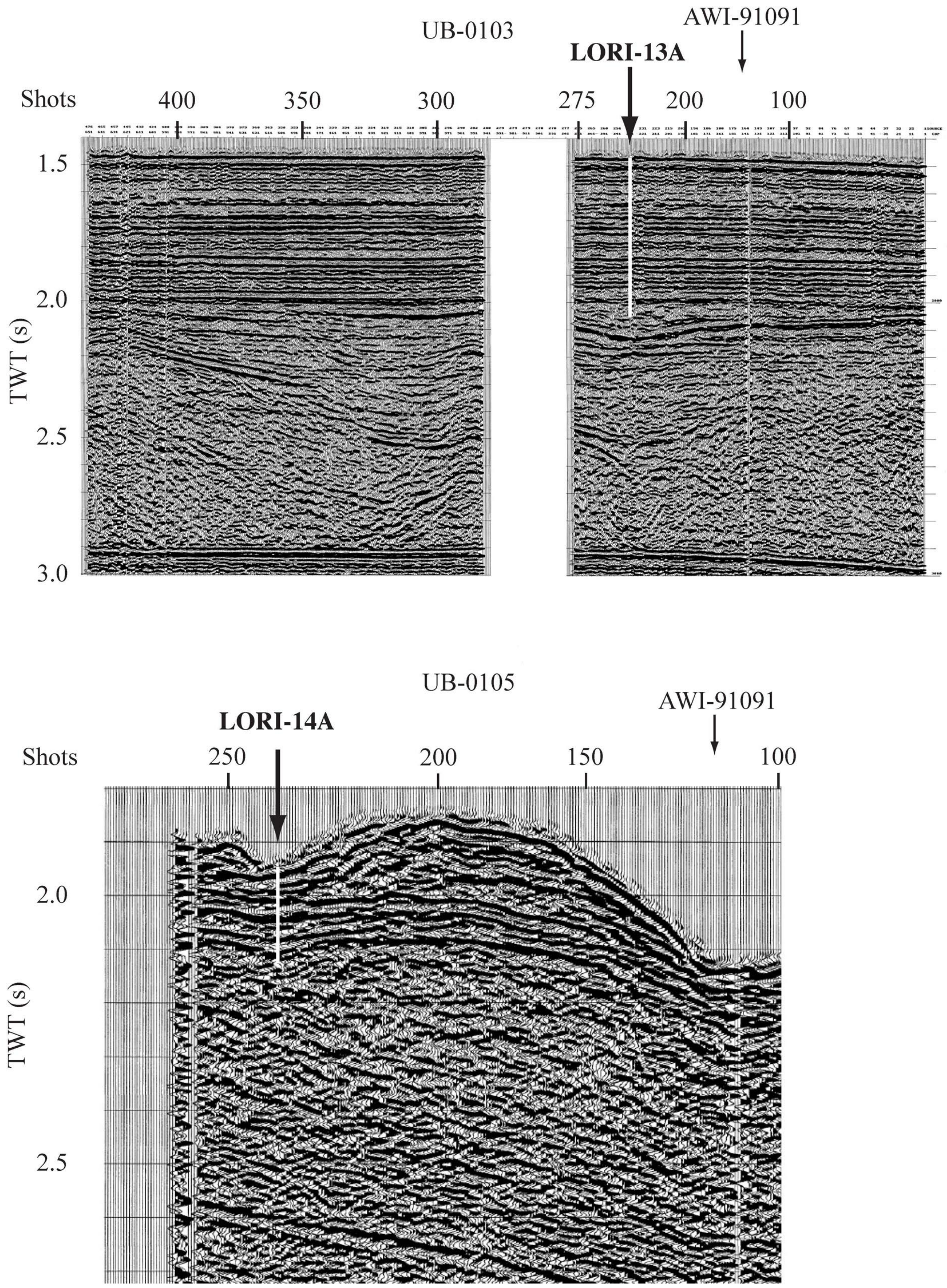



**Figure F2.** Primary paleoceanographic Site LORI-13A on seismic line UB-0103 (upper panel). Alternate tectonic Site LORI-14A on seismic line UB-0105 (lower panel). Crossline AWI-91091 marked. Geographic locations are shown in Figure F1.

## Proposed Site: LORI-06A

**Priority:** 2
**Position:** 81°28.54'N 140°50.71'E
**Water Depth:** 802m
**Sediment Thickness:** 400m
**Target Depth:**400m
**Approved Maximum Penetration:**

**Seismic Coverage:**
Primary Line(s): AWI 98590 Airgun
Location of Site on line (SP or Time only): SP 950

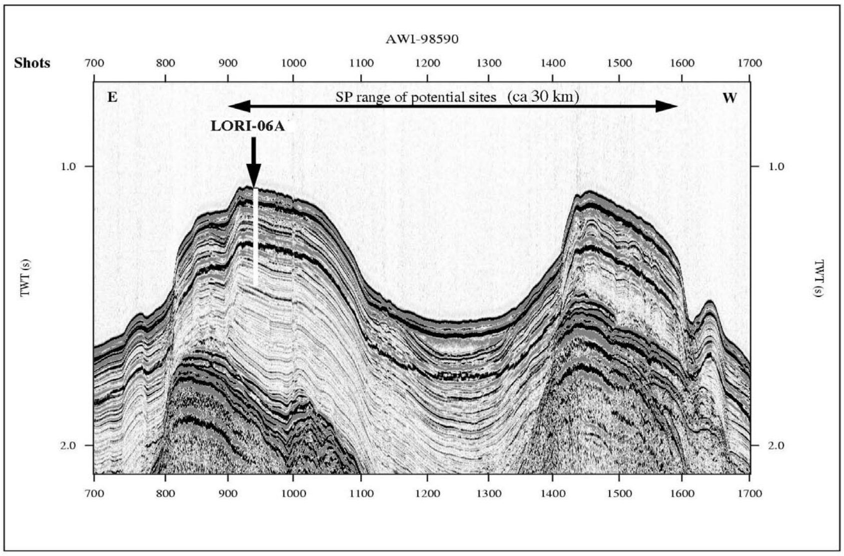
**Parasound Coverage:**
Primary Line(s): Parasound
Location of Site on line (SP or Time only)

**Objectives:**
Drill and sample the most complete stratigraphic pelagic sediment section to meet paleoceanographic objectives for Neogene climate history.

**Drilling Program:** Drill and sample 3 APC/XCB holes to 400 mbsf and log.

**Downhole Logging Program:**
Ice conditions permitting, the aim is to log at least one hole. At a minimum, formation density, porosity, resistivity, velocity, and gamma-ray spectrum will be logged.

**Nature of Rock Anticipated:** Silty clays, clays, siltstone, claystone.



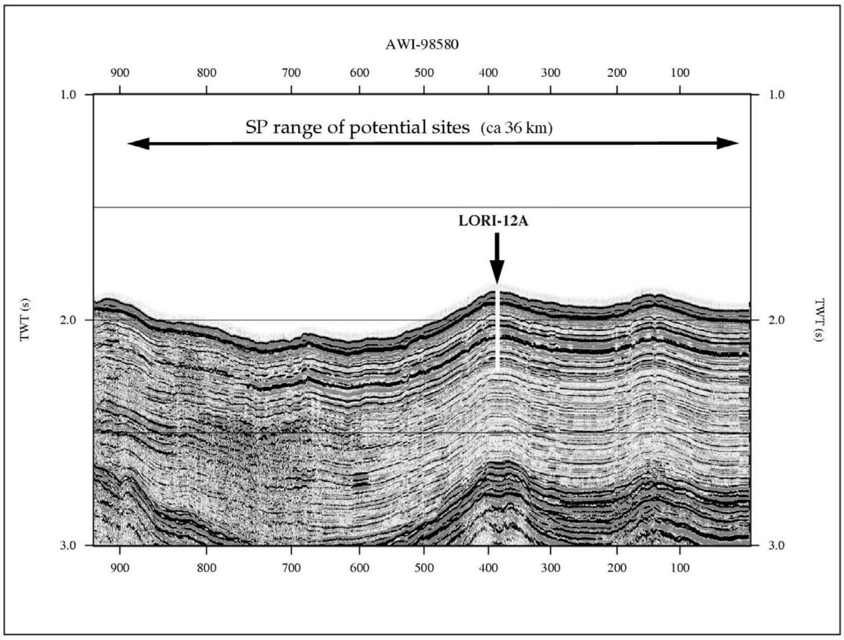




**Figure F5**. Primary (LORI-06A) and alternate (LORI-12A) high resolution Neogene sites from Priority Contingency Area (PCA) 2. Geographic locations are shown in Figure **F1**.

## Proposed Site: LORI-12A alternate site to LORI-06A

**Priority:** ?2A
**Position:** 82°04.3'N 142° 02.6'E
**Water Depth:**1392m
**Sediment Thickness:**400m
**Target Depth:** 400m
**Approved Maximum Penetration:**

**Seismic Coverage**
Primary Line(s): AWI 98580 Airgun
Location of Site on line (SP or Time only): SP 400

**Parasound Coverage:**

**Objectives:**
Drill and sample the most complete stratigraphic pelagic sediment section to meet paleoceanographic objectives for Neogene climate history.

**Drilling Program:**
Drill and sample 3 APC/XCB holes to 400 mbsf.

**Downhole Logging Program:**
Ice conditions permitting, the aim is to log at least one hole. At a minimum, formation density, porosity, resistivity, velocity, and gamma-ray spectrum will be logged.

**Nature of Rock Anticipated:** Silty clays, clays, siltstone, claystone

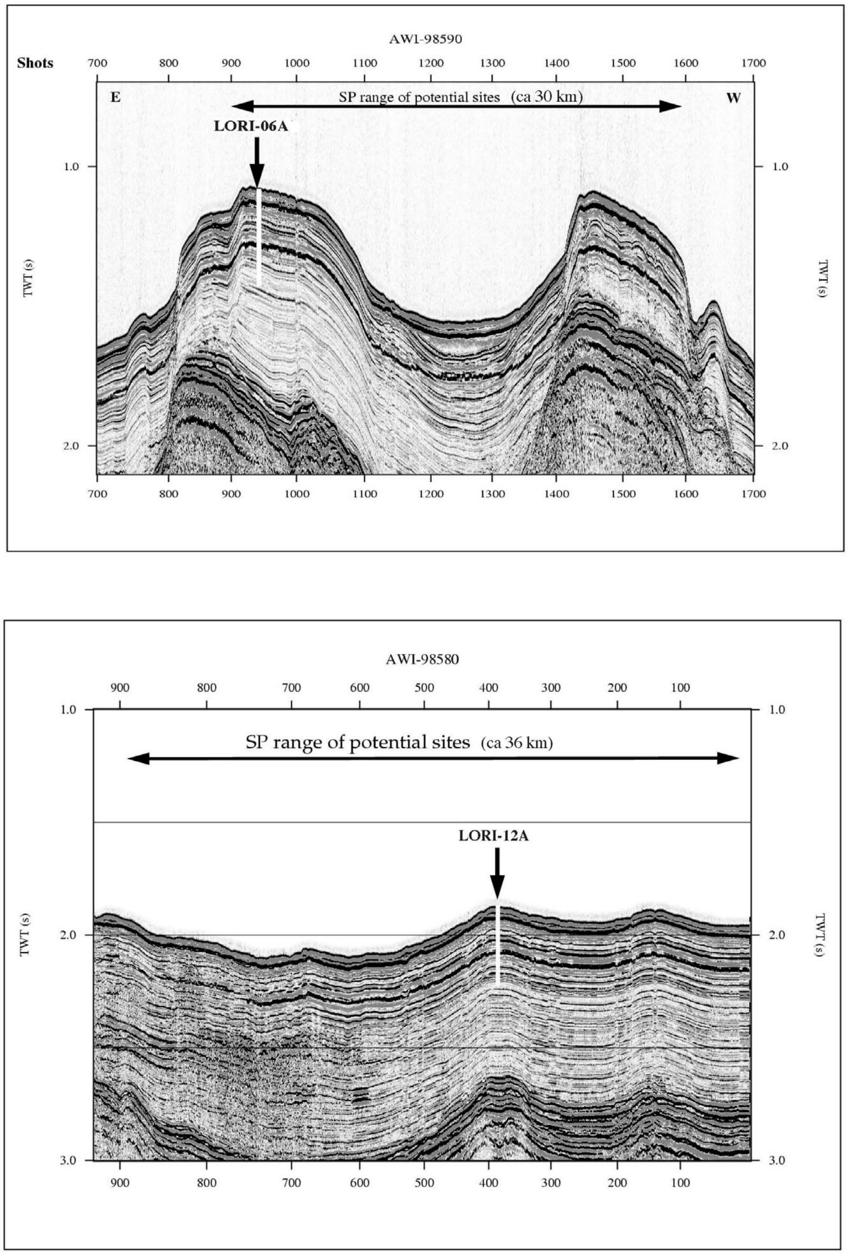



**Figure F5**. Primary (LORI-06A) and alternate (LORI-12A) high resolution Neogene sites from Priority Contingency Area (PCA) 2. Geographic locations are shown in Figure **F1**.

## Proposed Site: LORI-04A

**Priority:** 3
**Position:** 85°23.3'N 150°20.6'E
**Water Depth:** 794m
**Sediment Thickness:** 170m
**Target Depth:** 200m
**Approved Maximum Penetration:**

**Seismic Coverage**
Primary Line(s): AWI 96015
Location of Site on line (SP or Time only): SP 300

**Parasound Coverage:**
Primary Line(s): AWI 9Parasound

**Objectives:**
Penetrate and sample acoustic basement to meet the tectonic objectives.

**Drilling Program:**
Drill and sample a single RCB hole to 200 mbsf into basement.

**Downhole Logging Program:**
Ice conditions permitting, the aim is to log at least one hole. At a minimum, formation density, porosity, resistivity, velocity, and gamma-ray spectrum will be logged.

**Nature of Rock Anticipated:** Silty clays, clays, siltstone, claystone. Continental crust rock: lithology is not known, but could range from volcanics to carboniferous rocks.

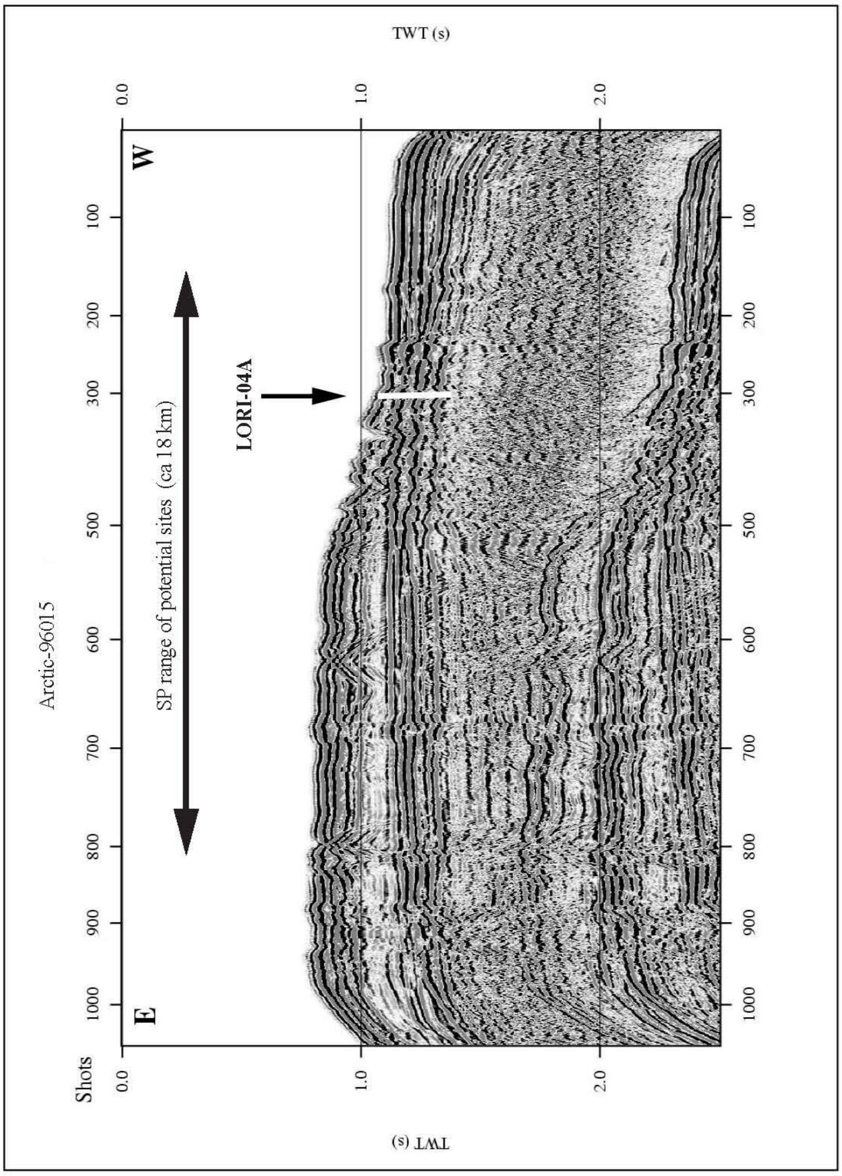



**Figure F7.** Reflection seismic cross-section of Lomonosov Ridge along profile Arctic-96015 from Priority Contingency Area (PCA) 4, showing relatively thin sediment cover (ca 70-90 m) above the regional unconformity at Site LORI-04A, designed to achieve tectonic objectives. Geographic location is shown in Figure **F1**.

## Proposed Site: LORI-05A

**Priority:** 4
**Position:** 83° 58.90’N; 147° 25.02’E
**Water Depth:** 989m
**Sediment Thickness:** 400m
**Target Depth:**
**Approved Maximum Penetration:**

**Seismic Coverage**
Primary Line(s): AWI 98565 Airgun
Location of Site on line (SP or Time only): SP 700

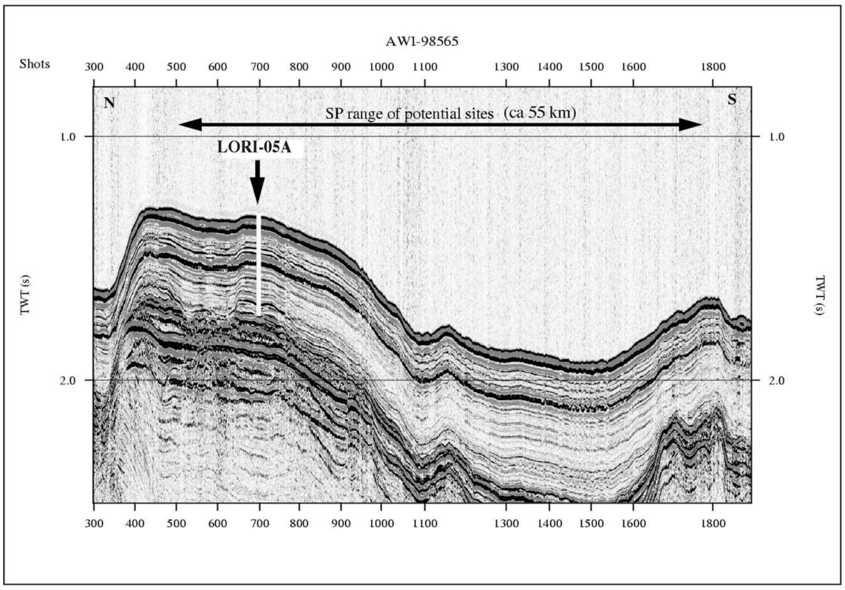
**Parasound Coverage:**

**Objectives:**
Drill and sample the most complete stratigraphic pelagic sediment section to meet paleoceanographic objectives.

**Drilling Program:**
Drill and sample 3 APC/XCB holes to 400 mbsf and log.

**Downhole Logging Program:**
Ice conditions permitting, the aim is to log at least one hole. At a minimum, formation density, porosity, resistivity, velocity, and gamma-ray spectrum will be logged.

**Nature of Rock Anticipated:** Silty clays, clays, siltstone, claystone.



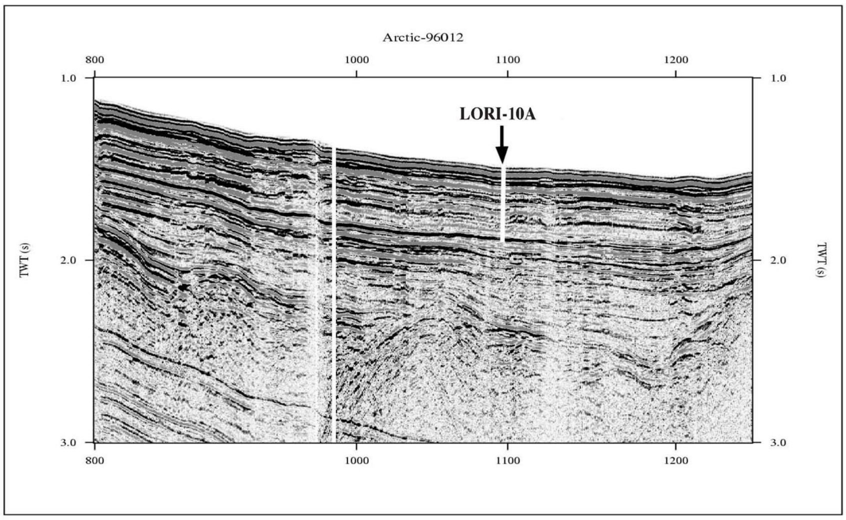
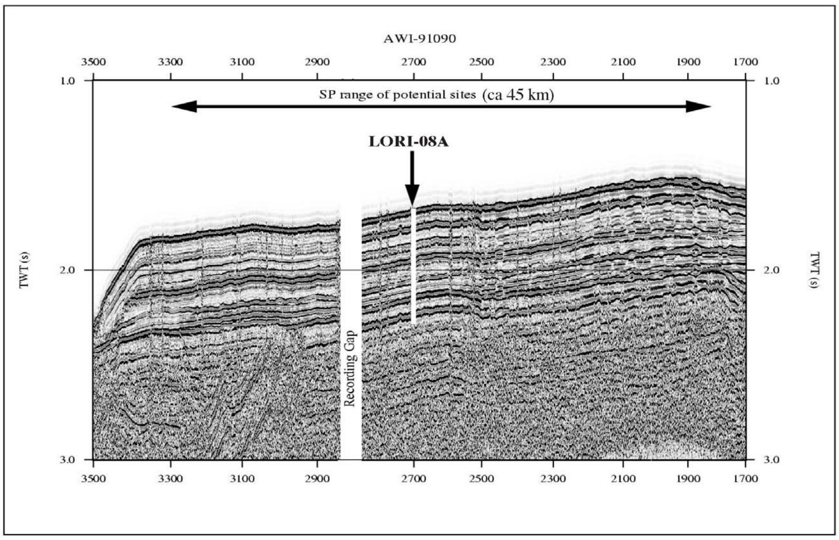




**Figure F6**. Primary paleoceanographic objectives can also be met by drilling in either Priority Contingency Area ( PCA) 4 at Site LORI-10A (lower panel) or in PCA5 at Site LORI-05A (upper panel). Geographic locations are shown in Figure **F1**.



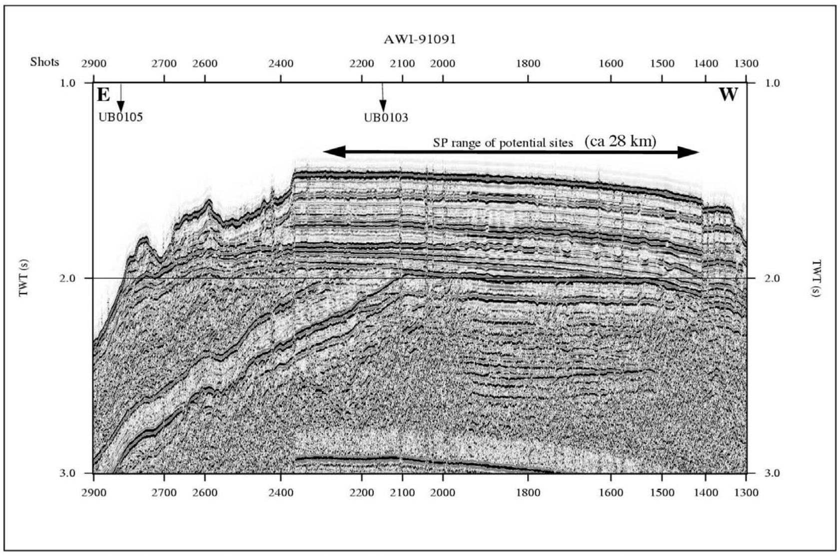




**Figure F3.** Reflection seismic cross-sections of Lomonosov Ridge along profiles AWI-91090(upper panel) and AW-91091 (lower panel). Shotpoint ranges of potential paleoceanographic sites are shown, e.g., Site LORI-08A. Geographic locations are shown in Figure **F1**. Vertical arrows show positions of seismic crosslines UB-0103 and UB-0105 (see Figure **F2**).

## Proposed Site: LORI-10A

**Priority:** 5
**Position:** 86° 24.89’N; 147°15.56’E
**Water Depth:** 1132m
**Sediment Thickness:** 400m
**Target Depth:** 400m
**Approved Maximum Penetration:**

**Seismic Coverage**
Primary Line(s): AWI 96012 Airgun
Location of Site on line (SP or Time only): SP1100

**Parasound Coverage:**

**Objectives:**
Drill and sample the most complete stratigraphic pelagic sediment section to meet paleoceanographic objectives.

**Drilling Program:**
Drill and sample 3 APC/XCB holes to 400 mbsf .

**Downhole Logging Program:**
Ice conditions permitting, the aim is to log at least one hole. At a minimum, formation density, porosity, resistivity, velocity, and gamma-ray spectrum will be logged.

**Nature of Rock Anticipated:** Silty clays, clays, siltstone, claystone

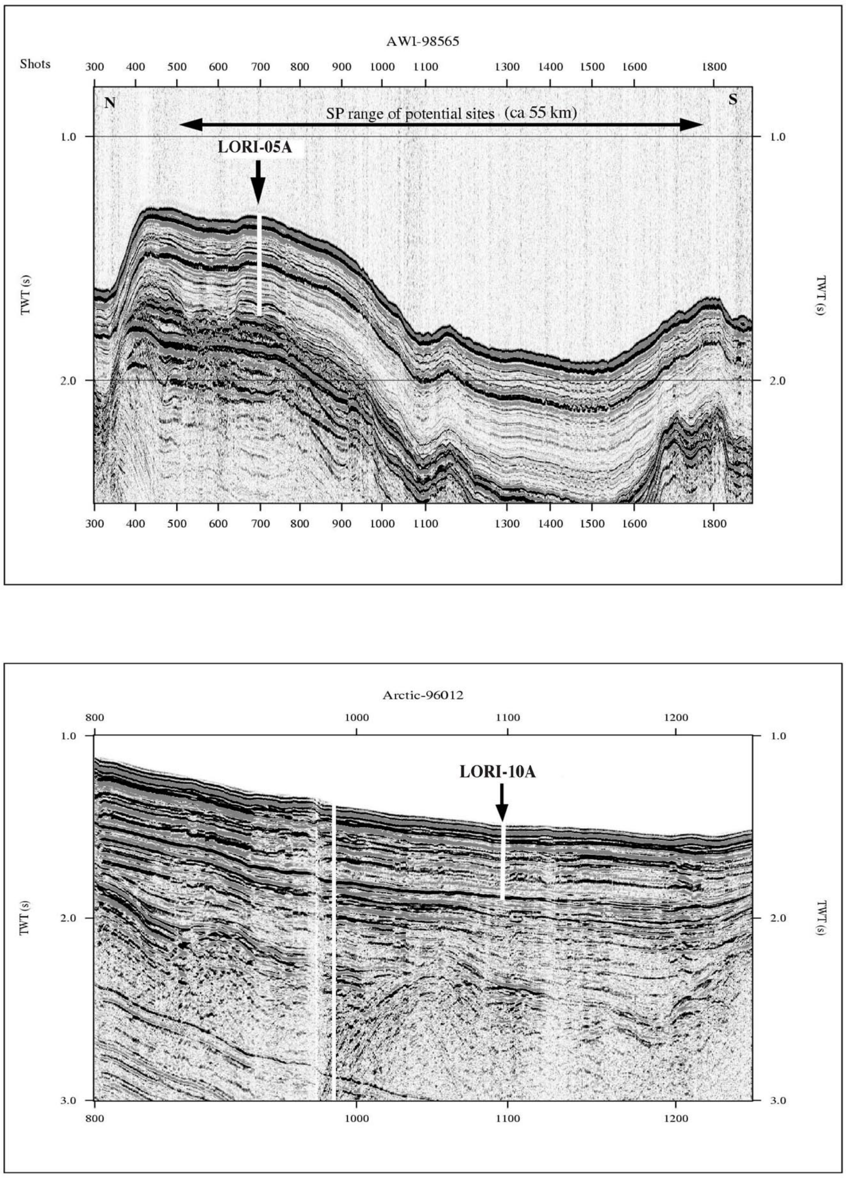



**Figure F6**. Primary paleoceanographic objectives can also be met by drilling in either Priority Contingency Area ( PCA) 4 at Site LORI-10A (lower panel) or in PCA5 at Site LORI-05A (upper panel). Geographic locations are shown in Figure **F1**.

# ACEX SCIENCE PARTY

## Onshore Participants

| *Name* | *Address* | *Role* |
|---|---|---|
| James L Cullen | Geological Sciences<br>Salem State College<br>Salem<br>MA 01970<br>USA<br>E-mail: **james.cullen@salemstate.edu** | Sedimentologist |
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| | | |
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## Onshore and Offshore Participants

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| Martin Jakobsson | Department of Geology and Geochemistry,<br>Stockholm University,<br>106 91,<br>Stockholm,<br>Sweden<br>E-mail: **martin.jakobsson@geo.su.se** | Physical properties/logging specialist |
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| | | |
|---|---|---|
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| Domenico Rio | Department of Geology, Paleontology and Geophysics,<br>University of Padova,<br>1 Via Giotto,<br>Padova,<br>35137,<br>Italy<br>E-mail: **domenico.rio@unipd.it** | Micropaleontologist – nannofossils |
| David Charles Smith | Graduate School of Oceanography,<br>University of Rhode Island,<br>Narragansett,<br>RI 02882,<br>USA<br>E-mail: **dcsmith@gso.uri.edu** | Microbiologist |
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| Kozo Takahashi | Department of Earth and Planetary Sciences ,<br>Kyushu University,<br>6-10-1, Hakozaki,<br>Higashi-ku,<br>Fukuoka 000-812-8581,<br>Japan<br>E-mail: **kozo@geo.kyushu-u.ac.jp** | Micropaleontologist – silicoflagellates/radiolaria |
| Alexey Krylov | Department of Lithology and Geochemistry,<br>VNIIOkeangeologia ,<br>1, Angliysky pr,<br>St. Petersburg,<br>190121,<br>Russia<br>E-mail: **akryl@vniio.nw.ru** or **akrylow@mail.ru** | Observer/sedimentologist |

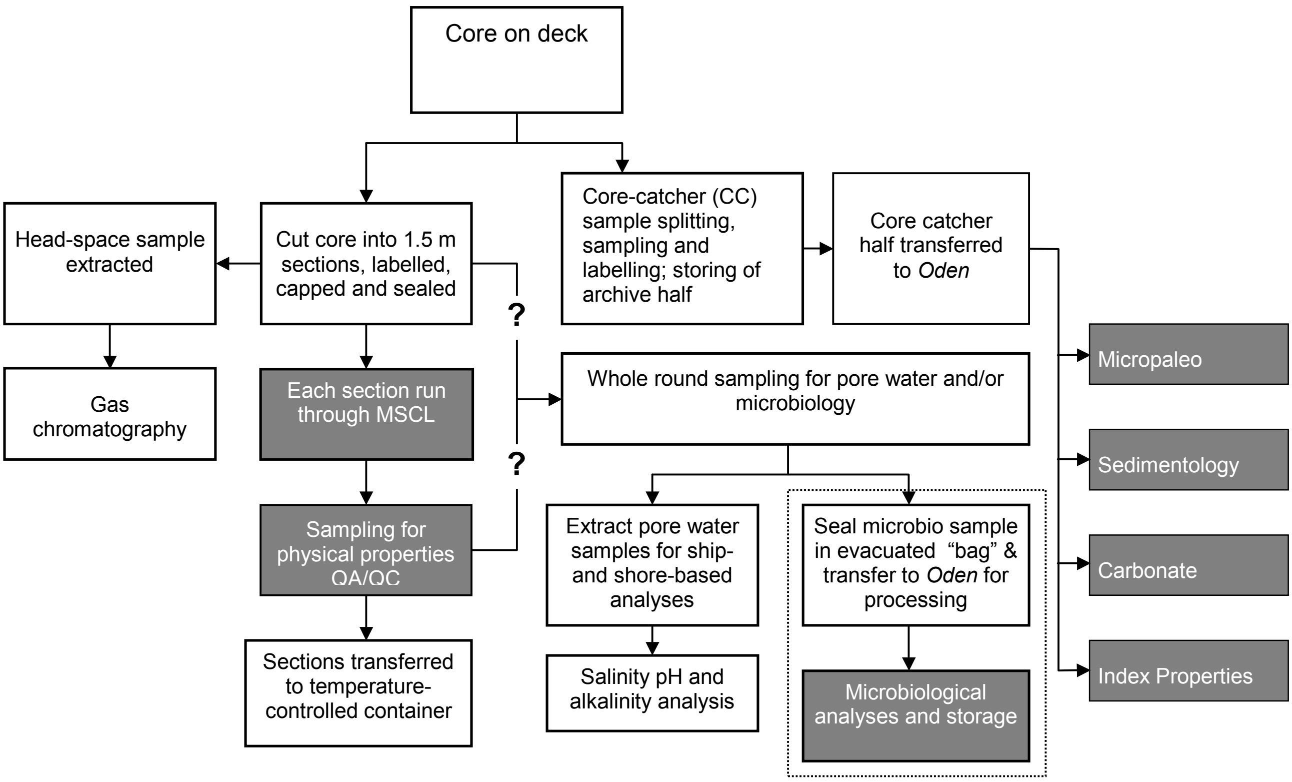
# APPENDIX I MEASUREMENTS PLAN

## Arctic Coring Expedition (ACEX)

## ESO Sampling and Measurement Plan

This plan is subject to amendment according to the scientific needs and interests of the Scientific Party of the expedition

## Offshore sampling and analysis (Figure A1-1)




### *Core curation*

A mobile core-curation laboratory container onboard the drill ship will be used to catalogue and maintain a database of recovered core. Two temperature-controlled core-storage containers will be on the drillship, with additional storage available on the *Oden* should more core be collected than anticipated.

### *Micropaleontology*

Core catcher samples will be collected on the drill ship and transferred to the *Oden* where the paleontologists and a technician will be based. The experienced technician is being contracted from the University of Stockholm, and there is suitable laboratory space for preparation. Microscopes will be provided as follows: the University of Stockholm (6), Bremen (2) and one other scientist (1). The following groups of microfossils will be studied:

- Nannofossils
- Diatoms
- Silicoflagellates, ebridians
- Foraminifera
- Ostracods
- Radiolarians
- Dinoflagellates, spores, pollen

## Organic geochemistry

A sniffer device will be used to check for the presence of gas as part of the drilling safety procedure. This sniffer detects $H_2S$, $CO_2$ and $C^1$–$C^4$, and will provide quantitative data which will be logged, and from which $C^1$:$C^2$ ratios can be determined. Headspace gas samples will also be collected for GC analysis both offshore and onshore.

Two samples will be taken; one for offshore analysis, the second will be refrigerated for analysis onshore. We will seal two 5mL sediment samples in dry 20 mL vials.

## Inorganic geochemistry

Several ephemeral properties in pore-water require that pore water should be extracted immediately from a core, and, depending on the parameter, might be specially treated in order to conserve it for later analyses. The pore waters may be sampled after core logging provided the logging is carried out sufficiently rapidly so that the quality of the pore-water is not compromised. Pore-water sampling will not be carried out in the A hole, but will begin in the B hole.

ESO propose a simple procedure for the proper preservation of interstitial water and some measurements of ephemeral parameters. This is a minimal scheme since both lab space and manpower are strictly limited, particularly on the *Vidar Viking*.

## Actions on Vidar Viking:

Whole round samples will be taken (beginning with the B-hole) after core logging, provided that the logging can be completed in about 20 to 40 minutes. Whole-round samples will be taken on a selected basis at an interval of approximately one every 2nd core depending on core recovery. If recovery allows, the upper 60 m (approximately) of the record will be sampled more frequently.

- Pore-water sampling with pore-water squeezers (20 to 40 ml); the squeezers will be installed in the core curation container.
- If time is available, in addition to the squeezers, a pore-water sampling with the new generation of "Rhizone pore water samplers" will be tested on this cruise, at least for the less indurated sediments of the record. Rhizone samplers are 2.5 mm in diameter and 5 cm in length; they can be inserted into the sediment from the cut face of core segments, or alternatively through tiny holes drilled into the liner like those for temperature measurement. The samples are collected in 10 mL vacuum tubes designed for medical use and requiring a minimum of experience and maintenance. **http://www.geochemie.uni-bremen.de/koelling/rhizon.html**

- Splitting and conservation of pore-water sample (if it turns out that this cannot be done on the *Vidar Viking* due to limited space, this work will be done onboard the ice breaker *Oden*). Subject to further discussion among the Co-chiefs and chemists.
- Analysis of alkalinity/pH on pore-water samples (titration with HCl).
- Analysis of salinity on pore-water samples (refractometer).
- Cool storage of all samples until they are transferred to the *Oden*.

### *Actions on Oden:*

- Splitting and conservation of pore-water sample only if it turns out that this cannot be done on the *Vidar Viking* due to space constraints.
- Analysis of chloride ($Cl^-$) on pore water samples (to be discussed if this can be postponed to onshore).
- Analysis of ammonia ($NH_4$) on pore-water samples. Subject to further discussion.
- Cool storage of all samples at 4°C or –20° C depending on scientific requirements.
- Preparation of material needed on the *Vidar Viking*

### *Microbiology*

Whole-round samples will be taken at an interval of approximately 1 per 20 m contingent on core recovery. The sample will be placed in a tri-laminate bag and transferred to the *Oden* for microbiological preparation (normally within 12 hours). Onboard *Oden*, where a microbiology laboratory will be set up, the whole core will be split into four sub-samples:

1. Stored cool for anaerobic cultivation.
2. Frozen at –80 $^{o}$ C for DNA and biomarker analyses.
3. Preserved in formalin for biomass estimates.
4. Measured onboard for H as a proxy for rate determinations.

The use of biodegradable polymer mud will often be used during drilling to maintain a stable borehole. Samples of the mud used will be taken periodically for later analysis.

## Offshore petrophysics measurements

### *Downhole logging*

The logging program is focused on recovering basic petrophysical parameters to supplement the core data.

It is planned to wireline log the deepest hole at each site using the following equipment:

- Triple Combo comprising the spectral natural gamma-ray tool (NGT), accelerator porosity sonde (APS), hostile environment litho-density sonde (HLDS), dual induction resistivity tool (DIT-E) and a caliper for determining borehole diameter and thus hole conditions.

- Formation MicroScanner (FMS)/sonic (borehole compensated sonic tool [BHC]) combination comprising the FMS which provides oriented, high-resolution, 3D images of the borehole wall, acoustic velocity (BHC) and natural gamma ray for matching tool string passes.

### Core logging

Cores will be logged on the *Vidar Viking* in a modified 20 ft container, housing a single MSCL track comprising magnetic susceptibility (x2 loops), density, velocity and resistivity sensors. The single core-logger system will include a full spares kit.

In Hole A, a full (or best sensor configuration) suite of physical properties will be logged on lab temperature equilibrated cores. In subsequent holes, to allow real-time direction of the coring, core sections will be logged immediately (not temperature equilibrated) using magnetic susceptibility and/or density. Data are output to the splicing software (accessible from both *Vidar Viking* and *Oden*) to keep the splice synchronized with the coring. The addition of a second magnetic susceptibility loop (both loops take a measurement at the same time, thereby reducing the measurement time) allows collection of susceptibility data at a significantly increased rate.

Points to note are:

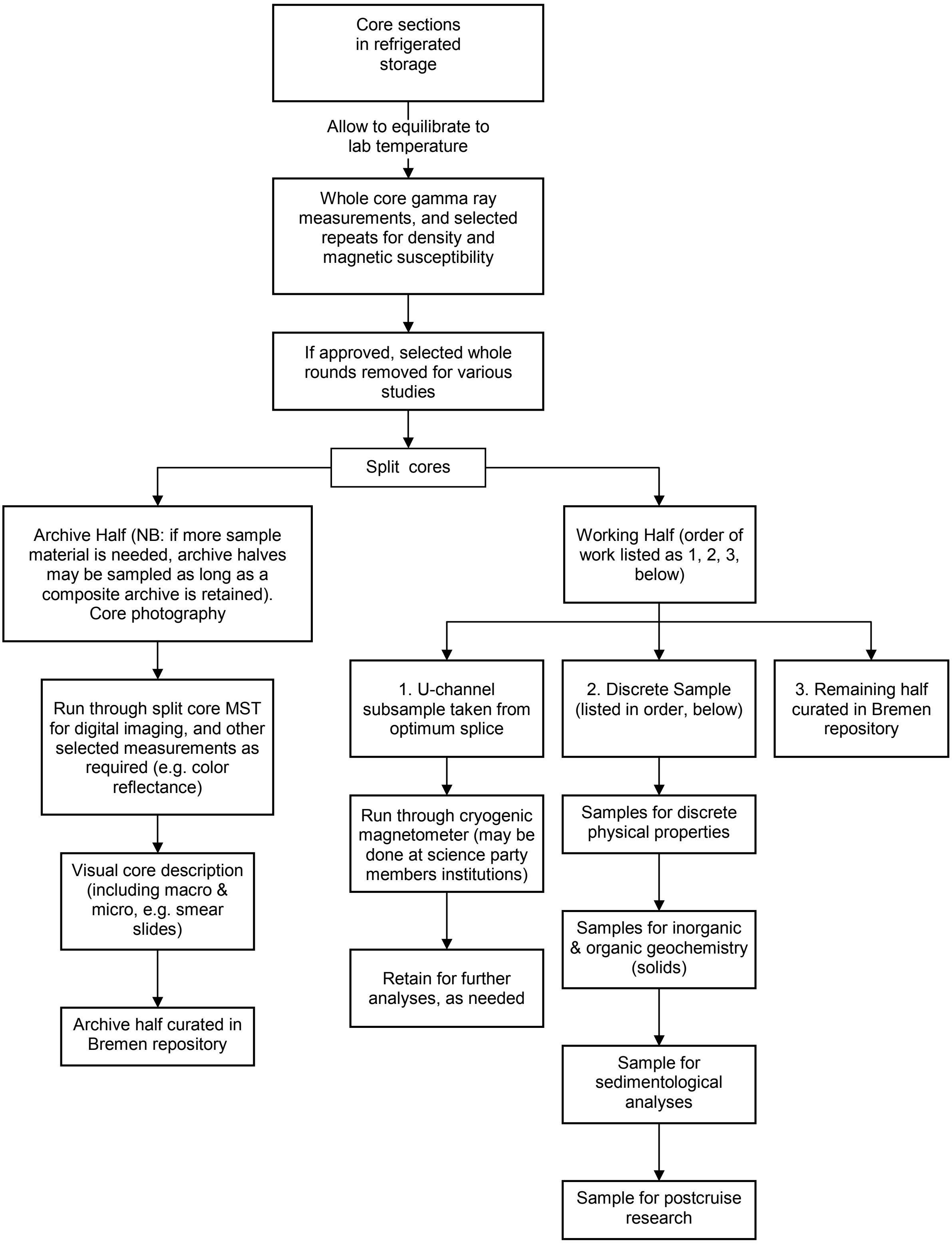
- If core recovery rates are fast, then as we near the bottom of hole A it may be necessary to run only magnetic susceptibility and density on non temperature equilibrated cores, in order to get all hole A cores logged before the B hole is spudded.
- It is proposed that, provided access to cores is possible (which is believed will be the case), during the transit following operations out to the ice edge, all cores logged under non temperature equilibrated conditions, will be temperature equilibrated and logged in the petrophysics container using the full sensor suite.

All the temperature-equilibrated core log data acquired at sea will provide QC/QA checks when compared to repeat measurements planned for Bremen.

### Discrete sample index properties

A reduced (compared with 'normal' ODP procedures) set of discrete sample index property measurements will be made at sea, by taking samples from core-section ends at an interval of one every four cores in Hole A and one every two cores in subsequent holes. Following ODP procedure, core samples will be weighed, oven-dried, the dried sample volume quantified using a pycnometer, and masses using acceleration corrected balance(s). The quality of these measurements is ultimately dependent upon resolving the ship movement problems, an issue complicated for these measurements as they will be undertaken on *Oden*, while it will be involved in ice management (breaking) duties. In the event that this problem cannot be satisfactorily resolved the discrete constant volume samples will be stored in watertight jars for subsequent onshore measurements.

## Onshore sampling and analysis (Figure A1-2)



## Location

The onshore Science Party will be undertaken at the existing ODP Core Repository and Laboratory at Bremen Docks (extended by renting another floor in the building for office space and, e.g., micropaleontology lab) in combination with access to the laboratories at the Department of Geosciences, the Research Center for Ocean Margin (RCOM), and the Center for Marine Environmental Research (MARUM).

## Planned analysis and available facilities

The following list of facilities or analyses briefly describes the succession of planned working steps. Depending on the core recovery and time available, two shifts might be introduced, especially as it is to be expected that the Scientific Party for this expedition will be relatively large (28 participants in total).

- CORE SPLITTING

An archive half will be set aside as per IODP policy

- COLOR REFLECTANCE MEASUREMENTS

- PHOTOGRAPHY AND/OR DIGITAL IMAGING (line scan camera on MSCL).

- CORE DESCRIPTION

ESO are working in co-operation with TAMU to generate a system that is at least equivalent to the ODP standard. For data entry, ESO will employ an Offshore DIS system that is entirely compatible with others being used in IODP.

- SMEAR SLIDES PREPARATION

- CORE SAMPLING

A detailed sampling plan will be devised at the completion of the offshore phase

- SOME MICROSCOPES (plus hood for sample preparation if acids needs to be applied)

- PALEOMAGNETICS

U channels will be collected during the Onshore Party for analysis at scientists' laboratories; analyses to be completed for distribution to science party within 2 months of the end of Onshore Party.

- OPTIONAL - INORGANIC GEOCHEMISTRY.

Analyses on pore water and sediment/hard rock, needs to be discussed with Scientific Party. Access to geochemical lab can be provided (on university campus), e.g., for analysis of pore water and sediment main and trace elements (ICP-OES, ED-XRF), carbonate content and total organic carbon (LECO).

- OPTIONAL – X-RAY DIFFRACTION ANALYSIS (XRD)

Bulk mineralogy on selected samples, to be discussed with Scientific Party

### Core logging

It is anticipated that EPC personnel and a number of the Science Party (stratigraphic correlators and physical properties specialists) will arrive in Bremen early and complete whole core logging activities before arrival of the remainder of the Science Party.

### Discrete sample index properties

Discrete intervals will be sampled from the core working half to complete the index property measurements (water content, porosity; bulk density, grain density, dry density). Following ODP procedure, core samples will be oven-dried, the dried sample volume quantified using a Quantachrome Penta-Pycnometer, and masses using a high-precision balance. Comparison of results with those made at sea will provide QC/QA checks on the preservation of the ephemeral physical properties.

### Other

Once cores have equilibrated to room temperature, thermal conductivity will be measured. Falling cone penetrometer WF21600 for the determination of liquid and plastic limits, plasticity index, and shear strength will also be available.

# APPENDIX II STAFFING OF *VIDAR VIKING*

The number of personnel on the *Vidar Viking* is restricted by certification, and cannot be exceeded for more than a temporary period, and only then with the authorisation of the Master. The *Vidar Viking* is therefore staffed to cope with the minimum requirements on board, and there cannot be more than 18 in the 'ESO Party' at any one time, and 8 of which are drillers.

Below is a provisional plan for distribution of labour on the *Vidar Viking*, emphasising the need for multitasking to cover all required tasks. The following is assumed in this plan:

- Unless otherwise agreed by a Co-chief, there will always be either 2 or 3* members of the Science Party on the Vidar Viking when coring takes place. These will normally include a Co-chief and a stratigraphic correlator.

  * Shift A currently has an ESO staff member acting as geochemist and deck operator. This individual may vary, and can equally be a suitable Science Party member.
- The staff noted in blue will be based on the *Oden*, and will be transferred on an approximate shift basis to and from the *Vidar Viking*. Transfer will be by basket or helicopter.
- Please note that precise end/start shift timing of the transfers cannot be guaranteed due to operational constraints.
- In the event that any transfer is not possible, there will be three bunks available on the *Vidar Viking* for those stranded.
- ESO staff in Shift A will initially be Luzie Schnieders or Dave McInroy.
- The logging contractor will assist with appropriate duties, probably on part of each shift.

The plan presented on the following page may be modified in the light of discussions during the offshore phase.

| Shift A | Additional tasks | Main task | Main task | Additional tasks | Shift B |
|---|---|---|---|---|---|
| Ali Skinner | Deck operation | Drilling supervision and gas safety analysis | Drilling supervision and gas safety analysis | Deck operation | SeaCore |
| Davie Baxter | Curation | Prime deck operator | Prime deck operator | Curation | Graham Tulloch |
| Kate Moran | Curation MST | Co-chief | Co-chief | Curation MST | Jan Backman |
| ESO | Deck operation, Curation | Geochem | Geochem | Deck operation, Curation | Jerry Dickens |
| Heiko Paelike | Curation | MST Strat correl | MST,Strat correl | Curation | Matt O'Regan |
| Alex Wülbers | Geochem | Curation | MST/Curation | MST | Brice Rea |

# APPENDIX III BGS MARINE WIRELINE CORING SYSTEMS

## BGS Marine Wireline Corebarrel System (New system)

Three full systems, plus spares, will be carried.

| Item | Description | Principal Dimensions | Hole Size | Core Size | Liner |
|---|---|---|---|---|---|
| Outer Barrel | Outer Core Barrel for all systems | 178mm OD, 6.25m Long | 242mm | n/a | n/a |
| Outer Barrel Core Bits | Roller Cone, TC and Diamond bits for all Fms. | Various OD, all 76mm ID | 242mm | n/a | n/a |
| Inner Barrel - Piston Coring | 'ODP' style Piston Corer | 4.5m core length | 92mm | 62mm | yes |
| Inner Barrel - non-rotating | T6 86 corebarrel used with main bit | 5m long core barrel | 241mm | 64mm | yes |
| Inner Barrel - Extended Coring | T6 86 corebarrel used ahead of main bit | 5m long core barrel | 92mm | 64mm | yes |
| Inner Barrel – Extended Coring | Piston coring tube extended as ODP XCB | Up to 5m core length | 93mm | 62mm | yes |
| Inner Barrel - rotating push | As above but with rotation linked to outer | | | | |
| Inner Rod - Insert Bit | Heavyweight inner tube with pilot drill bit | Makes main bit a drill bit | 242mm | n/a | n/a |
| Inner Rod - Push Coring | Heavyweight inner tube with valved head | Shelby tubes 2" & 3" | 56/77mm | 52/74mm | no |
| | | Heavy Wall + catcher (1.5&3) | 73mm | 59mm | yes |
| Inner Rod - temperature probe | Memory tool to sit in formation outside bit | Projection of up to 250mm | n/a | n/a | n/a |
| APC temperature shoe | Temperature shoe for piston corer | As piston core shoe | n/a | n/a | n/a |
| Overshot for retrieval | Longyear System with matching CB heads | Sliding hammer action | n/a | n/a | n/a |

Notes:
1) A system comprises an outer BHA and two working sets of an inner barrel system.
2) All coring systems except piston corer can be run with a NRV for additional safety.
3) All latch-in systems have a latch-in indicator to ensure proper latching before coring.
4) Main Bit is only currently planned to have one OD size but this may change in the future.

## Christensen - BGS System (Old system)

Three full sytems, plus spares, will be carried.

| Item | Description | Principal Dimensions | Hole Size | Core Size | Liner |
|---|---|---|---|---|---|
| Outer Barrel | Outer Core Barrel for all systems | 159mmOD x 6.25m Long | 216-232mm | n/a | n/a |
| Outer Barrel Core Bits | Roller Cone, TC and Diamond bits for all Fms. | Various OD, all 76mm ID | 216-232mm | n/a | n/a |
| Inner Barrel - non-rotating | Standard Inner Barrel - Competent Formations | 5m long core barrel | 216-232mm | 76mm | yes |
| Inner Barrel - push coring | Heavyweight inner tube with push core head | Geotech Shelby Tubes | 2" shelby | 50mm | no |
| | | Heavy Wall with catcher | 73mm | 57.5 | no |
| Inner Barrel - rotating push | As above but with rotation linked to outer | | | | |
| Inner Barrel - Extended Coring | Heavyweight inner tube with core bit ahead | 5m long (rarely used) | 75mm | 57.2mm | yes |
| Inner Rod - Insert Bit | Heavyweight inner tube with pilot drill bit | Makes main bit a drill bit | 216-232 | n/a | n/a |
| Inner Rod - temperature probe | Memory tool to sit in formation outside bit | Projection of up to 500mm | n/a | n/a | n/a |
| Overshot for retrieval | Longyear PQ-modified CB heads to accept | Sliding hammer action | n/a | n/a | n/a |

Notes:
1) A system comprises an outer BHA and two working sets of an inner barrel system except push/drill.
2) All coring systems and insert bit systems can be run with a NRV for additional safety.
3) Main Bit size refers to bits already available, other ODs could be provided.

## Additional equipment

PQ Overshot and Spares
PQ overshot fishing tool
Handling tools and workshop
Scorpion tongs