IODP Proposal Cover Sheet

708 - Full

Central Arctic Paleoceanography

Title	Arctic Ocean Paleoceanography: Towards a Continuous Cenozoic Record from a Greenhouse to an Icehouse World (ACEX2)
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Area	Lomonosov Ridge

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Abstract

Prior to 2004, the geological sampling in the Arctic Ocean was mainly restricted to near-surface Quaternary sediments. Thus, the long-term Pre-Quaternary geological history is still poorly known. With the successful completion of the Arctic Coring Expedition - ACEX (IODP Expedition 302) in 2004, a new era in Arctic research has begun. Employing a novel multi-vessel approach, the first Mission Specific Platform (MSP) expedition of IODP has proven that drilling in permanently ice-covered regions is possible. During ACEX, 428 meters of Quaternary, Neogene, Paleogene and Campanian sediment on Lomonosov Ridge were penetrated, providing new unique insights into the Cenozoic Arctic paleoceoceanographic and climatic history. While highly successful, the ACEX record also has three important limitations. Based on the original age model, the ACEX sequence contains a large hiatus spanning the time interval from late Eocene to middle Miocene, i.e., 44.4 to 18.2 Ma. This is a critical time interval, as it spans the time when prominent changes in global climate took place during the transition from the early Cenozoic Greenhouse world to the late Cenozoic Icehouse world. Furthermore, generally poor recovery during ACEX prevented detailed and continuous reconstruction of Cenozoic climate history. Finally, a higher-resolution reconstruction of Arctic rapid climate change during Neogene to Pleistocene times, could not be reached during ACEX in 2004. We believe, this justifies a return to the Lomonosov Ridge for a second MSP - type drilling campaign within IODP to fill these major gaps in our knowledge on Arctic Ocean paleoenvironmental history through Cenozoic times and its relationship to the global climate history.

Overall goal of the proposed drilling campaign is the recovery of a complete stratigraphic sedimentary record on the southern Lomonosov Ridge to meet our highest priority paleoceanographic objective, the continuous long-term Cenozoic climate history of the central Arctic Ocean. Furthermore, sedimentation rates two to four times higher than those of ACEX permit higher-resolution studies of Arctic climate change in the Pleistocene and Neogene. As demonstrated in the proposal, this goal can be achieved by careful site selection, appropriate drilling technology, and applying multi-proxy approaches to paleoceanographic, paleoclimatic, and age-model reconstructions. We propose one primary drill site with three APC/XCB/RCB holes to recover multiple sections of the sediment sequence to ensure complete recovery for construction of a composite section.

ACEX2 objectives are key elements in the IODP New Science Plan, Theme 1 Climate and Ocean Change, especially Challenges 1 and 2.

708 - Full

Scientific Objectives

A complete Cenozoic sedimentary sequence from the central Arctic Ocean will be studied to answer the following key questions:

- Did the Arctic Ocean climate follow the global climate evolution during its course from early Cenozoic Greenhouse to late Cenozoic Icehouse conditions?
- Are the Early Eocene Climate Optimum (poor recovery in the ACEX record) and the Oligocene and Mid-Miocene warmings also reflected in Arctic Ocean records?
- Did extensive glaciations (e.g., the OI-1 and Mi-1 glaciations) develop synchronously in both the Northern and Southern Hemispheres?
- What is the timing of repeated major (Plio-)Pleistocene Arctic glaciations as postulated from sediment echosounding and multi-channel seimic reflection profiling?
- What was the variability of sea-ice in terms of frequency, extent and magnitude?
- When and how did the change from a warm, fresh-water-influenced, biosilica-rich and poorly ventilated Eocene ocean to a cold, fossil-poor, and oxygenated Neogene ocean occur?
- How critical is the exchange of water masses between the Arctic Ocean and the Atlantic and Pacific for the long-term climate evolution as well as rapid climate change?
- What is the history of Siberian river discharge and how critical is it for sea-ice formation, water mass circulation and climate change?
- How did the Arctic Ocean evolve during the Pliocene warm period and succeeding cooling? How do the ACEX2 record correlate with the terrestrial record from the Siberian Lake Elḡygytgyn?
- What is the cause of the major hiatus recovered in the ACEX record? Does this hiatus in fact exist?

Non-standard measurements technology needed to achieve the proposed scientific objectives.

The sites are located in the seasonally ice-covered central Arctic Ocean (southern Lomonosov Ridge), and will need mission specific vessels to perform the drilling in the pack ice (marginal ice zone). A well organized ice-management strategy and support by an icebreaker (e.g., RV Polarstern) are needed.

Proposed Sites

Site Name	Position (Lat, Lon)	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
LORI-5B	83.80, 146.48	1334	1250	0	1250	Recovery of a complete stratigraphic sedimentary record on the central Lomonosov Ridge to meet our highest priority paleoceanographic objective, the continous long-term Cenozoic climate history of the central Arctic Ocean. (Alternate Site)
LORI-16A	80.78, 142.78	1752	1850	0	1850	Recovery of a complete stratigraphic sedimentary record on the southern Lomonosov Ridge to meet our highest priority paleoceanographic objective, the continous long-term Cenozoic climate history of the central Arctic Ocean. (Alternate Site)
LR-02A	80.97, 142.47	1450	1300	0	1300	Recovery of a complete stratigraphic sedimentary record on the southern Lomonosov Ridge to meet our highest priority paleoceanographic objective, the continous long-term Cenozoic climate history of the central Arctic Ocean (Alternate Site)

LR-01A	80.95, 142.97	1405	1225	0	1225	Recovery of a complete stratigraphic sedimentary record on the southern Lomonosov Ridge to meet our highest priority paleoceanographic objective, the continuous long-term Cenozoic climate history of the central Arctic Ocean (Primary site)

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Arctic Ocean Paleoceanography: Towards a Continuous Cenozoic Record from a Greenhouse to an Icehouse World (ACEX2)

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1. Introduction and Background

A major element in the global climate evolution during Cenozoic times has been the transformation from warm Paleogene 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 (e.g., Miller et al., 1987; Zachos et al., 2001, 2008). Throughout the course of the Cenozoic, the climate on Earth has thus changed from one extreme (Paleogene Greenhouse lacking major ice sheets) to another (Neogene Icehouse with bipolar glaciation).

A strong greenhouse effect probably contributed to global warmth during the early Cenozoic. CO_2 concentrations of more than 2,000 ppm have been estimated for the late Paleocene and earliest Eocene periods (about 60 to 52 Ma) (Fig. 1; Pearson and Palmer, 2000; Lowenstein and Demicco, 2006; Royer, 2006; Zachos et al., 2008). Bottom temperatures in the early Eocene, the time of maximum Cenozoic warmth that peaked with the early Eocene Climatic Optimum (about 52 to 50 Ma), were of the order of 12-14°C, and large-scale continental ice sheets were probably absent (Fig. 1; Miller et al., 1987; Lear et al., 2000; Pearson and Palmer, 2000; Zachos et al., 2008; Escutia, Brinkhuis, Klaus et al., 2010). The climate in lowland settings along the Wilkes Land coast/Antarctica, for example, supported the growth of highly diverse, near-tropical forests characterized by mesothermal to megathermal floral elements (Pross et al., 2012). Based on stable isotope data of fossil mollusk shells from Ellesmere Island and Alaska, Paleocene temperatures of Arctic (80°N) coastal waters of about 10 to 22°C were reconstructed (Bice et al., 1996; Tripati et al., 2001).

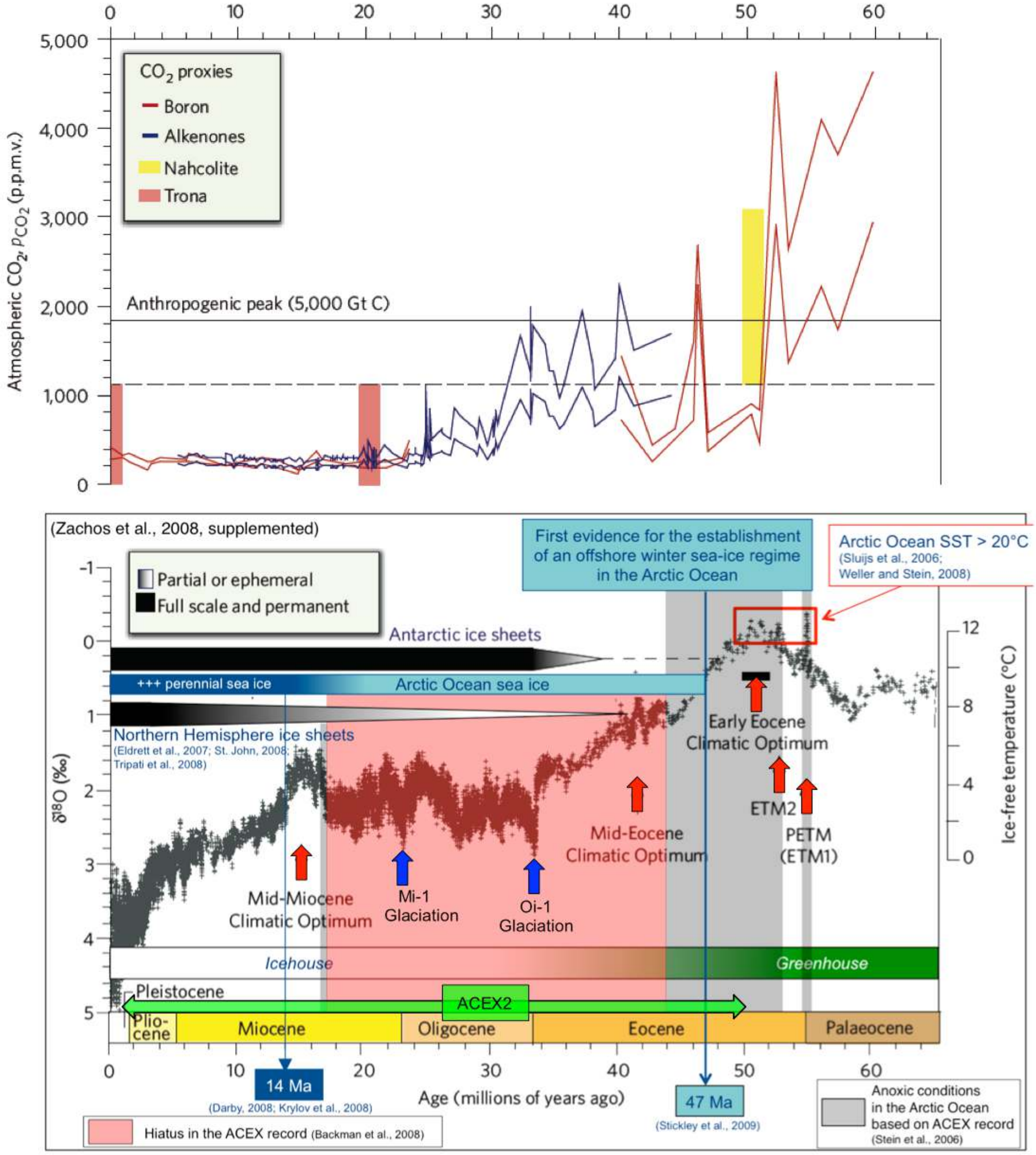

Fig. 1. (a) Cenozoic pCO_2 for 65 Ma. Data are a compilation of marine and lacustrine proxy records (based on Lowenstein and Demicco, 2006; Royer, 2006). (b) A smoothed global benthic foraminifer d^{18}O time series showing the long-term cooling and the Greenhouse/Icehouse transition through Cenozoic times (Zachos et al., 2008, supplemented). The occurrence of Cenozoic ice sheets on the Northern and Southern Hemisphere and Arctic sea-ice are shown (Eldrett et al., 2007; St. John, 2008; Tripati et al., 2008; Zachos et al., 2008; Stickley et al., 2009) The hiatus in the ACEX record (as based on the age model by Backman, et al., 2008; for alternate age model see Fig. 5) is indicated by a red bar, periods with anoxic water mass conditions are highlighted by gray bars (Stein et al., 2006). Figure from Zachos et al. (2008), supplemented by ACEX data.

The long-term history of Cenozoic high-latitude cooling starting at about 48 Ma, is characterized by four major steps in the early mid-Eocene (about 48-45 Ma), at the

Eocene/Oligocene boundary (near 34 Ma), in the mid-Miocene (at about 15 Ma), and in the late Pliocene (at about 3.5-2.6 Ma) (Fig. 1; Miller et al., 1987; Zachos et al., 1994, 2001; Lear et al., 2000). Reconstructions of past atmospheric CO_2 concentrations based on isotopic markers from marine algae (Pagani et al., 2005) and boron isotope composition of planktonic foraminifers (Pearson and Palmer, 2000), show – although with obvious differences in absolute values – distinct drops in atmospheric CO_2 between about 50 and 25 Ma that generally correspond to the global cooling trend and development of major polar ice sheets, except for the interval around the early mid-Eocene cooling (Fig. 1).

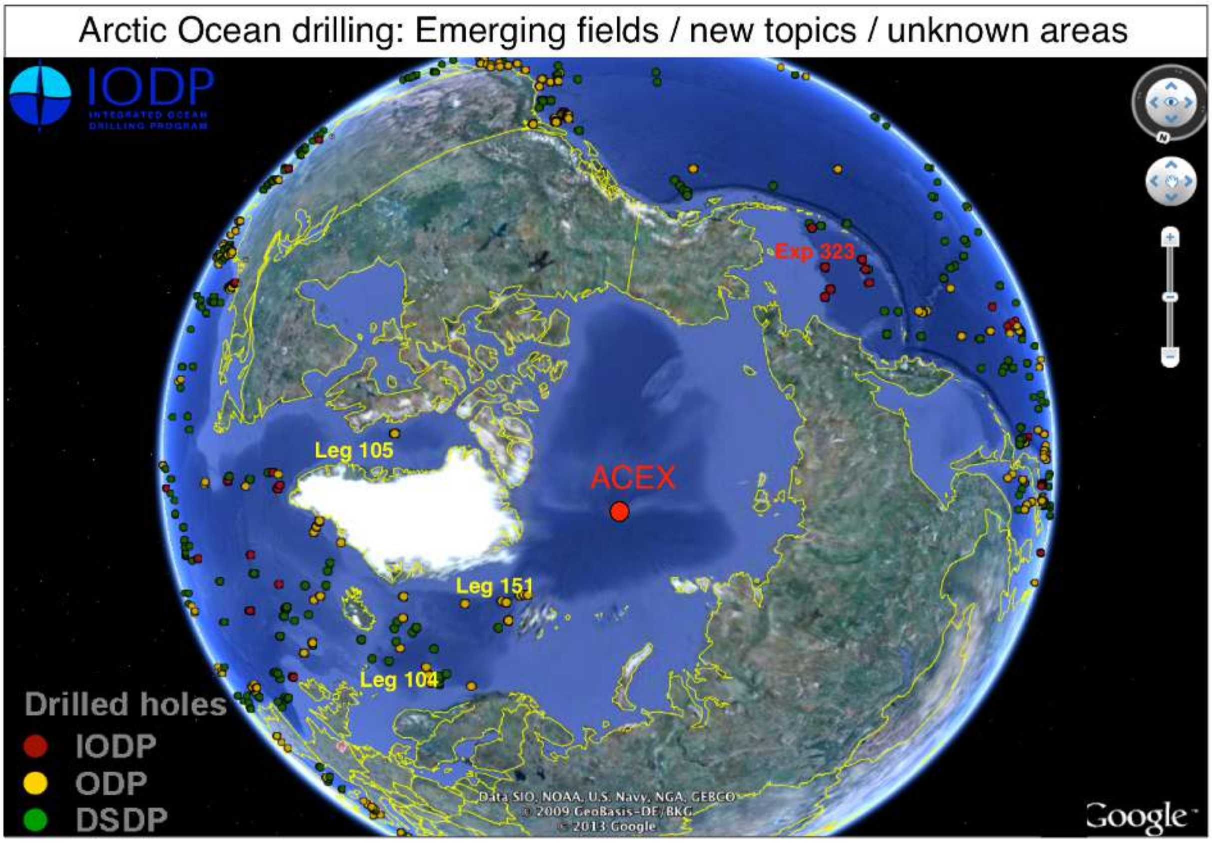

Fig. 2. Google map showing the Northern Hemisphere with locations of DSDP, ODP, and IODP sites.

On Antarctica, large ice sheets likely first appeared near the Eocene/Oligocene boundary at about 34 Ma ("Oi-1 glaciation"; e.g., Shackleton and Kennett, 1975; Kennett and Shackleton, 1976; Miller et al., 1987, 1991; Lear et al., 2000; Zachos et al., 2008), coincident with decreasing atmospheric carbon dioxide concentrations and a deepening of the calcite compensation depth in the world's oceans (van Andel, 1975; Pearson and Palmer, 2000; Coxall et al., 2005; Tripati et al., 2005). For the Northern Hemisphere, on the other hand, it was indirectly inferred from sub-Arctic ice-rafted debris records in the Norwegian-Greenland, Iceland, and Irminger seas and Fram Strait area that glaciations began much later, i.e., in the middle Miocene as early as about 14 Ma (e.g., Fronval and Jansen, 1996; Wright and Miller, 1996; Thiede et al., 1998, 2011; St. John and Krissek, 2002). Based on more recent modeling results as well as new ODP/IODP sediment core data, however, this general picture has to be revised significantly (see below).

Although it is generally accepted that the Arctic Ocean is a very sensitive and important region for global climate change (IPCC reports: Houghton et al., 1996, Solomon et al., 2007; Serreze et al., 2000; ACIA 2004, 2005), this region is the last major physiographic province on Earth where the short- and long-term geological history is still poorly known (Fig. 2). Our ignorance is due to the major technological/logistical problems in operating within the permanently ice-covered Arctic region which makes it difficult to retrieve long and undisturbed sediment cores. Prior to 1990, the available samples and geological data from the central Arctic Basins were derived mainly from drifting ice islands such as T-3 (e.g., Clark et al., 1980) and CESAR (Jackson et al., 1985). During the last ~20 years, several international expeditions, e.g., *Polarstern/Oden* 1991 (Fütterer, 1992), *Louis St. Laurent/Polar Sea* 1994 (Wheeler, 1997), *Healy/Polarstern* 2001 (Thiede, 2002), *Healy/Oden* 2005 (“HOTRAX“; Darby et al., 2005), *Oden* 2007 (“LOMROG“ 2007; Jakobsson et al., 2008), and *Polarstern* 2008 (Jokat, 2009), have greatly advanced our knowledge on central Arctic Ocean paleoenvironment and its variability through Quaternary times (for review see Stein, 2008). Prior to 2004, however, in the central Arctic Ocean piston and gravity coring was mainly restricted to obtaining near-surface sediments, i.e., only the upper 15 m could be sampled. Thus, all studies were restricted to the late Pliocene/Quaternary time interval, with a few exceptions. These include the four short cores obtained by gravity coring from drifting ice floes over the Alpha Ridge, where older pre-Neogene organic-carbon-rich muds and laminated biosiliceous oozes were sampled. These were the only samples recording the Late Cretaceous/Early Cenozoic climate history and depositional environment (e.g., Jackson et al., 1985; Clark et al., 1986; Firth and Clark, 1998; Jenkyns et al., 2004; Davies et al., 2009, 2011). In general, these data suggest a warmer (ice-free) Arctic Ocean with strong seasonality and high paleoproductivity, most likely associated with upwelling conditions.

With the successful completion of the Arctic Coring Expedition – ACEX (Expedition 302, the first Mission Specific Platform (MSP) expedition within IODP) in 2004, a new era in Arctic research began. For the first time, scientific drilling in the permanently ice-covered central

Arctic Ocean was carried out, penetrating 428 meters of Quaternary, Neogene, Paleogene and Campanian sediments (Fig. 3) on the crest of Lomonosov Ridge between 87 and 88°N (Backman, et al., 2006, 2008; Moran et al., 2006; Backman and Moran, 2008, 2009). This record provided a unique glimpse of the early Arctic Ocean history and its long-term change through Cenozoic times (see Chapter 3 for results and highlights). To date, the ACEX sites remain the one and only drill holes in the central Arctic Ocean (Fig. 2)!

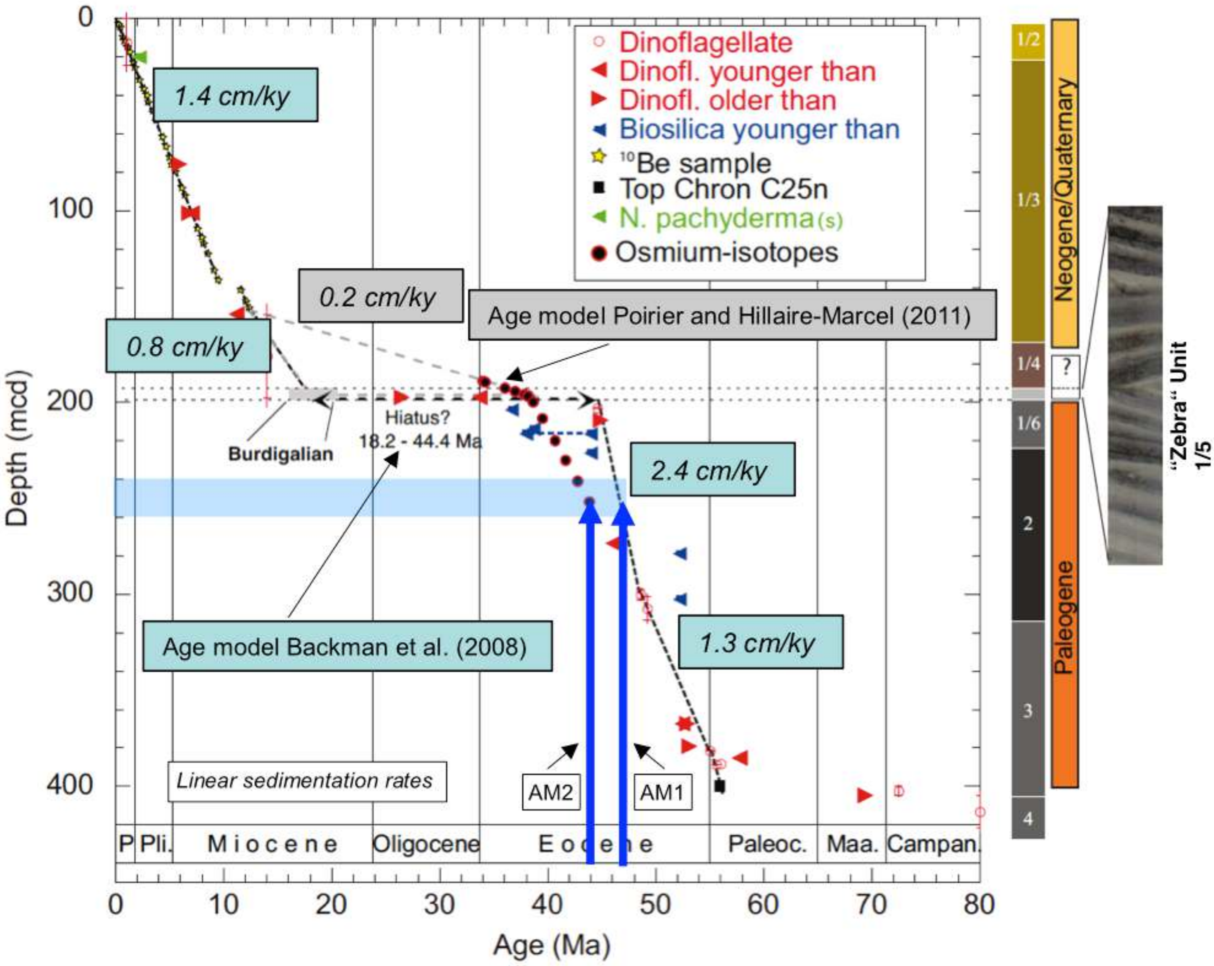

Fig. 3 Age-depth diagram and main lithological units of the ACEX section, based on the biostratigraphically-derived age model by Backman et al. (2008). In addition, an alternate chronology based on osmium isotopes (Poirier and Hillaire-Marcel, 2011) are shown. Depth of first occurrence of IRD between 240 and 260 mcd are marked as light blue horizontal bar. The different ages of the first occrrence of IRD, obtained by the two age models - AM1 = Backman et al. (2008), AM2 = Poirier and Hillaire-Marcel (2011) - are indicated by the large blue arrows. Mean sedimentation rates (cm/ky) are indicated. Figure from O'Regan (2011), supplemented.

While highly successful, the ACEX record also has three important limitations. Based on the original age model (Backman, et al., 2008), the ACEX sequence contains a large hiatus spanning the time interval from late Eocene to middle Miocene, i.e., 44.4 to 18.2 Ma, and encompassing nearly 45% of the Cenozoic history of Lomonosov Ridge (Fig. 3). This is a critical time interval, as it spans the time when prominent changes in global climate took place during the transition from the early Cenozoic Greenhouse world to the late Cenozoic Icehouse world (Fig. 1). Furthermore, generally poor recovery prevented detailed and continuous reconstruction of Cenozoic climate history. Finally, the second overall paleoceanographic objective of the original ACEX program, the high-resolution reconstruction of Arctic rapid climate change during Neogene to Pleistocene times, could not be reached because drilling on the southern Lomonosov Ridge was not carried out due to limited drilling time.

The above clearly justifies a return to the Lomonosov Ridge for a second MSP - type drilling campaign within IODP to fill these major gaps in our knowledge on Arctic Ocean paleoenvironmental history through Cenozoic times and its relationship to the global climate history. As will be demonstrated below, this goal can be achieved by careful site selection, appropriate drilling technology, and applying multi-proxy approaches to paleoceanographic, paleoclimatic, and age-model reconstructions.

2. Modern environment and geological setting of the Arctic Ocean

The Arctic Ocean is unique in comparison to the other world oceans: It is surrounded by the world´s largest shelf seas, is seasonally to permanently covered by sea ice, and is characterized by large, very seasonal river discharge which is equivalent to 10 % of the global runoff (Fig. 4; Aagaard and Carmack, 1989; Holmes et al., 2002; Jakobsson, 2002; for review see Stein 2008). The freshwater supply is essential for the maintainance of the ca. 200 m thick low-salinity layer of the central Arctic Ocean and, thus, contributes significantly to the strong stratification of the near-surface water masses, encouraging sea-ice formation. The melting and freezing of sea ice result in distinct changes in surface albedo, energy balance, and biological processes. Freshwater and sea ice are exported from the Arctic Ocean through Fram Strait into the North Atlantic. Changes in these export rates of freshwater would result in changes of North Atlantic as well as global oceanic circulation patterns. Because factors such as the global thermohaline circulation, sea-ice cover and Earth's albedo have a strong influence on the earth's climate system, climate change in the Arctic could cause major pertubations in the global environment.

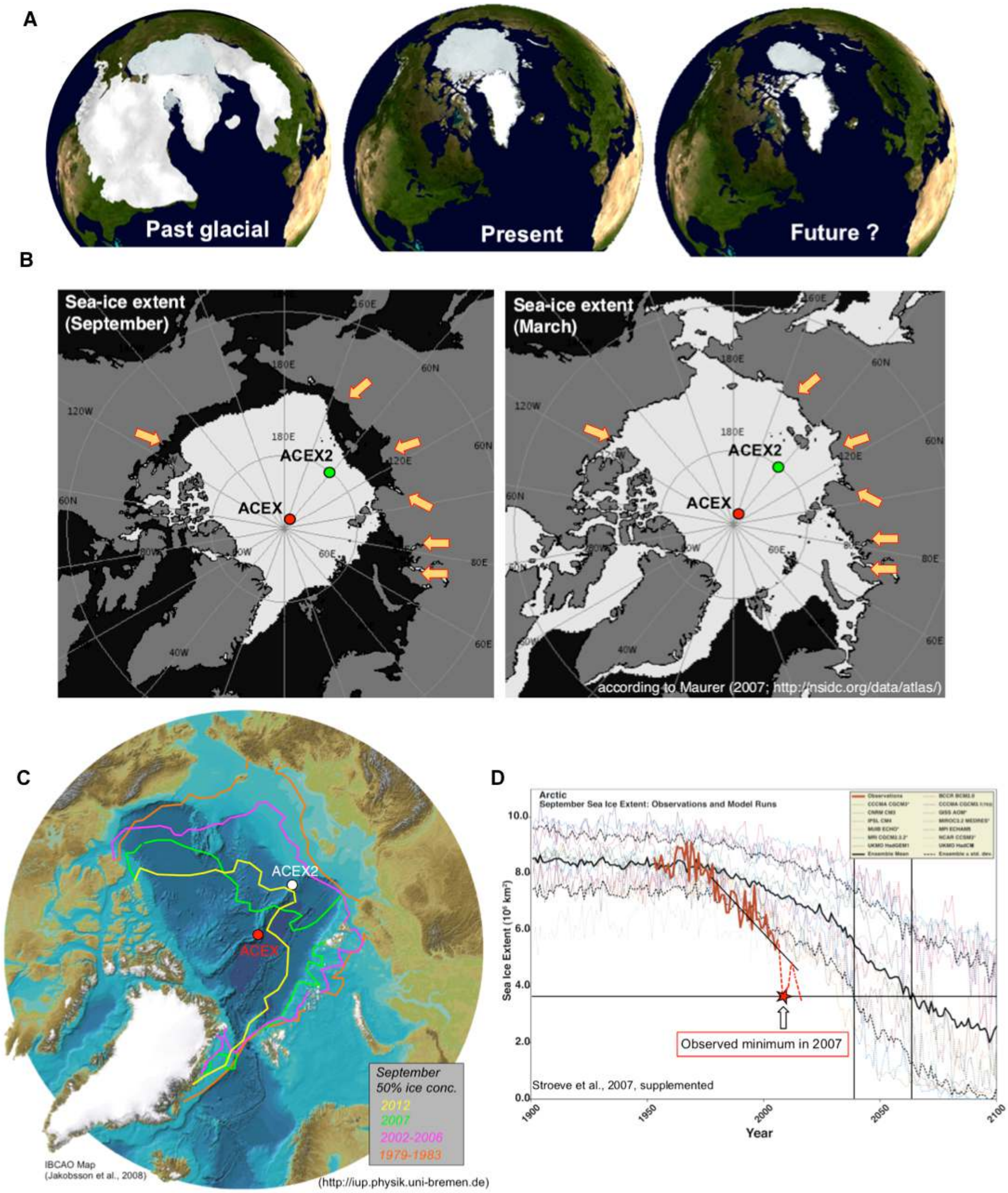

Fig. 4. (A) Distribution of ice sheets and sea ice during past glacials, Present and a possible scenario of the future (Courtesy Martin Jakobsson, Stockholm University, 2012).

(B) Map showing the average distribution of sea-ice in the Arctic Ocean in September (1979-2004) and March (1979-2005); according to Maurer (2007; http://nsidc.org/data/atlas/). Locations of ACEX and ACEX2 sites are indicated.

(C) Arctic sea-ice cover and recent change. Locations of ACEX and ACEX2 sites are indicated.

(D) Arctic September sea-ice extent ($x10^6$ km^2) from observations (thick red line) and 13 IPCC AR4 climate models together with the multi-model ensemble mean (solid black line) and standard deviation (dotted black line). The absolute minimum of 2007 is highlighted (from Stroeve et al., 2007, supplemented).

Due to complex feedback processes (collectively known as “polar amplification”), the Arctic is both the harbinger of change and the region that will be most affected by global warming. The need for further scientific drilling in the Arctic is motivated in part by climate change models predicting the greatest future temperature changes in polar regions, and because polar systems may be particularly sensitive to change now and in the past (e.g., IPCC Reports: Houghton et al., 1996; Solomon et al., 2007). There is a general consensus that the polar regions – and especially the Arctic Ocean and surrounding areas - are (in real time) and were (over historic and geologic time scales) subject to rapid and dramatic change. Over the last decades, for example, the extent and thickness of Arctic sea ice has decreased dramatically, and this decrease seems to be much more rapid than predicted by climate models (Fig. 4; e.g., Johannessen et al., 2004; ACIA, 2004, 2005; Francis et al., 2005; Serreze et al., 2007; Stroeve et al., 2007, 2011).

In order to study the Cenozoic climate evolution, we need to obtain undisturbed and complete sedimentary sequences. Scientific reasoning and sesimic evidence indicate that such sequences in the Arctic Ocean have been accumulating on isolated ridges such as the Lomonosov Ridge. The elevation of the ridge, ~3 km above the surrounding abyssal plains, indicates that sediments on top of the ridge have been isolated from turbidites and are likely of purely pelagic origin (i.e., mainly biogenic, eolian, and/or ice-rafted) – an observation born out by countless shorter cores collected from icebreakers in the past decades, and previous drilling during ACEX. After Heezen and Ewing (1961) recognized that the mid-ocean rift system extended from the North Atlantic into the Arctic Ocean, it was realized that the 1800 km long Lomonosov Ridge was originally a continental fragment broken off of the Eurasian continental margin and became separated by sea-floor spreading. Regional aeromagnetic data indicated the presence of sea-floor spreading anomalies in the basins north and south of the Gakkel Ridge, the active spreading centre located in the middle of the Eurasian Basin (Kristoffersen, 1990 and references therein). The interpretation of the magnetic anomalies in terms of seafloor spreading and their correlation with the geomagnetic time scale allowed linking the evolution of the Eurasian Basin to the opening of the Norwegian-Greenland Sea. According to this correlation, seafloor spreading was probably initiated in the Eurasian Basin between chron 24 and 25 in the late Paleocene near 56 Ma (e.g., Kristoffersen, 1990). As the Lomonosov Ridge moved away from the Eurasian plate and subsided, pelagic sedimentation on top of this continental sliver began.

3. Results from previous drilling campaigns with special emphasis on ACEX results

Prior to ACEX, information on the long-term evolution of the paleoenvironmental Arctic Ocean history, especially the onset and variability of Northern Hemisphere glaciations, was restricted to the sub-Arctic region. For example, ODP Legs 151 (see Fig. 2 for site locations) and 152 recovered a series of Neogene pulses of ice rafting (14 Ma, 10.8-8.6 Ma, 7.2-6.8 Ma, 6.3-5.5 Ma, and in sediments younger than 5 Ma) in the North Atlantic and Yermak Plateau regions (Larsen et al., 1994; Thiede et al., 2011). However, it is not clear whether these reflect local Svalbard and Greenland ice expansion or whether the events can be correlated with processes in the central Arctic.

ACEX was an outstanding success for two reasons. First, the biggest technical challenge was to maintain the drillship´s location while drilling and coring in heavy sea ice over the Lomonosov Ridge. ACEX has proven that with an intensive ice-management strategy, i.e., a three-ship approach with two powerful icebreakers (*Sovetskiy Soyuz* and *Oden*) protecting the drillship (*Vidar Viking)* by breaking upstream ice floes into small pieces, successful scientific drilling in the permanently ice-covered central Arctic Ocean is possible. The icebreakers kept the drillship on location in 90% cover of multi-year ice for up to nine consecutive days, a benchmark feat for future drilling in this harsh environment. Second, the first scientific results comprise a milestone in Arctic Ocean research and future results of ongoing studies on ACEX material will certainly bring new insights into the Arctic Ocean climate history and its global significance. Some of these highlights are:

- The Arctic Ocean surface-water temperatures reached peak values around 25° C during the PETM Event (Sluijs et al., 2006, 2008) and at the end of the Early Eocene Climatic Optimum - EECO (Weller and Stein, 2008), which is notably higher than previous estimates of 10–15 °C (Tripati et al., 2001) and indicates an even lower equator-to-pole temperature gradient than previously believed (Sluijs et al., 2006). In the middle Eocene, following the EECO, a strong step-wise drop in Arctic sea-surface temperature by about 15°C occurred (Fig. 5), contemporaneously with the onset/increase of Arctic sea ice as reflected in sea-ice diatoms and ice-rafted debris (St. John, 2008; Stickley et al., 2009, 2012; Stein et al., 2013).

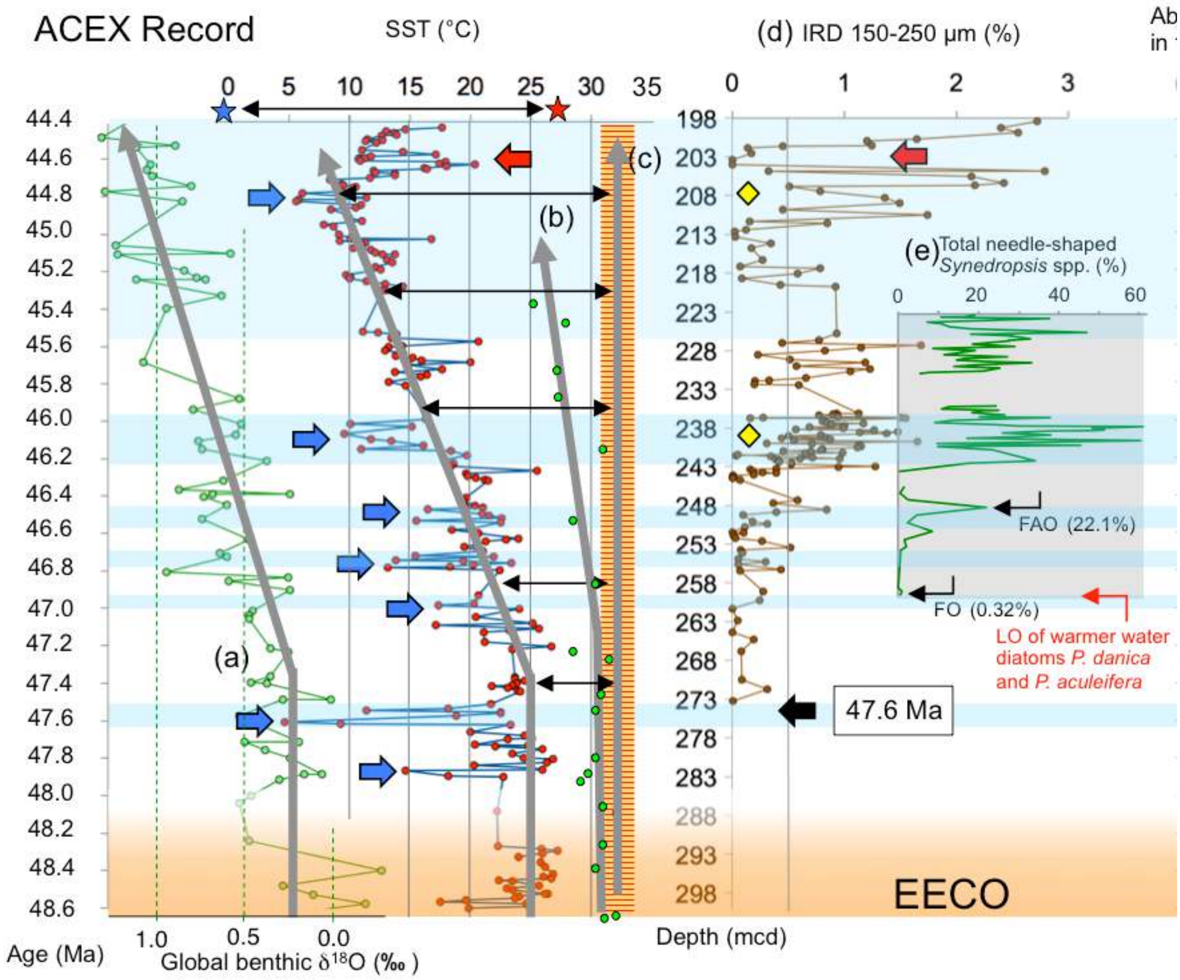

Fig. 5. Alkenone-based sea-surface temperature (SST) (red circles) (Weller and Stein, 2008; Stein et al., 2013), abundance of ice-rafted debris (IRD) (brown circles; yellow diamonds = large dropstones; record d) (St. John, 2006) determined in the ACEX sequence from 298-198 mbsf, representing the time interval from the end of the Early Eocene Climate Optimum (EECO) near 48.6 to 44.4 Ma. For the ACEX interval 260-223 mbsf, the abundance of sea-ice diatom species *Synedropsis* spp. is also shown (record e) (Stickley et al., 2009). In the diatom record, the first occurrence (FO) and the first abundant occurrence (FAO) of the sea-ice species and the last occurrence (LO) of warmer water diatoms *Porotheca danica* and *Pterotheca aculeifera* are also shown. Large blue arrows indicate major cooling events; the large red arrow highlights a major warming event near 44.6 Ma. Blue and red star shows modern pol-equator temperature gradient. In addition, (a) the global benthic d^{18}O stack (Zachos et al., 2008); (b) the TEX_{86} SST record of ODP Site 1172 at latitude 65°S (Bijl et al., 2009); and (c) the TEX_{86} SST range recorded at the Tanzania site at 20°S (Pearson et al., 2007) (Figure from Stein et al., 2013/in prep.).

- Near 49 Ma, a major occurrence of the freshwater fern *Azolla* and accompanying abundant freshwater organic-walled and siliceous microfossils indicate an episodic freshening of Arctic surface waters with cooler temperatures of about 10 °C during an 800,000-year interval. Although a deep-water connection did not exist between the Arctic Ocean basin and the other oceans at this time, the presence of freshwater in the Arctic may have triggered the initiation of sea-ice formation that increased albedo and contributed to global cooling (Brinkhuis et al., 2006; Moran et al., 2006).

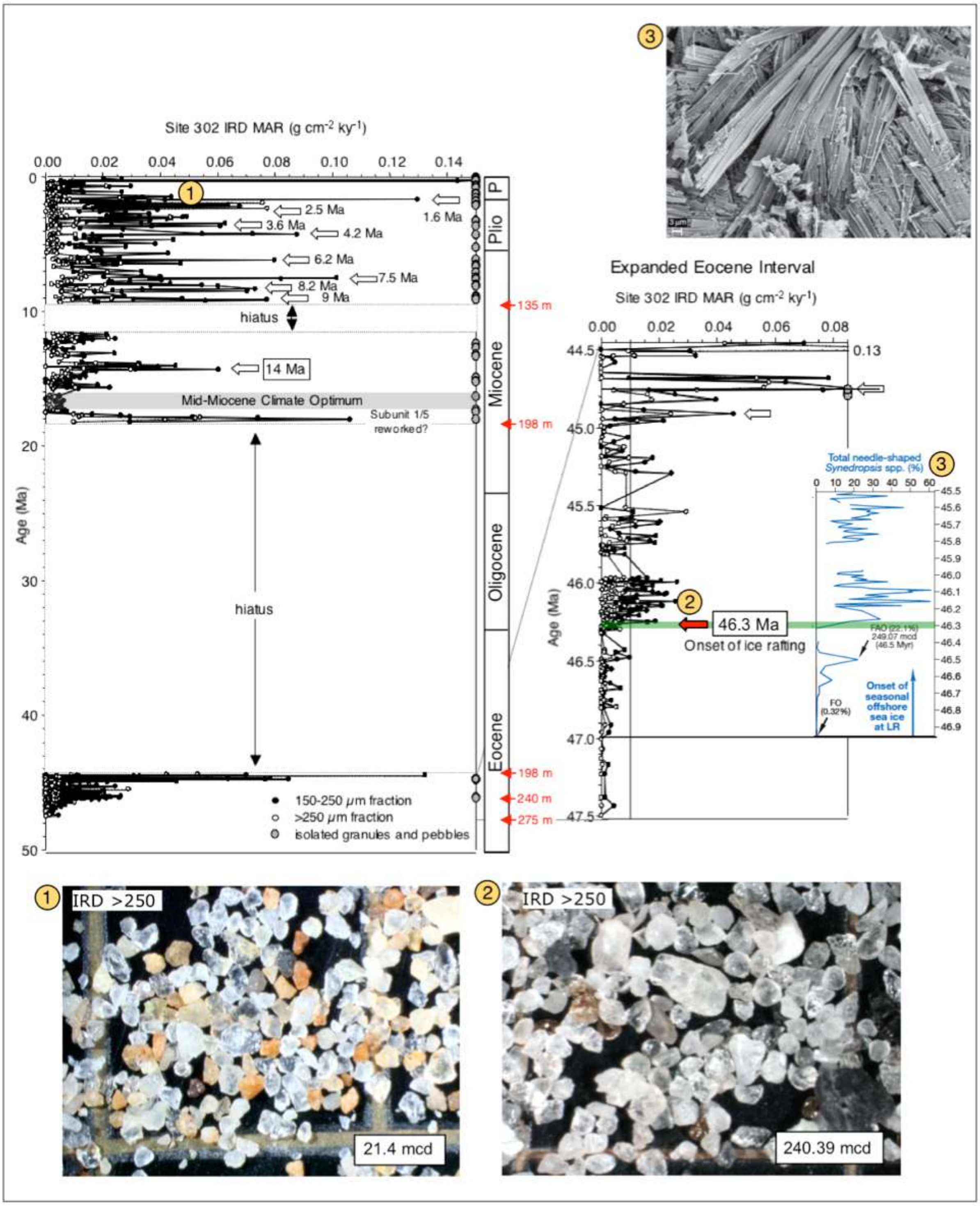

Fig. 6. IRD mass accumulation rates (g cm^{-2} ky^{-1}) in the >250 µm (dotted line and open circles) and 150-250 µm (black line and solid circles) size fractions of the Eocene to Pleistocene (270 to 0 mcd) section of the ACEX record (St. John, 2008, supplemented), along with isolated granules and pebbles (large gray circles) (from Backman, Moran, McInroy, et al., 2006) vs. age (Ma). Green line with red arrow marks onset of ice-rafting. Open arrows indicate major pulses of IRD input. The Mid-Miocene Climate Optimum (e.g., Flower and Kennet, 1995; Zachos et al., 2001) is marked as horizontal gray bar. Red numbers indicate „meters composite depth (mcd)". On the right, an enlargement of the middle Eocene interval (44.5 – 47.5 Ma) of this dataset and the concentrations of needle-shaped sea-ice diatom *Synedropsis* spp. (Stickley et al., 2009) are shown.

- Previous studies suggest that the Northern Hemisphere Glaciation (NHG) began no earlier than about 14 Ma (e.g., Thiede et al., 1998; Winkler et al., 2002), whereas glaciation of Antarctica began much earlier, i.e., as early as about 43 Ma (Lear et al., 2000). ACEX results, i.e., sea-ice diatom and IRD data, push back the date of Northern Hemisphere cooling and onset of sea ice into the Eocene as well. The first occurrence of sea-ice related diatoms, contemporaneously with IRD, was at about 47-46 Ma (when using the original ACEX age model of Backman et al., 2008) or ~ 43 Ma (when using the alternate chronology of Poirier and Hillaire-Marcel, 2011) (Figs. 3 and 6). Iceberg transport, however, was probably also present in the middle Eocene, as indicated by mechanical surface-texture features on quartz grains from this interval (St. John, 2008). An early onset/intensification of NHGs during Eocene times is also supported by IRD records from the Greenland Basin ODP Site 913 (Eldrett et al., 2007; Tripati et al., 2008). These findings suggest that the Earth's transition from the Greenhouse to the Icehouse world was bipolar, which points to greater control of global cooling linked to changes in greenhouse gases in contrast to tectonic forcing (Backman, et al., 2006, 2008; Moran et al., 2006; Stickley et al., 2009).
- One of the most profound changes in the character of sedimentation in the ACEX record was the mid-Cenozoic shift from freshwater-influenced biosilica- and C_{org}-rich deposits of a poorly ventilated and isolated Eocene ocean to fossil- and C_{org}-poor glaciomarine silty clays of a well-ventilated Miocene Ocean (Fig. 7; Moran et al., 2006; Stein et al., 2006; Stein, 2007). Based on the original ACEX age model (Backman, et al., 2008), the transition between these two modes of sedimentation is obscured by a large hiatus spanning the time interval from late Eocene to middle Miocene, i.e., 44.4 to 18.2 Ma (Fig. 3). This change from euxinic to well-oxygenated open marine conditions was correlated to the tectonically controlled widening of the Fram Strait in the late early Miocene (~17.5 Ma), which allowed a critical two-way surface exchange between the Arctic Ocean and Norwegian Greenland Seas to commence (Jakobsson et al., 2007). The recent Os-Re isotope dates from the cross-banded and underlying Eocene age biosiliceous rich sediments, however, suggest that the transition from euxinic to well-oxygenated conditions may have occurred much earlier, i.e., already in the late Eocene (Poirier and Hillaire-Marcel, 2009, 2011).

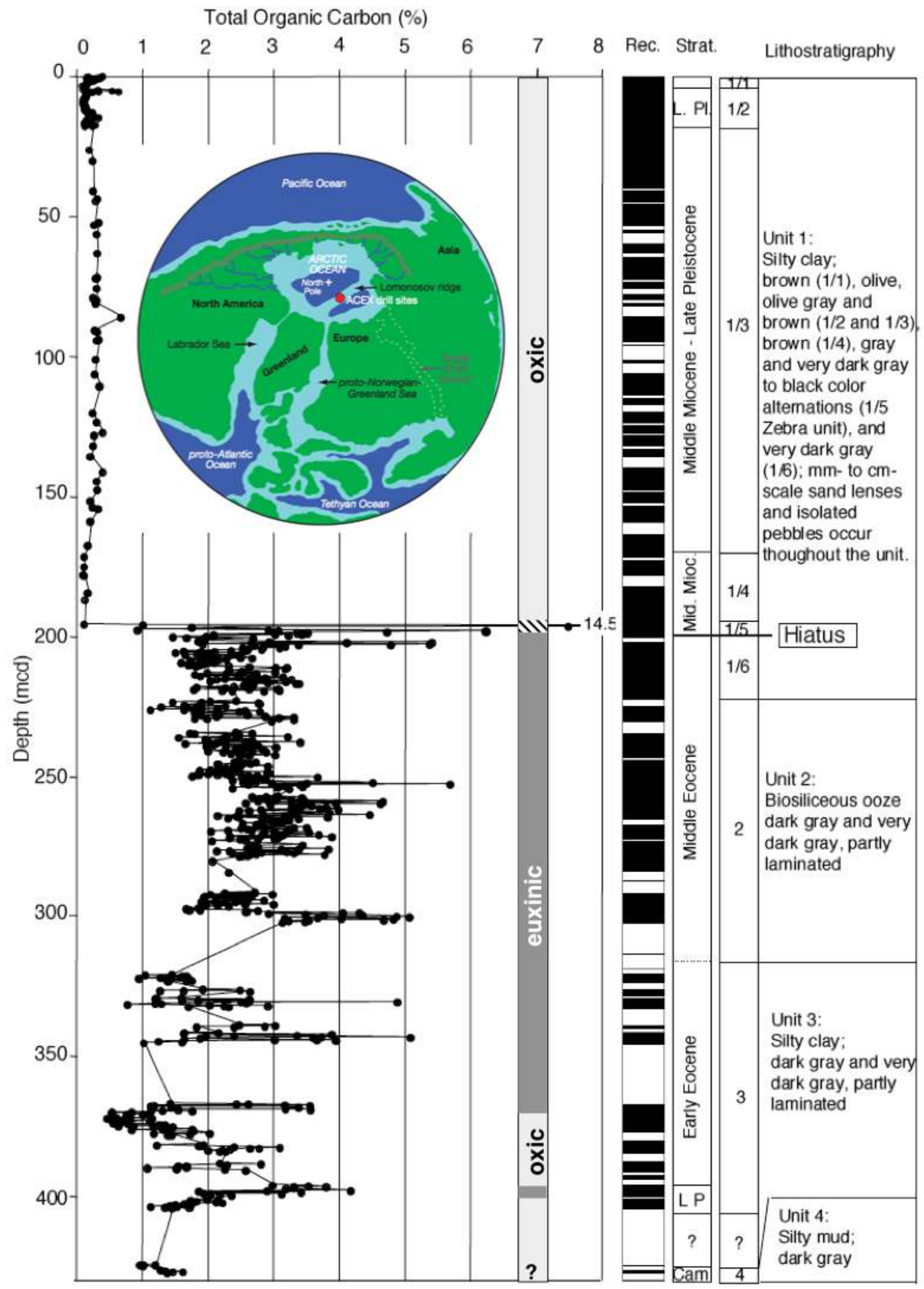

Fig. 7. Record of total organic carbon (TOC) contents as determined in the composite ACEX sedimentary sequence (Stein 2007). Data on recovery, stratigraphy, and lithological units (1-4) and subunits (1/1 to 1/6) from Backman, Moran, McInroy et al. (2006). Cam = Campanian; LP = late Paleocene; Mid Mioc. = middle Miocene; L.Pl. = late Pleistocene. Map with Eocene paleogeography from Stickley et al. (2009).

- Dating of Arctic Ocean sediments is a classic problem in stratigraphy. However, ACEX could prove that, with combination of existing techniques such as micropaleontology, Be isotopes, cyclostratigraphy and magnetostratigraphy, a stratigraphic framework adequate to answer the key scientific questions, could be established for the Cenozoic time interval (Backman, et al., 2008; Fig. 3). ACEX results did also once and for all confirm that we, at least in this part of the Arctic, have cm-scale rather than mm-scale sedimentation rates with implications for all paleoceanographic reconstructions based on sediment cores. A large mid-Cenozoic hiatus recognised in the original ACEX age model, however, was recently challenged by osmium isotope dates which suggest a condensed interval of very limited sedimentation (Fig. 3). The development of a multiproxy-based age model across a more expanded/continuous Eocene through Miocene section will be a major outcome of the proposed ACEX2 program. Furthermore, dating of Pliocene and Quaternary age sediments was also problematic in ACEX due to poor overlapping recovery. In ACEX2, the selection of sites in areas with higher surface water productivity (i.e. in the marginal ice zone), higher-resolution records, and complete and overlapping revocery in multiple holes, will provide a more robust framework for developing a Quaternary-Pliocene age model.

4. Scientific objectives and hypotheses to be tested

While the Arctic paleoceanographic and paleoclimate results from ACEX were unprecedented, key questions related to the climate history of the Arctic Ocean on its course from Greenhouse to Icehouse conditions during early Cenozoic times remain, largely due to the major mid-Cenozoic hiatus and partly low recovery of the ACEX record. In addition to elevated atmospheric CO_2 concentrations in the Cenozoic, other boundary conditions such as the freshwater budget, exchange between the Arctic and Pacific/Atlantic oceans as well as the advance and retreat of major circum-Arctic ice sheets have changed dramatically during the late Cenozoic. An understanding of how these boundary conditions have influenced the form, intensity and permanence of the Arctic sea ice cover can help improve our understanding of the complex modern ocean-atmosphere-ice system and how it has evolved with global climate (O`Regan et al, 2011). Therefore, the primary objectives of ACEX2 share several of those in the original 533-Full3 (ACEX) proposal, and also build on what we learned from ACEX:

Scientific (Key) Objective 1: A complete characterization of the Cenozoic transition from Greenhouse to Icehouse in the Arctic. The Cenozoic transition of the Earth's climate from one extreme (Paleogene Greenhouse lacking ice) to another (Neogene Icehouse with bipolar glaciation characterized by an Antarctic continental ice-cap and seasonally variable but persistent sea-ice cover in the Arctic) is linked to increased latitudinal gradients and oceanographic changes that connected surface and deep-sea circulation between high and low latitude oceans. The general Cenozoic cooling trend, however, is interrupted by warming intervals as well as short-term extreme cooling transients, such as the **late Oligocene warming and the Mid-Miocene Climatic Optimum, and the Oi-1 Glaciation and the Mi-1 Glaciation** (Fig. 1; Zachos et al., 2001, 2008; Coxall et al., 2005; Tripati et al., 2005).

Some of the related *key questions* for this objective are:
Did the Arctic Ocean climate follow the global trend shown in Figure 1? Are the Early Eocene Climate Optimum (poorly recovered in the ACEX record) and the Oligocene and Mid-Miocene warmings also reflected in Arctic Ocean records? Did **extensive glaciations** develop synchronously in both the Northern and Southern Hemispheres? Are the Oi-1 and Mi-1 glaciations bipolar (Fig. 1; Zachos et al., 2001, 2008), i.e., are there indications for major Northern Hemisphere glaciations at that time? The proposed ACEX2 sites are much closer to the Siberian shelf than the ACEX1 sites and thus should contain more clearly signals of past (Siberian) ice sheets if they have existed. What are the related scale and timing of short- and long-term **sea-level changes**? Does the mineralogical signature of sediments reveal changing source areas for Cenozoic glaciations, as was demonstrated in existing late Pliocene/Pleistocene records from ODP Leg 151 (Matthiessen et al., 2006)?

In addition, based on records of sediment and foraminiferal geochemistry, Tripati et al. (2005) report evidence for synchronous deepening and subsequent oscillations in the calcite compensation depth in the tropical Pacific and South Atlantic from 42 Ma, with a permanent deepening at 34 Ma, coinciding with changes in seawater oxygen isotope ratios. They suggest a lowering of global sea level through significant storage of ice in **both hemispheres** by at least 100 to 125 m. This hypothesis (not approved yet; cf., Edgar et al., 2007), i.e., the occurrence and variability of Northern Hemisphere glaciations during this time span, can be tested by the proposed drilling on southern Lomonosov Ridge.

During the major Pleistocene glaciations, it is generally accepted that huge ice sheets occupied western Eurasia, Greenland and North America and terminated at their continental margins (e.g., Svendsen et al., 2004; Ehlers and Gibbard, 2007). The exposed continental shelves in the Beringian region of Siberia, on the other hand, are thought to have been covered by a tundra landscape, i.e., large ice sheets did not exist at that time (Alekseev, 1997; Gualtieri et al., 2005). Based on detailed multibeam swath sonar system, sediment echosounding and multichannel seismic reflection profiling along the East Siberian continental margin, Niessen et al. (2013) postulated that huge, km-thick marine ice sheets occurred repeatedly off Siberia during Pleistocene glacial intervals (Fig. 8), maybe even already since the Pliocene (Hegewald and Jokat, 2013). The existence of such huge ice sheets must have had a significant influence on Earth albedo and oceanic and atmospheric circulation patterns, not considered in climate models so far (Niessen et al., 2013). For proving this hypothesis, however, long complete, undisturbed and well–dated sedimentary sections are needed. These sequences are planned to be recovered from the southern Lomonosov Ridge by drilling at Site LR-01A (Fig. 8).

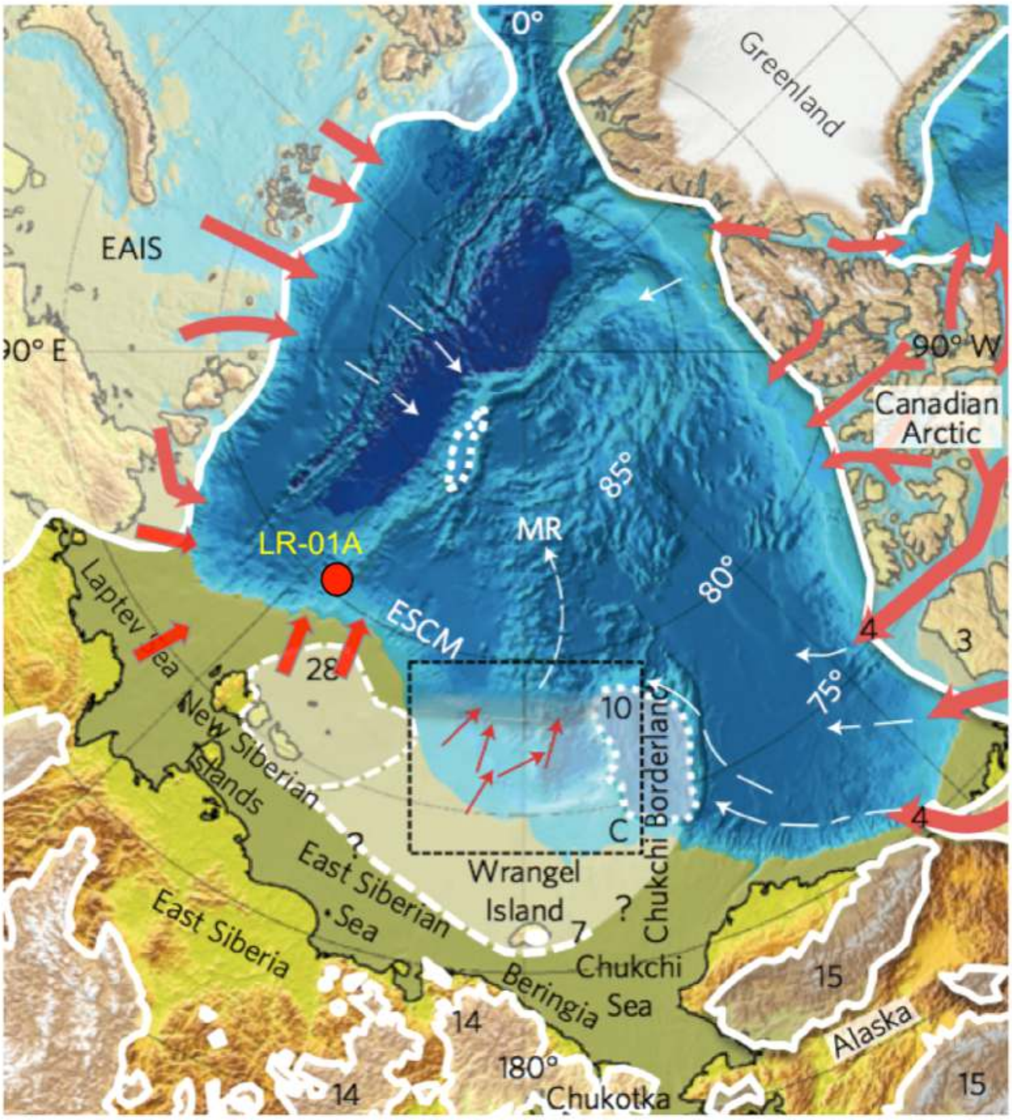

Fig. 8. Proposed maximum extent of an ice sheet on the East Siberian Continental Margin (Niessen et al., 2013) and compiled Pleistocene circum-Arctic ice sheets. Red arrows indicate major ice streams. White arrows indicate propagation of proposed ice shelves. Areas surrounded by dotted lines are proposed marine ice sheets. Numbers refer to different ice sheets discussed in the paper. The location of Site LR-01A is shown. (from Niessen et al. 2013, supplemented).

Even after several studies on ACEX material, the **variability of sea-ice in terms of frequency, extent and magnitude** remains a pressing scientific question. Specifically, there remains considerable debate concerning the onset and subsequent persistence of perennial sea-ice cover. Based on Fe-oxid and heavy-mineral data, Darby (2008) and Krylov et al. (2008) proposed that a perennial sea-ice cover was predominant in the central Arctic Ocean since the Middle Miocene. Matthiessen et al. (2009), on the other hand, stated that the co-occurrence of *Nematosphaeropsis* spp. and *Impagidinium* spp. found in the Neogene part of the ACEX sequence, points to seasonally open waters. How can these discrepancies be explained? New complete sedimentary sections from Lomonosov Ridge may prove or disprove the different hypotheses of onset, extent and variability of Arctic sea-ice cover.

Scientific Objective 2: History of Arctic Bottom and Surface-Water Circulation. Black biosiliceous silty clays and clayey silts rich in organic carbon were found throughout the upper early to middle Eocene section of the ACEX record, indicating poorly ventilated bottom waters and high but variable primary production (Stein et al., 2006; Jakobsson et al., 2007). When and how did the change to oxygenated bottom waters typical for the Neogene and Quaternary Arctic Ocean occur? Was it in the early-mid Miocene as proposed by Jakobsson et al. (2007) or the Late Eocene as proposed by Poirier and Hillaire-Marcel (2011)?

What are the implications for the gateway configurations of the Arctic and its connection to the World's oceans? How critical is the exchange of water masses between the Arctic Ocean and the Atlantic and Pacific oceans for the long-term climate evolution as well as rapid climate change? High-resolution records of Neogene/Quaternary Arctic Climate in comparison with similar records from the North Atlantic (ODP Leg 151 and IODP Expeditions 303/306) and the Bering Sea (IODP Expedition 323) may help to answer this question.

Scientific Objective 3: History of Arctic (Lena) River Discharge. The more proximal location of the proposed sites in ACEX2 to the Siberian margin allows a detailed study of the history of Arctic (Lena) river discharge and its paleoenvironmental significance. In this context, the Miocene uplift of the Himalayan-Tibetan region is of particular interest as it may have triggered enhanced discharge rates of Siberian rivers and changed the fresh-water balance of the Arctic's surface waters, considered to be a key factor for the formation of Arctic sea-ice and onset of major glaciations (Driscoll and Haug, 1998), a hypothesis to be tested by drilling.

Scientific Objective 4: High-Resolution Characterization of the Pliocene Warm Period in the Arctic. During the Pliocene warm period, sea surface temperature (SST) in several ocean basins was substantially warmer (Marlow et al., 2000; Haywood et al., 2005; Lawrence et al., 2006) and global mean surface temperature was estimated to be at least ~3ºC higher than today (Haywood and Valdes, 2004). Futhermore, cooling in the surface ocean seems to have started at least 1 My before the intensification of the NHG as shown, for example, in the Eastern Equatorial Pacific (EEP), implying that while the growth of Northern Hemisphere ice sheets undoubtedly played a major role as a climatic feedback during the Plio-Pleistocene transition, it did not force or initiate EEP cooling (Lawrence et al., 2006). How did the Arctic Ocean evolve during the Pliocene warm period and succeeding cooling? How do the marine climate records correlate with terrestrial records obtained from the Siberian Lake Elgygytgyn (Brigham-Grette et al., 2013)?

Scientific Objective 5: The "Hiatus Problem". What is the cause of the major hiatus spanning the late Eocene to early Miocene time interval in the ACEX record (based on the original age model of Backman, et al., 2008)? Does this hiatus in fact exist, or is it rather an interval of extremely reduced sedimentation rate as proposed by Poirier and Hillaire-Marcel (2009, 2011)? If there is a major hiatus, is it related to the subsidence history of Lomonosov Ridge? Was there a phase of uplift and exposure of the ridge in the Oligocene, tentatively linked to a transpressional/compressional episode in the formation of the Amundsen Basin caused in part by the northward motion of Greenland in the Paleogene (Brozena et al., 2003; O'Regan et al., 2008)? Was the hiatus a response to increased bottom-water currents during the opening of surface and deep-water connenctions via the Fram Strait (Moore et al., 2006)? Recovery of the complete mid-Cenozoic interval can be used to test these hypotheses.

5. Relation to the IODP New Science Plan (NSP)

Our highest-priority objective is getting a continuous record of the long-term climate history of the central Arctic Ocean, representing the transition from early Cenozoic Greenhouse conditions to Neogene/Quaternary Icehouse conditions. This overall goal is directly related to Research Theme 1 of the NSP, *Climate and Ocean Change*, especially Challenges 1 and 2. It exactly follows a key element of the NSP (p. 74):

"Recovering core from the high Arctic is a top priority of the IODP. Such samples will address climate-related research ..... It is expected that a minimum of two Arctic drilling expeditions will be required to achieve essential goals in high-latitude paleoceanography ...... provide information critical for answering .... questions relevant to poleward heat transport as high-latitude climate evolved from subtropical, to warm temperate, to its current ice-covered state."

We will focus on the detailed reconstruction of Arctic ice-sheet history and sea-ice distribution under different boundary conditions during the Cenozoic, with a special emphasis on the comparison of the climatic evolution of the northern and southern high latitudes. Data from the high Northern Latitudes will provide critical boundary conditions needed to investigate discrepancies between proxy records and modeling results and may help to improve climate models. These key objectives are fully in line with the NSP (p. 16):

„Differences between observations and simulations of past warmer climates are most profound in the polar regions, where the models tend to severely underestimate the warming inferred from paleoproxies. This potential for dramatic amplification of polar temperatures under elevated CO_2 conditions is important for predictions of sea ice and permafrost melting, and the future stability of ice sheets. The differences between north and south polar geography (a polar ocean versus a polar continent) offer an opportunity for ocean drilling to help resolve the complex linkages among the polar ocean, atmosphere, and high-latitude land surface processes. With such data we can better ground-truth Earth system models and quantify the strength of polar feedbacks."

The importance of proxy records for sea-ice variability, a key theme of the propsoed expedition, is again highlighted in the NSP Summary:

„.. decline of summer sea ice cover in the Arctic Ocean and polar ice covering Greenland and western Antarctica is occurring more rapidly than predicted by climate models. To better understand Earth's response to rapid climate changes, and how different parts of Earth's climate system interact to amplify or diminish the effects of increasing global temperatures, scientists must collect and analyze environmental information from deep-ocean sediments that were deposited millions to tens of millions of years ago when atmospheric CO_2 levels and global temperatures were much higher than today."

ACEX2 records on the temporal and spatial variability will also provide information on time scales of ice-sheet variability and related sea-level change under different boundary conditions. This aspect is also a key theme in the NSP (p. 16):

„Proposed drilling strategy from pole to pole IODP drilling platforms to collect records linking climate, ice sheet, and sea level histories on geologic time scales. The climate history derived from these records is used to ground-truth and test the performance of numerical ice-atmosphere-ocean models, thus improving their ability to project future sea level rise."

6. Drilling strategy: Site survey data, site characteristics, and drilling objectives

As the drill sites are located in the ice-covered Arctic Ocean, a **mission-specific platform (MSP)** is needed for the drilling operation. In comparison to the ACEX1 work area of 2004, ice conditions of ACEX2 are significantly less severe, especially when looking at the sea-ice cover in recent years. In 2007 and 2012, the area of proposed drilling operations was even completely ice-free during September (Fig. 4C). Furthermore, we will submit a *Polarstern* proposal for the next deadline (30 September 2014 for period 2016-2019) to get ***Polarstern*** **as supporting icebreaker and laboratory ship** (handling of ACEX2 cores: storing, logging, scanning; microscopy/stratigraphy, etc.; helicopter exchange; extended Science Party) during ACEX2. *Polarstern* may contemporaneously carry out some additional (and supplementary) reseach in the ACEX2 area (e.g., seismic profiling, sediment coring). If the *Polarstern* proposal will be reviewed positively and the ship will become available to support ACEX2, these activities may be handled as a **complementary contribution with funding from a third party source outside IODP/ECORD ("Complementary Project Proposal (CPP)"?).**

6.1. Site survey data

Deep-penetration reflection seismic profiles were acquired from the Lomonosov Ridge on icebreaker-based expeditions between 1991 and 2009 (Jokat et al., 1992, 1995, 1999; Jokat, 2005, 2009; Kristoffersen et al., 1997; Darby et al., 2005; Jakobsson, 2007b). The first high-resolution chirp profiles were collected in 1996 (Jakobsson, 1999). In 1999, the SCICEX program collected high-resolution chirp sub-bottom profiler data, swath bathymetry and sidescan sonar backscatter data from an USN nuclear submarine (Edwards and Coakley, 2003), contributing significantly to the much improved bathymetric chart of the Arctic Ocean (Jakobsson et al., 2008, 2012). In 1995 and 1998, an intensive Parasound survey in conjunction with a coring program of near-surface (Quaternary) sediments was carried-out in the area of the proposed sites (Stein et al., 1997; 2001; Jokat et al., 1999). Some site survey data from this area (lines AWI 98550, 98565, and 98567; Fig. 9a) are already included in the IODP Site Survey Data Bank; the new data will be uploaded to the SSDB for the November 01 deadline.

Based on the more recent *Polarstern* site survey in 2008 (Jokat, 2009), the primary and alternate ACEX2 sites were selected (Fig. 9a). Main factor for the site selection based on seismic data is the mapping of continuous and laterally conformable reflectors indicating continuous sedimentary sequences. Locations with any indications of faults, slumps or hiatuses were avoided to ensure flat-lying, unfaulted, undeformed and well-stratified deposits. Furthermore, locations were selected indicating appropriate thicknesses and depths feasible for drilling into and through the strata of interest. Depth-velocity information for estimating the thickness of the sedimentary units was derived from sonobuoys (Ickrath and Jokat, 2009) and interval velocities calculated from stacking velocities of selected CDP gathers (Weigelt et al., 2013).

The age control for the sedimentary units (Fig. 9b) was estimated via links of seismic lines to drill site data of the Chukchi Shelf, ACEX-drilling on central Lomonosov Ridge, and onshore geology from the New Siberian Islands (Fig. 10; Weigelt et al., 2013). Referring to basin-wide similarities of reflection pattern and configuration of strata, two distinguished seismic units were mapped throughout the area and are the constraints for dating the remaining units.

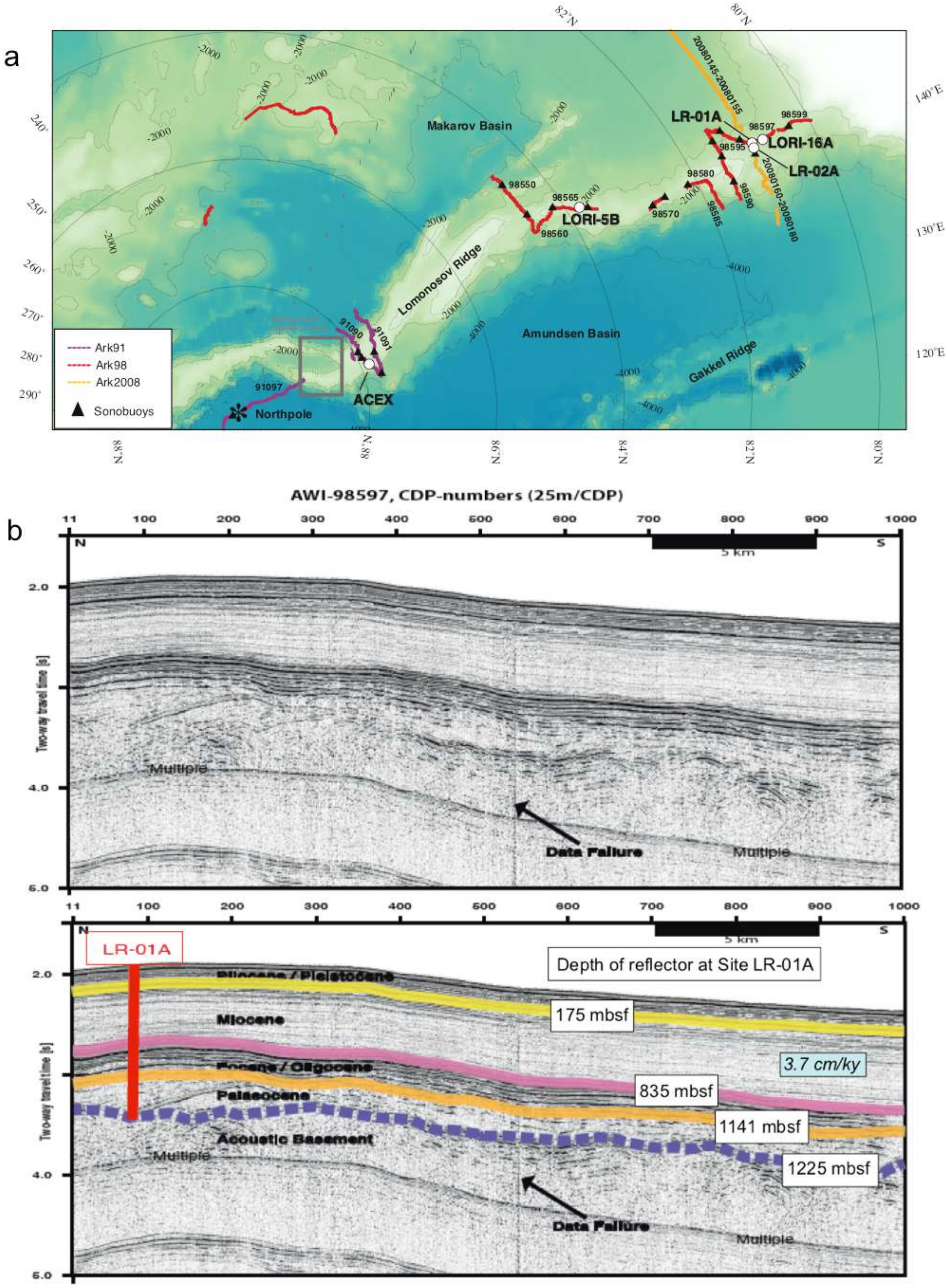

Fig. 9. (a) Map indicating seismic profiles (bold numbers AWI lines) and location of IODP Expedition 302 (ACEX) drill site and the new proposed (ACEX2) drill sites on Lomonosov Ridge (LR-01A, LR-02A, LORI-5B, LORI -15A, and LORI -16A). (b) Seismic profile across Site LR-01A with main seismic units and mean sedimentation rate. Unit thicknesses were calculated using velocitties from sonobuoys; see (a) for locations. Gray box in (a) shows HOTRAX study area.

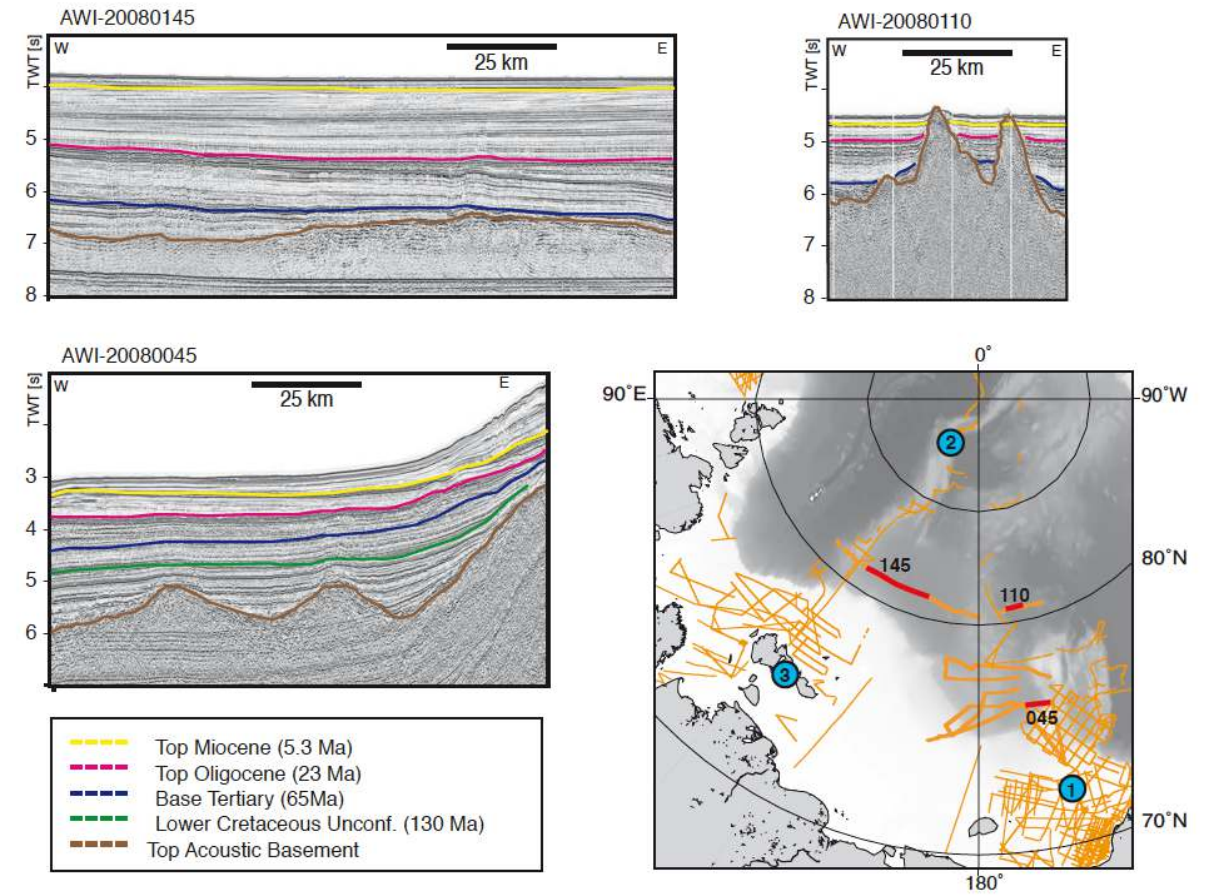

Fig. 10: Example of seismic sections (locations on map: red lines) demonstrating conformities in reflection pattern, marker horizons and reflector configurations across large parts of the Siberian part of the Arctic Ocean. These similarities enable a data-transfer from remote drill sites (map: blue circles) onto seismic profiles (map: yellow lines) (Weigelt and Jokat, submitted). Age-information was extrapolated from 1. drill sites on the Chucki Shelf (Sherwood et al., 2002), 2. ACEX-drilling on the central Lomonosov Ridge (Moran et al., 2006), 3. onshore geology from the New Siberian Islands (Franke et al., 2004; Kos'ko and Korago, 2009). In these examples marker horizons defined and inferred via the drill sites on the Chukchi Shelf after Hegewald and Jokat (2013) are shown: Top of Miocene (yellow), Top of Oligocene (pink), Base of Tertiary (blue), and lower Cretaceous Unconformity (green).

The lower one, a pronounced sequence of high-amplitude reflectors is the most striking feature in the Siberian Arctic Ocean. It indicates a strong and widespread change in depositional conditions. Originally - in the 708 prepoposal - the top of this reflector sequence ("pink" marker, Fig. 9b) was proposed as post-rift subsidence sequence. But based on the new data and correlations (Hegewald and Jokat, 2013; Weigelt et al, 2013), the top of the reflector sequence is interpreted to be much younger, i.e., presenting the base of the Miocene. Likely the whole high-amplitude reflector sequence developed during Eocene-Oligocene times after the breakup of the Eurasian Basin, followed by a reorientation of Arctic Plates during the Oligocene, and accompanied by a widespread regression of sea level. During the Oligocene, the Fram Strait opened gradually, and a modern current system evolved in the Arctic Ocean since Early Miocene times. The reflector band likely corresponds to the hiatus, or extremely condensed lithologic unit recorded on the ACEX site on the central Lomonosov Ridge. Consequently, an age of latest Oligocene/Early Miocene is assigned to the top of the reflector sequence (i.e., the "pink" reflector in ~965 mbsf at Site LR-02A and in ~835 mbsf at Site LR-01A; Fig. 9b). An age estimate for the base of the reflector band ("orange" reflector in ~1270 mbsf at Site LR-02A and in ~1140 mbsf at Site LR-01A; Fig. 9b) is less clear, but most likely corresponds to base of Eocene (˜56 Ma) times.

The second marker unit detected on the seismic lines parallels the seafloor in a depth of about 200ms (i.e., the "yellow" reflector in ~220 mbsf at Site LR-02A and in ~175 mbsf at Site LR-01A; Fig. 9b). It is characterized by a change from weak-amplitude to high-amplitude reflectors and interpreted to mark the transition to large-scale glaciation of the Northern Hemisphere during the Pliocene. From correlation of seismic profiles and drill site data (Hegewald and Jokat, 2013), the age of the yellow reflector is 5.3 Ma (base of the Pliocene). Based on this age model, the mean sedimentation rate for the entire LR-01A and LR-02A sequence is about 3.7 and 4 cm/ky, respectively, i.e., significantly higher than at the ACEX Site (see below).

The preferred Site LR-01A is located on perpendicular crossing seismic lines (Fig. 9a) on which continuous and widespread strata are documented. This site would enable an extrapolation of drilling data via seismic profiles onto strata along the Lomonosov Ridge, and across the Ridge into the adjacent Amundsen and Makarov Basins. Pliocene strata of 175 m, and Miocene strata of about 660 m thickness, respectively can be sampled. The target band of high-amplitude reflectors lies in a depth of 835 mbsf, Early Eocene/Palaeocene strata probably can be reached at 1140 mbsf (Fig. 9b). At the alternate site LR-02A, average sedimentation rates are slightly higher, but the basement depth ("purple" reflector) is significantly deeper (see below).

Although we are confident in reaching Eocene sediments in the lowermost part of the selected sites, we cannot guarantee that lower Eocene sediments will be drilled. We think, however, that even if we would miss these sediments, the recovery of a thick continuous Oligocene-Miocene sequence is such a major step forward in Arctic and global climate research and would enable us to address key primary scientific objectives described here, that it would justify carrying out ACEX2 as proposed.

6.2. Site characteristics: Lithologies, age model, sedimentation rates

Some general predictions about the type of sediments that will be recovered at the proposed ACEX2 sites can be obtained from the ACEX sequence and a couple of gravity cores taken in the vicinity of the ACEX2 area. Based on the visual core description and smear slide analysis as well as TOC and XRD data determined in core catcher samples, the ACEX sequence was divided into four main lithologic units (Fig. 7):

Unit 1 (Top to 223.6 mcd; Quaternary to Middle Eocene) is dominated by silty clay, ranging from light olive brown at the top, through olive and gray to very dark gray at the bottom; color banding is strong. Millimeter-to-centimeter-scale sandy lenses and isolated pebbles occur in Unit 1. Unit 1 is subdivided into 6 subunits. Based on the original ACEX age model, a major hiatus was identified at about 198.7 mcd separating subunits 1/6 and 1/5 and spanning the time interval from about 44.4 to 18.2 Ma; another shorter hiatus lasting 2.2 my, occurs within Subunit 1/3 in the late Miocene 9.4-11.6 Ma (Fig. 3; Jakobsson et al., 2007; Backman et al., 2008). Subunit 1/5 is outstanding due to its very prominent black and white color banding (“Zebra Unit“; Fig. 3).

Unit 2 (223.6 to 313.6 mcd; Middle Eocene) is dominated by very dark gray mud-bearing biosiliceous ooze with submillimeter-scale laminations as well as isolated pebbles.

Unit 3 (about 313.6 to 404.8 mcd; Late Paleocene to Early Eocene) is dominated by very dark gray clay with submillimeter-scale laminations. Units 3 and 4 are separated by a second major hiatus representing the time interval of about 56 to 79 Ma (Backman, et al., 2008).

Unit 4 (424.50 mbsf to 427.63 mbsf; Campanian) is dominated by very dark gray clayey mud and silty sands.

Whereas the upper (middle Miocene to Quaternary) part of the ACEX sequence (Subunits 1/1 to 1/4) is composed of silty clay with very low OC contents of < 0.5%, i.e., values very similar to those in upper Quarternary records from Lomonosov Ridge (Stein et al., 2004), the

Campanian and Paleogene sediments (Units 2 to 4) are characterized by high TOC values of 1 to >5% (Fig. 7). In Subunit 1/5 (about 193 to 199 mcd; late early Miocene) characterized by distinct gray/black color bandings, even OC contents up to 14.5% were measured in samples from the black horizons (Fig. 7). Hence, organic rich sedimentation, with good potential for the preservation of organic and siliceous walled microoragnisms, can be expected for Eocene age sediments and may also characterize Oligocene-Miocene sediments, if the early mid-Miocene opening of the Fram Strait was the major factor in driving the ventilation of the Arctic (Jakobsson et al., 2007).

Based on the original ACEX age model, sedimentation rates in the region of the ACEX sites (87°56'N, 140°E) are between about 0.8 and 2.4 cm/ky (Fig. 3; Backman, et al., 2008). Following the recent Os-Re isotope age model, the hiatus was instead interpreted as a period of very low sedimentation rates of 0.2 cm/ky for the middle part of the sequence representing the late Eocene to early Miocene time interval (Fig. 3).

During Polarstern Expedition ARK-XI/1 in 1995 (Rachor, 1997), 10 gravity cores were recovered on a transect across Lomonosov Ridge very close to the proposed ACEX2 primary sites (Fig. 11). Main lithologies of these <8 m long sediment cores are brown, beige, gray to dark gray, and olive green, partly bioturbated or laminated silty clays, representing Marine Isotope Stages (MIS) 6 to 1 (Fig. 11; Stein et al., 1997, 2001). The dark gray lithologies in the lower part of the more eastern cores (MIS 6) are characterized by increased organic-carbon contents of > 1% (Stein et al., 2001; Stein, 2008). Sand-sized material is more or less absent in these sequences. For cores PS2757 and PS2761, a huge amount of sedimentological, geochemical and mineralogical data (i.e., grain-size distributions; heavy, bulk and clay mineralogy; organic-carbon composition; biomarker data including IP_{25} as sea-ice proxy; MSCL logging data; paleomag, etc.) are available and successsfully used for reconstruction of past glaciations, oceanic circulation patterns, depositional environment, etc. during the late Quaternary time interval (e.g., Behrends, 1999; Müller, 1999; Stein et al., 2001; Stein, 2008, unpubl. data). Mean sedimentation rates vary between 3.5 and 6 cm/ky. That means, these are values very similar to those estimated for the proposed Site LR-01A (and alternate LR-02A) based on seismic stratigraphy (Fig. 9b).

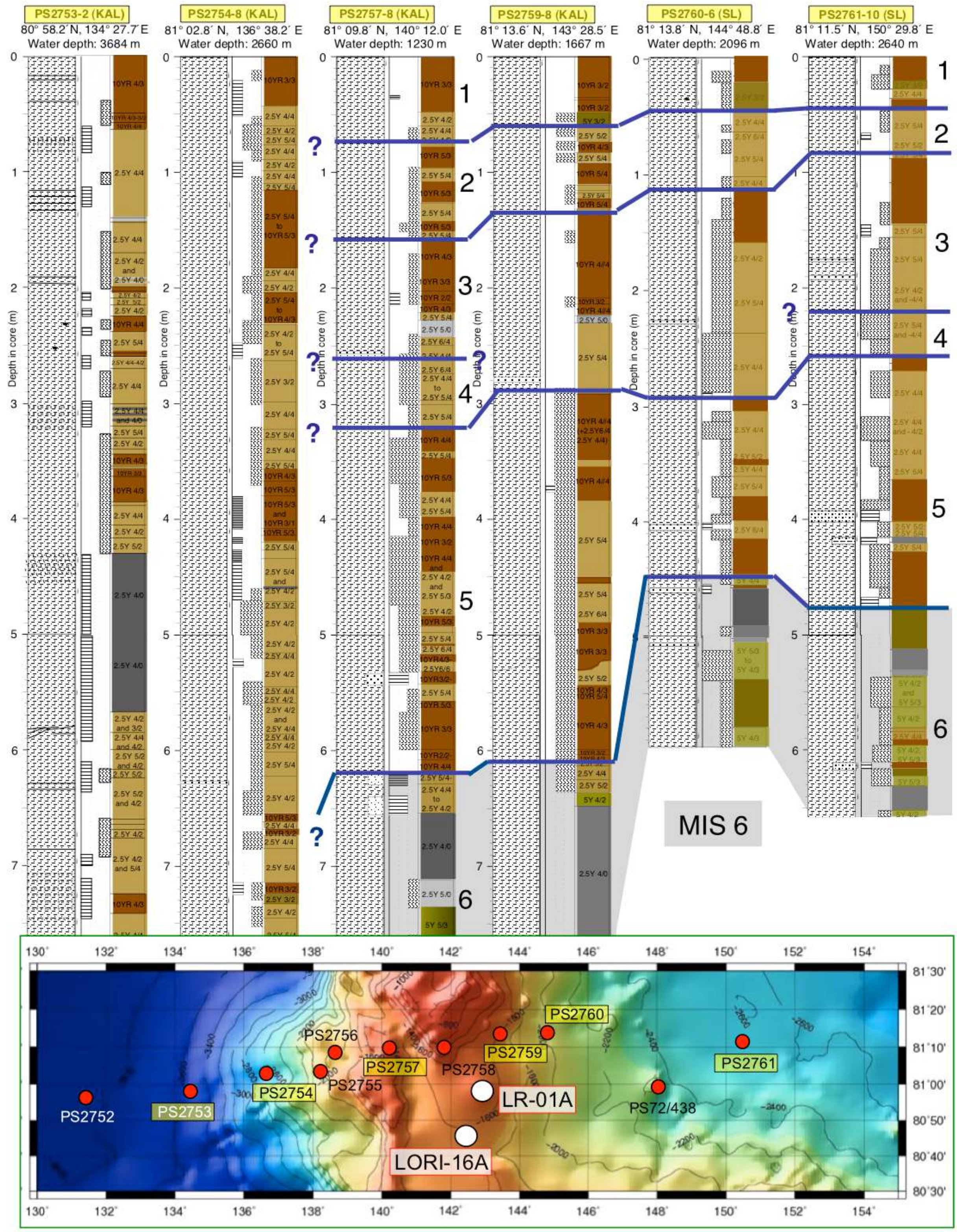

Fig. 11. Transect of sediment cores recovered across the southern Lomonosov Ridge during Polarstern Expedition ARK-XI/1. Main lithologies and isotope stratigraphy of six selected cores are shown (from Stein et al., 1997, supplemented).

6.3. Drilling and logging objectives

We propose one primary drill site on southern Lomonosov Ridge, Site LR-01A, located on crossing point of line AWI-98597 and line AWI-20080160 (Fig. 9a). At this site, we propose drilling three APC/XCB/RCB holes down to basement (the “purple” reflector in ~1225 mbsf; Fig. 9b). This is required to ensure recovery of a complete composite stratigraphic sediment record and to meet our highest priority paleoceanographic objective, the **continuous long-term Cenozoic climate history of the central Arctic Ocean**. Based on its protected location and the existing seismic profiles, a continuous record without a major hiatus is very probable. Logging should be carried out at one of the holes. For the entire drilling, coring, and logging activities, a total 29 days is estimated. As alternate drilling locations Site LR-02A, LORI-16A and LORI-05B (located on line AWI-20080160, AWI-98597 and AWI-98565, respectively; Fig. 9a) are proposed.

If time is left after finishing all activities at Site LR-01A, we propose a secondary drill site with three APC holes to about 250 mbsf (~4.5 days of operations) at alternate sites LR-02A or LORI-16A, both characterized by higher sedimentation rates. This permits some higher-resolution studies of Plio-Pleistocene Arctic climate change.

7. Methodology and scientific outcome

As shown by the ACEX studies, getting a reliable age model for a Cenozoic sedimentary sequence is possible when using a multi-proxy approach. Furthermore a large number of common as well as new proxies have been successfully used for reconstructions of past sea-ice cover, ice-sheet history, oceanic circulation patterns, primary productivity, oxygenation of deep-water sphere etc (e.g., Backman and Moran, 2008, 2009). In Figure 12, a large number of these different approaches applicable to studying Arctic sediments are summarized.

- An age model of the ACEX2 will be based on a combination of existing techniques such as micropaleontology (dinoflagellates, silicoflagellates, diatoms), Be isotopes, Os-Re isotopes, cyclostratigraphy and magnetostratigraphy (Backman et al., 2006, 2008; Frank et al., 2008; O’Regan et al., 2008; Poirier and Hillaire-Marcel, 2009, 2011).

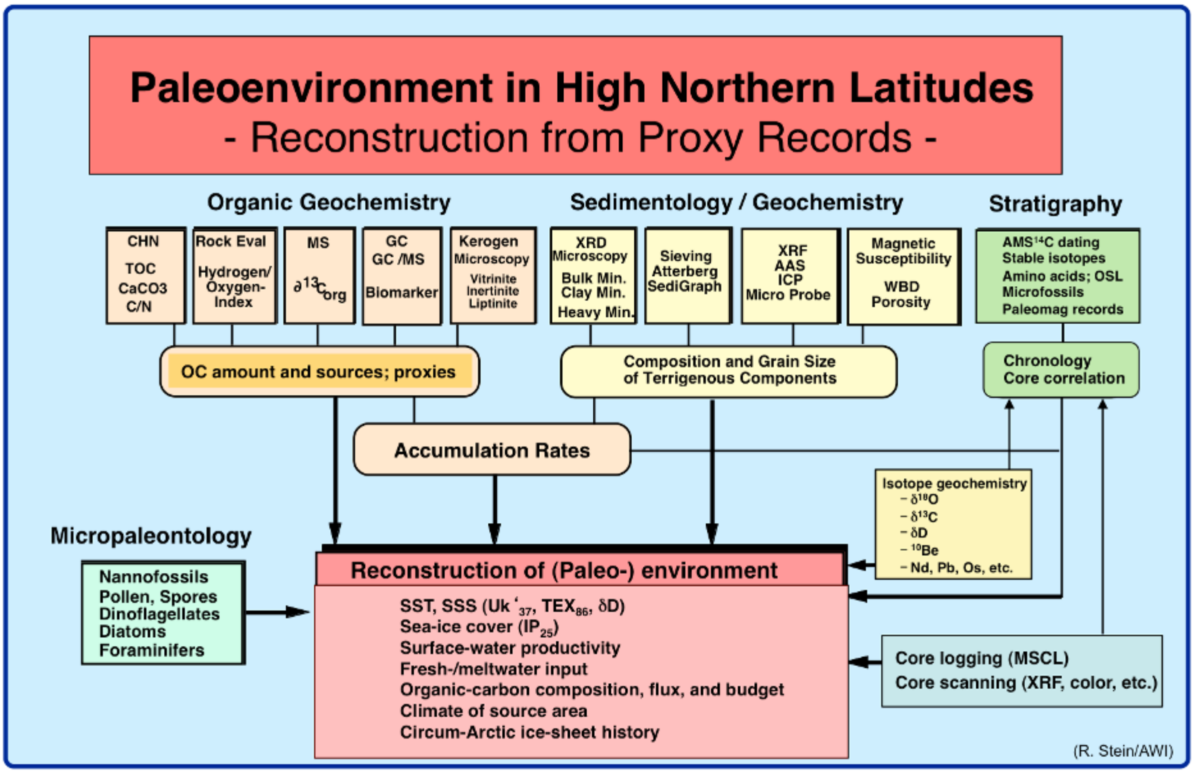

Fig. 12. A compilation of methods to be used for studying ACEX2 material.

- For reconstruction of past sea-ice cover well established micropaleontological proxies (dinoflagellate cysts, diatoms etc.) (e.g., de Vernal et al., 2001; Stickley et al., 2009) as well as grain-size data/IRD and mineralogical and inorganic geochemical tracers (e.g., St. John, 2008; Darby, 2003, 2008; Stein, 2008; Krylov et al., 2008; Jakobsson et al., 2010; Polyak et al., 2010; Fagel et al., 2012; Immonen et al., 2011) will be studied. In addition, a newly developed biomarker approach based on the determination of specific highly-branched isoprenoids („IP_{25}“) may give even more quantitative information of sea-ice distribution (e.g., Belt et al., 2007; Müller et al., 2009, 2011; Stein et al., 2012; Belt and Müller, 2013). Very recently, IP_{25} was found in sediments from ODP-Leg 151 sites 911 and 910, indicating that this biomarker approach for sea-ice reconstruction can be successfully used at least back to 4 Ma (Stein and Fahl, 2013 and unpubl. data).
- Grain-size and surface texture data, major and minor elements, mineral composition, neodymium and strontium isotopes, terrigenous biomarkers will all be used to reconstruct transport processes and pathways of sediments, terrigenous sediment input (by icebergs/sea ice, rivers, and winds), oceanic circulation patterns, and circum-Arctic ice-sheet history (e.g., Wahsner et al., 1999; Phillips and Grantz, 2001; Tütken

et al., 2002; Viscosi-Shirley et al., 2003; Spielhagen et al., 2004; Haley et al., 2008a, 2008b; Stein, 2008; St. John, 2008; Strand et al., 2008; Gleason et al., 2009; März et al., 2010; Martinez et al., 2009; Fagel et al., 2012; Immonen, 2013; Jang et al., 2013).

- The reconstruction of sea-surface conditions (temperature, salinity, and primary productivity) will be carried out by means of specific biomarker aproaches (TEX_{86} and U^{k}_{37}; alkenones, sterols, n-alkanes, δD, etc.), Mg/Ca ratios of forams and ostracods, faunal and floral composition, and transfer function techniques, etc. (e.g., de Vernal et al., 2001; Brinkhuis et al., 2006; Sluijs et al., 2006, 2009; Stein, 2008; Weller and Stein, 2008; Cronin et al., 2012).
- Information about deep-water ventilation can be obtained from faunal composition, specific biomarkers, and major and minor elements (Sluijs et al., 2006; Cronin et al., 2008; Weller and Stein, 2008; März et al. 2011; Kender and Kaminski, 2013).

Summary

The polar regions – and especially the Arctic Ocean and surrounding areas - are (in real time) and were (over historic and geologic time scales) subject to rapid and dramatic change because of complex feedback processes (collectively known as “polar amplification”). The cascades of feedback processes that connect the Arctic cryosphere, ocean and atmosphere remain incompletely constrained by observations and theory and are difficult to simulate in climate models. A complete Cenozoic record from the Arctic (as to be obtained within ACEX2) is needed to assess the sensitivity of the Earth‘s climate system to changes of different forcing parameters (e.g. CO_2) and to test the reliability of climate models by evaluating their performance under conditions very different from the modern climate. Precise knowledge of past rates and scales of climate change are the only means to separate natural and anthropogenic forcings and will enable us to further increase the reliability of prediction of future climate change. While the Arctic paleoceanographic and paleoclimate results from ACEX were unprecedented, key questions related to the climate history of the Arctic Ocean on its course from Greenhouse to Icehouse conditions during Cenozoic times remain, largely due to the major mid-Cenozoic hiatus and partly low recovery of the ACEX record. We are convinced that our ACEX2 key goal, i.e., getting a complete record of Cenozoic climate history, can be achieved by careful site selection, appropriate drilling technology, and applying multi-proxy approaches to paleoceanographic, paleoclimatic, and age-model reconstructions.

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IODP Proposal 708-Full

Arctic Ocean Paleoceanography: Towards a Continuous Cenozoic Record from a Greenhouse to an Icehouse World (ACEX2)

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February-June 2002: Research stay at the Institute of Ocean Sciences, Sidney/Canada
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Expertise Sedimentology - Organic Geochemistry - Paleoceanography

Major research interests (Key words)

- Paleoclimate and paleoceanography of the Arctic Ocean and adjacent Eurasian continental margin, and the North Atlantic Ocean.
- History of circum-Arctic ice sheets and paleoceanic circulation patterns.
- Arctic Ocean organic carbon flux and its relationship to surface-water productivity, sea-ice cover, sea-surface temperature, and terrigenous input; biomarker approach: IP25, Uk37, TEX86).
- The paleoenvironment of the early (Mesozoic/Cenozoic) Arctic Ocean and its transition from Greenhouse to Icehouse conditions.

Involvement in the Deep Sea Drilling Project (DSDP), Ocean Drilling Program (ODP), and Integrated Ocean Drilling Program (IODP)

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- Representative of Germany in the ODP *Ocean History Panel* (OHP) (1989 - 1990)
- Representative of Germany in the IODP *Science Steering and Evaluation Panel* (SSEP) (2004 - 2007)
  October 2005 - September 2007 <u>co-chair of SSEP</u>
- Representative of Germany/ECORD in the IODP *Science Planning Committee* (SPC) (2009 - 2011)
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  <u>ESSAC Chair</u> (October 2009 – September 2011)
  Outgoing ESSAC Vice-chair (October 2011 – March 2013)

- Representative of Germany/ECORD in the IODP *Scientific Implementation and Policy Committee* (SIPCOM) (2011 – September 2013)

- Co-Koordinator von IODP Germany (since 2009)
http://www.bgr.bund.de/DE/Themen/MarineRohstoffforschung/IODP/Koordinationsbuero/koordinationsbuero_node.html

- Member of the ECORD *Magellan-Plus Steering Committee* (since 2011)

Participant of international expeditions

* Meteor-Cruise 60 (NE-Atlantic, Mar-Apr 1982)
* DSDP-Leg 90 (SW-Pacific, Nov 82-Jan 1983)
* ODP-Leg 105 (Baffin Bay, Labrador Sea; Aug-Oct 1985)
* ODP-Leg 108 (NE Atlantic; Feb-Mar 1986)
* ODP-Leg 128 (Japan Sea, Aug-Oct 1989)
* Polarstern-Cruise ARK-VIII/3 (Central Arctic, Aug-Oct 1991)
* ODP-Leg 151 (Arctic Gateways, Aug-Oct 1993)
* Polarstern-Cruise ARK-X/2 (East Greenland Continental Margin, Aug-Oct 1994)
* Polarstern-Cruise ARK-XI/1 (Kara/Laptev Sea and adjacent continental margin)
* ACSYS-Expedition (Swedish Icebreaker Oden; Central Arctic Ocean, Jul-Sep 1996)
* Polarstern-Cruise ARK-XIII/2 (Yermak Plateau, Jun-Aug 1997; Chief-scientist)
* Polarstern-Cruise ARK-XIV/1a (Alpha Ridge, Lomonosov Ridge; Aug-Sep 1998)
* Akademik Boris Petrov Cruise 1999 (Kara Sea, Aug-Sep; Co-chief-scientist)
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* Polarstern-Cruise ARK-XX/3 (Yermak Plateau, Sep-Oct 2004; Chief-scientist)
* IODP-Leg 302 (Lomonosov Ridge, Aug 2004; Member of Science Party)
* IODP-Leg 306 (North Atlantic Paleoceanography, Mar-Apr 2005; Co-chief scientist)
* Polarstern-Cruise ARK-XXIII/3 (Mendeleev Ridge/East Sib. Sea, Aug-Oct 2008)
* Merian-Cruise MSM 12/2 (Eirik Drift/Labrador Sea, Jun-Jul 2009)
* Araon (Test) Cruise (Japan Sea, June 2011)
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Publications

In total > 190 peer-reviewed publications in international scientific journals

Five selected (ACEX-related) publications

Stein, R., Boucsein, B., and Meyer, H., 2006. Anoxia and high primary production in the Paleogene central Arctic Ocean: First detailed records from Lomonosov Ridge, Geophysical Research Letters, 33, L18606, doi:10.1029/2006GL026776.

Stein, R., 2007. Upper Cretaceous/Lower Tertiary black shales near the North Pole: Organic-carbon origin and source-rock potential. Marine and Petroleum Geology 24, 67-73.

Stein, R., 2008. Arctic Ocean Sediments: Processes, Proxies, and Palaeoenvironment. Developments in Marine Geology, Vol. 2, Elsevier, Amsterdam, 587 pp..

Weller, P. and Stein, R., 2008. Paleogene biomarker records from the central Arctic Ocean (IODP Expedition 302): Organic-carbon sources, anoxia, and sea-surface temperature Paleoceanography *23,* PA1S17, doi:10.1029/2007PA001472.

Stein, R. and Fahl, K., 2013. Biomarker proxy IP_{25} shows potential for studying entire Quaternary Arctic sea-ice history. Org. Geochemistry 55, 98-102; doi: 10.1016/j.orggeochem.2012.11.005.

IODP Site Summary Forms:

Form 1 – General Site Information

708 - Full

Section A: Proposal Information

Title of Proposal:	Arctic Ocean Paleoceanography: Towards a Continuous Cenozoic Record from a Greenhouse to an Icehouse World (ACEX2)
Date Form Submitted:	2013-10-04 22:40:44
Site Specific Objectives with Priority (Must include general objectives in proposal)	Recovery of a complete stratigraphic sedimentary record on the central Lomonosov Ridge to meet our highest priority paleoceanographic objective, the continous long-term Cenozoic climate history of the central Arctic Ocean. (Alternate Site)
List Previous Drilling in Area:	IODP Expedition 302 (ACEX)

Section B: General Site Information

Site Name:	LORI-5B	Area or Location:	central Lomonosov Ridge
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 83.80	Jurisdiction:	International waters
Longitude:	Deg: 146.48	Distance to Land: (km)	900
Coordinate System:	WGS 84		
Priority of Site:	Primary: no Alt:	Water Depth (m):	1334

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Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	1250	0
	Total Sediment Thickness (m) 1750	
	Total Penetration (m): 1250	
General Lithologies:	Silty clay, clay, biosiliceous ooze; siltstone, claystone; some ice-rafted debris	

Coring Plan: (Specify or check)

one drill site with three APC/XCB/RCB holes down to about 1250 mbsf to recover multiple sections of the sediment sequence to ensure complete recovery for construction of a composite section (Alternate Site)

APC [X] XCB [X] MDCB [ ] PCS [ ] RCB [X] Re-entry [ ]

Wireline Logging Plan:

Standard Measurements		Special Tools			
WL	[X]	Magnetic Susceptibility	[ ]		
LWD	[X]	Magnetic Field	[ ]	Formation Image (Acoustic)	[ ]
Porosity	[X]	Borehole Temperature	[ ]	Formation Fluid Sampling	[ ]
Density	[X]	Nuclear Magnetic Resonance	[ ]	Formation Temperature & Pressure	[ ]
Gamma Ray	[X]	Geochemical	[ ]	VSP	[ ]
Resistivity	[X]	Side-Wall Core Sampling	[ ]	Others:	
Sonic (Δt)	[X]				
Formation Image (Res)	[X]				
Check-shot (upon request)	[ ]				

Max. Borehole Temp.: °C

Mud Logging: (Riser Holes Only)

Cuttings Sampling Intervals

from m to m m intervals

from m to m m intervals

Basic Sampling Intervals: 5m

Estimated Days: Drilling/Coring: 27 Logging: 2 Total On-site:

Observatory Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Potential Hazards/ Weather:

						Preferred weather window
Shallow Gas	[ ]	Complicated Seabed Condition	[ ]	Hydrothermal Activity	[ ]	August-September (time interval of minimum ice extent)
Hydrocarbon	[ ]	Soft Seabed	[ ]	Landslide and Turbidity Current	[ ]	
Shallow Water Flow	[ ]	Currents	[ ]	Gas Hydrate	[ ]	
Abnormal Pressure	[ ]	Fracture Zone	[ ]	Diapir and Mud Volcano	[ ]	
Man-made Objects (e.g., sea-floor cables, dump sites)	[ ]	Fault	[ ]	High Temperature	[ ]	
H_2S	[ ]	High Dip Angle	[ ]	Ice Conditions	[X]	
CO_2	[ ]	Sensitive marine habitat (e.g., reefs, vents)				
Other:						

IODP Site Summary Forms:

Form 2 - Site Survey Detail

Proposal #:	708	Site #:	LORI-5B	Date Form Submitted:	2013-10-04 22:40:44

*** Key to SSP Requirements**

X=required; X=may be required for specific sites; Y=recommended; Y*=may be recommended for specific sites; R=required for re-entry sites; T=required for high temperature environments; † Accurate velocity information is required for holes deeper than 400m.*

Data Type	In SSDB	SSP Req.	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no		High-resolution seismic reflection, line AWI-98565 (will be uploaded tot he SSBD before the Nov 01 deadline) Location: CDP 2580
1b High resolution seismic reflection (crossing)	no		Location:
2a Deep penetration seismic reflection (primary)	no		Location:
2b Deep penetration seismic reflection (crossing)	no		Location:
3 Seismic Velocity	no		
4 Seismic Grid	no		
5a Refraction (surface)	no		
5b Refraction (bottom)	no		
6 3.5 kHz	no		AWI Parasound profile
7 Swath bathymetry	no		AWI Hydrosweep profile
8a Side looking sonar (surface)	no		
8b Side looking sonar (bottom)	no		
9 Photography or video	no		
10 Heat Flow	no		
11a Magnetics	no		
11b Gravity	no		
12 Sediment cores	no		sediment cores from Polarstern expeditions 1991 and 2007
13 Rock sampling	no		
14a Water current data	no		
14b Ice Conditions	no		more perennial sea ice (8-9/10)
15 OBS microseismicity	no		
16 Navigation	no		Navigation data for seismic line AWI-98565 exist and will be uploaded tot he SSDB before the Nov 01 deadline.
17 Other	no		

IODP Site Summary Forms:

Form 3 – Detailed Logging and Downhole Measurement Plan

Proposal #:	708	Site #:	LORI-5B	Date Form Submitted:	2013-10-04
Water Depth (m):	1334	Sed. Penetration (m):	1250	Basement Penetration (m):	0

Are high temperatures or other special requirements (e.g., unstable formations), anticipated for logging at this site?

Estimated total logging time for this site: 2

Measurement Type	Scientific Objective	Relevance (1=high, 3=low)
Check Shot Survey		0
Nuclear Magnetic Resonance		0
Geochemical		0
Side-wall Core Sample		0
Formation Fluid Sampling		0
Borehole Temperature		0
Magnetic Susceptibility		0
Magnetic Field		0
VSP		0
Formation Image (Acoustic)		0
Formation Pressure & Temperature		0
Other (SET, SETP, ...)		0

IODP Site Summary Forms:

Form 4 – Environmental Protection

Proposal #:	708	Site #:	LORI-5B	Date Form Submitted:	2013-10-04 22:40:44

Pollution & Safety Hazard	Comment
1. Summary of Operations at site.	Triple APC to refusal, continued by XCB and RCB to final depth
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling.	N/A
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows.	N/A
4. Indications of gas hydrates at this location.	No
5. Are there reasons to expect hydrocarbon accumulations at this site?	No
6. What "special" precautions will be taken during drilling?	severe/perennial ice conditions
7. What abandonment procedures need to be followed?	support by an icebreaker needed (e.g., RV Polarstern)
8. Natural or manmade hazards which may effect ship's operations.	ice
9. Summary: What do you consider the major risks in drilling at this site?	ice could delay operations

Proposal #:	708 - Full	Site #:	LORI-5B	Date Form Subm.:	2013-09-25 13:02:53

Subbottom depth (m)	Key reflectors, Unconformities, faults, etc	Age	Assumed velocity (km/sec)	Lithology	Paleo-environment	Avg. rate of sed. accum. (m/My)	Comments
0-180	Reflector "yellow"	5.3	1.6	silty clay	pelagic	34	
180-660	Reflector "pink"	23.8	2.2	silty clay	pelagic	26	
660-1000	Reflector "orange"	54.8	3.4	silty clay, biosiliceous ooze	pelagic	>10	
1000-1250	below Reflector "orange"	>54.8	>5	silty clay	pelagic		

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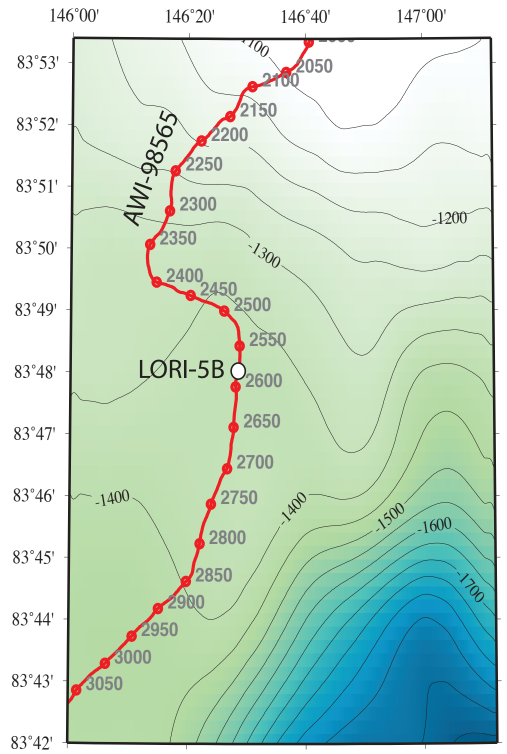
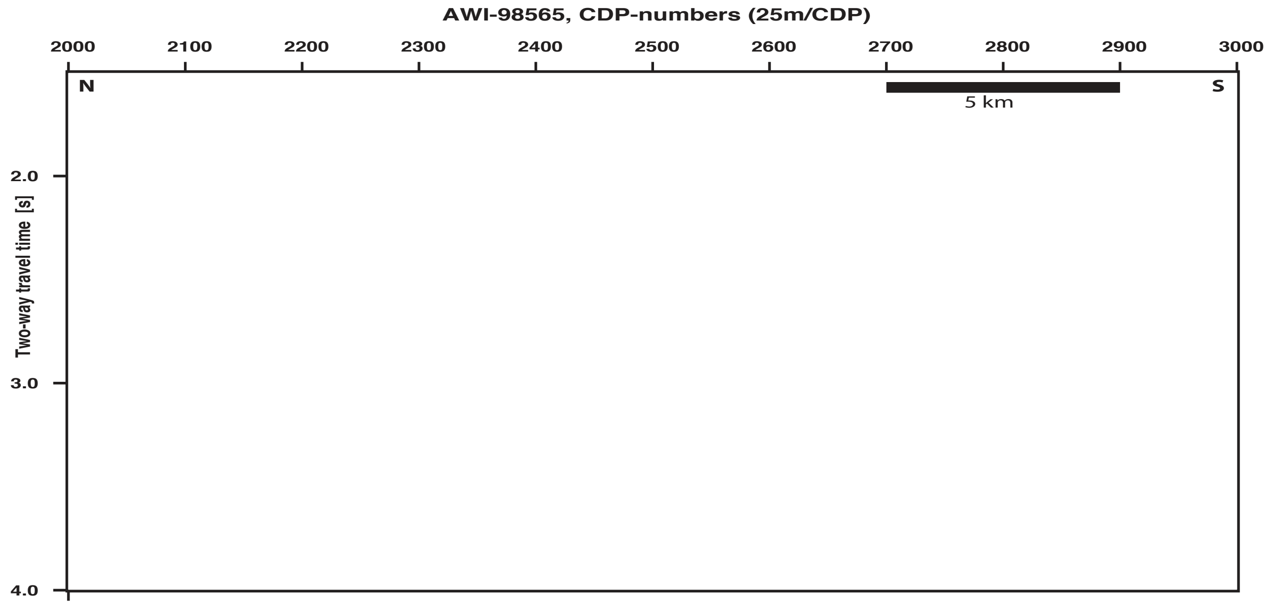
Proposal #:	708 - Full	Site #:	LORI-5B	Date Form Subm.:	2013-09-25 13:02:53

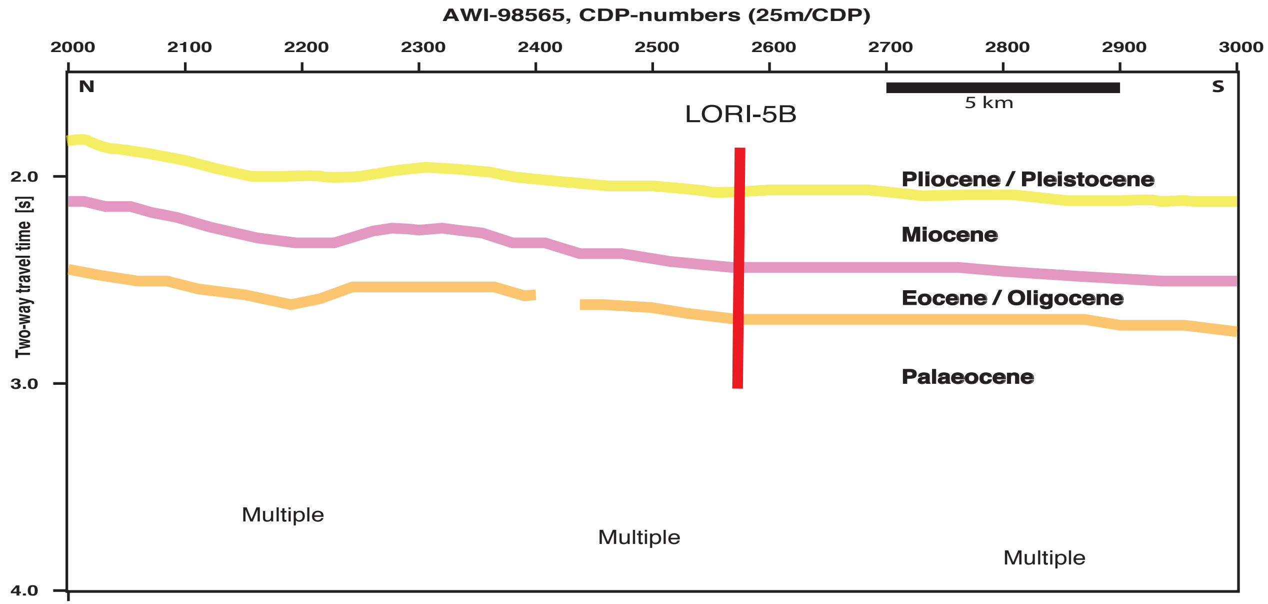
Site Summary Figure Comment	

Site Summary Form 6 IODP Proposal 708 Site LORI-5B



Profiles annotated using CDP numbers





Coordinates:	83° 48.03'N, 146° 28.5'E
Water-depth:	1334 m
Top Miocene (yellow):	180 mbsf
Top Oligocene (pink):	660 mbsf
Lower Eocene (orange):	1000 mbsf
Penetration:	1750 m

SSDB locations of these graphics and supporting data:

-Location map:	LORI-5B_map.pdf
-Seismic figures:	LORI-5B_AWI-98565.pdf
-SEGY data:	AWI-98565stack.sgy
-Navigation data:	98565_cdplocs.asc

IODP Site Summary Forms:

Form 1 – General Site Information

708 - Full

Section A: Proposal Information

Title of Proposal:	Arctic Ocean Paleoceanography: Towards a Continuous Cenozoic Record from a Greenhouse to an Icehouse World (ACEX2)
Date Form Submitted:	2013-10-04 22:40:44
Site Specific Objectives with Priority (Must include general objectives in proposal)	Recovery of a complete stratigraphic sedimentary record on the southern Lomonosov Ridge to meet our highest priority paleoceanographic objective, the continous long-term Cenozoic climate history of the central Arctic Ocean. (Alternate Site)
List Previous Drilling in Area:	IODP Expedition 302 (ACEX)

Section B: General Site Information

Site Name:	LORI-16A		Area or Location:	Southern Lomonosov Ridge
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#				
Latitude:	Deg: 80.78		Jurisdiction:	International waters
Longitude:	Deg: 142.78		Distance to Land: (km)	590
Coordinate System:	WGS 84			
Priority of Site:	Primary: no	Alt:	Water Depth (m):	1752

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	1850	0
	Total Sediment Thickness (m) 2160	
		Total Penetration (m): 1850
General Lithologies:	Silty clay, clay, biosiliceous ooze; siltstone, claystone; some ice-rafted debris	

Coring Plan:
(Specify or check)

one drill site with three APC/XCB/RCB holes down to about 1850 mbsf to recover multiple sections of the sediment sequence to ensure complete recovery for construction of a composite section (Alternate Site)

APC	XCB	MDCB	PCS	RCB	Re-entry
☒	☒	☐	☐	☒	☐

Wireline Logging Plan:

Standard Measurements		Special Tools			
WL	☒	Magnetic Susceptibility	☐		
LWD	☒	Magnetic Field	☐	Formation Image (Acoustic)	☐
Porosity	☒	Borehole Temperature	☐	Formation Fluid Sampling	☐
Density	☒	Nuclear Magnetic Resonance	☐	Formation Temperature & Pressure	☐
Gamma Ray	☒	Geochemical	☐	VSP	☐
Resistivity	☒	Side-Wall Core Sampling	☐	Others:	
Sonic (Δt)	☒				
Formation Image (Res)	☒				
Check-shot (upon request)	☐				

Max. Borehole Temp.: °C

Mud Logging: (Riser Holes Only)

Cuttings Sampling Intervals

from m to m m intervals

from m to m m intervals

Basic Sampling Intervals: 5m

Estimated Days:	Drilling/Coring: 33	Logging: 2	Total On-site:

Observatory Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Potential Hazards/ Weather:

						Preferred weather window
Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐	August-September (time interval of minimum ice extent)
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐	
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐	
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐	
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐	
H_2S	☐	High Dip Angle	☐	Ice Conditions	☒	
CO_2	☐	Sensitive marine habitat (e.g., reefs, vents)				
Other:						

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IODP Site Summary Forms:

Form 2 - Site Survey Detail

Proposal #: 708	Site #: LORI-16A	Date Form Submitted: 2013-10-04 22:40:44

*** Key to SSP Requirements**

X=required; X=may be required for specific sites; Y=recommended; Y*=may be recommended for specific sites; R=required for re-entry sites; T=required for high temperature environments; † Accurate velocity information is required for holes deeper than 400m.*

Data Type	In SSDB	SSP Req.	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no		High-resolution seismic reflection, line AWI-98597 (will be uploaded tot he SSBD before the Nov 01 deadline) Location: CDP 1060
1b High resolution seismic reflection (crossing)	no		Location:
2a Deep penetration seismic reflection (primary)	no		Location:
2b Deep penetration seismic reflection (crossing)	no		Location:
3 Seismic Velocity	no		
4 Seismic Grid	no		
5a Refraction (surface)	no		
5b Refraction (bottom)	no		
6 3.5 kHz	no		Parasound profile
7 Swath bathymetry	no		Hydrosweep profile
8a Side looking sonar (surface)	no		
8b Side looking sonar (bottom)	no		
9 Photography or video	no		
10 Heat Flow	no		
11a Magnetics	no		
11b Gravity	no		
12 Sediment cores	no		Numerous sediment cores from Polarstern expeditions 1995 and 2008
13 Rock sampling	no		
14a Water current data	no		
14b Ice Conditions	no		seasonal sea ice
15 OBS microseismicity	no		
16 Navigation	no		Navigation data for seismic line AWI-98597 exist and will be uploaded tot he SSDB before the Nov 01 deadline.
17 Other	no		

IODP Site Summary Forms:

Form 3 – Detailed Logging and Downhole Measurement Plan

Proposal #:	708	Site #:	LORI-16A	Date Form Submitted:	2013-10-04
Water Depth (m):	1752	Sed. Penetration (m):	1850	Basement Penetration (m):	0

Are high temperatures or other special requirements (e.g., unstable formations), anticipated for logging at this site?

Estimated total logging time for this site: 2

Measurement Type	Scientific Objective	Relevance (1=high, 3=low)
Check Shot Survey		0
Nuclear Magnetic Resonance		0
Geochemical		0
Side-wall Core Sample		0
Formation Fluid Sampling		0
Borehole Temperature		0
Magnetic Susceptibility		0
Magnetic Field		0
VSP		0
Formation Image (Acoustic)		0
Formation Pressure & Temperature		0
Other (SET, SETP, ...)		0

IODP Site Summary Forms:

Form 4 – Environmental Protection

Proposal #:	708	Site #:	LORI-16A	Date Form Submitted:	2013-10-04 22:40:44

Pollution & Safety Hazard	Comment
1. Summary of Operations at site.	Triple APC to refusal, continued by XCB and RCB to final depth
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling.	N/A
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows.	N/A
4. Indications of gas hydrates at this location.	No
5. Are there reasons to expect hydrocarbon accumulations at this site?	No
6. What "special" precautions will be taken during drilling?	ice management
7. What abandonment procedures need to be followed?	support by an icebreaker (e.g., RV Polarstern)
8. Natural or manmade hazards which may effect ship's operations.	ice
9. Summary: What do you consider the major risks in drilling at this site?	ice could delay operations

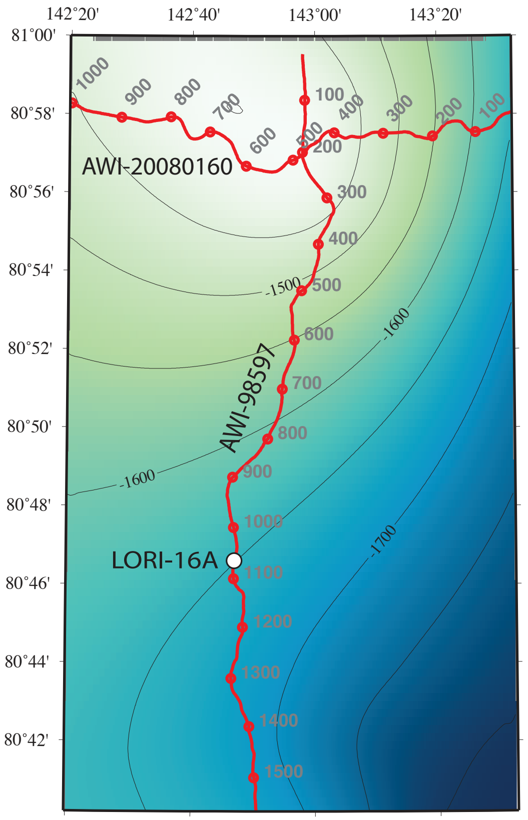
Proposal #:	708 - Full	Site #:	LORI-16A	Date Form Subm.:	2013-09-25 12:39:16

Subbottom depth (m)	Key reflectors, Unconformities, faults, etc	Age	Assumed velocity (km/sec)	Lithology	Paleo-environment	Avg. rate of sed. accum. (m/My)	Comments
0-195	Reflector "yellow"	5.3	2.2	silty clay	pelagic	38	
195-1395	Reflector "pink"	23.8	2.2	silty clay	pelagic	65	
1395-1850	Reflector "orange"	54.8	2.2	silty clay, biosiliceous ooze	pelagic	15	

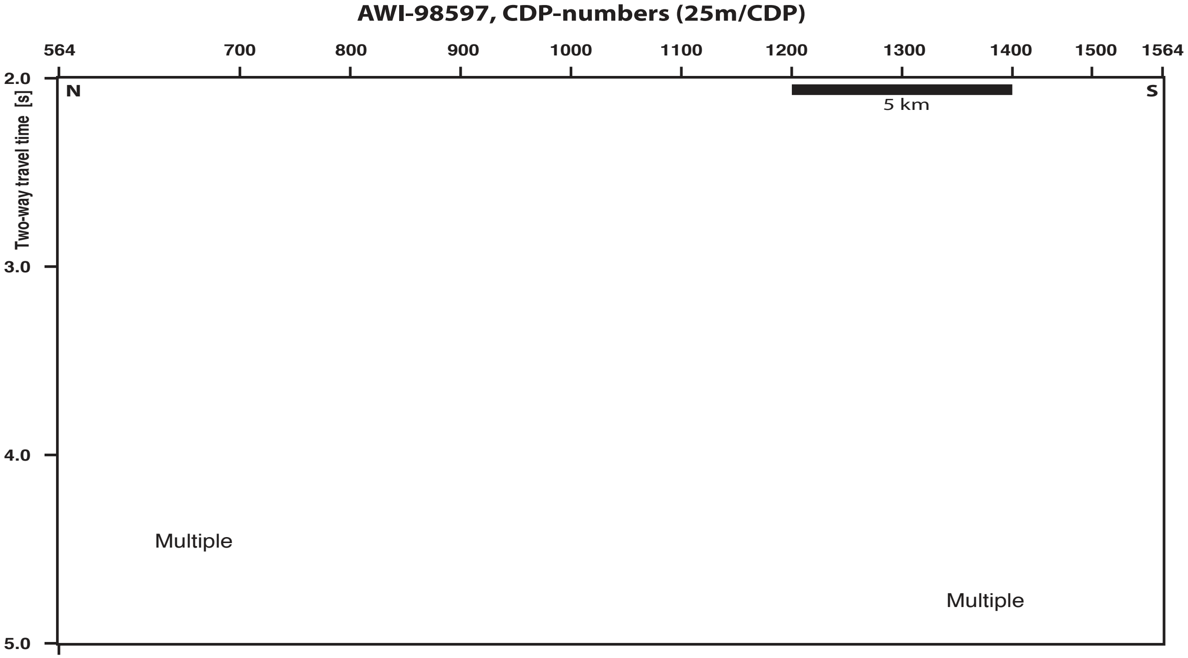
Proposal #:	708 - Full	Site #:	LORI-16A	Date Form Subm.:	2013-09-25 12:39:16

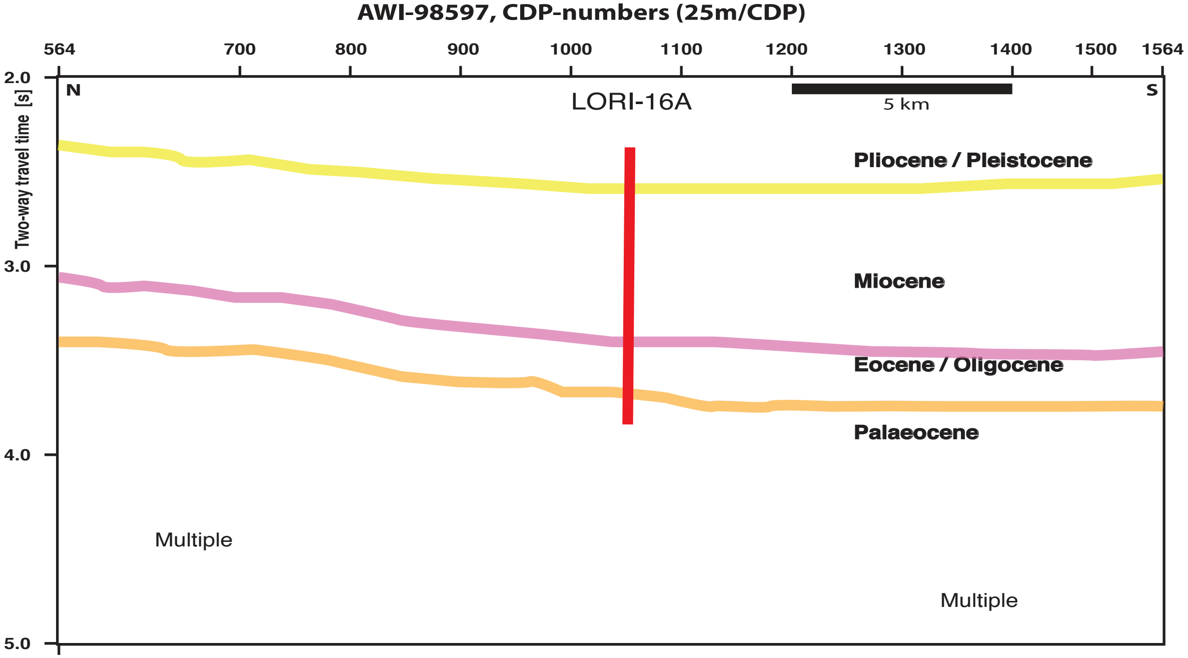
Site Summary Figure Comment	

Site Summary Form 6 IODP Proposal 708 Site LORI-16A



Profiles annotated using CDP numbers





Coordinates: 80° 46.6'N, 142° 46.9'E
Water-depth: 1752 m
Top Miocene (yellow): 195 mbsf
Top Oligocene (pink): 1395 mbsf
Lower Eocene (orange): 1840 mbsf
Penetration: 2160 m

SSDB locations of these graphics and supporting data:
-Location map: LORI-16_map.pdf
-Seismic figures: LORI-16A_AWI-98597.pdf
-SEGY data: AWI-98597stack.sgy
-Navigation data: 98597_cdplocs.asc

IODP Site Summary Forms:

Form 1 – General Site Information

708 - Full

Section A: Proposal Information

Title of Proposal:	Arctic Ocean Paleoceanography: Towards a Continuous Cenozoic Record from a Greenhouse to an Icehouse World (ACEX2)
Date Form Submitted:	2013-10-04 22:40:44
Site Specific Objectives with Priority (Must include general objectives in proposal)	Recovery of a complete stratigraphic sedimentary record on the southern Lomonosov Ridge to meet our highest priority paleoceanographic objective, the continous long-term Cenozoic climate history of the central Arctic Ocean (Alternate Site)
List Previous Drilling in Area:	IODP Expedition 302 (ACEX)

Section B: General Site Information

Site Name:	LR-02A	Area or Location:	Southern Lomonosov Ridge
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 80.97	Jurisdiction:	International waters
Longitude:	Deg: 142.47	Distance to Land: (km)	590
Coordinate System:	WGS 84		
Priority of Site:	Primary: no Alt:	Water Depth (m):	1450

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	1300	0
	Total Sediment Thickness (m) 2150	
		Total Penetration (m): 1300
General Lithologies:	Silty clay, clay, biosiliceous ooze; siltstone, claystone; some ice-rafted debris	0

Coring Plan:
(Specify or check)

one drill site with three APC/XCB/RCB holes down to about 1300 mbsf to recover multiple sections of the sediment sequence to ensure complete recovery for construction of a composite section (Alternate Site)

APC [X] XCB [X] MDCB [ ] PCS [ ] RCB [X] Re-entry [ ]

Wireline Logging Plan:

Standard Measurements		Special Tools			
WL	[X]	Magnetic Susceptibility	[ ]		
LWD	[X]	Magnetic Field	[ ]	Formation Image (Acoustic)	[ ]
Porosity	[X]	Borehole Temperature	[ ]	Formation Fluid Sampling	[ ]
Density	[X]	Nuclear Magnetic Resonance	[ ]	Formation Temperature & Pressure	[ ]
Gamma Ray	[X]	Geochemical	[ ]	VSP	[ ]
Resistivity	[X]	Side-Wall Core Sampling	[ ]	Others:	
Sonic (Δt)	[X]				
Formation Image (Res)	[X]				
Check-shot (upon request)	[ ]				

Max. Borehole Temp.: °C

Mud Logging: (Riser Holes Only)

Cuttings Sampling Intervals

from m to m m intervals

from m to m m intervals

Basic Sampling Intervals: 5m

Estimated Days: Drilling/Coring: 27 Logging: 2 Total On-site:

Observatory Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Potential Hazards/ Weather:

Shallow Gas	[ ]	Complicated Seabed Condition	[ ]	Hydrothermal Activity	[ ]
Hydrocarbon	[ ]	Soft Seabed	[ ]	Landslide and Turbidity Current	[ ]
Shallow Water Flow	[ ]	Currents	[ ]	Gas Hydrate	[ ]
Abnormal Pressure	[ ]	Fracture Zone	[ ]	Diapir and Mud Volcano	[ ]
Man-made Objects (e.g., sea-floor cables, dump sites)	[ ]	Fault	[ ]	High Temperature	[ ]
H_2S	[ ]	High Dip Angle	[ ]	Ice Conditions	[X]
CO_2	[ ]	Sensitive marine habitat (e.g., reefs, vents)			
Other:					

Preferred weather window: August-September (time interval of minimum ice extent)

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IODP Site Summary Forms:

Form 2 - Site Survey Detail

Proposal #:	708	Site #:	LR-02A	Date Form Submitted:	2013-10-04 22:40:44

*** Key to SSP Requirements**

X=required; X=may be required for specific sites; Y=recommended; Y*=may be recommended for specific sites; R=required for re-entry sites; T=required for high temperature environments; † Accurate velocity information is required for holes deeper than 400m.*

Data Type	In SSDB	SSP Req.	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no		High-resolution seismic reflection, line AWI-20080160 (will be uploaded tot he SSBD before the Nov 01 deadline) Site location close to crossing point AWI-20080160 and AWI-98597 Location: CDP 900
1b High resolution seismic reflection (crossing)	no		Location:
2a Deep penetration seismic reflection (primary)	no		Location:
2b Deep penetration seismic reflection (crossing)	no		Location:
3 Seismic Velocity	no		
4 Seismic Grid	no		
5a Refraction (surface)	no		
5b Refraction (bottom)	no		
6 3.5 kHz	no		Parasound profile
7 Swath bathymetry	no		Hydrosweep profile
8a Side looking sonar (surface)	no		
8b Side looking sonar (bottom)	no		
9 Photography or video	no		
10 Heat Flow	no		
11a Magnetics	no		
11b Gravity	no		
12 Sediment cores			Numerous sediment cores from Polarstern expeditions 1995 and 2008
13 Rock sampling	no		
14a Water current data	no		
14b Ice Conditions	no		seasonal sea ice
15 OBS microseismicity	no		
16 Navigation	no		Navigation data for seismic line AWI-20080160 exist and will be uploaded tot he SSDB before the Nov 01 deadline.
17 Other	no		

IODP Site Summary Forms:

Form 3 – Detailed Logging and Downhole Measurement Plan

Proposal #:	708	Site #:	LR-02A	Date Form Submitted:	2013-10-04
Water Depth (m):	1450	Sed. Penetration (m):	1300	Basement Penetration (m):	0

Are high temperatures or other special requirements (e.g., unstable formations), anticipated for logging at this site?

Estimated total logging time for this site: 2

Measurement Type	Scientific Objective	Relevance (1=high, 3=low)
Check Shot Survey		0
Nuclear Magnetic Resonance		0
Geochemical		0
Side-wall Core Sample		0
Formation Fluid Sampling		0
Borehole Temperature		0
Magnetic Susceptibility		0
Magnetic Field		0
VSP		0
Formation Image (Acoustic)		0
Formation Pressure & Temperature		0
Other (SET, SETP, ...)		0

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IODP Site Summary Forms:

Form 4 – Environmental Protection

Proposal #: 708	Site #: LR-02A	Date Form Submitted: 2013-10-04 22:40:44

Pollution & Safety Hazard	Comment
1. Summary of Operations at site.	Triple APC to refusal, continued by XCB and RCB to final depth
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling.	N/A
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows.	N/A
4. Indications of gas hydrates at this location.	No
5. Are there reasons to expect hydrocarbon accumulations at this site?	No
6. What "special" precautions will be taken during drilling?	ice management
7. What abandonment procedures need to be followed?	Support by an icebreaker (e.g., RV Polarstern)
8. Natural or manmade hazards which may effect ship's operations.	ice
9. Summary: What do you consider the major risks in drilling at this site?	ice could delay operations

Proposal #:	708 - Full	Site #:	LR-02A	Date Form Subm.:	2013-09-25 11:44:26

Subbottom depth (m)	Key reflectors, Unconformities, faults, etc	Age	Assumed velocity (km/sec)	Lithology	Paleo-environment	Avg. rate of sed. accum. (m/My)	Comments
0-220	Reflector "yellow"	5.3	1.6	silty clay	pelagic	41	
220-965	Reflector "pink"	23.8	2.2	silty clay	pelagic	40	
965-1270	Reflector "orange"	54	3.4	silty clay, biosiliceous ooze	pelagic	>10	

Proposal #:	708 - Full	Site #:	LR-02A	Date Form Subm.:	2013-09-25 11:44:26

Site Summary Figure Comment	

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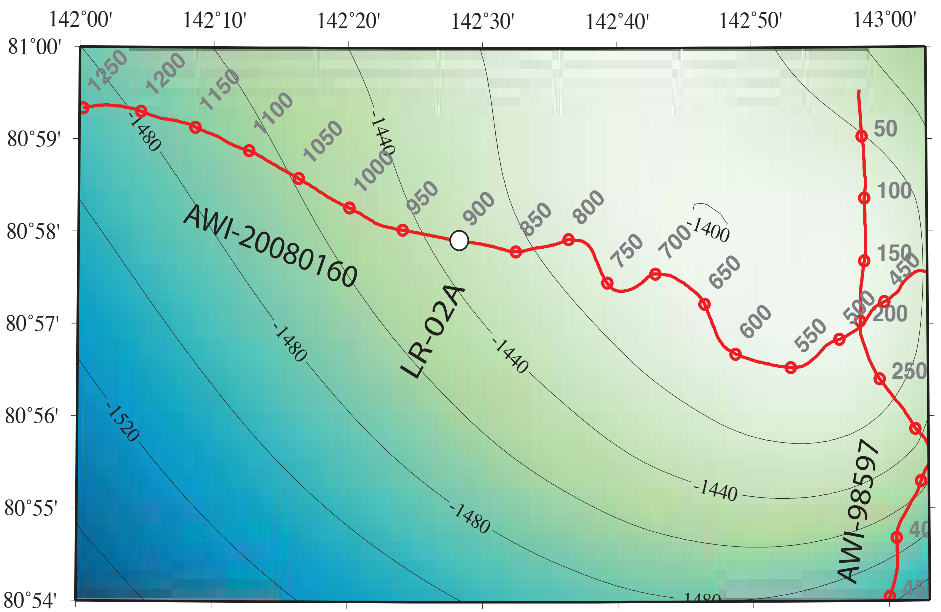
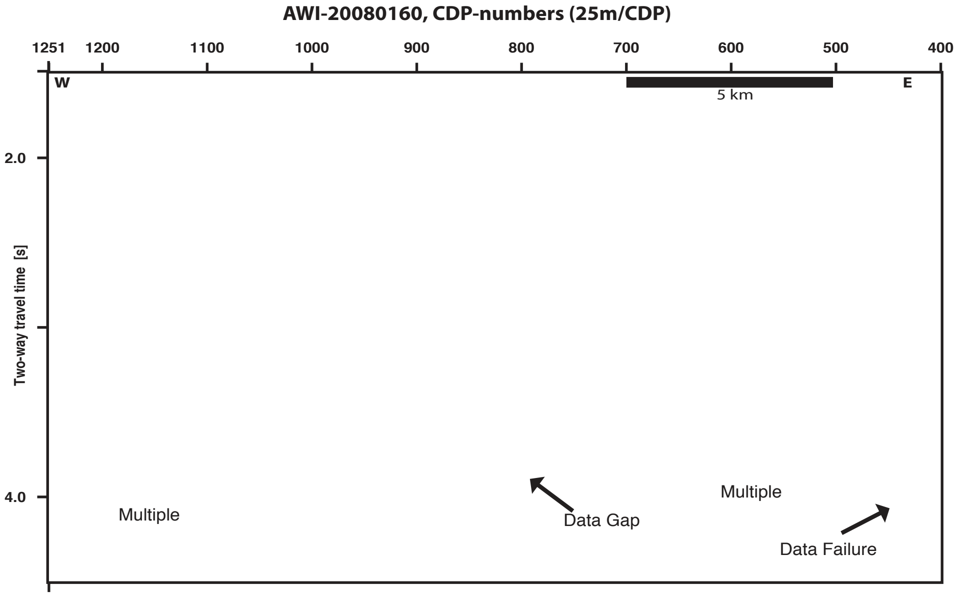
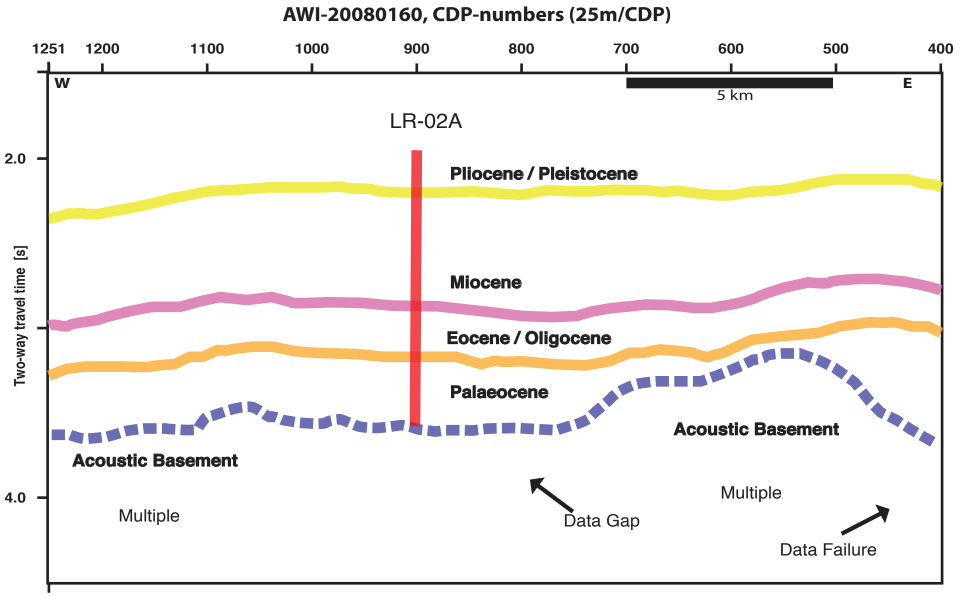
Site Summary Form 6 IODP Proposal 708 Site LR-02A



Profiles annotated using CDP numbers





Coordinates:	80° 57.9'N, 142° 28.3'E
Water-depth:	1450 m
Top Miocene (yellow):	220 mbsf
Top Oligocene (pink):	965 mbsf
Lower Eocene (orange):	1270 mbsf
Basement (purple):	2150 mbsf
Penetration total:	2150 m

SSDB locations of these graphics and supporting data:

-Location map:	LR-02A_map.pdf
-Seismic figures:	LR-02A_AWI-20080160.pdf
-SEGY data:	AWI-20080160stack.sgy
-Navigation data:	20080160_cdplocs.asc

IODP Site Summary Forms:

Form 1 – General Site Information

708 - Full

Section A: Proposal Information

Title of Proposal:	Arctic Ocean Paleoceanography: Towards a Continuous Cenozoic Record from a Greenhouse to an Icehouse World (ACEX2)
Date Form Submitted:	2013-10-04 22:40:44
Site Specific Objectives with Priority (Must include general objectives in proposal)	Recovery of a complete stratigraphic sedimentary record on the southern Lomonosov Ridge to meet our highest priority paleoceanographic objective, the continuous long-term Cenozoic climate history of the central Arctic Ocean (Primary site)
List Previous Drilling in Area:	IODP Expedition 302 (ACEX)

Section B: General Site Information

Site Name:	LR-01A	Area or Location:	Southern Lomonosov Ridge
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 80.95	Jurisdiction:	International waters
Longitude:	Deg: 142.97	Distance to Land: (km)	590
Coordinate System:	WGS 84		
Priority of Site:	Primary: yes Alt:	Water Depth (m):	1405

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	1225	0
	Total Sediment Thickness (m) 1225	
		Total Penetration (m): 1225
General Lithologies:	Silty clays, clays, biosiliceous ooze; siltsone, claystone; some ice-rafted debris	

Coring Plan: (Specify or check)

one primary drill site with three APC/XCB/RCB holes down to about 1225 mbsf to recover multiple sections of the sediment sequence to ensure complete recovery for construction of a composite section (Primary site)

APC [x] XCB [x] MDCB [ ] PCS [ ] RCB [x] Re-entry [ ]

Wireline Logging Plan:

Standard Measurements		Special Tools			
WL	[x]	Magnetic Susceptibility	[ ]		
LWD	[x]	Magnetic Field	[ ]	Formation Image (Acoustic)	[ ]
Porosity	[x]	Borehole Temperature	[ ]	Formation Fluid Sampling	[ ]
Density	[x]	Nuclear Magnetic Resonance	[ ]	Formation Temperature & Pressure	[ ]
Gamma Ray	[x]	Geochemical	[ ]	VSP	[ ]
Resistivity	[x]	Side-Wall Core Sampling	[ ]	Others:	
Sonic (Δt)	[x]				
Formation Image (Res)	[x]				
Check-shot (upon request)	[ ]				

Max. Borehole Temp.: °C

Mud Logging: (Riser Holes Only)

Cuttings Sampling Intervals

from m to m m intervals

from m to m m intervals

Basic Sampling Intervals: 5m

Estimated Days: Drilling/Coring: 27 Logging: 2 Total On-site:

Observatory Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Potential Hazards/ Weather:

						Preferred weather window
Shallow Gas	[ ]	Complicated Seabed Condition	[ ]	Hydrothermal Activity	[ ]	August-September (time interval of minimum ice conditions)
Hydrocarbon	[ ]	Soft Seabed	[ ]	Landslide and Turbidity Current	[ ]	
Shallow Water Flow	[ ]	Currents	[ ]	Gas Hydrate	[ ]	
Abnormal Pressure	[ ]	Fracture Zone	[ ]	Diapir and Mud Volcano	[ ]	
Man-made Objects (e.g., sea-floor cables, dump sites)	[ ]	Fault	[ ]	High Temperature	[ ]	
H_2S	[ ]	High Dip Angle	[ ]	Ice Conditions	[x]	
CO_2	[ ]	Sensitive marine habitat (e.g., reefs, vents)				
Other:						

IODP Site Summary Forms:

Form 2 - Site Survey Detail

Proposal #:	708	Site #:	LR-01A	Date Form Submitted:	2013-10-04 22:40:44

*** Key to SSP Requirements**

X=required; X=may be required for specific sites; Y=recommended; Y*=may be recommended for specific sites; R=required for re-entry sites; T=required for high temperature environments; † Accurate velocity information is required for holes deeper than 400m.*

Data Type	In SSDB	SSP Req.	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no		High-resolution seismic reflection, line AWI-20080160 (will be uploaded to the SSDB before the Nov 01 deadline) Location: CDP 475
1b High resolution seismic reflection (crossing)	no		High-resolution seismic reflection, line AWI-98597 (will be uploaded to the SSDB before the Nov 01 deadline) Location: CDP 184
2a Deep penetration seismic reflection (primary)			Location:
2b Deep penetration seismic reflection (crossing)			Location:
3 Seismic Velocity			
4 Seismic Grid			
5a Refraction (surface)			
5b Refraction (bottom)			
6 3.5 kHz	no		Parasound profile
7 Swath bathymetry	no		Hydrosweep profile
8a Side looking sonar (surface)	no		
8b Side looking sonar (bottom)	no		
9 Photography or video			
10 Heat Flow			
11a Magnetics	no		
11b Gravity	no		
12 Sediment cores	no		Numerous sediment cores from Polarstern expeditions 1995 and 2008
13 Rock sampling	no		
14a Water current data	no		
14b Ice Conditions	no		
15 OBS microseismicity	no		
16 Navigation	no		Navigation data for seismic lines AWI-20080160 and AWI-98597 exist and will be uploaded to the SSDB before the Nov 01 deadline
17 Other			

IODP Site Summary Forms:

Form 3 – Detailed Logging and Downhole Measurement Plan

Proposal #:	708	Site #:	LR-01A	Date Form Submitted:	2013-10-04
Water Depth (m):	1405	Sed. Penetration (m):	1225	Basement Penetration (m):	0

Are high temperatures or other special requirements (e.g., unstable formations), anticipated for logging at this site?

Estimated total logging time for this site: 2

Measurement Type	Scientific Objective	Relevance (1=high, 3=low)
Check Shot Survey		0
Nuclear Magnetic Resonance		0
Geochemical		0
Side-wall Core Sample		0
Formation Fluid Sampling		0
Borehole Temperature		0
Magnetic Susceptibility		0
Magnetic Field		0
VSP		0
Formation Image (Acoustic)		0
Formation Pressure & Temperature		0
Other (SET, SETP, ...)		0

IODP Site Summary Forms:

Form 4 – Environmental Protection

Proposal #:	708	Site #:	LR-01A	Date Form Submitted:	2013-10-04 22:40:44

Pollution & Safety Hazard	Comment
1. Summary of Operations at site.	Triple APC to refusal, continued by XCB and RCB to final depth
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling.	N/A
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows.	N/A
4. Indications of gas hydrates at this location.	No
5. Are there reasons to expect hydrocarbon accumulations at this site?	No
6. What "special" precautions will be taken during drilling?	Ice management
7. What abandonment procedures need to be followed?	support by an icebreaker (e.g., RV Polarstern)
8. Natural or manmade hazards which may effect ship's operations.	ice
9. Summary: What do you consider the major risks in drilling at this site?	ice could delay operations

IODP Site Summary Forms:

Form 5 – Lithologies

Proposal #:	708 - Full	Site #:	LR-01A	Date Form Subm.:	2013-09-25 08:51:04

Subbottom depth (m)	Key reflectors, Unconformities, faults, etc	Age	Assumed velocity (km/sec)	Lithology	Paleo-environment	Avg. rate of sed. accum. (m/My)	Comments
0-175	Reflector "yellow"	5.3	1.6	silty clay	pelagic	33	
175-835	Reflector "pink"	23.8	2.2	silty clay	pelagic	36	
835-1141	Reflector "orange"	54	3.4	silty clay, biosiliceous ooze	pelagic	>10	
1141-1225	Reflector "purple"	?65	>5	Slity clay, clay-/siltstones	(hemi-) pelagic		

Proposal #:	708 - Full	Site #:	LR-01A	Date Form Subm.:	2013-09-25 08:51:04

Site Summary Figure Comment	

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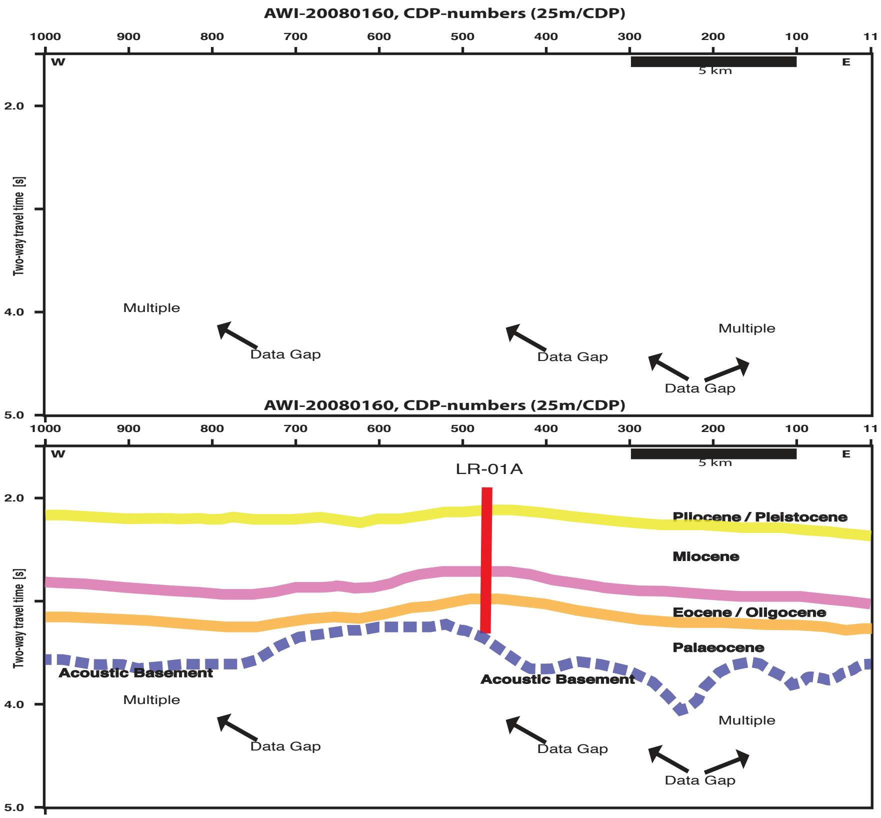
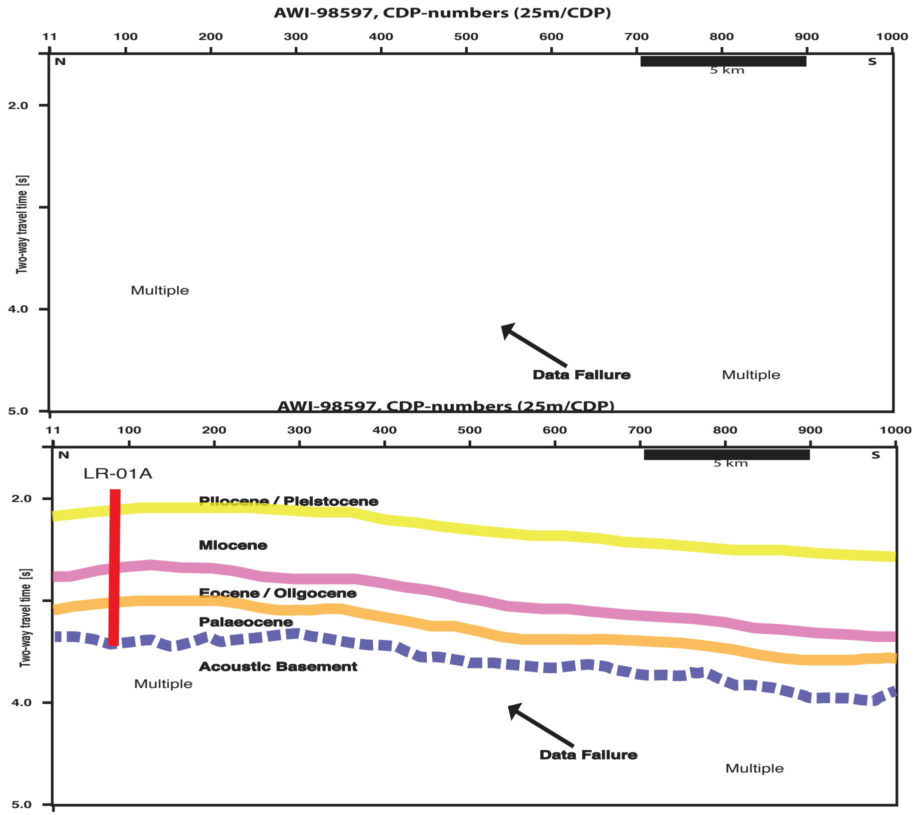
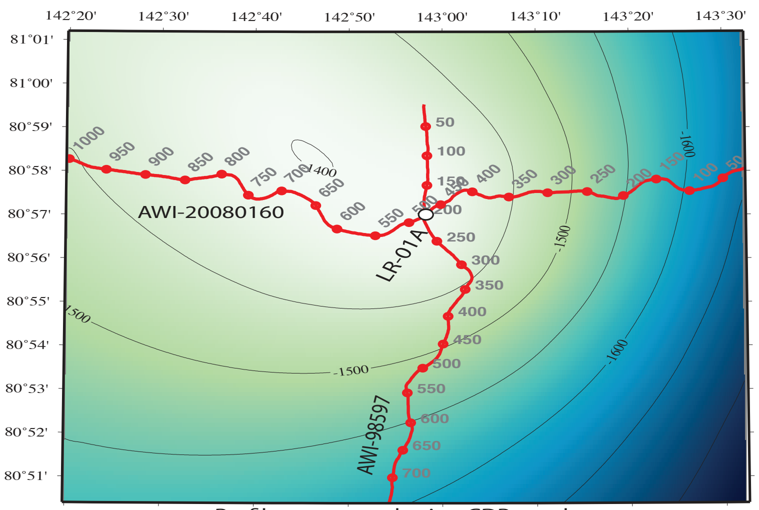
Site Summary Form 6 IODP Proposal 708 Site LR-01A







Profiles annotated using CDP numbers

Coordinates:	80° 57.01'N, 142° 58.3'E
Water-depth:	1405 m
Top Miocene (yellow):	175 mbsf
Top Oligocene (pink):	835 mbsf
Lower Eocene (orange):	1141 mbsf
Basement (purple):	1225 mbsf
Penetration total:	1225 m

SSDB locations of these graphics and supporting data:

-Location map:	LR-01A_map.pdf
-Seismic figures:	LR-01A_AWI-20080160.pdf
	LR-01A_AWI-98597.pdf
-SEGY data:	AWI-20080160stack.sgy
	AWI-98597stack.sgy
-Navigation data:	20080160_cdplocs.asc
	98597_cdplocs.asc