SURFICIAL GEOLOGY OF THE BRANDON-TICONDEROGA 15-MINUTE QUADRANGLES, VERMONT

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INTRODUCTION

Geographic Setting

The Brandon and Ticonderoga quadrangles are located in west-central Vermont between Lake Champlain and the Green Mountains. The quadrangles are bounded by 43° 45′ and 44° North Latitude and by 73° and 73° 30′ West Longitude. Lake Champlain divides the Ticonderoga quadrangle into an eastern and western half. The western half lies in the State of New York and will not be referred to hereafter in this report. East of Lake Champlain the quadrangles include southern Addison County and northern Rutland County.

The eastern quarter of the Brandon quadrangle contains the frontal ridge of the Green Mountains. West of these mountains is the Otter Creek Lowland, a northern continuation of the Vermont Valley to the south. Between Otter Creek and Lake Champlain, in the southern portion of the map area, lies the northern tip of the Taconic Range. The remaining northwestern portion of the quadrangles is part of the Champlain Lowland. Physiographic features are outlined in Figure 1.

The major population center is the village of Brandon, located in Rutland County, adjacent to the Otter Creek valley. Salisbury and East Middlebury are smaller villages adjacent to Otter Creek north of Brandon. The villages of Orwell, Shoreham, and Bridport are located in Addison County, not far from Lake Champlain. The economy of the region is based on extensive dairy farming and a limited amount of tourism.

The most prominent topographic feature is the frontal, north-south ridge of the Green Mountains. The maximum elevation is 2659 feet on Mount Moosalamoo, overlooking Lake Dunmore, five miles southeast of East Middlebury. The lowest point on the Brandon quadrangle is 330 feet in the Otter Creek valley; however, Lake Champlain (Ticonderoga quad.) has a mean elevation of 95 feet above sea level. Although the total relief in the area is over 2500 feet the maximum elevation of the Taconic Range is approximately 1300 feet and almost the entire Champlain Lowland lies below 600 feet.

Otter Creek, a northward flowing stream, is the principal drainage feature in the region (Fig. 2). Two major tributaries are the Neshobe and Middlebury rivers that drain the Green Mountains. Most of the drainage from the map area finds its way into Otter Creek, either directly or through two western tributaries, the Lemon Fair River in the center and Dead Creek in the west. All drainage eventually enters Lake Champlain.

Geologic Setting

Knowledge of the bedrock geology of the Brandon and Ticonderoga quadrangles comes from many sources. Cady (1945), Rodgers (1958) and Welby (1961) have reported on the rocks of the Champlain Lowland. Osberg (1952 and 1960) has reported on the geology of the Green Mountain anticlinorium and Zen (1961) reported the stratigraphy of the northern end of the Taconic Range.

The major structural features as shown by Doll, Cady, Thompson and Billings (1961) are the axial anticline, represented by the Green Mountains; the Middlebury synclinorium to the west; and the Taconic klippe to the south. The axial anticline is composed of a core of Precambrian crystalline rocks

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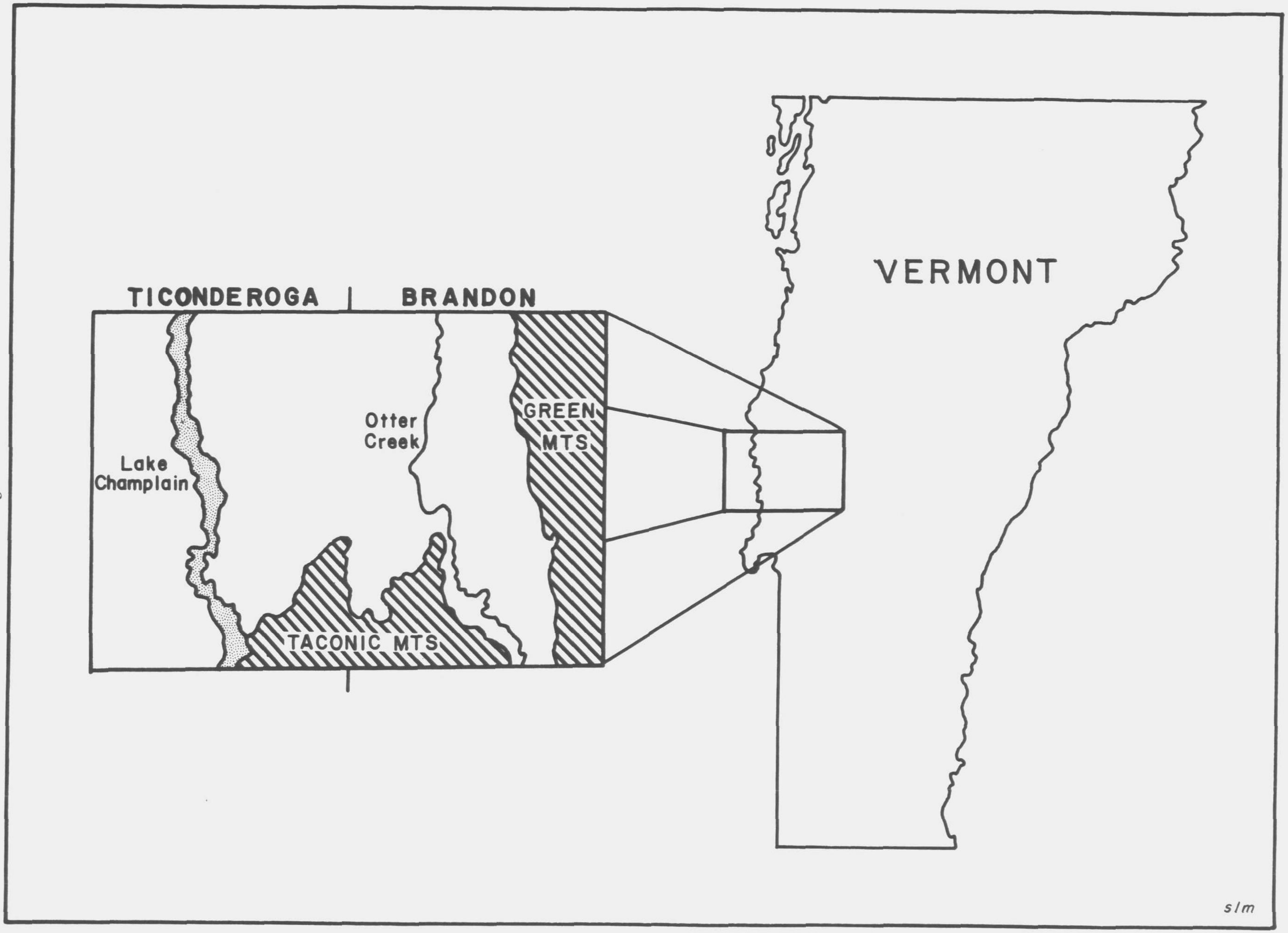

Figure 1. Physiographic Features of the Brandon and Ticonderoga Quadrangles.

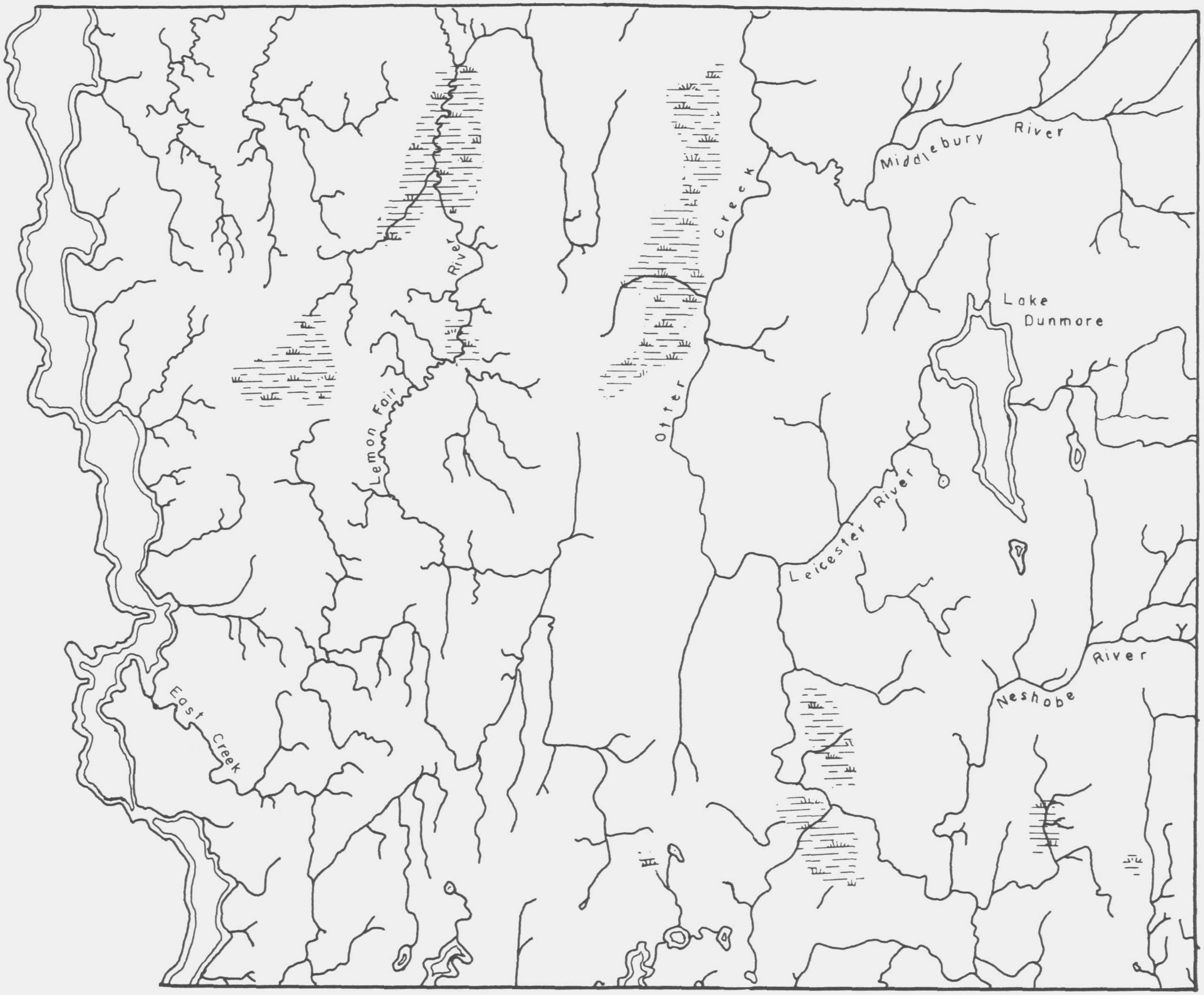

Figure 2. Drainage Features of the Brandon and Ticonderoga Quadrangles.

overlain unconformably by Cambrian meta-sediments. The Middlebury synclinorium, located between the axial anticline and Lake Champlain is composed of a sequence of Cambrian and Ordovician limestones, dolostones and marbles with intercalated quartzites. The Taconic klippe is dominated by meta-sediments of Cambrian age; usually slates or phyllites but with some carbonate rocks. Exclusive of the Taconic sequence most of the rocks strike north-south, although complicated fault patterns are present in the vicinity of Shoreham. No data on the jointing is available.

The surficial geology is dominated by a cover of Wisconsinan till and proglacial lake sediments. Weathered bedrock crops out along the front of the Green Mountains and in the Taconic Range. Freshly eroded knobs of bedrock protrude through the surficial blanket in the Champlain Lowland. Ice-contact deposits are present flanking the Green Mountains north of the Neshobe River. A broad alluvial floodplain with extensive swamps has developed along Otter Creek in post glacial time.

Geomorphic Setting

There is little doubt that the Green Mountains existed as a highland mass and the Champlain Valley as a broad lowland prior to glaciation. However, small-scale reduction of topographic relief has taken place on a large scale. The local carbonate and quartzite lithologies are well displayed in the glacial drift attesting to wide-spread glacial erosion. In contrast, preglacial valleys have been filled with 100 to 200 feet of glacial debris. The topography evidently has been gentled considerably, first by the erosion of knobs, next by the addition of glacial till, and then by filling of the lowlands by lacustrine sediments. Although some stream segments are re-excavating their ancestral valleys, in few places has the preglacial bedrock floor been reached.

The regional drainage pattern can best be classified as deranged west of Otter Creek and dendritic to the east where consequent streams drain the Green Mountains, (Fig. 2). The parallel (or sub-parallel) pattern of Dead Creek and the general south-north drainage exhibited by the Lemon Fair River and Otter Creek suggest that the preglacial drainage system was rectangular, adjusted to the underlying bedrock structure. The tributaries to the major streams and to Lake Champlain are resequent or obsequent segments reoccupying ancestral valleys. Many of these tributaries flow in east-west valleys but currently exhibit a dendritic pattern as they excavate lacustrine fill.

Most streams are readjusting to bedrock structure when it is encountered during downcutting. Beheading has taken place where streams adjust from their initial, east-west, consequent paths on the lake plain, to underlying north-south bedrock ridges. Arnold Creek, four miles northwest of Brandon appears to be a beheaded remnant of the Neshobe River. However, during one phase the Neshobe River failed to adjust and superposed itself on a bedrock ridge north of Brandon.

Otter Creek is classified as an old age stream. It flows northward on a broad alluvial floodplain that lacks meanders, oxbow lakes and natural levees. Leopold, Wolman and Miller (1964, p. 281) would classify this as a straight stream with a sinuosity close to 1.0 despite the low gradient that approximates only one foot per mile. Otter Creek falls from 350 feet south of Brandon to 330 feet in Middlebury just north of the Brandon quadrangle. Local base level for Otter Creek is controlled by a bedrock falls at 330 feet in the Middlebury quadrangle. The writer suggests that Otter Creek has been prematurely aged by regional tilt and the relative uplift of the bedrock lip in Middlebury.

Previous Work

Chapman (1937 and 1942) and Stewart (1961) have summarized the work of many investigators on lake levels, lacustrine sediments, and subsequent marine invasion of the Champlain Lowland. Chapman and earlier workers paid particular attention to the hanging delta of the Neshobe River at Brandon and to lake clay present in the northern portion of the Ticonderoga quadrangle. No previous work has been reported on the glacial geology of the Brandon-Ticonderoga region.

Present Work

Field work for this report was carried out during the summer of 1965. The writer, with the assistance of Mr. Franklyn Paris mapped the surficial geology on the Crown Point, Bridport, Ticonderoga, Orwell, Cornwall, East Middlebury, Sudbury and Brandon $7\frac{1}{2}'$ quadrangles. The information from the first four quadrangles was transferred to the 1960 edition of the Ticonderoga 15' quadrangle and from the latter four to the 1902 edition of the Brandon 15' quadrangle. The Brandon and Ticonderoga 15' quadrangles accompany this report as Appendix 2.

The writer wishes to acknowledge the assistance and encouragement of Dr. Charles G. Doll, State Geologist, State of Vermont; Dr. David P. Stewart of Miami University; the late Dr. Paul MacClintock of Princeton University; and Dr. Parker E. Calkin of the State University of New York at Buffalo.

GLACIAL EROSION

It is evident from examining the gravel deposits in the map area that stones of local lithologies predominate. Many distinctive lithologies may be noted and perhaps traced back to their outcrops (e.g. the Monkton Quartzite). Thus, an unknown thickness of pre-

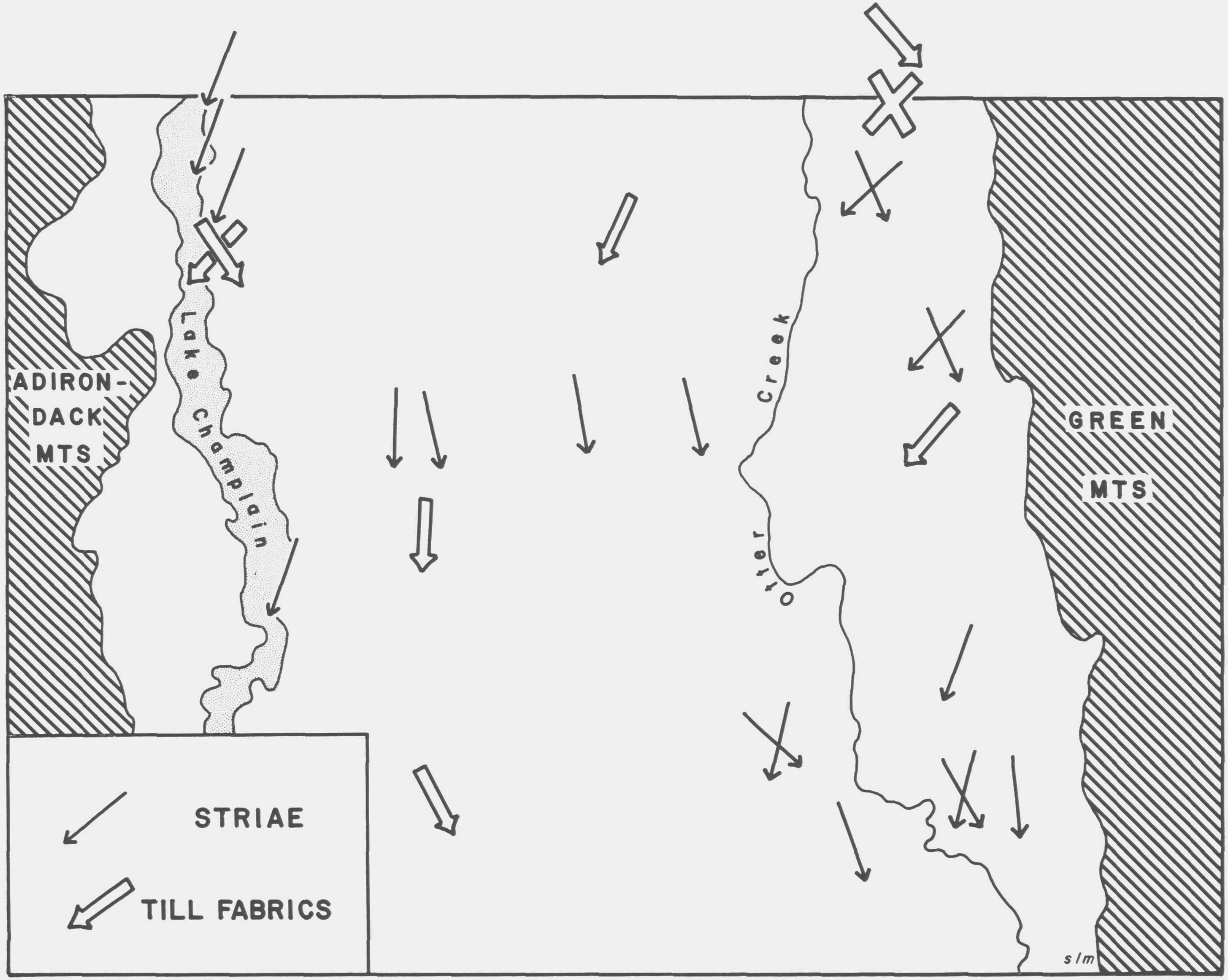

Figure 3. Striae Recorded in the Brandon and Ticonderoga Quadrangles.

Plate 1. Glacial striae on limestone adjacent to Lake Champlain.

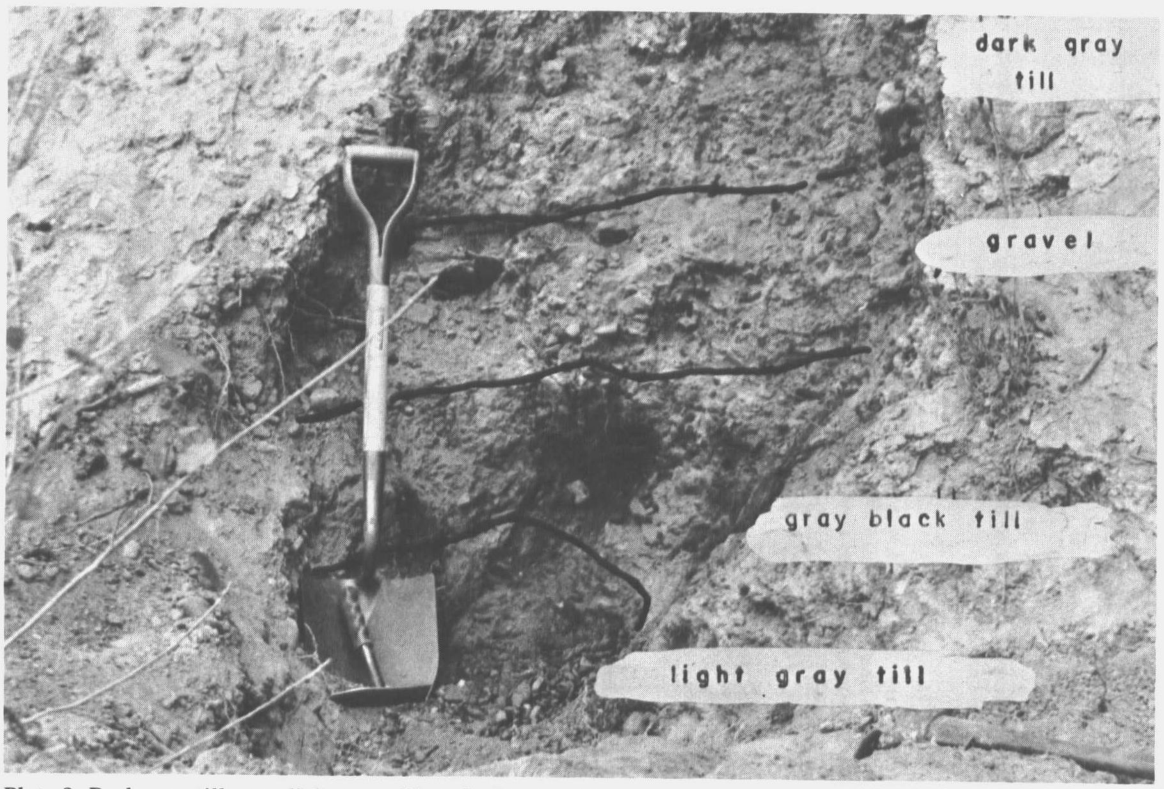

Plate 2. Dark-gray till over light-gray till at the West Bridport multiple till section. Fabrics for the till units are given in Appendix 1.

Pleistocene bedrock evidently was eroded during Pleistocene glaciation.

When one notes the nature of the crystalline rocks that the glaciers were able to erode, it is surprising to find a Tertiary saprolite preserved beneath till and outwash. This saprolite was described by Burt (1930) as part of the Brandon Residual Formation. Burt, in summarizing earlier work by others, associated the saprolite with the Miocene (or Eocene) lignite once mined east of Brandon. The saprolite has been observed in three localities along the outcrop belt of Cheshire Quartzite and apparently developed from it. The saprolite is highly kaolinitic, white, pink or red clay that may contain floating quartz grains. It has been found beneath a beach deposit northwest of Brandon and in a well to the southeast. In addition, it has been recognized in outcrop above the Middlebury River where kaolinitization has occurred along phyllite layers within the quartzite.

Small-scale erosion is evident in many places. Smooth, polished striated surfaces are particularly well preserved on freshly exposed carbonate rock in the Champlain Valley, but are rarely preserved on the crystalline rocks on the adjoining upland (Plate 1). The upland rocks have been exposed to intense weathering, perhaps since deglaciation. Due to a thick cover of glacial till and lacustrine sediment exposures of bedrock are scarce.

Figure 3. shows the distribution of 15 striae observations.

GLACIAL DEPOSITION

Ground Moraine

Ground moraine is a discontinuous blanket of *glacial till* that lies on the glacially eroded bedrock surface. The ground moraine is overlain in turn by lacustrine sediment in the Champlain Valley lowland. The ground moraine is composed of material of all sizes from clay-size to boulders (erratics) a few feet in diameter in the lowlands and tens of feet in length in the Green Mountains. In the absence of well data it is not possible to estimate the thickness of ground moraine at present.

Where subsequent erosion was sufficient to remove some of the till matrix and leave a lag deposit of boulders, *washed till* was mapped. Washed till is usually a product of wave action but fluvial activity may have played a part in some places.

In many places the till has been eroded, weathered to a thin residual soil, or reorganized into colluvial deposits. In all three cases *bedrock* has been mapped, even where it is not directly exposed. Just as the stratigrapher ignores colluvium or soil and map the underlying stratigraphic unit, so the glacial geologist should map only the underlying unit, be it till, bedrock or some other surficial deposit.

There are four lithologic types of till present in the Brandon-Ticonderoga area. The four types are summarized in Table 1. Three types are basal (lodgement) till that is compact, stony to bouldery, and commonly calcareous. The till stones are composed of carbonates and a lesser proportion of shales and phyllites.

The first lithologic type is lodgement till with a clay-loam matrix and a dark-gray (N 3) color according to the Munsell system (Rock Color Chart distributed by the Geological Society of America) and was observed in two localities in the lake shore province. This till is lithologically similar to the Shelburne till of Stewart (1961) in the Burlington area to the north.

A second lithologic type is stony to bouldery, has a loam to sandy-loam matrix and a light-olive-gray (5Y 5/2 or 4/2) color. This till has been found in the lake shore province; however, it is prevalent in the Otter Creek province. One can differentiate between the dark-gray and light-olive-gray tills only where a complete weathering profile is present, because the dark gray till oxidizes to light-olive-gray when exposed to weathering or groundwater activity.

At one locality on the lake shore, just south of the old ferry landing southwest of West Bridport, the two lithologies were found in superposition (Plate 2). The section overlies polished limestone bearing striae oriented N 10° E. The basal unit (unit #1) is a light-olive-gray (light-gray), calcareous, sandy-loam till four feet thick. The lower till is overlain uncon-

TABLE 1.

Major Lithologic Differences Between the Tills of the Brandon and Ticonderoga Quadrangles

Till Color	Till Texture
Dark Yellowish Orange (10YR 6/6)	Sandy-loam to Loamy-sand
Dark to Moderate Yellowish Brown (10YR 4/2)	Silt-loam to Sandy-loam
Dark Gray (N3)	Clay-loam
Light Olive Gray (5Y 5/2)	Loam to Sandy-loam

formably by a 12-18 inch smear of grayish-black (N2) till (unit #2) that is overlain by 12-18 inch layer of oxidized gravel (unit #3). The gravel is overlain conformably (?) by four feet of dark-gray, clay-loam till (unit #4) that is overlain by 16 feet of lacustrine silt (unit #5). The uppermost unit (unit #6) is a laminated clay, two feet thick, containing ice-rafted pebbles and boulders. The gray-black till, oxidized gravel and dark-gray till are inferred to be conformable and to represent a single glacial event.

The third type of till was interpreted as lodgement till in many places. This till is a dark to moderate yellowish brown (10 YR 4/2 or 4/4), sandy-loam to silt-loam till and very compact, usually with a platy structure and a variable percentage of till stones. Where the matrix has a high silt content, few stones are present, while an increase in till stones is accompanied by a coarser matrix. In at least two localities the platy structure appears to be inherited from incorporated lacustrine silts and clays. One mile east of West Bridport a yellowish brown till overlies and incorporates gravel. The matrix is sandy loam to loamy sand reflecting the incorporated sediment. This type of till usually indicates areas where oxidized lacustrine sediments were overridden, eroded and redeposited in more or less undigested form.

The fourth type of till is sandy or gravelly, exhibiting limited size-sorting. Stewart (1961) adopted the name ablation till for this type of drift. Ablation till is variable in texture and color; however, it usually has a sandy-loam to loamy-sand matrix and is dark-yellowish orange (10 YR 6/6) in color. This till appears on the surface in most exposures within or adjacent to the Green Mountains. It is possible that this till represents a distinct glacial advance separate from that which deposited the basal till, but presumably it is merely a superglacial or upland facies deposited by the wasting of highland ice related to the glaciers depositing the dark-gray or light-gray till in the Champlain Valley.

Till Fabric

Stewart (1961), MacClintock and Stewart (1965), and Stewart and MacClintock (1964) have demonstrated the utility of till fabric in differentiating glacial events on the basis of glacier movement. Stewart (1961) in the Burlington region has described two tills having different fabrics. The basal "black" till exhibits a northeast fabric and has been named the Shelburne till. The overlying "blue" till exhibits a northwest fabric and was named the Burlington till. The Shelburne and Burlington tills appear to be lithologically similar to the dark-gray and light-olive-gray tills respectively, in this map area.

Till fabrics were recorded from the orientation of 50-100 prolate pebbles using the till fabric rack of MacClintock (1959).

In both localities where dark-gray till was observed a northwest fabric was recorded (Fig. 4) including the West Bridport multiple till section where the underlying light-gray till exhibited a northeast fabric. Thus, although the West Bridport section shows a reversal of lithology, it does suggest a northwest advance overlying a northeast advance similar to the Burlington area. Unfortunately, the northeast fabric for the light-gray till is not consistent.

Two miles southwest of Shoreham, in a road cut, a fabric of N 10° W was recorded for light-gray till. Three additional fabrics have been determined for light-gray till in the Otter Creek province. Southeast of Middlebury, a northwest fabric was recorded by Calkin (1965) in this till. About one mile south of the Middlebury quadrangle Calkin (written communication) found a random fabric in identical till. Five miles further south the writer recorded a strong northeast fabric in identical, light-gray till. Fabric diagrams appear as Appendix 1.

Three hypotheses may be proposed to account for the relationship between fabric and lithology. In both exposures the dark-gray till exhibits a northwest fabric. Only the light-gray till exhibits a northeast fabric beneath the dark-gray till at West Bridport and west of Lake Dunmore in the Otter Creek province. If one assumes that fabric defines a glacial till, and therefore a glacial advance, then the light-gray till in the Middlebury quadrangle and that near Shoreham represent a facies variation of the dark-gray till, all representing a late northwestern glacial advance. Assuming this as Hypothesis I, the northeast till at West Bridport and that west of Lake Dunmore represent an earlier northeast advance.

In Hypothesis II the till fabric is a reflection of glacial flow that may be controlled by the underlying topography. This is strongly suggested by the divergent fabrics exhibited in identical till exposures five miles apart between Middlebury and Lake Dunmore. Assuming Hypothesis II, the dark-gray till would represent a late glacial advance, probably from the northwest, while the light-gray till represents an earlier advance, probably from the north as suggested by striae, but whose flow direction was altered locally by subglacial topography.

In Hypothesis III the dark-gray till represents the youngest northwest advance and the light-gray till represents an older northeast advance; the younger advance preferentially reorienting the fabric in the northeast till, southwest of Shoreham and in the vicinity of Middlebury.

One drumlin was noticed in the Brandon quadrangle, four miles north of Brandon and one mile south of Leicester. The topographic form suggests glacial advance from slightly west of north; however, this may represent the strike of underlying bedrock that is inferred to be quite near the surface.

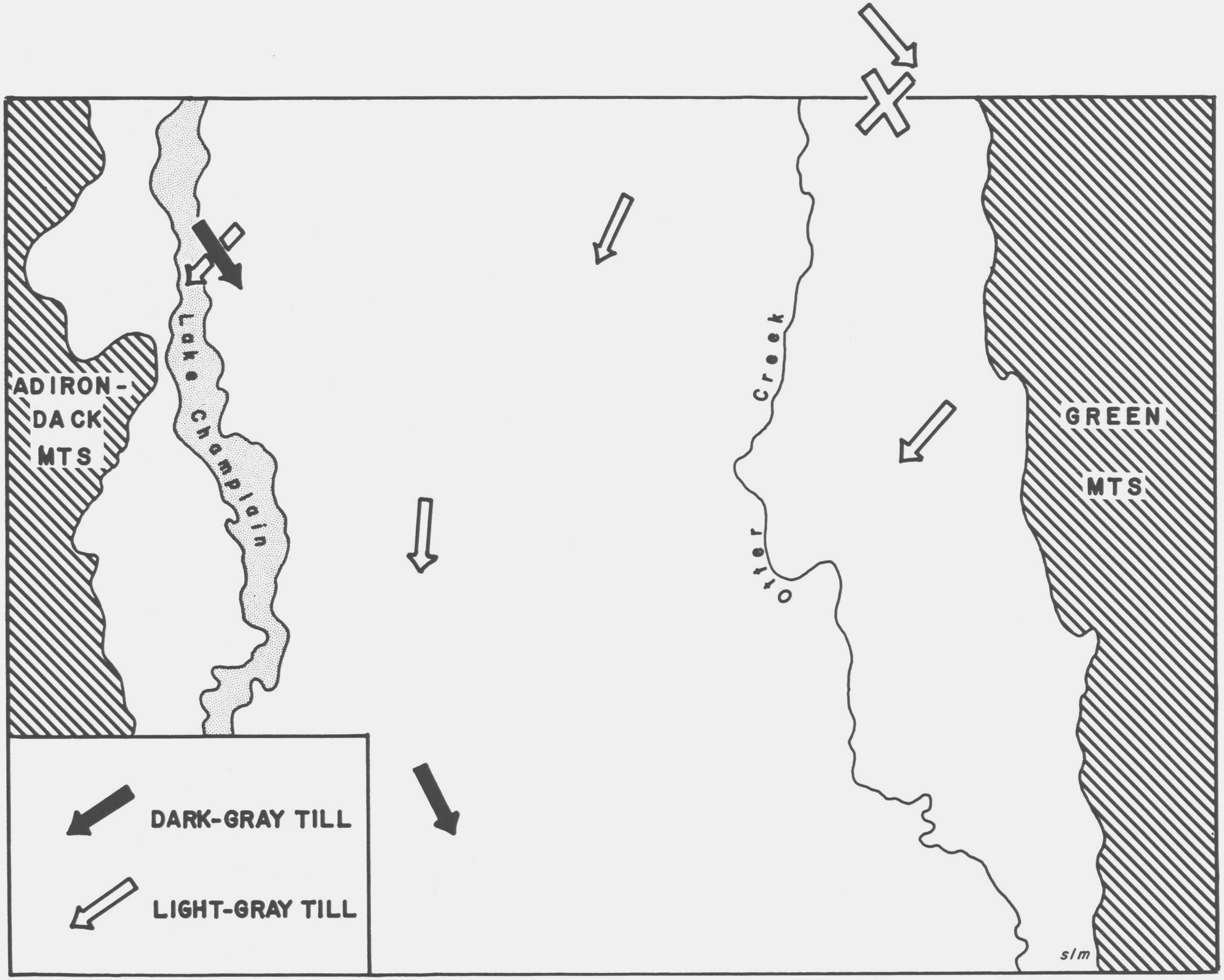

Figure 4. Till Fabrics Recorded in the Brandon and Ticonderoga Quadrangles.

End Moraines

No well-developed end moraines are present in the map area. In almost all localities the till is smoothly molded and morainal (knob and kettle) topography is absent. Linear north-south ridges of till, e.g., Sisson Hill west of Shoreham, suggest morainal configuration. Even where till is not exposed linear ridges of lake clay suggest buried moraine or bedrock strike ridges. Two miles west of Bridport the till core of a linear ridge has been exposed at 200 and 220 feet by wave action.

Although further work is needed, the writer suggests the presence of an end moraine from Shoreham to Sisson Hill, southwestward along a ridge 1½ miles west of Barnum Hill School, thence southwestward toward Mount Independence. A moraine in this position would account for certain drainage derangement and also for an outwash deposit south of this position, one mile east of Chipman Point.

Ice-Contact Deposits and Outwash

Included in this category are stratified, waterlaid sediments deposited on top of the ice, within the ice, between ice and topographic highs, or beyond the margin of the ice. These deposits are usually categorized as kames, eskers, kame terraces, and outwash on the basis of topographic form and the presence or absence of ice-contact structures (Flint, 1957). Actually these sediments form a continuous spectrum of glacio-fluvial deposits and cannot be separated adequately according to genesis. They are differentiated in the field only for the sake of convenience in mapping.

Kame terraces are linear features, composed of stratified, waterlaid sediments deposited between stagnant ice and valley walls. A sufficient number of accordant, flat-topped remnants are present so that a smooth upper surface can be reconstructed with confidence. Kame terraces have been mapped west and southwest of Hogback Mountain at 1760 feet and south of this in the Neshobe River valley west of Goshen Four Corners (Rochester quadrangle) at about 1400 feet. Kame terraces have been mapped flanking the Green Mountains surrounding Lake Dunmore on the south and east at 640 feet and north of the Middlebury River where two levels may be present at 600 and perhaps 660 feet. South of the Middlebury River between Pine Hill and a bedrock spur, material that may be kame terrace at 700 feet is mapped as outwash because of the lack of exposure to prove ice contact.

Kame terraces have been mapped west of Brandon in Willow Brook at about 500 feet, southwest of Brandon in Bresee Mill Brook at about 560 feet, and adjacent to the Lemon Fair River, south of Sudbury, at 500 feet. Small isolated kame terraces have been mapped northeast and southwest of Lake Hortonia. These latter localities are in the Taconic Range and are inferred to represent the last remnants of stagnant ice left in protected valleys in these mountains after recession of the last glacier.

The terraces high in the Green Mountains are inferred to represent an early phase of melting of the main glacial mass shortly after the uplands had been uncovered by downwasting. The kame terraces in the Lake Dunmore depression and north of the Middlebury River may represent either later stages in downwasting or remnants of stagnant ice protected from rapid melting by the adjacent mountain front.

Kame terraces lie along valley sides and their accordant tops suggest graded deposition from streams flowing beside the glacier. Where similar sediment was deposited on top of stagnant ice, the resulting collapse caused irregular topography lacking accordant, flat-topped remnants and deposits such as this are mapped as *kame moraine* rather than kame terraces, although they probably have a similar origin. Kame moraine has been mapped south of Lake Dunmore between Fernville and the Neshobe River in a linear belt trending northwestward for 2½ miles. This kame moraine is thought to be an ice marginal deposit marking the distal end of the stagnant ice block responsible for the Lake Dunmore kame terraces (Plate 3).

A second belt of kame moraine (?) 1½ miles long was mapped 1½ miles south of West Cornwall. This ridge can be traced for ¼ mile from DeLong Hill to another bedrock ridge to the east. The kame moraine is missing from the bedrock ridge but continues again on the east side. The fragmental nature, and a tendency toward a flat top at 520 feet, suggest that this is a crevasse filling or esker and should be mapped and discussed as an ice-channel filling rather than kame moraine.

Isolated hills of stratified drift were mapped as *kames*. There is a cluster of kame deposits three miles south of Orwell along the headwaters of the South Fork of East Creek. These kames are inferred to mark an ice marginal position, probably the margin of a stagnant ice block in this valley between a small highland to the west and the Taconic Ridge to the east. These kames have caused derangement of ancestral consequent drainage to Lake Champlain. Other kames are found along the north flank of the Taconic Range.

Only one *ice-channel filling* (esker) was noted. This filling is reconstructed from discontinuous segments from the Leicester drumlin to a swampy lowland two miles to the south. In many places the Brandon esker has been reworked into beach gravel at 430 feet. The ice channel may have carried waters from the Middlebury River when ice was present in the Otter Creek Valley. The waters flowed southward at East Middlebury along the outwash apron, across stagnant ice where the Leicester River depression (Salisbury Swamp) is located and through the ice channel re-

Plate 3. A north-facing view of the distal slope of the Lake Dunmore kame moraine with outwash in the lower right foreground.

Plate 4. A view of the Brandon kame complex showing outwash from the Brandon esker (foreground) with Lake Quaker Springs lacustrine clays.

constructed from the Brandon esker. This drainage is inferred to have emptied into open water in the vicinity of the Brandon kame complex.

The Brandon kame complex is found draped over bedrock 3/4 mile southwest of the village of Brandon. The foreset beds suggest deltaic deposition from the north or north-northwest, showing that it is not related to the Neshobe River to the northeast. Several examples of ice-contact slump were observed in a large gravel pit. This deposit is 1 1/2 miles south of the Brandon esker and probably relates to it. Gravels in the kame complex are shown to interfinger with, and be overlain by, lacustrine sediments between 400 and 440 feet (Plate 4).

Outwash has been mapped in three separate situations. Extensive outwash was mapped south of East Middlebury, west of the Green Mountain front. Many exposures show southerly drainage suggesting that it is the connection between the Middlebury River outwash and the Brandon esker. Outwash from the ice present north of the Middlebury River also must have contributed to this deposit.

A similar outwash apron is found south of the Lake Dunmore kame moraine and undoubtedly originated from the ice block to the north. That this deposit is not more extensive is attributable to recent erosion by the Neshobe River.

Outwash has been mapped in the headwaters of the Neshobe River and its North Branch, as well as in the upper reaches of the Middlebury River and its North Branch. The deposits in the North Branch of the Middlebury River were originally mapped as high level, fluvial, terrace gravel. However, Calkin (1965) mapped similar deposits in the Middlebury quadrangle as outwash from protected mountain remnants of stagnant ice. The writer adopted outwash as the designation for the southern continuation of these deposits and has mapped it in the Middlebury River and the Neshobe River as a matter of consistency. The presence of kame moraine near Breadloaf (Rochester quadrangle) in the headwaters of the Middlebury River and near Goshen Four Corners in the headwaters of the Neshobe River support the outwash designation.

A third outwash deposit overlain by lake clays is present, one mile east of Chipman Point. This outwash is hypothesized to lie south of, and result from, the buried Sisson Hill moraine to the north.

Lacustrine Deposits

Many early workers noted the thick lacustrine deposits in the Champlain Lowland. Chapman (1937 and 1942) summarized knowledge of proglacial lake history in the Champlain Valley and formalized names for various stages. Stewart (1961) has added substantially to the knowledge of the deposits and the nomenclature. Chapman specifically mentioned the Brandon delta, but other lacustrine deposits in the map area have remained undescribed.

Fine-textured lake deposits mantle till and bedrock alike in the northwestern part of the map area. These deposits rise abruptly from 100 feet adjacent to Lake Champlain to 200 feet a short distance to the east. There is a continued gradual rise to over 300 feet west of Otter Creek. On the east side of Otter Creek, these sediments are found at 400 feet with a maximum of 440 feet between Middlebury and East Middlebury. Coarser textured lake, deltaic, and beach deposits are common to 500 feet with isolated beaches to 700 feet southeast of Brandon. It is not known whether the consistent west-east rise is due to differential rebound, graded east-west deposition, a reflection of sublacustrine topography, or to erosion of easterly deposits adjacent to shrinking water bodies. A combination of the latter two possibilities appears to be the most reasonable explanation at present.

Most of the finer textured deposits have been lumped into a single mapping unit called *silty-clay*. This mapping unit usually represents rhythmically bedded (varved?) alternations of silt- and clay-sized laminae. Also included are deposits of massive and rhythmically layered, silt-free, clays usually found in protected valleys in the Taconic Range or adjacent to Otter Creek. Near the Neshobe River a deposit of almost pure silt was found and mapped as silty-clay. Silty-clay is the dominant lacustrine deposit throughout the map area.

A second type of fine-textured material, lacustrine for the most part, is mapped as *bouldery clay*. This unit is identical to the silty-clay on surface exposure and is differentiated by the presence of a large number of boulders in plowed fields or fence rows. A decision to map bouldery clay was made on the basis of the percentage of boulders observed. One or two boulders per acre could represent civilized intrusion so the writer mapped bouldery clay only where the concentration appeared significant.

Some exposures show bouldery clay to consist of rhythmically bedded lacustrine sediments containing ice-rafted boulders. Examples of this are found between Middlebury and East Middlebury and in the upper unit of the West Bridport section. In other exposures the boulders are seen to be a lag deposit resting on, or slightly above, an eroded till or bedrock surface. In the northern portion of the Ticonderoga Quadrangle lag deposits prevail. A third type of deposit that may be mapped as bouldery clay is the yellowish-brown (10 YR 4/4), silt-loam, sparsely stony till. Without adequate, unweathered exposures, it is impossible to differentiate between the various types of bouldery clay.

Lacustrine sand has been mapped extensively in the Brandon area but sparsely elsewhere. It is thought to be a deltaic or beach facies of the lacustrine clays. In some localities a sufficient quantity of granules or pebbles is present to map *pebbly sand* rather than lake sand.

The Brandon delta of Chapman is composed entirely of sand deposited by the Neshobe River. The sand probably represents reworked outwash from the headwaters of the River or perhaps from the vicinity of Forest Dale. The eastern part of the Brandon delta is composed of sands smoothly graded from 560 feet near Forest Dale at 380 feet on Otter Creek. This eastern portion of the delta lies in a north-south channel between the Green Mountain front and isolated ridges of marble ½ mile to the west. It is interrupted east of Brandon by the Smalley Swamp depression. The lack of deltaic sediment in this depression suggests the presence of a stagnant ice block during deposition. This part of the Brandon delta is inferred to have been continuous with the outwash and kame moraine north of Forest Dale.

The younger portion of the delta is located west of Forest Dale with a flat top at 500 feet. This level is coincident with many beach deposits and is thought to represent the next youngest event designated the Quaker Springs stage that is discussed in a later section on Lake Vermont. The 500-foot level is smoothly graded to 460 feet where an erosional scarp is present east of Brandon. This 460-foot scarp may indicate an independent event. The most recent feature appears to be an erosional escarpment on the distal side of the delta at about 405 feet with a flat-topped deposit rising to 420 feet on the proximal side. Although sands extend down to 380 feet in the vicinity of Otter Creek, the 405-foot level is thought to be the youngest level present in the Brandon delta and represents the Coveville stage as discussed later.

North of Brandon at 450 feet an isolated prong of lake sand may be an erosional remnant or may represent a spit related to the 500-foot level. In 1965 a foundation exhibited a four-foot frost crack (ice wedge cast?). This frost crack may be an indication of periglacial conditions.

Isolated sand deposits are found south of Leicester at 400 feet and appear to be the result of reworking of the kame moraine to the southeast. A sandy beach deposit occurs south of Middlebury between 400 and 420 feet and north of East Middlebury between 460 and 480 feet. The latter deposit was formed from reworking of the adjacent kame terrace.

Other isolated sand deposits are found as hanging deltas at 380 feet near West Cornwall and Salisbury and at 400 feet near West Salisbury. These probably represent the Fort Ann stage as discussed later. Lake (beach?) sand deposits are found in patches near many of the lakes in the Taconic Range. Lapham Island, between Lapham and Leonard Bays on Lake Champlain is also a sand deposit, of unknown origin.

Beach gravel is found wherever a suitable source was present and is the coarsest lacustrine facies. Along the Green Mountain front isolated high-level beaches are found at 700, 620, and 565 feet. Although they are not continuous deposits, they are frequently traceable to weak erosional escarpments at the same elevations. These beaches are found only to the south of Forest Dale. Beach terraces, wave-washed till, and beach gravels are associated along the eastern channel of the Brandon delta. Other beaches are restricted to the western slopes of ridges which faced open waters of Lake Vermont to the West.

An extensive deposit of gravel and sand was mapped as beach gravel between 500 and 540 feet at the north end of the eastern Brandon delta channel. At 500 feet, beach gravel is found on the west side of the ridge west of Smalley Swamp and the north end of Hog Hill. A deposit that may be kame terrace with beach sand below at 500 feet is found along Pine Hill Cemetery, northwest of Brandon. A 400-to 500-foot beach is present over kame material at the mouth of Bresee Mill Brook, south of Brandon.

A badly disturbed sand deposit caps a ridge of lake clay one mile northwest of East Middlebury. This ridge may be a beach or may outline the western border of the ice block responsible for the kame terrace north of East Middlebury.

On the Ticonderoga quadrangle a well-marked beach deposit is present on the west flank of Sisson Hill at 400 feet. An anomalous deposit is found at 340 feet west of Hardigan Hill, three miles south of Shoreham and may represent a beach.

An interesting deposit mapped as *delta gravel* is found 3½ miles southeast of Orwell, just north of the Rutland County line. This deposit has a flat top at 500 feet and exhibits well-developed foreset beds deposited from the North. As no ice-contact structure was observed, this delta is interpreted as reworked glacial drift deposited by meltwater flowing south into a 500-foot lake level in the Hubbardton River valley. A lower outlet at 400 feet exists east of the ridge bounding the delta on the east. The swampy depression within the 400-foot outlet must have held stagnant ice while the western channel functioned as a meltwater outlet at 500 feet.

Marine Deposits

No marine deposits have been reported in the Brandon or Ticonderoga quadrangles. While no marine fossils were found during the 1965 field season, a rigorous search for them is not implied.

Adjacent to Lake Champlain at the north edge of the Ticonderoga quadrangle there is a prominent erosional escarpment developed at 200 feet. A similar scarp is found farther south at 180 feet, west of Shoreham. These scarps probably resulted from erosion during marine occupation (The Champlain Sea) farther north.

POST GLACIAL DEPOSITION

Stream Deposits

Medium- to fine-textured floodplain deposits were mapped as *alluvium*. Usually, alluvium is just barely mappable; however, along Otter Creek, the Leicester River, and the lower reaches of the Middlebury River, extensive floodplain alluvium is present.

The total thickness of alluvium is probably small in most valleys. In the Otter Creek system the bedrock threshold at 330 feet at Middlebury serves as a lower limit for stream scour and therefore for stream deposition. Thus, the maximum thickness of alluvium in the Otter Creek valley does not exceed 20 feet, with the possible exception of the Salisbury Swamp. The Leicester River is not large enough to have eroded the broad depression that this Swamp occupies. Therefore, the depression is inferred to be an area of non-deposition due to occupation by stagnant ice and may be deeper than the stream-scoured portions of the valley.

Fluvial gravel was mapped in an abandoned channel of the Leicester River where the deposit is composed of coarse cobble and boulder gravel.

Swamp Deposits

There are several recent *bogs and swamps* that presumably represent the end phase of filling of lakes and undrained depressions. Several bog deposits are present filling of abandoned meltwater channels and ice block depressions between Otter Creek and the Green Mountains, as, for example, Smalley Swamp. Cedar Swamp and the undrained depression surrounding the Lemon Fair River, in the Ticonderoga Quadrangle, are undoubtedly areas formerly occupied by stagnant ice.

The extensive swamps developed along the eastern bank of Otter Creek may be due to a rise in base level and subsequent filling of the stream valley. Differential upwarp of the bedrock threshold at Middlebury would account for this rise and also for subsequent changes in regional drainage of low lying areas. Another effect due to the uplift of the northern end of Lake Champlain is the drowning of southern tributaries, e.g., East Creek. These lake-level swamps contrast with those mentioned above, as they represent the initial stages of drowning rather than the end stage.

Doll (personal communication) and the writer, independently noticed the flat-bottomed nature of the stream valleys tributary to Dead Creek in the northwestern portion of the map area. The flat bottoms often support marsh-like vegetation at about 170 feet. Typical stream alluvium is deposited above 170 feet while the valleys appear erosional below this elevation. The 170-foot level may represent a migrating nickpoint, suggesting that the valleys were once graded to an earlier lake stage (The Champlain Sea?) at this elevation. Alternately, the flat bottoms may be caused by intersection with the regional water table, suggesting that the valleys are presently migrating headward and perhaps laterally by spring sapping rather than by fluvial erosion.

GLACIAL HISTORY

Glacial Advance

Although the movement of ice in this region is sparsely documented, due to intensive weathering of the uplands and the mantle of surficial materials in the lowland, it can be interpreted from the striae observations, till fabrics and one drumlin. The drumlin strikes a little west of north in the eastern part of the map area, but has little bearing on the following discussion.

The striae appear to define two small "provinces"; a "lakeshore province" on the west and an "Otter Creek province" on the east. In the lakeshore province the striae are all slightly northeast (N 01°E - N 16°E), while they are northwest (N 11° W - N 55°W) in the Otter Creek province, including two localities where the upper, northwest set is superposed on the northeast set. In two other localities it was not possible to determine superposition of striae, but a similar relationship is assumed to be present at all four sites where both sets were found.

Two hypotheses can be presented to account for the observed relationships. Hypothesis I would explain all northeast striae as products of a southwesterly moving glacier and all northwest striae as products of a southeasterly moving glacier. The four sites, where superposed striae were observed, tend to support this hypothesis with the southeast-moving ice being the younger. If Hypothesis I is accepted, then one must further hypothesize a thick sediment cover, since stripped away, for the preservation of the northeast striae of the lakeshore province, or alternately, that water buoyed the advancing ice along the present Champlain Valley axis, thus preventing erosion.

Hypothesis II would accept the superposed striae of the Otter Creek province as recording two separate advances as outlined above, but would propose that the northwest striae of the Otter Creek province and the northeast striae of the lakeshore province were produced simultaneously by the latest glacier advance (Fig. 5). In this case one would hypothesize a lobate advance with the central part of the glacier advancing east of the present lake shore and perhaps splitting into two lobes at the Taconic Range.

Till fabrics show essentially a reversed situation to that of the striae. Those near the lake shore indicate southeasterly moving ice while those in Otter Creek suggest a southwesterly advance. Assuming Hypothesis I, the northeast fabrics in the east (and the lower till at West Bridport) would represent the older glaciation while the northwest fabrics near the

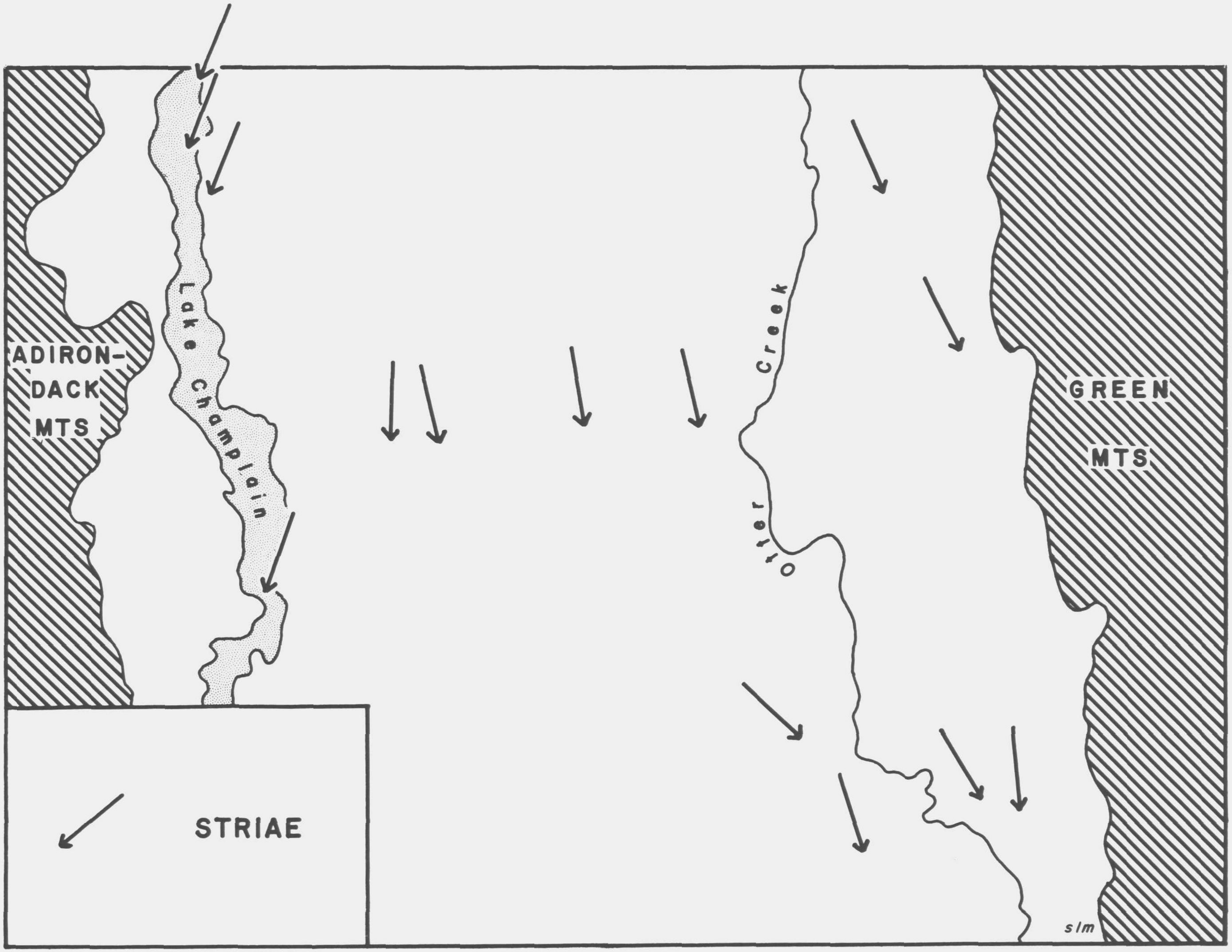

Figure 5. Striae of the Latest Advance of the Champlain Lobe.

lake shore were caused by the younger advance. Presumably the younger advance was not thick enough in proximity to the Green Mountains to affect preexisting northeast fabrics.

When the data discussed previously under the section on Till Fabrics is taken into consideration, Hypothesis II must be accepted. Assuming Hypothesis II, the fabrics would be interpreted as the response of basal flow to local subglacial topography. An early glacial advance is inferred from the northeast, responsible for the northeast striae near the Green Mountains. Presumably this is the Shelburne advance of Stewart and MacClintock (1964). A later glacier advanced southward, down the Champlain Valley, with its axis more than a mile east of present Lake Champlain. This advance was responsible for the fan-like trend of the remaining lakeshore and upper Otter Creek striae, defining a lobate advance. A later thickening of this ice over the eastern Adirondack Mountains might account for the northwest fabrics near the lake shore. Presumably this is the same glacier that deposited the Burlington drift to the north.

At the West Bridport multiple-till section, two tills were seen to overlie striae of the later, lobate advance. Thus, the light-gray and dark-gray tills may both be the equivalents of the Burlington till to the north. In almost all localities the oxidized lake clays overlie the gray tills, suggesting that the yellow-brown till that incorporates lacustrine sediments is younger than either the light-gray or dark-gray tills. The yellow-brown till represents the Bridport readvance that will be discussed under a separate section.

It is now possible to summarize the sequence of events during glacial advances. As shown in Table 2, the first event is the advance of southwesterly moving ice from the Green Mountains, followed by the southward advance of the Champlain lobe. During the latter advance, three lodgement tills were deposited in the lowlands.

Glacial Recession

Retreat of the Champlain lobe was evidently accomplished by downwasting and stagnation of the ice terminus. As the ice thinned, movement ceased and separate blocks of stagnant ice were left in protected valley bottoms in the Green Mountains and nestled against the base of these mountains in the Champlain Lowland. The sequence concept of Jahns (1941 and 1953) appears to be applicable to the ice-contact deposits in the lowland and suggests that active ice was present a short distance to the north. Meltwater from the stagnating ice drained southward and was trapped against the highlands forming proglacial lakes. If one assumes continuous lake levels throughout the region, it is possible to correlate isolated patches of ice-contact drift associated with these lakes.

Lake Vermont

Chapman (1937 and 1942), Stewart (1961) and most recently, LaFleur (1965) have all commented on the fluctuation of proglacial lake waters in the Champlain and Hudson Valleys. Chapman (1937) named two levels of Lake Vermont, the upper Coveville stage and the lower Fort Ann stage. Stewart recognized a lake level higher than the Coveville and named this the Quaker Springs stage. LaFleur has suggested that the Quaker Springs and Coveville stages were continuous with waters in the Hudson Valley and that their levels were controlled by

TABLE 2.

The Sequence of Events of Glacial Advances in the Brandon and Ticonderoga Quadrangles Showing the Regional Event to which Each is Related

Local Event	Regional Event
5. Deposition of the Yellow Brown Till (incorporating lacustrines)	Bridport Readvance
4. Deposition of the Dark Gray Till (upper till at West Bridport)	
3. Deposition of the Light Olive Gray Till (lower till at West Bridport)	Burlington Advance
2. North-to-South Lobate Advance (Lake Champlain striae)	
1. Northeast-to-Southwest Advance (NE striae in Otter Creek)	Shelburne Advance

outlets far to the south.

According to Chapman, the Fort Ann stage should be present at 360 feet in the north end of the area and about 290 at the south end. The Coveville stage can be expected at 420 feet in the southern part of the quadrangle and close to 500 feet in the north. Stewart's projection of the Quaker Springs stage suggests its presence at 460 feet in the south and 560 feet at the north end of the area.

The lake levels present on the Brandon delta and associated beach deposits correlate closely with projected levels. The 405-foot level is the undoubted equivalent of the Coveville stage and the 460-foot level (?) is in the right position to be Quaker Springs stage. However. the 460-foot level is problematical at best and the 500-foot level is here proposed as the Quaker Springs equivalent at the Brandon delta.

In the northern portion of the quadrangle, hanging deltas are present between 380 and 400 feet and are proposed as deposits in shallow branches of the Fort Ann stage. The Coveville stage is documented by a lacustrine beach sand and wave-washed till between 400 and 440 feet south of the Middlebury River and by lacustrine sand between 460 and 480 feet north of the Middlebury River. The latter deposit is thought to have been winnowed from the kame terrace to the east during Coveville time.

No evidence of a lake higher than Coveville is present north of Brandon.

Deglacial Sequences

Five separate sequences are inferred adjacent to the Green Mountains. Evidence for the first three sequences consists of scattered ice-contact deposits and associated meltwater drainage features. In order to understand the reconstruction of the earlier sequences, it is necessary to describe sequence 4 first.

Sequence 4 consists of the Lake Dunmore kame terraces, kame moraine to the south, the Forest Dale outwash, the eastern channel of the Brandon delta, and the 565-foot lake (?) level. A graded profile can be reconstructed from 640 feet on the kame terraces to 600 feet on the kame moraine and to 560 feet on the outwash. The outwash grades continuously into the Brandon delta lake sands, ending at 380 feet at Otter Creek.

An erosional escarpment, west of Forest Dale, shows that the 500-foot Quaker Springs delta is erosional, or inset, at the head of the 560-foot level. Therefore, sequence 4 must be related to a lake level higher than Quaker Springs. A 565-foot level is documented by a pocket of beach gravel east of Brandon and a weak erosional scarp between the 620- and 507-foot levels farther south. This level descends to 540 feet at the southern edge of the quadrangle.

Only two breaks are present in the graded profile of sequence 4, the Neshobe River channel and the Smalley Swamp. A stagnant ice block is inferred in the Smalley Swamp depression during deposition of the sequence 4 lacustrine sands. The Smalley Swamp ice block is a remnant of earlier sequence 3, related to a higher meltwater drainage level. South of Smalley Swamp an escarpment is capped by gravel at 600-620 feet. This scarp can be traced southward at 622 feet and is correlated with a beach deposit developed between 590 and 620 feet at the southern edge of the map.

The only evidence for sequence 2, pre-dating sequence 3, is a still higher drainage level developed west and northwest of Brandon. A pocket of beach gravel is found between 720 and 740 feet flanked by a smoothly washed terrace at about 700 feet, ½ mile southeast of Forest Dale. This level is presumably correlative with a deposit of beach gravel mapped between 680 and 720 feet east of Brandon. The high level of drainage evidently was caused by ice blockage to the south and west.

Sequence 1 can be reconstructed from a kame terrace of Hogback Mountain. This kame terrace has a flat top at 1760 feet and probably is continuous with the lacustrine sand to the south at 1700 feet. These sediments are tentatively grouped with kame terrace levels at 1480 feet in Gould Brook and 1400 feet in the Neshobe River. Although several events may be lumped together, sequence 1 presumably formed shortly after thinning exposed the highest peaks along the Green Mountain front.

Sequence 5 is the final stage of deglaciation in the Brandon-Ticonderoga region. The northern portion of this sequence is the kame terrace north of the Middlebury River. South of this River extensive, flat-topped outwash is at 580 feet, with outwash at 700 feet thought to have been contributed penecontemporaneously by highland ice still present in the Green Mountains. The outwash drained southward over stagnant ice in the Salisbury Swamp and through a well-developed channel of washed till one mile northeast of Leicester Corners. Drainage led southward along terraces cut in till and funnelled into the ice-channel reconstructed from the Brandon esker. Drainage eventually reached open water in the vicinity of the Brandon kame complex which is interbedded with Quaker Springs lake clays between 400 and 450 feet.

It is possible that the Brandon esker represents a sixth sequence related to a 460-foot level (?) of the Brandon delta; however, no adequate source of sediment would exist after melting of the stagnant ice in the vicinity of East Middlebury. Thus, sequence 5, including the Brandon esker, is inferred to be contemporaneous with the 500-foot Quaker Springs level of the Brandon delta and the attendant 500-foot beach gravels east and south of Brandon.

The kame terraces in Bresee Mill Brook, Willow Brook and flanking the headwaters of the Lemon

Fair River all appear to be graded to the Quaker Springs level. Indeed, kame material at the mouth of Bresee Mill Brook has been reworked into a beach between 460 and 500 feet. Assuming the 500-foot level to be continuous throughout, the final remnants of stagnant ice left in the lowest valleys of the Taconic Range also are correlative with sequence 5 in the vicinity of the Middlebury River.

The flat-topped, 500-foot delta southeast of Orwell is inferred as an outlet for the Quaker Springs lake into the Hubbardton River to the south. If the Hubbardton River were the only outlet, then active ice must have been present westward, perhaps related to the kames at the headwaters of the South Fork of East Creek. The East Creek kames may have been deposited south of active ice that formed the buried Sisson Hill moraine to the northwest.

Initial drainage for the Quaker Springs stage is inferred southward through the headwaters of the Hubbardton River. As this channel does not appear nearly large enough to account for the entire Quaker Springs drainage, it may have been only one of several outlets or may have represented an initial, short-lived phase of southerly drainage.

Well-developed benches cut in till at 500 feet near Sudbury were referred to the Coveville stage by Chapman (1942), however, the writer would assign them to the 500-foot Quaker Springs stage. Quaker Springs drainage may be responsible for the col between Bald Hill and Millers Hill, 2½ miles northeast of Sudbury; from whence it continued around the northern end of the Taconic Range and southward along the Sudbury bench, over stagnant ice in the Lemon Fair River valley, and then east and south to the Hubbardton River.

As no higher regional level than Quaker Springs has been reported, the 565-, 620- and 720- foot levels east and southeast of Brandon are thought to represent isolated meltwater lakes (?) confined to the Vermont Valley to the south. Outlets for these initial, high-level lakes might be found to the south or to the north into and through stagnant ice; thence southward through the Champlain Valley. The relationship between the five sequences and glacial lake levels is shown diagrammatically in Figure 6.

As stated previously, there is no evidence of a lake higher than the Coveville lake north of Brandon. This is not surprising as the stagnant ice related to sequence 5 is inferred in the vicinity of the Middlebury River during Quaker Springs time. Reworking of the sequence 5 kame terrace produced the Coveville beach. If sequence 5 ice was present during Quaker Springs time, the bouldery clay in the Middlebury River area could not have been deposited until Coveville time and the Coveville lake had been initiated. This suggests the presence of active ice in the vicinity of, or north of, Middlebury during Coveville time.

The Bridport Readvance

Evidence for a late-glacial readvance in the northern portion of the map area comes from West Bridport where till overlies gravel (Plates 5 & 6); from east of Middlebury (just north of the Brandon Quadrangle) where bouldery lacustrine clays have been badly contorted, suggesting overriding and incorporation at the base of a glacier; and from the ice-rafted boulders present in the lake clay south of Middlebury and west of the East Middlebury kame terrace.

The ice-rafted boulders may be deposits from the Middlebury River, or the kame terrace north of it, washed onto the frozen surface of Lake Vermont and dropped during summer melting. Alternatively, they may be coarse material dropped from the base of the stagnant ice responsible for the kame terrace when the ice became buoyed by the waters of Lake Vermont and floated free of the underlying surface. A third possibility is that the boulders were deposited from floating icebergs, calved from active ice to the north.

In the light of the undoubted evidence for readvance at West Bridport, and the contorted clays in the Middlebury Quadrangle, the writer suggests a readvance and soling of active ice on the lake clays east of Middlebury. This active ice would then have acted as a source of supply for the calving icebergs that furnished the ice-rafted boulders to the south. The area covered by this readvance is approximated by the bouldery clay pattern south of Burlington and shown on the new Surficial Geologic Map of Vermont (Stewart, D.P. and MacClintock P., Surficial Geologic Map of Vermont, C.G. Doll, Ed., Vermont Geological Survey). A major glacial advance is not postulated, merely a readvance of the active ice that must have been present to supply sediment to the stagnant ice sequences described above.

Champlain Sea

After ice retreated from the St. Lawrence Valley following the Fort Ann stage of Lake Vermont and prior to post-glacial rebound, there was a marine invasion of the Champlain Valley (Chapman, 1937). No evidence of marine deposition was observed in the Ticonderoga Quadrangle; however, erosional escarpments at 200 feet at the north edge of the map and 180 feet west of Bridport probably date from this event.

Summary

In summary, a sequence of events can be postulated in the Brandon-Ticonderoga region based on evidence found only in those two quadrangles. The

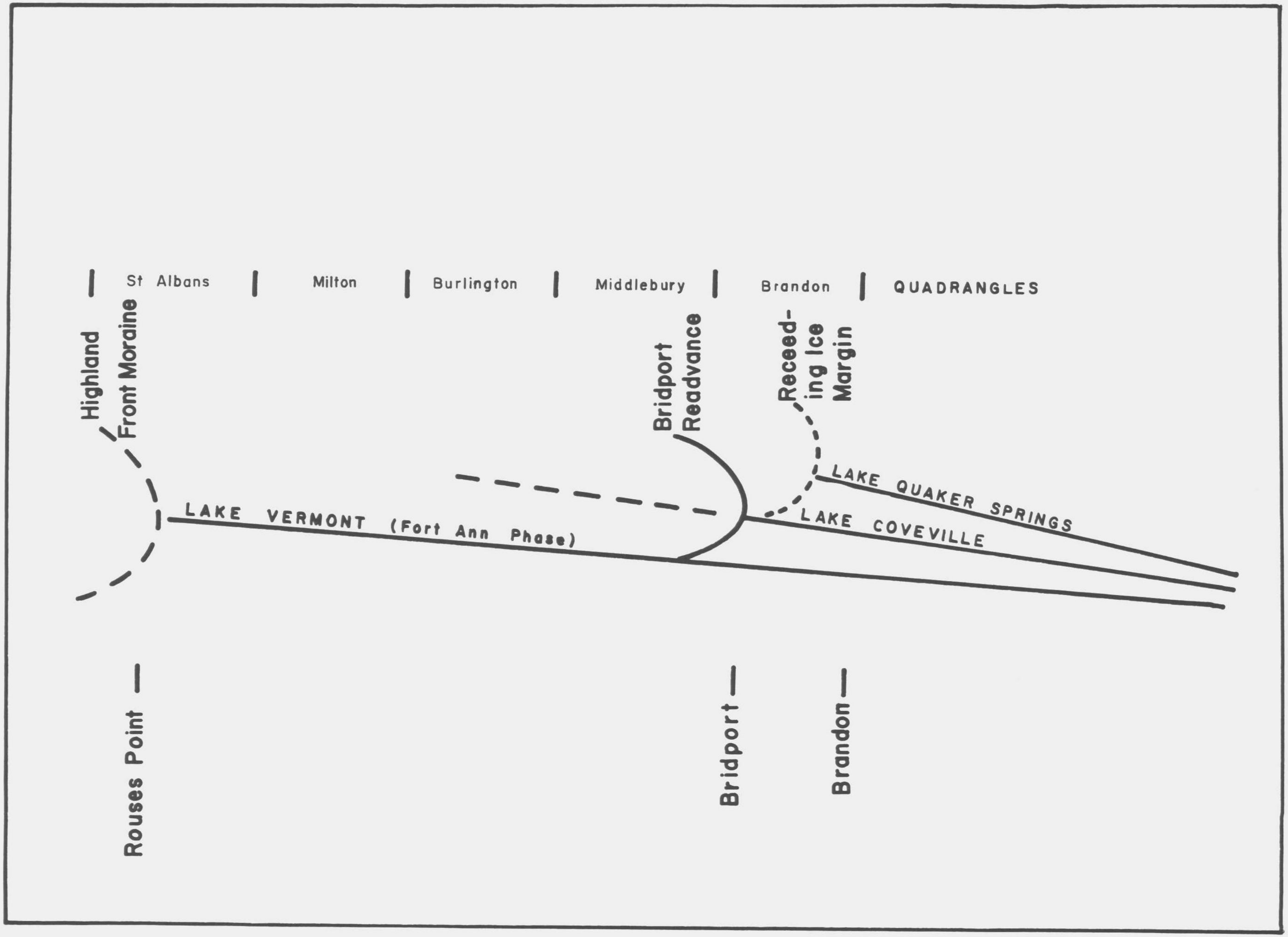

Figure 6. A Diagrammatic Illustration of the Relationship Between Deglacial Sequences and Lake Levels.

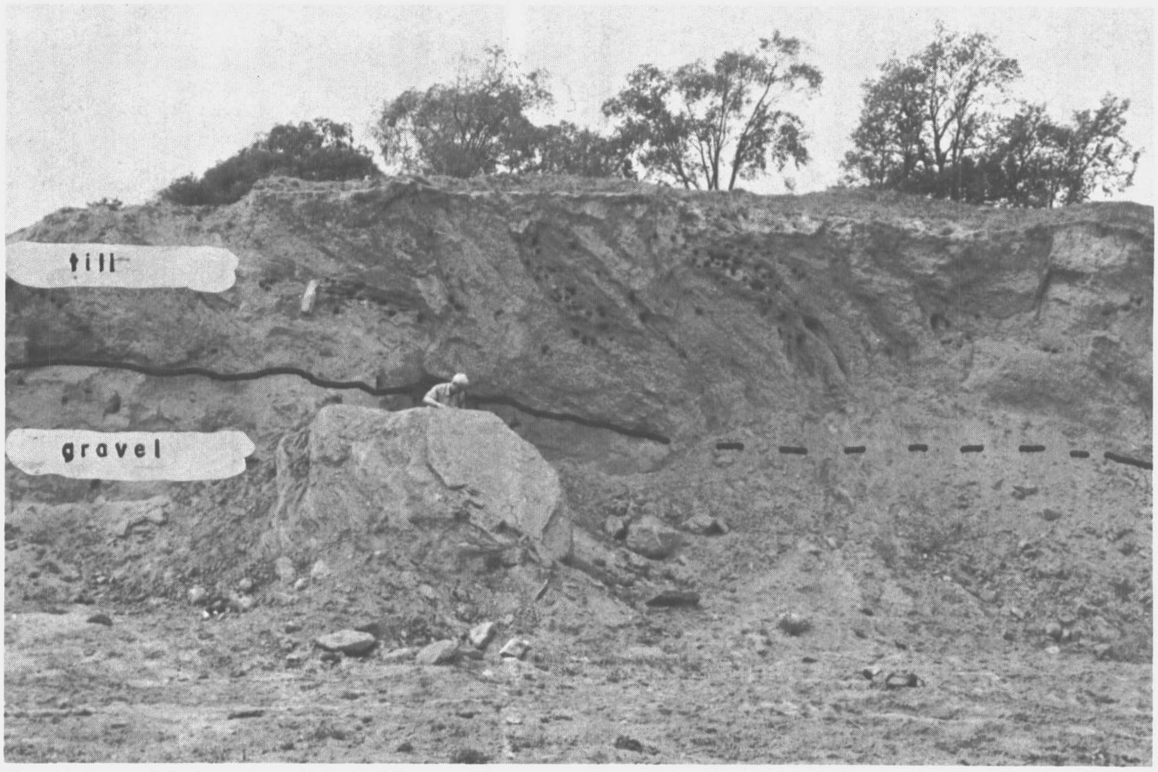

Plate 5. A south-facing view of the Bridport readvance till over outwash or lacustrine gravel. The large erratic of limestone has slipped down the working face onto the floor of the gravel pit.

Plate 6. A closer view of Plate 5 showing incorporation of underlying gravel along apparent shear planes in the till. The cliff swallow holes are preferentially developed in the gravel lenses.

establishment of the Bridport readvance as contemporaneous with or slightly post-dating the Coveville stage permits the correlation of glacial events with lake history as shown in Table 3.

TABLE 3.

A summary of the Glacial and Deglacial Events of the Champlain Valley as Illustrated in the Brandon and Ticonderoga Quadrangles

9. The Champlain Sea
8. Recession and the Fort Ann Stage of Lake Vermont
7. Readvance and Deposition of the Yellow Brown Till
6. Recession and the Coveville Stage of Lake Vermont
5. Recession and the Quaker Springs Stage of Lake Vermont
4. Readvance (?) and Deposition of the Dark Gray Till
3. Deposition of the Light Olive Gray Till
2. Advance of the Champlain Valley Lobe from the North
1. Initial Ice Advance from the Northeast

POST GLACIAL HISTORY

The principal post-glacial events have been the trenching of the headwaters of the Middlebury and Neshobe rivers and excavation of sediments in their lower reaches and in the Otter Creek valley. Although Otter Creek may have been active initially in excavating Pleistocene deposits, rebound of the bedrock threshold at Middlebury prematurely aged the stream and the alluvial floodplain ensued. On the Champlain lake-plain, consequent drainage was initiated immediately after each drop in lake level. In the northern portion of the Ticonderoga Quadrangle dendritic, consequent streams are actively developing, probably through the process of groundwater sapping. In the southern part of the quadrangle the dendritic pattern is still evident for streams excavating lacustrine sediment; however, as the surficial mantle is removed, the streams are adjusting to ancestral, rectangular drainage on the bedrock topography beneath.

Adjustment to basement topography is best illustrated by the Neshobe River. Initially, perhaps shortly after Quaker Springs time, the Neshobe River flowed westward through Arnold Brook. When the till ridge was encountered, the river turned southward leaving Arnold Brook as a beheaded remnant. The Neshobe River then followed a southward channel, perhaps that north of Johns Brook southwest of Brandon. However, the river shortly cut a southwestward channel through Brandon, superposing itself on a bedrock ridge north of the village in the process. After crossing the bedrock threshold at Brandon, the Neshobe River appears to have flowed westward, removing evidence of the Brandon esker. Finally, perhaps following the Coveville stage, the Neshobe River excavated its present channel southward from Brandon. Thus, the Neshobe River illustrates both adjustment to the underlying, north-south bedrock trend and limited superposition upon it.

As the bedrock threshold at Middlebury was raised during post glacial rebound, drainage in Otter Creek became more and more sluggish. The slow rise of base level evidently caused alluviation, development of the swamps seen along the Otter Creek floodplain, and the trenching of the channel north of the threshold observed in the Middlebury Quadrangle.

Differential post glacial rebound is continuing today, gradually raising the north end of Lake Champlain with respect to the southern end and gradually drowning the southern tributaries, e.g., East Creek, west of Orwell. The slow rise of water level in East Creek and similar streams initiated the marsh conditions now present in their lower reaches.

ECONOMIC GEOLOGY

Gravel

Extensive deposits of clean, crystalline gravel are located in sequence 4 in the vicinity of Lake Dunmore and Forest Dale, and in sequence 5 north and south of the Middlebury River. These deposits are being worked currently on a large scale. Smaller, isolated kame deposits south of West Cornwall and at the headwaters of the South Fork of East Creek may be useful locally.

Sand

One pit in the eastern channel of the Brandon delta shows more than 100 feet of clean sand. Another extensive deposit, in addition to the Brandon delta, is located west of the kame terrace north of the Middlebury River. This deposit is estimated to be 40 to 60 feet thick adjacent to the kame terrace.

Clay

An extensive kaolin deposit has been developed through weathering and/or hydrothermal alteration of the Cheshire Quartzite in the northern portion of the Middlebury Quadrangle. The presence of kaolinitic saprolite associated with the Cheshire outcrop belt in the Brandon Quadrangle indicates possible commercial deposits here also.

Burt (1930) has discussed the origin of the Brandon Residual Formation, including kaolin, ocher, and lignite as the product of Tertiary weathering. He gives a regional picture and includes cross sections of the Forest Dale deposits. Jacobs (1940) gives a brief account of the mining operations at Forest Dale.

It appears that prospecting can be limited to the belt of Cheshire Quartzite between East Middlebury and the southern edge of the map. It is not possible to predict either quantity or purity of possible deposits.

A large quantity of silty-clay, present in the southern part of the Ticonderoga Quadrangle might prove economically attractive. The bouldery clay to the north, however, contains coarse clastic materials that would be detrimental to the development of either ceramic or brick industries.

Peat

Although there are small bogs present throughout the two quadrangles, it is doubtful that they could be used for any purpose except humus for local agriculture. These deposits are neither extensive nor thick enough, as presently estimated, to be commercially attractive. The bogs west of Brandon might prove to be the thickest and most attractive. Cedar Swamp, northwest of Shoreham, also represents a possible supply of peat or a possible site for a profitable muck farming operation.

Foundations

As noted before, the nature of the till is variable. Where sandy ablation till is present, foundations can be excavated easily by hand. In the compact till, or in areas of heavy lake clay, mechanized labor is necessary for excavation. In areas surrounding mapped bedrock outcrop, bedrock is probably present at shallow depths and would require blasting.

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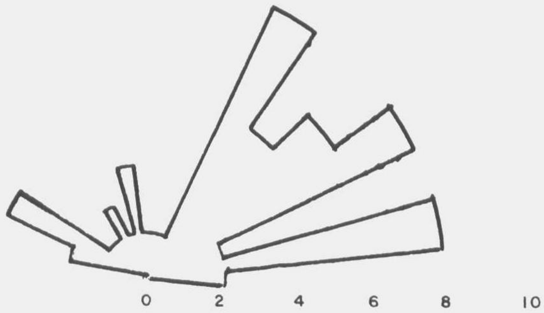
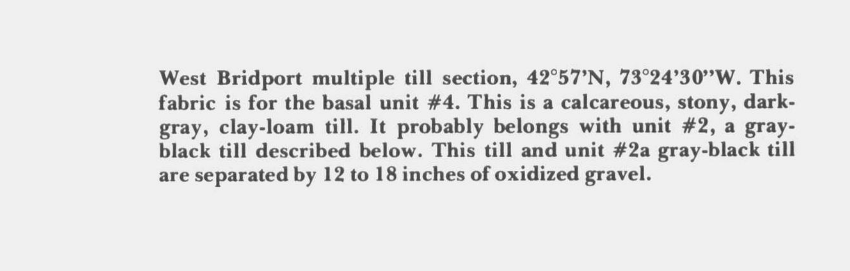
APPENDIX 1., TILL FABRIC DIAGRAMS

The following rose diagrams show the fabric recorded from six single-till localities and one multiple-till locality in the Brandon and Ticonderoga quadrangles. The fabrics were recorded following the technique of Stewart and MacClintock (1964).

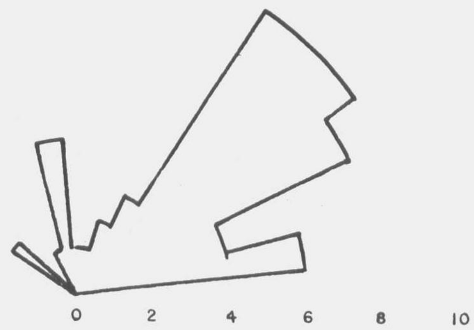
Each locality is identified by both a site name and its geographic coordinates. The numbers recorded are the actual number of till stones found in each of the 10° divisions.



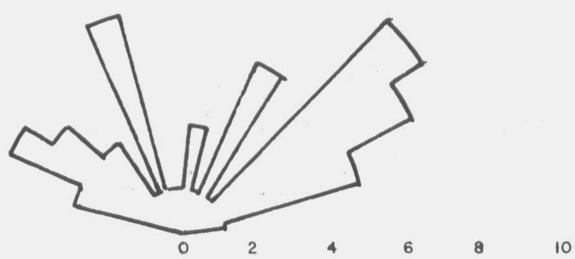
Northern Otter Creek site, 42°58'N, 73°15'W. A borrow pit 2 miles south of State Rt. 125. The till is dark-yellowish brown, pebbly, and has a loam matrix.



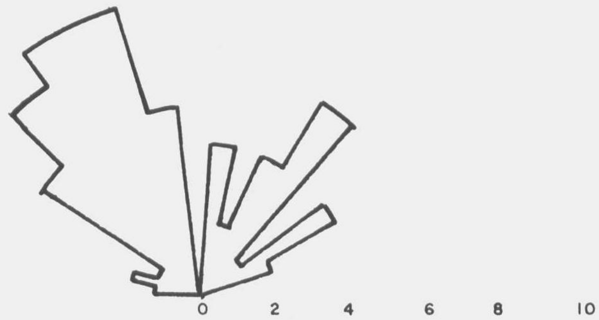
West Bridport multiple till section, 42°57'N, 73°24'30"W. This fabric is for the basal unit #4. This is a calcareous, stony, dark-gray, clay-loam till. It probably belongs with unit #2, a gray-black till described below. This till and unit #2a gray-black till are separated by 12 to 18 inches of oxidized gravel.



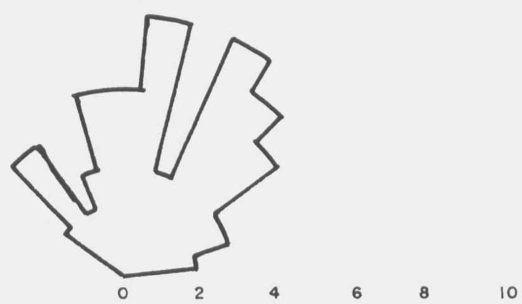
West Bridport multiple till section. This fabric is for unit #2 that underlies the dark-gray till (unit #4). This is a moderately stony, calcareous, gray-black till with a clay-loam matrix like unit #4 but contains somewhat more clay.



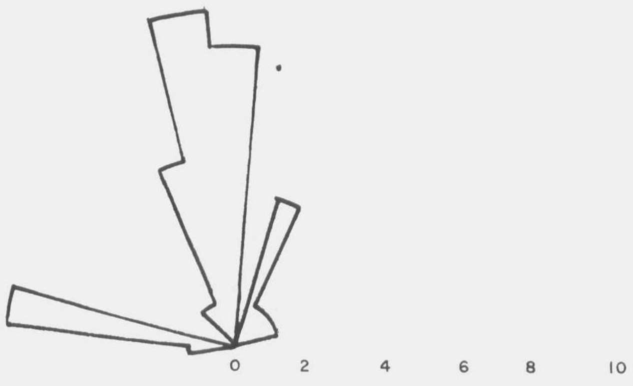
West Bridport multiple till section. This fabric is for the lowest till in the section (unit #1). This is a very compact, moderately stony, calcareous, light olive-gray till with a sandy-loam matrix.



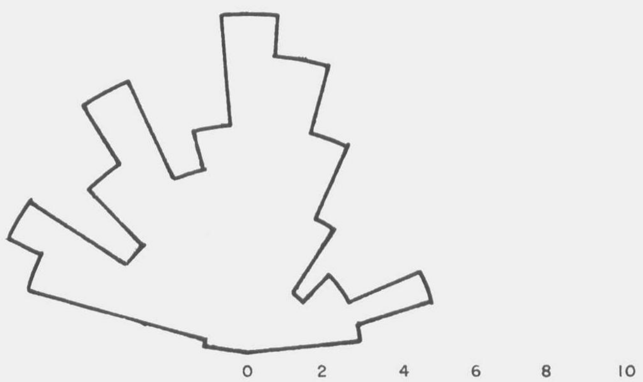
East Creek site, 43°48'N, 73°19'45"W. This is a cutbank below the lowest falls on East Creek. The till is a silt-loam or silty-clay till with sparse pebbles and cobbles but many granules. It is light olive-gray in color and is calcareous.



Salisbury borrow pit site, 43°54'N, 73°07'W. This old borrow pit is located just west of U.S. Rt. 7, below Holiday Hill. The till overlies kame gravel and contains many large, striated cobbles oriented toward the northeast. The till is stony, compact, and calcareous with a light olive-gray, loam to sandy-loam matrix.



Sisson Hill till-ridge site, 43°52'30"N, 73°20'W. A stony, compact, calcareous, clay-loam till with a light olive-gray matrix.



South Middlebury shopping center site, 43°59'30"N, 73°07'30"W. This excavation was fabricked by Parker Calkin at my request. While the site was open the writer was working in the Mt. Mansfield quadrangle to the north. The deposit, a light olive-gray, sandy-loam till, is identical to the Salisbury borrow pit to the south.