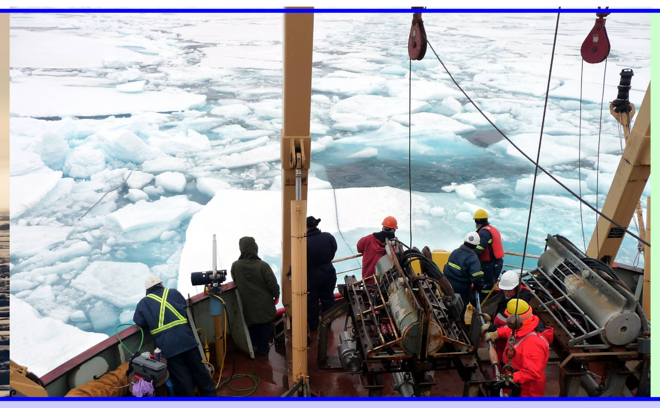

Open File 6822: Evidence for an important tectonostratigraphic seismic marker across Canada Basin and southern Alpha Ridge of the Arctic Ocean

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ABSTRACT

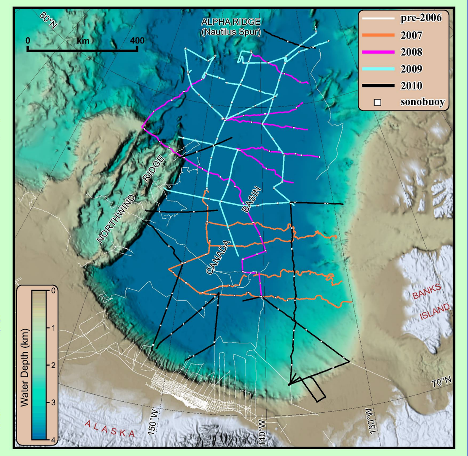
An extensive modern dataset of short-offset seismic reflection profiles coupled with wide-angle reflection and refraction sonobuoy records enable new insights into the crustal types, rifting processes, subsidence history, and sedimentary sequences of Canada Basin, Northwind Ridge, and southern Alpha 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).

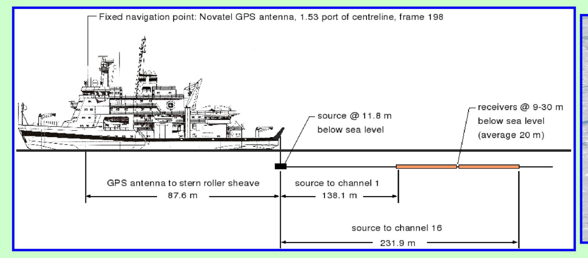


In total, 14030 km of seismic reflection data have been acquired along with 144 wide-angle reflection and refraction records obtained using expendable sonobuoys.

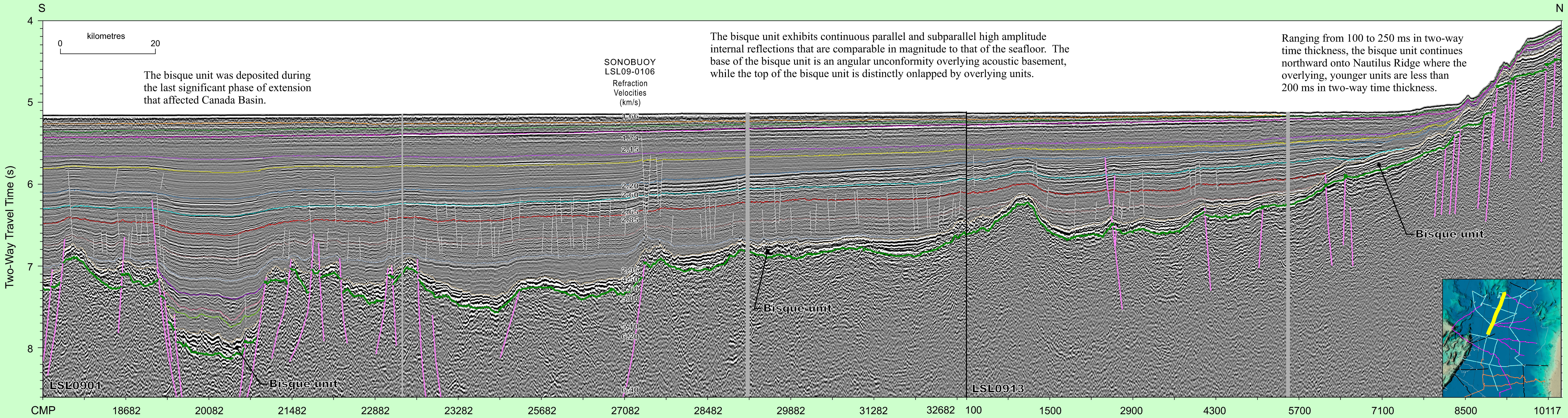
METHODS

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 velocties, 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.

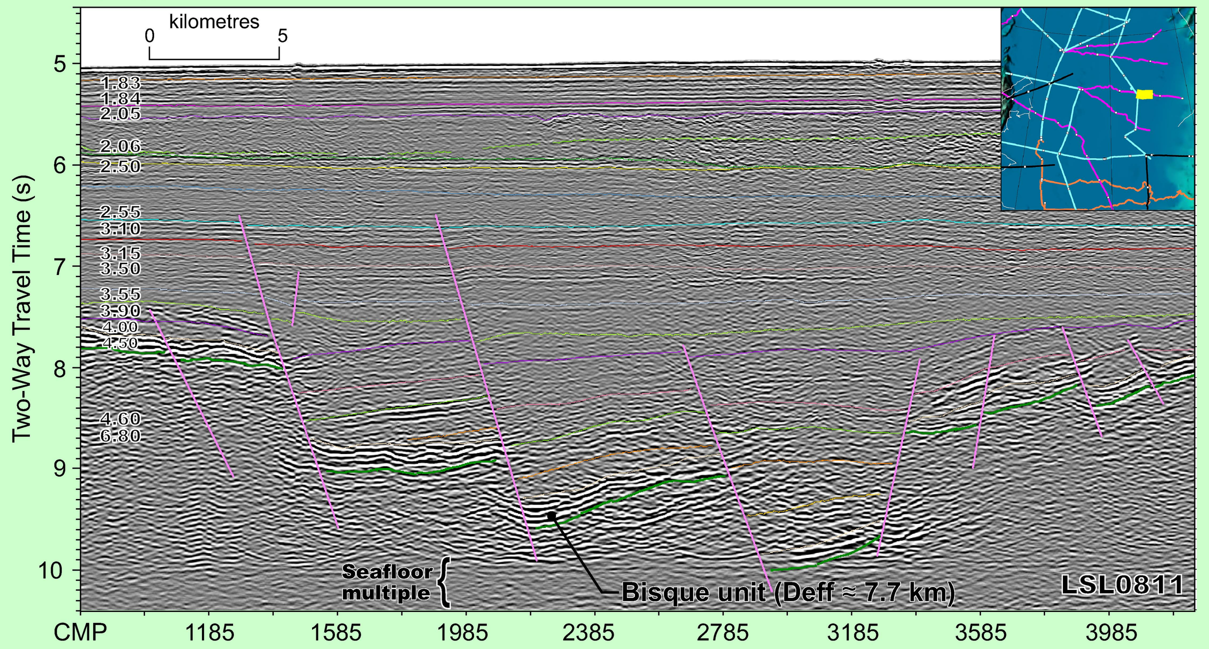


RESULTS



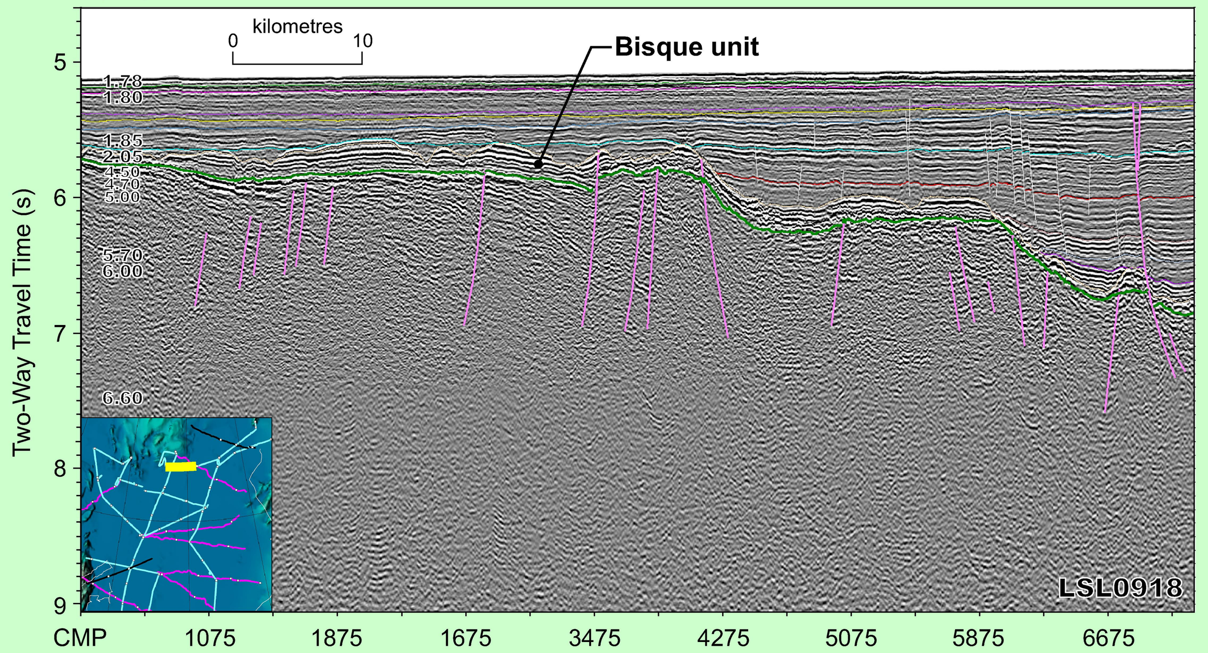
SONOBUOY LSL09-2801 Refraction Velocities (km/s)

The internal reflection characteristics of the bisque unit are mapped with reasonable certainty across northern Canada Basin. Although bisque is deeply buried in this example, reflection magnitudes within the unit are still comparable to that of the seafloor.



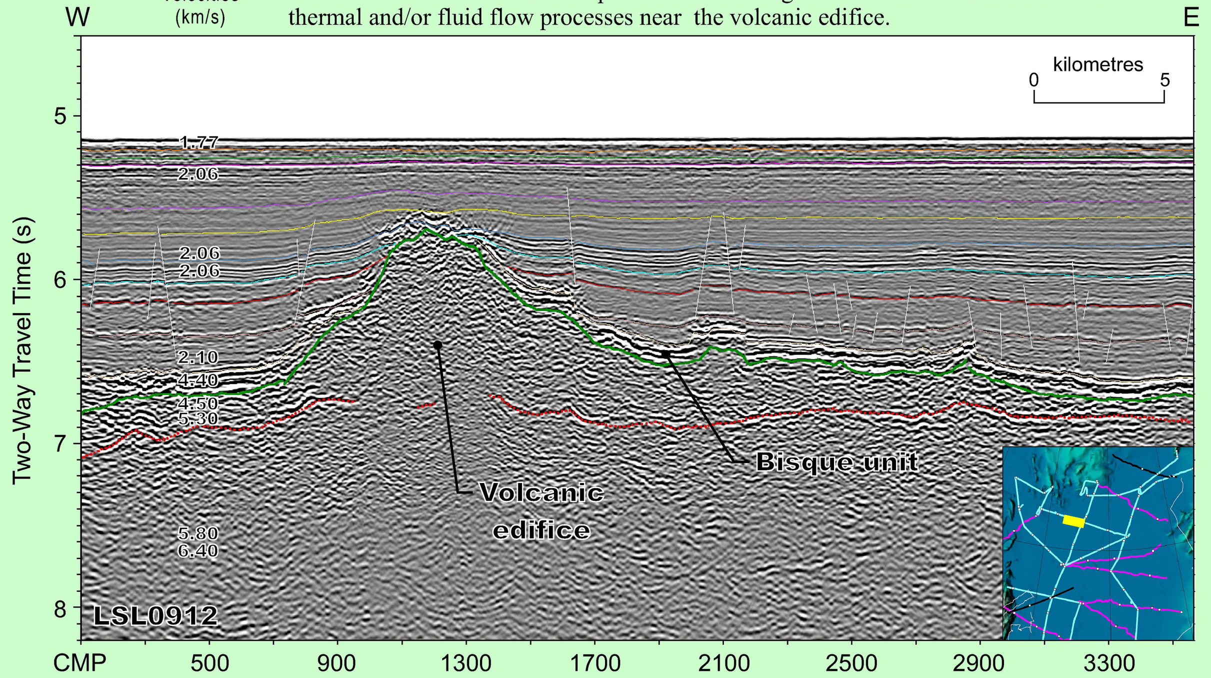
SONOBUOY LSL09-1801 Refraction Velocities (km/s)

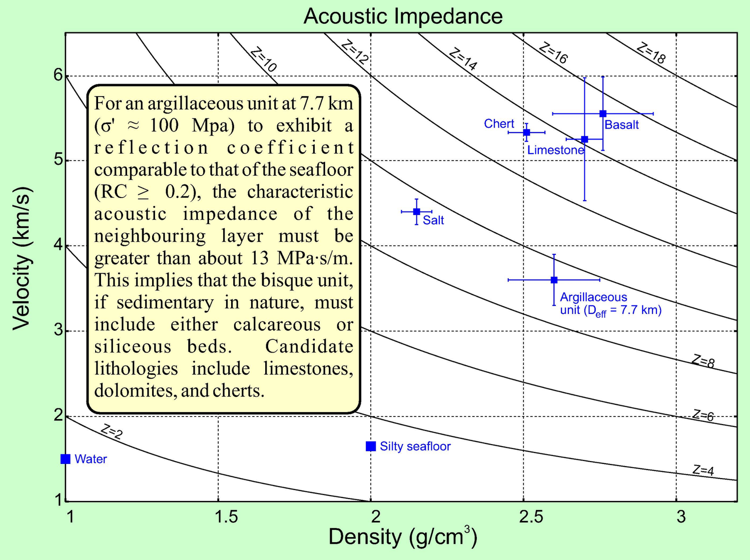
At this location, on the southern tip of Nautilus Spur, the top of the shallowly buried bisque unit is distinctly eroded. A prominent angular unconformity marks the base of bisque, below which are low-amplitude, continuous reflections forming a dipping series of off-lapping packages. These are interpreted to be volcanic on the basis of the refraction velocities.

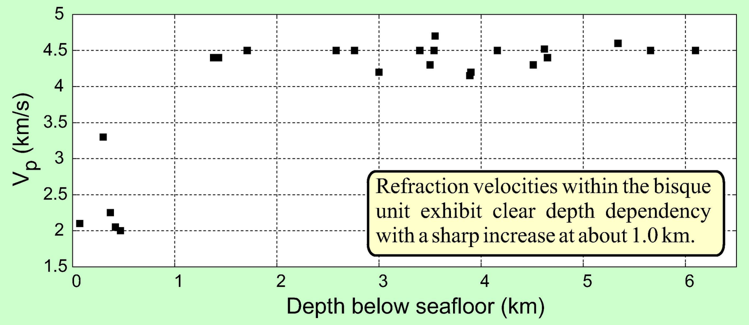


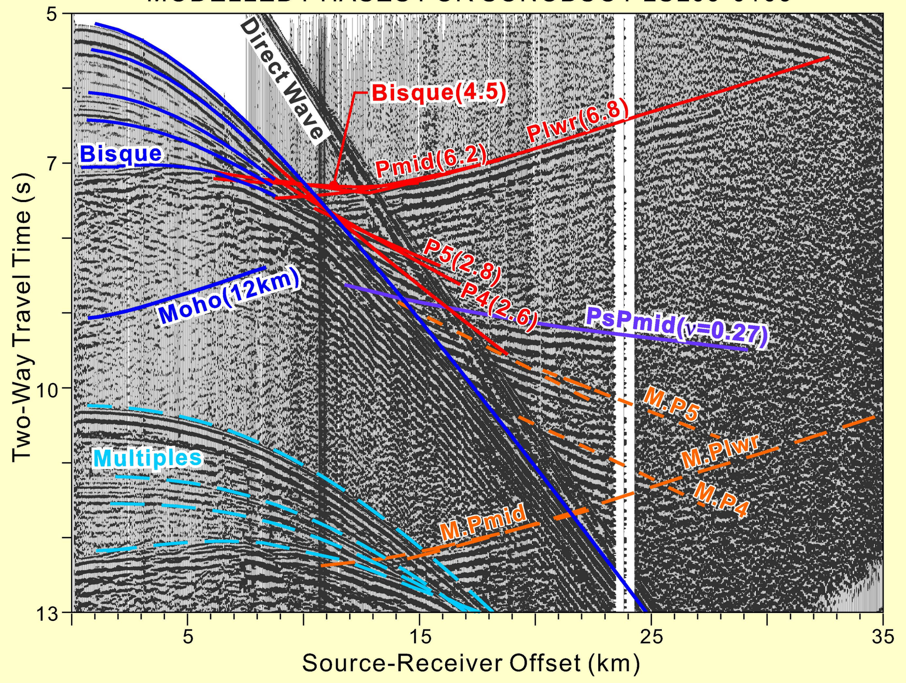
SONOBUOY LSL09-1201 Refraction Velocities (km/s)

The large mounded structure is interpreted to be a volcanic edifice on the basis of its internal reflection characteristics, geometry, and refraction velocities. The bisque unit overlies the flanks of the structure but is not continuous across the summit. Overlying units (marked by the tan, cyan, and cadet horizons) also exhibit high-amplitude anomalies in proximity to the mounded structure. These are speculated to be diagenetic effects associated with elevated thermal and/or fluid flow processes near the volcanic edifice.

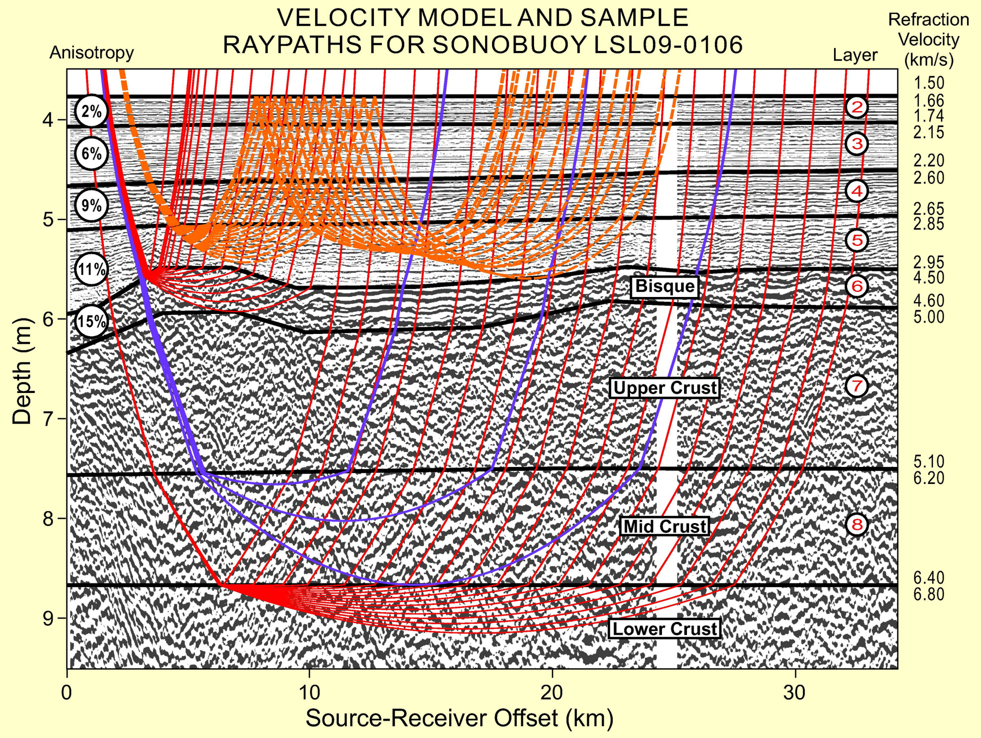






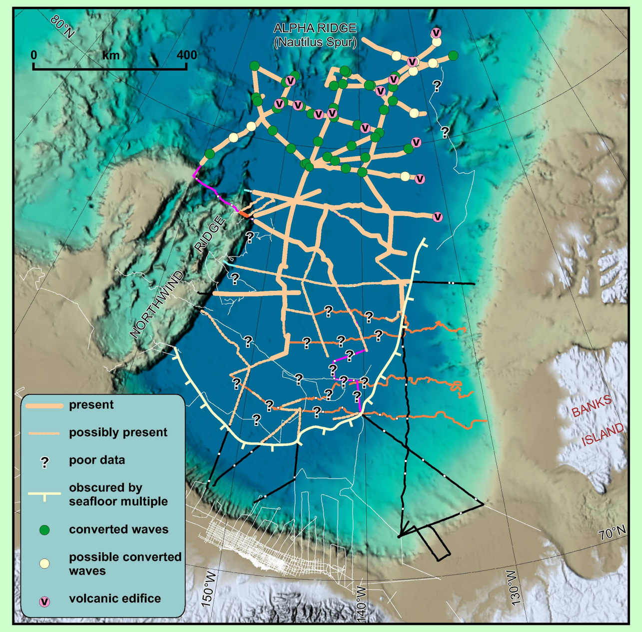


Ray-trace modelling results were obtained using a modified version of the RAYINV code (Zelt and Ellis, 1988; Zelt and Smith, 1992). Modelled phases include wide-angle reflections, reflection multiples, refractions, and refraction multiples. The PsPmid phase is a converted wave with down-going P-to-S 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



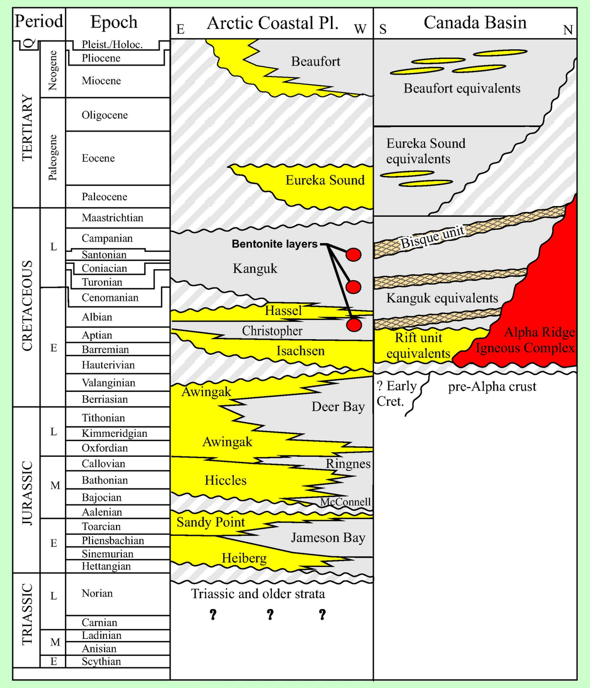
The bisque unit is mapped with confidence across northern Canada Basin on the basis of its high amplitudes, internal reflection characteristics, unconformable base, and also the onlap relationships of overlying units. Deep burial combined with poor data quality hinders confidence in the central basin, 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 Learning, 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.

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doi:10.4095/289234

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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