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SEISMIC STUDY OF RIDGES ON THE LAKE FLOOR IN ROCHESTER BASIN, EASTERN LAKE ONTARIO, NEW YORK: EVIDENCE FOR TILL COMPOSITION

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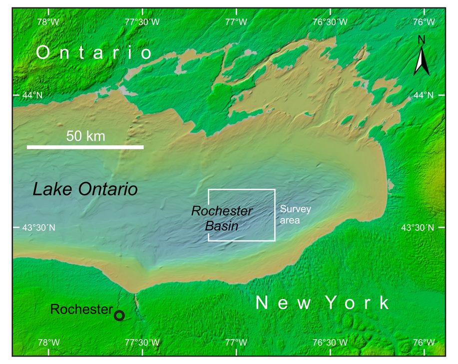
1. Introduction



The seismic reflection data analysed in this study were collected during the CCGS *Risley* 94800 expedition using a surface-towed sleeve gun (164 cm^3) in the Rochester Basin in eastern Lake Ontario (Figure 1). The receiver set was a 7.5 metre-long eel and the data were recorded with a 0.198 ms sampling interval. The data subset shown here provides a cross section of a number of ridges on the lake floor (Figure 1). Hutchinson *et al.* (1993) suggest that the ridges are drumlins while Thomas *et al.* (1993) propose that the ridges are the result of bedrock faulting. Interpretation of the Huntec Deep Tow Seismic (DTS) boomer system record and the unprocessed analogue output of the sleeve gun record (see Section 4, below) could, erroneously, indicate that faulting occurred in the area owing to incomplete reflections from the bedrock surface and high vertical exaggeration. This study was conducted to resolve the base of the ridges and to determine if faulting has occurred to cause their formation.

Figure 1. Location map of Rochester Basin in eastern Lake Ontario. The bathymetric data used in this figure and Figure 2 are from a compilation released by the National Oceanic and Atmospheric Administration (NOAA) (Virden *et al.*, 1999).

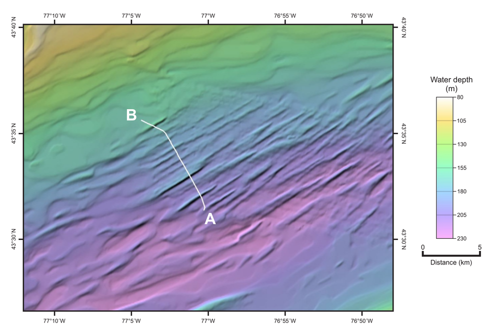


Figure 2. Detail of Rochester Basin bathymetry and location Huntec DTS profile (white line).

2. Data Processing

The high frequency Huntec DTS system does not have enough energy to penetrate through the lake floor ridges (see Section 4, below); thus seismic processing was undertaken using the high energy sleeve gun data. Processing steps reduced noise and more clearly delineated the base of the ridges. Time migration was undertaken using a simplified velocity model to better approximate the geometry of the ridges. To test the processing steps, only a subset of the seismic data was used, specifically day-of-year 206 from Greenwich Mean Time 0000 to 0032. The record is 0.31 seconds long, and was recorded with a fixed 10 ms delay with a Nyquist frequency of 2300 Hz. (Nyquist frequency is equal to half the sampling frequency).

2.1 Data set challenges

As with all single channel seismic surveys, noise is a significant factor. Standard noise attenuation techniques, which are usually applicable for multi-fold seismic data, were not entirely applicable to this data set. Noise attenuation techniques which do not create coherent noise were used so that the data would not be contaminated. To do this, a small amount (1%) of white noise was added to the processing at a number of steps to stabilize the signal processing algorithms.

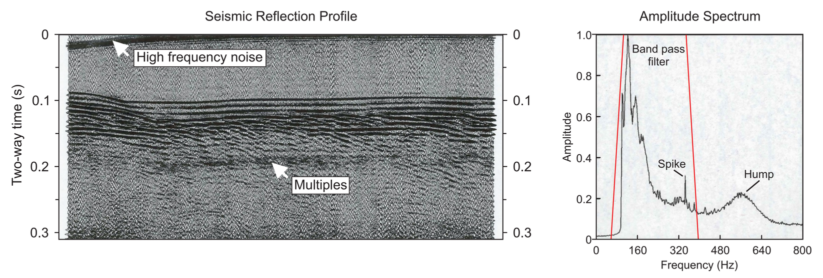


Figure 3. The unprocessed seismic section and its corresponding amplitude spectrum. Note the high frequency noise at the top of the section and additional noise at around 0.2 seconds. Strong multiples hide data at the top of the bedrock and the thin lake sediments. Strong multiples here are strong repetative reflections which mimic initial reflections and follow one another by about 0.01 seconds. The red line on the amplitude spectrum is the band pass filter that was used to attenuate noise (see Section 2.2, below). The spike on the right side of the band-passed section is the part removed by the notch filter. The "hump" on the right of the amplitude spectrum is part of the noise caused by the profiler and is removed by the band pass filter.

2.2 Frequency filtering

Since the data set was collected simultaneously with the Huntec DTS system, the high frequency zone of the sleeve gun data was contaminated with the profiler signal. These high frequency signals cannot be used to determine the structure of the ridges so they were eliminated by applying a band pass filter. This filter also eliminated the low frequency noise. The band pass frequency filter was 81–97–328–368 Hz, which reduced signals outsdie the pass band (See Figure 3, above). Coherent noise at the top of the section was a concern. This part of the signal is the spike (Figure 3) from the Huntec DTS system. The profiler was not fired synchronously between firings of the sleeve gun to avoid signal contamination, so a notch filter of 340–342–344–346 Hz was applied to remove this source of noise.

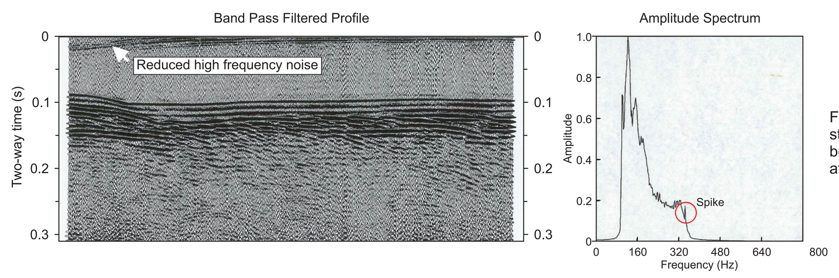


Figure 4. The section shown after band pass filtering, and the corresponding amplitude spectrum. There is still some noise in the early part of the section (from 0 to 0.05 seconds) but the noise near 0.2 seconds has been reduced. The red circle in the amplitude spectrum indicates the noise spike that the notch filter will attempt to reduce (see Section 2.3, above right).

2. Data Processing (continued)

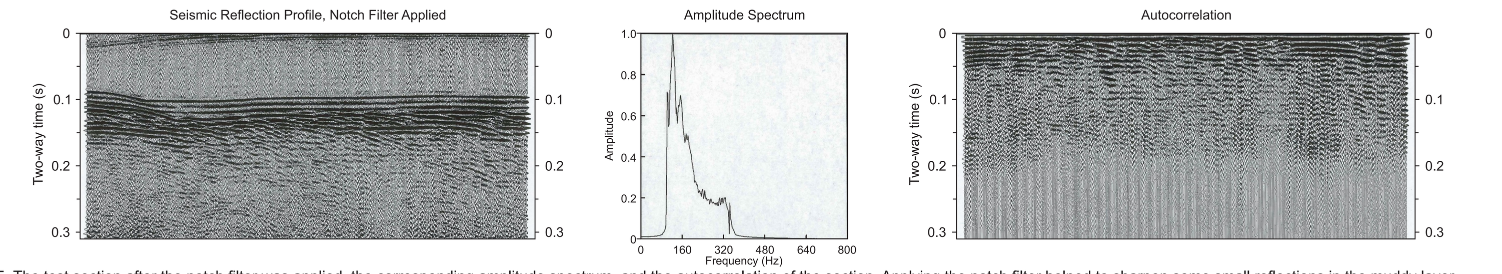


Figure 5. The test section after the notch filter was applied, the corresponding amplitude spectrum, and the autocorrelation of the section. Applying the notch filter helped to sharpen some small reflections in the muddy layer.

2.3 Spiking deconvolution

Spiking deconvolution effectively compresses the wavelet (an outgoing seismic wave with a limited number of cycles or zero crossings) that emanates from the sleeve gun into a short duration spike. This reduces wavelet interference by giving each reflection event a short, more finite duration. As a result, closely timed reflection events are more easily discriminated. As the sleeve gun source wavelet is unknown, a minimum phase wavelet was assumed for the spiking deconvolution. The standard approach to designing a spiking deconvolution operator is to examine the autocorrelation of the input data; the length of the operator is equivalent to the time for the second zero crossing and the operator lag is one sampling interval. For the Lake Ontario sleeve gun data, the operator length is 5 ms and the lag is 0.198 s. Strong multiple signals (reflections) are evident in the autocorrelation diagram between 0 and 0.1 s two-way time. The effectiveness of the spiking deconvolution is also highlighted by comparing the band-passed reflection section (Figure 4) with the processed section (Figure 6).

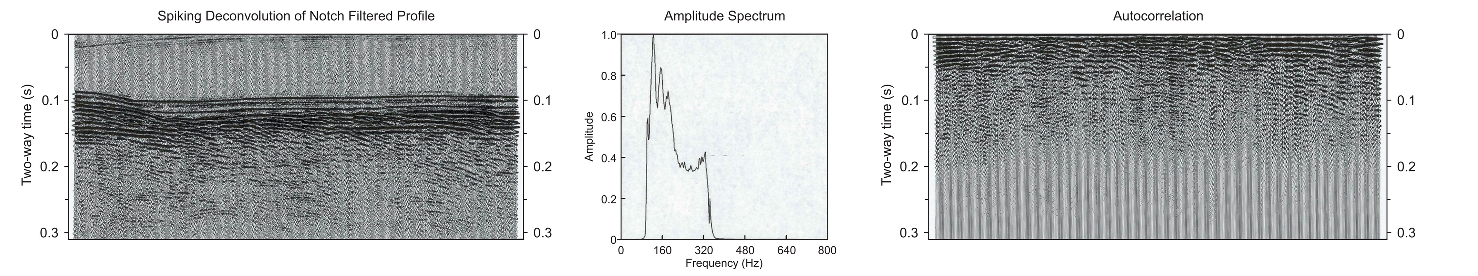


Figure 6. The test section after a spiking deconvolution was applied to the post-notch filtered section, as well as the corresponding amplitude spectrum and autocorrelation. The reflections are somewhat sharper and more confined spatially. Strong multiples still exist throughout the section, which are evident in the autocorrelation by the presence of multiple signals from 0 to >0.1 s.

2.4 Predictive deconvolution

Another problem that affects many seismic reflection surveys, and marine surveys in particular, is the contamination of the section by multiples. Multiples are not genuine reflections, but are repetitions of the initial, or primary, signals, that have already been received. These multiples can mask real reflections. Multiples can be identified by long trains of signals in an autocorrelation (Figures 5 and 6). The periodicity of multiples from the autocorrelation can be used as a tool to supress them. In the case of many multiples of different periods, predictive deconvolution may have to be applied several times. The length of this deconvolution operator is determined by the length of the repeated wave train and the operator lag should be long enough so that the predictive deconvolution operator will not remove the first, or primary, reflection.

Examination of the eastern Lake Ontario data revealed many sets of multiples of short periods. The multiples interfere with each other and with the real reflections, making multiple suppression challenging. An iterative approach was used, involving variation of the operator length and lag and the examination of the autocorrelation results.

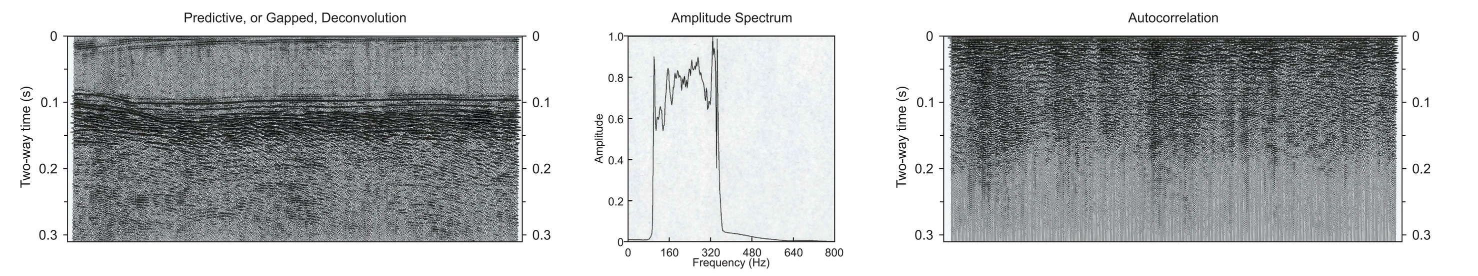


Figure 7. A predictive, or gapped, deconvolution was applied to the data. Many of the strong, longer period multiples have been removed, but there are a few shorter period multiples that have not been removed and continue to contaminate the signal, especially near the intersection with the acoustic basement. This suggests that perhaps one, two, or more more levels of predictive deconvolution could be applied, but with the high noise content of the section, it may be difficult to design one to effectively handle the short period multiples Compared to Figure 6 (above), the section is somewhat clearer, with reflecting surfaces being represented by fewer multiples.

2. Data Processing (continued)

2.5 Migration

Migration was performed to obtain a better approximation of the geology in the Rochester Basin, and to lend support to either the Hutchison *et al.* (1993) or the Thomas *et al.* (1993) geological interpretations. The migration processing moved dipping reflectors to their true subsurface positions when the migration velocity function was correct. As the seismic data are single channel, conventional methods to approximate a migration velocity function were not applicable. Two simplified velocity models were used: a constant field and a layered velocity field.

The constant migration velocities were varied from a water velocity of approximately 1500 m/s to 3800 m/s. The layered fields used velocities typical of water (1489 m/s), mud and other soft sediments (2000 m/s), and undeformed sedimentary bedrock (3000 to 4000 m/s).

Three time migration algorithms were applied: f–x (frequency–space), f–k (frequency–wavenumber), and phase shift. Due to the high noise content and the low fold of the seismic data, the f–x and f–k migrations did not perform well. Phase shift migration was better in dealing with the highly variable data. The main features of the subsurface can be estimated, but the horizontal continuity of the reflectors is not definite in the illustrated sections below.

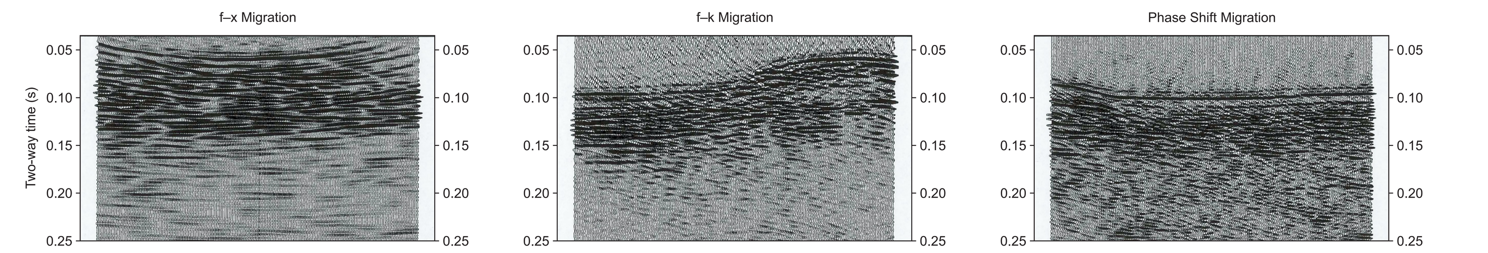


Figure 8. Frequency–space(f–x), frequency–wavenumber (f–k), and phase shift migration on three different sections of the seismic profile.

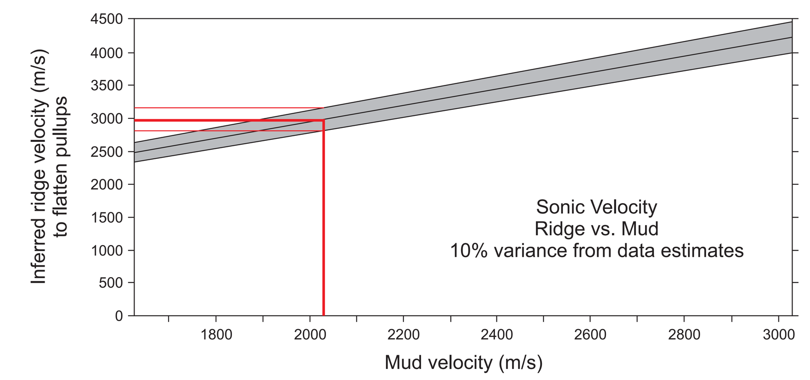
2.6 Velocity estimates

Conventional velocity analysis methods are not readily applicable to single channel seismic data, thus an alternative method was used. The apparent velocity pull-up beneath the ridges compared to the surrounding regions (see Section 4, Huntec profile), caused by faster seismic velocities in ridge material, was used to estimate the possible velocity ranges in the ridges. Three assumptions were made in the velocity calculations:

1. The velocity of the mud layer and the ridges are different but internally constant;
2. The surface of the underlying bedrock is flat and the bedrock is undeformed; and
3. The sediment is of similar thickness except where draped over the ridges.

Although these assumptions, particularly number 3, may be restrictive, the method provides approximate velocity values to estimate the lithology of the ridges and bedrock.

Figure 9. Using apparent velocity pullups for reflections of assumed flat bedrock beneath ridges, a range of possible ridge velocities was estimated for a range of assumed mud velocities. As it is unrealistic for lacustrine sediments to have velocities above 2000 m/s, and measured velocities are commonly less than 1600 m/s (Morgan, 1969), the average velocity within the ridges is less than 3000 m/s and commonly less than 2500 m/s, values consistent with seismic velocities in till on the north shore of Lake Ontario found by Hobson and Mirynech (1974). Since there could be error in the time picks used in establishing velocity pullups, a 10% error was assumed and the resulting differences in the ridge velocities were plotted with the grey zone.



3. Evaluation of Results

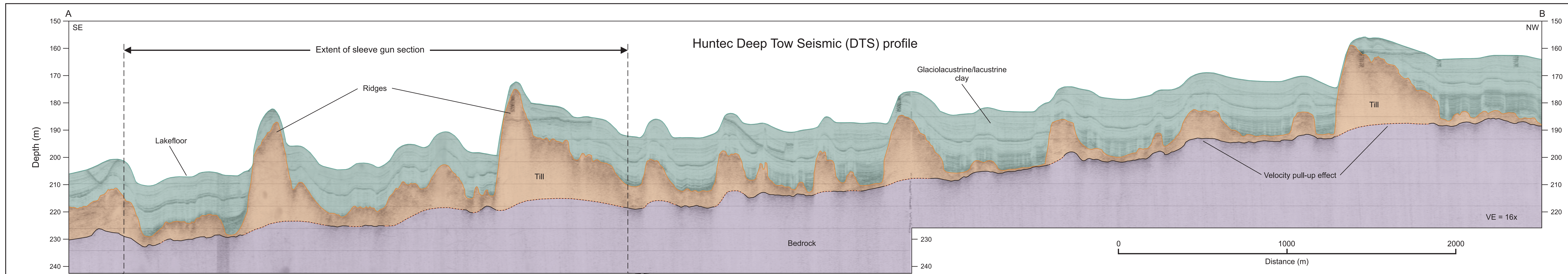
3.1 Qualitative analysis

Despite the high amount of noise in the data, the processing and different display scales used in the analysis improved the resolution and interpretation of the data. However, the amount of noise, coupled with the low fold of the data, made it difficult to resolve the bedrock surface everywhere. Phase shift migration using a layered velocity field improved resolution under some sections of the ridges and suggests that reflectors under the ridges are continuous with no evidence of faulting.

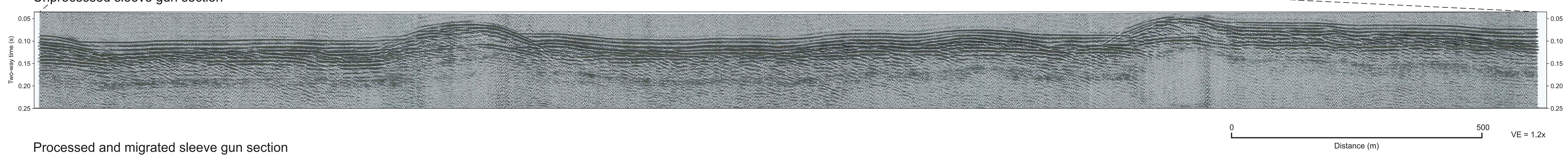
3.2 Sediment type predictions based on velocity

The velocity pull-up based on velocity estimates indicates a velocity of 2500 to 3000 m/s in the ridge material; this is within the established velocity range for till. For example, Mullins *et al.* (1996) report velocities of 1700 m/s for the Valley Heads Moraine in New York State, and Pugin *et al.* (1999) and Pullan *et al.* (2002) measured velocities of 2200 to 3000 m/s in Newmarket Till of southeastern Ontario. These velocities are substantially less than the velocities of 3350 to 5800 m/s found for sedimentary rocks in the same area (southcentral Ontario) by Hobson (1960).

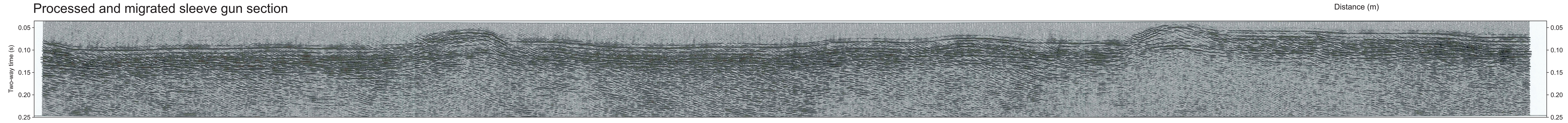
Analysis of the single channel seismic sleeve gun data supports the geological interpretation that the ridges in eastern Lake Ontario are glacial deposits of subglacial diamicton resting on an undeformed bedrock surface. Given other information revealing the streamline shape and finite length (<10 km) of the ridges (Mayer *et al.*, 1994), this analysis supports the interpretation of Hutchinson *et al.* (1993) that the ridges are drumlins.



Unprocessed sleeve gun section



Processed and migrated sleeve gun section



4. Seismic profiles

The upper profile at left (Huntec DTS) illustrates the lakefloor ridges in high resolution (Risley 94800, day 205/2357 to day 206/0132). Ridges of till up to 40 m high and 600 m wide are conformably draped by glaciolacustrine and lacustrine clay up to about 20 m thick. Although the clay deposit is thin in places where it drapes the till ridges, it is continuous and the till is not exposed at the lakefloor.

Despite the disadvantages of using a single channel record, these analyses of the available sleeve gun seismic data (lower two profiles, left) offer improvements for their interpretation. Specifically:

- Increased resolution of edges and beneath edges of ridges,
- Reduction of multiples and better resolution of reflecting surfaces,
- Better imaging of bedrock surface beneath and adjacent to some ridges, revealing its essential continuity and lack of offsets,
- Pull up analysis shows the ridge velocity is more characteristic of diamicton (glacial till) than bedrock.

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