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

Stephen F. Wright
Department of Geology, University of Vermont
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View looking west, down the Johnson Brook valley with "The Darning Needle" in the background. The mostly mined out gravel pit in the foreground is part of a delta complex deposited where Johnson Brook and a smaller tributary to the left (south) entered a glacial lake that occupied the South Branch of the Tweed River valley and its tributaries as the ice sheet retreated northward.

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Executive Summary/Significant Findings

The following summary integrates observations made while mapping the surficial geology of both the southern half (2011) and northern half (2012) of the Pico Peak 7.5-minute quadrangle, central Vermont. Detailed mapping focused on the uppermost Ottauquechee river valley to the south and the uppermost South Branch of Tweed river valley to the north.

Ice-flow History

The direction of ice sheet movement across the area was determined through observations of striations and grooves on glacially abraded outcrop surfaces. While most outcrops observed at the lower elevations are weathered, outcrops along the the trail system on the high ridges expose many well-preserved glacial striations. An older generation of striations indicate that the oldest preserved 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. A third set of striations oriented almost due south suggest that the thinning ice sheet was constrained by and flowed parallel to the north-south valleys that parallel the Green Mountains as the ice margin retreated northwards.

Glacial Deposits

Glacial till is the ubiquitous surficial material in all high elevation areas. 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, lodgement till 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. New exposures produced by landslides initiated during Tropical Storm Irene show that the lodgement till is sometimes overlain by a less dense and crudely layered grey diamict that is likely formed by debris flows or other forms of mass movement shortly after the ice retreated from the area.

Ice-Contact Deposits

Two segmented eskers were mapped, one along the western boundary of the quadrangle parallel to the Wheelerville Road and the other within the Ottauquechee and South Branch of the Tweed river valleys. 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 but in many areas it is buried beneath younger sediments. The esker system in the South Branch of the Tweed river valley is not well developed, likely a result of the adverse gradient of the subglacial tunnel system in this valley. Much of the surficial material filling the Ottauchequee 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. A third isolated esker was mapped just north of the drainage divide between the Ottauquechee and South Tweed rivers.

Lacustrine Deposits

Lacustrine sediments occur in the South Branch of the Tweed river valley to an elevation of 1,350 feet indicating that the northward-retreating ice sheet dammed a small lake with its outlet at the drainage divide between the Ottauquechee and South Branch of the Tweed rivers (Route 100 crosses this divide at the east end of the

Killington Municipal Golf course). Several deltas were mapped where tributary streams flowed into the lake. Fine sand, very fine sand, and silt, deposited in the quieter parts of the lake occur throughout the valley below the outlet elevation of 1,350 feet and have, historically, provided some of the better farmlands on the otherwise steep and till-covered valley sides.

Holocene Deposits

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 the river agains 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. Once the lake that occupied the South Branch of the Tweed river valley drained, the Tweed river and its tributaries began eroding channels through the lacustrine sediments (mostly sand and silt). Alluvial fans in the South Branch of the Tweed river valley are deposited on top of these older lacustrine sediments.

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. Alluvium in the South Branch of the Tweed river valley is very limited where the valley bottom is narrow and the stream has eroded down to the till or underlying bedrock. Elsewhere in the valley old alluvial terraces with a thin veneer of alluvium are underlain by lacustrine sediments or till.

Introduction

This report describes the results of mapping surficial geologic materials and landforms at a scale of 1:24,000 in the northern half of the Pico Peak 7.5' Quadrangle during the summer of 2012 and complements an earlier report describing the results of mapping the southern half of the Quadrangle during the summer of 2011 (Wright, 2011).

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 and Tweed Rivers and areas west by Mendon Brook. Glaciofluvial (ice-contact) and glaciolacustrine materials are restricted to the Ottauquechee and Tweed River valleys on the east side of the mountains and the Mendon Brook valley on 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.

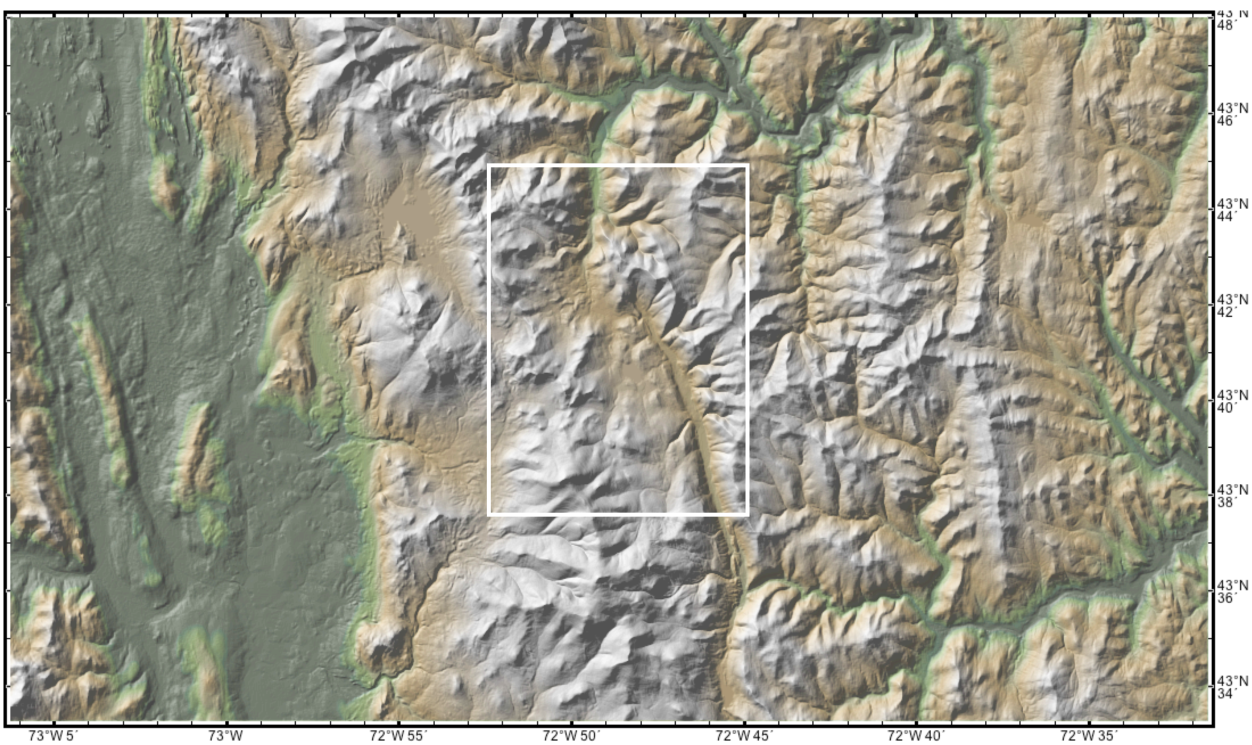

Figure 1: Digital Elevation Model of the Champlain Valley (west) and Green Mountains at the latitude of Rutland, Vermont (created with GeoMapApp). White box outlines the boundaries of the Pico Peak 7.5' Quadrangle. Pico Peak is the prominent mountain in the southwestern corner of the quadrangle. The 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. The distribution of surficial materials, in addition to measurements of glacial striations, provide the basis for an interpretation of ice flow history across the area as well as the depositional environments that existed during and immediately following ice sheet retreat. Other landforms and associated surficial materials offer insight into processes occurring during the Holocene, long after the ice retreated.

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, e.g. rouches moutonnée. Areas where surficial materials were identified are shown on the geologic map as waypoints. Areas where additional observations and measurements were made were also 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 were previously submitted and complement this report:

(1) A surficial geologic map of the area and a brief explanation of mapping units (see this report for a more detailed description of mapping units);

(2) A geologic cross-section extending across the South Branch of the Tweed river valley. This cross-section is included as part of this report and as separate Adobe Illustrator file;

(3) A spreadsheet file containing location information (UTM coordinates) and descriptions of all field sites.

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. Bedrock in the area consists of both Precambrian “Grenville” rocks that were thrust faulted into the core of the Green Mountains during the Taconic Orogeny and a sequence of metasedimentary and metavolcanic cover rocks that are in fault contact with the older basement rocks (Ratcliffe et al., 2011). Outcrops were inspected for signs of glacial abrasion and the orientation of striations were measured and are discussed in a later section. The most common outcrops preserving good striations occur along the trails that generally run along the crest of the mountains. Many of the high-elevation outcrops and almost 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. Most of the till occurring in this part of the Green Mountains is lodgement till consisting of materials eroded, deformed, and deposited beneath the ice sheet directly on top of bedrock. 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.

Figure 2: Dense, grey lodgement till exposed by a landslide following Tropical Storm Irene (August 2011) along the north side of an unnamed brook draining Kent Pond.

In the southern half of the quadrangle 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.

Good landslide exposures along an unnamed brook draining Kent Pond (north of Kent Brook) show a second diamict overlying the lodgement till (Fig. 3). This upper diamict is sometimes weakly layered and thin sand lenses sometimes occur between it and the underlying till. This may be a second till deposited by a readvance of the ice sheet, but could also be a debris flow deposit (remobilized till) down the stream valley shortly after deglaciation. While the distinction between the lodgement till below and the diamict above is clear in fresh landslide exposures, it's impossible to distinguish the two units in the woods and, consequently, all diamicts have been mapped as till.

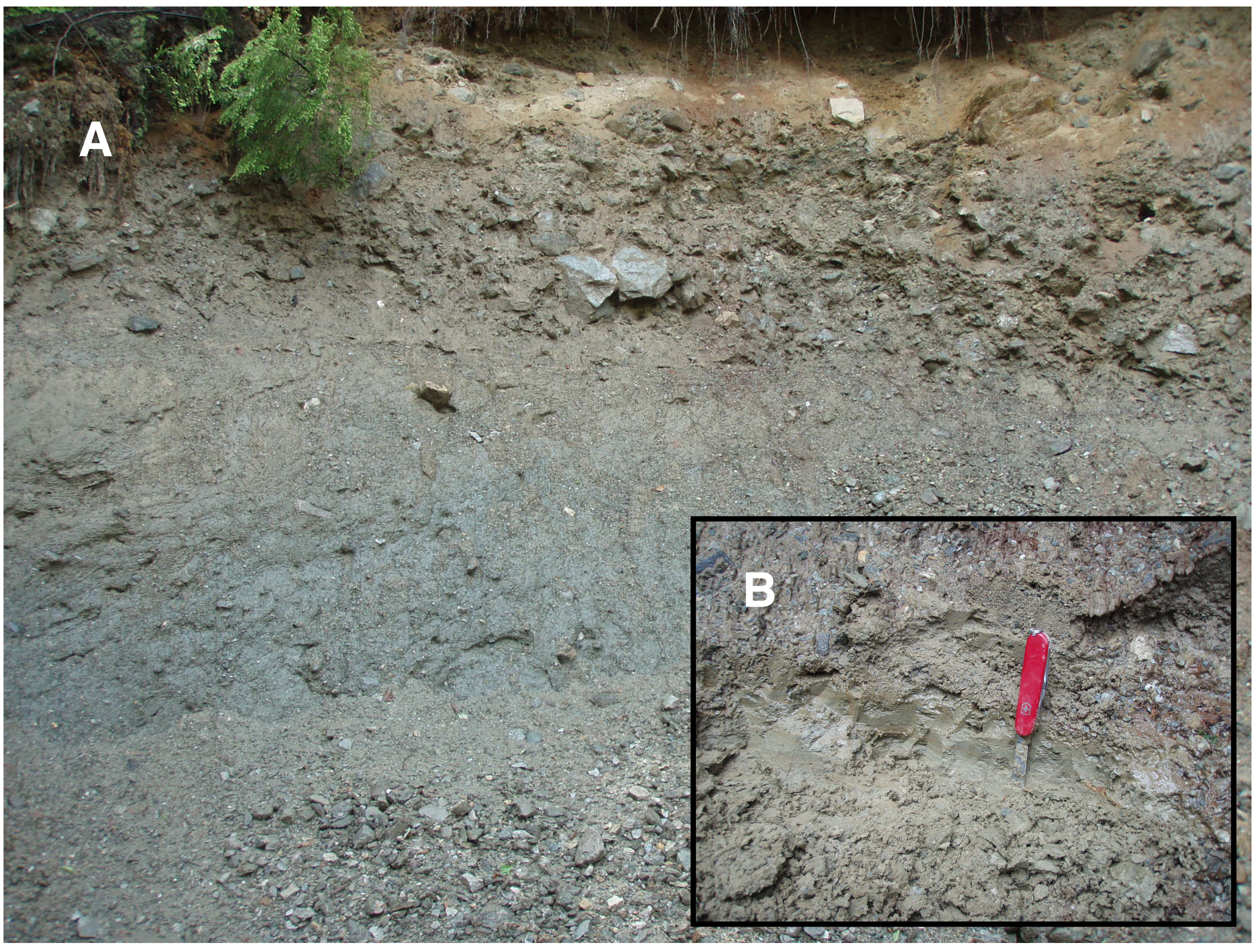

Figure 3: (A) Dense grey lodgement till is overlain by 1.5–2 m of weakly layered diamict exposed in a landslide scarp along the north side of an unnamed brook draining Kent Pond. (B) A thin, discontinuous layer of sand occurs in some areas between the two units.

Figure 4: Very large erratic deposited along the crest of the Green Mountains just east of the Long Trail. This is one of many large, conspicuous erratics occurring along a 1–2 km reach of the Green Mountain ridge line.

Along the crest of the Green Mountains between South Pond and Daves Peak, just beyond the NW boundary of the quadrangle, large (3–10 m diameter) erratics occur quite frequently and are readily visible from the Long Trail (Fig. 4). These may result from a particular event (e.g. large-scale water pressure fluctuations) or a series of events at the base of the ice sheet, closely spaced in time and space, that successfully dislodged and removed these large blocks of rock. None of these large rocks are truly erratic suggesting that they have traveled a relatively short distance from where they were quarried before the ice sheet thinned and they were deposited.

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 (Wright, 2011). The western esker follows a meandering almost 2 km-long north-south path between the Wheelerville Road and the western boundary of the quadrangle. A second segmented esker was mapped in the Ottauquechee River valley on the east side of the mountains. Short segments of this esker rise above the modern alluvium in some areas but in most areas where the esker is a prominent landform it has been largely quarried away although the esker ridge landform is visible on the topographic map which predates the quarrying (Figs. 5 and 6). Segments of this esker system occur near the drainage divide between the south-flowing Ottauquechee river and the north-flowing South Branch of the Tweed river. Coarse gravel deposits at and immediately north of the drainage divide are interpreted to glacial outwash deposits (Fig. 7). Farther north, only one small segment of this esker was mapped along the east side of the Tweed River valley just north of Johnson Brook.

In one small area adjacent to this esker segment a gravel “apron” was mapped along the valley side. This gravel apron may have been deposited where a stream, flowing on the glacier surface, flowed to the base of the glacier between the valley side and the glacier. One additional, relatively short, esker segment was mapped along the west side of Route 100 between Kent Pond to the south and Colton Pond to the north.

Figure 5: View looking north along the uppermost Ottauquechee river valley. Grassy strip in foreground is the trace of an old overgrown pit that was the former trace of an esker. A short, unquarried section of the esker remains to the north of this pit. Water flow in the subglacial tunnel was from north to south, toward the viewer.

Water well logs in the South Branch of the Tweed river valley generally do not record coarse gravel and sand deposits in the subsurface that could be interpreted as a buried esker. This suggests that sedimentation events were relatively rare (in space) within the esker tunnel where it had an adverse (uphill) slope. The esker is much more extensively developed in the Ottauquechee river valley and well logs indicate buried esker sediments in many areas overlain by younger alluvial sediments (Wright, 2011). However, two good landslide exposures along the Tweed river and a small tributary stream (Waypoint numbers 14, 218) both show a fining up sequence of sediments ranging from coarse sand/pebble-cobble gravel at the base (subaqueous fan facies?) to fine silt and sand (lacustrine facies).

Sediments within the esker (the esker tunnel facies) range from coarse sand to well rounded pebble-cobble-boulder gravel (Fig 6). These coarse sediments have been extensively used for construction purposes and most accessible sections of this esker have been quarried leaving relatively few sections retaining the original esker landform (Fig. 5).

Figure 6: Cross-section of the esker in the uppermost Ottauquechee river valley exposed where the esker is cut by a small tributary stream. Lenses and layers of well rounded pebble-cobble-boulder gravel interlayered with coarse sand make up most of the esker.

Figure 7: Well-rounded cobbles and boulders exposed in an old stone wall near the drainage divide between the south-flowing Ottauquechee river and the north-flowing South Branch of the Tweed river. This extensive area of coarse boulder gravel is interpreted to be a glacial outwash deposit (possibly redeposited esker tunnel facies materials). Several small kettles also occur in this area.

Lacustrine Sediments

No lacustrine deposits were mapped in the southern half of the Pico Peak quadrangle. Specifically, no evidence exists to indicate that a lake ever occupied the upper reaches of the Ottauquechee river valley. Meltwater from the retreating ice sheet could freely drain down the Ottauquechee river depositing the extensive alluvial sediments (glacial outwash) that fill the valley.

Exposures in recent landslides along streams draining the western slope of the Green Mountains show extensive deposits of very fine sand and silt in areas approaching the western boundary of the quadrangle at elevations as high as 1,500 feet. 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.

Lacustrine sediments do occur in the South Branch of the Tweed river valley to an elevation of 1,350 feet (the elevation of the drainage divide between the Ottauquechee and Tweed rivers) indicating that a glacial lake occupied this north-sloping valley as the ice sheet retreated to the north. Lake bottom sediments largely consist of very fine sand and silt deposits (Fig. 8) although rare exposures of coarser sand deposits occur lower in the section. These sediments are thin and patchy on the steep valley sides, but can be quite thick in the valley bottom where they are usually overlain by a thin veneer of alluvium. Finer silt/clay sections of lacustrine deposits are restricted to isolated patches in the Johnson Brook valley where the depositional environment must have been quiet enough for these fine sediments to accumulate. All exposures in this valley were overlain by colluvium.

Figure 8: Slumped and disrupted lacustrine sediments consisting of medium to very fine sand (summer sedimentation) and grey silt (winter sedimentation) exposed in a deeply gullied woods road on the west side of the steeply-sloping South Branch of the Tweed river valley approximately 1 km south of the northern quadrangle boundary.

Deltas formed where tributary streams entered this lake predictably at elevations close to 1,350 feet (see cover photo). The region occupied by the lake in the mapped area is small enough that isostatic tilt hasn't created significant differences in the elevations of the delta surfaces across the area. Most of the mapped deltas are small and consist of both stream-deposited sand and gravel and debris flow deposits. One larger delta, formed where Johnson Brook and an unnamed tributary to the south entered the lake, has been largely quarried away (see cover photo). Distributary stream channels are well preserved on the delta surface created where Jimmy Dean Brook entered the lake (Waypoints 210 and 211).

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. Large fans emanate from the larger tributary brooks and have spread across most of the otherwise flat Ottauquechee River valley forcing the river to the opposite side of the valley. In contrast to the fans developed in the Tweed river valley, all of the fans in the Ottauquechee river valley are constructional and consist entirely of materials eroded from the stream valleys feeding the fans. 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.

The depositional history of alluvial fans in the Tweed river valley is more complicated because this valley was occupied by a glacial lake and partially filled with lacustrine sediments. When this lake drained the lacustrine sediments were partially eroded by both the Tweed river and its tributary streams. The alluvial fans created by those tributaries (e.g. Jimmy Dean Brook, Johnson Brook, and Townsend Brook) all consist of alluvium and limited debris flow material deposited over older lacustrine sediments, i.e. the coarse alluvium is a relatively thin veneer overlying fine-grained lacustrine sediments (Fig. 9, see also geologic cross-section, Fig. 10).

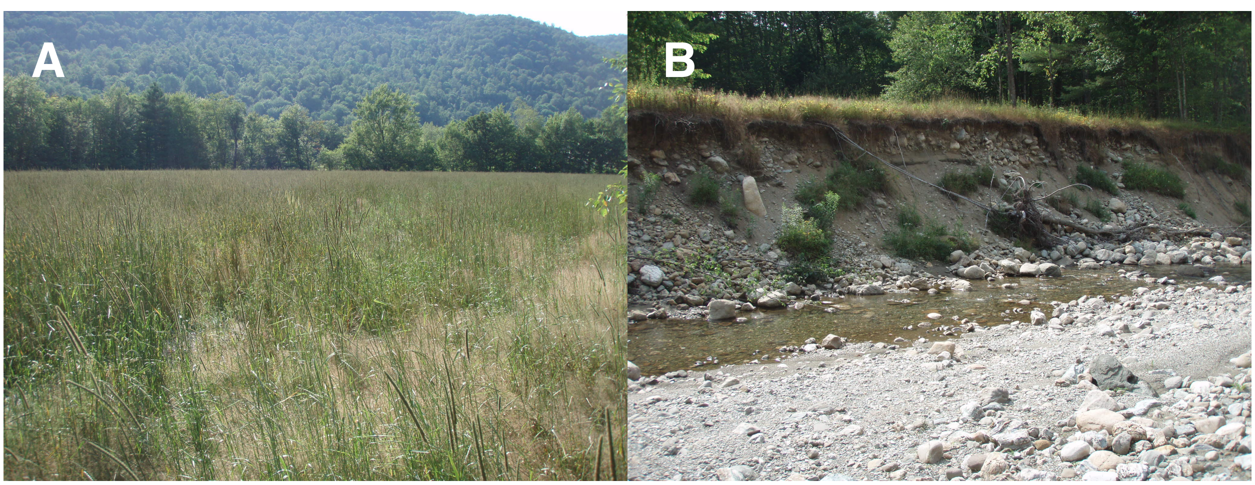

Figure 9: (A) Gently sloping surface of the Johnson Brook alluvial fan. Several meters of coarse fluvial sediments unconformably overlie fine lacustrine sediments (see geologic cross-section, Fig. 10). (B) Cut bank along the Tweed River just upstream of its confluence with Townsend Brook. Coarse fluvial sediments exposed in the cut bank occur on a terrace above the modern channel that is incised into the toe of an alluvial fan produced by Townsend Brook.

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 18th and early 19th 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 on terraces above and adjacent to the modern channels of the Tweed and Ottauquechee rivers (Fig. 9B). Most of the terraces underlain by alluvium are less than 10–20 m above the modern stream channel. The alluvium consists of layered, generally coarse-grained sediments (pebble-cobble-boulder gravels) whose grain size varies widely over short distances across the terraces. Beaver ponds are extensively developed in the upper Ottauquechee river valley and the gradient along significant reaches of this valley provides environments for the accumulation of both fine clastic sediment and significant quantities of organics. In the Tweed river valley alluvium is most frequently deposited as a relatively thin veneer (1–2 m thick) on older fine-grained lacustrine sediments. In some areas, however, the alluvium is deposited on terraces eroded into older, coarse-grained, ice-contact deposits. Note that many of the smaller tributary streams have deposited discontinuous, thin layers of alluvium that were not mapped.

Description of the Geologic Cross-Section

A geologic cross-section was drawn across the South Branch of the Tweed River valley near it's intersection with Johnson Brook (Fig. 10; see geologic map for exact location). In addition to the mapped surficial geology, logs from 5 located water wells were used to constrain the subsurface geology. Vertical and horizontal distance units are in feet to conform with units used on the topographic base map.

A thin, discontinuous mantle of till covers the steep slopes where bedrock outcrops are common. The interface (contact) between the till and the underlying bedrock is not shown on the cross-section. Till was not clearly described in any of the water well logs. Erosion by subglacial streams may have removed this till or the material logged as "clay" may in fact be till.

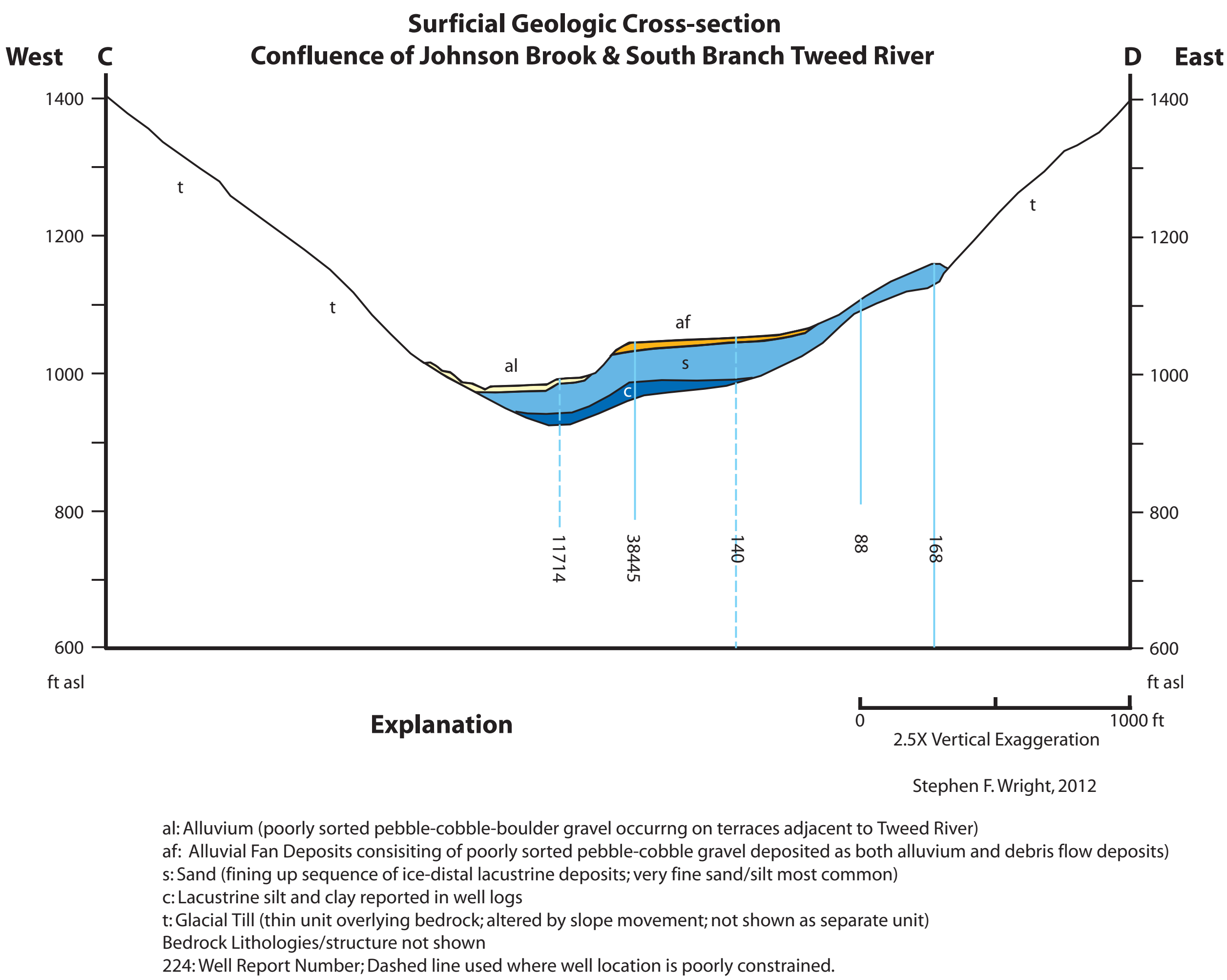

Figure 10: Surficial geologic cross-section drawn across the South Branch of the Tweed River valley near the confluence of Johnson Brook and the Tweed River where Johnson Brook has deposited an alluvial fan on top of lacustrine sediments. Several terraces mantled with alluvium comprise the valley bottom and extend up the west side of the valley. Blue vertical lines (dashed where wells have been projected into the section) show the location of water wells used to constrain the subsurface geology.

The largest volume of surficial material in the section consists of fine and very fine sand, silt, and clay deposited in the glacial lake that used to occupy the valley (Fig. 10). Fine and very fine sand and silt deposits are common in the valley up the elevation of the lake surface (1,350 ft) and the Tweed River valley in the vicinity of the cross-section was likely infilled with these sediments to an elevation of 1,100–1,200 feet. A significant volume of these lacustrine sediments has been eroded by the Tweed River and its tributaries following the draining of the glacial lake that once occupied the valley.

Several meters of alluvium overlie the fine lacustrine sediments on the surface of the alluvial fan (Fig. 9A). As noted earlier, unlike the fans in the Ottauquechee River valley that are entirely constructional landforms consisting entirely of coarse alluvial materials eroded by the streams producing the fans, the Johnson Brook fan and similar fans in the Tweed River valley are largely erosional landforms with a relatively thin cover of alluvial fan material (Fig. 10). Johnson Brook has subsequently incised a deep channel through both the older fan deposits and the lacustrine sediments they were deposited on.

The last surficial material shown on the cross-section is Tweed River alluvium (Figs. 9B, 10). Fluvial terraces on the west side of the valley step down to the modern flood plain and are underlain by a relatively thin (1–2 m) layer of coarse alluvium unconformably deposited on older lacustrine sediments or till. Most of the original farms in the valley and Route 100 are situated on these terraces.

Interpretation of the Late Pleistocene/Holocene History

The following interpretation of the glacial and post-glacial history of the area encompassed by the Pico Peak quadrangle is based on field observations within the quadrangle and related observations and interpretations of Vermont's glacial history made by the author and other workers.

Glacially striated bedrock outcrops were mostly observed along trails traversing the main range of the Green Mountains from Pico Peak on the south to and beyond the northwestern map boundary (see geologic map). Additional striations were measured along the Appalachian Trail near the eastern boundary of the quadrangle and in rare locations at lower elevations. Two primary 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 to NNE–SSW. One well-preserved roches moutonnée not far from the Rolston Shelter on the Long Trail (Waypoint 86) confirms that ice flow was from the northeast and towards the southwest. 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 and ice flowed obliquely across the state towards Cape Cod, during this phase of retreat the elevation of the ice sheet east of the mountains exceeded that occurring west of the mountains causing the ice to flow obliquely from NE to SW across the mountains. This was most likely due to 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. Relatively few N–S striations record this motion.

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, specifically in the drainage basin of Brewers Brook, a tributary to Mendon Brook. 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 it's likely that this small lake was largely confined to the Brewers Brook basin the outlet of which is a drainage divide at almost 1,800 feet. Any lacustrine sediments deposited at higher elevations in the area are covered by collovium or till deposited during a readvance of the ice sheet 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.

On the east side of the mountains the thinning ice sheet retreated up the Ottauquechee River valley and then down the South Branch of the Tweed River valley. No landforms or sediments produced during this transition were observed, i.e. no abandoned ice-marginal meltwater channels were observed east of the mountains. There is a well-developed esker system in the Ottauquechee River valley and a less well preserved esker system in the Tweed 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-sourced 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.

When the ice sheet retreated northward over the drainage divide between the south-sloping Ottauquechee River valley and the north-sloping Tweed River valley the ice sheet at the height of the divide thinned and stopped flowing. Evidence of this ice behavior are several small kettles (produced by blocks of stagnant ice) mapped near the drainage divide. It's likely that larger masses of dead ice occupied the areas where Colton pond is situated to the west of Route 100 and the large unnamed swampy area east of Route 100, respectfully immediately west and east of the drainage divide. Coarse fluvial sediments occur throughout this area and were originally deposited both on and along the margins of the stagnant ice blocks.

As the ice sheet retreated northward, down the Tweed River valley, it dammed the valley and created a small glacial lake (Glacial Lake Pittsfield, Fig. 11) whose outlet was at the drainage divide with the Ottauquechee River valley (1,350 feet). South of the divide fine-grained glaciolacustrine sediments were deposited in this narrow lake that became progressively deeper as the ice retreated down the valley. This lake was small and relatively short-lived. Once the ice sheet retreated to the confluence of the Tweed River the White River (near the current intersection of Routes 100 and 107), this lake would have catastrophically drained down the White River valley which was occupied by Glacial Lake Hitchcock (local elevation ~760 feet). While mapping sections of Glacial Lake Hitchcock sediment in the Third Branch valley between Bethel and Randolph, Larsen in Larsen et al. (1993) has noted several consecutive abnormally thick sediment layers. One possible source of that sediment was the flood resulting from the ice-dam failure of Glacial Lake Pittsfield and the subsequent rapid erosion of the now-exposed lake bottom sediments.

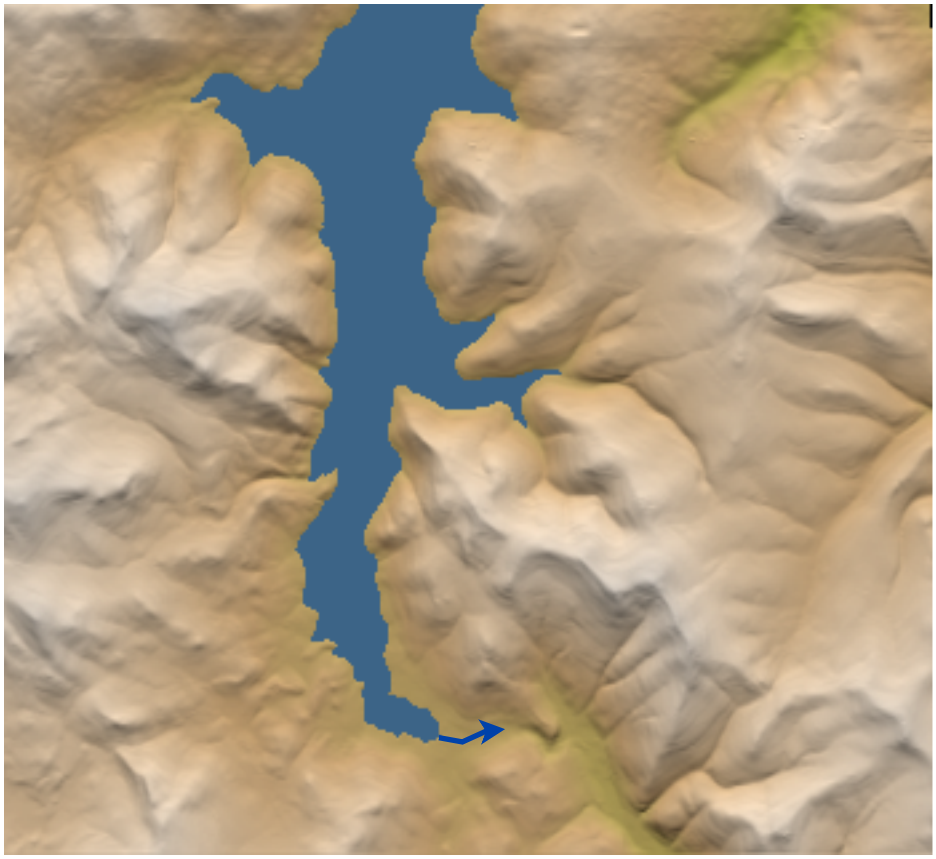

Figure 11: DEM of parts of the Pico Peak and Rochester Vermont quadrangles showing the extent of the glacial lake that occupied the Tweed River valley (Glacial Lake Pittsfield). The outlet of the lake was across the drainage divide between the Tweed and Ottauquechee rivers (Elevation 1,350 feet, see arrow).

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. In the Tweed River valley river erosion through lacustrine sediments began when the ice dam holding back Glacial Lake Pittsfield failed. Fluvial terraces preserved along the sides of the valley record river incision. At the confluence between tributary valleys and the main river, alluvial fans have formed where fan sediments unconformably overlie the partially eroded lacustrine sediments.

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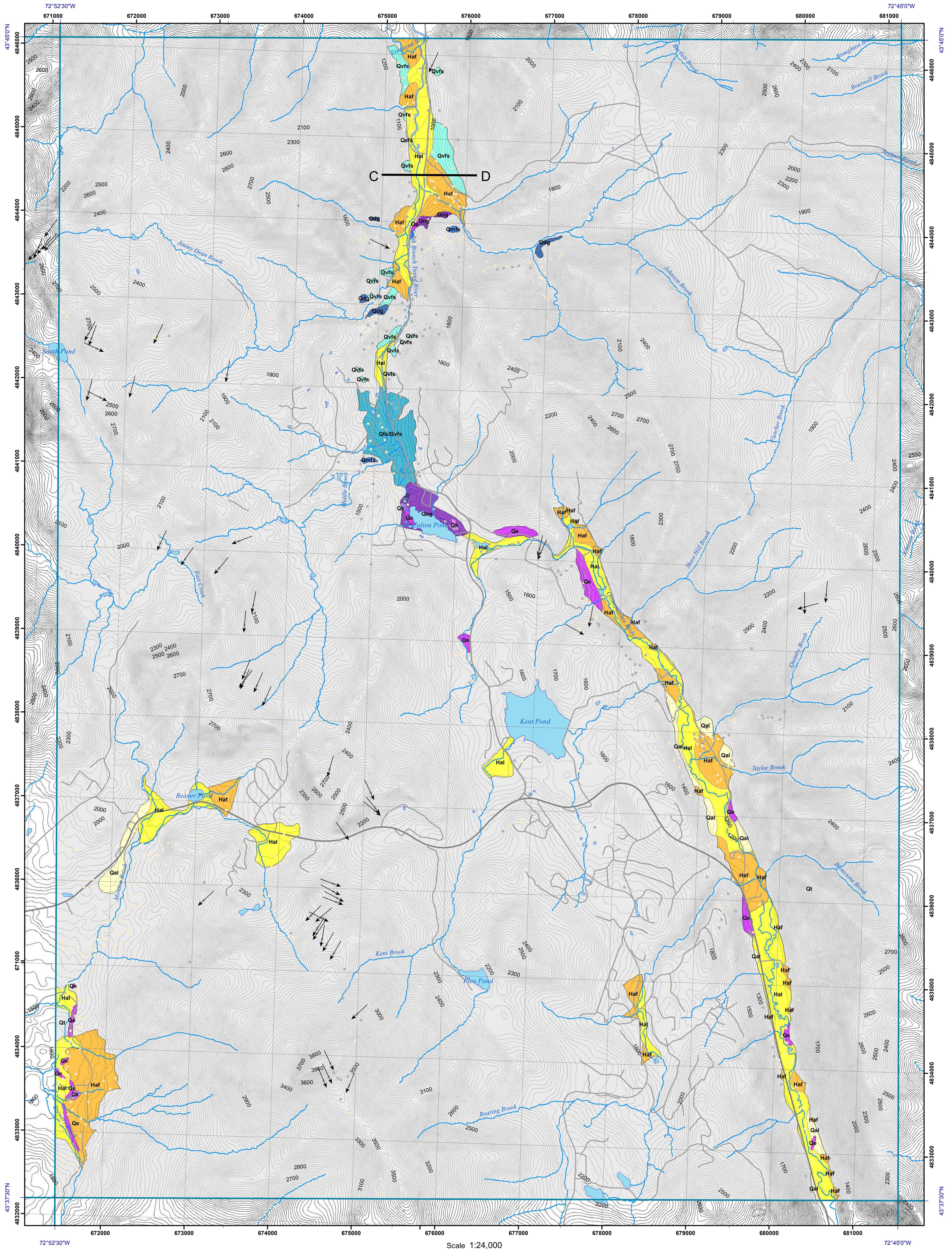
UTM locations of photographs in this report.

Figure	Waypoint	NAD27 UTM Coordinates		NAD83 UTM Coordinates	
Front Page	79	676941	4843640	676977	4843644
2	14	677488	4839113	677524	4839117
3	15	677450	4839382	677486	4839386
4	985	671112	4843155	671148	4843159
5	6	677591	4839730	677627	4839734
6	11	677676	4839536	677712	4839540
7	186	675526	4840740	675562	4840744
8	163	675229	4845624	675265	4845628
9A	118	675779	4844420	675815	4844424
9B	146	675401	4846000	675437	4846004



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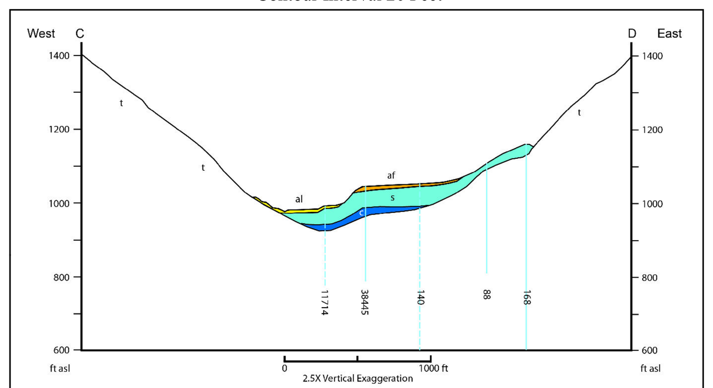
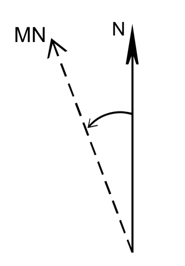


Explanation
al: Alluvium (poorly sorted pebble-cobble-boulder gravel occurrng on terraces adjacent to Tweed River)
af: Alluvial Fan Deposits consisiting of poorly sorted pebble-cobble gravel deposited as both alluvium and debris flow deposits)
s: Sand (fining up sequence of ice-distal lacustrine deposits; very fine sand/silt most common)
c: Lacustrine silt and clay reported in well logs
t: Glacial Till (thin unit overlying bedrock; altered by slope movement; not shown as separate unit)
224: Well Report Number; Dashed line used where well location is poorly constrained.



Base map: Vermont Agency of Natural Resources.
Coordinate System: Vermont State Plane, meters, NAD 83.
Geographic coordinates shown at corners are in NAD 83.
Grid overlay on map is Universal Transverse Mercator, Zone 18N, NAD 27.

Digital Cartography by Abigail Ruksznis, August 2012

DESCRIPTION OF MAP UNITS

Holocene Deposits

Haf — Alluvial Fan: Fan-shaped deposits of poorly sorted to moderately well sorted boulder-cobble-pebble gravel, pebble gravel, pebbly sand, sand, silt, and clay deposited as stream alluvium or debris flows at the base of steep slopes. Sediments are coarsest towards the fan apex and fine towards the toe.

Hal — Holocene Alluvium: Moderately well to poorly sorted pebble-cobble gravel, sand, silt, clay, and organic sediments, frequently in fining-upward sequences, formed by lateral migration of modern stream channels and flooding of adjacent flood plains.

Late Quaternary Deposits

Qal — Quaternary Alluvium: Moderately well to poorly sorted pebble-cobble gravel, sand, silt, clay, and organic sediments, frequently in fining-upward sequences.

Qvfs, **Qfs/Qvfs**, **Qmfs** — Quiet Water Deposits: Most commonly very fine sand and silt (Qvfs), but finer material (silt and clay) occurs in the Johnson Brook valley and medium (Qmfs) to fine sand (Qfs) occurs in areas lower in the section and/or closer to the lake outlet.

Qdg — Delta Deposits: Poorly to moderately sorted coarse sand and pebble, cobble, boulder gravel deposited as topset and foreset beds in deltas. Includes debris flow deposits.

Qk — Kettles: Closed depressions formed by melting blocks of stagnant ice. May contain water if the bottom is below the water table.

Qe — Esker and related Ice Contact Deposits: Poorly to moderately sorted coarse sand and pebble-cobble-boulder gravel in eskers. Medium to fine sand may be associated with the tunnel fan facies.

Qog — Outwash Gravel: Poorly to moderately sorted coarse sand and pebble, cobble, boulder gravel deposited near the drainage divide between the Ottauquechee and South Branch of the

Qt — Glacial Till: Unsorted, dense, heterogeneous mixture of clay though boulder-size sediment deposited directly under glacial ice (lodgement till). Mantles the upland area as a thin discontinuous blanket, but reaches thicknesses exceeding 30 m in some areas. Includes areas of diamict that formed as slumps and debris flows deposited on top of the lodgement till.

- Striation
- Bedrock Outcrops
- Field Station
- Line of Cross Section
- Stream
- Road
- Town Boundary
- USGS Quadrangle Boundary
- Contour, labelled in feet

Research supported by the Vermont Geological Survey, Dept. of Environmental Conservation, VT ANR.
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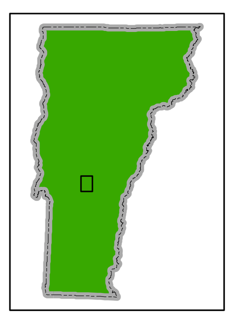
The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.



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Laurence Becker, State Geologist
Department of Environmental Conservation
Agency of Natural Resources
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VERMONT
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SURFICAL GEOLOGIC MAP OF THE PICO PEAK 7.5 MINUTE QUADRANGLE, VERMONT

by
Stephen Wright
2012