Terminoglacial lacustrine sediments and other deposits in the Glacial Lake Proven basin, Riding Mountain, Manitoba

R.A. McGinn, Brandon University (mcginn@brandonu.ca)
D.J. Wiseman, Brandon University (wiseman@brandonu.ca)
K. Zaniewski, Lakehead University (kamil.Zaniewski@lakeheadu.ca)

Abstract: The 2005-06 core-sampling program in the Glacial Lake Proven basin was designed to provide subsurface sedimentological data to the base map data previously collected and estimate of the nature and thickness of lacustrine sediment in the terminoglacial Lake Proven basin. The secondary objective was to integrate the terminoglacial stratigraphy with the previously described supraglacial sequence of lake sub-stages. A third objective was to search for datable organics and diatoms. Five cores extracted from the terminoglacial Lake Proven basin indicate a rich sediment supply and a variety of terminoglacial lacustrine facies: lacustrine complexes, lacustrine bottomsets and lacustrine complexes grading to shallow water lake-margin deposits. These glacigenic facies represent a continuum of supraglacial/terminoglacial lacustrine sedimentation throughout the history of the glacial lake. The terminoglacial lacustrine facies represent a major sub-stage in the lake history and the general stratigraphic sequence of facies exposed in the cores suggests that water levels in terminoglacial Lake Proven fluctuated periodically. While no datable material or diatoms were found in the cores, sedimentation rates, as indicated by rhythmic laminations exposed in the cores and stratigraphic sections, could help estimate the duration of both the supraglacial and terminoglacial lake sub-stages.

Introduction

The Lake Proven basin covers an area of approximately 340 km² on the Riding Mountain Uplands in Manitoba (Figure 1). The topography is generally less than 625 m in elevation and includes the present day; Clear Lake, Bottle Lake, Proven Lake, Jackfish Lake and Otter Lake. Higher elevations, in excess of 670 m, are located to the north and east of the Lake
Figure 1: Physiography of the Glacial Lake Proven basin.
Proven Basin (Figure 1). The Rolling River drains the southern portion of the basin to the south; the northern portion of the basin drains towards the west by way of Clear Creek. Both drainage routes join the Little Saskatchewan River and eventually drain into the Assiniboine River to the south.

Klassen initially mapped the southwestern third of the Lake Proven area as “silt, deposited in part in a superglacial lake” and referred to this supraglacial lake as “Glacial Lake Proven” (Klassen 1966, 117). The associated 1:250,000 map published in 1965, however, makes no reference to the name Glacial Lake Proven or to the mode of origin of the deposits. In later work, Klassen (1979, Map 1469a) describes the supraglacial lacustrine deposits as “a gently irregular to hummocky glaciolacustrine complex composed of mainly silt and sand.” Associated lacustrine deposits are described as “silt and clay or organic deposits on poorly drained flats” (Klassen 1979, Map 1469a). There is no mention of Glacial Lake Proven in the 1979 memoir. The Quaternary surficial map of Riding Mountain (Manitoba Energy and Mines 1980), based on Klassen’s 1979 map, describes the deposits as “lacustrine silt and clay deposited in basins peripheral to the main Lake Agassiz basin.”

In these small-scale surficial mapping studies (1:250,000) there are virtually no details regarding the environmental conditions, depositional mechanisms, and lithologic characteristics, which are associated with the Glacial Lake Proven deposits. Furthermore, the actual extent of the deposit is poorly mapped due to its relative small size and the fact that some of the sediments have been subsequently buried.

Detailed surficial mapping based on stratigraphic descriptions obtained from road and river cuts (McGinn 1991, 1997, 2000, 2002, McGinn et. al. 2004 and 2007) has determined that early Glacial Lake Proven deposits (Proven I Complex) occur at elevations above 615 m in the region to the west and southwest of the topographic basin (Figure 2). These rhythmite deposits exposed at the Bottle Lake (BL), Hwy 45 (45) and Rolling River (RR) sections represent a supraglacial lacustrine facies (McGinn 2002). The deposits of the later phases of Glacial Lake Proven (Proven II Complex) are believed to represent a topographically controlled terminoglacial lacustrine facies, perhaps supraglacial, but with only a thin ice base (McGinn 2002). Exposures of the Proven II complex are found in the upper units of the Rolling River section (McGinn 2002). No other natural or anthropogenic exposures of the terminoglacial lacustrine facies have been found.

To date, diatoms, pollen, and other datable organics have not been found in the Glacial Lake Proven basin deposits. Consequently, there is no absolute or relative chronology for the Glacial Lake Proven stratigraphy or any estimates as to the longevity of the lake. To some extent this is not
surprising, as the supraglacial subenvironment is located a significant distance from acknowledged ice margins. Stratigraphic position and interpretation become the default relative dating technique. Consequently, the authors undertook a coring project in the summers of 2005 and 2006.
Objective of the 2005 Coring Project

The objectives of the Glacial Lake Proven coring project were fourfold:

1. To verify the presence of glaciolacustrine sediments in the terminoglacial Lake Proven basin,
2. To identify the types of terminoglacial lacustrine sediments,
3. To integrate the terminoglacial lacustrine sediment facies into the general Glacial Lake Proven facies model (McGinn 2002) and
4. To search for datable organics and diatoms in the core material.

Glaciogenic Sediments

In 1989, the INQUA Commission on the Genesis and Lithology of Quaternary Deposits published a Genetic Classification of Glaciogenic Deposits (Goldthwaite and Matsch, eds. 1989). In this volume, Ashley (1989) reviews the sedimentary processes and lithofacies units in glacier-fed lakes and establishes lithofacies groups with commonly occurring lithofacies units. The lithologic criteria outlined in this publication will be used in this research.

Brodzikowski and Van Loon (1991) present a synthesis of Glaciogenic Sediments and establish a four-level systematic classification based on a general “glacial” or “periglacial” environment, the depositional subenvironment (e.g. supraglacial, englacial, subglacial), facies and the characteristics of the deposits. The fourth level indicates the deposits associated with a specific depositional mechanism. For example three types of deposits can be distinguished in the continental glacial, supraglacial, lacustrine facies; complexes, lake-margin deposits and bottomsets. The Brodzikowski and Van Loon (1991) nomenclature is employed in this research.

Procedures and Methodologies

The Bottle Lake and Highway 45 stratigraphic sections and the previously described Rolling River sections (Figures 1 and 2) of supraglacial Lake Proven deposits (Proven I Complex) were visited and examined. Five GeoProbe® cores were taken in the terminoglacial Lake Proven basin (Figures 1 and 2), split and logged.

GeoProbe® is a truck-mounted direct push hydraulic coring unit that can extract up to 15 m of soft unconsolidated sediment such as fine gravels,
sands and silt (McGinn et al. 2007). Thick diamictons and massive clays are rarely penetrated. Wiseman and Zaniewski (2008) have identified data logging problems associated with the direct push hydraulic coring procedure, specifically core-wall deformation in fine sediment beds and of primary sedimentary structures, under representation/exclusion of thin sediment beds and significant inaccuracies in bed thickness measurements. Detailed logging of lithofacies and transition facies is not recommended. Despite these typical soft sediment coring issues, GeoProbe® cores provide a reconnaissance stratigraphic log of subsurface sedimentary stratigraphy were road and river cuts are unavailable.

Standard sedimentological observations were made (Stow 2005); specifically, site locality and lithofacies descriptions. Lithofacies observations include bed thickness, texture (use of comparator charts, hand lens and experience) and a description of sedimentary structures present: erosional, deformational, and bedding/lamination (parallel, wavy, cross, and graded). Observable paleocurrent indicators and fabric were measured with a conventional pocket transit (Brunton compass). Other lithofacies parameters recorded include (Munsell colour, grain/clast morphology and lithology. Digital photographs were taken and sectional sketches, sketch logs and graphic logs constructed. Geoprobe® and other cores are conventionally logged from the top down, whereas stratigraphic sections are described from the base unit upwards (Stow 2005, 17).

Lithofacies units identified in the stratigraphic section logs and core descriptions are compared to the characteristics of the Brodzikowski and Van Loon (1991) four-level classification system derived for glacigenic sediments. Specifically, the characteristics of the “melting ice,” “fluvial,” “lacustrine” and “mass-transport” facies and the deposits associated with the “supraglacial” and “terminoglacial” subenvironments. The Brodzikowski and Van Loon (1991) criteria formulate the basis used for all facies interpretations in this text.

Fence diagrams founded on identified lithofacies, stratigraphic position and geographic location are employed to correlate core and section logs across the Glacial Lake Proven basin.

Supraglacial Sediments Exposed in Stratigraphic Sections in the Glacial Lake Proven Basin

Bottle Lake Sections (E424281, N5604557, Zone 14, NAD 83):

Section BL₁ is located approximately 4 m above section BL₂ at an estimated elevation of 623 m (Figure 1). All elevations are either measured
from a hand held GPS, interpolated from the 1:50,000 National Topographic Map Sheets 62K9, 62K J12 (cross-sections) or derived from Google Earth. The upper Bottle Lake section exposes approximately 2.0 metres of rhythmically bedded fine sand and silt (Figure 3). The rhythmites are generally 2.0 - 4.0 cm thick. There is noticeable ironstaining along fine-grained bedding planes. Based on the Brodzikowski and Van Loon (1991) criteria, the section is interpreted to be lacustrine bottomsets.

Section BL2 (Figure 1) is located 200 m downslope from BL1 at an estimated elevation of 619 m. Here, 2.6 metres of laminated fine sand and silt are exposed. There is some regular lamination of the finer sand and silt, evidence of coarse intercalations and material supplied by mass movements or wash off (a 33 cm thick sandy-silt diamict) and numerous dropstones (Figure 3). These lithofacies characteristics are consistent with supraglacial lake margin deposits and a subaqueous mass transport complex as described by Brodzikowski and Van Loon (1991). The section is interpreted to be a supraglacial lake margin - subaqueous mass transport complex.

Provincial Highway 45 Sections (E425904, N 5597211, Zone 14, NAD 83)

Two stratigraphic sections are exposed on provincial trunk road 270 near the intersection of provincial highway 45 (Figure 1). The first section 451 is approximately 3 metres deep in a small erosional gully from the 628 m surface elevation. The slightly deformed (tilted) alternating layers of sands and silt are interpreted as a supraglacial lacustrine complex.

Stratigraphic section 452 is located 5.5 metres below the surface of section 451, 50 metres south at the intersection with provincial highway 45 (Figure 1). Here, over 2.5 metres of rhythmically bedded fine sand and silt lacustrine bottomsets are exposed. Silt units are 1- 3 cm thick. Occasional, 2 cm thick, units of fine to medium sand are present. There are no apparent deformation features.

Rolling River Section (E430772, N5593749, Zone 14, NAD 83):

McGinn (2002) describes the Rolling River section in detail. A supraglacial melting-ice facies (Zelena Formation; a melt-out complex) is exposed at the base of the sequence (Figure 3). Klassen (1979) suggests that the Zelena formation was deposited during the final stages of glacial stagnation during the Late Wisconsinan. Consequently, the Zelena formation represents the uppermost tills and intertill sediments on the Riding Mountain Uplands. Oxidized Zelena Till is usually yellowish brown or very dark grey brown in colour (Munsell Colour Chart). Fresh (unoxidized) exposures are dark olive grey or very dark grey (Klassen 1979). The till is massive and of moderate compaction. The prominent clasts are typically the more resistant Interlake region carbonates and shield metasedimentaries, such as the local Odanah Shale clasts, which
Figure 3: The Rolling River and Bottle Lake stratigraphic sections and terminoglacial Lake Proven cores.
are quickly crushed or abraded to matrix size or terminal grade during glacial transport. Some larger shale clasts are evident but difficult to remove without fracture, so it is difficult to determine a percentage composition of shales. Carbonates constitute approximately 26% - 36% of the clasts (Klassen 1979).
Depositional evidence suggests that there was an abundant sediment supply into early Glacial Lake Proven depositing a 0.73 metre thick supraglacial lacustrine complex that conveys an impression of alternating layers of coarse sands and gravels and silty-clay diamict (Figure 3). These relatively coarse paralacustrine deposits, interpreted as Incipient Glacial Lake Proven deposits (McGinn 2002) are overlain by a 2.69 m thick sequence of lacustrine bottomsets consisting of sands and granules and silty-clay rhythmites that fine upwards to fine-medium sands and silt rhythmites (Figure 3). The lacustrine bottomsets are interpreted as early supraglacial Lake Proven deposits (McGinn 2002) and mapped as “Proven I Complex” (Figure 2). A 0.65 m lacustrine complex consisting of alternating laminae of fine sand and silt and coarser sands, represents the transitional phase from a supraglacial lacustrine environment to the terminoglacial lacustrine environment as the ice-walled lake expanded to the north and east (McGinn 2002).

In the upper 2.2 m of the section, seven distinctive very fine sand-silt beds (Figure 3) are interpreted to be low energy (ice cover) sedimentary units interbedded with higher energy (open-water) coarser material and ice rafted mass transported diamicts. Regular lamination of the finer sand and silt, evidence of coarse intercalations and material supplied by mass movements or wash off are the lithofacies characteristics of a supra/terminoglacial lake-margin deposit (Brodzikowski and Van Loon 1991).

Terminoglacial Lake Proven Cores

Glacial Lake Proven North core (N) (E430263, N5611299, Zone 14, NAD 83) was extracted a few hundred metres from the south shore of Clear Lake (Figures 1 and 2). The site elevation is recorded to be 618 m a.s.l.; approximately 4 m above current lake level. The 7.59 m core is generally described as 2.72 m of coarse to medium sands grading upward to thickly bedded fine sands (Figure 3). Below this unit, 2.2 m of laminated (parallel) fine to medium sands and silt is underlain by 2.67 m of rhythmitically bedded fine sand and silt (Figure 3). Zelena Till was encountered at the base of the core. No datable material was present in the core.

The Glacial Lake Proven North Central core (NC) (E428085, N5606833, Zone 14, NAD 83) was extracted approximately 4.75 km SSE of the Glacial Lake Proven North (N) core location (Figures 1 and 2). Site elevation is 612 m a.s.l. Approximately 1.97 m of laminated (parallel) medium sands overlie 0.95 m of alternatively bedded fine sand and silt (Figure 3). This unit overlies 1.08 m of massive medium sands. A few centimetres of Zelena Till
were incorporated into the base of the core. No datable material was found in the North Central core.

The 7.62 m Glacial Lake Proven South Central core (SC) (E427549, N5603563, Zone 14, NAD 83) was taken on the Dudman farm approximately 3.5 km south of the NC core location (Figures 1 and 2). Site elevation is measured to be 612 m. Approximately 0.64 m of medium to fine sands are underlain by 2.04 m of laminated fine sand and silt (Figure 3). A 42 cm thick bed of medium sands separate the laminated fine sands and silt from 1.79 m of rhythmically bedded grey silt and fine sand. This unit is underlain by 0.97 m of fine sand and shale clasts. Zelena Till marks the base of the 7.62 m SC core. No datable material was present in the Dudman core.

A fourth core, Glacial Lake Proven South (S) (E427567, N5597887, Zone 14, NAD 83), was extracted at the Proven Lake Farms homestead, 5.67 km south of the Dudman farm core site (Figures 1 and 2). The site elevation is 611 m a.s.l. Here, 3.37 m of faintly laminated fine sand and silt with occasional dropstones overlies Zelena Till (Figure 3). There was no datable material present in Proven Lake Farms core.

The fifth Geoprobe® core, Glacial Lake Proven East (E) (E436913, N5601034, Zone 14, NAD 83) was taken east of the Rolling River along the eastern shore of the lake (Figures 1 and 2). The site was selected to provide a west to east transit through terminoglacial Lake Proven. Site elevation is measured to be 618 m a.s.l. Approximately 2.50 m of medium sands alternating with fine to medium sands overlie 0.80 m of partly deformed rhythmically laminated fine sands and silt. These stratigraphic units are underlain by 2.40 m of alternating layers of coarse sands and gravels, silty diamicts and laminated silty-clay beds (Figure 3). Zelena Till is present at the base of the core. No datable material was found in the fifth Glacial Lake Proven core.

Interpretation and Discussion

The nature of the glaciolacustrine sediments in terminoglacial Lake Proven:

Glaciolacustrine sediments appear in all five terminoglacial Lake Proven cores. Depositional evidence suggests that there was a more abundant sediment supply into the terminoglacial lake stages than previously hypothesized (McGinn 2002) depositing over 7.0 m in deeper parts of the lake. Most of the sediment units are classified as glacial lacustrine complexes (LC on Figure 3), in that there is no sedimentological distinction evident between lacustrine bottomsets and lake margin deposits. These lacustrine complexes consist of mixtures of dropstone-
rich fine sand and silty-clay varvites, and subaqueous debrisflow mass transport diamicts. Lacustrine bottomsets (LB on Figure 3) consist of rhythmites constructed of laminae of fine to medium sand grading to silt/clay. Massive sand strata can occur but are uncommon. Massive silt units or fine sand-silt units are frequent. Occasional dropstones can be found in these massive fine sand-silt rhythmites. Deeper water lacustrine complexes grade to lake margin deposits when water levels fluctuated. The lake margin deposits (LMD on Figure 3) are relatively thick units (up to 1.5 m) of laminated medium sands/fine sands or fine sands/silts. There is evidence of frequent coarse intercalations and material supplied by mass movement or wash-off, and numerous dropstones. Massive coarse sands and gravelly beds are indicative of periods of higher energy (open water); fine sand/silt units are characteristic of low energy ice cover conditions.

**Integrating stratigraphic cross-sections and core data:**

Figure 4 illustrates a topographic/stratigraphic cross-section from south to north through the Rolling River section and the S, SC, NC, and N terminoglacial Lake Proven cores (Figure 1). The Bottle Lake and Highway 45 sections are transposed to the appropriate positions on the diagram.

Hypothesized ice walls enclose the early supraglacial Lake Proven. A supraglacial lacustrine complex and lake margin - subaqueous mass

---

**Figure 4:** Composite south to north cross-section through stratigraphic sections and cores.
transport complex are overlain by approximately 2 m of supraglacial lacustrine bottomsets and 3 to 8 m of a supra/terminoglacial lacustrine complex (RR). The steep 10 m bluff, coincident with an early ice wall position, separates the higher elevation supraglacial lake sediments (45\textsubscript{1}, 45\textsubscript{2}, BL\textsubscript{1} and BL\textsubscript{2}) from the deposits of the terminoglacial lake sub-stages (Figure 4). Subaqueous mass transport deposits occur adjacent this steep bluff (e.g. BL\textsubscript{2} section).

Hydrothermal wastage resulted in a recessional sequence of ice wall positions northward across the relatively flat Lake Proven plain. In terminoglacial Lake Proven a 3.0 m thick lacustrine complex overlies discontinuous supraglacial lacustrine deposits (S, SC, NC and N). There is no evidence of deformation in the extensive and continuous lacustrine complex. This supports the hypothesis that Glacial Lake Proven was now a topographically controlled terminoglacial lake. The underlying supraglacial deposits are characterized as a lacustrine complex fining upward into lacustrine bottomsets. Towards the north the overlying extensive and continuous lacustrine complex thins to approximately 2.2 m and is overlain by shallow-water lake margin deposits (SC, NC and N) and a supraglacial fluvial facies (sandar plain deposits, Figure 2).

Figure 5 illustrates a topographic/stratigraphic cross-sectional from west to east and includes the Upper Bottle Lake stratigraphic section (BL\textsubscript{1}) and the SC and E terminoglacial Lake Proven cores (Figures 1). The

![Figure 5: Composite west to east cross-section through stratigraphic sections and cores.](image-url)
Bottle Lake 2 section is transposed to the appropriate position on the Figure 5 cross-section.

As in Figure 4, supraglacial lake deposits appear at elevations above 615 m (BL₁ and BL₂). A prominent ice shoved hill composed of Odanah Shale (McGinn 2000) is surrounded by terminoglacial Lake Proven deposits Figure 5). West of the glaciotectonic ridge (SC), a supra/terminoglacial lacustrine complex grades into lacustrine bottomsets that are overlain by a 2.0 m thick terminoglacial lacustrine complex. East of the glaciotectonic ridge, the basal supraglacial lacustrine complex contains two 8 - 13 cm thick diamicts that may be the down-flow extension of a subaqueous mass transfer facies originating in the Otter Lake sub-basin (McGinn et al. 2007). The overlying 0.8 m thick terminoglacial lacustrine complex is itself overlain by over 2 m of glaciofluvial deposits associated with the Holocene Rolling River (E).

**Summary and Conclusions**

The glacigenic facies in Glacial Lake Proven basin represent a continuum of supraglacial/terminoglacial lacustrine sedimentation throughout the history of the glacial lake. Two lacustrine sedimentary environments are represented in the sediments; the supraglacial and terminoglacial. Supraglacial lacustrine facies are exposed in several road and river cuts in the southwestern regions at elevations above 615 m. There are no known natural or anthropogenic exposures of the terminoglacial lacustrine facies on the Proven Lake plain.

The 2005-06 core-sampling program in the Glacial Lake Proven basin was designed to provide subsurface sedimentological data to the base map data previously collected and provide estimates of nature and thickness of lacustrine sediment in the terminoglacial Lake Proven basin. The secondary objective was to integrate the terminoglacial stratigraphy with the previously described supraglacial sequence of lake sub-stages (McGinn 2002) and search for datable material.

Five cores extracted from the terminoglacial Lake Proven basin indicate that there was a rich supply of sediment into the lake in that up to seven metres lacustrine material was deposited in the deeper regions of the lake. Sediments exposed in the cores represent a variety of terminoglacial lacustrine facies: lacustrine complexes, lacustrine bottomsets and lacustrine complexes grading to shallow water lake-margin deposits. Coarser sediments associated with fluvial environments occasionally overlay the glacial lacustrine deposits.
The terminoglacial lacustrine facies represent a major sub-stage in the lake history. The general stratigraphic sequence of facies exposed in the cores suggests that water levels in terminoglacial Lake Proven fluctuated periodically. As the northern ice-wall lakeshore hydrothermally wasted towards the northeast, water levels are believed to have dropped as the lake surface area to meltwater volume ratio increased. During this phase of the Glacial Lake Proven a relatively coarse-grained supra/terminoglacial lacustrine complex was deposited in the deeper regions of the lake (SC). Stagnant ice wastage within the glacial lake watershed account for a return to high water levels in the evolving terminoglacial lake. Rising water levels and a high sediment to runoff volume ratio resulted in a 2 metre thick sequence of rhythmic bottomsets deposited in the deeper areas of the lake (SC and N). A 2 - 3 metre thick lacustrine complex overlies the discontinuous lacustrine bottomsets facies. These two terminoglacial lacustrine facies (bottomsets overlain by a lacustrine complex) are themselves overlain by shallow water lake margin deposits (SC, NC and N) which are believed to have been deposited during the final drainage phase of Glacial Lake Proven.

While no datable material was found in the cores, sedimentation rates as indicated by rhythmic laminations exposed in the cores and stratigraphic sections could help estimate the duration of both the supraglacial and terminoglacial lake sub-stages. More detailed stratigraphic data on mean rhythmite thickness however, is required to pursue this approach.

References

ASHLEY, G.M. 1989 ‘Classification of glaciolacustrine deposits’ in Genetic Classification of Glaciogenic Deposits, eds. R.P. Goldthwait and C.L. Matsch (Rotterdam: Balkema) 243-360


GOLDTHWAIT, R.P. and MATSCH, C.L. eds. 1989 Genetic Classification of Glaciogenic Deposits (Rotterdam: Balkema)


KLASSEN, R.W. 1966 The Surficial Geology of the Riding Mountain Area, Manitoba-Saskatchewan Ph.D. Thesis (Saskatoon: University of Saskatchewan)

KLASSEN, R.W. 1979 ‘Pleistocene geology and geomorphology of the Riding Mountain and Duck Mountain areas, Manitoba-Saskatchewan’ Geological
Survey of Canada Memoir 396 (Hull: Canadian Government Publishing Centre)


MANITOBA ENERGY and MINES 1980 Quaternary Surficial Map AR80-05 (Winnipeg: Manitoba Mineral Resources Division)


WISEMAN, D.J. and ZANIEWSKI, K. 2008 ‘An assessment of deformation and sampling error in Geoprobe cores’ paper presented at Prairie Division of the Canadian Association of Geographers Annual Meeting, Boissevain, Manitoba