EOS

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 90 NUMBER 23

9 JUNE 2009

PAGES 197–204

Acquiring Marine Data in the Canada Basin, Arctic Ocean

PAGES 197–198

Despite the record minimum ice extent in the Arctic Ocean for the past 2 years, collecting geophysical data with towed sensors in ice-covered regions continues to pose enormous challenges. Significant parts of the Canada Basin in the western Arctic Ocean have remained largely unmapped because thick multiyear ice has limited access even by research vessels strengthened against ice [*Jackson et al.,* 1990]. Because of the resulting paucity of data, the western Arctic Ocean is one of the few areas of ocean in the world where major controversies still exist with respect to its origin and tectonic evolution [*Grantz et al.,* 1990; *Lawver and Scotese,* 1990; *Lane,* 1997; *Miller et al.,* 2006].

This article describes the logistical challenges and initial data sets from geophysical seismic reflection, seismic refraction, and hydrographic surveys in the Canada Basin conducted by scientists with U.S. and Canadian government agencies (Figure 1a) to fulfill the requirements of the United Nations Convention on the Law of the Sea to determine sediment thickness, geological origin, and basin evolution in this unexplored part of the world. Some of these data were collected using a single ship, but the heaviest ice conditions necessitated using two icebreakers, similar to other recent Arctic surveys [e.g., *Jokat,* 2003].

Overall, the quality of the resulting data is excellent, and the many lessons learned in the past three seasons of field programs have resulted in steady improvements to strategies for maximizing geological information in these difficult conditions. In the past, air guns and hydrophone streamers have been used for marine seismic reflection profiling in this part of the Arctic [*Grantz et al.,* 2004], but recent advances in the design, electronics, and reliability of the components of the seismic system have resulted in much improved data quality.

By D. R. Hutchinson, H. R. Jackson, J. W. Shimeld, C. B. Chapman, J. R. Childs, T. Funck, and R. W. Rowland

Data Collected

To measure sediment thickness accurately beneath ice-covered oceans, where ice poses significant risk to survey equipment, the preferred strategy is to use a short-offset hydrophone streamer for reflection data concurrently with expendable sonobuoys to record long-offset refraction data. The reflection data provide images of subsurface sedimentary layers and the underlying crust, while the refraction data yield measurements of seismic velocity for accurate depth and thickness conversions. The short-offset streamers (<300 meters long) are readily deployed and recovered, minimizing potential damage by ice if the survey vessel becomes stuck or needs to maneuver in limited space. The expendable sonobuoys transmit recorded signals to the survey ship for intervals of up to 8 hours and ranges of up to 30 kilometers, enabling the seismic survey to proceed continuously without stopping for the recovery of ocean-bottom or on-ice seismometers.

For the first full season of data collection in 2007, a digital multichannel streamer with 16 channels (6.25 meters per channel) was used. Signal-to-noise ratios were better than those recorded with an analog streamer during a 2006 test cruise. Two Sercel G-gun air guns having a total volume of 1040 cubic inches constituted the source signal. The streamer and air gun cluster (Figure 1b) were deployed from a weighted sled that was towed immediately aft of the icebreaker at a depth of about 12 meters. The 2007 expedition collected approximately 3000 kilometers of data using a single icebreaker, Canadian Coast Guard Ship (CCGS) *Louis S. St-Laurent*.

In 2008, the same equipment was used to collect approximately 1300 kilometers of seismic data in single-icebreaker mode with three air guns totaling 1190 cubic inches. As part of the collaboration between Canada and the United States to collect useful data in thick ice in the northern part of the Canada Basin, a second icebreaker, U.S. Coast Guard Cutter (USCGC) *Healy*, joined the experiment for 3 weeks to break ice ahead of *Louis* during seismic profiling, enabling acquisition of an additional 1500 kilometers of seismic data. *Louis*, with seismic gear stowed, broke ice ahead of *Healy* in the heaviest ice so that *Healy* could collect quality swath bathymetric and high-resolution subbottom data along the Canadian continental margin. Approximately 950 kilometers of multibeam/high-resolution data were collected in this configuration. *Healy* also collected marine gravity data. During the 2007 and 2008 field programs, about 70 expendable sonobuoys acquired wide-angle data.

Logistical Challenges

Single-ship operations with towed gear in the Arctic are limited to operating in light to moderate ice cover where the ship can avoid backing and ramming to move through the ice field. For the single-ship work in 2007, the track lines were rarely straight because of the need to seek open-water leads or areas with new ice where the need to back and ram through ice was minimized. Although 3000 kilometers of data were collected, the straight-line distance covered was much less. Using two ships increased safety and efficiency in these polar operations and made possible the collection of data along straighter paths in areas where surveying otherwise would have been impossible.

Equipment is most vulnerable to damage during deployment and recovery when, for instance, the streamer could become entangled and damaged in ice or when gear could freeze. Multiple deployments of equipment are impractical and inefficient in cold environments and also are difficult for the deck crew. With two ships operating in 2008, the towed gear was more protected. On multiple occasions, *Healy* broke *Louis* out of ice when *Louis*, towing the seismic array, was stuck. Although the seismic streamer hung vertically in the water when *Louis* was stuck, the gear did not need to be recovered while *Healy* cleared a path. With *Louis* freed, the seismic profiling then continued without incident.

Data quality sometimes was compromised by the ice. Because of the interference from ice beneath the hull, hull-mounted sensors, such as the multibeam and high-resolution 3.5-kilohertz subbottom profiler on *Healy*, were seriously degraded when *Healy* was the lead vessel in heavy ice. These hull-mounted sensors worked far better when *Healy* followed *Louis*. Also, there were occasions when it was impractical for either ship to lead because of the high likelihood of

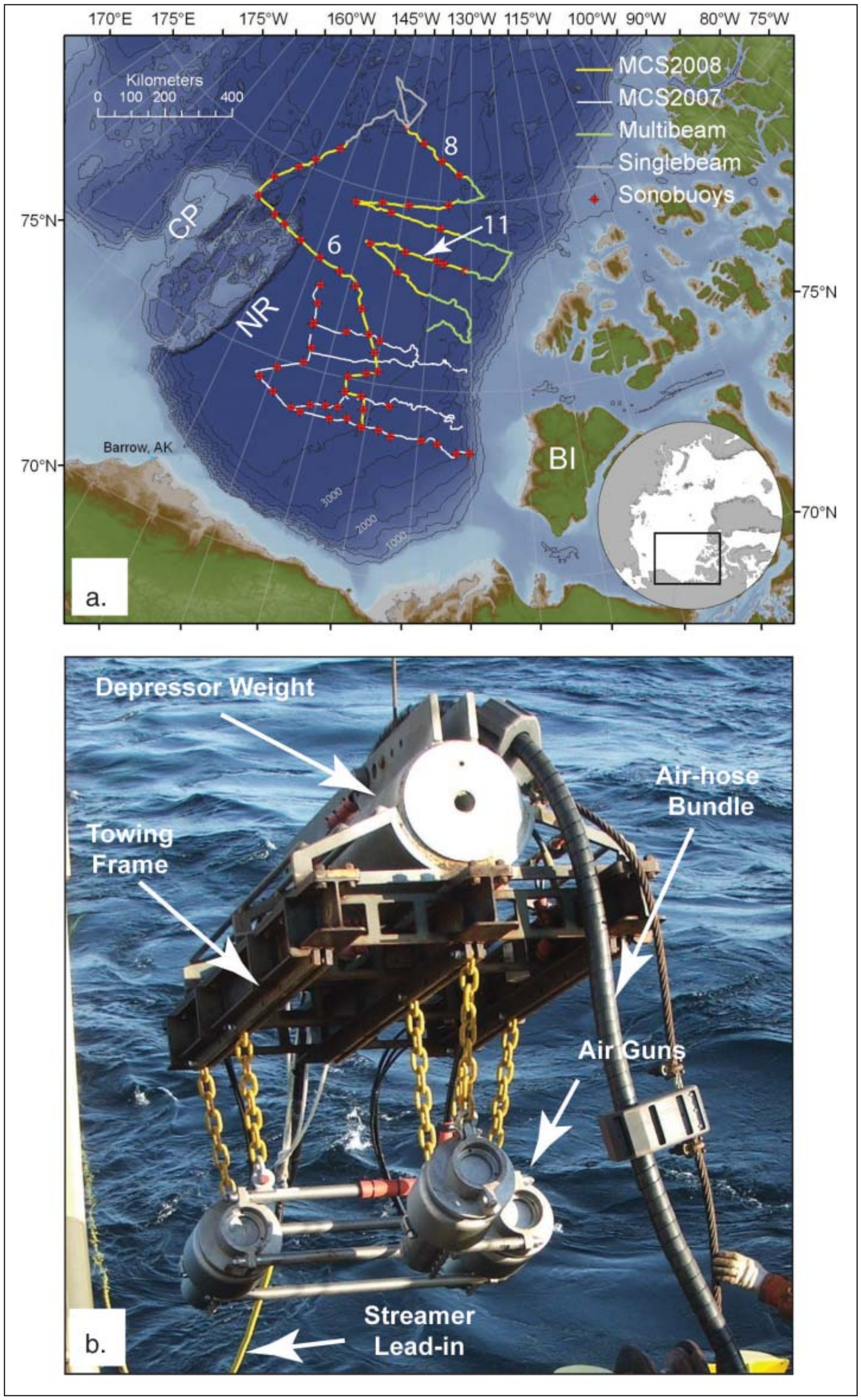

Fig. 1. (a) Location map of the Canada Basin showing track and sonobuoy locations for the 2007 and 2008 field programs. Numbers indicate line numbers of seismic profiles shown in Figure 2. NR, Northwind Ridge; CP, Chukchi Plateau; BI, Banks Island. Bathymetric contours are drawn every 500 meters. The 1000-, 2000-, and 3000-meter isobaths are labeled. (b) Air gun and streamer towing system aboard Canadian Coast Guard Ship (CCGS) Louis S. St-Laurent. *The depressor weight to sink the air guns is about 2100 kilograms. The two aft air guns are held apart by rigid spreader bars. The streamer lead-in cable tows from a connection at the back of the towing frame. The air gun/hose bundle holds air hoses, firing lines, and streamer coaxial cable.*

getting stuck. In these situations, the ships ran side by side so that the path broken by each relieved the ice pressure to allow the other to make forward progress. During such times, the seismic system was on deck until reaching lighter ice conditions when normal two-ship operations could resume.

Preliminary Observations

The quality of the seismic data collected with the two ships in even the heaviest ice was excellent. Figure 2 compares portions of three seismic lines from the Canada Basin; one was collected in light-ice conditions when *Louis* was operating in single-ship mode (Figure 2a), and the other two were collected from two-ship lines (Figures 2b and 2c). Despite the thick sediments in the Canada Basin (up to about 4 seconds two-way travel time), crystalline basement rock beneath the flat-lying sediments is clearly imaged on each profile. Distinct and mappable sedimentary seismic stratigraphic horizons are evident. Many of these horizons are traceable regionally across the basin and will provide constraints on the relative timing and magnitude of tectonic and depositional events as well as test hypotheses of the rotational origin and seafloor spreading geometry of the basin [*Grantz et al.,* 1990; *Lawver and Scotese,* 1990].

Shipboard analysis identified three different basement types. The basement just east of Northwind Ridge (Figure 2a) is flat and planar and dips uniformly eastward. *Grantz et al.* [1990] postulated that there is highly stretched continental crust in this region. In the northern part of the Canada Basin (Figure 2b), many subbasement reflections occur, including dipping events, similar in geometry to fan-shaped features that could represent extensional rift basins or seaward dipping reflections associated with magmatism. Neither interpretation can be ruled out because of the known history of multiple rifting events in the area [*Harrison and Brent,* 2005] and because of the area's proximity to Alpha Ridge, part of the High Arctic large igneous province [*Maher,* 2001]. In the central Canada Basin (Figure 2c), the basement is more deeply buried, highly faulted, and of higher relief than elsewhere in the basin. Once the depth, shape, and extent of these basement horizons are merged with potential field and velocity measurements, a more constrained model of the rifting, subsidence, and tectonic history can be developed, yielding a better understanding of the complex plate interactions that formed the basin.

Future Plans

The Convention on the Law of the Sea has provided coastal nations with incentives for collaborating to collect geophysical data in areas such as the Arctic, where logistical challenges of working in remote and ice-covered regions have long prevented routine data collection. With modifications to strengthen the towing package to better withstand ice, conventional high-resolution multichannel data were collected in single-icebreaker mode in the Canada Basin of the western Arctic Ocean in 2007 (about 3000 kilometers) and 2008 (about 1300 kilometers). Two icebreakers working collaboratively in 2008 enabled the data collection of an additional

1500 kilometers in the eastern portions of the Canada Basin, where conventional seismic reflection and refraction data are sparse to nonexistent. Additional programs involving two icebreakers are planned for 2009 and 2010. When finished, these cruises will be invaluable for fulfilling the mapping requirements of the Convention on the Law of the Sea as well as for understanding the tectonic and geological origin of this controversial polar region.

Acknowledgments

We wish to thank the captains and crews of the CCGS *Louis S. St-Laurent* 2006–2008 and USCGC *Healy* 2008 cruises. We gratefully acknowledge the support provided by the U.S. Interagency Task Force for the Extended Continental Shelf. The use of trade names is for descriptive purposes only and does not constitute endorsement by the U.S., Canadian, or Danish governments. U. ten Brink, D. Houseknecht, M. Salisbury, and S. Dehler provided constructive reviews. Geological Survey of Canada contribution 20080653.

References

Grantz, A., S. D. May, P. T. Taylor, and L. A. Lawver (1990), Canada Basin, in *The Geology of North America,* vol. L, *The Arctic Ocean Region,* edited by A. Grantz, L. Johnson, and J. F. Sweeney, pp. 379–402, Geol. Soc. of Am., Boulder, Colo.

Grantz, A., P. E. Hart, and S. D. May (2004), Seismic reflection and refraction data acquired in Canada Basin, Northwind Ridge and Northwind Basin, Arctic Ocean in 1988, 1992 and 1993, *U.S. Geol. Surv. Open File Rep., 2004-1243.* (Available at http://pubs.usgs.gov/of/2004/1243/)

Harrison, J. C., and T. A. Brent (2005), Basins and fold belts of Prince Patrick Island and adjacent areas, Canadian Arctic Islands, *Bull. Geol. Surv. Can., 560,* 195 pp.

Jackson, H. R., D. A. Forsyth, J. K. Hall, and A. Overton (1990), Seismic reflection and refraction, in *The Geology of North America,* vol. L, *The Arctic Ocean Region*, edited by A. Grantz, L. Johnson, and J. F. Sweeney, pp. 153–170, Geol. Soc. of Am., Boulder, Colo.

Jokat, W. (2003), Seismic investigations along the western sector of Alpha Ridge, central Arctic Ocean, *Geophys. J. Int., 152*(1), 185–210.

Lane, L. S. (1997), Canada Basin, Arctic Ocean: Evidence against a rotational origin, *Tectonics, 16,* 363–387.

Lawver, L. A., and C. R. Scotese (1990), A review of tectonic models for the evolution of the Canada Basin, in *The Geology of North America,* vol. L, *The Arctic Ocean Region,* edited by A. Grantz, L. Johnson, and J. F. Sweeney, pp. 593–618, Geol. Soc. of Am., Boulder, Colo.

Maher, H. D., Jr. (2001), Manifestations of the Cretaceous High Arctic large igneous province in Svalbard, *J. Geol., 109,* 91–104.

Miller, E. L., J. Toro, G. Gehrels, J. M. Amato, A. Prokopiev, M. I. Tuchkova., V. V. Akinin, T. A. Dumitru, T. E. Moore, and M. P. Cecile (2006), New insights into Arctic paleogeography and tectonics from U-Pb detrital zircon geochronology, *Tectonics, 25,* TC3013, doi:10.1029/2005TC001830.

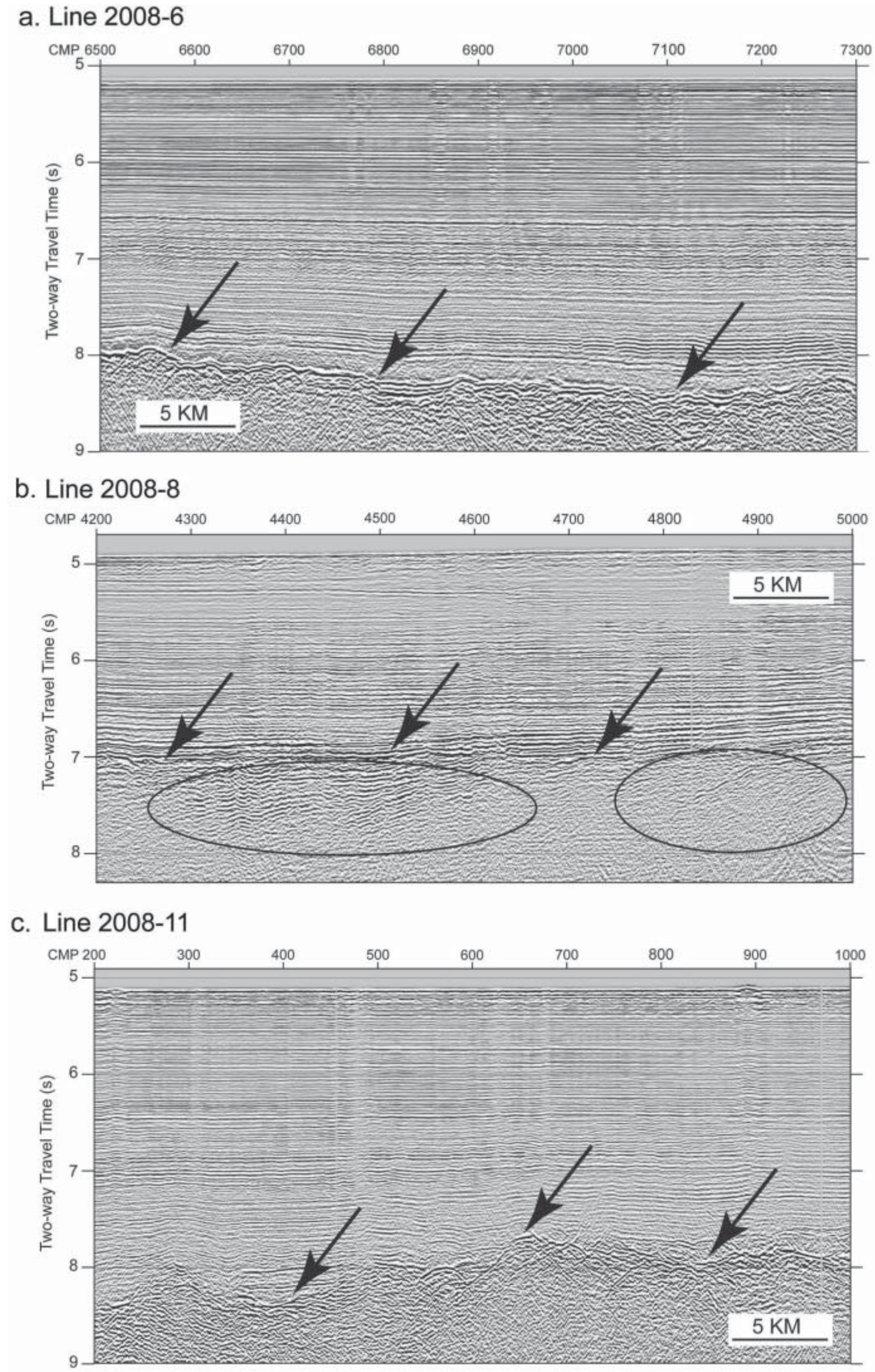

Fig. 2. Seismic profiles showing basement in the Canada Basin. See Figure 1a for locations. All sections are plotted with southeast to the right. Arrows indicate location of the interpreted basement horizon. (a) Smoothly dipping basement east of Northwind Ridge (line 2008-6). (b) Basement in the northern part of Canada Basin (line 2008-8). General areas of dipping reflections are shown by ovals. (c) Rough, irregular basement in the central Canada Basin (line 2008-11).

Author Information

Deborah R. Hutchinson, U.S. Geological Survey (USGS), Woods Hole, Mass.; E-mail: dhutchinson@usgs.gov; H. Ruth Jackson, John W. Shimeld, and C. Borden Chapman, Natural Resources Canada, Geological Survey of Canada, Dartmouth, Nova Scotia, Canada; Jonathan R. Childs, USGS, Menlo Park, Calif.; Thomas Funck, Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark; and Robert W. Rowland, USGS (retired), Elkhart, Indiana