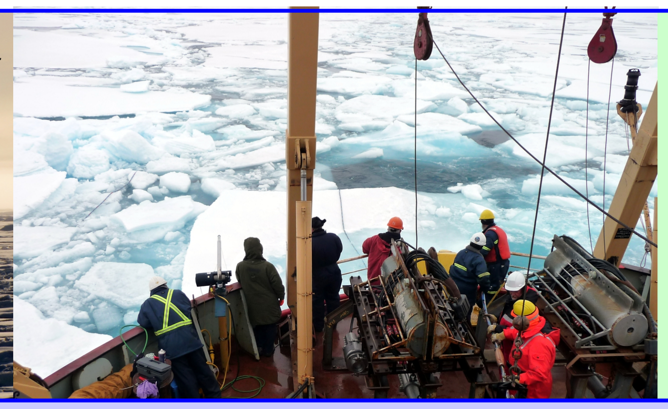


Open File 6822: Evidence for an important tectonostratigraphic seismic marker across Canada Basin and southern Alpha Ridge of the Arctic Ocean

J.W Shimeld[1], D. Chian[2], H.R. Jackson[1], D. Hutchinson[3], D.C. Mosher[1], J.A. Wade[1] and C.B. Chapman[1]

[1]Geological Survey of Canada (Natural Resources Canada), [2]Chian Consulting Incorporated, [3]United States Geological Survey (Department of the Interior)

ABSTRACT

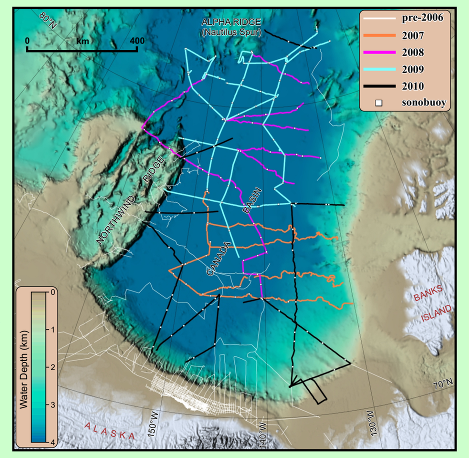
An extensive modern dataset of short-offset seismic reflection profiles coupled with wide-angle reflection and refraction sonobuoy records enable new insights into the crustal types, rifting processes, subsidence history, and sedimentary sequences of Canada Basin, Northwind Ridge, and southern Alpha Ridge. Exceeding 6.5 km in thickness across southern Canada Basin and thinning northward to Alpha Ridge, the sedimentary succession is divided into more than a dozen regional seismostratigraphic units, the oldest of which is informally named the bisque unit. Characterized by anomalously high-amplitude reflections, this unit is of interest since it immediately overlies acoustic basement and may indicate something about the nature of basement and its tectonic history. Along southern Alpha Ridge, including Nautilus Spur, the base of the bisque unit is marked by a prominent angular unconformity that can be traced southward into Canada Basin before becoming obscured by deep burial. The bisque unit appears to be concordant with basement topography and it is clearly offset by faults created during the most recent significant extension of the basin. Distinct onlap of overlying units indicates that extension was accompanied by apparently rapid subsidence and then quiescence. Large basement structures interpreted to be volcanic edifices are immediately overlain and at least partially covered by the bisque unit which might indicate a genetic linkage.

On sonobuoy records, two distinct phenomena are observed for the bisque layer: 1) wide-angle reflections and refractions on records distributed widely across the study area; and 2) high amplitude phases of anomalously low apparent velocity across northern Canada Basin and Nautilus Spur. The latter are modelled as converted waves with down-going P-to-S and up-going S-to-P conversions occurring at the bisque layer. This is an important phenomenon since it presents the possibility of estimating Poisson's ratio for crustal layers beneath bisque which would be a valuable constraint in determining crustal types.

Though not yet sampled, the bisque unit is interpreted to consist of high-velocity siliceous oozes interbedded with hemipelagic and pelagic sedimentation. In Canada Basin, it may correlate with mid-to-upper Cretaceous tuffs of the Christopher and Kanguk formations found on Banks and Prince Patrick islands. The unit may become increasingly younger northward over Alpha Ridge.

STUDY AREA

Heavy ice conditions hindered seismic acquisition across most of the study area until 2006 when the GSC designed and tested a specialized digital seismic system for deployment from an icebreaker. The first production survey with this system was in 2007 using a single icebreaker, the CGGS *Louis S. St-Laurent* (Jackson, 2008). Subsequent surveys, from 2008 through 2010, were conducted using two icebreakers, the CGGS *Louis S. St-Laurent* and USCGC *Healy*, under a collaborative agreement with the United States Geological Survey (Jackson and DesRoches, 2008; Hutchinson *et al.*, 2009; Mosher *et al.*, 2009; Shimeld *et al.*, 2009).

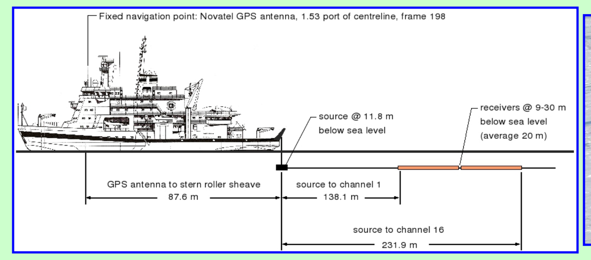


In total, 14030 km of seismic reflection data have been acquired along with 144 wide-angle reflection and refraction records obtained using expendable sonobuoys.

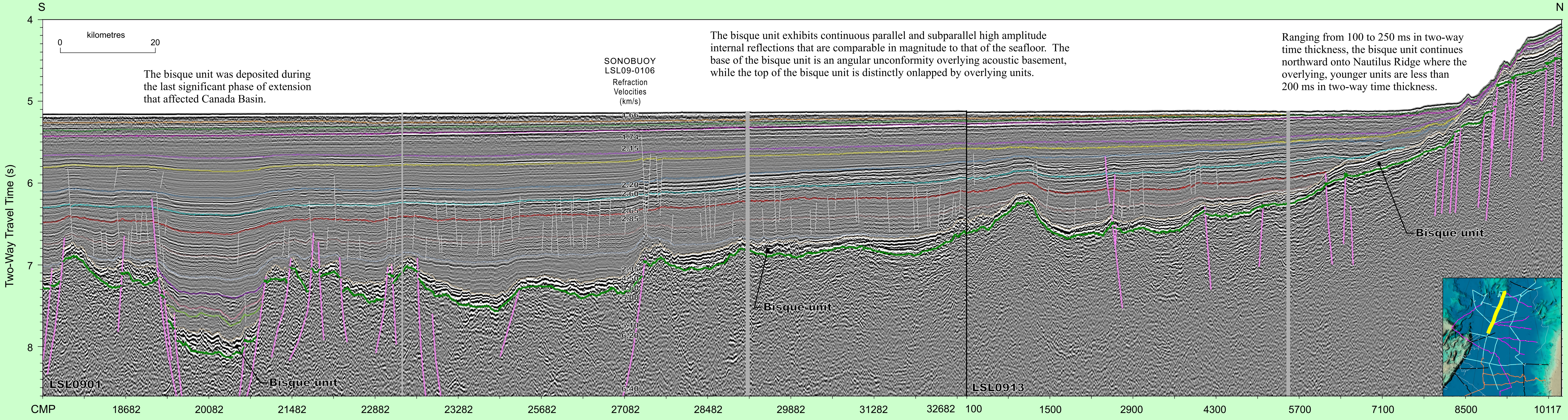
METHODS

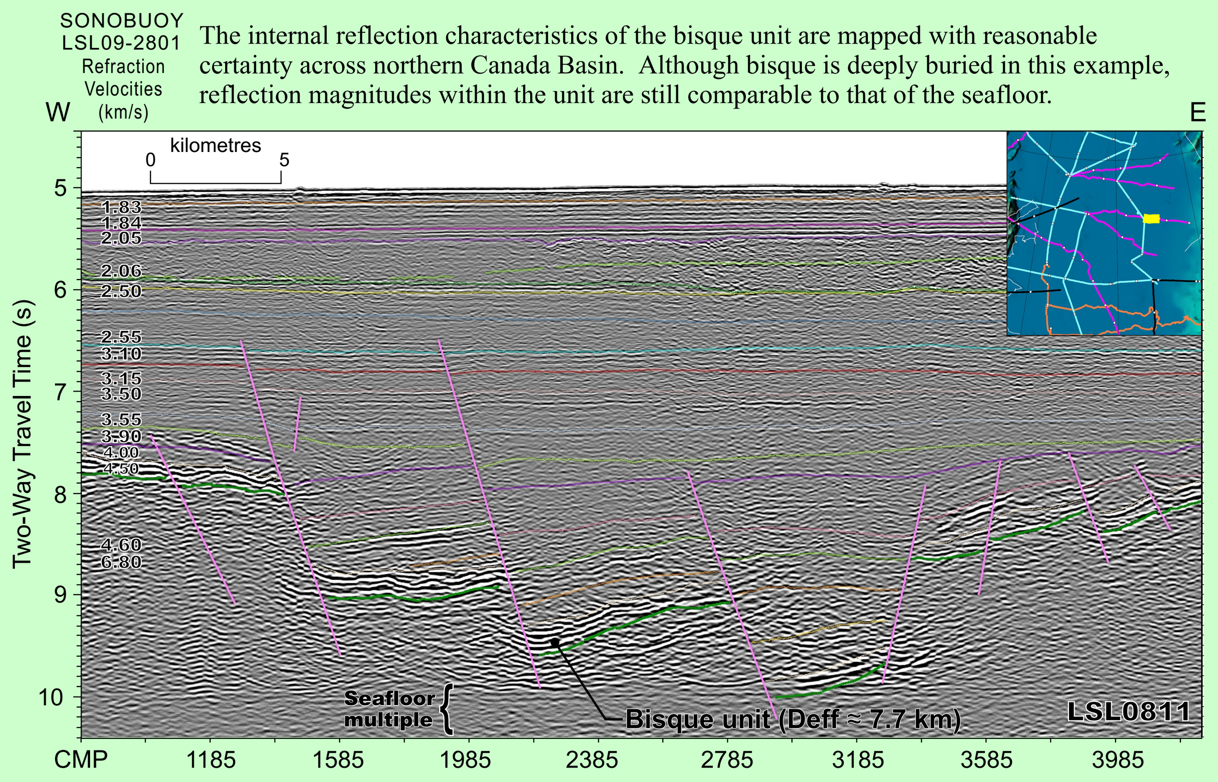
Short-offset, 16-channel seismic reflection data were acquired along crooked tracks through highly variable ice and open-water conditions. The source was fired at constant time intervals, so fluctuations in vessel speed produced shotpoint intervals ranging from 0 to 50 m (average ~30 m). Common midpoint bins were designed at 12.5 m intervals, typically yielding 12–20 traces per gather from adjacent shots. Bandpass filtering was applied with low-cuts dependant on noise level (3–8 Hz for 84% of the data). High amplitude coherent noise from cable strum and prop wash was removed with F-K filtering before spherical divergence scaling and trace balancing. Minimum phase conversion and source signature deconvolution were applied using source wavelets measured in the field with a receiver ghost correction, followed by predictive deconvolution. Time shifts were applied to account for firing and recording delays as well as average source-receiver depths below sea level. Normal moveout corrections were then applied to the common midpoint gathers and residual shifts were calculated to optimize stacking power. After stack, the primary seafloor multiple was attenuated with an adaptive subtraction algorithm (Wang, 2003) and residual bubble pulse was suppressed with predictive deconvolution. Random noise was attenuated with time-variant bandpass filtering (3/8/70/100 Hz at 1 s below seafloor to 3/8/40/60 Hz at 3.5 s below seafloor), F-X deconvolution, singular value decomposition filtering, and trace mixing. Using a 1-D function of refraction velocities, finite difference migration was applied to the data followed by a trace balance using 1 s windows with 50% overlap.

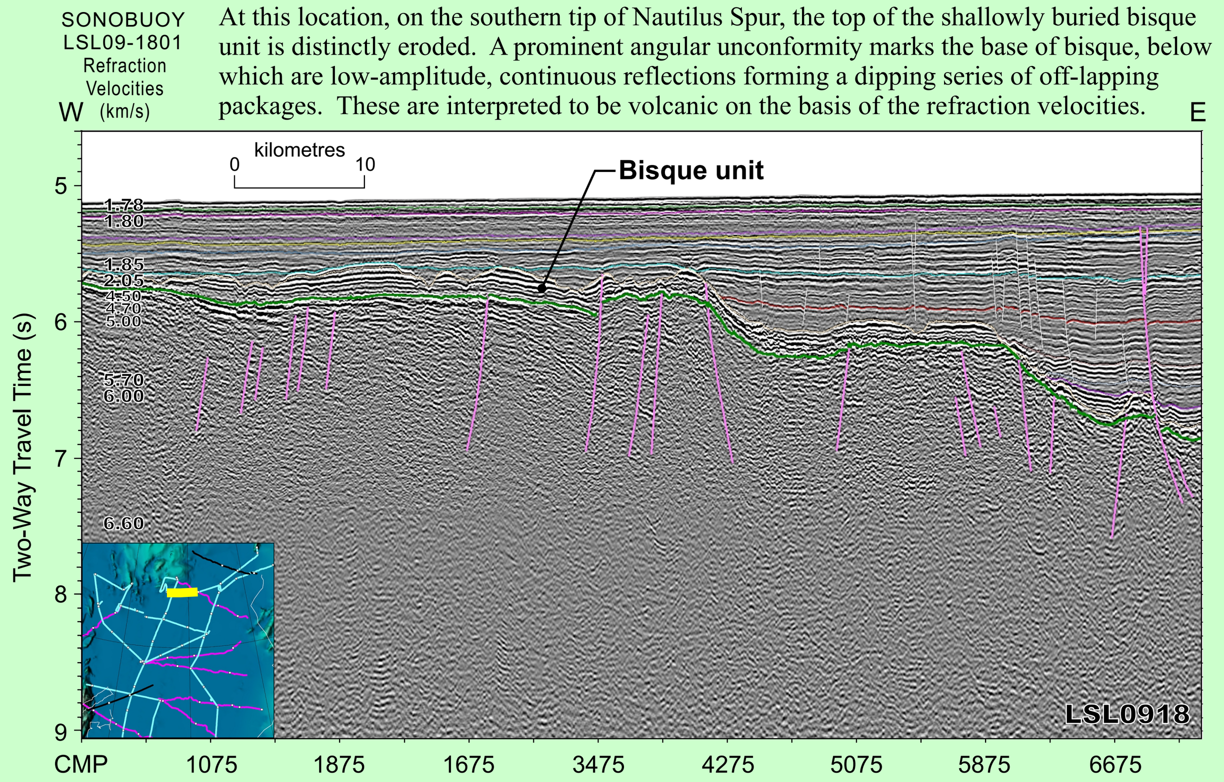
For the sonobuoy records, source-receiver offsets were calculated using direct water waves. Subsequent processing included spherical divergence amplitude scaling, despiking, deconvolution, and low-pass filtering.

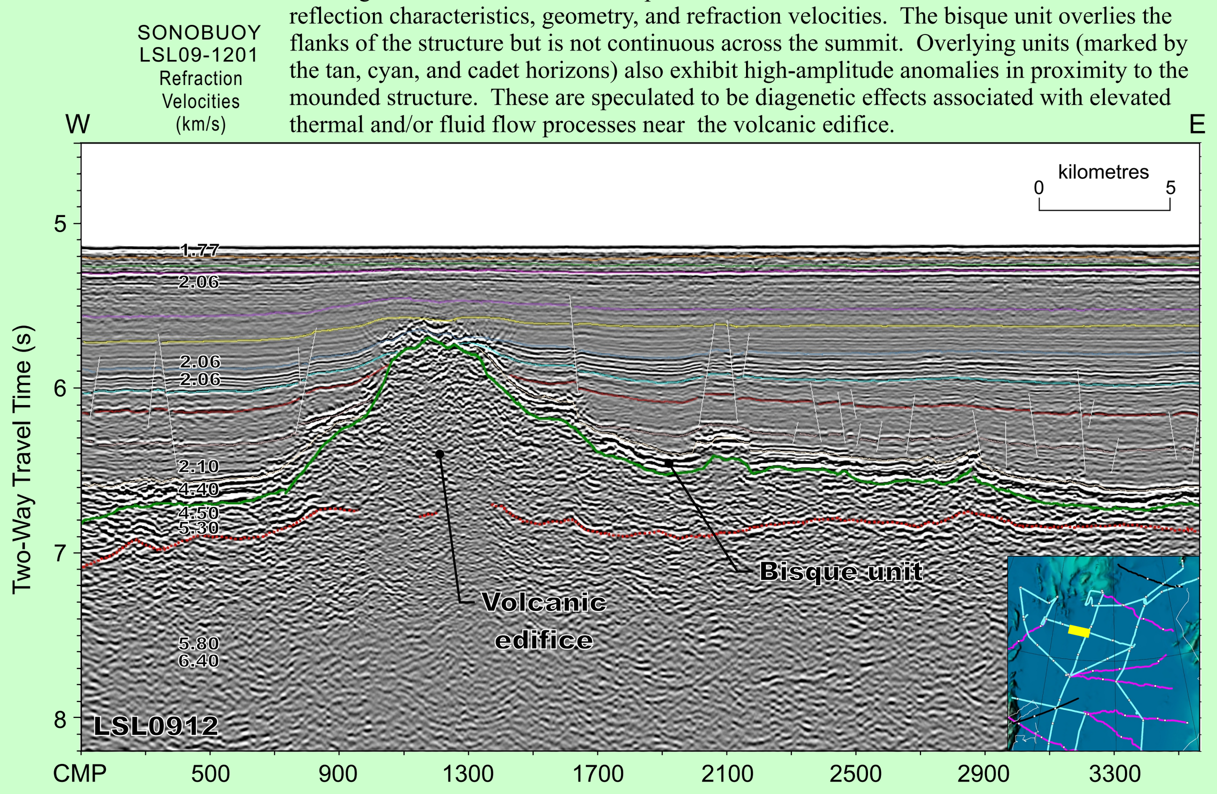


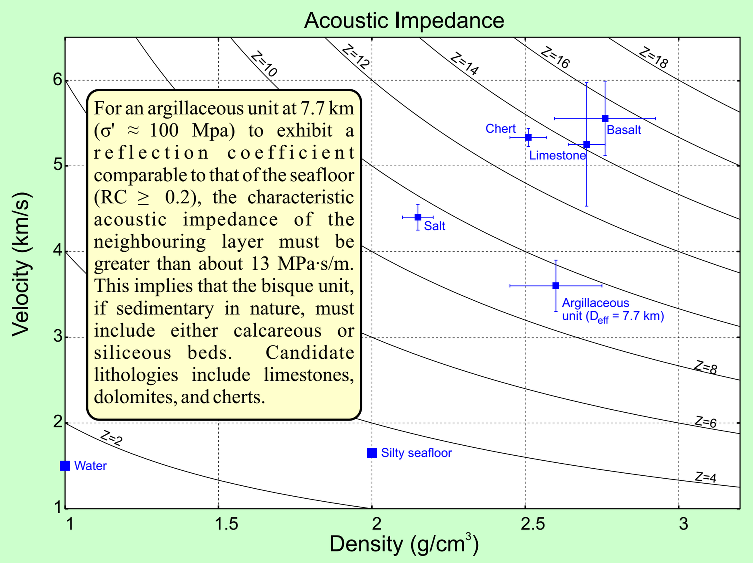
RESULTS

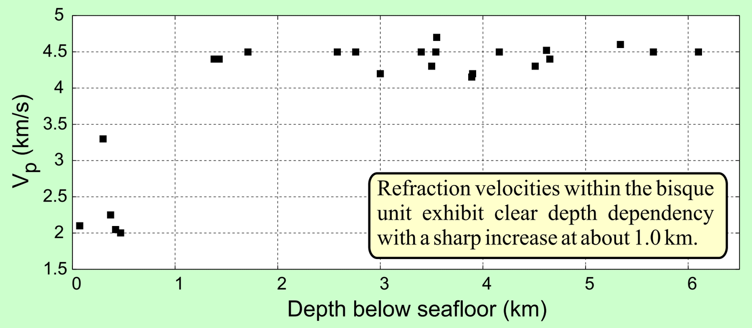


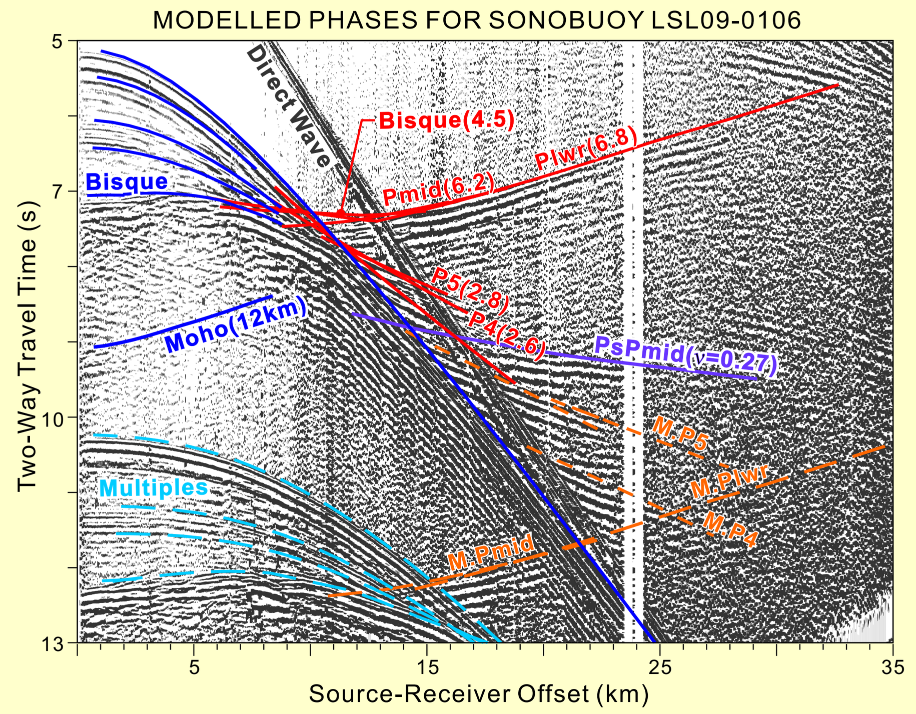




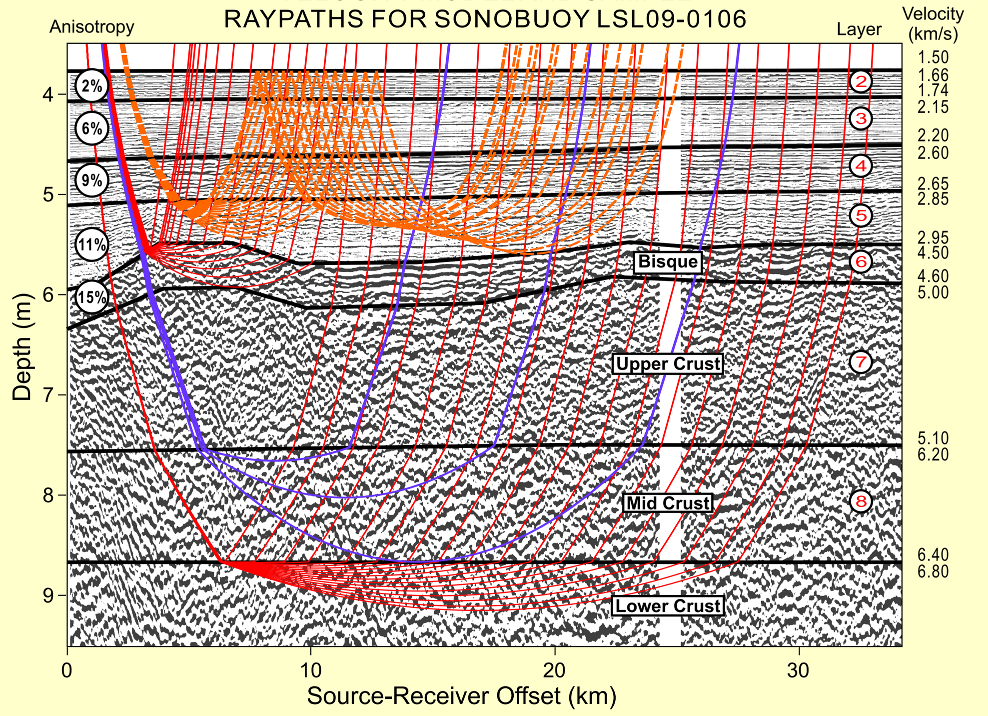






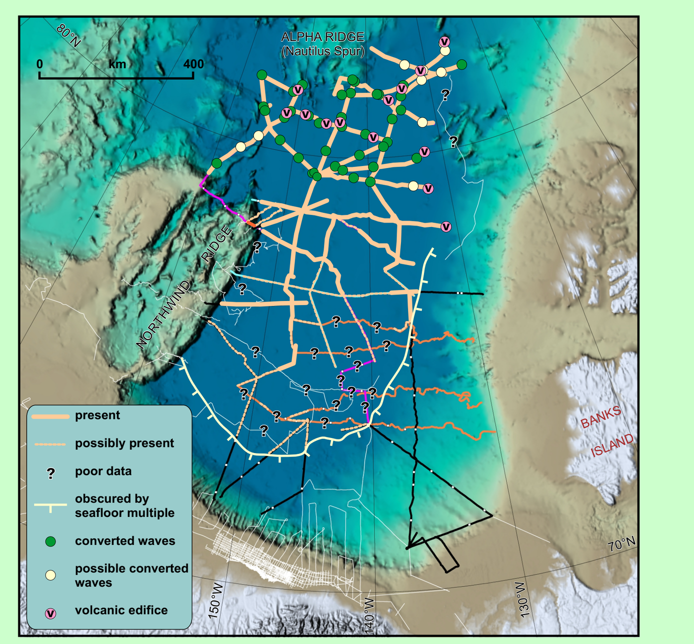


Ray-trace modelling results were obtained using a modified version of the RAYINV code (Zelt and Ellis, 1988; Zelt and Smith, 1992). Modelled phases include wide-angle reflections, reflection multiples, refractions, and refraction multiples. The PsPmid phase is a converted wave with down-going P-to-S and up-going S-to-P conversions occurring at the top of the highly reflective bisque unit. This phase travels through the mid-crustal layer as a shear wave, which permits an estimate of Poisson's ratio (ν = 0.27).



Sample raypaths are shown for Plwr, PsPmid, M.P5, and P6 (which corresponds to the bisque unit). To best match the observed PsPmid phase, a simple ray-angle dependant model of transverse anisotropy was derived using data from Bachman (1983) and Wang (2002).

DISTRIBUTION OF THE BISQUE UNIT



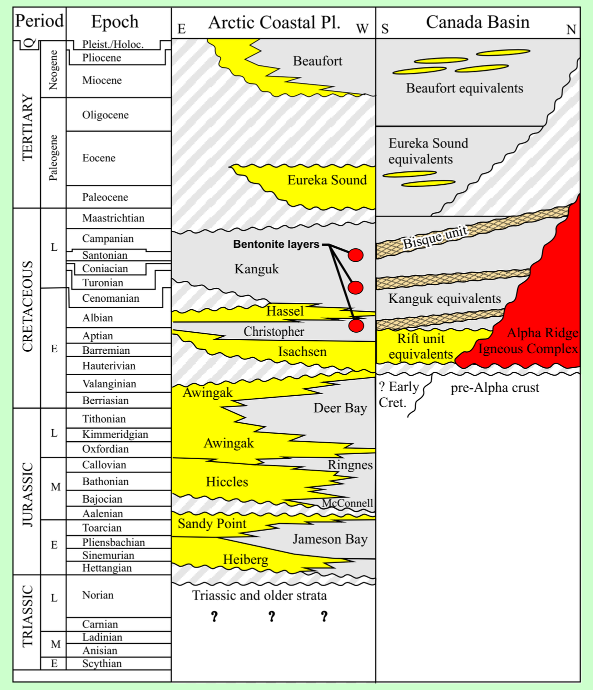
The bisque unit is mapped with confidence across northern Canada Basin on the basis of its high amplitudes, internal reflection characteristics, unconformable base, and also the onlap relationships of overlying units. Deep burial combined with poor data quality hinders confidence in the central basin, while primary seafloor multiples obscure the deeply buried basement along the southern and eastern margins. Converted waves are observed only in the northern portion of the study area where the sedimentary velocities immediately above bisque are less than the S-wave velocity.

INTERPRETATION AND DISCUSSION

The widespread distribution and consistent seismic signature of the bisque unit (to a first-order level of detail) suggests that it formed in a marine setting. One hypothesis is that the unit is comprised of biosiliceous oozes interbedded with pelagic and hemipelagic clays. Given the proximity of the Alpha Ridge igneous complex, there could also be significant components of pyroclastics and volcaniclastics. A useful analogue might the Hawaiian Ridge, which was investigated during Leg 136 of the Ocean Drilling Program (Wilkens *et al.*, 1993). At Sites 842 and 843, 200 m of layered chert are interbedded with pelagic carbonate muds overlying oceanic layer 2 volcanics. Seismic reflection characteristics of the chert unit are very similar to those of the bisque unit, and refraction profiles also exhibit high amplitude converted waves (Brocher and Brink, 1987).

Seismic examples published by Jokat (2003) and also Bruvoll *et al.* (2010) show high amplitude reflection units over acoustic basement from various regions of Alpha-Mendeleev Ridge that might be similar or even correlatable with the bisque unit. Sonobuoy SB9803 from the Jokat (2003) study exhibits a low apparent velocity phase that seems similar to the converted waves found in Canada Basin. Further analyses might support the inference that a unit equivalent or similar to the bisque unit is widespread across Alpha Ridge.

Biosiliceous oozes are documented from three separate sites over Alpha Ridge (T3 cores 422 and 437, CESAR core 6 ; Clark *et al.*, 1980 ; Mudie and Blasco, 1985 ; Stoffyn-Egli, 1987 ; Clark *et al.*, 1990). Though age constraints are poor, it is possible that the processes which formed biosiliceous oozes over Alpha Ridge were active across Canada Basin, though likely at an earlier time.



In Canada Basin, we speculate that the bisque unit is coeval with the Late Cretaceous Kanguk Formation found along the Canadian Arctic Island Margin. This formation contains widespread bentonite layers 1-4 m in thickness and corresponds to a period of extensive volcanism on Ellesmere and Axel Heiberg islands (Harrison and Brent, 2005). It is possible that the bisque unit is diachronous, or that older equivalents exist in central regions of the basin.

CONCLUSIONS

The bisque unit is a key tectonostratigraphic marker across Canada Basin and southern Alpha Ridge. Post-dating extrusive volcanism, at least in localized regions of northern Canada Basin and Nautilus Spur, the bisque unit was deposited during a phase of significant extension. This was accompanied by apparently rapid subsidence.

Although visible in some regions, syn- and pre-Alpha crust is generally obscured by high reflectivity and attenuation within the bisque unit, and also by deep burial in central portions of Canada Basin.

An accurate understanding of the converted waves thought to be associated with the bisque unit will permit calculation and regional mapping of Poisson's ratio. This could be valuable information to identify different crustal types across the basin.

ACKNOWLEDGEMENTS

Seismic system: Jim Etter, Thomas Funck, Paul Girouard, Fred Leaming, Rodger Oulton, Ryan Pike, Dwight Reimer, Nelson Ruben, Peter Vass. **Officers and Crew** of the CCGS *Louis S. St-Laurent* and USCGC *Healy*. **Program management:** Jacob Verhoef. **Onshore support:** Cheryl Boyd, Terry Hayes, Julie Mills, Barb Vetese. **Marine mammal observation:** Jonah Nakimayak, Dale Ruben, John Ruben. **Cartographic support:** Phil O'Regan.

REFERENCES

Brocher, T. and Brink, U., 1987. Variations in Oceanic Layer 2 elastic veolocities near Hawaii and their correlation to lithospheric flexure; Journal of Geophysical Research, v. 92, p. 2647–2661.

Zelt, C.A. and Ellis, R.M., 1988. Practical and efficient ray tracing in two-dimensional media for rapid traveltime and amplitude forward modelling; Canadian Journal of Exploration Geophysics, v. 24, p. 16-31.

Zelt, C.A. and Smith, R.B., 1992. Seismic traveltime inversion for 2-D crustal velocity structure; Geophysical Journal International, v. 108, p. 16–34.

Wilkens, R.H., Christensen, N.I., and Collins, J.A., 1993. Seismic properties and reflectivity of north Pacific ocean cherts; Proceedings of the Ocean Drilling Program, Scientific Results, v. 136, p. 99–104.

Wang, Y., 2003. Multiple subtraction using an expanded multichannel matching filter; Geophysics, v. 68, no. 1, p. 346-354.

Harrison, J.C., Brent T.A., 2005. Basins and fold belts of Prince Patrick Island and adjacent areas, Canadian Arctic Islands; Geological Survey of Canada, Bulletin 560, p. 1–211.

Shimeld, J., 2008. Chapter 5: Seismic data recording and processing; in Field report for the 2007 CCGS Louis S. St-Laurent seismic cruise to the Canada Basin, (ed.) H. Jackson; Geological Survey of Canada; Geological Survey of Canada (Atlantic), Open File 5818, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, p. 105–120.

Shimeld, J., 2008. Chapter 6: Acquisition and processing of the seismic reflection data; in 2008 Louis S. St-Laurent Field Report, August 22–October 3, 2008, (ed.) H. Jackson and K. DesRoches; Geological Survey of Canada; Geological Survey of Canada (Atlantic), Open File 6275, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, p. 135–159.

Hutchinson, D.R., Jackson, H.R., Shimeld, J.W., Chapman, C.B., Childs, J.R., Funck, T., and Rowland, R.W., 2009. Marine geophysical data acquisition over Canada Basin, Arctic Ocean; EOS Transactions, v. 90, no. 23, p. 197–204.

Hutchinson, D.R., Mosher, D.C., and Shimeld, J.W., 2009. Chapter 3: Initial science results; in 2009 Canada Basin Seismic Reflection and Refraction Survey, Western Arctic Ocean: CCGS Louis S. St-Laurent Expedition Report, (ed.) D. Mosher, J. Shimeld, and D. Hutchinson; Geological Survey of Canada (Atlantic), Open File 6343, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, p. 99–101.

Mosher, D.C., Shimeld, J.W., and Hutchinson, D.R., 2009. Chapter 1: Expedition report; in 2009 Canada Basin Seismic Reflection and Refraction Survey, Western Arctic Ocean: CCGS Louis S. St-Laurent Expedition Report, (ed.) D. Mosher, J. Shimeld, and D. Hutchinson; Geological Survey of Canada; Geological Survey of Canada (Atlantic), Open File 6343, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, p. 1–76.

Shimeld, J., Jackson, R., Chapman, B., Funck, T., and Verhoef, J., 2009. Breaking hard ice: Development of a seismic system to define the Extended Continental Shelf and garner geological secrets from Canada Basin beneath the Arctic icepack; in Bedford Institute of Oceanography—2008 In Review; Fisheries and Oceans Canada and Natural Resources Canada, p. 22–24.

Bruvoll, V., Kristoffersen, Y., Coakley, B., and Hopper, J., 2010. Hemipelagic deposits on the Mendeleev and northwestern Alpha submarine Ridges in the Arctic Ocean: acoustic stratigraphy, depositional environment and an inter-ridge correlation calibrated by the ACEX results; Marine Geophysical Research, v. 31, p. 149–171.

doi:10.4095/289234

This publication is available from the Geological Survey of Canada Bookstore (http://gsc.nrcan.gc.ca/bookstore_e.php).
It can also be downloaded free of charge from GeoPub (http://geopub.nrcan.gc.ca/).

OPEN FILE
DOSSIER PUBLIC
6822
GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA
2011

Open files are products that have not gone through the GSC formal publication process.

Les dossiers publics sont des produits qui n'ont pas été soumis au processus officiel de publication de la CGC.

Recommended citation:
Shimeld, J.W., Chian, D., Jackson, H.R., Hutchinson, D., Mosher, D.C., Wade, J.A., and Chapman, C.B., 2011. Evidence for an important tectonostratigraphic seismic marker across Canada Basin and southern Alpha Ridge of the Arctic Ocean; Geological Survey of Canada, Open File 6822. doi:10.4095/289234