Final Report
Surficial Geologic Maps of the
Mt Worcester (NW Quadrant) and Warren Quadrangles, Vermont[1]

Report accompanies Vermont Geological Survey Open File Maps VG2023-3, 4

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Introduction

The Mt Worcester and Warren 7.5-minute Quadrangles both lie along the Worcester/Northfield mountain ranges in north-central Vermont (Fig. 1). They are two of 36 quadrangles lying within the Montpelier 1-degree sheet which has been the focus of surficial geologic mapping during the past 20 years. This report compliments surficial geologic maps and cross-sections for the two quadrangles (Vermont Geological Survey Open File Reports VG2023-3 and VG2023-4), summarizes the results of surficial geologic mapping during the 2022 field season, and offers a brief interpretation of the geologic history of these areas based on those findings. The Waterbury and Middlesex Quadrangles were also part of this project and maps, cross-sections, and a report for these areas are available as Vermont Geological Survey Open File Reports VG2023-1 and VG2023-2 (Fig. 1).

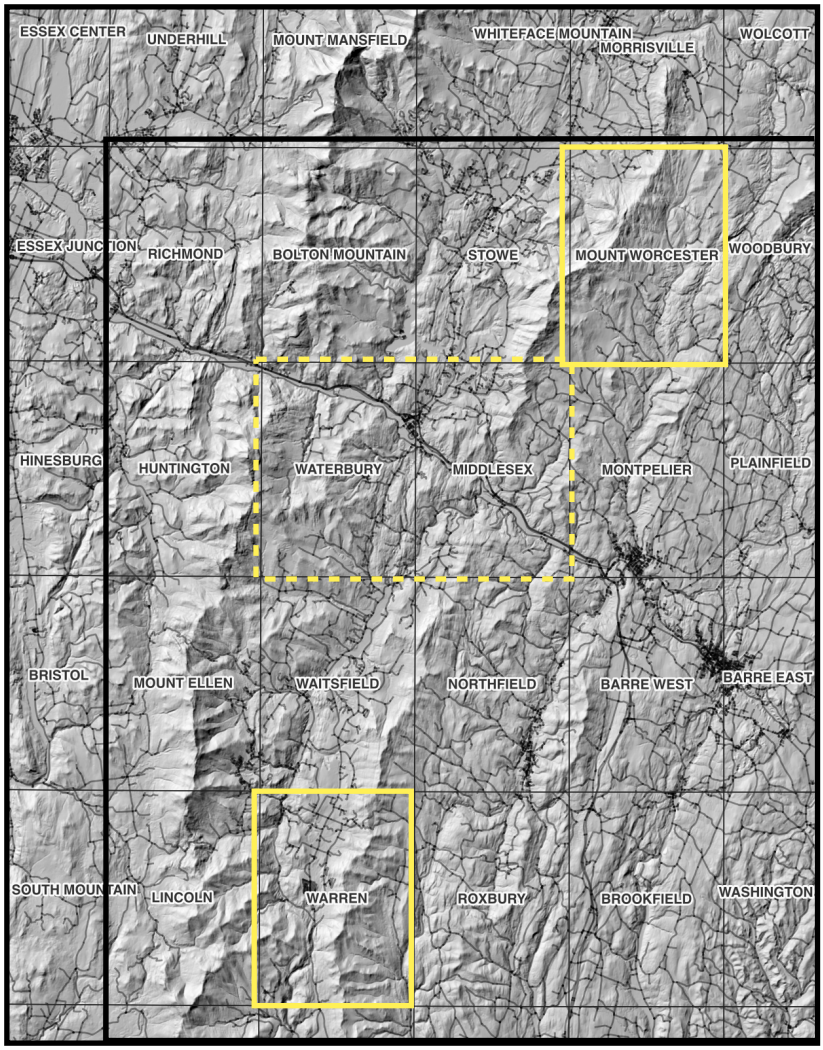

Figure 1: Solid yellow boxes outline the locations of the Mount Worcester and Warren Quadrangles whereas dashed yellow box shows the location of the Waterbury and Middlesex Quadrangles that are also part of this larger project. Black box outlines the western half of the Montpelier 1-degree sheet.

This report outlines the results of mapping the surficial geology of just the northwestern corner of the Mount Worcester Quadrangle, areas northwest of the crest line of the Worcester Range. George Springston is mapping the remainder of the quadrangle and our combined work will eventually be compiled as a single map. Figure 2 shows individual field observation points within the area. In general, areas below the elevation of Glacial Lake Winooski demanded the most field time as they

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contained a wide variety of lacustrine sediments in addition to glacial till, both in place and transported via landslides after its initial deposition. Numerous landslides along tributaries to Moss Glen Brook provided insights to the thick accumulations of surficial materials in the headwaters of this brook. In particular, there is good evidence that a glacial lake occupied the upper reaches of this valley well above the elevation of Glacial Lake Winooski.

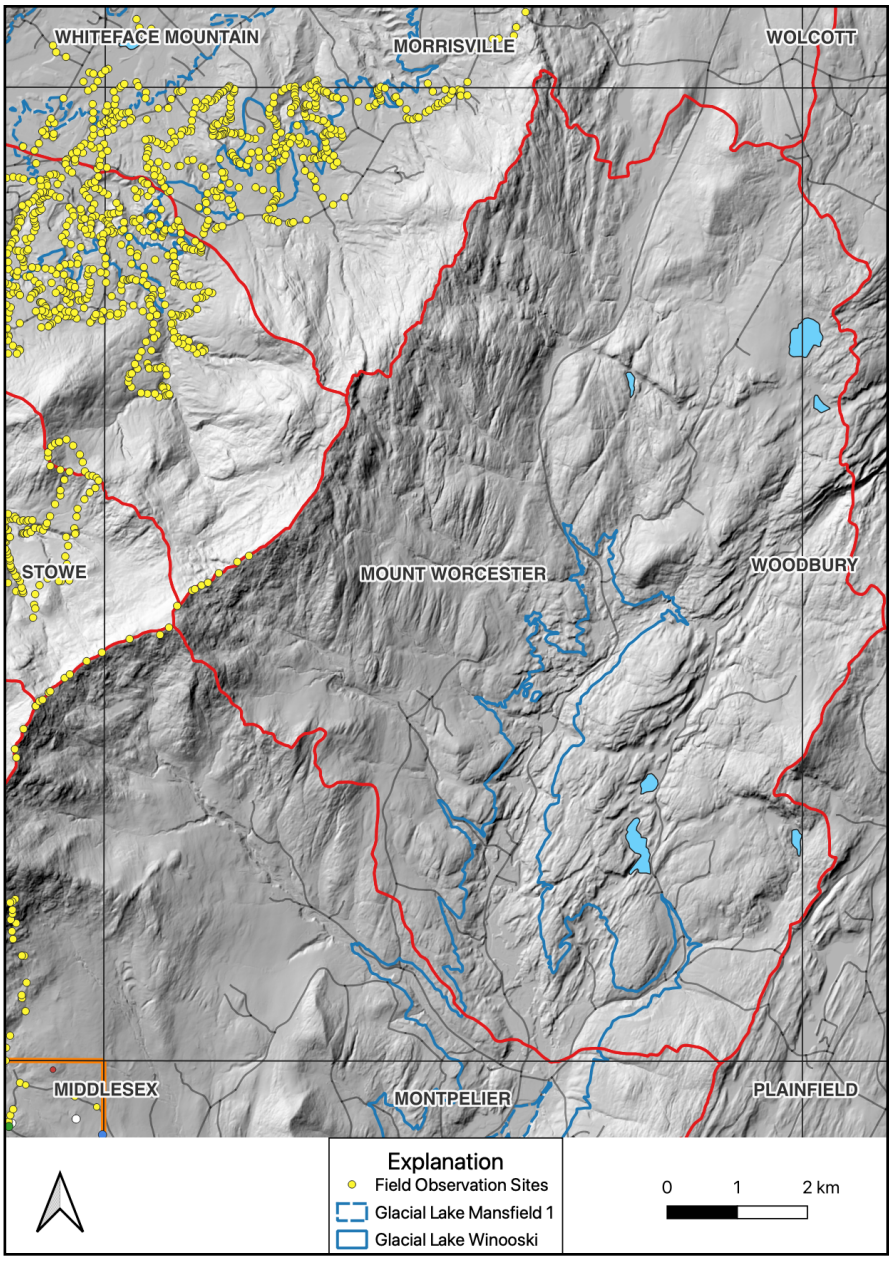

Figure 2: Yellow points on LiDAR hillshade map mark field observation sites within the Mount Worcester and adjacent quadrangles. The area mapped as part of this project lies northwest of the ridgeline marking the crest of the Worcester Mountains. Observations were concentrated in areas near and below the elevation Glacial Lake Winooski. Red lines outline watershed boundaries.

The Warren Quadrangle is the second area described in this report. This quadrangle and adjacent areas are depicted in Figure 3. The northwestern part of the quadrangle lies within the Mad River watershed that was previously mapped by Dunn and others (2007b). The southeastern part of the quadrangle lies within the watershed of the Third Branch of the White River that was mapped by Larsen and others (2003a), but this work was never published. The unmapped north-eastern and southwestern corners of this quadrangle were mapped as part of this project (Fig. 3). Unlike many areas that lie at or below the elevation of one or more glacial lakes, the surficial geology of the mapped area is fairly simple in that almost all of the surficial materials underlying this upland area consist of glacial till, modern alluvium, or wetlands deposits. Glacial striations were observed and measured on numerous bedrock outcrops, particularly along the Warren Mountain road.

Location and Geologic Setting

The Mount Worcester and Warren quadrangles are both topographically rugged areas; both quadrangles straddling the Worcester/Northfield Range (Figs. 1—3). The Warren Quadrangle contains the drainage divide (Granville Gulf) between the north-flowing Mad River and the south-flowing First Branch of the White River (Fig. 3) whereas the Mount Worcester Quadrangle is dominated by small tributary streams draining west.

The bedrock geology of the area is summarized on the Vermont Bedrock Geologic Map (Fig. 2; Ratcliffe et al., 2011). Rocks underlying both quadrangles largely consist of metasedimentary rocks (schist and phyllite) that were originally deposited as sediments in the Iapetus ocean along the margin of Laurentia from late Precambrian through early/middle Ordovician time. Locally igneous rocks intruded these sediments or erupted across the ocean floor. These rocks were subsequently deformed and metamorphosed during the Taconic Orogeny and again during the Acadian Orogeny. 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.

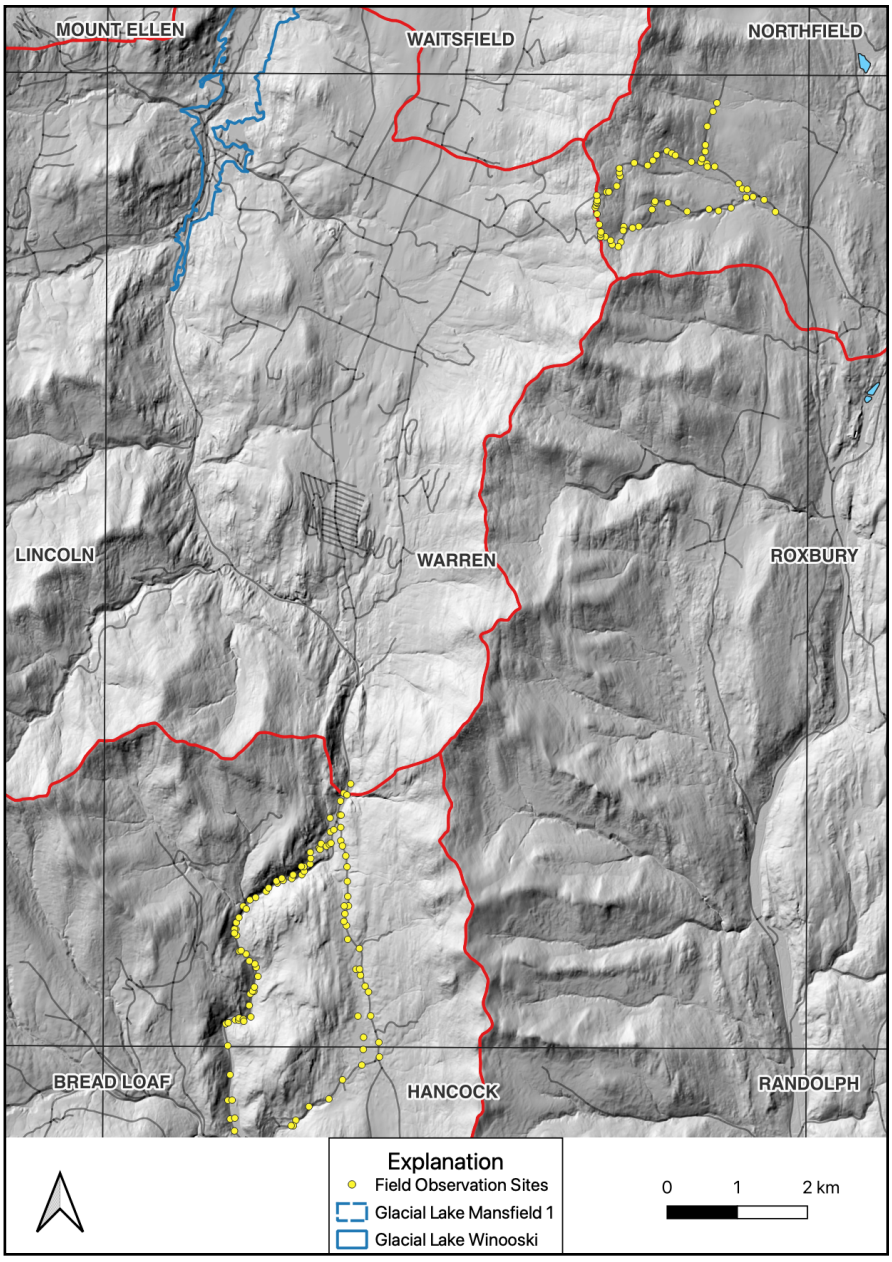

Figure 3: LiDAR hillshade map of the Warren Quadrangle. Yellow points show field observation points garnered during the current field season in the northeast and southwest corners of the quadrangle. The Mad River Watershed (northwest corner of quadrangle) was mapped by Dunn et al., 2006 and the watershed encompassing the Third Branch of the White River was mapping by Dunn, Larsen, Springston and Donahue (Unpublished, ~2005). Red lines mark watershed boundaries.

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 mountains. 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 north-south in the valley between the Green Mountains and Mount Worcester/Northfield Range and flowed ESE up the Winooski River valley (Wright, 2015). As a consequence of this complete ice cover during peak glaciation, the mountains are largely mantled by till with isolated pockets of organics occurring in wetland areas.

As the ice sheet thinned and retreated to the north and northwest, subglacial drainage systems within the waning ice sheet deposited eskers in most of the major valleys (Wright, 2018b, 2020). When the ice sheet retreated north of the drainage divide separating the White River drainage to the southeast from the Winooski River drainage to the northwest a lake began to grow between the divide and the retreating ice front. This lake, Glacial Lake Winooski, would grow to become the largest glacial lake in north-central Vermont (Larsen, 1972a, 1987; Larsen et al., 2003b; Wright, 2018a). Consequently, in most of the region's valleys older ice-contact sediments are partially or completely overlain by younger glaciolacustrine sediments. In addition to extensive deposits of fine-grained sediments deposited in the deeper waters of these lakes, deltas formed along the lake margins where streams entered. After the glacial lakes drained these same streams have eroded channels through the glaciolacustrine sediments during the Holocene leaving abandoned fluvial terraces along their valleys. Further stream erosion in the uplands has led to the deposition of numerous alluvial fans at the base of steep slopes (Bierman et al., 1997).

Prior Work

Surficial geologic mapping in the Mount Worcester and Warren quadrangles was undertaken during the 1950's and 1960's and these unpublished open file maps assembled into the Vermont State Surficial Geologic Map (Stewart and MacClintock, 1970). This mapping was done on 15-minute (1:62,500 scale) base maps. Due to the large areas involved, much of this work was conducted in a reconnaissance fashion. The Mount Worcester 7.5-minute quadrangle comprises the northeastern quadrant of the Montpelier 15-minute quadrangle which was mapped by Stewart (1956-1961). No subsequent mapping has occurred in the northwestern quadrant of the Mount Worcester quadrangle prior to the work described here. However, the adjacent Stowe quadrangle (immediately west) was recently mapped by Wright (2020) and materials and contacts continued into the Mount Worcester quadrangle.

The Warren 7.5-minute quadrangle comprises the southeastern quadrant of the Lincoln Mountain 15-minute quadrangle which was mapped by Calkin and MacClintock (1965). Subsequent to this mapping the general glacial geology of this part of Vermont was extensively updated by Larsen (1972a, 1987) and Larsen et al. (2003b). Detailed surficial geologic mapping of large portions of the Warren quadrangle occurred when the Mad River watershed was mapped by Dunn and others (2007b) and the geologic history of the area and field stops described in a field guide to region (Dunn et al., 2011). A small area along the eastern boundary of the Warren quadrangle was mapped by Larsen and others (2003a) as part of a larger project focused on mapping the Third Branch of the White River.

Methods

Traditional field techniques and digital mapping were employed to generate a surficial geologic map of the area. Specifically, field observations and 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. A stand-alone GPS unit allowed most field observations to be located with an accuracy of 3–5 m. Field mapping utilized LiDAR hillshade imagery with.LiDAR-derived contours as a base map supplemented by traditional topographic maps and satellite imagery. The locations and observations gathered in the field were imported into GIS software (QGIS) and utilized to draw geologic 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, 2022b) and conform to the unified set of mapping units developed by the Vermont Geological Survey.

In the Warren quadrangle new field work was largely confined to areas not mapped by either Dunn and others (2007b) or Larsen and others (2003a). However, their mapping and compilations were limited to the 1:24,000 topographic basemap available at the time of their work. Consequently, the locations of geologic units and contacts were substantially revised utilizing the LiDAR hillshade imagery and detailed topography gleaned from the LiDAR derived digital elevation models (DEM's). These changes were reviewed and generally agreed to by Dunn and Springston (pers. comm. 2023).

One geologic cross-section was constructed within each of the two quadrangles. Surface observations were augmented by private water well logs to interpret the subsurface surficial geology in these areas. The cross-sections appear both on the geologic maps and further along in this report.

Mount Worcester and Warren Surficial Geologic Maps

The surficial geologic maps that accompany this report shows the aerial distribution of different types of surficial materials, landforms constructed of these materials, glacial striations, large erratics, landslides, and other geological phenomena (Wright, 2023; Wright et al., 2023). During the spring of 2018 the Vermont Geological Survey developed a uniform set of mapping units which are utilized on these 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 and these locations were recorded and used when constructing the map. However, in most areas the location of these contacts is interpreted from field observations, distinctive landforms, and aerial imagery. Every effort was made to make these contacts as accurate as possible, but there is an element of interpretation in their placement.

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, 2022b, c). 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 gradually thinned and retreated across the area. (2) Lacustrine Deposits were deposited in ice-dammed glacial lakes that occupied the 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 . Outcrops are abundant where glacial till and other surficial materials are thin. No attempt was made to map all outcrops, especially in the upland areas where outcrops are numerous and closely spaced.

The orientation of glacial striations and grooves were measured where they were observed in the field. Both these and an earlier compilation by Wright (2015) are included on the geologic maps.

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 also appear in landslides where the till is medium to dark gray and very dense. 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 most areas, the till cover is thin (less than 2 to 3 meters) and abundant outcrops are present. However, in limited areas the till is sufficiently thick to completely bury the underlying bedrock.

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

Meltwater streams flowing in tunnels beneath the thinning and retreating ice sheet deposited sand and gravel in distinctive ridges referred to as eskers (Pie). Areas of sand and gravel inferred to be ice-contact deposits but not forming distinctive landforms were mapped as undifferentiated ice-contact deposits (Pi). These deposits may be the eroded remnants of eskers, kames, or may be irregular accumulations of sand and gravel deposited in subaqueous fans close to the margin of the ice sheet. Abandoned ice-marginal channels are sometimes preserved.

Lacustrine Deposits

Lacustrine deposits are those that accumulated in one of several different ice-dammed glacial lakes that occupied the Winooski river valley and its tributary valleys as the ice sheet retreated across the area. Specifically in order of occurrence, lakes occurring in these two quadrangles are named Glacial Lakes Granville (outflow through Granville Gulf), Winooski (outflow through Williamstown Gulf), and Mansfield (outflow through both the Gillette Pond and the Huntington Valley). The projected shorelines of these lakes are shown on the geologic maps. Below the elevations of these lakes, the valleys contain a variety of sediments uniquely deposited in lakes.

Fine-grained lacustrine sediment (Plf)

A widely distributed lacustrine sediment mapped in the quadrangles consists of silt, clay, fine-, and very fine-grained sand. These sediments were deposited in quiet-water environments where fine-grained sediments could settle to the bottom of the lake.

Glacial Lake Deltas (Pld)

Sand/gravel deposits occurring at the mouths of tributary streams with terrace surfaces at or near the projected elevations of these lakes are mapped as deltas (Pld). Gravel pits have been established in many of these deposits.

Stratified diamict (Pldi)

Stratified diamict consists of interlayered diamict (remobilized till that entered the lake as debris flows—mud slides—from the steep surrounding hillsides) and layers of sand/silt/clay. In most areas this material looks like till, but rare exposures (landslides) reveal the layering. Areas mapped as stratified diamict are marked by (1) thick accumulations of sediment in tributary valleys forming gently sloping surfaces, (2) surface exposures of both diamict and lacustrine sediments in close proximity, and (3) well logs similarly recording a mixture of diamict (“hardpan”) and lacustrine sediments. Thick sections of stratified diamict were deposited in many of the lakes occupying the steep-sided valleys common in the mountains. Stratified diamict also extends above the projected lake shorelines where it

consists of layers of diamict with no intervening lacustrine sediments. This indicates that landslides continued to accumulate in tributary valleys after the glacial lakes had completely filled with sediment. It is nearly impossible to accurately map this unit because it consists largely of transported glacial till and cannot be distinguished from in-place till.

Holocene Deposits

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.

Alluvium (Ha)

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 mapped areas are relatively small and have deposited correspondingly limited areas of alluvium. However, the alluvium transported by branches of the White River and the Mad River in the Warren quadrangle and Moss Glen Brook in the northwestern quadrant of the Mount Worcester quadrangle occur on a larger scale.

Alluvial terrace deposits (Hat)

Alluvial terrace deposits are stream sediments (alluvium) occurring on terraces above but adjacent to modern streams. As streams eroded channels more and more deeply through earlier-deposited sediments, older channels and adjacent flood plains were 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.

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. Relatively few wetland areas were mapped in these two quadrangles and most occur in areas underlain by till.

af Artificial Fill

Artificial fill was mapped where significant volumes of material were utilized for the construction of state highways, town roads, and dams. In most cases fill consists of sand and gravel.

Glacial and Post-Glacial history of the Warren and Mount Worcester Quadrangles

The surficial geologic materials and landforms mapped in the Warren and Mount Worcester 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 History

Glacial till, erratics, and striations on the summits of the region's highest mountains indicate that the ice sheet in northern New England was sufficiently thick to completely cover the mountains. At the Last Glacial Maximum the ice sheet surface was well over 2 km above the Green Mountain ridge-line and almost 3 km above the ground surface in the Champlain valley.

Striations measured in the map area in addition to those compiled from other sources indicate that regional ice flow was from northwest to southeast across northern Vermont (see maps; Wright, 2015). Striations in the broad valley separating the Green Mountains from the Northfield-Worcester Range and one area of grooved till in the northwestern quadrant of the Mount Worcester quadrangle (Fig. 1) are oriented parallel to this valley indicating that the valley guided ice flow when the ice sheet had thinned sufficiently to be topographically controlled.

Ice Retreat Timeline

The ice sheet was at its maximum extent, the Last Glacial Maximum (LGM) ~25,000 years ago when it built terminal moraines southeast of New England marked by Block Island, Martha's Vineyard, and Nantucket (Ridge, 2016). From this terminal moraine, the ice margin retreated to southeastern Vermont (the junction of Vermont, New Hampshire, and Massachusetts) by ~15,600 years ago and was at the Québec border by ~13,300 years ago (Ridge, 2016), a span of a little over 2,000 years. As was noted earlier, most of the surficial materials and landforms mapped in the Warren and Mount Worcester Quadrangles were deposited during this period of rapid ice sheet thinning and retreat.

Ice Sheet Hydrology

Rapid thinning and retreat of the ice sheet across northern New England occurred because the ice sheet was melting (losing mass) much more rapidly during the summer months than it was gaining mass by snowfall during the winter months. A consequence of this was that tremendous volumes of meltwater (melted snow and ice) were routed beneath and along the margins of the ice sheet during those summer months.

Ice-marginal meltwater channels were mapped along the western flank of the mountains in the Mount Worcester quadrangle. These channels are parallel to the inferred margin of the ice sheet and are in places eroded into till and in other areas eroded in areas of sand and gravel.

Most of the meltwater generated from the rapidly thinning and retreating ice sheet traveled along the base of the ice sheet in subglacial tunnels. Eskers are sinuous ridges of sand and gravel that accumulated in these subglacial tunnels. An esker is inferred from deposits in the upper Mad River valley mapped by Dunn and others (2007b; 2011). Sediments discharged from the mouth of this esker tunnel are likely the source of ice-contact deposits mapped immediately north of Granville Gulf.

Glacial Lake History

A series of glacial lakes were impounded by the retreating ice sheet on both sides of the Green Mountains. Larsen (1972b, 1987), expanding and clarifying earlier work by Merwin (1908), recognized that the three north-flowing tributaries to the Winooski River east of the Green Mountains were each occupied by ice-dammed lakes (Fig. 4). The Mad River valley hosted Glacial Lake Granville which drained across the drainage divide at Granville Notch. Most of the glaciolacustrine sediments mapped within the Warren quadrangle were deposited in this lake.

Larsen (1972b, 1987) also recognized that the elevation of Lake Granville fell dramatically when the ice sheet retreated north of the Winooski River valley and the three smaller lakes previously restricted to the tributary valleys merged to form one larger lake, Glacial Lake Winooski (Fig. 5). This lake drained out the lowest outlet in the basin adjacent to Williamstown Gulf. Paleo-lake-level elevations, determined by the elevations of deltas in these valleys, confirm this sequence of lake formation east of the Green Mountains (Dunn et al., 2007a; Larsen, 1972b, 1987).

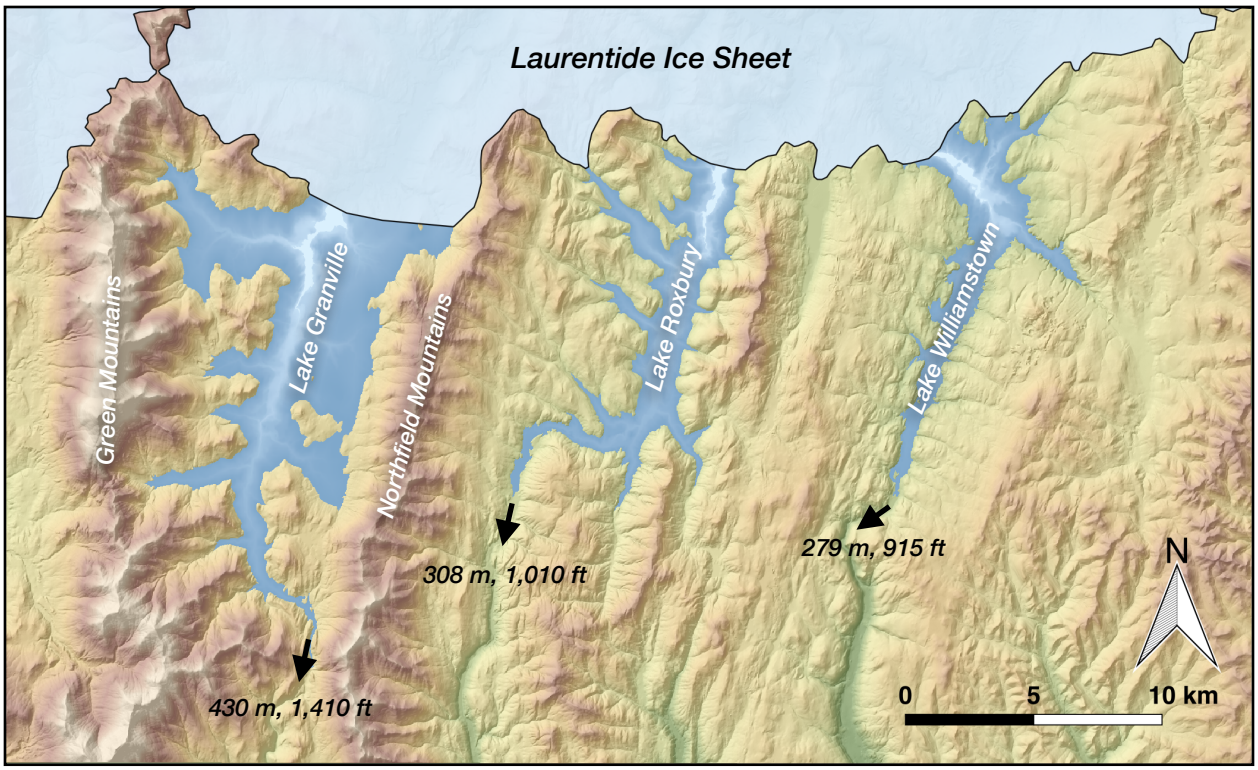

Figure 4: Configuration of glacial lakes in north-flowing tributaries to the Winooski River (Larsen, 1972, 1987; Wright, 2018). Elevations of Lake Granville in the Mad River valley, Lake Roxbury in the Dog River Valley, and Lake Williamstown in the Stevens Branch valley were dictated by the elevations of the drainage divides at the south end of these valleys.

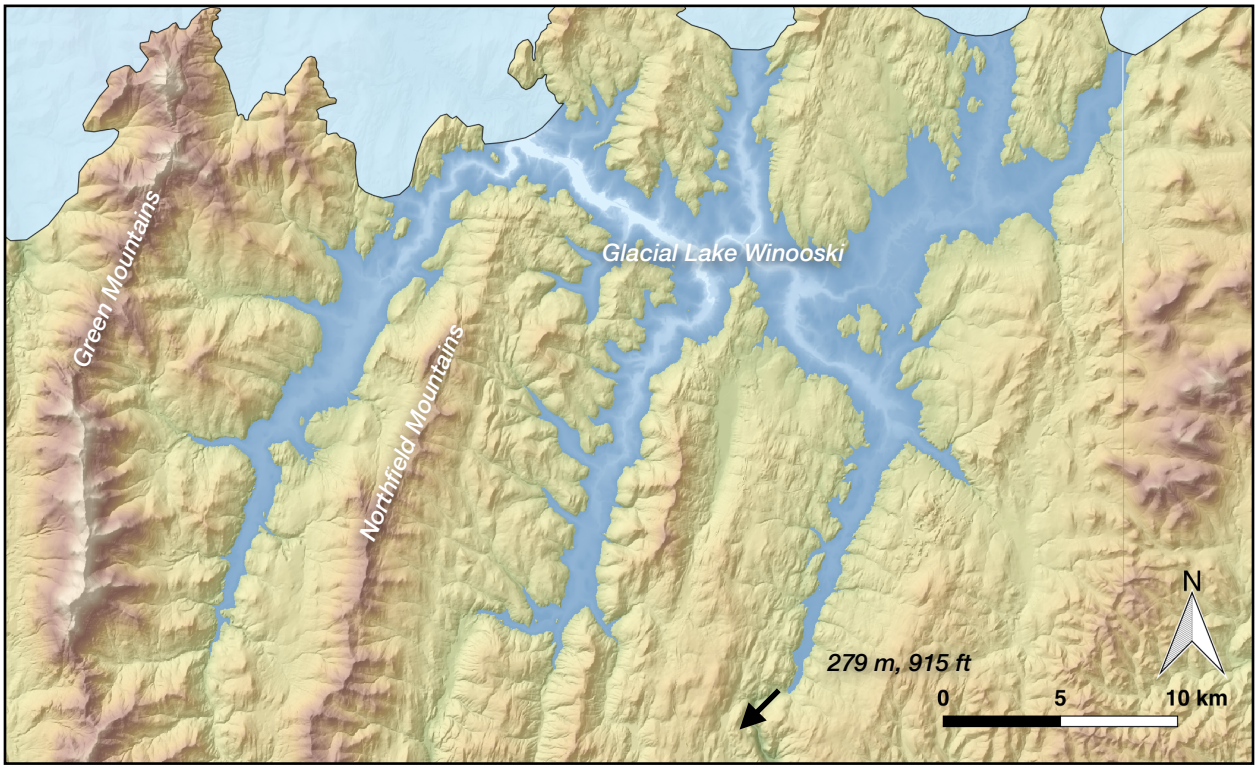

Figure 5: Retreat of the ice sheet to the north and west allowed smaller lakes dammed in the tributary valleys to merge forming Glacial Lake Winooski. This lake drained south through Williamstown Gulf, the lowest drainage divide in the basin.

Correlation of varve records indicates that Glacial Lake Winooski began ~14,170 yr BP and lasted for ~375 years (Wright, 2022b).

Retreat of the ice sheet WNW, down the Winooski River valley, uncovered a lower outlet allowing Glacial Lake Winooski to partially drain forming Glacial Lake Mansfield (Larsen, 1972a, 1987; Wright, 2018a). This drainage event is well recorded in exposures of glacial lake sediments at the Waterbury Reservoir and correlation with the varve record dates this event to ~13,794 yr BP (Larsen et al., 2003b; Wright, 2022a, b). Further ice retreat into the Champlain valley allowed Glacial Lake Mansfield to drain and the Winooski River valley was flooded as an arm of Glacial Lake Vermont, the very large lake dammed in the Champlain valley by the ice sheet.

In general, most of these glacial lakes contain a fining-upwards sequence of sediments. The oldest sediments accumulated close to the ice sheet and are dominated by coarse sand and gravel deposited in subaqueous fans near the mouths of subglacial tunnels or in eskers deposited in those tunnels. As the ice sheet retreated farther away the grain size dropped to fine sand then silt and clay as the energy of this depositional system correspondingly dropped. These younger, fine-grained lacustrine sediments bury older, coarser-grained sediments in most areas and are exposed across broad areas.

Deltas deposited by streams flowing off the surrounding mountains were recognized in many areas. Because the top surfaces of deltas lie very close to the elevation of the lakes they form in, deltas can be used to confirm and refine the projected shorelines of glacial lakes. In several areas Glacial deltas consist of relatively thin veneers of sand and gravel deposited on top of till or silt and clay. A cross-section from the Mount Worcester quadrangle shows deltaic sediments underlying broad, gently-sloping landforms interpreted as deltas that formed in Glacial Lake Winooski followed by Glacial Lake Mansfield (Fig. 6). Glacial till (hardpan) recorded in well logs may be in-place till or remobilized till (diamict) that was deposited as debris flows from the surrounding mountains.

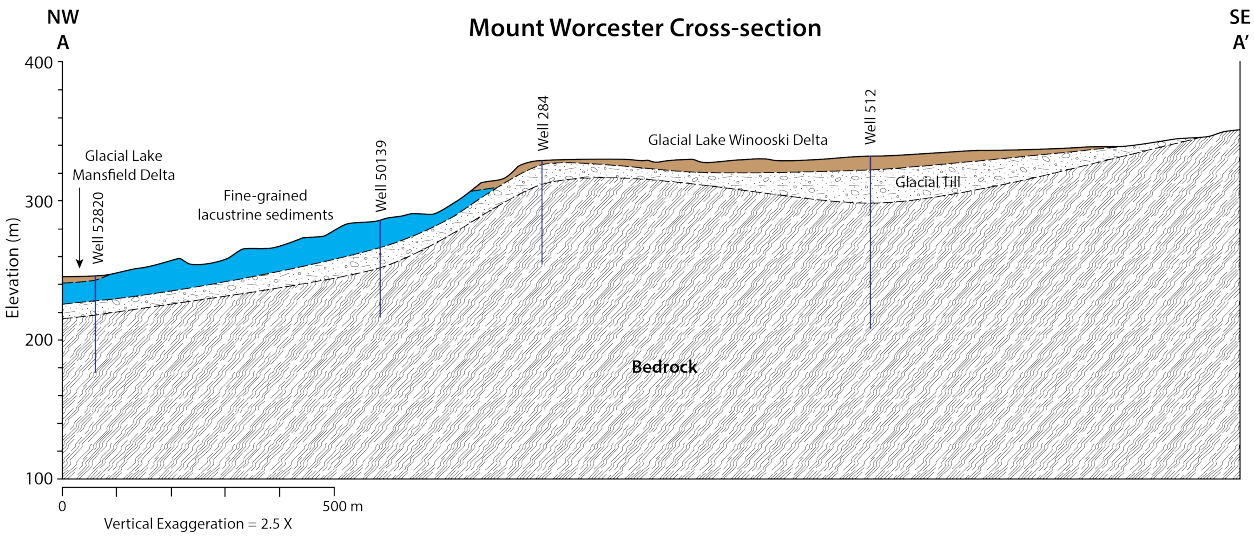

Figure 6: Northwest-southeast geologic cross-section from the Mount Worcester quadrangle (see map for location; Wright, 2023) is dominated by glaciolacustrine sediments. A broad, very gently sloping area of sand and gravel near the projected elevation of Glacial Lake Winooski is interpreted as a thin delta deposited by small streams flowing northwest off the adjacent slopes of Mount Worcester. A broad area of fine-grained lacustrine sediments deposited in Glacial Lake Winooski is overlain by sand and gravel deposited on a Glacial Lake Mansfield delta.

A cross-section across the Mad River immediately south of Warren Village similarly shows a broad terrace of sand/gravel interpreted as a Glacial Lake Winooski delta deposited by Freeman Brook (Fig. 7). Glaciolacustrine sediments mapped in the area above this elevation were deposited in the higher-elevation Glacial Lake Granville. Holocene

erosion of glacial, ice-contact, and glaciolacustrine sediments by the Mad River and its tributaries has left alluvial terraces marking times when these valleys were partially filled by large volumes of sediment (Fig. 7).

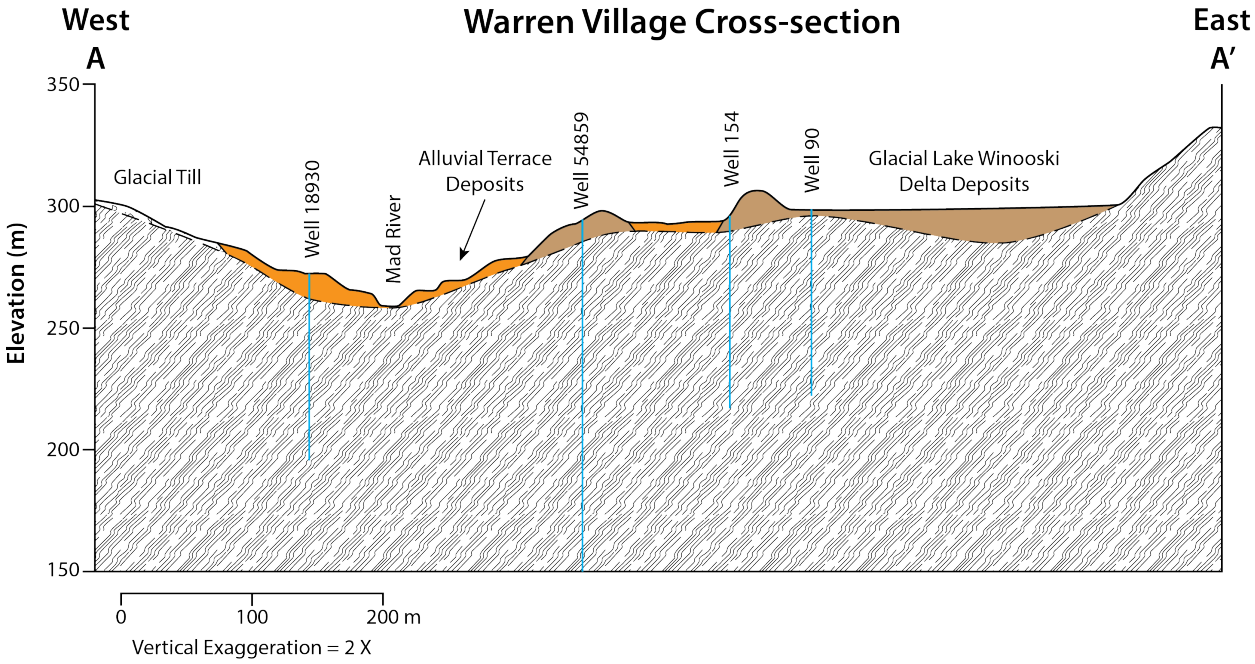

Figure 7: Geologic cross-section across the Mad River valley at Warren Village. Terrace above the village is underlain by sand and gravel interpreted to be part of a Glacial Lake Winooski delta deposited by Freeman Brook where it entered the lake. Subsequent erosion by both Freeman Brook and the Mad River have left an abandoned channel and a series of alluvial terraces above the modern streams.

Several nicely exposed sections fine-grained glacial lake sediment and diamict occur at high-elevations along Moss Glen Brook indicating that a small, high-elevation lake was trapped in the upper reaches of this valley during ice retreat (Fig. 8).

Stratified diamict, a deposit consisting of interbedded debris flows and lacustrine silt/sand was mapped across extensive areas in the Mount Worcester quadrangle based on field observations, well logs, and thick accumulations of surficial materials revealed by landform patterns. These deposits grade from pure debris flow material (remobilized till) above the lake surface to deposits with increasing amounts of fine sand/silt interbedded with the debris flows farther into the lake basin.

Post-glacial History

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 growing here.

The glacial lakes described previously were all dammed by the receding ice sheet. Those lakes all drained, either completely or in stages as the ice sheet both thinned and retreated to the north. Streams began eroding the sediments deposited in those lakes as soon as they drained. Abandoned stream channels and terraces are evidence of this erosion as are the uneroded patches of lake sediments scattered along the hillsides (Fig. 7). Broad areas of alluvium in all the major stream valleys are sourced from both older lake sediments as well as till eroded from the uplands.

Figure 8: Landslide along Moss Glen Brook (Mount Worcester quadrangle) reveals fine-grained glaciolacustrine sediment capped by gravel occurring ~50 m above the projected elevation of Glacial Lake Winooski.

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