

Mapping in the Arctic Ocean in Support of a Potential Extended Continental Shelf

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Introduction

Under Article 76 of The United Nations Convention on the Law of the Sea (UNCLOS; U.N. 1997), coastal states may, under certain circumstances, gain sovereign rights over the resources of the seafloor and subsurface of “submerged extensions of their continental margin” beyond the recognized 200 nautical mile (nmi) limit of their Exclusive Economic Zone (EEZ). The establishment of an “extended continental shelf” (ECS) under Article 76 involves the demonstration that the area of the ECS is a “natural prolongation” of a coastal state’s territorial landmass and then the application of a series of formulae and limit lines that are based on determination of the “foot of the slope,” (defined in Article 76 as the maximum change in gradient at it’s base), the underlying sediment thickness, and the locations of the 2500 m isobath and the 350 nmi line from the territorial sea base line. Although the United States has not yet acceded to the UNCLOS, increasing recognition that implementation of Article 76 could confer sovereign rights over large and potentially resource-rich areas of the seabed beyond its current 200 nautical mile (nmi) limit has renewed interest in the potential for accession to the treaty and spurred U.S. efforts to map area of potential “extended continental shelf”.

A detailed analysis of the relevance of current U.S. data holdings to a potential U.S. submission under Article 76 was conducted by Mayer, et al., (2003). This analysis included the identification of regions where the collection of new, modern multibeam sonar data would substantially improve the quality of a potential submission for an extended continental shelf under Article 76. These regions include the east coast of the U.S., the Bering Sea, the Gulf of Mexico, the Chukchi Cap region of the Arctic and potentially the Gulf of Alaska and areas around Hawaii and other Pacific islands (Guam,

Johnston Atoll, etc.). Since the publication of this study, the Center for Coastal and Ocean Mapping/Joint Hydrographic Center at the University of New Hampshire has, through direction and funding from NOAA and the U.S. Extended Continental Shelf Task Force (a multi-agency task force chaired by the State Dept. and co-chaired by NOAA and the USGS), collected more than one million square kilometers of new, high-resolution multibeam sonar data in regions where the U.S. has the potential for an ECS; the most recent overview of these data was presented at the 2008 Canadian Hydrographic Conference (Gardner, et al., 2008).

The greatest potential for an extended continental shelf beyond the current 200 nmi limit of the U.S. EEZ is found in the area of the Chukchi Borderland, a tightly clustered group of generally high-standing, N-S-trending bathymetric elevations that form a natural prolongation from the Chukchi Shelf north of Alaska. As noted in the Mayer et al., (2003) study, this area is also an area where the existing database of bathymetric data was far too sparse to support a well-defended ECS submission. For these reasons, the Arctic has become a particular focus for the collection of new high-resolution multibeam sonar data. In addition, new multibeam data in the Arctic significantly adds to the scientific database needed to support the growing recognition of the critical role that the Arctic Ocean plays in the climatic and tectonic history of Earth. New bathymetric and high-resolution subbottom profiler data (as well as associated CTD measurements) can also help define the nature of deep circulation in the Arctic Basin as well as the history and distribution of ice in the region, a key component in understanding the global climate system.

The Chukchi Borderland juts northward between eastern Siberia and western Alaska into the deep Amerasia Basin north of the Chukchi Sea (Fig. 1). The borderland occupies a rectangular area about 600 by 700 km, or some 4 percent of the Arctic Ocean. This area encompasses three, approximately north-south-trending segmented topographic highs: the Northwind Ridge, the Chukchi Cap and Rise, and the western (Arlis, Sargo, and T3) plateaus which are located beyond (westward of) an agreed maritime boundary line with Russia. The plateau-like crests of the Chukchi Borderland rise, in some cases, as much as 3,400 m above their surroundings and they are relatively shallow (depths

between 246 and 1,000 m). The ridges have steep flanks, which in some places exhibit remarkable linearity over hundreds of kilometers, especially along the east side of the Northwind Ridge.

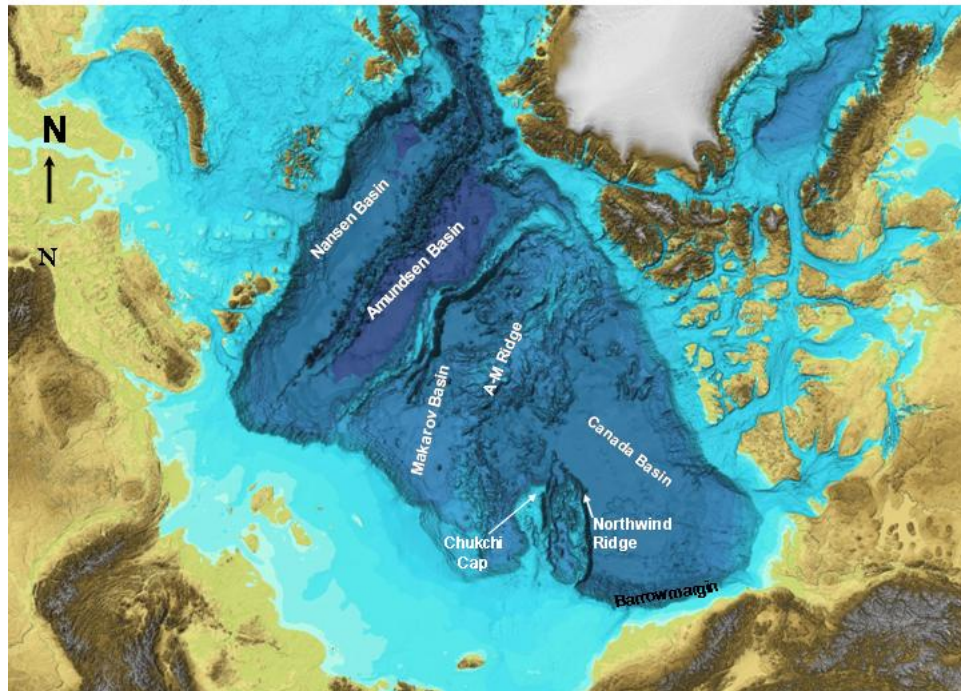


Figure 1. Physiographic map of the Arctic Ocean (Jakobsson et al., 2008; 2003). A-M Ridge is Alpha-Mendelev Ridge.

Since 2003, the University of New Hampshire's Center for Coastal and Ocean Mapping-Joint Hydrographic Center (CCOM-JHC) has conducted four cruises to the Chukchi region (2003, 2004, 2007 and 2008) to collect data in support of a potential submission for an extended continental shelf under UNCLOS Article 76. From a bathymetric perspective, the key targets for the establishment of an extended continental shelf for the U.S. in the Arctic are the determination of the location of the foot of the slope and the 2500 m isobath. All of the UNH cruises were conducted aboard the U.S. Coast Guard Ice Breaker *Healy* (WAGB-20 -- Fig. 2) using a 12-kHz L3 Communications Seabeam 2112 multibeam system as the primary bathymetric data source. Additionally, high-resolution sub-bottom profiles were collected using a Knudsen 320/BR profiler; these profiles proved to be extremely useful for determining

morphologic features critical to establishing an ECS. This report summarizes the accomplishments to date of the CCOM-JHC Arctic Ocean mapping.



Figure 2. Photo of the USCGC Healy in Arctic Ocean ice.

HEALY 0302:

The initial mission in 2003 was a 10 day, 3000 km long, exploratory cruise (September 1-11, 2003) to demonstrate the viability of using the multibeam echo-sounder to follow specific bathymetric targets (in particular the 2500 m isobath) in ice-covered waters. The 2003 cruise began at the US-Russian boundary line at 78° 30'N 168° 25'W and followed the 2500 m contour around to 78° 35'N 159° 07'W (Fig. 3). Ice conditions ranged from 7/10 to 9/10 coverage of mostly first-year ice. The cruise collected ~3000 km of high-resolution multibeam echo-sounder data and made several significant discoveries including:

- substantially changing the mapped position and complexity of the 2500-m isobath (a critical component of a Law of the Sea submission for an ECS),
- finding further evidence for pervasive ice and current erosion in deep water (flutes and scours),

- finding evidence for gas-related features (pock-marks), and
- discovering a previously unmapped seamount that rises more than 3000 m above the surrounding seafloor. This NE-SW trending feature, some 18 km wide and 40 km long with a slightly concave and northward tilted crest, has been officially named Healy Seamount (Fig 4).

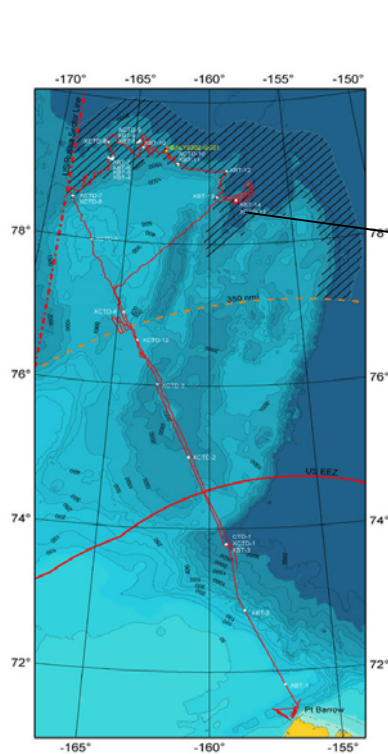


Figure 3. Track of HEALY-0302 September 2003.

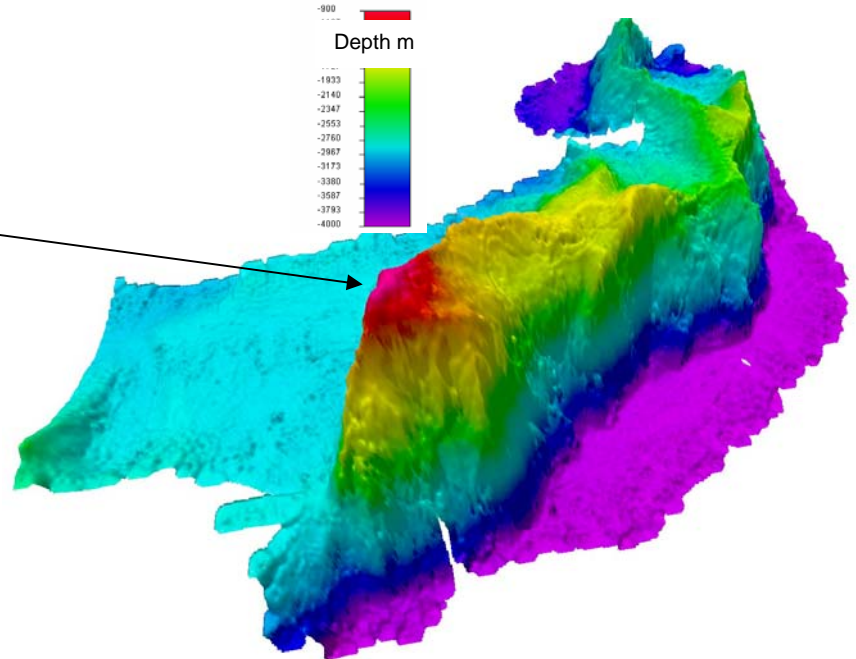


Figure 4. HEALY Seamount VE 5x looking N

Most importantly, the 2003 cruise demonstrated that it was possible to collect useful data while operating in 9/10 ice cover and to follow critical bathymetric targets.

HEALY-0405:

In 2004, a second, 20-day cruise was conducted from October 6 to October 26, originating in Nome and ending in Barrow, Alaska. This cruise covered approximately

6700 km in 20 days and completed most of the mapping of the 2500-m isobath (begun the previous year) as well as a detailed survey of the foot of the slope over a segment of the continental margin east of Barrow, AK. The total area surveyed during HE-0405 was approximately 20,000 sq. km (5830 sq. nmi).

The *Healy* transited northward from Nome over the Northwind Ridge until it intersected the 2500-m isobath at approximately 77° 10'N, 154° W, the point where the 350 nmi cutoff limit from the coast of northern Alaska intersects the 2500-m isobath on the eastern flank of the Northwind Ridge. Ice was first encountered at about 76°N and by 77°N the ice was very heavy (9/10 to 10/10) with many ridges and very few leads. Progress was slow and the *Healy* often had to backup and ram, nonetheless, the 2500-m isobath was mapped along the Northwind Ridge to approximately 78° 45'N. During this time, only ~100 nmi were covered in 4 days. Data was difficult to collect in these conditions and data quality suffered but the 2500 m isobath was still clearly defined. About 5000 sq. km (1458 sq. nmi) of seafloor was mapped during the transect to the north and back (Fig 5).

At 78° 45'N, the *HEALY* had great difficulty breaking through the multiyear ice ridges (one ridge took more than 8 hours to break through) and the decision was made to move south to the relatively ice-free waters of the continental slope east of Barrow. This area was chosen so that the foot of the slope could be defined in the central portion of the northern Alaskan margin. The foot of the slope can be used in this region as a starting point for determination of the “Gardiner Line” – one of the formula lines used for making an ECS submission under UNCLOS Article 76. During this survey, complete overlapping multibeam sonar data was collected over a region of approximately 15,435 sq. km (4500 sq. nmi), that ranges in water depth from about 650 m to 3900 m. This margin is dominated by a series of 400- to 600-m high ridges that extend to the NNW for more than 80 km from the upper slope. The ridges appear to be, at least in part, sedimentary in origin, possibly through an interaction of a strong geostrophic slope current and Mackenzie River sediment that has reached the slope (Fig 6).

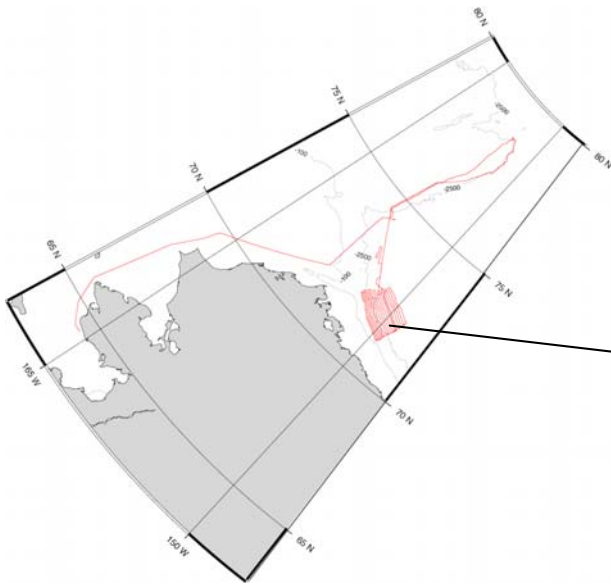


Fig 5. Shiptrack for HEALY 0405

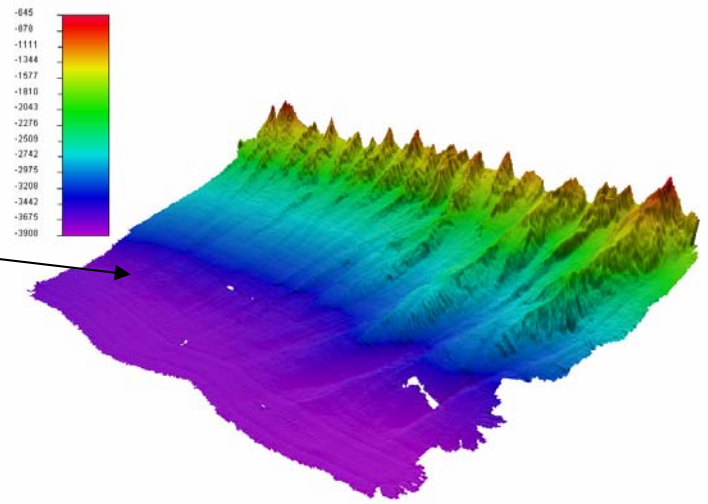


Figure 6. Barrow Margin survey. VE 16x – looking SW

HEALY-0703:

HEALY-0703 was conducted from August 17 to September 15, 2007, with both embarkation and disembarkation from Barrow, Alaska. The cruise track covered approximately 10,000 km (5400 nm) in 30 days (Fig. 7). Using a nominal swath width of approximately 7 km, the total area surveyed during HE-0703 was approximately 70,000 sq. km (20,400 sq nm). The primary objectives of the cruise were: 1) to complete the mapping of the 2500m isobath that began on HEALY 0302 and HEALY 0405; 2) to begin to define the foot of the slope around the northern and eastern edges of Chukchi Cap; and; 3) to further map an area of pockmarks originally discovered on HEALY-0302. All objectives were achieved, far beyond expectations.

Ice was first encountered at approximately 76°N. Although the ice was pervasive, it was mostly large pieces of thick, multiyear ice broken up enough to allow relatively easy passage at 3- 6 kts (though backing and ramming was required occasionally). Beginning at the U.S./Russian maritime boundary line, an exploratory, zig-zag pattern was run to better define the foot of the slope. No definitive foot of the slope was apparent until a

long excursion to the north revealed a clear transition (both bathymetrically and on the high-resolution sub-bottom profiles) between the slope and flat-lying abyssal plain sediments at approximately $81^{\circ} 15' \text{N}$ (Fig 8). Several more north–south transits consistently found that this same slope/abyssal plain transition occurs on the northern end of the cap above 81°N . Several prominent topographic highs, one that shoaled above 2500 m, which may allow the re-definition of the 2500 m isobath, were also discovered and mapped.

A well-developed foot of the slope was traced down and then back up the eastern side of Northwind Ridge, revealing a very sharp and clear slope/abyssal plain transition where the abyssal plain sediments consistently occur at a depth of approximately 3820 m. Following this transition to the north allowed the clear definition of a continuous foot of the slope around the northern most extreme of Chukchi Cap to the northern-most point of the survey ($82^{\circ} 17' \text{N}$); at this point, the slope/abyssal plain transition appears to continue to the north and east.

On HEALY-0302, several large and well-defined pockmarks (probably related to gas extrusion) were discovered in a shallow region of the Chukchi Cap at approximately $76^{\circ} 30' \text{N}$ and $163^{\circ} 50' \text{W}$. The survey of this region was extended in 2007 to generate a better map of the distribution of these pockmarks. An approximately 40 km x 14 km area was mapped revealing numerous pockmarks of various sizes, but typically about 300-400 m in diameter and 30 – 50 m deep (Fig. 9). Simultaneous collection of subbottom profiles revealed an apparent relationship to subsurface faulting but the nature of this relationship will need further study. A remarkable circle of pockmarks (approximately 20) were mapped that form a ring that is approximately 4 km in diameter (Fig. 9).

Abutting the pockmark area is a series of closely spaced, NW-SE oriented, parallel grooves in water depths of approximately 400 to 500 m. Given the parallel nature of these features, they appear to be related to ice-sheet flow rather than individual icebergs scours. Even more intriguingly, south of these grooves, as the water depths get a bit deeper, there is a series of large, dune-like features that appear erosional in origin in

the high-resolution subbottom profiles (Fig 10). We speculate that these may be related to flow under an ice-shelf that was not grounded but was near the seafloor.

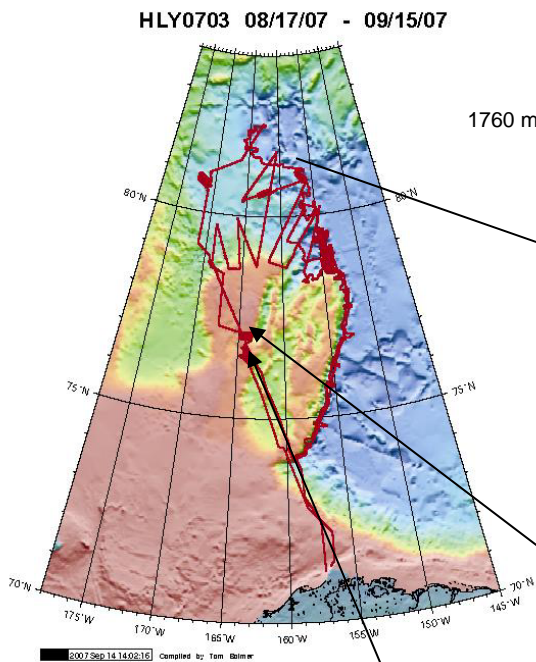


Figure 7 – HEALY0703 Shiptrack

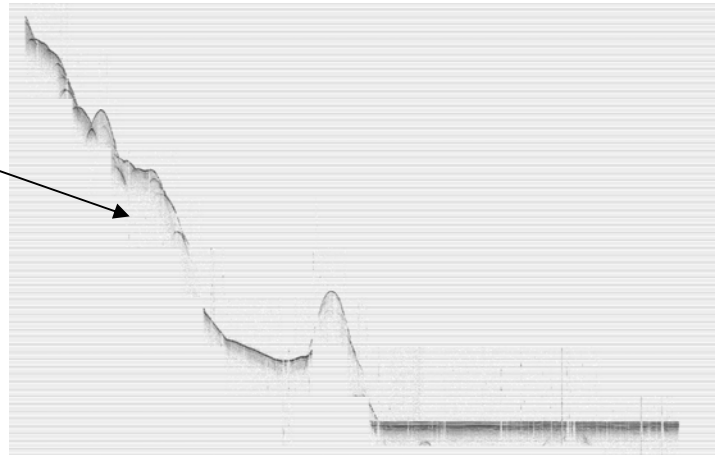


Figure 8- 3.5 kHz sub-bottom profile of slope/abyssal plain transition

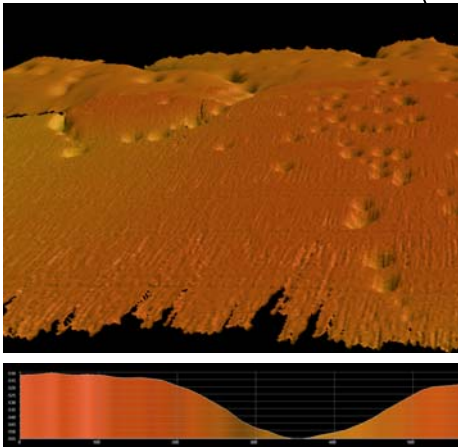


Fig. 9. Pockmarks mapped at about 400 m water depth on Chukchi Cap

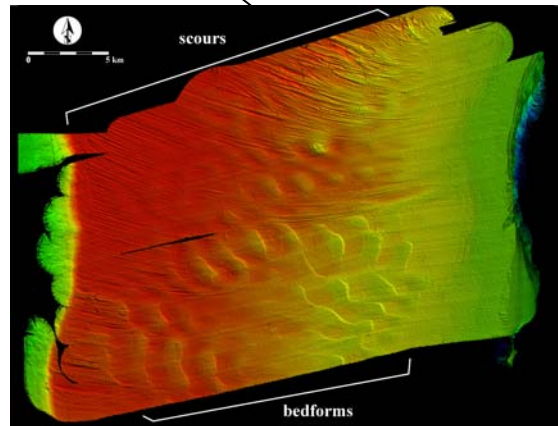


Fig. 10. Plan view of ice-related grooves and bedforms found at approximately 450m water depth on Chukchi Cap.

HEALY-0805:

The fourth bathymetric survey leg, HEALY 0805, departed Barrow on 14 Sept steaming north to pick up mapping of the region thought to represent the foot of the slope in the vicinity of 82° N and 162° W. Surveying continued east to follow the morphologic expression of the base of the slope until approximately 150° W where the character of the base of the slope changed and the surveying switched to a reconnaissance mode. This mode of survey continued until the eastern-most extent of the survey was reached at approximately 139° W. At this point, several regions that were suspected to shoal above 2500 m were mapped. A total of 3114 nautical miles were surveyed (5767 km) on HEALY0805 covering an area of approximately 34,600 sq. km (assuming an average swath width of 6 km) (Fig. 11).

HEALY-0805 also attempted to dredge key areas on the Alpha-Mendelev Ridge complex and the Chukchi Cap-Northwind Ridge in order to better understand the geologic and tectonic history of this remote region. A total of seven dredges were taken, four on the southern portions of the Alpha-Mendelev Ridge complex, two on ridges north of the Chukchi Borderland and one in the northwestern Northwind Ridge area. The first dredge site on the southern Alpha-Mendelev Ridge complex yielded samples from an outcrop of layered tuffaceous rock (hyaloclastite) that appears to represent a deposit of a shallow phreatomagmatic eruption (Mayer et al., 2008; Brumley et al., 2008). The second dredge from the same vicinity contained over 200 lbs of mud and ice rafted debris (IRD). The third dredge, from another feature on the southern Alpha-Mendelev Ridge Complex, also brought back only mud and IRD. The fourth dredge, from the same general vicinity as the third, was predominantly mud and IRD, however, the dredge haul also included iron concretions and manganese crusts along with one sample of a possible altered ash deposit. The fifth dredge, from the northern margin of the Chukchi Borderland, recovered more than 1000 lbs of mud with about 10 lbs of IRD of various rock types. The sixth dredge from a very steep (about 60°) slope on the northern Chukchi Borderland was mud free and contained more than 200 lbs of what appear to be basalts, some with fresh glassy rims and pillow-like structures (Andronikov, et al., 2008). Finally, the seventh dredge from the western wall of Northwind Ridge had very little mud but

more than 700 lbs of rocks that probably represent both outcrop and angular talus from the foot of the steep slope from which it was dredged. Samples from this dredge contain a range of rock types including sedimentary (including sandstones and mudstones), metamorphic, and basaltic, all supporting the notion that Chukchi Cap is of continental origin. Further analyses of all of the dredge samples are currently underway.

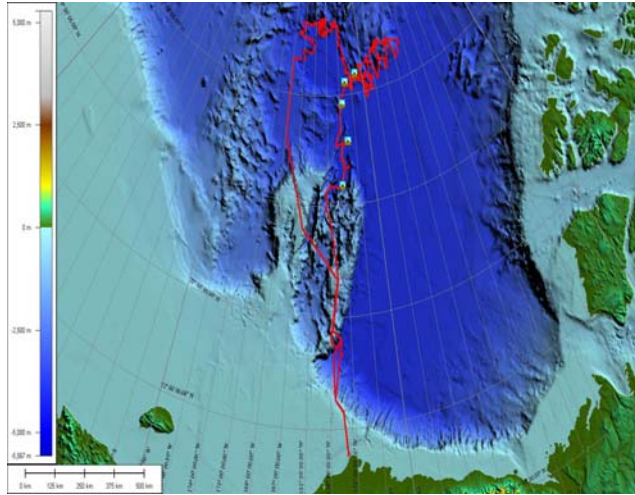


Figure 11. *Healy 0805 – Ship Track 14 Aug –5 Sept. 2008 – Dredge sites indicated by small blue icons. Dredges are numbered sequentially (1–7) from north to south, Dredge Sites 1 and 2 are at the same location and represented by a single icon; dredge sites 3 and 4 are at the same location and represented by a single icon.*

A second expedition took place in 2008 (HEALY-0806) which was a collaborative effort between Canada and the U.S. During this two-ship effort, *Healy* broke ice ahead of the Canadian icebreaker *Louis St. Laurent* while the *Louis St. Laurent* collected deep seismic reflection profiler data (in order to measure sediment thickness) in the open water created by the *Healy*. A 2009 cruise to the Arctic is planned, again in company with the *Louis St. Laurent* and again with the primary purpose of collecting seismic data from the *Louis St. Laurent*. All bathymetric data collected during Law of the Sea cruises on the *Healy* and full cruise reports of each of the expeditions described here can be found at the CCOM/JHC website: <http://www.ccom.unh.edu/>

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