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Abstract
As part of a reconnaissance sub-bottom acoustic profiling (SAP) survey, 29 SAP were collected from the southern area of the east basin of Larder Lake, Ontario, on July 20, 2014. An additional 25 SAP were collected from Leroy, Northwest and Fitzpatrick bays of the west basin on July 23, 2014. Good penetration of the sub-bottom was obtained within the profiled areas. Three facies can be identified within the SAP returns that represent lacustrine, glaciolacustrine and mass movement deposits. The profiles collected from Larder Lake demonstrate the presence of mass movement deposits within this basin. However, deep water conditions in many of the profiled areas represent a challenge to coring, depending on the coring equipment used.

Introduction

Large areas of northwestern Quebec-northeastern Ontario were inundated by a succession of glacial lakes, known as Barlow, Barlow-Ojibway and Ojibway, that evolved within the Timiskaming and Hudson Bay basins between 10 570 and 8470 ± 200 cal BP (Vincent and Hardy 1979; Veillette 1994; Breckenridge et al. 2012). A legacy of these glacial lakes is the regional occurrence of glaciolacustrine deposits that form the Great and Lesser clay belts areas, as has been described in early geological reports (e.g., Coleman 1909, 1922; Wilson 1918; James 1923). Studies in the 1920s by Antevs (1925; 1928) interpreted that the rhythmically laminated couplets composing the deposits are varves which represent annual accretions. He recognized that the varves form a time series that can be correlated throughout the region, based on varve thickness patterns, as subsequent research has verified (Hughes, 1959; 1965; Breckenridge et al., 2012). Many reports mention the presence of beds of "contorted", "deformed", "disturbed" and "slidden" varves within the glaciolacustrine deposits (Wilson 1918; Antevs 1925, 1928; Hughes, 1959; Breckenridge, 2012). Some of these disturbed deposits have been interpreted or inferred to be stratigraphic evidence of paleoearthquakes that occurred during local deglaciation (Adams 1982, 1989; Doughty et al. 2011, 2013).

Recent literature indicates that lake basins are promising areas for investigating paleoseismicity, by identifying stratigraphic levels that contain the deposits of multiple, synchronous, submarine landslides and/or turbidity currents (e.g., Moernaut et al. 2007, 2009; Upton and Osterberg, 2007; Bertrand et al. 2008; Anselmetti et al. 2009; Beck 2009, 2011; Maloney et al. 2013; Morey et al. 2013; Strasser et al. 2013). Mass movement deposits have been recognized within the deposits of lake basins in eastern Canada, including northwestern Quebec-northeastern Ontario, that are attributed to both modern and prehistoric earthquakes (e.g., Shilts, 1984; Shilts and Clague, 1992; Shilts et al., 1992; Ouellet, 1997; Normadeau et al., 2013; Doughty et al., 2010; 2014). Brooks (2015) advocated applying an integrated seismo- and chrono-stratigraphic approach to investigating mass movement deposits as evidence of paleoseismicity preserved in lake basins.

To identify the occurrence of disturbed deposits (i.e., landslide, turbitidy currents and/or soft sediment deformation) preserved in the sub-bottoms of lakes, reconnaissance sub-bottom acoustic profiling (SAP) surveys were collected by the Geological Survey of Canada in July 2014 at eight lakes in the Rouyn-Noranda-Kirkland Lake area, northwestern Quebec-northeastern Ontario (Fig. 1). The results allow an assessment of the extent and character of disturbed deposits in the region and can be used to identify lake basins (or portions thereof) for more detailed SAP surveys to investigate regional paleoseismicity.

This report contains the results of the reconnaissance SAP surveys undertaken at Larder Lake, Ontario, on July 20 and 23 (Figs. 1 and 2). It summarizes the SAP methodology, includes maps of profile lines, provides a generalized overview of the deposits contained in the sub-bottom, and a brief notation of the content of the individual profiles. The report contains digital data of the SAP profiles in .keb and .sgy formats, and raster images of the profile returns (bmp). It also contains .kea files that list the date and time of collection, water depth, and geographical coordinates for the profile routes. This report is one of eight that summarize the results of the July 2014 reconnaissance SAP surveys, as listed in Table 1.

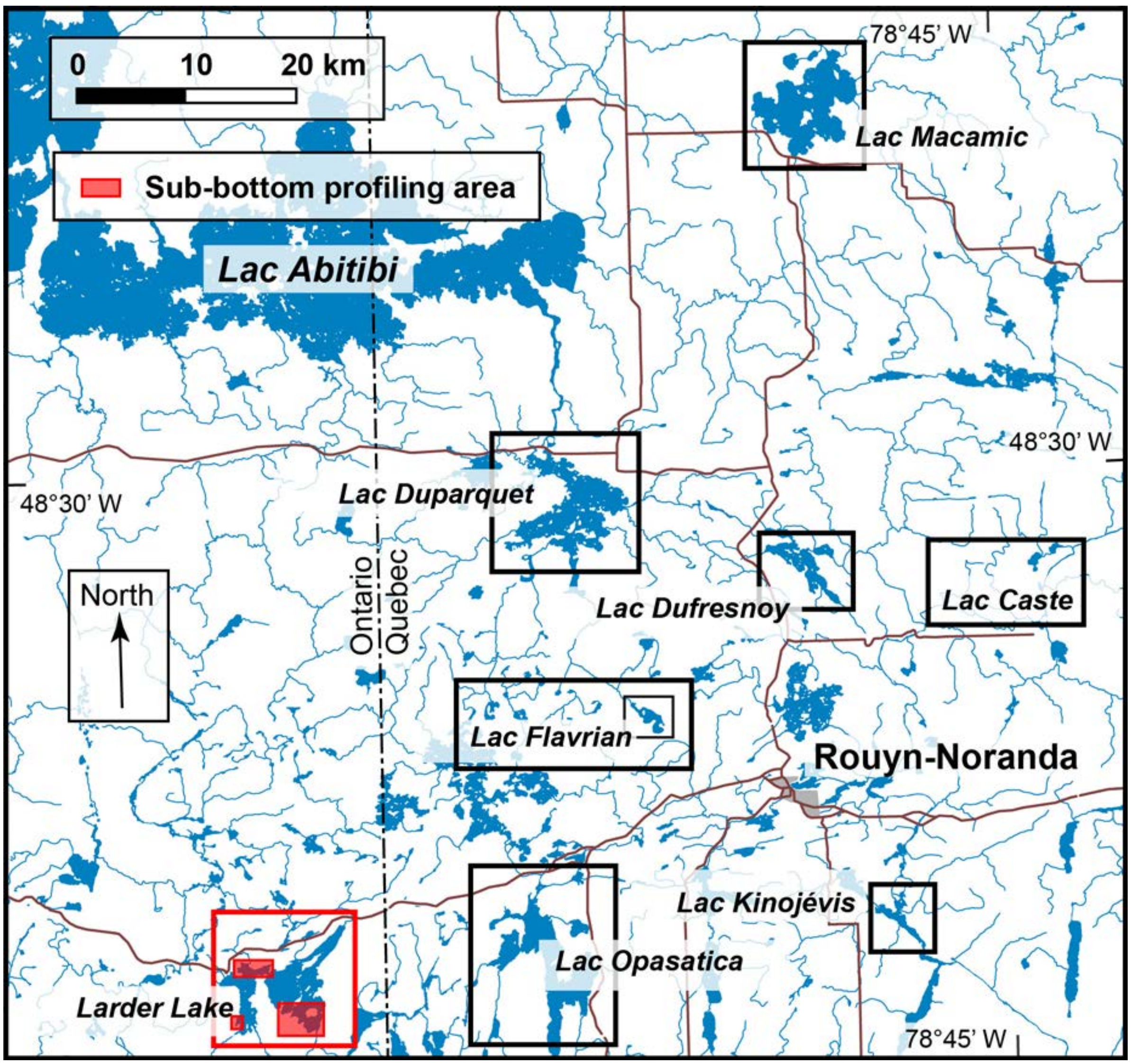

Fig. 1 Map showing the three locations within Larder Lake as well as the other seven lake basins in the Rouyn-Noranda area, Quebec, where reconnaissance sub-bottom profiling surveys were conducted in July, 2014.

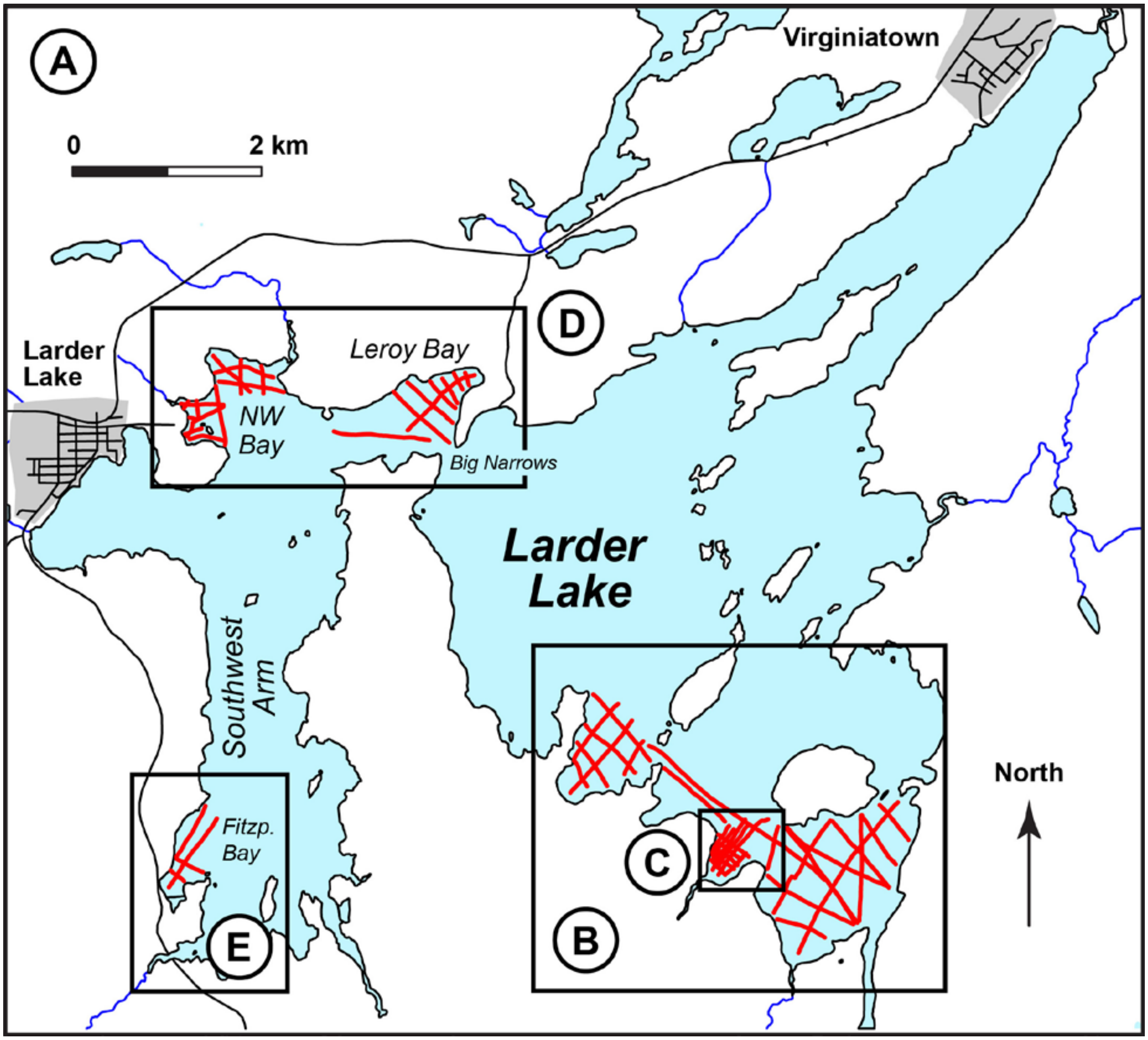

Fig. 2A Map of Larder Lake showing the general location of the three areas where sub-bottom profile lines were collected on July 20 (B) and July 23 (D and E), 2014.

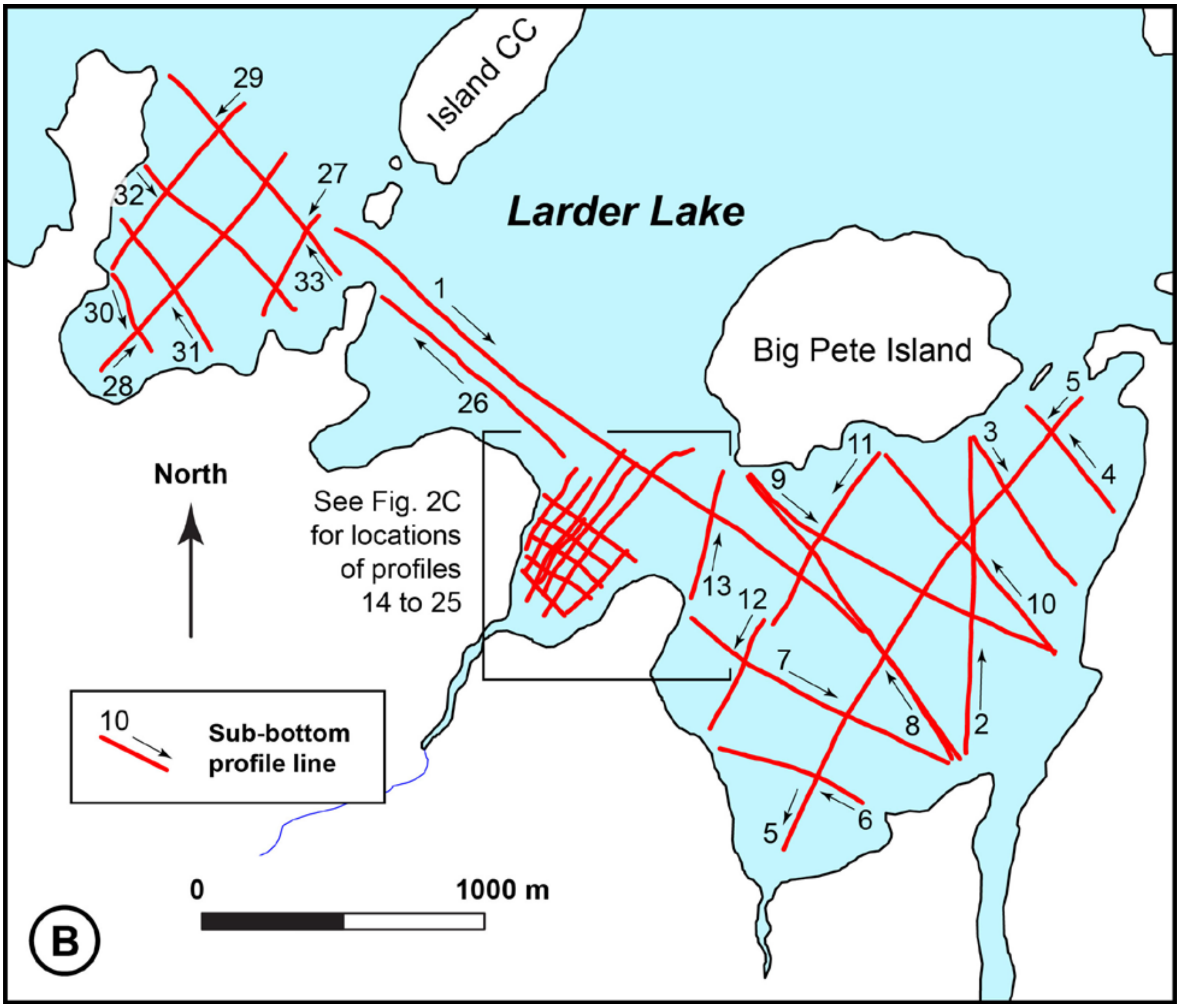

Fig. 2B Inset map of the southern area of the main basin of Larder Lake showing the locations and numbering of the sub-bottom profile lines 1 to 13 and 26 to 33. Refer to Fig. 2C for the locations of profiles 14 to 25, which are concentrated within the smaller bay in the middle of the figure. All of the profiles in Fig. 2B (and 2C) were collected on July 20, 2014.

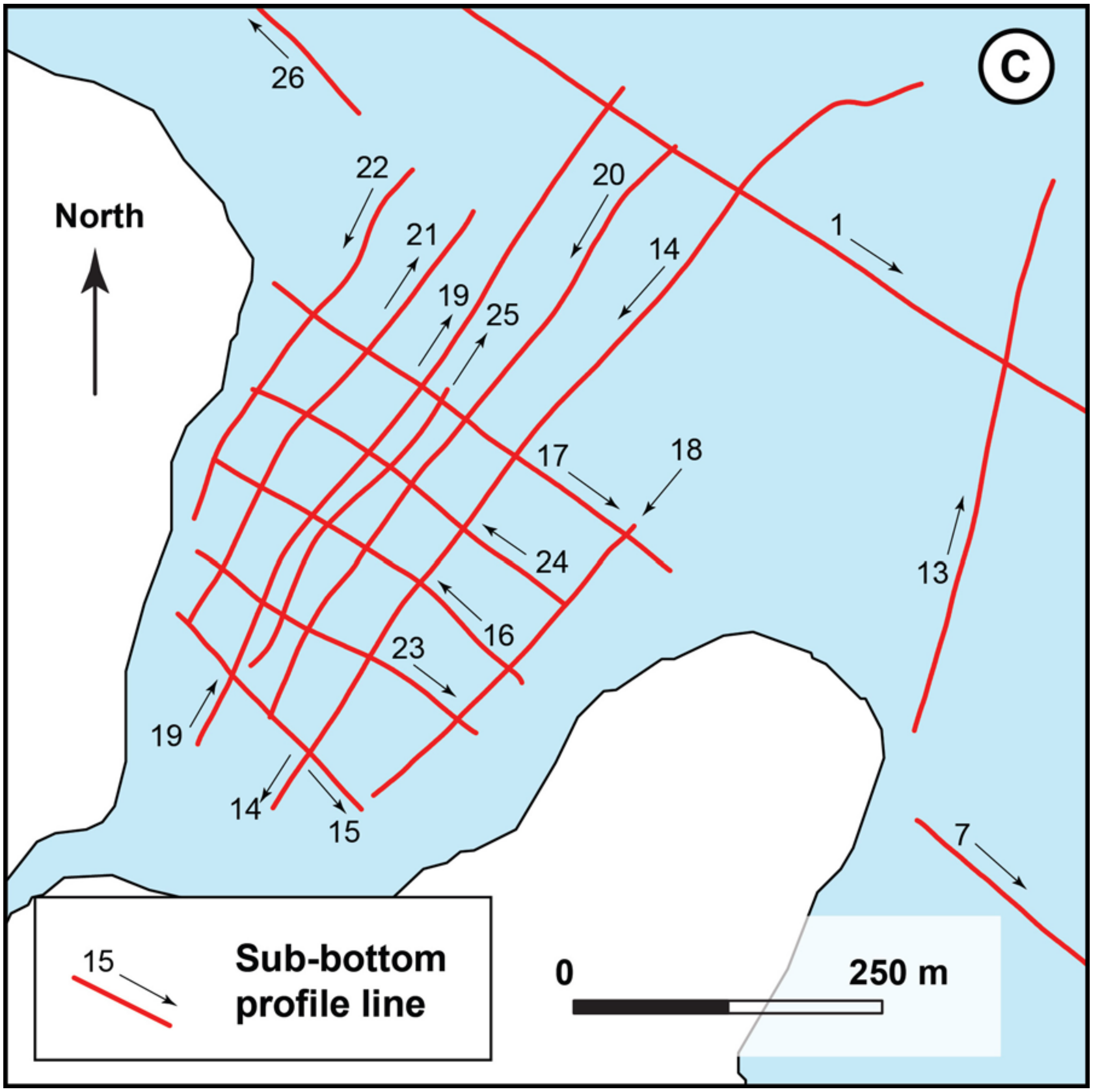

Fig. 2C Inset map of the middle area depicted in Fig. 2B showing the locations and numbering of the sub-bottom profile lines 14 to 25.

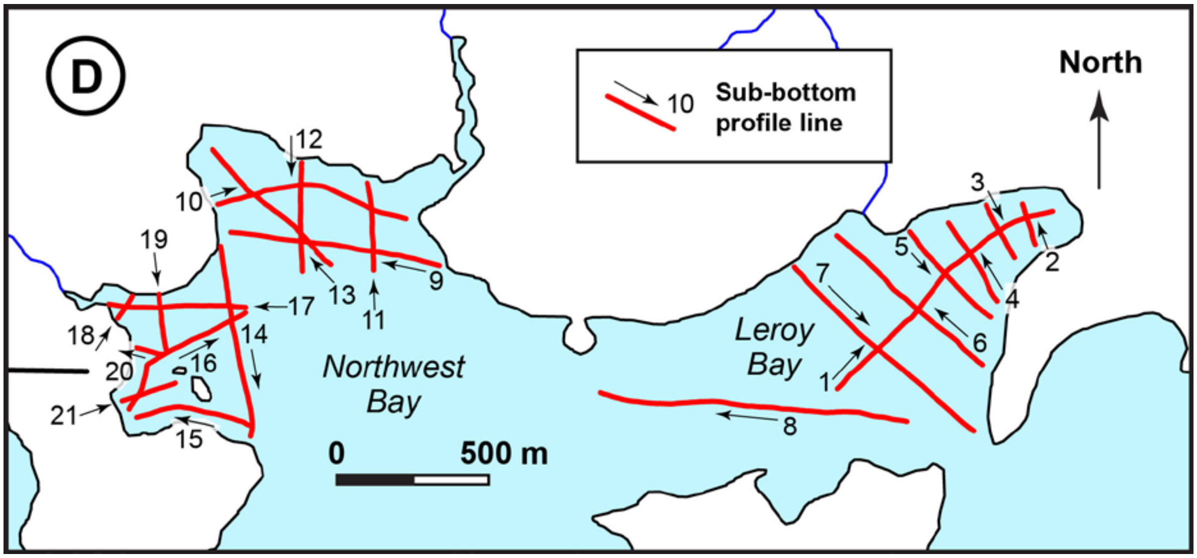

Fig. 2D Inset map of Leroy and Northwest bays. Larder Lake, showing the locations and numbering of the sub-bottom profile lines 1 to 21 collected on July 23, 2014.

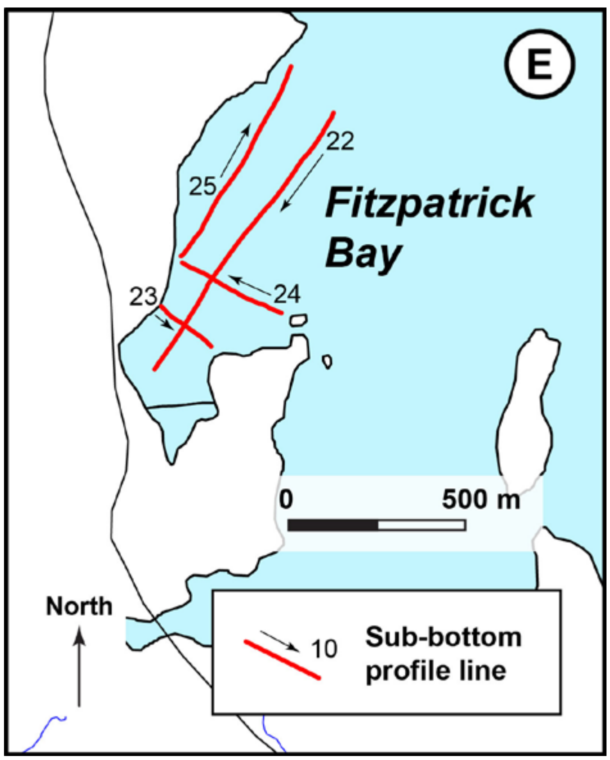

Fig. 2E Inset map of Fitzpatrick Bay, Southwest Arm of Larder Lake, showing the locations and numbering of the sub-bottom profile lines 22 to 25 collected on July 23, 2014.

Table 1 List of Open Files containing reconnaissance sub-bottom profiling of eight lakes in the Rouyn-Noranda-Kirkland Lake area, northwestern Quebec-northeastern Ontario.

Profiled lake basin	GSC OF number
Larder Lake	This report
Lac Dufresnoy	7990
Lac Duparquet	7989
Lac Flavrian	7988
Lac Kinojévis	7987
Lac Caste	7991
Lac Macamic	7985
Lac Opasatica	7984

Larder Lake

Larder Lake is located ~49 km west-southwest of Rouyn-Noranda, Quebec. The lake is about 13.5 km long and 40 km^2 in area (Fig. 2). The lake consists of two distinct basins that are separated by the 'Big Narrows'; the eastern basin is the larger of the two. A number of bedrock islands are present in the lake, particularly in the eastern basin. The towns of Larder Lake and Virginiatown are located on the lake. Access to the lake was obtained using a public boat launch at the town of Larder Lake at the northwestern end of the lake.

Methodology

The SAP surveys on Larder Lake were undertaken on July 20 and 23, 2014, using a Knudsen 320M™ profiler coupled to low (28 kHz) and high (200 kHz) frequency transducers. The pole-mounted transducers were attached on the side of a 4.9 m (16 ft) aluminum boat powered by a 30 hp motor. Traversing speed during profiling ranged between 5 to 7 $km.hr^{-1}$. Profiling routes were mapped using streamed differentially-corrected GPS coordinates collected with a Novotel Smart-V1 antenna-receiver and recorded in combination with the digital SAP data. The active depth window of the profiler was set to 20 or 50 m, as necessary, depending on the depth of water. The profiling routes are depicted in Fig. 2.

Profiler and GPS data for each profile were recorded digitally on a notebook computer as .keb and .kea files. A .keb file is a Knudsen proprietary format that can be opened with Knudsen PostSurvey™ v1.61[1] software, which is included with the download of this Open File. In the .keb format, the profile returns include a depth scale and vertical line stamps which display time and geographical coordinates (degree-decimal minutes). The vertical line stamps are made at the start/end of the profiles as well as at 20 sec intervals during profiling (Fig. 3).

To further facilitate profile viewing, the .keb file of the 28 kHz channel returns for each profile has been converted to a .sgy format file as well as a .bmp raster image. The .kea file contains the date and time of data collection, water depth, and geographical coordinates of the profile routes.

[1] PostSurvey v1.61 is proprietary property of Knudsen Engineering Ltd.™ and is intended for authorized use only. Any use, other than the specific purpose of playback/displaying Knudsen data is prohibited. PostSurvey v1.61 has been included in the download of OF-7986 with the permission of Knudsen Engineering Ltd.™. The software has been provided for the convenience of the OF-7986 user. A user of this software does so entirely at their own risk.

The .kea files are an ASCII format and can be opened through a spreadsheet software, such as Microsoft Excel®. Depths on the profiles in the .keb and .kea files are based on a sound velocity in water of 1500 $m.s^{-1}$.

The .keb, .sgy, .bmp and .kea files for each profile are contained in designated profile folders. The folders are contained in appendices A and B that accompanies the download of this report and are organized by date of collection.

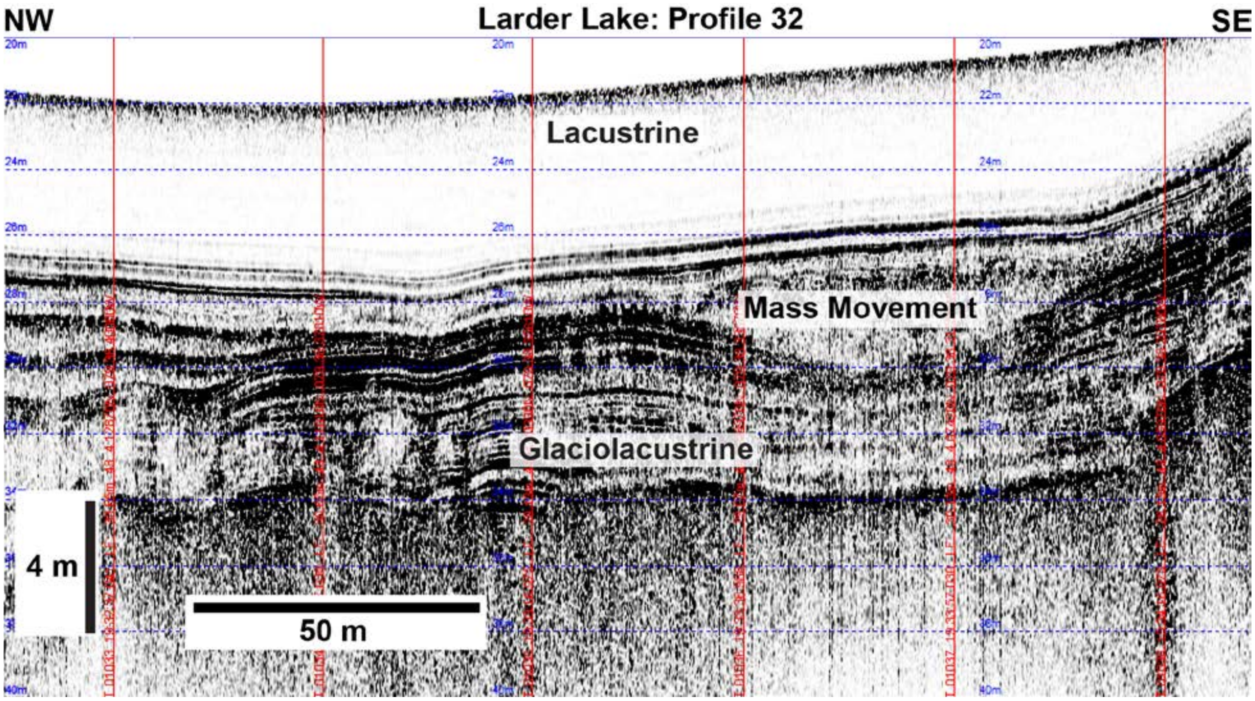

Fig. 3 Example of a sub-bottom acoustic profile (portion of profile 32) from the southern area of Larder Lake, collected on July 20, 2014, showing lacustrine, glaciolacustrine and mass movement facies. See Fig. 2B for the location of the profile. There are several mass movement deposits in this profile, including at the location of the “mass movement” label and on the left side of the profile. The horizontal dashed lines show depth at 2 m intervals and the vertical lines are time-geographical coordinates stamps.

Results

Sub-bottom profiles with Larder Lake were collected on July 20, 2014, in the southern area of the eastern basin (Fig. 2B), and on July 23, 2014, in two areas of the western basin (Fig. 2D and 2E).

Up to three depositional facies are present in the SAP profiles, as exemplified in Fig. 3 and summarized as follows:

Lacustrine facies – consists of transparent to weakly bedded deposits (Fig. 3); bed spacing is variable. The basal boundary is conformable and commonly well defined by a strong impedance layer. Deposits of this facies are interpreted to have aggraded in the post-glacial basin of Larder Lake.

Glaciolacustrine facies – consists of multiple, decimetre-scale, parallel reflectors that are draped on the underling topography (Fig. 3). Deposits exhibiting this facies are common to many lakes on the Canadian Shield and reflect sedimentation within a glaciolacustrine depositional environment. The deposits of this facies in Larder Lake deposits are inferred to have aggraded within glacial Lake Ojibway.

Mass movement facies – consist of transparent or diffuse returns (Fig. 3), possibly including blocks (clasts) of intact glaciolacustrine deposits the bedding of which may be rotated with respect to the glaciolacustrine facies. The upper surface of the facies may be smooth or irregular. Bed thickness is variable from decimetres to several metres in scale and may pinchout laterally. Basal contact can be conformable or erosive along a given profile.

A bedrock facies is present in many profiles. This facies generally forms a strong, opaque reflector with a smooth, curved, or irregular surface topography. Where occurring near the start or end of a profile, the bedrock likely outcrops along the shoreline, island or shoal. Isolated pinnacles of bedrock appear occasionally in some profiles.

Southern area of the eastern basin

Thirty-three SAP profiles were collected within the southern area of the east basin. Profiles 2 to 13 were collected in the bay south of Big Pete Island, profiles 14 to 25 within a small bay southwest of Big Pete Island, and profiles 27 to 33 within the bay southwest of Island CC (Fig. 2b and 2C) Profiles 1 and 26 extends between the bays.

Good penetration of the sub-bottom was obtained in all of the profiles south of Big Pete Island (profiles 2 to 13). Water depths are up to 19 m deep along the profile tracks. Mass movement deposits are present in all of the profiles. Profiles 4, 5 and 7 contain particularly good examples of mass movement deposits. A localized disruption to the glaciolacustrine beds occurs in the middle of profile 5 that may be a water escape structure.

In the bay southwest of Big Pete Island, profiles 14 to 25 were collected within a relatively dense grid (Fig. 2C). Good penetration was obtained along all of the profiles except for profile 22. Mass movement deposits are present in all of the profiles, except 16 and 18. A possible ice-block melt-out structure is present in profile 17. This area appears as a series of hummocks in profile 19, which is oriented perpendicular to profile 17. Water depth is up to 21 m deep in the areas off the mouth of the bay.

Profiles 27 to 33 were collected in the bay southwest off Island CC (Fig. 2B). Good penetration was obtained along all of the profiles. Mass movement deposits are present in all of the profiles, except profile 29. Water depth is up to 29 m deep in the profiles of the mouth area.

Profiles 1 and 26 span the area between the bays. The returns in profile 1 are noisy. Mass movement deposits are present in both profiles.

Northern area of the eastern basin

Twenty-one SAP profiles were collected in the northern area of the eastern basin of Larder Lake (Fig. 2D). Profiles 1 to 8 were collected within or off Leroy Bay and profiles 9 to 21 were collected within Northwest Bay.

Good penetration of the sub-bottom was obtained in all of the profiles collected within or off Leroy Bay (profiles 1 to 8; Fig. 2D). Water depths are up to 29 m deep along the profile tracks. Mass movement deposits are present in all of the profiles, except 2, 3 and possibly 6. Bedrock forms an obvious facies in all of the profiles, as noted in Table 3.

Good penetration of the sub-bottom was obtained in all of the profiles collected from Northwest Bay (profiles 9 to 21; Fig. 2D). Water depths are up to 27 m deep along the profile tracks. Mass movement deposits are present in all of the profiles. Bedrock forms an obvious facies many of the profiles, as noted in Table 3.

Fitzpatrick Bay

Good penetration of the sub-bottom was obtained in all of the profiles collected from Fitzpatrick Bay (profiles 22 to 25; Fig. E). Water depths are up to 21 m deep along the profile tracks. Mass movement deposits are present in all of the profiles. The returns in profiles 23 to 25 exhibit a shimmering caused by wave-induced boat heave during profiling.

Summary and conclusions

Twenty-nine SAP were collected from the southern area of the east basin of Larder Lake, Ontario, on July 20, 2014. An additional 25 SAP were collected from Leroy, Northwest and Fitzpatrick bays of the west basin on July 23, 2014.

Good penetration of the sub-bottom was obtained within the profiled areas.

Three facies can be identified within the SAP returns that represent lacustrine, glaciolacustrine and mass movement deposits.

The profiles collected from Larder Lake demonstrate the presence of mass movement deposits within this basin. However, deep water conditions in many of the profiled areas represent a challenge to coring, depending on the coring equipment used.

Acknowledgements

I thank Jim Hunter for reviewing this report. Matt DeGeer assisted with the collection of the SAP profiles. Figures 2 and 3 were made by Katie MacDonald, who also compiled Table 2. This research was supported through the Public Safety Geoscience Program, Earth Sciences Sector, Natural Resources Canada.

Table 2 Summary listing of the Larder Lake sub-bottom profiles collected from the southern bay of the east basin on July 20, 2014.

Profile number	Direction	Length (m)	Comments
1	SE	2935	- Moderate to good penetration throughout. Returns noisy. - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
2	N	1116	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
3	SE	634	- Good to moderate penetration along most of profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits - Scale range in profile adjusted to account for changes in depth
4	NW	481	- Good penetration along most of the profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits
5	SW	1928	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits - Localized disrupted(?) structure in middle portion of profile - Scale range in profile adjusted to account for changes in depth
6	WNW	546	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits
7	SE	1050	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
8	NW	1237	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
9	SE	1263	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
10	NW	924	- Good to moderate penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
11	SW	717	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits - Scale range in profile adjusted to account for changes in depth
12	SW	431	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits, and bedrock - Scale range in profile adjusted to account for changes in depth
13	NNE	460	- Good penetration along most of profile, but no penetration at beginning - Returns show lacustrine, glaciolacustrine and several mass movement deposits - Scale range in profile adjusted to account for changes in depth

14	SW	809	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
15	SE	218	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits
16	NW	312	- Good penetration along most of profile, poor penetration locally in middle section - Returns show lacustrine and glaciolacustrine deposits
17	SE	397	- Good penetration locally in the middle of the profile - Returns show lacustrine and glaciolacustrine deposits - A isolated depression representing a possible melt-out structure is situated within the middle of the profile - Scale range in profile adjusted to account for changes in depth
18	SW	305	- No penetration along first third of profile, good penetration elsewhere - Returns show lacustrine and glaciolacustrine deposits
19	NE	638	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - A series of hummocks are present within the middle of the profile that may be part of the melt-out(?) structure that appears in profile 17 - Scale range in profile adjusted to account for changes in depth
20	SW	572	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
21	NE	407	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
22	SW	338	- Limited penetration and poor quality returns along entire profile
23	SE	271	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits
24	NW	310	- Poor to good penetration along entire profile - Returns show lacustrine and glaciolacustrine deposits - Scale range in profile adjusted to account for changes in depth
25	NE	279	- Good penetration along entire profile - Returns show lacustrine and glaciolacustrine deposits
26	NW	859	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
27	SW	404	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
28	NE	1008	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits - Scale range in profile adjusted to account for changes in depth

29	SW	750	- Good penetration along entire profile - Returns show lacustrine and glaciolacustrine deposits - Scale range in profile adjusted to account for changes in depth
30	SSE	307	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and mass movement deposits
31	NW	560	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits
32	SE	738	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits - Scale range in profile adjusted to account for changes in depth
33	NW	926	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits - Scale range in profile adjusted to account for changes in depth

Table 3 Summary listing of the Larder Lake sub-bottom profiles collected from the west basin on July 23, 2014.

Profile number	Direction	Length (m)	Comments
Leroy Bay			
1	NE	940	- Good penetration along first half of profile, no penetration elsewhere - Returns show lacustrine, glaciolacustrine and mass movement deposits, and hummocky bedrock - Scale range in profile adjusted to account for changes in depth
2	NNW	139	- Good penetration along entire profile - Returns show lacustrine deposits and bedrock - Scale range in profile adjusted to account for changes in depth
3	SE	197	- Good penetration along most of profile - Returns show lacustrine and glaciolacustrine deposits, and bedrock - Scale range in profile adjusted to account for changes in depth
4	NW	305	- Good returns along first three quarters of profile but no returns elsewhere - Returns show lacustrine, glaciolacustrine and mass movement deposits, and bedrock - Scale range in profile adjusted to account for changes in depth
5	SE	390	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and mass movement deposits, and bedrock - Scale range in profile adjusted to account for changes in depth
6	NW	643	- Good penetration along most of profile - Returns show lacustrine and glaciolacustrine deposits, and bedrock - Scale range in profile adjusted to account for changes in depth
7	SE	803	- Good penetration along most of profile, poor penetration at very beginning - Returns show lacustrine, glaciolacustrine and several mass movement deposits - Scale range in profile adjusted to account for changes in depth
8	W	1023	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits, and bedrock - Scale range in profile adjusted to account for changes in depth
Northwest Bay			
9	WNW	699	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits, and bedrock - Scale range in profile adjusted to account for changes in depth
10	ENE then ESE	650	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and mass movement deposits, and bedrock - Scale range in profile adjusted to account for changes in depth
11	N	289	- Good penetration along most profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits - Scale range in profile adjusted to account for changes in depth

12	S	358	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and several mass movement deposits, and bedrock - Scale range in profile adjusted to account for changes in depth
13	NW	548	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
14	SSE	636	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
15	W	391	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and mass movement deposits, and bedrock - Scale range in profile adjusted to account for changes in depth
16	NNW then NW	528	- Good to moderate penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
17	W	453	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
18	NW	89	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits
19	SSE	184	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
20	W	96	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth
21	WSW	185	- Good penetration along entire profile - Returns show lacustrine, glaciolacustrine and mass movement deposits
Fitzpatrick Bay			
22	SW	891	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and mass movement deposits
23	SE	184	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and mass movement deposits
24	NW	318	- No penetration along first third of profile, good penetration elsewhere - Returns show lacustrine, glaciolacustrine and mass movement deposits, and bedrock
25	NE	627	- Good penetration along most of profile - Returns show lacustrine, glaciolacustrine and mass movement deposits - Scale range in profile adjusted to account for changes in depth

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