Sediment Thickness Profiling and Water Properties of Selected Lakes in the Winnipeg River Watershed, northwestern Ontario – Trip 2 (7-23 July, 2008) of NSERC-CRD Research Grant "Assessment of Water Availability within the Winnipeg River Drainage Basin over the Past 2 Millennia"

C.F.M. Lewis[1], T.W. Anderson[2], M.V. Kingsbury[3]

[1] Geological Survey of Canada Atlantic, Natural Resources Canada, Bedford Institute of Oceanography, Box 1006, 1 Challenger Drive, Dartmouth NS B2Y 4A2, Canada. Email miklewis@nrcan.gc.ca.

[2] 25 Dexter Drive, Ottawa ON K2H 5W3. Email thane.anderson@gmail.ca.

[3] Department of Biology, Queen's University, Kingston ON K7L 3N6. Email 7mk18@queensu.ca.

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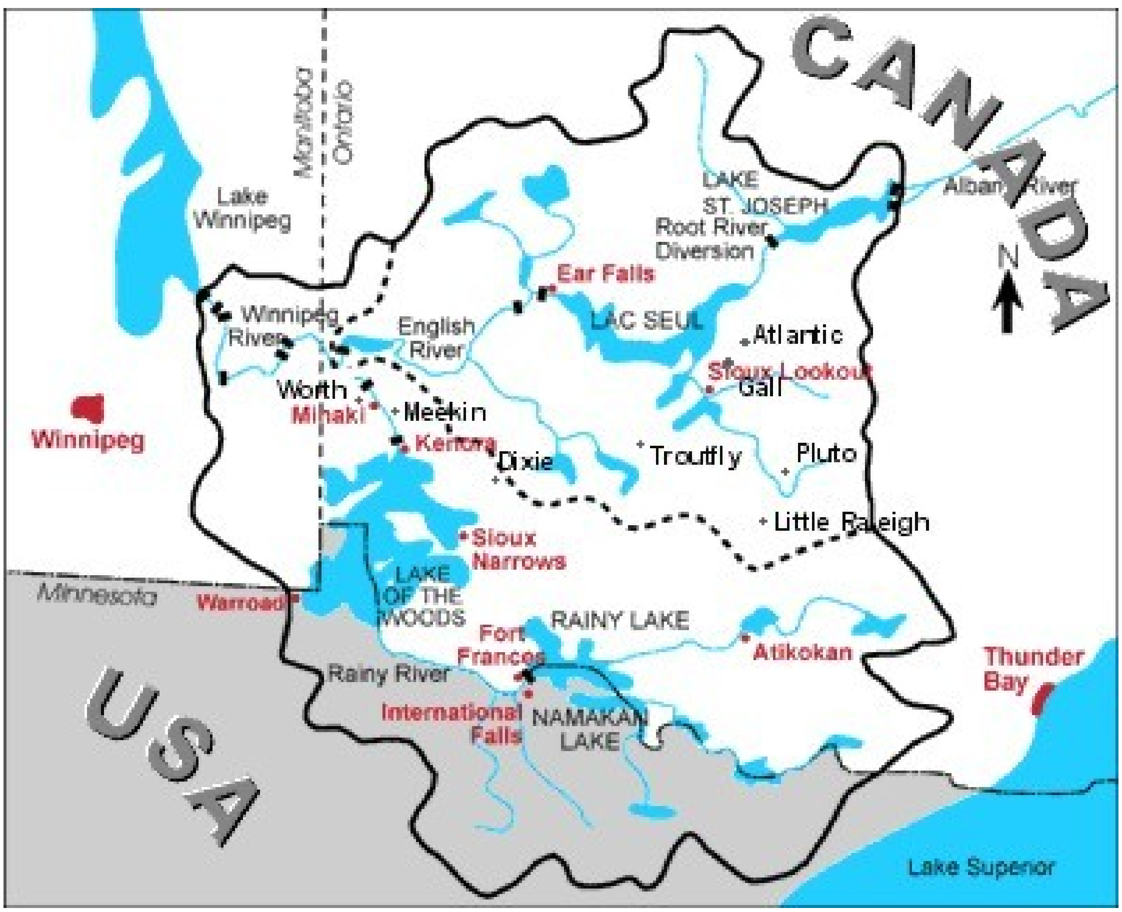
Introduction

This trip is an activity and milestone of an NSERC-CRD research grant to Professor B. Cumming and Dr. K. Laird of the Department of Biology at Queen's University, Kingston, Ontario, funded jointly by Manitoba Hydro and the Natural Sciences and Engineering Research Council of Canada. The overall objective of the research is to select key sites within the Winnipeg River drainage basin from which analyses of lake sediments can provide a picture of long-term patterns in lake levels. The general objective of the present activity (milestone 3) is to acquire information about the thickness and distribution of sediments in 8 lakes in the watershed of the Winnipeg River (Fig. 1), selected on the basis of existing information (milestone 1), and bathymetric surveys and reconnaissance sediment sampling conducted in late May and June, 2008 during Trip 1 (milestone 2) of the research project.



(Base map from Lake of the Woods Control Board website (http://www.lwcb.ca/))

Figure 1. Map of Winnipeg River basin showing study lake locations (Atlantic, Dixie, Gall, Little Raleigh, Meekin, Pluto, Troutfly, Worth).

Table 1. Lake locations, areas, elevations, and other properties.

Lake	Lake Order	Size (ha)	Max Depth (m)	Mean Depth (m)	Eleva tion (m)*	Sub-Watershed	WA: SA[1]	Lat.	Long.
Atlantic	Closed?	54	30	12	374	Lac-Seul	7.5	50 14 38.6	91 27 26.8
Gall	1	18	15	8.5	383	Lac-Seul	5.3	50 11 01.4	91 41 55.6
Pluto	2	160	24		412	Lac-Seul	4.8	49 39 48.0	91 39 14.0
Little Raleigh	1	74	19	7	457	Lac-Seul	2.8	49 27 13.0	91 5346.0
Troutfly	2	200	32	12	400	Lac-Seul	5	49 51 08.0	92 26 56.0
Dixie	1	20	19	9	397	English R.	3	49 49 58.0	93 56 56.0
Meekin	1	75	15	7.2	356	Winnipeg R.	2.7	49 49 04.0	94 46 16.0
Worth	2	115	29	10	330	Winnipeg R.	3.3	50 00 10.0	94 45 53.0

*from Google Earth, [1]Watershed Area to (lake) Surface Area ratio

The specific objectives of Trip 2 (milestone 3) are:

1. Obtain transects of sediment thickness in the 8 selected lakes. The sediment of interest is the upper part of that which accumulated since the lakes were isolated from the last ice cover or glacial Lake Agassiz.
2. Measure water properties and collect water samples for further analysis from the same 8 lakes.
3. On an opportunity basis, survey sediment thickness in Caribou Lake and core peat sediments in Serpent River bog, both located north of Lake Huron between Sault Ste. Marie and Espanola, Ontario; also obtain profiles of sediment thickness in Loughborough Lake near Kingston, Ontario.

Personnel

Dr. C.F.M. Lewis, Emeritus Scientist, Geological Survey of Canada, and project collaborator.
Dr. T.W. Anderson, Geological Survey of Canada (retired), and project volunteer.
Ms. M.V. Kingsbury, MSc student, Department of Biology, Queen's University.

Methods and Equipment

1. Lake sediment profiling

A Knudsen 320M marine sounder with 200 kHz and 28 kHz transducers, powered by two 12-volt wet batteries was used. Lakefloor and sub-bottom acoustic reflections were recorded graphically on thermal recording paper. Timelines were marked every 20 seconds with geographic coordinates determined by an onboard global positioning system (GPS) receiver. These coordinates provide the position at which a core could be recovered to sample sediments of interest imaged in the sounding record.

An onboard Trimble GPS receiver was set to log geographic position coordinates at 5-second intervals on the WGS84 (NAD83) horizontal datum with an estimated accuracy of 15-20 m. The GPS system was powered by one of the onboard 12-volt wet batteries.

Sub-bottom profiling transects were generally run twice across areas of moderate gradient from shallow to deep water or vice versa in each lake using a 14-foot Starcraft aluminum boat powered by a 4.5 hp Mercury outboard motor. Transects were navigated visually while sighting on shore landmarks. Boat operations were managed by 3 persons – T. Anderson as boat operator, M. Lewis as sounding recorder operator, and M. Kingsbury as navigator and monitor of GPS position logging.

2. Lake water property measurement and sampling

The water sampling was done in the basin of the lake at or near the deepest point. GPS coordinates were taken with a Garmin handheld GPS unit using WGS84 (NAD83) horizontal datum with an estimated accuracy of 15-20 m at this location. An anchor was used to stabilize the location of the boat for consistency. On each lake, the water column was analyzed, Secchi depth was read, and water samples were taken. Observations and measurements were managed by M. Kingsbury.

A YSI 650 Multi-parameter Display System (650 MDS) with a 600XL probe was used to collect the following parameters for the water column: dissolved oxygen (mg/L), specific conductivity (µs/cm), temperature (°C), and pH. These parameters were recorded at 1 meter intervals to a depth of 10-12 meters at which point measurements were made every 2 meters to the bottom.

Secchi depth was also recorded using a 12 in. diameter Secchi disk attached to a rope marked with 1 meter intervals. The disk was lowered into the water until it just disappeared from view. The depth at which this occurred was then recorded.

Concurrently, water was collected using an integrated water sampler provided by the Ontario Ministry of the Environment. A water sample was collected from the top 5 meters of the water column. Two litres were collected from each lake for water analysis. One litre of the water was filtered using 0.45µm mesh, and the other kept as a whole water sample. The water samples were kept in a refrigerator or on ice for the duration of the trip in Nalgene or PET containers. Upon return, the samples were sent to Ontario Ministry of the Environment Dorset Environmental Science Centre in Dorset, ON where they will be analyzed for all the major anions and cations, phosphorous, nitrogen, silica, and dissolved organic carbon.

3. Peat sampling

Two commonly used samplers, the Hiller peat sampler and Livingstone piston corer (Mott, 1966) were used to obtain cores from the peat bog and underlying lacustrine sediments at Serpent River bog. The Hiller peat sampler was mainly used to probe different parts of the peat bog to determine the thickness of the bog deposit, lithology of the underlying sediments, and depth to refusal. The Livingstone piston corer was used to recover cores from within the base of the peat down through the lacustrine sediments to refusal at the base.

Study lakes and their setting

The 8 study lakes in the Winnipeg River basin are located in small depressions of approximately 10-50 m depth which were eroded from Precambrian metamorphic bedrock of the Canadian Shield, Superior Province. Bedrock outcrop is common in areas around the three western study lakes (Fig. 1). Glacial and glacial lake deposits are more common to the east around the other 5 study lakes. Soft organic lake sediment would have begun accumulating in the study lake basins when the recession of the Laurentide Ice Sheet and regression of glacial Lake Agassiz in the region were completed just prior to 8000 BP (Fig. 2). Forest vegetation in the northern part of the study region is characteristically dominated by coniferous species typical of the Boreal Forest. The Boreal Forest grades southward in the region to a mixed forest with deciduous tree species.

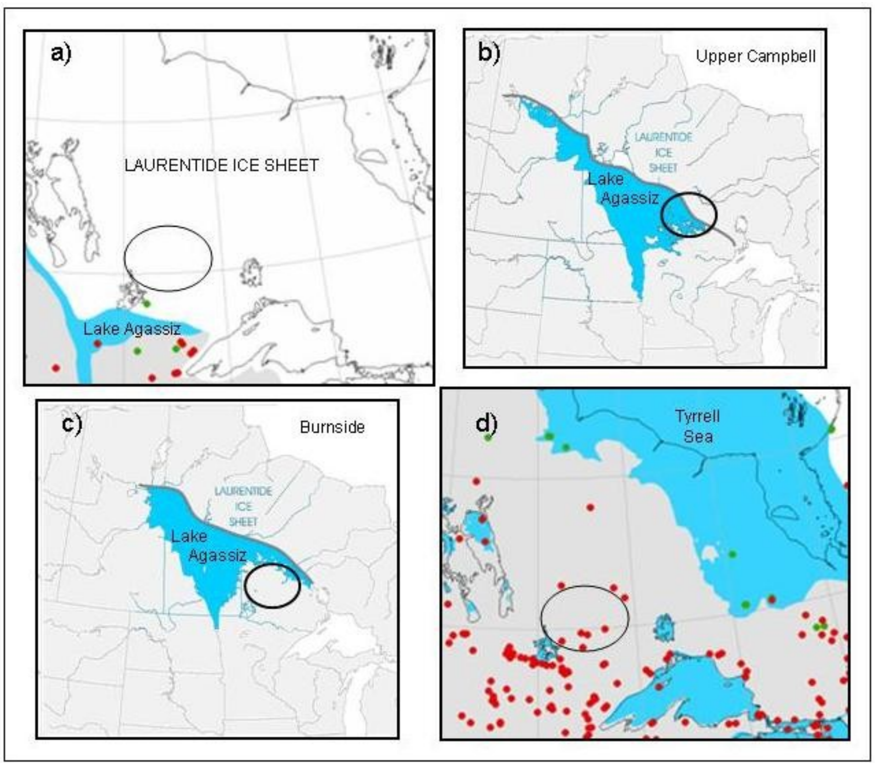


Figure 2. Map(s) of ice retreat and regression of glacial Lake Agassiz. Black ovals contain the 8 study lakes. Red and green dots on a) and d) are reference sites for the presence or absence of an ice cover. a) Map showing ice cover over all the study lake basins at 11,500 ^{14}C years before present (BP) (from Dyke et al., 2003). b) At its Upper Campbell phase about 9500 ^{14}C years BP, Lake Agassiz inundated most lake sites. Some high basins such as Little Raleigh may have been located on islands above the glacial lake (from Teller and Leverington, 2004). c) By the time of its Burnside phase, 8500-8300 ^{14}C years BP, Lake Agassiz had regressed from the study lake sites (from Teller and Leverington, 2004). d) By 7600 ^{14}C years BP, ice had

retreated from Ontario and Manitoba allowing the sea (Tyrrell Sea) to flood Hudson Bay and the Hudson Bay lowlands (from Dyke et al., 2003).

Narrative

July 7. The survey team assembled at the Department of Biology, Queen's University. M. Lewis had flown from Halifax the previous evening and was hosted overnight at the home of T. Anderson in Ottawa. Lewis and Anderson were driven with bog coring equipment to Kingston in the morning of July 7 by Mrs. Anderson in the Anderson vehicle (van).

A rental crew-cab pick-up truck with trailer, boat, motor and related field equipment was provided by Dr. B. Cumming. Over lunch, the 8 selected study lakes were discussed by principal project investigators, Drs. B. Cumming and K. Laird using bathymetry maps prepared by M. Kingsbury from data acquired during Trip 1.

The field party drove from Kingston to Brampton and met with Mr. Marten Douma, Geological Survey of Canada, who provided the sounder and GPS equipment for the lake surveys. M. Douma demonstrated operation of the GPS equipment in the evening.

July 8. In the morning, M. Douma continued tutoring us in the operation of the Knudsen sounder and GPS recorder in the Brampton area. During the afternoon and evening the party drove to Sault Ste. Marie.

July 9. Drove from Sault Ste. Marie to Thunder Bay, Ontario.

July 10. Acquired a plank and clamps at Home Hardware, Thunder Bay, for attaching the sounder transducers to the aluminum survey boat. Drove to Kenora where batteries, rubber boots and other supplies were purchased to complete the survey gear.

July 11. High winds, thunder and lightning prevented work on the lakes.

July 12 and 13. High winds and rough water continued to prevent work on the water. Viewed Worth Lake and visited Mr. J. Jorgensen at Meekin Lake on July 12.

July 14. Wind speeds were low. Surveyed and sampled both Worth and Meekin lakes.

July 15. Departed Kenora, surveyed and sampled Dixie and Troutfly lakes, and arrived Sioux Lookout.

July 16. Surveyed and sampled Atlantic and Gall lakes. Stayed in Sioux Lookout overnight.

July 17. Departed Sioux Lookout, surveyed and sampled Little Raleigh Lake and drove to Ignace.

July 18. Departed Ignace, surveyed and sampled Pluto Lake and drove to Thunder Bay.

July 19. Had trailer light bulbs tested and replaced at Canadian Tire service store in Thunder Bay, then drove to Sault Ste. Marie.

July 20. Departed Sault Ste. Marie. Surveyed Caribou Lake north of Bruce Mines and initiated reconnaissance of Serpent River bog adjacent to Highway 17 between Cutler and Spanish. Drove to Blind River to stay overnight.

July 21. Departed Blind River. Probed and cored Serpent River bog. Drove to Espanola.

July 22. Departed Espanola and drove to Ottawa and Harrowsmith where T. Anderson and M. Kingsbury, respectively, stayed overnight in their homes. M. Lewis drove to Kingston and stayed overnight.

July 23. B. Cumming, M. Kingsbury, and M. Lewis obtained sediment thickness profiles in Loughborough Lake near Kingston. Survey conditions were less than ideal due to strong winds and rough water in exposed areas of the lake. T. Anderson arrived with his van at Department of Biology, Queen's University, about 4 pm and transported sounder, GPS, and coring equipment with M. Lewis back to Ottawa.

July 24. M. Lewis returned to Halifax from Ottawa.

July 25. T. Anderson returned the sounding and GPS equipment to the Geological Survey of Canada at 601 Booth Street, Ottawa.

Lake sediment profiling results

The acoustic profiles, on record paper 20 cm wide (21.4 cm overall), all span 20 m vertical depth and were adjusted downward during surveys in increments of 10 m as the lake floor sloped into deep water, e.g. from 0 to 20 m, then 10 to 30 m, etc. The smallest divisions in the vertical scale of the records equal 0.2 m. The horizontal dimension is divided in 20-second intervals which equate to about 39 m distance at an average boat speed of 7 km per hour. On average, the vertical dimension in the profiles is exaggerated about 24 times.

In all lakes a nearly transparent acoustic unit up to 3 to 13 m thick in deep water lies below the water bottom reflection. This unit generally overlies a unit marked by a strong or dense black reflection or reflections. A lower unit with a single or few reflections is interpreted as a glacial sediment or bedrock. A basal unit with closely-spaced parallel reflections is inferred to be a laminated deposit of glacial lake sediments, likely of glacial Lake Agassiz. The nearly transparent unit is interpreted as soft organic and fine-grained lake sediment deposited since the lake basin was isolated from the former ice cover and glacial Lake Agassiz prior to 8000 ^{14}C years BP.

Besides a map figure showing the Knudsen sounding transects superposed on lake bathymetry, one or two figures illustrate the typical profile obtained in each lake. The tables list, for each transect or group of transects, the minimum water depth at which soft lake sediment has been deposited, the deepest water, and the thickest lake sediment measured. Notes about special features in each transect are listed in the right-hand table column.

Worth Lake

The acoustic records show deposition of soft lake sediment in water depths as shallow as 2 m on some transects. The maximum water depth and maximum lake sediment thickness recorded is 30.5 m and about 13 m, respectively. Reflections typical of glacial Lake Agassiz sediment are evident on the lake margins beneath soft lake sediment. Acoustic scattering (gas masks?) obscures sub-bottom reflections beneath the thickest lake sediment, particularly in deeper water. In places, the soft sediment surface is tilted suggesting that deposition is controlled to some degree by lake currents. There are some indications in the lake sediment morphology and stratigraphy that past water levels may have been lower than present by a few metres(?).

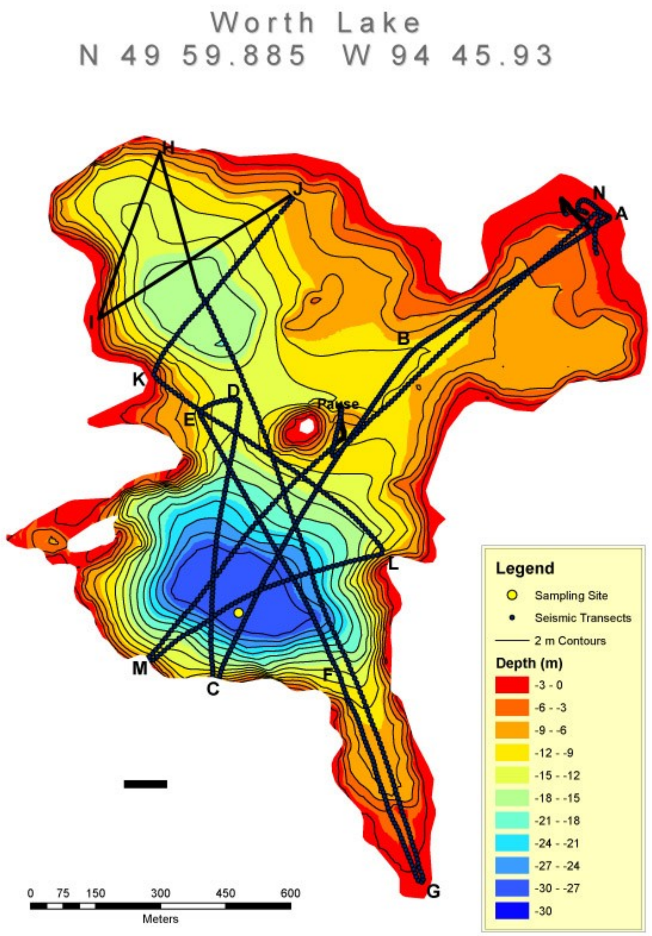


Figure 3a. Map of Worth Lake bathymetry with superposed Knudsen sounding transects identified by letters, AB, BC, etc.

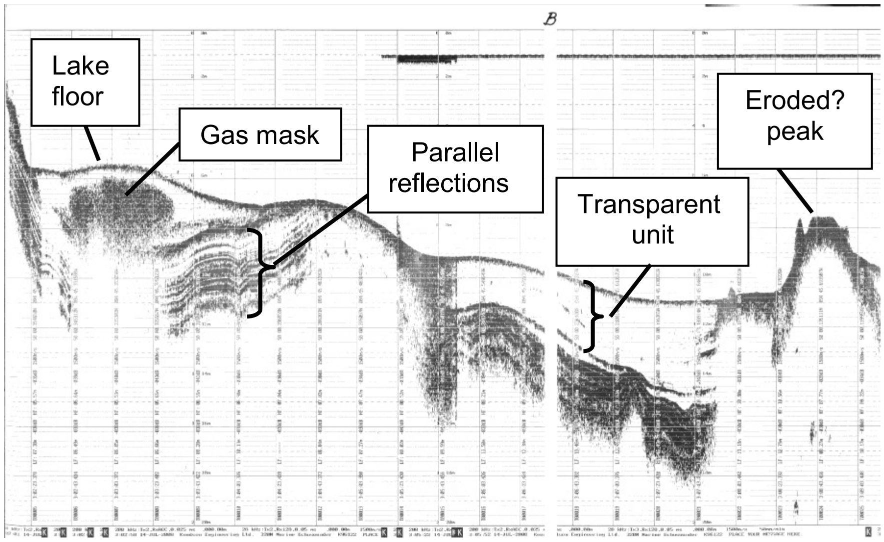


Figure 3b. Parts of Worth Lake transects AB and BC (0-20 m) showing strong parallel reflections of glacial Lake Agassiz sediment under a nearly transparent unit of soft lake sediment with a local gas mask that obscures underlying reflections. Note the clipping (erosion?) of the sediment-covered peak at 7.5 m water depth at right, suggesting an episode of lower-than present lake level.

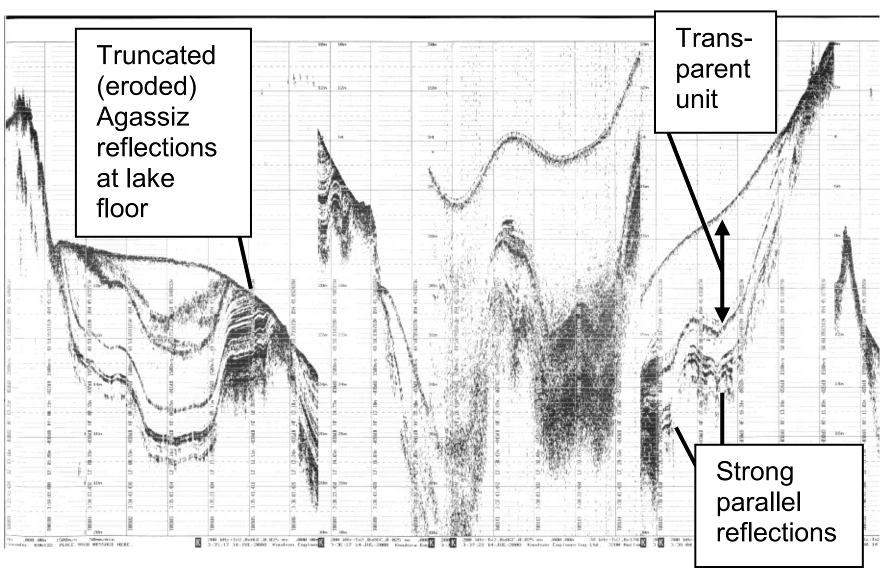


Figure 3c. Worth Lake transect GH (part) showing strong parallel reflections of Lake Agassiz sediment beneath the nearly transparent unit of soft lake sediment. The erosion terrace at left at 8-10 m water depth may have formed in a previous phase of the lake with lower-than present water level.

Table 2. Worth Lake transects: water depth to soft sediment and maximum sediment thickness

Transects	Minimum water depth (m) over soft sediment	Maximum water depth (m)	Maximum soft sediment thickness (m)	Comments
ABC	5.5	30.5	>10?	Gas mask in deepest part. AB & part BC are shallow basins at 6 m & 11 m depth. L. Agassiz sediment underlies transect.
CDE	11	30.2	>9?	Gas mask. L. Agassiz sediment exposed at lakefloor 14-15 m depth.
EFG	2 near G 16.8 m near E	28.5	>12?	Electrical? interference on record. Strong reflection in lower ¼ of soft lake sediment. Erosion terrace at 8-9 m truncates soft sediment reflection. Reflection truncation occurs down to 17 m
GHI	3 near G 7 near I	26.3	13?	Interference & gas in deep basin. Truncation of soft sediment and Agassiz sediment reflections near G on terrace at 8-10 m and downslope to 16.5 m may indicate erosion by currents or waves in a previous lower level lake
IJ	8 near J 7 near I	17.5	8?	
JK	8.2 near J ~10 near K	16	~1?	
KL	12	16	~1	Lake floor is tilted – a circulation effect? Truncation of basal soft sediment reflection ~16.3 m depth, under 1 m of sediment could be circulation erosion at a previous lowstand?
LM	17.2?	30.5	>7?	
MN	17?	30.0	>8?	Deep basin.
	7.5 & 2.2	9.8	~3.2	Shallower nearshore basin. Lake floor truncates lower soft sediment reflection 8-10 m depth. A strong reflection beneath 1-2 m sediment is a possible lowstand erosion surface.

Meekin Lake

The acoustic records show deposition of soft lake sediment in water depths possibly as shallow as 2 m on some transects. The maximum water depth and maximum lake sediment thickness recorded is 15 m and >8? m, respectively. Gas masking obscures sub-bottom reflections in basins below 10-14 m water depth. Parallel reflections of Lake Agassiz sediment are visible below the soft lake sediment near the basin margins where gas masking is not present. An erosion surface with reflection truncations occurs within lower lake sediment down to about 11 m depth below lake surface. Lake sediment onlaps the basin margins above the erosion surface, suggesting a lake lowstand within the period of lake sediment deposition.

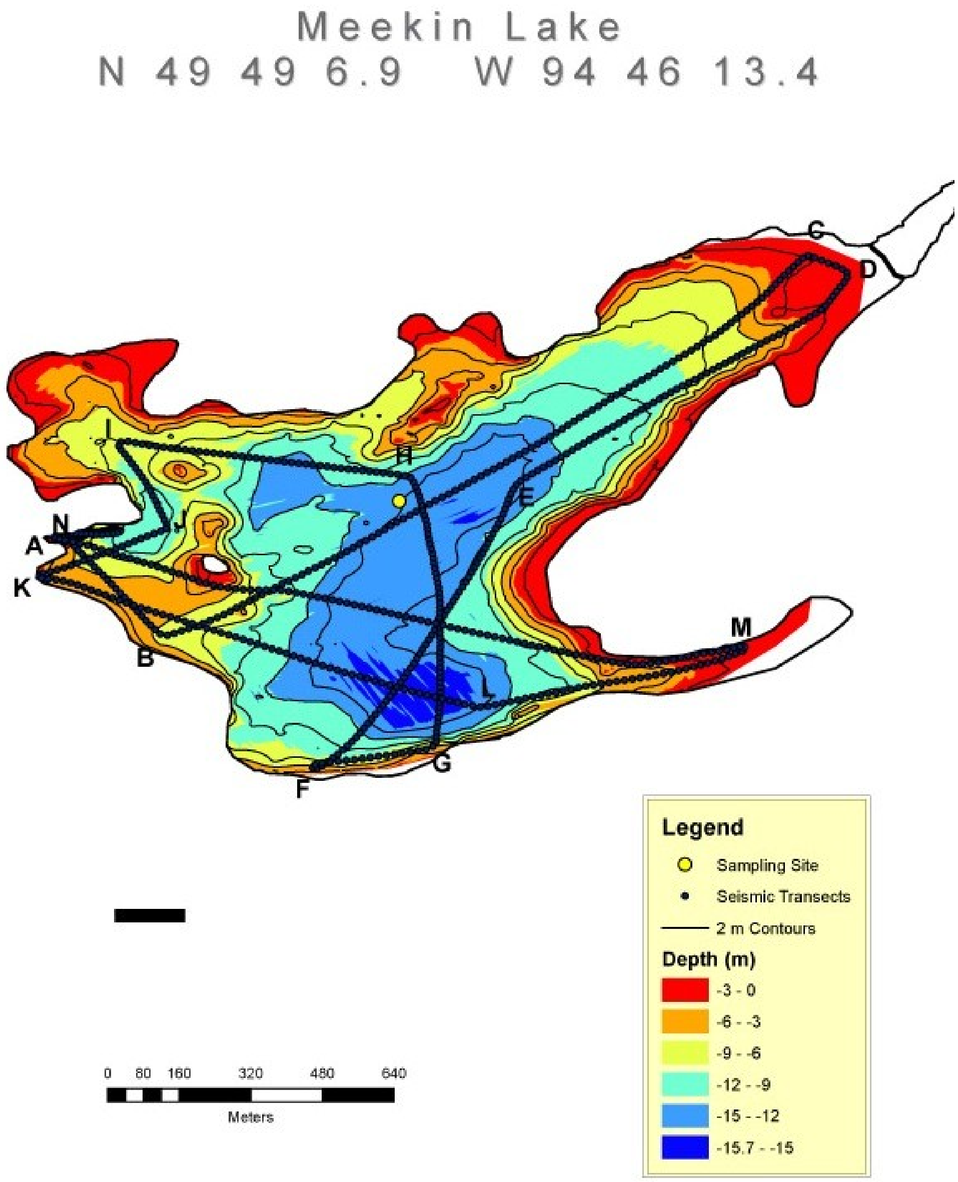


Figure 4a. Map of Meekin Lake bathymetry with superposed Knudsen sounding transects identified by letters AB, BC, etc.

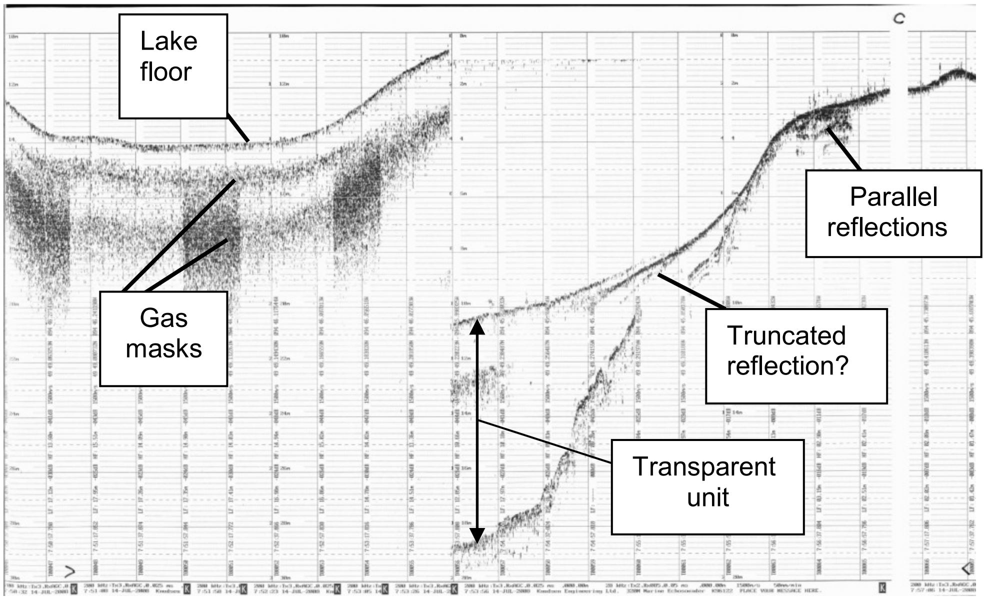


Figure 4b. Parts of Meekin Lake transects BC and CD showing a strong reflection in lake sediment possibly truncating an underlying reflection about 8 m below lake surface. This erosion surface is overlain by onlapping younger lake sediment. Parallel reflections typical of Lake Agassiz sediment are visible at the lake margin, 3-4 m below lake surface.

Table 3. Meekin Lake transects: water depth to soft sediment and maximum sediment thickness

Transects	Minimum water depth (m) over soft sediment	Maximum water depth (m)	Maximum soft sediment thickness (m)	Comments
Pre-A	6.8			Conformable lake sediment
ABCD	5	14.1	>8?	Gas in deep basins. Reflection truncation in lake sediment close to C at 8 m depth indicates erosion. Parallel sub-bottom reflections in AB are typical of Lake Agassiz sediment.
DEF	Possibly 2-6 and 6.5	15.0	>7?	Gas in deep basins. Some parallel sub-bottom reflections. Onlap of youngest sediment up to 9 m.
FG	7	8.6	1.3	
GHIJK	7.5	14.9	>6?	Gas in deep basins. Some parallel sub-bottom reflections. An erosion surface with reflection truncation in lower lake sediment 10.6-11.3 m near I.
KLM	Possibly 4-5.6 and 7.2	14.9	>8?	Gas in deep basins. Some parallel sub-bottom reflections. Early reflection truncation and later onlap at K basin

				margin in lake sediment.
MNO	9.6	14.5	>6?	Gas in deep basins. Clear parallel sub-bottom reflections. Onlap in later lake sediment above 12 m.
OP	6	8.3	>5.5	Gas in basin.

Dixie Lake

The acoustic records show deposition of soft lake sediment in water depths as shallow as 3 m on some transects. The maximum water depth and maximum lake sediment thickness recorded is 20.4 m and >9? m, respectively. The sub-bottom of the main basin is largely obscured by diffuse reflections from gas in the lake sediment. Reflections below the soft lake sediment are vaguely multiple but not parallel; evidence for Lake Agassiz sediment is not as strong as in some other lakes.

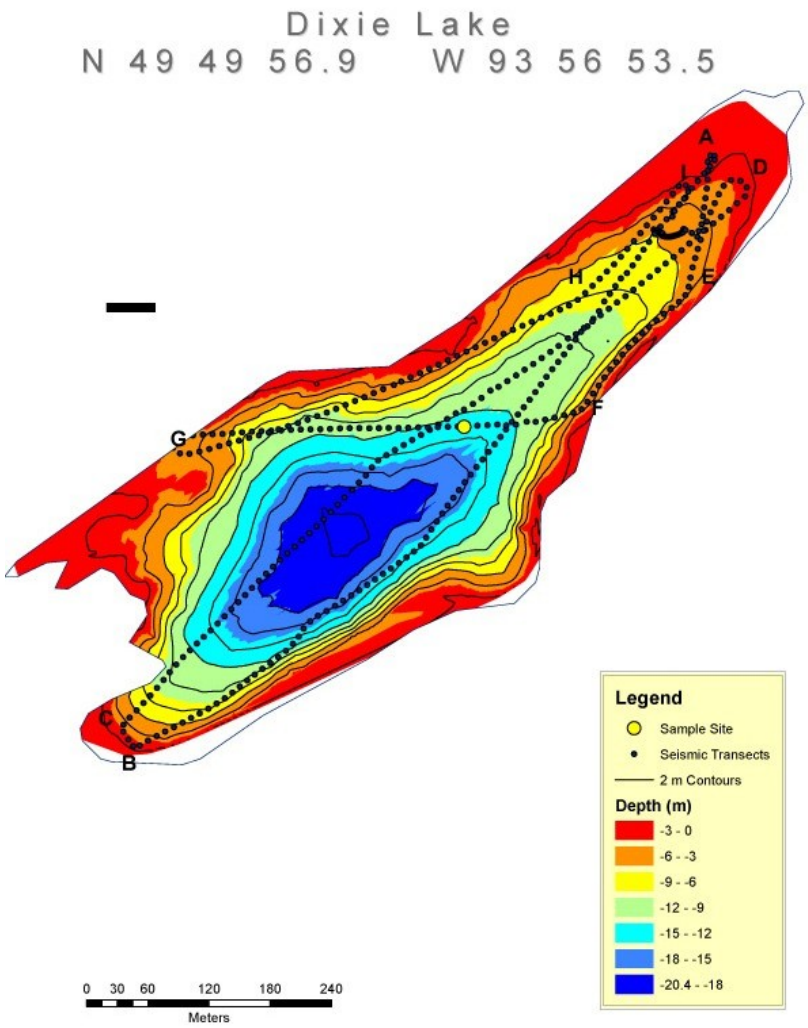


Figure 5a. Map of Dixie Lake bathymetry with superposed Knudsen sounding transects identified by letters AB, BC, etc.

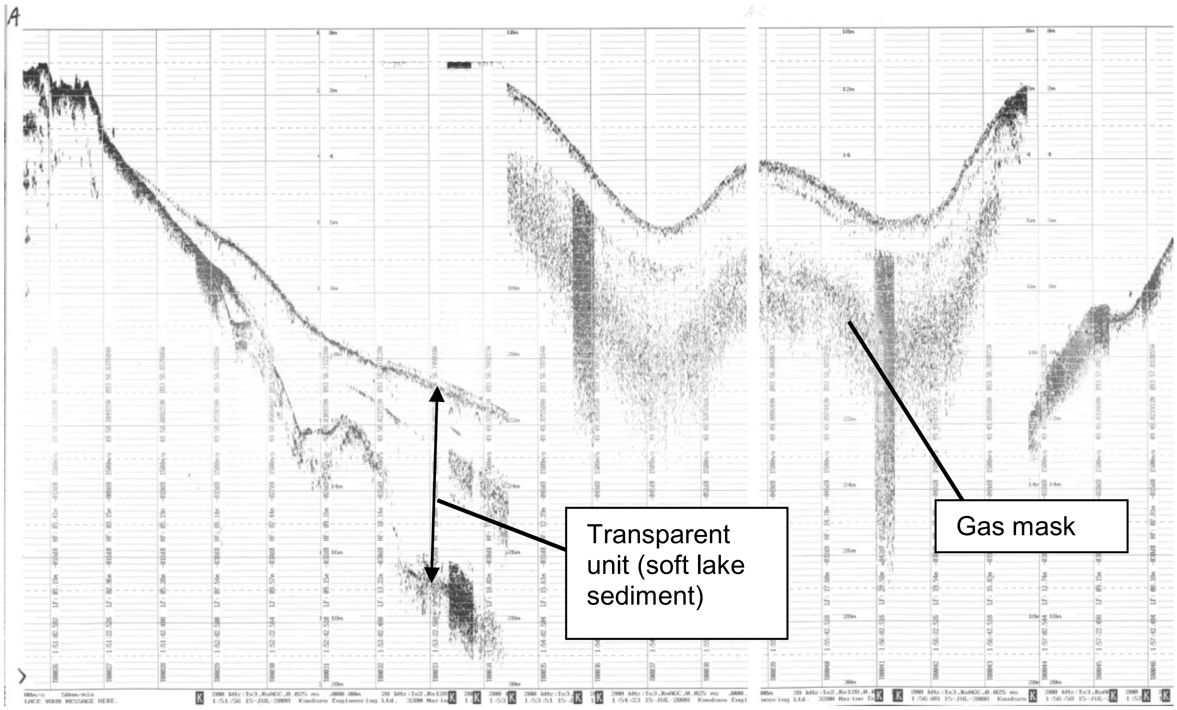


Figure 5b. Transect AB across the main basin of Dixie Lake shows a thick fill of lake sediment below 4 m water depth. A gas mask obscures deep sub-bottom reflections in the basin below 11m water depth. Discontinuous, irregular, and weak sub-bottom reflections occur at the base of the lake sediment on the basin margins down to about 11 m water depth.

Table 4. Dixie Lake transects: water depth to soft sediment and maximum sediment thickness

Transects	Minimum water depth (m) over soft sediment	Maximum water depth (m)	Maximum soft sediment thickness (m)	Comments
AB	4.3	16.0	>7?	Gas obscures deepest areas.
BCDE	3.0	20.4	>9?	Gas obscures deepest areas.
EFG	5.8	12.7	>6?	Gas obscures deepest areas.
GHI	5.2	11.0	>3?	Some gas obscures deepest areas.

Troutfly Lake

The acoustic records show deposition of soft lake sediment in water depths as shallow as 4.5 m on some transects. The maximum water depth and maximum lake sediment thickness recorded is 25.4 m and about 10 m, respectively. The basal sediment beneath the soft lake sediment is characterized by strong parallel reflections typical of glacial Lake Agassiz sediment. On the lake margins, truncations of the Agassiz reflections under a thin (~0.4 m) cover of lake sediment are common down to 10 m depth below lake surface, possibly indicating an earlier episode of lower lake level.

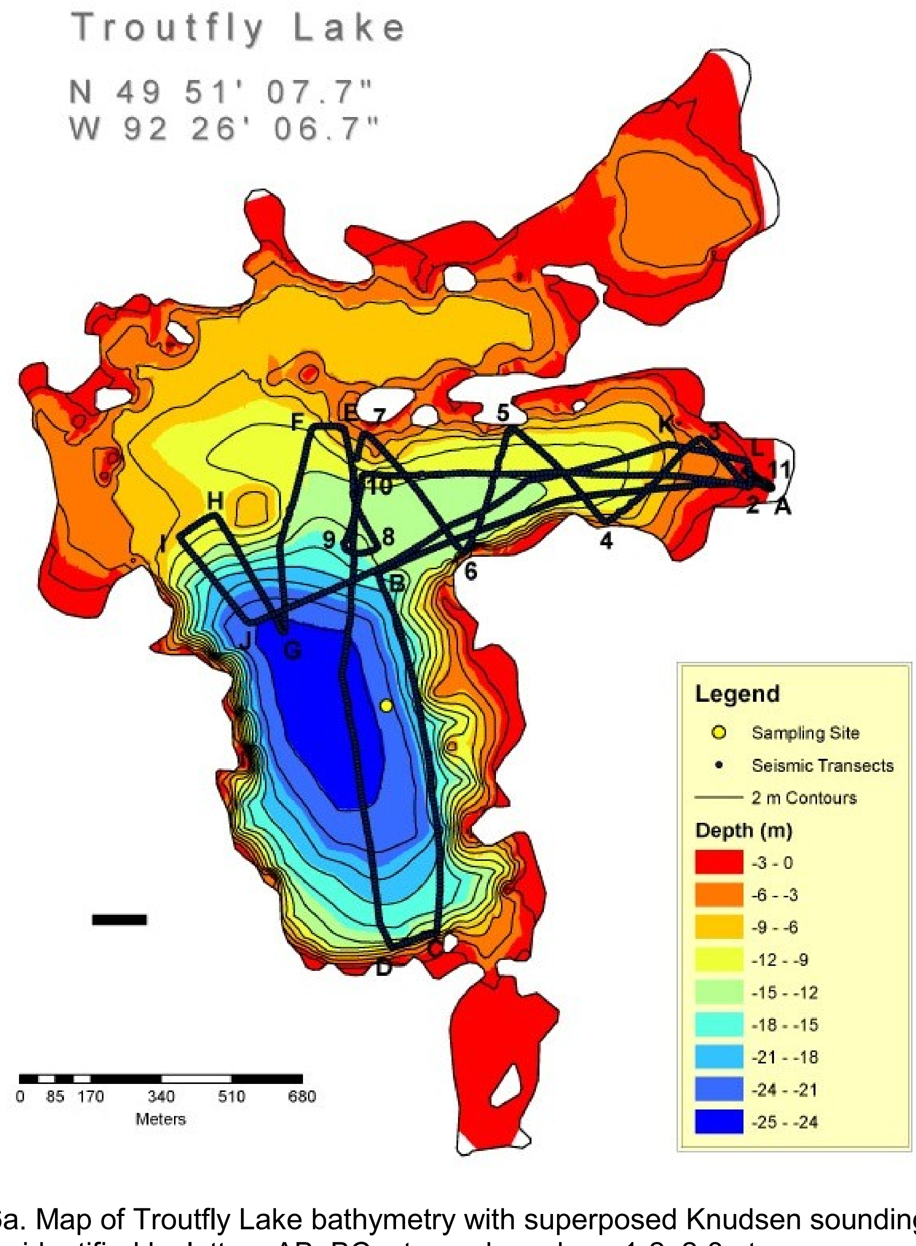


Figure 6a. Map of Troutfly Lake bathymetry with superposed Knudsen sounding transects identified by letters AB, BC, etc. and numbers 1-2, 2-3 etc.

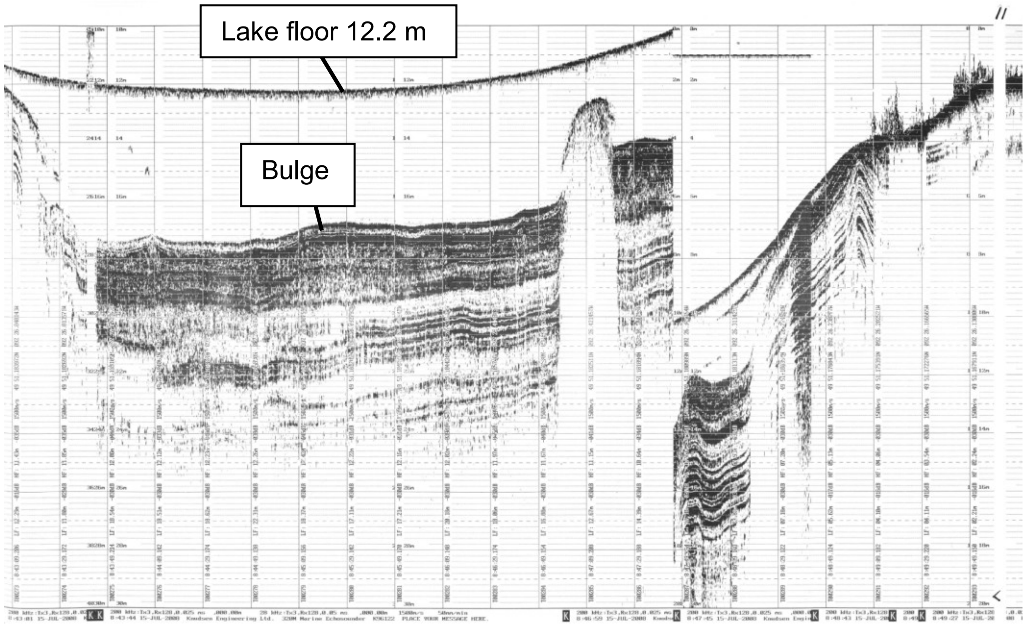


Figure 6b. Transect 10-11 in Troutfly Lake shows thick lake sediment in a shallow basin below 4.5 m-12.2 m water depth. Lake sediments up to 5.6 m thick overlie strong parallel reflections typical of Lake Agassiz sediment. The upward bulge of ~0.4 m in the surface of the Agassiz sediment is likely due to an earlier Agassiz debris flow that brought sediment from higher slopes rapidly downward in the basin.

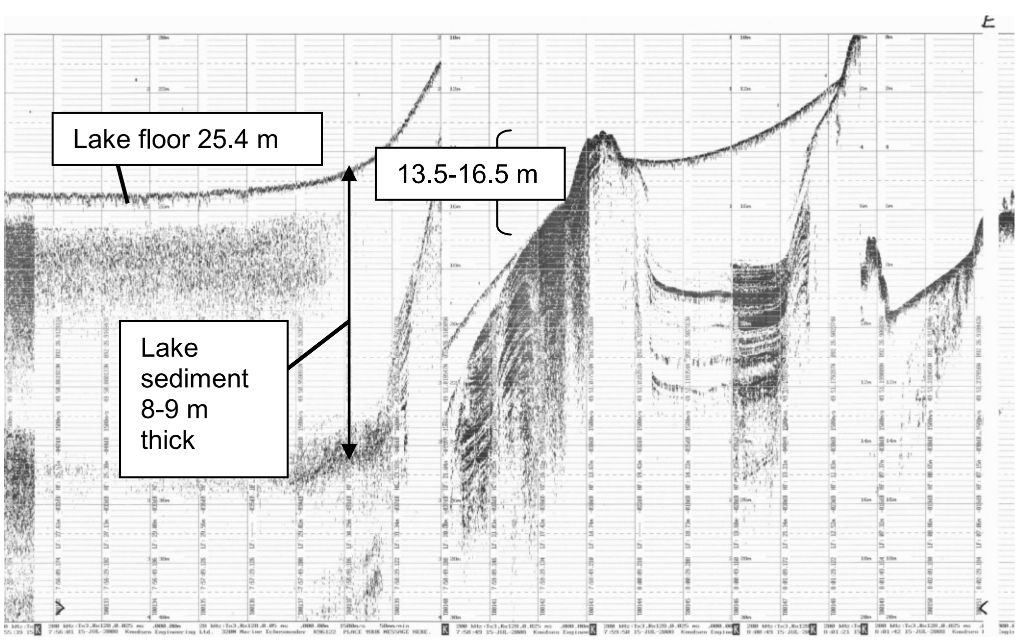


Figure 6c. Transect DE (part) in Troutfly Lake showing lake sediment up to 8-9 m thick in a deep (25.4 m) basin. Parallel reflections of Lake Agassiz sediment come to the lake floor in 13.5-16.5 m water depth.

Table 5. Troutfly Lake transects: water depth to soft sediment and maximum sediment thickness

Transects	Minimum water depth (m) over soft sediment	Maximum water depth (m)	Maximum soft sediment thickness (m)	Comments
AB	6.4	13.9	3.6	Agassiz reflections are truncated at 5 m depth.
BC	15.5	21.9	~8	Some gas.
CDE	11.5	25.4	~8-9	Some gas.
EFGHI	6	25.3	~8-9	Some gas. Agassiz truncation at 10 m under lake sediment.
IJK-1-2	5.5	24.5	~10	Some gas. Agassiz truncation at 4-5 m; no sediment cover.
2-3-4	6	9.2	~3	Agassiz truncation at 5-6 m; no sediment cover.
4-5	9	11.8	5	Debris flow in Agassiz sediment.
5-6	9.7	11.5	5.5	Sediment thicker towards 5.
6-7	10.6	12.5	5.2	Sediment thicker towards 7.
7-8	11.5	13	5-5.5?	Sediment thicker towards 7.
8-9-10	11	13	5-5.5?	Sediment thicker towards 10.
10-11	4.5	12.2	5.6	

Atlantic Lake

The acoustic records show deposition of soft lake sediment in water depths as shallow as 1.5 m on some transects. The maximum water depth and maximum lake sediment thickness recorded is 30.8 m and about 6.5 m, respectively. The lake sediment acoustic unit contains reflections suggesting the presence of sediment density variations. Strong parallel reflections typical of glaciolacustrine sediment underlie the lake sediment indicating that the basin was inundated by the former glacial Lake Agassiz. In places on the lake margins, the Agassiz sediment reflections are truncated at 3 to 5 m water depth, suggesting erosion, either by present-day circulation, or in the past by wave action as Lake Agassiz declined, or during an episode of lower water level after the lake basin was isolated from Lake Agassiz. Some areas of the deeper basins contain 'gas masks' that obscure sub-bottom acoustic reflections.

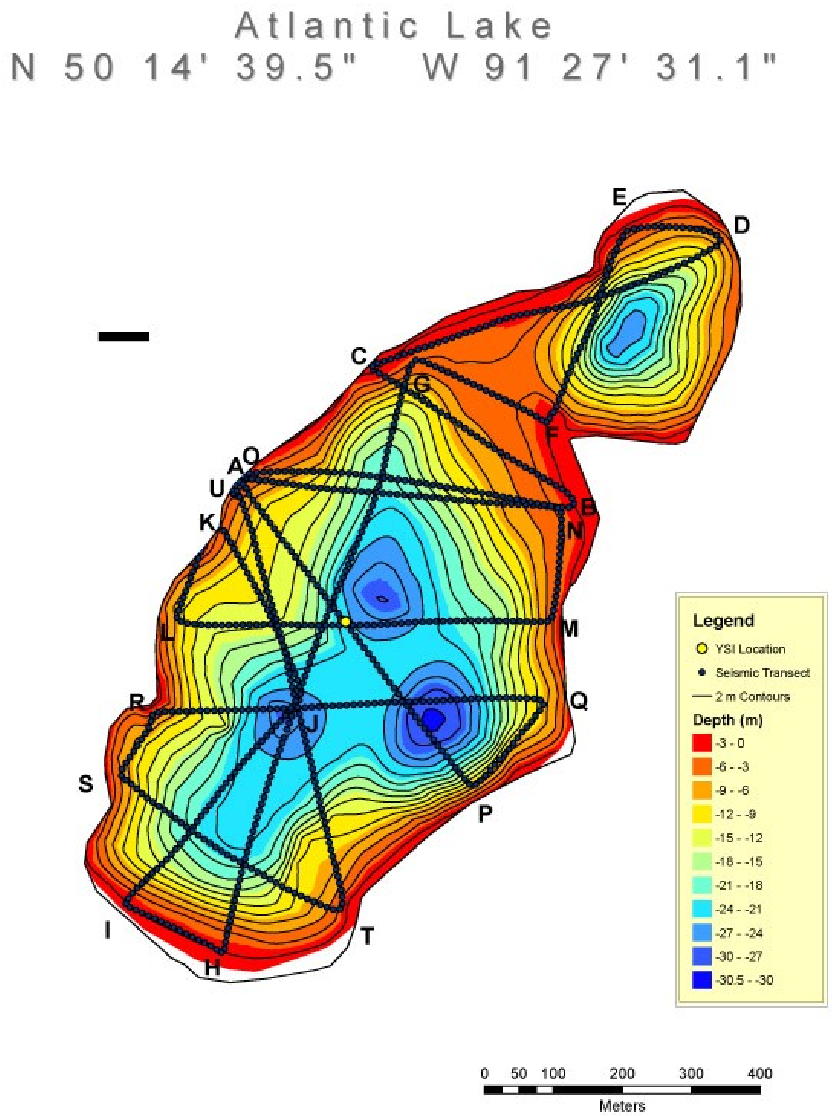


Figure 7a. Map of Atlantic Lake bathymetry with superposed Knudsen sounding transects identified by letters AB, BC, etc.

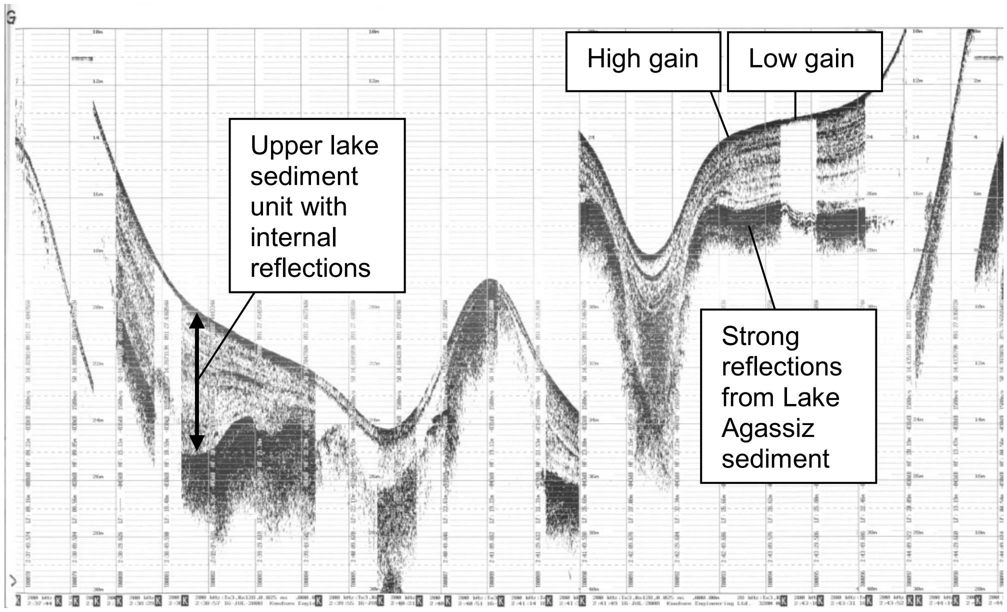


Figure 7b. Transect GH (part) of Atlantic Lake showing reflections within the upper lake sediment unit (visible where a higher gain was used) overlying stronger reflections of Lake Agassiz sediment.

Table 6. Atlantic Lake transects: water depth to soft sediment and maximum sediment thickness

Transects	Minimum water depth (m) over soft sediment	Maximum water depth (m)	Maximum soft sediment thickness (m)	Comments
AB	~5	21.5	3.5	
BC	~5.8	11.2	~4+	Agassiz reflections truncated in 3 to 5 m water depth; no sediment cover.
CDE	4.5	17.3	3-5?	Some gas masking.Clear truncation of Agassiz reflections at 3 m depth near C.
EF	1.5	14.4	~4	
FGHI	2	28	~6	
IJK	~5	28.4	~6.5?	Some gas masking.
KLMN	~4	26.8	~6	Some gas masking.
NO	5.7	20.6	~4	
OP	8	30.8	~5	
PQR	~8	30.3	~5.5	
RST	~6	22	4.2	
TA	2.5	26.7	~2.8	

Gall Lake

The acoustic records show deposition of soft lake sediment in water depths as shallow as 1.5 m on some transects. The maximum water depth and maximum lake sediment thickness recorded is 16.5 m and about 5 m, respectively. Strong parallel reflections beneath the soft lake sediment indicate the presence of glacial Lake Agassiz sediments. In the deep basin, some gas masking obscures subbottom reflections.

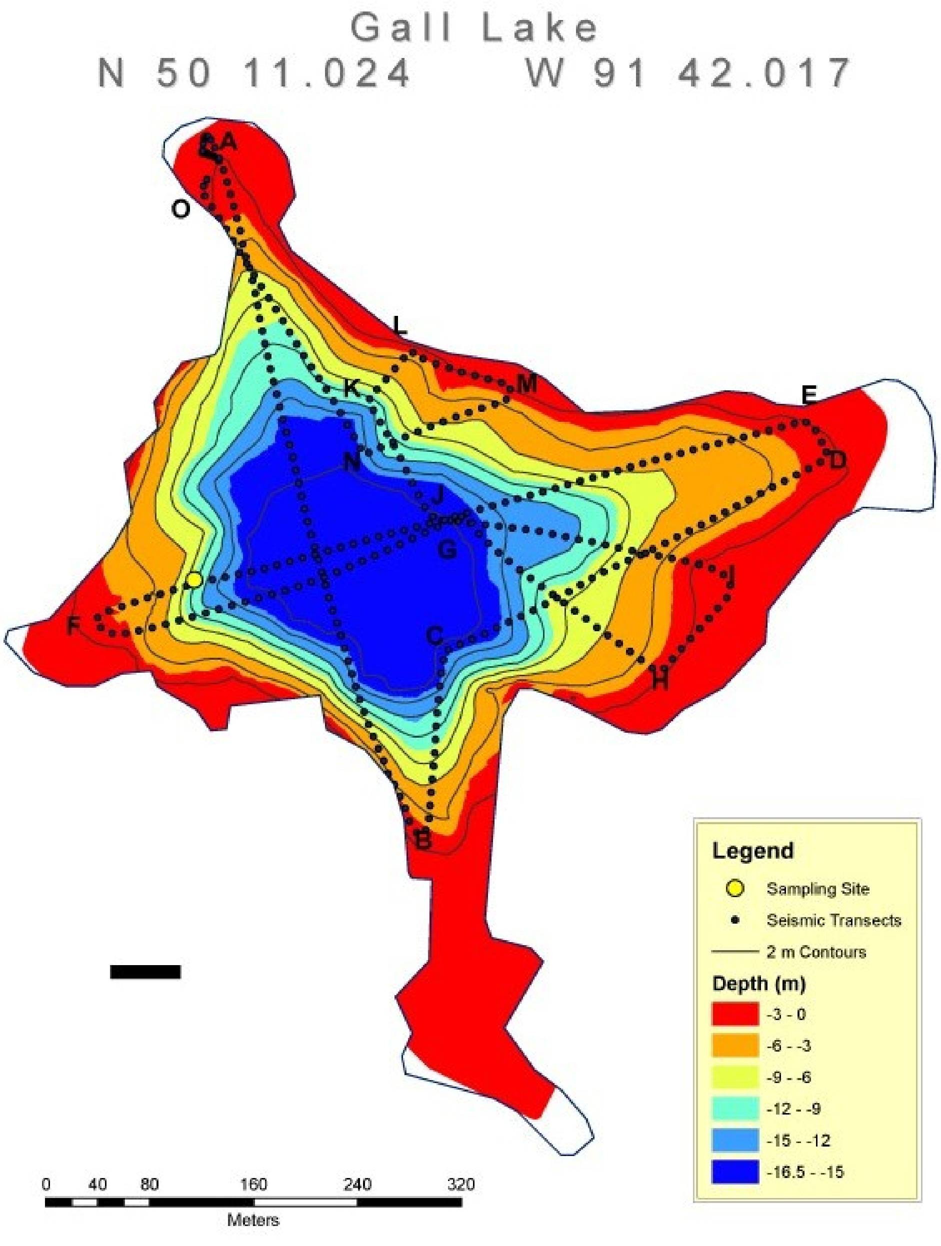


Figure 8a. Map of Gall Lake bathymetry with superposed Knudsen sounding transects identified by letters AB, BC, etc.

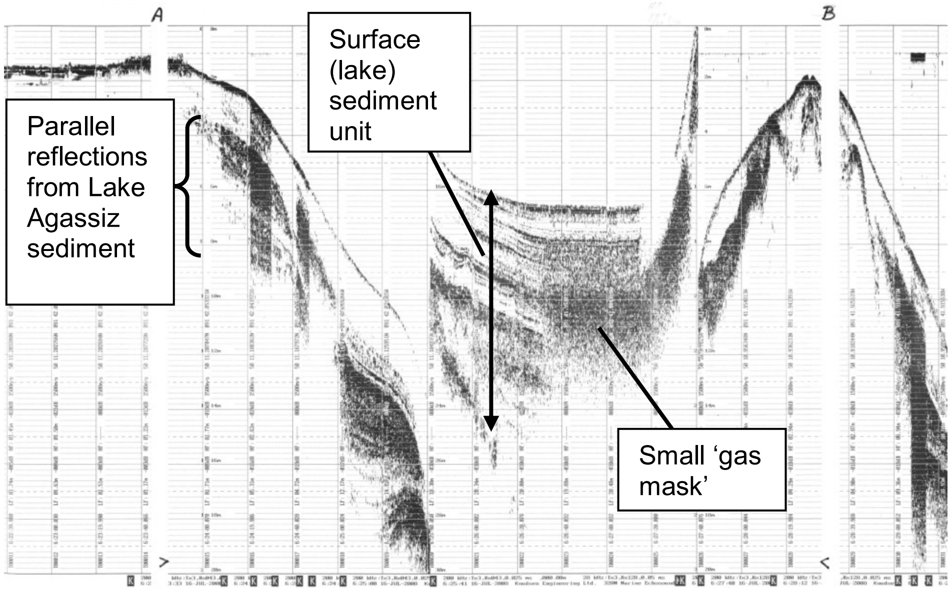


Figure 8b. Gall Lake transect AB showing a unit of relatively thick and continuous surface (lake) sediment at shallow to deep water depths (2 to 16.5 m) over a unit of strong parallel reflections, probably Lake Agassiz sediment. Here the lake sediment exhibits internal reflections. A small 'gas mask' obscures sub-bottom reflections in the deepest part of the basin.

Table 7. Gall Lake transects: water depth to soft sediment and maximum sediment thickness

Transects	Minimum water depth (m) over soft sediment	Maximum water depth (m)	Maximum soft sediment thickness (m)	Comments
AB	1.5	16.5	~3-4?	Some gas masking.
BCDE	2.0	16.4	~3-4?	Some gas masking.
EF	1.9	16.5	~3-5?	Some gas masking.
FGHI	2	16.5	~5?	Some gas masking.
IJKLM	3	16.3	~4	
MNA	1.5	15.5	~4?	

Little Raleigh Lake

The acoustic records show deposition of soft lake sediment in water depths as shallow as 5 m on some transects. The maximum water depth and maximum lake sediment thickness recorded is 19.7 m and about 4 m, respectively. Parallel strong reflections are absent in the records below the lake sediment unit, suggesting that this basin was not inundated or was inundated only very briefly by glacial Lake Agassiz. The single strong basal reflection may be from a surface of glacial diamict (till).

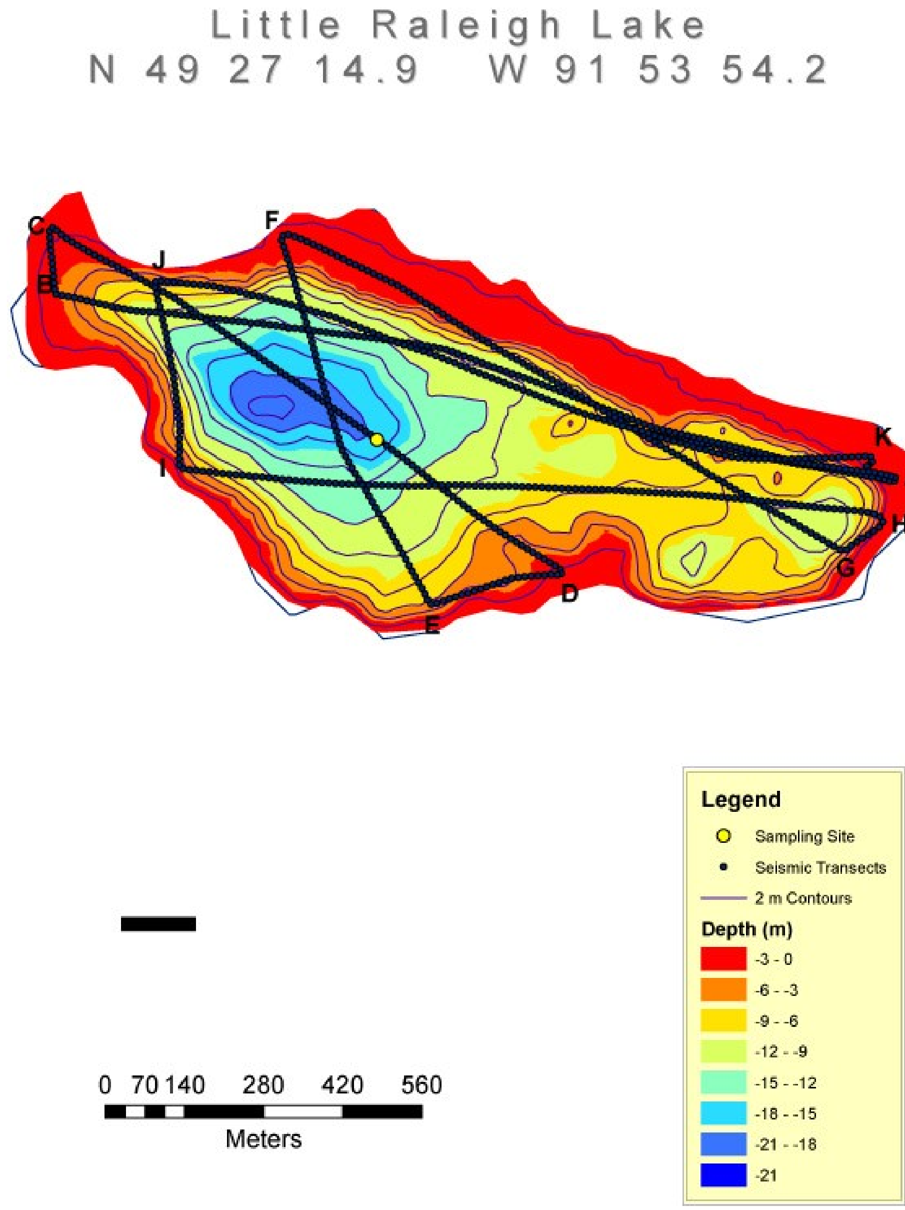


Figure 9a. Map of Little Raleigh Lake bathymetry with superposed Knudsen sounding transects identified by letters AB, BC, etc.

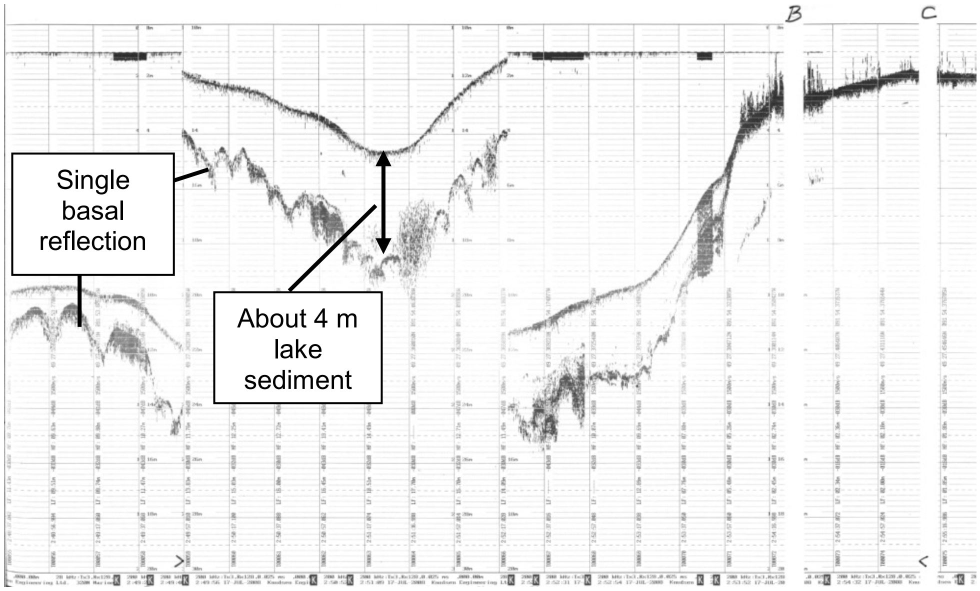


Figure 9b. End of transect ABC in Little Raleigh Lake showing a maximum of ~4 m of soft lake sediment (transparent unit) in the deepest water (here 14.6 m) over a single wavy reflection, possibly a surface of subglacial sediment (e.g. till).

Table 8. Little Raleigh Lake transects: water depth to soft sediment and maximum sediment thickness

Transects	Minimum water depth (m) over soft sediment	Maximum water depth (m)	Maximum soft sediment thickness (m)	Comments
ABC	5	14.6	4.0	
CD	5.5	19.7	~3+	Gas masking obscures sub-bottom reflections.
DEF	5.6	19.5	~3+	Gas masking obscures sub-bottom reflections.
FGH	7.5	11.9	~3+	Gas masking obscures sub-bottom reflections.
HI	6.5	13.9	~3.3	Some gas.
IJ	6.0	11.7	4.0	Some gas.
JK	6.0	12.3	4.0	Some gas.

Pluto Lake

The acoustic records show deposition of soft lake sediment in water depths as shallow as 1 m on some transects. The maximum water depth and maximum lake sediment thickness recorded is 23.7 m and about 5 m, respectively. Basal parallel reflections indicate that glacial Lake Agassiz sediment probably underlies the soft lake sediment in this basin. The Agassiz reflections are truncated at the lake floor in places around the margins of the lake. The truncations are not covered with later sediment so the erosion could be occurring at present or may relate to wave action in an earlier lowstand or in the declining phases of Lake Agassiz.

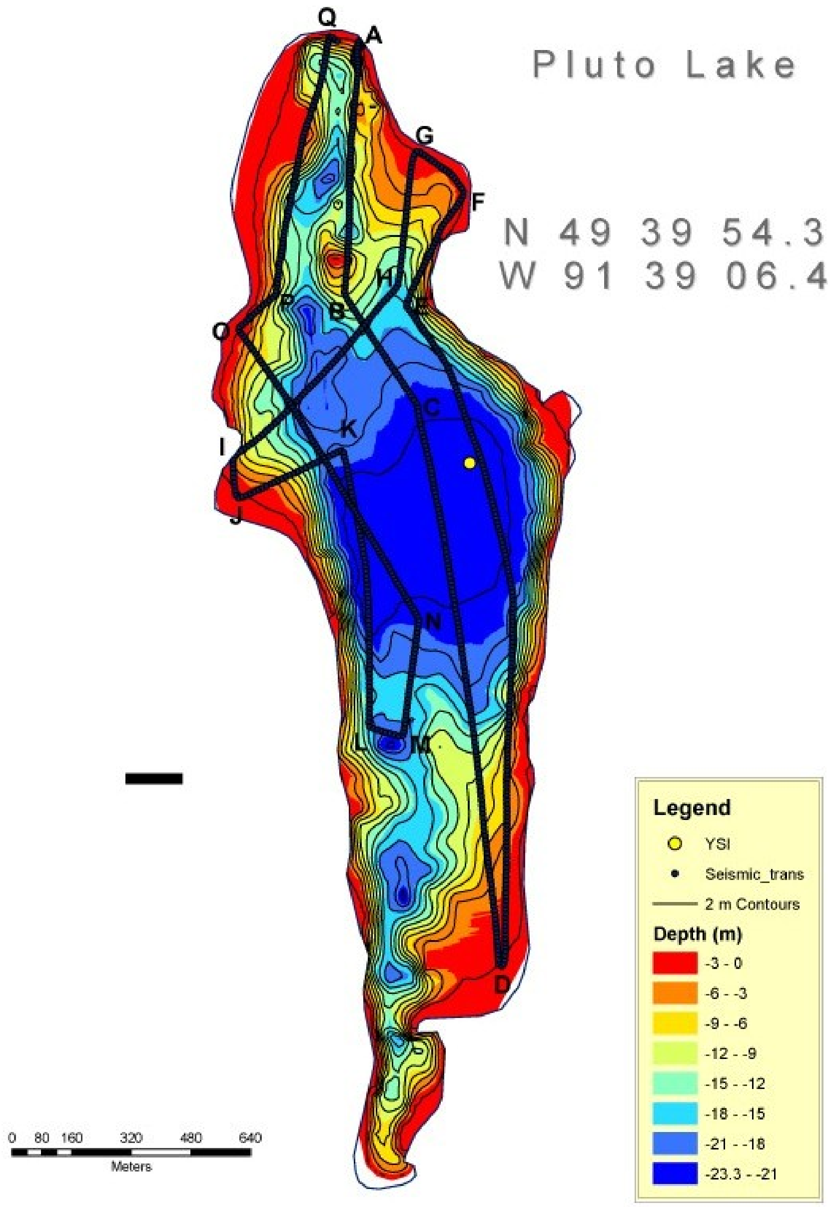


Figure 10a. Map of Pluto Lake bathymetry with superposed Knudsen sounding transects identified by letters AB, BC, etc.

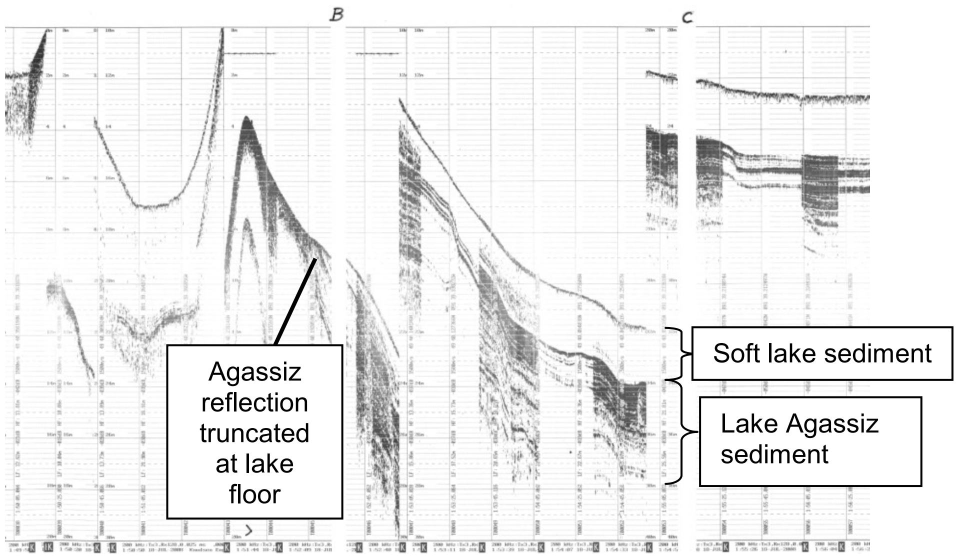


Figure 10b. Pluto Lake transect BC and parts of AB and CD showing strong parallel refections typical of glacial Lake Agassiz sediment beneath a unit of near-transparent soft lake sediment about 1-2 m thick below ~10 m water depth.

Table 9. Pluto Lake transects: water depth to soft sediment and maximum sediment thickness

Transects	Minimum water depth (m) over soft sediment	Maximum water depth (m)	Maximum soft sediment thickness (m)	Comments
AB	1	17	5	A truncation of an Agassiz reflection occurs at lake floor at 8.5 m.
BC	9	21.7	2	
CD	8.3	22.7	2.4	
DE	6	22.7	2.4	
EF	10	16.3	2.3	
FG	1.5	2.2	0	Truncations of Agassiz reflections occur 1-1.2 m depth at lake floor.
GH	~6.8	15.7	2.3	Truncations of Agassiz reflections occur 6-7 m depth at lake floor.
HI	7	21.3	3.1	
IJ	1.7	4.7	~0.3+	
JK	8	20.8	2.8	
KLM	17	23.7	3	
MN	16	21.8	2.4	
NO	7	23.2	2.9	
OPQ		16	4.3	

Lake water properties and sampling

Location of sampling sites on each of the eight lakes sampled in northwestern Ontario.

Location:	N			W			Max	# of
	Deg.	Min.	Sec.	Deg.	Min.	Sec.	Depth (m)	Readings
Worth	49	59	53.1	94	45	55.8	18.64	16
Meekin	49	49	6.90	94	46	13.40	14.02	13
Dixie	49	49	58.5	93	56	49.4	12.10	10
Troutfly	49	50	53	92	26	50.4	22.13	18
Atlantic	50	14	37.6	91	27	29.7	22.10	17
Gall	50	11	1.5	91	42	4.2	15.12	16
Little Raleigh	49	27	14.9	91	53	54.2	10.03	11
Pluto	49	39	55.4	91	39	6.4	22.90	18

Secchi depths recorded in the eight lakes surveyed in northwestern Ontario.

Lake Name	Secchi Depth (m)
Worth	3.0
Meekin	2.5
Dixie	3.5
Troutfly	3.5
Atlantic	3.0
Gall	1.5
Little Raleigh	4.75
Pluto	3.0

YSI results of the eight lakes surveyed in northwestern Ontario.

Worth

Depth (m)	pH	Temp °C	Spec Cond. (µs/cm)	DO (mg/L)
0.19	6.46	18.27	48	10.16
1.20	6.63	18.07	48	10.15
2.18	6.65	17.84	48	10.16
3.21	6.69	17.75	48	10.14
4.05	6.72	17.71	48	10.15
5.09	6.76	17.67	48	10.10
6.05	6.76	17.63	48	10.06
7.12	6.77	15.36	48	10.45
8.12	6.72	11.38	49	10.73
9.04	6.54	9.09	51	10.28
10.04	6.43	8.18	51	9.50
11.02	6.19	7.57	52	8.23
13.06	6.08	6.56	53	7.10
15.09	6.06	6.29	53	6.79
17.20	6.03	5.84	53	6.31
18.64	5.95	5.67	56	4.17

Meekin

Depth (m)	pH	Temp °C	Spec Cond. (µs/cm)	DO (mg/L)
0.19	7.03	18.63	44	10.36
1.09	7.03	18.63	44	10.33
2.15	7.02	18.61	43	10.31
3.17	7.02	17.96	43	10.29
4.26	7.00	17.84	43	10.24
5.22	6.98	17.82	43	10.22
6.08	6.95	17.66	43	10.20
7.07	6.89	14.70	44	11.25
8.10	6.74	10.79	45	10.02
9.12	6.52	9.20	45	6.95
10.00	6.24	8.32	45	4.88
12.01	6.10	7.55	47	1.88
14.02	6.03	7.02	71	0.33

Dixie

Depth (m)	pH	Temp °C	Spec Cond. (µs/cm)	DO (mg/L)
0.22	6.88	18.00	245	10.37
1.03	7.00	17.96	245	10.36
2.05	7.05	17.76	245	10.34
3.24	7.07	17.65	245	10.29
4.40	7.08	17.49	245	10.28
5.10	7.08	17.41	245	10.25
6.07	7.08	17.14	245	10.25
7.05	7.09	13.40	256	11.67
8.23	7.06	9.36	275	12.90
10.07	6.91	6.44	294	12.25
12.10	6.65	4.74	323	7.22

Troutfly

Depth (m)	pH	Temp °C	Spec Cond. (µs/cm)	DO (mg/L)
0.17	7.22	17.85	76	10.25
1.05	7.27	17.80	76	10.22
2.12	7.28	17.72	76	10.19
3.21	7.27	17.35	76	10.17
4.23	7.25	16.77	76	10.14
5.15	7.23	16.67	76	10.05
6.19	7.18	16.26	76	9.71
7.15	6.95	13.12	79	8.26
8.17	6.85	10.38	80	7.62
9.12	6.80	8.85	80	7.49
10.15	6.77	7.90	80	7.83
11.07	6.75	7.44	80	8.05
12.16	6.73	7.16	80	8.25
14.05	6.69	6.79	80	7.80
16.20	6.67	6.56	80	7.69
18.16	6.62	6.19	80	6.75
20.00	6.58	6.00	80	5.89
22.13	6.52	5.78	81	4.12

Atlantic

Depth (m)	pH	Temp °C	Spec Cond. (µs/cm)	DO (mg/L)
0.27	7.58	18.56	104	10.38
1.15	7.62	18.03	104	10.42
2.04	7.64	17.56	104	10.44
3.07	7.65	17.01	104	10.41
4.19	7.63	16.67	104	10.29
5.15	7.54	16.04	102	10.09
6.31	7.51	11.27	107	10.84
7.15	7.40	9.03	107	11.13
8.08	7.30	7.64	107	11.23
9.02	7.19	6.57	107	10.85
10.18	7.09	6.05	108	9.88
12.06	7.02	5.55	109	9.01
14.05	6.98	5.15	110	8.52
16.02	6.94	4.78	111	7.93
18.23	6.90	4.59	111	7.40
20.12	6.86	4.51	112	6.77
22.10	6.86	4.49	112	6.44

Gall

Depth (m)	pH	Temp °C	Spec Cond. (µs/cm)	DO (mg/L)
0.25	6.39	21.16	27	10.00
1.05	6.34	18.28	26	10.30
2.09	6.30	16.03	27	9.78
3.07	6.26	15.49	27	9.49
4.07	6.09	14.24	28	8.50
5.05	5.94	10.35	30	7.76
6.08	5.86	7.19	32	7.32
7.12	5.85	6.09	32	6.68
8.15	5.78	5.45	32	6.13
9.09	5.72	4.95	32	5.92
10.13	5.71	4.81	33	5.74
11.09	5.71	4.51	33	5.48
12.20	5.68	4.30	33	5.31
13.12	5.71	4.18	34	4.92
14.20	5.65	4.13	34	4.10
15.12	5.66	4.12	34	3.63

Little Raleigh

Depth (m)	pH	Temp °C	Spec Cond. (µs/cm)	DO (mg/L)
0.21	6.83	18.71	25	10.13
1.01	6.85	18.52	25	10.18
2.11	6.88	18.12	25	10.19
3.07	6.89	17.72	25	10.21
4.01	6.87	17.44	25	10.10
5.05	6.84	16.72	25	10.04
6.04	6.78	16.12	25	9.99
7.07	6.74	12.63	26	10.80
8.11	6.61	9.78	27	9.76
9.06	6.43	8.70	27	8.69
10.03	6.14	7.88	27	7.51

Pluto

Depth (m)	pH	Temp °C	Spec Cond. (µs/cm)	DO (mg/L)
0.18	6.91	18.29	28	9.99
1.11	6.90	18.29	28	9.99
2.23	6.91	18.15	28	9.99
3.16	6.90	17.52	28	10.07
4.16	6.89	16.88	28	9.98
5.16	6.85	16.33	28	9.88
6.34	6.80	15.94	28	9.78
7.19	6.72	14.80	28	9.79
8.25	6.60	13.38	29	9.87
9.08	6.54	10.47	29	10.06
10.13	6.49	8.20	29	10.10
11.03	6.39	7.61	29	10.01
12.09	6.32	7.33	29	10.00
14.15	6.25	6.90	29	9.85
16.00	6.22	6.78	29	9.76
18.31	6.18	6.63	29	9.67
20.16	6.19	6.38	29	9.61
22.90	6.06	6.06	38	6.40

Acknowledgements

B. Cumming and K. Laird selected the study lakes and provided professional guidance. We thank M. Douma for helpful instructions on the operation and file handling for the Knudsen sounder and GPS systems, and J. Jorgensen for hospitality and access to Meekin Lake.

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Appendix: Activities north of Lake Huron and near Kingston

Figure A-1. Map of the area north of Lake Huron showing locations of Caribou Lake and Serpent River Bog.

Caribou Lake

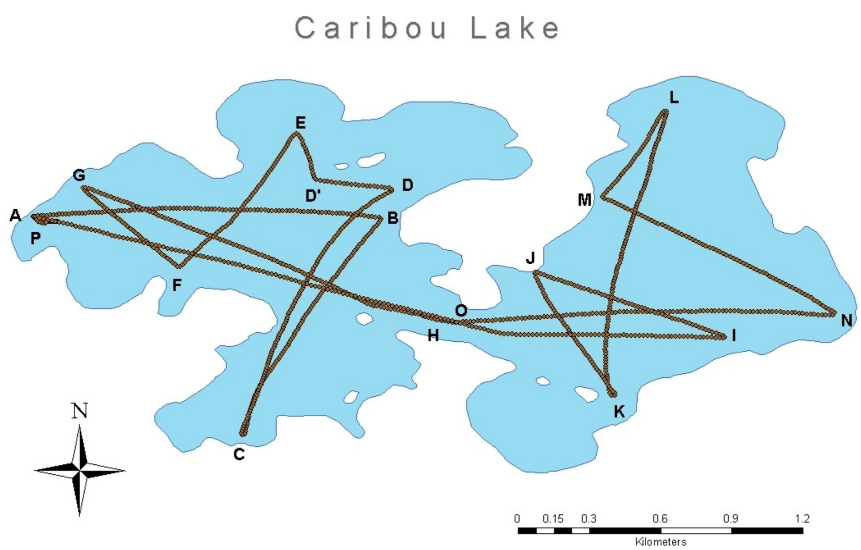

Figure A-2. Map of Caribou Lake with superposed Knudsen sounding transects identified by letters, AB, BC, etc. The lake elevation is between 213 m and 228 m asl.

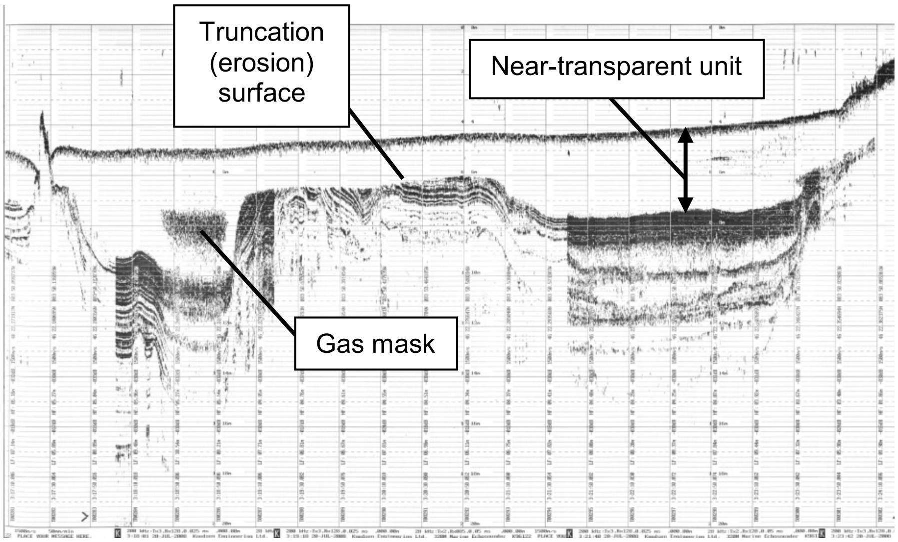

Figure A-2b. Part of transect OP in Caribou Lake. Strong reflections, some parallel, underlie a near-transparent unit of surface sediment 2 to 5 m thick. A gas mask obscures sub-bottom details in the thicker parts. The lower reflections are clearly truncated at 6 to 6.7 m depth and the truncation (erosion) surface is buried under ~1.5 m of younger sediment. The strong lower reflections may be from sediments deposited from early Holocene floodwaters from the Superior basin, and/or they may date from deposition in glacial Lake Algonquin. Reflection surfaces in these sediments were eroded later by wave action in a lower lake than at present. Caribou Lake is positioned above the altitude of the Nipissing shoreline in the region (~200 m), so sediments from the Nipissing Great Lake were excluded from the basin.

Serpent River bog probing and coring

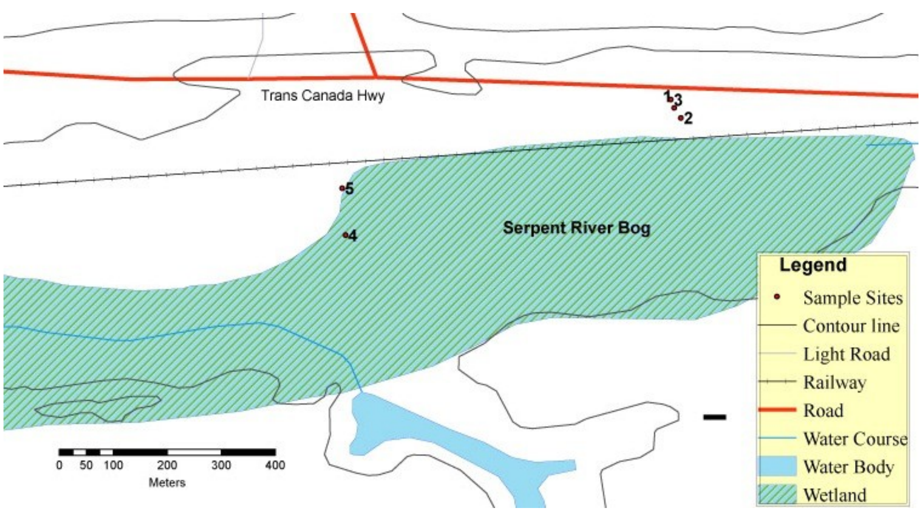

Figure A-3. Map of a portion of Serpent River Bog showing probe and coring sites, 1-5.

Hiller probe logs at Serpent River bog

Site 1: 46º 12’ 13.8”N 82º 22’ 51.0”W

Sedge vegetation at surface. Probed to refusal at 2.0 m depth. Basal sample from 1.5 to 2.0 m shows:
0-26 cm – Soft dark grey clay without silt, over
26-44 cm – Soft to firm grey clay with silt and sand grains, over
44-50 cm – Firm pink clay with trace of silt.

Site 2: 46º 12’ 13.2”N 82º 22’ 50.6”W

Sedge vegetation at surface. Probed to refusal at 2.0 m. Basal sample from 1.5 to 2.0 m shows:
0-2 cm – Soft grey clay, over
2-7 cm – Peaty gyttja, over
7-25 cm – Soft to firm grey clay, over
25-35 cm – Firm grey clay without silt or sand grains, over
35-50 cm – Very firm grey clay with silt.

Site 3: 46º 12’ 14.3”N 82º 22’ 51.2”W

Typha (cattail) vegetation at surface. Probed to refusal at 1.8 m. Basal sample from 1.3 to 1.8 m shows:
0-47 cm – Soft to firm grey clay with some sand, darker near top, over
47-50 cm – Stiff grey (with hint of pink) clay with silt.

Site 4: 46º 12’ 6.2”N 82º 23’ 10.7”W

Dense alder and sphagnum surface vegetation. Maximum 7 m drive did not reach refusal. Drive was without resistance below 1 m. Sampler was almost empty, some silty clay and gyttja on basal auger point. Suspect that a water layer underlies the surface vegetation at this site.

Site 5: 46º 12’ 9.0”N 82º 23’ 10.9”W

a) 3-m drive to refusal. Drive was easy below 1.2 m below bog surface. 0.5 m sampler at base shows 20 cm soft grey sandy clay over firm grey clay with silt. Firm to stiff grey clay at base.
b) 1-m drive. Sample from 0.5 to 1.0 m shows 40 cm woody peat over 10 cm fine decomposed peat.
c) 2-m drive. Sample from 1.5 to 2.0 m shows 10 cm soft grey clay grading down to clay with organic fragments over 12 cm peat at base.
d) 2.5 m drive. Sample from 2.0 to 2.5 m shows 7 cm fibrous peat over 8 cm blue-grey clay with some silt; a sharp contact then 5 cm woody peat over 3 to 5 cm soft grey clay with sand grains grading downward to 15 cm soft clay with organic fragments over light grey laminated clay. Clay is soft and smooth to touch.

Livingstone cores at Serpent River bog

Cores 1 and 2 at site 5.

Core 5-1 was taken 1.2 m west of #5 probe site. Drive 1 from 30 to 130 cm with 26 cm recovery. Drive 2 from 130 to 230 cm with full recovery, brown clay with organic fragments at base. Drive 3 from 230 to 300 cm and refusal. Drives oriented to each other by vertical black stripe on core tubes.

Core 5-2 was taken 1 m east of #5 probe site. Drive 1 from 25 to 125 cm. Drive 2 from 125 to 225 cm. Drive 3 from 225 to 295 cm and refusal. Drives oriented to each other by vertical black stripe on core tubes.

Core 3 at site 1

Core 3 comprising two drives was taken 1 m west of #1 probe site. Drives not oriented with respect to each other.

Loughborough Lake

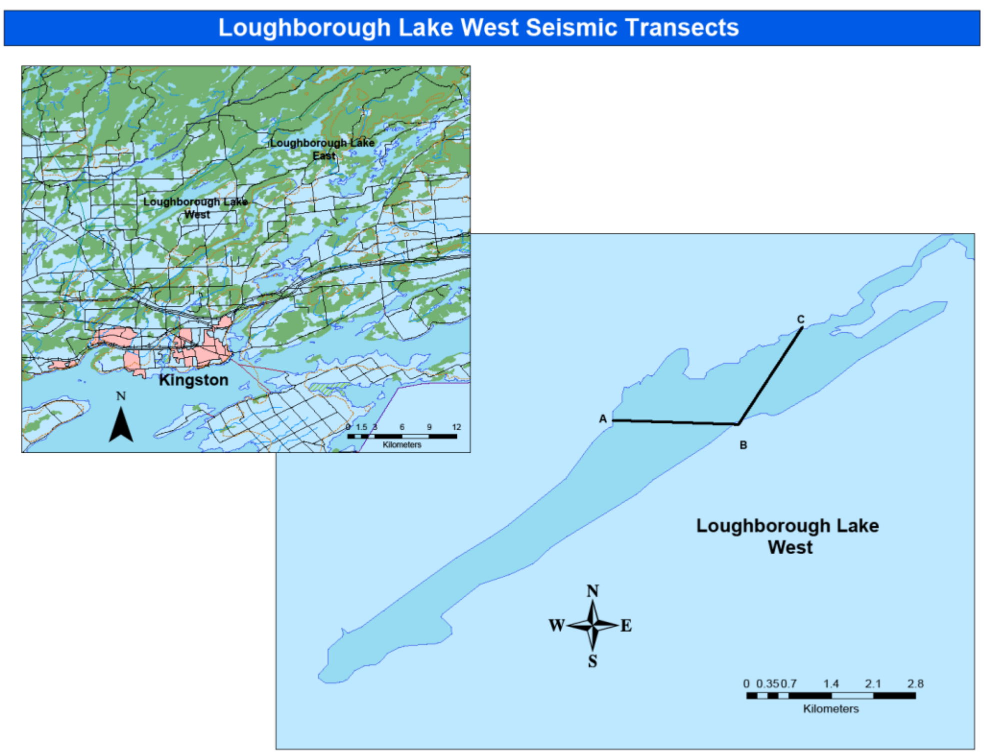

Figure A-4a. Map showing the location of Loughborough Lake about 18 km north of Kingston, Ontario, and showing locations of sounding transects AB, and BC in Loughborough Lake West.

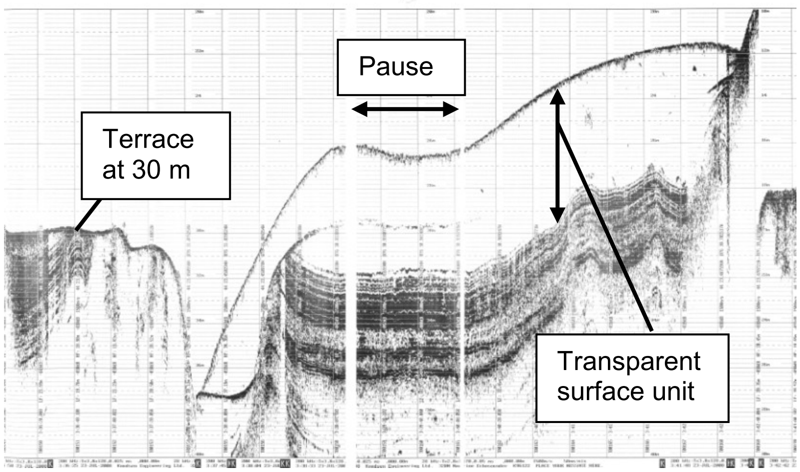

Figure A-4c. Part of transect AB (B towards the right side) in Loughborough Lake West. The transparent surface unit up to 5-6 m thick (soft lake sediment?) is asymmetrically distributed onto the south side of the lake basin. The terrace at left at 30 m water depth is devoid of lake sediment and may be undergoing erosion at present; strong parallel reflections from glacial lake sediment (probably deposited in a phase of Lake Iroquois) are truncated (eroded) and outcrop at the lake floor. An early erosion surface reflection is apparent beneath the lake sediment on the south side of the deep (~37 m) central trough where parallel reflections of the glacial lake sediment are truncated. This erosion surface extends upward to about 28 m depth and suggests the lower postglacial lake sediment was eroded also.