HLY0503 CRUISE REPORT

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CORING AND SEAICE SEDIMENTS

INTRODUCTION

Background

The Healy-Oden Trans Arctic Expedition 2005 (HOTRAX'05) expedition grew from a suggestion of the Swedish Polar Research Secretariat (SPRS) of a joint crossing of the central Arctic Ocean between Swedish icebreaker Oden and USCGC Healy. SPRS organized the Beringia 2005 Research Program near the Bering Straits in July and early August and the Oden/Healy crossing comprised the third leg of this undertaking. A group of marine geologists lead by Dr. Martin Jakobsson, Stockholm University, formerly at the University of New Hampshire, approached several marine geologists and geophysicists from the U.S. about the joint ship operation and the opportunity to mount a long overdue coring and acoustical profiling cruise across the central Arctic. The last (and the only US-organized) expedition 11 years ago was not able to obtained high-resolution acoustic data from the central Arctic Ocean, but did retrieve 14 piston sediment cores (Arctic Ocean Section, AOS'94). The recent discoveries of high resolution sediment records along the Alaskan and Chukchi Sea shelf edge and slope generated excitement within the paleoceanographic community about the possibility of obtaining more and longer (older) records with high sedimentation rates (more than a few cm/kyr). This expedition was motivated by these discoveries and the deduction from studies in the Eurasian Basin and Lomonosov Ridge area that the established stratigraphy in the central Arctic Ocean might be in error in some areas and that the rates determined from this older stratigraphic model might be too low by nearly an order of magnitude. Except for two cores collected just offshore of Barrow, Alaska, there had not been any new material collected by US researchers since 1994 and the need for longer cores and fresh sediment material had grown acute. Also the recent discovery of ice gouging as deep as nearly 1,000 meters along parts of the Lomonosov Ridge, probably of Marine Isotope Stage 6 (MIS 6) age and in the Chukchi Borderland area inferred to be MIS 2 raised an urgent need for multibeam mapping of these features in the latter area and dating of the gouges requiring sediment cores. Subsequently, several proposals were submitted to Arctic Natural Science of the Office of Polar Programs in NSF and thus began the planning and execution of HOTRAX'05.

Once funding was secured, the initial planning meeting for coordination of the two ships during HOTRAX took place onboard Healy in Seattle at the Coast Guard station (October, 2004). The project leader of the Swedish side, Anders Karqvist from the SPRS and Jim Swift from Scripps Institution, one of the Principal Investigators (PI) represented the physical oceanographic projects onboard Oden and Dennis Darby and Bernard Coakley, co-Chief Scientists for the Healy represented the coring and geophysics projects respectively, at this meeting. The coring program was also funded for an initial two week cruise that was requested to be immediately before the trans-Arctic crossing with Oden but was pushed to an earlier time slot in mid June because of a scheduling conflict with a NOAA sponsored cruise that needed to go farther north into the Canada Basin than the early coring cruise headed by D. Darby. A separate planning meeting for this earlier coring cruise was held over one-half day just before the annual AGU meeting in San Francisco (December, 2004). A follow-up meeting for the trans-Arctic crossing part of HOTRAX was scheduled aboard Oden in Luleå, Sweden and then a day later at Stockholm University (February, 2005). Here the track line for the joint crossing was discussed and preliminary agreements on this and initial discussion of many issues concerning joint operations of the ships and science stations took place. Because the Healy would begin work in the central Arctic in the area of the Chukchi Borderland and Mendeleev Ridge nearly three weeks prior to Oden and that the oceanographic program onboard the Oden planned to carry out a transect across the Canada Basin, a rendezvous date was agreed upon at 84°N 145 °W. Subsequent to this rendezvous location on the Alpha Ridge the ships would go together and planned to depart the North Pole no later than September 12 in order to avoid the onset of refreeze and adverse winter conditions. The decision to have the science party board Healy in Dutch Harbor instead of Barrow was also made at this last meeting in order save some ship time by avoiding the necessity to travel east to Barrow and then backtrack west to the beginning of the ship track line for science operations.

Early in 2005, several additional projects were added to the HOTRAX'05 expedition in order to take advantage of this unique opportunity for a trans-Arctic cruise. These included the NSF funded sea ice program, headed by Don Perovich and two foreign-funded projects on sea ice and oceanographic properties using deployed buoys. These included Kazu Tateyama's underway ice profiler project and Takashi Kikuchi's buoy deployment project, both JAMTEC affiliated.

Goals

The coring and sea ice studies have the following overall scientific goals as detailed in the individual project proposals:

1. Establish a pan-Arctic Quaternary chrono-stratigraphy across the entire Arctic Ocean.
2. Determine a paleoclimate record from key areas across the Arctic Ocean, such as the Beaufort Slope, Chukchi Borderland, the Mendeleev and Apha Ridge complex, the Lomonosov Ridge, the Gakkel Ridge, and the Yermak Plateau.

3. Investigate the glacial erosion on the Chukchi Borderland (Northwind Ridge and Chukchi Plateau) in order to better constrain the age and processes involved in these events.
4. Determine the source, extent, and mineral-grain daylight-exposure ages of dirty ice in the central Arctic.
5. Improve the database for sea ice properties across the central Arctic.
6. Map in collaboration with the oceanographers onboard the Oden an area of the central Lomonosov Ridge where deep-water exchange may take place between the Amundsen and Makarov basins.

Objectives

In order to achieve the above goals, the following objectives were established by the individual projects and coordinated during the cruise:

A) Collect cores from key locations across the Arctic for chrono-stratigraphic and paleoclimate studies. These locations include 1) potential high sedimentation areas or drifts and 2) areas where earlier cores were taken and used to construct the existing chrono-stratigraphic model in the Arctic. These cores will be studied to develop a pan-Arctic stratigraphy in order to test the two alternative existing chrono-stratigraphic models (Clark et al., 1989; Jakobsson et al., 2000), implying very slow deposition (~ 0.1 cm/kyr) versus the moderately fast accumulation (1-2 cm/kyr). Paleoclimate studies will investigate the history of climate change suggested by the sequential sedimentary patterns in the central Arctic Ocean cores. In addition, the higher resolution continental shelf/slope cores can be used to construct detailed climate change in the local areas such as north of Alaska including the history of sea ice rafting and thus atmospheric pressure changes over the Holocene.

B) Map the seafloor with multibeam swath technology in order to determine the geologic context of the cores and to better understand modern and past processes affecting the seafloor.

C) Obtain chirp sonar sub-bottom profiles along the ship's track in order to determine the thickness and nature of the sediments for optimum core locations and for seismo-stratigraphic correlations. This includes the location of possible drift deposits and erosional surfaces.

D) Collect dirty sea ice samples where possible in order to determine the source of the sediment and thus the net ice drift, as well mineral-grain daylight-exposure ages.

E) Perform detailed measurements on the sea ice thickness and physical properties at sites across the HOTRAX transect as the opportunity arises.

F) Profile the sea ice thickness underway in order to collect a more or less continuous transects.

G) Deploy one or more ice buoys to monitor ice conditions over several seasons.

ACKNOWLEDGEMENTS

Captain Dan Oliver, the officers and crew of the USCGC Healy are acknowledged for their facilitation of the cruise goals and for their expertise in accomplishing all tasks that the science required. In particular, we express our appreciation to Captain Dan Oliver, Executive Officer Jeffery Jackson, Operations Officer James Dalitsch, Engineering Officer John Reeves, Senior Chief Navigator Timothy Sullivan, and all of the helmsmen that negotiated some rather difficult ice conditions. A special thanks goes to the marine science technician (MST) crew lead by Chief Don Snider and consisting of Dan Gaona, Rob Olmstead, Erick Rocklage, Josh Robinson, and Chad Klinestekaer. LtJG Jessica Noel was instrumental in overseeing the MST crew and science operations and we are indebted to her for making the science operations a success. The aviation department led by Lt. Andrea Sacchetti played a key role in ice reconnaissance, ice photo surveys, and the collection of dirty ice samples as well as the deployment of various ice buoys. The entire shipboard science contingent is indebted to Dave Forcucci for cruise planning and support.

The core technician, Dale Hubbard and the logistic help from the University of Oregon (Nick Pisias) provided excellent support, resulting in the recovery of quality piston core material totaling nearly 300 meters (HLY0503 alone), plus multicores for the upper half meter and trigger cores.

The Office of Polar Programs, Arctic Division at NSF and the USCG supported the research. We are particularly grateful for the logistic support added to the project by Simon Stephensen and William Weisman at the Office of Polar Programs, NSF.

We also thank Captain Tomas Årnell and crew onboard the Oden for contributing to make our collaboration program between the two icebreakers a great success. In particular we like to thank pilot Sven Stenval for providing his superb expertise in flying helicopter ice reconnaissance for both ships during difficult Arctic conditions. The Swedish Polar Secretariat is greatly acknowledged for their effort in collaborating with us, in particular we thank expedition leader Anders Karlqvist.

Cruise Participants

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Leonid Polyak	Ohio State University	Scientist/Project P
Yngve Kristoffersen	University of Bergen	Scientist/Project P
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John Hopper	Texas A&M University	Scientist/Project P
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Paul Henkart	Scripps Institution of Oceanography	Scientist/Seismic data processin
Don Perovich	US Army Cold Regions Research Lab (CRREL)	Scientist/Ice Program P
Tom Grenfell	University of Washington	Scientist/Ice Program Co-P
Takashi Kikuchi	JAMSTEC	Scientist/Project PI: Ice Drift Buo Progran
Kazu Tateyama	Kitami Institute of Technology, Hokkaido	Scientist/Project PI: EM Ice Thicknes Profile
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Captain Germain Tremblay	Canadian Coast Guard, retired	Ice Navigatio
Bruce Elder	CRREL	Ice Program technicia
Jeremy Harbeck	University of Washington	Ice Program technicia
Hedda Breien	University of Oslo, Norway	Grad Student/ Journalist/G& Watchstande
Beth Haley	LGL Ltd	Marine Mammal Observe
Howie Goldstein	Lamont-Doherty Earth Observatory	Marine Mammal Observe
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Dale Hubbard	Oregon State University	Coring Technicia
Steve Roberts	LDEO, Columbia Univ.	Underway Data Acquisitio
Will Handley	LDEO, Columbia Univ.	Underway Data Acquisitio
Doug White	Hawaii Mapping Research Group	underway multi-beam processin
Walter Luis Reynoso-Peralta	Argentinean Navy/Univ. of New Hampshire	underway multi-beam processin

Åsa Lövenvald Stockholm write

CRUISE TRACK

The most fundamental component of any oceanographic research cruise is the ship track. While everyone involved in the planning of this expedition knew that the final ship's track would be determined by ice conditions, mechanical problems, medical emergencies, and available time, only one coring site was missed, and this Gakkel Ridge site was replaced by an alternative site on this ridge. Ice conditions did play a role in suspension of towed seismic operations in several locations, namely the Alpha Ridge area prior to the rendezvous of the two icebreakers (Fig. 1), the Markarov Basin and the Marvin Spur (missed completely due to the need to deviate south and skirt very heavy ice in this area), and the Gakkel Ridge area due to heavy ice and time limitations. Overall, the planned ship's track (Fig. 2) was not very different from the actual ship's track due to the unusually light ice conditions encountered during the initial three weeks of operations and the joint operations of the two icebreakers thereafter.

Recommendations

Future geologic and/or geophysical expeditions will benefit by scheduling them during the lightest ice months (mid-August to mid-September) as was done in this expedition. Coring operations can be accomplished by the Healy in even heavy ice conditions, but with more time allotted for opening ice areas on the starboard side for coring and ship positioning once the core site is selected. Heavy ice conditions mean that the multibeam swath mapping data are poor to non-existent and the chirp 3.5 kHz profiling data are of dubious quality and also sometimes non-existent due to ice under the transducers. This then requires more cores to insure that coring objectives are fulfilled. The ship's drift in the ice pack cannot be controlled and often exceeds more than a few tens of a knot. This drift rate requires the near impossible task of positioning

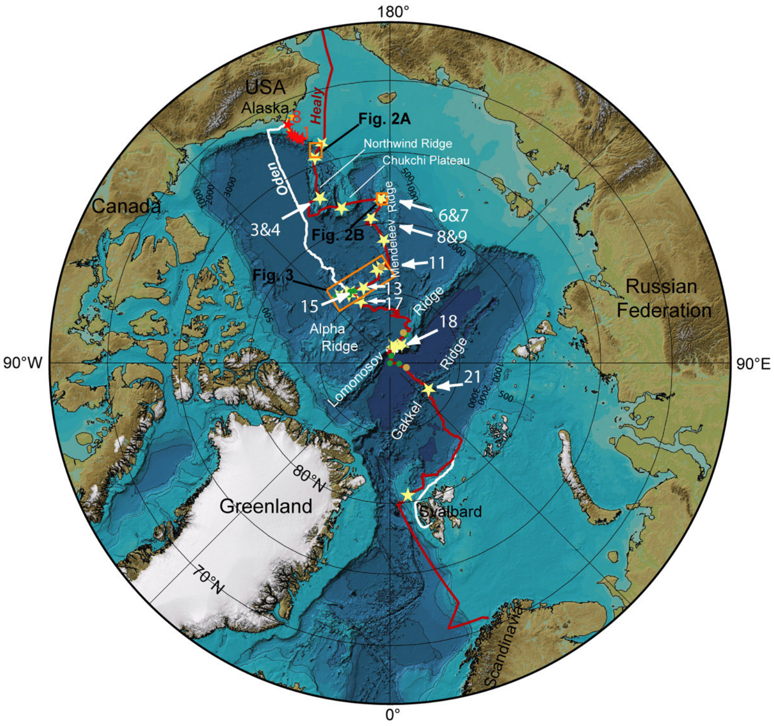

Figure 1a. Actual HOTRAX cruise track for USCGC Healy (red). Oden's cruise track is white. Light yellow stars (white core numbers) indicate core sites from HLY0503, red stars (red core numbers) from HLY0501 in June. Green dots are sea ice sample stations. Locations of examples of chirp sonar profile in Fig. 2a,b and correlation of cores using magnetic susceptibility in Fig. 15 are outlined in tan.

the ship up-drift the exact amount to insure that the core site is hit when the core is deployed and finally reaches the bottom. While this is not a problem when the core site is larger than several hundred meters, it does require a guess as to the time required to prepare the core for deployment because much of this must be done after the ship is stopped on site and cannot be moved until the core is retrieved. Ship maneuvering time during set-up and the efficiency of the ship's crew in deploying the coring device is often unknown entities. Frequently, the location most suitable for set-up and the occurrence of some open-water, are not ideally located to account for the ship's drift in the ice or wind over a potential core site. Also, because of the frequent turn-over of Coast Guard personnel, particularly the marine science techs (MSTs), this efficiency factor and thus time for core deployment improves dramatically during the first few coring stations. This should be taken into account in the core program planning and more time than normally required should be allocated for coring operations, especially if heavy ice conditions are expected.

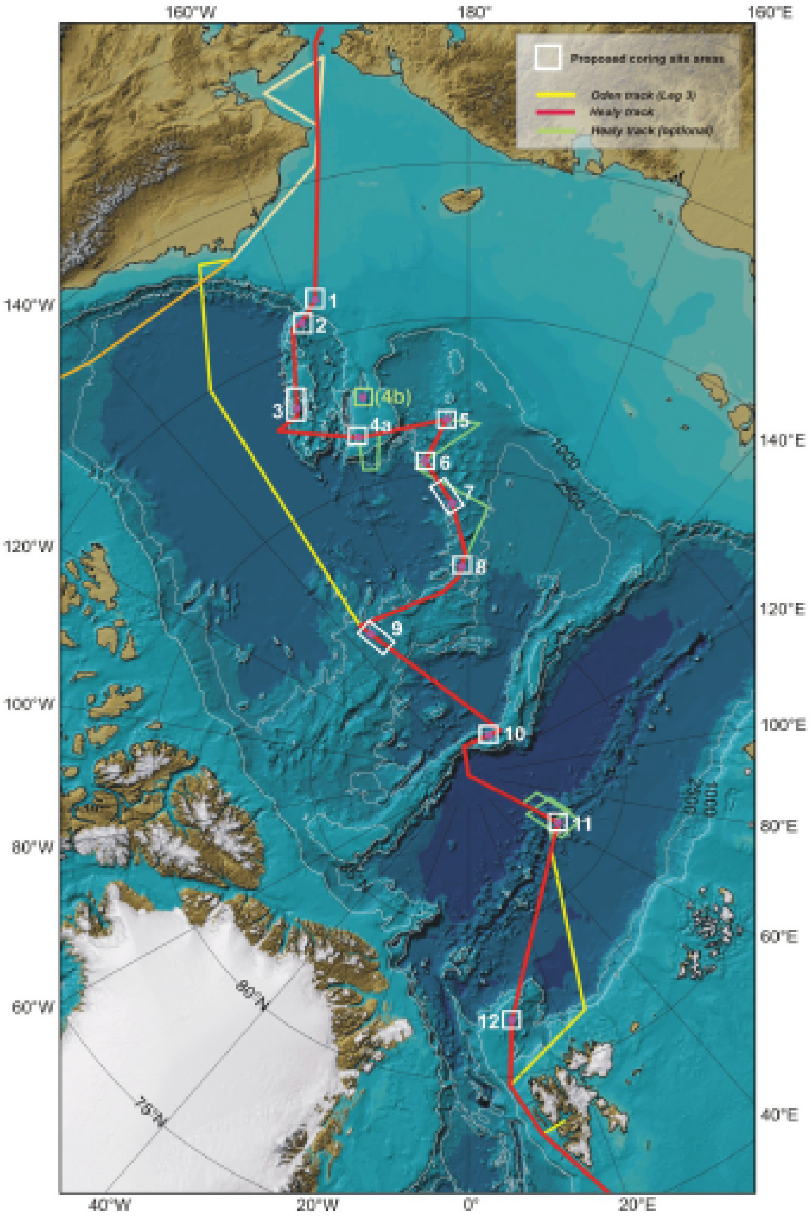

Figure 1b. Planned HOTRAX ships' tracks for USCGC Healy (red) and Swedish icebreaker, Oden (yellow) with white rectangles indicating potential core areas. In some cases multiple core sites were planned within one rectangular core area. Alternate ship's track for seismic operations and core stations for Healy are indicated by green. Ice conditions or time limitations precluded the addition of alternative survey or core sites.

GEOLOGICAL SETTING

UNDERWAY SAMPLING AND SURVEYS

Chirp sonar sub bottom profiling

The USGCS Healy has a Knudsen 320B/R dual frequency echo sounder (~3.5 kHz and 12 kHz). Only the low frequency channel was used during the HLY0503 cruise since the sonar's main function was to produce sub bottom information and not optimal bathymetry (Fig. 2a,b). Continuous bathymetry was acquired with the ship's Seabeam *2112* multibeam and since this system operates at 12 kHz, it may experience some interference if the Knudsen's 12kHz channel is used simultaneously.

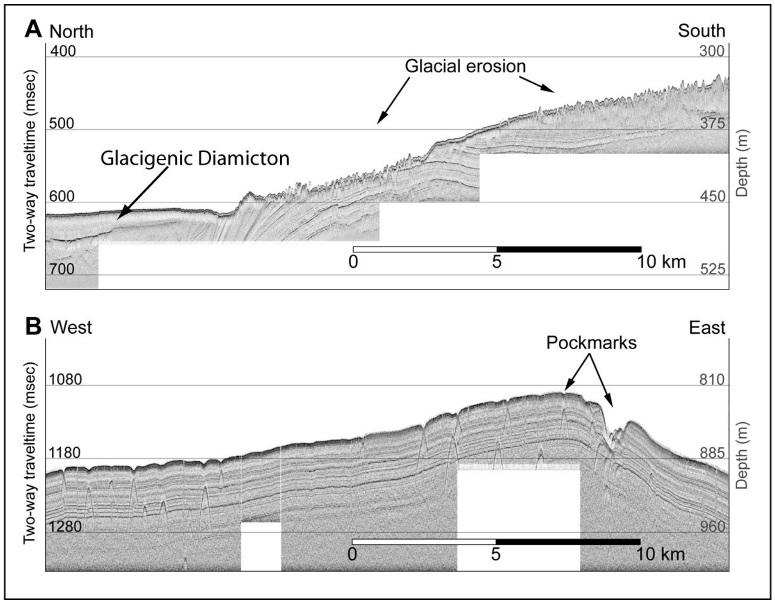

Figure 2a,b. Examples of Healy's Knudsen chirp sonar (center frequency 3.5 kHz) records showing glacial erosion and diamictons on the Northwind Ridge (A) and pockmark collapse structures on the Mendeleev Ridge (B). Area of profiles shown in Figure 1.

The Knudsen system is capable of producing chirp pulses with lengths of 3, 6, 12 or 24 ms of which the two latter pulse lengths were used during the cruise. The low frequency chirp mode sweeps from 3-6 kHz (center is 4.5 kHz) and the high frequency sweeps from 10.5-13.5 kHz (center is 12 kHz). The recorded echoed pulse is correlated (matched filtered) and compressed using a digital correlation filter. The correlations from the match filtering are recorded to SEG-Y files and the envelopes of the traces are recorded to Knudsen's format (**filename.keb**).

Knudsen control "autophase" automatically adjusts the acoustic sampling window's size (depth range) and its location (phase). However, there were two main factors that soon were found to greatly affect the performance of the automatic control of the sampling window during the HLY0503 cruise: 1) The depth variations of the surveyed sections of the Arctic Ocean are on the order of thousands of meters; 2) The heavy ice breaking frequently caused large disturbances of the recorded chirp signal and even occasional complete data loss. These two factors could cause the autophase function to fail and every time this happens the Knudsen acquisition system creates a new SEG-Y file. For this reason, the system was continuously monitored during the entire cruise and the acquisition window's size and phase was instead adjusted manually for optimal performance. However, on occasions during the 56 day-long cruise the acoustic sampling window setting was not properly monitored, which resulted in some data loss. On these occasions, the window was commonly set to high above the seafloor resulting in some sub bottom data loss.

Multibeam bathymetry

USCGC Healy is equipped with a 12 kHz Seabeam 2112 multibeam bathymetric sonar. It has 151 beams and produces a swath with of about 2.5 – 3.5 times the water depth. Multibeam bathymetry was collected continuously during the HLY0503 cruise with minor interruptions due to acquisition software problems that will be explained further below (Fig. 3). However, the ice

conditions greatly affected the quality of the acquired bathymetric data. During heavy ice breaking noise and possibly also ice gliding underneath the hull of the ship occasionally caused complete data loss.

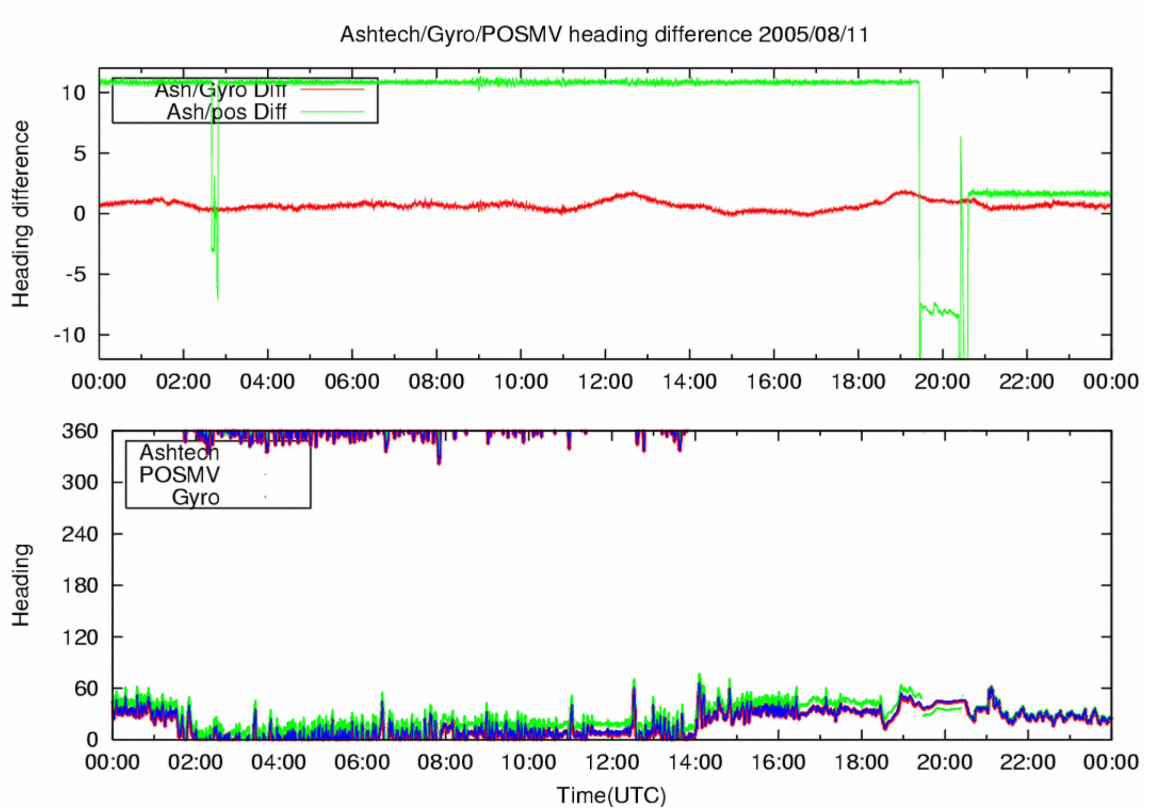

Figure 3. Comparison between Ashtech, Gyro, and POS-MV heading on August 11, 2005. A 10° offset was discovered and this problem was adjusted through a survey calibration on August 11 UTC 20:00.

Sound speed profiles of the water column for calibration of the Seabeam system were acquired at least once a day throughout the cruise. During the initial phase over the shallow Chukchi Sea, XBTs (Sippican XBT-5 and Sparton XBT-7) were launched once a day. Subsequently XCTDs (Tsurumi-Seiki's XCTD-1) that are capable of retrieving a sound speed profile of the upper 1100 m of the water column were used regularly (at least once every coring station). The CTD stations included in the scientific program were in addition used to calibrate the multibeam for sound speed variations. After the rendezvous with icebreaker Oden their comprehensive oceanographic program including regular CTD casts provided sound speed profiles on a regular basis.

The installed Applanix POS-MV provided position and heading information to the Seabeam system. A comparison between the heading from the POS-MV and Healy's Ashtech GPS revealed a constant offset of about 10° (Fig. 3). This problem was adjusted through a survey calibration on August 11 UTC 20:00. After the calibration, the offset was reduced to generally less than 2° and remained stable throughout the cruise. Most probably the POS-MV was in error but this has not been confirmed. This problem was not discovered before the 10th of August because the Ashtech GPS system was offline until this date.

A second problem with the Seabeam multibeam acquisition appeared at the North Pole. A recent software update had never been tested in geographic locations with three digit meridians and after the North Pole crossing the acquisition system crashed and no data could be acquired. The reason for the crash was an incompatibility between the software and the NMEA string; the software expected a leading zero to the 2-digits longitudes. This caused system failure and acquisition software crash. This incompatibility was fixed through consultation with shore support and the system was back in operation after a few days.

7. Shipboard data processing and archiving

Chirp sonar data

The Knudsen sub-bottom profiling data were post processed using two primary software packages: *Sioseis* (http://sioseis.ucsd.edu) and SonarWeb by Chesapeake Technology. All collected data stored in Knudsen's format (.keb) were initially processed with SonarWeb. The software output reports in html format including images of the sub bottom profiles. These html-reports were linked to an Access database configured for the GIS software Geomedia Professional (see GIS section for further details). This provided a good quick spatial overview of the acquired data and its quality. Time Varied Gain (TVG) was applied using SonarWeb to some of the profiles. Selected profiles over areas of interest were subsequently thoroughly processed using the routines available in Sioseis. In this case the correlations stored in SEG-Y format were used. The processing in Sioseis can be summarized in the following steps:

1. Envelopes of the traces (correlates) were computed through standard signal processing procedures (e.g., Sheriff and Geldart, 1999). These consist of three main steps:

    1.1. The time domain amplitude traces *a (t)* were converted to frequency domain using a Fast Fourier Transform (FFT).
    1.2. An analytic time domain trace was formed through an inverse FFT and the resulting time domain trace consists of an interleaving of the input trace and the Hilbert transformed (90° phase shifted) trace: $c\ (t) = a\ (t) + ib\ (t)$, where *c (t)* is a complex trace of *a (t),* the input trace, and *b (t)* is the phase shifted trace.
    1.3. The envelope, or instantaneous amplitude, was finally formed by a modulus of the complex trace: $a(i) = \sqrt{(a(2i-1)^2 + a(2i)^2)}$, where *a (i)* is the trace.
2. A gain function was applied.
3. Plotting the envelopes as gray scale images.

Details of how the above processing steps can be implemented using *Sioseis* may be found at: http://sioseis.ucsd.edu.

Experiments of using Time Varied Gain (TVG) instead of AGC were carried out and Figure 4 shows comparative gray scale plots between the two types of gain. The TVG was stared from the bottom reflection by first converting the data from time to depth domain using a flat sound velocity of 1500 m/s. Figure 5 also shows a comparison plot of the raw correlations without forming an envelope.

Multibeam bathymetry

Underway processing of the Seabeam 2112 data were done with the software, MB Systems and Caris HIPS and Sips in parallel. The MB system allows filtering and maps to be made quickly using command line batch routines. These products were useful for underway planning and data analysis.

A further more detailed processing was carried out using Caris. Due to the high latitudes of the surveys all data were processed with a Polar Stereographic projection setup. Caris provides a pre-defined Universal Polar Stereographic projection (True scale: 81°:06.871' N; Longitude of origin: 0°; Latitude of origin: 90°N; False Easting 2x10^6 m; False Northing: 2x10^6 m). However, export from Caris HIPS of the produced grids on this projection proved that the

Figure 4. Knutsen 3.5 kHz sub-bottom profile showing two-way travel time and distance as ship time along the long axis. A. Unprocessed data. B.

system generated erroneous projected coordinates. On the other hand, the software worked with its own projection setup internally and geographic coordinates could be exported successfully.

The cleaned multibeam bathymetry soundings were compiled into digital terrain models (DTM) with a Polar Stereographic projection and grid-cell resolutions that range from 25 to 100 m depending on the water depth. In general, on the ridge crests the resolution of the DTMs are 25 to 50 m, which allow features with spatial dimensions larger than between ~50 to 100 m to be resolved. The final visualization of the multibeam was done using Fledermaus by Interactive visualization System (IVS).

Chirp sonar sub bottom profiles

The chirp sonar sub bottom profiling along the track over the Northwind Ridge and Chukchi Plateau, together forming the Chukchi Borderland, resulted in collection of high quality data due to light to moderate ice conditions (Fig. 4). The ice was mainly first year in these areas and large sections with open leads prevailed. Ice conditions continued to be light along the HLY0503 cruise track along the Mendeleev Ridge, but became more difficult over the Alpha Ridge.

Jumbo Piston Coring (JPC)

Piston coring during both HLY0501 and HLY0503 was conducted using a system designed by Jim Broda (Woods Hole Oceanographic Institute) with components from both this and the Oregon State University coring equipment. During HLY0501 the 4,000 lb core weight was used exclusively but during HLY0503, the adjustable Oregon State University core head weight (bomb) was used. This allowed for greater weight for penetrating the stiffer central Arctic Ocean sediments. The JPC system consisted of 10 ft. (~3 m) pipe sections with couplers connecting each section (Fig. 5). The maximum feasible core length that can be safely rigged on Healy is 22 m and this requires extrusion of the core liner largely over the ship's rail at the end of the pipe. The maximum core length rigged during HLY0503 was 18m due to the cold weather, necessitating rapid removal of the PVC liner and the stiffness of the central Arctic Ocean sediments due to the high IRD content. Sub-bottom chirp data were used to determine the probable stiffness of the bottom sediments along with the experience of the senior cruise scientists in dealing with the sediments from each area cored.

Figure 5. Jumbo Piston Core deployed from the starboard “A-frame” showing the 2 ton weight and the first 3 meter segment of 10 cm diameter core barrel below. The trigger arm extends out from above the weight and holds the 3 meter-long (10 cm diam.) trigger (gravity) core , not shown below the water surface. Also shown is the hero platform, extending out from the deck adjacent to the core weight bucket (out-of-view).

The primary difficulty in coring central Arctic Ocean sediments from the ridges is the layers of high IRD, which adds tremendously to the sediment strength. The IRD can be of any size and thus there was always the danger of striking a clast equal or larger than the 10 cm core pipe. This occurred only once, for HLY0503-JPC21, resulting in a bent core barrel. The core was reduced from 18 m to 15 m rigged length prior to deployment because of the chirp data and the potential for large IRD. The layer encountered at 3 m depth below the sea floor (dbsf) contained unusually large clasts for the Gakkel Ridge area and it is likely that damage would have occurred even if the core were rigged for 12 m. The only other bent core barrel occurred on HLY0501 in June when the ship drifted rapidly off station during deployment and into much deeper water where bottom currents had winnowed the bottom and a muddy sand layer occurred for the first 2 m dbsf. Other than these bent core barrels (4 damaged sections in total), the only other problem occurred on the first core taken in HLY0501 when a coupler connecting two core barrel sections failed. This failure was determined to be due to a previous use where the core struck the bottom rather hard and the impact caused the set screws holding the coupler to the barrel lengths to elongate the holes in the barrel section where the set screws fit. These setscrews do not thread into the barrel, only into the coupler. When the hole became elongated, the nipple of the set screw no longer fit snuggly into the barrel hole and probably pulled-out when the core was pulled-out of the seafloor. Fortunately, the failed coupler was located above the retrieval line attachment so this held the lower sections from detaching completely and falling to the seafloor as the core was hauled up. When the core was being hoisted out of the water by this retrieval line, the barrel separated at the failed coupler and shortly thereafter, the PVC liner bent and then severed in two. This left two halves of the core over the ship’s side, one attached to the retrieval line, the other attached to the core head weight, which was secured in the weight basket. After some difficulty, both halves were hoisted onboard and secured with amazingly only about 1.5 m of core sediment being lost overboard.

One recurring problem in coring was the presence of water gaps in the core. Usually, these occurred near the bottom of the core in longer cores consisting of less stiff sediment overlying stiffer sediment near the bottom. Often, the gaps occurred above the sediment/water interface. This is usually due to failure of the core barrel to achieve maximum penetration, but several times the mud on the core barrel indicated penetration of 3-4 meters greater than the sediment recovered in the barrel. While we did not have time to experiment at any one site with different scope lengths, we did begin to keep close track of the penetration depth as indicated by the thick mud on the barrel outside. Combined with the scope used we were able to reduce the water gap between the piston and sediment by increasing the scope. However, it is unclear as to whether this solution worked or it was just coincidence that the water gap above the piston was less on this one core because the next core in a different location had about the same water gap as earlier cores. Thus, we consistently achieved about 2-4 meters greater penetration than core material.

Overall, the core recovery was better than most previous coring expeditions in the Arctic, especially the central ridge areas. We were able to consistently recover cores of better than 10 meters length where previous cores from the same general vicinity were mostly less than 5 meters. A total of 29 JPC cores and 27 multicores were obtained across the entire Arctic Basin including both the HLY0501 and HLY0503 cruises and over a ship track line distance of more than 4,000 nautical miles (Table 1). The actual length of sediment in each core segment differs somewhat from the liner length or the logged (Multisensor Core Logger) lengths due to gaps, some filled with Styrofoam tubing. Due to these differences, the lengths of each are listed in Table 2.

Recommendations

Due to the failure of the core barrel couplers, the set screws should be tapped all the way into the core barrel to prevent such failures in the future. After the failure, all core barrel sections used during HOTRAX were visually inspected for over-size holes in the core barrel due to previous impacts. This inspection seemed beneficial, although this is not a solution that promises to preclude future failures of the coupling between core barrel sections.

The problem of water gaps at the top of the core and 3-4 meters less sediment than penetration indicated might be resolved with some planned experimentation in Arctic sediments. When possible this should be done at the same location so that each change in scope length or other core parameters might be noted with the resulting core recovery from the one location.

Table 1. List of Jumbo Piston Cores (JPC) and Trigger Cores (TC) taken during HLY0503 including section lengths. Location, water depth, ice and wind conditions as well as details of the core rig are also provided.

JPC number	02JPC	03JPC	04JPC
Date	10-Aug-05	12-Aug-05	13-Aug-05
Location	Northwind Rdge	Northwind Rdge	Northwind Rdge
Latitude	74° 29.547' N	77° 14.698' N	77° 13.121' N
Longitude	159° 53.386' W	157° 03.602' W	157° 02.912' W
Water Depth (m)	627	594	520
Ice Condition	7/10	8/10	8/10

Temp./Wind Condition		0℃/4kts	1.5℃/12kts	3℃/6kts
Rigged Length (ft)		50	40	40
Scope Length (ft)		22	22	22
Head Wt (lbs)		3500	3500	4700
TC Line Length (ft)		62	52	52
TC Weight (lbs)		480	480	480
TC Section Lengths (cm)	1	86	82	124
	2	78		
TC Total Length (m)		1.64	0.82	1.24
JPC Section Lengths (cm)	1	69	57	41
	2	152	151	150
	3	148	153	152
	4	101	152	151
	5	77	100	131
	6	149	54	
	7	138		
	8			
	9			
	10			
	11			
	12			
JPC Total Length (m)		8.34	6.67	6.25
JPC number		05JPC	06JPC	07JPC
Date		16-Aug-05	18-Aug-05	19-Aug-05
Location		Chukchi Plateau	Mendeleev Ridge	Mendeleev Ridge
Latitude		78° 26.435’ N	78° 17.629’ N	78° 17.923’ N
Longitude		162° 40.944’ W	176° 59.169’ W	176° 52.592’ W
Water Depth (m)		660	800	802
Ice Condition		8/10	8/10	8/10
Temp./Wind Condition		0℃/11kts	1.5℃/8kts	0.5°C/calm
Rigged Length (ft)		40	50	60
Scope Length (ft)		22	22	22
Head Wt (lbs)		4700	4700	5300
TC Line Length (ft)		52	62	72
TC Weight (lbs)		480	480	480
TC Section Lengths (cm)	1	85	88	116
	2	87	107	81
TC Total Length (m)		1.72	1.95	1.97
JPC Section Lengths (cm)	1	142	98	68
	2	152	153	150
	3	150	155	153

	4	142	144	78
	5		152	86
	6		65	145
	7		149	151
	8		155	151
	9		139	111
	10			48
	11			49
	12			141
JPC Total Length (m)		5.86	12.10	13.31
JPC number		08JPC	09JPC	10JPC
Date		20-Aug-05	21-Aug-05	22-Aug-05
Location		Mendeleev Ridge	Mendeleev Ridge	Mendeleev Ridge
Latitude		79° 35.565’ N	79° 35.605’ N	81° 13.563’ N
Longitude		172° 30.095’ W	172° 27.663’ W	177° 11.610’ W
Water Depth (m)		2792	2783	1865
Ice Condition		9/10	8/10	9/10
Temp./Wind Condition		-0.5°C/calm	0°C/calm	-0.5°C/8kts
Rigged Length (ft)		50	70	60
Scope Length (ft)		24	25	24
Head Wt (lbs)		5300	6000	5900
TC Line Length (ft)		62	82	72
TC Weight (lbs)		480	500	540
TC Section Lengths (cm)	1	113	106	123
	2	117	107	108
TC Total Length (m)		2.30	2.13	2.31
JPC Section Lengths (cm)	1	63	126	91
	2	151	159	147
	3	149	154	150
	4	143	151	153
	5	152	150	152
	6	154	150	153
	7	151	146	82
	8	157	152	36
	9	68	133	151
	10		73	157
	11		146	
JPC Total Length (m)		11.88	15.40	12.72
JPC number		11JPC	12JPC	13JPC
Date		25-Aug-05	26-Aug-05	28-Aug-05

Location		Alpha Ridge	Alpha Ridge	Alpha Ridge
Latitude		83° 08.615’ N	83° 17.465’ N	84° 18.337’ N
Longitude		174° 32.231’ W	171° 57.464’ W	160° 40.753’ W
Water Depth (m)		2644	1585	1400
Ice Condition		10/10	10/10	10/10
Temp./Wind Condition		0°C/20kts	-1°C/11kts	-2°C/15kts
Rigged Length (ft)		50	50	50
Scope Length (ft)		25	23	23
Head Wt (lbs)		6000	5900	5900
TC Line Length (ft)		62	62	62
TC Weight (lbs)		540	540	540
TC Section Lengths (cm)	1	108	80	92
	2	99	113	83
TC Total Length (m)		2.07	1.93	1.75
JPC Section Lengths (cm)	1	114	115	65
	2	152	150	151
	3	153	152	152
	4	154	152	144
	5	149	152	153
	6	151	144	149
	7	146	25	153
	8		151	149
	9		145	84
	10			
JPC Total Length (m)		10.19	11.86	12.00

JPC number		14JPC	15JPC	16JPC
Date		29-Aug-05	30-Aug-05	31-Aug-05
Location		Alpha Ridge	Alpha Ridge	Alpha Ridge
Latitude		84º 18.196’ N	83º 57.014’ N	84º 10.142’ N
Longitude		149º 02.041’ W	143º 10.967’ W	150º 54.494’ W
Water Depth (m)		1856	2047	2506
Ice Condition		10/10	9/10	10/10
Temp./Wind Condition		-1°C/12kts	-3ºC/10kts	-3ºC/10kts
Rigged Length (ft)		50	50	50
Scope Length (ft)		24	24	25
Head Wt (lbs)		5900	5900	5900
TC Line Length (ft)		62	62	62
TC Weight (lbs)		540	540	540
TC Section Lengths (cm)	1	93	99	95
	2	100	93	108
TC Total Length (m)		1.93	1.92	2.03

JPC Section Lengths (cm)	1	88	25	66
	2	149	153	151
	3	148	151	149
	4	154	150	157
	5	152	151	149
	6	150	152	151
	7	151	150	135
	8	141	142	
	9			
	10			
JPC Total Length (m)		11.33	10.74	9.58
JPC number		17JPC	18JPC	19JPC
Date		2-Sep-05	9-Sep-05	10-Sep-05
Location		Alpha Ridge	Lomonosov	Lomonosov
Latitude		85º 07.631’ N	88º 27.029’ N	88º 42.904’ N
Longitude		154º 46.703’ W	146º 33.652’ E	169º 47.139’ E
Water Depth (m)		1741	2598	1023
Ice Condition		9/10	8/10	8/10
Temp./Wind Condition		-5.5ºC/calm	-8ºC/13kts	-2ºC/16kts
Rigged Length (ft)		50	60	60
Scope Length (ft)		27	26	24
Head Wt (lbs)		5900	5900	5900
TC Line Length (ft)		62	72	72
TC Weight (lbs)		540	540	540
TC Section Lengths (cm)	1	135	114	146
	2	55	73	
TC Total Length (m)		1.90	1.87	1.46
JPC Section Lengths (cm)	1	65	57	141
	2	145	77*	141
	3	153	67*	156
	4	152	152	152
	5	150	150	151
	6	153	151	138
	7	153	149	66
	8	114	148	124
	9	127	153	
	10		151	
JPC Total Length (m)		12.12	12.55	10.69

* These sections were spilled onto deck and recovered into split liners with 3.5cm from the top of section 2 placed into two end caps spliced together.

JPC number		20JPC	21JPC	22JPC
Date		10-Sep-05	18-Sep-05	26-Sep-05
Location		Lomonosov	Gakkel Ridge	Yermak Plat
Latitude		88º 48.358’ N	86º 39.739’ N	80º 29.386’ N
Longitude		163º 34.777’ E	055º 42.994’ E	007º 46.141’ E
Water Depth (m)		2654		798
Ice Condition		8/10	9/10	10/10
Temp./Wind Condition		0.5ºC/17kts	-4ºC/25kts	-11.5ºC/calm
Rigged Length (ft)		60	50	50
Scope Length (ft)		26	24	22
Head Wt (lbs)		5900	5900	5900
TC Line Length (ft)		72	62	62
TC Weight (lbs)		540	540	540
TC Section Lengths (cm)	1	94	22	77
	2	101	110	77
TC Total Length (m)		1.95	1.32	1.54
JPC Section Lengths (cm)	1	148	97	134
	2	152	111	149
	3	149	143	149
	4	139		155
	5	18		150
	6	145		152
	7	153		141
	8	154		153
	9			148
	10			
JPC Total Length (m)		10.58	3.51	13.31

Table 2. Lengths of JPC and TC segments (liner, logged length, and actual measured sediment).

HLY0503 - # JPC		02JPC			03JPC		
Length Measured		Liner	MST	Sediment	Liner	MST	Sediment
TC Section Lengths (cm)	1	88.9	87.6	86	84.4	83.6	82
	2	84.3	83.0	78			
TC Total Length (m)		1.73	1.71	1.64	0.84	0.84	0.82
JPC Section Lengths (cm)	1	80.2	77.6	69	62.0	61.6	57
	2	151.3	151.2	152	150.4	149.0	151
	3	148.3	147.2	148	152.8	152.2	153

	4	108.8	107.2	101	151.1	151.0	152
	5	73.4	72.2	77	149.4	147.8	100
	6	149.7	148.4	149	69.6	70.2	54
	7	150.3	149.2	138			
JPC Total Length (m)		8.62	8.53	8.34	7.35	7.32	6.67

HLY0503 - # JPC		04JPC			05JPC		
Length Measured		Liner	MST	Sediment	Liner	MST	Sediment
TC Section Lengths (cm)	1	123.7	122.6	123	92.2	90.6	85
	2				89.1	87.6	87
TC Total Length (m)		1.24	1.23	1.23	1.81	1.78	1.72
JPC Section Lengths (cm)	1	149.7	40.6	41	142.4	140.6	142
	2	149.0	148.0	150	151.0	150.2	152
	3	153.0	151.6	152	151.3	149.2	150
	4	151.8	149.8	151	150.8	149.4	142
	5	136.6	135.2	131			
JPC Total Length (m)		7.40	6.25	6.25	5.96	5.89	5.86

HLY0503 - # JPC		06JPC			07JPC		
Length Measured		Liner	MST	Sediment	Liner	MST	Sediment
TC Section Lengths (cm)	1	88.8	86.6	88	115.8	113.6	116
	2	113.8	112.2	107	98.3	93.4	81
TC Total Length (m)		2.03	1.99	1.95	2.14	2.07	1.97
JPC Section Lengths (cm)	1	98.3	96.6	98	101.2	99.6	68
	2	152.8	152.2	153	149.9	148.8	150
	3	155.3	154.2	155	153.3	151.4	153
	4	145.0	143.6	144	77.6	77.4	78
	5	152.3	151.0	152	85.4	84.0	86
	6	152.5	150.6	65	145.1	144.2	145
	7	149.3	147.2	149	151.2	150.2	151
	8	155.6	153.8	155	154.6	152.8	151
	9	146.8	145.4	139	150.7	149.8	111

	10				74.0	72.4	48
	11				59.2	57.4	49
	12				150.3	149.4	141
JPC Total Length (m)		13.08	12.95	12.10	14.53	14.37	13.31

HLY0503 - # JPC		08JPC			09JPC		
Length Measured		Liner	MST	Sediment	Liner	MST	Sediment
TC Section Lengths (cm)	1	111.9	111.6	113	117.9	116.6	106
	2	125.3	124.0	117	112.0	110.0	107
TC Total Length (m)		2.37	2.36	2.30	2.30	2.27	2.13
JPC Section Lengths (cm)	1	63.1	60.6	63	152.0	150.6	126
	2	151.8	149.6	151	152.0	152.6	159
	3	149.2	148.4	149	153.5	152.4	154
	4	143.7	142.0	143	150.5	148.2	151
	5	151.7	151.2	152	149.8	149.2	150
	6	155.9	154.8	154	151.0	149.0	150
	7	148.7	148.6	151	147.5	146.2	146
	8	157.1	156.8	157	151.9	150.6	152
	9	146.3	144.8	68	151.4	150.8	133
	10				81.6	80.2	73
	11				150.3	149.4	146
JPC Total Length (m)		12.68	12.57	11.88	15.92	15.79	15.40

HLY0503 - # JPC		10JPC			11JPC		
Length Measured		Liner	MST	Sediment	Liner	MST	Sediment
TC Section Lengths (cm)	1	123.2	121.6	123	107.7	105.6	108
	2	113.2	112.4	108	102.6	101.2	99
TC Total Length (m)		2.36	2.34	2.31	2.10	2.07	2.07
JPC Section Lengths (cm)	1	91.8	89.6	91	114.3	112.6	114
	2	146.6	145.4	147	151.6	151.2	152
	3	149.0	149.0	150	151.8	151.6	153
	4	153.4	151.8	153	151.6	151.0	154

	5	152.7	151.6	152	148.3	147.8	149
	6	152.0	151	153	149.8	148.8	151
	7	82.6	81.2	82	153.4	153.8	146
	8	37.3	35.6	36			
	9	150.8	149.2	151			
	10	159.6	157.2	157			
JPC Total Length (m)		12.76	12.62	12.72	10.21	10.17	10.19
HLY0503 - # JPC		12JPC			13JPC		
Length Measured		Liner	MST	Sediment	Liner	MST	Sediment
TC Section Lengths (cm)	1	100.1	98.6	80	115.3	113.6	92
	2	80.6	79.0	113	87.8	86.4	83
TC Total Length (m)		1.81	1.78	1.93	2.03	2.00	1.75
JPC Section Lengths (cm)	1	117.0	115.6	115	74.6	72.6	65
	2	150.4	149.6	150	151.7	149.4	151
	3	151.4	151.4	152	153.0	152.0	152
	4	151.1	151.0	152	144.0	142.8	144
	5	152.4	151.8	152	153.3	151.6	153
	6	150.7	148.8	144	149.4	147.6	149
	7	32.7	32.2	25	154.1	151.4	153
	8	151.2	150.0	151	148.9	147.6	149
	9	152.8	152.2	145	146.0	146	84
JPC Total Length (m)		12.10	12.03	11.86	12.75	12.61	12.00
HLY0503 - # JPC		14JPC			15JPC		
Length Measured		Liner	MST	Sediment	Liner	MST	Sediment
TC Section Lengths (cm)	1	97.6	95.6	93	103.0	100.6	99
	2	99.6	98.0	100	96.5	95.2	93
TC Total Length (m)		1.97	1.94	1.93	2.00	1.96	1.92
JPC Section Lengths (cm)	1	102.5	100.6	88	33.5	32.6	25
	2	149.5	147.0	149	152.8	149.8	153
	3	147.7	146.2	148	151.8	149.4	151
	4	153.7	152.2	154	150.0	148.2	150
	5	152.1	150.4	152	151.3	149.6	151

	6	150.4	149.4	150	152.2	150.4	152
	7	151.0	149.4	151	150.8	149.0	150
	8	149.1	148.4	141	142.1	140.6	142
JPC Total Length (m)		11.56	11.44	11.33	10.85	10.70	10.74
HLY0503 - # JPC		16JPC			17JPC		
Length Measured		Liner	MST	Sediment	Liner	MST	Sediment
TC Section Lengths (cm)	1	94.9	93.6	95	153.8	149.6	135
	2	107.2	105.8	108	57.4	54.8	55
TC Total Length (m)		2.02	1.99	2.03	2.11	2.04	1.90
JPC Section Lengths (cm)	1	76.2	73.6	66	71.7	70.6	65
	2	151.3	148.8	151	145.5	143.8	145
	3	149.1	148.4	149	152.0	150.6	153
	4	156.4	155.0	157	152.0	150.8	152
	5	148.8	148.2	149	149.9	148.6	150
	6	150.9	149.8	151	153.0	151.2	153
	7	135.0	133.6	135	152.7	152.2	153
	8				151.8	149.8	114
	9				129.0	126.4	127
TC Total Length (m)		9.68	9.57	9.58	12.58	12.44	12.12
HLY0503 - # JPC		18JPC			19JPC		
Length Measured		Liner	MST	Sediment	Liner	MST	Sediment
TC Section Lengths (cm)	1	117.8	116.6	114	148.0	146.6	146
	2	78.9	78.0	73			
TC Total Length (m)		1.97	1.95	1.87	1.48	1.47	1.46
JPC Section Lengths (cm)	1	67.1	64.6	57	151.8	150.6	141
	2*	68.1	67.4	77	140.8	140.0	141
	3*	77.3	76.8	67	155.7	156.8	156
	4	152.6	152.0	152	151.9	151.2	152
	5	149.5	149.2	150	150.7	149.6	151
	6	150.5	150.0	151	140.0	138.8	138
	7	148.5	147.8	149	66.3	64.8	66
	8	148.5	147.8	148	128.3	127.6	124

	9	152.2	151.8	153			
	10	150.3	150.2	151			
JPC Total Length (m)		12.65	12.58	12.55	10.86	10.79	10.69

* These sections were spilled onto deck and recovered into split liners with a small section of 3.5cm from the top of section 2 placed into two end caps spliced together.

HLY0503 - # JPC		20JPC			21JPC		
Length Measured		Liner	MST	Sediment	Liner	MST	Sediment
TC Section Lengths (cm)	1	100.6	99.6	94	21.2	19.6	22
	2	101.2	99.8	101	108.8	107.4	110
TC Total Length (m)		2.02	1.99	1.95	1.30	1.27	1.32
JPC Section Lengths (cm)	1	148.6	147.6	148	108.9	106.6	97
	2	151.0	148.8	152	109.9	108.6	111
	3	149.7	149.4	149	143.0	142.8	143
	4	138.2	136.8	139			
	5	24.3	23.4	19			
	6	153.5	152.0	145			
	7	152.3	151.4	153			
	8	153.0	151.6	153			
JPC Total Length (m)		10.71	10.61	10.58	3.62	3.58	3.51

HLY0503 - # JPC		22JPC		
Length Measured		Liner	MST	Sediment
TC Section Lengths (cm)	1			114
	2			77
TC Total Length (m)		0.00	0.00	1.91
JPC Section Lengths (cm)	1	134.2		134
	2	149.6		149
	3	147.6		149
	4	155.6		155
	5	149.6		150
	6	152.3		152
	7	140.2		141

	8	152.8		153
		148.6		148
JPC Total Length (m)		13.31	0.00	13.31

Multi-Coring

To guarantee recovery of an intact sediment-water interface, Multi-coring was conducted. This also provided a large quantity of such sediment for use by different researchers. The particular multi-corer (MC) used was the 8-tube model produced by Ocean Instruments, Inc (Fig. 6). (USA), and owned by Oregon State University. In practice, unlike on leg-1 (cruise HLY0501), the bottom sediment encountered on leg-2 (HLY0503) was stiffer, so that even the trigger core generally recovered good sediment-water-interface material. However, one consequence of this increased stiffness was that we had to use nearly maximum-capacity Pb weights. Maximum capacity is 600 lbs, consisting of equally distributed (between two off-center stacks) 25-lb Pb bricks. Because of freezing temperatures encountered frequently on leg-2, we had to insert ca. 6-cm bushings beneath one of these stacks to permit manual access to a socket-nut drain plug beneath the central ‘compression’ pipe. On down casts this normally contains air which, being compressible, acts as a hydraulic cushion when the weight-stack mechanism is triggered to initiate penetration. Water will drain (slowly) from this pipe when on deck after MC recovery. However, this water can freeze before draining and thus prevent the designed compression function being performed and lead to a failure in penetration, as happened on leg-2 at station 13. Consequently, with the bushings in place, we were limited to a maximum weight stack of 500 lbs on leg-2, with concomitant shorter recovered lengths of core than might otherwise have been possible. Another limitation was a probable obstruction at station 13 of the protruding corners (on one side of the stack) of some of

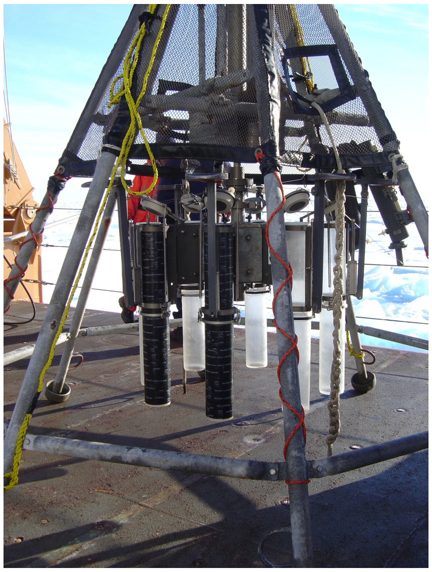

Figure 6. Multicorer rigged for deployment on the aft deck of Healy. The black-taped tubes are for light-sensitive cores for possible use in luminescence dating.

the Pb bricks. Thereafter, their corners were filed to roundness, but this geometric limitation needs monitoring on each cruise. In any case, the number of 25-lb Pb bricks was monitored and adjusted (if needed) at each station depending upon the observed penetration of the same-station trigger core. Generally at each station, multi-coring took place after the JPC/TC operation.

Each multi-core tube is fabricated of a special, non-brittle, transparent plastic ca. 70 cm long and ca. 10 cm in diameter. For both leg-2 and leg-1, tubes 3 and 4 were wrapped in adhesive Al tape then a protective layer of 10-mil thick black PVC 'pipe-wrap' tape. The Al tape ensures complete opaqueness, necessary for recovery of the maximum possible quantity of useful sediment for later luminescence studies. The Ocean Instruments' multi-corer requires extrusion vertically upward of the tube contents via an air-powered, gear-driven, worm shaft supporting a Teflon piston having consecutive neoprene gaskets around its circumference to ensure no significant loss of sediment during extrusion into tubes for transport. Extrusion of tubes 3 and 4 was into wrapped (thus opaque), inexpensive plastic tubes of equal diameter to the MC tubes. The contact between the MC tube and the plastic tube was secured and kept relatively light tight by the use of a metal band clamp. In future operations for luminescence sampling, probably a metal band with an integral inner, deformable band of neoprene rubber would provide optimum light blockage along the contact.

A useful procedure that we followed (after the initial part of the cruise) before any extrusion was to measure the pre-extrusion sediment lengths (of the transparent tubes; Table 3), and then to cut the pre-split (and sealed) empty extrude tubes to lengths only somewhat (2-5 cm) longer than the average measured sediment lengths. Thus a shorter length of closed-cell foam plug is needed at the top of each capped extrude tube, and later shipping requires less space. Of course, while on board all MC tubes were stored vertically in a cooler, maintained somewhat above freezing temperature (by a few degrees). Before off-loading, such vertical MC tubes were inspected, and additional closed-cell foam plugs were inserted to fill any new void space caused by compaction. This ensures minimum core disturbance during any subsequent shipment horizontally.

Extrusion of other MC tubes (1, 2, 5, 6, 7 and/or 8) was into transparent plastic tubes for transport (also of equal diameter to the tubes on the MC). All transport tubes (1-8) were pre-split, then sealed along the split with wide duct tape, prior to use as receptacles for the sediment. Such pre-splitting greatly facilitates later core splitting when the tubes are full of sediment. We note that only the highest quality (thickest, with best adhesive) duct tape should be used. Transport tubes 2 and 5 were logged by ^{137}Cs gamma-ray transmission (for density estimation) and for magnetic susceptibility on the GEOTEK Multi-sensor-track (MST) system. For each station, one or two MC tubes were split, described and photographed on board.

For MC tubes from HLY0501, MST scans were conducted as follows: tubes 2 & 4 from core 04MC; tubes 4 & 8 from each of 06MC and 07MC; and tubes 2 & 4 from 08MC. For tubes from HLY0503, MST scans were conducted as follows: tubes 2 & 6 from 01MC and 11MC; tubes 2 & 5 from 02MC, 03MC, 05MC, 06MC, 08MC, 10MC, 12MC, 14MC, 15MC, 16MC, 17MC, 18MC, 19MC, 20MC, and 22MC.

For MC tubes from HLY0501, the following were split and described on board by Leonid Polyak: tubes 2 & 4 from core 04MC; tube 8 from 06MC; tube 4 from 07MC; and tube 4 from 08MC. For MC tubes from HLY0503, the following were split and described: tube 6 from 01MC; tubes 2 & 5 from cores 02, 03, 05, 06, 08, 10, 12, 14, 15, 16, 17, 18, 19, and 20MC; tubes 2 & 6 from 11MC.

Table 3. HLY0503 Multicore locations, water depth and weights used as well as details of post-extrusion sediment lengths in each tube.

Station *	Water depth (m)	Latitude N	Longitude	Date	Pb Weight (lb)
01MC	189	73°42.378'	162°46.211'W	9.AUG.05	450
02MC	613	74°29.411'	159°52.331'W	10.AUG.05	450
03MC	583	77°14.847'	157°02.676'W	12.AUG.05	500
05MC	666	78°25.893'	162°40.294'W	16.AUG.05	500
06MC	794	78°17.494'	176°56.144'W	18.AUG.05	450
08MC	2791	79°35.653'	172°27.535'W	20.AUG.05	450
10MC	1841	81°13.696'	177°12.973'W	22.AUG.05	500
11MC	2570	83°07.730'	174°41.570'W	25.AUG.05	500
12MC	1586	83°17.797'	171°54.994'W	26.AUG.05	500
13MC	1378	84°18.603'	160°38.187'W	28.AUG.05	500
15MC	2100	83°57.242'	143°11.236'W	30.AUG.05	500
16MC	2495	84°10.112'	150°58.211'W	31.AUG.05	500
17MC	1726	85°07.759'	154°48.174'W	2.SEPT.05	500
18MC	2654	88°26.228'	146°40.989'E	9.SEP.05	500
19MC	1017	88°43.052'	170°05.437'E	10.SEPT.05	500
20MC	2652	88°48.743'	164°01.573'E	10.SEPT.05	500
21MC	2015	86°39.595'	056°56.207'E	18.SEPT.05	500
North Pole	4224	89°59.333'	158°01.305'E	12.SEPT.05	500

Station *	Post-extrusion capped-tube sediment length (cm)							
	Tube #1	Tube #2	Tube #3[a]	Tube #4[a]	Tube #5	Tube #6	Tube #7	Tube #8[b]
01MC	40	44.5	40.8	44.5	43.3	43	46	45.2
02MC	45.7	48.5	46.8	48.7	48.6	48.9	49.7	49.5
03MC	27.5	28.4	27.3	27.5	28.4	28.6	28.4	27.7
05MC	37.9	37	36.8	39	38.7	37.4	37	38.5
06MC	47.7	49.3	49.8	47.7	46.7	49.6	49	49.5
08MC	47.9	45.7	47.6	47.3	48.2	48.5	48.4	48.3
10MC	39.2	37.8	37.4	39	36	39.7	41.5	40.5
11MC	38	35.6	38.7	35.5	27.3 [c]	38.4	39.5	38.5
12MC	37.5	38	38.2	38.6	36.6	38	38.8	37.8
13MC	4.8	4.8	5.2	5.7	5.1	4	4.5	5.5 [d]
15MC	37.8	36.5	37.7	37	37.1	37.8	38.9	37.3
16MC	38.2	39.8	37.4	36	38.5	38	38.7	37.5
17MC	36.7 [e]	37.1	36.3	37.2	36.2	37.4	37.5	36.5
18MC	49.7	48.2	47.7	48.4	48.2	49.7	49.4	49.4

19MC	34.9	34.6	35.1	35	35.2	35.8	35.7	35.3
20MC	36.5[f]	32[f]	37.7	43	36.2	37.8	38.5	39.2
21MC	26.7	27	27.5	29.4	28.1	27.8	28.3	28.5
North Pole[g]	--	--	--	23.1	--	23	19.5	ca. 26

[*] This number equals the nearest JPC station number, and for some JPC stations no multi core was taken.

[a] Tubes 3 and 4 were opaque, and extruded cores were shipped to Berger's laboratory for later luminescence studies.

Station 1-- #3 for pore water, #7 for future slicing at GEOTOP: Station 2-- #7 sliced, #8 for pore water: Station 11-- #5 for pore water, #8 for future slicing:

Station 17-- #8 for future slicing: Stn 19-- #8 for future slicing; Station 20-- #7 sliced, #8 for pore water: Station North Pole-- #8 sliced.

[c] Lost ca. 8 cm from bottom while on deck because of incomplete closure of bottom baffle.

[d] In this tube (#8), there is a large void at ca. 2 cm depth, thus only 3-4 cm of mud was recovered. MC malfunction (compression tube not pre-drained) caused penetration problem.

[e] A 2x4 cm void occurred at 3-9 cm depth in this tube.

[f] Surface contaminated with a few small bits of plastic from saw cutting (before extrusion).

[g] Most tubes were used only for 'souvenir' mud for interested expedition members, but tubes 4, 5, 6 and 8 were saved. Tube #4 (black tube) was extruded for G. Berger's luminescence studies, tube #5 extruded for ODU, tube #7 extruded for scientists on the Oden, and tube #8 sliced for GEOTOP use.

SHIPBOARD CORE CURATION

The following labeling convention was used: **HLY050X – YY JPC – ZZ** where HLY = Ship (Healy); 05 = Year; 0X = HOTRAX '05 Leg (1 or 3); YY = Sampling Station Number; JPC = Device (JPC = Jumbo Piston Core, TC = Trigger Core, MC = Multicore); ZZ = Section Number. Details of the JPC and TC processing are provided here. Details regarding the multicore processing are provided elsewhere in this report.

Prior to deployment of the JPC, the core liner was numbered with Roman numerals (I, II, etc from the core bottom) and marked with a core orientation line. Upon extrusion, the core was cut into 1.5 m segments and rapidly transported inside to prevent freezing. Shorter segments were cut to accommodate water gaps and the final (top of core) length. On days of exceptional cold (< -9°C), the core was initially cut to 3 m lengths and moved inside prior to making the 1.5 m cut. Cuts were immediately packed with plastic foam rod if a gap existed, and capped. The cut sections were staged on racks in the lab. Renumbering from the top with Arabic numerals (1,2, etc) was done during logging.

Problems occurred with cores JPC 18 and 21. In addition, some minor water gaps were encountered in some of the early cores. The contents of JPC 18 – Sec 2 & 3 were spilled in the lab during cutting. The material was coherent and was mostly recovered by teasing it into a split liner. JPC 21 impacted a dense till-like layer at about 3.2 m, which halted penetration and bent the core barrel. Extrusion required extensive labor on the deck during windy cold (-10°C) conditions. It is likely the top section of core partially (or totally) froze; the lower sections and the trigger core were recovered and stowed inside quickly.

Following logging, splitting was performed with a rack-mounted circular saw. The saw cut-depth was set to a minimum to limit plastic-shred contamination of the sediment. A final cut using a box cutter usually was also required. All cuts of JPC samples were made along the pre-marked core orientation line. A 0.20 cm plastic trimmer cord was used to cut the sediment. The Archive half was scraped across the width of the core half with a large spatula (cake decorating spatula) to create a smooth surface, plastic depth markers inserted, and immediately wrapped in plastic and sealed in a D-tube. The Working half was similarly scraped, described, and photographed using a Nikon 12 MP digital camera and reflector lights for indoor photography. The split halves were wrapped and sealed in separate D-tubes as soon as possible to prevent drying.

All D-tubes, including the multicores, were packaged in cardboard boxes (5/box) and loaded into a refrigerated van (temperature range 4°C ± 4°C) for shipment. The cooling unit in the van was inoperative for the entire cruise, so heat lamps and a temperature sensor were installed and monitored to maintain proper temperature while onboard Healy. Repair was to be affected upon arrival in Tromso. Cores taken during leg 1 (HLY0501) in June were stored in the Science Lab Refrigerator set at 40°F until they were MSCL-logged during the first week of the leg 2 cruise, opened and described.

Photographic documentation of cores onboard Healy during Hotrax-05

Overview

In the general workflow of the shipboard core processing digital images were taken before the cores were packed into D-tubes for archiving. These pictures are to be used as “index cards” for the cores. The technical quality of the shipboard core photos does not permit any detailed measurements or color analysis to be made on the digital images. 1-6 sections are photographed at the same time. In case a core consisted of more than 6 sections, several pictures were taken and later brought together during post processing.

Equipment and settings

The camera used was a *Nikon D2X*, which has a DX 23.7x15.7 mm sized 12-bit sensor with 12.84 million pixels (4288x2848). The D2X was equipped with an AF-S Nikon 17-55mm 1:2.8 G ED lens. The camera settings used for the core photography are summarized in Table 4. The core sections were placed on a makeshift table with room for up to 6 sections (most often1-5). The camera was typically used handheld since the ships movements and vibrations prevented using the camera in a fixed position (Figs. 7 and 8). All images were recorded using Nikon’s compressed RAW (NEF) format. After post processing the final images were stored in *Adobe Photoshop* format. All images were taken using flash light. A *Profoto ProAcute 6 Alfa* unit provided power to two flash heads with attached bouncers. The flash heads were placed one at each side of the cores, approximately 1.5 m from the floor (Figure 8). To minimize reflection on the core surface the bouncers were used indirectly and aimed at the ceiling. In addition, for particularly wet cores a circular polarizing filter was used to reduce additional unwanted reflections.

Table 4. Camera settings applied for the shipboard core photography.

ISO	400
Aperture	11
Exposure time	1/125
White balance	Flash/A
Lens	~20mm*

* Varied depending on core section lengths and number of core sections to be photographed.

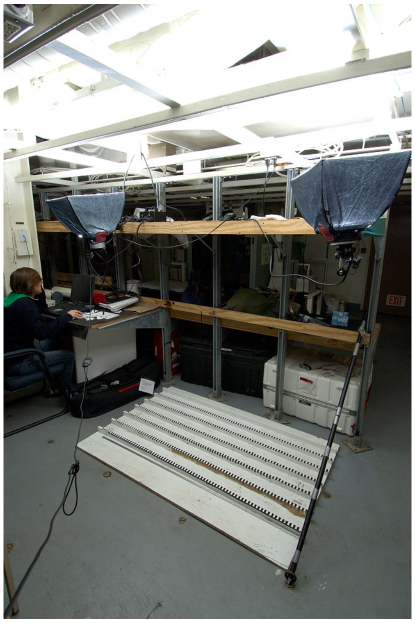

Figure 7. Shipboard core photography setup.

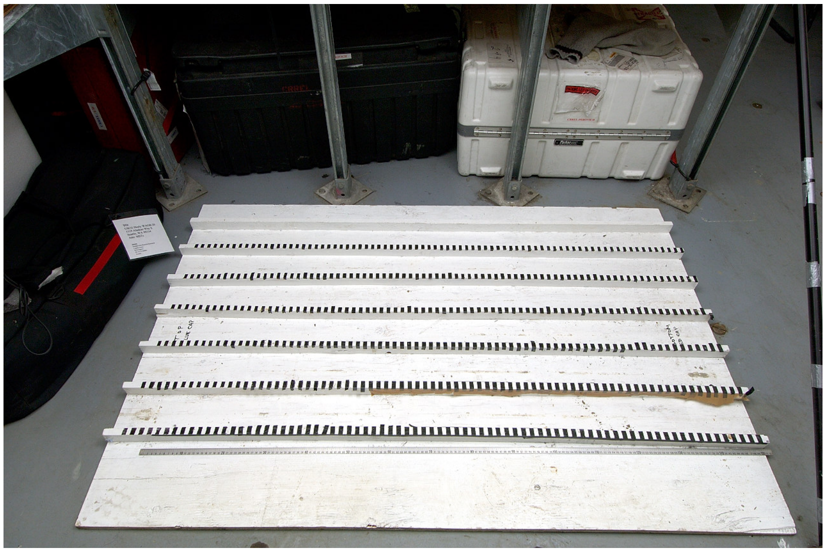

Figure 8. Manufactured photography table for placing core sections.

Post processing

The RAW files from the camera where opened in *Nikon View 6* and the automatic settings for contrast, low sharpening and in some cases white balance where applied. No other processing regarding exposure, contrast, color balance or sharpness was done beyond this point. The files were then exported as TIFF files and opened in *Adobe Photoshop* where they were resaved in Photoshop's own format. These files were then, if needed, corrected geometrically and oriented vertically. A montage of each core was then produced using Adobe Photoshop.

Problems

The low roof made the use of a short focal length necessary. This made it difficult to align the plane of the camera sensor with the plane of the table were the core sections where placed, thus introducing geometrical faults in the images. These faults could to a large extent be corrected in *Adobe Photoshop*. The short focal length also made lens distortion and in some cases spherical aberration apparent, especially towards the edge/corner of the image.

Multi Sensor Core Logging (MSCL)

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Methods

The GeoTek Multi sensor core logger (MSCL) from University of Stockholm was installed onboard USCGC Healy before departure from Dutch Harbor. The system was mounted in the Science Core Lab, and strapped to the deck to withstand movements of the ship. The MSCL was equipped with the following sensors/units; gamma-density (^{137}Cs source), core-diameter, p-wave transducers and the 125mm diameter whole core magnetic susceptibility (WCMS) loop for the MS2-unit. Temperature was measured with a PRT-probe (±0.1°C).Gamma-density integration time was set to 15 seconds, using the largest beam-aperture (5mm). WCMS was measured in SI-units and with Range 1.0 and the measurement interval was 1cm. Core caps from each 1.5 m long core segment were removed and thin 10.5 cm in diameter and approximately 1mm thick heavy duty plastic discs were fastened to the core-ends prior to logging. The MSCL successfully logged all cores retrieved during HOTRAX leg 1 (8 JPC cores), the HLY0503-leg (21 JPC cores) as well as 56 core tubes (20-50 cm in length) retrieved by the multi-corer from 28 sites (2 cores/site usually) during legs HLY0501 and HLY0503.

Calibration

Calibration of gamma-density, p-wave and core-diameter was performed every morning according to the procedures described in the instruction manual. The magnetic susceptibility (MS) instrument was set to make a zero reading when the core was 20cm away from the loop. During re-logging, diameter-calibration was not performed until core HLY0503-7TC

Data processing parameters

The following settings were used for processing the raw data:

- Sediment thickness: Liner outer diameter: 11.4 cm
    - Thickness of liner: 0.6 cm
- P-wave velocity: p wave off set (PTO) from calibration
- Temperature: 18°C, salinity: 35 ppt, depth 0 m
- Gamma density constants from calibration – no adjustment for density: A=1, B=0
- Butt error distance: 0.4 cm

Problems

Logging started immediately after departure from Dutch Harbor. During the first 3 days, the system stopped logging at random intervals. This was a nuisance, and even after extensive brainstorming, we did not locate any specific source interfering with the MSCL. After the fourth day the system stopped logging for no obvious reason once or twice a day. The core pusher sometimes failed to move two full-segment lengths of core sections due to the large friction. The rails were therefore covered with a thin layer of silicon every morning. The manual speed controller-knob was accidentally broken off when loading a core section. The knob was successfully glued in place, and an aluminum plate was mounted above the controller unit to prevent further accidents. The pusher sometimes got stuck at the right end of the track. This was because some of the cogs of the drive-belt did not pass smoothly when the pusher was in the right-end position. This problem was fixed with a knife.

The instrument worked with no apparent affect due to the shaking and vibration of the ship during ice breaking. Small ‘jumps’ on especially the diameter-log were observed. However, permanent variations in core-diameter sometimes occurred without any apparent relationship to the physical conditions around the instrument.

A simple test was performed in order to monitor the performance of the diameter-transducers. The results indicated that the left transducer did not work properly (Fig. 9). No action was taken, since we could not envisage any way to solve this problem.

After logging JPC12, it was discovered that the bolt for the left (front) transducer was no longer in place. The missing nut was immediately found on the floor, and mounted. The overall mechanical condition of the system was therefore inspected every day.

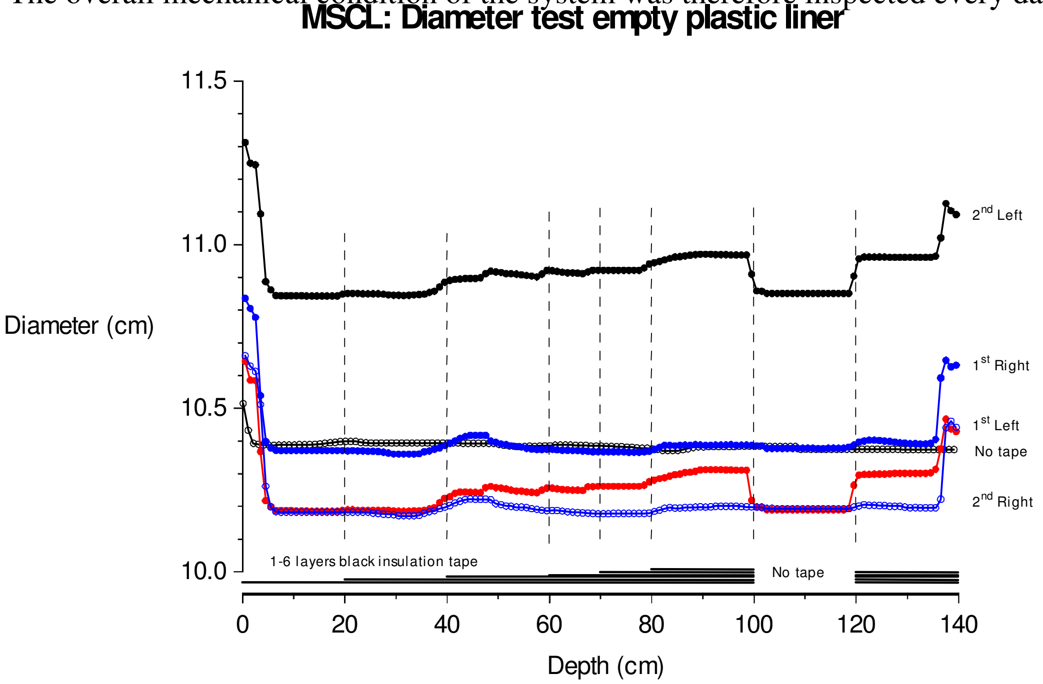


Figure 9. Results of the diameter-test. Black insulation tape was fastened along a 150cm long empty core-liner. The number of layers of tape is shown above the depth scale. A core-diameter test was run at every 1cm. It is evident that the left transducer (black and red lines) records thickness-variations more or less in accordance with the pattern of the insulation tape for the two runs. The right transducer (blue lines) shows good repeatability with respect to relative changes, but these are not in accordance with the left transducer. Also note the large spread in core-diameter. All measurements were performed within 1.5 hours. MS is in 10^{-5} SI

Test of repeatability

Distinct and permanent changes in diameter occurred during measurements of a number of cores. In order to determine if this was due it some random effects, or was systematic, a repeat-run was done on core HLY0503-12JPC (Fig. 10). This core was chosen because of a sharp and fairly large jump in diameter at around 6.7m. We wanted to find out if this ‘jump’ was repeatable, and 5 core sections were logged the next day.

- Diameter-variations along the core are definitely not reproduced.
- Gamma-density curves exhibit comparable features, but there is a systematic trend towards higher values for the second logging.
- MS is the only parameter that shows a fairly reasonable agreement between the two runs.
- During logging and re-logging of this core the front diameter transducers had probably loosened.

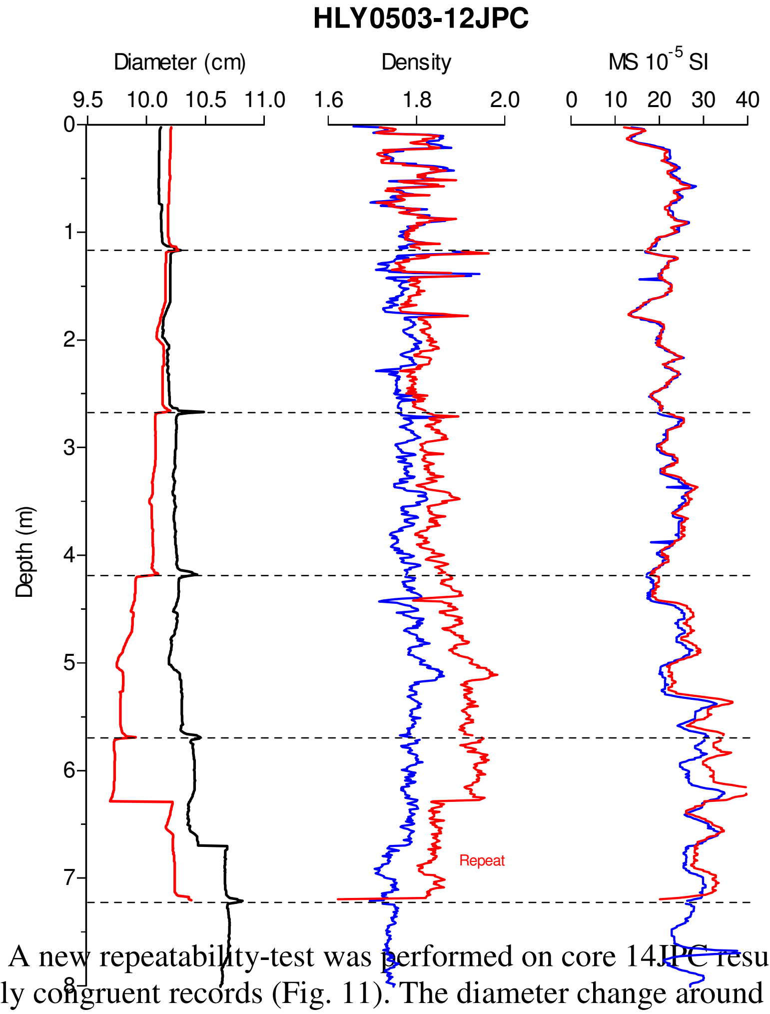


Figure 10. Results of repeatability-test performed on core 12JPC. Note that the Diameter-axis (left diagram) spans 1.5cm. First log-run in black and blue. Replicate log in red. Note the last section was not measured the second time. Horizontal, broken lines indicate core-section breaks. MS in 10^{-5} SI

A new repeatability-test was performed on core 14JPC resulting in almost perfectly congruent records (Fig. 11). The diameter change around 6.7m in the first run did not repeat itself in either depth or amplitude. During the second run, there was also a much larger permanent change in diameter occurring almost 0.5m higher up in the core. Diameter readings varied within 1mm, while density and MS-curves overlap more or less along the whole core. We have not identified any unique external source(s) for the origin of the sudden 'jumps' in diameter-readings. During the second test, the bolt of the front (left) diameter-transducer had been fastened with its nut. It should be noted, however, that the ship was vibrating significantly more intensely during the second test compared to the first test, suggesting that vibration is not the main cause of the observed jumps in diameter.

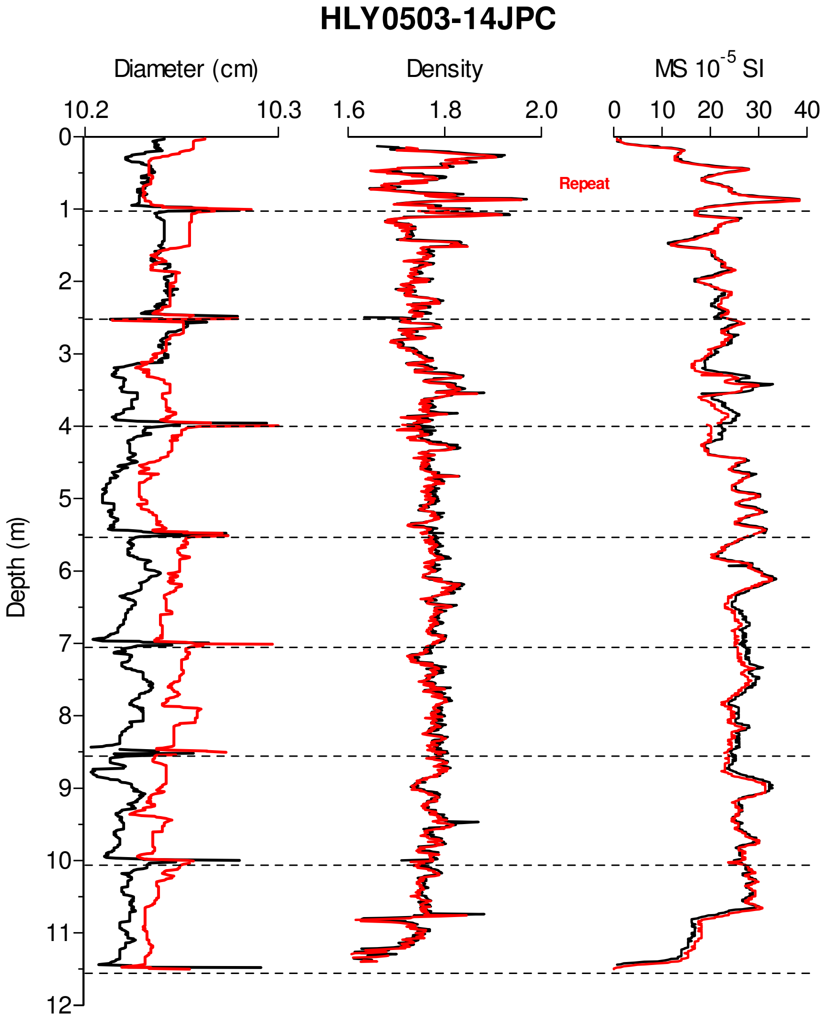


Figure 11. Results of second repeatability-test performed on core 14JPC. First log-run in black and blue. Replicate log is in red. Horizontal, broken lines indicate core-section breaks. MS in 10^{-5} SI.

P-wave velocity

Data from the p-wave travel-time unit fluctuated wildly. The core-liner and roller-sensors were kept wet by sprinkling water from a squirt bottle, but only occasionally did this really improve the data quality. The poor data quality is attributed to the sediment not always filling the core-liner completely. This was readily observed when changing the end-caps of the core sections. The inadequate sediment volume inside the liner probably results from stretching during core-retrieval, causing a permanent volume change of the sediment.

Density calibration

Density-calibration readings resulted in regression coefficients of the order of 0.99. However, the observed data points were systematically above the 'standard' line in the calibration plot. We did not pay much attention to this fact until the system was set up for measuring cores from the multi-corer. These cores have a slightly smaller diameter, and the gamma-density unit had to be lowered a bit. During this procedure, it was realized that the gamma-beam probably had not passed exactly through the center of the JPC-cores.

A simple procedure to find the correct position of the core-tube relative to the gamma ray is to measure the gamma-counts for the 6cm in diameter aluminum part of the standard, while systematically increasing (decreasing) the height of the gamma-unit. The correct position is associated with a minimum in gamma counts, implying maximum penetration length.

Gamma- *versus* volumetric densities

The density derived from the gamma-log must be calibrated by volumetric density determinations of the cores in questions. Volumetric densities were determined by retrieving sediment samples of a specific volume (19.8 and 6.0 cm^3). Volume samples were obtained by pressing thin-walled plastic cylinders into the cleaned surface of the working half of the cores after they had been split, photographed and described.

The volume of the sampler was determined by weighing it full of water. Weighing was done on a Mettler Toledo (PB1502-S) electronic balance (±0.01g). Weighing took place when the ship was not sailing. The sediment was extruded from the sampler into a 50ml beaker of glass after wet-weight was determined. The sediment was dried in air at 100°C overnight and re-measured for the dry weight. The sampling procedure not only removes material from the cores, it also deforms the sediment affecting the paleomagnetic signature at these levels. Therefore a minimum number (4 to 5) of density samples were collected from each core.

The gamma-density is systematically lower than the volume derived values (Fig. 12). The largest discrepancies are observed for the first set of measurements using a density-sample volume of 19.8 cm^3. Estimated errors in the volume-density determinations are:

Weight: ±0.01g
Volume: ±0.05cm^3

A conservative estimate of errors in volume density is of the order of 10% that is too small, however, to account for the significant discrepancy between the two density determinations. Another likely source of the large differences in densities may be erroneous diameter-values. In the calculation of the gamma-derived density, diameter enters the equation. However, even differences in diameter of 20% (i.e. 2cm, the largest observed diameter-difference) cannot account for the large density discrepancies.

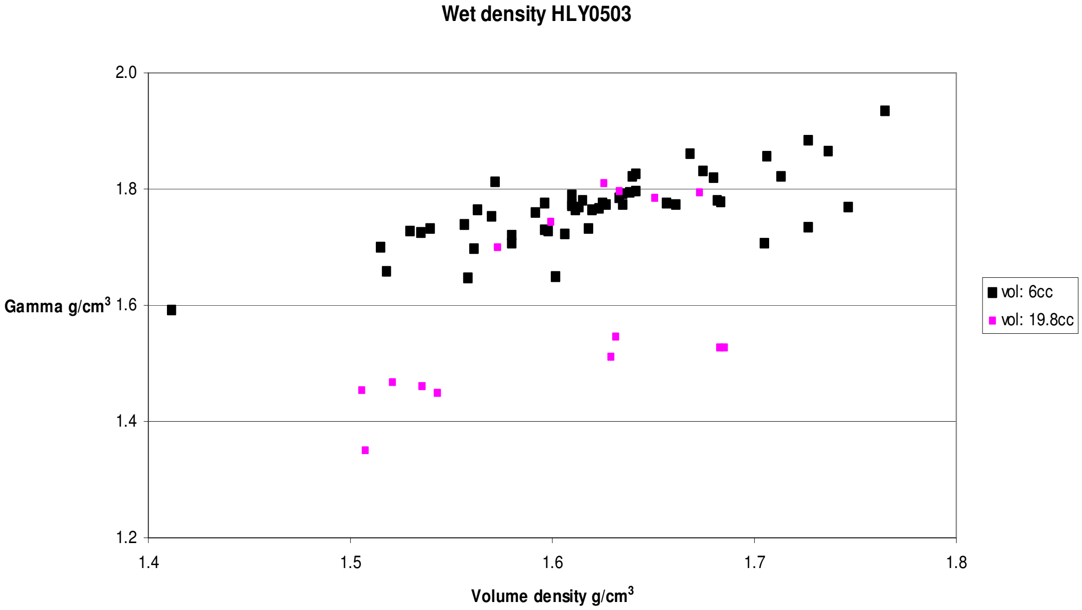


Figure 12. Scatter plot of Gamma and volume-derived wet densities for 13 HLY0503 cores (N=69).

MS-records of TWC and JPC

MS turned out to be the most reliable physical parameter obtained from the MSCL.

Since MS may be assumed to reflect variations in the overall composition of sediments, we have used MS to determine the stratigraphic agreement between the uppermost core-levels in corresponding JPC and TC. MS curves versus depth for 13 sets of HLY0503 cores are fairly consistent for a number of sites, implying that JPC-coring does not necessarily causes loss of the sediment/water interface (Fig. 13). This was also confirmed during dismantling and cutting of the cores. It is evident that JPC sediments may become somewhat compacted compared to TC. However, the JPC-TC records from HLY0503-JPC-11 and HLY0503-TC-11 apparently show the opposite trend, features on the JPC-record indicate that this core has a higher resolution compared to the TC taken at the same time and only a few meters distance.

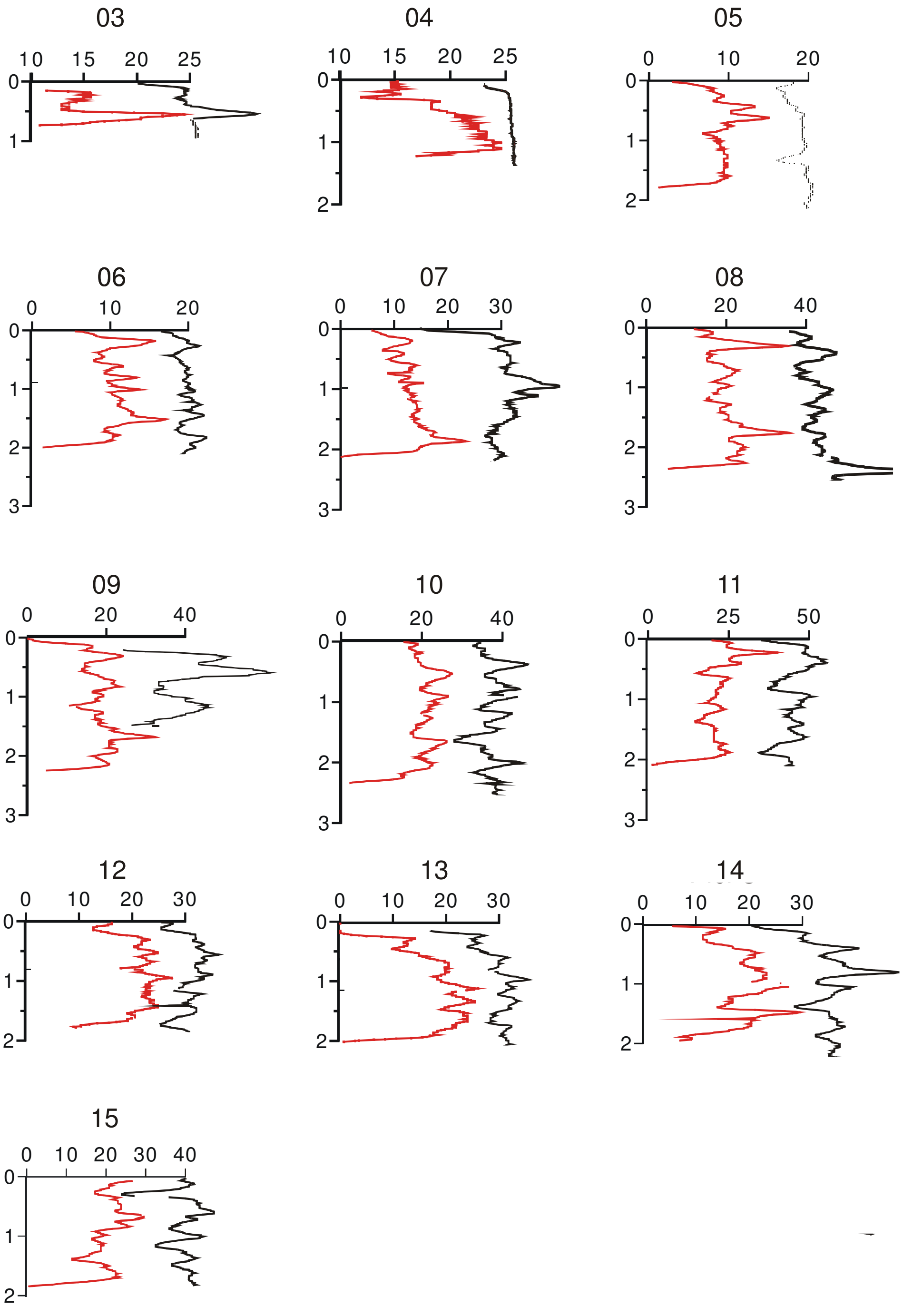


Figure 13. MS-records of TC and corresponding JPC for 13 HLY0503-cores. TC-data in red, and JPC-data in black. JPC-curves are shifted to the right in order to simplify

comparison. A number of cores exhibit very good agreement in MS-records. Curve-breaks indicate section-breaks. MS in 10^{-5} SI.

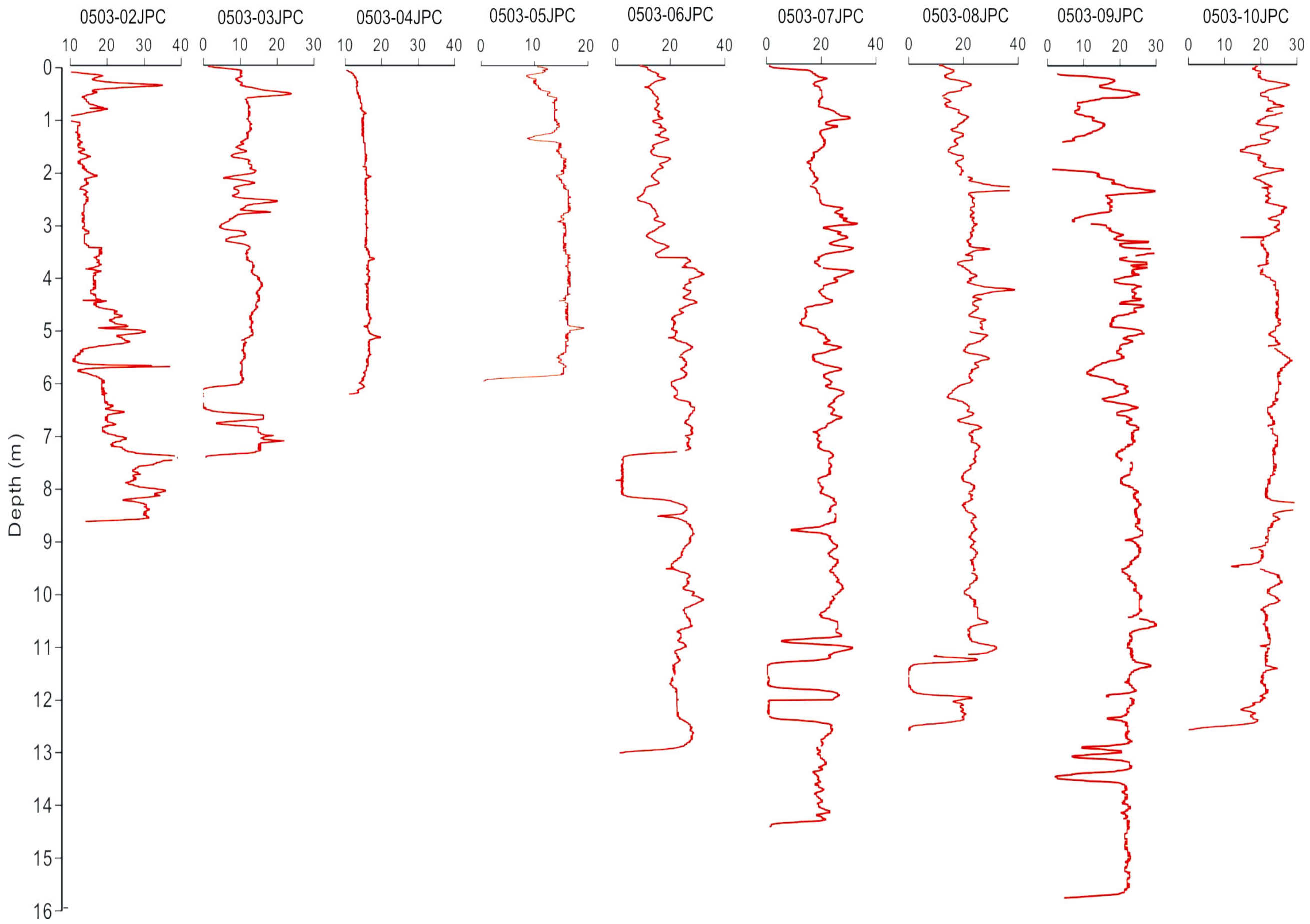


Figure 14. MS versus depth for the first eight HLY0503 cores (JPC2 to JPC9). The data have not been corrected for empty or water-filled intervals. MS in 10^{-5} SI.

Stratigraphic correlation

Whole core magnetic susceptibility (WCMS) turned out to be the most robust parameter obtained from the MSCL. MS reflects stratigraphic variations in mineralogical composition, and is a routine parameter for first order correlation between sedimentary cores. The JPC-MS data retrieved during leg HLY0503 are presented in stratigraphic plots (Figs. 15 and 16). The data have not been corrected for gaps and water-filled intervals that became evident after core splitting.

Comments

MS variations along cores JPC-02 to -10 (Fig. 14) do not generally show comparable curve patterns that would suggest any close agreement in lithology along cores. Cores JPC-06 and -07 were cored very close, and some MS features may be correlated, but overall the congruence is poor. Data from cores JPC-11 to –17 however, exhibit unusually good agreement in MS patterns, considering that this suite of cores was retrieved from different depths and areas (Fig. 15). Wiggle matching may produce 15 to 20 tie lines, based on curve pattern and intervals with coinciding sequences of curve shapes. This is a very promising result, since high-resolution dating of one of these cores may produce correlatable high-resolution ages for the rest of the cores in this suite. The surprisingly good correlation is based on WCMS data that represent a highly smoothed record of MS variations. It is recommended to obtain high-resolution split-face-surface susceptibility records from all of these cores. Such records are likely to improve the resolution as well as the reliability of stratigraphic correlation.

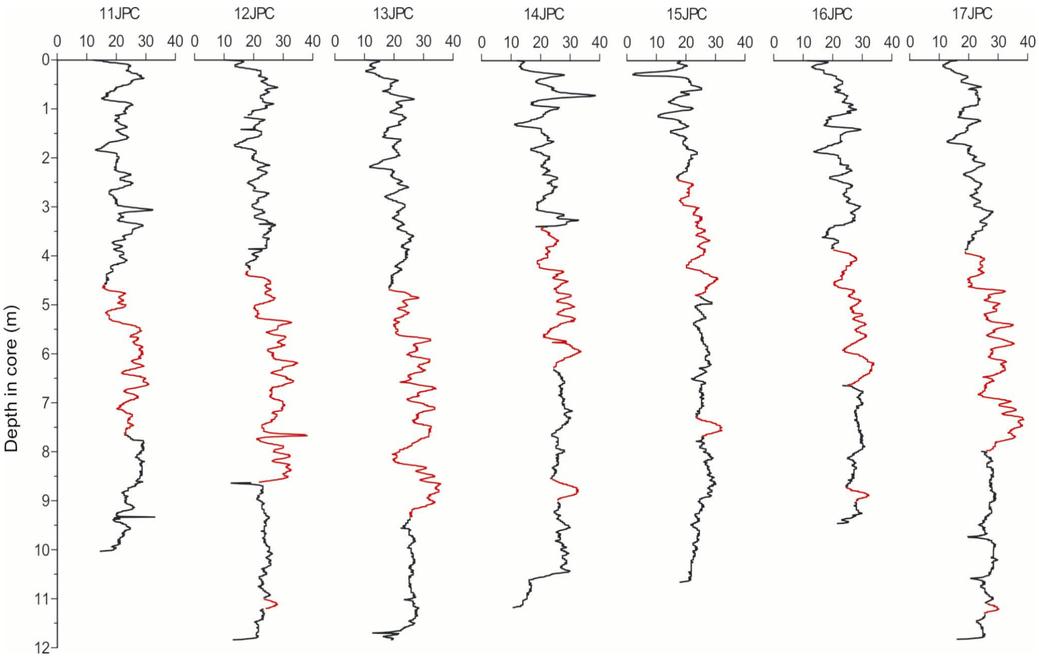


Figure 15. MS-variations with depth in cores JPC 11 to 17. The curves show a high degree of similarity. The long interval in red represents a postulated main feature that can easily be recognized on all curves. Up to 15 distinct wiggles may tentatively be correlated between the curves. MS is in 10^{-5} SI.

LITHOSTRATIGRAPHY

After multi-sensor core logging (MSCL), all trigger and piston cores and at least one sub-core from the multicoring were split, described, and photographed. Altogether almost 500 m of core material from HLY0501 and HLY0503 was described. Lithological description was based on sediment color (Munsell Color Chart), texture, and structures. Hydrochloric acid (10%) was used on small amounts of material removed from the cores to confirm calcareous material such as fossil tests and calcareous ice-rafted detritus (IRD). Where obvious in the cores, microfossils and diagenic features were sampled and examined under a binocular microscope. Descriptions were recorded in the electronic ODP log format (Apple Core). After being described and photographed, the core splits were put into D-tubes, labeled, and stored at curation temperature (between 2-5°C).

Described sediments are mostly composed of fine-grained to slightly sandy muds with variable amounts of IRD, scattered or concentrated in layers, and lenses/layers of sandy muds or muddy sands. The size of IRD is mostly on a scale of millimeters to a few centimeters, but in some cases, notably on the Alaskan margin and on the Gakkel Ridge, reaches >10 cm. The colors of deep-sea sediments are predominantly in the brown hues (10YR, sometime 7.5YR or 2.5Y), whereas on the Alaskan margin sediments are more in the olive-gray hue (5Y). Interlamination of brown to dark brown with lighter colored yellowish (grayish, olive) brown sedimentary intervals on decimeter to centimeter scale is characteristic for the central Arctic Ocean. On the Alaskan margin where sedimentation rates are much higher, thick, relatively homogenous units are common, notably the uppermost (Holocene) olive-gray, fine-grained unit that reaches up to 12+ m in the recovered cores. Sediments are typically bioturbated to some extent; in the central Arctic Ocean bioturbation results in characteristic sediment mottling. Other common features are dark aggregates of Fe-Mn micronodules at certain stratigraphic levels in deep-sea deposits and black Fe-monosulfide speckles in reduced Holocene sediments on the Alaskan margin. Macroscopically identifiable fossils are mostly mollusk shells that are common in Holocene deposits on the margin. On some occasions, peculiar fossil assemblages were encountered such as mats of calcareous worm tubes and bryozoans on the Lomonosov Ridge.

Based on the field-core descriptions combined with MS logging data, a provisional lithostratigraphy is proposed for these sediment cores. The most persistent feature of the sedimentary records from the central Arctic Ocean is the interlamination of brown to dark brown and lighter colored yellowish (olive, grayish) brown intervals on a decimeter to centimeter scale. The sequence formed by this interlamination is most obvious in cores obtained on the Mendeleev Ridge. A composite sequence constructed by correlation of cores along the Mendeleev Ridge (JPC-6 to -10) comprises approximately 80 brown-yellowish, decimeter scale cycles. Superimposed on this interlamination are larger-scale, more general lithological features that form a consistent stratigraphic pattern along the Mendeleev and Alpha ridges. Sand and IRD layers that consistently occur at certain stratigraphic levels constitute additional stratigraphic markers. The combination of larger- and smaller-scale lithostratigraphic features controlled by various parameters allows a robust correlation of sediment cores along the Mendeleev-Alpha ridges (Fig. 16).

Based on a comparison with published stratigraphic data, it is possible to extend the correlation to sediment cores from the Alpha Ridge beyond the HLY0503 track, notably with the CESAR study area (Jackson et al., 1985). The distinct trend in sediment distribution along the Mendeleev-Alpha ridges is the overall thinning of sedimentary strata from the Eurasian to the Canadian end by an order of five, with some intermittent thickening in the northern Alpha area (JPC-13 & 17) (Figs. 16 & 17). This pattern suggests that cores from the Mendeleev Ridge are more suitable for a detailed study of paleoceanographic changes in the central Arctic Ocean, whereas cores from the Alpha Ridge have a better potential for accessing deeper stratigraphic levels.

Sediment cores from other regions of the central Arctic Ocean such as the Northwind, Lomonosov, and Gakkel ridges are generally characterized by interlamination of darker/lighter brown to yellowish/greyish intervals similar to the Mendeleev-Alpha ridges, but also have regional specifics in the distribution of coarse-grained material, color variations, and thickness of strata. For example, layers of calcareous IRD from the Canadian Archipelago are characteristic for cores from the Amerasian Basin, but are not evident in the Eurasian Basin. Because of this variability, long-distance lithostratigraphic correlations may not be attainable without independent stratigraphic data such as obtained by paleontological, paleomagnetic, and geochronological methods.

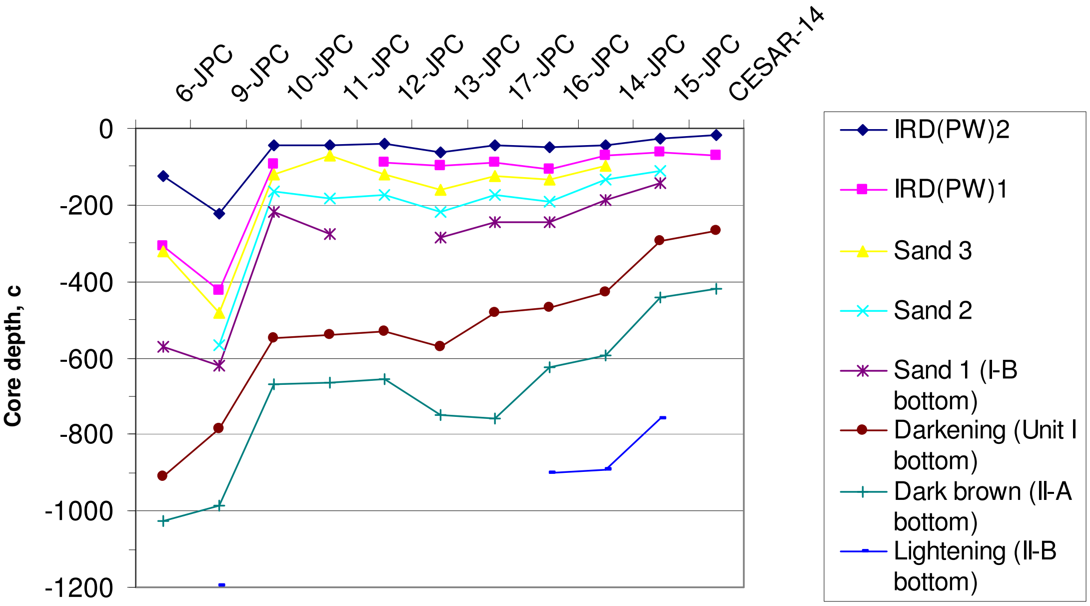


Figure 16. Tentative lithostratigraphic correlation of HLY0503 sediment cores along the Mendeleev to Alpha Ridge, with core CESAR-14 added.

Radiochemistry, Foraminifera and Dinocyst Analyses in the Sediment and Water Column.

Sandrine Solignac (University of Quebec in Montreal and GEOTOP)

Claude Hillaire-Marcel and Anne de Vernal (UQAM and GEOTOP)

All the below sediment and water samples will be shipped back, further processed and curated at GEOTOP (Montreal, Canada).

Radioisotope, foraminifera and dinocyst analyses in the sediment

The following multicores were sampled at 0.5 cm intervals for 1) stable isotope measurements in foraminifera, 2) dinocyst population studies and 3) radioisotope analyses:

- HLY0503-02MC-7
- HLY0503-03MC-8
- HLY0503-05MC-8
- HLY0503-06MC-8
- HLY0503-08MC-8
- HLY0503-10MC-8
- HLY0503-12MC-8
- HLY0503-13MC-8
- HLY0503-14MC-8
- HLY0503-15MC-8
- HLY0503-16MC-8
- HLY0503-18MC-8
- HLY0503-20MC-7
- HLY0503- North Pole MC-8

Pore water sampling

Radiochemistry analyses of the sediment pore waters will be conducted at GEOTOP. Pore waters were extracted from a few selected multicores with the use of hydrophilic microporous polymer tubes (2.5 mm diameter) connected to syringes. The tubes were inserted into the sediment at regular intervals after splitting the core liner.

The following multicores were sampled with this technique:

Multicore number	**Sampling interval**
HLY0503-01MC-3	Every cm from 0 to 29 cm
HLY0503-08MC-7	Every cm from 0 to 30 cm, Every 2 cm from 30 to 42 cm
HLY0503-11MC-5	Every cm
HLY0503-18MC-7	Every cm from 0 to 20 cm, Every 2 cm from 21 to 46 cm

An alternative method for collecting pore waters, consisting of sampling 5-cm thick sediment slices, was used on the following multicores:

- HLY0503-05MC-7
- HLY0503-06MC-7
- HLY0503-10MC-7
- HLY0503-12MC-7
- HLY0503-14MC-7
- HLY0503-15MC-7

- HLY0503-16MC-7
- HLY0503-17MC-7
- HLY0503-18MC-7
- HLY0503-19MC-7
- HLY0503-20MC-8

Water column sampling (CTD casts)

Three hydrocasts were collected for post-cruise radiochemical analyses (Fig. 17). On every cast, between 13 and 17 water depths, more or less evenly spaced in the water column, were sampled.

- **HLY0503-11CTD**

Bottle number	Water depth (m)	Sampled quantity
1	2692.2	~10L
2	2480.4	~10L
3	2290.9	~10L
4	2092.1	~10L
5	1891.1	~10L
6	1691.5	~10L
7	1491.4	~10L
8	1290.9	~10L
9	1091.5	~10L
10	891.9	0L – bottle did not close
11	691.5	~10L
12	491.3	~10L
13	292.5	~10L
14	100.0	~10L
15	20.1	~10L

- **HLY0503-18A-CTD**

Bottle number	Water depth (m)	Sampled quantity
1	4028.6	~10L
2	3720.8	~10L
3	3371.3	~10L
4	3062.9	~10L
5	2752.3	~10L
6	2441.3	~10L
7	2138.6	~10L
8	1830.4	~10L
9	1523.3	~10L

10	1217.6	~10L
11	913.6	~10L
12	610.4	~10L
13	408.8	~10L
14	258.2	~10L
15	127.0	~10L
16	20.5	~10L
17	2.2	~10L

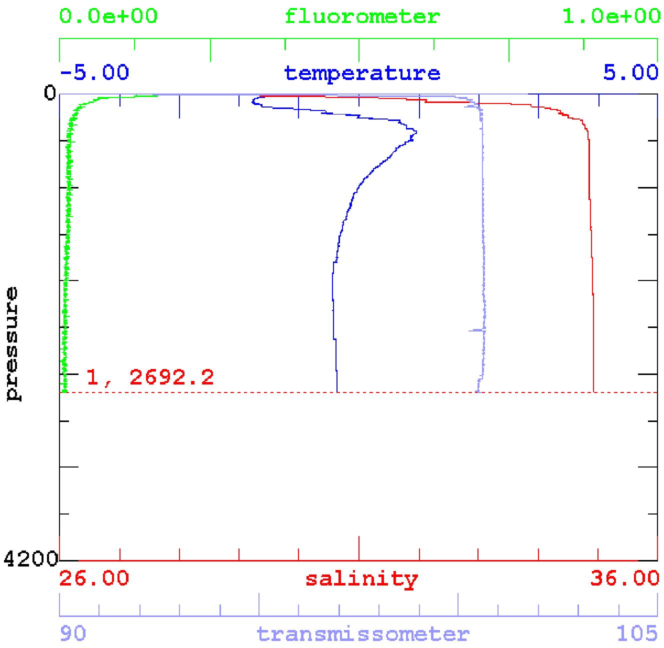
- **HLY0503-21CTD**

Bottle number	Water depth (m)	Sampled quantity
1	4447.3	~10L
2	4043.5	~10L
3	3645.6	~10L
4	3246.6	~10L
5	2846.4	~10L
6	2446.3	~10L
7	2046.6	~10L
8	1647.2	~10L
9	1247.2	~10L
10	847.6	~10L
11	329.7	~10L
12	140.8	~10L
13	19.3	~10L

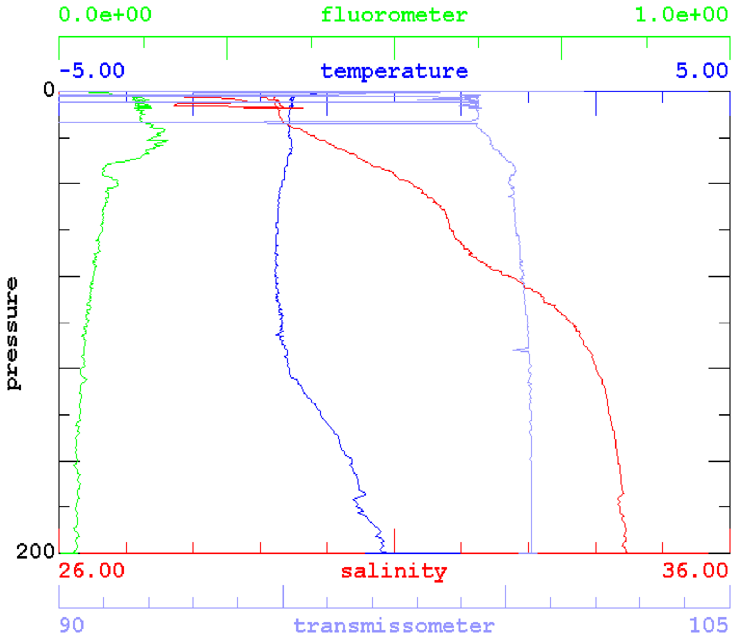
Preliminary results

- HLY0503-11CTD

Entire water column:

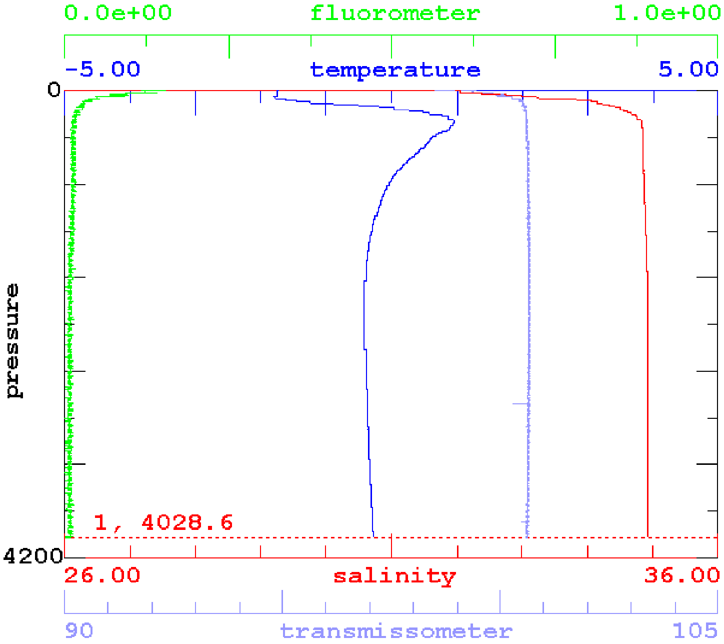


Top 200 meters:

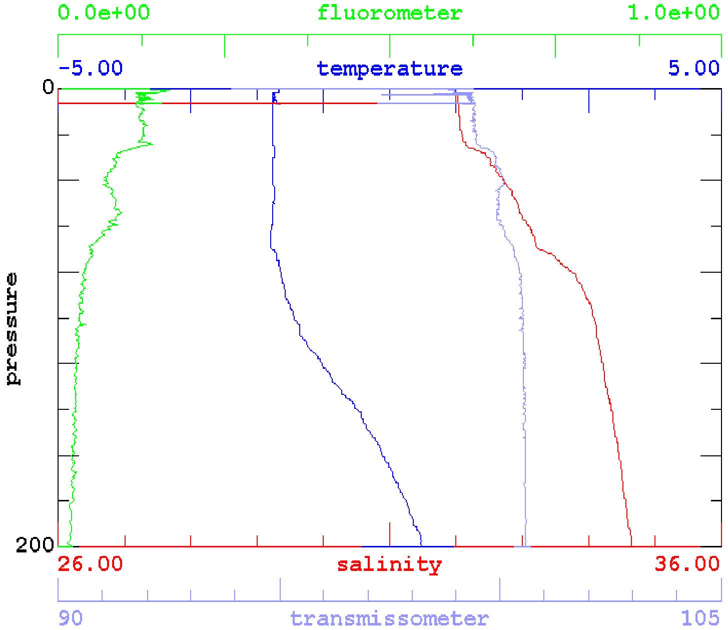


- HLY0503-18A-CTD

Entire water column:

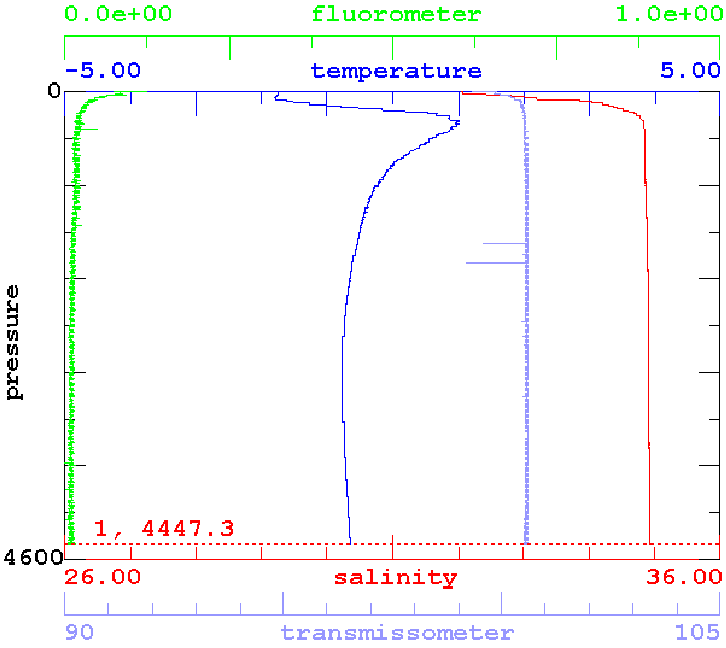


Top 200 meters:



- HLY0503-21CTD

Entire water column:



Top 200 meters:

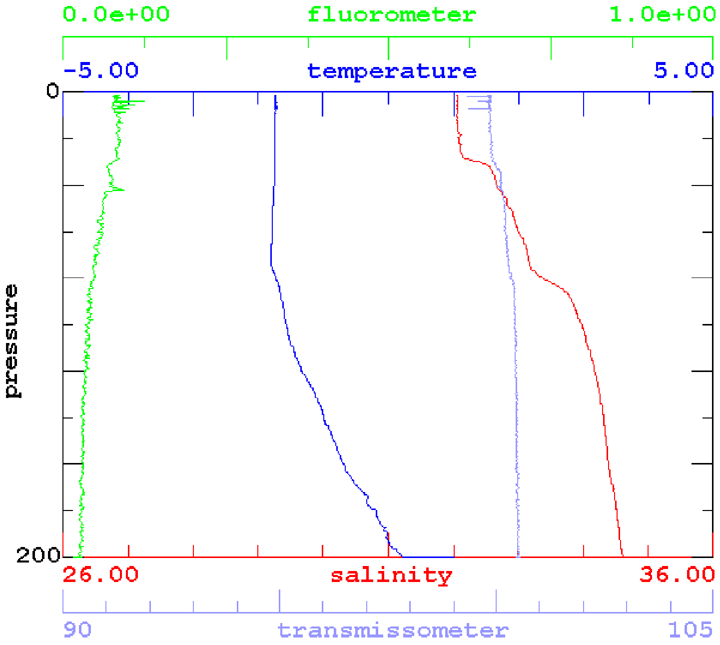


Figure 17. CTD casts from the three stations. Upper 200 meters water depth is shown separately for greater detail.

Dirty Ice Sampling and Processing

Dennis Darby, Glenn Berger, John Rand, Paula Zimmerman

Cruise HLY0503 of HOTRAX-05 provided a unique opportunity to resample the central Arctic for dirty sea ice. The Arctic Ocean Section (AOS94), the first crossing of the central Arctic Ocean by two surface vessels (the USCGC Polar Star and the Canadian Louis St. Laurent) in 1994 provided the first such opportunity. Several dirty sea ice samples were collected by this historic expedition and now the HOTRAX-05 provided an opportunity to return to the central Arctic Ocean sea ice 11 years later.

The two main objectives of this 2005 sampling were to obtain additional samples for provenance studies (using Fe oxide chemical fingerprinting, e.g., Darby, 2003) and to obtain the first such samples for luminescence studies. Fe oxide traits can be used to infer the source area(s) for the sediment, thus providing the net drift of the sea ice from the shallow source area to where they were sampled. For such studies, the requirements of sample collection are straightforward: spot the dirty ice, get there, then scoop or break it into any clean container (e.g., plastic bags, buckets). For luminescence studies, there is the additional requirement to minimize exposure of the sediment to daylight during collection, and to prevent any subsequent exposure.

Luminescence sediment dating is a well established tool for Quaternary terrestrial sediments (e.g., Aitken, 1998; Murray and Olley, 2002) but it has only recently been tested with Arctic Ocean sediments (Berger, 2006; Berger and Jones, 1996; Jakobsson et al., 2003), for which an additional such geochronometer is urgently required to reach beyond the conventional upper limit (30-35 ka) of radiocarbon dating. Since the luminescence sediment-dating tool has as its main assumption that all mineral grains are exposed to daylight before burial (clock zeroing is by daylight exposure), and since most of the grains in Arctic Ocean sediments rain down from melting pack ice, then to be usefully accurate for the Arctic Ocean, luminescence dating requires that mineral grains within pack ice be well exposed to daylight. Depending upon the sub-method of luminescence dating to be used, the required clock zeroing time ranges from tens of seconds to several hours. Given that individual components of pack ice are at least one year old (and up to 5-6 yrs, perhaps), then this requirement would seem to be satisfied easily. However, there are several ways that discrete grains can be shielded from light while being transported around and across the Arctic Ocean in ice (Berger, 2006). For example, if the fine grains are maintained in preformed pellets, then many of the grains will not be exposed to daylight while in the ice, and a resulting luminescence age could greatly exceed the deposition age. Since pellets have been observed within ocean-bottom sediments (Goldschmidt et al., 1992), then important questions are: are they formed in sea ice, or before incorporation into first-year ice, and are they ubiquitous in sea ice?

At only one of the sample sites (GWB-ice-1, Table 6) for luminescence studies were clearly preserved pellets (3-7 mm diameters) observed (and collected), in this case within a thin, unfrozen layer of mud at the base of a recently uplifted, tilted and drained melt pond. The mini-morphologies of the ice-sediment context of most of the observed pellets suggest some hypotheses (and future experiments for their testing) for the formation of pellets within sea ice.

Samples for luminescence studies were collected by either breaking off fragments and small blocks of dirty ice or, if unfrozen mud layers, by scraping, using (on this cruise) the adze blade of an ice axe. Samples were put quickly into an opaque 15 L lidless barrel covered by an opaque layer of black plastic bag. In this way, only during the brief (up to 5 s) handling were ice fragments or mud scrapings exposed to daylight. In every case many or most aggregations or pellets of sediment were preserved, so that grains within pellets and aggregations were not exposed to additional daylight during and after sampling. Samples for provenance studies were collected in a similar manner, using a scoop or geological hammer as required, with the opaque containers replaced with a 20 L bucket.

We have collected 15 samples of dirty sea ice, 3 of these for luminescence studies. Most samples were collected by disembarking to floes adjacent to the ship when dirty ice had been spotted visually from the ship. On two occasions some such ice was obtained during helicopter reconnaissance. However, because we did not encounter noticeable dirty ice (usually brown or 'black' bands within and on ship-broken ice) until after late August (when we entered the central ice pack) and because by then most sea ice and pressure ridges were covered by at least 1-2 cm of fresh snow, spotting suitable sites from a helicopter became difficult or impossible during most of this cruise. After we departed from the North Pole, dirty ice was not observed, only algae-rich ice (orange-brown, lowest 5-50 cm of ship-broken ice), which was common. En route to the pole, we spotted many more zones of dirty ice than we could sample, because we could not stop the ship for sampling due to time limitations. Furthermore, many potential sampling zones were missed because we did not have a dedicated spotter/observer for dirty ice on the bridge at all times. Future expeditions should include such an observer, with a schedule that permits more frequent stops.

Samples for luminescence studies were kept in their opaque containers until any ice had melted, then the wet sample/slurry/suspension was concentrated (by decanting, in a photo darkroom, illuminated by only a special orange-filtered lamp) into progressively (after 2 days settling per step) smaller (opaque) containers until a 1 L or less volume was attained. These 1 L opaque bottles subsequently were transported back to Berger's laboratory at the Desert Research Institute.

Samples for provenance studies were melted and dewatered using a combination of NaCl to promote flocculation of the mud, settling, micro-filtering, and evaporation at low temperature in a small oven. At least a few filter pads of sediment were filtered (45µm pore size) from the bulk sample for clay mineral analyses. Where an adequate quantity of the finest clay fraction had been obtained from the filtering, portions of the remaining suspension were decanted directly to disposal. The final concentrates, ranging from a few ml to nearly 2 L, were packaged into plastic bottles or glass vials for shipment back to Darby's laboratory at Old Dominion University.

Table 6. Summary of sea ice samples collected for provenance and luminescence studies.

Sample ID	Latitude	Longitude	Date	Sample Description/Comments
HLY0503-01ICE	84.2466	-153.624533	8/28/2005	Substantially dirty floes, fairly abundant. Grain size appears to be silt and clay

HLY0503-02ICE	84.31233	-149.0852	8/29/2005	Substantially dirty floes in an area 300 x 300 m. Might be much more, but new snow cover hides dirty ice. Grain size appears to be silt and clay, Similar appearance as sample HLY0503-01ICE
HLY0503-03ICE	83.891667	-141.136667	8/30/2005	Helicopter flight to sampling location. Multiyear flow with a 1-1-5 m block sticking up with dirty ice. Less dirty than 01ICE and 02ICE sites. Could not sample dirtiest site because of melt ponds and no clear landing area.
HLY0503-04ICE	83.9502	-143.1828	8/30/2005	Dirty ice floes next to ship at coring station HLY0503-15-JPC. Sampled using Healy-1, small rubber boat
HLY0503-05ICE & separate sample -GWBice1	83.9513	-143.1792	8/30/2005	Glenn Berger sampled this location at the same time as Dennis Darby sampled HLY0503-04ICE. Due to unusually thick layer of mud concentrated just below new ice, a large volume of mud was sampled.
HLY0503-06ICE & Separate sample -GWBice3	84.166367	-151.0166	8/31/2005	About centimeter thick layers of pure mud incorporated in the ice.
HLY0503-7AICE	87.623034	156.087209	9/6/2005	Have observed dirty ice in wake of ship for last 3 days, hard to see extent of dirty ice due to snow cover beyond ship's wake.
HLY0503-7BICE	87.623954	156.086359	9/6/2005	Hard to see extent of dirty ice due to snow cover. This site was about 100 m from HLY0503-7AICE
HLY0503-8AICE	87.66335	150.874417	9/7/2005	Hard to see extent of dirty ice due to snow cover. Very dirty underneath snow. Sample is about 20 m from 8AICE
HLY0503-8BICE	87.66353	150.87298	9/7/2005	Hard to see extent of dirty ice due to snow cover. Very dirty underneath snow. Sample is about 20 m from 8BICE

HLY0503-9ICE	89.47833	168.86	9/11/2005	Very sparse sediment; sampled 4 sites, each 20-60 m apart and 300m for last location.
HLY0503-10AICE	89.99318	-12.88937	9/13/2005	North Pole dirty ice sampling. About 200 m from 10BICE
HLY0503-10BICE	89.99134	-0.20712	9/13/2005	Chunks of ice thrown up by ship with sediment encased. About 200 m from 10AICE
HLY0503-11ICE	89.3405	-86.1369	9/13/2005	Snow cover made it hard to find dirty ice. Smaller concentration sampled than at previous sites

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