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

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Arctic Ocean, Paleoceanography, Cenozoic - Lomonosov Ridge

Scientific (Key) Objectives

0: Overall goal: recovery of a complete stratigraphic sedimentary record on the southern Lomonosov Ridge to the highest priority paleaoceanographic objective: **the continuous long-term Cenozoic climate history of the central Arctic Ocean**.

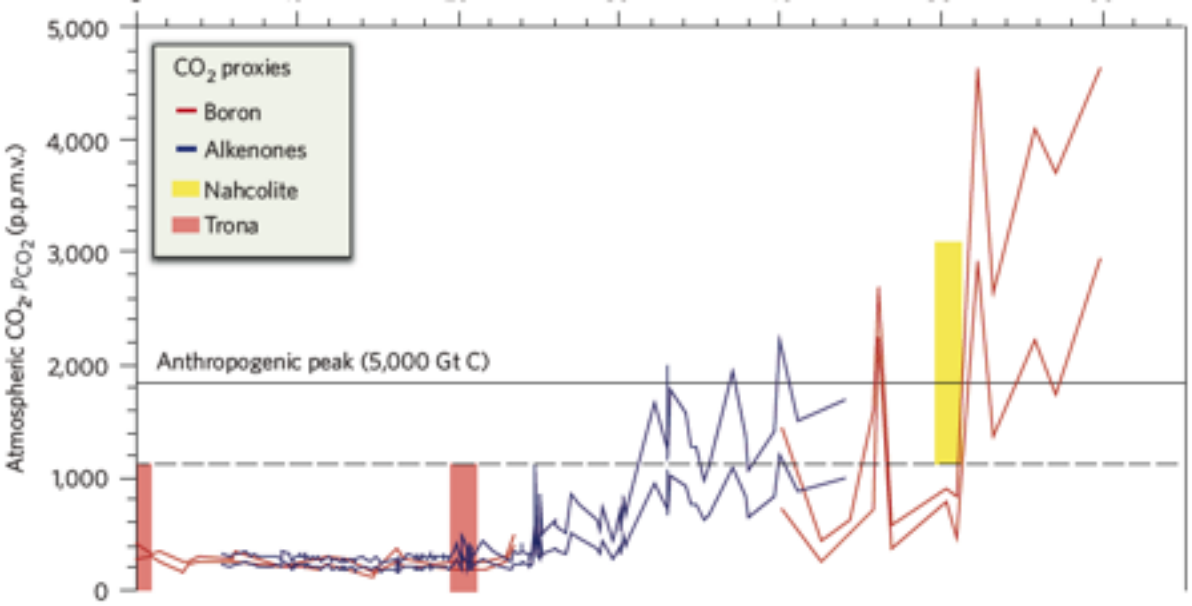
1: A complete characterization of the Cenozoic transition from Greenhouse to Icehouse in the Arctic.

2: History of Arctic Bottom and Surface-Water Circulation.

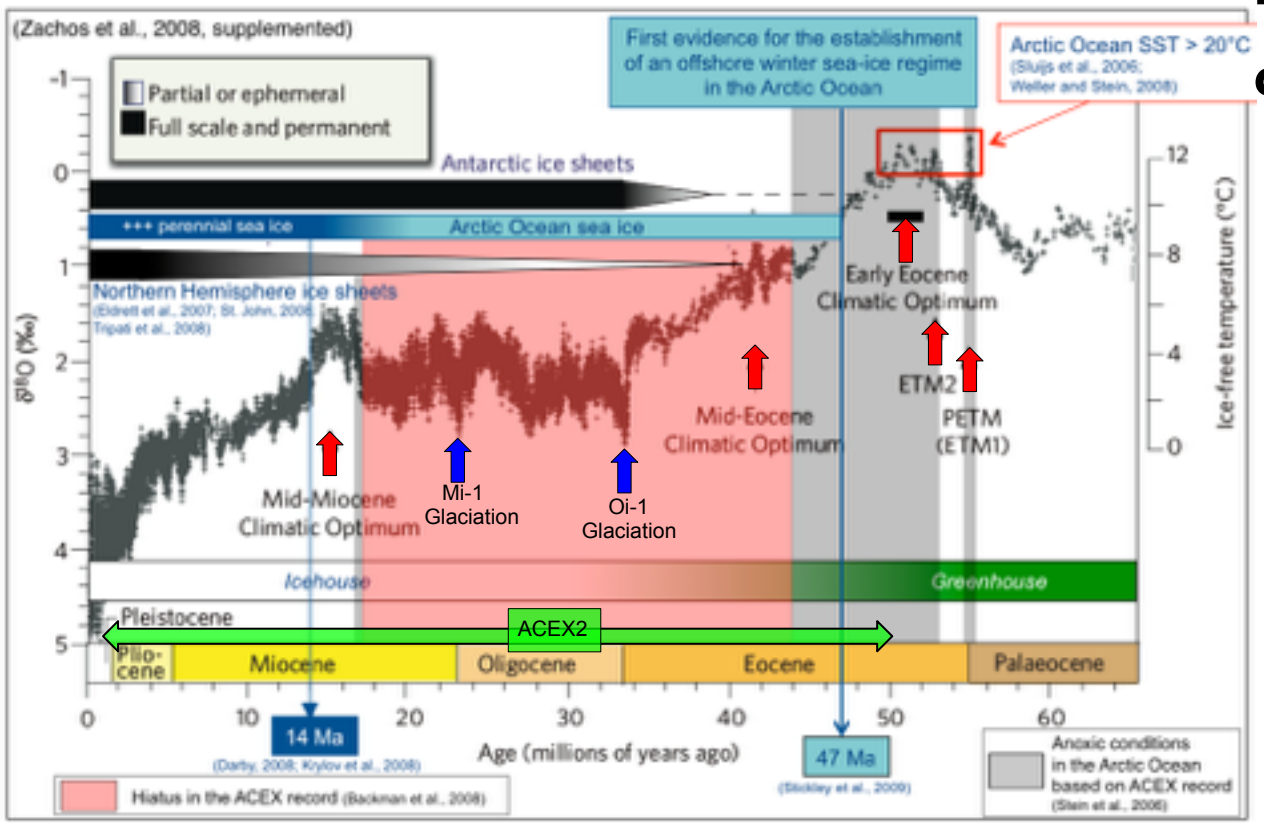
3: History of Arctic (Lena) River Discharge.

4: High-Resolution Characterization of the Pliocene Warm Period in the Arctic.

5: The “Hiatus Problem“.

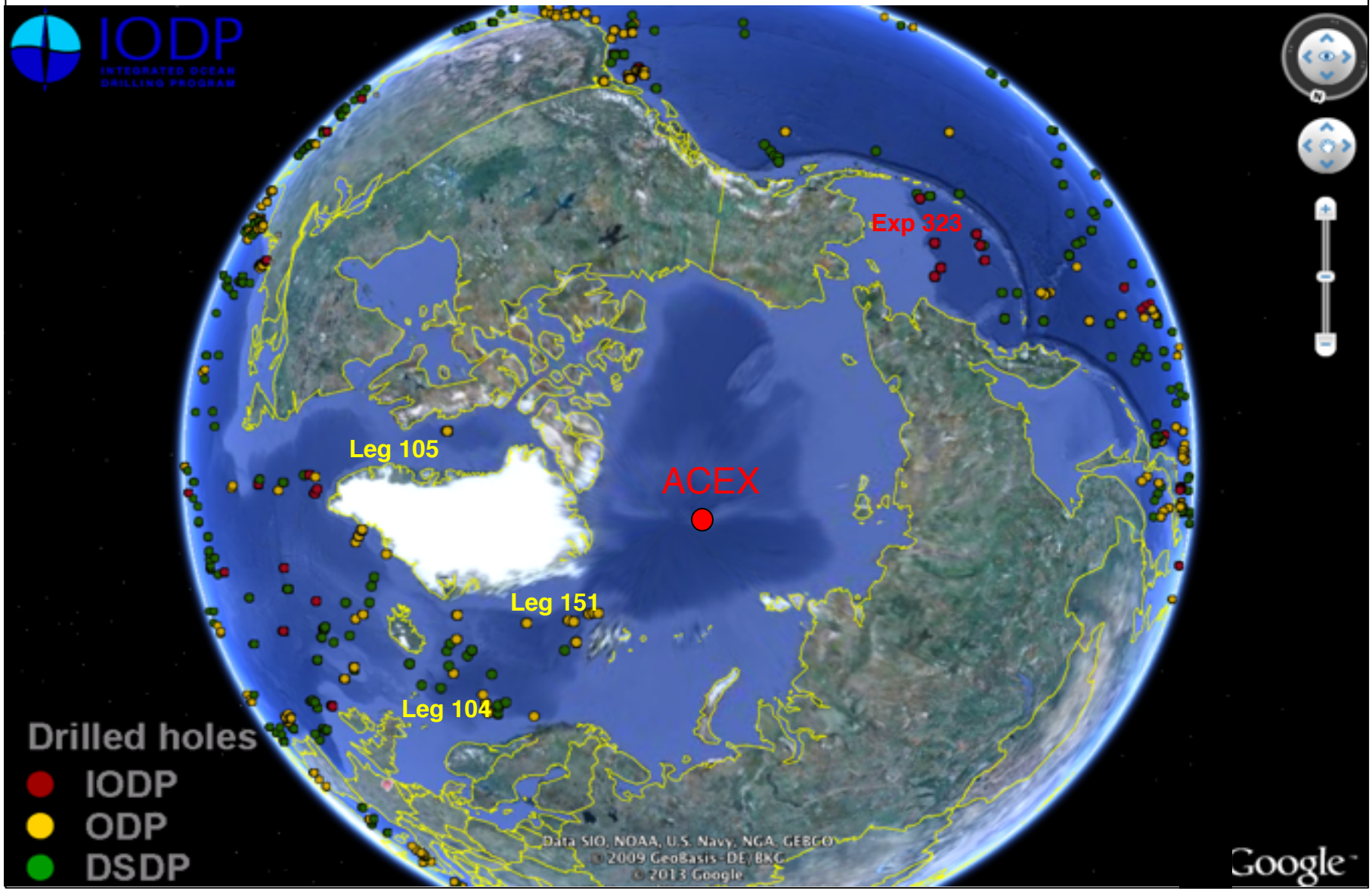


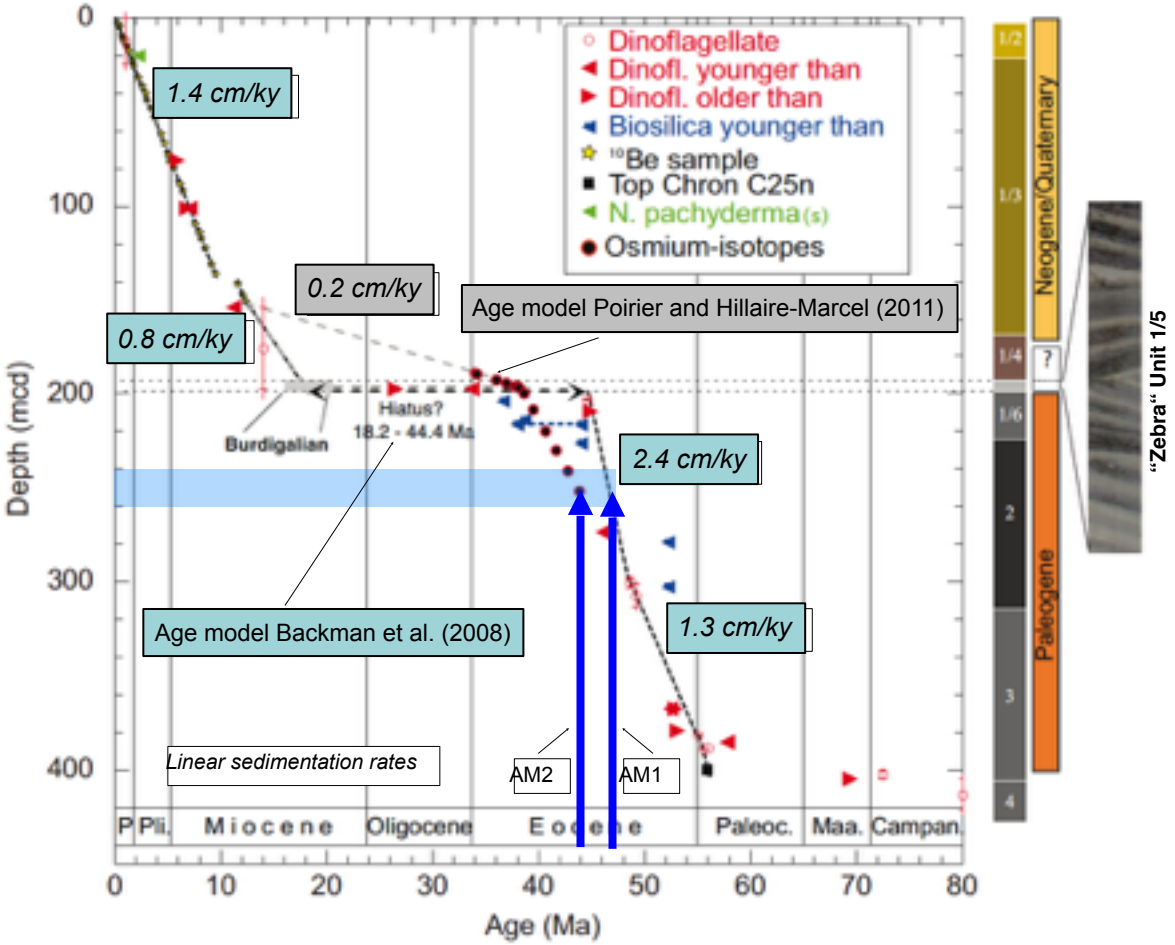
Cenozoic pCO_2 for 65 Ma



Smoothed global benthic foraminifer $d^{18}O$ time series

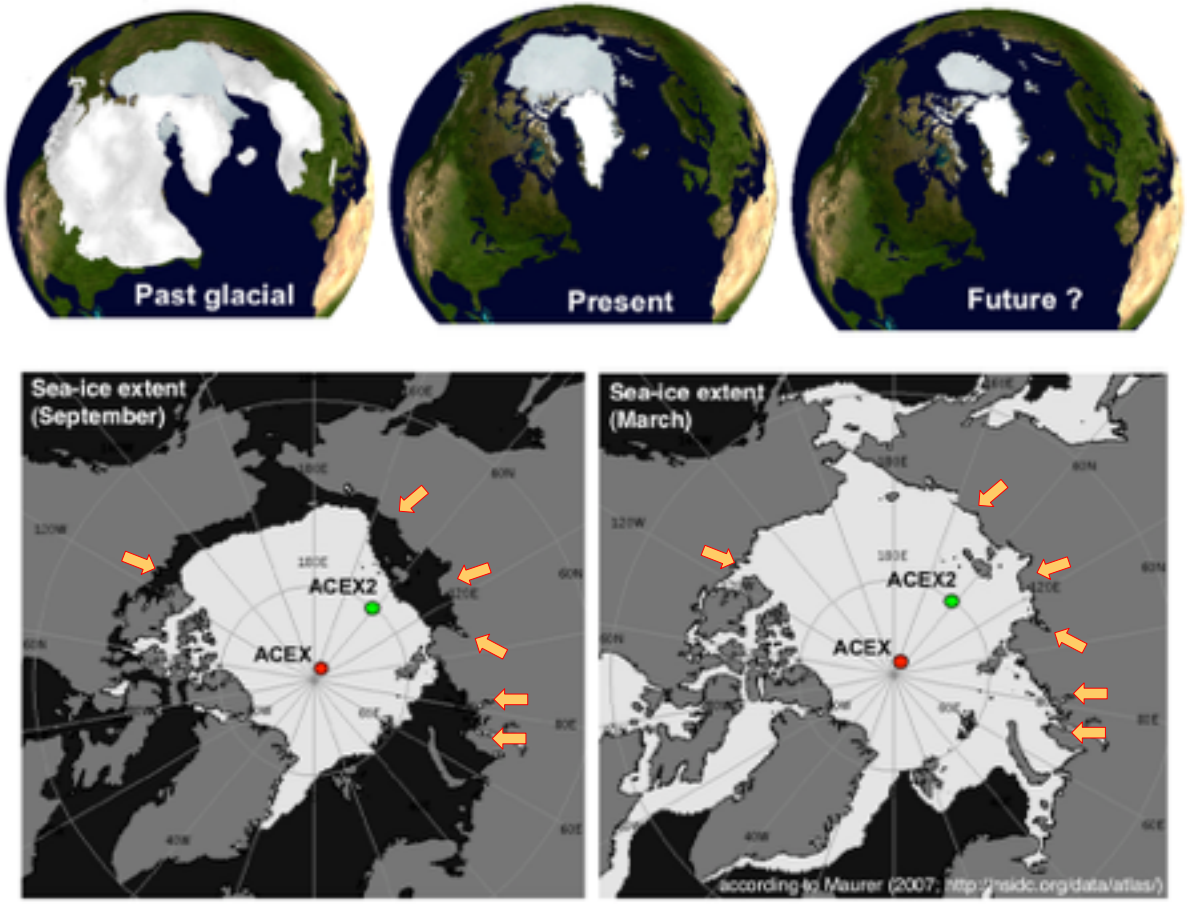
Arctic Ocean drilling: Emerging fields / new topics / unknown areas





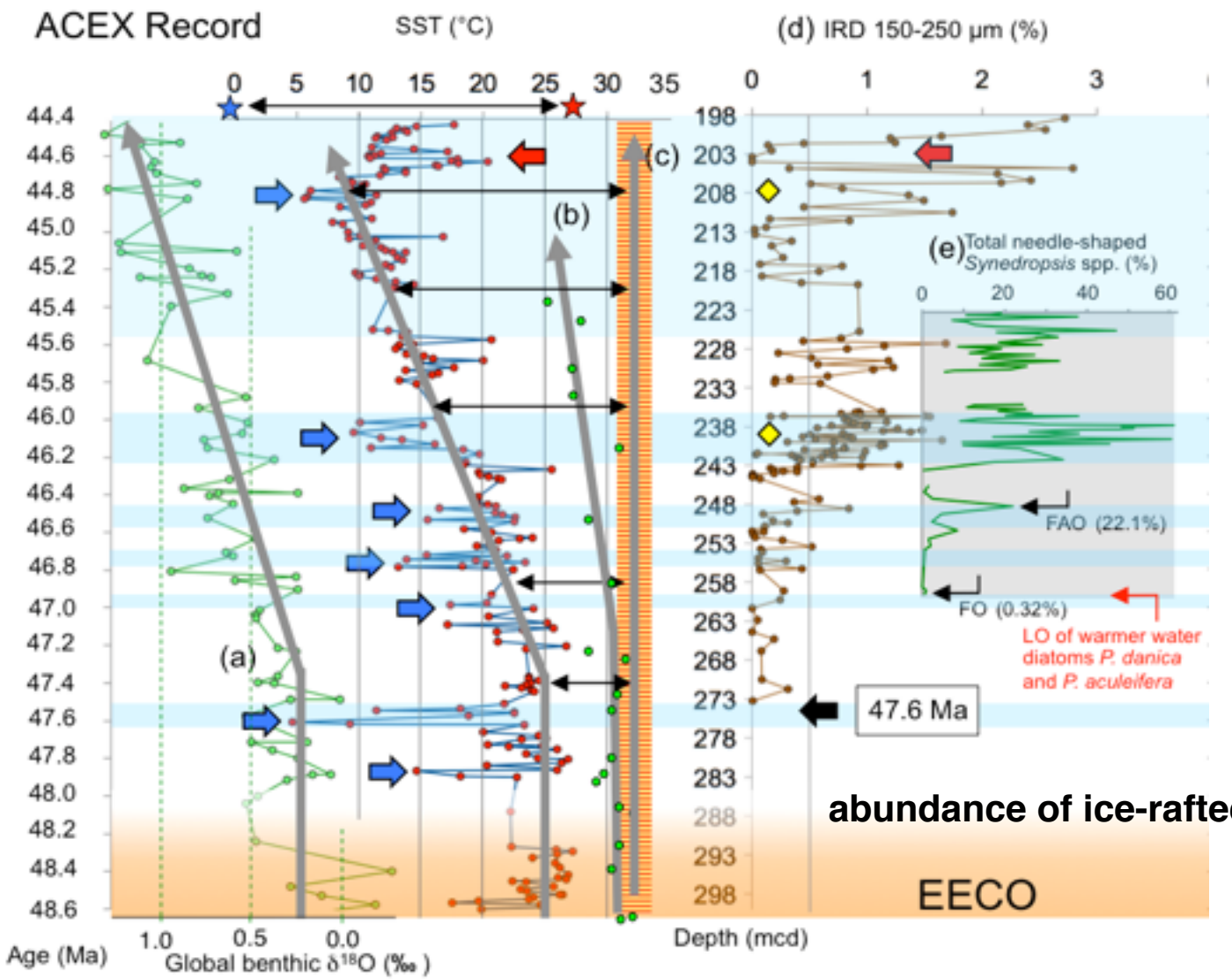
Age-depth diagram and main lithological units of the ACEX section

Distribution of ice sheets and sea ice during past glacials



Map showing the average distribution of sea-ice in the Arctic Ocean in September (1979-2004) and March (1979-2005)

Alkenone-based sea-surface temperature (SST) (red circles)



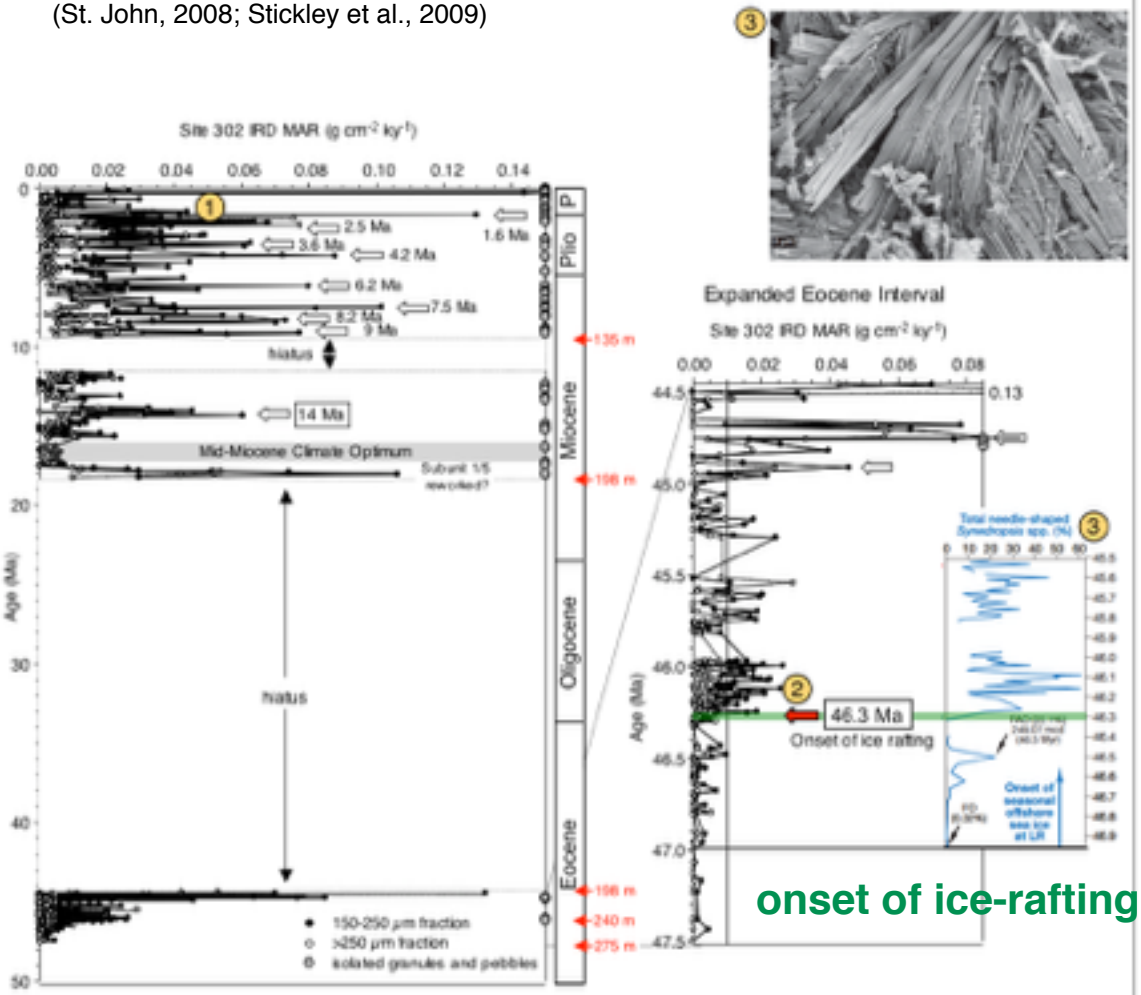
cooling events

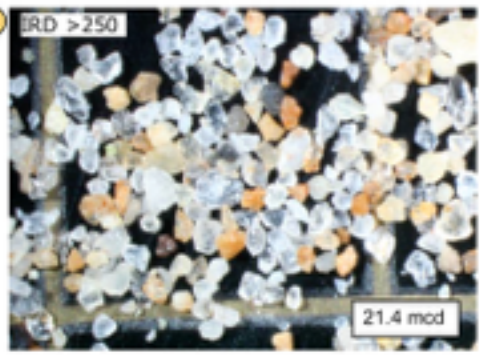
abundance of ice-rafted debris (IRD)

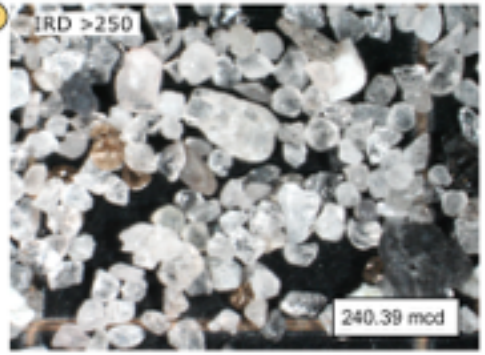
(from Stein et al., 2014; further references therein)

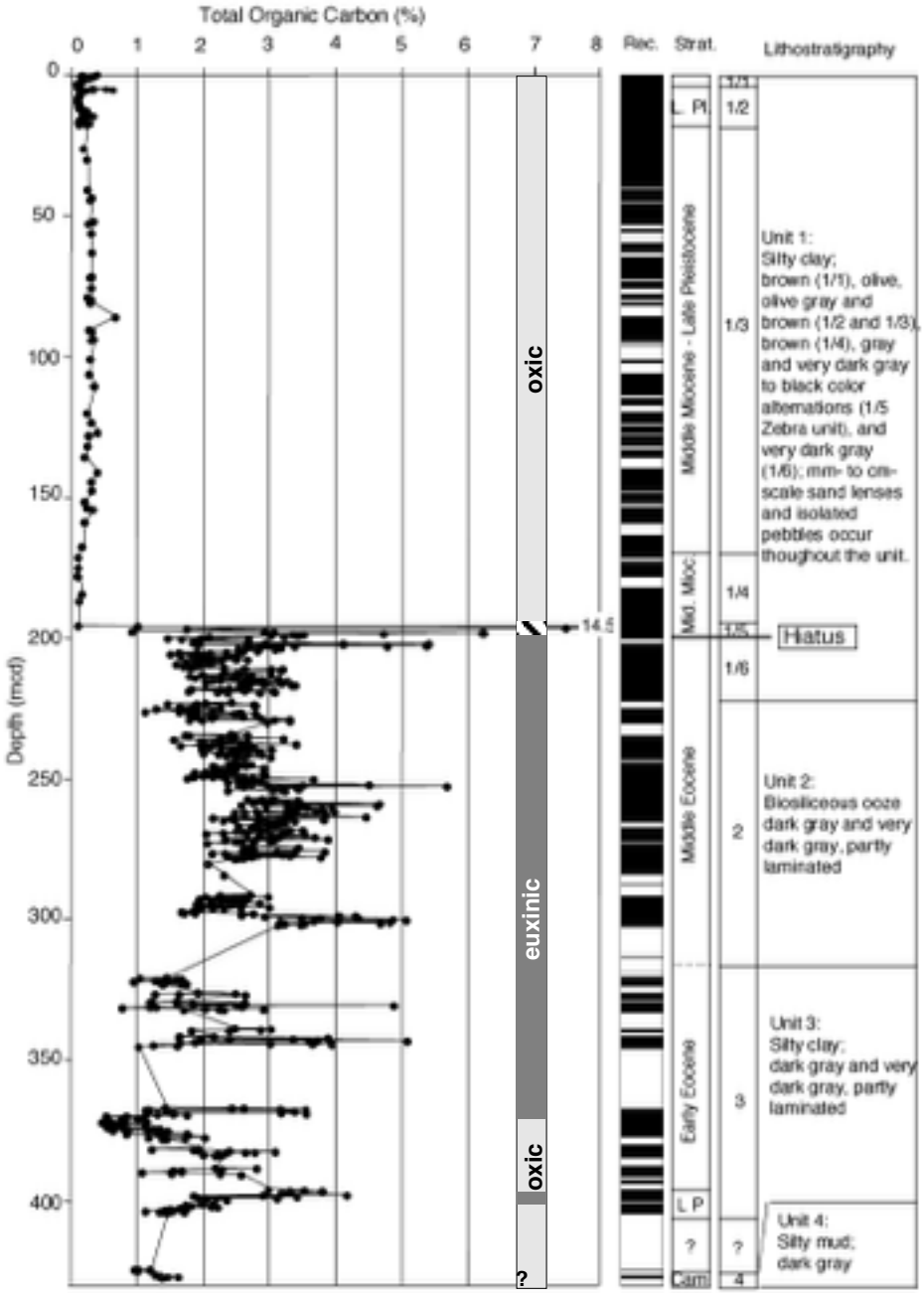
IRD mass accumulation rates (g cm-2 ky-1) in the >250 µm (dotted line and open circles) and 150-250 µm (black line and solid circles) size fractions of the Eocene to Pleistocene (270 to 0 mcd) section of the ACEX record

(St. John, 2008; Stickley et al., 2009)

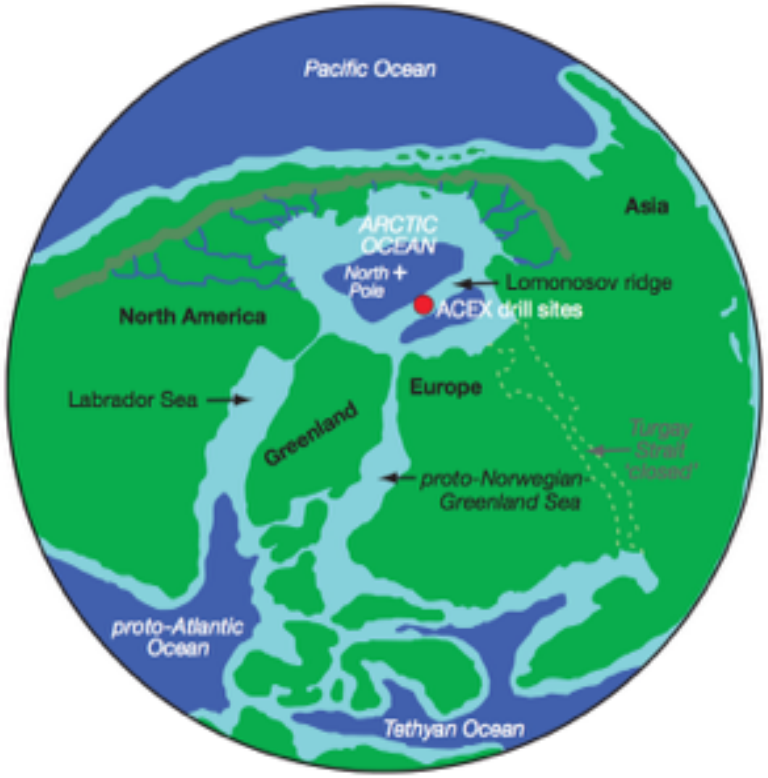








(Stein, 2007)



(Stickley et al., 2009)

Record of total organic carbon (TOC) contents

Proposal 708-Full1
- ACEX 2 -

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 Elgygytgyn?
- What is the cause of the major hiatus recovered in the ACEX record? Does this hiatus in fact exist?

EFB meeting in Bremen, 2014.

Limitations of ACEX (IODP 302, 2004 - first three were noted in proposal):

(1) A significant amount of the stratigraphic sequence (~25 Myrs; Upper Eocene-Lower Miocene, critical time interval where prominent changes in global climate took place) is absent because of a prominent hiatus;

(2) Large portions of the record have moderate to poor sediment recovery. This is because coring was collected using XCB, and because of major coring gaps below 200 mbsf;

(3) No interval has particularly high sedimentation rate, including notably the Plio-Pleistocene part of the record (which is about 1.4 cm/kyr);

(4) There is significant diagenesis, such that no calcareous microfossils are found below the upper few meters, and no siliceous microfossils are found below ~315 m (the Unit 2/Unit 3 boundary, which is equivalent to the opal A/opal CT transition).

The submitted proposal 708-Full aimed to accomplish a set of **important goals** by **triple coring 1225 m of sediment** at a single site (LR-01A) in 1425 m water depth.
Largely absent from the proposal were potential problems with this strategy as one can infer from the ACEX experience:

(A) The total pipe depth (2650 m) would require *a drilling vessel significantly larger* than Vidar Viking, the ship used during ACEX. This problem could be solved, but likely at much higher cost.

(B) The present drilling plan would require *maintenance of station in moving ice for considerable time* (approximately 29 days, although see comment C below). As correctly noted in the proposal, "the icebreakers kept the drillship on location in 90% cover of multi-year ice for up to nine consecutive days" at operations at Site M0004
of ACEX. The problem of keeping a drill ship on station in the central Arctic may be lessened by drilling in a region of thinner sea-ice, but the concern remains.

(C) The estimated time of drilling operations is unclear. The 29 days presumably refer to three holes, each drilled to APC refusal and subsequently drilled by XCB and RCB for 9 days, and 2 days of logging. During ACEX operations, the 7 days at Hole M0002A achieved 270 m of cored section and no logging, and the 9 days at Site M0004 with 3 holes achieved 206 m of cored section and a logging run.
While it should be acknowledged that these slow rates include some technical problems, *1225 m of penetration in 9 days* seems largely optimistic, especially considering slower drilling with greater depth.

(D) The seismic lines show a sharp change ("pink reflector") inferred to separate Miocene sediment from Oligocene/Eocene sediment. It is unclear *why this reflector does not represent an Upper Eocene-Lower Miocene hiatus*. Here it should be noted, though, that documentation of a hiatus on southern Lomonosov Ridge, similar to that found in the ACEX cores, would be a fascinating and important discovery.

(E) If silica diagenesis is related to *some combination of depth or sub-seafloor temperature*, significant portions of the record may contain no common microfossils.
The use of organic compounds for paleoceanographic and pale oceanographic purposes may also be comprised at significant depth.

EFB meeting in Aix. Letter to PI, March 30 2015

"The EFB decided to schedule an expedition for your proposal for the fiscal year 2018, provided that the following conditions are met: that the maximum ECORD contribution will not exceed 15 million $US, and that primary objectives in the original proposal and addenda remain targets of drilling."

The main problem with the present proposal concerns cost. The estimated cost to drill the primary site of interest (LR01-A) as planned would greatly exceed 15 million $US. This is because of three reasons:
(1) It will necessitate ice-breaker support;
(2) It would require a long time (>60 days) to drill, core and log three adjacent holes to 1200+ m below the seafloor (20 days per hole minimum, possibly up to 30 days per hole);
(3) It would necessitate a special drilling platform because of the required pipe length (> 2 km).

The required time on location raises another potential problem: it is not obvious that a drill ship can maintain position in sea ice for 20-30 days.

There are furthermore some minor problems with the placement of sites. They do not appear correctly located in comparison to the seismic lines. Please edit the site survey data and insure that all is correct.

EFB meeting in Aix. Letter to PI, March 30 2015 – cont'd

All the above issues likely can be addressed, and hence the tentative scheduling of an expedition. Ice-breaker support may come through in-kind contributions. The time and platform issues can be addressed by changing locations and drilling strategy. A major increase in cost (~6 million $US) occurs if the total pipe length exceeds 2 km.

For comparison, the combined water depth and target depth at LR01-A is 2.6 km, whereas it is only 1.9 km at LR05-A. In the opinion of the panel, all major expedition objectives could be realized by double coring at LR05-A at much lower cost. There would also be the possibility of drilling a second short site to recover an expanded Quaternary-Upper Neogene sequence.

The EFB therefore requests that you justify your final drilling strategy, in close consultation with ESO members to insure that all above concerns can be addressed, so that the drilling program can be accomplished within the upper ECORD contribution of 15 million $US, while still addressing the drilling objectives as approved by SEP.

UPDATE by the proponents after March 2015 (see addendum to proposal April25 2016):
7 additional alternate sites have been added to increase flexibility of site selection, and to include a site location where the Oligocene-Eocene strata could be reach in shallower depths. The main objectives have not been changed.

New site survey data from RV Polarstern 2014 Cruise PS87 (see slides further down).
Supports the original four sites.

UPDATE by the proponents after March 2015 (see addendum to proposal April25 2016):
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New site survey data from RV Polarstern 2014 Cruise PS87.
Supports the original four sites. All marker horizons and seismic units can also be clearly identified by their reflection pattern and configuration on the new seismic lines.

SEP comments:
total pipe depth (2650 m) would require a drilling vessel and drill rig significantly larger than the Vidar Viking and Seacore R100 rig used during ACEX. This problem could be solved, but likely at much higher cost.
Site LR-01A is still the primary site, with a total penetration depth of about 1225m, i.e. total pipe length (water plus sediment) over 2500m! The new alternate sites provide a slight reduction of the total pipe length to <2000m, by splitting the entire sequence in two subsequences (Eocene-Oligocene-Miocene part, and Pliocene-Quaternary part).

estimated time of drilling operations is unclear.
Calculations were done using the IODP coring estimator (for JR operations)! Too optimistic for MSP operations, so new estimate is 20 days (from 9 before) for 1200 m of penetration.
Total for 2.5 holes plus time for logging, total needed 50 days.

There are many more SEP comments, with answers (not all relevant) in pages 6 to 10 of the addendum, including the discussion about the presence of the hiatus (or not).

Addendum: 708Full1 ACEX2

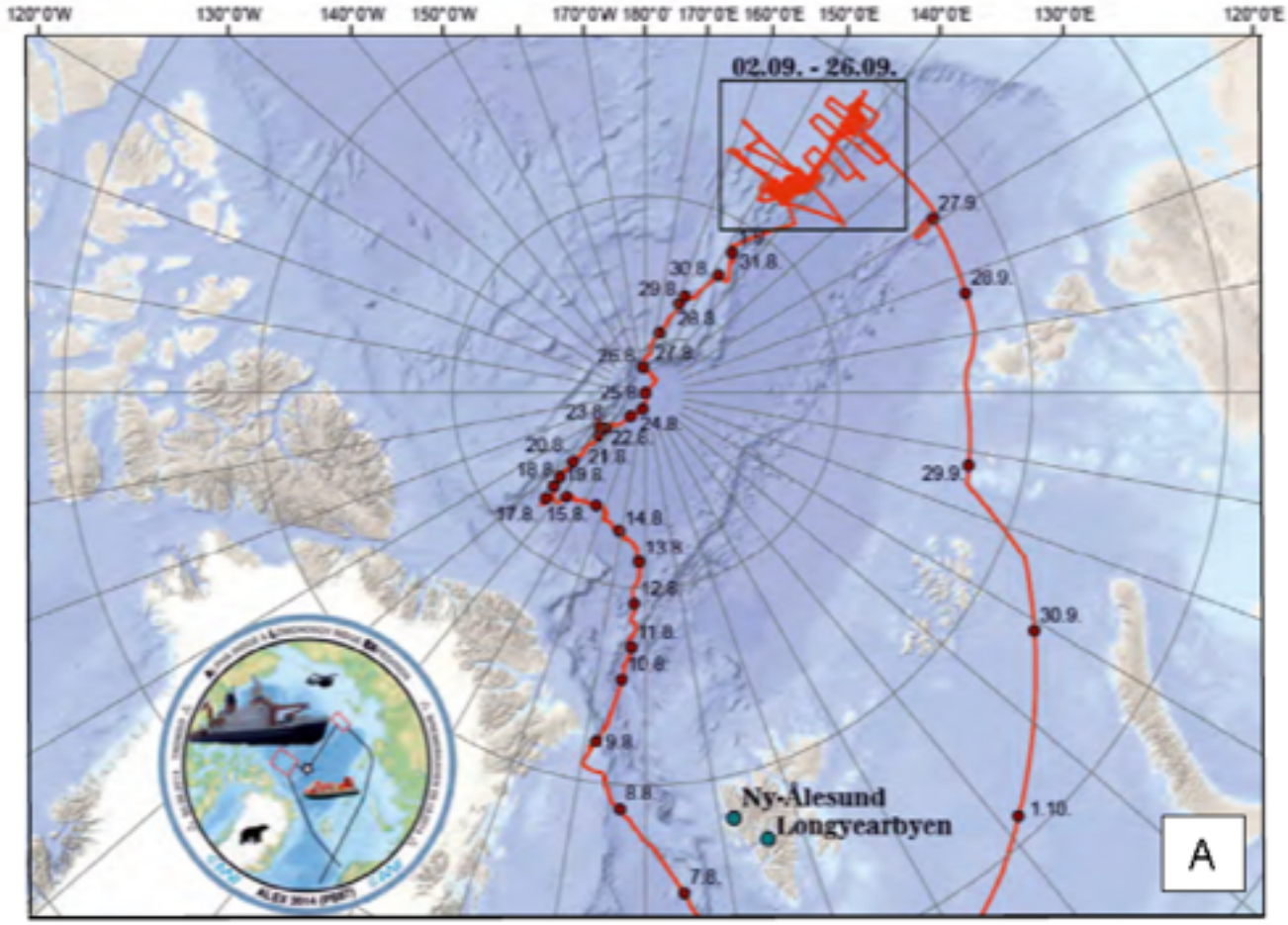
Scientific objectives are exactly the same.

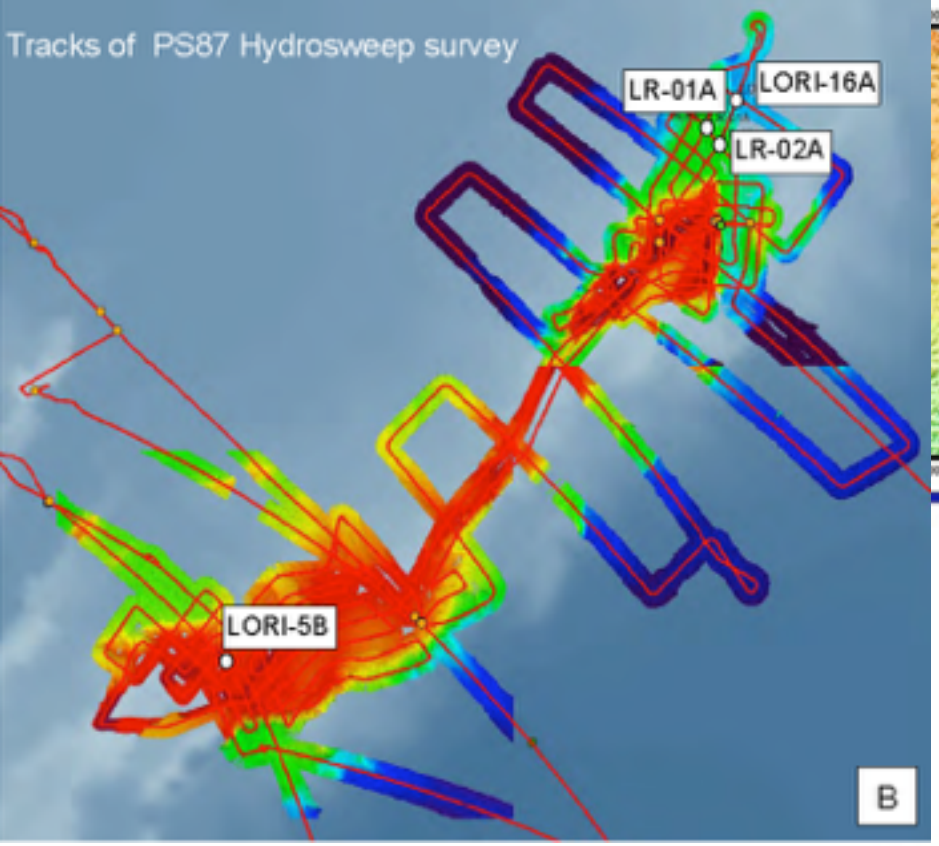
The sites are located in the seasonally ice-covered central Arctic Ocean (southern Lomonosov Ridge), and will need mission specific vessels to perform the drilling in the pack ice (marginal ice zone). A well organized ice-management strategy and support by an icebreaker (e.g., RV *Polarstern*) are needed.

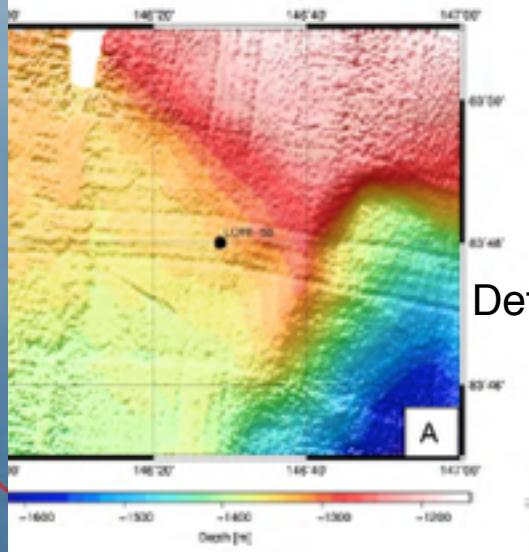
Cruise track of Polarstern Expedition PS87, 05 August to 07 October 2014

New site survey, multibeam-bathymetry, parasound and seismic profiling, + sediment coring at the four proposed drill sites.

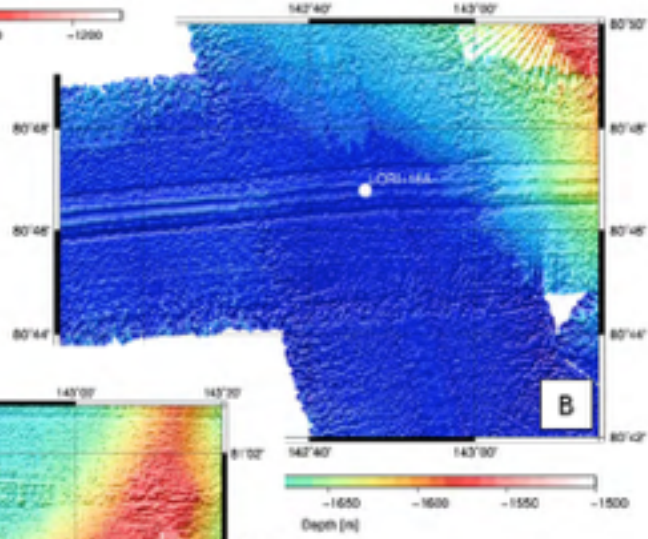
Also SWERUS-C3 Expedition Leg 2, vessel Oden. No additional information, so not added by the proponents.

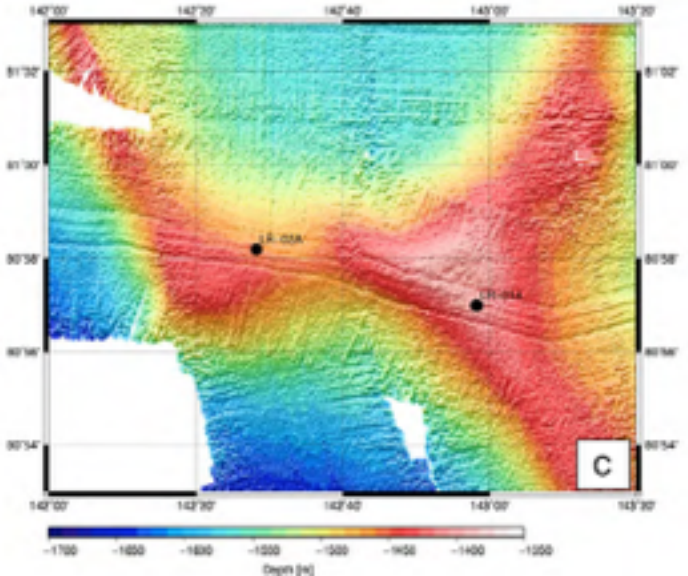




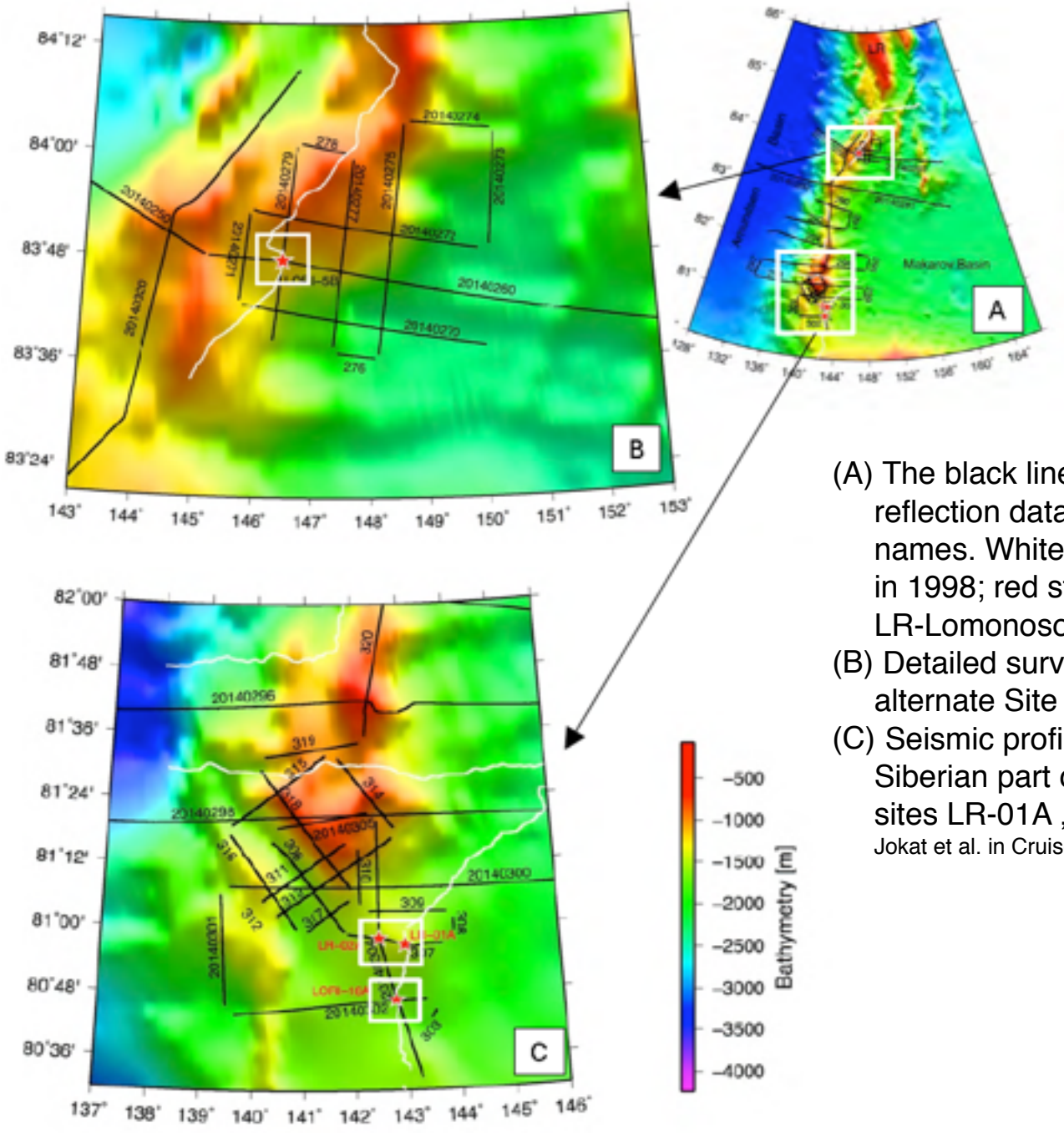


Detailed bathymetric maps





Siberian part of the Lomonosov Ridge

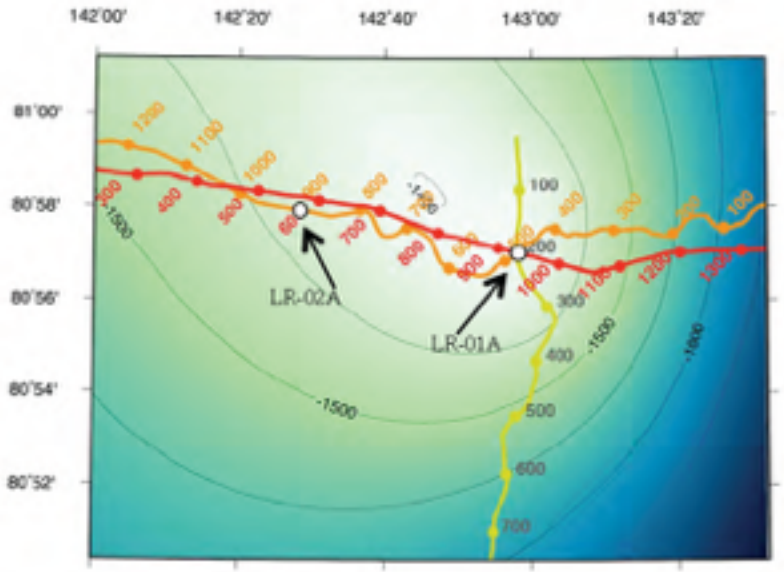


(A) The black lines indicate the PS87 seismic reflection data. The numbers are the profile names. White lines: Seismic profiles acquired in 1998; red stars: proposed IODP drill sites, LR-Lomonosov Ridge.

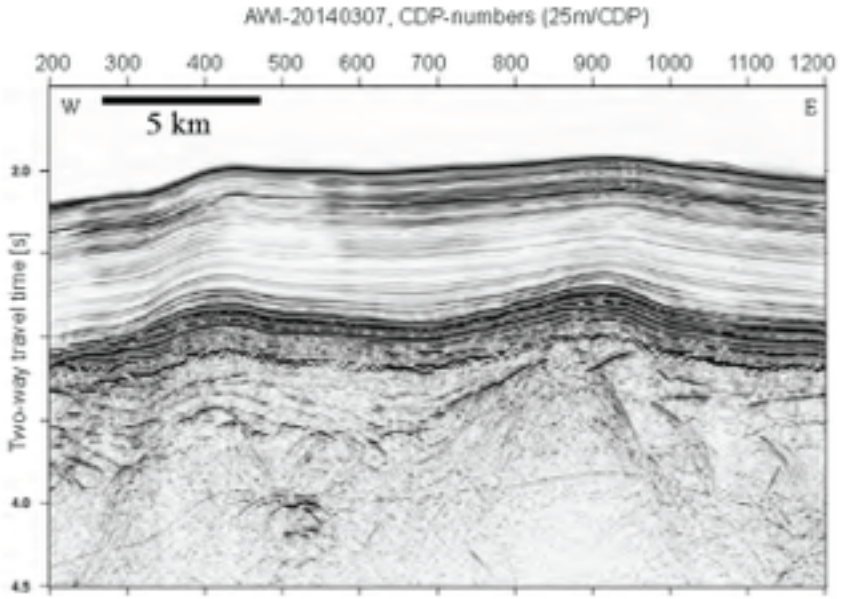
(B) Detailed survey in the area of proposed alternate Site LORI-5B;

(C) Seismic profiles on the southernmost Siberian part of the Lomonosov Ridge around sites LR-01A , LR-02A and LORI-16A. (from Jokat et al. in Cruise Report Stein et al., 2015).

IODP Proposal 708 Sites LR-01A and LR-02A



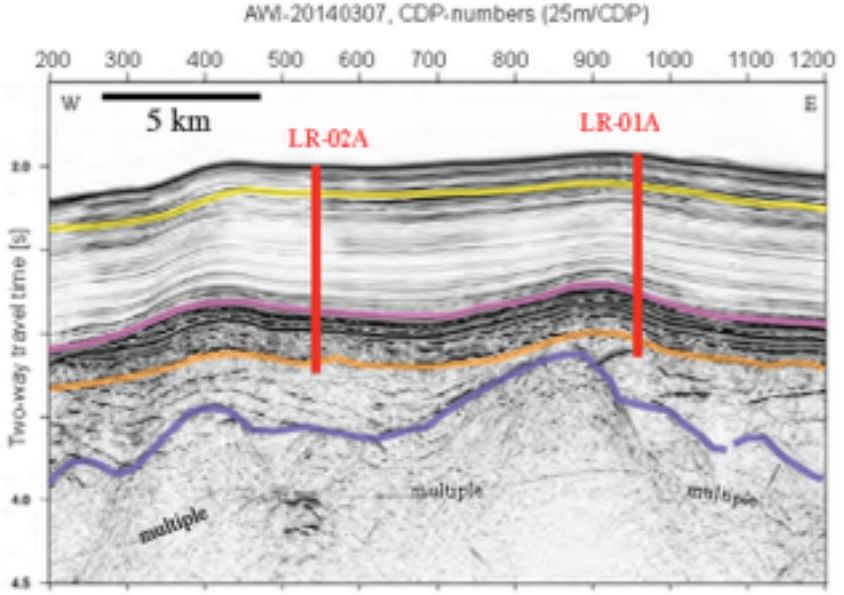
Profiles AWI-96597 (yellow), AWI-20080160 (orange), and AWI-20140307 (red) annotated using CDP numbers



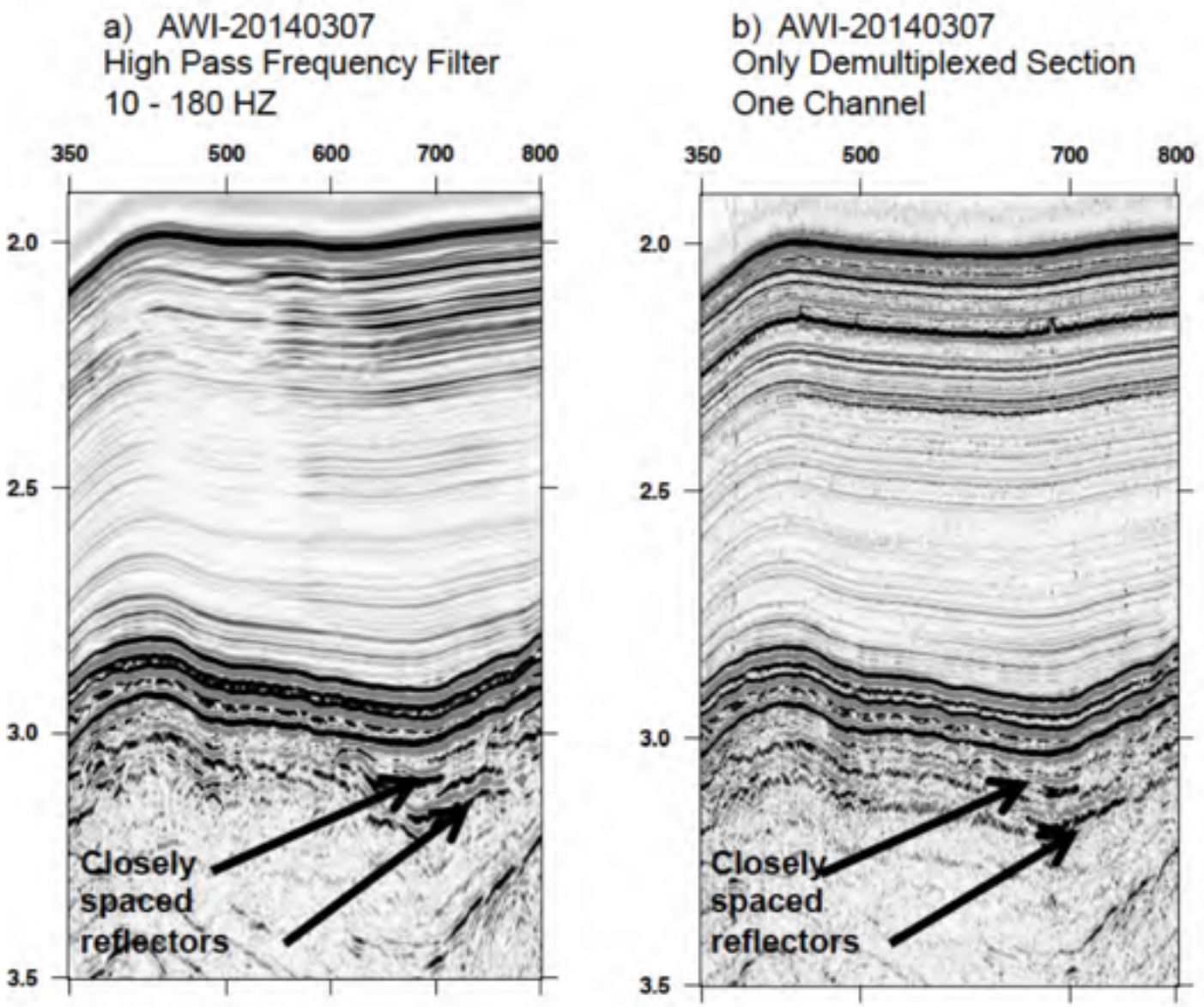
High-quality multi-channel seismic profiles with crossing lines

Site:	LR-01A	LR-02A
Latitude:	80.95 °N	80.97 °N
Longitude:	142.97 °E	142.47 °E
Water-depth:	1405 m	1454 m
Top Miocene (yellow):	170 mbsf	218 mbsf
Top Oligocene (pink):	800 mbsf	920 mbsf
Lower Eocene (orange):	1029 mbsf	1211 mbsf
Basement (purple):	1879 mbsf	1882 mbsf
Penetration total:	122.5 m	1300 m

SSDB locations of these graphics and supporting data:
-Location map: LR-01A_LR-02A_map.pdf
-Seismic figures: LR-01A_LR-02A_AWI-20140307.pdf
-SEGY data: AWI-20140307stack.segy
-Navigation data: 20140307_odplocs.asc



Enlarged section of line AWI-20140307.
Red bars show the location of the proposed drilling sites LR-01A and LR-02A.
Coloured lines mark horizons of interest: **yellow: top Miocene, pink: top Oligocene, orange: Lower Eocene, purple: acoustic basement.**



Base of the HARS (Lower Eocene) - not easy to identify.

Fig. 5. Enlarged section of line AWI-20140307 (a) stacked and high-pass filtered) and (b) single channel to demonstrate the two closely spaced reflectors on the base of the high-amplitude reflector sequence.

High-resolution Parasound profiles

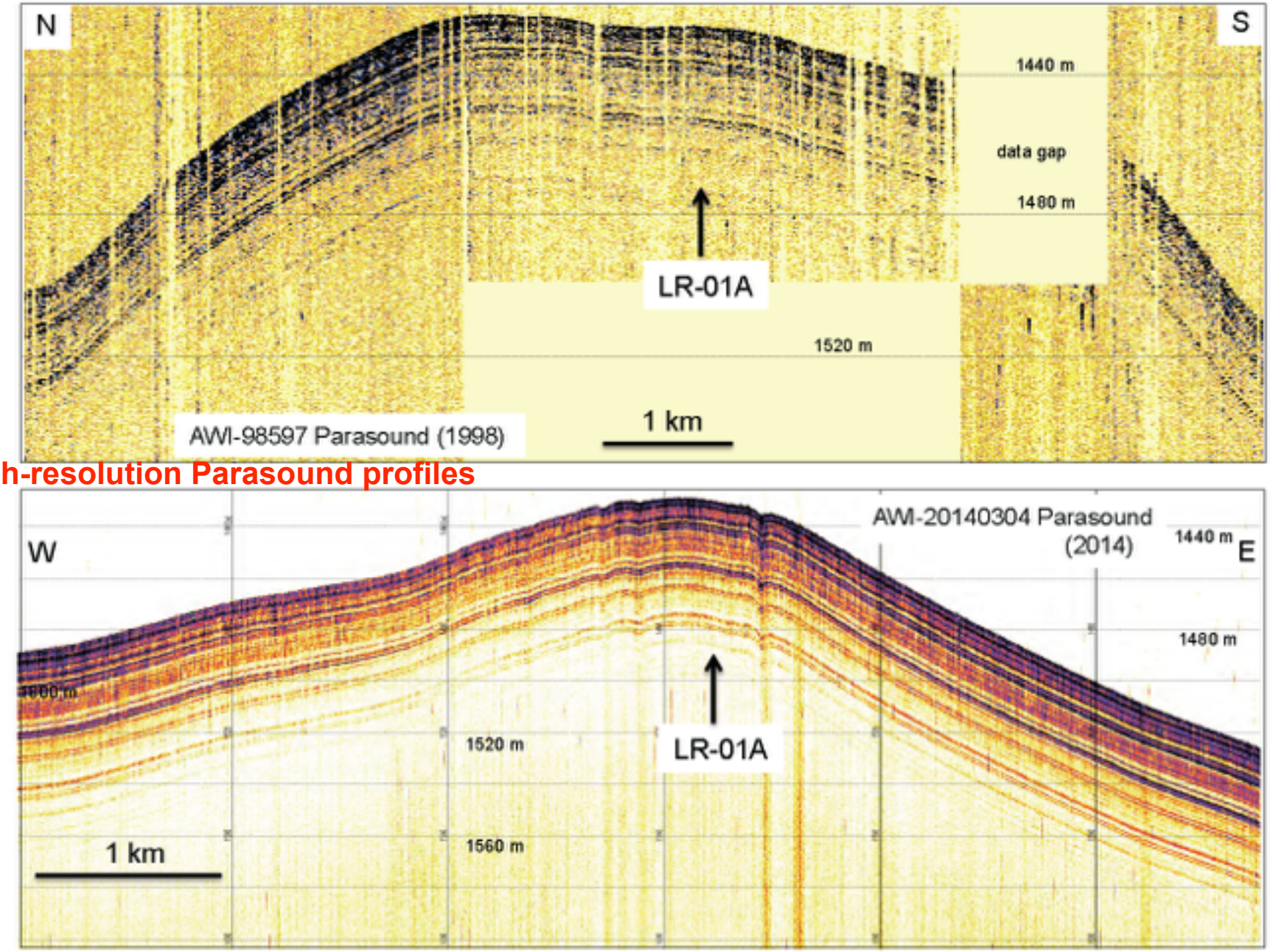


Fig. 6. Sediment-echosounding (Parasound) data of location LR-01A. Depth is calculated using 1500 m/s as constant velocity. SEGY-data in files LR-01A-98597Para_Part1, LR-01A-98597Para_Part2 (N-S) and LR-01A-20140307Para_Part1, LR-01A-20140307Para_Part2 (W-E), respectively.

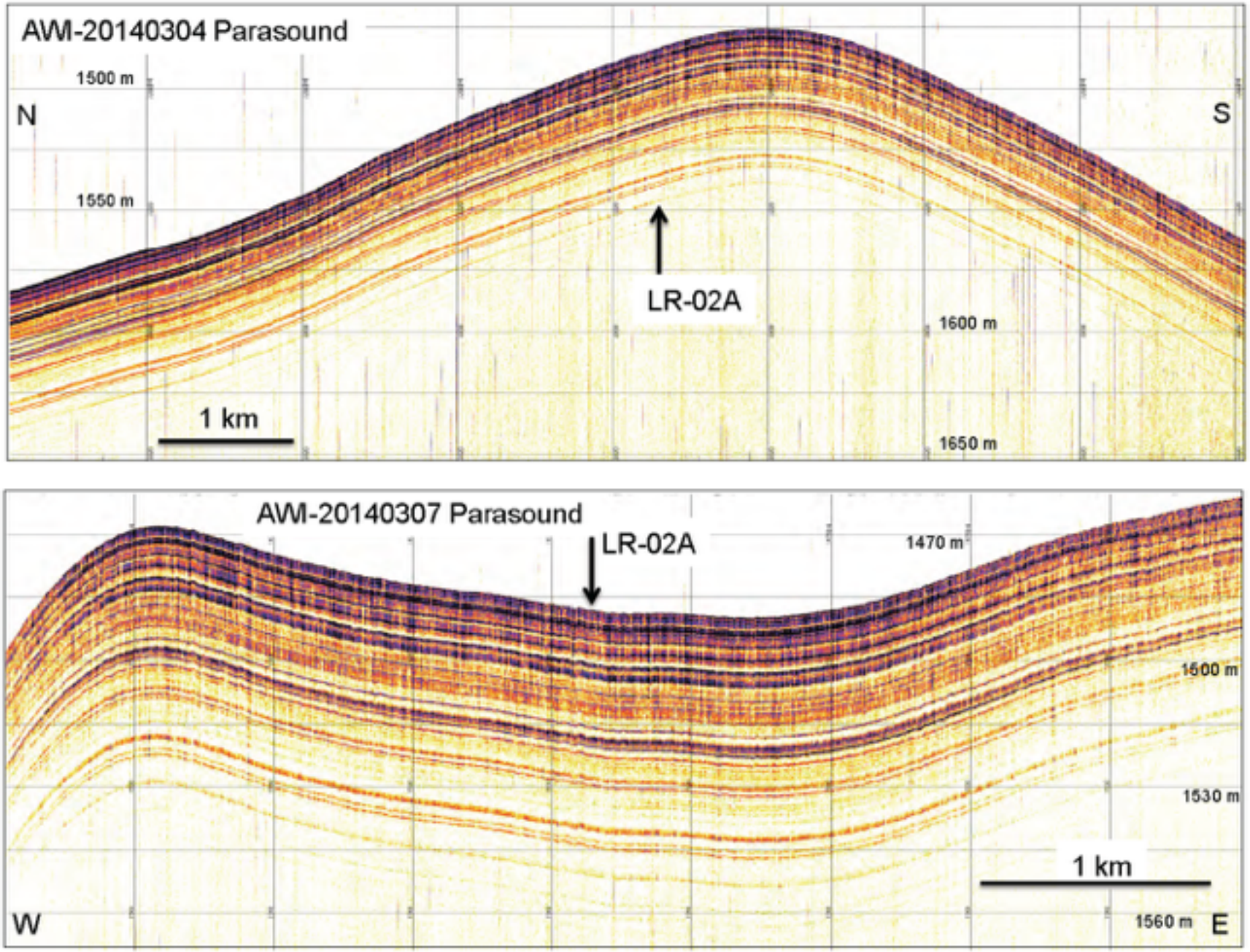


Fig. 7. Sediment-echosounding (Parasound) data of location LR-02A. Depth is calculated using 1500 m/s as constant velocity. SEGY-data in files LR-02A-20140304Para_Part1, LR-02A-20140304Para_Part2 (N-S) and LR-02A-20140307Para_Part1, LR-02A-20140307Para_Part2 (W-E), respectively.

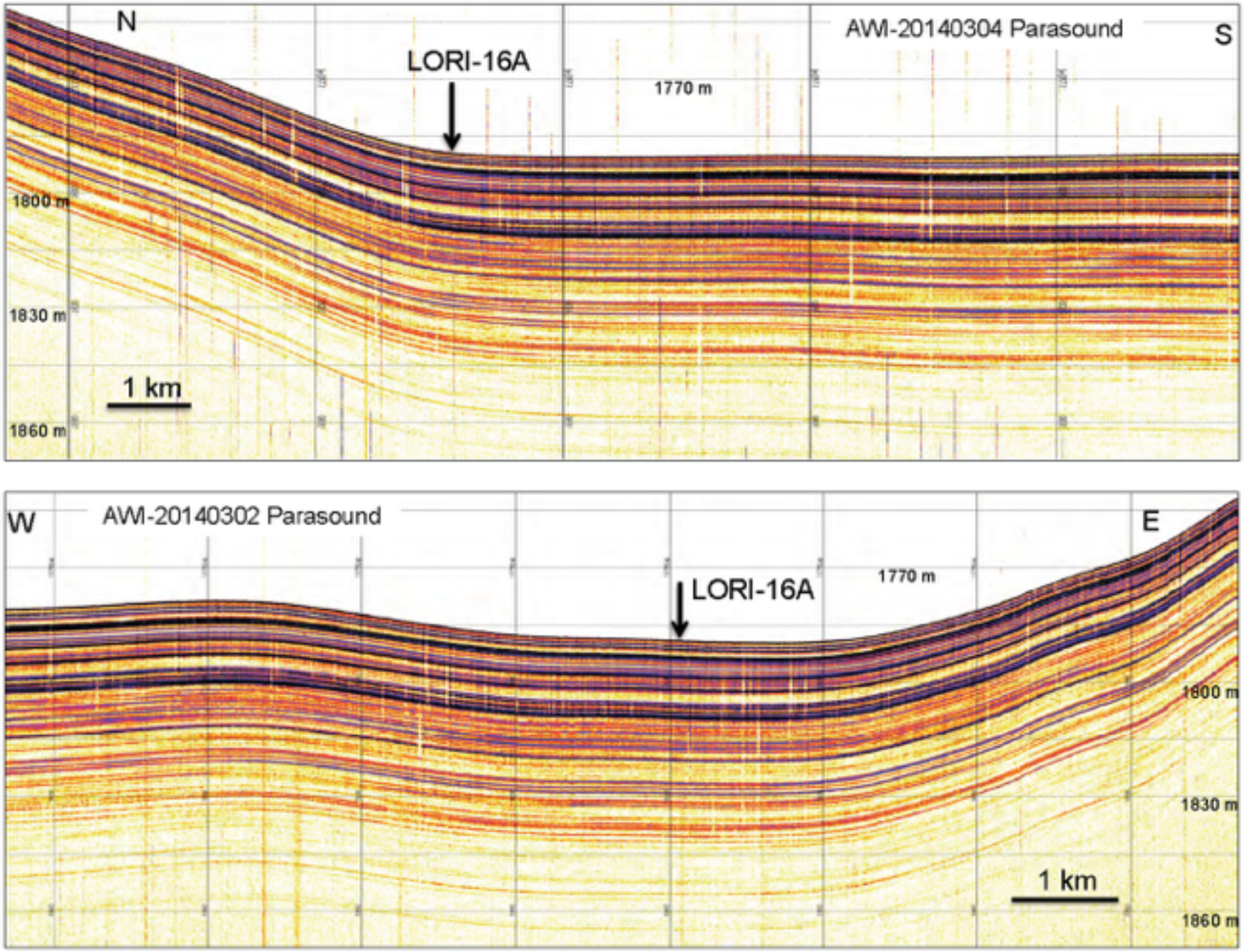


Fig. 8. Sediment-echosounding (Parasound) data of location LORI-16A. Depth is calculated using 1500 m/s as constant velocity. SEGY-data in files LORI-16A-20140304Para_Part1 to Part4 (N-S) and LORI-16A-20140302Para (W-E), respectively.

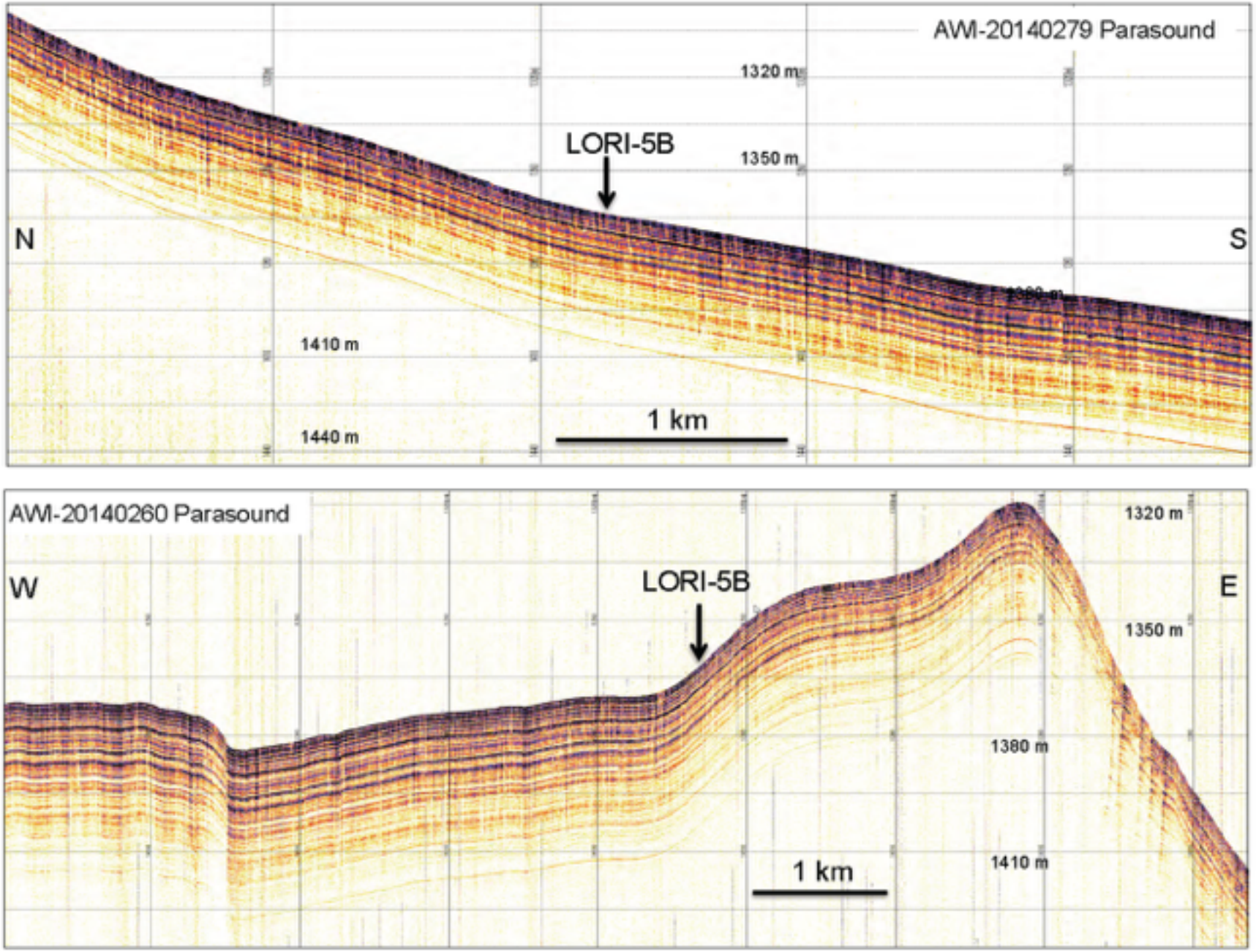
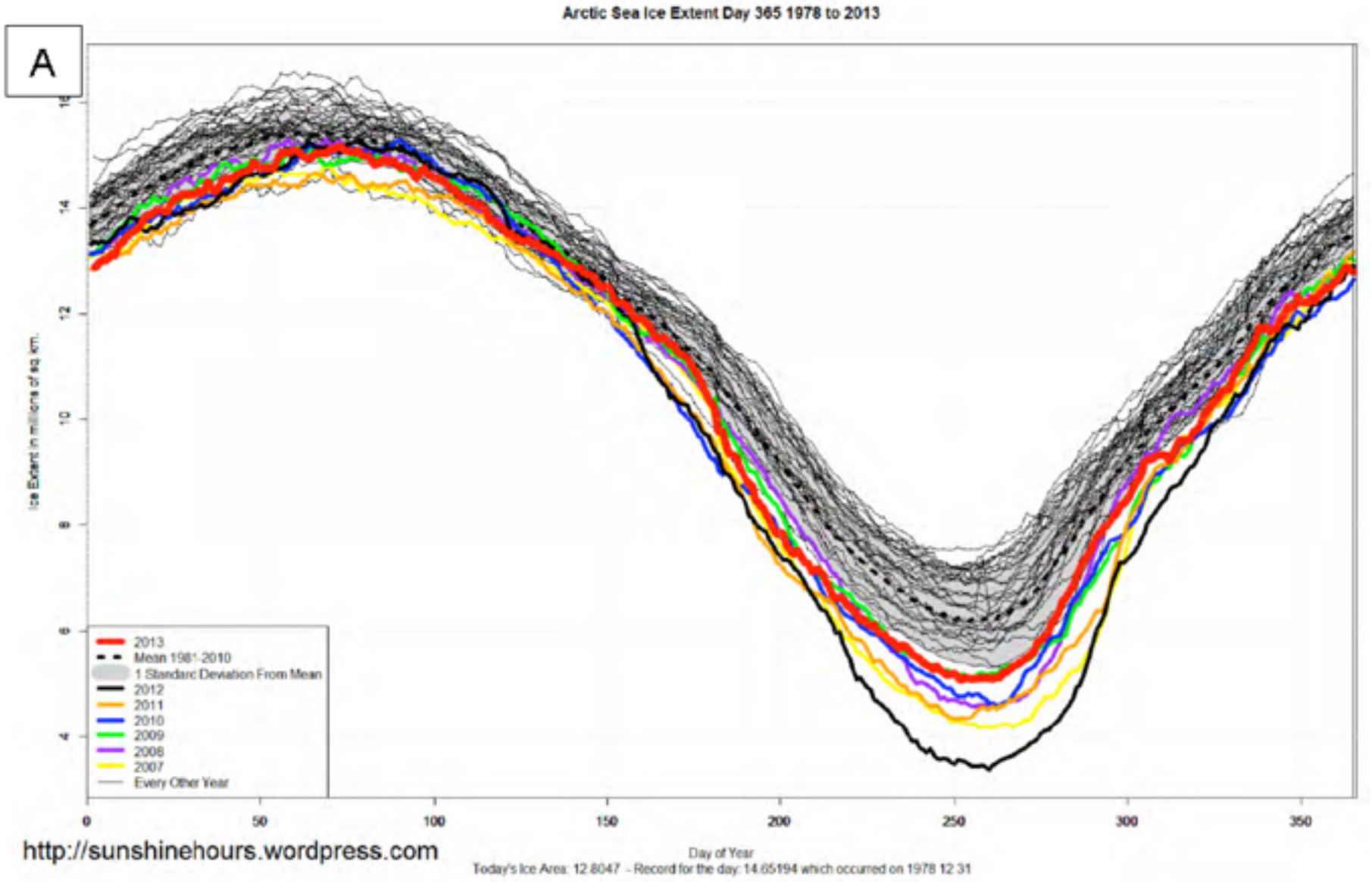
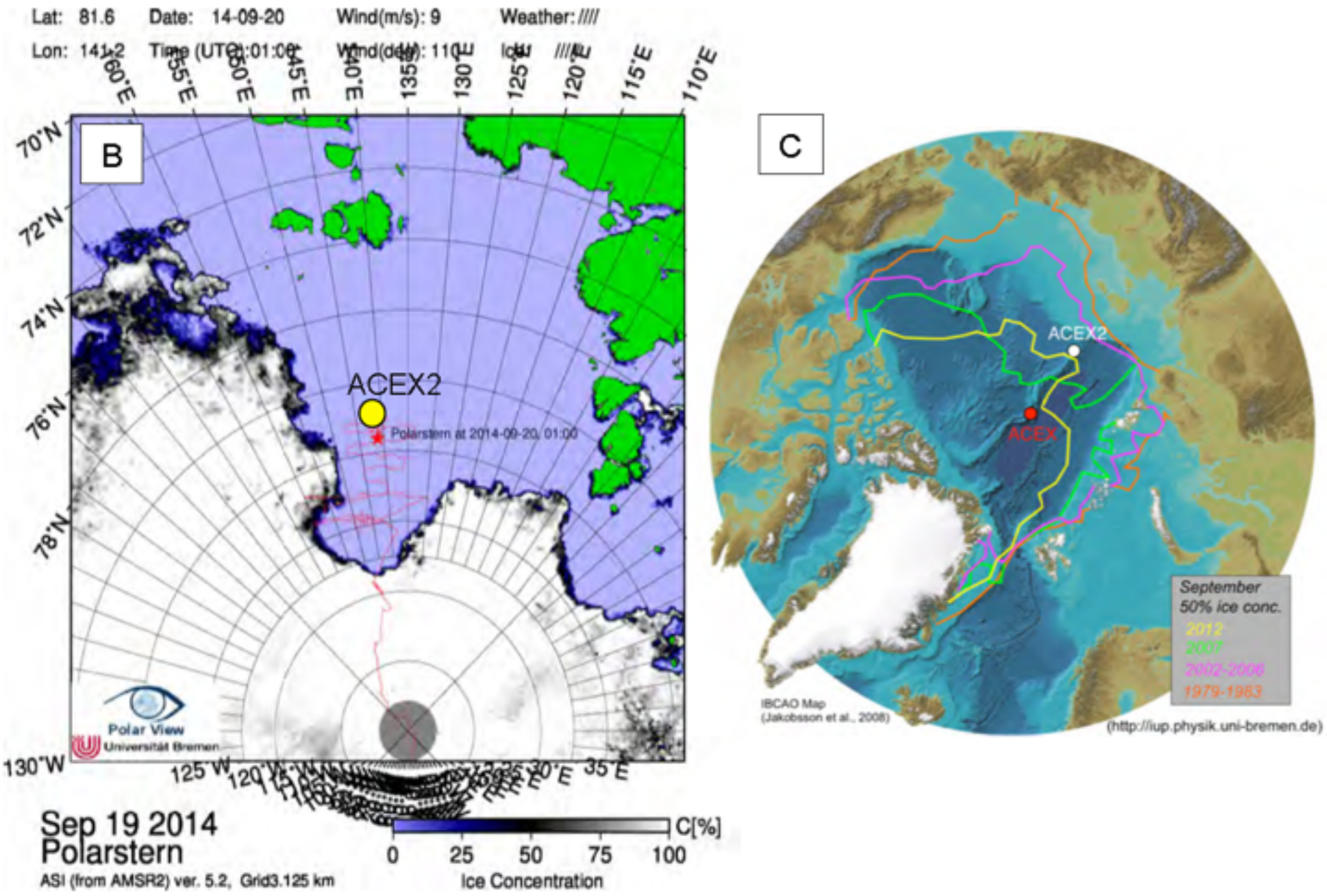


Fig. 9. Sediment-echosounding (Parasound) data of location LORI-5B. Depth is calculated using 1500 m/s as constant velocity. SEGY-data in files LORI-5B-20140279Para.sgy (N-S) and LORI-5B-20140260Para_Part1.sgy, LORI-5B-20140260Para_Part2.sgy (W-E), respectively.



Seasonal variability of sea-ice concentration for selected years



(B) sea-ice concentration mid-September 2014 with PS87 cruise track and ACEX2 location, and
(C) map with minimum sea-ice concentration during September for selected periods with locations of ACEX1 and ACEX2.

Revised objectives/Comments

Still 1200 m penetration depth (total pipe depth remains high, >2500 m)
12 days for 1200 m - three holes, and time for logging: total 38 days

Comments: - Might be lower, at 1030 mbsf

- One complete (composite) sequence and planning with three holes - two might be enough.

- First priority is (1) to get a complete/continuous Miocene- Pliocene-Pleistocene section (primary Site LR-01A: appr. upper 800 m; alternate Site LR-02A: upper 920 m, i.e., section above the pink reflector),
- (2) to drill through the pink reflector that can be correlated more or less across the entire Arctic Ocean), and
- (3) to sample the section between the orange and pink reflectors (primary Site LR-01A: appr. 800-1030 m; alternate Site LR-02A: appr. 920-1210 m, probably representing the Eocene-Oligocene time interval) as continuously as possible.

- If – for what ever reason (ice conditions, technical problems, budget limits, etc.) - we cannot fulfil all three aspects, however, most of the scientific objectives outlined in the main Full1 Proposal can be studied when getting (1) and (2), or even only (1).

- Two icebreakers, Polarstern and Oden - ice-free or marginal ice conditions since 2007

- Hiatus presence: no guarantee

- Silica diagenesis, and overprint at greater depth: can’t guarantee the absence > 500m

Scientific Objectives of ACEX 2 (708-Full1)

A complete stratigraphic sedimentary sequence representing the continuous Cenozoic climate history of 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?
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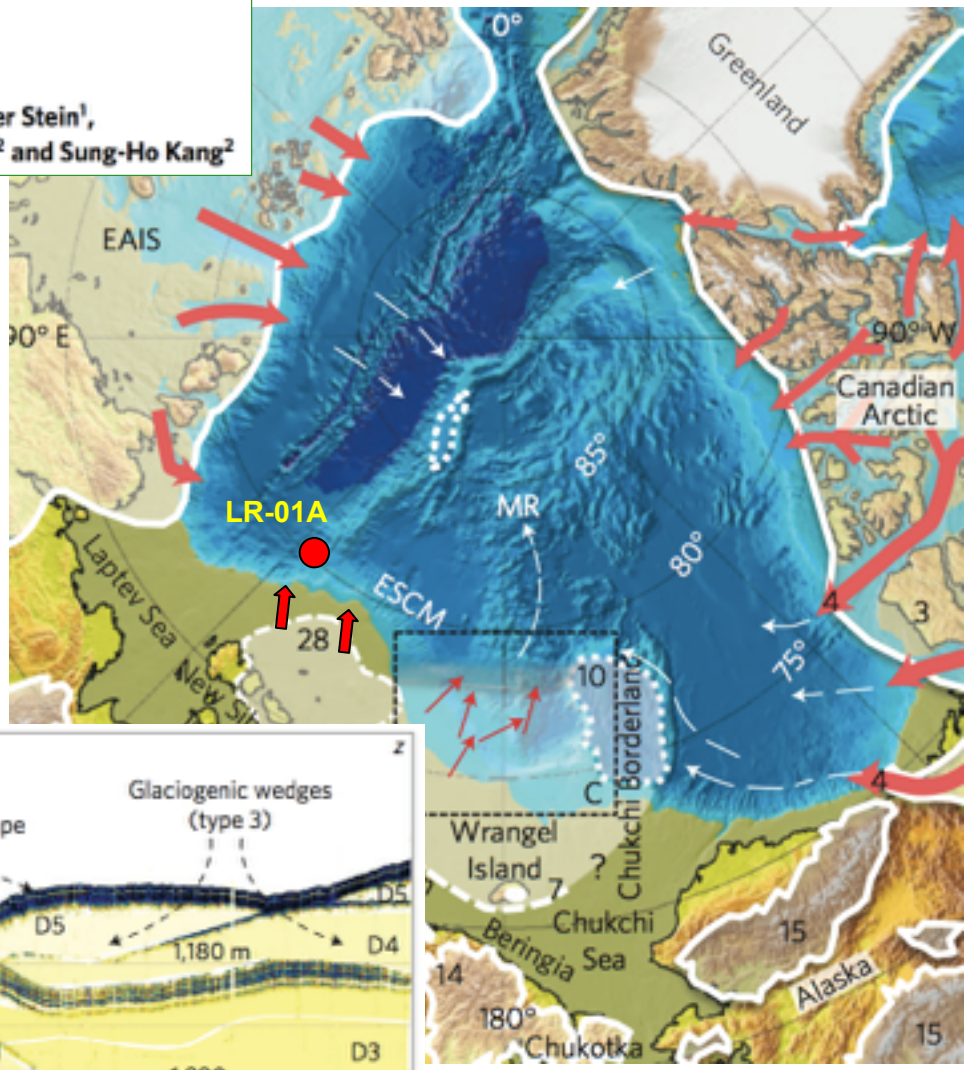
✚✚✚	What was the variability of sea-ice in terms of frequency, extent and magnitude?
✚✚✚	When and how did the change from a warm, fresh-water-influenced, biosilica-rich and poorly ventilated Eocene ocean to a cold, fossil-poor, and oxygenated Neogene ocean occur?
✚✚✚	How critical is the exchange of water 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 El'gygytgyn?
✚✚✚	What is the cause of the major hiatus recovered in the ACEX record? Does this hiatus in fact exist?

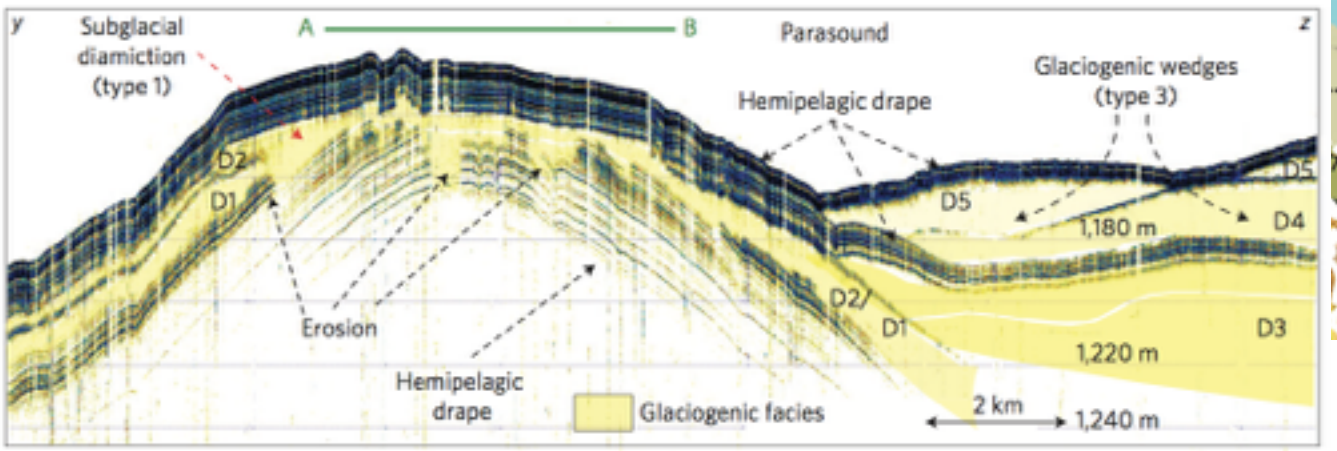
✚	Key questions can be answered getting the Miocene-Pliocene-Pleistocene (upper 800-900 m, i.e., sequence between seafloor and pink reflector)
✚	Key questions can be answered when drilling through/below the pink reflector
✚	Key questions can be fully answered when reaching the orange reflector

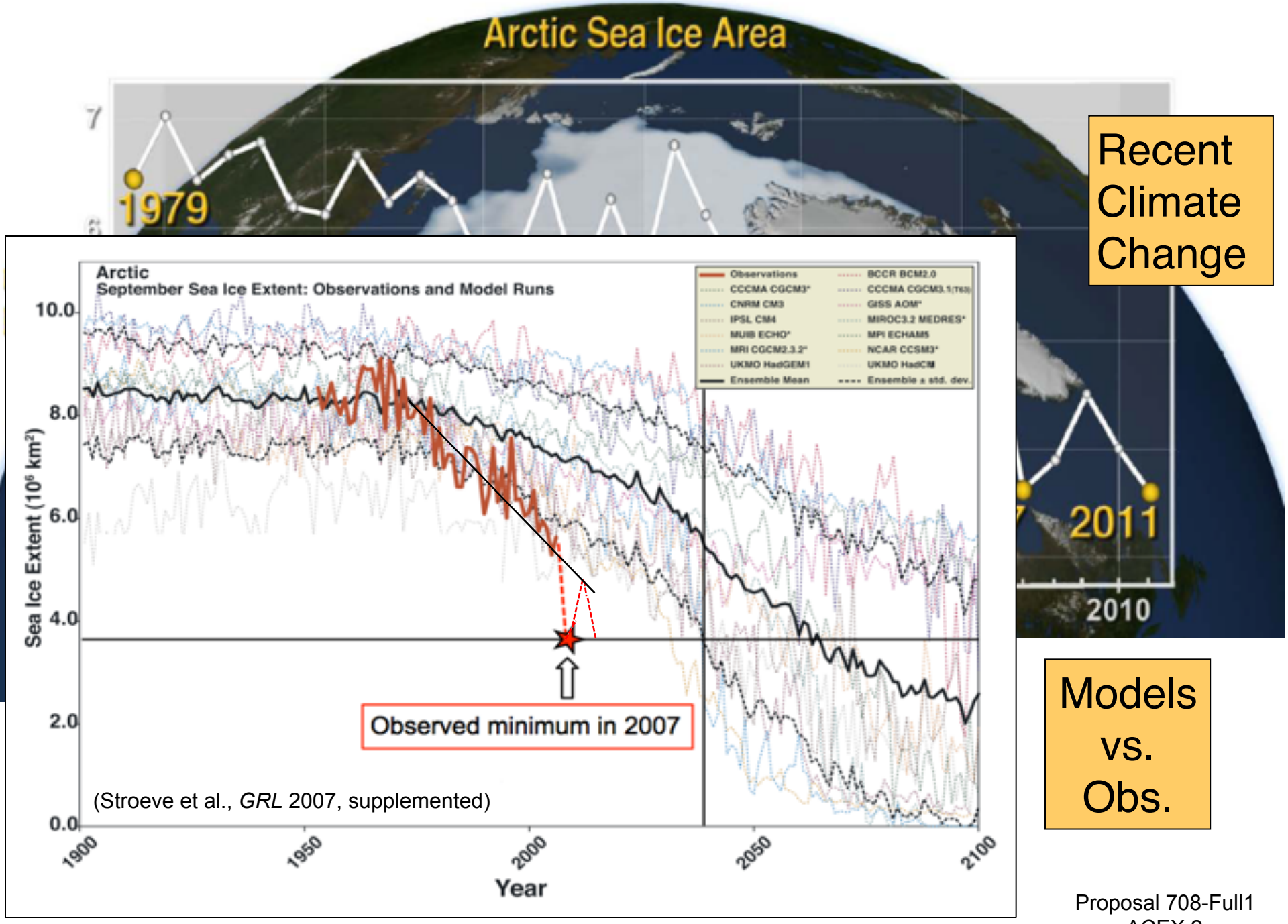
nature geoscience (2013) LETTERS
PUBLISHED ONLINE: 11 AUGUST 2013 | DOI: 10.1038/NGEO1904

Repeated Pleistocene glaciation of the East Siberian continental margin

Frank Niessen[1]*, Jong Kuk Hong[2]*, Anne Hegewald[1], Jens Matthiessen[1], Rüdiger Stein[1], Hyoungjun Kim[2], Sookwan Kim[2,3], Laura Jensen[1], Wilfried Jokat[1], Seung-Il Nam[2] and Sung-Ho Kang[2]







Recent Climate Change

Arctic
September Sea Ice Extent: Observations and Model Runs

Observations
CCCMA CGCM3*
CNRM CM3
IPSL CM4
MUIB ECHO*
MRI CGCM2.3.2*
UKMO HadGEM1
Ensemble Mean
BCCR BCM2.0
CCCMA CGCM3.1(T63)
GISS AOM*
MIROC3.2 MEDRES*
MPI ECHAM5
NCAR CCSM3*
UKMO HadCM
Ensemble ± std. dev.

Sea Ice Extent (10^6 km^2)

10.0
8.0
6.0
4.0
2.0
0.0

1900
1950
2000
2050
2100

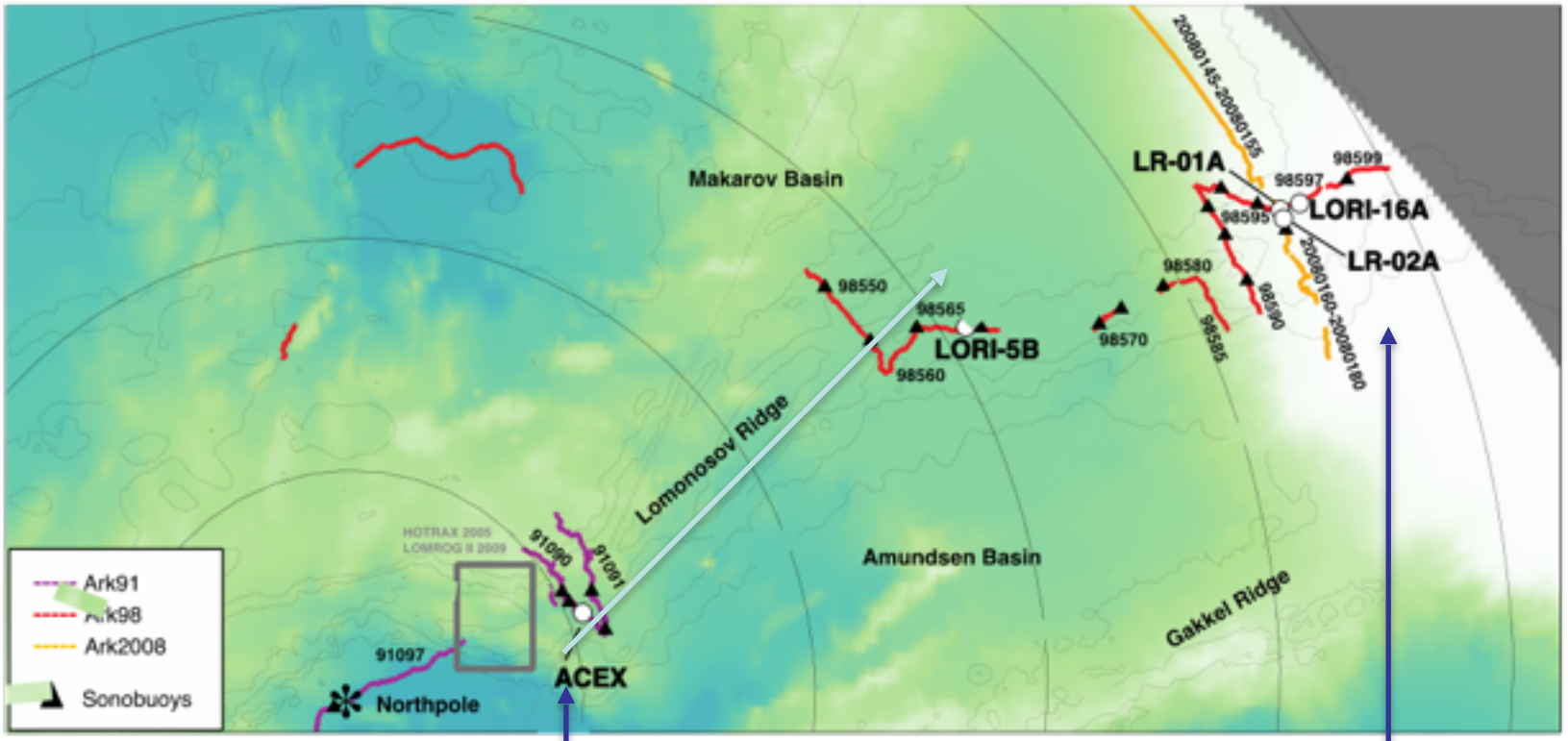
Year

Observed minimum in 2007

(Stroeve et al., *GRL* 2007, supplemented)

Models vs. Obs.

Map indicating seismic profiles (bold numbers AWI lines)



Original comments, 1st EFB meeting.

Reviews/comments:

SSEP: enthusiastically welcomes this timely proposal to build on and complete ACEX 1 (Expedition 302).
High priority scientific objectives, relevant to the IODP Initial Science Plan theme Environmental Change, Processes and Effects (extreme Climates and Rapid Climate Change initiatives). Two proposed themes:
1) Cenozoic Paleoceanography (long stratigraphic gap of ACEX 1) and
2) Neogene/Quaternary high-resolution records (skipped by ACEX 1)
To provide a complete picture of the Paleogene and Neogene.

Drill three APC/XCB(/RCB) holes at each site to recover multiple sections of the sediment sequence to ensure complete recovery for construction of a composite section is appropriate.

SEP reviews in 2006, 2007 (required additional site surveys), 2009, global review 2010, 2011
Full proposal, review January 2014

SEP Comments

1. Are the scientific questions/hypotheses being addressed exciting and of sufficiently wide interest to justify the requested resources?

SEP's consensus view is that the scientific value of recovering a continuous (or nearly continuous) stratigraphic record of Cenozoic paleoceanographic change in the Arctic Ocean is of utmost importance to the broader paleoceanography community. The results of ACEX1, notwithstanding the 44-18 Ma hiatus/condensed-section issue, yielded groundbreaking new science. We think that ACEX2 has similar potential.

2. Will the proposal significantly advance one or more goals of the Science Plan?

Clearly meet Challenges 1 and 2 of the Climate and Ocean theme of the IODP Science Plan 2013-2023, and have the potential to provide valuable paleoceanographic/paleoclimate data. Additionally, the importance of recovering records from polar regions is clearly met.

3. Would the proposal engage new communities or other science programs into the drilling program?

The proponents would potentially engage with the ice sheet modeling community.

4. To what degree does the integrated experimental design of site characterization, drilling, sampling, measurements, and downhole experiments constitute a compelling and feasible scientific proposal?

Overall, the panel deems that the drilling/coring plan as laid out in the proposal, which includes ice breaker support, is robust;

however, there are a few issues we believe are worth highlighting here:

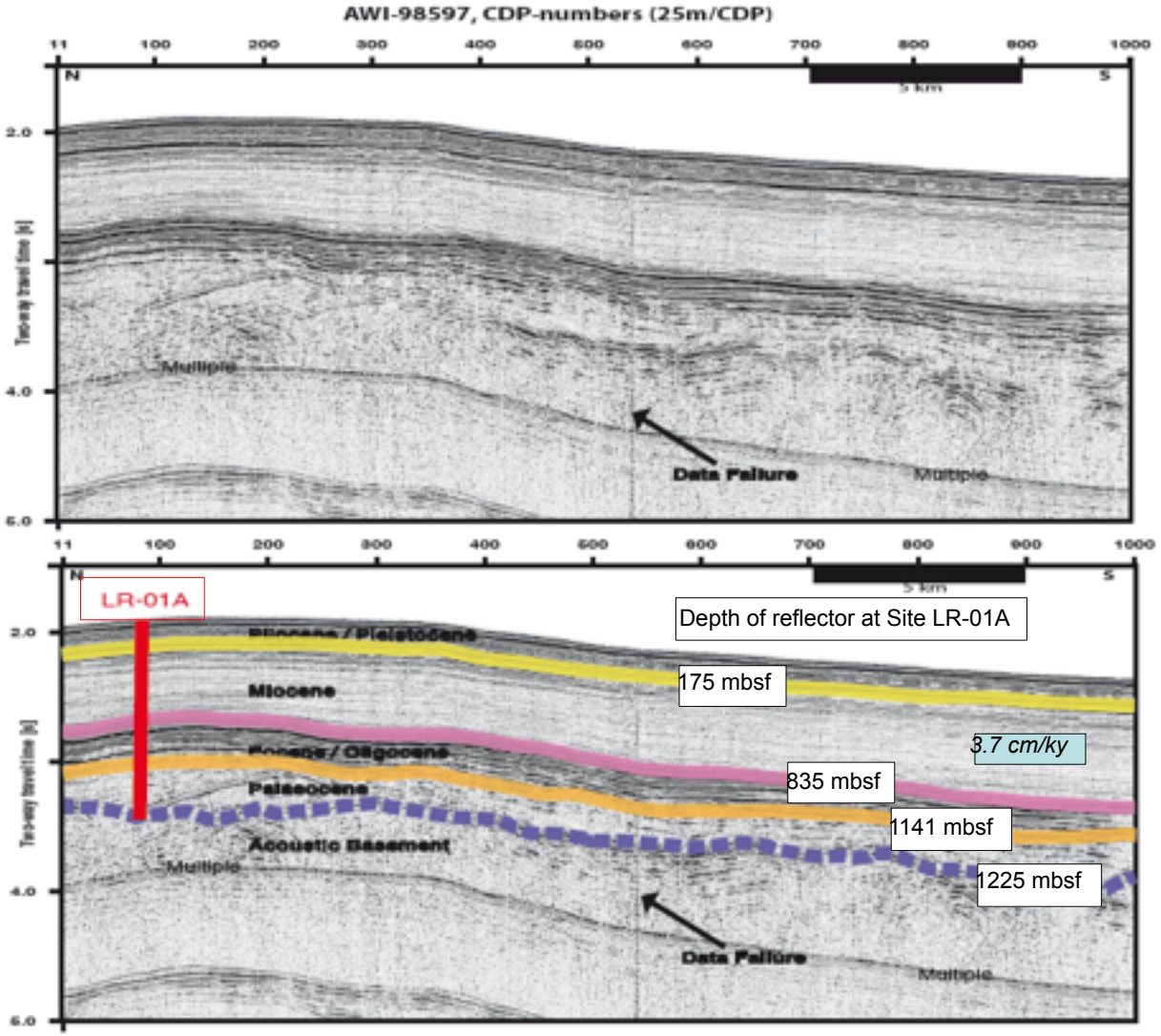
• The scientific risk of the encountering the same hiatus/condensed-section should be acknowledged. The proponents do address this by showing some additional seismic stratigraphic illustrations that help to constrain age. However, the panel thought a comparison of the key interval of interest shown on the seismic profile (between orange and pink and labeled as 'Eocene/Oligocene') with the seismic from ACEX1 would have been very helpful. That said, we think this is a scientific risk worth taking.

• The poor core recovery of ACEX1 was mentioned but how the proposed plan will improve core recovery at ACEX2 was not clear in the drilling/coring plan.

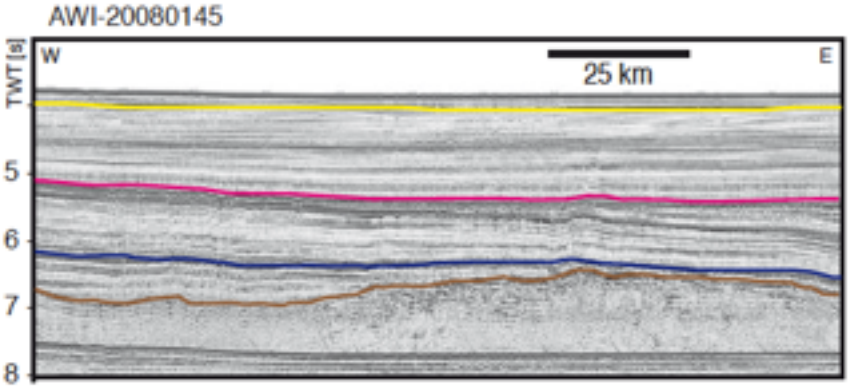
• To what extent might the Eurasian ice sheet influence the ice-sheet discharge signal (instead of solely an East Siberian origin)? We recommend the proponents research this possibility and to what extent provenance analysis could help resolve.

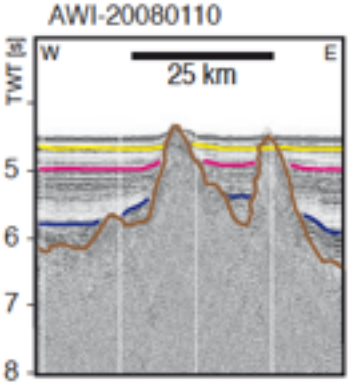
We propose one primary drill site on southern Lomonosov Ridge, Site LR-01A, located on crossing point of line AWI-98597 and line AWI-20080160 (Fig. 9a). At this site, we propose drilling three APC/XCB/RCB holes down to basement (the "purple" reflector in ~1225 mbsf; Fig. 9b). This is required to ensure 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.

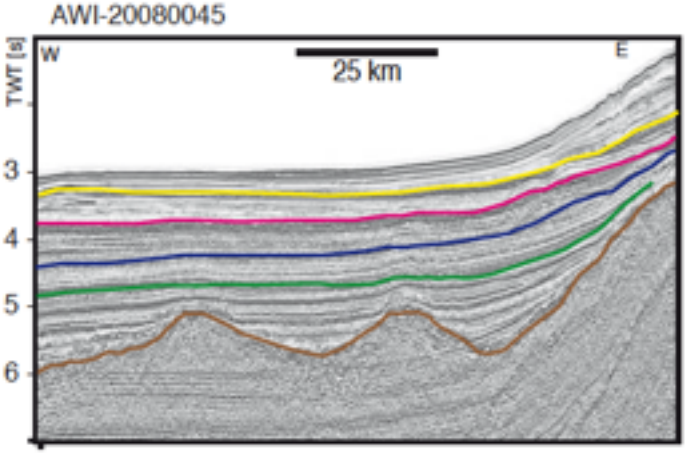
Seismic profile across Site LR-01A with main seismic units and mean sedimentation rate

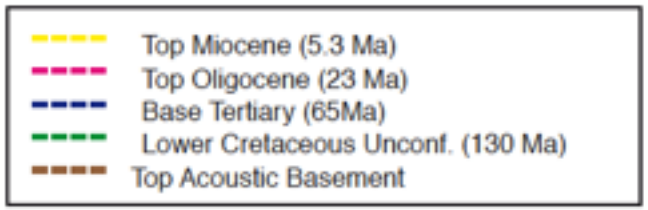


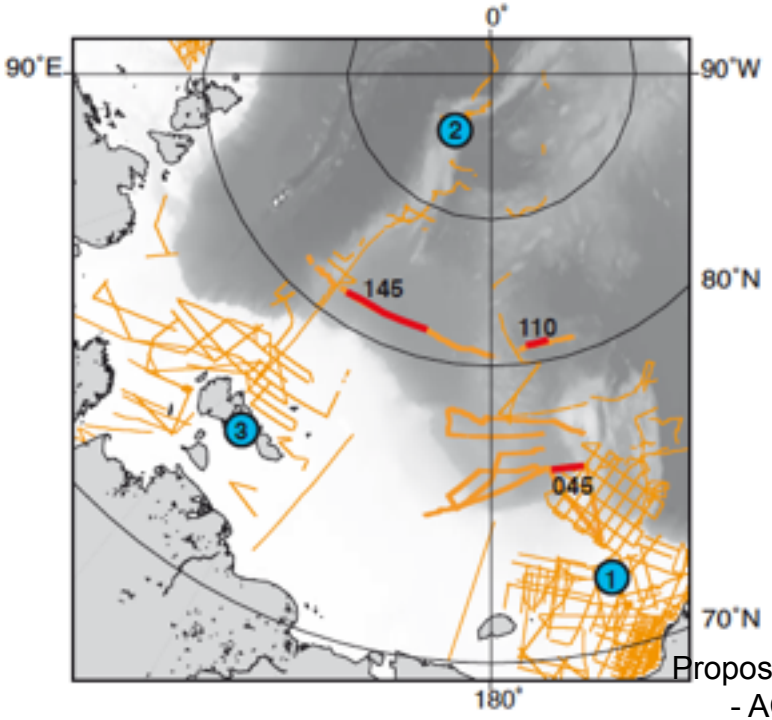
Example of seismic sections (locations on map: red lines) demonstrating conformities in reflection pattern, marker horizons and reflector configurations across large parts of the Siberian part of the Arctic Ocean. These similarities enable a data-transfer from remote drill sites (map: blue circles) onto seismic profiles (map: yellow lines)





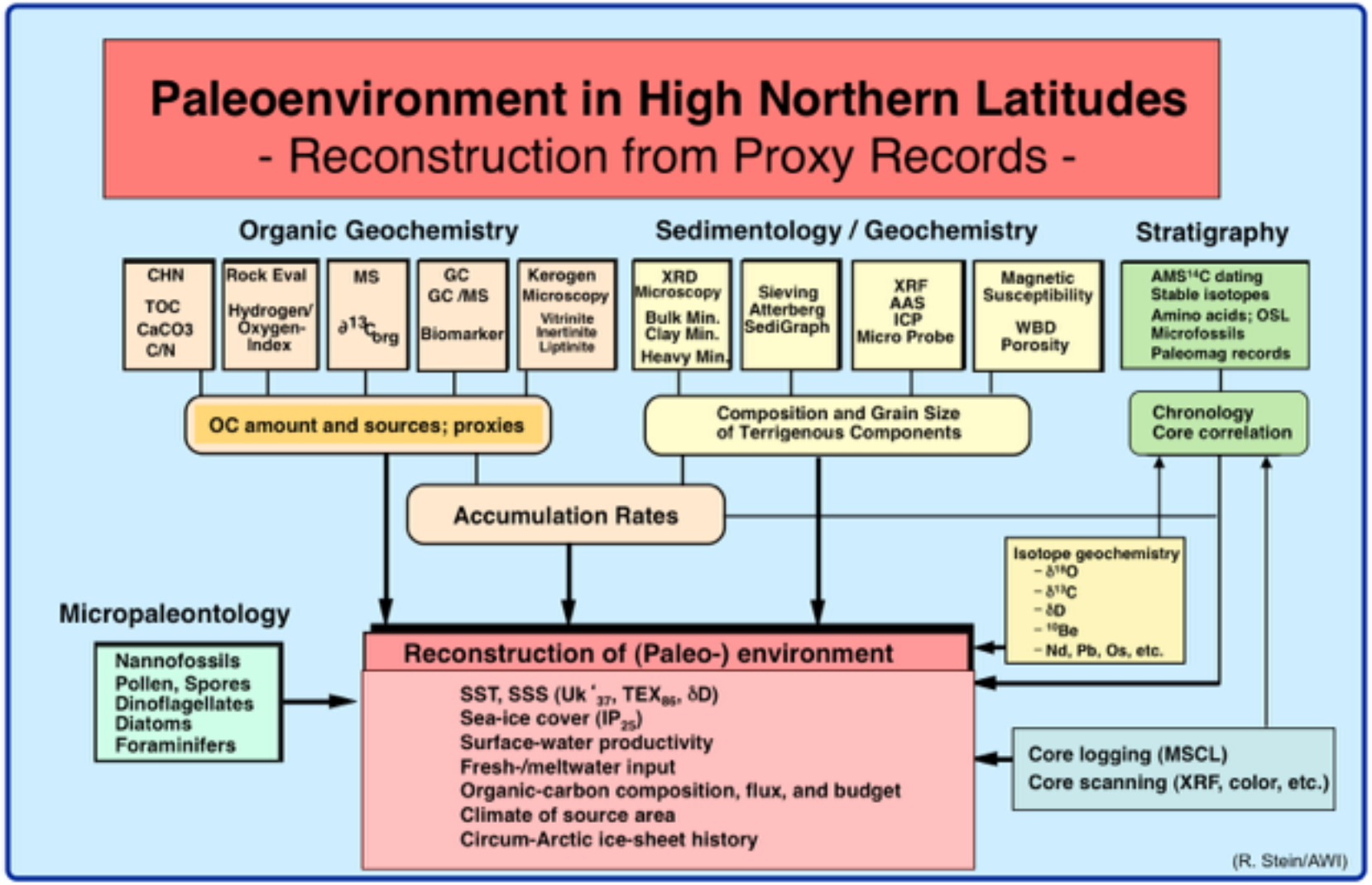




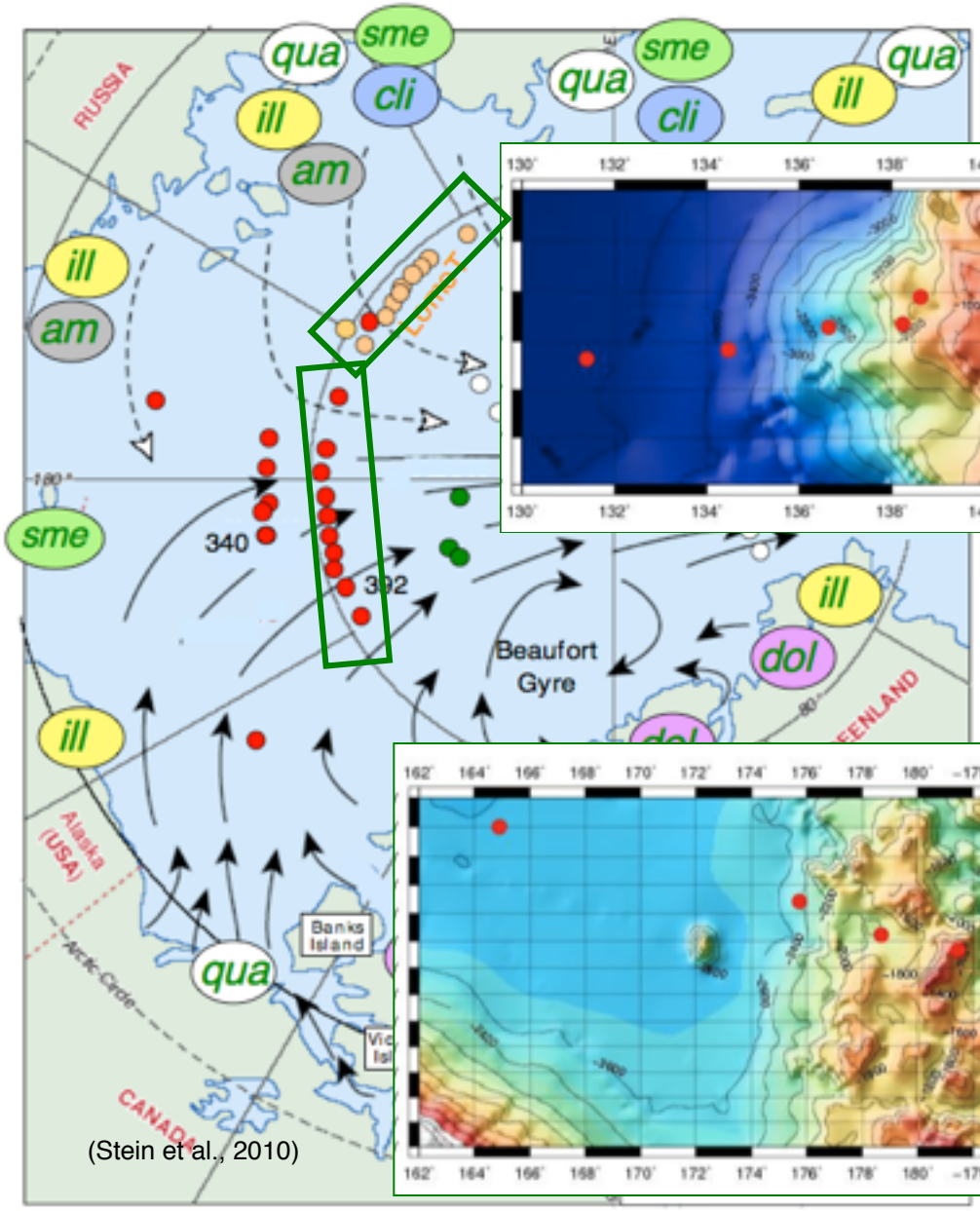


Proposed Sites

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)

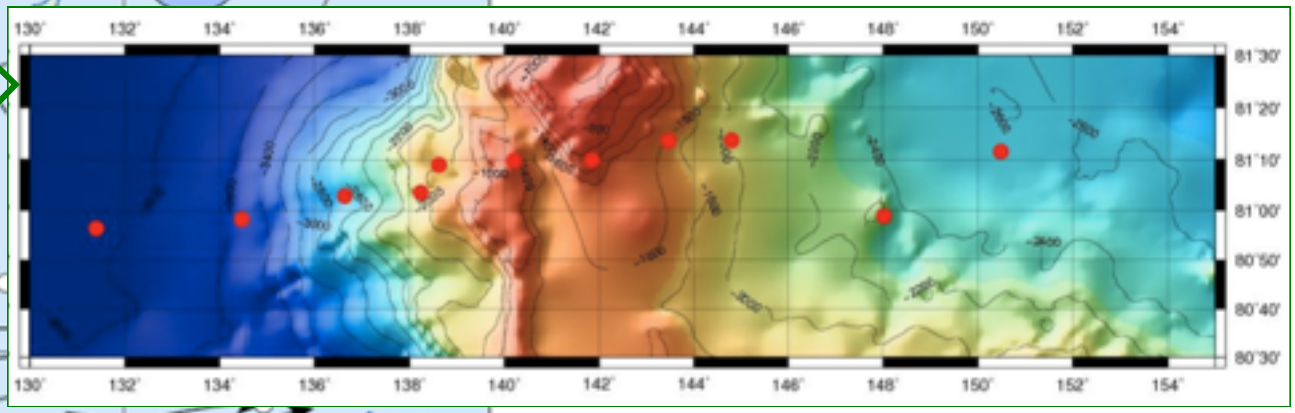

Paleoenvironment in High Northern Latitudes
- Reconstruction from Proxy Records -
Organic Geochemistry
Sedimentology / Geochemistry
Stratigraphy
CHN
TOC
CaCO3
C/N
Rock Eval
Hydrogen/
Oxygen-
Index
MS
GC
GC /MS
Biomarker
Kerogen
Microscopy
Vitrinite
Inertinite
Liptinite
XRD
Microscopy
Bulk Min.
Clay Min.
Heavy Min.
Sieving
Atterberg
SediGraph
XRF
AAS
ICP
Micro Probe
Magnetic
Susceptibility
WBD
Porosity
AMS14C dating
Stable isotopes
Amino acids; OSL
Microfossils
Paleomag records
OC amount and sources; proxies
Composition and Grain Size
of Terrigenous Components
Chronology
Core correlation
Accumulation Rates
Isotope geochemistry
– δ18O
– δ13C
– δD
– 10Be
– Nd, Pb, Os, etc.
Micropaleontology
Nannofossils
Pollen, Spores
Dinoflagellates
Diatoms
Foraminifers
Reconstruction of (Paleo-) environment
SST, SSS (Uk '37, TEX86, δD)
Sea-ice cover (IP25)
Surface-water productivity
Fresh-/meltwater input
Organic-carbon composition, flux, and budget
Climate of source area
Circum-Arctic ice-sheet history
Core logging (MSCL)
Core scanning (XRF, color, etc.)
(R. Stein/AWI)

Transect of sediment cores recovered across the southern Lomonosov Ridge during Polarstern Expedition ARK-XI/1

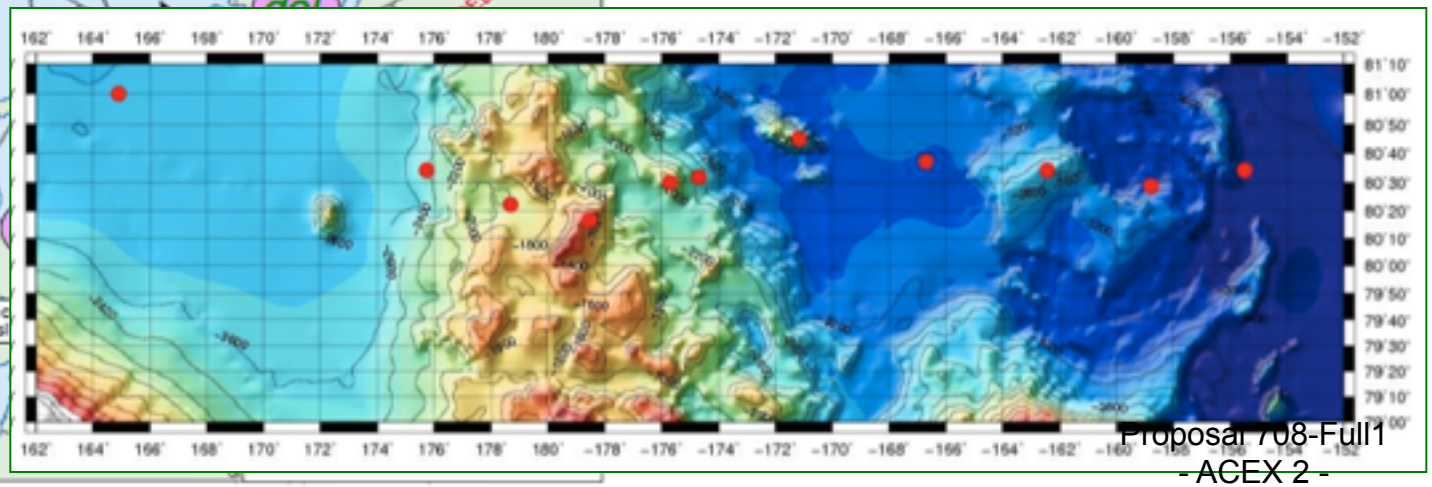


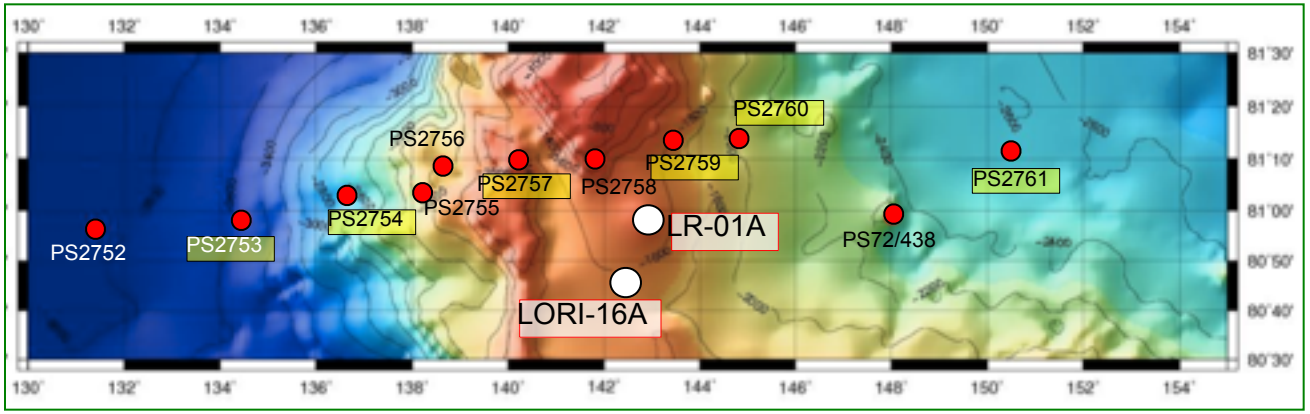
(Stein et al., 2010)

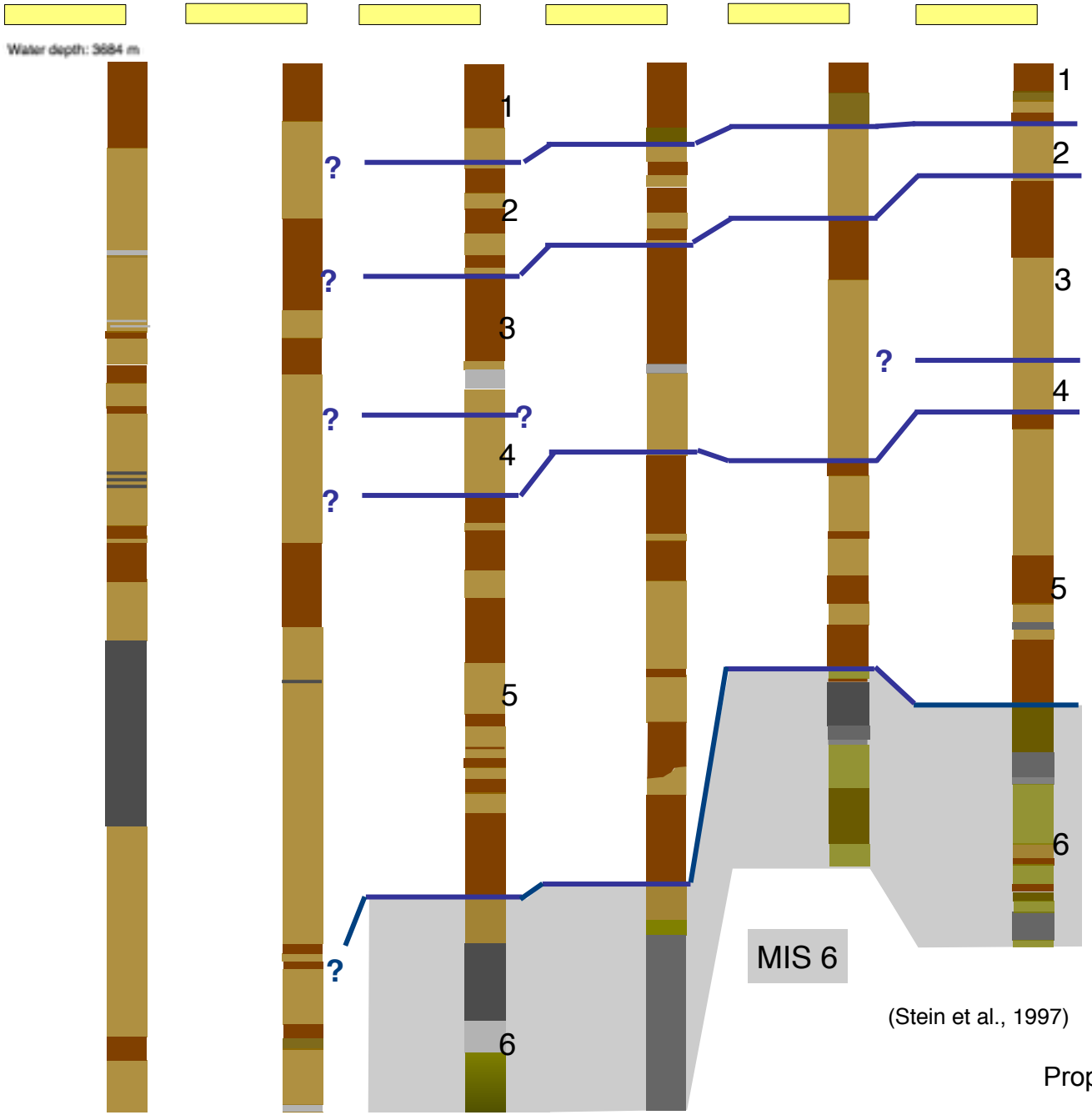
Lomonosov Ridge Transect



Mendeleev Ridge Transect

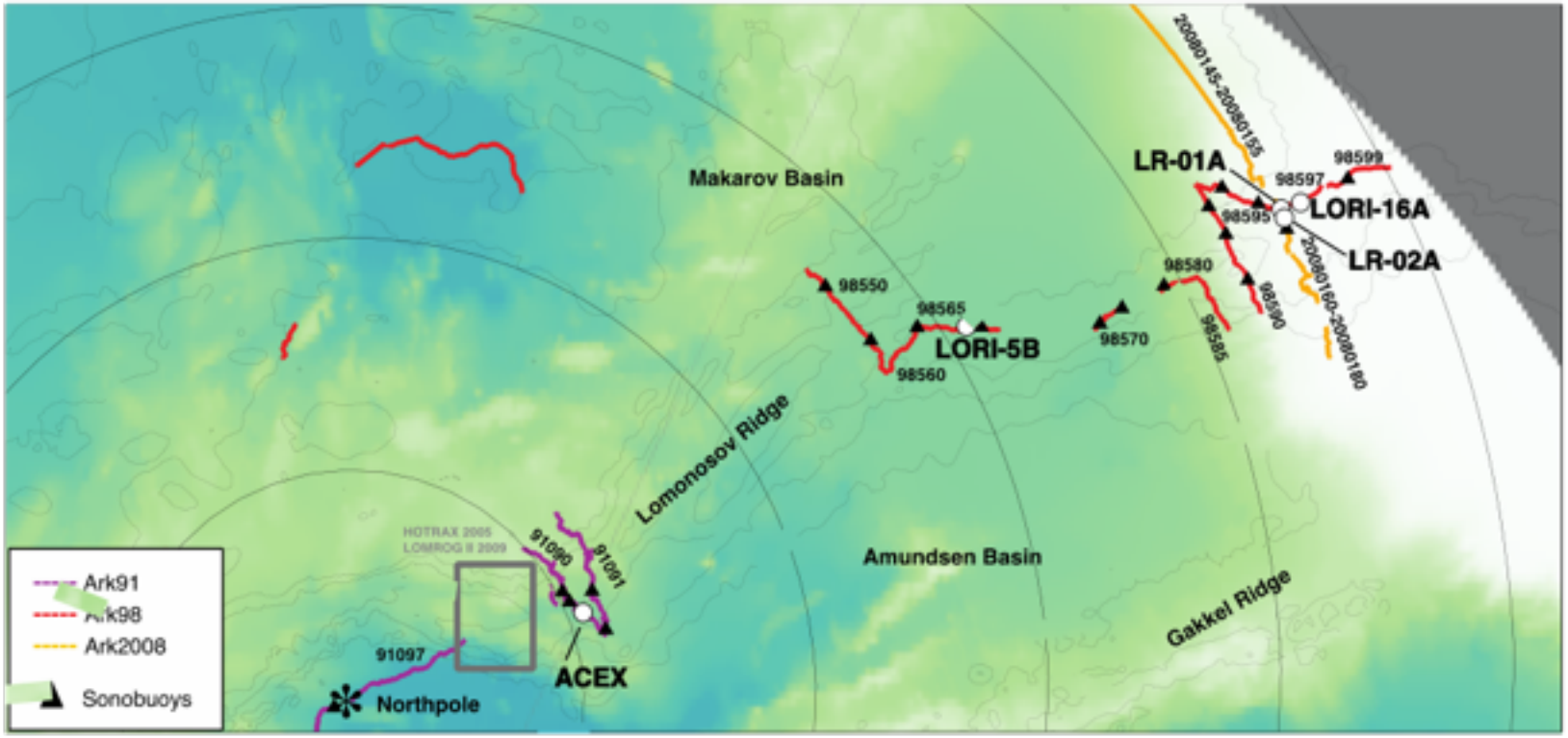



130°
132°
134°
136°
138°
140°
142°
144°
146°
148°
150°
152°
154°
81°30'
81°20'
81°10'
81°00'
80°50'
80°40'
80°30'
PS2752
PS2753
PS2754
PS2755
PS2756
PS2757
PS2758
PS2759
PS2760
PS2761
PS72/438
LR-01A
LORI-16A

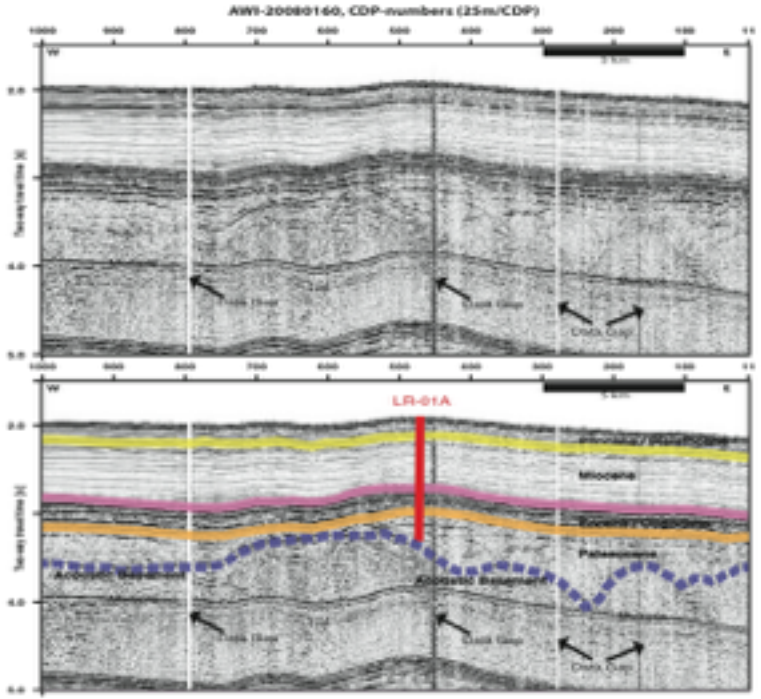


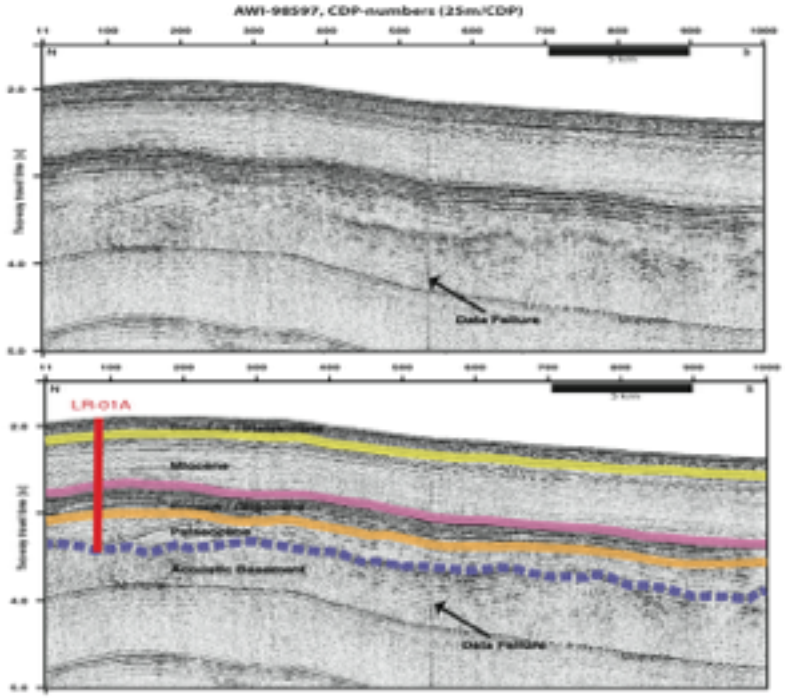
Proposal 708-Full1
- ACEX 2 -

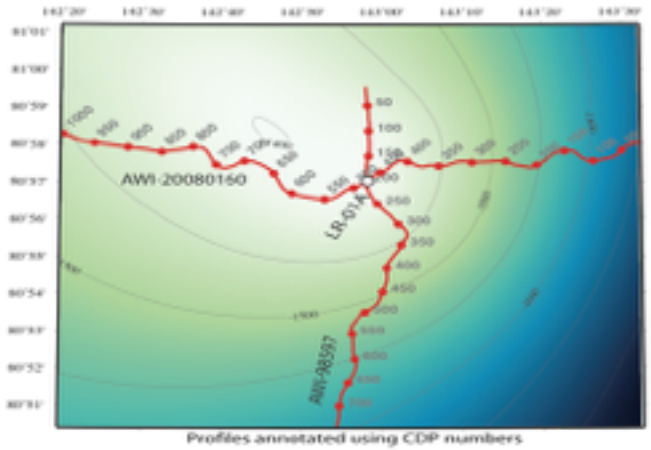
708-Full: ACEX-2 Sites



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







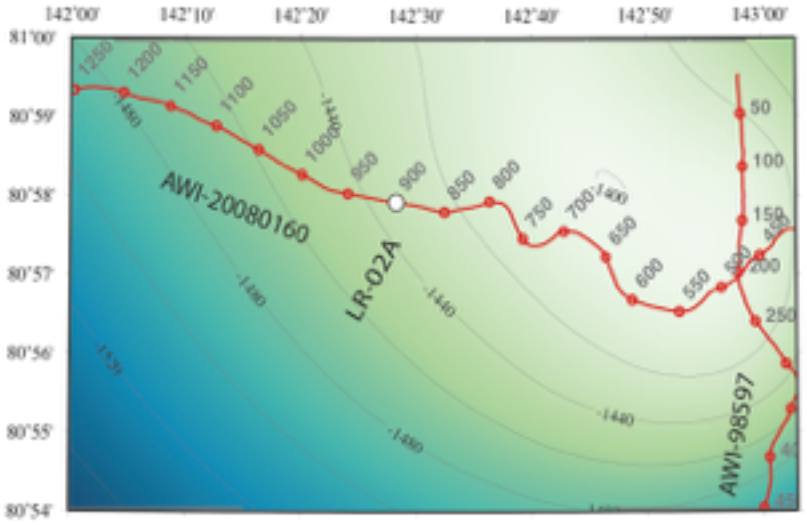
Profiles annotated using CDP numbers

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

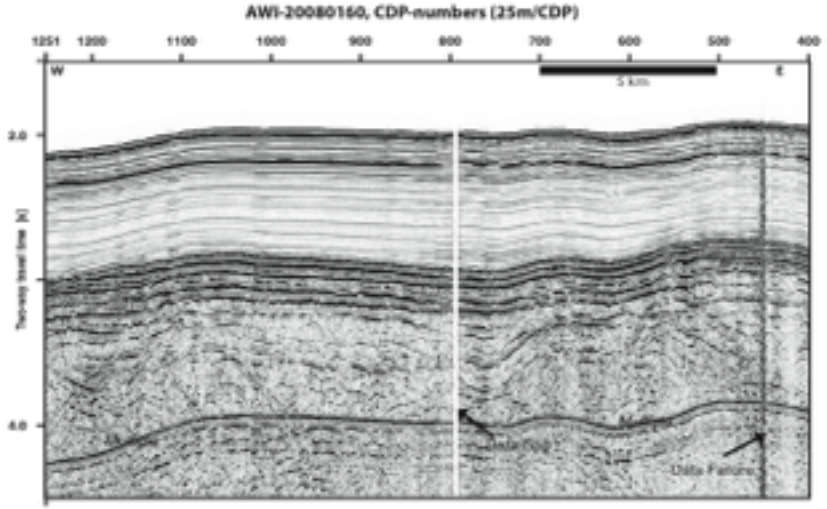
SSDB locations of these graphics and supporting data:

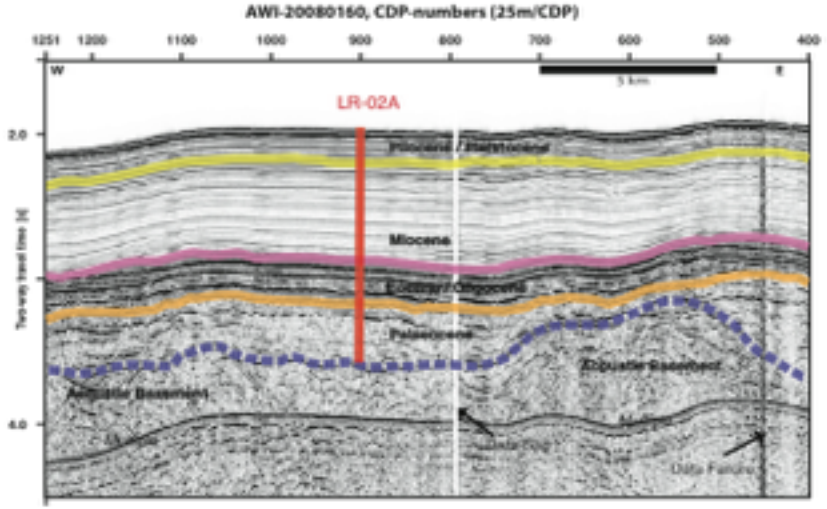
-Location map:	LR-01A_map.pdf
-Seismic figures:	LR-01A_AWI-20080160.pdf
	LR-01A_AWI-98597.pdf
-SEGY data:	AWI-20080160stack.sgy
	AWI-98597stack.sgy
-Navigation data:	20080160_cdplocs.asc
	98597_cdplocs.asc

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



Profiles annotated using CDP numbers



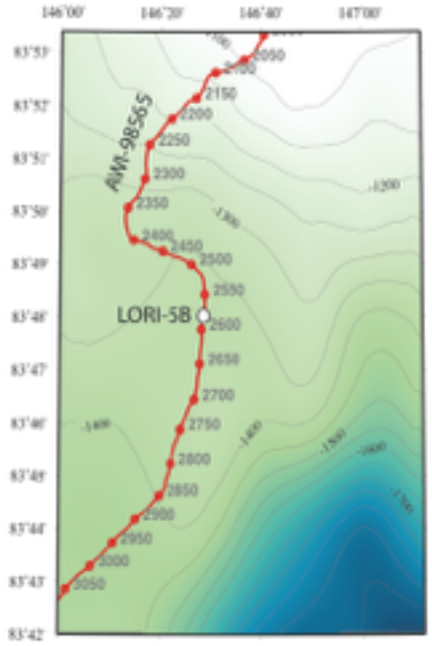


Coordinates:	80° 57.9'N, 142° 28.3'E
Water-depth:	1450 m
Top Miocene (yellow):	220 mbsf
Top Oligocene (pink):	965 mbsf
Lower Eocene (orange):	1270 mbsf
Basement (purple):	2150 mbsf
Penetration total:	2150 m

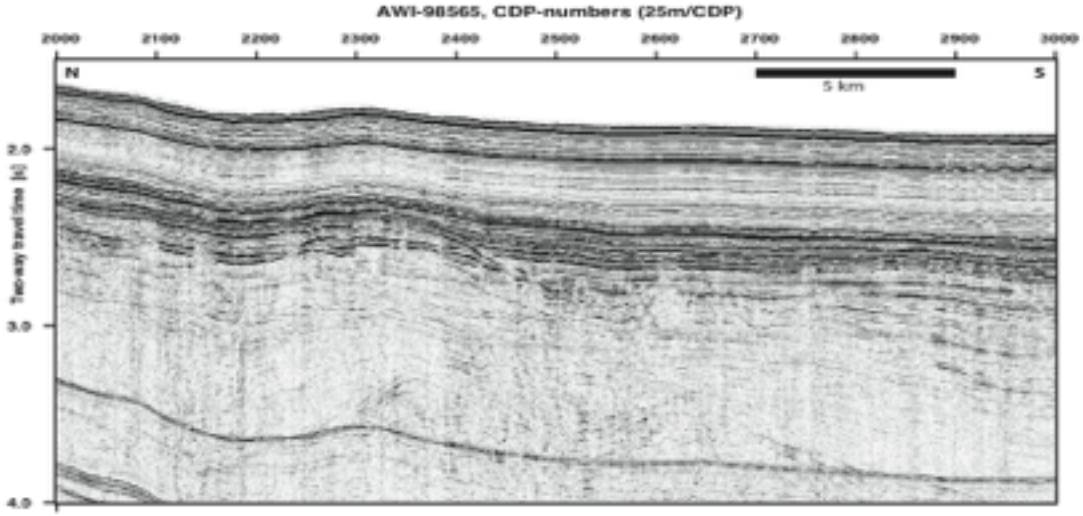
SSDB locations of these graphics and supporting data:

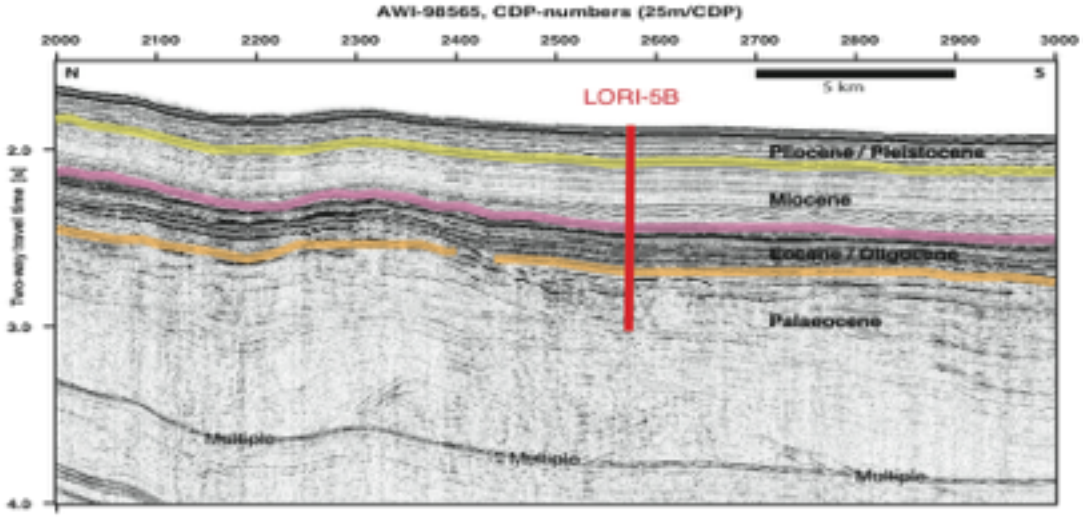
-Location map:	LR-02A_map.pdf
-Seismic figures:	LR-02A_AWI-20080160.pdf
-SEGY data:	AWI-20080160stack.sgy
-Navigation data:	20080160_cdplocs.asc

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



Profiles annotated using CDP numbers

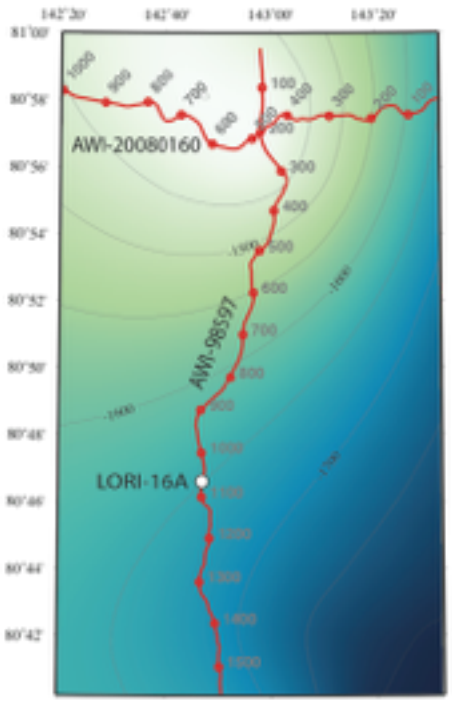




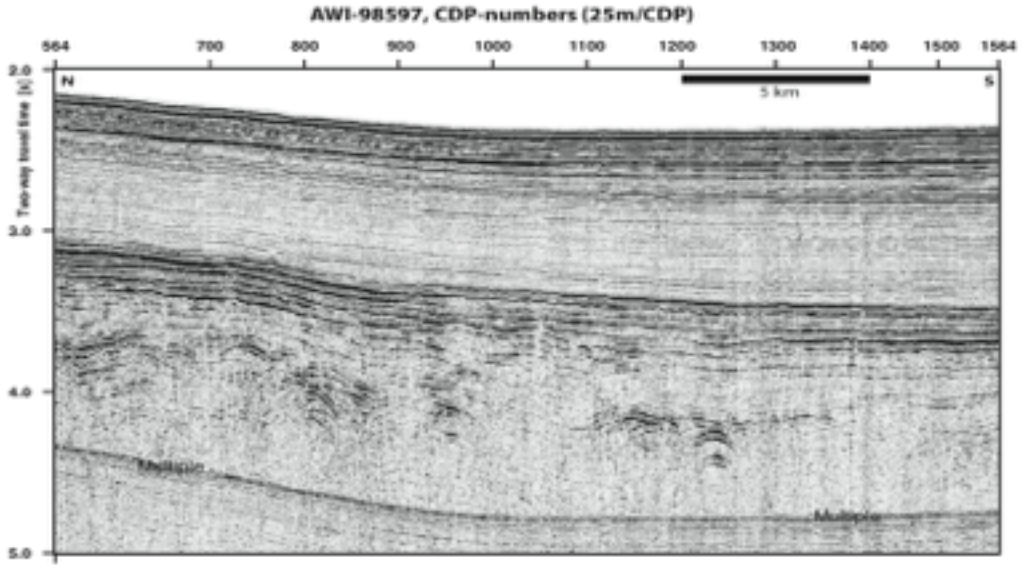
Coordinates: 83° 48.03'N, 146° 28.5'E
Water-depth: 1334 m
Top Miocene (yellow): 180 mbsf
Top Oligocene (pink): 660 mbsf
Lower Eocene (orange): 1000 mbsf
Penetration: 1750 m

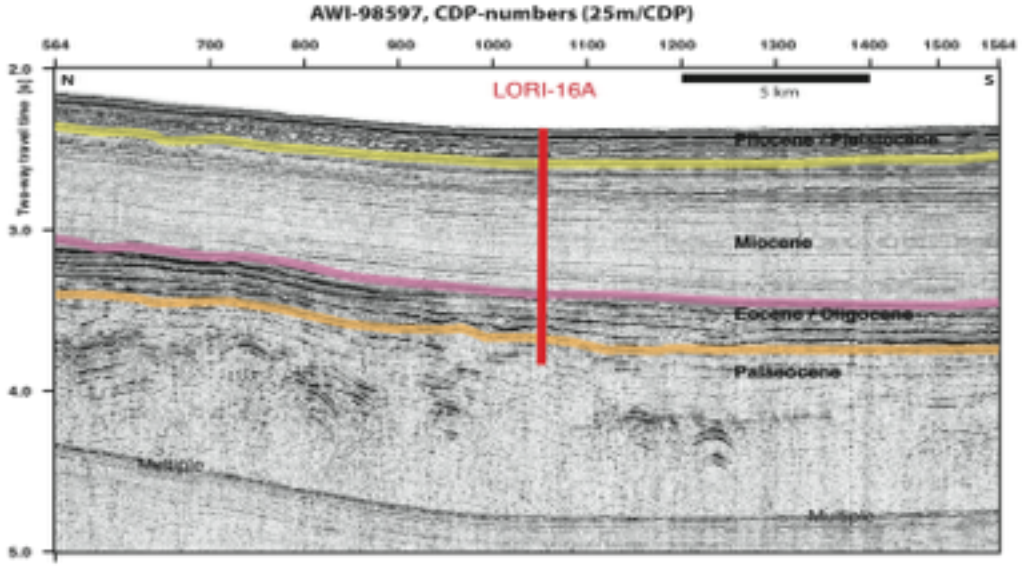
SSDB locations of these graphics and supporting data:
-Location map: LORI-5B_map.pdf
-Seismic figures: LORI-5B_AWI-98565.pdf
-SEGY data: AWI-98565stack.sgy
-Navigation data: 98565_cdplocs.asc

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



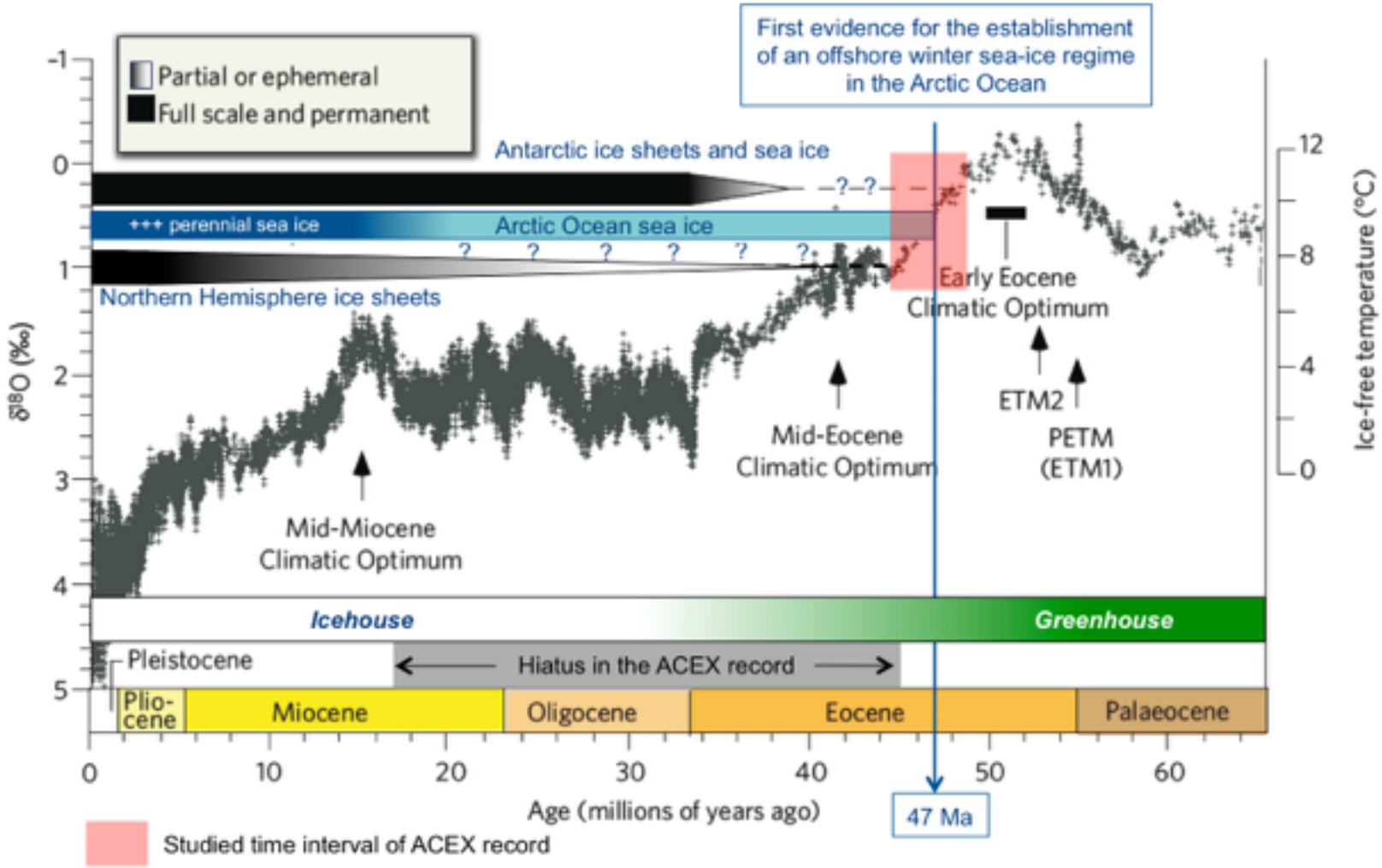
Profiles annotated using CDP numbers

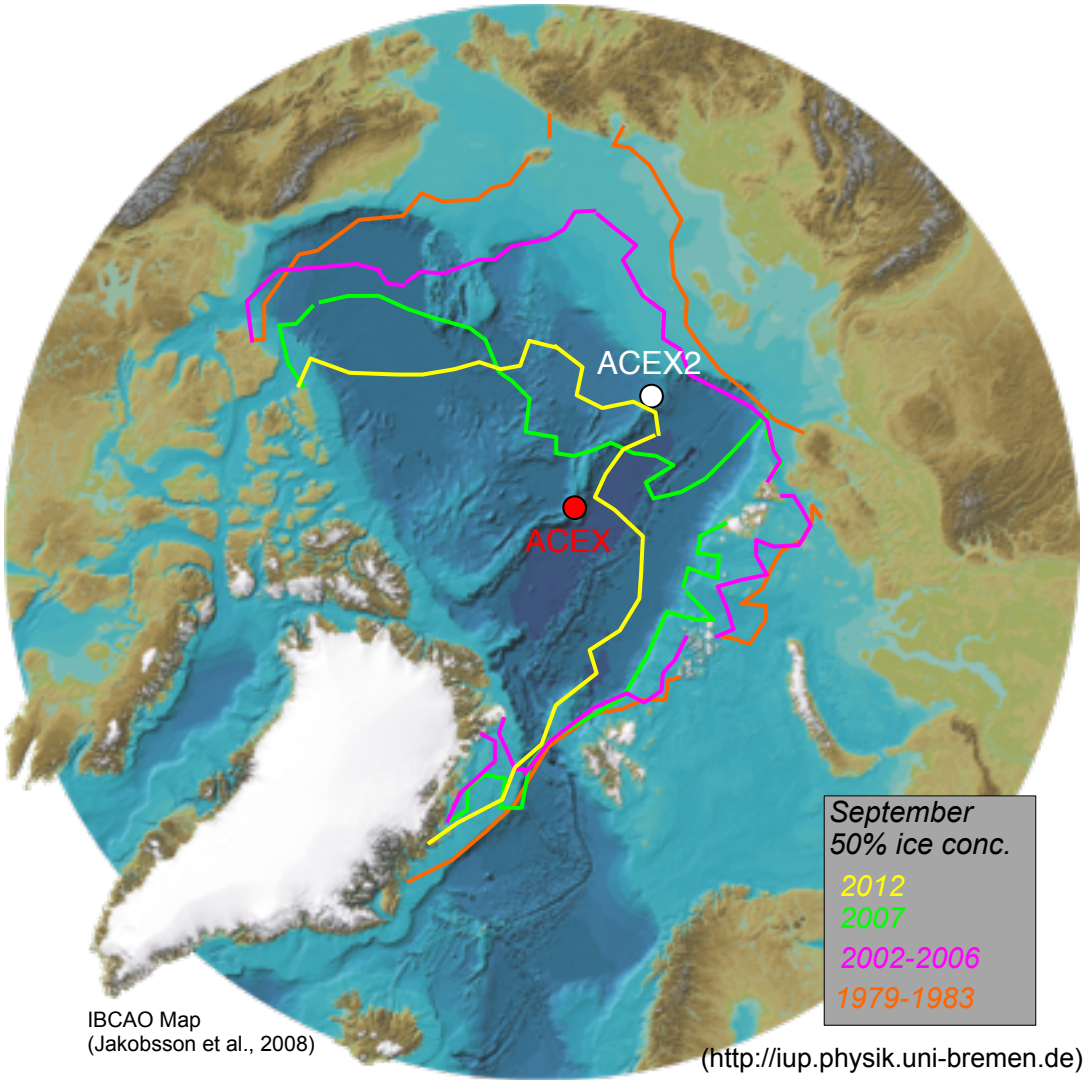




Coordinates: 80° 46.6'N, 142° 46.9'E
Water-depth: 1752 m
Top Miocene (yellow): 195 mbsf
Top Oligocene (pink): 1395 mbsf
Lower Eocene (orange): 1840 mbsf
Penetration: 2160 m

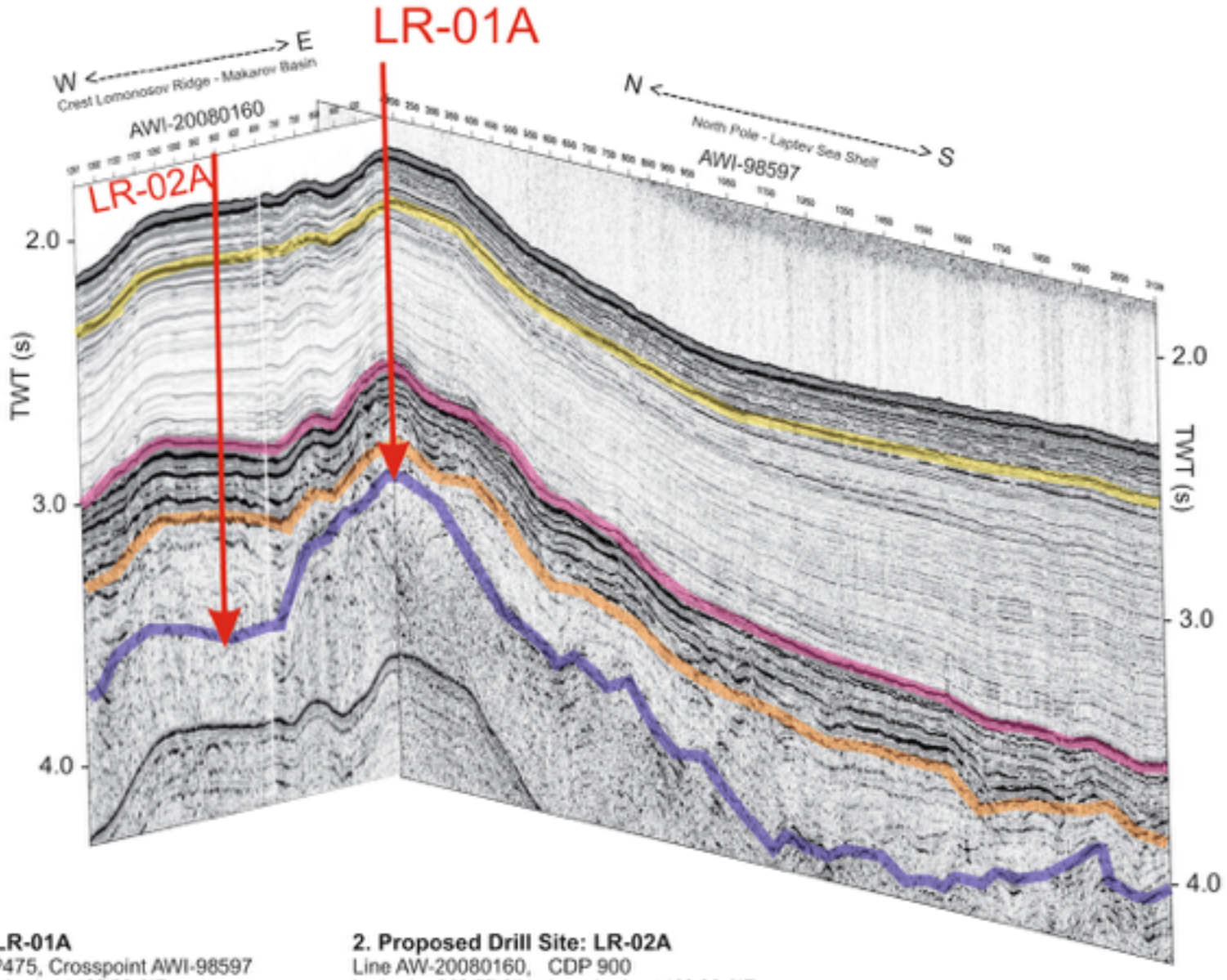
SSDB locations of these graphics and supporting data:
-Location map: LORI-16_map.pdf
-Seismic figures: LORI-16A_AWI-98597.pdf
-SEGY data: AWI-98597stack.sgy
-Navigation data: 98597_cdplocs.asc


First evidence for the establishment of an offshore winter sea-ice regime in the Arctic Ocean
Partial or ephemeral
Full scale and permanent
Antarctic ice sheets and sea ice
+++ perennial sea ice
Arctic Ocean sea ice
Northern Hemisphere ice sheets
Early Eocene Climatic Optimum
ETM2
PETM (ETM1)
Mid-Eocene Climatic Optimum
Mid-Miocene Climatic Optimum
δ18O (‰)
Ice-free temperature (°C)
Icehouse
Greenhouse
Pleistocene
Hiatus in the ACEX record
Plio-cene
Miocene
Oligocene
Eocene
Palaeocene
Age (millions of years ago)
47 Ma
Studied time interval of ACEX record



IBCAO Map
(Jakobsson et al., 2008)

(http://iup.physik.uni-bremen.de)

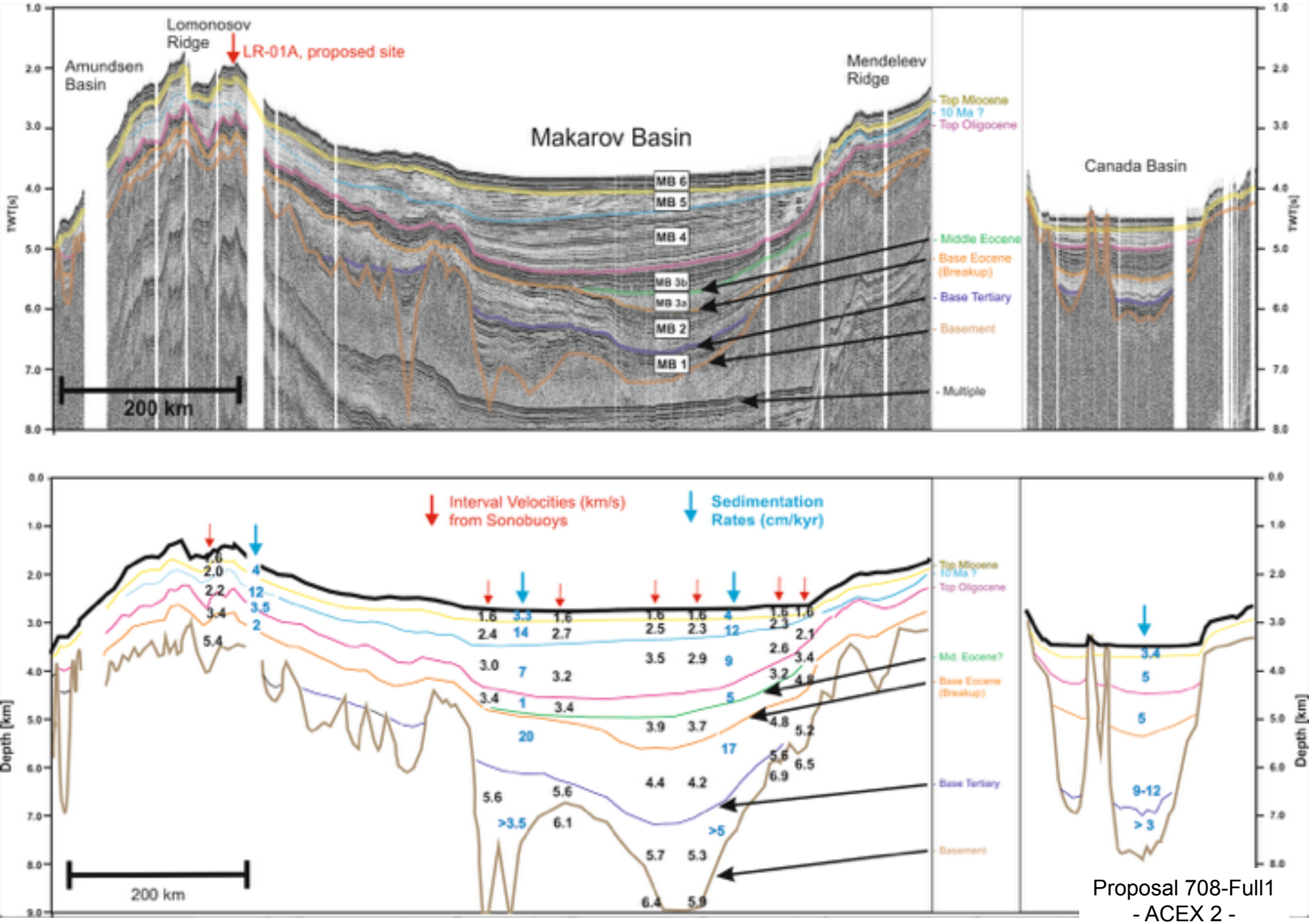


1. Proposed Drill Site: LR-01A
Line AW-20080160, CDP475, Crosspoint AWI-98597
Latitude: 80° 57.01'N Longitude: 142° 58.3'E

Depth (m)	Depth (mbsf)	Horizon
1405	0	--- Seafloor
1580	175	--- Top Miocene (5.3 Ma)
2240	835	--- Top Oligocene/Early Miocene
2546	1141	--- Lower Eocene
2630	1225	--- Acoustic Basement

2. Proposed Drill Site: LR-02A
Line AW-20080160, CDP 900
Latitude: 80° 57.9'N Longitude: 142° 28.3'E

Depth (m)	Depth (mbsf)	Horizon
1450	0	--- Seafloor
1670	220	--- Top Miocene (5.3 Ma)
2415	965	--- Top Oligocene/Early Miocene
2720	1270	--- Lower Eocene
3600	2150	--- Acoustic Basement



Proposal 708-Full1
- ACEX 2 -