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PART A: Introduction and objectives

This *Laurentian* 95800 expedition report provides scientific context for the geophysical and geological data available from the Geological Survey of Canada (of Natural Resources Canada). All the expedition metadata are available for download from two databases:

1. Expedition Database (http://ed.gdr.nrcan.gc.ca/index_e.php) and
2. Physical Archive Data Base (http://ed-dev.gsca.nrcan.gc.ca/pad/index_e.php).

In these two databases, the expedition is identified as "LH95"; this identifier may be corrected to "95800" in the future. Figure 1 illustrates the *Laurentian* 95800 survey lines and sample locations in Lake Michigan and Lake Huron.

Laurentian 95800 expedition participants:

Chief Scientists:

Theodore C. Moore, University of Michigan
David K. Rea, University of Michigan
C.F. Michael Lewis, Geological Survey of Canada–Atlantic

Technicians:

Ken Aspry, Geological Survey of Canada–Atlantic
Austin Boyce, Geological Survey of Canada–Atlantic

Students:

Holly Godsey, University of Michigan
Libby Prueher, University of Michigan
David Dobson, University of Michigan
Sean Paulsen, University of Michigan
Egon Weber, University of Michigan
Leah Joseph, University of Michigan
Karen Boven, University of Michigan

Observers:

Linda Nicks, Western Michigan University
Stan McClellan, Parks Canada

R/V *Laurentian* expedition 95800 forms the fieldwork phase of a 3-year study of the climatic history of the North American mid-continent during and following the retreat of the Laurentian Ice Sheet. The current project is a follow-up to a successful study by the same investigators that began in 1991 with *Laurentian* 91800 to northern Lake Huron and Georgian Bay.

The general expedition objectives were to refine the stratigraphy and paleoclimatic history defined based on the *Laurentian* 91800 expedition and to extend this record to other lake basins, especially northern Lake Michigan, Green Bay, and North Channel. The project involves collection of high-resolution seismic-reflection profiles to provide an acoustic stratigraphy and information on past lake levels, sampling the lake-floor sediments with piston and gravity cores, and analysis of the cored sediments for paleoclimatic information. Based on the results of the 1991 expedition and ensuing analyses of both sediments and seismic data, three main objectives were established for the 95800 expedition and ensuing data analysis. The first objective was to define further the nature and extent of the lake lowstand at about 7500 BP, which is characterized by the presence of glacial meltwaters in the old low lake in the Huron Basin. The second objective is to recover cores containing the varved intervals noted in the 91800 cores, in order to construct annual to seasonal records of climate variability and climate forcing for the times represented by these 9000- to 12000-year old sediments. The third objective is to sample the oldest part of the lake sedimentary section to determine when glacial retreat was complete and open water deposition began.

This project is a U.S.A.–Canada international joint effort by the University of Michigan under the sponsorship of the National Science Foundation and the Geological Survey of Canada (Project 920067-UM). The U.S Department of State designated the expedition as Expedition No. 95-059, and the project was authourized by the Canadian Department of Foreign Affairs and International Trade, Letter No. TPS-0705. Members of the shipboard scientific party were from the University of Michigan, Ann Arbor, Michigan, and the Geological Survey of Canada–Atlantic, Dartmouth, Nova Scotia.

The scientific party assembled in Grand Haven, Michigan, on the evening of the 9th of July 1995, loaded the ship on the 10th, and sailed on the morning of July 11. The 21-day expedition conducted high-resolution seismic-reflection profiling, side-scan sonar surveys, and piston and gravity coring operations in northern Lake Michigan, Green Bay, northern Lake Huron, North Channel and in Georgian Bay (Figure 1). During the three weeks of the expedition, port calls were made at Escanaba, St. Ignace, De Tour Village, and Alpena, Michigan, in order to change scientific party members, and restock food and water supplies.

During expedition 95800, high-resolution seismic-reflection profiles were collected. These data are in analog form on paper and film rolls. Copies of these records were initially kept at both Ann Arbor and at the Geological Survey of Canada–Atlantic (GSCA) in Dartmouth, Nova Scotia. Later, the original seismic records were archived at Dartmouth. Digital tapes of the seismic profiles are at the GSCA. Both groups have analog copies of the side-scan records, but the digital tapes for those records reside in Ann Arbor.

Piston and gravity cores and surface sediment samples from most stations were collected. All the cores are curated in the Core Laboratory of the Geological Survey of Canada–Atlantic, Dartmouth;

samples will be available for all legitimate investigators. Some of the surface sediment samples were returned to Ann Arbor.

Prior to the results of laboratory analysis, we can point out only some general results that became apparent during the expedition. First, very thick sediment accumulations in northern Lake Michigan and Green Bay imply a proximal setting and significant drainage from proto-lake Superior across the Upper Peninsula of Michigan to these lakes before about 9500 BP. To a lesser extent, the thick sediments of North Channel and Georgian Bay hold similar implications. Secondly, a survey of the Mackinac Channel that connects Lake Michigan and Lake Huron will allow re-evaluation of the sill depths of that hydrographic link during past times of lowered lake level. The high quality of the seismic reflection profiles will allow improved resolution of the depositional/erosional history of the five lake basins studied (Fig. 1). In addition, finally, the extensive suite of piston cores should allow us to resolve the questions set forth at the beginning of the project.

Part B: Expedition narrative

In the following text, written by D.K. Rea, seismic reflectors and sequence boundaries mentioned by colour are probably similar to those described for Lake Huron and Georgian Bay by Moore *et al*. (1994) and Rea *et al*. (1994).

9 July 1995

UM people (Dave Rea, Ted Moore, Dave Dobson, Holly Godsey, Libby Prueher, and Sean Paulsen) arrive from Ann Arbor about 1330h, Canadians (Mike Lewis, Ken Asprey, and Austin Boyce) and relief captain (Mark Costello) arrive at Grand Rapids airport in the evening,

10 July 1995

Expect truck with container, core liner, and profiling sled from BIO-Halifax in early to mid-morning. It arrives at 2115. Off loaded by 2230. Most work until 0100 getting things on board, Electronic Technician Austin works longer hooking all together. All sleep on board.

11 July 1995

Morning spent stowing deck gear, tying down electronics, setting up the navigation - GPS. Only 128 pieces of liner (expected 150), two of the boxes had 4.1-inch OD liner instead of our 2.875-inch OD liner. We left port in Grand Haven shortly after noon. Ken Aspry and Austin Boyce managed to get the navigation and seismic gear working in time for us to cross over the coring site to which we have been taking students for several years (42° 55.7´N; 86° 30´W; 81 m water depth). From there we steamed over a site sampled and dated by Jack Hough (43° 09´N, 86° 49´W), but he never had the high resolution seismic gear that we have.

After passing the core location of his first dated core, the seismic gear was pulled and we headed for the next location at normal cruising speed (9 knots). We anticipated reaching this second Hough core location (44° 00´N, 87° 14´W) by 4 AM next day.

Lost over the side today: right work glove, by Godsey.

12 July 1995

Slowed to stream the Seistec sled at 4:00 AM. Record shows good basement return below 30 to 40 m of sediment with apparently very thin lacustrine sediment cover over the tills. Will cross Hough site 2 at about 6 AM, and then turn west for about 8 miles to investigate a likely (based on bathymetry) coring opportunity. We would like 6+ m of sediment on the seismic record before trying the core.

Station 1, 44° 01.04´ N, 87° 25.19´ W, 77 m (@1480 m/s).

Took surface sediment Ponar grab, the dark gray fluffy (mousse-like) sandy silt. One little pebble. Coring target was 3 m of sediment over a strong reflector, older lacustrine materials below. Best looking spot in the past several hours. Core penetrated to 1 meter below the weight stand collar,

had bright pink mud on outside of core cutter. Recovered 525 cm in four sections. Upper-most liner segment showed signs of partial collapse and there may be flow-in in the lower part of the core. We have interpreted this as resulting from greatly slowed penetration upon hitting stiff glacio-lacustrine clays at the 3-meter reflector, so have not changed rigging for next core. Station required about 2 hours, anchoring at 0800 and departing at 1000.
Mike Lewis fired up the bees' wax pot and we will seal the cores after lunch.

Run at 9 kt to Whitefish Delta Survey waypoint 1 (DS-1). Begin delta survey about 2000. Side scan not working so after moderate fiddling, we turned it off. The delta shows lots of sediment accumulated below the prominent scarp at 75-100 m depth, and very thin sediment cover over eroded till (?) at depths shallower than the scarp. NOAA map quite good in some places, but incorrect in others.

13 July 1995

Continue survey of Whitefish Delta. Two warblers on board at breakfast time, we hope they like to eat flies. Delta survey continues. Squall in early afternoon with 50+ knot wind gusts causes some deterioration of records for about an hour; weather then returns to our very pleasant normal conditions. Good resolution of reflectors at foot of delta slope and in the basin. Only minor indications of low stand deposition. Numerous subbottom channels found. One at 2235 local, shows gas "curtain" at Light Green (sequence boundary) level. On delta plain, there is very little acoustic penetration. There is some indication of listric slump faults that may have over-steepened main delta front. Big Questions: What is character of sediments forming the main delta lobe? Why do we not see any clear clinoforms there?

14 July 1995

Continue survey of Whitefish Delta. Find that the 50-60 m depth platform is swept clean of sediment, all of which is piled up below, between about 100 and 200 m depth. Very thick sediments, up to 75+ meters beneath deep lake floor to east of delta. Suggests very large supply of pre (syn?) Algonquin sediment. Enter Green Bay late at night to flashes of lightning and rumbles of thunder as squall (40+ kts of wind) moves by. Cross Whitefish channel in lower reaches of Bay. Deeply eroded several times, pronounced feature.

15 July 1995

Continue survey of Green Bay. Thick glaciolacustrine sediment accumulations up to and through the Yellow sequence. Not much of Light Green or Light Blue reflectors. Deeper central trough has up to 6 to 8 m of "modern" sediment that overlies the entire older sequence. Many units subcrop beneath the modern layer. We are impressed by the thick accumulation of sediments here, and are starting to think about all the material that must have crossed over the Upper Peninsula of Michigan to make this deposit.

Station 2 was a coring site in the central trough aimed at penetrating the upper lens and

recovering the unconformity below. Seemed to have worked. Finished station 02 at about 9 AM, continued surveying in the direction of Escanaba. Survey crossed a smaller channel and had three crossings of the large Whitefish channel.

Arrived in Escanaba about 4:50 PM, docked at the city park pier, and found a wedding going on in the park. Several photos of us taken while docking. Egon Weber and Leah Joseph arrived about 6:45 PM with the new EPC recorder from AGC and a new cellular phone for the ship. Dave D., Libby P. and Sean P. will leave tomorrow morning. Shopping in the evening, including new gloves for HG.

Lost over the side today: a Glenn Tomkins core barrel grabbing device (joint responsibility)

July 16 1995

Departed Escanaba about 0700 in light rain and moderate wind for a day of coring in Green Bay. Station 3 was intended to be a gravity core, but hard sandy bottom resulted in zero penetration of steel-barreled gravity corer, thus surface sediment (sand) sample only. Station 04 coring target was the Yellow series of reflectors that were near the surface. The grab sample recovered a lag of sand, fine gravel, ash/clinker, clay rip ups, etc. over pink clay. Fe/Mn nodule 2-cm across from this grab (probably - found later on deck by EW). Gravity core did not penetrate the stiff clay. Piston core recovered 404 cm in three sections. Station 5 coring target was the Light Green and older reflector sequence. All samplers at station 5 recovered some to none sand (and a stone in the surface grab), including a 23 cm piston core. Station 6 coring target was the Light Blue and Light Green reflectors. Here the surface grab found sand and a rock, the gravity core recovered 142 cm, and the piston core recovered 572 cm of sediment. Best cores in Green Bay so far. Station 7 coring target was the Light Blue and Light Green reflectors. Recovered sand in the grab sampler, nothing in the gravity corer, and 427 cm of sediment in the piston core.

The day ended by starting a nighttime survey to find more coring targets in Green Bay.

July 17 1995

No good coring sites found in overnight survey, so we left Green Bay for northern Lake Michigan. Cored two sites on middle and upper part of the slope, trying for the Light Blue and underlying reflectors. Piston cores 8 and 9 both came up with sand layers - presumably on the Light Blue (or deeper) horizon.

Began survey of northwestern slope of Lake Michigan at about 1700. We expect a better selection of coring targets along this 30-mile stretch of lake floor.

July 18 1995

Continued survey of northwestern slope. Found a few good coring targets. Tried four piston cores on spots chosen from last survey. They were generally not as good as hoped (389 cm, 379 cm, and 516 cm) but probably did the basic task of hitting at/near the reflectors targeted. Last core station,

13, finished at sunset - a rather spectacular sunset with clouds, rain ribbons and calm waters. Many photos. Core 13PC came up with only one and a half sections, 255 cm, of mud despite apparently perfect coring conditions, calm weather, easy target, soft sediment, good trip, mud on weight stand. Have improved inter-liner seal but not sure that is the problem. Northwest Lake Michigan slope survey continued through the night. Ever-thicker sediment as we go north.

Lost over the side today: stainless steel nut and lock washer, by Rea.

July 19 1995

Continued survey through the morning. First core station, 14, at about 1130, targeting the light blue reflector again. No trip-jerk, mud on weight stand, and 471 cm core. New inter-liner seal worked. Found 4 mm thick hard oxide crust on lake floor in grab and atop upper piston core section (!). Station 15 was two gravity core attempts to collect some black bands in the surface sequence for Bob Owen, University of Michigan. Not very successful, so will try again elsewhere. Station 16 was targeted at the light blue reflector on mid slope. Surface grab had thin, hard, oxidized crust. Piston core recovered only 379 cm even though mud was observed on top of fins (!). Therefore, penetration not a problem, something else not allowing full cores. Re-rigged to allow 3 feet more drop (now 21 inches in clamp to core loop). Grab sample at station 17 showed many little shells (Pisidium?) in pink clay beneath surface layer. PC-17, aimed at the light green reflector couplet came up with mud on weight stand (and Pisidium shells in pink clay on the barrel) but water only. Ensuing discussion decides that it probably tripped early, drawing in water before hitting the sediment. Perhaps because gravity core was 2 feet too long (wrong liner piece). Re-rigged with normal gravity core and 21-inch drop loop and sent it back. Recovered full core. It is still magic. Station 18, late in the day, was an attempt at a deep reflector target that crops out at 50 m depth. Tried the heavy gravity corer first to check for possible non-penetration and it fell over twice, so we were content with a surface grab only. Weather deteriorating so we put in the sled and side-scan and began the survey up to the Mackinac Channel.

Lost over the side today: piston core safety pin, by Weber.

July 20 1995

Spent the day running the survey of the Mackinac Channel. Weather much better than last night. Found 10 to 20 meters of sediment in the shallower parts, suggesting re-evaluation of Michigan-Huron sill depths may be necessary. Mike L. calculated the uplift rebound history of the four main bodies of water we will investigate, Green Bay, Michigan, Huron, and Georgian Bay. Uplift (or depression) increases markedly to the northeast, with important inferences as to the direction of paleo-flow. A few big ships in the Mackinac shipping channel that we have to avoid while surveying. About 10:40, we pull in the gear and begin running at full speed toward the start of the Little Traverse Bay survey and coring operations.

July 21 1995

Surveyed in and around Little Traverse Bay (LTB), coming on the first core station about

0700. LTB has a thick collection of sediment, strongly truncated by the light green reflector. First target was a yellow sequence under this angular unconformity. Core 19-PC had mud on weight stand but recovered only two sections. Probably did not penetrate the unconformity. Following core 19, we went to find John Ezra Moore's peat layer and took a heavy gravity core in 41 meters of water, and extruded it on deck. Sure enough there were sticks in the bottom of it at about 90 cm with shells just above. We bagged the appropriate samples. 20-PC at this same spot was a three-section core that would have penetrated the peat. Therefore, some 35 or 40 years after the first sample, we finally found the LTB peat layer again.

After coring in Little Traverse Bay, we ran north to pick up the Mackinac Channel survey and did three more crossings before coming in to St. Ignace. There Karen Boven joined us and Egon left.

July 22 1995

Joined for the day by Linda Nicks, someone Mike Lewis and the Canadians know, for a one-day ride as an observer. We surveyed east-southeast from St. Ignace to the wreck of the Newell Eddy and took a side-scan pass over it. Fairly good rendering. Two piston cores aimed at the light blue and light green reflectors were disappointingly short, only two sections each. We are becoming exasperated in trying to understand why we are not doing better. All cores penetrate fully but have incomplete recovery. We continue to wonder about the piston travel/stroke. At the end of the day, we cut 11 meters off the wire and re-rigged the fiege fitting. The trimmed wire included one major and one lesser kink that may have resulted in irregularities in the drop. We may be grasping at straws here, but at least the wire will be easier to work with without the big kink.

Arrived in DeTour Village about 2000 where Linda was met by her family and went back to her vacation.

July 23 1995

Left De Tour Village at 0700 and steamed through the many islands to the west end of North Channel where we will spend the next day and a half. Beautiful country. First core was 23PC, 485 cm long, so better but not yet the 5.5 m we strive for. Core 24 was 394 cm in rather hard material, and core 25 was only 146 cm with a partially collapsed liner and separated sediment sections. So plenty of piston suction but now inadequate penetration (only a few feet of mud up the barrel). Therefore, we took it all apart and added two more weights, 50 kg total, onto the core head. Now have 225 kg (495 lb.) of lead on the corer.

Lost over the side today: one lock washer by Rea.

Core 26 and 26A were another attempt at the light blue but hit a fine sand or coarse silt and were unable to penetrate. Finished re-rigging about 2200 and began nighttime survey of North Channel.

24 July 1995

A spectacular night, moonless till about 4 AM, with bright stars, colorful northern lights, and shooting stars. Arrive at entrance to passage into Whalesback Channel at about 0620 accompanied by colorful northern lights and calls of loons. Whalesback Channel on a sparkling day is the prettiest place the science party has ever seen on the Great Lakes. We ran a basic figure-4 survey over the deep portion of the bay and took core 27PC in there along with a couple of gravity cores for geochemistry. Whalesback Channel is the catchment basin for the river draining the Sudbury mining-refining complex. Coring in North Channel followed with three more good cores in a row. Adding the last 50 kg seems to have made the difference. Final coring attempt was the Light Blue over Light Green reflectors. The remarkably sticky silt at the Light Blue stopped penetration and the piston withdrawal collapsed almost the entire lower liner. A rare and time-consuming failure. We tried the usual pulling on vice grips with a crane or winch, but they just pulled the end of the liner apart. Therefore, we unscrewed the barrels at the coupler, set the collar in the good end, and banged it through with a sledgehammer (Glenn doing the banging). This all required an hour or more. Departed for Tobermory about 2130 and will be an hour or more late for our rendezvous with Stan McLellan (Parks Canada).

25 July 1955

Arrived off Tobermory at 0800 but waited until 0840 for McClellan. Ran a line down a channel coming into Georgian Bay at Lucas sill point as requested by Stan M. Spent the remainder of the day coring the light blue and light green reflectors. Got three good cores of 5+ m, and one OK core of 4+ meters. Rain sprinkles ended just as we started and began again in the evening just after we stopped - we must be in Camelot. Today we put together the phenomena of: Mike's mid-Mattawa possible brief low (the “Blip”), five extant dates centered at 8200 C-14 years, and a much more highly reflective layer of Main Mattawa age in Georgian Bay than elsewhere including an obvious reflector between the Light Blue and the Light Green. We will core it tomorrow. Nighttime survey for more spots in the older reflector groups to core.

July 26 1995

Three cores before midday, all about a meter short, so four short ones in a row. More discussion and we added 2 feet to the drop for a total of 21. Cores recovered appeared to have reached their targets, however. Core 39 PC no better than before. Core 40 was of the basal sediments and hit basement as indicated by the dented core cutter. Gray sediment in the lowest section, grading up to pink by section 3.

July 27 1995

Cored the deep basin near Tobermory at about 0700. Afterwards the anchor chain came up tangled in two places so took an extra half hour to get going. Ran one-hour survey up a newly discovered channel towards Tobermory where we dropped off Stan McClellan. Night time survey of eastern Georgian Bay ending a few miles from Tobermory. Near Tobermory at about 0700 and recovered a nice long core of the last few thousand years of deposition. Began the run across Lake Huron to Alpena about 0930 and arrived about 1900. Egon W. and the Moore family were waiting for

us on the dock. Leah J. went back to Ann Arbor in the evening. The automatic pilot failed this morning, just after the anchor was untangled, and a person is due in from New Orleans at 0100 this coming morning to fix/replace it. All students got a chance to steer by hand on the trip across the lake.

July 28 1995

Left Alpena at 0700 with the automatic pilot repaired. Cored three sites in the Alpena basin, 42, 43, and 44. Rain at the first station but the weather improved during the day. Noticeable swell running from the south. We noticed that the pink color of the older sediments is much fainter in the Alpena Basin than other places to the north and west. Perhaps brightest in northern Lake Michigan. The fourth core of the day was taken in fair weather after dinner in the Manitoulin Basin and showed somewhat more color. Every core today was 545 cm or longer. We are hoping that we finally have the system tuned well, including the new scorpion-loop wire coil, 19-foot drop, relatively unkinked wire, seven of eight weights, and a tight piston seal. Nighttime survey laid out for about 12 hours of work before coring in the morning.

Subsequently, surface samples and cores were collected at stations 46 to 50 in northwest Lake Huron before ending the expedition.

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Figure 1: *Laurentian* 95800 geophysical survey (black lines) and sample locations (white dots) in Lake Michigan, Lake Huron and Georgian Bay.