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Icebreaker Expedition Collects Key Arctic Seafloor and Ice Data

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The recently completed *Healy-Oden* Trans-Arctic Expedition 2005 (HOTRAX'05) retrieved 29 piston cores averaging nearly 12 meters in length from a complete transect across the central Arctic Ocean (Figure 1). These cores provide a critically-needed sample cache for both a pan-Arctic stratigraphy and a long-awaited paleoclimate record that it is hoped will greatly improve the understanding of how deepwater is exchanged between Arctic basins, how the climate system in the Arctic works over longer time intervals, and how the Arctic system interacts with global systems. The coring was done from the U.S. Coast Guard Cutter (USCGC) *Healy*, while oceanographic measurements were made from the Swedish icebreaker *Oden*.

In addition to coring and oceanography, HOTRAX mapped the seafloor with multibeam bathymetry and collected chirp sonar profiles that not only mapped the strata to a sub-bottom depth of 50–100 meters, but also provided detailed information on the geologic context of the core sites.

The multibeam bathymetry revealed more extensive and deeper glaciogenic features on the Chukchi Borderland than previously mapped; showed pockmark fields on the Mendeleyev Ridge; and, for the first time, discovered large mud waves (>500 meter wavelength, 5–30 meter amplitude) in the Alpha Ridge area, indicating bottom currents in the deep Arctic Ocean. Sediment erosion, including unconformities with older strata, was observed over the Northwind Ridge by chirp sonar and multibeam, and nearly uniform sediment drapes were profiled over much of the Mendeleyev and Alpha ridge system (Figure 2). A separate geophysical component of HOTRAX collected 2200 kilometers of multichannel seismic data across some of the most inaccessible parts of the Arctic Ocean. This data and pending results will help to resolve the structure of the central Arctic ridges and thus how the early Arctic basins formed.

A New Pan-Arctic Stratigraphic Framework

One core objective for HOTRAX was the establishment of a pan-Arctic Quaternary stratigraphy and thus the determination of sedimentation rates in the central Arctic. Both the stratigraphy and sedimentation rates are needed in order to determine a viable paleoclimate history of the area.

Earlier work in the Arctic was hampered by the lack of good core material extending more than a few meters in length. Nearly all of the Ice Island expedition T-3 cores collected in the 1960s and 1970s by the U.S. Geological Survey for heat flow studies were only three centimeters in diameter, and they contained very little of the upper 20–30 centimeters due to the small core pipe's propensity to not sample the soft surface layers. As expected, such narrow cores also presented problems in providing adequate volumes of material for many paleoclimatic proxy measurements.

Some larger-diameter cores were later collected in the central Arctic Ocean [e.g., *Backman et al.,* 2004, and references therein], but they covered only localized areas and were still relatively short (maximum length of eight meters). HOTRAX has changed this situation, and while there are

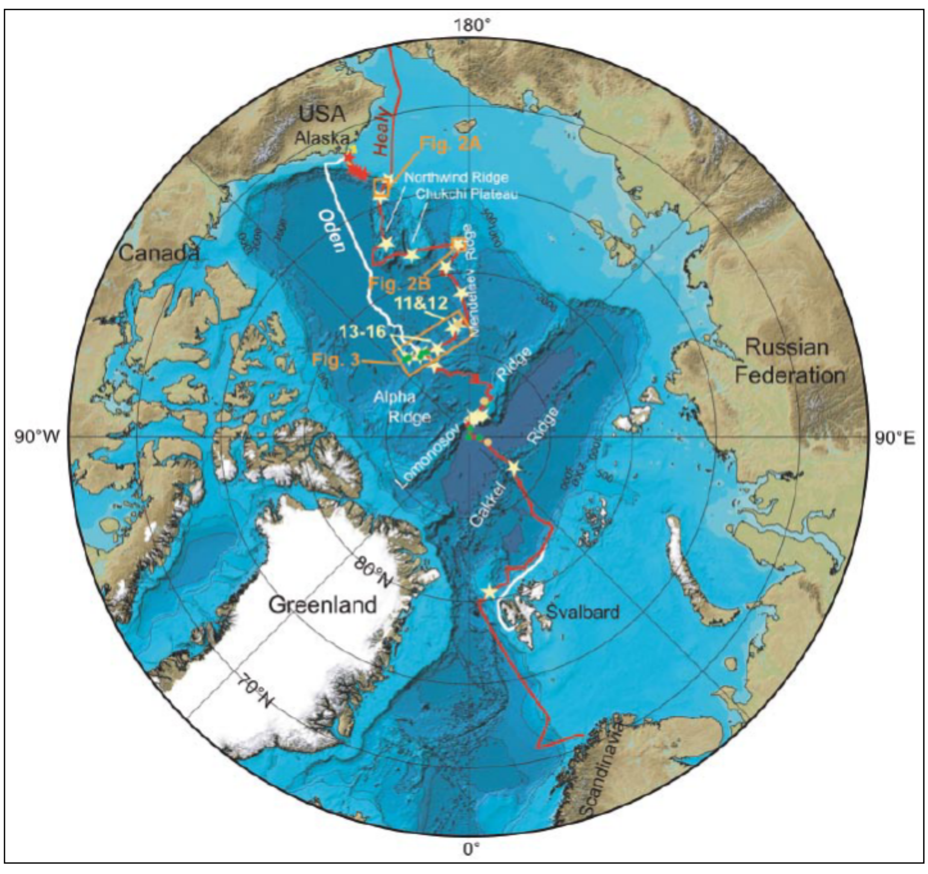

Fig. 1. Map of the HOTRAX '05 transect showing the tracks of the U.S. Coast Guard Cutter Healy *with a red line and the icebreaker* Oden *in white. Coring sites are represented by yellow stars (yellow numbers for the trans-Arctic leg) or red stars (*Healy's *first leg at the Alaskan margin), and dirty ice sampling stations are represented by green dots. The locations of Figures 2 and 3 are outlined in orange. The complete transect from Dutch Harbor, Alaska, to Tromsø, Norway, is 8200 kilometers long.*

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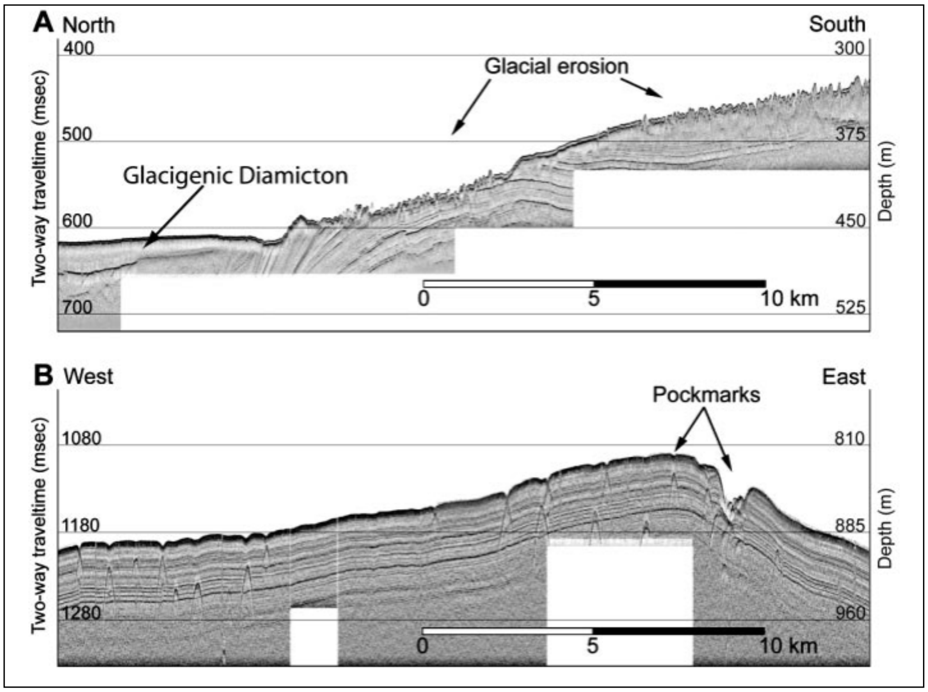

Fig. 2. Examples of Healy's Knudsen chirp sonar (center frequency 3.5 kHz) records showing (a) glacial erosion and probable glacially deposited diamictons on Northwind Ridge and (b) pockmark collapse structures, perhaps caused by gas escape from possible methane build-ups in the sediment on Mendeleyev Ridge as well as uniform sediment drapes. Data was processed using Sioseis software.

still many areas that need to be cored, there is sufficient quality core material to meet most of the Pleistocene stratigraphic and paleoclimate objectives driving HOTRAX.

The long cores obtained by HOTRAX along the Mendeleyev and Alpha ridges show excellent preliminary correlations from onboard lithological description and multi-sensor core logs such as those of magnetic susceptibility (MS), which peak when concentrations of fine-grained magnetic minerals are present and thus allow matching of such deposits among different cores (Figure 3). Furthermore, some unique stratigraphic features, such as distinctive changes in lithology and prominent layers of coarse detritus deposited by icebergs, provide a basis for correlation with previously recovered sediment records [e.g., *Jakobsson et al.*, 2000], including the 2004 drilling on the Lomonosov Ridge [*Shipboard Scientific Party,* 2005]. This correlation indicates a pronounced increase in sedimentation rates from the Alpha Ridge to the southern Mendeleyev Ridge closer to the areas where ice retreats during summer.

In the longer cores, up to 80 distinct cycles, thought to be glacial-interglacial fluctuations, were described based on color changes and texture. Similar but fewer cycles have been described previously in cores from various areas of the Arctic Ocean [e.g., *Jakobsson et al.,* 2000]. However, the processes behind these clearly visible sediment cycles are not fully understood. The HOTRAX cores may help in resolving this enigma, which is a key to the Arctic Ocean's paleoenvironmental history. Some of the deeper units, below 8-10 meters in the HOTRAX cores from the Alpha Ridge, have never been encountered by previous cores from this area. In addition, several high-resolution cores from the shelf and slope north of Alaska with over 12 meters of probable Holocene sediments were collected.

Evidence for Glacial Erosion

The expedition started on the Northwind Ridge and immediately discovered glacial erosion markings on the seafloor to depths of nearly 1000 meters, which is more than 200 meters deeper than previously mapped in this area [*Polyak et al.,* 2001]. Some of these glacial features were mapped for the first time, greatly expanding the extent of grounded ice that once existed in this area (Figure 2).

The coring objective in this area was to determine the age of these grounded glacial masses and their origin, and thus several cores were taken that penetrate the compacted diamicton (poorly-sorted sediments) below or at the margins of ice-grounding features. In several locations along the Chukchi Borderland, at least two stratigraphically different diamictons were discovered, suggesting multiple ice-grounding events. An important result from the HOTRAX transect is that the seabed of the shallowest mapped areas of the Mendeleyev Ridge (about 800 meters below sea level) did not contain any signs of glacial erosion. This constrains the deepest glacial activity in the Arctic Ocean as mapped so far to the Lomonosov Ridge and Chukchi Borderland.

New Evidence for Bottom Currents in the Central Arctic

The mechanisms of deepwater exchange between Arctic basins, such as the nature and location of deep currents, are long-running enigmas that several researchers have tried to resolve [e.g., *Jones et al.*, 1995]. To study these mechanisms, the cores from Lomonosov Ridge were taken in a depression along the ridge where deepwater exchange between the Amundsen and Makarov basins is thought to occur. Evidence of bottom currents on the ridge and expanded sediment stratigraphy in this depression or gap will be the focus of future investigations to determine a more detailed Pleistocene paleoclimate record for this area than previously possible.

The bottom mapping indicates that the deepest passage in Lomonosov Ridge, located on the Makarov Basin side of the intra-basin, is shallower than shown on the current International Bathymetric Chart of the Arctic Ocean and on the Russian bathymetric map published in 1999 by the Russian Head Department of Navigation and

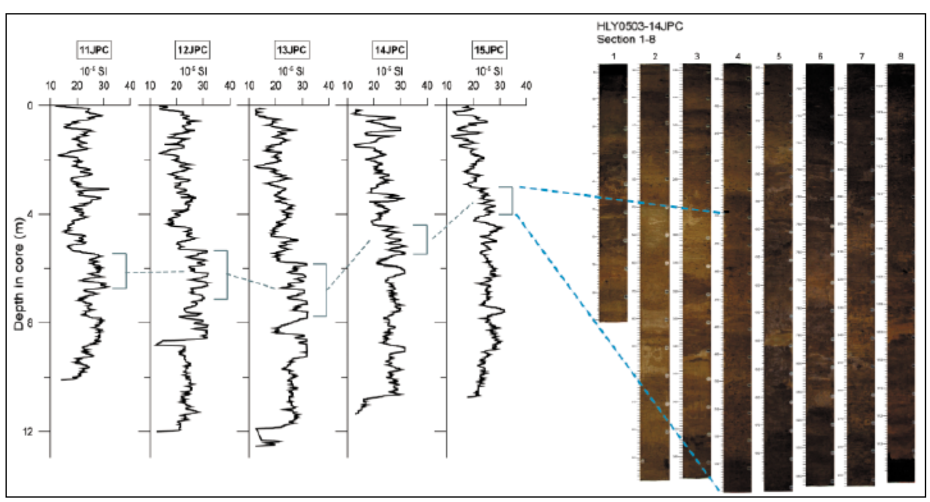

Fig. 3. Magnetic susceptibility logged on board with the multi-sensor core logger and a photograph of the core HLY0503-14JPC showing the prominent cycles that were observed in all retrieved cores from the central Arctic Ocean. The logged cores are from the Alpha and Mendeleyev ridges, and a preliminary correlation is exemplified by selected tie lines.

Oceanography. Evidence of bottom currents, including disturbed sediment stratification and extensive ripple fields, was found in a broader area than expected here.

Another important region of uncertain bottom current activity between basins is the 'Cooperation Gap' area where the Mendeleyev and Alpha ridges join and where deep water exchange between the Canada and Markarov basins should occur. HOTRAX mapped and cored this gap (low area in the ridge). Like the Lomonosov Ridge gap, this area also showed evidence of bottom currents, seen by the presence of manganese coatings on dropstones due to low sedimentation rates expected from current movements. Thus, in addition to a new paleoclimate record, the multibeam bathymetric data and sediment cores from Lomonosov Ridge and the 'Cooperation Gap' area contain similar evidence of bottom currents, and together with hydrographic data may provide a new picture of bottom water movement in the central Arctic Ocean.

Sea Ice Observations

This expedition was only the second crossing of the central Arctic basin to be done the hard way, by breaking ice (the first involved the USCGC *Polar Sea* and the Canadian icebreaker *Louis St. Laurent* in 1994). Because of its ambitious science agenda, the two icebreakers (*Healy* and *Oden*) did not reach the North Pole until 12 September 2005, later in the year than any previous non-nuclear surface vessels.

Although 2005 was undoubtedly the most ice-free summer in recorded history within the Amerasian Arctic Ocean, HOTRAX encountered many patches of very thick ice in the central basin and Eurasian Arctic. While this cruise started in early August with easy ice conditions around the southern Mendeleyev Ridge area, conditions quickly changed over Alpha Ridge and Makarov Basin. Surprisingly large open leads in the ice were encountered in the Lomonosov Ridge area only to be followed by a sudden return to severe conditions. Ice thicknesses occasionally greater than three meters were encountered as the two ships neared the North Pole; similar conditions prevailed as the expedition moved south toward Franz Josef Land in mid-September.

Continuous ice thickness profiles were collected from an EM-31 electromagnetic induction sensor hung over the side of the ship near the bow as well as from 30 stations across the entire Arctic for spot measurements of ice physical properties. Several patches of extremely concentrated sea ice sediment were encountered and sampled, especially in the trans-polar drift, the major ice drift pattern from the Laptev Sea area to the Fram Strait across the central Arctic Ocean.

Plans for International Polar Year and Beyond

Work has already begun to establish the stratigraphy and chronology of HOTRAX cores with a variety of measurements, including paleomagnetic fluctuations, radiocarbon and beryllium-10 dating, optical stimulation luminescence, and biostratigraphy. The goal is to establish a correlated late-Cenozoic stratigraphic record from this transect across the entire Arctic Ocean. This record would provide the chronological framework for a wide variety of paleoclimate proxies in the Arctic Ocean. This work will be timed for the International Polar Year in 2007, and this initiative will be used to launch a comprehensive investigation of the Arctic Ocean paleoceanography and its links with the global paleoclimate.

For more information about HOTRAX, visit the Web site: http://www.odu.edu/sci/oceanography/hotrax/index.htm

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