GSA Data Repository Item 2017268
Teller, J.T., Rühland, K.M., Smol, J.P., Mellors, T.J., and Paterson, A.M., 2017, Holocene history of Lake of the Woods: Ontario, Manitoba, and Minnesota: GSA Bulletin, doi:10.1130/B31790.1.

SUPPLEMENTARY INFORMATION

CORING TECHNIQUE

The Kullenberg corer is a steel gravity corer that recovers a single cylinder of sediment when released from the mast structure and free-falls through the water column. The sediment penetrated below the lake floor is contained within a polycarbonate (plastic) tube ~3½ inches (~9 cm) in diameter which is inside the steel core barrel assembly. The core barrel assembly is driven downward by the weight assembly attached to the top of the barrel (see https://gec.cr.usgs.gov/archive/lacs/piston.htm) (Figs. S1 and S2). During this process, a piston rises within the core barrel and a core catcher assists in retention of the core as it is raised to the surface by the hydraulically-driven pulley assembly. Ten cores were recovered, then cut into manageable lengths (up to 1.5 m long) and transported to walk-in coolers at the Limnological Research Center facilities in Minneapolis. Six cores were selected for detailed study, were split lengthwise and then scanned using a Geotek multi-sensor core logger at LRC, which records density and magnetic susceptibility values continuously along the core. A smoothed surface of individual core segments was photographed with the LRC photo-scanning system.

CORE DESCRIPTIONS

Core 1A

General Description

Core 1A was retrieved from the southern part of the Lake of the Woods (LOW) basin (Fig. 2) in 10.7 m of water; 3.3 m of sediment were recovered and cut into 3 segment lengths of 65, 117, and 150 cm (see Fig. S3). The site is ~2.5 km offshore from Long Point Resort at 48.89121° N latitude, −94.82602° longitude (UTM Zone 15; E359287; N5428381), in the Minnesota portion of Big Traverse Bay, 17 km northwest of the mouth of the Rainy River.

The entire sequence is faintly to distinctly laminated (see Fig. S3) and there are occasional mm-thick organic laminae and organic fragments. The upper 2.2 m of the core is composed of silty clay to clayey silt, with an increasing percent of very fine sand below ~0.85 m depth; the upper 2.2 m is defined as unit 1. Between 2.2 and 2.82 the sequence becomes distinctly more clayey, lower in moisture content, and firmer (unit 2). Unit 3 lies below a depth of 2.82 m, where there is an abrupt decrease in moisture content, an increase in firmness, and a weak fine granular structure, suggesting alteration by subaerial exposure and pedogenesis; there is also an increase in sand content.

Ostracodes, Thecamoebians, and Other Macrofossils

Ostracodes are abundant only below the top of the pedogenic zone at 2.82 m, although there are a few valves in the sample immediately overlying that zone. Three species of ostracodes were identified in core 1A, but *Candona subtriangulata* is by far the most abundant (Fig. 6). Thecamoebians first appear above a depth of 1.4 m in the core, corresponding with an increase in insect macrofossils and a decrease in lithic grains (Fig. 6); up to five species of thecamoebians were observed in some intervals including *Difflugia oblonga* and *Centropyxis aculeate.*

Organic fragments are present throughout the core (Fig. 6), and include seeds, leaf fragments, and wood, as well as insects and larvae cases (Mellors, 2010; Table A-2). Numerous mammal molars, an incisor, a claw attached to a bone, and vertebrae were found in the interval from 1.8 to 2.3 m, which is below the thecamoebian interval where plant and insect biota increase and ~0.5 m above the top of the ostracode and pedogenic interval. Achenes of curlytop knotweed (*Polygonum lapathifolium*, Fig. S10) and bulrush (*Scirpus* sp.) were identified by Alice Telka and dated.

Lithic Fragments and Bulk Mineral Analyses

Grains of various lithologies (lithic fragments) are scattered throughout the sequence, mostly in the coarse sand and granule fraction (Fig. 6). X-ray diffraction analyses of bulk mud samples indicate that dolomite is present below a depth of ~2 m and calcite occurs below the top of the pedogenic zone where ostracodes are also found (Fig. 6).

Core 4A

General Description

Core 4A was retrieved from a northeast-southwest trending channel near Cyclone Island in the Northwest Angle region of Lake of the Woods in 7.3 m of water at latitude 49.33830°, longitude −94.85979° (UTM Zone 15; E3664908; N5466509); the site was located ~10 km east of a docking facility at Young's Resort. Total length of the core is 2 m, which was cut into 2 segments of 51 and 150 cm (Fig. S4).

The sequence was divided into 5 units and contains 3 pedogenically altered zones (see Fig. S4). The upper 10 cm is sandy gyttja (unit 1). Below that are 2 silty clay units—23 and 17 cm thick—each with a distinct paleosol developed in them with a characteristic fine angular blocky structure that diminishes downward in each unit. Finely disseminated black organics and organic laminae are abundant in these pedogenic zones. Below this is a 4-cm-thick silty clay gyttja and that overlies a third paleosol at 1.55 m depth that is developed in a non-laminated sandy clayey silt with low moisture content that contains finely disseminated organics in the upper 2 cm (unit 5, Fig. S4). This third pedogenic zone has a high magnetic susceptibility and a distinct gleyed greenish gray color (5GY 5/1), with oxidation (yellowish red, 5YR 4/6) along root tubes below 1.82 m.

Ostracodes, Thecamoebians, and Other Macrofossils

Only the ostracode *Candona subtriangulata* was identified in Core 4A, and it was found in two samples below ~1.8 m (Fig. 7), well below the top of the lowermost pedogenic zone; this coincides with where detrital carbonate grains were found and where plant fragments and charcoal are low in abundance (Fig. 7). Ostracode shells are thin and mostly broken, but do not appear to be corroded.

Thecamoebians are not abundant in the core and are present in only 3 samples in the upper 0.8 m of the sequence; species identified include *Difflugia oblonga* and *Centropyxis aculeate.* As can be seen in Figure 7, the lithics decrease above the lowermost pedogenic zone, and organic materials increase substantially above this and include charcoal fragments, insect macrofossils, wood, various plants, and seeds of terrestrial and near shore plants (see Mellors, 2010; Table A-4) such as curlytop knotweed (*Polygonum lapathifolium*) and bulrush (*Scirpus validus*) identified by A. Telka; a variety of fish vertebrae and scales were found between 0.6 and 0.3 m.

Lithic Fragments and Bulk Mineral Analyses

Bulk mineral analyses by X-ray diffraction show dolomite and a small percent of calcite are present in the lower part of the core below the top of the lowermost pedogenic zone, where lithic grains of carbonate and ostracodes occur (Fig. 7). However, dolomite rises substantially again in the upper part of the sequence, above the top of the second pedogenic zone at a depth of 0.9 m, unlike ostracodes and lithic grains of carbonate which are absent above 1.5 m. Interestingly, dolomite is present within the upper and lower pedogenic zones, as well as in the overlying sediments, but is absent in the middle pedogenic zone (see Fig. 7), suggesting removal by weathering or a reduction in supply of carbonate ions to this part of the basin at that time.

Core 5A

General Description

Core 5A was collected from the central part of Lake of the Woods in 8.1 m of water (Fig. 2), in a large, partially sheltered bay near Massacre Island ~7 km from the western shore, adjacent to the U.S./Canada border. The site is at 49.27928° latitude, −94.82007° longitude (UTM Zone 15; E367641; N5459872). The core recovered was 5.48 m long, which was cut into 5 segments of 15, 82, 150, 150, and 150 cm lengths (see Fig. S5).

The core contains 3 pedogenic zones and is divided into 4 units, based on zones of subangular blocky structure with lower moisture content (Fig. S6) that lie below unconformities in the sequence (Fig. S5); these are interpreted as resulting from subaerial exposure. The upper 2.5 m (unit 1) is a silty clay grading downward into very silty clay and then to a clayey silt with very fine sand in the lower 10 cm of the unit; moisture content decreases downward in this unit, with a noticeable drop in the lower 10 cm, and in underlying unit 2 (Fig. S5). The lower moisture content in the sandy lower 10 cm of unit 1 results from the presence of hard and dry, angular to rounded silty clay granules; these appear to have been reworked from the 18-cm-thick pedogenic zone developed in the 46-cm-thick silty clay of unit 2; that unit becomes organic rich in the lower 10 cm. At ~3 m depth, unit 2 overlies a silty clay unit (unit 3) that has a weakly granular structure in the upper 6 cm, which may be another pedogenically altered zone or sediment reworked from a pedogenic zone. Unit 3 becomes dominantly organic detritus in the basal 3 cm and overlies a distinct unconformity at 3.35 m depth (Fig. S5). Unit 4 underlies the unconformity and the upper 40 cm consists of very dry and crumbly fine granular peds in a matrix of silty clay. This 40-cm zone is interpreted as having been reworked from a nearby soil; this is supported by the abrupt rise in moisture content below 4.5 m, which is not typical in an *in situ* soil.

Ostracodes, Thecamoebians, and Other Macrofossils

Ostracodes are absent in the younger part of the sequence (unit 1) above the pedogenically-altered units. Only a few ostracode valves are present in the 3 altered zones (mainly *Limnocythere friabilis, Cyclocypris sharpi,* and *Fabaeformiscandona rawsoni)*, with a large rise in *Candona subtriangulata* below the weathered zone in unit 4 (Fig. 8). Ostracodes in the lowermost part of the sequence are exclusively *Candona subtriangulata*. Most ostracode shells appear crushed and corroded, although there are some articulated shells present.

Thecamoebians appear only above a depth of 0.8 m (Fig. 8). In general, the cored sequence shows an abundance of plant material, including seeds, needles, various vegetal fragments, birch nutlets, and twigs, and charcoal and insect parts in the upper 4 m; there are occasional gastropod and pelecypod shells, fish bones, and beetle carapaces throughout the core (Mellors, 2010; Table A-6). Below ~2.9 m, including in the second and third paleosols, seeds of shallow water plants were identified, including S*cirpus* sp. (bulrush), and other terrestrial seeds such as *Rumex maritimus* (golden dock) and *Chenopodium* sp. (goosefoot) (Figs. S11 and S12) (A. Telka, personal commun., 2010).

Lithic Fragments and Bulk Mineral Analyses

Coarse grains of various lithologies (lithics), including carbonates and calcareous clay pellets, are most abundant in the lower part of the sequence below ~4 m, which is below the lower thicker pedogenically-altered part of unit 4 that may be reworked soil, and coincides with where ostracodes are most abundant (Fig. 8). Based on X-ray diffraction analyses, dolomite and calcite are present below the top of the lower pedogenic zone, but dolomite extends upward in the core to the top of the upper pedogenic horizon; above this, there is only one sample at 2.37 m that contains dolomite and calcite (Fig. 8), which coincides with a thin zone of hard clayey granules (~peds) and lithic grains in the sediments, and is interpreted as being reworked from an older pedogenic zone.

Core 6A

General Description

Core 6A site was collected in the central part of the basin, ~6 km west of Core 5A and ~1.5 km from the western shore of LOW (Fig. 2) at latitude 49.28098°, longitude −94.89926° (UTM Zone 15; E361907; N5460214). Water depth at this site is 5.9 m. Core length is ~3.8 m, which was cut into 3 segments measuring 90, 140, and 150 cm (Fig. S7).

The upper 180 cm of the sequence (unit 1) is very clayey silt to very silty clay that is poorly laminated and soft; there are scattered hard granules of silty clay in the lower 4 cm of unit 1 that may have been reworked from the underlying unit. Below a color boundary at 180 cm (Fig. S7) is an 8-cm-thick zone with abundant hard and dry granules composed of clay and silt in a silty clay matrix, which appears to have been reworked from a desiccated zone, probably a paleosol. Below this to the bottom of the core is a 1.9 m sequence of silty clay, clayey silt, and silt in distinct 1–5 mm-thick laminations (unit 2).

Ostracodes, Thecamoebians, and Other Macrofossils

All ostracodes in Core 6A occur below the granule-rich zone at 1.8 m. Most ostracodes identified were *C. subtriangulata,* with a few valves of *L. friabilis* in the same interval and one valve of *Cyclocypris sharpei* at 3.1 m (Fig. 9). Most shells are broken, thin, and have a corroded appearance except those near the bottom of the core. As in other cores, thecamoebians were only found in the younger part of the sequence (Fig. 9); several species were observed but not identified.

Figure 9 shows the relative abundance of plant fragments, charcoal, and insect material in Core 6A. Mellors (2010; Table A-8) found a variety of plant fragments scattered throughout the core, including leaves, needles, seeds, and wood. Bivalve shell fragments are present in the 8-cm-thick granule zone just below 1.8 m that is interpreted as resulting from the reworking of a subaerialy-exposed surface.

Lithic Grains and Carbonates

Coarse grains and granules of various bedrock types (lithics) are present throughout the core, with carbonates found mainly below the top of the reworked pedogenic zone at 1.8 m (Fig. 9). Clay pellets (possibly reworked peds) are widely scattered in the sequence between a depth of ~1.5 and 3.3 m, with a concentration around 1.8–1.9 m.

Core 7A

General Description

Coring site 7A is located in the northern part of the basin in a complex mosaic of lakes in the Precambrian Shield, south of the town of Kenora (Fig. 2). The core was collected in 6.1 m of water at 49.72984° latitude, –94.51310° longitude (UTM Zone 15; E390931; N5509911). 4.65 m of core were recovered and cut into 4 segments of 90, 75,153, and 153 cm (Fig. S8).

Sediment throughout this core varies little in grain size, and consists of silty clay with varying small amounts of fine sand. The top meter is a non-laminated, gelatinous sandy silty clay, with a very high moisture content. Below that there is an increase in sand, a decrease in water content, and an increase in firmness. There is a subtle change in color at the 75–85 cm depth that coincides with a small rise in magnetic susceptibility (Fig. 12). At a depth of 97–115 cm, there is another small color change and a distinct rise in magnetic susceptibility. No change in grain size was apparent in either of these. There are distinct laminae below 2.8 m and there is a distinct change in color to lighter gray below a depth of 3.3 m, which is where we place the boundary between units 1 and 2 (see Fig. S8).

As can be seen in Figure S8, at a depth of ~4 m, there is a very distinct 0.5-cm-thick "pink" (10R 4.5/1, reddish gray) silty clay laminae. The upper and lower boundaries are diffuse (gradational) (see also Fig. 5). This thin unit is finely laminated. It contains no sand in contrast to the overlying unit, but is similar in grain size to sediment immediately underlying it. The 0.5 cm below this "pink" laminae is "tan" (2.5Y 5/2, greyish brown) (Figs. 5 and S8), and together we call this uniquely colored pair of laminae unit 3.

Below the pink and tan laminae are 63 cm of laminated silty clay (unit 4) with a dark gray color (5Y 3.5/1) that grades downward into a lighter gray (5Y 5/1) sandy silty clay with silty sand laminae below ~4.2 m and sand laminae in the lowermost 6 cm (see Fig. S8); lithic grains are abundant in this part of the core.

Ostracodes, Thecamoebians, and Other Macrofossils

Ostracodes were only present in a few samples in core 7A (Fig. 10). *C. subtriangulata* is present in the lower part of the core, mainly just above and below the pink laminae; there are a few valves of *L. friabilis* and *F. rawsoni* above the pink laminae. Interestingly, no ostracodes were found in the pink laminae, although the volume of sediment available was very small. 1–3 valves of *Cyclocypris sharpie* were found in several samples higher in the sequence (Fig. 10). Many ostracode shells are fragile and broken, except just above the pink clay laminae where they are heavily coated with carbonate and are associated with clay granules.

Thecamoebians appear mainly above a depth of 1 m in the core (Fig. 10). Plant macrofossils, charcoal, and insect fragments increase in abundance above ~3 m, which is close to where countable numbers of diatoms first appear, chlorophyll-*a* starts to increase, and where the abundance of lithic fragments decreases (Figs. 10 and 12). A pelecypod hinge was found below the pink clay at 4.2 m. Wood, stems, leaves, and other plant materials are scattered throughout the core (Mellors, 2010; Table A-10). The diatom and chlorophyll-*a* record are shown in Figure 12 and discussed in detail in Rentz (2015), and a summary is given in the main text of this paper.

Lithic Fragments and Bulk Mineral Analyses

Coarse grains of various lithologies are common throughout the sequence, but are most abundant below 2.8 m (Fig. 10). Calcite is absent from the sequence, although ostracodes around the pink zone are coated with carbonate and a few samples contain sand to granule-sized carbonates. A small percent of dolomite was identified by XRD in several samples in the lower part of the core. Magnetic susceptibility is relatively high and variable below 3 m (see Fig. 12).

Core SHO-2A

General Description

Core SHO-2A was recovered from Shoal Lake, which is a distinct sub-basin in the LOW complex (Fig. 2) that serves as the source of water for the city of Winnipeg. It is separated from LOW by a narrow and shallow channel. The 6.85-m-long core was taken from 9.2 m of water ~1 km from the shoreline at 49.74471° latitude, –94.52096° longitude (UTM Zone 15; E353057; N5495918), and was cut into 6 segments that are 107, 83, 46, 150, 150, and 150 cm long (Fig. S9).

Sediment in this core is nearly uniform throughout, consisting of non-laminated clayey silty gyttja in the upper 2.6 m grading downward to a soft laminated silty clay that is high in fine organic matter in the lower part. There is an increase in clay content and decrease in silt in the lower meter. No pedogenic horizons were observed (Fig. S9).

Ostracodes, Thecamoebians, and Other Macrofossils

There are 4 species of ostracodes in the core below 3.2 m (Fig. 11), *Cyclocypris sharpi, L. friabilis, Candona subtriangulata,* and *F. rawsoni*; their numbers are highly variable. No change in lithology is apparent at 3.2 m. Many valves were intact and some were articulated; only between 5.3 and 5.6 m did shells appear corroded.

Thecamoebians are abundant and all occur above 2.8 m in the core (Fig. 11), nearly a meter above the top of the ostracode zone; 5 species were identified (Mellors, 2010). Plant and insect macrofossils (larvae cases and exoskeletons) are relatively abundant throughout the core, as is charcoal (Fig. 11); fish vertebrae, bones, teeth, and scales are all scattered throughout the cored sequence (Mellors, 2010; Table A-12).

Lithics and Minerals

Small numbers of coarse grains of clay aggregates and various bedrock lithologies (mostly Precambrian crystalline rocks) are scattered throughout the sequence. Carbonate grains are present mainly in the lower part of the core below 3 m depth, where ostracodes are present (Fig. 11).

SELECTED PHOTOS OF DATED ORGANICS

Figure S10. Five curlytop knotweed achenes.
Figure S11. Two golden dock with bristles.
Figure S12. Two bulrush achenes.
Figure S13. *Drepanocladus* sp. moss fragments.

REFERENCES CITED

Mellors, T., 2010, Holocene Paleohydrology from Lake of the Woods and Shoal Lake Cores Using Ostracodes, Thecamoebians, and Sediment Properties [M.Sc. thesis]: Winnipeg, Canada, University of Manitoba, 455 p.
Rentz, K., 2015, Diatom Assemblage Trends in Lake of the Woods, Ontario, Throughout the Holocene [B.Sc. thesis]: Kingston, Ontario, Canada, Queens University, 35 p.

FIGURE CAPTIONS

Figure S1. Core recovery operations using the LRC Kullenberg rig. (A) preparing to lower the core barrel and weight assemblies using the hydraulic winch system, (B) retrieving the core barrel and weight assemblies through the moon pool in the deck floor, (C) floating rig in the southern basin of Lake of the Woods (LOW).

Figure S2. Kullenberg gravity piston corer schematic showing the major core barrel assembly components and the operation of the sliding vacuum piston used to help retain the sediments (from https://gec.cr.usgs.gov/archive/lacs/piston.htm).

Figure S3. Three segments of core 1A collected in southern end of LOW basin. Top is to left. Numbers along line below core indicate total depth (m); each colored bar is 10 cm long. “?” may be an unconformity that correlates with a change in mineralogy and grain size. Note 3 cm green foam plug in top of segment 1.

Figure S4. Core 4A was collected in the Northwest Angle area of LOW basin in 7.3 m of water. Top is to left. G = gyttja. Numbers along line indicate total depth (m); each colored bar along core is 10 cm long.

Figure S5. Core 5A was collected in the Northwest Angle area of LOW in 8.1 m of water. Top is to left. Numbers along line below core indicate total depth (m); each colored bar is 10 cm long. *** = zone with hard clay granules. Depths are adjusted for green foam plug in top 10 cm.

Figure S6. Moisture content of core 5A, determined by loss of water by freeze drying, and tops of 3 pedogenic zones (grey lines). A refers to a zone of reworked soil peds in sediment overlying a pedogenic horizon, B relates to a weakly developed soil zone, and C to a thick pedogenic zone that may have been reworked from an *in situ* soil.

Figure S7. Core 6A was collected in the Northwest Angle area of LOW in 5.9 m of water ~6 km west of core 5A. Top is to left. Numbers along line below core indicate total depth (m); each colored bar is 10 cm.

Figure S8. Four segments of core 7A collected in northern end of LOW basin in 6.1 m of water. Top is to left. Note pink laminae at depth of ~4 m (89 cm in segment 4). Numbers along line below core indicate total depth (m); each colored bar is 10 cm long. Note 8 cm green foam plug in top of segment 1.

Figure S9. Six segments of core SHO-2A collected in Shoal Lake sub-basin in 9.2 m of water. Top is to left. Numbers along line below core indicate total depth (m); each colored bar is 10 cm long.

Figure S10. Five curlytop knotweed (*Polygonum lapathifolium*) achenes from Core 1A at 282 cm depth, weighing 2.86 mg and dated at 7375 ± 20 yrs. B.P.

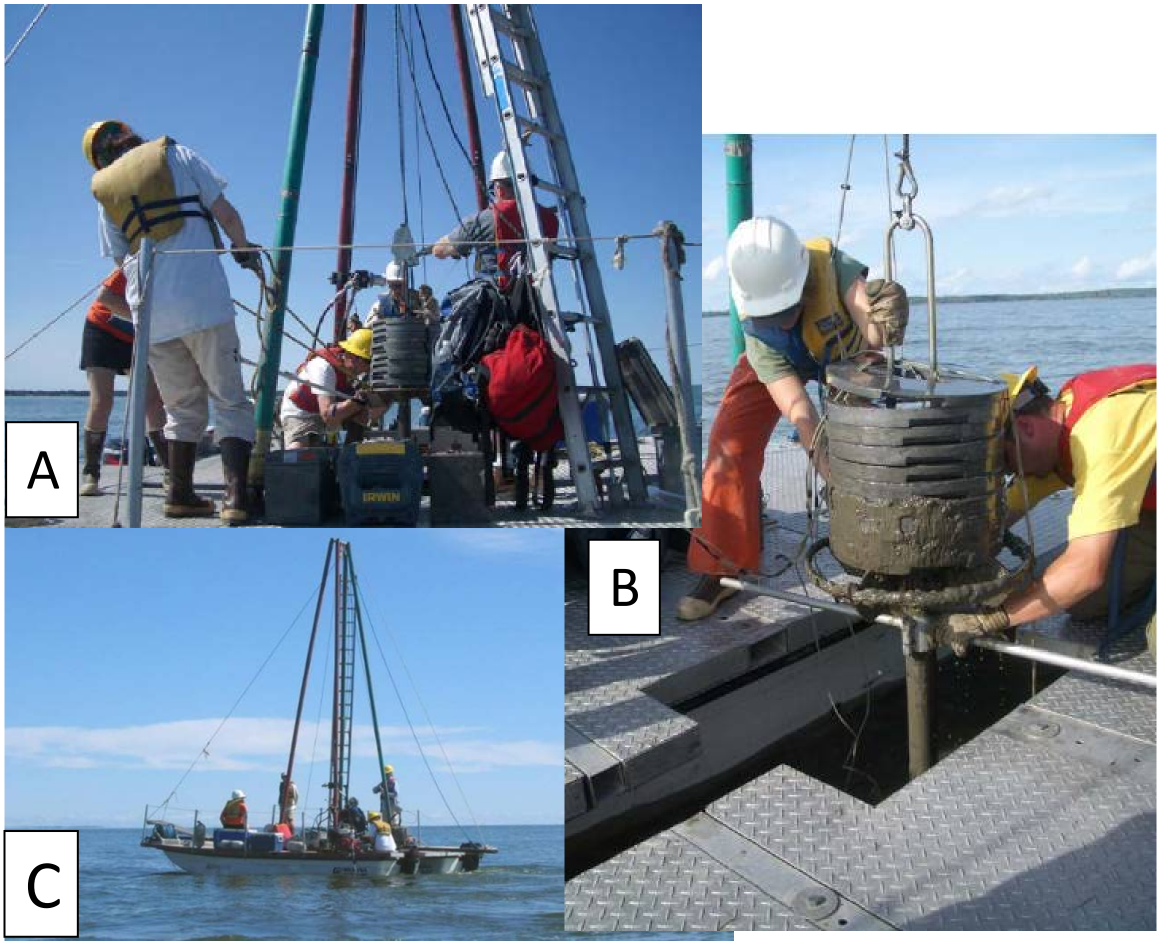
Figure S11. Two golden dock (*Rumex maritimus*) seeds with bristles on calyx from Core 5A at 293 cm depth dated at 7630 ± 25 yrs. B.P.

Figure S12. Two bulrush achenes (*Scirpus* sp.) weighing 2.23 mg from Core 5A at a depth of 323 cm and dated at 8065 ± 20 yrs. B.P.

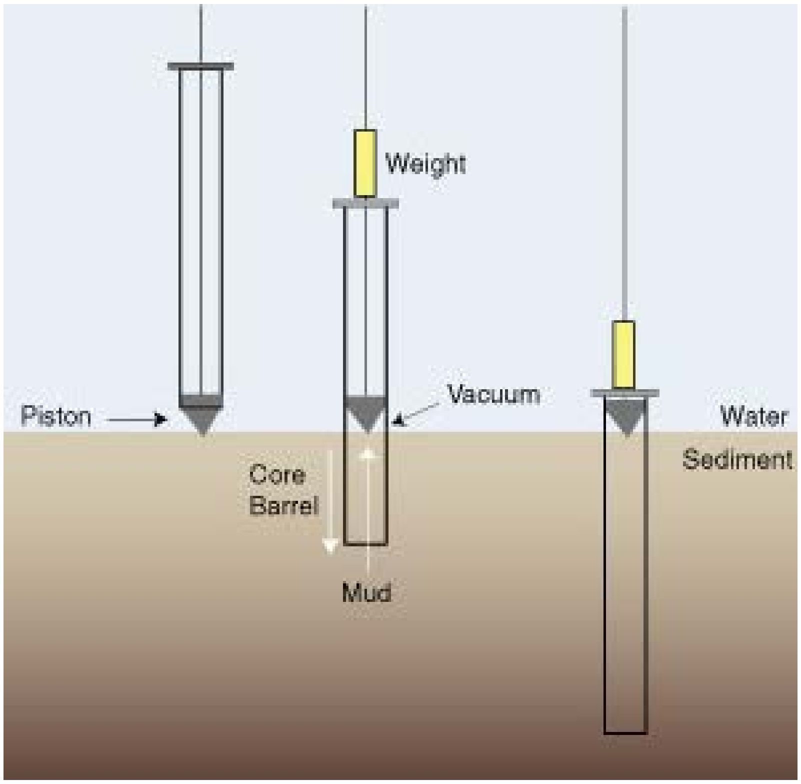
Figure S13. *Drepanocladus* sp. moss fragments from Shoal Lake Core 2A, weighing 19.85 mg, at a depth of 450 cm and dated at 6170 ± 25 yrs. B.P.

Figure S14. South to north profile of modern topography across Lake of the Woods basin from core sites WOO1 to WOO7, constructed by Z. Yang based on Yang and Teller (2005). Location of profile shown in Figure S15.

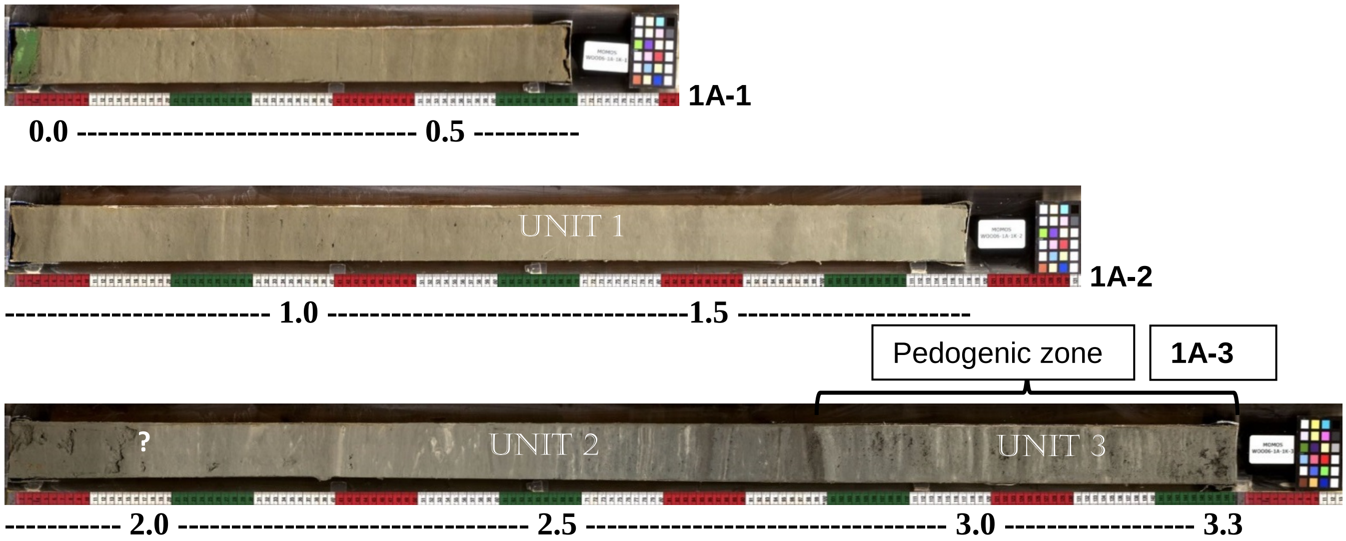
Figure S15. Location of topographic profile shown in Figure S14. Colors defined in Figure 2.



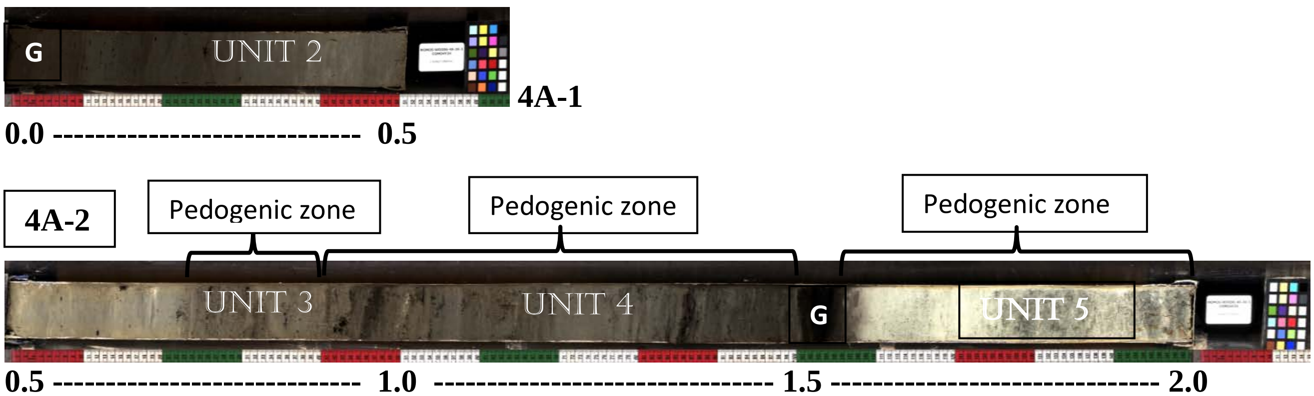
Teller et al.   FIGURE S1



Teller et al. FIGURE S2



Teller et al. Fig. S3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4A-2
Pedogenic zone
Pedogenic zone
Pedogenic zone
UNIT 3
UNIT 4
G
UNIT 5
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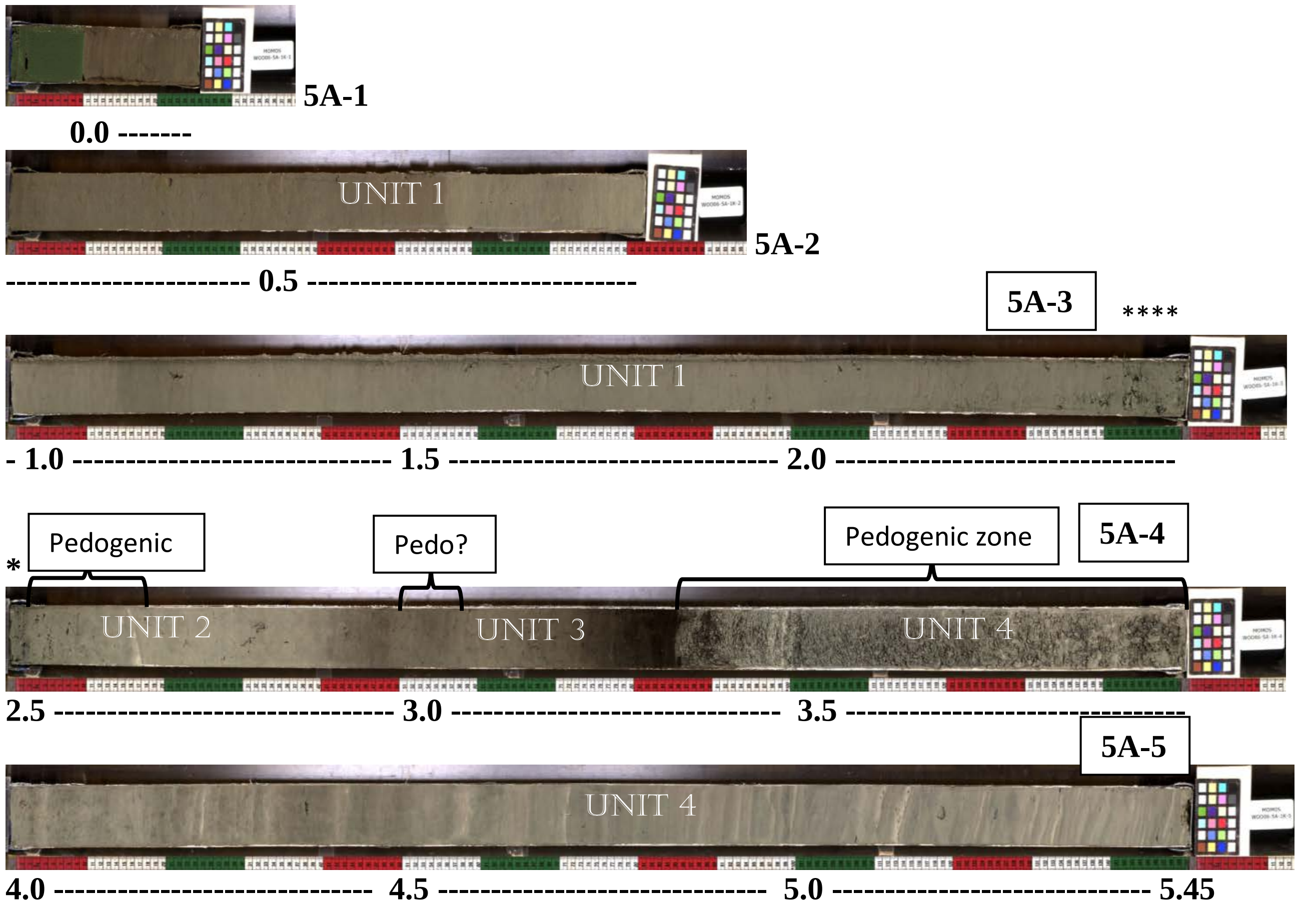
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5A-3
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UNIT 1
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1.5
2.0
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Pedogenic
Pedo?
Pedogenic zone
5A-4
UNIT 2
UNIT 3
UNIT 4
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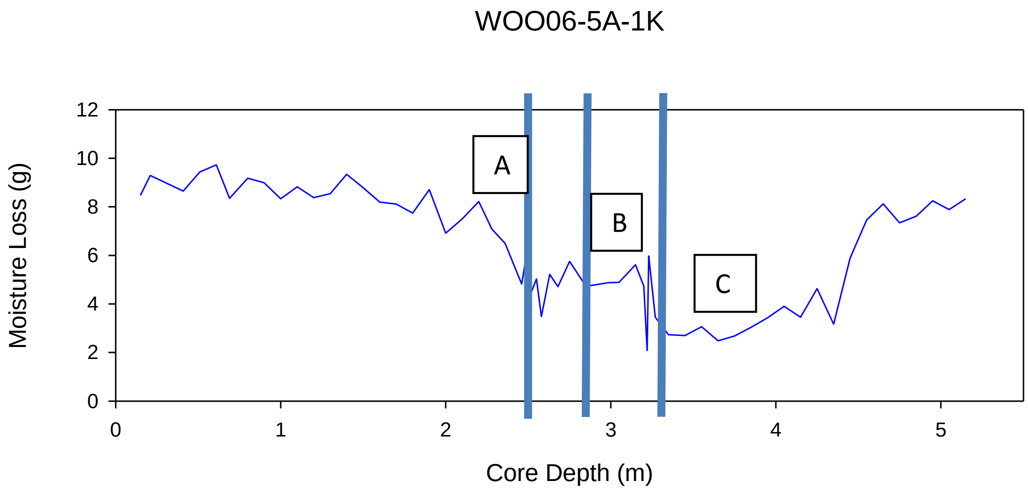
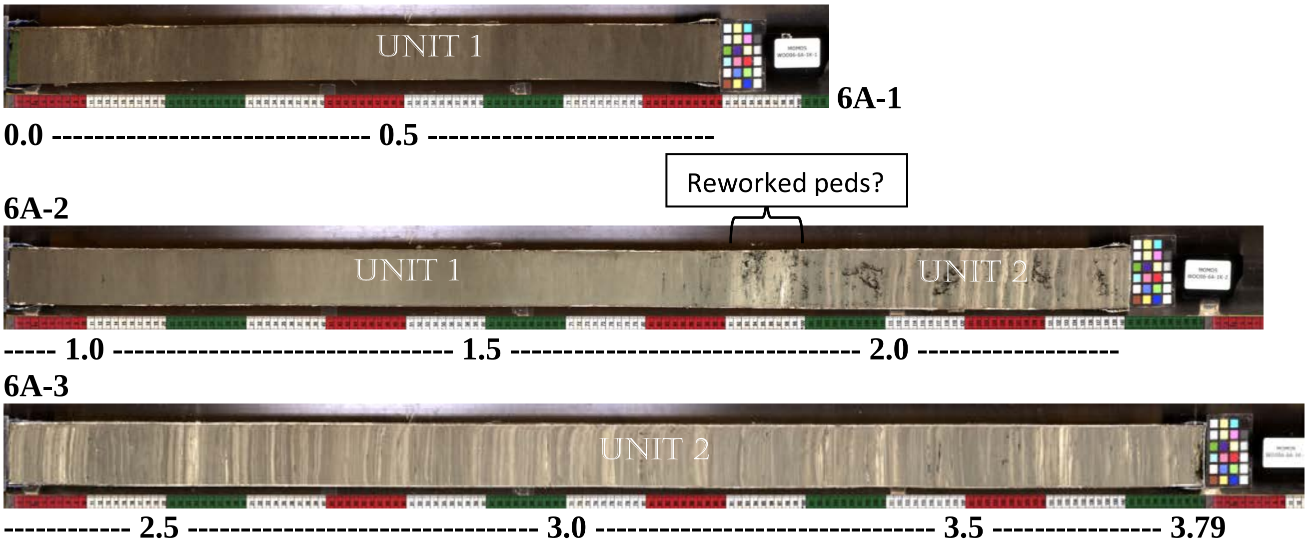
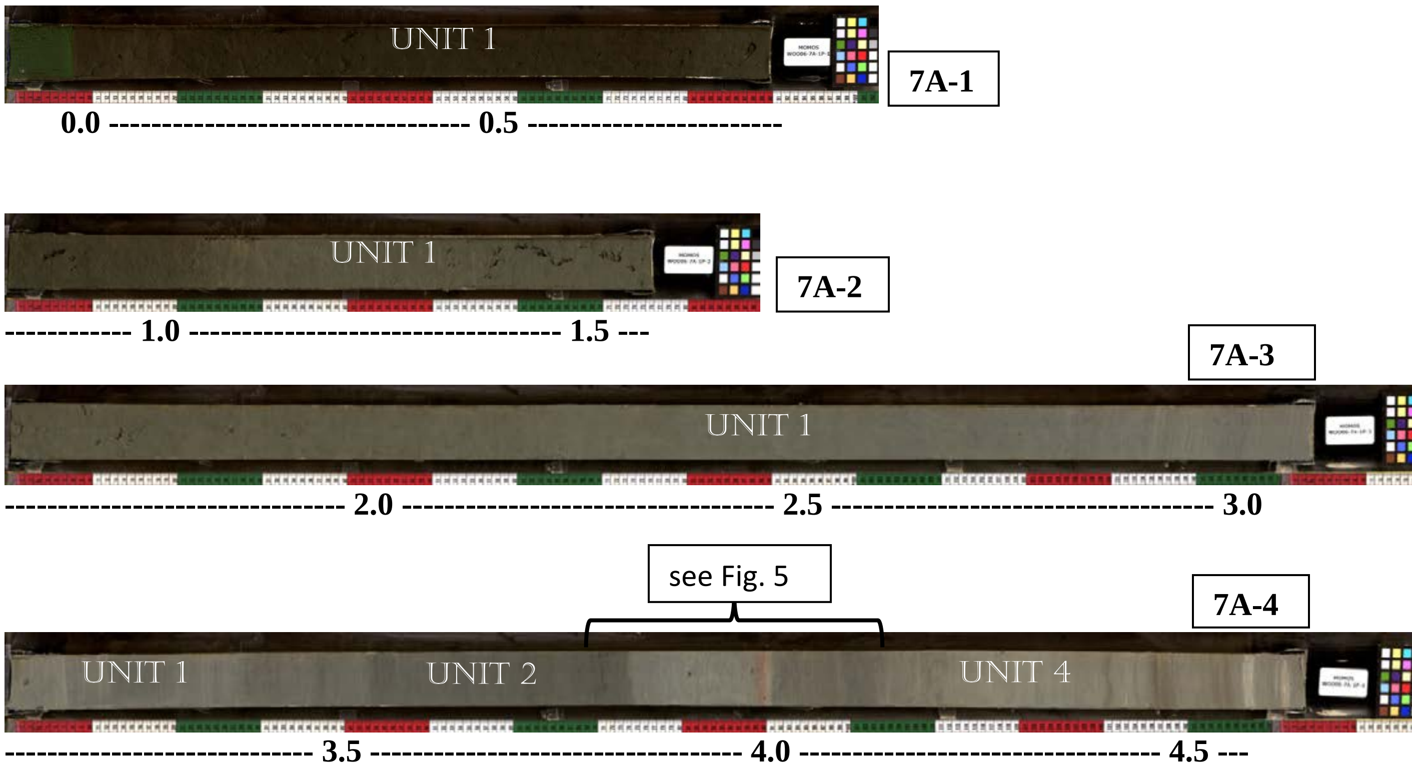


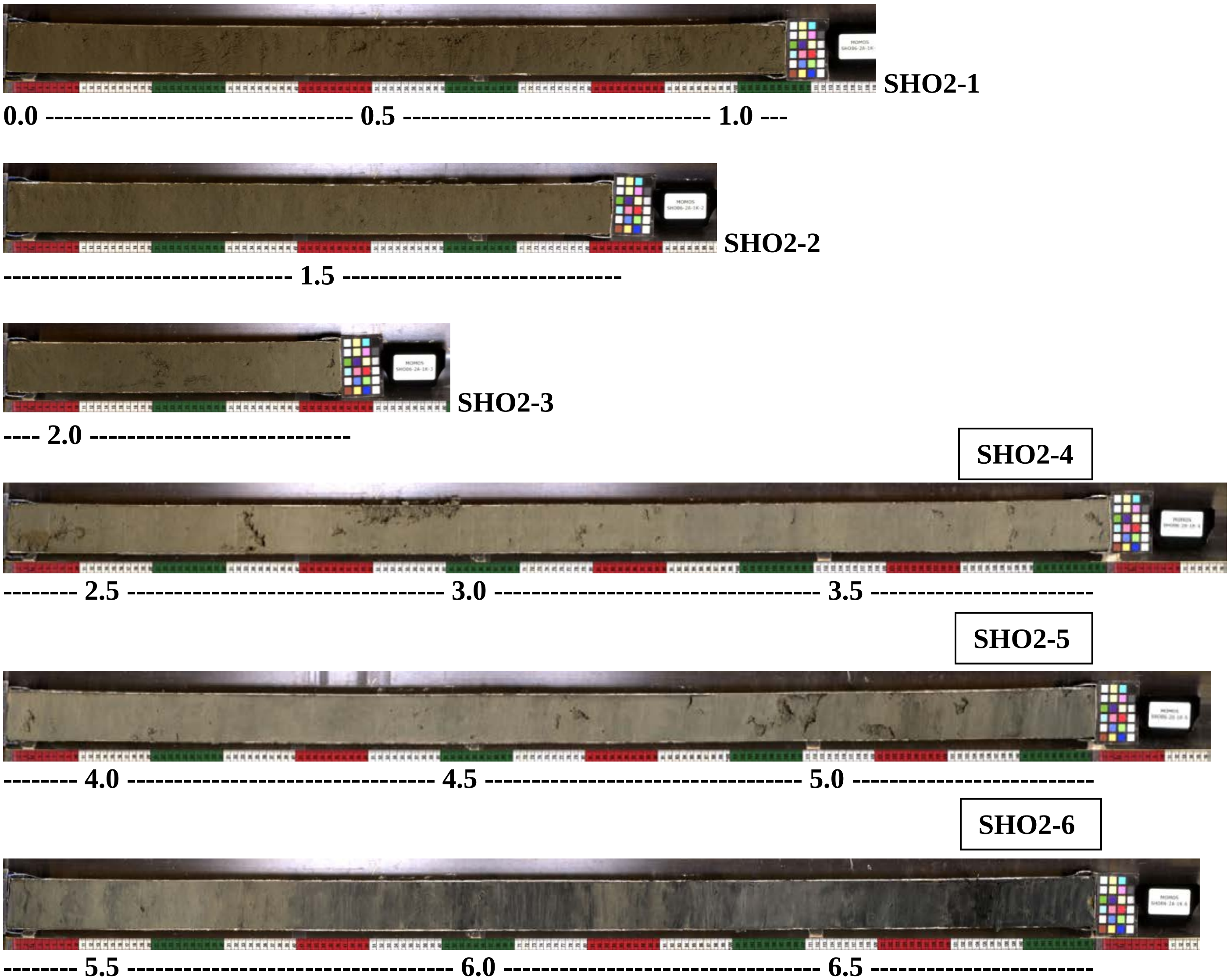
Teller et al. Figure S6



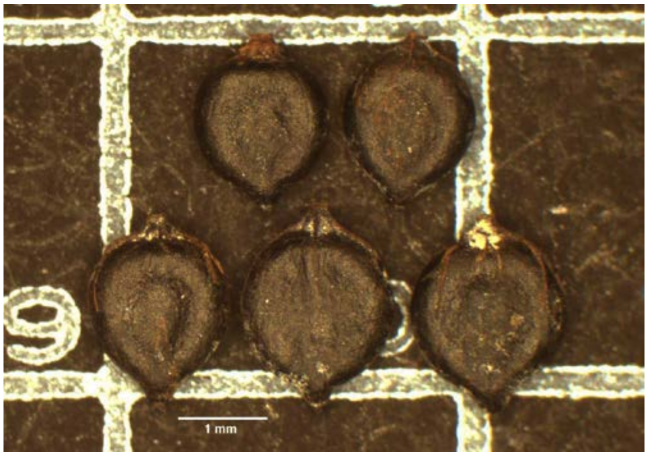
Teller et al. FIGURE S7



Teller et al. FIGURE S8



Teller et al. FIGURE S9

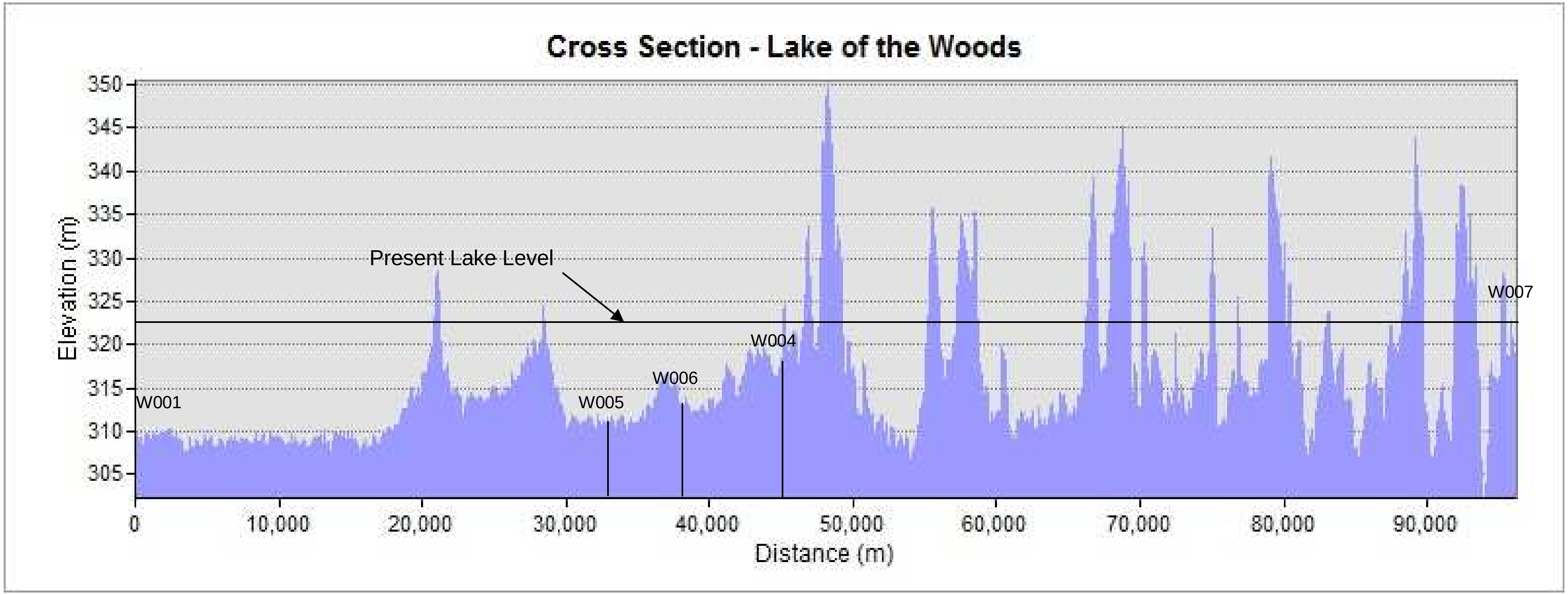


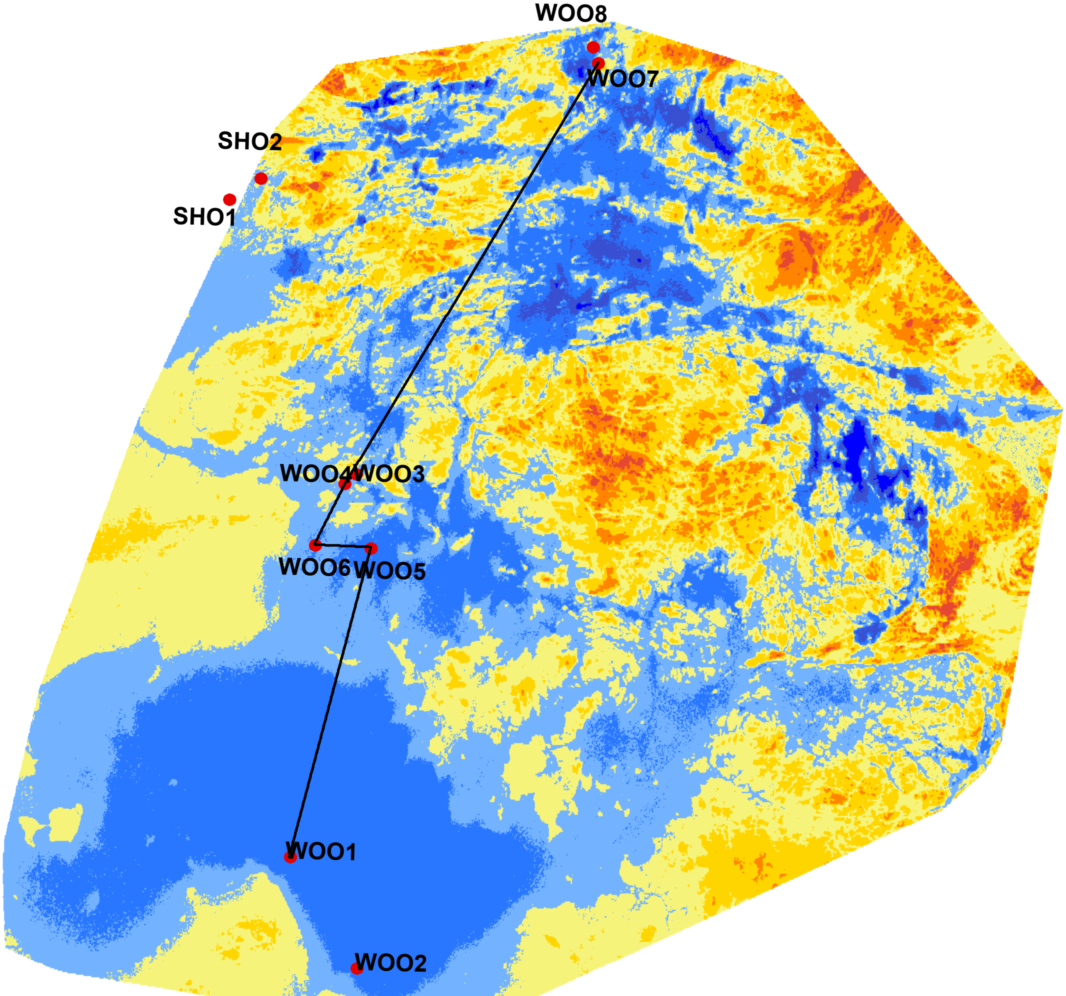
Teller et al. FIGURE S10

Teller et al. FIGURE S11

Teller et al. FIGURE S12

Teller et al. FIGURE S13


Cross Section - Lake of the Woods
Elevation (m)
350
345
340
335
330
325
320
315
310
305
Present Lake Level
W001
W005
W006
W004
W007
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
Distance (m)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WOO7
SHO2
SHO1
WOO4
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WOO5
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WOO2