Surficial Geology of the Newport and Newport Center 7.5-Minute Quadrangles, Northern Vermont[1]

Stephen F. Wright
Department of Geography and Geosciences, University of Vermont
April, 2025

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

Executive Summary/Significant Findings 2
Introduction 3
Location and Geologic Setting 3
Prior Work 4
Methods 5
Newport & Newport Center Surficial Geologic Map: Mapping Units 6
Interpretation of the Glacial and Post-Glacial History 22
References 31

[1] Report describes Vermont Geological Survey Open File Map: VG2025-1, VG2025-2. 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 and Newport Center 7.5-minute Quadrangles along Vermont's norther border with Québec during the 2023 and 2024 field seasons (Fig. 1). These new surficial geologic maps significantly update earlier 1:62,500-scale maps by Stewart (1956-1966a) and MacClintock (1966a), mapping incorporated into the Vermont State Surficial Geologic Map (Stewart and MacClintock, 1970). These new maps provide (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. Detailed surficial geologic maps and cross-sections accompany this report (Wright, 2024b, 2025a).

Location and Geologic Setting

The Newport and Newport Center 7.5-minute Quadrangles lie along Vermont's northern border with Québec (Fig. 1). Most of the Newport Quadrangle lies within portions of the Black, Barton, and Clyde River drainage basins, all of which flow generally north and drain into Lake Memphremagog. The lake extends some distance into Québec and drains via Rivière Magog and eventually into the St Lawrence River. Most of the Newport Center Quadrangle lies within the north-flowing portion of the Missisquoi basin. Just north of the border this river turns west and drains into Lake Champlain.

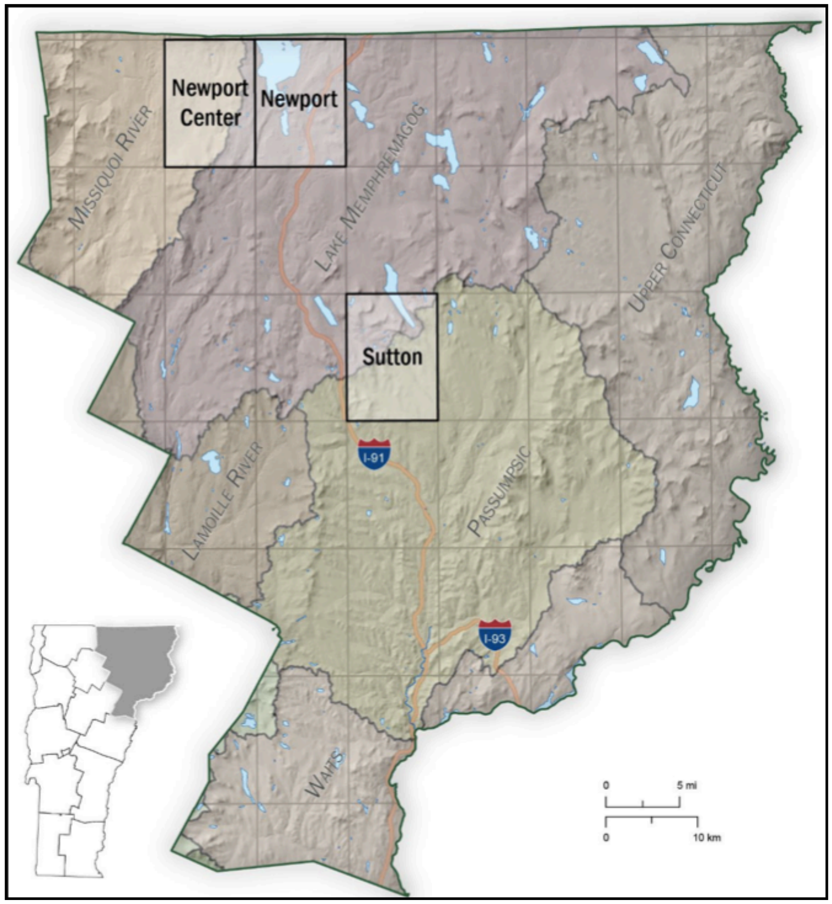

Figure 1: Map depicts the location of the Newport and Newport Center quadrangles and the large-scale drainage basins in northeastern Vermont. Note that geologic mapping includes the narrow strip between the northern border of these quadrangles and the border with Québec. The Sutton Quadrangle, lying astride a major drainage basin boundary, was part of the same mapping effort and results from that mapping are reported separately. Map from the 2023 RFP for this project 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 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 this area will likely revise the contacts shown in Figure 2 and may reveal one or more generations of younger faulting.

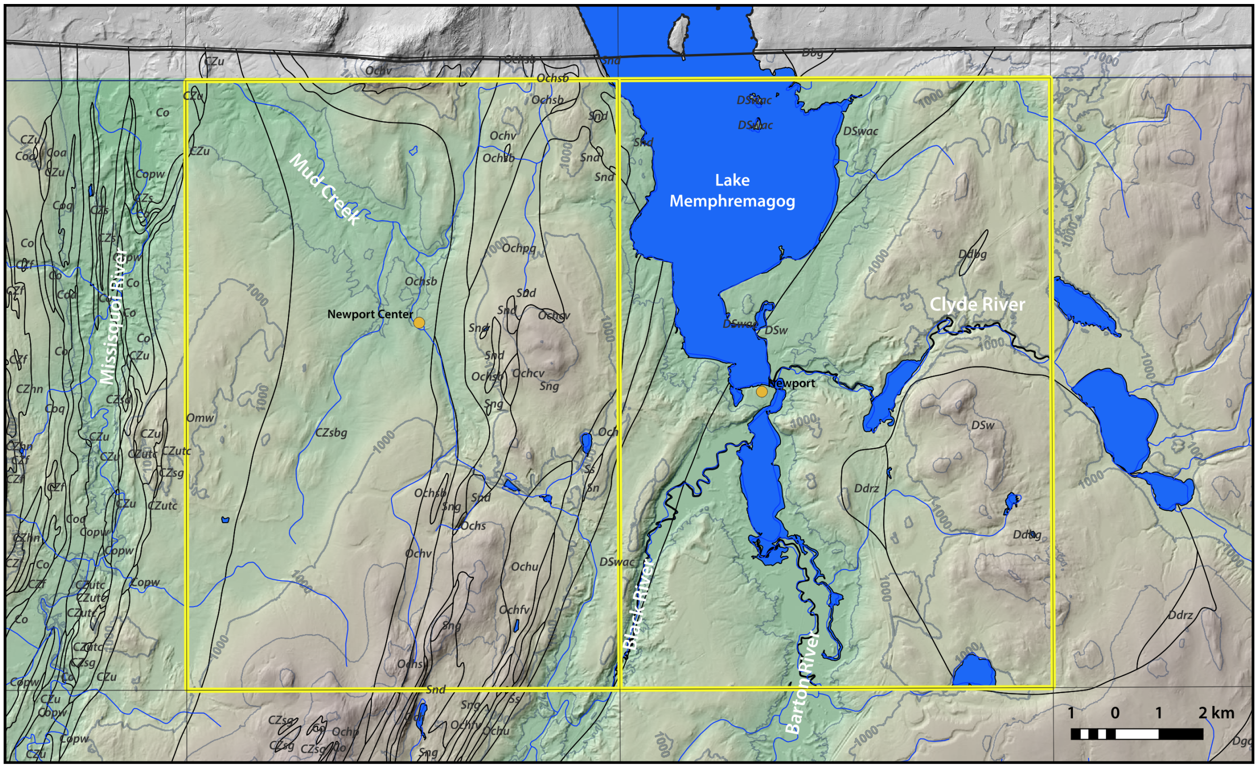

Figure 2: Bedrock underlying the Newport and Newport Center Quadrangles largely consists of Precambrian through Devonian metasedimentary rocks intruded by gabbroic to granitic plutons. The Black, Barton, and Clyde Rivers flow north into Lake Memphremagog, whereas Mud Creek and the Missisquoi River flow first north then west into Lake Champlain.

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 these quadrangles follows in a later section of this report.

Prior Work

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

McClintock's map (Fig. 3A) shows three areas with significant accumulations of surficial materials. He shows the Mud Creek valley northwest of Newport Center and a second broad valley south of Route 100 to be largely filled with fine-grained lacustrine sediments. In contrast, MacClintock's map depicts the east and south-flowing Stony Brook valley largely filled with kame deposits (Fig. 3A). Stewart's map (Fig. 3B) 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.

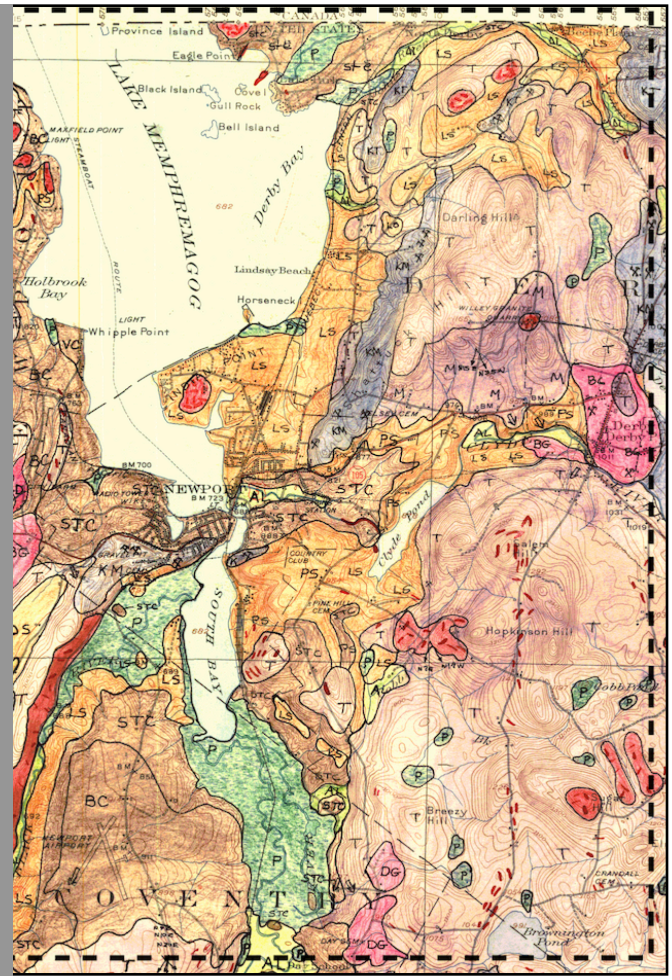

Figure 3A: Surficial geology of the northeast quadrant of the Irasberg 15-minute quadrangle as mapped by MacClintock (1966).

Figure 3B: Surficial geology of the northwest quadrant of the Memphremagog 15-minute quadrangle showing map units outlined by Stewart (1956-1966).

Methods

Traditional field techniques and digital mapping were employed to generate a surficial geologic map of the Newport and Newport Center Quadrangles. Specifically, ~4,000 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 (Fig. 4). 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; Springston and Wright, 2024; Wright et al., 2023) 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, 2025a). 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.

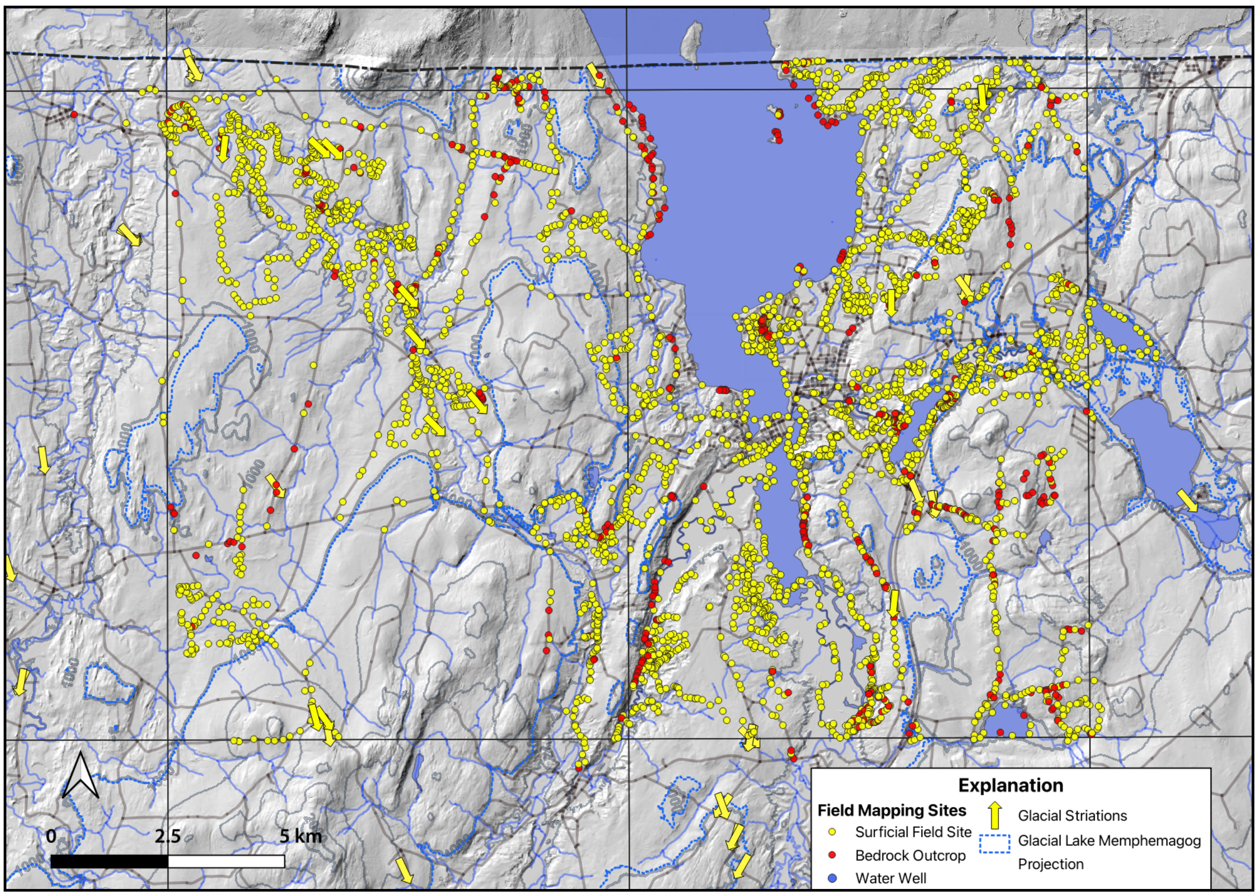

Figure 4: Map shows the distribution of ~4,000 separate field observations across the two quadrangles. Observations are concentrated in low-lying areas where the largest variety of surficial materials exist. Glacial striations record both regional NW to SE ice flow as well as younger, generally southward ice flow that occurred when the ice sheet thinned sufficiently to be topographically controlled.

Newport & Newport Center Surficial Geologic Maps

The surficial geologic maps that accompany this report show the aerial distribution of different types of surficial materials, landforms constructed of these materials, glacial striations, landslides, and other geological phenomena (Wright, 2024b, 2025a). 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 four groups: (1) Glacial Deposits are the surficial materials that were initially deposited directly by the ice sheet. (2) Ice-contact deposits consist of materials generally deposited by water beneath or adjacent to the ice sheet as it thinned and retreated across the area. (3) Lacustrine Deposits were deposited in ice-dammed glacial lakes that occupied the region's valleys during ice sheet retreat. (4) A last 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 as the bedrock geology geology of the Newport Quadrangle is mapped 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. 6).

Much of the field area is underlain by the Waits River Formation which weathers very quickly and rarely preserves glacial striations ("Dwr" unit in Fig. 2, Fig. 6). Similarly, the plutonic rocks also weather relatively quickly and rarely preserve striations. The striations shown on the geologic map and Figure 4 include both those recorded during this study, those recorded on earlier maps (MacClintock, 1966b; Stewart, 1956-1966a), and several additional striations recorded by the Vermont Geological Survey on interstate outcrops. Ice flow was also interpreted from crag and tail structures visible on LiDAR imagery available in 2024 (Fig. 5)

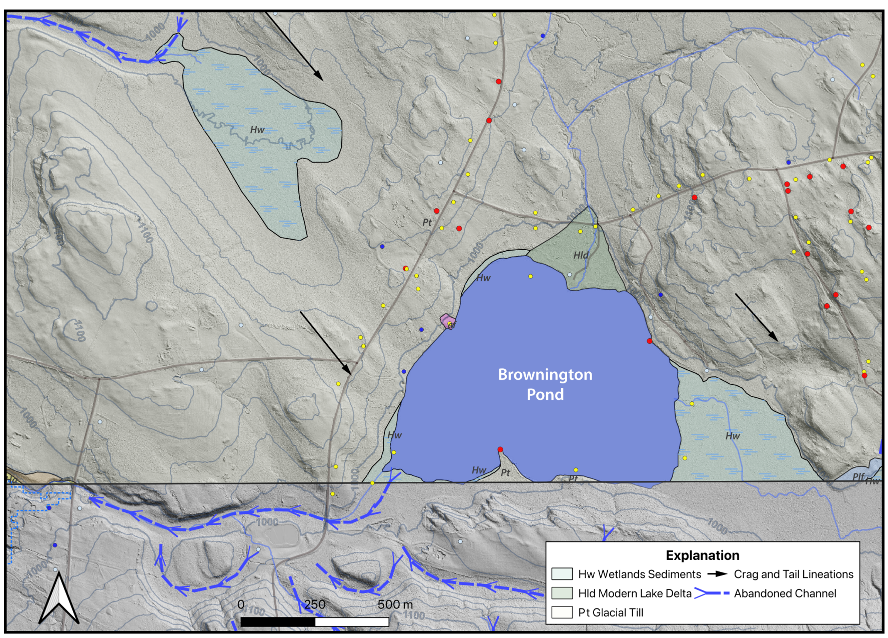

Figure 5: Crag and tail landforms (streamlined till extending down-ice from bedrock knobs) indicate NW to SE ice flow across the southern edge of the Newport Quadrangle. Abundant meltwater channels are also present.

Striations within and adjacent to the Newport Quadrangle are largely aligned either NW-SE or N-S. These orientations mimic those across much of

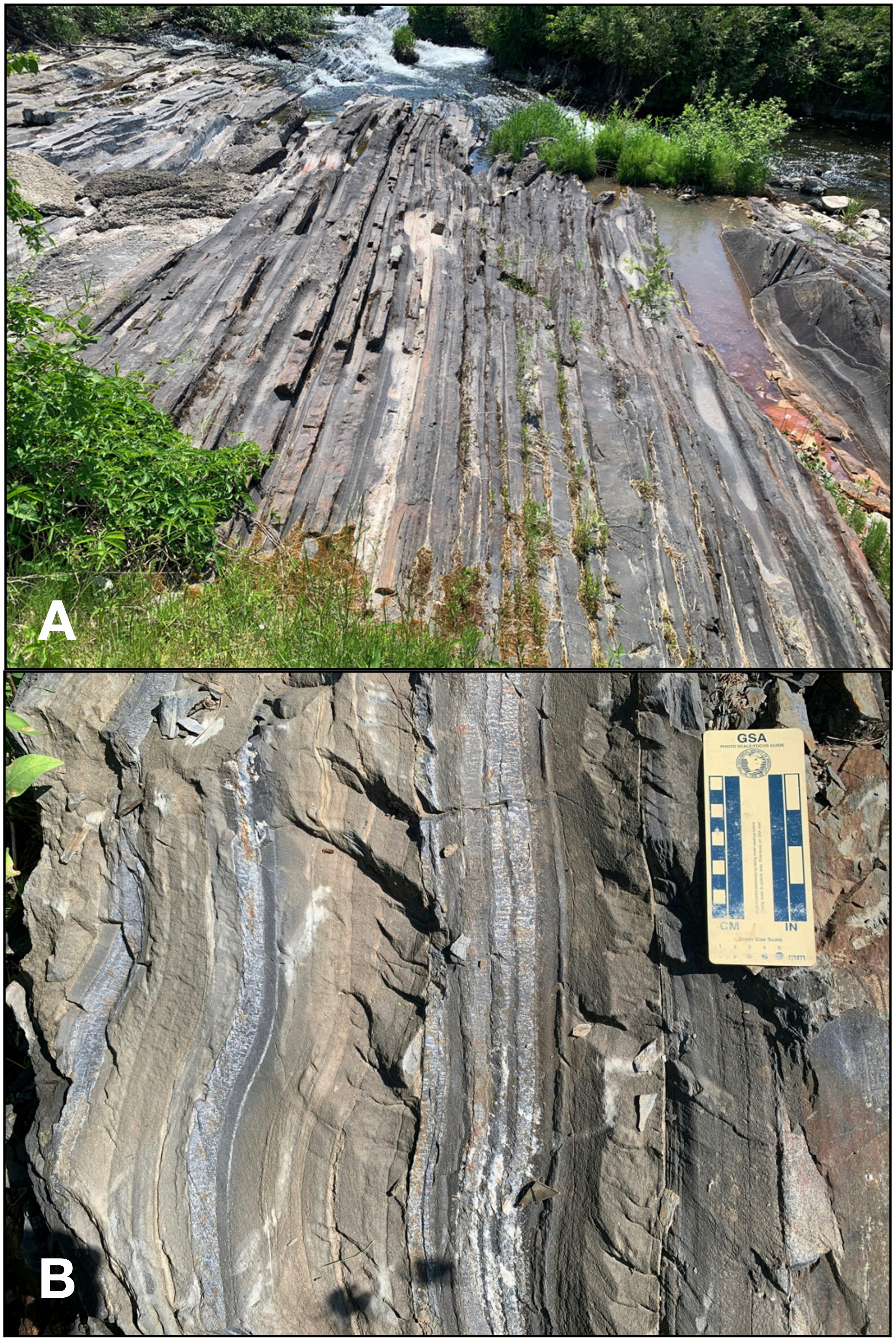

Figure 6: (A) Outcrop of steeply-dipping, generally N-S striking Silurian/Devonian Waits River Formation exposed along the Clyde River immediately below the Clyde Pond dam. Differential erosion of this metamorphosed turbidite leaves the metasandstone layers high-standing relative to the more easily eroded, 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.

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 (Figs. 4, 5). The N-S set developed later when the ice sheet had thinned sufficiently to be topographically controlled and flow parallel to the elongate North-South basin occupied by Lake Memphremagog and its tributaries (Wright, 2015; Fig. 4).

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. 7). 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.

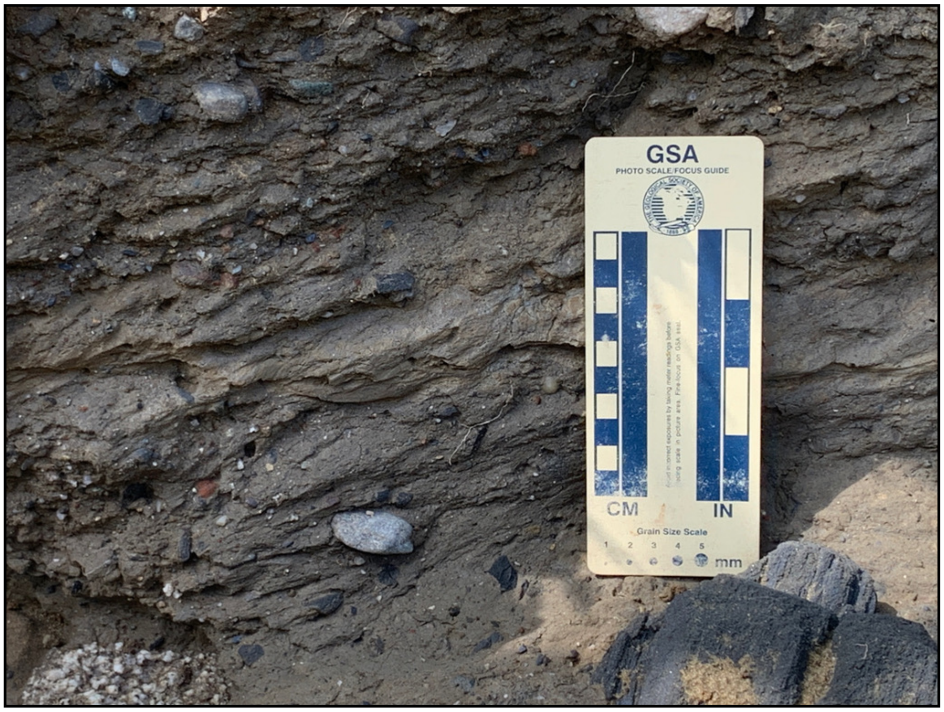

Figure 7: Glacial till exposed in erosional gully between Newport and Derby. Fissility in the till may result from shear stresses applied during movement of the overlying ice sheet.

Moraines (Ptm)

Well defined moraines are rare in northern Vermont. Along the western border of the Newport Center quadrangle two subparallel till ridges were mapped as moraines and a third diffuse ridge between them may also be a moraine (Fig. 8). These ridges consist of glacial till and lie almost perpendicular to the north-south bedrock ridges in the area. If these are moraines, they likely formed along the margin of the ice sheet as the ice sheet was retreating northwards, broadly down the upper Missisquoi River valley. They may have formed during short-lived standstills or during a succession of minor readvances.

An extensive rectilinear ridge was mapped close to and parallel to the border between the Newport and Newport Center quadrangles on the western side of Lake Memphremagog (Fig. 9). This landform consists of both glacial till and gravel and has also been interpreted as a moraine that may have formed along the western margin of the ice sheet as it thinned and retreated in the Lake Memphremagog basin. These moraines are younger than the White Mountain Moraine System that was deposited during the Littleton-Bethlehem Readvance during the Older Dryas, ~14.0-13.8 cal. kyr BP (Thompson et al., 2017) because the ice sheet margin was well south of here at that time.

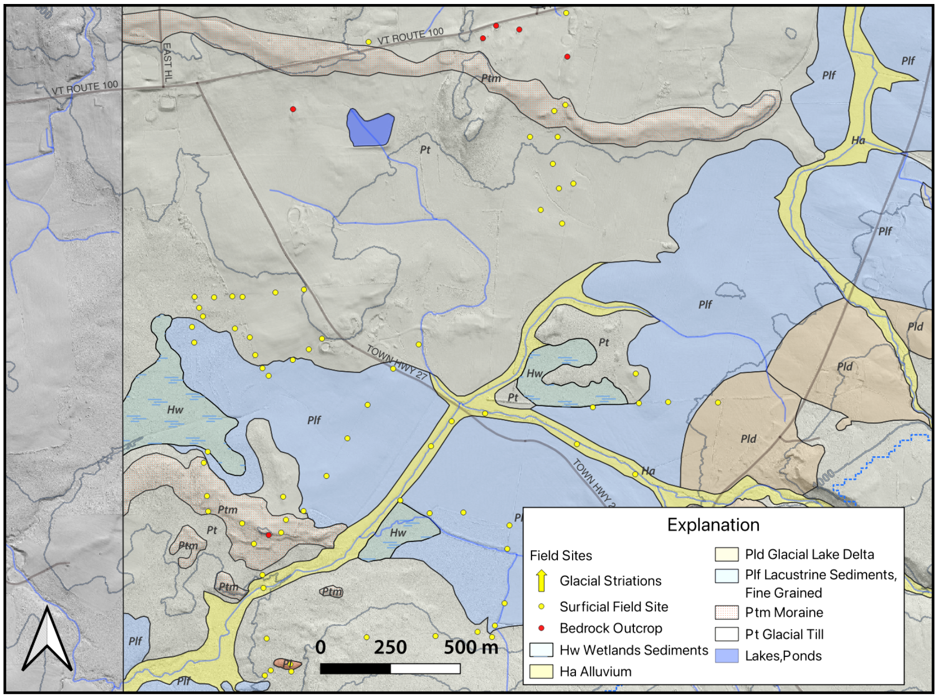

Figure 8: LiDAR hillside map of area along the western border of the Newport Center Quadrangle. Two approximately east-west ridges of till are mapped as moraines (Ptm). A third subparallel diffuse ridge of till lies between these and may be another moraine.

Ice-Contact (Glaciofluvial) Deposits:

Eskers (Pie)

Meltwater streams flowing in tunnels beneath the thinning and retreating ice sheet deposited sand and gravel in distinctive ridges referred to as eskers (Pie). Two eskers occur in the mapped area. One lies in the northern part of the Newport Quadrangle where it extends ~NNE-SSW, crossing the Johns River valley and continuing across the border into Québec (Fig. 10). Several glacial kettles occur in the ice-contact sediments adjacent to the esker, some of which host wetlands (Fig. 10).

A second prominent esker follows the Stony Brook valley (utilized by Vermont Route 14) along the eastern margin of the Newport Center Quadrangle (Fig. 12). This esker consists of boulder gravel interlayered with finer gravel and coarse sand. Extensive areas bordering the esker are underlain by subaqueous fan deposits consisting of interlayered gravel and fine lacustrine sand. Both the esker and subaqueous fan deposits have been extensively quarried and several of the pits are currently very active. The esker deposits do not appear to continue NW beyond the drainage divide separating Stony Brook from Mud Brook.

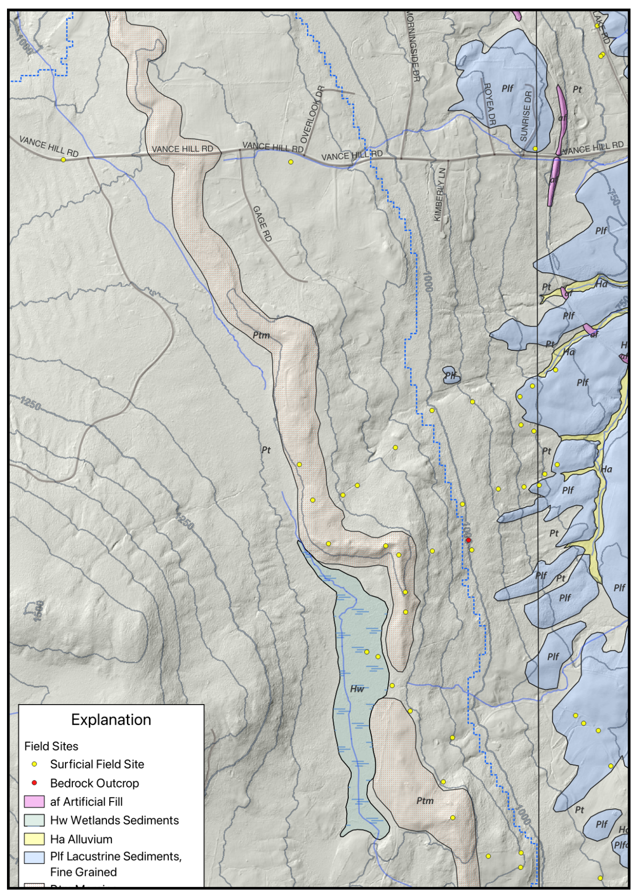

Figure 9: Map depicts a rectilinear ridge west of the modern Lake Memphremagog that is interpreted as a moraine. Vertical line is quadrangle boundary.

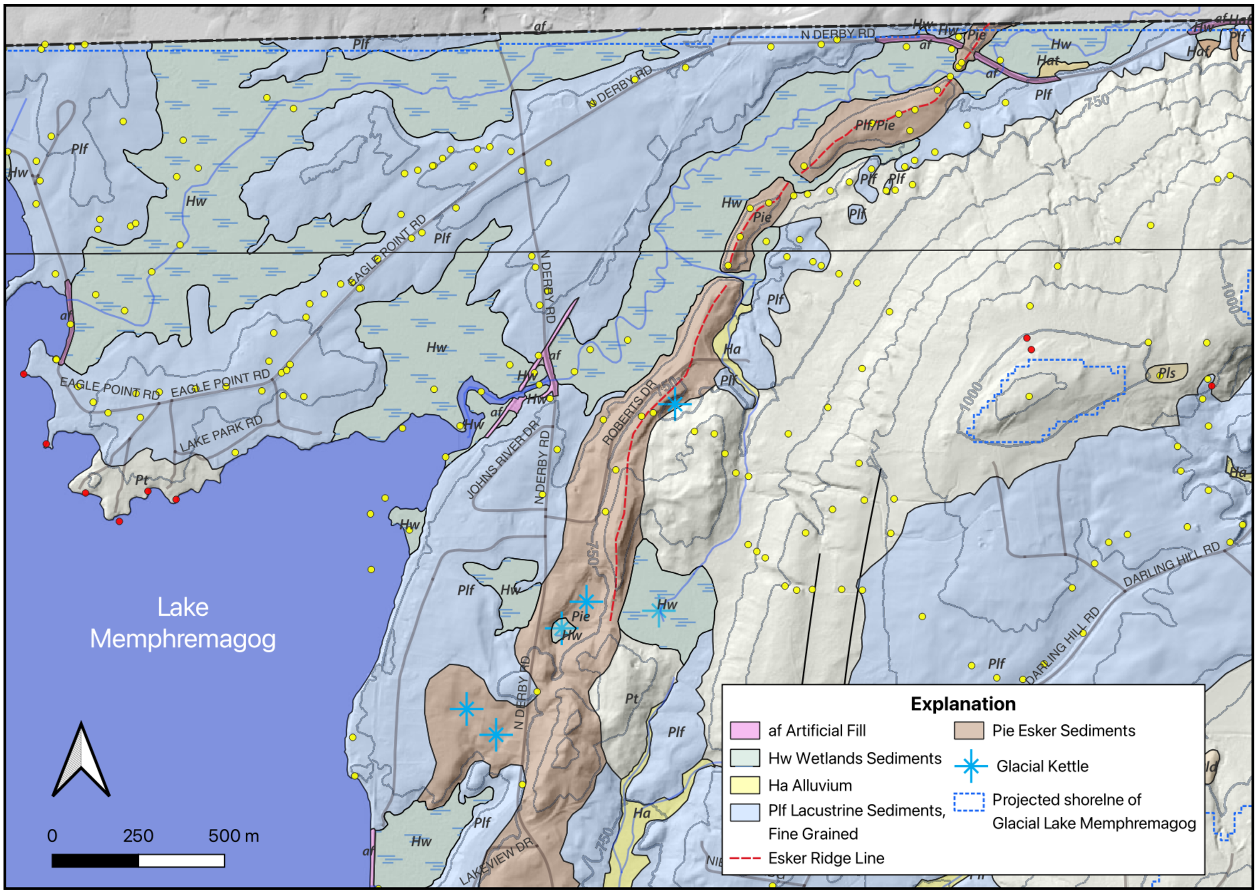

Figure 10: Northern border of the Newport Surficial Geologic map showing an esker extending approximately NNE-SSW across the middle of the map and likely continuing into Québec. Numerous kettles lie adjacent to the esker. Esker is bordered by till (Pt) mantling the steeper slopes to the east and extensive areas of fine-grained glacial lake and wetlands sediments along the northern border of the map, part of the Missisquoi National Wildlife Refuge.

Ice-Contact Deposits, Undifferentiated (Pi)

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. 11). 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. Alternatively, these deposits could also

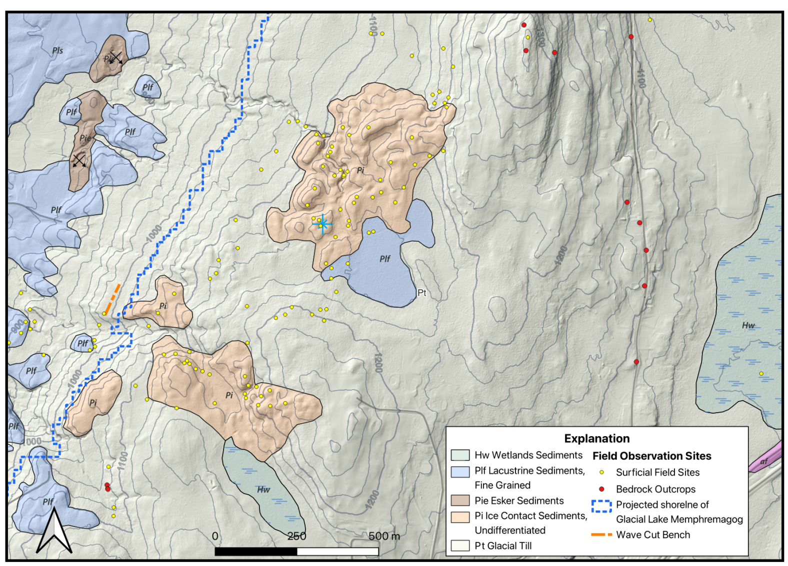

Figure 11: Map of Darling Hill showing areas of hummocky sand, gravel, and till, inferred to be undifferentiated ice-contact deposits (Pi). Sediments were likely deposited along the margin of the ice sheet by a variety of processes that included stream flow, slumping, and collapse associated with melting 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.

be mapped as hummocky moraine which form by a similar array of processes. Another large area of undifferentiated ice-contact deposits was mapped immediately east of Derby Village (Fig. 13). Along the eastern quadrangle border these deposits have been modified by glacial streamflow.

Glacial Outwash (Po)

Glacial Outwash (Po) was mapped in one area along the quadrangle's eastern boundary (Figs. 13, 14). 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. 13). Both Derby Pond and Salem Pond are likely glacial kettles and were filled with dead ice when meltwater streams flowed across them. The network of abandoned channels south of Derby Pond are distributary channels on top of a delta that formed in Glacial Lake Memphremagog. The coarse gravels deposited in these topset beds are extensively exposed around the perimeter of Derby Pond (Fig. 13). The adjacent deposits mapped as outwash could alternatively also be interpreted as delta deposits that formed in a higher elevation glacial lake in the Clyde River valley (Fig. 13). These interpretations will be clarified following future mapping of the West Charleston Quadrangle.

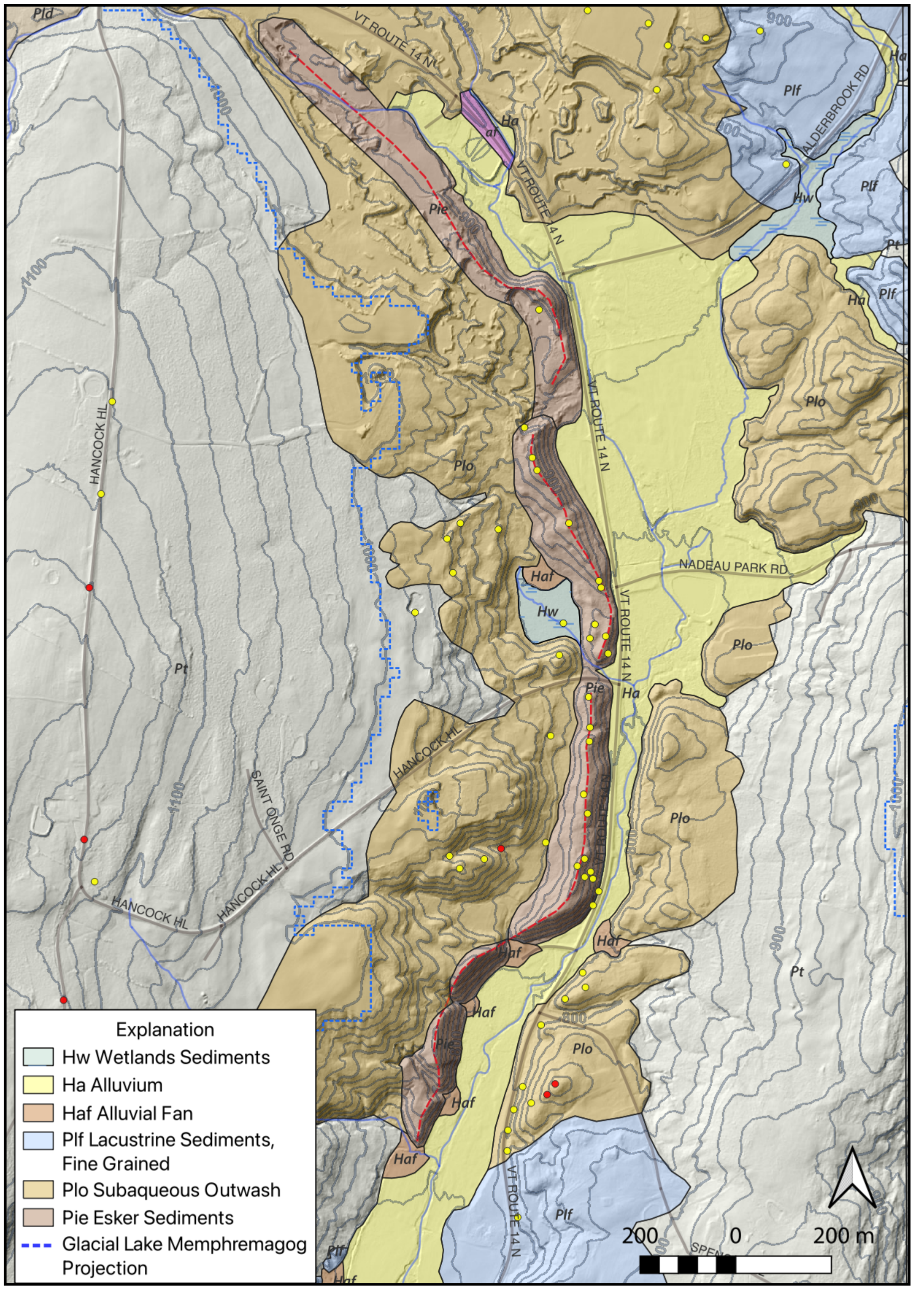

Figure 12: A prominent esker (Pie) extends along the Stony Brook valley. Extensive deposits of subaqueous outwash (Plo) were deposited as subaqueous fans in the shallow glacial lake water near the mouth of the esker tunnel as the ice sheet retreated to the north. Both esker and subaqueous outwash sediments have been extensively quarried.

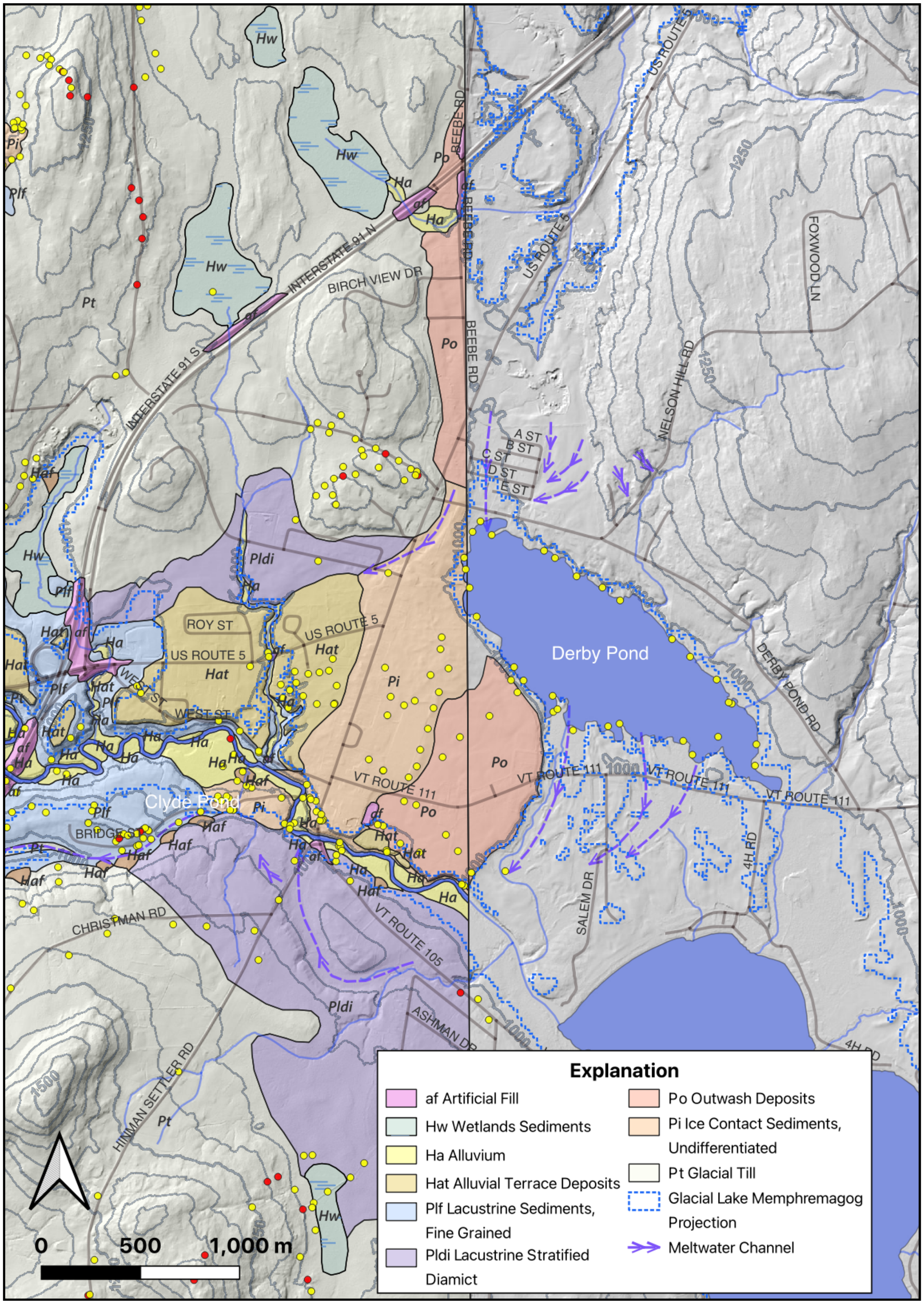

Figure 13: Portion of the Clyde River valley straddling the boundary between the Newport (west) and West Charleston (east) quadrangles centered on Derby Village. Undifferentiated ice-contact deposits (Pi) underlying the high ground above the village have been eroded by glacial streams leaving multiple 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 (Pldi) deposited in both Glacial Lake Memphremagog and a higher-elevation glacial lake in the Clyde River valley.

Figure 14: Rounded cobbles and small boulders were mapped around in the perimeter of Derby Pond in the adjacent West Charleston Quadrangle (Fig. 13). These are interpreted to be topset beds of a large delta that formed along the eastern edge of Glacial Lake Memphremagog. The stream feeding this delta was not the Clyde River, but a broad meltwater stream extending north to the vicinity of Derby Line.

Glacialacustrine Deposits

As the ice sheet retreated to the north it dammed a large glacial lake referred to as Glacial Lake Memphremagog. This lake filled the modern Lake Memphemagog Basin and its tributary valleys to an elevation of ~302 m or ~990 ft in the Newport area although isostatic tilting increases the elevation of the lake to the northwest and lessens its elevation to the southeast. A discussion of this lake's evolution occurs later in this report.

Fine-Grained Lacustrine Sediments (Plf)

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, the "Plf" (Figs. 10, 15). Two cross-sections along the eastern side of Lake Memphremagog both depict a relatively simple stratigraphy consisting of these fine lacustrine sediments overlying till (Fig. 15). These fine-grained sediments underlie many of the wetlands in the area providing the low-permeability substrate necessary to maintain water tables at or above the ground surface in these basins.

In the Clyde River valley along the Quadrangle's eastern border fine-grained glacial lake sediments were mapped at elevations above the projected elevation of Glacial Lake Memphremagog and thick sections of "clay" are recorded in well logs from this area. These sediments offer evidence that a higher-elevation lake occupied this part of the Clyde River valley.

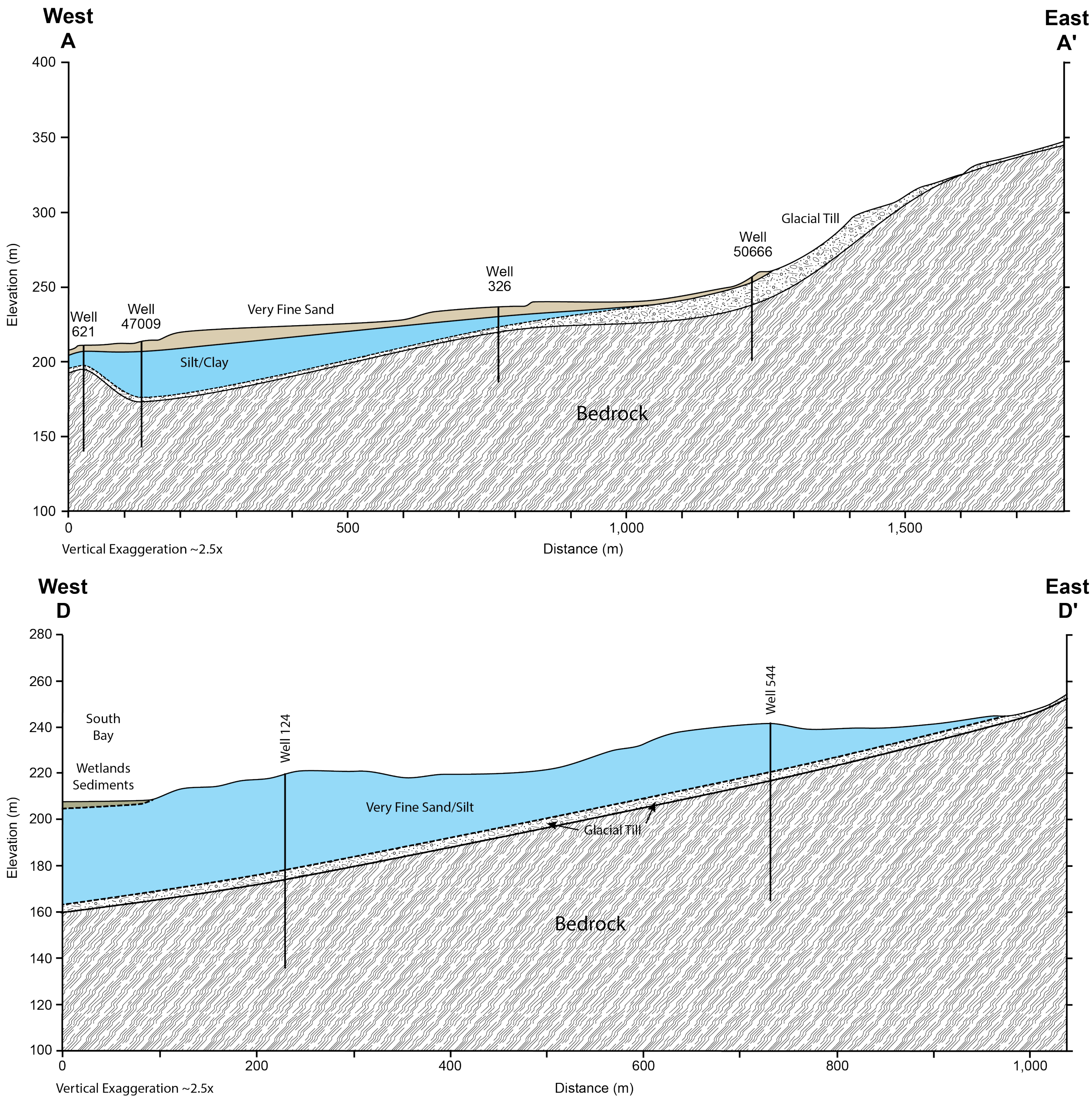

Figure 15: Cross-sections A-A' and D-D' both depict variable thicknesses of fine-grained glacial lake sediments directly overlying till, a common depositional setting for these sediments in the Newport Quadrangle. See Newport Quadrangle geologic map for location of sections.

<u>*Subaqueous Fan Deposits (Plo) and Lacustrine Shoreline Deposits (Pls)*</u>

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 medium to 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 (Figs. 12, 16). 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 16: 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.

Glacial Lake Delta Deposits (Pld)

Terraces of sand and gravel occurring at or close to the projected elevation of Glacial Lake Memphremagog and also near tributary streams have been mapped as glacial deltas. The largest example is exposed in a large, active gravel pit on the east side of South Bay (directly opposite Newport City; Figs. 17-19). Large-scale, southwest-dipping foreset beds indicate deposition of these sediments by the Clyde River as it flowed into Glacial Lake Memphremagog (Fig. 17). 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. 18, 19). 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.

In the vicinity of the Coventry landfill a more complex stratigraphy occurs (Fig. 20). 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

Figure 17: 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 in this area.

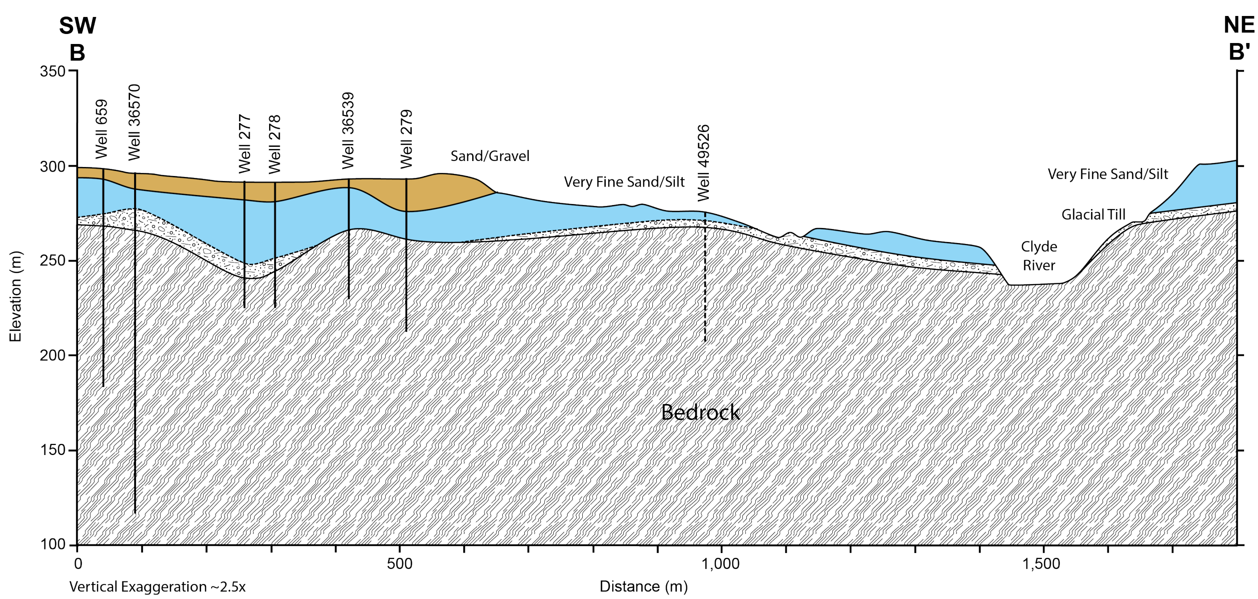

Figure 18: Cross-section B-B' depicts a coarsening upwards sequence of lake sediments deposited as the Clyde River delta grew across Glacial Lake Memphremagog. The Clyde River has eroded through a thick section of glacial lake sediments down to bedrock. See Figure 19 for location of cross-section.

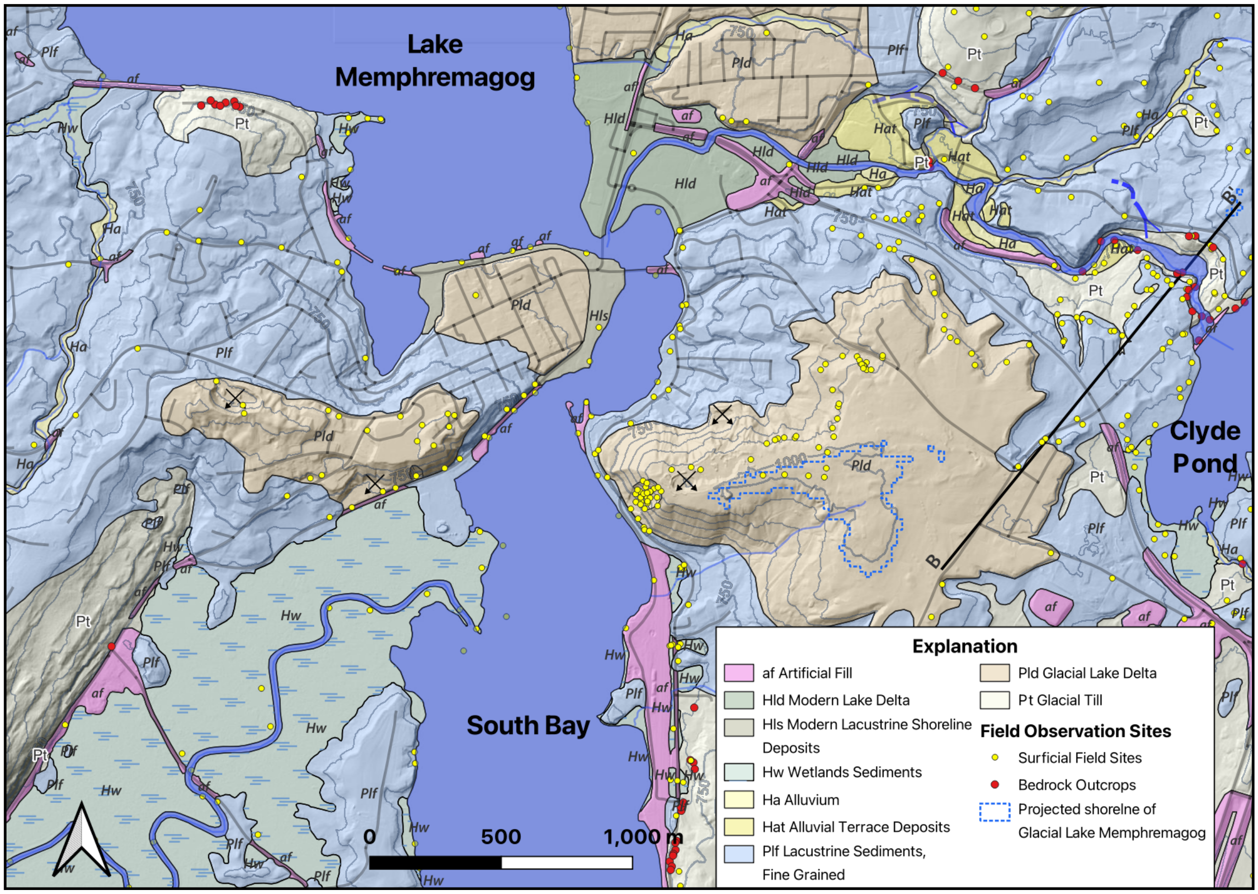

Figure 19: Coarse sand and gravel deposits on either side of Lake Memphremagog are interpreted to be parts of a delta (Pld) deposited by the Clyde River in Glacial Lake Memphremagog. The delta extended across the lake dividing the lake into two separate basins. Following a significant drop in lake level 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.

accumulates on their surfaces as they melt and periodically slumps off into the adjacent lake water.

Lacustrine Stratified Diamict Deposits (Pldi)

In several areas within the two mapped quadrangles lacustrine sediments and diamict frequently occur in close proximity, both as mapped at the surface and in water well logs. These areas are interpreted to be lacustrine stratified diamict (Pldi), i.e. interlayered lacustrine sediments and landslide deposits of till from the surrounding hillsides). Sediments both north and south of the Clyde River near the village of Derby are interpreted as stratified diamict deposits (Fig. 13).

The Mud Brook valley in the Newport Center Quadrangle is another area where extensive deposits of stratified diamict occur. The well field for the village of Newport Center provided good logs used to constrain a cross-section across the Mud Creek valley which clearly shows that the modern Mud Creek lies well above a deeply eroded bedrock valley now filled with glacial sediments (Fig. 21). The full extent of this buried bedrock valley hasn't been investigated nor is it clear when the valley formed. Diamict is exposed at the surface in this area, but the well logs record interlayered lacustrine deposits and diamict or "gravel." The cross section shows these diamict/gravel layers as individual landslide deposits into Glacial Lake Memphremagog sourced from the slopes above the lake.

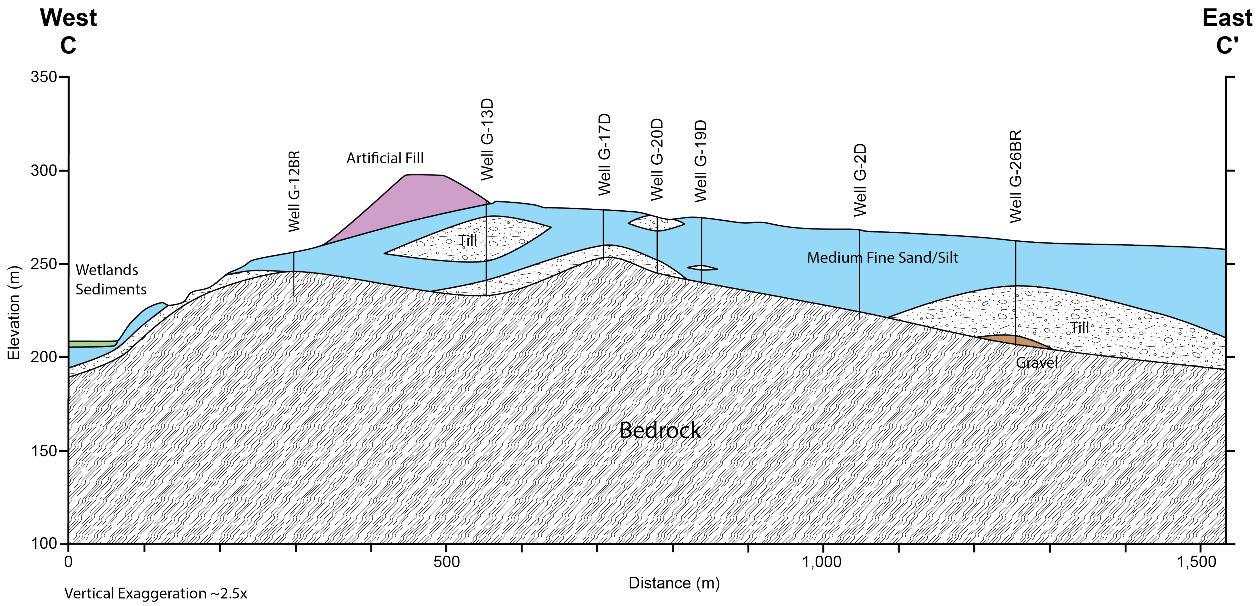

Figure 20: Geologic cross-section across part of the Coventry Landfill (Newport Quadrangle). Lacustrine and wetland sediments fill the Black River valley on the west side of the section. As recorded in monitoring well logs, the bedrock is overlain by a complex stratigraphy of both sand and diamict that 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.

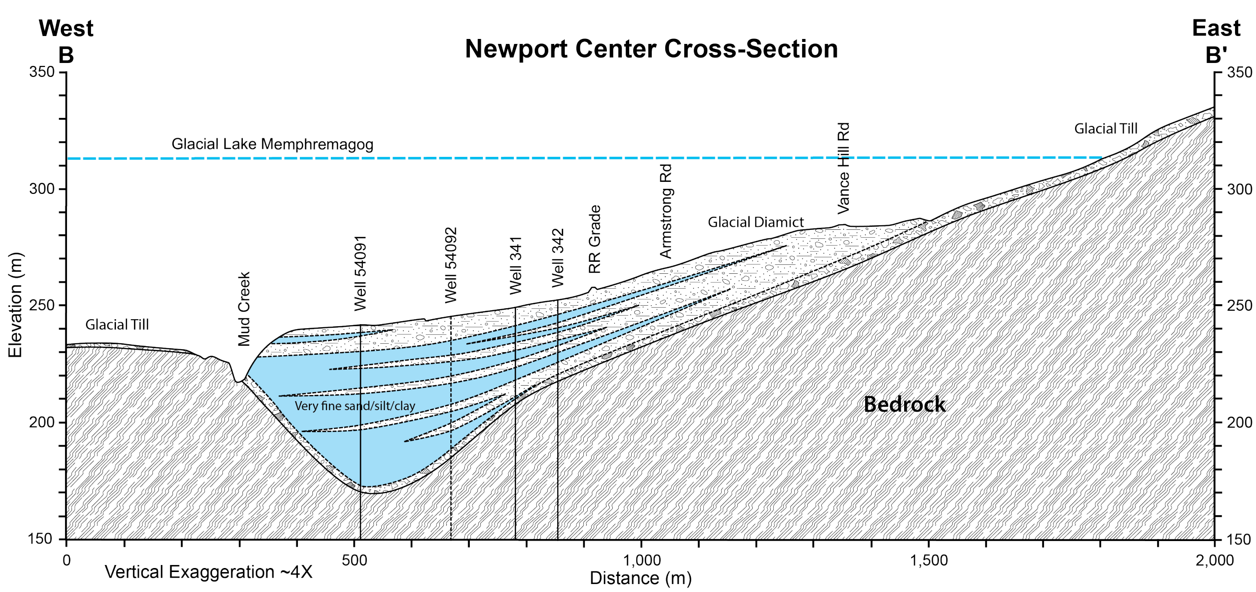

Figure 21: Geologic cross-section across the Mud Brook valley in the vicinity of Newport Center (village). The water well logs, drilled for the Newport Center water system, define a deep buried valley. Sediments filling this valley consist of both lacustrine sediments and diamict or "gravel." The diamict/gravel layers are interpreted to be landslide deposits, i.e. remobilized till that slid into Glacial Lake Memphremagog.

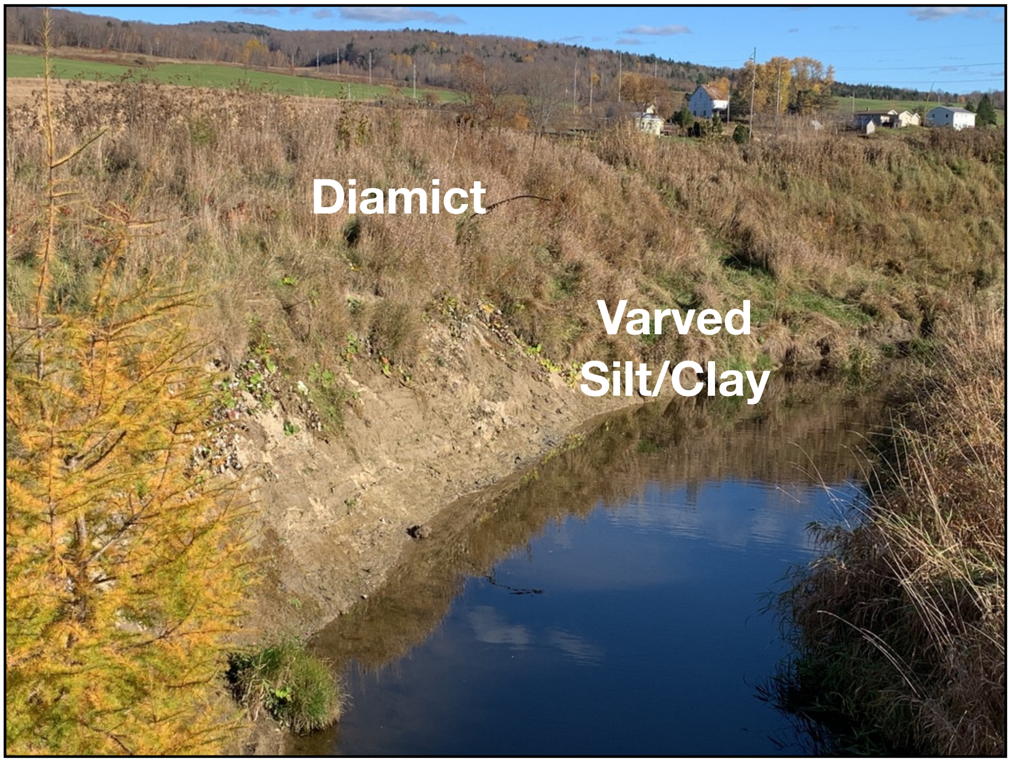

Figure 22: Horizontally layered varved silt/clay immediately above Mud Brook is overlain by diamict mapped across the corn field extending from the stream bank to Route 105 in the middle distance. The hill slopes beyond are also underlain by diamict (glacial till?).

Diamict is extensively exposed in the Mud Brook valley (Newport Center Quadrangle), both on terraces immediately above the brook and the adjacent hillslopes. In two places within the valley vertical exposures show that the diamict directly overlies fine-grained glacial lake sediment (Figs. 22, 23). Neither of these exposures show significant deformation in the underlying lacustrine sediments suggesting that it's unlikely the diamict was deposited during a glacial readvance. A more likely interpretation is that the diamicts in these two areas are landslide deposits, from slides that occurred while Glacial Lake Memphremagog existed or shortly after the lake drained.

Figure 23: Thinly layered, horizontally bedded glaciolacustrine silt below the scale card is overlain by apparently structureless silt behind the scale card which in turn is overlain by coarse sand and pebbles in a silt matrix (diamict) that extends the the ground surface.

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 and Mud Brook 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 has deposited a modern delta (Pld), although fill may be elevating this area above lake level. Newport's sewage treatment facility, a small city park, and a shopping center are built on this delta. Other 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 (Fig. 24). 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

Figure 24: 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.

includes inorganic fine-grained clastic sediment, “mud,” washed into these areas by streams and overland flow. In areas above the *modern* 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 (Fig. 24).

Glacial and Post-Glacial history of the Newport Quadrangles

The surficial geologic materials and landforms mapped in the Newport and Newport Center Quadrangles provide the basis for the following interpretation of the glacial and post-glacial history of this area. Insight gathered from mapping the Sutton Quadrangle a short distance to the southeast is also incorporated in this history (Wright, 2025b). This local history is fit within our broader understanding of northern Vermont’s glacial history based on earlier work, much of which is summarized by Wright and others (2024).

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 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 (Fig. 25). During the ensuing ~12,000 years the ice sheet both thinned and retreated across New England deglaciating north-central Vermont between ~14,200–13,500 years ago (Corbett et al., 2019; Halsted et al., 2022; Ridge et al., 2012; Fig. 25). 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 et al., 2024). No good sections of varved glacial lake sediments were observed while mapping the Newport and Newport Center Quadrangles preventing correlation with the North American Varve Chronology. However, samples of sediment deposited in Glacial Lake Memphremagog were collected during the fall of 2024 and are currently being processed for dating using the Optically Stimulated Luminescence (OSL) method.

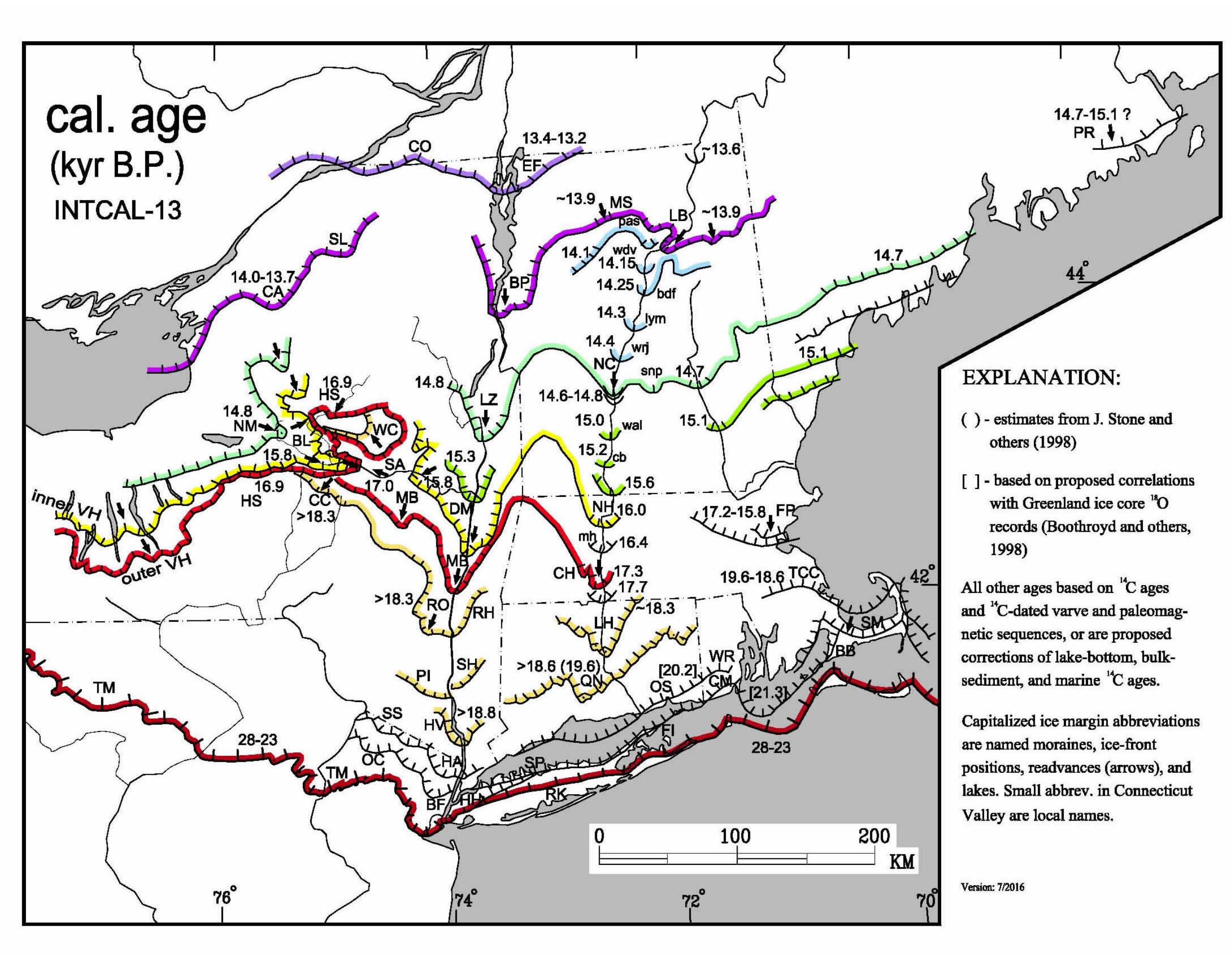

Figure 25: Map depicts the southern margin of the Laurentide Ice Sheet as it retreated across New England and New York (Ridge et al., 2012). Well constrained timelines in the Connecticut River valley are derived from the North American Varve Chronology. While not well-constrained, this map brackets the timing of ice retreat across northern Vermont.

Ice-Contact Environment

While the ice sheet was rapidly thinning and retreating across the Newport area, at least two subglacial drainage systems developed within the ice sheet and are preserved as the eskers described earlier along the northeastern shore of Lake Memphremagog and in the Stony Brook valley (Figs. 10, 12). 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. 11) and in Derby Center. In some areas these deposits could also be mapped as hummocky moraine. 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. Good exposures in similar landforms in the Gaick of Scotland indicate the hummocks are accumulations of debris flow materials (dicamict) and gravel originating from the margin of the adjacent ice (Chandler et al., 2020). Similar landforms covering a more extensive area have been mapped in the nearby Sutton Quadrangle (Wright, 2025b). 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. 11).

Evolution of Glacial Lake Memphremagog

East of the Green Mountains several major north-flowing rivers (the Black, Barton, and Clyde Rivers) flow into lake Memphremagog whereas the adjacent north-flowing upper Missisquoi River turns west and drains into Lake Champlain. Multiple glacial lakes evolved in each of these river valleys as the ice sheet retreated to the north of their respective drainage divides (Fig. 26; 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. 27).

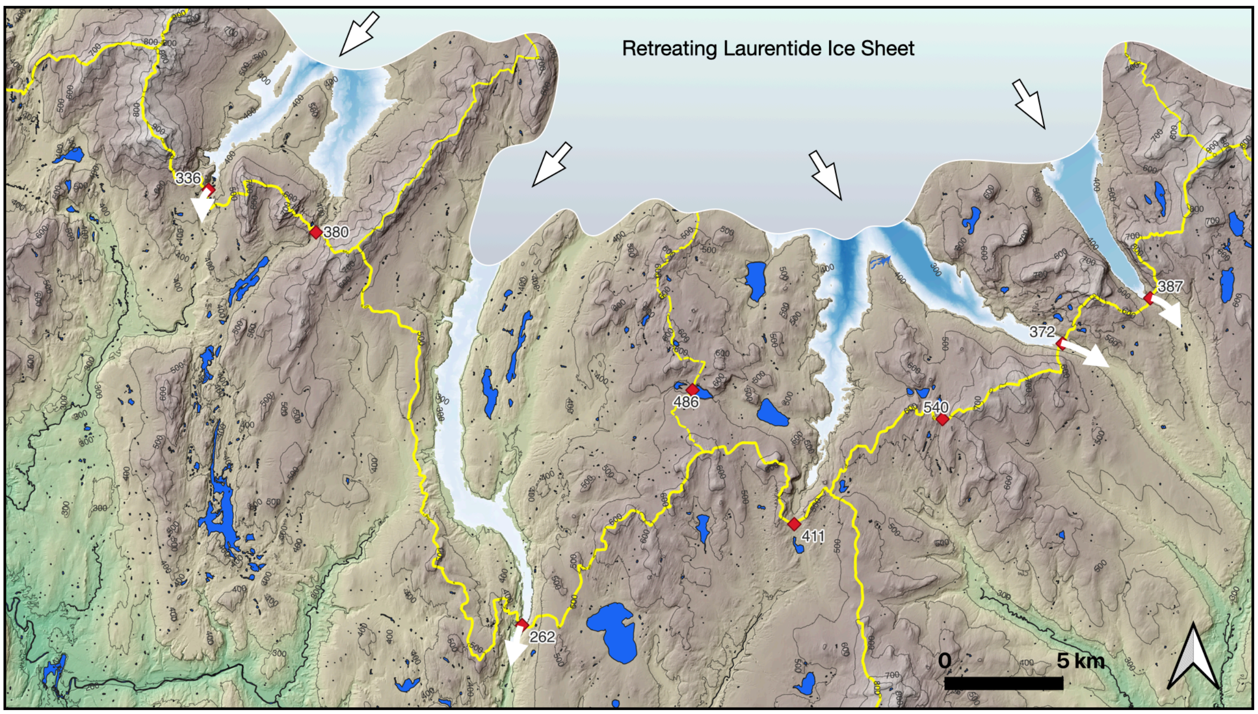

Figure 26: Map shows multiple glacial lakes forming in the (from west to east) Missisquoi, Black, Barton, and Clyde River valleys as the ice sheet retreated to the north. Red diamonds mark the drainage divides and their elevations (meters) on the isostatically tilted land surface. As the ice sheet retreated 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.

Across the broad Lake Memphremagog basin drainage from higher-level to lower-level lakes is recorded by abandoned meltwater channels, often occurring in subparallel sets that record successive routing of meltwater along the thinning ice sheet margin (Wright, 2024a, 2025b). Two of these channels are shown in Figure 28. Note that part of the upper (southernmost) channel is not bounded by land and therefore must have been bounded by ice. These channels formed as water from a lake dammed in the upper Missisquoi River valley “leaked” along the ice sheet margin into Glacial Lake Memphremagog in the Black and Barton River valleys (Fig. 29). Deltas formed where these drainage channels entered the lake (Pldm in Fig. 28). A cross-section shows the inferred distribution of esker,

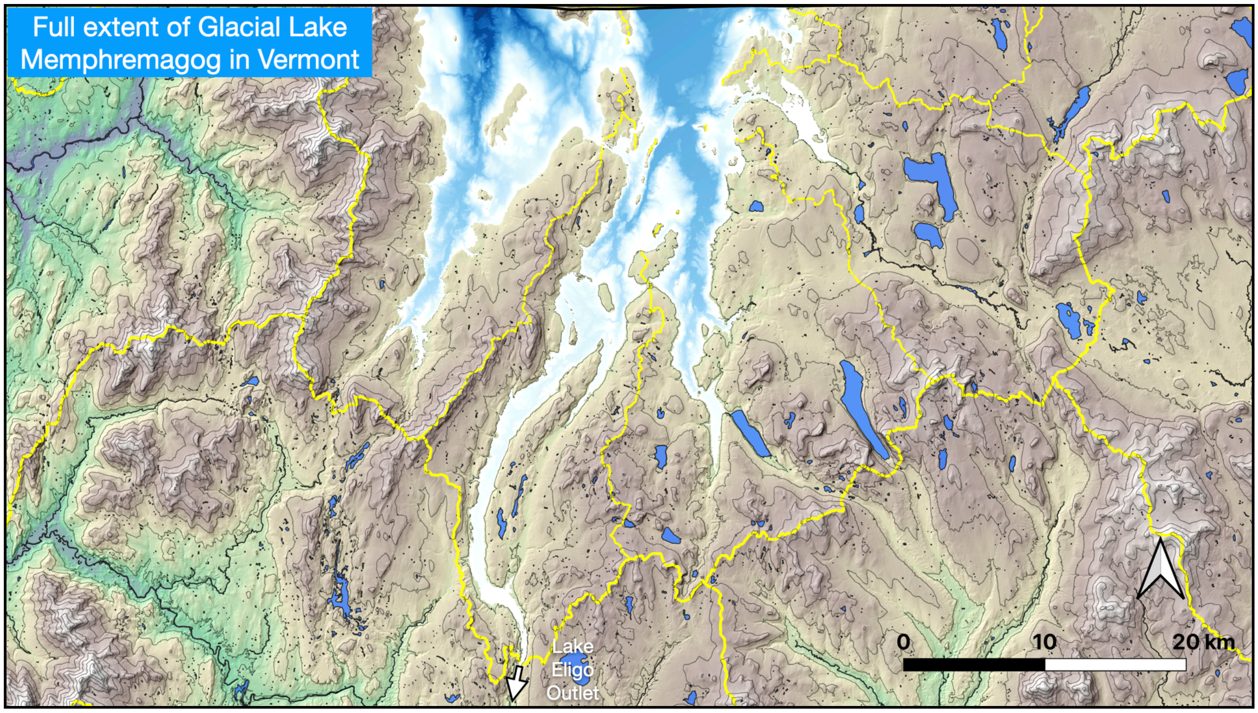

Figure 27: Full extent of Glacial Lake Memphremagog in Vermont. Most of the glaciolacustrine sediments occurring in the Newport and Newport Center Quadrangles were deposited in this glacial lake.

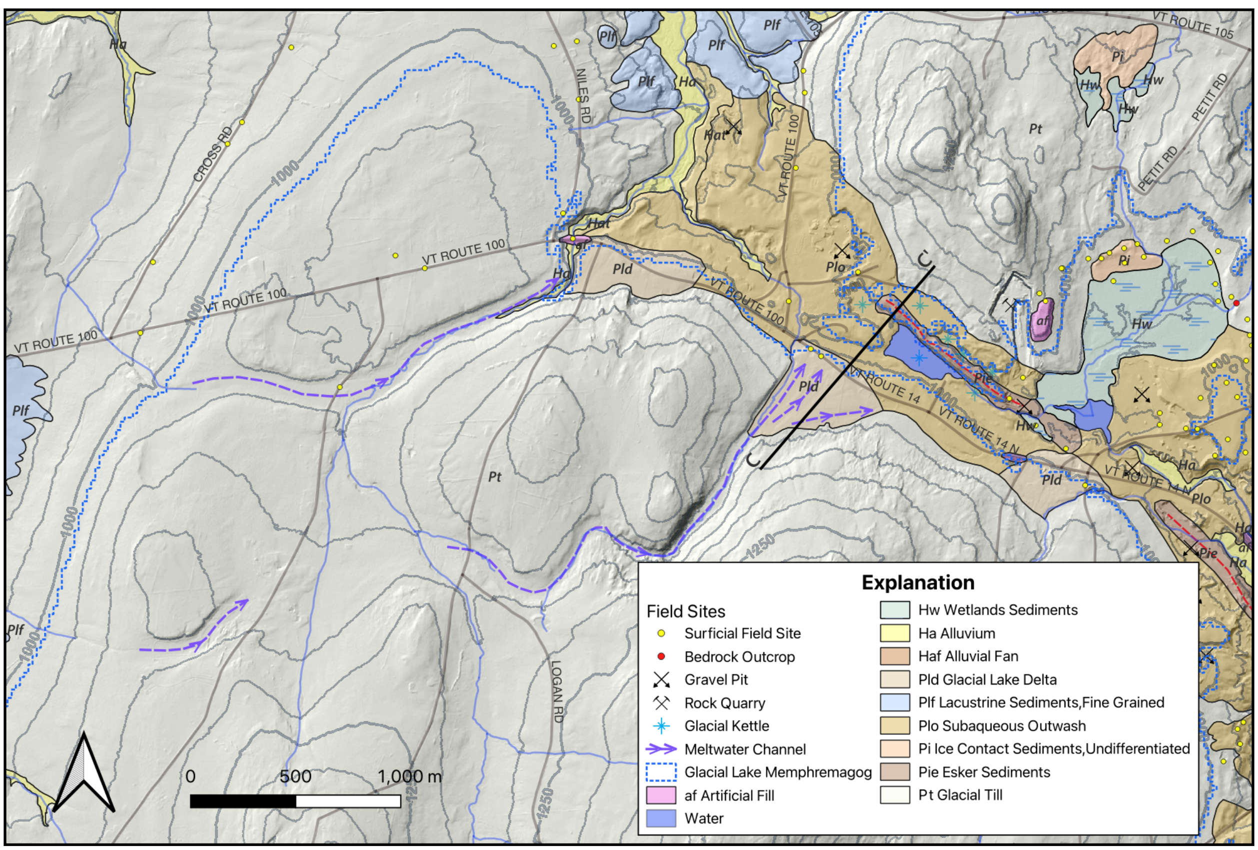

Figure 28: Two abandoned ice-marginal channels are shown with dashed blue lines. Arrows indicate the inferred flow direction. Both channels flowed into Glacial Lake Memphremagog (dotted blue line) depositing deltas (Pldm).An esker and associated subaqueous outwash occupies the valley at the drainage divide between Mud Brook to the northwest and Stony Brook to the southeast. The large wetlands area (Hw) is underlain by fine-grained glacial lake sediments.

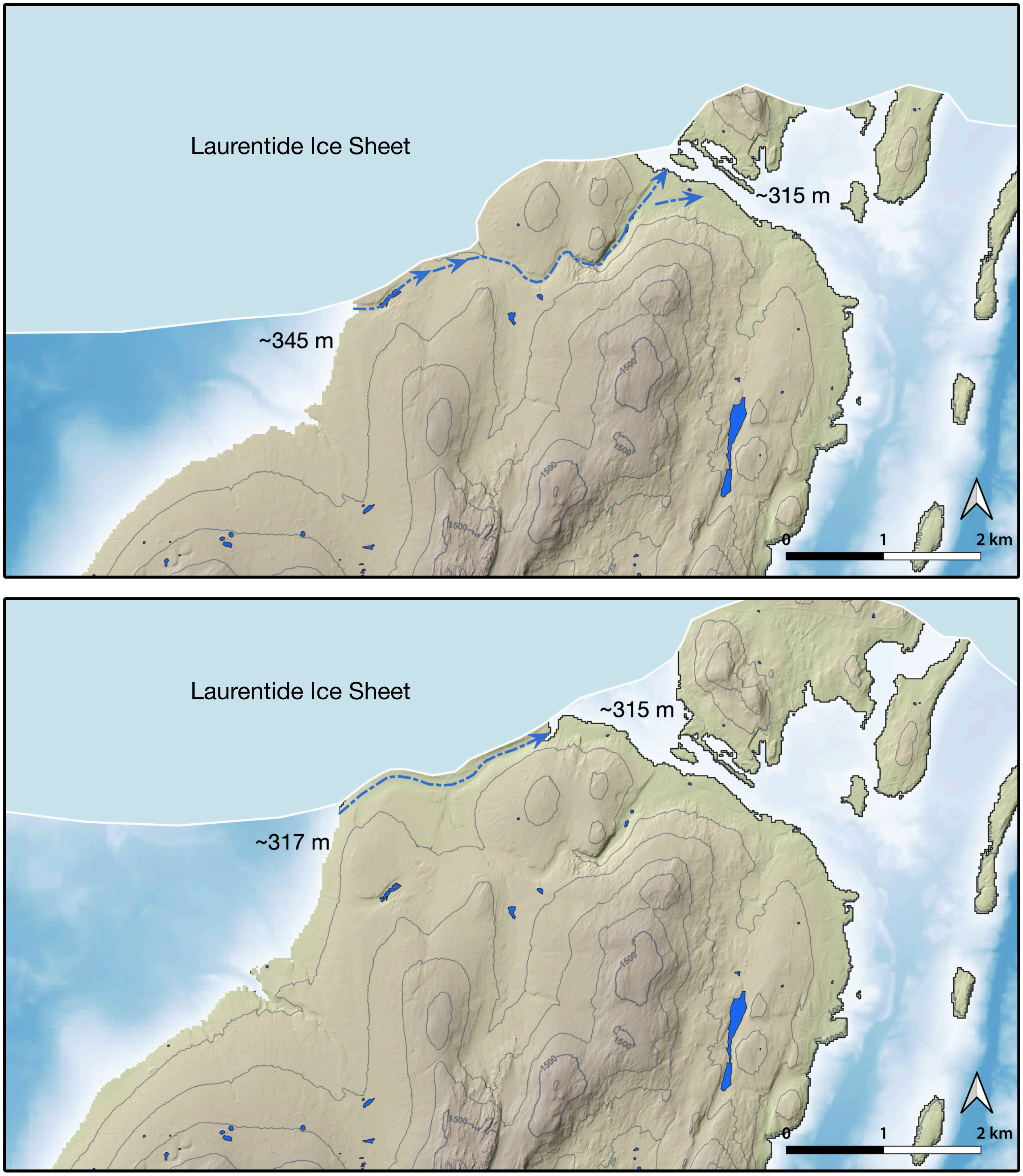

Figure 29: Maps depict the sequential drainage of a glacially-dammed lake in the Missisquoi River valley (left) into a lower elevation glacial lake in the Black/Barton River valleys (right) via two meltwater channels. The glacial lake to the right utilizes the lowest outlet in the basin and grows to form Glacial Lake Memphregog.

subaqueous outwash, and deltaic sediments deposited in this area (Fig. 30).

Glacial Lake Memphremagog grew to a considerable size as the ice sheet retreated into Québec (Fig. 31). The generally SW-NE orientation of the ice sheet margin is taken from multiple moraines mapped by Parent and Occietti

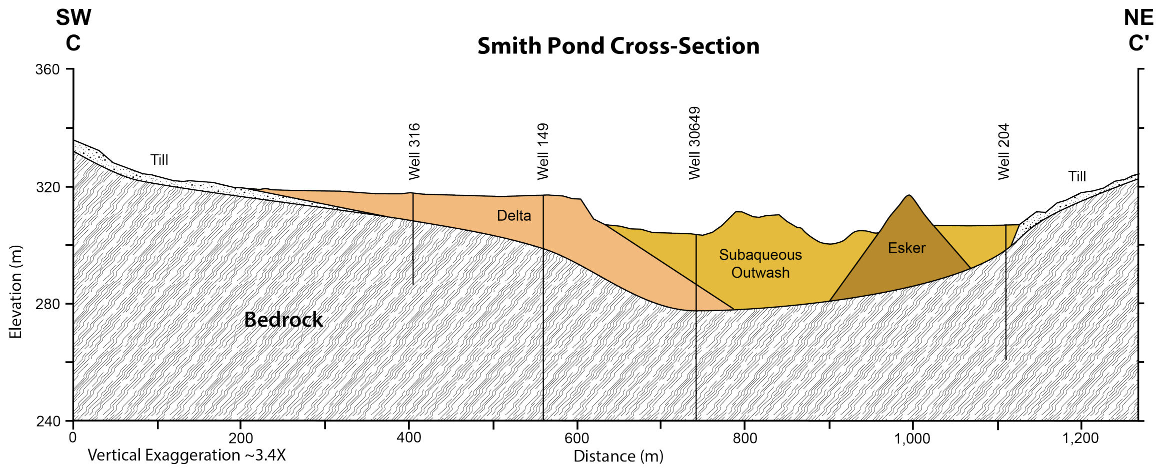

Figure 30: Cross-section C-C' (Newport Center Quadrangle) shows the distribution of esker, subaqueous outwash, and deltaic sediments near the drainage divide between Mud Brook and Stoney Brook (see Fig. 28 for location of section). The stream feeding the delta flowed along a meltwater channel from a glacial lake dammed in the Missisquoi River valley. Note that all well logs record sand and gravel and contacts between units are inferred from the mapped landforms.

(1999). The Lake Eligo outlet remained the stable long-term outlet for this lake and must have hosted a very large discharge sourced 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 (Fig. 31).

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. 32). While the elevation of this lake was only ~14 m higher than the modern lake, its extent was considerable, particularly in Québec (Fig. 32; Parent and Occhietti, 1999).

As noted earlier, the Clyde River had deposited a large delta in the higher stage of Glacial Lake Memphremagog that extended across the lake basin (Fig. 19). When the Lac Nick outlet was uncovered and lake level fell, this delta dammed water south of the delta (the area where South Bay is today). Shortly after water levels fell in the main lake, the ponded water quickly eroded a channel through the delta, what is now the narrow channel connecting South Bay to the main lake (Fig. 33).

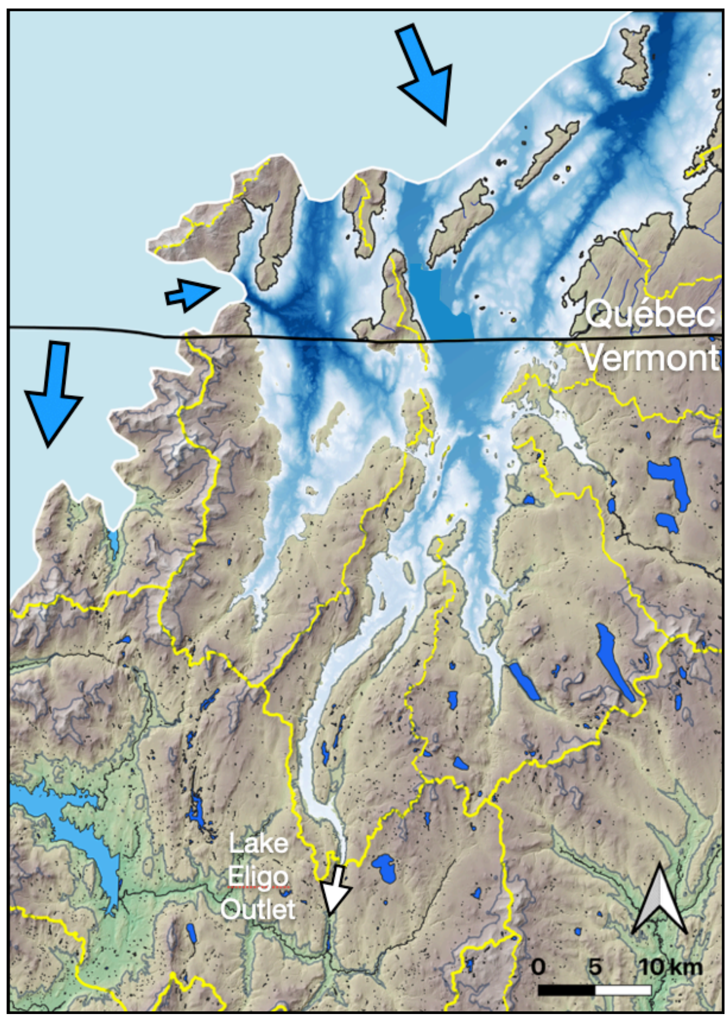

Figure 31: Extent of Glacial Lake Memphremagog in both Vermont and Québec. Ice sheet margins in Québec are from multiple moraines mapped by Parent and Occhietti (1999). Blue arrows show inferred ice sheet flow.

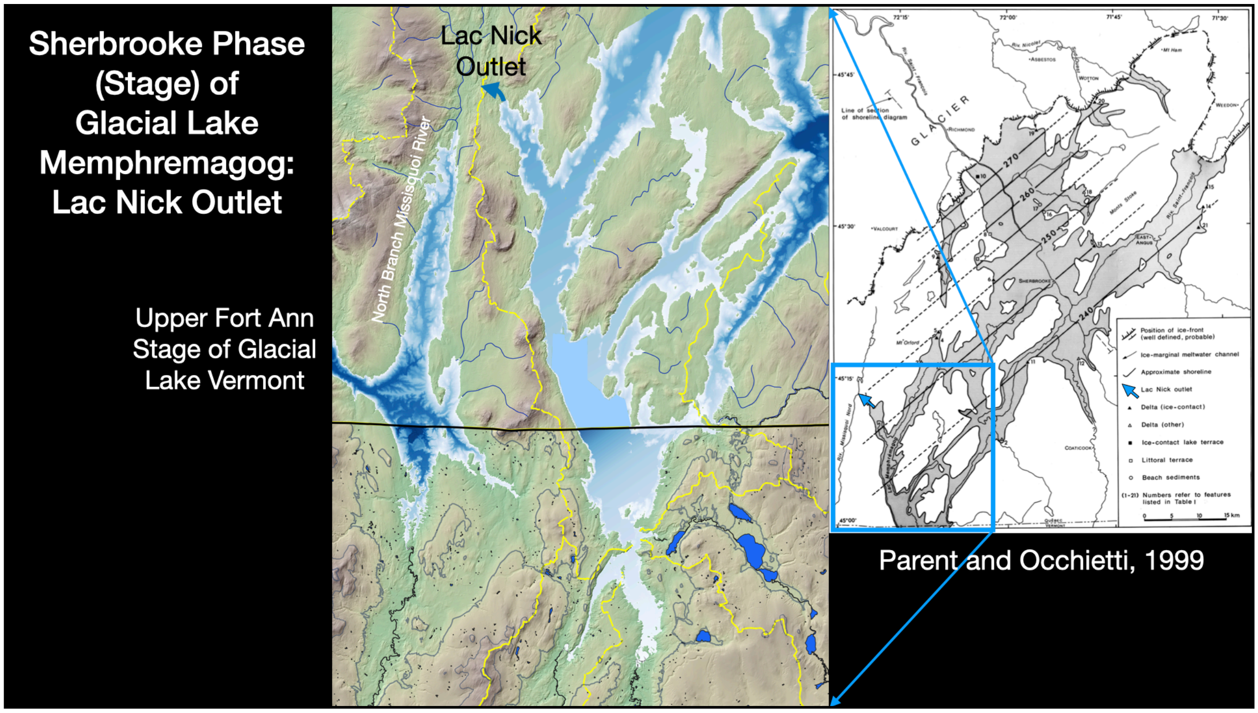

Figure 32: Sherbrooke Stage of Glacial Lake Memphremagog. Continued northwestward retreat of the ice sheet uncovered a lower outlet, the Lac Nick outlet. Lake level fell ~85 m and outlet waters now flowed into an arm of Glacial Lake Vermont (Fort Ann Stage) occupying the North Branch of the Missisquoi River valley.

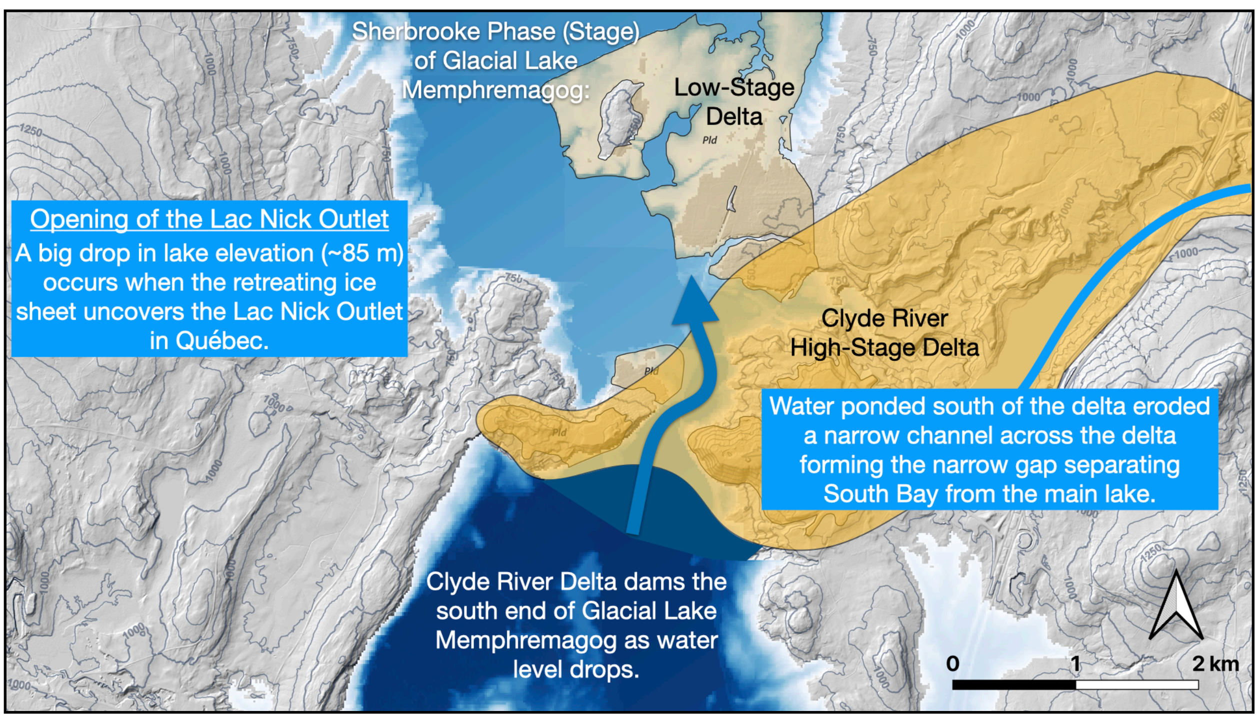

Figure 33: When the Lac Nick outlet was uncovered and lake level fell ~85 m, lake water ponded south of the Clyde River delta eroded a channel through the delta, what is now the narrow channel separating South Bay from the main lake. During the Lac Nick stage, the Clyde River deposited a delta at this 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.

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. 33).

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. 34; 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.

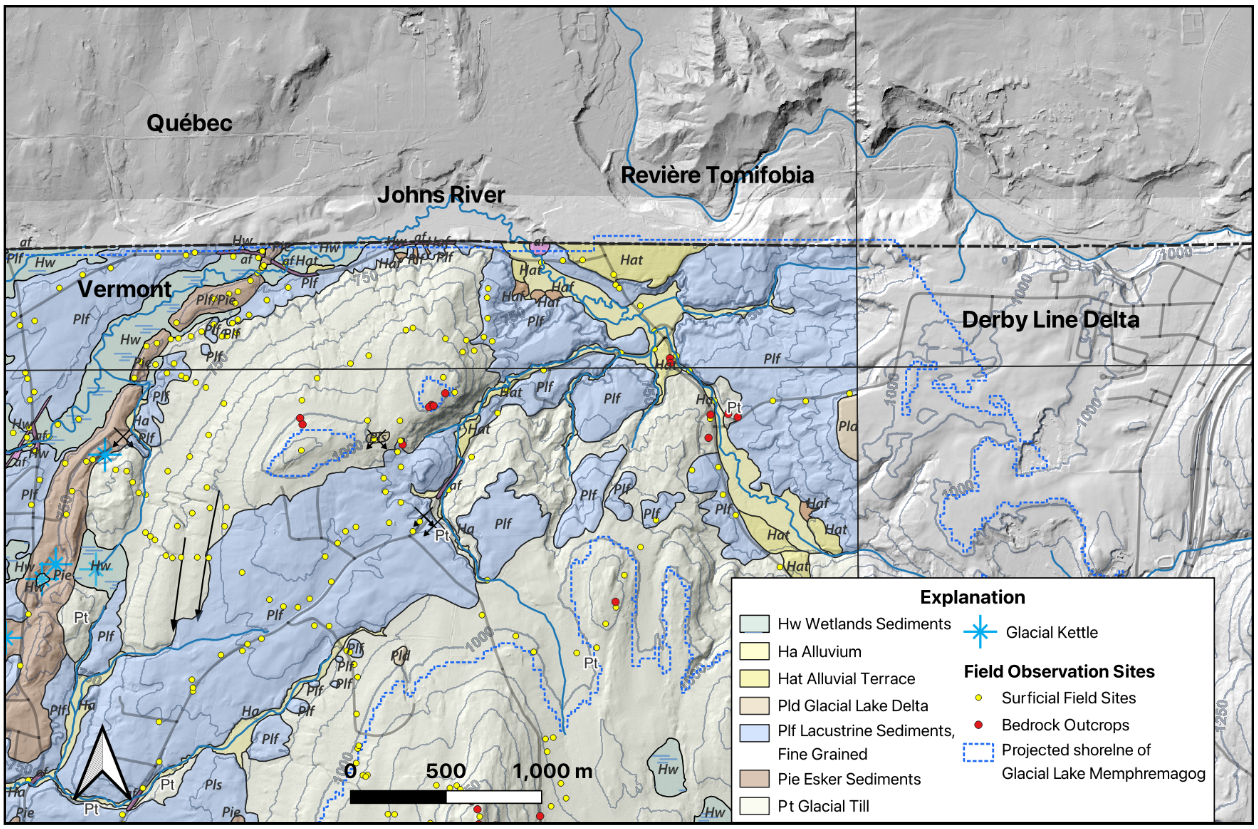

Figure 34: Map depicts the area surrounding the NE corner of the Newport Quadrangle. During the high, stable phase of Glacial Lake Memphremagog, the Revière Tomifobia deposited a large delta where Derby Line is located. This delta buried the former Revière Tomifobia channel which followed the course 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 and the site of the Newport's sewage treatment plant. Smaller streams too are depositing deltas where they enter the lake. In addition to deltas, streams have deposited sediments in alluvial fans, however most fans mapped within the Newport area are relatively small.

Landslides are common along streams where slopes are oversteepened by stream erosion (Fig. 35). 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.

Figure 35: Small landslide along Mud Brook (Newport Center Quadrangle) provides fresh exposures of glacial till. Lag boulders sourced from the underlying till litter the channel of Mud Brook.

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.

Chandler, B. M. P., Lukas, S., and Boston, C. M., 2020, Processes of 'hummocky moraine' formation in the Gaick, Scotland: insights into the ice-marginal dynamics of a Younger Dryas plateau icefield: Boreas, v. 49, no. 2, p. 248-268.

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.

MacClintock, P., 1966a, Glacial Geology of the Irasburg 15' Quadrangle, Vermont, Vermont Geological Survey Open-File Report VG66-2 and map (1:62,500).

-, 1966b, Glacial geology of the Irasburg quadrangle, Montpelier, Vt., Vermont Geogical Survey, Open-file report / Vermont Geological Survey, v. no 1966-2, 14 leaves p.:

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.

Springston, G. E., and Wright, S. F., 2024, The Surficial Geology of the Montpelier 1:100,000 Quadrangle, Vermont: Vermont Geological Survey Open File Report VG2024-1.

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.

Thompson, W. B., Dorion, C. C., Ridge, J. C., Balco, G., Fowler, B. K., and Svendsen, K. M., 2017, Deglaciation and late-glacial climate change in the White Mountains, New Hampshire, USA: Quaternary Research, v. 87, no. 1, p. 96-120.

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.

-, 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.

-, 2025a, Surficial Geologic Map and Cross-sections of the Newport Center 7.5-minute Quadrangle, Vermont: Vermont Geological Survey Open File Report VG2025–1.

-, 2025b, Surficial Geologic Map and Cross-sections of the Sutton 7.5-minute Quadrangle, Vermont: Vermont Geological Survey Open File Report VG2025-2.

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.

Wright, S. F., Dunn, R. K., Springston, G. E., and Grigg, L. D., 2024, The Glacial, Late-Glacial, and Postglacial History of North-Central Vermont: Field Trip Guidebook for the 85th Reunion of the Northeast Friends of the Pleistocene, p. 1-58.