Surficial Geology of the Newport 7.5-Minute Quadrangle, Northern Vermont[1]

Stephen F. Wright
Department of Geography and Geosciences, University of Vermont
April, 2024

View looking northwest across the South Bay of Lake Memphremagog. The bay was flooded by Glacial Lake Memphremagog during ice sheet retreat and is underlain by fine-grained glacial lake sediments, fine-grained deltaic sediments deposited by the Black and Barton rivers, and Holocene wetland sediments.

Table of Contents

---

[1] Report describes Vermont Geological Survey Open File Map: VG2024-2. Research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number G23AC00462.
The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Executive Summary/Significant Findings

The surficial geology of the Newport 7.5-Minute Quadrangles was mapped during the summer/fall of 2023. Mapping during June was assisted by five University of Vermont students. Almost 3,000 separate field observations were recorded utilizing a digital app and LiDAR hillside imagery and contours as a base map. Considerable detail has been added to mapping conducted during the 1960's by Stewart (1956-1966a) at a scale of 1:62,500 and later incorporated into the Surficial Geologic Map of Vermont by (Stewart and MacClintock, 1970). A surficial geologic maps and four geologic cross-sections compliment this report (Wright, 2024b).

The Newport Quadrangles contain a variety of glacial landforms and sediments that formed as the Laurentide ice sheet flowed across northernVermont and then thinned and retreated from the area. Glacial striations are poorly preserved on the area's underlying bedrock. Observed striations are oriented either NW-SE, parallel to regional ice flow across New England or N-S, parallel to the Lake Memphremagog lake basin a topographically controlled ice flow direction that occurred when the ice sheet had thinned sufficiently to be topographically controlled.

Till mantles all of the upland areas. Most is dense lodgment till, but some may be till remobilized as debris flows sourced from the steep mountain hillsides and some too may be ablation till let down on the ground surface as the ice sheet thinned. Most of the till cover is thin, but many areas exist where the till is thick enough to completely mask the underlying bedrock topography. Most rocks occurring in the till are sourced locally from metamorphic and intrusive rocks underlying the nearby area.

During ice retreat rapid summer melting of ice and snow generated large volumes of water that flowed sub glacially to the ice sheet margin. One esker was mapped along the northeastern shore of Lake Memphremagog. This esker bends into the Johns River valley and likely continues northward into Québec. A second extensive esker system occupies the Stony Brook valley in the adjacent Newport Center Quadrangle. In the South Bay area water-supply well logs show sand/gravel deposits directly above the bedrock. These may also be part of an esker system. Several areas of hummocky sand, gravel, and diamict were mapped as ice-contact deposits. These sediments were likely deposited along the margin of the thinning ice sheet, possibly in areas where portions of the ice sheet became too thin to flow (dead ice terrains).

Extensive areas within the quadrangle are underlain by several different facies of glaciolacustrine sediment. These sediments accumulated in Glacial Lake Memphremagog, a large lake which flooded large portions of the Missisquoi, Black, Barton, and Clyde river valleys. The outlet of this lake was at the drainage divide at the head of the Black River, the Lake Eligo Outlet. The most common lake sediment in the quadrangle is fine-grained and was deposited in the quiet water parts of the lake. Interlayered fine sand and gravel occur in several areas and were deposited in a near shore environment adjacent to the surrounding mountain slopes or as subaqueous fans in ice-proximal setting near the mouth of an esker tunnel. Several deltas were mapped where streams flowed into Glacial Lake Memphremagog. The largest of these was deposited by the Clyde River and portions of the delta are preserved on both sides of the lake near the City of Newport. When the elevation of Glacial Lake Memphremagog dropped, lake water ponded south of the delta eroded a narrow channel through the delta, what is now the narrow channel separating South Bay from the main lake. Deltas deposited by both the Clyde River and the Revière Tomifobia buried the older channels of these rivers. An older Clyde River channel likely exists beneath Rt 105 and the valley currently occupied by the Johns River was the former path of the Revière Tomifobia to Lake Memphremagog.

On the geologic map the lake shoreline is drawn using an isostatic tilt of 1.2 m/km to N35W. This lake projection will be refined following further mapping in the region.

Stream erosion is the most significant process affecting the landscape since the glacial lake drained. While some eroded sediments are stored as alluvium along stream courses, the majority of these sediments have been deposited In Lake Memphremagog. Alluvial fans have also been active forming where the gradient of streams flowing off the steep mountainsides abruptly changed where they encountered valley bottoms. Relatively small alluvial fans are common in the area.

Landslides are common along many of the streams in the region, but no active landslides were observed. However, numerous historic landslides have been documented in the Clyde River valley, many of which have affected the surrounding roads or the hydroelectric facilities along the river.

Introduction

This report summarizes the results of mapping the surficial geology of the Newport 7.5-minute Quadrangle along Vermont's norther border with Québec during the 2023 field season (Fig. 1). During this same period of time the eastern half of the Newport Center Quadrangle was also mapped, but the results of that work will be reported separately following completion of the western half of the quadrangle during the 2024 field season (Fig. 1). The new Newport Surficial Geologic Map map significantly updates earlier mapping by (Stewart, 1956-1966a) and provides (1) a foundation for understanding the glacial history of the area, (2) a framework for understanding groundwater flow between recharge areas in the uplands and discharge to area rivers and Lake Memphremagog, and (3) a means of assessing potential potential geologic hazards, e.g. landslides. A detailed surficial geologic map and cross-sections accompany this report (Wright, 2024b).

Location and Geologic Setting

The location of the Newport Quadrangle is shown on the adjacent map of northeastern Vermont (Fig. 1). Most of the Newport Quadrangle lies within portions of the Black, Barton, and Clyde River drainage basins, all of which drain into Lake Memphremagog. The lake extends northward into Québec and drains via Rivière Magog and eventually into the St Lawrence River.

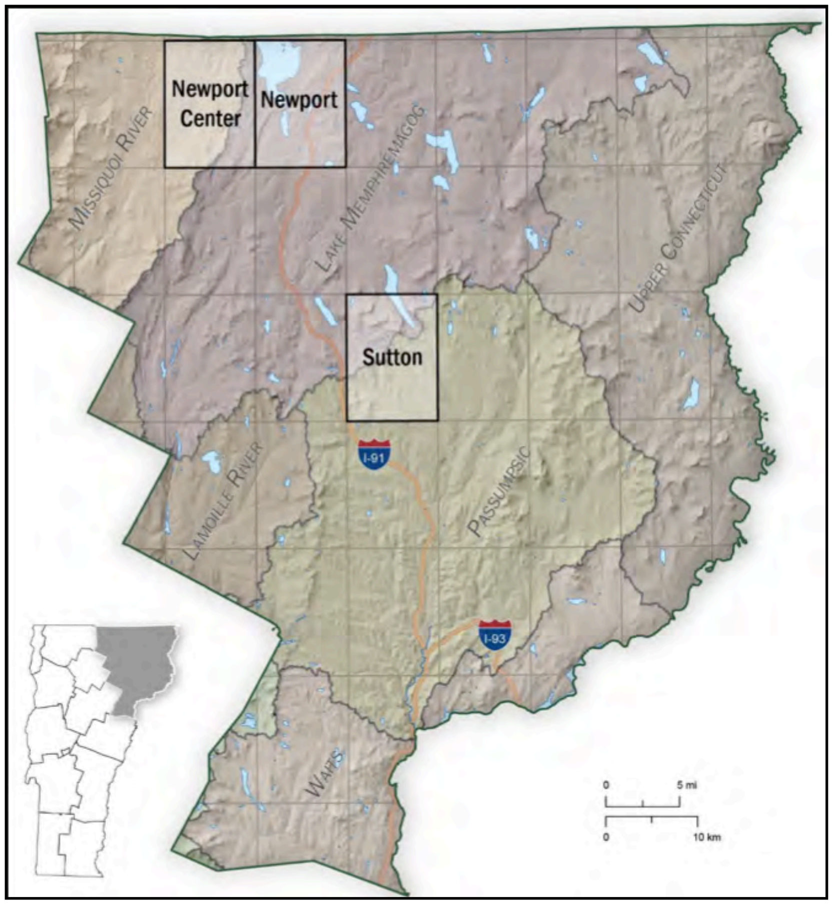

Figure 1: Map depicts the location of the Newport quadrangle (the focus of this report) and the large-scale drainage basins in northeastern Vermont. Also shown are the Newport Center and Sutton Quadrangles, where mapping is currently ongoing (from the 2023 RFP issued by the Vermont Geological Survey).

The bedrock geology of the Newport area is depicted on the Vermont Bedrock Geologic Map (Ratcliffe et al., 2011; Fig. 2). Rocks underlying this area fall broadly into three groups. The first group, present only along the western edge of the quadrangle, consists of metasedimentary rocks (schist and phyllite) originally deposited as sediments in the Iapetus ocean prior to late middle Ordovician time (Fig. 2). They were subsequently metamorphosed and deformed during the Taconic Orogeny. A second group of rocks consists of lower grade metasedimentary rocks deposited after the Taconic Orogeny (Silurian and Devonian time periods) and deformed and metamorphosed during the Acadian Orogeny, an orogeny that also affected the older group of rocks (Fig. 2). Numerous plutonic igneous rocks, generally of granodioritic composition, comprise the third group of rocks and were intruded during the Acadian Orogeny (Fig. 2). Rock units in this area are typically bounded by north-south striking thrust faults and lesser normal faults occurring on a wide range of scales that generally mimic the north-south trend of the mountain belt (Ratcliffe et al., 2011). Ongoing mapping of the bedrock geology of the quadrangle will likely revise the contacts shown in Figure 2 and may reveal one or more generations of younger faulting.

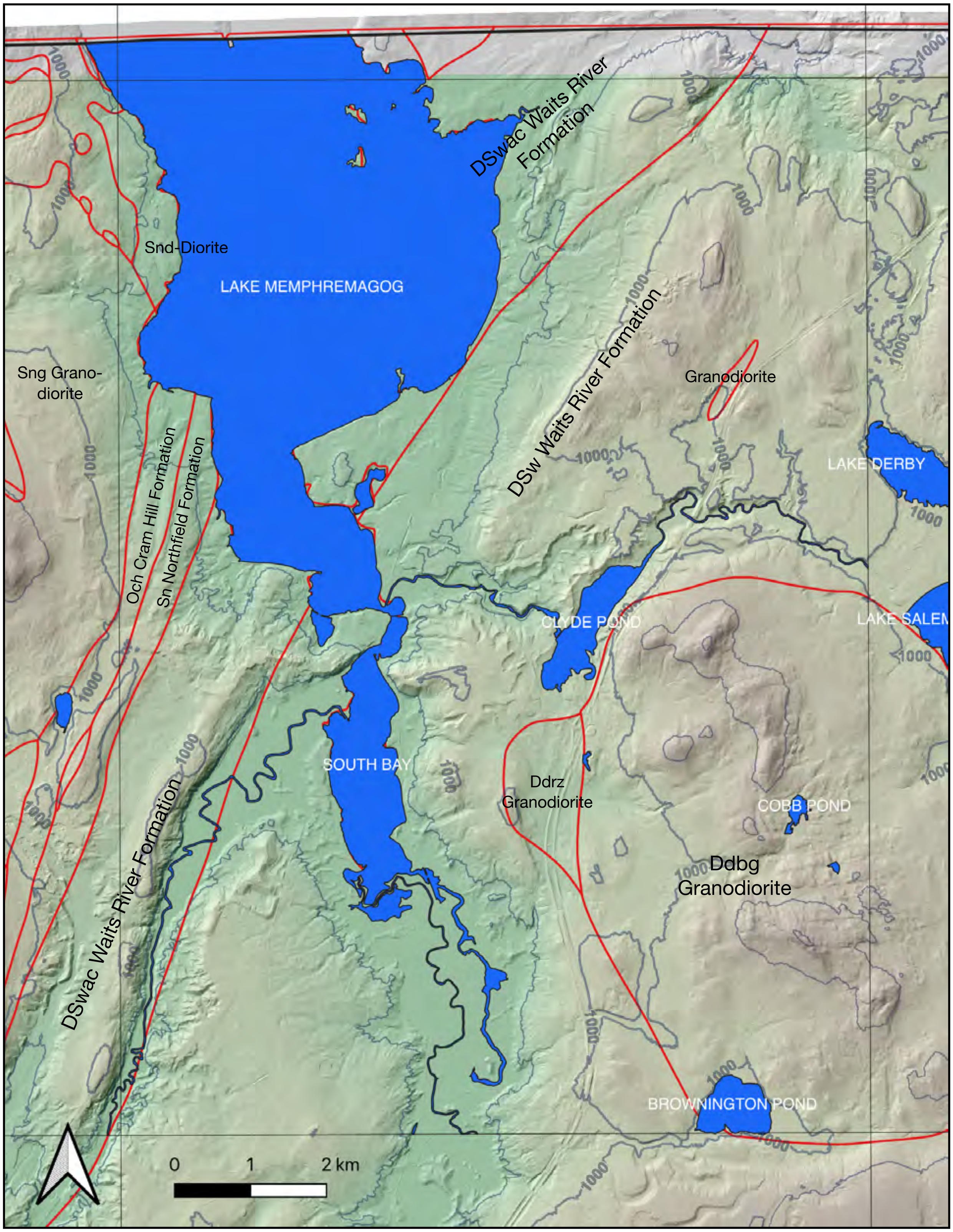

Figure 2: Bedrock geologic map of the Newport Quadrangle is dominated by generally NNE-SSW striking lower Paleozoic metasedimentary rocks intruded by both large and small Silurian/Devonian plutonic rocks. Geologic contacts and unit acronyms are from Ratcliffe et al. (2011).

The surficial geologic materials occurring in this region were predominantly deposited during the most recent (Wisconsinan) glaciation in glacial or periglacial environments existing during or shortly after the Laurentide ice sheet retreated across this area ~14,200–13,500 years ago (Corbett et al., 2019; Ridge et al., 2012). The ice sheet in northern New England was sufficiently thick to completely cover the region's mountains. An interpretation of the glacial history of this area based on mapping in the Newport Quadrangle follows in a later section of this report.

Prior Work

The Newport 7.5-minute Quadrangle lies in the northwest quadrant of the Memphrema-gog, Vermont 15-minute quadrangle, the surficial geology of which was mapped by Stewart (1956-1966b; Fig. 3). Mapping was conducted at a scale of 1:62,500 on quadrangle maps published during the 1950's with topography from the 1920's. This geology depicted on this map was incorporated into the Surficial Geologic Map of Vermont (Stewart and MacClintock, 1970).

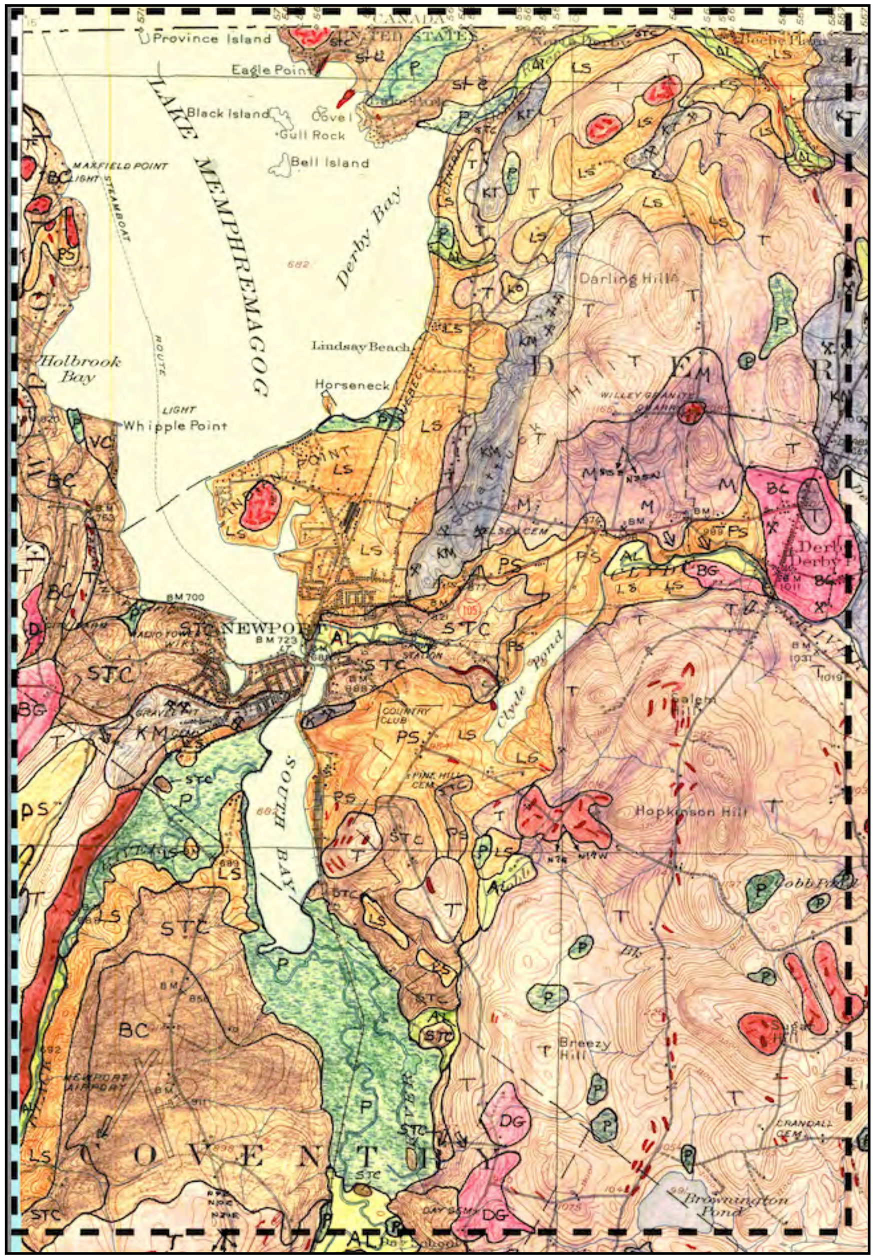

Figure 3: Black dashed line outlines the northwest quadrant of the Memphremagog 15-minute surficial geologic map showing map units outlined by Stewart (1956-1966).

Stewart's map (Fig. 3) shows extensive deposits of ice-contact and glacial lake sediments occurring in the valleys and upland areas largely underlain by till. Hodges and Butterfield (1967) utilized these surficial geologic maps to create a derivative map indicating those areas underlain by ice-contact sediments as areas within the Lake Memphremagog basin with extensive groundwater resource potential. The mapping described in this report largely confirms the large-scale distribution of surficial materials mapped by Stewart.

Earlier geological work in the area recognized that the drainage basin of the modern Lake Memphremagog once hosted a much larger glacial lake, Glacial Lake Memphrema-gog (Hitchcock, 1908). Building on work by Canadian geologists in the Memphremagog Basin (e.g. Parent and Occhietti, 1999), Wright (2006) worked out the ice flow history across the area as well as the history of early, high-elevation glacial lakes that occupied the Missisquoi and Black River valleys during ice sheet retreat.

Methods

Traditional field techniques and digital mapping were employed to generate a surficial geologic map of the Newport Quadrangle. Specifically, ~3,000 separate field observations recording the locations of different surficial materials, landforms, bedrock outcrops, glacial striations, kettles, landslides, and other geologic phenomena pertinent to this study were recorded using the Fulcrum App, a mobile mapping application. Most field observations are located with an accuracy of 3–10 m. Field mapping utilized LiDAR hillshade imagery with LiDAR-derived contours as a base map supplemented by traditional topographic maps and satellite imagery. Field observations were imported into GIS software (QGIS) and utilized to draw contacts between different surficial mapping units. Mapping units are consistent with those used on recently completed surficial geology maps within the Montpelier 1-degree sheet (e.g. Springston, 2019; Wright, 2020; Fig. 1) and conform to the unified set of mapping units developed by the Vermont Geological Survey.

Geologic cross-sections were constructed and are included both on the geologic map and in this report (Wright, 2024b). Surface observations were augmented by private water well logs and monitoring well logs around the Coventry Landfill to interpret the subsurface surficial geology in the area.

Five University of Vermont students assisted with the field mapping effort during the month of June, 2023. The author gratefully acknowledges the work of Jared Berlin, Sulemaan Bokhari, Bren Cable, Bryce Doherty, and Mackenzie Patterson. Assistance was also provided by Vermont Geological Survey geologist Peter Strand during several field days during the Fall of 2023.

Newport Surficial Geologic Map

The surficial geologic maps that accompanies this report shows the aerial distribution of different types of surficial materials, landforms constructed of these materials, glacial striations, landslides, and other geological phenomena (Wright, 2024b). During the spring of 2018 the Vermont Geological Survey developed a uniform set of mapping units which are utilized on the Newport Surficial Geologic Maps (Springston et al., 2018). The boundaries between these different materials are geologic contacts and are shown in most places as solid lines on the geologic map. It's important to realize, however, that these contacts are non-planar 2-D surfaces that extend out-of-sight below Earth's surface and their extension above Earth's surface has eroded away. In some areas geologic contacts could be closely located in the field. However, in most areas the location of these contacts is interpreted from a combination of field observations, distinctive landforms, and aerial imagery. Every effort was made to locate these contacts as accurately as possible on the geologic map.

Stratigraphic Framework/Surficial Geologic Mapping Units

The different surficial materials and landforms mapped within the quadrangle are described below, in stratigraphic order, from oldest to youngest. These generally follow the mapping units used on recently published maps by the principal author (e.g. Wright, 2022a, b; Wright et al., 2023). These materials and landforms fall into three groups: (1) Glacial Deposits are the surficial materials that were initially deposited by or immediately adjacent to the Laurentide ice sheet as it flowed across and then subsequently gradually thinned and retreated across the area. (2) Lacustrine Deposits were deposited in ice-dammed glacial lakes that occupied the region's valleys during ice sheet retreat. (3) A third group of surficial materials largely consists of older glacial or lacustrine surficial materials that have been eroded and redeposited by processes occurring during the Holocene, the time span extending roughly from ice sheet retreat to the present.

Bedrock Outcrops/Glacial Striations

While surficial materials and landforms are the focus of this project, bedrock outcrops were also mapped when they were encountered during field traverses . Additionally, most outcrops occurring along town roads and state highways were mapped. However, no attempt was made to map all outcrops, especially those occurring in the upland areas where outcrops are numerous and closely spaced. Similarly, outcrops occurring along Interstate-91 were not visited with the understanding that these will be closely surveyed during the 2024 field season as the bedrock geology geology of the Newport Quadrangle is mapping by the Vermont Geological Survey. Outcrops are abundant where glacial till and other surficial materials are thin, generally in the upland areas. Streams in the area have also frequently eroded down to bedrock (Fig. 4).

Figure 4: (A) Outcrop of steeply-dipping, generally N-S striking Silurian/Devonian Waits River Formation exposed along the Clyde River immediately below the Clyde Pond dam. Differential erosion of this metamorphosed turbidite leaves the metasandstone layers high-standing relative to the more easily eroded, now mica-rich metapelite layers. View looks south. **(B)** Detailed outcrop of the Waits River Formation along Route 5 between Newport and Derby shows nicely graded bedding indicating tops to the left. View looks north.

Much of the field area is underlain by the Waits River Formation which weathers very quickly and rarely preserves glacial striations (Fig. 4). Similarly, the plutonic rocks also weather relatively quickly and rarely preserve striations. Across the area only three glacially striated outcrops were observed. Several additional striations recorded by Stewart (1956-1966a) were digitized from his field maps and several additional striations recorded by the Vermont Geological Survey on interstate outcrops are also included.

Striations within and adjacent to the Newport Quadrangle are largely aligned either NW-SE or N-S. These orientations mimic those across much of northern Vermont where the NW-SE striations formed during regional ice flow when the ice sheet was thick enough to flow obliquely across the mountains and the N-S set developed later when the ice sheet had thinned sufficiently to flow parallel to the elongate North-South basin occupied by Lake Memphremagog (Wright, 2015).

Glacial Deposits

Glacial Till (Pt)

Glacial till directly overlies the bedrock in most areas. Within the quadrangle, till is the ubiquitous surficial material on the ground surface in areas above the valley bottoms. The freshest exposures are produced by stream erosion and in landslides where the till is medium to dark gray and very dense (Fig. 5). Till in the area consists of angular to subrounded pebbles, cobbles, and boulders, many with striated surfaces) suspended in a fine clay/silt/sand matrix. In most areas the materials occurring in till consist of materials eroded, deformed, and deposited beneath the ice sheet: lodgment till . Frost heaving, plant roots, and animal borrows have loosened the till near the surface. Large glacially-transported boulders, some of which are far-traveled erratics, are common and were mapped where encountered. The thickness of till in the upland areas of the quadrangle varies considerably. In many areas, the till is thin (less than 2 to 3 meters) and abundant outcrops are present. However, in other areas the till is sufficiently thick to completely bury the underlying bedrock.

Figure 5: Glacial till exposed in erosional gully between Newport and Derby. Fissility in the till may result from shear stresses applied during movement of the overlying ice sheet.

Moraines (Ptm)

Two small ridges of glacial till were mapped along the southeastern boundary of the quadrangle. These are mapped as moraines and may represent two successive recessional moraines deposited along the ice sheet margin as the ice sheet was thinning across the region.

Ice-Contact (Glaciofluvial) Deposits: Eskers (Pie), Undifferentiated Deposits (Pi), and Outwash (Po)

Meltwater streams flowing in tunnels beneath the thinning and retreating ice sheet deposited sand and gravel in distinctive ridges referred to as eskers (Pie). In the northern part of the quadrangle an esker extends ~NNE-SSW, crossing the Johns River valley and continuing across the border into Québec (Fig. 6). Several glacial kettles occur in the ice-contact sediments adjacent to the esker, some of which host wetlands (Fig. 6).

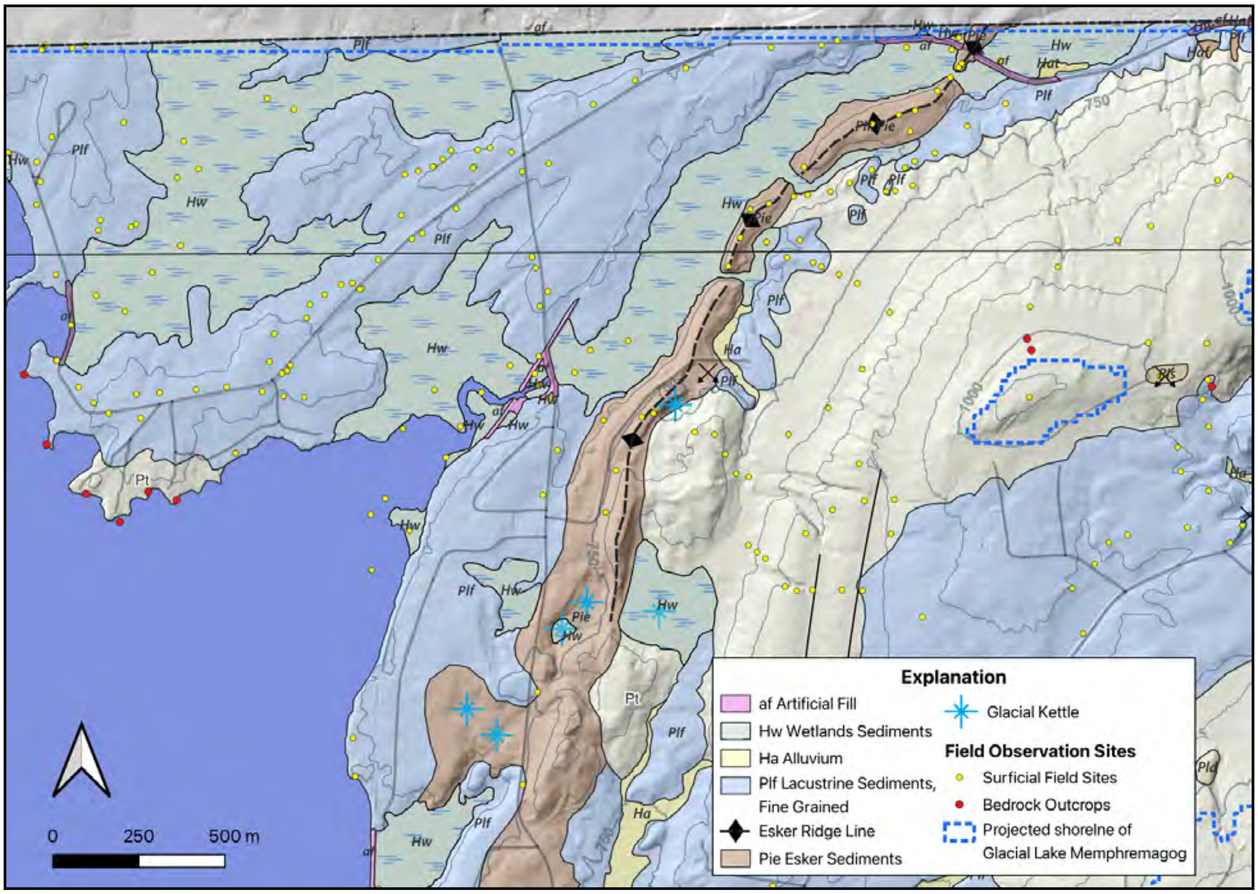

Figure 6: Clipped portion of the Newport Surficial Geologic map showing an esker extending approximately NNE-SSW across the middle of the map and likely continuing into Québec. Numerous kettles lie adjacent to the esker. Esker is bordered by till (Pt) mantling the steeper slopes to the east and extensive areas of fine-grained glacial lake and wetlands sediments along the northern border of the map, part of the Missisquoi National Wildlife Refuge.

Several areas of hummocky sand/gravel, and till lie along the flanks of Darling Hill and are most likely a product of processes occurring along the margin of the retreating ice sheet and are mapped as Undifferentiated Ice-Contact deposits (Pi, Fig. 7). These processes likely include sediments deposited by ice-marginal streams, slumping of ablation till accumulating on the ice sheet surface, accumulations of sand and gravel deposited in subaqueous fans within small ponds close to the margin of the ice sheet, and collapse of sediments deposited on the ice sheet following melting of the underlying ice. Another large area of undifferentiated ice-contact deposits was mapped immediately east of Derby Village (Fig. 8). Along the eastern quadrangle border these deposits have been modified by glacial streamflow.

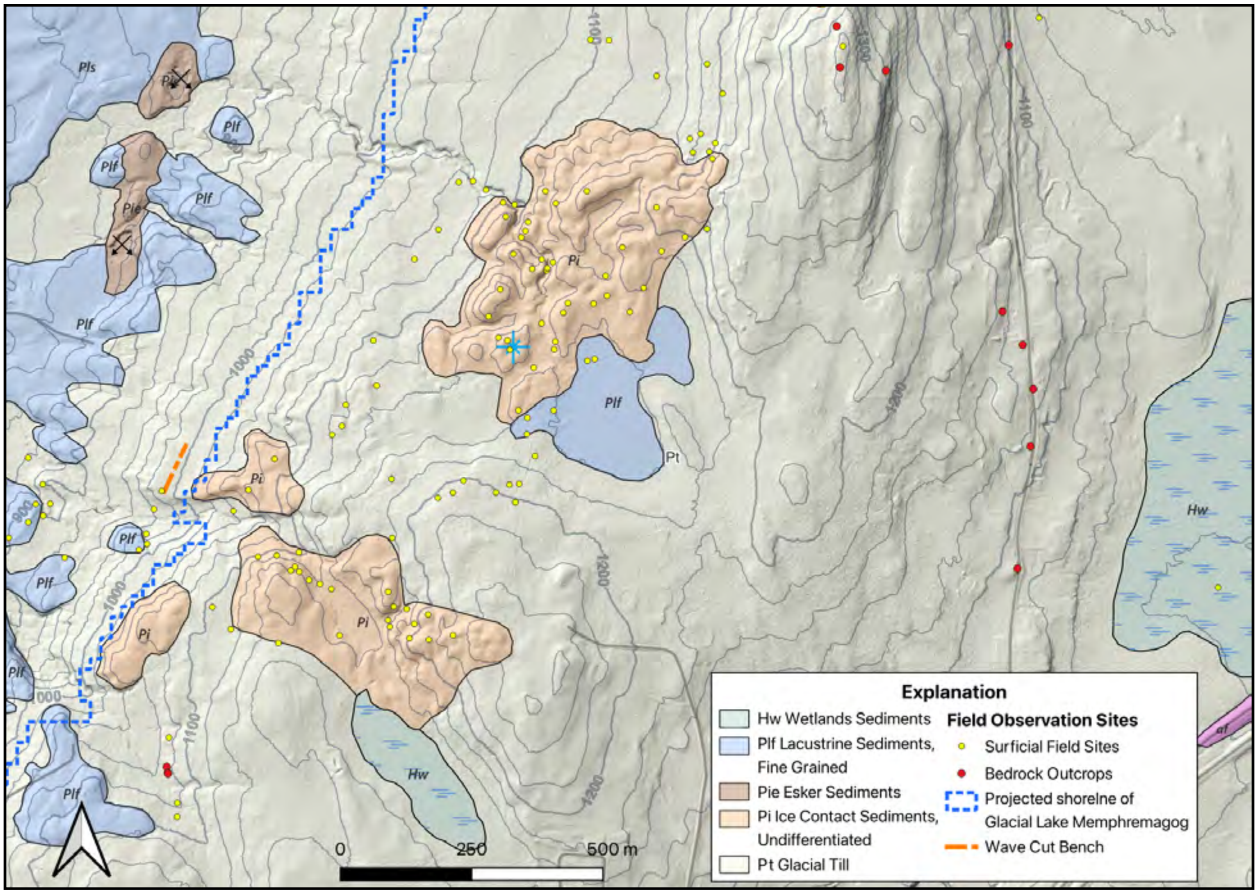

Figure 7: Map of Darling Hill showing areas of hummocky sand, gravel, and till, inferred to be undifferentiated ice-contact deposits (Pi). Sediments were likely deposited along the margin of the ice sheet by a variety of processes that included stream flow, slumping, and collapse associated with melting of buried glacial ice. This landform association is quite distinct from the adjacent till-covered land surface where the underlying N-S trending bedrock is readily visible.

Glacial Outwash (Po) was mapped in one area along the quadrangle's eastern boundary (Figs. 8, 9). This area is a small section of a broad alluvium-filled valley that extends north to Derby Line (West Charleston quadrangle). Numerous abandoned stream channels and extensive boulder-cobble gravel deposits around the perimeter of Lake Derby indicate these sediments were likely deposited by a high-discharge stream fed by glacial meltwater (Fig. 8). Both Derby Pond and Salem Pond are likely glacial kettles and were filled with dead ice during this period of glacial stream flow (Fig. 8).

Figure 8: Rounded cobbles and small boulders are exposed along the perimeter of Derby Pond and are interpreted to be part of a larger deposit of glacial outwash (Fig. 9).

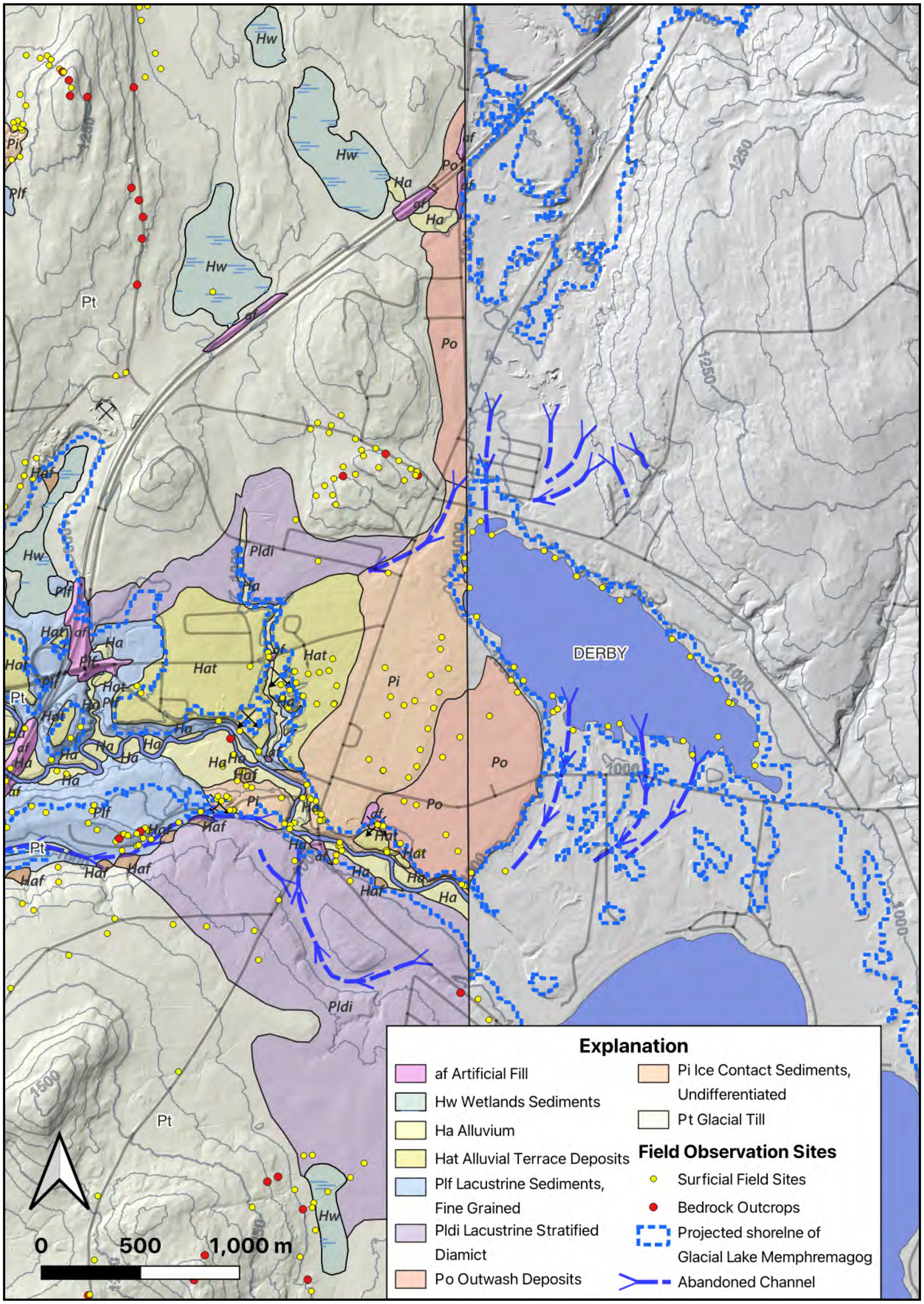

Figure 9: Portion of the Clyde River valley straddling the boundary between the Newport (west) and West Charleston (east) quadrangles centered on Derby Village. Undifferentiated ice-contact deposits (Pi) underlying the high ground above the village have been eroded by glacial streams leaving multiple channels and outwash deposits (Po). Derby and Salem Ponds may have been filled with dead ice during this period of time. Mixed diamict and lacustrine sediments on the valley sides are interpreted as stratified diamict deposited in both Glacial Lake Memphremagog and a higher-elevation glacial lake in the Clyde River valley.

Glacialacustrine Deposits

Areas below the elevation of Glacial Lake Memphremagog often preserve a variety of glaciolacustrine sediments. The most common of these consist of fine to very fine sand, silt, and clay deposited in the quiet-water parts of this lake. Current mapping has revealed broad areas underlain by these fine-grained sediments (Plf). See, for example, the map in Fig. 6. In the Clyde River valley along the Quadrangle's eastern border fine-grained glacial lake sediments were mapped at higher elevations and thick sections of "clay" are recorded in well logs from this area. Typically, these lacustrine sediments directly overlie glacial till (Fig. 10). A higher-elevation lake occupied this part of the Clyde River valley and these fine-grained sediments were likely deposited in that lake. Several abandoned channels have been mapped that mark outflow from higher-elevation to lower-elevation lakes, e.g. see channels mapped in the SW portion of the Figure 8 map. A discussion of the evolution of glacial lakes in the region occurs elsewhere in this report.

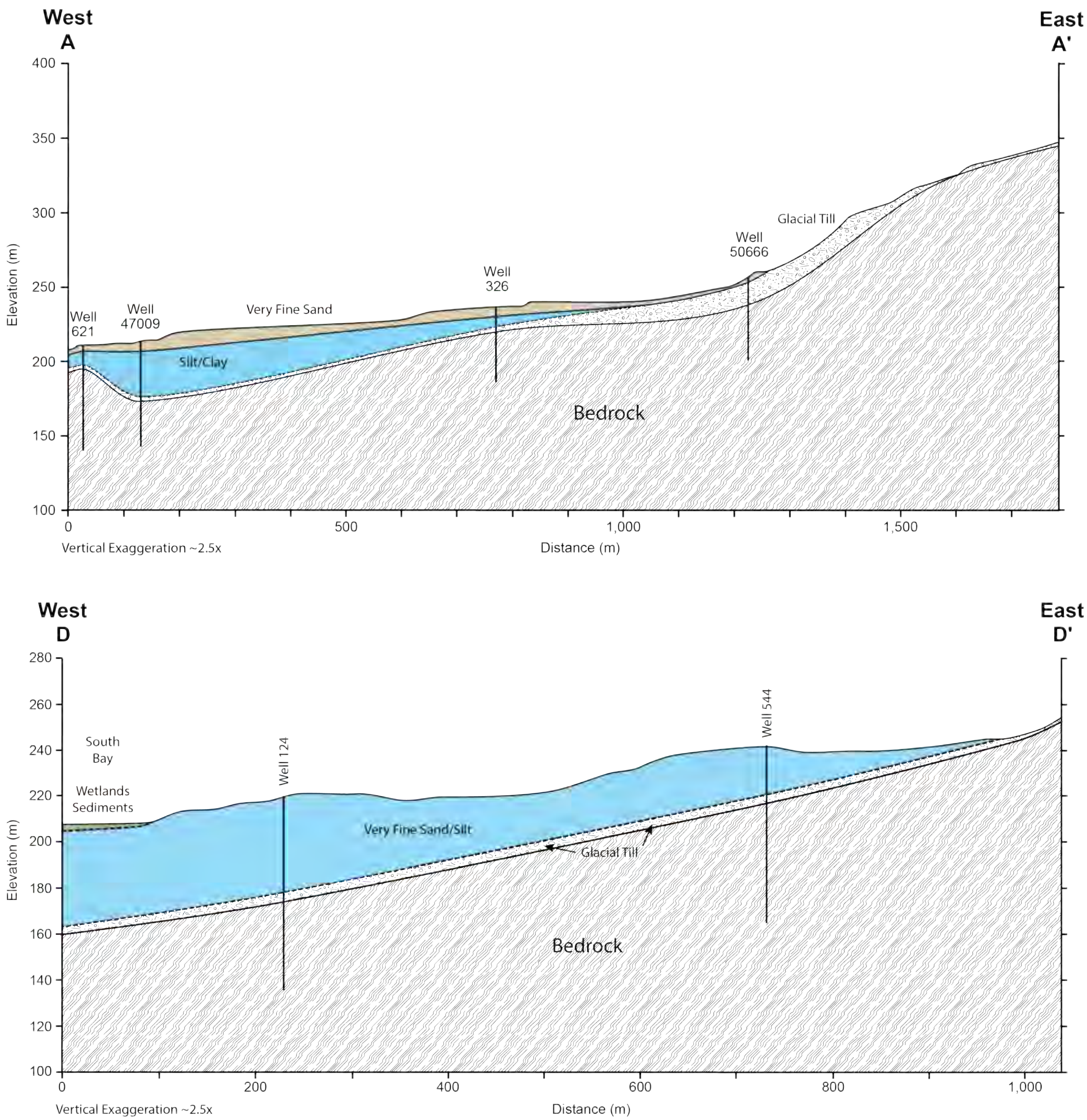

Figure 10: Cross-sections A-A' and D-D' both depict variable thicknesses of fine-grained glacial lake sediments directly overlying till, a common depositional setting for these sediments in the Newport Quadrangle. See geologic map for locations of sections.

Along the steep slopes of the Clyde River valley lacustrine sediments and diamict frequently occur in close proximity. These areas are interpreted to be interlayered lacustrine sediments and landslide deposits of till from the surrounding hillsides comprising a mapping unit designated Lacustrine Stratified Diamict (Pldi; Fig. 8).

In addition to the extensive deposits of fine-grained lacustrine sediments (Plf) in the quadrangle, two other closely related glaciolacustrine facies were mapped: Subaqueous Outwash (Plo) and Lacustrine Shoreline Deposits (Pls). Both consist of interlayered fine to very fine sand and coarser sediments, e.g. coarse sand to pebble gravel. Subaqueous Outwash was mapped where those sediments were deposited near to or blanketing an esker and the sediments inferred to be sourced from the esker tunnel (Fig. 11). Lacustrine Shoreline Deposits were mapped where those sediments occur adjacent to the glacial lake shore and no esker was present. The inference here is that the principal source of the sediments, particularly the coarser fraction, is from the adjacent hill slopes.

Figure 11: Cross-bedded sand and pebble gravel layers exposed in a gravel pit along Stony Brook. These sediments were deposited as part of an extensive subaqueous fan system in Glacial Lake Memphregog that originated from the mouth of a subglacial tunnel that also hosted an esker. Vermont Geological Survey geologist Peter Strand for scale.

In several of the tributary valleys deposits of sand and gravel have been mapped at or close to the projected elevation of Glacial Lake Memphremagog. These deposits likely formed as deltas (Pld). One example of a delta is exposed in a large, active gravel pit in a on the east side of South Bay (directly opposite Newport City; Figs. 12-14). Large-scale, southwest-dipping foreset beds indicate deposition of these sediments by the Clyde River as it flowed into Glacial Lake Memphremagog (Fig. 12). A coarsening-up section of very fine sand to Interlayered gravel and medium/fine sand underlies the city of Newport and this sequence of sediments is also interpreted as part of the same Clyde River delta as there's no other source of sediment in the area adjacent to the city, i.e. no evidence of subglacial or supraglacial water flow (Figs. 13, 14). The implication is that this delta grew to extend across Glacial Lake Memphremagog effectively dividing the lake into two separate parts, albeit at the same elevation.

Figure 12: South-dipping foreset beds of sand and gravel exposed in a large gravel pit above the east shore of South Bay, directly across the lake from the City of Newport. Topset beds underlie a terrace at ~305 m (~1,000 ft), the projected elevation of Glacial Lake Memphremagog.

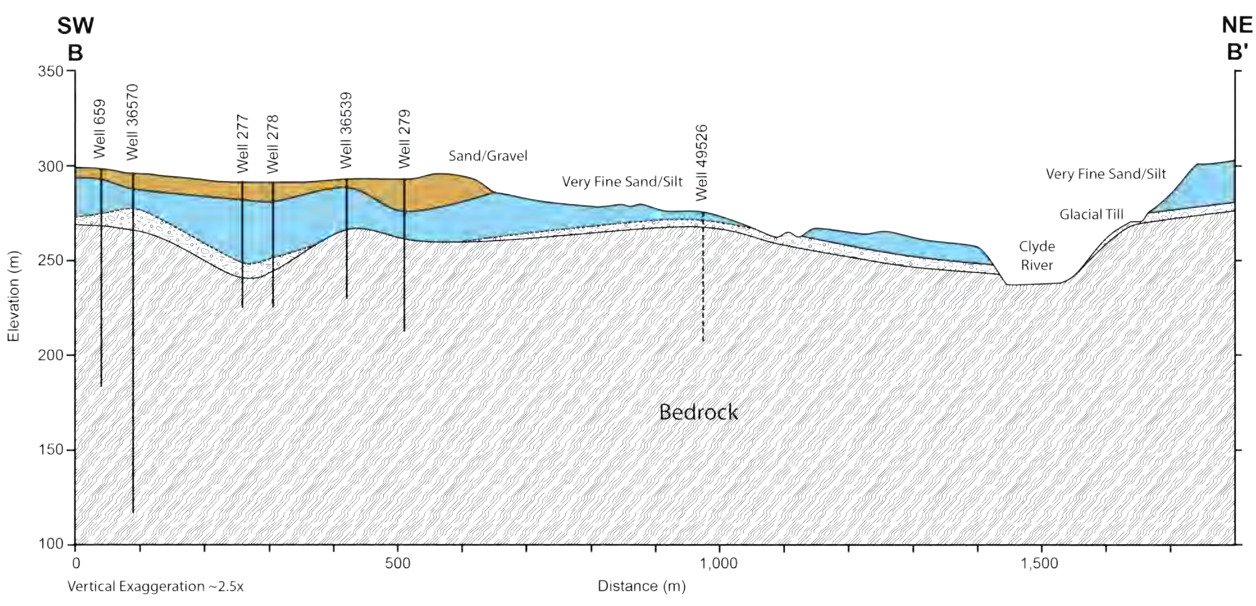

Figure 13: Cross-section B-B' depicts a coarsening upwards sequence of lake sediments deposited as the Clyde River delta grew across Glacial Lake Memphremagog. The Clyde River has eroded through a thick section of glacial lake sediments down to bedrock. See Figure 14 or geologic map for location of cross-section.

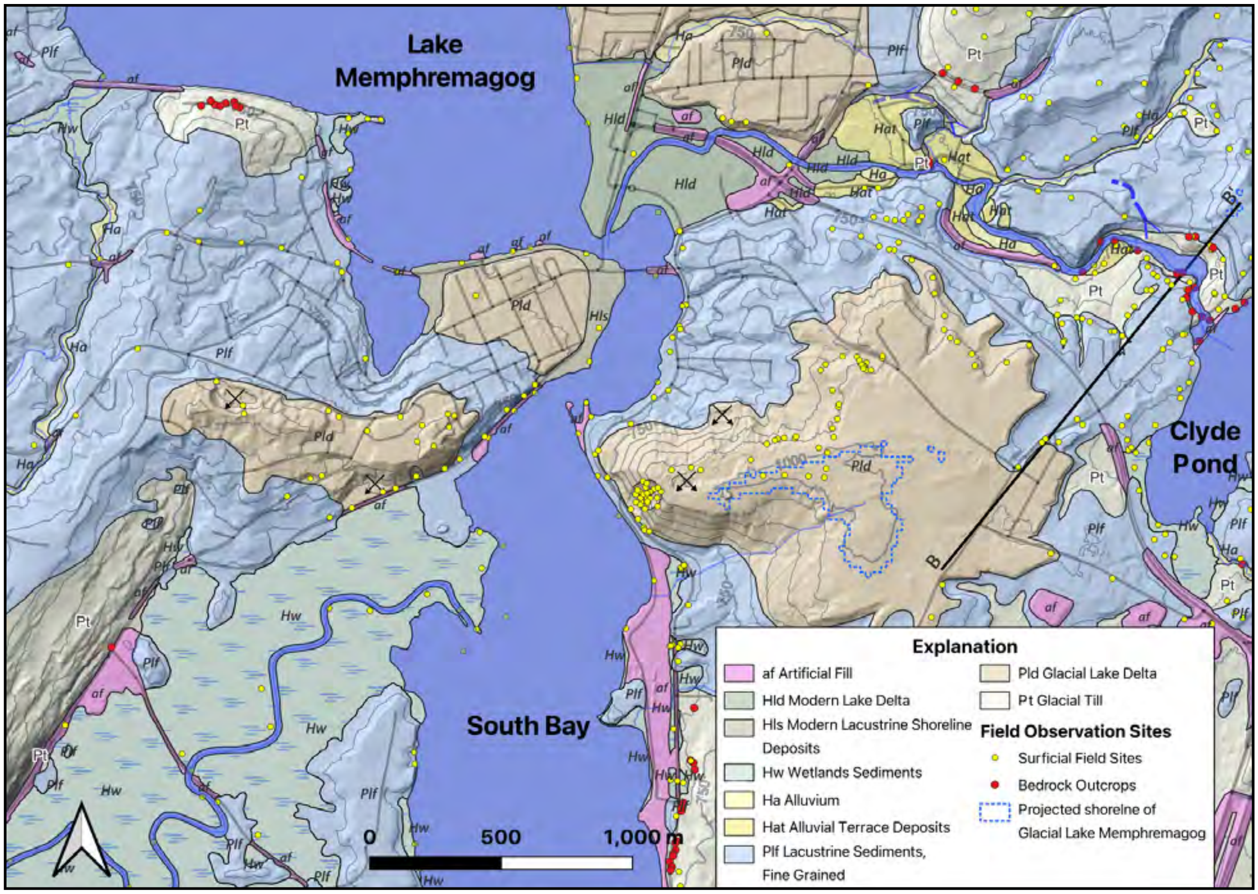

Figure 14: Coarse sand and gravel deposits on either side of Lake Memphremagog are interpreted to be parts of a delta (Pld) deposited by the Clyde River in Glacial Lake Memphremagog. The delta extended across the lake dividing the lake into two separate basins. Following a significant drop in lake level water ponded to the south of the delta eroded a narrow channel through the delta, the narrows that separates the main lake from South Bay. A lower-elevation delta underlies Newport City, both north and south of the bridge across the lake. A modern delta is being deposited by the Clyde River (Hld). The Black River, flowing into the lake from the SW, has also deposited a modern delta, but most of this area is dominated by wetlands sediments (Hw). Fine-grained glacial lake sediments (Plf) partially blanket the prominent SW-NE striking bedrock ridge along the western side of the map.

In the vicinity of the Coventry landfill a more complex stratigraphy occurs (Fig. 15). Numerous monitoring wells have been drilled in the vicinity of the landfill providing a large volume of subsurface data. However, closely spaced wells frequently record very different stratigraphies in the underlying surficial sediments. Cross-section C-C' is located where a new cell of the landfill is being constructed and is an attempt to interpret what has been recorded in the well logs. While much of the section is composed of medium, fine, and very fine sand, sediments clearly deposited in Glacial Lake Memphremagog, many of the borings also record variable thicknesses of till (diamict) within the lacustrine section. The cross-sections depicts these as till lenses as they don't appear to extend between wells. While the till lying directly on bedrock is likely a glacially deposited till, the lenses of diamict higher in the section may have originated from (1) till slumping off the surface of the adjacent grounded ice sheet into the adjacent lake (the lake was very shallow in this area) or (2) till deposited from melting ice bergs. When the ice sheet was retreating across this part of the lake basin, Glacial Lake Memphemagog was relatively narrow and may have been choked with ice bergs in a manner similar to many modern Greenland fjords. Debris entrained within the icebergs accumulates on their surfaces as they melt and periodically slumps off into the adjacent lake water.

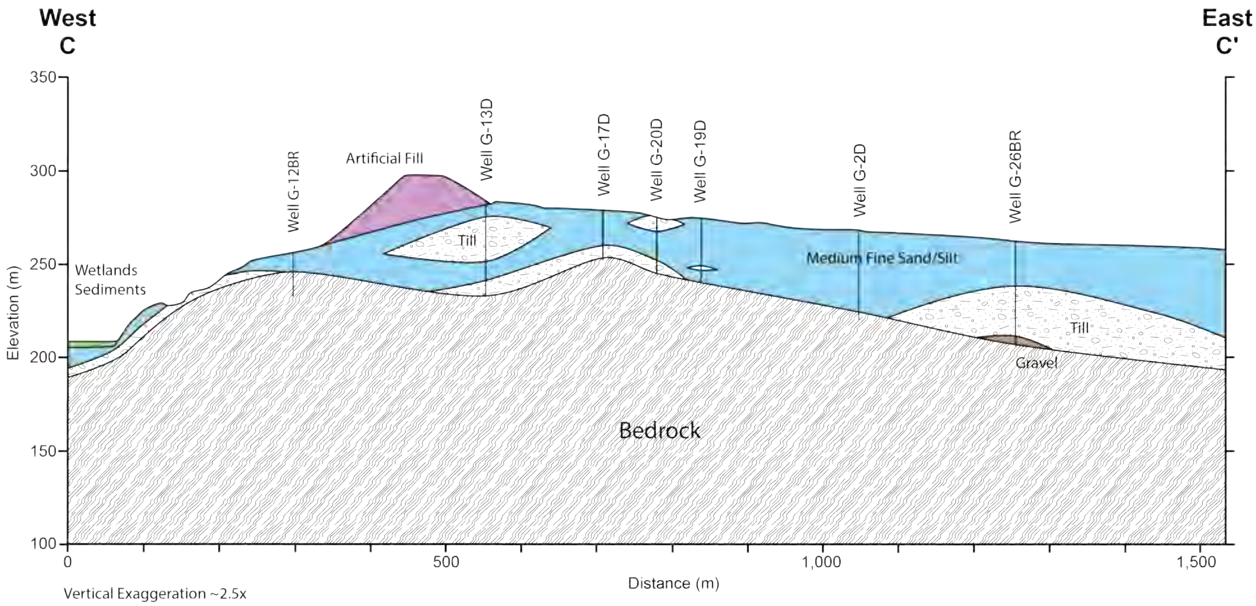

Figure 15: Geologic cross-section across part of the Coventry Landfill. Lacustrine and wetland sediments fill the Black River valley on the west side of the section. As recorded in monitoring well logs, the bedrock is overlain by a complex stratigraphy of both sand and diamict that lacks continuity between adjacent wells. Lenses of diamict may originate from the surface of the adjacent ice sheet or from ice bergs. See geologic map for section location.

Holocene Deposits

A variety of sediments have been mapped that were deposited in the Holocene Epoch. These largely consist eroded and redeposited Pleistocene sediments transported by both fluvial and hill slope processes.

Alluvium (Ha), Modern Delta (Hld), and Modern Shoreline (Hls) Deposits

Alluvium refers to sediments deposited by modern rivers and streams. These sediments include sand and gravel deposited in river channels and point bars as well as sand and silt deposited on floodplains. Organic materials are a frequent component of modern alluvium. These sediments were first deposited when streams began flowing across recently deglaciated valley sides and later when valleys occupied by glacial lakes drained. The thickness of alluvium corresponds to the depth of the modern stream channel. Most of the tributary streams in the area are relatively small and have deposited correspondingly limited areas of alluvium. However, the alluvium transported by the Clyde, Black, and Barton Rivers occurs on a much larger scale. The Barton and Black Rivers both flow into Lake Memphremagog in different parts of South Bay. In these areas stream-transported sediment inter fingers with and is generally overlain by extensive wetlands sediments. The Clyde River enters Lake Memphremagog farther north and this area is mapped as a modern delta (Pld), although fill may be elevating this area above lake level. Small deltas and associated wetlands deposits have also been mapped where smaller streams enter Lake Memphremagog.

Alluvial terrace deposits (Hat)

Alluvial terrace deposits are stream sediments (alluvium) occurring on terraces above but adjacent to modern streams. As streams erode channels more and more deeply through earlier-deposited sediments, older channels and adjacent flood plains are abandoned. Alluvial terraces are underlain by a veneer of sand and gravel corresponding in thickness to the depth of the stream channel that deposited the sediment. Most alluvial terrace deposits mapped within the quadrangle occur where streams have been eroding through glaciolacustrine sediments, e.g. along the sides of the Clyde River valley.

Hw Wetlands Deposits

Wetlands commonly occur in closed basins, adjacent to low-gradient streams, and areas dammed by beaver. They display varying amounts of open water depending on the season and the water table elevation. The dominant surficial material in wetland areas consists of both living and partially decayed organic materials but also includes inorganic fine-grained clastic sediment, “mud,” washed into these areas by streams and overland flow. In areas above Lake Memphremagog but below the elevation of Glacial Lake Memphremagog many wetland areas occupy broad, almost level basins. Field work indicates that the wetlands sediments in these areas are underlain by fine-grained glacial lake sediments. These low-permeability sediments and the basin settings keep water tables high facilitating the accumulation and preservation of organic remains.

Alluvial Fan Deposits (Haf)

Alluvial fans form where stream-transported sediment is deposited in a fan-shaped landform where the stream gradients abruptly lessen where they flow out of the mountains onto terraces or other gently-sloping landforms.The apex of these fans frequently consists of coarse, unsorted debris flow deposits. Farther down the fan slope fan sediments consist of lenses of sand/gravel that may fine to silt at the far edge of the fan. In most areas these fans have been deposited on older surficial deposits, frequently delta or alluvial terraces. Work on alluvial fans in northern Vermont suggests that fans have been episodically active throughout the Holocene and many received their most recent pulse of sediment following European land clearing in the late 18th and early 19th centuries (Bierman et al., 1997; Jennings et al., 2003). Related work by Noren et al. (2002) recording pulses of clastic sediment deposited in ponds and small lakes, indicates that pre-European settlement erosion has not been uniformly distributed throughout the Holocene and seems instead to be concentrated during periods of increased high-intensity storms. If future climate shifts produce a greater frequency of high-intensity storms, further sedimentation on the area’s alluvial fans seems likely.

af Artificial Fill

Artificial fill was mapped where significant volumes of material were utilized for the construction of state and federal highways, town roads and railroad grades, particularly beneath large portions of Interstate I-91. In most cases fill consists of sand and gravel. Additionally, the large accumulation of refuse in the Coventry Landfill is also mapped as fill (Figs. 15, 16).

Figure 16: The Coventry landfill is situated in an area where the underlying bedrock is mantled by a thick section of both till and fine-grained glacial lake sediments. Shallow borings and deep wells indicate that the wetlands vegetation and organic sediment along the Black River in South Bay (pictured above) is underlain by a thick section of fine-grained glaciolacustrine sediment, e.g. very fine sand, silt, and clay.

Glacial and Post-Glacial history of the Newport Quadrangles

The surficial geologic materials and landforms mapped in the Newport Quadrangles provide the basis for the following interpretation of the glacial and post-glacial history of this area. This local history is fit within our broader understanding of northern Vermont's glacial history based on earlier work. The surficial geologic materials occurring in the region were predominantly deposited during the most recent (Wisconsinan) glaciation in glacial or periglacial environments. The peak of this last glaciation occurred ~25,000 years ago when the ice sheet was thickest and at its farthest extent. During the ensuing ~12,000 years the ice sheet both thinned and retreated across New England deglaciating north-central Vermont between ~14,200–13,800 years ago (Corbett et al., 2019; Halsted et al., 2022; Ridge et al., 2012).

Ice Flow

During the time of complete ice cover, regional ice flow was generally from northwest to southeast obliquely across the north-south mountain ranges (Wright, 2015). When the ice thinned sufficiently to be topographically controlled, ice flow shifted to broadly north-south in the N-S valleys lying east of the Green Mountains (Wright, 2015). Glacial striations in the Newport area are oriented either NW-SE or N-S. While the relative age of these two sets could not be ascertained locally, it seems reasonable to conclude that regional SE directed ice flow was followed by ice flow to the south, parallel to the Lake Memphremagog Basin and the bedrock ridges that bound it.

Timing of Ice Retreat

The North American Varve Chronology has been utilized in the Connecticut River valley (along Vermont's eastern border) to show that the ice sheet was approaching the Québec border ~13.6 ky BP (Ridge et al., 2012). In the much larger Champlain valley to the west, the ice sheet retreated somewhat later reaching the Québec border ~13.4—13.2 ky BP (Ridge et al., 2012). Cosmogenic dating along an elevation profile on Mount Mansfield, ~60 km SSW of the field area, indicates that the ice sheet was thinning very rapidly ~13.9 ka, exposing 800 m of relief in less than 1,000 years (Corbett et al., 2019). Varve correlation work in the Glacial Lake Winooski Basin east of the Green Mountains also indicates rapid (~300 m/year) retreat of the ice sheet at this same time (Wright, 2022a).

Ice-Contact Environment

While the ice sheet was rapidly thinning and retreating, at least one subglacial drainage system developed within the Lake Memphremagog basin and is preserved as the esker mapped along the lake's eastern shore (Fig. 6). A second prominent esker has been mapped in the adjacent Newport Center Quadrangle within the Stony Brook (Route 14) valley. One or more other eskers may lie beneath the lake buried by younger glaciolacustrine sediments. Evidence of a buried Lake Memphremagog esker comes from several of the large Newport City water-supply wells drilled in South Bay. Those well logs record coarse-grained sediments sandwiched between the underlying bedrock and a thick sequence of overlying fine-grained glacial lake sediments, a classic confined aquifer.

Within the quadrangle ice-contact sediments accumulated along the margin of the ice sheet in restricted areas, e.g. along the western slopes of Darling Hill (Fig. 7) and in Derby Center. Sediment accumulation in these areas may be related to the local geography and glaciology of the ice sheet that allowed ice in these small areas to thin, stop flowing, and become disconnected from active ice in the valley. Fine-grained lake sediments and wetlands sediments (likely underlain by fine-grained lake sediments) distributed up-valley from these deposits suggest that the ice sheet in these areas, flowing or stagnant, dammed small, short-lived lakes (Fig. 7).

Evolution of Glacial Lake Memphremagog

East of the Green Mountains several major rivers flow into lake Memphremagog. Multiple glacial lakes evolved in the north-flowing Missisquoi, Black, Barton, and Clyde river valleys as the ice sheet retreated to the north of their respective drainage divides (Fig. 17; Wright, 2006, 2024a). These lakes progressively coalesced into a single large lake, Glacial Lake Memphremagog, as the ice sheet uncovered successively lower outlets. This lake utilized the lowest drainage divide as an outlet, the Lake Eligo Outlet at the head of the Black River valley (Fig. 18). Across the broad Lake Memphremagog basin drainage from higher-level to lower-level lakes is recorded by multiple abandoned channels, often occurring in flights that may record yearly ice thinning (Wright, 2024a).

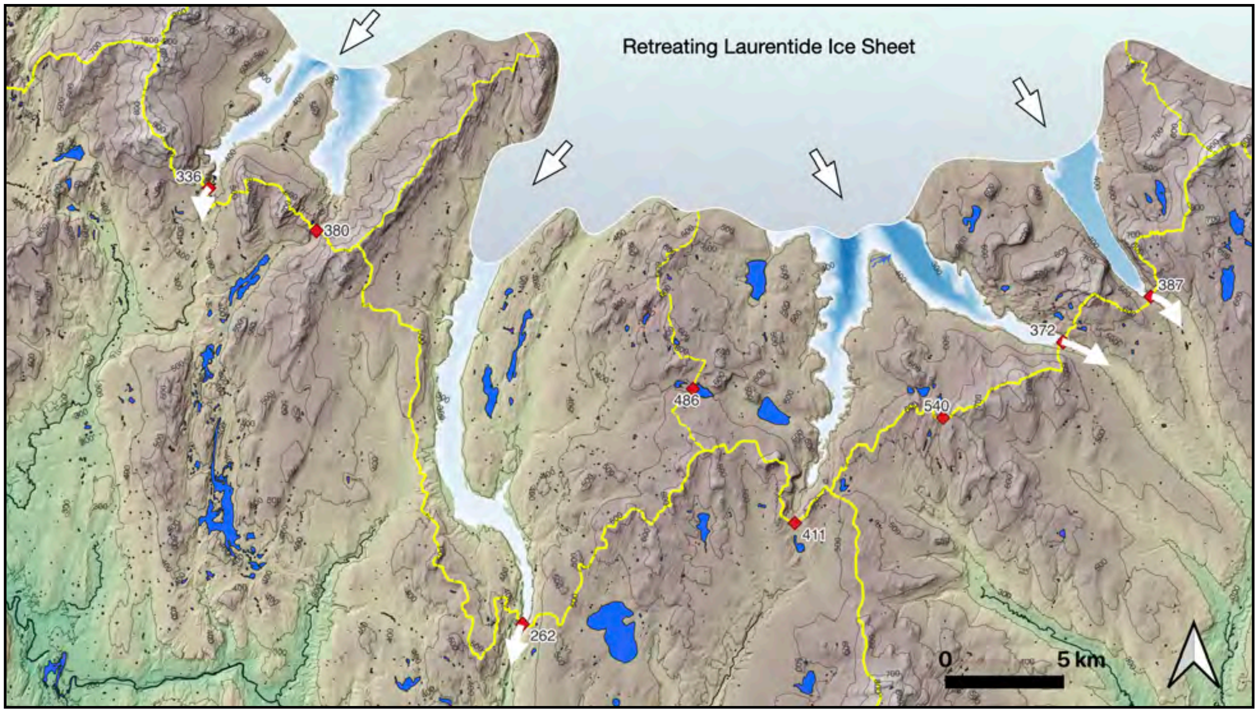

Figure 17: Map shows multiple glacial lakes forming in the (from west to east) Missisquoi, Black, Barton, and Clyde River valleys as the ice sheet retreated to the north. Red diamonds mark the drainage divides and their elevations (meters) on the isostatically tilted land surface. As the ice sheet retreated farther north, these lakes coalesced into a single lake, Glacial Lake Memphremagog that drained across the lowest drainage divide (Lake Eligo Outlet 262 m) at the head of the Black River valley.

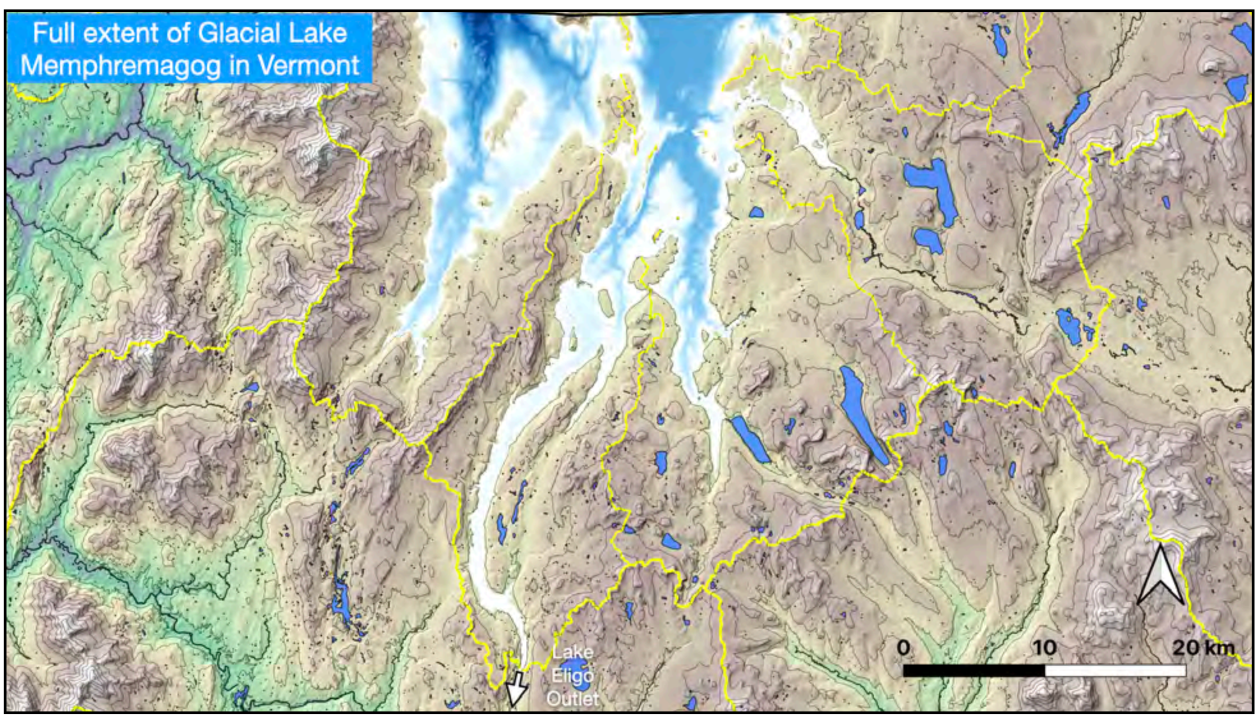

Figure 18: Full extent of Glacial Lake Memphremagog in Vermont. Most of the glaciolacustrine sediments occurring in the Newport Quadrangle were deposited in this glacial lake.

Glacial Lake Memphremagog grew to a considerable size as the ice sheet retreated into Québec (Fig. 19). The generally SW-NE orientation of the ice sheet margin is taken from multiple moraines mapped by Parent and Occietti (1999). The Lake Eligo outlet remained the stable long-term outlet for this lake and must have hosted a very large discharge from a large portion of the rapidly retreating ice sheet. In the Newport area, Glacial Lake Memphremagog remained at a stable elevation during this time.

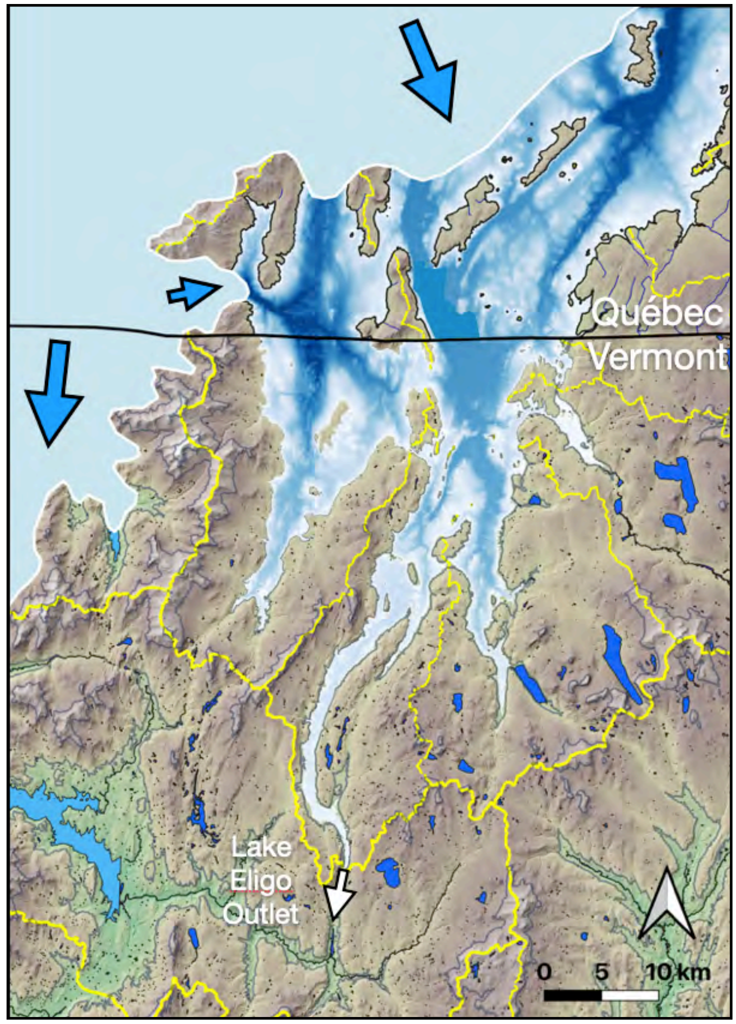

Figure 19: Extent of Glacial Lake Memphremagog in both Vermont and Québec. Ice sheet margins in Québec are from multiple moraines mapped by Parent and Occhietti (1999). Blue arrows show inferred ice sheet flow.

Continued retreat of the ice sheet to the northwest eventually uncovered a lower outlet, the Lac Nick outlet (Parent and Occhietti, 1999). The elevation of Glacial Lake Memphemagog fell ~85 m to form the Sherbrooke Phase (Stage) of the lake (Fig. 20). While the elevation of this lake was only ~14 m higher than the modern lake, its extent was considerable, particularly in Québec (Fig. 20; Parent and Occhietti, 1999).

As noted earlier, the Clyde River had deposited a large delta in the higher stage of the lake that extended across the lake basin (Fig. 21). When the Lac Nick outlet was uncovered and lake level fell, this delta ponded (dammed) water south of the delta (the area where South Bay is today). This ponded water eroded a channel through the delta, what is now the narrow channel connecting South Bay to the main lake (Fig. 21).

During this lower, Sherbrooke Phase of Glacial Lake Memphremagog, the Clyde River eroded a new channel through a thick section of previously deposited lacustrine sediment, both fine-grained quiet water and coarser-grained deltaic sediments. These eroded sediments were redeposited in a delta that is now a terrace of fine sand/gravel that much of Newport City is built on, both north and south of the narrow channel separating South Bay from the main lake (Low Stage Delta in Fig. 21).

Just beyond the northeastern corner of the Newport Quadrangle the Revière Tomifobia built a large delta during the high, stable phase of Glacial Lake Memphremagog (Fig. 22; Boissonnault and Gwyn, 1983). Derby Line and adjacent parts of Québec are built on this delta. This delta likely buried the former channel of the Revière Tomifobia which extended across the border and joined what is now the Johns River valley, a stream very underfit to its valley. Similar to the Clyde River, the Revière Tomifobia downcut through its high-level delta when the elevation of Glacial Lake Memphremagog dropped, turning abruptly north at Beebe Plains instead of following its former channel WSW into Lake Memphremagog.

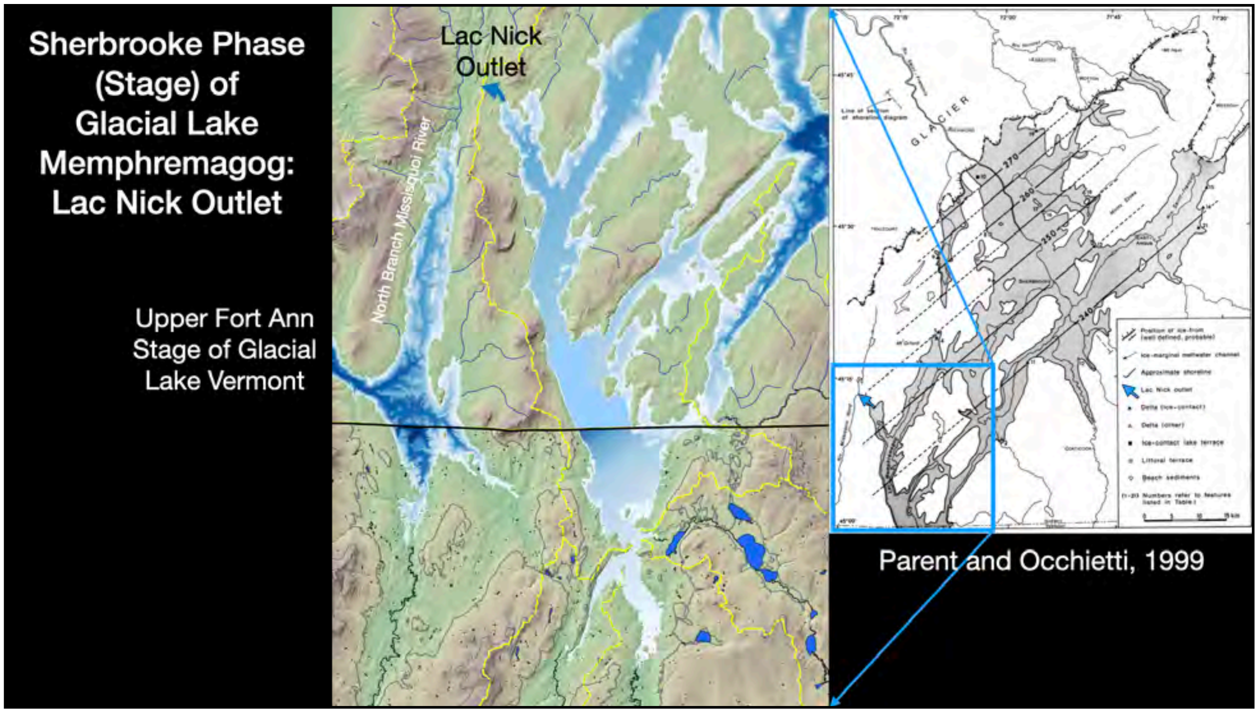

Figure 20: Sherbrooke Stage of Glacial Lake Memphremagog. Continued northwestward retreat of the ice sheet uncovered a lower outlet, the Lac Nick outlet. Lake level fell ~85 m and outlet waters now flowed into an arm of Glacial Lake Vermont (Fort Ann Stage) occupying the North Branch of the Missisquoi River valley.

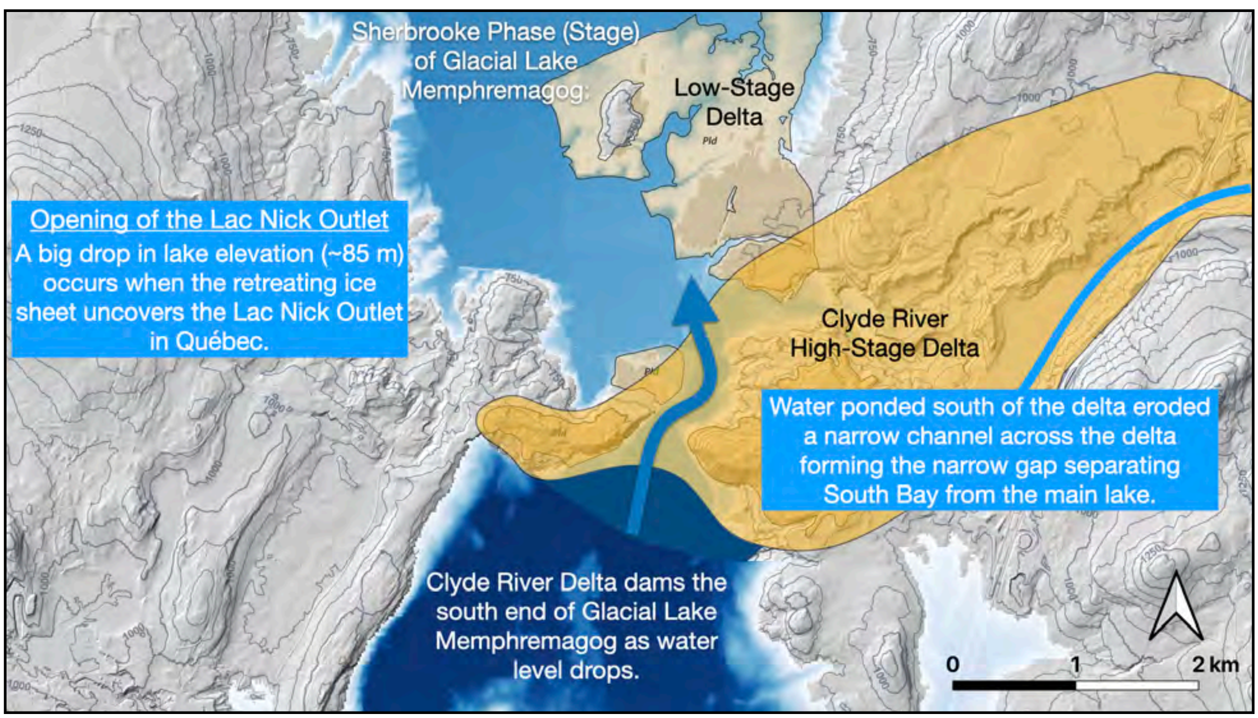

Figure 21: When the Lac Nick outlet was uncovered and lake level fell ~85 m, lake water ponded south of the Clyde River delta eroded a channel through the delta, what is now the narrow channel separating South Bay from the main lake. During the Lac Nick stage, the Clyde River deposited a delta at this low-stage lake. These delta sediments currently underlie significant portions of the city of Newport, both north and south of the isthmus separating South Bay from the main lake.

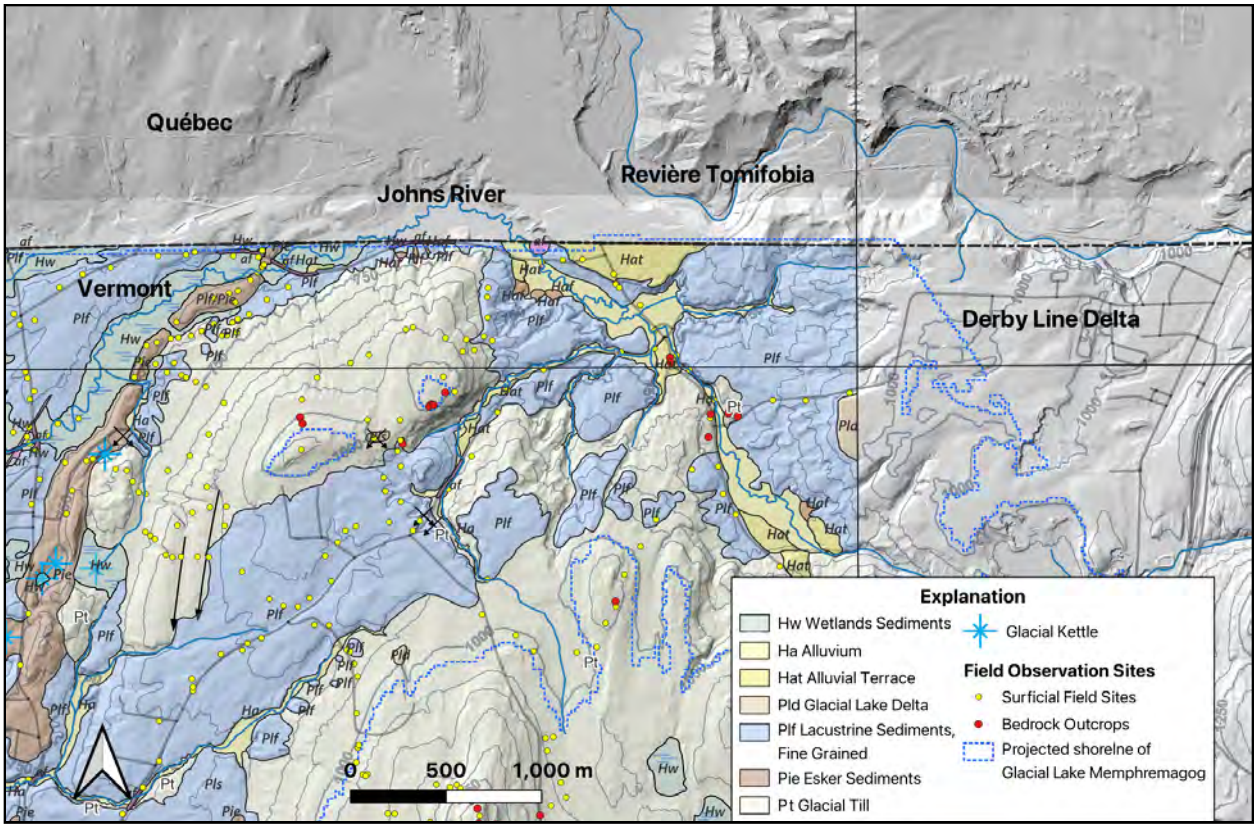

Figure 22: Map depicts the area surrounding the NE corner of the Newport Quadrangle. During the high, stable phase of Glacial Lake Memphremagog, the Revière Tomifobia deposited a large delta where Derby Line is located. This delta buried the former Revière Tomifobia channel which followed the course of the Johns River into Lake Memphremagog.

Holocene Processes

The Holocene Epoch is the geologic period of time that generally encompasses Earth's history since the retreat of the ice sheets. That time epoch formally extends from 11,700 years ago to the present, but locally it's convenient to group those processes that have occurred since the ice receded from a particular area and the last glacial lakes drained as being "post-glacial" a time interval that includes both the latest Pleistocene and the Holocene Epochs, roughly the last 13,000 years. During this time interval the landscape has changed considerably in response to an array of geologic processes augmented by changes in our climate and the populations of plants and animals living here.

A variety of weathering and erosional processes have affected Earth's surface following the retreat of the ice sheet and the final drainage of Glacial Lake Memphremagog. Stream erosion and associated slope failures are the most widespread and persistent erosional processes and vary in scale with the size of the stream. In the upland areas erosion has affected till covered slopes with numerous streams incising channels in the till. Streams in areas below the elevation of Glacial Lake Memphremagog have eroded large volumes of glacial lake sediment and redeposited these sediments in Lake Memphremagog. In many areas erosion has removed most of the lake sediment leaving just patches of uneroded lake sediment scattered on the hillsides. The Clyde River has dramatically incised its channel through a thick section of previously deposited glaciolacustrine sediments and even relatively small tributary streams have effectively eroded large volumes of fine-grained glacial lake sediment. While the Clyde River currently flows through Clyde Pond, it's very likely that older channels exist buried beneath the sediments immediately north of its present course, essentially beneath the pathway of Route 105 between the modern lake and the interstate. As noted earlier, the Revière Tomifobia is similarly following a post-glacial channel that's different from the one it followed pre glacially.

The Clyde River is currently depositing a delta in Lake Memphremagog, the area currently used as a city park. Smaller streams too are depositing deltas where they enter the lake.
In addition to deltas, streams have deposited sediments in alluvial fans. Most fans mapped within the quadrangle are relatively small

Landslides are common along streams where slopes are oversteepened by stream erosion. While several landslide scarps are shown on the map, no recent large-scale landslides were observed. However, several historic landslides have occurred in the Clyde River valley, particularly the steep reach of the river between Clyde Pond and Lake Memphremagog (Scott et al., 2001). Some of these landslides have affected the stability of VT Route 191.

References

Bierman, P. R., Lini, A., Davis, P. T., Southon, J., Baldwin, L., Church, A., and Zehfuss, P. H., 1997, Post-glacial ponds and alluvial fans: Recorders of Holocene landscape history: GSA Today, v. 7, p. 1-8.

Boissonnault, P., and Gwyn, Q. H. J., 1983, The evolution of proglacial Lake Memphremagog, Southern Québec: Géographie physique et Quaternaire, v. 37, p. 197-204.

Corbett, L. B., Bierman, P. R., Wright, S. F., Shakun, J. D., Davis, P. T., Goehring, B. M., Halsted, C. T., Koester, A. J., Caffee, M. W., and Zimmerman, S. R., 2019, Analysis of multiple cosmogenic nuclides constrains Laurentide Ice Sheet history and process on Mt. Mansfield, Vermont's highest peak: Quaternary Science Reviews, v. 205, p. 234-246.

Dunn, R. K., Springston, G. E., and Wright, S. F., 2011, Quaternary Geology of the Central Winsooski River Watershed with focus on Glacial Lake History of Tributary Valleys (Thatcher Brook and Mad River), *in* West, D. P., Jr., ed., New England Intercollegiate Geological Conference Guidebook, Volume 103, p. C3-1-C3-32.

Halsted, C. T., Bierman, P. R., Shakun, J. D., Davis, P. T., Corbett, L. B., Caffee, M. W., Hodgdon, T. S., and Licciardi, J. M., 2022, Rapid southeastern Laurentide Ice Sheet thinning during the last deglaciation revealed by elevation profiles of in situ cosmogenic 10Be: Geological Society of America Bulletin.

Hitchcock, C. H., 1908, Glacial Lake Memphremagog: Geol. Soc. America Bulletin, v. 18, p. 641-642.

Hodges, A. L., and Butterfield, D., 1967, Ground Water Favorability Map of the Lake Memphremagog Baisn, Vermont: Vermont Department of Water Resources in cooperation with the U.S. Geological Survey.

Jennings, K. L., Bierman, P. R., and Southon, J., 2003, Timing and style of deposition on humid-temperate fans, Vermont, United States: Geological Society of America Bulletin, v. 115, no. 2, p. 182-199.

Noren, A. J., Bierman, P. R., Steig, E. J., Lini, A., and Southon, J., 2002, Millennial-scale storminess variability in the northeastern United States during the Holocene epoch: Nature, v. 419, no. 6909, p. 821-824.

Parent, M., and Occhietti, S., 1999, Late Wisconsinan deglaciation and glacial lake development in the Appalachians of southeastern Québec: Géographie physique et Quaternaire, v. 53, no. 1, p. 117-135.

Ratcliffe, N. M., Walsh, G. J., Gale, M. H., Masonic, L. M., Estabrook, J. R., Geological Survey (U.S.), Vermont. Agency of Natural Resources., and Vermont Geological Survey., 2011, Bedrock geologic map of Vermont, scale 1:100,000.

Ridge, J. C., Balco, G., Bayless, R. L., Beck, C. C., Carter, L. B., Dean, J. L., Voytek, E. B., and Wei, J. H., 2012, The new North American Varve Chronology: A precise record of southeastern Laurentide Ice Sheet deglaciation and climate, 18.2-12.5 kyr BP, and correlations with Greenland ice core records: American Journal of Science, v. 312, no. 7, p. 685-722.

Scott, J., Bedard, J., and Van Gilder, G., 2001, Clyde River Landslide, Unpublished Geomorphology Report, The University of Vermont Department of Geology.

Springston, G. E., 2019, Surficial geology and hydrogeology of the Huntington 7.5-minute Quadrangle, Vermont: Vermont Geological Survey Open File Report VG2019-3, Report plus 1 map.

Springston, G. E., Gale, M. H., and Dowey, C., 2018, Vermont Surficial Geologic Mapping Standards, Vermont Geological Survey Unpublished Document.

Stewart, D. P., 1956-1966a, Surficial Geologic Map of the Memphremagog 15’ Quadrangle, Vermont, Vermont Geological Survey Open-File Map Manuscript Map.

-, 1956-1966b, Surficial Geologic Map of the Memphremagog 15’ Quadrangle, Vermont, Vermont Geological Survey Open-File Map.

Stewart, D. P., and MacClintock, P., 1970, Surficial Geologic Map of Vermont: Vermont Geological Survey, scale 1:250,000.

Wright, S. F., 2006, Ice flow directions, ice-contact environment, and the early history of Glacial Lake Memphremagog in northern Vermont, Geological Society of America Abstracts with Programs, Volume 38, p. 15.

-, 2015, Late Wisconsinan ice sheet flow across northern and central Vermont, USA: Quaternary Science Reviews, v. 129, p. 216-228.

-, 2018, Surficial Geology and Hydrogeology of the Bolton Mountain Quadrangle, Vermont: Vermont Geological Survey Open File Report VG2018-4, scale 1:24,000.

-, 2020, Surficial geology and groundwater hydrology of the Stowe 7.5 minute quadrangle, Vermont: Vermont Geological Survey Open File Report VG2020-1, Report plus 5 maps.

-, 2022a, Surficial Geology and Groundwater Hydrology of the Brookfield 7.5-minute Quadrangle, Vermont: Vermont Geological Survey Open File Report VG2022-1, Report plus 5 maps.

-, 2022b, Surficial Geology and Groundwater Hydrology of the Lincoln 7.5-minute Quadrangle, Vermont: Vermont Geological Survey Open File Report VG2022-3, Report plus 5 maps.

-, 2024a, Ice-marginal channels and the evolution of Glacial Lake Memphremagog along Vermont’s northern border: Geological Society of America Abstracts with Programs. Vol. 56, No. 1.

-, 2024b, Surficial Geologic Map and Cross-Sections of the Newport 7.5-minute Quadrangle, Vermont, v. Vermont Geological Survey Open File Report VG2024-1.

Wright, S. F., Dunn, R. K., and Springston, G. E., 2023, Surficial Geologic Map and Cross-Sections of the Waterbury 7.5-minute Quadrangle, Vermont, v. Vermont Geological Survey Open File Report VG2023-1.