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Surficial Geology of the Eastern Half of the Saint Johnsbury 7.5 x 15 Minute Quadrangle

by

George E. Springston
and
George M. Haselton

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Current Addresses:

George E. Springston
81 East Hill Road
Plainfield, VT 05667
(802) 454-1220

George M. Haselton
7 Esty Road
Westmoreland, NH 03467-4506
(603) 399-8425

Executive Summary

The purpose of this study is to map and interpret the surficial geologic deposits and related landforms of a part of the St. Johnsbury/Danville area.

The depth to ledge across most of the study area is generally less than 20 feet and is commonly less than 10 feet. Only in the major stream valleys is the depth to bedrock generally 20 feet or more. By far the greatest depths to bedrock are in the Passumpsic River Valley, where the surficial deposits are commonly greater than 100 feet thick.

The oldest surficial deposits encountered in the study area consist of two varieties of glacial till: The lowermost of these is a firm, silt-rich till known as *basal till* and the uppermost is a looser, sandy till known as *ablation till.* These materials were deposited by the North American Ice Sheet during the last of several glacial episodes which occurred during the Pleistocene Epoch.

Deposits of sand and gravel in the study area are of two broad types: *Ice-contact deposits* which formed from sediments deposited in contact with glacial ice, and *glacial outwash* which formed from sediments deposited beyond the margin of the glacial ice. The most extensive ice-contact deposits are the gravels and sands of the spectacular *esker* in the Passumpsic River Valley (An esker is a long, usually sinuous ridge of sand and gravel which formed as a stream deposit in or under a stagnant glacier. When the surrounding ice melted away, the gravel and sand were left behind as a ridge.) Large glacial outwash deposits of sand and gravel flank the esker and smaller deposits occur at a few other locations in the valleys.

In the lower portions of the valleys the till, sand, and gravel are commonly overlain by fine-grained lake deposits of silt, silty clay, and clay. These *lacustrine* materials were deposited as annual layers (known as *varves*) which formed in Glacial Lake Hitchcock, a lake which filled the Connecticut and Passumpsic Valleys as the continental ice sheet retreated at the close of the Pleistocene.

In the most recent epoch of Earth's history, the Holocene, stream deposits consisting of silt, sand, gravel, and/or boulders have formed in the valleys, a few small talus deposits have accumulated at the bases of ledges, and small landslide and mudflow deposits have formed where steep slopes in basal till are being actively eroded by streams.

Sand and gravel deposits are abundant along the Passumpsic Valley Esker System in the eastern part of the study area but are otherwise quite limited. However, a previously unrecognized esker and outwash deposit was discovered south of Pumpkin Hill in Danville. If portions of this are exploited as a source of sand, it is hoped that a significant portion of it can be preserved as a natural landmark.

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Introduction

Location

The study area is located in Caledonia County in northeastern Vermont, approximately 25 miles northeast of Montpelier (Figure 1). It includes the southwestern portion of the town of St. Johnsbury, the eastern portion of Danville, the northernmost part of Barnet, and the western part of Waterford. St. Johnsbury is located at the intersection of two Interstate highways (I-91 and I-93), two U.S. Highways (Routes 2 and 5), and three railroads (Lamoille Valley, Canadian Pacific, and Maine Central). It serves as the county seat and as a regional center for light industry, shopping, and tourism.

Purpose

The purpose of this study is to map and interpret the surficial geologic deposits and related landforms of the study area, with a particular focus on the thickness and physical characteristics of the stratigraphic units.

Climate

The climate information below is for the Sleepers River watershed in the northern part of the study area and is from Kendall and others (in press). The mean annual air temperature is 43°F, with January having a mean of 18°F and July a mean of 68°F. The mean annual precipitation of approximately 43 inches is well-distributed throughout the year with 25-35% falling as snow, which typically covers the ground from late November to mid-April. The annual peak streamflow typically occurs during spring melt, with minimum flows occurring from mid summer to early fall. High streamflows due to intense thunderstorms do occur in the summer though, as evidenced by the storm of August 11-12, 1998, the effects of which are described below.

Bedrock Geology

The bedrock in the study area consists of metamorphosed rocks of the Connecticut Valley trough of Hatch (1988). Most of the study area is underlain by the calcareous granulite, calcareous schist, and lesser amphibolite of the Waits River Formation, with the phyllite, slate and micaceous quartzite of the Gile Mountain Formation underlying the easternmost section of the area. These units are of probable Devonian age (Hall, 1959; Hatch, 1988). A small, poorly exposed body of granite of probable Devonian age is exposed in the southwestern portion of the study area to the west of Morses Mills (Hall, 1959).

Bedrock exposures are common throughout the study area, especially along stream courses and on hill tops. The only major exception to this generalization is in the lower parts of Passumpsic River Valley, where bedrock outcroppings are scarce. Even there, the river has been able to cut through the thick sand and gravel deposits to disclose bedrock in a few locations. Bedrock outcrop locations are shown on Plate 4.

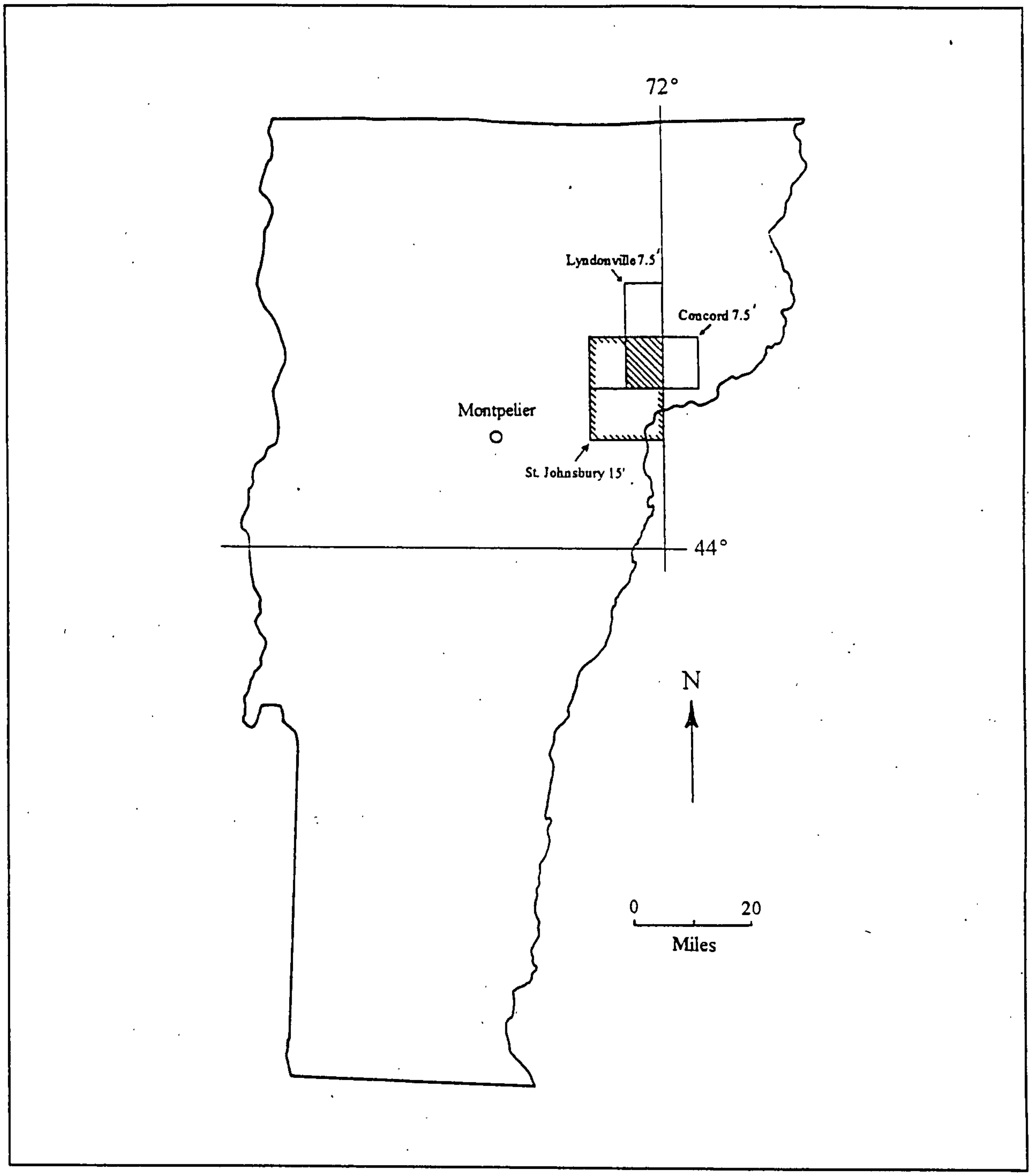


Figure 1. Location map. The study area is indicated by diagonal ruling. The St. Johnsbury 15 minute quadrangle is indicated by the larger rectangle with shaded margin. The northern half of the 15 minute quadrangle comprises the St. Johnsbury 7.5 x 15 minute quadrangle. Other quadrangles referred to in the text are labeled.

Physiography

The study area is located in the rolling hills of the Vermont Piedmont physiographic province of Stewart and MacClintock (1969). Viewed from a regional perspective, it is a part of the Central Highlands province (Denny, 1982). The general distribution of landforms and the drainage pattern are shown in Figure 2. Relief is moderate, with the high point being approximately 480 meters (1,575 feet) above sea level near the top of an unnamed hill in Danville on the western boundary of the study area and the low point being approximately 156 meters (512 feet) on the Passumpsic River at the southern margin of the study area. To the west of the field area the Kittredge Hills rise to an elevation of approximately 745 meters (2,444 feet).

All of the streams in the study area drain into the Passumpsic River, which in turn drains southward into the Connecticut at East Barnet, approximately four miles south of the study area. The major tributaries of the Passumpsic in the study area are Stark Brook and the Sleepers River in the north and Water Andric and Joes Brook in the south. The named tributaries of the Sleepers River, from north to south, are Burroughs, Houghton, Pope, Badger, Morrill, Roy, and Whiteman Brooks.

The general stream pattern across the field area is dendritic with a subtle subparallel arrangement of the master streams, which flow from northwest to southeast.

The eastern flank of the Kittredge Hills, up to an elevation of approximately 510 to 540 meters (1670 to 1770 feet), has a topographic form which suggests that it is a pediment produced by the coalescing of alluvial fans. This feature is best seen on the 1:62,500 scale St. Johnsbury topographic map (1943). Certainly there is little sign of bedrock exposures on this feature but it should be pointed out that it was not investigated in detail. Except for the two apparent kames at "Pierce's Pit" (see Ice-contact Deposits, below), the only material we have encountered on this feature is till. Thus, if it is a pediment, it is of pre-glacial origin.

Acknowledgments

This projects was funded by the Vermont Geological Survey with support from the Statemap Program of the U.S. Geological Survey. We would like to express our sincere appreciation to Laurence Becker, Vermont State Geologist, and Marjorie Gale, Geologist with the Survey.

We extend our thanks to the U.S. Geological Survey for allowing us to stay at their "Town Line Cabin" in the Sleepers River Research Watershed. G. Scot Applegate compiled a massive spreadsheet of water well drilling logs, highway borings, and miscellaneous test boring data which was an important source of data for our maps. Mike Williams of the University of Massachusetts at Amherst kindly loaned us the manuscript bedrock geologic map for the area produced by the

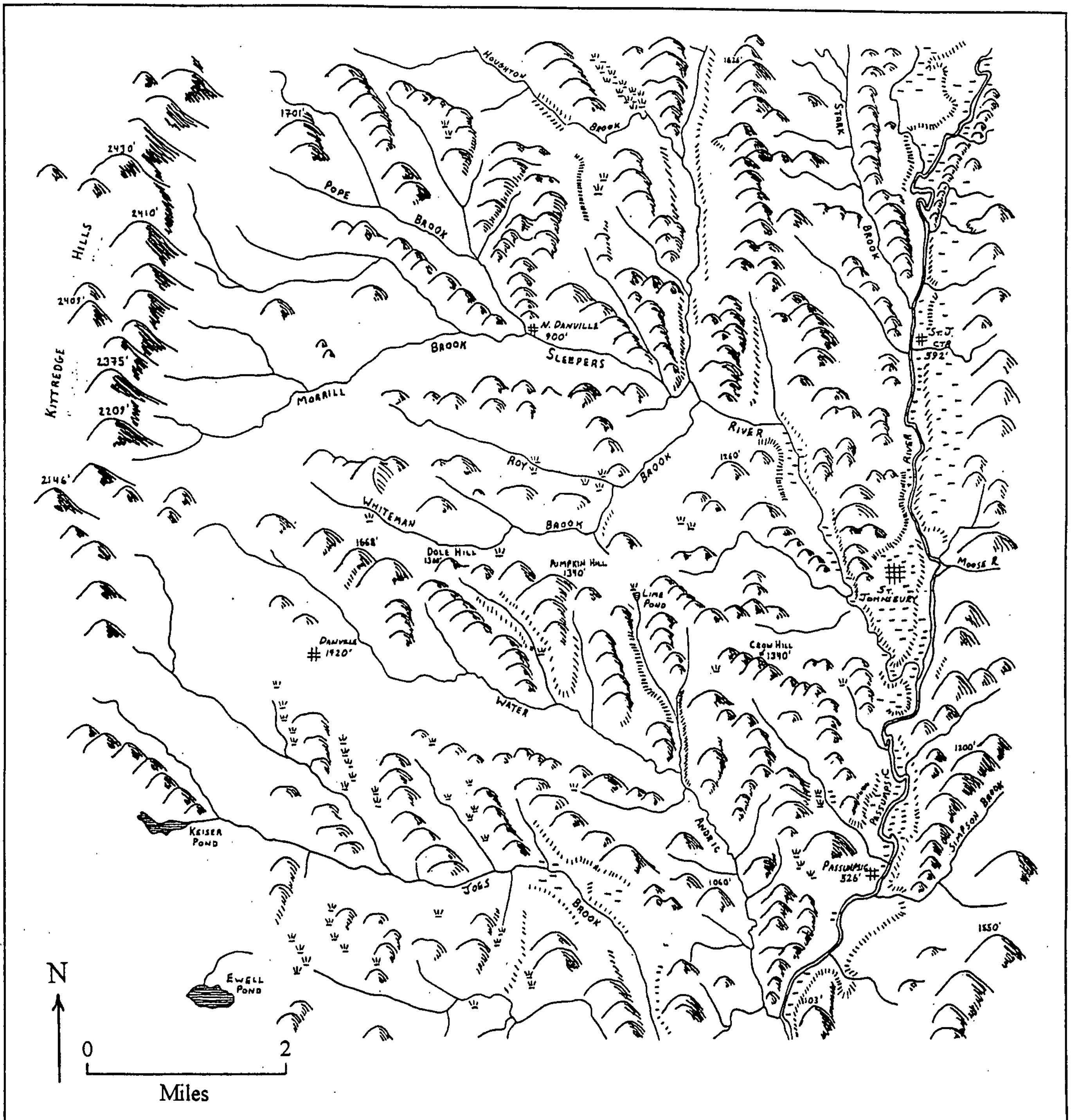


Figure 2. Landform map of the study area and vicinity.

late Leo M. Hall. This served as a major source of data for locations of bedrock outcrops. Roger DeKett of the Natural Resource Conservation Service Office in St. Johnsbury helped us in many ways: He patiently answered many questions about the soils in the area; he supplied us with a copy of a digital soil parent material map of the Sleepers River watershed at 1:24,000 and copies of soil mapping on unrectified aerial photographs for much of the rest of the study area; he loaned us copies of the 1943 black-and-white aerial photographs of the area; and he accompanied us for a day in the field. Thor Smith of the U.S. Geological Survey office in Montpelier, Vermont supplied us with helpful test well boring data from the Sleepers River Watershed. Stephen Parker, Administrative Assistant to the Town of Danville, supplied helpful information on the recent flood and on the Pumpkin Hill Town Forest.

Finally, we would like to thank the landowners of the study area. Every person we spoke with was helpful and cooperative, with many people going out of their way to help us with our explorations. Their friendliness made this study possible.

Methods

Field work was conducted during the summer and fall of 1998. The St. Johnsbury 7.5 x 15 minute topographic quadrangle (U.S. Geological Survey, 1:25,000 scale, 1983) was used as the base map. Locations were determined by pace, compass, altimeter, and in some cases by a hand-held Global Positioning System unit. Where locations are recorded in the text in Universal Transverse Mercator (UTM) coordinates, all locations are in Grid Zone 18 and the NAD27 datum is used.

Natural stream-bank exposures and pre-existing man-made excavations such as gravel pits were examined wherever possible, with shovels and a hand auger being used where these were not available.

Soil colors are described using the Munsell Soil Color Chart, 1994 Revised Edition. Color determinations were made on moist samples in direct sunlight.

The old St. Johnsbury 15 minute quadrangle (1:62,500 scale, 1943), although of relatively small scale, was found to be very helpful in interpreting subtle landscape features as the plane-table topographers of years past included a great amount of fine topographic detail, much of which simply does not show up on the modern 1:25,000 scale quadrangle.

We examined black-and-white aerial photos from 1943 and 1963-64 and color infrared aerial photographs from 1992-93 in order to plan our field work and to supplement our field sites. The older aerial photos were especially helpful for identifying areas with very shallow depths to bedrock as the ribs of bedrock often showed up quite clearly on the less forested landscape of decades past.

Previous Work

Ernst Antevs (1928) undertook studies of varve stratigraphy at four sites in the quadrangle (his Stations 171-174). He also included some intriguing observations about a supposed moraine at St. Johnsbury and its possible correlation with the Littleton-Bethlehem Moraine (see section on Moraines below).

The first overall study of the surficial deposits of the area was undertaken in the 1950's or 1960's by David Stewart as part of his study of the St. Johnsbury 15 minute quadrangle (Stewart, no date). This work was incorporated into the Surficial Geologic Map of Vermont (Doll, 1970) and is described in general terms by Stewart and MacClintock (1969).

Subsequent surficial geologic work in the study area appears to be limited to Wayne Newell's study of the surficial deposits in the Passumpsic River Valley (Newell, 1970) and limited test borings and depth to bedrock measurements in the Sleepers River Research Watershed (Thor Smith, U.S.G.S., Montpelier, personal communication, 1999).

Stratigraphy

Introduction

The oldest surficial deposits encountered in the study area consist of firm, silt-rich basal till overlain by friable to loose, sandy ablation tills. Ice-contact deposits of sand and gravel in the form of kames and kame terraces occur at several locations throughout the area. A system of esker deposits of ice-contact gravels and sands are spectacularly well-developed in the Passumpsic River Valley. This esker system is flanked by extensive outwash deposits of gravel, sand, and silt. In the valleys, all of this is overlain by fine-grained lacustrine deposits of varved silt and clay associated with glacial Lake Hitchcock. All of the preceding materials are of Pleistocene age. Holocene alluvial deposits consisting of silt, sand, gravel, and/or boulders are common in the valleys. A few small Holocene talus deposits occur, and both landslide and mudflow deposits are common where steep slopes in basal till are being actively eroded by streams.

Till

As Plate 1 clearly shows, glacial till is the most widespread surficial material in the study area. It underlies nearly all of the upland areas and it also floors most of the stream valleys, although in the lower topographic settings it is commonly overlain by glacial outwash, lacustrine deposits, or alluvium. Only in the lower portions of the Sleepers River Valley and in the bottom of the Passumpsic River Valley does it appear to be absent (natural exposures are generally lacking in these locations and water well data is too sparse and ambiguous to definitively settle this question). Although thicknesses of 70 feet or more of till were occasionally encountered, such thicknesses are limited to parts of the stream valleys. Depth to bedrock was generally shallow throughout most of the study area, especially in the areas underlain by till (Compare Plates 1 and

7). The depth to bedrock in the upland areas underlain by till was generally less than 20 feet and often less than 5 or 10 feet.

Following Newell (1970) two principal types are recognized: A firm, fine-grained basal or lodgement till and a looser, sandy to loamy ablation till. An important complication is that some exposures show till with physical characteristics intermediate between these two types of till. As described below, we have tentatively interpreted this material as a weathering product of the lodgement till.

Basal Till

Throughout the study area the streams occasionally expose a firm, unweathered, dark gray (N4/) till containing predominantly unweathered, striated and faceted pebbles, cobbles and boulders of calcareous granulite, quartzite, schist, amphibolite, and granitic rock. This material has a subtle bluish cast to it despite the Munsell designation cited above and is sometimes locally referred to as "blue clay" or "blue till". It's firmness leads to yet another local designation as "hardpan". In some localities this material has a marked fissility. It is well-exposed at numerous locations on the Sleeper's River, Pope Brook, Morrill Brook, Roy Brook, Whiteman Brook, and Water Andric. Joe's Brook is the only major stream where this material was not encountered, although some of the less firm till observed in the Joe's Brook Valley could easily be a weathered version of this material (see below). Although this material underlies the stream valleys throughout the area, it is unclear as to the full extent of this material. It is not encountered in the upland interfluves between the streams. This is either because it was 1) not deposited in these areas, 2) eroded away from these areas, or 3) the till in the interfluves is a weathered version of the till exposed in the stream valleys in which the clay has been removed by soil-forming processes. The material is interpreted to be a lodgement till that was deposited beneath active ice.

Although no granulometric analyses have been undertaken as part of this study, a field examination of this material indicates that the matrix of the basal till is dominated by silt. According to Roger Dekett the clay content is roughly 10% (personal communication, 1998). Fine sand is also typically present in the matrix. These observations fit well with those of Cannon (1964) as reported by Stewart and MacClintock (1969), that the clay content of basal tills in northern Vermont was less than 30% and usually less than 10%.

Several locations in the study area show till that has characteristics intermediate between the basal till and the ablation till described below. This material is interpreted to be weathered basal till. See the discussion under Till Stratigraphy and Correlations below.

On many of the stream channel floors in the study area, the unweathered basal till acts as a firm pavement that appears to be capable of resisting significant erosion at normal stream velocities. Given the extreme toughness of this material, it appears that the streams can only begin to effectively erode it at the highest of flow levels (see the discussion of the flash flood of August, 1998 in Appendix A).

Ablation Till

The second major variety of till found in the study area is a friable to loose, unstructured, sand-matrix till with weathered rounded pebbles, cobbles, and boulders of similar compositions to the basal till described above. The matrix color is typically olive (5Y4/3) with weathered clasts of calcareous granulite which are dark olive gray (5Y3/2). From field examinations the matrix of this material is dominated by medium to fine sand with lesser amounts of silt and clay. Thus, in soils terminology it is generally a fine sandy loam. In at least some localities (such as Station SJ-82 described below) it contains more large boulders than the basal till. This material is interpreted to represent an ablation till formed during stagnant downwasting of an ice sheet.

Till Fabric

A conspicuous feature in the lower, basal till is a strong preferred orientation of the clasts. Three sets of reconnaissance till fabric measurements were undertaken as part of this study: A single set of basal till fabric measurements was made at Station SJ-99 near Morrill Brook and two sets were measured at Station SJ-39 on Morrill Brook. Due to the intense weathering which clasts in the upper, ablation till have undergone, it was not practicable to attempt to measure fabrics in the ablation till.

Station SJ-99 is located at UTM coordinates 4,926,330m N and 728,840m east and consists of a fresh, steep exposure of basal till on the west side of a steep-sided gully which drains into Morrill Brook. A fabric diagram based on 53 clasts from this station shows a strong maximum at approximately N0°E (Figure 3a).

Station SJ-39 is located at UTM coordinates 4,926,480m N and 731,340m E on the south bank of the Sleepers River. Here unweathered basal till is overlain by weathered basal till, laminated sand and clayey silt (outwash) and is topped with ablation till with a fine sandy matrix. A fabric diagram based on 50 clasts in unweathered basal till at this location shows a clear maximum at approximately N10°W (Figure 3b), while a diagram based on 62 clasts in the weathered, upper portion of the basal till at the same location shows a maximum at approximately N5°E (Figure 3c).

Newell (1970, Figure 3-1) also shows till fabric diagrams for two sites in the study area: the Roy Brook area and the South Danville–Morses Mills area in the vicinity of Joes Brook. The Roy Brook diagram shows a maximum at approximately N45°E (by far the most easterly till fabric reported or observed) while the South Danville-Morses Mills site shows a maximum at approximately N5°W, in good agreement with the basal till measurements at Stations SJ-39 and SJ-99.

All of these diagrams, with the exception of Newell's for the Roy Brook area, correspond reasonably well with vector means for "subsurface till" (presumably basal till) at four localities studied by Stewart and MacClintock (1969, p. 192, Fabrics 19-22).

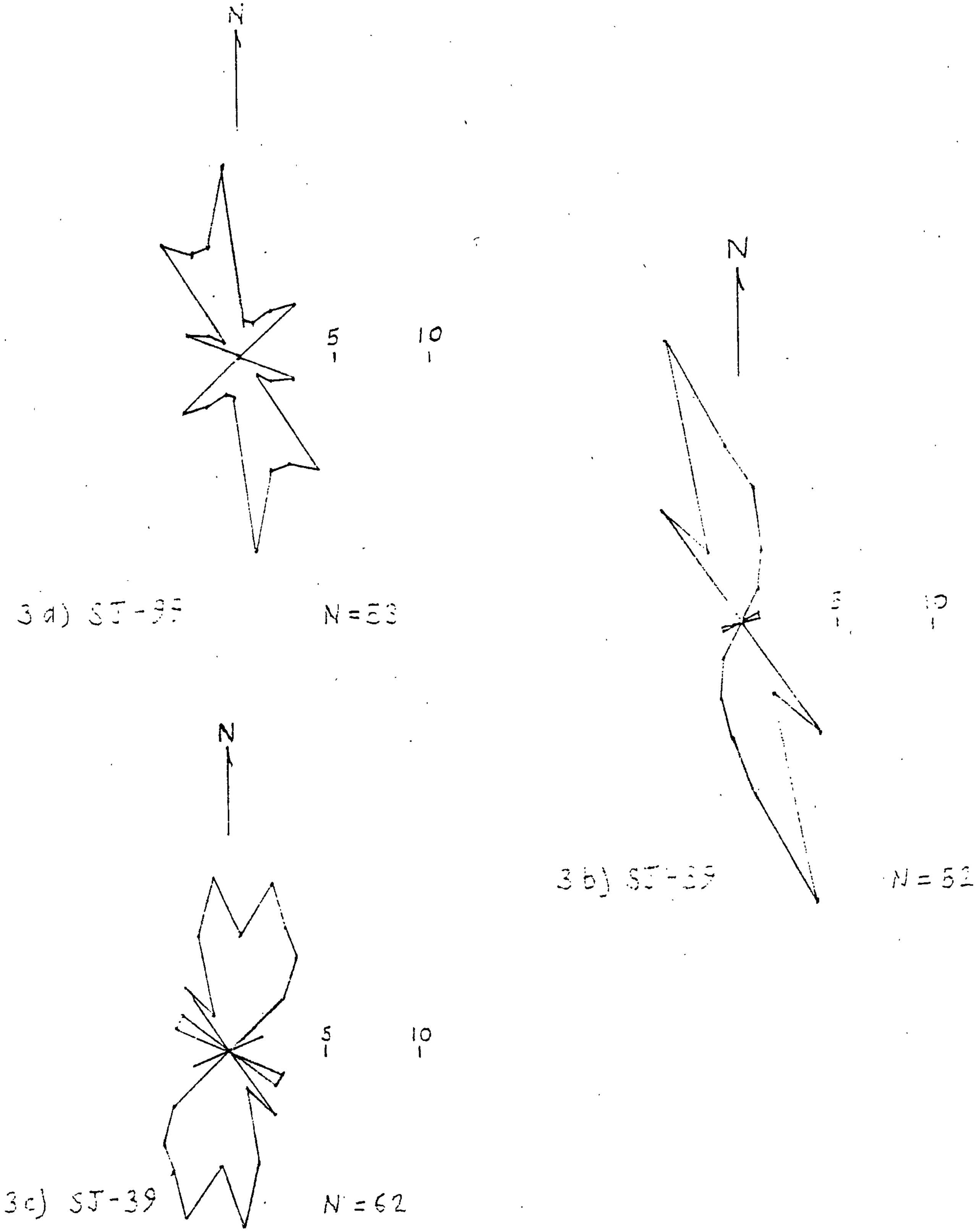


Figure 3. Till fabric diagrams. 3a) Station SJ-99, basal till; 3b) Station SJ-39, lower portion of basal till; 3c) Station SJ-39, upper portion of basal till. See text for descriptions.

Till Stratigraphy and Correlations

In New England the number of glacial tills which should be recognized at a site, the number of distinct glaciations that they represent, and their absolute ages have been ongoing subjects of controversy for many years (See for example, Koteff and Pessl, 1985). In Vermont in particular, there has been much argument as to whether or not there was evidence for three separate and distinct glacial advances as contended by Stewart and MacClintock (1969). See Larsen, (1972, 1987) for discussions on this topic.

As examples of the multiple-till sections encountered during our study, descriptions of two sites are given below.

An excellent example of basal till overlain by weathered ablation till can be seen at Station SJ-82, located 0.75 miles east-southeast of North Danville on the south side of the Sleepers River (UTM Coordinates 4,926,350mN, 732,280mE). There 16 feet of firm, fissile, clay-silt matrix till (N4/) with unweathered cobbles and small boulders is overlain by 1.2 feet of weathered, clay-silt till (5Y3/2) which, in turn, is overlain by friable till with a coarse sand matrix (5Y 2.5/2) with weathered cobbles and boulders. The basal and ablation tills are separated by a sharp contact. At this location the uppermost till has more large boulders than the lower, clay-silt till.

Two tills, separated by lacustrine clay and capped by additional lacustrine clayey silt are beautifully exposed at Station SJ-28 on the southwest bank of Water Andric, approximately 0.3 miles east of Lime Brook (UTM Coordinates 4,919,500mN, 733,250mE). A schematic stratigraphic section is shown in Figure 4. The lower till unit consists of 24 feet of the standard firm, fissile, silt-clay matrix till (N4/), overlain by 16 feet of weathered basal till (5Y4/1) with numerous weathered pebbles and cobbles. Above this is 1.7 feet of laminated clay (5Y4/1.5). This in turn is overlain by 3.3 feet of sandy matrix till with numerous weathered boulders. At the top of the section is 4 feet of rhythmically laminated clayey silt (5Y5/1).

The lower till at this site is clearly the basal till seen throughout the study area. The overlying lacustrine material represents at least a brief interval of ice recession. The upper sandy till is identical in appearance to many of the exposures that we have interpreted as ablation till. At this site at least, it appears to represent an actual readvance of the ice. The uppermost lacustrine material indicates a second ice recession, which we interpret to be the final late Wisconsinan ice recession from the area. Although it is tempting to correlate the sequence described here with the Littleton-Bethlehem Readvance discussed below, further study is needed.

Ice-contact Deposits

By far the largest ice-contact deposit in the study area is a portion of the Passumpsic Valley Esker System. This is one of the longest and finest in Vermont, if not New England. It extends from St. Johnsbury northward past Lyndonville, where it splits into two branches: One extending up the valley of the Sutton River to West Burke and the other extending on up the Passumpsic River Valley to East Haven. In the study area this feature is a composite of a true esker and vast flanking deposits of outwash sands and gravels, all overlain by lacustrine deposits. Plate 1 shows

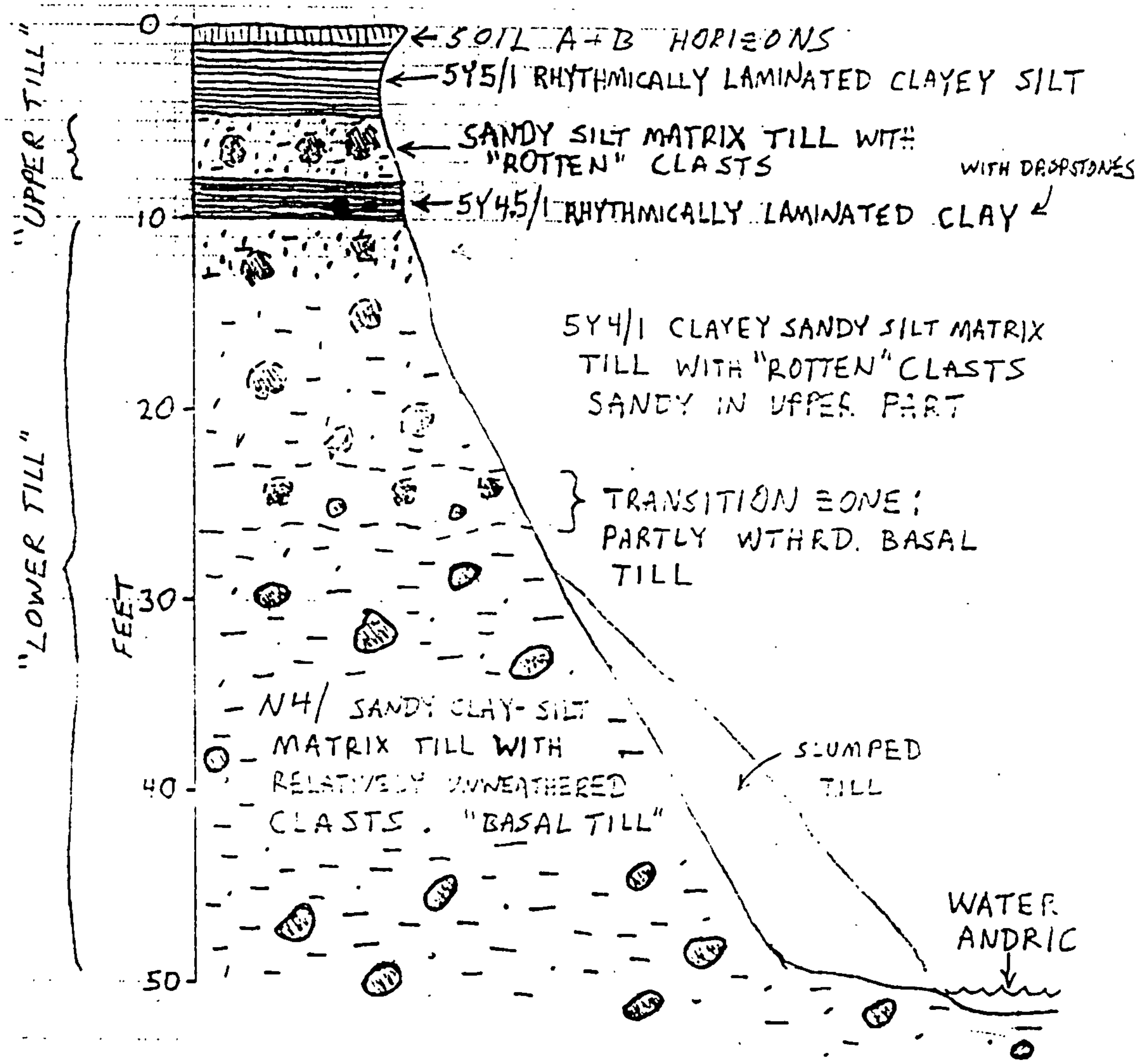


Figure 4. Two-till section at Station SJ-28 on Water Andric.

the overall extent, Plate 2 shows locations of sand and gravel pits on the feature and a summary of the materials present, Plate 5 shows cross sections which include the esker, Plate 6 details the stratigraphy at selected points along the feature, and Plate 7 shows the approximate thickness of surficial deposits. From these last three plates it is clear that the deposit is greater than 100 feet in thickness in numerous locations and in some spots exceeds 150 feet.

The numerous sand and gravel pits excavated in the deposit reveal a complex variety of features. In the core of the esker the material varies from medium and coarse sands up through pebbly and cobbly sands and pebble and cobble gravels all the way up to occasional boulder beds. Primary sedimentary features include massive cut and fill structures and cross-bedding at various scales. Post-depositional deformation includes slumping and both normal and reverse faults. The above features are consistent with deposition in an englacial or subglacial setting with subsequent collapse following glacial melt-out. Cross-bedded sands and ripple-drift cross-laminated sands and silty fine sands appear to make up the bulk of the flanking outwash deposits, most of which appear to have been deposited as proximal to distal subaqueous outwash after the model of Larsen (1987).

A second, smaller, esker system in Danville extends from 0.4 to 1.1 miles due south of Pumpkin Hill, north of the point where Penny Lane, Trestle Road, and Water Andric Road intersect. This esker system has several branches which are flanked by fields of kame and kettle topography. For the most part the crests are on the order of 10 to 20 feet higher than the surrounding land, however in some places the esker crests rise more than 30 feet above their surroundings. On the south end of the westernmost esker, the western flank appears to be approximately 100 feet high. The material encountered in several auger holes and shovel pits was generally medium to fine sand or medium to fine sandy loam, although in a few spots we encountered pebbly or cobbly sand.

An extensive deposit of sand and gravel is located in the Whiteman Brook Valley approximately 0.5 miles north of Pumpkin Hill. This is well-exposed at Station SJ-156G, a pit being operated by the Town located west of Trestle Road (UTM Coordinates 4,923,260mN, 731,900mE). This site exposes more than 30 feet of variably bedded sands and pebble to cobble gravel. Stewart (no date) and Doll (1970) show this feature as a kame terrace, a designation in accord with our observations to date. Although this feature appears to cover a large area, in no place does it appear to be very thick. The limited thickness and variable quality appear to limit its usefulness as a source of sand and gravel.

Two kames were encountered just to the west of the study area. These are at a sand and gravel extraction site locally known as "Pierce's Pit" located 1.25 miles to the south-southwest of Pope Cemetery (UTM coordinates 4,926,239mN and 727,780mE). On the 1943 aerial photographs they are clearly visible as two small, conical hills rising above their surroundings. At the former location of the southern hill, the margins of a gravel pit contain exposures of bedded sand up to 6 feet thick while large erratics of Waits River Formation litter the floor of the pit. The northern hill has only been partly excavated. There, approximately 24 feet of bedded sand and silt are currently exposed. Although there has been some apparent load deformation and there are some clasts of medium sand in a fine sand and silt matrix (perhaps transported while frozen), there is no obvious ice-contact deformation.

The site of another possible kame is located 1.8 miles due north of Danville (UTM Coordinates 4,924,200mN, 727,900mE). This feature has been almost entirely destroyed as a result of sand and gravel extraction.

Outwash Deposits

Besides the outwash deposits described above as part of the Passumpsic Valley Esker System, deposits of sand and gravel which do not appear to be of ice-contact origin also occur in the Sleeper River Valley, and in the Burroughs Brook Valley. These deposits were not investigated in detail.

Lacustrine Deposits

Fine-grained lacustrine deposits of varved silt, clayey silt, silty clay, and occasionally sand are common in the valleys of the study area, especially in the Passumpsic and Sleepers River Valleys (Plates 1 and 2). In the Passumpsic River Valley such deposits are very common, ranging in thickness from a few feet to as much as 100 feet (see Plates 6), the thickest deposits being encountered in the valley bottom with only a few feet of material covering the crest of the esker. Although areally extensive deposits of fine-grained lacustrine material were not encountered above an elevation of 270 meters, several small deposits of varved silty clay were seen in tributaries of the Sleepers River at elevations up to approximately 300 meters.

These deposits are interpreted to represent annual deposits in glacial Lake Hitchcock (Antevs, 1928; Koteff and Larsen, 1989; Ridge and others, 1996, 1999). The approximate Lake Hitchcock shoreline shown on Plate 1 is a modification of the projected lake level data of Koteff and Larsen (1989).

Based on the correlations and dating work reported in Ridge and others (1999), the lowermost lake deposits at the southern end of the study area (Passumpsic) would have formed in the lake at approximately 12.0 ^{14}C ka. Following the Littleton-Bethlehem readvance at approximately 11.9-11.8 ^{14}C ka, the ice-margin again retreated and the lake may have persisted in the upper Connecticut Valley until at least as late as 10.4 ^{14}C ka (Ridge and others, 1999).

Alluvium

Holocene alluvial deposits of silt, sand, gravel, and boulders are quite common in the valleys of the study area. These typically take the form of coarse-grained point bar deposits and finer grained overbank deposits. Because of their generally limited size and discontinuous nature, only some of the more obvious alluvial deposits are shown on Plate 1.

A typical example of a very recent alluvial deposit can be seen along the lower reaches of Roy Brook, just above its junction with the Sleepers River (UTM Coordinates 4,925,550mN, 733,840mE). There, during the night of August 11 and 12, 1998, a flash flood generated by a severe thunderstorm (described in more detail in Appendix A) swept down Roy Brook. After the flood subsided, coarse-grained deposits of boulders and cobbles (not to mention tree trunks) were left behind in the lower reaches of the brook bed and in the narrow floodplain on either side of the brook while sheets of sand and silt were laid down in the vicinity of the brook mouth on the relatively flat valley floor of the Sleepers River.

Landforms

No attempt is made in the following discussion to analyze all of the various landforms in the study area. Instead, only a few features of interest will be discussed.

Weathered Bedrock

In general, the Pleistocene glaciations have removed all traces of interglacial or preglacial soils throughout the region. However, in a few spots in the region there are exposures of weathered bedrock which appear to date from before the last glaciation. A good example of such a site is located on the east side of I-91, 0.75 miles north-northeast of the interchange with Route 2 (UTM Coordinates 4,924,575mN, 736,500mE). Here, 5-10 feet of weathered bedrock are exposed at the top of a ledge of calcareous granulite of the Waits River Formation. The weathering zone crosscuts the primary layering in the bedrock and has itself been truncated by glacial erosion. Thus, the weathering predates the last glaciation.

Another convincing example of preglacial weathering was observed in a temporary exposure in a road washout in the lower part of the Roy Brook Valley, where a thin zone of 6-12 inches of weathered bedrock was overlain by unweathered basal till.

Similar weathered bedrock was seen at three locations in the Joes Brook Valley. Although in the Joes Brook sites the till is weathered as well, so that it is possible to that the weathering of the bedrock is post-glacial, the thickness of the weathered bedrock (greater than 6 feet in one location), and the absence of similar deposits in less topographically protected locations both argue for a pre-glacial origin.

Although at a minimum, the age of these deposits must be pre-late Wisconsinan, the actual age is unclear. LaSalle and others (1985) argued for a Tertiary rather than an interglacial age for sub-till saprolites in New England and Quebec. More recent work by Bouchard and Pavich (1989) indicates on the basis of mineralogy, geochemistry, and cosmogenic ^{10}Be age dating that saprolites in the Gaspé Peninsula of Quebec are at least pre-Wisconsinan in age, although they differ with LaSalle and others (1985) in arguing on the basis of weathering profile characteristics that the saprolites formed in a Pleistocene interglacial setting rather than during the Tertiary Period.

Glacial Striations

Glacial striations are scratches made in bedrock by stones carried in the base of an overriding ice sheet. Their orientations record the directions of local ice movement. Only a few examples of glacial striations were encountered during our work in the field area (Plate 3), apparently because of the high carbonate content in much of the bedrock, which means that most striated surfaces which were exposed to the weather would be likely to have been destroyed due to chemical weathering. In support of this idea, the sites where we observed striations were all places where the bedrock had been recently exposed either because of road-building or recent erosion of overlying surficial material.

Superb glacial striae are visible at Stations SJ-57 and SJ-58 on the east side of U.S. Route 2 at the I-91 interchange. A rose diagram of 21 striation measurements from these two sites indicates a dominant trend of N10°E. At SJ-58 there are several examples of NNW striae clearly cross-cutting those with NE orientations.

Excellent striae, glacial polish, and stoss-and-lee features are visible at Station SJ-60, a set of road cuts on both sides of U.S. Route 2 in Danville. A rose diagram of 16 striation measurements indicates two maxima at N5°W and N45°W. At several spots N-S striae are observed to crosscut the NW-SE striae. Stoss-and-lee features observed at these outcrops indicate that movements were generally southward.

At Station SJ-73 on the south side of U.S. Route 2 in Danville we observed striations with an orientation of N0-10°E cut by N20-30°E striations.

On ledges adjacent to I-93 in and near the southeastern portion of the study area striae were observed at two locations: the first is at Station SJ-66 on the northwest side of I-93 north-bound, where striae range in orientation from N30°W to N10°E with a maximum at N0°E, and the second is in the Concord quadrangle at Station CO-1 on the east side of the south-bound lane of I-93, where striae with an orientation of N0°E were observed.

To the north of the study area in the Lyndonville quadrangle we observed striations at Station LY-3 on the east side of I-91. There, striae had a variety of orientations ranging from N40°W to N10°E with the dominant trend to the northwest. Several clear examples of N10°E striae being cut by N10°W striae were observed here.

Newell (1970, Figure 3-1) measured glacial striations on bedrock and the orientation of what he called "grooved topography" at several locations in the Sheffield–Wheelock area to the north of the study area. These varied in orientation from approximately N45°E to N10°W. Although these are roughly in agreement with the measurements described above, none of our observations of striae, till fabrics, or streamlined landforms, indicate ice movement from a northeasterly direction.

In general, both the striation directions and the till fabric maxima described above indicate a generally north-northwest to south-southeast direction of The variations in striation directions are probably due to a combination of control of ice-flow direction by underlying topography and a presumably lobate pattern of ice flow during the late Wisconsinan. See Ackerly and Larsen

(1986) for a more detailed discussion of regional striation patterns and their relationships to patterns of glacial movement.

Glacially Streamlined Landforms

Although the general pattern of hills and valleys in the study area appears to be of pre-glacial origin, the fact that many of the hills are elongated in a roughly north-northwest orientation, parallel to the indicators of ice movement direction discussed above, suggests that they are at least partly shaped by the movement of glacial ice. Also, as with the roches moutonées described below, the southern slope of each of these hills is typically steeper than the northern slope, giving an indication that glacial plucking has occurred on the lee sides of these hills. However, it should be pointed out that the principal foliation in the underlying metamorphic rocks in the area commonly strikes approximately north-northwest to north-northeast (Hall, 1959, Plates 1 and 2) and thus non-glacial differential erosion would also tend to produce landforms with a similar elongation.

Roches Moutonées

A pair of small roches moutonées was observed at Station SJ-55 on the east side of U.S. Route 5, approximately 0.4 miles SSW of the Northeastern Vermont Regional Hospital (UTM Coordinates 4,924,975mN, 737,640mE). These glacially sculpted bedrock forms trend approximately north-south and have gently-sloping, polished northern ends and abrupt, craggy southern faces, clearly indicating ice movement from the north to the south. These feature are exposed at the rear of a parking lot which has been excavated into the esker complex.

Moraines

Earlier workers have reported two moraines from the study area. The first is supposed to have been located in the lower Sleepers River Valley west of the center of St. Johnsbury. The second is supposed to occur in the southwestern portion of the study area.

Moraine at St. Johnsbury

In 1928 Ernst Antevs published the second of his superb memoirs on ice retreat at the close of the last glaciation in New England (Antevs, 1928). In this publication he makes the statement that, "The formation of the alternating clay and gravel beds at locality 171 in the southern edge of St. Johnsbury (see p. 199) seems to prove that the ice edge stood in the vicinity for at least 200 years. Morainal deposits at St. Johnsbury also indicate halt and readvance." (pp. 119-120). In reference to this moraine Crosby (1934, pp. 411-412 states "Antevs believed, from his studies of varved clay and other features, that there was a re-advance of the ice with the formation of a moraine at St. Johnsbury; and he suggested that this moraine might correspond with the Bethlehem-Littleton moraine 15 miles to the east." Crosby's Figure 1 indicates a section of moraine just west of St. Johnsbury in the lower Sleepers River Valley. However, this is a rough, small scale map and it is impossible to be sure exactly where this feature was located.

A search of the later maps and materials dealing with the St. Johnsbury area reveals no further references to such a moraine and in our field work we could discover no evidence of such a feature. Given the extensive earth moving which occurred in this valley during the construction of I-91, it is possible that the feature has been destroyed. The only nearby site which contains a suggestion of a late readvance of ice is Station SJ-160, a 45-foot high bank on the west side of the solid waste transfer station (Marked as "Sanitary Landfill" on the topographic map. UTM Coordinates 4,921,450mN, 736,875mE) which shows silty fine sand and fine sand overlain by a lens of approximately one foot of sandy till, which in turn is overlain by one to two feet of sand, which in turn is overlain by three feet or more of sandy till.

Danville Moraine

In the southwestern part of the study area the manuscript surficial map of the St. Johnsbury 15 minute quadrangle by David P. Stewart (at Vermont Geological Survey, no date) shows an area that is mapped as "moraine". This is part of the feature designated as the Danville Moraine by Stewart and MacClintock (1969) and shown on the Surficial Geologic Map of Vermont (Doll, 1970). These authors show this feature extending from Bradford to Glover, a distance of approximately 50 miles.

As it turns out, the portion of the "Danville Moraine" in the study area is actually an area of very thin till overlying bedrock and is in no way distinguished from other upland parts of the study area. Numerous auger holes, examination of aerial photographs, water well drillers logs, and inspection of the excavations for a municipal water line constructed during the fall of 1998 in the center of Danville showed that bedrock in this portion of the map area is within 3-10 feet of the surface. In other parts of New England where moraines have been mapped, one sees a blanket of thick drift including a great concentration of boulders, together with distinct ridge forms that can be traced as features across the countryside. Our investigations showed no such forms in the study area, although based on an examination of aerial photos the distinct possibility remains that such features exist to the west of the study area. Further detailed mapping would be needed to determine whether, in fact, the moraine does exist to the west.

Glacial Meltwater Channels

There are several locations across the field area where one can find good evidence of glacial meltwater channels. These are found as much as 200 feet above the level of present-day streams. Perhaps the most striking set of channels is located 1.6 miles north-northwest of Danville Center on the west side of Cormier Road (UTM Coordinates 4,924,800mN, 728,500mE), where a series of closely spaced channels formed in stair-step fashion on a northeast-facing slope of sandy till. These may have formed as remanent dead ice slowly melted away from the upland slope. Such channels are rather common along retreating ice margins of present-day glaciers in Alaska and elsewhere.

On the ridge extending east from this site there are several distinct notches cut into the bedrock of the ridge top. These appear to represent the sites of glacial spillways which formed during melting of the last stagnant ice in the valleys. It appears likely that the drainage through the channels was northward from stagnant ice in the valley of Whiteman Brook while the upper Sleepers River Valley to the north was already free of ice.

Talus Deposits, Landslides and Mudflows

Small talus deposits of angular blocks fallen from adjacent cliffs do occur, but for the most part they seem to be conspicuously absent. This may because the dominant carbonate-rich Waits River Formation in the study area is so susceptible to chemical weathering that there are few prominent cliffs and thus few talus deposits of any size. The only mappable talus deposit encountered is located on the east side of the Lamoille Valley Railroad approximately 1.0 miles east-southeast of Danville Center and north of Old Stagecoach Road (UTM coordinates 4,922,740mN, 730,650mE).

Small rotational landslides and mudflows, on the other hand, are quite common, especially in the valley bottoms underlain by lodgement till (Plate 1). Examples are common along Morrill Brook above North Danville, alongside the Sleepers River below North Danville, and along Water Andric, where the streams are continually undercutting steep slopes of lodgement till. Although the most active slump deposits are bare of vegetation, it is quite common for many of these slump features to be forested with the northern white cedar trees which are so common in these valleys. As a result, one can often spot the slumps from several hundred feet away just by observing the crazily "drunken" trunks of the cedars. The toes of the slump blocks, where ground water concentrates, become active mudflows and the till material extends outward into the streams as distinct lobes.

Glacial and Postglacial History

The oldest surficial deposits in the study area consist of the basal glacial till. From regional correlations it appears that this material is unlikely to be older than early Wisconsinan (Koteff and Pessl, 1985) and it is more probably of late Wisconsinan age.

Using the deglaciation chronology of Ridge and others (1999, Figure 15), the St. Johnsbury area would have been free of ice for the first time at approximately 12.0 ^{14}C ka bp (their date for the first deposits associated with Glacial Lake Hitchcock) and then, following the Littleton-Bethlehem Readvance at approximately 11.9-11.8 ^{14}C ka the area would have finally been ice-free by approximately 11.8 ^{14}C ka. The intriguing two-till section at Station SJ-28 and the section with till over outwash at Station SJ-160 may well represent this readvance.

If the Littleton-Bethlehem Readvance is a reality, it would appear necessary that the Passumpsic Valley Esker System was formed after the readvance (otherwise it would have been destroyed or at the very least greatly disrupted by the overriding ice) and is thus a feature of very latest Wisonsinan age. The deposits certainly indicate that the valley served as one of the major regional drainage channels during deglaciation. It is unclear whether or not parts of the Passumpsic Valley outwash deposits are parts of morphosequences in the sense of Koteff and Pessl (1981). Although they do not approach the maximum elevation of Glacial Lake Hitchcock, which had a shoreline elevation in the vicinity of 300 meters (see Plate 1 and discussion above), no deltaic facies have been observed in these deposits which could indicate the maximum level to which they were graded. In the absence of such evidence we can only say that these deposits represent a series of glaciofluvial to glaciolacustrine deposits at the boundary between the retreating ice sheet and Glacial Lake Hitchcock.

If the chronology of Ridge and others (1999) is correct, final ice recession would have been completed to the Canadian border by approximately 11.5 ^{14}C ka and Lake Hitchcock would have persisted until at least 10.4 ^{14}C ka.

In the immediate post-glacial time, the climate may have warmed sufficiently rapidly that no significant permafrost features such as pingo scars or patterned ground were produced. Certainly no evidence of such features was encountered during this study.

Analysis of peat deposits containing pollen and plant fragments indicates that tundra vegetation had spread through the area soon after the retreat of the glaciers and that mixed woodlands of poplar, spruce, fir, and other species followed soon after (Davis and Jacobson, 1985; McDowell and others, 1971).

During the Holocene Epoch, the vegetation has continued to change in response to a combination of northward range extensions, soil profile development, and a changing climate. In the meantime, stream erosion has continued to modify the landscape, with much of the energy of the streams being devoted to the reworking of the deposits of the last glaciation.

Sand and Gravel Deposits

A tremendous volume of sand and gravel is available within the study area. That said, it is important to understand that almost all of it is located within one narrow strip of land near the Passumpsic River. This is the Passumpsic Valley Esker and its flanking deposits of outwash sands and gravels. It is well over 100 feet in thickness at many locations. See the section on Ice-contact Deposits above and the plates for more information.

It should be pointed out that although there is still a vast amount of sand and gravel in this deposit, the population growth in St. Johnsbury in recent decades has led to the construction of homes and businesses over much of the surface of the deposit. Thus, the amount of sand and gravel which is actually available for use is far smaller than the total amount of material in the deposit.

In the uplands west of St. Johnsbury the only usable sand and gravel prospects appear to be the ice-contact deposits in the vicinity of the crossing of Trestle Road over Whiteman Brook, on the south flank of Pumpkin Hill, and southeast of Morses Mills on the south side of Joes Brook (Plate 1). The deposit near Whiteman Brook and the one southeast of Morses Mills both appear to be of limited potential as sources of sand and gravel due to limited thickness and variable quality.

Conclusions

The cross sections on Plate 5, the stratigraphic sections on Plate 6, and the isopach map on Plate 7 reveal the general thickness of units in the study area. Only in the major stream valleys is the depth to bedrock generally 20 feet or more. By far the greatest depths to bedrock are in the Passumpsic River Valley.

Reconnaissance till fabric studies and measurements of glacial striations indicate ice motion was generally from a north-northwest or northerly direction.

No evidence was found for the moraine at St. Johnsbury described by Antevs (1928). However, at least two sites provide indications that there was at least a minor readvance of glacial ice over lacustrine deposits.

No trace of the Danville Moraine of Stewart and MacClintock (1969) was found in the study area. All we could discern was very thin till over bedrock.

Sand and gravel deposits are abundant along the Passumpsic Valley Esker System in the eastern part of the study area but are otherwise quite limited. However, a previously unrecognized esker and outwash deposit was discovered south of Pumpkin Hill. As this is an unusual landscape feature in the uplands of the Danville-St. Johnsbury area, it is hoped that while part of this deposit may be exploited for sand and gravel extraction, a significant part of it can be given appropriate protection and be maintained as a natural landmark for future generations to appreciate.

Appendix A: Observations on the Flash Flood of August 11-12, 1998 and the Stability of Stream Channels

On the night of August 11 and 12, 1998, a heavy thunderstorm occurred in the Danville area. Coming on the heels of a very wet summer, almost 6 inches of rain fell overnight. Morrill Brook, Roy Brook, Whiteman Brook, and Water Andric quickly exceeded bankfull discharge and expanded out into adjacent floodplains. Extensive scouring and undercutting of banks occurred. Over channel reaches hundreds of feet long, all unconsolidated material was swept away down to the level of fresh, unweathered basal till. The scoured reaches are intermingled with areas of deposition in which log jams and cobble- and boulder-dominated point bars were deposited. Material transported during this event ranged in size up to large boulders. In the adjacent floodplains all non-woody vegetation was flattened, trees and shrubs showed scour marks and contained flood debris, and overwash deposits ranging from a fraction of an inch to several feet in thickness were deposited.

Heavy damage occurred to roads in the area, with Roy Road, Cormier Road, Jamieson Road, the North Danville Road, Morrill Road, Trestle Road, and the roads in the vicinity of Water Andric receiving the worst damage. Some of the damage to culverts and bridges appears to be due to their being of insufficient size–they simply became clogged with debris and the water then rose up and overtopped the roads. Several sections of road hundreds of feet long simply disappeared, either through gullying from overtopped roadside ditches or because of a stream being deflected into the roadbed. Many culverts and several small bridges were destroyed or simply bypassed. The total cost of road repairs from this storm (not including any damage to private property), will exceed $500,000 (Stephen Parker, personal communication, 1999).

Most of the downcutting and almost all of the lateral cutting resulting from this event occurred in the softer materials overlying the firm, unweathered basal till. In most cases it appears that despite the severity of the storm the streams were unable to significantly erode the unweathered basal till. In no place did we observe greater than one or two feet of erosion into the firm basal till in the stream bed and the average appears to be less than two or three inches–this during a flood which moved boulders weighing several tons and which eroded thousands of cubic yards of softer materials. It could well be that occasional flash floods such as these expose fresh basal till, which then gradually weathers and becomes more susceptible to entrainment at the stream discharge levels normally encountered during spring runoff and normal summer thunderstorms.

By undercutting the banks of streams in numerous locations it is anticipated that this event will, in the next several years, lead to increased earthflows on steep slopes in basal till which are adjacent to streams.

It is anticipated that the channels will rapidly become carpeted with silt, sand, cobbles, and boulders as a result of minor slumps and smaller storms. Therefore, there may soon be little evidence to remind the residents of this event, even though flash floods of similar magnitude are probably quite important in the shaping of these streams and can be expected to recur.

References Cited

Ackerly , S.C., and Larsen, F.P., 1987, Southwest-trending striations in the Green Mountains, central Vermont: *in* Westerman, D.S., ed., Guidebook for New England Intercollegiate Geological Conference 79th meeting, p. 369-382.

Antevs, E., 1928, The last glaciation with special reference to the ice retreat in Northeastern North America: American Geographical Society Research Series, No. 17, 292p.

Bouchard, M., and Pavich, M.J., 1989, Characteristics and significance of pre-Wisconsinan saprolites in the northern Appalachians: Zeitschift fur Geomorphologie, N.F.: Suppl.,-Bd.72, p. 125-137.

Cannon, W.F., 1964, The petrology of tills in northern Vermont: M.S. Thesis, Miami University, Oxford, Ohio.

Crosby, I.B., 1934, Extension of the Bethlehem, New Hampshire, Moraine: Journal of Geology, v. 42, p. 411-421.

Davis, R.B., and Jacobson, G.L., Jr., 1985, Late glacial and early Holocene landscapes in northern New England and adjacent areas of Canada: Quaternary Research, v. 23, p. 341-368.

Denny, C.S., 1982, Geomorphology of New England: U.S. Geological Survey Professional Paper 1208, 18p.

Doll, C.G., 1970, Surficial geologic map of Vermont: Vermont Geological Survey, 1:250,000.

Hall, L.M., 1959, The geology of the St. Johnsbury quadrangle, Vermont and New Hampshire: Vermont Geological Survey Bulletin 13, 105p.

Hatch, N.L., Jr., 1988, Some revisions to the stratigraphy and structure of the Connecticut Valley trough, eastern Vermont: American Journal of Science, v. 288, p. 1041-1059.

Kendall, K.A., Shanley, J.B., and McDonnell, J.J., in press, A hydrometric and geochemical approach to test the transmissivity feedback hypothesis during snowmelt: Journal of Hydrology.

Koteff, C., and Larsen, F.D., 1989, Postglacial uplift in western New England: Geologic evidence for delayed rebound: *in* Gregersen, S., and Basham, P., eds., Proceedings of a NATO symposium on Causes and effects of earthquakes along the passive margins on both sides of the Atlantic in areas of postglacial uplift, Vordingborg, Denmark.

Koteff, C., and Pessl, F., 1981, Systematic ice retreat in New England: U.S. Geological Survey Professional Paper 1179, 20p.

_____, 1985, Till stratigraphy in New Hampshire: Correlations with adjacent New England and Quebec: *in* Borns, H.W., Pierre LaSalle, and W.B. Thompson, eds., Late Pleistocene history of northeastern New England and Adjacent Quebec: Geological Society of America Special Paper 197, p.1-12.

Larsen, F.D., 1972, Glacial history of Central Vermont: *in* Doolan, B.L. and Stanley, R.S., eds., Guidebook for New England Intercollegiate Geological Conference 64th meeting, p. 297-316.

Larsen, F.D., 1987, Glacial Lake Hitchcock in the valleys of the White and Ottauquechee Rivers, east-central Vermont: *in* Westerman, D.S., ed., Guidebook for New England Intercollegiate Geological Conference 79th meeting, p. 29-52.

LaSalle, P., De Kimpe, C.R., and Laverdiere, M.R., 1985, Sub-till saprolites in southeastern Quebec and adjacent New England: Erosional, stratigraphic, and climatic significance: *in* Borns, H.W., Pierre LaSalle, and W.B. Thompson, eds., Late Pleistocene history of northeastern New England and Adjacent Quebec: Geological Society of America Special Paper 197, p.13-20.

McDowell, L.L., Dole, R.M., Jr., Montague, H.,Jr., and Farrington, R.A., 1971, Palynology and radiocarbon chronology of Bugbee Wildflower Sanctuary and Natural Area, Caledonia County, Vermont: Pollen et Spores, v.13, p. 73-91.

Newell, W.L., 1970, Surficial geology of the Passumpsic Valley, northeastern Vermont: Ph.D. Dissertation, Johns Hopkins University, Baltimore, 104p.

Ridge, J.C., Thompson, W.B., Brochu, M., Brown, S., and Fowler, B., 1996, Glacial geology of the Upper Connecticut Valley in the vicinity of the Lower Ammonoosuc and Passumpsic Valleys of New Hampshire and Vermont: *in* Van Baalen, M.R., ed., 1996, New England Intercollegiate Geologic Conference, 88th Annual Meeting Guidebook, p. 309-339.

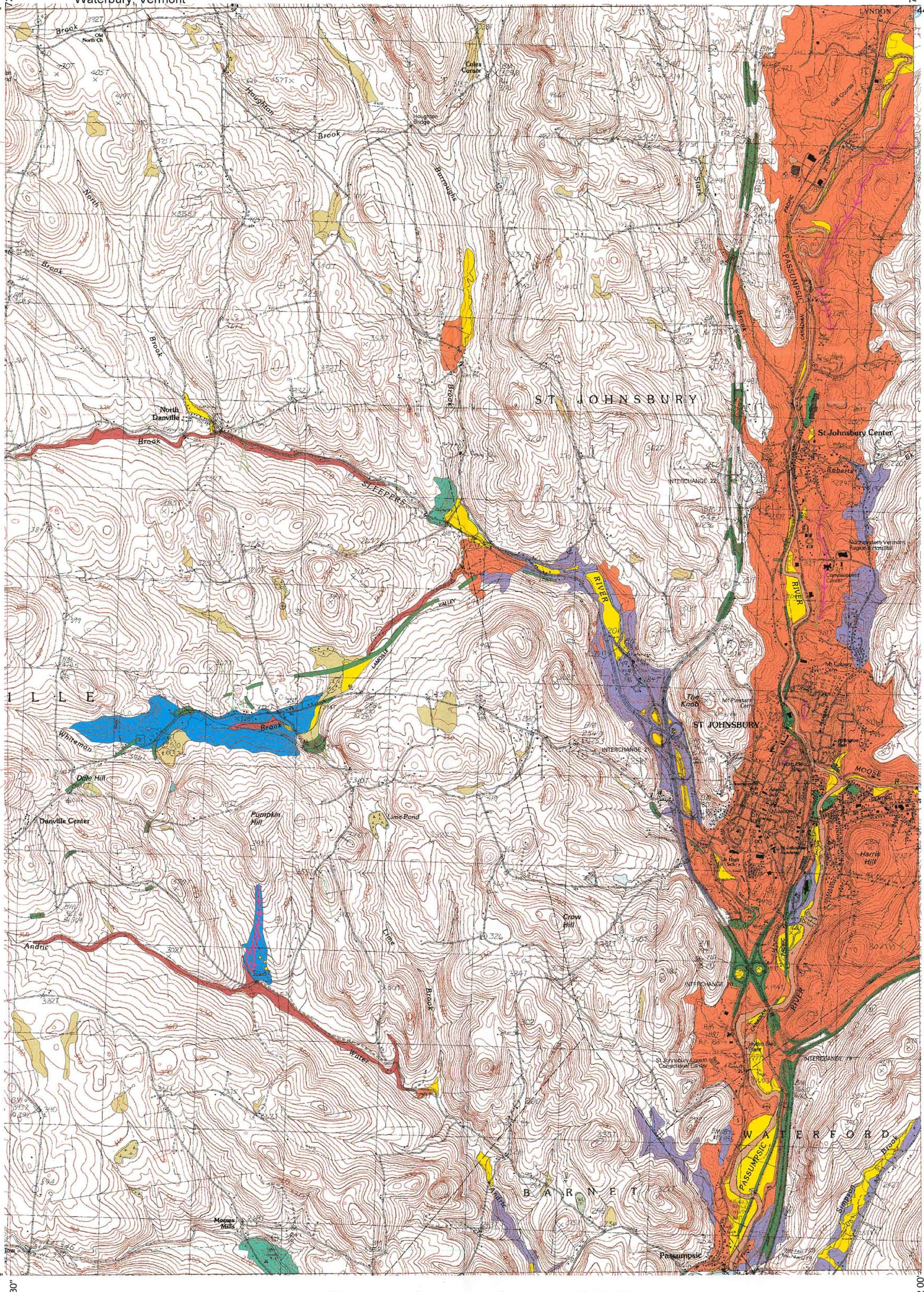
Ridge, J.C., Besonen, M.R., Brochu, M., Brown, S.L., Callahan, J.W., Cook, G.J., Nicholson, R.S., and Toll, N.T., 1999, Varve, paleomagnetic, and ^{14}C chronologies for Late Pleistocene events in New Hampshire and Vermont, U.S.A.: Géographie physique et Quaternaire, v. 53, p.1-31.

Stewart, D.P., no date, Manuscript surficial geologic map of the St. Johnsbury 15 minute quadrangle, on file at the Vermont Geological Survey, Waterbury.

Stewart, D.P., and MacClintock, P., 1969, The surficial geology and Pleistocene history of Vermont: Vermont Geological Survey, Bulletin 31, Montpelier, 251p.

Vermont Geological Survey
Department of Environmental Conservation
Vermont Agency of Natural Resources
Waterbury, Vermont

VGS Open-File Report VG99-8



0.9 0 0.9 1.8 Kilometers

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Surficial Geologic Map of the Eastern Portion of the St. Johnsbury Quadrangle, Vermont

Authors: George Springston and George Haselton

Edited and Digitized by Jonathan Kim

Map Produced: September 27, 1999

Legend

- Ha- Alluvium
- Htal-Talus
- Hw- Wetland
- Pgf- Glaciofluvial Deposits: Sand and/or Gravel
- Pgfs- Glaciofluvial Deposits: Sand
- Pl- Lacustrine Silt or Silty Clay
- Pow- Subaqueous Glacial Outwash: Sand and/or Gravel
- Pt- Till, Undifferentiated
- Ptl- Lodgement Till: Firm Silt/Clay Matrix
- af- Artificial Fill
- bedrock outcrops

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Laurence Becker, State Geologist
103 South Main Street
Waterbury, Vermont 05671-0301
802/241-3608
larryb@dec.anr.state.vt.us

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Plate 2

Surficial Materials Data for the Eastern Half of the St. Johnsbury, Vermont 7.5 x 15 Minute Quadrangle

George Springston and George M. Haselton

April, 1999

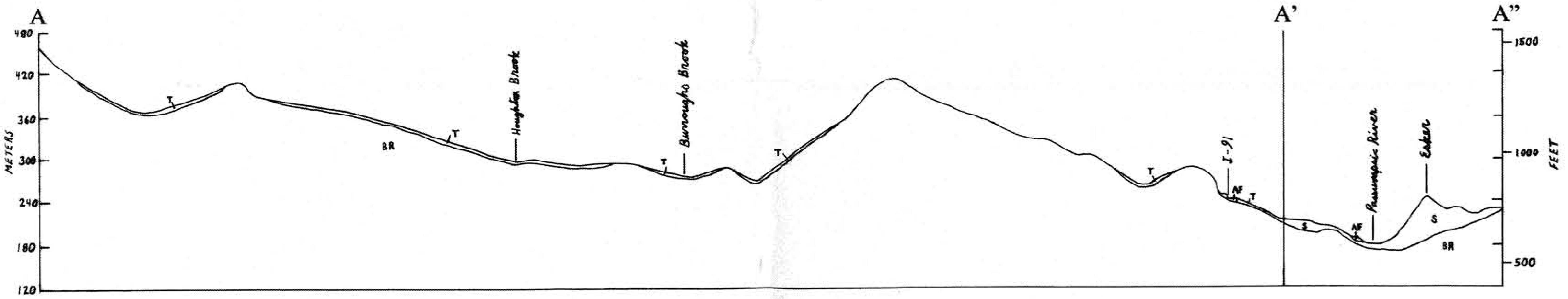
Scale 1:25,000

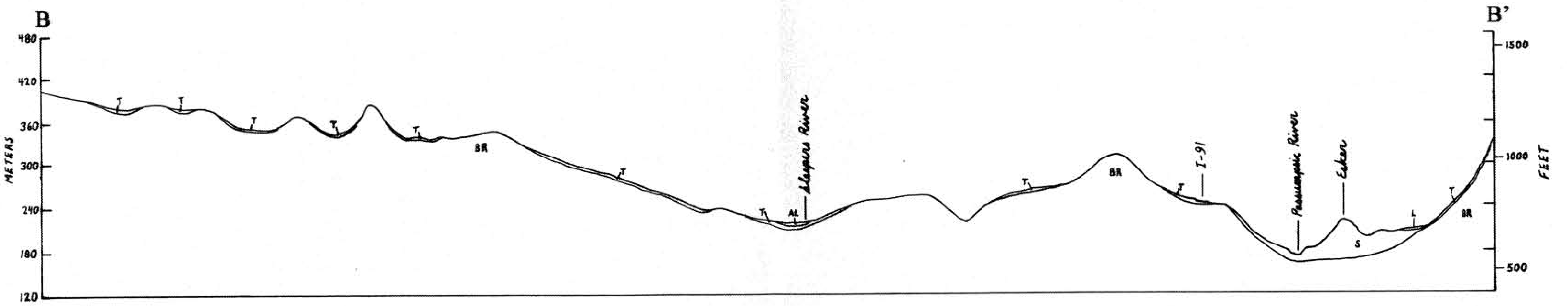
Gravel: **G** undifferentiated gravel; **B** boulder gravel; **C** cobble gravel; **P** pebble gravel.
Mixed Units: **GS** gravelly sand; **SG** sand and gravel.
Sand: **S** undifferentiated sand; **VCS** very coarse sand; **CS** coarse sand; **FS** fine sand; **VFS** very fine sand.
Silt: **ST**
Clay: **CY**

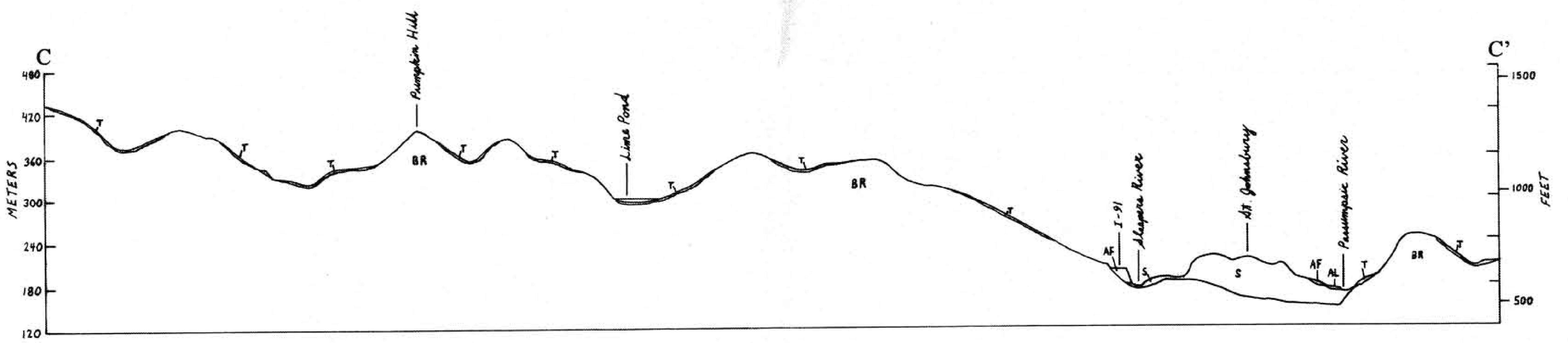
T	till, undifferentiated
TA	ablation till
TL	lodgement till
PT	peat
AF	artificial fill
BR	bedrock
RS	rottenstone or saprolite
TAL	talus

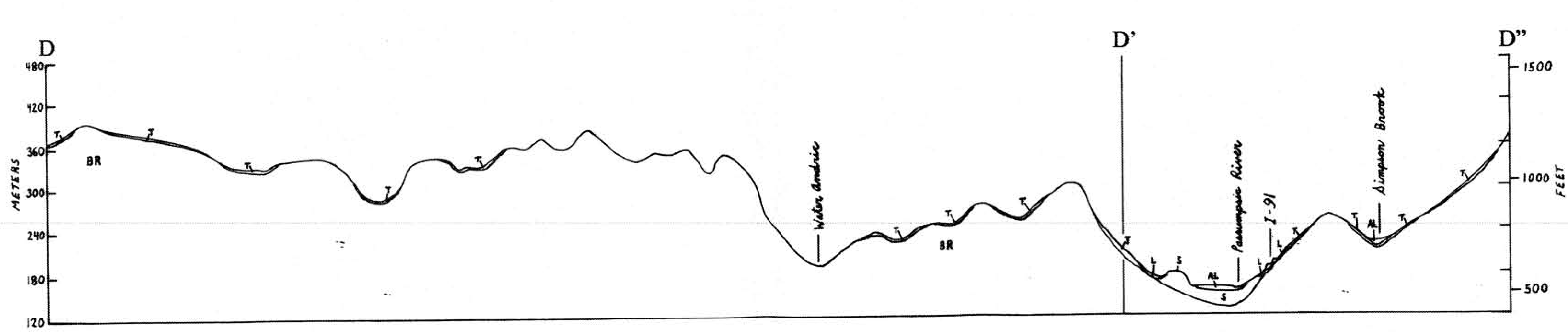
·	shovel hole, natural exposure, or auger hole
▲	test boring
⊙	water well
⚒	sand or gravel pit

Plate 5









Cross Sections of Surficial Deposits in the Eastern Half of the St. Johnsbury, Vermont 7.5 x 15 Minute Quadrangle

George Springston and George M. Haselton

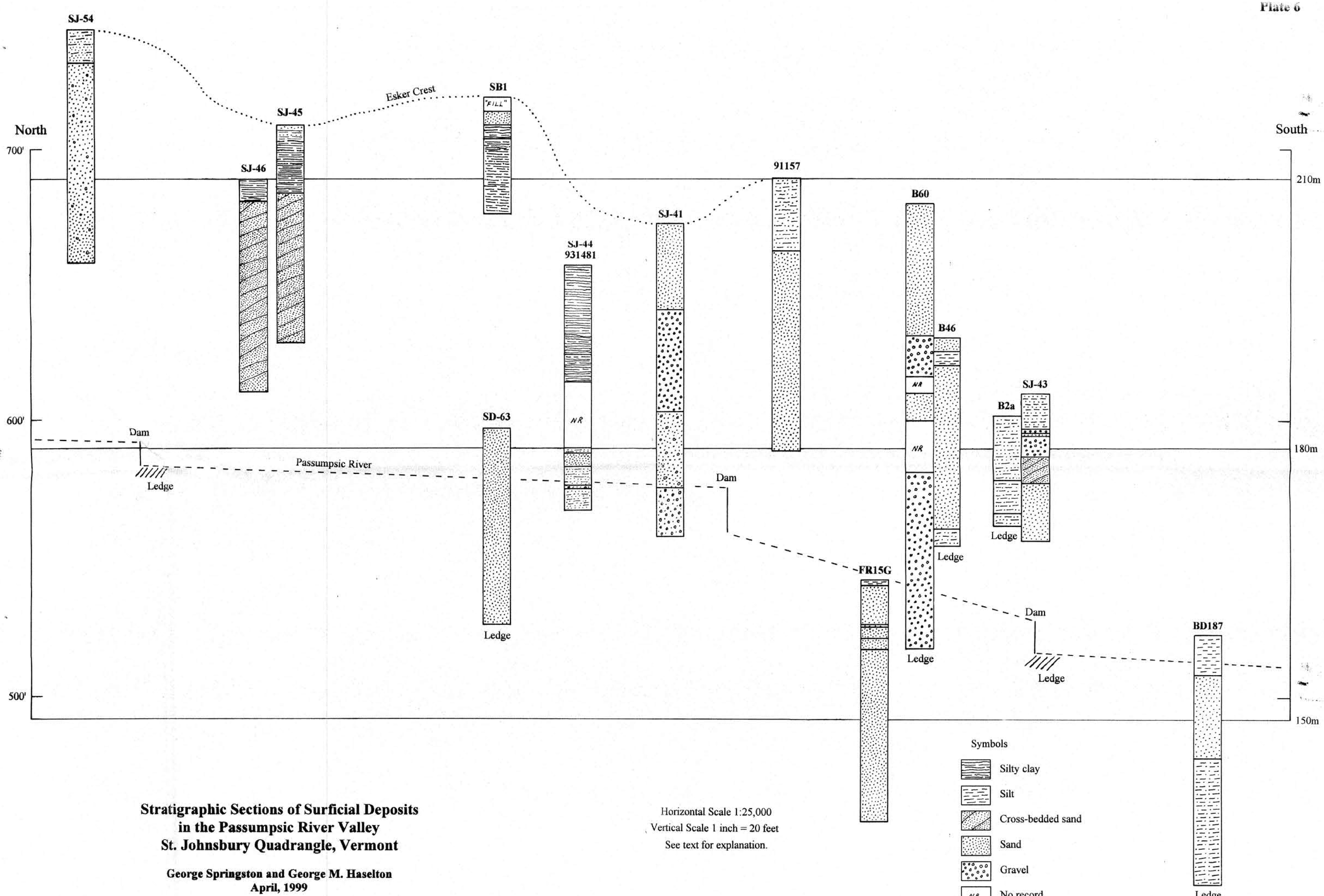
April, 1999

Horizontal Scale 1:25,000
Vertical Exaggeration 5x
See Plate 1 for Cross Section locations.

Symbols

AF	Artificial Fill
AL	Alluvium
L	Lacustrine Deposits
S	Sand and/or Gravel
T	Till
BR	Bedrock

Plate 6



Stratigraphic Sections of Surficial Deposits in the Passumpsic River Valley St. Johnsbury Quadrangle, Vermont

Horizontal Scale 1:25,000
Vertical Scale 1 inch = 20 feet
See text for explanation.

George Springston and George M. Haselton
April, 1999

Plate 7

Isopach Map of Surficial Deposits in the Eastern Half of the St. Johnsbury, Vermont 7.5 x 15 Minute Quadrangle

George Springston and George M. Haselton
April, 1999

Scale 1:25,000
Contour Interval 20 feet

Note: The 100 foot contour encloses areas of 100 feet or greater in depth. Contours representing greater thicknesses are not shown due to the limited number of data points.