

# Report on the Surficial Geology of the Southern Half of the Pico Peak 7.5-Minute Quadrangle, Vermont

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View looking north, up the Ottauquechee River valley. Thin till covers steep mountain slopes on both sides of the valley. The valley bottom is filled with modern river alluvium, here covered by a beaver pond. Route 4 (left side of photo) is built on a sand and gravel terrace interpreted to be old river alluvium. Tree-covered ridge on right is an esker, segments of which rise above the alluvium.

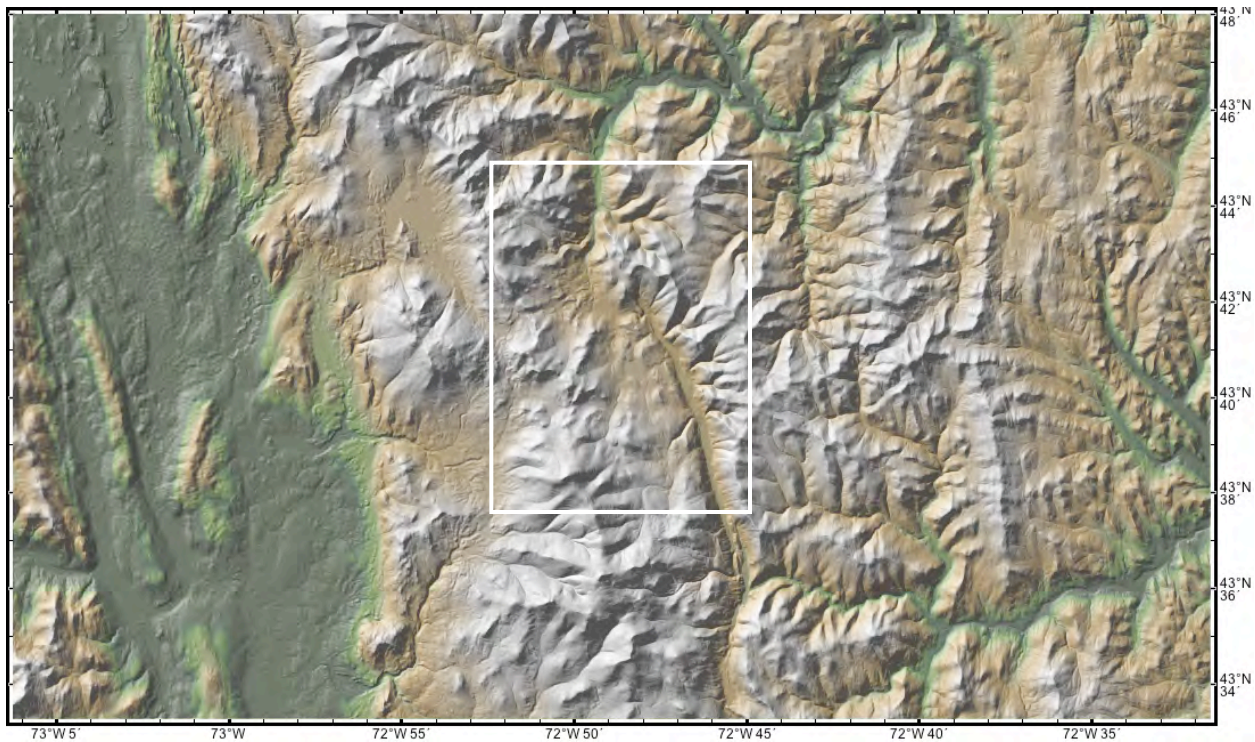
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## Introduction

This report describes the results of mapping surficial geologic materials and landforms at a scale of 1:24,000 in the southern half of the Pico Peak 7.5' Quadrangle during the summer of 2011. The remainder of the Quadrangle will be mapped next summer and the fully-mapped Quadrangle will provide an key data set that will be utilized to analyze the groundwater hydrology of the area. Most of the mapping presented here was completed before the extensive flooding following Tropical Storm Irene on August 28, 2011. The field area was inaccessible or marginally accessible until late October. Consequently, the upper part of the Killington Access Road was not mapped in as much detail as other areas on the map. This area will be revisited and the mapping revised as needed during the 2012 mapping season.

The Pico Peak Quadrangle lies within the Green Mountains east of Rutland, Vermont (Fig. 1). Most of the area is rugged and mantled by a generally thin veneer of glacial till. The main range of the Green Mountains forms an east/west drainage divide where most of the area east of this divide is drained by the Ottauquechee River and areas west by Mendon Brook. Part of the northern quadrangle east of the divide is drained by the Tweed River. In the southern half of the quadrangle, glaciofluvial and glaciolacustrine materials are restricted to the Ottauquechee River valley on the east side of the mountains and the lowest western slopes of those same mountains. The quadrangle comprises the NE corner of the Rutland 15' Quadrangle, the surficial geology of which was mapped by Stewart (1956–1966) and incorporated into the Surficial Geologic Map of Vermont (Stewart and MacClintock, 1970). Disparities between Stewart's mapping and that presented here will be noted later in this report.



**Figure 1:** Digital Elevation Model of the Champlain Valley (west) and Green Mountains at the latitude of Rutland, Vermont (created with GeoMapApp). White box outlines the boundaries of the Pico Peak 7.5' Quadrangle. Pico Peak is the prominent mountain in the southwestern corner of the quadrangle. The linear NNW–SSE valley in the eastern half of the quadrangle contains the upper reaches of the Ottauquechee River.

A major objective of this work was to describe the three-dimensional distribution of surficial materials in the mapped area. This compilation, in addition to the glacial striations data recorded, provide the basis for an interpretation of ice flow history across the area as well as the depositional environments that existed immediately following ice retreat from this area. Other landforms offer some insight into processes occurring during the Holocene, long after the ice retreated.. When mapping of the entire quadrangle is complete in 2012, water well data will be combined with the mapped distribution of surficial materials to to gain a better understand the groundwater hydrology of the area.

Mapping was completed using the 1997 U.S.G.S./Forest Service Pico Peak quadrangle map (1:24,000) as the base map. Surficial materials, where not visible at the surface, were sampled using an ~1 m-long soil probe or ~1.5 m-long soil auger. Map locations were fixed using a GPS meter utilizing the NAD27 coordinate system that is the basis of the grid system on the Pico Peak map. In all locations and instances the NAD27 locations gleaned from the GPS meter were consistent with the landforms and cultural features shown in the map. In almost all areas the stated GPS meter accuracy (horizontal location) was within 5 m, considerably less than the width of a pencil point on a 1:24,000 scale map. Bedrock outcrops were also mapped where they were encountered on traverses, but no attempt was made to map all bedrock outcrops. Outcrops were inspected for striations or other indicators of ice flow direction. Areas where surficial materials were identified are shown on the geologic map as points. Areas where additional observations and measurements were made were given field identification numbers and recorded as GPS waypoints. Every effort was made to traverse all parts of town where one could reasonably expect to find materials other than till. Geologic contacts that could be located with certainty are shown with solid lines. Areas where contacts have been interpolated or extrapolated with less certainty are shown with dashed lines.

The following materials are submitted as the final products of this project:

- (1) A surficial geologic map of the area showing geologic contacts, the location of bedrock outcrops, and a brief explanation of mapping units (see this report for a more detailed description of mapping units);
- (2) A geologic cross-section extending from the Ottauquechee valley at Sherburne village west-southwest to the Killington Access road. This cross-section is included as part of this report and as separate Adobe Illustrator file;
- (3) An isopach map of the entire town depicting the thickness of surficial geologic materials (depth to bedrock) based on field mapping and water well data;
- (4) A file containing location information (UTM coordinates) of field sites;
- (5) Files containing scans of field maps and field notebook entries.

**Significant Findings/Executive Summary**

Outcrops of metamorphic rock occur in all areas across the mapped area except some of the stream valleys where they are deeply buried beneath surficial materials. While most outcrops observed at the lower elevations are weathered, outcrops along the trail system on the high ridges expose many well-preserved glacial striations. An older generation of striations indicate that the oldest direction of ice flow was to the southeast, obliquely across the mountains. This is consistent with the regional ice flow across both northern Vermont and the rest of New England. Younger cross-cutting striations are aligned almost perpendicular to the older striations and indicate that ice flow shifted to the southeast, again obliquely across the mountains. This shift in ice flow may reflect rapid drawdown of the ice surface in the Champlain/Hudson River valleys in response to either the low elevation of that valley or to a calving ice margin in Glacial Lakes Albany and Vermont.

Glacial till is the ubiquitous surficial material in all areas above the elevation of the valley bottoms. Till in the area is light brown where weathered and grey where fresh. Fresh exposures show this material to be a very dense, unsorted, unlayered, material containing clay through boulder sized material. While most of the rock in the till is locally derived, distinctive erratics on the western slope of the mountains include white quartz sandstone from the Cheshire Formation and sandstones and conglomerates from the Pinnacle Formation, both occurring in outcrop to the north and west of the mapped area. In some areas erratics as large as 8 m in diameter were observed. Till thickness is generally <10 m, but reaches more than 30 m in restricted areas interpreted to be buried preglacial stream valleys.

Two segmented eskers were mapped, one along the western boundary of the quadrangle parallel to the Wheelerville Road and the other within the Ottauquechee River valley. The western esker meanders along the western slope of the mountains and is partially buried by alluvial fan deposits on its eastern side. The crest of the eastern esker rises above the Ottauquechee River valley in some places and but in most areas it is buried beneath younger sediments. Much of the surficial material filling the Ottauquechee River valley consists of sand and gravel that most likely was deposited in (a) the esker tunnel, (b) an esker fan deposited at the mouth of the esker tunnel, and (c) in streams flowing away from the retreating ice margin (glacial outwash). The coarse alluvium filling the Ottauquechee River valley to depths exceeding 30 m is a superb, albeit unconfined aquifer. Both eskers have been extensively quarried.

The Ottauquechee River has downcut no more than 10 m through the glacial outwash sediments filling the valley leaving relatively few terraces of old alluvium perched above the modern floodplain. Much of this material has been quarried. The modern Ottauquechee River has a very low gradient and is commonly dammed by beaver creating an extensive area of swampy ground. Consequently the modern alluvium contains a considerable amount of organic material.

Alluvial fans are extensively developed in the area on a variety of scales. The larger fans fed by the larger brooks, extend completely across the Ottauquechee River valley forcing the river against the opposite valley side. The apex of these fans contain very large boulders likely deposited during debris flows. Most of the mapped fans were active and received a new layer of coarse sediment during Tropical Storm Irene in late August 2011. These alluvial fans and the old alluvial terraces are the only areas suitable for farming or residential development in the Ottauquechee River valley, along the Mendon Brook valley, and along the western slope of the mountains parallel to the Wheelerville Road. Even though they aren't classic flood plains these alluvial fans are susceptible to flooding and inundation by sudden deposits of coarse alluvium during high-intensity storm events.

### Description of the Mapping Units

The mapping units used on the Pico Peak Surficial Geologic Map are described below, arranged in geologic order, from oldest to youngest.

#### *Bedrock Outcrops*

Bedrock outcrops were mapped when they were encountered during traverses, particularly in the valleys. No attempt was made to map all outcrops, especially in the extensive upland areas. Outcrops were inspected for signs of glacial abrasion and the orientation of striations were measured and are discussed in a later section. The only outcrops preserving good striations occur along the trails that generally run along the crest of the mountains. Many of the high-elevation outcrops and all of the lower elevation outcrops have weathered to a degree where the effects of glacial abrasion are no longer apparent.

#### *Glacial Till:*

Glacial till directly overlies the bedrock and, within the quadrangle, is the ubiquitous surficial material in areas above the valley bottoms. The freshest exposures appear in landslides above streams and in excavations where the till is gray to light brown and very dense (Fig. 2). Till in the area consists of angular to subrounded pebbles, cobbles, and boulders suspended in a fine clay/silt/sand matrix. No attempt was made to systematically measure the composition of the till by either grain size or composition nor were any till fabric measurements made. Conspicuous white quartz sandstone erratics are very common, especially on the west side of the mountains, and are most likely pieces of the Cambrian Cheshire Formation (Fig. 3A). Most of these quartz sandstone erratics show a myriad of arcuate fractures on their surfaces most likely formed by the stress induced from the point of another strong rock entrained in the till (Fig. 3A). Other erratics consist of lithologies outcropping northwest of the field area (i.e. on the west slopes of the Green Mountains and the Champlain Valley) reflecting the regional direction of ice flow during most of the Wisconsin glacial period (Fig. 3B). In most areas till thickness is less than 10 m, but exposures in some landslides and well logs indicate that till has accumulated to thicknesses of 20 to 30 m or more in restricted areas (see Isopach Map).



**Fig. 2:** Photographs of fresh exposures of glacial till from Pico Peak area. Both contain angular to subrounded pebbles, cobbles, and boulders in a fine matrix. Photo “A” is a post Irene landslide exposure along Brewers Brook approximately 2 km west of the western boundary of the quadrangle. Photo “B” shows till exposed in a small active pit along old Route 4 ~half a kilometer southeast of Kent Pond.



**Figure 3:** Boulder erratics occurring along the western side of the Green Mountains. (A) Quartz sandstone erratics (Cheshire Formation) are typically white, subrounded, and frequently retain a glacially smoothed and sometimes striated surface. Conspicuous arcuate fractures are common and are likely formed by point stresses imparted by other rocks in the till as the till is sheared beneath almost 3 km of glacial ice. (B) Quartz cobble conglomerate boulder (Pinnacle Formation?) eroded from till along Mendon Brook.

Most of the till occurring in this part of the Green Mountains is lodgement till eroded, deformed, and deposited beneath the ice sheet directly on top of bedrock. Reconnaissance inspection of landslide exposures along Mendon Brook, Brewers Brook, and a few tributary streams to these brooks on the west side of Green Mountains following Tropical Storm Irene (all of these exposures are limited to areas immediately west of the quadrangle boundary) indicates that a second “readvance till” overlies lacustrine sediments deposited on top of the older lodgement till (Fig. 4). In isolated exposures (without the intervening lacustrine sediments) there is no clear way to distinguish the older till from the younger till. Consequently, it has not been possible to ascertain how far east this glacial readvance extended except to note that the easternmost exposure of till overlying glaciolacustrine sediments occurs at a landslide along the Wheelerville Road at an elevation of ~1,500 feet.

**Figure 4:** Thick exposure of glacial till in landslide exposure along small stream along south side of Mendon Brook valley above Route 4. Dense, overconsolidated glaciolacustrine fine sand not visible in photograph) occurs immediately beneath till.



### Ice-Contact Deposits

Two segmented eskers were mapped in the southern half of the quadrangle, one on the western side of the mountains and one on the eastern side. The western esker follows a meandering almost 2 km-long north-south path between the Wheelerville Road and the western boundary of the quadrangle (Fig. 5). Several small overgrown gravel pits immediately adjacent to the Wheelerville Road lie along the trace of the esker. At its northern end the esker may be buried by alluvium, eroded away by the brook draining Beaver Pond, or was never deposited in this region. It's likely that this esker continues to the northwest, beyond the margin of the map. To the south, the esker rises along east side of Brewers Brook until disappearing at an elevation of ~1,660 feet (Fig. 5).

Coarse pebble, cobble, boulder gravel, visible along the margins of the old pits in the esker, constitute the material deposited within the esker tunnel (the ice-tunnel facies). The eastern (uphill) flank of the esker is bordered and partially buried by alluvial fan deposits. The alluvial fan deposits likely bury any finer sand and gravel deposited from the mouth of the esker tunnel (esker fan deposits) as the ice front was retreating to the north. The western (downhill) side of the esker is largely bordered by a poorly drained swampy area that eventually drains to Brewers Brook. While currently drowned by beaver ponds and a thin veneer of modern alluvium and swamp deposits, this area too may be underlain by significant thicknesses of esker fan deposits. One small kettle (see "K" on map, Fig. 5) was mapped adjacent to the eastern side of the esker indicating the existence of at least one small piece of stagnant ice. The poorly drained swampy ground on the opposite (west) side of the esker may be another stagnant ice area.



**Figure 5:** (A) Map of meandering esker ridge between the western border of the map and the Wheelerville Road. (B) Crest of esker ridge along the east side of Brewers Brook. Esker relief in this area is 10–15 m.

A second segmented esker was mapped in the Ottawaquechee River valley on the east side of the mountains. Short segments of this esker rise above the modern alluvium in some areas (Fig. 6) and in other areas large segments have been quarried away although the esker ridge landform is visible on the topographic map which predates the quarrying. The esker hasn't been found north of the Riverside Cemetery (~1 km north of Sherburne Center) but mapping next summer farther up the valley may delineate its continuation. Extensive deposits of sand and gravel (recorded in water well logs) fill the Ottawaquechee River valley and, except for a thin veneer of modern river alluvium, most of these clastic sediments are interpreted to be either esker tunnel deposits or esker fan deposits that grade into glacial outwash (see discussion of the geologic cross-section across the Ottawaquechee River valley).



**Figure 6:** Esker ridge on the east side of the Ottawaquechee River valley ~2 km south of Sherburne Center. River in foreground is dammed by a beaver pond.

These eskers and associated esker fan and glacial outwash sediments may host the most voluminous aquifer in the southern half of the Pico Peak quadrangle. Much, if not most, of the esker and related ice-contact sediments are below the grade of the river, hence below the water table. No confining sediments appear to overlie these sediments.

#### *Lake Bottom Sediments*

No lake bottom deposits were mapped in the southern half of the Pico Peak quadrangle. However, as noted earlier, recent landslides following Tropical Storm Irene along streams draining the western slopes show extensive deposits of very fine sand and silt in areas approaching the western boundary of the quadrangle. It's possible that some of these lake bottom sediments extend into the quadrangle, but if so, they are currently buried by a readvance



till or alluvial fan deposits. To date, no evidence exists to indicate that a lake ever occupied the upper reaches of the Ottawaquechee River valley.

#### *Stream Terrace Deposits (Old Alluvium)*

Stream Terrace deposits are old stream alluvium deposited on terraces at elevations less than 10–15 m above the modern flood plain of the Ottawaquechee River. Route 4 is partially built on one of these terraces that extends along the western side of the valley. These deposits largely consist of coarse-grained sediments, e.g. moderately well to poorly sorted pebble-cobble gravel and sand. Many of these deposits have been extensively quarried. Stewart (1956–1966) mapped these as kame deposits implying that they were deposited by ice marginal streams. While he may have been able to observe collapse structures (normal faults) in some of these deposits that would support his hypothesis, no exposures of sedimentary structures currently exist in these deposits. While these may indeed be kame deposits they may also have originated as glacial outwash deposited by streams emanating from the retreating glacier and later reworked by the early Ottawaquechee River.

On the west side of the mountains several old alluvial terrace deposits were mapped along the upper reaches of Mendon Brook and its tributaries, which extend from the base of the Pico Peak ski area to the western boundary of the quadrangle (Fig. 7). The largest of these deposits has been quarried and is now the site of the AOT garage. In other areas Route 4 is built on these terraces.



**Figure 7:** Thin (1–2 m) layer of alluvium deposited on an abandoned stream terrace above Mendon Brook ~3 km west of the western quadrangle boundary. Alluvium unconformably overlies fine sand and silt deposited in a glacial lake that locally flooded the western slope of the mountains to an elevation of at least 1,500 feet. The fine lacustrine sediments are interrupted by a coarse diamict layer that may be a till deposited by a glacial readvance or, more likely, a debris flow deposit.

Many old abandoned stream channels were mapped along the western slope of the mountains and are shown with arrows (some double ended where stream flow direction was uncertain) on the geologic map. Most of these channels are eroded into till (strath terraces) and have little or no alluvium associated with them. Some of these channels parallel modern stream channels and probably mark former positions of the modern streams when the fill of till in the valleys was thicker soon after ice retreat. In other cases the channels parallel the valley sides, form stair steps down the valley sides, and are cut by the modern stream channels. These abandoned channels most likely formed by ice-marginal streams as the ice sheet was retreating up the Champlain Valley.

#### *Alluvial Fan Deposits*

Alluvial fans consisting of “fan-shaped” deposits of poorly-sorted to moderately well-sorted material are very common in the area, especially in the Ottauquechee River valley. These deposits all emanate from steep stream valleys many of which are occupied by intermittent streams. Some of the material in these fans is very coarse (boulders common) and probably originated as debris flows. Most of the mapped fans in the area were active during Tropical Storm Irene and received a new layer of sediment consisting of both poorly sorted and rounded stream sediment as well as angular to subrounded rocks eroded from till on the valley sides during the storm.

Alluvial fans (and the old alluvial terraces) provide the only land suitable for farming and residential development in the Ottauquechee River valley. Large fans emanate from the larger tributary brooks (e.g. Kent, Quimby, Taylor, and Roaring Brooks) and spread across most of the otherwise flat Ottauquechee River valley forcing the river to the opposite side of the valley. The entire village of Sherburne Center is built on a large fan at the base of Roaring Brook and many of town’s municipal and recreational buildings as well as many private dwellings farther up the valley are also built on fans at the mouths of Quimby and Taylor Brooks. Many of these areas were affected by the new layer of fan debris deposited during Tropical Storm Irene.

Studies in northern Vermont indicate that alluvial fans similar to these have been active episodically throughout the Holocene and have often received their most recent pulse of sediment following European land clearing in the late 18<sup>th</sup> and early 19<sup>th</sup> centuries (Bierman et al, 1997, Jennings et al., 2003). Related work by Noren and others (2002) utilizing 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 climate shifts produce a greater frequency of “Irene-like” storms in the future, further sedimentation on the area’s alluvial fans seems likely.

#### *Alluvium*

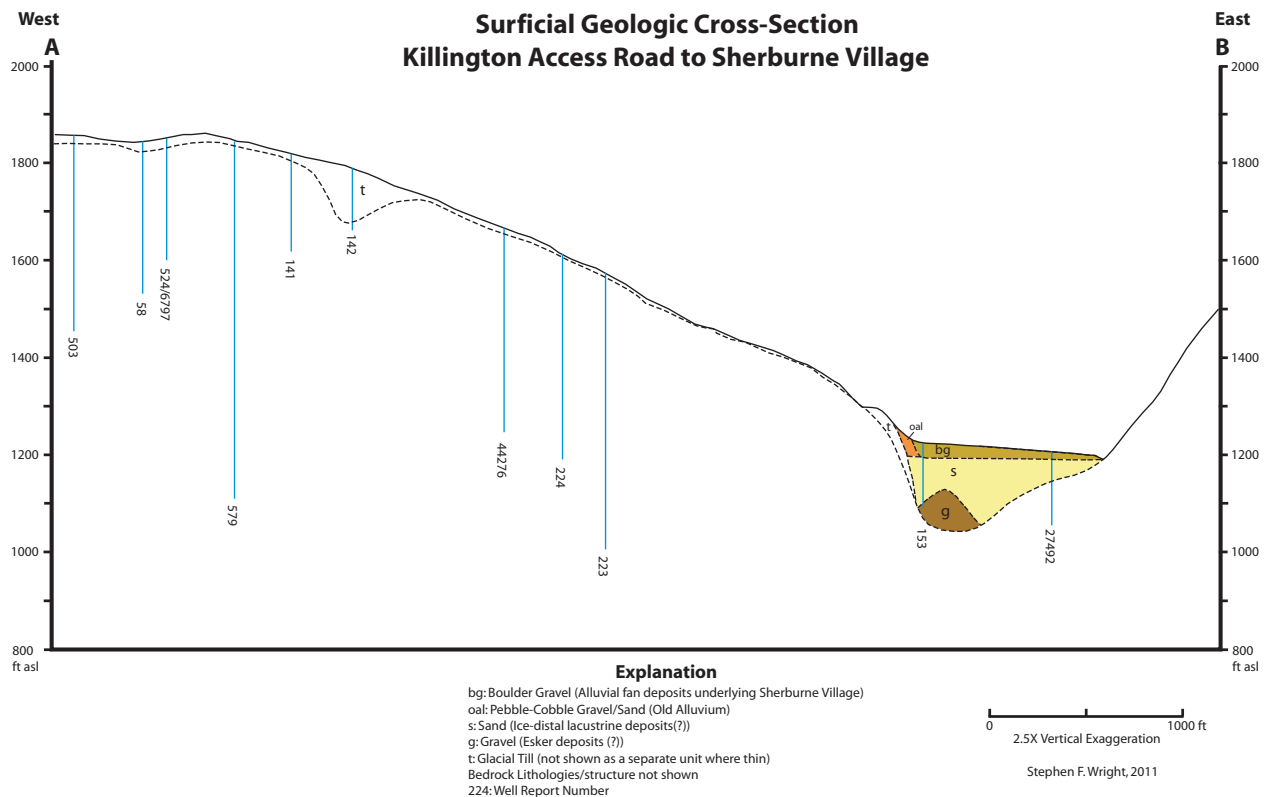
Areas mapped as alluvium are underlain by sediments deposited in the modern channel and flood plain of the Ottauquechee river and some of its larger tributaries on the east side of the mountains and along reaches of Mendon Brook and some of its tributaries on the west side of the mountains. The alluvium consists of layered, generally coarse-grained sediments whose grain size varies widely over short distances across the flood plain. Beaver ponds are extensively developed and the gradient along significant reaches of these valleys which provides environments for the accumulation of both fine clastic sediment and significant quantities of organics.

In most areas where streams are not aggrading, the thickness of alluvium is similar to the depth of the stream channel. Within the upper reaches of the Ottauquechee River this depth is at most 2–3 meters. Most other streams in the area are smaller and the expected thickness of alluvium is correspondingly thinner. Note that many of the small streams have deposited discontinuous, thin layers of alluvium that were not mapped.

**Description of the Geologic Cross-Section**

A geologic cross-section was drawn along an approximately west–east line extending from the Killington Access Road, through the village of Sherburne Center, across the Ottauquechee River valley, and a short ways up the eastern side of the valley (see geologic map and Fig. 8). In addition to the geologic map, well logs from eleven water wells falling on or close to the line of section were used to ascertain the depth to bedrock and the existence and thickness of buried surficial materials. The location of water wells in the uplands was taken from the Agency of Natural Resources Well Locator maps. Two wells in the Ottauquechee River valley were located in the field and their GPS coordinates recorded.

A relatively thin veneer of glacial till mantles the bedrock in most of the upland areas. The steep mountainside east of the river contains numerous outcrops and a very thin cover of till. No attempt was made to show the till as a separate unit here. Bedrock outcrops along the blasted west side of Route 4 above Sherburne Center. Farther up the hill individual outcrops were not mapped, but well logs indicate that in most areas the till is less than 20 feet (6 m) thick. A notable exception is Well 142 where the log indicates that the depth to bedrock is slightly more than 100 ft (30 m). This is most likely a pre-Wisconsinan stream valley that has been completely filled with till.



**Figure 8:** Geologic cross-section depicting surficial geologic materials occurring between the Killington Access Road and the Ottauquechee River valley. Vertical blue lines show water wells falling on or close to the line of section. The logs from these wells were used to show the thickness of surficial materials as well as contacts between different types of surficial materials.

Where the section crosses the Ottauquechee River valley two wells were used to constrain the subsurface geology. One of those wells (153) bottomed in gravel and graded up into a thick section of sand. The other well (27492) recorded the same sand unit before entering bedrock. In the cross-section I’ve shown that the gravel encountered in the first well is part of an esker. This interpretation is based on (1) mapping an esker in the valley

south of the cross-section and (2) extensive experience in other north-south valleys in Vermont where coarse gravel overlain by finer clastic sediments is a common esker facies comprising the transition from deposition in an esker tunnel environment to deposition in an esker fan/outwash environment as the ice front retreats farther up the valley. The cross-section also shows these esker/outwash sediments overlain by a wedge of coarse sediments deposited in an alluvial fan. As noted earlier, much of the fan material consists of a mix of material, including large boulders, slurred down the hillside during debris flows.

### **Interpretation of the Late Pleistocene/Holocene History**

What follows is an interpretation of the glacial and post-glacial history of the area encompassed by the southern half of the Pico Peak quadrangle based on field observations. Continued work next summer in the northern half of the quadrangle will shed further this interpretation.

Glacially striated bedrock outcrops were only observed along trails traversing the main range of the Green Mountains from Pico Peak on the south to “The Elbow” to the north (see geologic map). Two directions of ice flow can be inferred from the striations and their relative age can be inferred by cross-cutting relationships and the relative sharpness of the two different striation sets in outcrops where they both occur.

The older set of glacial striations are oriented NW–SE. While no sense-of-motion indicators were observed in the area, numerous observations in northern Vermont and elsewhere in New England show that when the ice sheet was thick enough to flow over the mountains, the ice was flowing from the northwest to the southeast obliquely across the mountains (Wright, 2006, 2009). The younger set of striations are oriented generally NE–SW. Similar NE–SW oriented striations have been observed by Ackerly and Larsen (1987) farther north along the Long Trail from Appalachian Gap to Middlebury Gap. These striations imply that during ice retreat the ice surface slope changed significantly. Whereas previously, during the peak of glaciation, the main accumulation area of the ice sheet was northwest of Vermont, during this phase of retreat the elevation of the ice sheet east of the mountains exceed that occurring west of the mountains. This was most likely due to more rapid ice retreat in the Hudson/Champlain Valleys because of rapid ice loss facilitated by the lower elevations in the valley and/or calving of the ice sheet margin into Glacial Lake Albany and Glacial Lake Vermont.

When the surface elevation of the ice sheet was no longer high enough to cover the mountains, the direction of ice sheet flow shifted again and was guided by the orientation of the valleys; the Champlain valley to the west and the upper reaches of the Ottauquechee River valley to the east.

On the west side of the mountains abandoned south-sloping stream channels eroded in till indicate that meltwater streams were pinned between the ice sheet (now confined to the Champlain Valley) and the steep mountain sides. The one esker mapped on the west side of the mountains is oriented approximately north-south suggesting that it may have formed at this stage when the ice surface sloped to the south and the subglacial drainage was also oriented this way. Further retreat of the ice sheet created a ice marginal lake in the Mendon Brook drainage basin. A readvance of the ice sheet covered these lake sediments with till. The extent of this lake isn't known, but lacustrine sediments were observed to an elevation of 1,500 feet and they may extend higher but, if they exist, are covered by till deposited during the readvance or younger alluvial fan deposits. Abandoned stream channels along the upper reaches of Mendon Brook indicate that this stream has eroded through as much as 20 m of till during the Holocene.

As noted earlier, on the east side of the mountains the thinning ice sheet was eventually confined to the Ottauquechee River valley although no landforms or sediments were observed that were produced during this transition, e.g. no abandoned ice-marginal meltwater channels were observed east of the mountains. There is a well-

developed esker system in the Ottauquechee River valley suggesting that this subglacial drainage system may not have developed until the ice sheet had thinned below the crest of the mountains and was flowing roughly south, a situation observed in many of the north-south river valleys in central Vermont (Larsen, 1987, Larsen et al, 2003, Wright, 1999a, b, 2010). Well logs from the Ottauquechee River valley indicate that the bedrock valley bottom is deeply buried and largely filled with sand and gravel. Some water wells have penetrated as much as 160 feet (50 m) of sand and gravel before reaching bedrock and many wells bottom in gravel without reaching bedrock. While the only descriptions of sediments filling the river valley comes from the water well logs, these sediments most likely represent a succession from those deposited within the confines of a subglacial tunnel to those deposited at the mouth of that tunnel (esker fans) to those deposited by streams emanating from the retreating ice sheet (glacial outwash). With continued northward retreat of the ice sheet there was a transition from streams fed in part by glacial meltwater to a stream fed solely by meteoric water originating within the drainage basin of the river—the early Ottauquechee River. Abandoned alluvial terraces imply that the river has downcut through no more than 10 m of old alluvium.

Alluvial fans started forming in the mapped area as soon as the ice sheet retreated from the Ottauquechee River valley on the east and the steep mountain slopes to the west of the mountain range and have remained active, albeit sporadically, throughout the Holocene and most recently during Tropical Storm Irene. The larger fans extend completely across the Ottauquechee River valley forcing the river to the opposite side of the valley.

### **Isopach Map**

An isopach map of surficial materials occurring in the southern half of the Pico Peak quadrangle is included with this report. The data utilized for this map largely comes from water wells occurring in the mapped area and their associated logs. Other data includes mapped bedrock outcrops and interpretations of sediment thickness typical of surficial landforms, e.g. alluvial fans, eskers. The locations of the water wells were supplied to the contractor knowing that their locations have only been “screen digitized,” but their ground locations have not been confirmed. Several wells were located by the contractor in the Ottauquechee River valley to facilitate construction of the geologic cross-section. Several of the well locations shown on the isopach map are known to be inaccurate and were not used. The accuracy of the contouring is obviously constrained by how well the wells are located.

Contours were only drawn where there was a sufficient density of wells to reasonably constrain the contours. Contours depicting the thickness of surficial materials were drawn at 20 feet, 60 feet, and 100 feet corresponding to the map supplied by the Vermont Geological Survey.

The largest and thickest accumulation of surficial materials occurs in the Ottauquechee River valley. The river in the mapped area has a very low gradient and much of the valley bottom is unsuitable for farming or residential development. Consequently, relatively few wells have been drilled in the middle of the valley, but those that have frequently penetrate more than 100 feet of surficial material. Note that the relatively few wells in the valley do not allow this area to be contoured very accurately.

On the western side of the mountains several relatively thick accumulations of surficial material lie within the Mendon Brook valley. One of these areas is partly occupied by the parking lot of the Pico Peak ski area, an area interpreted to consist of alluvial fan deposits at least partially reworked by the brook. Another area with surprisingly thick (>100 ft) accumulations of surficial material lies at the base of Willard Gap. It's unclear at the present whether all this material consists of till (what's mapped at the surface) or whether the till overlies something else. Farther down the Mendon Brook valley relatively thick accumulations of old alluvium underlie terraces that Route 4 is build on.

Another area with thick accumulations (>100 ft) of surficial materials occurs in the north-south valley traversed by the Elbow Road along the western boundary of the quadrangle. Well control is poor here, but it's possible that the bedrock valley was eroded by ice flow and is deeply buried. This area will be mapped in more detail during the summer of 2012.

Most of the upland areas have a relatively thin mantle of surficial material and bedrock outcrops are frequent. Dense residential developments have been built in some of these upland areas, especially along the Killington Access Road allowing these areas to be contoured. The till cover in most of the area is less than 20 feet, but significant areas, largely paralleling the valley of Roaring Brook, show till and/or alluvium thicknesses in the 20 to 60 foot range and a few isolated pockets show thicknesses exceeding 100 feet. Most of these thick accumulations probably occur in preglacial stream valleys that were filled with till.

### **References**

- Ackerly, S.C. and Larsen, F.D., 1987, Southwest-trending striations in the Green Mountains, Central Vermont; in Westerman, D.S., ed., *New England Intercollegiate Geological Conference Guidebook*, pp. 370–382.
- Bierman, P., Lini, A., Davis, P.T., Southon, J., Baldwin, L., Church, A., and Zehfuss, P., 1997, Post-glacial ponds and alluvial fans: recorders of Holocene landscape history: *GSA Today*, v. 7, p. 1-8.
- Jennings, K., Bierman, P., and Southon, J., 2003, Timing and style of deposition on humid-temperate fans, Vermont, United States: *Geological Society of America Bulletin*, v. 115, p. 182-199.
- Larsen, F.D., 1987, History of lakes in the Dog River Valley, central Vermont: in Westerman, D.S., ed., *New England Intercollegiate Geological Conference Guidebook*, p. 213–237.
- Larsen, F.D., Wright, S.F., Springston, G.E., and Dunn, R.K., 2003, Glacial, Late-Glacial, and Postglacial history of Central Vermont; *Guidebook for the 66th Annual Meeting of the Northeast Friends of the Pleistocene*, 62 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, p. 821-824.
- Stewart, D.P., 1956–1966, Surficial geology of the Rutland, Vermont 15-minute Quadrangle: Unpublished map, Vermont Geological Survey.
- Stewart, D.P. and MacClintock, 1970, Surficial Geologic Map of Vermont, 1:250,000, Vermont Geological Survey.
- Wright, S.F., 1999a Surficial Geologic map and cross-sections of the Barre West, Vermont, 7.5-minute quadrangle: Vermont Geological Survey Open File Report VG99-6, Waterbury, Vermont.
- Wright, S.F., 1999b, Deglaciation of the Stevens Branch valley, Williamstown to Barre, Vermont, in Wright, S.F. ed., *New England Intercollegiate Geological Conference Guidebook Number 91*, p.179–199.
- Wright, S.F., 2006, Ice flow directions, ice-contact environment, and the early history of Glacial Lake Memphremagog in northern Vermont; *Geol. Soc. of Am. Abstr. w. Prog.*, Vol. 38, No. 2, p. 15.
- Wright, S.F., 2009, Ice flow, subglacial hydrology, and glacial lake history, northern Vermont, in Westerman, D.S., ed., *New England Intercollegiate Geologic Conference Guidebook*, A4-1 – A4-27.
- Wright, S.F., 2010, Report on Surficial Mapping and Interpretations of Groundwater Hydrology, Randolph, Vermont; Unpublished Open File Report, Vermont Geological Survey.

**GPS Coordinates of Photographs appearing in this paper**

Figure	NAD 27 UTM Coordinates		NAD 83 UTM Coordinates	
	Easting	Northing	Easting	Northing
Front Page	680030	4834340	680066	4834344
2A	669397	4834315	669433	4834319
2B	677731	4837038	677767	4837042
3A	671416	4833984	671452	4833988
3B	667919	4835067	667955	4835071
4	667656	4834938	667692	4834942
5B	671563	4833007	671599	4833011
6	680030	4834340	680066	4834344
7	667919	4835067	667955	4835071