3-D ground-penetrating radar surveys on a frozen river lagoon

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ABSTRACT

Ground-penetrating radar (GPR) surveys were acquired at Bowness Park, Calgary to characterize the ice and shallow subsurface of a frozen lagoon. We used Sensors and Software Inc.'s 250-MHz NOGGIN and Smart Cart system as well as a Pulse EKKO 4 system with 100 MHz antenna. 3-D GPR surveys were acquired over the frozen lagoon in two consecutive years (2003 and 2004). Hyperbolic velocity analysis gave ice velocities of about 0.15 m/ns with velocities decreasing in the sediments to about 0.11 m/ns. We interpret the ice thickness to be about 0.4 m from the GPR profiles, which is consistent with auger holes drilled through the ice. Channel sediments and stratigraphy beneath the ice are interpretable from the 3D radar reflectivity. Penetration of the 250 MHz data reached about 2 m at several locations in the area.

INTRODUCTION

Ground-penetrating radar (GPR) provides a powerful tool for mapping the thickness of ice as ice is largely transparent to radio-wave signals and the underlying ice-sediment or ice-water interfaces can be quite reflective. To investigate ice thickness and its underlying sediments, we acquired two 3D GPR surveys on a frozen lagoon at Bowness Park in Calgary (Figure 1). Bowness Park is situated in NW Calgary, on the south side of the Bow River and covers about 30 hectares of land. The ice on the lagoon is created by first draining the lagoon and then slowly filling it with water that freezes. Much of the topographic relief in the City of Calgary is a result of Quaternary rivers downcutting through the near-surface Paleocene units. Lithologically and stratigraphically, the area is composed of unconsolidated sediment, mostly tills, glaciolacustrine deposits and alluvium, overlying sandstone and shale (Osborn and Rajewicz, 1998).

FIG. 1. Dr. Larry Bentley and Ms. Julie Aitken of the University of Calgary and Mr. Greg Johnson of Sensors and Software Inc. conduct a GPR survey, with the Noggin 250-MHz SmartCart®, over the frozen lagoon at Bowness Park, Calgary.

The 2003 3-D GPR survey covered an ice surface of 25 m by 45 m (Figure 2) with 26 N-S lines set 1 m apart (one of the investigators actually wore skates to help with the traverses). These lines were acquired in a forward/reverse manner (every second line was collected in the reverse direction). The data were collected with Sensors and Software Inc.'s NOGGIN 250-MHz system. As indicated, the centre frequency is 250 MHz and the internal antennae separation is 0.28 m. A trace was acquired automatically every 0.10 m as controlled by a counter on the SmartCart wheel. To process the data, we used Win EKKO and EKKO Mapper software from Sensors & Software Inc. Plan-view maps of the near-surface structure at different times and depths were computed to analyze the horizontal distribution of the subsurface features. A single line, from the survey, is shown in Figure 3. The 2004 survey covered a surface of 20 m by 20 m (Figure 2), but with lines in orthogonal direction. In this case, we acquired a total of 42 GPR profiles, 21 lines on the E-W direction (X axis) and 21 lines on the N-S direction (Y axis). The NOGGIN system was again used, but with a trace acquired every 0.05 m.

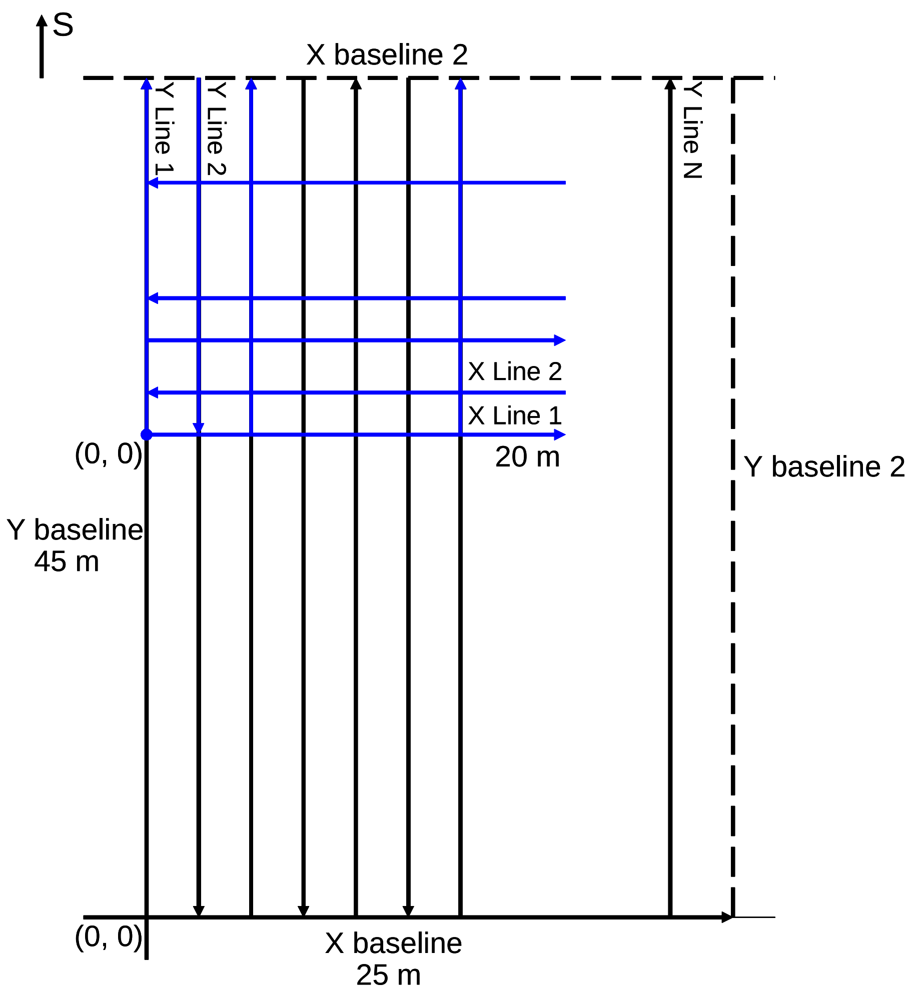

FIG. 2. The grid surveying pattern on the lagoon at Bowness Park. The X baseline has a length of 25 m and the Y baseline has a length of 45 m (2003 survey). In the 2003 survey we acquired just N-S lines while in the 2004 survey we acquired both N-S and E-W lines. The area covered by the 2004 survey (20 m by 20 m) is represented in blue.

DATA ANALYSIS

The raw GPR field data acquired were of reasonably good quality. Nonetheless, we used GPR data processing procedures as outlined by various authors (e.g. Young et al., 1995, Fisher et al., 1996, Peretti et al., 1999) to further enhance the signals. The processing steps included: temporal filtering ("de-wowing") to remove very low-frequency components, time gain (an automatic gain control) to compensate for the rapid attenuation of the radar signal and to enhance deeper reflectors, and background subtraction to remove the air and ground waves from the time section and enhance shallow reflections. We interpret a reflection from the bottom of the ice and also reflections from the sediments beneath the ice (Figure 3).

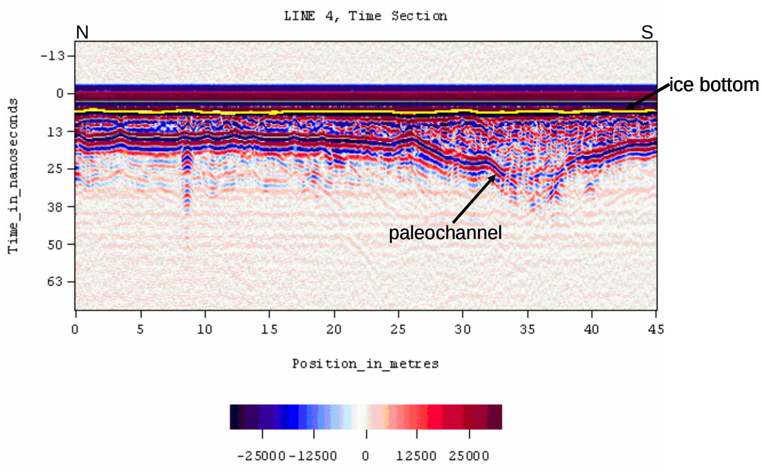

FIG. 3. A 2-D line from the 3-D survey acquired over the frozen lagoon at Bowness Park. The interpreted ice bottom is indicated in yellow.

The channel area of the lagoon was re-surveyed in 2004 to provide a more detailed look at the channel (Figures 4 and 5).

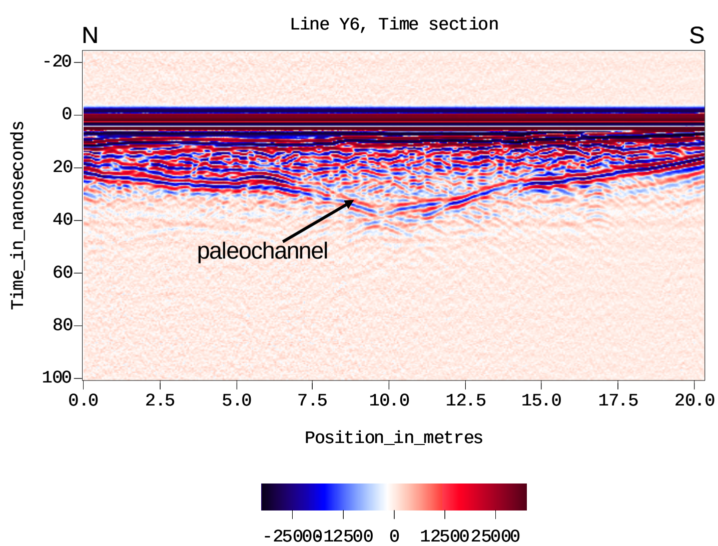

FIG. 4. A 2-D line from the more detailed 2004 survey of the channel area.

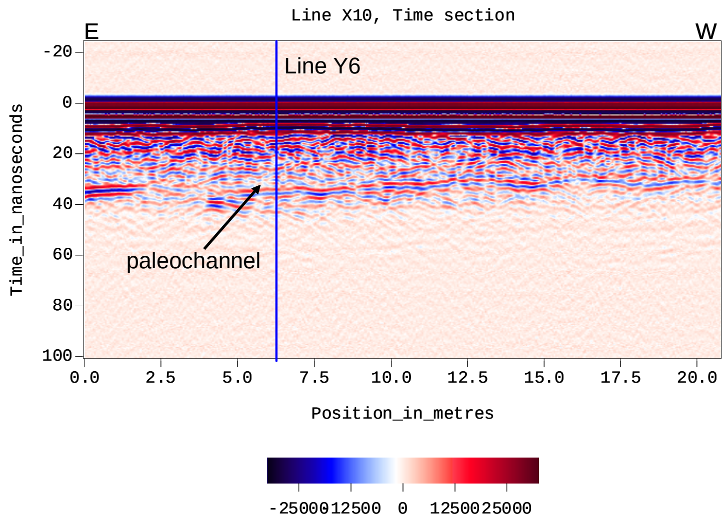

FIG. 5. Crossline acquired during the 2004 survey. The intersection with the line Y6 is marked on the figure.

In addition, we also acquired a CMP gather using the PulseEKKO system with source and receiver antennae at different offsets, for the purpose of performing velocity analysis. This CMP gather, acquired on frozen ground near the lagoon, gave velocities from 0.13 m/ns in the very near surface to 0.11 m/ns at several metres depth (Figure 6).

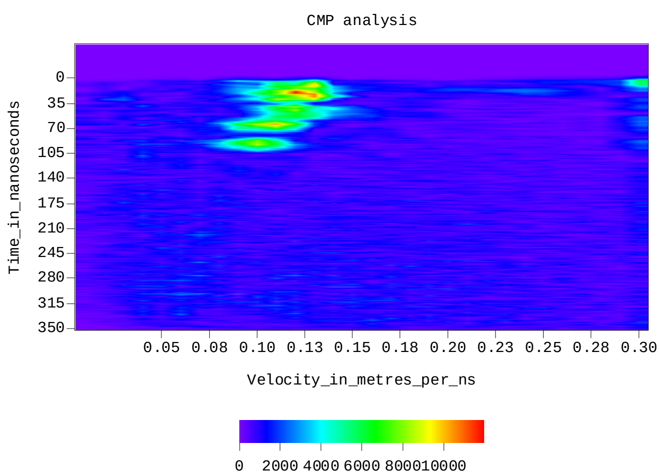

FIG. 6. Velocity analysis from a CMP GPR gather adjacent to the lagoon. The air wave (at 0 ns in the top right corner) has a velocity of 0.3 m/ns. The events between 0 and 100 ns have velocities varying between about 0.13 m/ns and 0.11 m/ns.

The velocity value for ice, determined during acquisition by fitting a hyperbola to diffracting objects in the ice or just below it, was 0.15 m/ns. Migrating the data with this velocity (Figure 7) provided a good image (i.e., the diffractions were collapsed and continuity increased). We also used this velocity to map the section to depth and interpret the event at 0.42 metres to be the ice bottom. Holes augered through the ice gave a thickness of about 0.4 m. The maximum depth of penetration of the reflected GPR signals is about 2 m, based on a velocity of 0.11 m/ns and 40 ns two-way traveltime.

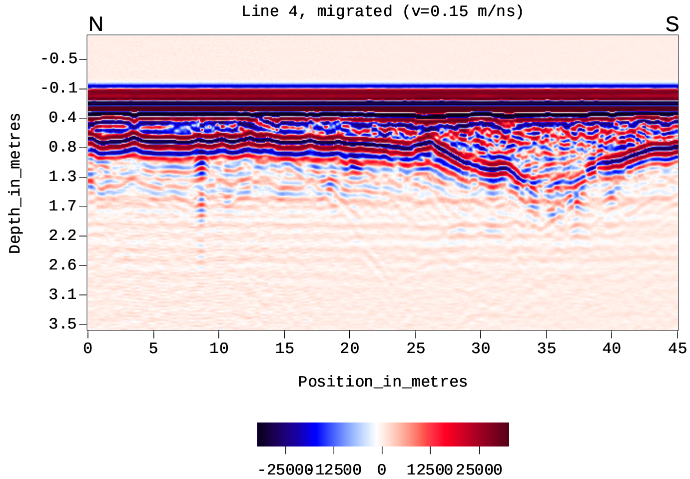

FIG. 7. A 2-D line from the 3-D survey acquired over the frozen lagoon at Bowness Park, Calgary. The data were migrated with a velocity of 0.15 m/ns. The bottom of the ice is interpreted at 0.42 m depth.

Areas of low-amplitude reflectivity may indicate more uniform materials or soils, while those of high amplitude denote areas of larger subsurface contrast such as significant stratigraphic changes (Conyers and Goodman, 1997). From three time slices (at 5 ns, 18 ns, and 26 ns two-way traveltime), we can determine some subsurface structures. In particular, we can see detail at the bottom of the ice layer (5 ns time slice) as well as the shape and orientation of the channel (18 ns time slice) (Figure 8).

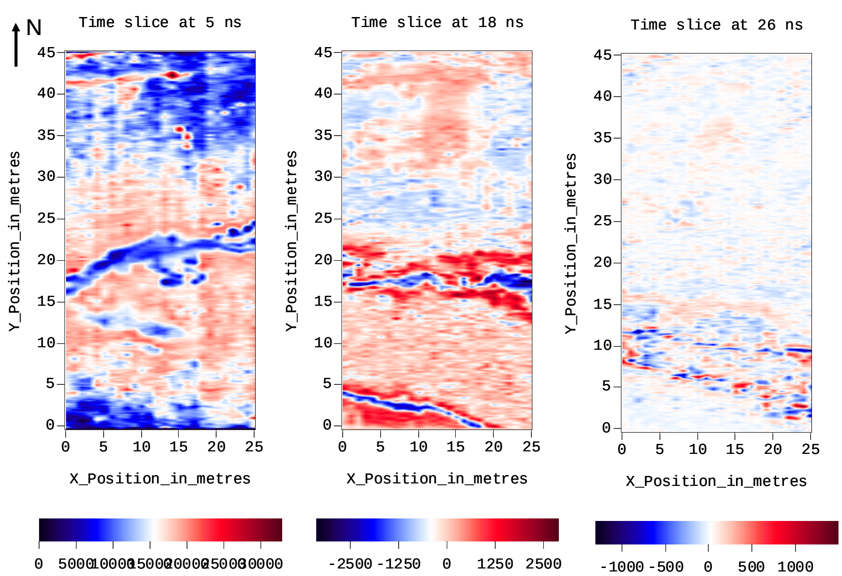

FIG. 8. Time slices of the 3-D data acquired on the ice at Bowness Park. Amplitude increases from black to red. On the first slice at 5 ns, we are in the region of the bottom of the ice. The low amplitude features (blue) on the 18 ns slice were interpreted as being a paleochannel. On the 26 ns slice we can identify the feature with a NW-SE orientation as the bottom of the paleochannel.

We know that $d = vxt/2$ (where d represents the depth in metres, v is the velocity in m/ns, and t is the two-way traveltime in ns). We used this expression to calculate the depth of the ice bottom and the depth of the paleochannel. These are 0.375 m (based on an ice velocity of 0.15 m/ns) and 0.99 m respectively (based on a sediment velocity of 0.11 m/ns). Therefore, the thickness of the sediments was determined to be 0.6 m. The paleochannel has a NW-SE orientation, and the bottom of the channel was determined to be at 1.43 m depth.

Dipping structures that are an indication of sediment deposition in a fluvial environment are also evident on lines acquired over frozen land several hundred metres north of the lagoon (Figure 9). The cross-bedding in the sediments was likely laid down in moving water and is similar to river environment profiles illustrated by Jol (1993).

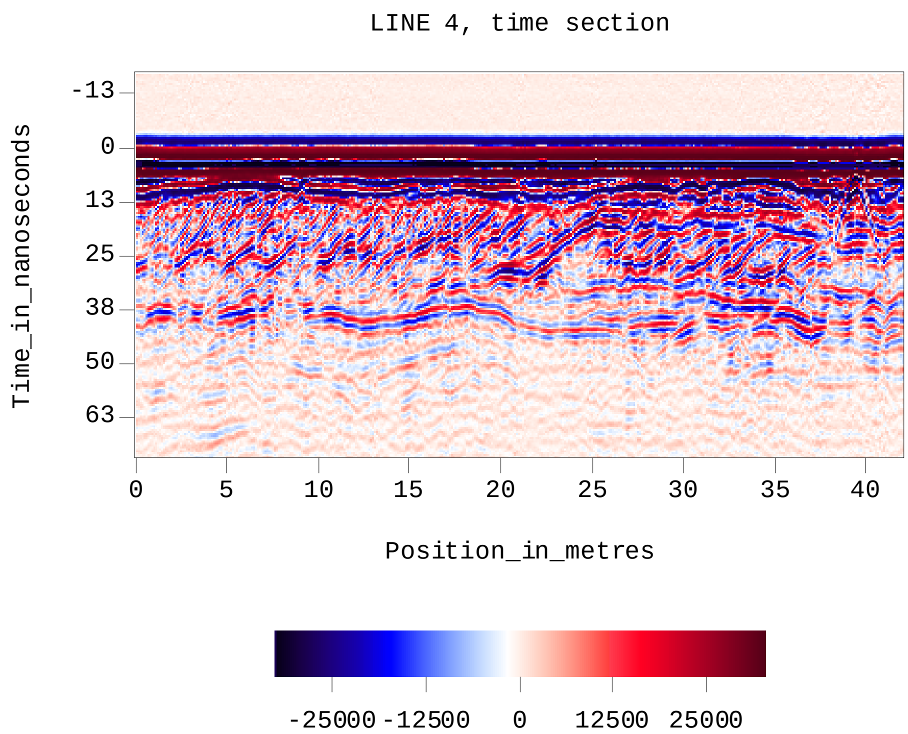

FIG. 9. 2-D line acquired on frozen ground, adjacent to the lagoon, at Bowness Park, Calgary. Dipping structures are an indication of the earlier fluvial environment.

CONCLUSIONS

The GPR investigation over a frozen lagoon in Bowness Park, Calgary was useful in determining the thickness of the ice (about 0.4 m as confirmed by augering) and imaging fluvial structures beneath the ice. Velocity of the radar waves through ice was determined to be approximately 0.15 m/ns and the maximum depth from which we have information was approximately 2 m (using the deepest coherent reflections and a velocity of 0.11m/ns).

ACKNOWLEDGEMENTS

We would like to acknowledge Dr. Larry Bentley and Ms. Julie Aitken of the University of Calgary, and Mr. Greg Johnston of Sensors & Software Inc. for their assistance in the 2003 survey. We would also like to thank Messrs. Malcolm Bertram and Eric Gallant for their assistance in both 2003 and 2004 surveys. We appreciate the help of Mr. John Szureck of City of Calgary Parks and Recreation.

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