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High resolution marine seismic surveying in the Sudbury Basin

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Summary

High resolution marine surveying in the Sudbury Basin was conducted at Fairbank Lake and Lake Vermillion in 2013, with a selective high density survey carried out solely at Lake Vermillion in 2014. Data collection was carried out using an acoustic sub-bottom profiler employing a 'chirp' pulse signal to provide normal incident reflection data for up to ~ 50 m of sediment and shape of the bedrock basement. Paleochannels and truncations observed in the seismic profiles indicate recent fluctuations in the behavior of Lake Vermillion and its outlet channel. Slumping and faulting suggest tectonic influences in the area. Future work will be focused on high resolution mapping and imaging of these key features, including the possibility of 2.5D-3D seismic models.

Introduction

Sediments are an excellent indicator of the Quaternary landscape and environmental evolution. Lake bottom sediments are preferentially preserved and produce a more intact sediment record, unlike terrestrial sediments which are more sensitive to natural and anthropogenic processes. Sediment preservation becomes increasingly important in areas that have been subjected to large scale erosive processes such as in Ontario which has undergone several glaciations. The area of study was the

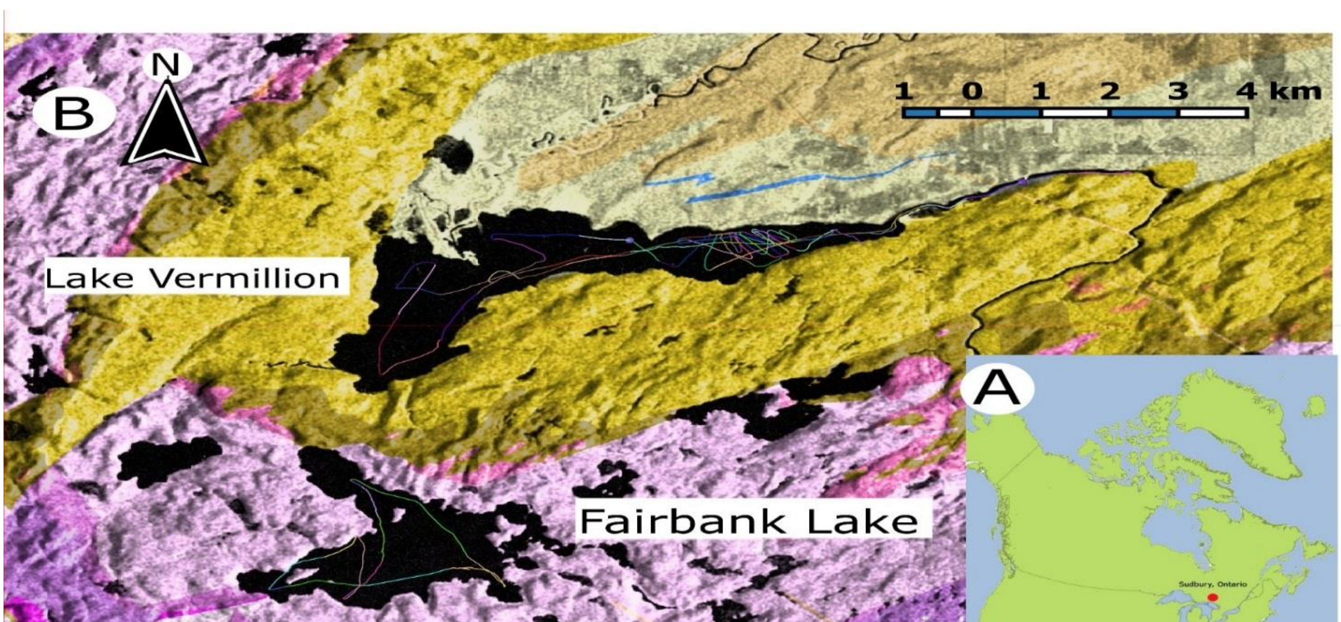

Figure 1- (A) A map of Canada with Sudbury, Ontario (red dot) indicating the location of the study area (Modified from Canada Centre for Mapping and Earth Observation, 2014). (B) DEM and bedrock geology of the study area with Lake Vermillion and Fairbank Lake displayed along with the track lines collected during the surveys (Modified from Ames, Singhroy, Buckle, & Molch, 2006).

southwestern section of the Sudbury structure (Figure 1A), a unique geologic structure which is the result of a meteorite impact roughly 1.8 billion years ago (Card et al., 1984). The lake-bottom stratigraphy of two lakes within the Sudbury basin, Fairbank Lake and Lake Vermillion (Figure 1B), were surveyed to delineate their underlying geology and sediments to ultimately gain a better understanding of the development of local hydrology, post glacial sediment deformation and seismicity in the area.

The Sudbury basin can be divided into three fundamental units: the basement footwall breccia, the Sudbury Igneous Complex (SIC) and the overlying sedimentary Whitewater group (Dressler, 1984). The Whitewater group contains the Onaping, characterized by fall back breccia, as well as the mudstone dominated Onwatin formation (Dressler, 1984). Lake Vermillion lies at the border of the Onwatin and Onaping while Fairbank Lake is situated within the SIC. Both of these lakes are in close proximity to recent seismic activity: 3.3 and 3.8 magnitude earthquakes in 2011 and 2014 respectively (Natural Resources Canada, 2013; Natural Resources Canada, 2014).

Theory and/or Method

Closely spaced survey data was recorded for an area of interest in the eastern portion of Lake Vermillion in 2014 using an Edgetech SB-216S towfish with 3200-XS Sub-bottom profiling system. The towfish, responsible for sending and receiving the signal, was run at approximately 3 knots (approximately 6 km/hr) at a running depth of around 2 m from the surface. A 'chirp' pulse, sweeping from 2-12 kHz over 20 ms, was used resulting in an estimated vertical resolution of 8cm (Edgetech, 2009). The coupled source and receiver configuration along with Edgetech's proprietary amplitude and phase weighting correlation filter is able to produce zero offset reflection profiles in real time (Edgetech, 2009). Coordinate data stored in each trace header were extracted to reconstruct the survey track lines for geometry and plotting purposes. Depth sections were produced by converting the two way time assuming an acoustic wave velocity of 1500 m/s for the water column and unconsolidated sediments (Muller et al., 2002). Using WesternGeco VISTA software vertical stacking was performed and an envelope was created before the results were imaged.

Work by Lazorek et al. (2006) in Lake Wanapitei, which lies on the eastern rim of the Sudbury basin, provides a reference for interpretation of varying stratigraphic units based on their acoustic character. Laminated sediments can be identified by strong high frequency reflectors whereas homogenous sediment layers are acoustically transparent. Lazorek et al. (2006) interpreted these laminated units as varved, glaciolacustrine, late glacial sediments (< 10 500 ka) with the overlying transparent sediment being a more recently deposited post glacial sediment. These divisions allow for a rudimentary chronology and stratigraphy to be established without available cores.

Examples

Several notable features were observed in the high resolution seismic profiles gathered in Fairbank Lake and Lake Vermillion (Figure 2, 3). The survey in Fairbank Lake revealed evidence for seismicity and faulting. An offset of laminated sediments in figure 2A revealed likely faulting in the underlying bedrock basement. In figure 2B acoustically transparent, likely mixed, sediment can be seen downslope truncating adjacent laminated sediments deposited along the bottom of the depression in the lake bottom. This feature is interpreted as a slump, an indicator of local seismicity which causes downslope sediment movement.

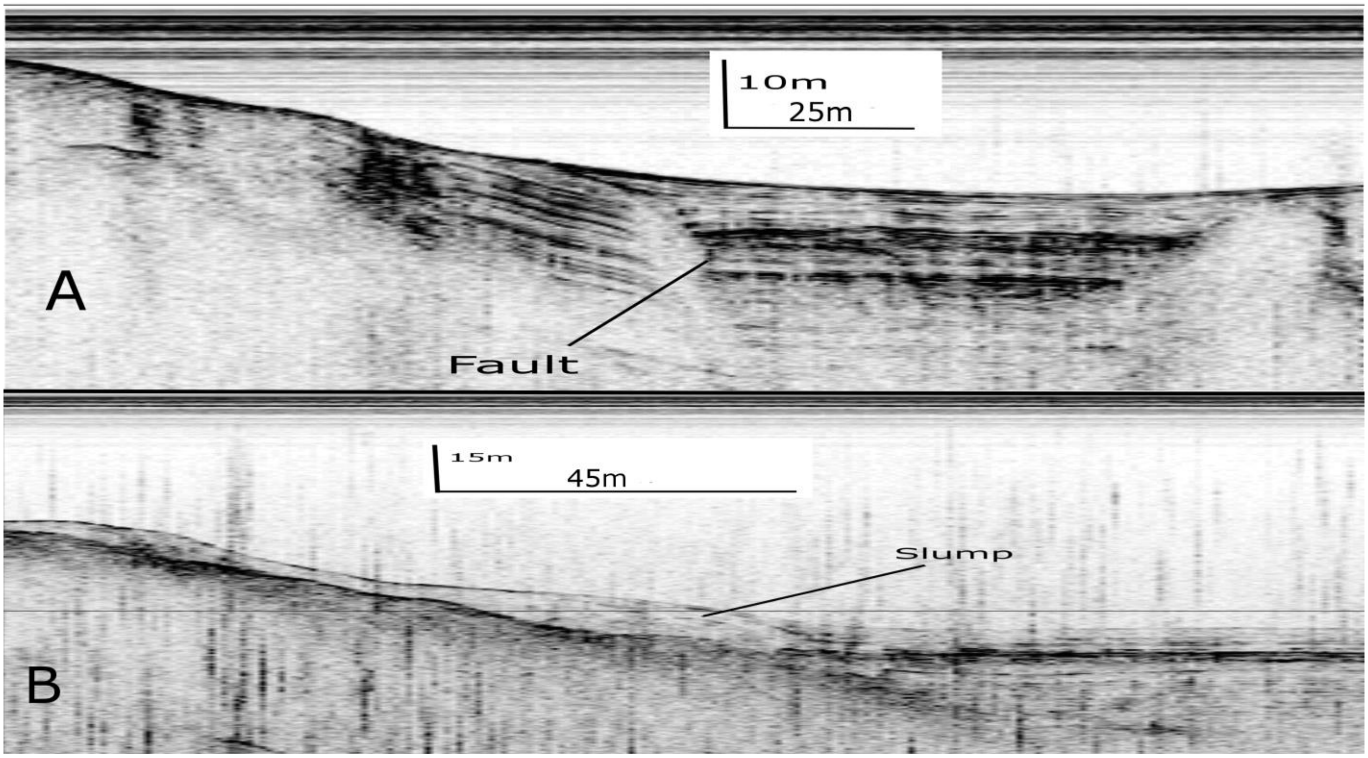

Figure 2- Features observed in Fairbank Lak seismic profiles. (A) Faulting within Fairbank Lake identified by displaced adjacent laminated sections. (B) Slumping observed cross cutting a laminated sediment package. A vertical exaggeration of 2.5 and 3 was used for figures (A) and (B) respectively.

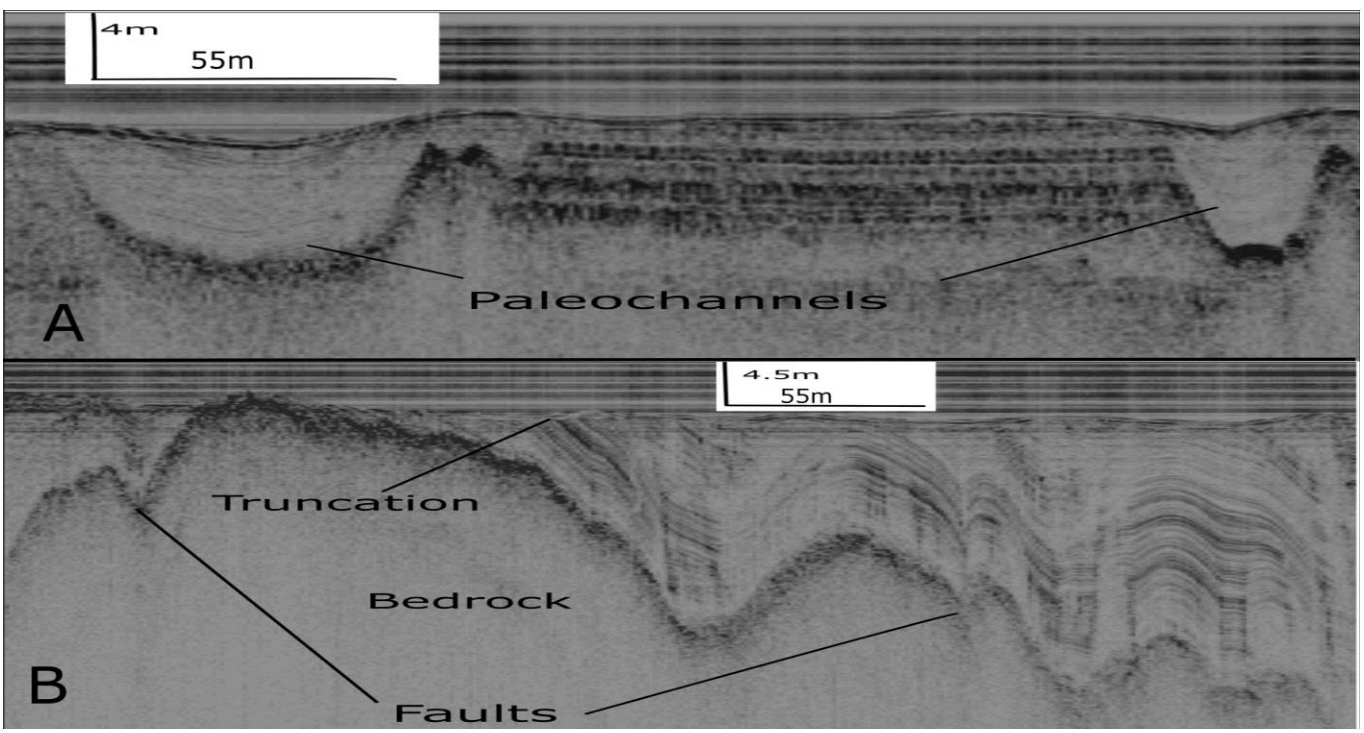

Figure 3- Notable features observed in Lake Vermillion seismic sections. (A) Bedrock overlain by thick laminated sediments truncated at the water-sediment boundary with possible faults indicated. (B) Paleochannels cutting in late glacial sediments in the outlet channel. A vertical exaggeration of approximately 14 and 12 was used for figures (A) and (B) respectively.

The survey carried out in Lake Vermillion provided a comprehensive first look into the sub-bottom characteristics of the lake, primarily in the eastern section neighbouring the present outflow channel which was densely surveyed in 2014. From the survey it is evident that Lake Vermillion is dominated by acoustically transparent sediment deepest through the east-west cross section of the lake and near the river inlet in the north-west. This highlights the sediment transport pathway through the lake between the inflow and outflow channels. The post glacial sediments thin along the Northern shore of the lake in conjunction with increased laminated sediment and underlying bedrock peaks (Figure 3B).

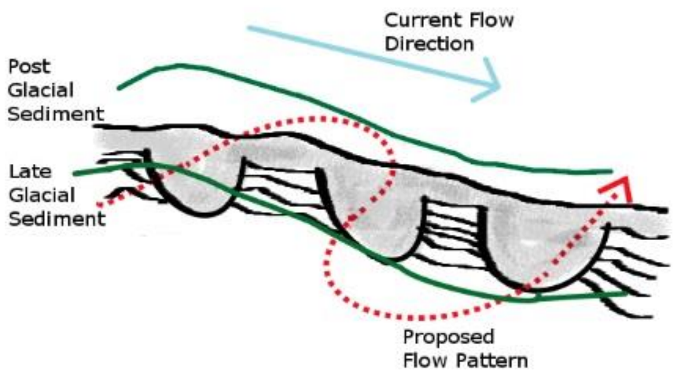

Figure 2- Meandering behavior (red dotted line) inferred from the paleochannels observed at Lake Vermillion's outlet channel.

Paleochannels are observed in both the main body of Lake Vermilion and the outflow channel cutting into the late glacial deposits (Figure 3A). The combination of paleochannels neighbouring unconformities in the late glacial sediments suggests a period of erosion induced by low water levels where the north shore was more susceptible to erosion and the lake was reduced to a channel along its cross section. This notion is further supported by paleochannels in the outflow channel being perpendicular to the present direction, inferring meandering behavior relative to the current system (Figure 4). This is possibly the result of a decrease in water level or downstream block movement which can effect river sinuosity (Zamolyi et al., 2010). Tectonic control of the outlet is supported by a cross cutting fault, as described by Ames, Davidson, Buckle, & Card (2013), which extends through the mouth of the outlet similar to Lake Wanapitei whose inlets and outlets are controlled by faults (Lazorek et al., 2006). The existence of additional outflow channels is also hypothesized along the southern shore of Lake Vermillion. North-south paleochannels across were seen in the main body of the lake in addition to possible valleys along the southern shore hinted in the DEM maps. Evidence for changing outlet patterns could describe the development and propagation of faults in the vicinity.

Conclusions

Continued work on the data will be focused on producing a high resolution 2D/3D model of the lake bottom. Unlike conventional 3D marine seismic surveys, only a single receiver was utilized and as a result the track line lengths and orientations are not equivalent to a two parallel streamer system. Therefore in order to construct a high resolution 2.5D-3D seismic model re-binning will be necessary. Different re-binning strategies will be employed and contrasted to create a small scale, high resolution 2.5D model of the sub bottom using the high frequency source data collected similar to the work completed by Muller et al (2002). Primary reflectors representing sequence boundaries, which can be consistently delineated beneath the closely spaced survey lines in the eastern portion of Lake Vermillion, will be a target for the 2.5D models. Nearest neighbour and weighted re-binning methods will be compared and adapted to reach optimal results.

Acknowledgements

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