THE SURFICIAL GEOLOGY AND PLEISTOCENE HISTORY OF VERMONT

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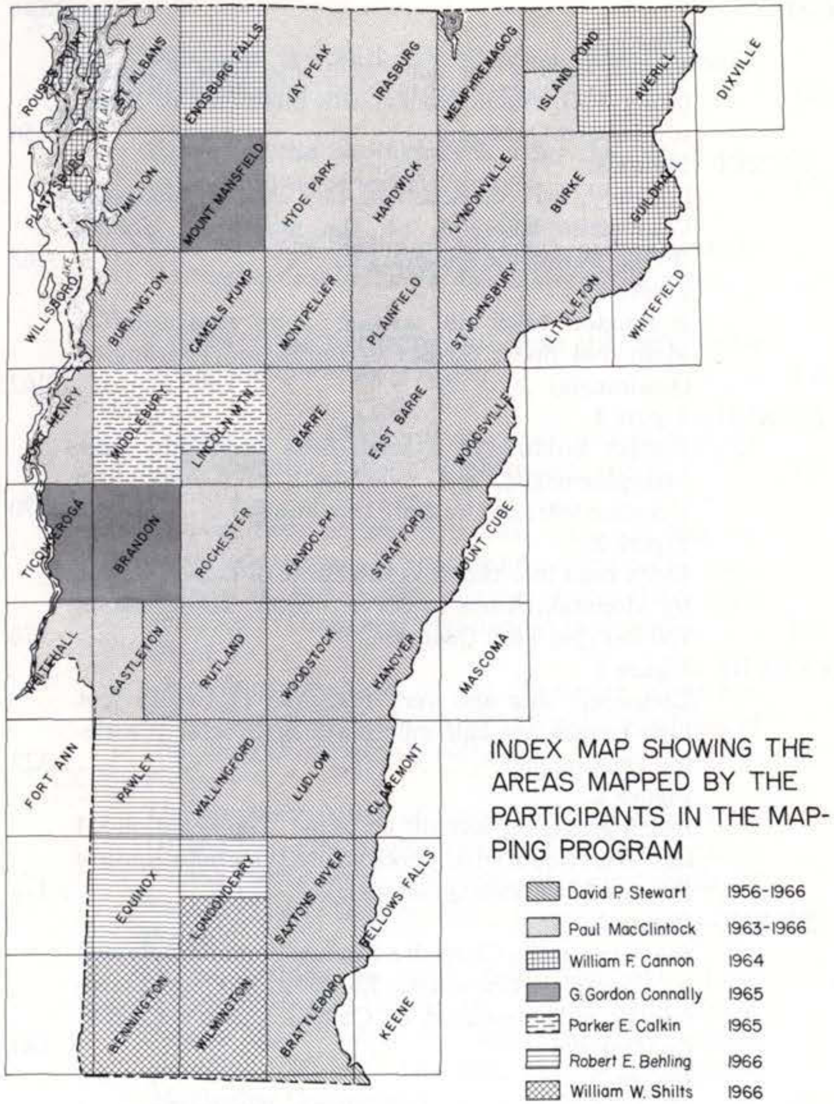

Figure 1

THE SURFICIAL GEOLOGY AND PLEISTOCENE HISTORY OF VERMONT

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INTRODUCTION

This report is based on the investigations made and the data collected during an eleven-year mapping program begun in 1956. The survey was sponsored by the Vermont Geological Survey and the Vermont Highway Department. The entire program was carried out under the direction and supervision of Dr. Charles G. Doll, the State Geologist. This bulletin is a companion publication to *The Surficial Geologic Map of Vermont*, produced by the same survey and scheduled for publication at the approximate same time.

Early Studies

Interest in the surficial deposits and glacial history of New England dates from the publication of the glacial theory by Louis Agassiz in 1840. The following year, Edward Hitchcock (1841, pp. 232–275), in his presidential address to the first annual meeting of the Association of American Geologists, discussed the Agassiz theory at length. He, on this occasion, gave several reasons why he agreed with Agassiz, but he also stated that water and ice were both important and that he was not sure which had been the more effective erosive agent. It soon became apparent that Hitchcock had decided water was the more important agent. He then proposed an iceberg theory of drift that confused the interpretation of the glacial deposits for the next fifty or sixty years (Stewart, 1961, p. 8).

Investigations of the glacial deposits of Vermont began almost immediately after the publication of the glacial theory. C. B. Adams, the young and energetic State Geologist, did some rather detailed study of the surficial deposits and the manifestations of glaciation. In his first and second annual reports, published in 1845 and 1846, he included much data on the striae direction and surficial materials. Adams, however, had been a tutor at Amherst College under Hitchcock (Jacobs, 1946, p. 4), and was therefore greatly influenced by the iceberg theory. He also proposed another, even more amusing, theory of elevations that involved violent earthquakes and high elevations. Whether or not the elevation theory was original with Adams is not known to the writers of this report, but his second annual report is one of the few places where it does appear in print (Adams, 1846). Like the iceberg theory, the mechanics of the elevation theory were quite vague. In 1847, Adams gave up geology and the systematic study of the glacial deposits of Vermont ceased for the next ten years (Jacobs, 1946, p. 5).

Edward Hitchcock became the State Geologist of Vermont in 1856, and immediately began the first systematic geological survey of the state. The survey, which resulted in the 1861 publication of *The Geology of Vermont,* included surficial geology and Pleistocene history. Interpretations of the surficial deposits and the glacial history were, of course, in accordance with the iceberg theory and local glaciation. The report also introduced the confusing terms drift and modified drift that were used to designate deposits made by the icebergs and the sea invasion that was necessary to float them (Stewart, 1961, p. 8).

One of Edward Hitchcock's assistants at the time of the survey of Vermont was his son, Charles H. Hitchcock, who did much of the surficial work for the 1861 report. He, naturally, was also a firm advocate of the iceberg theory. Charles H. Hitchcock was the only member of the survey that continued to study the surficial geology of Vermont after 1861. In spite of the accuracy of his data and the otherwise competency of his work, the iceberg theory and local glaciation continued to be the basis for his interpretations. It was not until 1904 that any change is noted in his writings, and at that time he stated that "icebergs had given way to glaciers."

Even after his acceptance of the glacial theory, Charles H. Hitchcock still had much difficulty visualizing continental glaciers over New England and continued to emphasize valley glaciers from the mountains. Here again he was influenced by his father who did admit mountain glaciation, but never continental ice sheets. The debate concerning local vs. continental glaciation continued until 1916. In that year, J. W. Goldthwait (1916, pp. 42–73) published his arguments for continental glaciation and gave conclusive evidence that ice sheets had indeed covered Vermont. That settled the question once and for all.

It seems, as we interpret the literature, that two major questions motivated the investigations of the surficial deposits during the three-quarters of a century prior to 1916. The two questions concerned, first of all, whether or not Vermont had been glaciated, and, secondly, whether local or continental glaciation had been responsible. When, in 1916, these

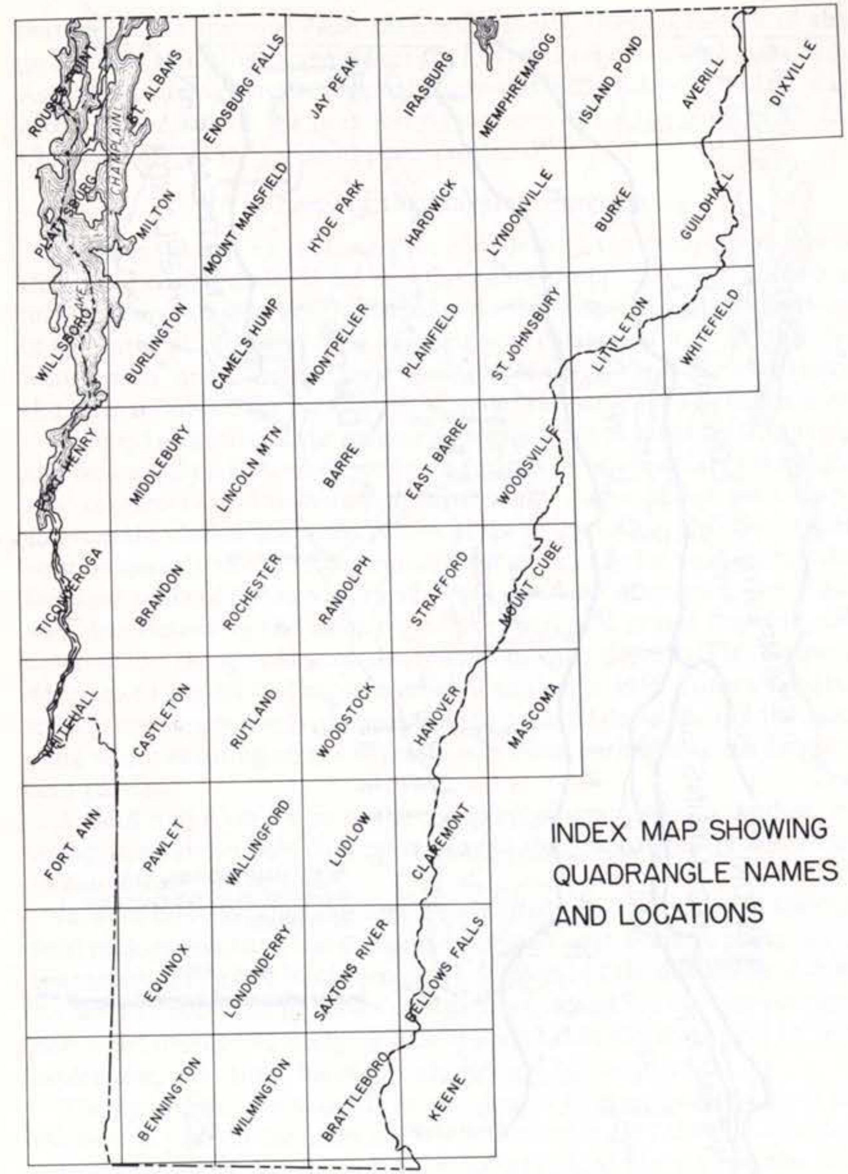


Figure 2

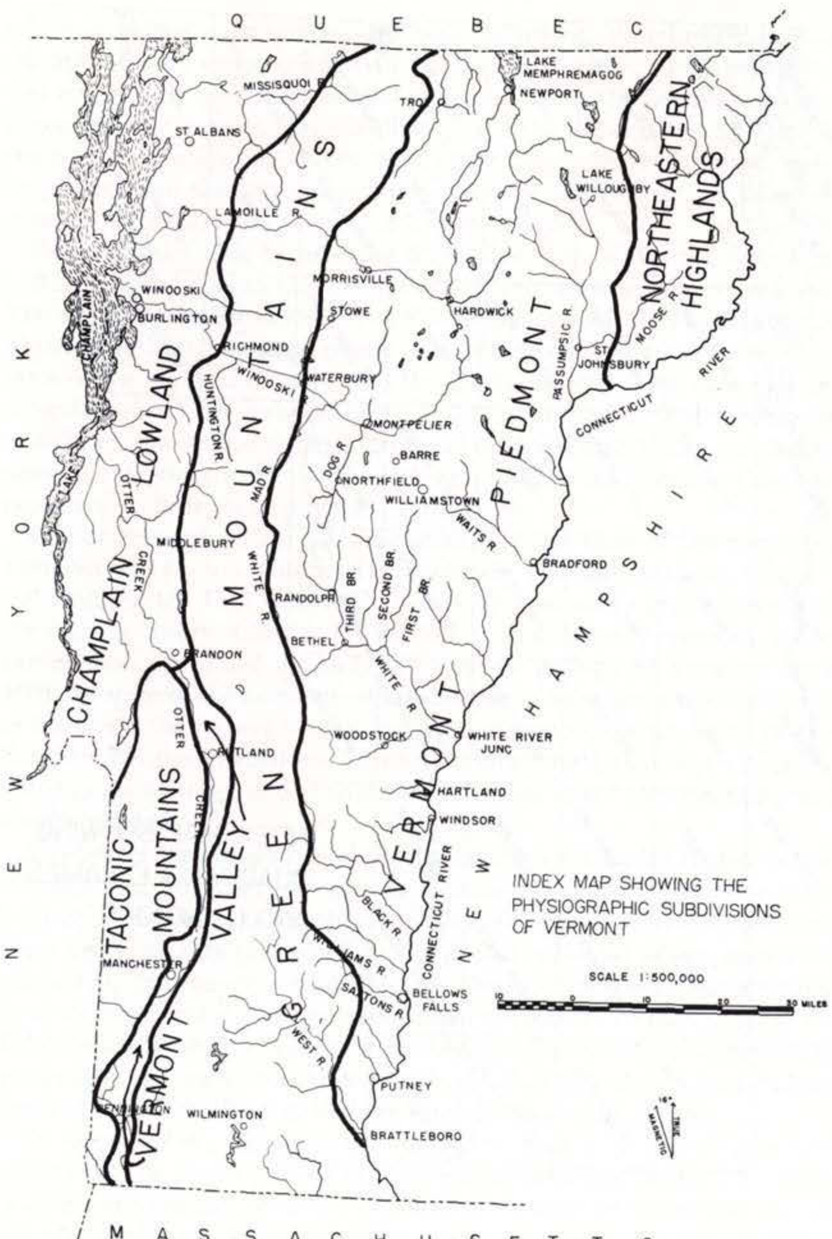


Figure 3

two important questions had been answered to the satisfaction of the geologist of that time, the impetus for further study no longer persisted. As a result, no significant regional study was undertaken and little was accomplished during the next forty years except for the work of C. D. Chapman (1937) in the Champlain Lowland.

The Scope of the Mapping Program

The original and most immediate objective of the mapping program that supplied the material for this report was to produce and publish a map of the state showing the classification, description and distribution of the surficial deposits. The mapping was completed during the 1966 field season and *The Surficial Geologic Map of Vermont*, as already stated, is scheduled for publication at about the same time as this report.

A second objective of the mapping program was to investigate, sample and map sand and gravel deposits that might be of importance for highway construction. The highway department was supplied with maps showing the classification and extent of these deposits so that they could be subsequently tested to determine their suitability for use. During the first four years of the survey, much work was done in assisting the highway department in the sampling of the sand and gravel deposits and determining the quantity of the reserve in each deposit. The highway department established its own geology section in 1958. After that date this survey supplied only the maps of the surficial deposits, and the sampling and measuring of the deposits was done by highway department field parties.

A third major objective of the mapping program was to conduct investigations and collect data pertaining to the glacial geology and Pleistocene history of the state.

It is not intended that this report be limited to a description of the surficial geologic map and the deposits delineated on it. Some explanation of the materials mapped is, of necessity, included, but the discussion of these is chiefly to point out problems of classification and to note new concepts developed during the study. It was intended that the state map be self-explanatory and that this report also should be complete.

The senior geologist started the mapping in 1956 and worked alone for the first six years of the program. It was decided in 1962 that the program should be expanded and Paul MacClintock joined the staff as the field consultant and party leader. He remained on the staff until the mapping was completed. William F. Cannon was the leader of a third field party in 1964. In 1965, four parties were in the field, the third and fourth led

Figure 1. The crest of the Green Mountains in southern Vermont. Hancock Mountain in the foreground (Rochester Quadrangle).

Figure 2. The crest of the Green Mountains in the vicinity of Mt. Snow (Mt. Pisgah). Picture taken looking north from the summit of Mt. Snow, elevation 3556 feet, across the Somerset Reservoir (Wilmington Quadrangle).

PLATE I

by Parker E. Calkin and G. Gordon Connally. Robert E. Behling and William W. Shilts were leaders of the third and fourth parties in 1966. The areas mapped by the participating geologists are shown on the accompanying map (Figure 1), and each of these persons contributed to this report the data included from those areas.

Stewart, in 1961, published a report on *The Glacial Geology of Vermont* (Vermont Geological Survey, Bulletin 19) in which he summarized the literature of the Vermont Pleistocene Epoch. That account included material from an extensive search of the literature, data collected during the first four years of the survey and a progress report for the 1960 field season. Inasmuch as a large amount of new data has been collected since 1960 plus the fact that much of the area mapped during the first four years of the survey has been restudied, and in part reclassified, Bulletin 19 will probably not be reprinted when the present supply is exhausted. For this reason, the pertinent material contained in the earlier report is included in this bulletin, particularly the data that is relevant to the interpretation of the Pleistocene history. Certain other sections of the earlier publication are repeated in Appendix D because of their significance or because the information is introductory to the study of the Pleistocene Epoch.

The reconnaissance mapping was done using the fifteen-minute quadrangle maps of the U. S. Geological Survey as base maps. For convenience, the quadrangles are used as areas of reference, and a map showing the names and locations of the quadrangles is included (Figure 2).

Geomorphic and Tectonic Setting

The geomorphic subdivisions comprising the topography of Vermont (Figure 3) include parts of five major sections of the New England Province. Tectonically, the whole state, with the exception of the Champlain Lowland and Vermont Valley, lies within the province described by King (1959, p. 53) as the Crystalline Appalachians. The Champlain Lowland and Vermont Valley are a part of the Sedimentary Appalachians (King, 1959, p. 53). The fabric of the topography as well as the rock is generally north-south; a fact that had major influence on the advance and retreat of the glacial invasions both from northeast and northwest directions.

The Green Mountains cross the state from north to south and form the backbone of the topography. They are twenty-one miles wide at the Canadian border and thirty-six miles wide at the Massachusetts boundary. The summit elevations average approximately 2,000 feet with five peaks rising above the 4,000-foot contour. The mountains, rising abruptly from the lowlands on the west and the rolling plateau on the east, are rugged, the crests are sharp, and the slopes, in general, are steep (Plate 1, Figures 1 and 2).

The Taconic Mountains, in the extreme southwestern part of the state, lie to the west of the Green Mountains and to the south of Brandon. They are, although lower, also quite rugged with sharp crests and steep slopes very much like the Green Mountains. The bedrock, however, is somewhat less complex and less metamorphosed.

The Vermont Valley, which separates the Taconic and Green Mountains, is a long, narrow lowland, underlain by noncrystalline rock, that trends southward from Brandon to the Massachusetts border, a distance of about eighty-five miles. The width of the valley varies from one to five miles, and the mountains rise sharply on either side.

The New England Upland (Fenneman, 1938, pp. 358–68) extends into eastern Vermont and covers the state east of the Green Mountains except for the northeast corner. Jacobs (1950, p. 79) used the name Vermont Piedmont to designate that part of the upland within the boundary of the state. The surface of this subdivision can best be described as a plateau that has been dissected by streams and subdued by glaciation. The topography, although subdued as compared to the mountains, is undulating to rough because of the numerous, steep-sided valleys. Rising above the plateau are several small mountains, such as Northfield, Worcester and Lowell; "monadnocks" such as Mt. Ascutney; and plutons, both acidic (silicic) and basic (mafic), of various sizes that intrude the metasediments. The Connecticut River, south of St. Johnsbury, is entrenched in a bedrock channel cut into the complex, crystalline rock of the upland. The valley is very narrow in some sections and a few miles wide in others, but in all sections the valley walls are abrupt and steep.

The Northeast Highlands (Jacobs, 1950, p. 83) in the northeast corner of the state between the Connecticut and Passumpsic rivers, are actually the western margin of the White Mountains of New Hampshire. In this region, the mountains are more isolated and less linear than in other parts of the state. Many of the mountains are erosional remnants of the White Mountain and New Hampshire plutonic intrusions (Doll, Cady, Thompson and Billings, 1961, Tectonic Map). North of St. Johnsbury the Connecticut River has cut its valley into the crystalline rock. North of Guildhall the valley widens and exhibits characteristics of lateral cutting more than in any other section north of Massachusetts.

The Champlain Lowland, a structural trough between the Green Mountains and the Adirondacks of New York, has the lowest elevations as well as the most nearly horizontal and least metamorphosed bedrock.

Whereas the other subdivisions are composed of sediments deposited in a most active (eugeosynclinal) part of the Appalachian geosyncline, the sediments of the Champlain Lowland and Vermont Valley were formed in a much less active (miogeosynclinal) environment (Doll, Cady, Thompson and Billings, 1961). The surface is not level, however, since hills are scattered all over the lowland. The hills, according to Jacobs (1950, p. 59) are horizontal klippen separated from the Green Mountains and eroded thrust blocks of the Champlain fault. The lowland includes Lake Champlain that extends for one hundred miles north and south along the New York-Vermont border.

Acknowledgments

As has already been stated, the mapping program was begun as a joint undertaking of the Vermont Geological Survey and the Vermont Highway Department. The senior geologist was supported jointly by these two agencies during the first ten years of the survey. The support of the other field parties and the total support of the eleventh and final year of the program was by the Vermont Geological Survey.

Each field party was composed of a party leader and an assistant Since the assistants made a substantial contribution to the work of the survey, it is appropriate that acknowledgment be made of their work. Table 1 lists the names of the assistants, the year, or years, that they participated and their present location.

Vermont has proven to be a most pleasant area for study. Not only is the summer climate delightful and scenery beautiful, but the people of Vermont have been most cooperative. The property owners on whose land it was necessary to trespass, study, dig, drill or otherwise examine the surface material were very helpful and obliging. In eleven years, with only a half-dozen exceptions, no problems of any kind developed as a result of restrictions placed on property by the owner. Few areas can boast such a record.

The assistance of Miami University in the preparation of this and other reports and the editing of the state map is gratefully acknowledged. A graduate research assistant was supplied during the 1966–67 and 1967–68 school years to assist in the research necessary to the preparation of the manuscript. Myron J. Blackman and Walter Coppinger were graduate research assistants during the 1966-67 and 1967-68 school years respectively. Miami University also supplied funds for typing this and other reports and the drafting and reproducing of maps, plates, and diagrams. The support of Miami University continued throughout the research work that began in 1957.

TABLE 1.

FIELD ASSISTANTS WHO PARTICIPATED IN THE MAPPING PROGRAM, THE DATES THEY SERVED AND THEIR PRESENT STATUS

1956–57	Lawrence D. Perry, Geologist, Gulf Oil Corp., Bolivia
1958–59	Thomas H. Hawisher, Geologist, Ottawa, Illinois
1959–60	Hugo F. Thomas, Assistant Professor of Geology, University of Connecticut
1961	Gordon L. Heele, Geologist, Mobil Oil Co., Corpus Christi, Texas
1962	William B. North, Geologist, Department of Army, Washington, D. C.
	Lance Meade, Geologist, Vermont Marble Co., Proctor, Vermont
1963	William F. Cannon, Geologist, U.S.G.S., Marquette, Michigan
	Marvin Saines, Ph.D. Student, University of Massachusetts
1964	Robert E. Behling, Ph.D. Student, Ohio State University
	William W. Shilts, Ph.D. Student, Syracuse University
	Dirk Van Hart, Geologist, Texaco Inc., Oklahoma City, Oklahoma
1965	James Robertson, Graduate Student, University of Michigan
	James Lehmann, Graduate Student, Buffalo State University
	Franklin D. Paris, Geologist, Ruberoid Company, Vermont Asbestos Mines
	Joseph Jackimoviez, Graduate Student, University of Missouri
1966	G. Allan Brown, Geologist, U.S.G.S., Richmond, Virginia
	Myron J. Blackman, Ph.D. Student, Ohio State University
	Frank Janik, Graduate Student, University of California, Los Angeles
	Kenneth Beam, Ph.D. Student, University of Cincinnati

We acknowledge the support of Princeton University in the preparation and drafting of illustrations, typing of reports and the use of computer time and personnel. We are particularly grateful to W. C. Krumbein and Ron Flemal who wrote the program for computing the vector mean, and to Jason Morgan who assisted with the computer work.

The associations with Dr. Charles G. Doll, the State Geologist, were most pleasant. His great interest and his persistent efforts to seek support (both administrative and legislative), made possible the continuing of the project to its successful completion.

We also acknowledge the assistance of Raymond E. Janssen, Marshall University, who read the manuscript and made many helpful comments, criticisms and suggestions.

SURFICIAL MATERIAL

It is appropriate that some discussion of the surficial materials legended on the surficial map (Map of the Surficial Geology of Vermont, Vermont Geological Survey, in press) be presented in this report. Although the map is self-explanatory, it does not show the significant differences among the various units. Secondly, since there is such an admixture of glacial, glaciofluvial, lacustrine, marine and fluvial materials, the characteristics of deposits that are most difficult to classify should be noted. And, thirdly, there are those people, particularly the non-geologists, who are not familiar with the language of the surficial geologist whose understanding of this report should be enhanced by this chapter.

It is not intended that the description of specific deposits be included in this section except as it is necessary to do so to explain more adequately various types of deposits. The descriptions of the more significant features will be included in subsequent chapters in the discussion of the areas and/or stratigraphic sequences in which the deposits occur.

Till

Till is the pebbly, sandy, clayey deposit of unsorted debris left by the glacier. It is the most widespread of all of the surface materials in Vermont inasmuch as it covers the uplands. Although it is most commonly less than twenty-five feet in thickness, it does vary from a thin, discontinuous veneer on the uplands to over one hundred feet in some valleys. The composition and texture of the till varies from clay to sand. Sandy till is much more common and more widespread than clayey till. The fact is, most Vermont till is very low in clay content. The unweathered till is commonly blue-grey to grey in color, but it weathers rapidly to tan, buff or brown. Some of the unweathered tills, however, are buff or brown and a few are almost black, depending on the source rock.

It is customary when mapping glacial deposits to designate the topographic form made of the till. That is, it is ordinarily possible to distinguish terminal, recessional and ground moraines which by definition are composed of till. In Vermont few frontal (terminal and recessional) moraines are found. Most areas of till therefore may be described as ground moraine inasmuch as the till was deposited directly by glacial ice. The surface expression, however, is not the depositional topography of a ground moraine, except in scattered local areas, but is everywhere a reflection of the irregular surface of the underlying bedrock. Evidences of plastering or overriding by ice, as the name ground moraine implies, are rare. The till, though usually thin, varies greatly in thickness within short distances. For these reasons, the till areas, other than those that could be designated frontal moraines, were simply mapped as till with no other qualifying designator.

There are two distinctly different kinds of till in Vermont. One is a loosely packed, very sandy till containing angular boulders of local bedrock, and the other is a compact till containing more rounded, striated boulders with a higher content of erratics. The loose sandy till is designated ablation till in this report as the term has been used by Lee (1957). The compact till is called basal till.

Basal Till. The material that is designated basal till in this report is a dense, compact till that varies in color and texture with the incorporation of local bedrock. It is often blue-grey in color when unweathered, but in some areas it is dark grey to black and in others it is buff or brown. The compactness suggests much clay in the till but this is not generally true. According to Cannon (1964a, Figure 5), who made size analyses of approximately forty samples collected in northern Vermont, the clay content is less than thirty percent, and most samples contain less than ten percent. Silt content, however, is usually higher than clay. It is apparent that the compactness of the clay is due to the combined effect of the silt and clay (Plate XI, Figure 1).

The basal till contains much more erratic fragmental material than ablation till, the fragments are more rounded, and faceting is more pronounced. Many of the boulders are striated, but striations are not as conspicuous as in tills with carbonate and other softer rock. In spite of the compaction, and because of the high sand content, the water penetrates even the basal tills to considerable depths. As a result, decomposition, oxidation and discoloration are deeper than in regions of clayey till, such as, for example, the midwest. The basal till is often fissile, whereas the ablation till never is.

The basal till fits the description of subglacial till as defined by Upham (1891, pp. 377–78), but the inference is that the basal till is a lower unit of a two- or three-unit deposit made by the same glacier. In Vermont, however, where exposures occur with a basal till underlying ablation till, the fabric orientation of the two tills is usually distinct enough to suggest in these cases that they were deposited at different times by different episodes of glaciation.

Ablation Till. The most conspicuous characteristics of the ablation till include its high content of sand with little or no clay; its tannish, reddish or brownish color due to oxidation; the angularity of the cobbles and boulders; and the high percentage of the fragments that are composed of local bedrock (Plate XIII, Figure 2; Plate XXIV, Figure 2). Except for the color, these characteristics are the most difficult to explain. Cannon (1964a, Figure 5) made size analyses of nine samples of ablation till from northeastern Vermont. His results show that the tills contain less than 15% clay, 65% to 88% sand and 10% to 35% silt.

The ablation till, here described, has been recognized as different from basal till since before 1890. It must have been this kind of material that prompted Upham (1891, p. 376) and Chamberlain (1894, p. 527) to propose a till classification separating a drift sheet into two or three units, namely superglacial, and/or englacial and subglacial. The same, or similar, detritus had, even before 1890, been called upper till by Torrell (1877), Hitchcock (1861) and others. Upham (1891, pp. 376–77) describes englacial till as having "more boulders that were more angular" than subglacial till, and that the englacial till was "more gravelly and sandy with loose texture." As noted above, however, the designation englacial or superglacial suggests that the till was deposited by the same glacial ice that deposited the subglacial till that it supposedly covers. In Vermont, however, this is not the case because the ablation till may or may not overlie another, more compact till. In many areas, it lies directly on the bedrock whereas in other areas it covers a basal till commonly having a different fabric orientation which had been deposited by an earlier ice advance.

Similar tills that we suggest to be ablation till, as here described, have been noted in many parts of New England. Denny (1958, pp. 76–82) describes a sandy, loose surface till in the Canaan area of New Hampshire. White (1947, pp. 757–58) notes a sandy, porous, till containing mostly angular fragments in the Stafford Springs region of Connecticut. Currier (1941, pp. 1895–96), working in eastern Massachusetts, found a grey to white, loosely packed surficial till. Judson (1949, pp. 7–48) and Flint (1961, pp. 1688–91) have also recorded the presence of till with similar description in the Boston area of Massachusetts and in southern Connecticut. If our suspicions that all of these occurrences are of ablation till, then it follows that this kind of till is quite widespread in northeastern North America. It should be pointed out here that the literature cited above does not use the term ablation till. Some of the references interpret the loose surface till as englacial or superglacial while others believe it to be a distinctly different till sheet.

The literature has little to say about ablation till, its characteristics and/or its origin, and, except for the works of Lee (1953, 1955, 1957), the term is not generally used. It is not the intention of this report to define a new term or redefine an old one. The purpose is to use a term as it seemingly has been defined in prior literature and to add description to the material that was thusly defined. Most of the former uses of this term have been as a synonym for superglacial or englacial. Such a usage is not needed nor is it correct according to our interpretations.

The literature implies that ablation till should not have a fabric or that only the larger fragments should be oriented. The present survey investigated the pebble orientation of the ablation till at over 250 localities and these have shown that not only does this till have a fabric, but that there is a regional fabric orientation that indicates the movement of the ice that deposited it. The orientation of the fragments has no bearing on their size, and small pebbles have a preferred orientation the same as the large. There are those, of course, who argue that the fabric proves that this material is not an ablation drift and should be designated by a different name. Our own answer to this argument is that insufficient research had been done on the ablation till, prior to this study, to ascertain definitely whether or not it had a fabric.

It is apparent that much of the fragmental debris in the ablation till was transported only a short distance. This conclusion is based on the fact that the boulders and cobbles are angular and that most of these are composed of local bedrock. Because of the high percentage of angular, local bedrock the till resembles a residual rock mantle, but close inspection reveals that many of the boulders are striated and that some erratics from distant regions are present.

Two examples of the content of local bedrock are worthy of note. Ablation till exposed in a borrow pit two and three-quarter miles southwest of Groton (Woodsville Quadrangle) contains approximately 75% grey, granitic rock. According to White and Billings (1961, Plate 1), the pit is located to the south of several outcrops of Ryegate granodiorite, the nearest of these being three-quarters of a mile to the northeast. Outcrops of the same rock also occur to the northwest and the Blue Mountain granite area is five miles to the northeast. In another borrow pit, one and one-half miles north of Concord (Littleton Quadrangle), a fabric was made of an exposed ablation till. The till contained approximately 75% igneous rock, predominantly diabase. The bedrock under the till at this location is the Albee Formation which, according to Eric and Dennis (1958, Plate 1), has abundant diabase dikes and sills. Granitoid dikes and sills are numerous to the northeast.

A certain amount of sorting and stratification is common to the ablation till. It may be crudely bedded and a separation of fragments according to size is sometimes apparent. Sand lenses and stringers, and to some extent gravel lenses, are not unusual. The degree of sorting and the amount of sorted material varies greatly from one locality to another, but there seems to be a rather constant sorting factor in all deposits of a particular area. In the Rutland region, as an example, the ablation till appears to be transitional between lodgment or basal till and outwash. In some parts of the Rutland area, the sorting is good, bedding is conspicuous, and, from a distance, a similarity to kame terrace gravel is seen. The material, however, is very angular, the fragments are mostly local bedrock and a regional fabric direction is for certain. The origin of ablation till is discussed in a following section of this report.

Glacio-Fluvial Deposits

Glacio-fluvial deposits include all ice marginal and proglacial materials deposited by meltwaters from the ice. Because they are deposited by running water, they are sorted and stratified. The ice-marginal or ice-contact deposits include kames, kame terraces, kame moraines and eskers, all of which are quite common in Vermont. The most characteristic features of these forms is that they contain slumping or ice-contact structures formed when the ice against which they were deposited melted away. Cobbles and boulders that were dumped directly from the ice into the accumulating deposit as well as masses of basal till, which may have been frozen when they were incorporated in the gravel, are also characteristic. The proglacial deposits consist chiefly of outwash plains or outwash aprons and valley train or spillway deposits. No outwash plains or aprons beyond the terminus of former glacial borders have been identified and mapped in Vermont. Spillway gravel, deposited in valleys that carried the meltwater away from a local melting ice margin, is frequently found.

Kame Terraces. Kame terraces are among the most common ice-contact gravel deposits in Vermont. It was stated in Bulletin 19 (Stewart, 1961, p. 37) that these were the most common land forms made in Vermont during the Pleistocene. We now question this statement because of other forms that subsequently have been discovered to be very common and because of the reclassification of several deposits that had been identified as kame terraces during the early years of the survey. It is a fact, nonetheless, that kame terraces are widespread and of much importance, particularly as a source of gravel.

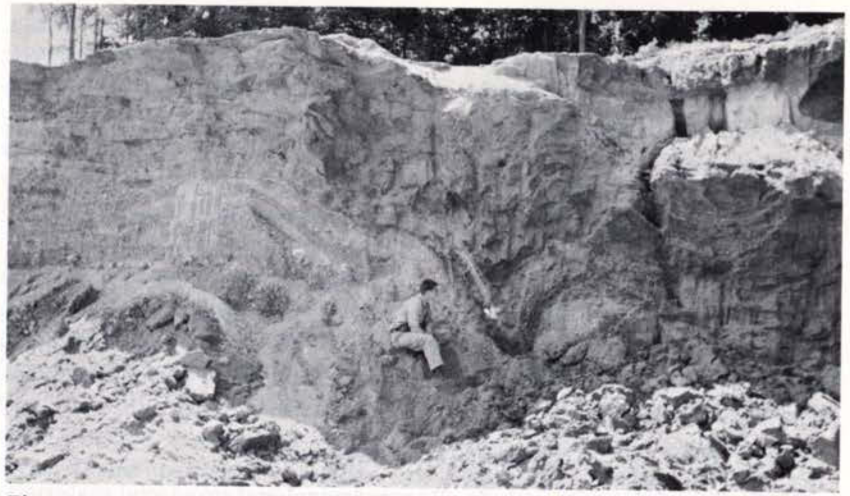


Figure 1. Slumping structures in lake sediment caused by the melting of ice in the underlying kame gravel. Two miles east-southeast of Jericho Center (Camels Hump Quadrangle).

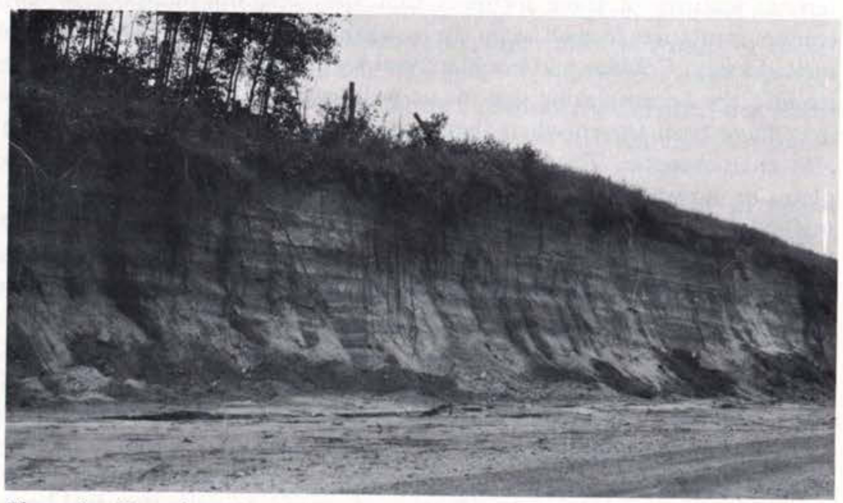


Figure 2. Varved and laminated lake sediment capped by beach gravel. Top elevation 840 feet. Two miles northeast of Lyndonville (Burke Quadrangle).

PLATE II

The distribution of the kame terraces, although widespread, is not uniform all over the state nor is the quality of the gravel they contain everywhere the same. In some areas the rock fragments making up the gravel are soft and easily weathered, decreasing considerably the value of the deposit for road metal, cement aggregate and other construction purposes. In other areas the gravel contains a high percentage of fine sand and/or silt which also reduces the quality. The sand and silt content is particularly high in kame deposits in valleys that formerly contained ice dammed lakes since the gravel was deposited into the waters of ice marginal lakes or gentle streams. In these valleys, it seems, the deposition of the kame terrace gravel was in slack water and contemporaneous with the deposition of lake sediment. For this reason, the kame gravel is interfingered and interbedded with the lacustrine sediment, and the lake sediment exhibits ice-contact (slumping) structures similar to the kame gravel (Plate II, Figure 1). In these deposits, the lake sediment and glacio-fluvial deposits are difficult to differentiate.

Kame Moraines. The kame moraine is a gravel deposit, made along the margin of a glacier. It is a complex of frontal kames that has a morainic topography similar to a frontal moraine composed of till. The position of a kame moraine is significant inasmuch as it develops along an ice border in the same manner as a terminal or recessional moraine and hence marks the position of a considerable still-stand of the ice edge. The sporadic distribution of any kind of a frontal deposit in Vermont increases the importance of the kame moraine, since in a few areas it is possible to connect kame moraines and till moraines to mark the position of a former glacial border. This is particularly true in the St. Johnsbury region in the northeastern part of the state.

Eskers. Eskers are the conspicuous ridges composed of outwash sand and gravel found within glaciated regions. Some are short (a mile or so) whereas others are long (a score of miles or more). Some are notably continuous, whereas others are somewhat discontinuous either because of original interruptions or because of post-glacial erosion by adjacent streams. They are all now attributed to the deposition of gravel as channel deposits of subglacial streams flowing in tunnels at the base of an ice sheet or a valley glacier. Many of these eskers not only have winding courses, but they rise and fall over local topographic features showing that the ice was stagnant at time of origin. Had the glacier been moving at that time, the deposits would have been spread out rather than concentrated into the striking features which the eskers display. Theory now holds that there may have been a zone of stagnant ice along the

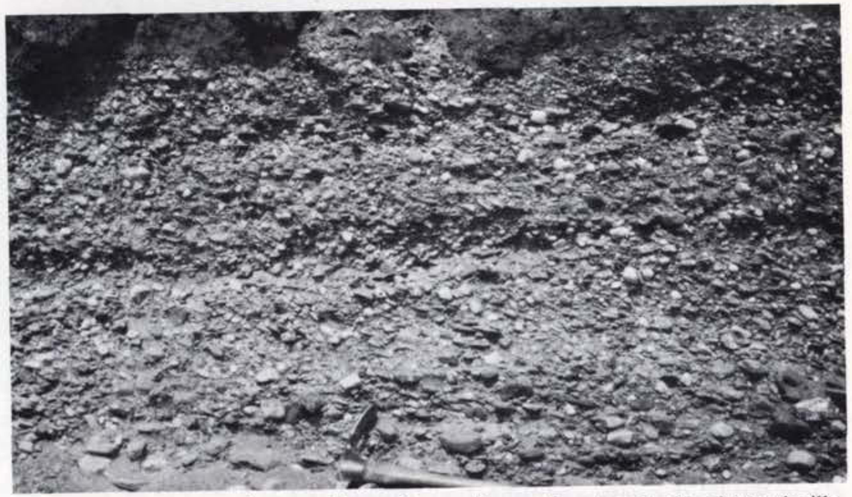


Figure 1. Beach gravel exposed in a pit near the southeastern limits of Morrisville. Elevation 800 feet. (Hyde Park Quadrangle).

Figure 2. Gravel pit in a small delta near the crest of the hill at Heath School. Elevation 1180 feet. Two miles southeast of Orleans (Memphremagog Quadrangle).

PLATE III

outer or peripheral margin of a waning ice sheet (Flint, 1933), within which eskers and other stagnant ice features could have been formed. Evidence has not been found, however, to establish how wide this zone of stagnation was at the time these features were made.

The esker in the Passumpsic Valley, described later in this report, is twenty-four miles in length. It extends from West Burke, on the West Branch, and New Haven, on the East Branch, southward through and beyond St. Johnsbury. It is remarkably continuous with only local interruptions. In places, as near Lyndonville and St. Johnsbury, it is buried by late glacial lake sediments, but the bedding of the eskerine sediments is easily distinguished from the lacustrine material exposed in large gravel pits along the river. The significant scientific point is that here we have a dendritic pattern to this great esker system, twenty-four miles in extent, that could have been formed only in a zone of stagnant ice at least that wide. The stagnant zone occurred along the margin of the Shelburne ice sheet as it waned from the region. In this way, this phenomenon contributes to our understanding of glaciation of the State.

Spillway Gravel (*Valley Trains*). Outwash gravel deposited in a valley that acted as a spillway for a melting glacier is called spillway gravel or a valley train deposit. Such deposits are not as common as might be expected in this region for at least three reasons. In the first place, many of the streams that acted as spillways had such steep gradients that no gravel was deposited along the route. For example, the Nulhegan River (Averill and Island Pond quadrangles) must have been a spillway for the melting ice that terminated in the vicinity of Island Pond. The gradient of the Nulhegan is so steep, however, that the gravel was carried to the Connecticut Valley and spread out over the lacustrine sediment in that valley. A second reason for the scarce occurrence of spillway gravel is the fact that so many of the valleys were jammed with stagnant ice and the outwash was deposited along the margins of the ice as kame terraces. And, thirdly, where lakes existed, often between the blocks of stagnant ice, the detritus that might have formed valley trains ended up as lake sediment.

Lacustrine Sediment

Lacustrine sediment is most common in the stream valleys and the lowlands of Vermont. Inasmuch as the valleys and lowlands were the sites of the final melting of stagnant ice, drainage was restricted and many small lakes developed. Larger lakes were dammed by advancing

Figure 1. Bouldery topset beds of a small delta built into Lake Winooski. North Branch River valley two miles north of Montpelier (Montpelier Quadrangle).

Figure 2. Boulders exposed in a gravel pit penetrating the topset beds of the North Springfield Delta (Lake Hitchcock). One mile west of North Springfield (Ludlow Quadrangle).

PLATE IV

and retreating glaciers and some were dammed by glacial deposits. It should be remembered that the weight of glacial ice depressed the region to the north and the north-south gradient of the streams was considerably less during the glacial stages than now. Lakes were also formed along the margin of the ice as it melted down and lake sediment is often found in isolated patches at high elevations.

During the survey of the surficial deposits, the lake sediments were mapped in accordance with standard classifications insofar as it was possible to do so. That is to say, the silts and clays deposited in the deeper parts of the lake (bottom sediment) were mapped as one category. The sandy, shallow-water (littoral) sediment was a second group, and beach gravel was a third (Plate II, Figure 2; Plate III, Figure 1). Deltas were mapped separately and, when significant, sandy deltas were distinguished from those composed predominantly of gravel (Plate III, Figure 2).

The valley lakes, however, did not always conform to the standard description of slack-water bodies. Down-valley currents were often active even when a lake occupied the valley. In most cases, the earlier lakes were the highest, and the lake level was subsequently lowered. A great amount of water and sediment was carried into the lake by tributary streams. Melting ice in the region, particularly in the case of ice marginal lakes, also supplied a great amount of sediment. The large amount of sediment often so completely filled the valley that shoaling occurred. Blocks of stagnant ice often partially filled the valley, particularly in the early stages of the lake. In larger lakes, specifically those of the Champlain Lowland, floating ice blocks from a calving glacier often reached the proportions of icebergs.

As a result of the above special characteristics, the deposits made in glacial lakes are often modified to significantly change the character and appearance of the deposit. The down-valley currents formed cut-and-fill structure and undercut the deposits causing slumping. Cross-bedding commonly occurs, and textural changes are numerous due to increases or decreases in the velocity of the currents. The fact that ice often occurred in the valleys caused lacustrine sediments to be deposited in contact with the ice, and when melting occurred, ice-contact structures were formed by slumping. As already stated, the lake sediment may interfinger or be interbedded with kame terrace gravel or the dipping beds on the flank of an esker.

As shoaling took place, sand began to completely fill the valley, and as the level of the sand approached the level of the water, pebbly sand

and gravel were deposited. In this manner, the valleys completely filled in a relatively short time. In some valleys, the top layer of gravel is quite thick; in others, the sand contains a high percentage of pebbles. The gravel thus deposited is not a beach gravel, although it may resemble such in many respects. The shoaling gravel, however, resembles more the topset beds of a deltaic deposit than any other types of lacustrine gravel.

The high velocities of the streams that flowed from the mountains and the volume and types of sediment they carried into the lakes is best manifested in the deltaic deposits of these streams. Because the streams carried large amounts of sediment, deltas were built into the lakes in a short time. Proglacial lakes that existed for a short time as well as long lakes, too narrow to develop beaches, may, therefore, have well-developed deltas deposited in them. These strand-line features, such as beach ridges, spits, hooks, and deltas, are some of the best markers of former lake levels in Vermont.

The mountain streams, because of steep gradient and high velocities, carried a wide range of different sizes of fragments including large boulders. The larger fragments are not conspicuous in the foreset beds inasmuch as they either drop out before the delta is reached or they roll to the bottom of the foreset slope. As the deltas build up to near lake level, however, topset beds begin to develop on the delta, and at this stage the large boulders start to be deposited on the top and are included in the topset beds (Plate IV, Figures 1 and 2). The topset beds, for this reason, are difficult to distinguish since they resemble deposits of recent stream and kame terrace gravel which also contains large rounded boulders. It is therefore necessary to see the foreset beds to accurately distinguish deltas, inasmuch as a gravel pit in the topset beds may resemble kame gravels more than any other kind. Another interesting characteristic of the deltas of mountain streams is the occurrence of armored mud balls in both the foreset and topset beds. The term "lake gravel" was used on the state map to designate the shoaling gravel and the topset beds of deltas that do not exhibit the underlying foreset beds.

The lake occupying the Champlain Basin during the retreat of the last ice sheet was large and deep enough for calving of the ice to take place. The lake expanded as the ice edge retreated and thus the ice formed the northern boundary of the lake until it had melted northward to the St. Lawrence River. It is obvious that floating blocks of ice were common on the surface of the lake. Debris from the melting ice blocks

fell to the bottom of the lake and became incorporated in the bottom sediment of the lake. Lacustrine silts and clays therefore commonly contain ice rafted cobbles and boulders.

Local Origin Hypothesis for the Lake Sediment. The vast amount of lake sediments in the stream valleys of Vermont has long posed a problem as to their source. It is reasoned that these lacustrine sediments were related to the glaciation of the region. Just how glaciation gave rise to this great quantity of fine sediment is the problem. The hypothesis here proposed suggests that the silts and clays were liberated, transported and deposited in valleys during the formation of the ablation till which now covers the uplands.

In an effort to test the above hypothesis quantitatively, a study area was chosen in the Plainfield Quadrangle. The area selected included the valleys of the Winooski River, its tributary the Kingsbury Branch, and the Cooper River. In these valleys, exposures of basal till show this material to contain roughly fifty to sixty percent by volume of the finer sediment whereas the ablation till on the adjacent uplands contains only ten to twenty percent of the clay and silt, (Cannon, 1964a, Figure 5c). These percentages allow the conclusion that the fines removed during formation of ablation till was fifty percent of the total debris load. Or, stated another way, if the fines were restored, the thickness of till debris would be twice the present thickness of ablation till.

It was reckoned that, if the area of the drainage basin were measured and the thickness of the lake sediments estimated, calculations could be made that would allow quantitative comparison of the volume of lake sediment with the decreased volume of the finer sediment in the ablation till. Two major assumptions had to be made based on observations during this survey and on experience of many years in this and other areas. In the first place, exposures show that lake silts and clays were deposited on an irregular surface, so that accurate measurement of the thickness could not be made. The study of many exposures, however, did allow a considered estimate of 45 feet (15 yards) for the average thickness of the lake sediment. The second estimate involves the thickness of the ablation till which was judged to average approximately six feet (two yards).

The area of the lake sediment in the valleys of Winooski, Kingsbury Branch and the Cooper River was measured with a polar planimeter to be 13.5 square miles. The Winooski drainage basin itself within the Plainfield Quadrangle measures 120 square miles.

The volume of the lake sediment could therefore be calculated as follows:

3097600	square yards in one square mile
$\times 13.5$	square miles (area of the lake sediment)
40827600	square yards of lake sediment
$\times 15$	yards (thickness of lake sediment)
612414000	$= \pm 6 \times 10^8$ cubic yards of lake sediment.

Assuming that one-half of the debris (the fines) was removed to leave the present till thickness, the 120 square miles of the drainage basin supplied two yards of fine sediment. The amount supplied can be calculated.

371712000	square yards in 120 square miles
$\times 2$	yards (thickness removed)
743424000	$= \pm 7 \times 10^8 =$ cubic yards of fines removed

These figures of 6×10^8 and 7×10^8 lie within a reasonable order of magnitude.

Stewart's 1961 map of the Winooski drainage basin shows 150 square miles of lake sediment in a drainage basin that covers an area of 980 square miles. Using the same thicknesses as above, calculations show $\pm 69 \times 10^8$ cubic yards of lake sediment and 60×10^8 cubic yards of fines from the till.

As crude as the above assumptions are, they do show a comparable order of magnitude which we believe add support to the local origin hypothesis. The hypothesis also suggests some of the complicated mechanisms responsible for the Pleistocene deposits in that region. The two types of till, basal and ablation, have two different origins even though both have till fabric orientation of the pebble-sized material. The ablation till lost most of the clay and silt fraction during deposition and is believed to have been deposited during the down-wasting of stagnant ice in the peripheral zone as defined by Flint (1933) and Currier (1941). The basal till, on the other hand, was deposited by actively moving ice.

The lake sediments are commonly found in the valleys above kame terrace gravel that was deposited along margins of stagnant ice-masses in the valley bottoms. This relationship shows that the stagnant ice against which the kame gravel was deposited had mostly melted away

allowing lakes to occupy the valley prior to the deposition of the fine sediment. The "fines" from the uplands were washed into the valleys and deposited as lacustrine sediment.

Marine Sediment

Marine sediments have characteristics similar to, and are classified on the same basis, as lacustrine sediments. That is to say, marine deposits were mapped in three categories, namely, marine beach gravel, marine sand and marine clay. The marine sediment can be distinguished from lake detritus inasmuch as the sea deposits contain fossil shells and are not varved. The marine sediment, however, may not always have fossils and in many gravel deposits the fossils are restricted to certain layers. For this reason, fossils may be difficult to find where slumping, or other kind of movement, has occurred. Lake sediment, on the other hand, may not show varves. Some lake sediment was not varved during deposition, and in sediment that is varved the varves seem to appear and disappear depending on the amount of weathering. Many lake deposits that show varving at one time may not show such phenomena at a later time due to weathering of the deposit.

GLACIAL AND GLACIO-FLUVIAL EROSION

As noted by Stewart (1961, p. 26), it is difficult to discuss glacial erosion on a quantitative basis. It is even more arduous to attempt a discussion of the amount of glacio-fluvial sculpturing that took place during the melting phase of the glacial episodes. The former belief that continental glaciers greatly "changed the face of the earth" has been discarded by most glacial geologists and glaciologists. It has been replaced by a more logical, less profound concept of surficial removal with concentrated erosion in local areas. In spite of the fact that much work has been done on glacio-fluvial deposits, very little has been accomplished concerning the erosion of meltwater streams. These problems have been given consideration with little or no success during the mapping program in Vermont. Some general statement concerning erosion, both glacial and glacio-fluvial, however, can be made, and some specific examples can be cited.

Glacial Erosion

The erosion by glacial ice removes the rock mantle and planes off the outer few feet of the bedrock. The gross features of the topography, however, are not greatly changed. In Vermont, the rock mantle covering the bedrock is surely of glacial origin. It is most likely, however, that the rock mantle, produced by eons of weathering, was thicker before glaciation than it is at the present time.

Aside from the removal of the top layers of mantle and bedrock, most of the erosion by glacial ice is concentrated in local areas because of geologic conditions that existed before the Pleistocene Epoch. In Vermont, the most influential of these geologic factors were the structure, fabric and relative hardness of the bedrock, and the topography. The topographic control has two major aspects. First of all, the north-south trend of the gross features composing the geomorphic subdivisions (Figure 3) were important in that they modified the movement of the glaciers. Secondly, and more important to erosion, the erosional topography that had been produced by stream erosion prior to glaciation was a major factor in the glacial erosion.

Relative Hardness and Fabric of the Rock. The influence of the relative hardness, structure and fabric of the rock more or less controlled erosion in many areas. Inasmuch as cutting by the ice was concentrated on the softer rock, features carved by the ice were parallel to the fabric of the rock regardless of the direction of the ice movement. Many of these features were formerly called roches moutonnees, but, since this term generally implies a feature paralleling the ice direction, its use for features paralleling the fabric is confusing. As a result of this action on the rock, many lakes occupy basins that are cut in the softer rock while ridges and outliers are composed of harder rock.

Major Topographic Features. The major features of the geomorphic subdivisions were important mostly as they altered and inhibited the movement of the glaciers. The Green Mountains, naturally, were the most prominent of these, and regardless of whether the ice moved across the state from the northeast or the northwest the mountains influenced the movement. The Taconic Mountains had the same influence in the southwestern corner of the state. The ice, as it piled up in order to cross the mountains, moved parallel to the mountains and forced its way through stream valleys, cols, and gaps in the mountain crests, concentrating the erosion in those areas.

Erosional Topography. The most conspicuous effect produced by pre-glacial stream erosion was the concentration of erosion in the valleys. The stream valleys that were transverse to the ice direction were, in general, filled with glacial sediment, but the valleys that were trending in the same general direction were scoured by ice erosion. Valleys that were eroded in this manner were deepened and their sides were steepened

much like those that have been reshaped by valley glaciers.

Lake Basins. The Lake Champlain basin is an excellent example of the combined effect of the conditions that controlled glacial erosion. The basin is located on a lowland between two uplifts, the Adirondack and the Green Mountain. It is a structurally down-faulted trough floored with soft Paleozoic sediment. According to Fenneman (1938, pp. 217–22), a large, wide stream valley had been established on the lowland prior to glaciation. All of these geologic conditions concentrated the erosion of the glaciers and account for much erosion of the lowland and the basin in which Lake Champlain is located.

Lake Willoughby also occupies a basin shaped by glacial erosion. The lake basin, trending transversely through a mountain mass, was formed in a zone of faulted, softer rock. In the same region, Lake Seymour, the largest body of water lying wholly within the state, as well as Big Averill, Little Averill and Crystal lakes, are of similar origin. In the southwest, lakes Bomoseen, St. Catherine and Dunmore have basins that were, at least in part, carved by ice. Even on the crests of the Green Mountains, Lake of the Clouds and Bear Pond on Mt. Mansfield, and Sterling Pond on Spruce Peak, are contained in ice-eroded, bedrock basins.

Mountain Gaps. Many cols through the ranges of the Green Mountains, including Smugglers and Hazens notches, Lincoln, Middlebury, Mt. Holly and Brandon gaps and Sherburne Pass are, in part, formed by glacial erosion. Jacobs (1938, p. 41) and Christman (1959, p. 70) agree that Smugglers Notch is a col between the watersheds of the Brewster and West Branch rivers. No doubt much of the erosion of this feature was accomplished by pre-glacial stream erosion. The fact that a col did exist, however, allowed the ice to move through and, as suggested by Jacobs, glaciers must have reshaped it to some extent. The other passes through the mountains were probably all in existence before glaciation but they were reshaped as ice moved through them.

The Connecticut Valley. The Connecticut River valley is an example of glacial erosion of a valley trending more or less in the same general direction as the movement of the glaciers. Ice invading the valley from either the northeast or northwest was deflected down-valley. As a result, the valley was deepened and widened leaving valley walls that are quite steep and rise abruptly from the valley floor. Bedrock along the course of the valley had variable hardnesses, and therefore erosion was more intense in some sections than in others. The valley is wide in some areas and narrow in others. In some reaches there are thick accumulations of sediment indicating deepening, and in other places bedrock is exposed showing that erosion was less effective because of the hardness of the rock. The valleys of the Black, Barton and Passumpsic rivers, plus the branches of the White River, are similar examples of stream valleys that were similarly eroded.

The Vermont Valley. The Vermont Valley, like the Champlain Lowland, is located between two mountain uplifts and is floored with softer Paleozoic rock. The north-south trend of the valley diverted the ice down-valley much as the Connecticut. It is difficult to estimate the amount of erosion that took place inasmuch as the pre-glacial depth, width and steepness of the valley wall has not been determined. The total thickness of the present sediment in the valley is unknown in most areas since the depth and width of the valley below the sedimentary floor has not been determined. Much erosion, however, must have taken place as the ice moved through the valley.

Yellow Bog. The Yellow Bog, located in portions of the Averill, Island Pond and Burke quadrangles is a topographic low covering approximately forty-five square miles. The basin, according to Myers (1964) and Cannon (1964c) is floored by quartz monzonite and surrounded by hills composed of metasediments. In this particular case, pre-glacial and glacial erosion was concentrated at the top of the uplift due to its height and the fracturing of the top of the dome. After the removal of the metasediments covering the igneous core, the quartz monzonite, being less resistant due to abundant biotite, was eroded more than the surrounding metasediment forming the basin that contains the bog.

Glacio-Fluvial Erosion

For the convenience of discussion, glacio-fluvial erosion is subdivided into two different categories that seem to be most important in Vermont. The first of these is the erosion by streams beyond the melting ice margins that acted as spillways for the meltwater. The second is the erosion by subglacial, and to some extent englacial and superglacial, streams that flowed under, through and on the ice. It is assumed that both of the above-mentioned types of streams carried a load of sediment sufficient to cause much, probably maximum, erosion. There must have been an ample supply of sediment from the melting ice, and the amount carried was determined by the stream gradient.

Streams Beyond the Ice Margin. The term spillway is used in this report to refer to streams beyond the ice margin that carried meltwater and sediment away from the terminus. These streams, because of the amount of water and sediment they carried, must have been most effective

erosive agents. Many of the major stream courses were occupied by lake waters during the early stages of deglaciation. But, the higher, smaller streams with steep gradients must have accomplished a great amount of downcutting during the melting phase. There are many streams in Vermont with deep, bedrock valleys that must have been eroded in this manner. There is no way to determine, however, how much of the downcutting of these valleys took place during the interval when the streams acted as glacial spillways.

Subglacial, Englacial and Superglacial Streams. Many streams must have flowed on, through and under the ice during the melting of the glacier. The only one of these that could have effectively eroded land surface was the subglacial stream except where the other streams plunged to the bottom of crevasses and other openings. Eskers, as said earlier, are believed to be the deposits of streams flowing under the stagnant ice inasmuch as their trend is normal to the frontal moraines and they have a sinuous course. Many of the subglacial streams, however, in irregular terrain such as that in Vermont followed stream valleys. As in the case of the spillways, the amount of cutting done by these streams cannot be determined.

Potholes. The occurrence of potholes on the crests and slopes of hills and mountains are the best evidence of erosion by meltwater streams. The occurrence of a glacial pothole on a ridge of the Green Mountains near Fayston (Doll, 1937, pp. 145–51) is a classic example. Other potholes occur on the ridge just east of Stowe; on the east side of the Otter Creek valley one mile south of Proctor (Plate XI, Figure 2); and a semicircular pothole occurs one and one-half miles northeast of North Troy. These could have been formed only by running water flowing under the ice or by water plunging over openings in the ice to bedrock below the ice (moulins).

Many streams in Vermont, for example, the Huntington and Poultney rivers, contain numerous potholes that are often referred to as "glacial potholes." The glacial origin of these, however, is questioned. If these are related to glaciation, they were formed when the streams that formed them were acting as glacial spillways. It is impossible to ascertain whether the potholes were formed at that time or during the post-glacial erosion interval.

The Shattuck Mountain Channels. One of the best evidences of glacio-fluvial erosion found during the mapping program are the Shattuck Mountain Channels. These, as described by Cannon (1964b), occur in the notch between Peaked Mountain and Shattuck Mountain and on the north slopes of Shattuck Mountain (Enosburg Falls Quadrangle). The channels are cut fifty to eighty feet into bedrock, vary in width from five to fifty feet and are marked by an abundance of exceptionally large potholes. Those portions of the channels with steep gradients seem to have been formed by pothole action exclusively. The channels, which are now either completely dry or contain only minor streams, Cannon attributes to meltwater erosion.

PROBLEMS OF IDENTIFICATION AND CORRELATION OF DRIFT SHEETS

It has been common practice, in Pleistocene studies, to identify, differentiate and correlate till sheets in the field by using conventional field methods. The criteria used for the various tills differ, but, in general, identification has been based on differences in physical characteristics, weathering zones between tills, paleosols, striae, depositional topography and indicator fans. More recently field methods have been complemented by laboratory analyses. The laboratory studies have shown various compositional differences among drifts deposited by invasions from different directions. Laboratory procedures that have proven to be most effective include: size analyses, X-ray analysis, heavy mineral separation and identification, pH determination, and C^{14} dating of organic remains.

Various aspects of the geologic environment in New England, and particularly in Vermont, complicate the separation and correlation of the drift sheets on a regional scale. The most perplexing of the complicating factors are: 1) the rugged topography; 2) the complex bedrock; 3) multiple glaciation; 4) virtual absence of weathering zones between tills; and, 5) the absence thus far of datable organic remains. These make it impossible to use the conventional field and/or laboratory techniques for tracing the tills from one area to the next.

Effects of the Mountainous Terrain

The rugged topography complicates the "normal" advance and retreat of the actively moving glaciers and the deposition of sheets of till as the concept has been developed in the "classical" midwest. As noted in the earlier report on *The Glacial Geology of Vermont* (Stewart, 1961, pp. 23–26), glaciers do not advance and retreat over rugged topography as they supposedly do over the plains. (See appendix D of this report.)

One of the effects of the mountainous terrain results from the stagnation of the peripheral zone of the glacier after it thins to a level below

the tops of the mountains. The confined masses of stagnant ice then thin by downwasting until they finally occupy only the stream valleys. The glaciers consequently do not maintain stable margins of the kind that form frontal moraines. The outwash is carried away by streams with steep gradients and high velocities and thus outwash aprons do not mark marginal positions of the ice.

Numerous ice marginal lakes form in and around the masses of stagnant ice as soon as the ice has thinned and is confined between the mountains. Inasmuch as melting will be greatest at the contact with mountain slopes, lakes will be most common in these areas. Lakes also form in the valleys after the ice has diminished to the extent that it consists mainly of disconnected blocks. The deposits formed in association with these lakes are a mixture of glacial outwash, lacustrine sediment and commonly till.

Effects of the Complex Bedrock

Except for the Champlain Lowland and to some extent the Vermont Valley, the bedrock of Vermont is very complex and is composed chiefly of metasediments predominantly slates and schists. The Taconic Mountains in the southwest contain a high percentage of slate and phyllite, and the basement rock exposed along the crest of the Green Mountains south of Lookout Mountain is metaigneous rock such as granite gneiss. The rocks exposed in most areas lie within the biotite, garnet and staurolite-kyanite metamorphic zones. Exceptions of note include the rocks of the White Mountain complex in the extreme northeastern part, and the rocks of the chlorite metamorphic zone of the Champlain Lowland. Because of the complexity, the mineralogy is also quite complicated with a wide range of minerals of varied origins.

In spite of the complex bedrock, or perhaps because of it, the mineralogy of the various rock units is not significantly different. It is apparent, from laboratory studies of the tills, that the stable minerals are much the same in all of the different rock types (Cannon, 1964a; Behling, 1965; Shilts, 1965). At least the analyses of the tills have shown little difference in the till sheets from these parent rocks.

The metamorphic map of Vermont (Centennial Geologic Map of Vermont, 1961) shows that the metamorphic zones encircle an area of most intense metamorphism and therefore the rocks have been metamorphosed in decreasing intensity outward from the center.

Because of the climate, chemical decomposition is more prevalent than physical disintegration. The chemical attack of the mafic minerals, which are most rapidly decomposed, produces suites of secondary minerals that are essentially the same for all of the rocks containing these minerals. In a similar manner, the chemical weathering of the feldspars forms minerals that are the same for all rocks.

As a result of the more or less enclosed configuration of the metamorphic zones, the similarity of the mineralogy of the rock, and the comparable products of chemical decomposition, the rock waste picked up by the glacier, mixed during transport and deposited as a drift sheet, is generally not unique or distinctive. The composition of the glacial deposits, especially the till, is very similar regardless of the direction of glacial advance.

There are, of course, exceptions to the above statements concerning composition. In the Vermont Valley, for example, the rocks of the Green Mountains east of the valley are distinctly different from the rocks of the Taconic Mountains to the west. The rocks of the Champlain Lowland are less metamorphosed and differ considerably from those in all other sections of the state. Certain localities of the Northeast Highlands in the extreme northeastern region of the state are of different composition. Locally, of course, a distinctive rock type may exist but these cannot be used for identification and correlation from one area to the next. In general, the Green Mountain area and all of the state to the east of it have tills of very similar compositions, and this property cannot be used for correlation. In the southern part of the Vermont Valley, however, the lithology of the drift is diagnostic of the source.

Effects of Multiple Glaciation

In regions where multiple glaciation has occurred, and particularly in areas where the mineralogy of the bedrock is as described above, the characteristics of the tills became more similar with each succeeding glacial invasion. Each ice invasion removes the drift of former glaciations and mixes the debris of the former deposits with the bedrock load it has acquired in areas over which it has moved. Unquestionably, a considerable percentage of the sediment transported by glacial ice is composed of drift deposited by prior ice episodes and/or rock mantle formed by weathering during the preceding pre-glacial or interglacial interval.

The till sheets in Vermont, both basal and ablation, are very sandy and contain little clay or colloidal organic matter to bind the matrix. They are, therefore, easily broken up by overriding ice and by the subsequent intermixing during transport. For this reason, the blending with

other transported materials is complete and inclusions of older till in younger deposits has been rarely, if ever, found.

Conventional Field Methods that Proved Unsuccessful in Vermont

As has already been noted, the field methods commonly used for the identification and correlation of till sheets include: the physical characteristics of the drift; the presence of paleosols and weathering zones between till sheets; glacial striae; indicator fans and boulder trains; and the depositional topography marking ice margins. These methods were used in Vermont wherever it was possible to do so, but the tracing of the different tills from one locality to the next could not be achieved by these methods. It should be pointed out, however, that these "old reliable" field methods are not being used in other regions as successfully as they formerly were, even in the "classical" midwest.

Physical Characteristics of the Drift. The color and texture proved to be of little value for correlation. The color of the tills vary with the color characteristics of the local bedrock and the amount of weathering since deposition. In many areas, where two tills are found in a single exposure, their colors may be distinctly different, but the color of the same two tills might be reversed, or they might be the same color in the adjacent area.

The texture of the till varies significantly little from place to place. The ablation tills, of course, are consistently more sandy than the basal tills, but the identification of the ablation tills is not a problem of correlation. All of the Vermont tills contain much sand, little clay and moderate silt (Cannon, 1964a). The old usage of the term "boulder clay" as a synonym for till is surely not correct in this region. Size analyses of different tills, one above the other, sampled at the same exposure did not show conspicuous differences in till textures.

Because of the high sand and low clay content, water percolation and seepage through the tills is much greater than might be expected for such sediment. That is to say, the permeability is relatively high in spite of the low sorting coefficient of the tills. The fact is, water is produced for domestic use from wells, particularly dug wells, penetrating the till. Abundant water in the till increases the rate of chemical weathering, particularly oxidation and the decomposition of the mafic minerals. The resulting change of color and discoloration adds to the color problem inasmuch as the weathered tills are all tannish to brownish (iron) colored. The depth of the zone of oxidation and discoloration is much deeper than the zone of leaching, and in the loose, sandy ablation tills the total deposit is oxidized.

Features Resulting from Glacial Erosion. The use of striae as an indication of the direction of advance, as well as the direction of source, of the last glacier that traversed a particular area is here questioned for several reasons. The bedrock in Vermont over large areas is composed of metamorphosed, upturned layers of schists, gneisses, phyllites and slates. These weaker rocks do not retain the striae made by ice for a long period of time, particularly where the drift is thin or completely lacking. The upturned, foliated layers are differentially weathered producing a fine lineation on the surface of the rock parallel to the rock fabric. The lineations closely resemble striae and/or grooves and caution must be taken in correctly identifying the striae and other erosive features.

The investigations made during this survey have led to the conclusion that, in areas of multiple glaciation, the striae, grooves and/or fluting do not necessarily record the direction of the most recent glaciation or the ice advance that deposited the surface till. In many areas of Vermont, the direction of the most prevalent striae parallels the direction of an earlier ice advance but not the fabric maxima of the surface till. This is true even in situations where the till lies directly on striated bedrock. It is most difficult to formulate an hypothesis explaining why the striae of former glaciations remain whereas the most recent ice invasion seemingly made none or very weak ones, but the data accumulated in the field support such a conclusion.

It is not intended to imply here that the striae in Vermont could not be used for any practical purposes. This is not the case, but use was restricted by the factors just described. In many sections, and especially in the area covered by the last glaciation, the striae were no doubt made by the last glaciation, and till fabric and striae are parallel and supply complementary evidence of ice direction. The most valuable striae are those which cross, and the conditions are such that the relative ages (older and younger) can be seen (Plates X and XII). The fact remains, however, that a regional pattern of glacial movement could not be established from the study of the effects of glacial erosion alone.

Features Resulting from Glacial Deposition

The deposits made by continental ice sheets have been used in many regions to map, delineate and even correlate drifts of different ages. In plains areas, such as the Midwest, for example, the terminal moraine and associated outwash plains often mark the margin of an ice advance. In

spite of the fact that many of the older correlations based almost entirely on depositional topography have been questioned and are now being restudied using more up-to-date methods, the more or less continuous terminal and recessional moraines stretching across wide areas of the plains states are most valuable criteria for identification.

Moraines. As has already been noted, however, the rugged New England topography is not conducive to the formation of such depositional features. At the locality where the terminal moraine should have been deposited, the slope is usually so great that the debris was carried away down-valley. In other cases, where the slope was northward, lakes formed along the terminus and the glacial sediment was mixed with other clastics carried into the lake. The stagnation and downwasting of the ice also affected the type of deposition. Since the stagnant ice melted downward, from top to bottom, there were few, if any, stationary margins being fed with active, forward-moving glaciers.

Those moraines in Vermont that were mapped as terminal moraines were so designated only after the drift margins (terminus) had been determined by other methods, chiefly till fabrics. Most of these moraines are relatively insignificant insofar as the glacial history is concerned. The only really significant terminal moraines are those made by the last ice advance in the Rutland-Lake St. Catherine region (Figure 13).

The larger morainic accumulations are in the northeastern section of Vermont (Figure 7), and the significance of these moraines is not, at this time, clearly understood. The occurrence of the moraines in this area is probably due more to the subdued topography than to any other factor. These and other moraines will be discussed more fully in later chapters of this report.

Outwash Aprons. There are no ice marginal outwash deposits such as outwash aprons or fans in Vermont. Apparently the detritus from the melting glaciers that might have formed outwash was carried away by streams to the lower valleys.

Boulder Trains and Indicator Fans. The older literature abounds with descriptions of boulder trains and/or indicator fans previously used as indications of the direction of ice movement across the region. The boulder trains of New England are familiar to all those who have studied the phenomena customarily used to ascertain the direction of glacial flow. Four of the well known New England indicator fans occur in Vermont. These are the orbicular granite fan spreading out from the outcrop at Craftsbury, the quartzite fan at Burlington, the syenite fan at Cuttingsville and the syenite fan at Mt. Ascutney (Stewart, 1961, Plate II).

The above trains, or indicators, have been developed by assuming a straight-line transport of any erratic of these rocks to wherever they have been found without regard to the distance from the outcrop. Cobbles of the Craftsbury orbicular granite (commonly called prune granite), for example, have been found as far away as New Hampshire and southern Vermont. It has been assumed that these were carried to the locale where they were found by a single ice invasion. This interpretation is understandable when it is remembered that it was formerly assumed that all of New England was covered by a "last glaciation" that invaded from the north-northwest.

The writers believe that repeated ice advances redistributed the boulders of the indicator fans. This is true particularly where the direction of ice movement was different for each glacial invasion. After glaciation from two or more directions, it is impossible to retrace the path of an erratic from the outcrop to its present location or to develop a reliable indicator fan except in the close vicinity of the outcrop exposure.

In the specific case of the Vermont boulder trains, the Craftsbury "prune" granite proved to be the most reliable indicator. In the vicinity of the outcrop, however, the concentration had a north-south trend and it is suspected that movements from both the northeast and northwest were responsible. The survey was unable to get any satisfactory results from either the Cuttingsville or Mt. Ascutney syenites distribution. Boulders and cobbles that could be definitely identified were not plentiful enough to make a statistical study possible.

The Burlington boulder train was discounted in the 1961 report (Stewart, 1961, pp. 111–12). The unique rock here is the distinctive Monkton quartzite, and it is now known that this formation crops out along the western side of the state from Milton to the Massachusetts border and hence is useless as a directional indicator (Centennial Geologic Map of Vermont, 1961).

Boulder concentrations in the immediate vicinity of an outcrop can indicate the last ice movement across a region. But, as the distance from the outcrop increases, the reliability of the results diminishes particularly in areas of multiple glaciation. A statistical study such as that made by McDonald (1967, Figure 9) of the Stanstead-type grey granite of Hereford Mountain is most reliable, since the percentages of the grey granite were computed from traverses within only four miles of the outcrop.

Organic Remains, Paleosols, Interglacial Gravels and Weathering Profiles Between Drift Sheets. The most accurate method of dating and correlating drift sheets at the present time is by the carbon[14] dating of organic remains found in or between till sheets. This method gives an absolute date to the deposit and allows the correlation with other deposits which have been dated by the same method. No such datable organic remains have, as yet, been found and dated in Vermont. For this reason, an absolute date correlation of the tills cannot accurately be made with tills of known age in other areas.

No paleosols or interglacial gravel has been found buried beneath tills. Lacustrine sediments do occur between the drifts in many exposures, but this type of sediment may be formed at the ice margin as in other local lakes and is not generally reliable as a criterion for correlation. Fluvial deposits also occur between the tills in some areas. These, however, are also local deposits made by the stream occupying the valley in which they occur. All of the above-mentioned materials are useful in the study of a single exposure and aid in the separation of the various tills. They cannot be used when tracing a particular unit or sequence from one locality to the next.

A single weathering zone occurring between two tills was discovered during this survey at West Norwich. This significant find will be discussed in another section of this report.

TILL FABRIC

West and Donner (1956) give Hugh Millér (1850) the credit for being the first to declare that many stones contained in a till lie with their long axis parallel to the direction of the striae and thus parallel to the direction of the ice that deposited them. Upham (1891, pp. 377–78) specified, as a characteristic of subglacial till, that the long axis of "oblong stones" was parallel to "contiguous" glacial striae and therefore parallel to the "course of the glacial movement." In spite of these early disclosures of the preferred orientation of elongate fragments within a till, little, if any, attention was given to these facts in the study, identification and correlation of drift sheets. Proof of the concept of till fabric was not reported until after it had been tested with many measurements of pebble orientation by Richter (1932) and later by Holmes (1941).

Even after the testing and confirming of the concept by Richter and Holmes, acceptance and use by glacial geologists was very slow. The explanation of this delay is no doubt related to the fact that Pleistocene stratigraphy, as such, was not a concern of earlier glacial geologists. Even today, many Pleistocene geologists are skeptical of the results obtained by till fabric studies, and others use fabrics only to confirm data obtained

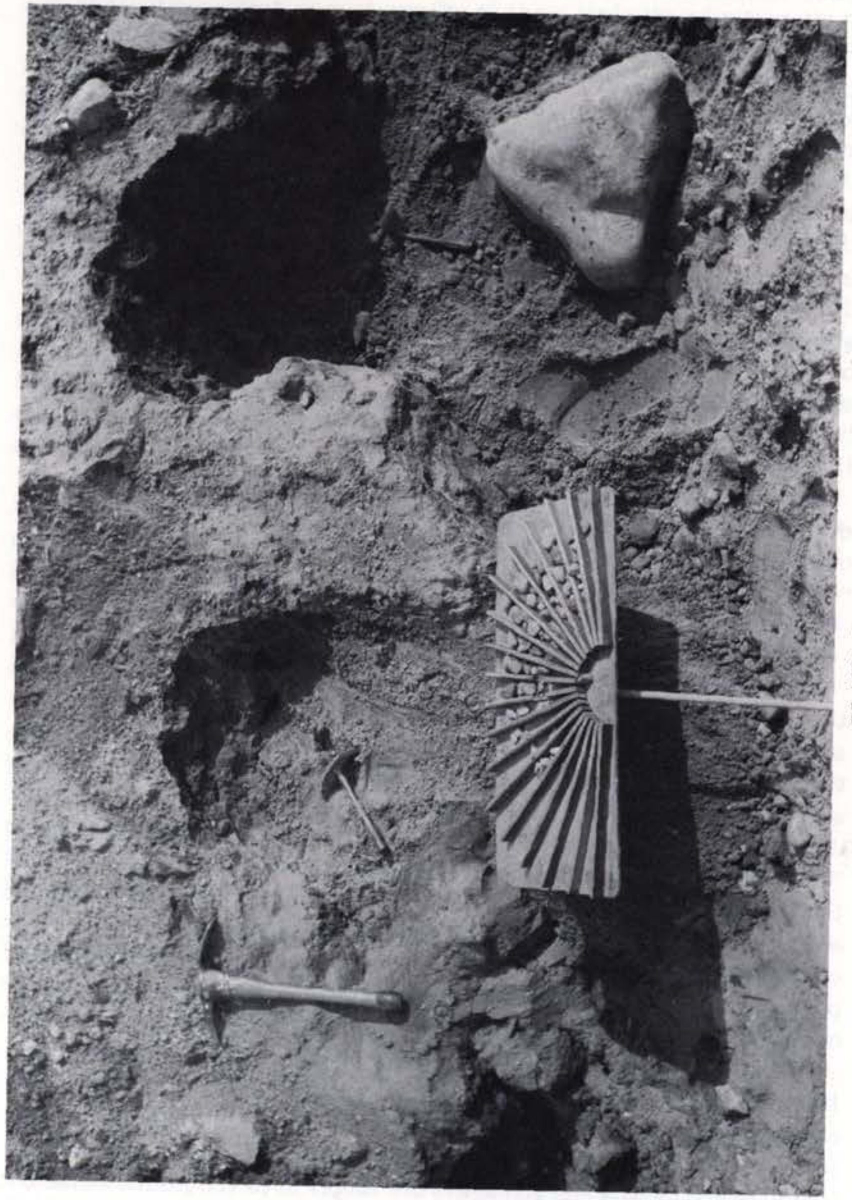


PLATE V

Till fabric rack showing a northeast fabric. Fabric taken in Shelburne ablation till three miles south of Plainfield (Plainfield Qaudrangle).

by other methods. In Vermont, however, where exposures of till are scattered among the hills and valleys of this mountainous state, other conventional methods of till identification, correlation and mapping could not successfully be used to develop a geologic sequence or the geographic distribution of the drift sheets. The fabric of the tills, however, did prove to be a successful method and has been used extensively in the study of the stratigraphy of the glacial deposits. The fact that the three till sheets that have been proposed to date in Vermont were deposited by ice invasions that came from three different directions has made it possible to differentiate the tills deposited by each of these glacial episodes.

Most methods for taking a fabric of a till at a specific location suggest that a large area of the till be exposed on a horizontal plane and that all of the pebbles contained in the till should be studied. Holmes (1941), for example, advises that the geographic orientation and the angle of inclination of each pebble be measured and recorded. The measurement of every pebble in the till at each location would take several days. It was therefore decided to select and measure the orientation of only the stones considered diagnostic of the ice-flow direction. According to results obtained by Richter (1932) and Holmes (1941), the ideal pebbles are those with A-axis equal to twice the B-axis and the B-axis equal to twice the C-axis. These blade-shaped stones should lie horizontally in the till showing that they have not been disturbed from their original position by frost heaving or any other post-depositional movement such as slumping.

Inasmuch as time was of the essence to this survey to complete the whole state and the till fabric methods described by Holmes and others are so time-consuming, the procedure had to be simplified. The method used during this study was that modified by MacClintock (1954b, 1958) for use in the St. Lawrence Lowland of New York State (MacClintock and Stewart, 1965). In accordance with the modified method, till stones are carefully selected to find flattish elongate pebbles that lie in a horizontal position. Specifically, every effort is made to select the diagnostic stones that "slid" into place where they were deposited, and to avoid those that rolled into position with their long axis normal (transverse) to the ice direction. The pebbles used for the present fabric analyses were collected and laid on a "fabric rack" marked off in ten-degree intervals of orientation. When enough pebbles were accumulated to show clearly a maximum orientation, the fabric was considered completed, and the pebbles were counted and recorded. In some cases fifty to a hundred pebbles proved to be sufficient. In other instances, where pebble shapes were somewhat irregular, two hundred or more pebbles may have been necessary before the fabric orientation became convincing enough to be accepted (Plate V).

Many objections and criticisms have been made to the method used in these investigations and described above. The most serious criticism has been that in selecting only the flat, elongate stones, the greater part of the fragments in the till is disregarded. A second objection has been that the selection of pebbles might be influenced by preconceived notions about what the fabric should be or what the investigator hoped it would be. We believe, however, that the careful selection of the stones is the most significant aspect of this method. The results of all former studies, by all methods, have corroborated the fact that the oblong fragments are the most consistently oriented with the ice direction. The most convincing argument for the validity of till fabrics, we think, is the regional picture of the glacial invasions that has resulted from their use.

The regional movement and stratigraphy inferred by the till fabrics was checked wherever it was possible to do so. In the Champlain Lowland and the Vermont Valley, particularly in the Rutland-Middlebury section, the striae confirmed the ice direction and the sequence. This is the area of the youngest drift, and also the area of most suitable bedrock. In numerous localities of this region, crossing striae on the bedrock definitely show that a northeast to southwest ice advance was followed by an invasion from the northwest. Many exposures studied in this area have till with a northwest fabric overlying till with northeast fabric. The striae in this section are better preserved because the bedrock is essentially horizontal in most localities and is composed of less metamorphosed, nonfoliated, marble and quartzite, and is usually covered with glacial or lacustrine sediment. It would have been possible to have established the direction of the two most recent ice episodes in this region without till fabric, but the stratigraphy of the tills and the extent of the glaciation could not have been ascertained.

The study of the fabric maxima of the tills exposed in Vermont has resulted in the identification, correlation and mapping of three different till sheets. The ice invasions were first from the northwest, second from the northeast and third from the northwest. Over 500 till fabrics were completed during the survey. The raw field data and the calculated vector mean of 482 of these are reproduced in appendices A, B and C of this report. Diagrams of approximately 40% of the fabrics are included in the text.

MULTIPLE GLACIATION

It is most interesting to find in the older literature numerous suggestions, and even definite conclusions, concerning the probability of multiple glaciation in Vermont and adjacent New England. The amazing thing about these published notes is the fact that they were overlooked or ignored for so long. For some reason, not yet discovered in the research for this report, it was assumed until rather recently that the ice sheet that covered all of New England was the last to invade the area, and that this glaciation removed all manifestations of earlier ice episodes. This belief is now being discarded as research progresses.

The second annual report of the first state geologist of Vermont (Adams, 1846) noted that approximately one-third of the striae he had studied, mostly in the northwestern part of the state, indicated movement from two or more different directions. Adams also explained that in many exposures it was possible to ascertain the relative ages of two sets and that in all cases northwest striae were younger than northeast. On Isle LaMotte, he was successful in ascertaining the relative ages of three sets of striae which he reported as follows, beginning with the older: N 10° W, N 8° E and N 47° W. The accuracy of these observations is most interesting inasmuch as most of the data came from the Champlain Lowland where striae and till fabric, as already stated, show the last two glaciations were first from the northeast (older) and then from the northwest (younger). The order of the three proven glacial invasions across Vermont is northwest (oldest), northeast (middle) and northwest (youngest).

The *Geology of Vermont* (Hitchcock, et al.) in 1861 reported the "drift directions," as shown by the study of striae, to be: first from the northwest, second from the northeast and third from the north. The term "drift directions" was used inasmuch as the interpretations of these directions was based on a mixture of the iceberg theory, ocean currents and local glaciation.

In 1889, Emerson (pp. 550–55) described two stratigraphic sections in Old Hampshire County, Massachusetts, that were exposed in railroad cuts which he referred to as the "Camp-Meeting Cutting." Three tills were exposed at this location with boulder beds and beach sand between the lower and middle tills and sand and clay separating the middle and upper. These Emerson explained by ice advance, retreat and readvance, but he said that the till had characteristics that suggested ice of an "earlier epoch." The report contains four full pages listing striae measurements from Franklin, Hampshire and Hamden counties, Massachusetts, (approximately 135 striae) and 30% of these trend from the northeast; the remainder are north and northwest.

Later, Jones (1916, p. 92) recorded striae one mile north of Greensboro village that indicated glacial movements from first the northwest, second the northeast and third the north. These, he said, agreed with striae directions south of Robeson Mountain. Richardson (1916, p. 117) reporting on the evidence of glaciation in Calais, East Montpelier, Montpelier and Berlin townships stated that the striae in each of the townships connote ice advances from first the northwest, second the north and third the northeast.

The above-mentioned references serve to point out three interesting facts. In the first place, the "old timers" were keen observers, and the data they published was quite accurate. Secondly, geologic observation was, in many respects, less difficult before the recent development of cities, towns, and highways. And, thirdly, this report is by no means the first to propose multiple glaciation in Vermont. It is difficult to explain the lack of attention that has been given to so much of the older literature. Perhaps it was the erroneous concepts used in the explanation of the data that prompted a lack of confidence in the facts.

THE PLEISTOCENE SEQUENCE IN VERMONT

One of the results of the mapping survey has been the development of a partial sequence of the glacial and post-glacial events in Vermont. It is probable that other ice episodes have covered Vermont in early Wisconsin and pre-Wisconsin time. The sequence here described must date from pre-classical Wisconsin to the present. From the data collected during the recent survey, the following Pleistocene sequence, in chronological order, can be deduced for the Vermont region.

I. A possible pre-Bennington glacial stade with glaciation from the northwest followed by a lake episode and erosion. The evidence for this glacial interval is too scant, too scattered and too indefinite at this time. It is merely noted in this sequence so that the possibility can be subsequently discussed in this report.

II. The Bennington Glacial Stade
- A. Glaciation from the northwest that covered all of Vermont and probably all of New England. (During this survey it has been found as far south as Williamstown and Charlemont in Massachusetts and east to New Hampton in New Hampshire).
- B. Probable lake episodes in the Champlain Lowland, Connecticut River valley and Vermont Valley as the Bennington ice waned.

III. The West Norwich Interstade
- A. Weathering and erosion of the Bennington till.

IV. The Shelburne Glacial Stade
- A. Glaciation from the northeast that covered all of Vermont with the exception of the extreme southern part.
- B. Deposition of dense basal till in some localities and loose, sandy ablation till over wide areas.
- C. Ice-marginal, high-level lakes formed in the eastward-flowing tributaries of the Connecticut River as the Shelburne ice melted down from the high lands to the west.
- D. Ice-marginal lakes in the Manchester-Bennington region of the Vermont Valley.

V. The Lake Hitchcock Interstade
- A. Lake episodes in the Connecticut River valley (Lake Hitchcock, etc.) during and after the retreat of the Shelburne ice sheet.
- B. Deposition of widespread lacustrine sediment in the Connecticut Valley.
- C. An interstadial lake episode in the Champlain Lowland with the deposition of varved sediment.

VI. The Burlington Glacial Stade
- A. Glacial advance from the north-northwest covering the Champlain Lowland, across all of the Green Mountains north of Brandon and across the Memphremagog Basin in northern Vermont. Ice invaded the Lamoille Valley as far as Hardwick, the Winooski to Barre and terminated in the Dog River and Third Branch valleys between Montpelier and Bethel.
- B. Ice-marginal and post-glacial lakes in north-central Vermont. Lakes in the Memphremagog Basin, Lamoille, Winooski, Huntington, Mad and Dog river valleys as the ice melted back from the margins and down from the mountains.

VII. Post-Burlington Lake Interval
- A. Lake Vermont occupied the Champlain Lowland during the retreat of the Burlington ice. The lake episode, from highest to lowest, are:
  1. Quaker Springs Stage
  2. Coveville Stage
  3. Fort Ann Stage

VIII. Post-Glacial Intervals in the Champlain Lowland

A. Post Lake Vermont erosion interval
   1. With the withdrawal of the ice from the St. Lawrence Valley, the waters of Lake Vermont drained completely to a low sea level.
   2. The Champlain Lowland was dry land subject to weathering and erosion.
B. Champlain Sea interval
   1. Marine waters slowly invaded the Champlain Basin due to an eustatic rise in sea level.
   2. The sea rose to a maximum and "stabilized" when the land and sea level were rising at about the same rate. Sea-cliffs and beach ridges made at this level.
C. Land emergence interval
   1. The land continued to rise and emerged to its present altitude above present sea level.
   2. The rise of the land was progressively more to the north giving the lake and marine shorelines a southerly dip.
D. Lake Champlain developed

IX. Post-Glacial Erosion and Deposition

A POSSIBLE PRE-BENNINGTON GLACIAL STADE

Evidences that suggested a pre-Bennington glaciation of north-central Vermont were reported in 1964 after studies were made of six stratigraphic sections that were exposed in the upper Lamoille Valley (Stewart and MacClintock, 1964, p. 1091). Five of the sections were located along Stannard Brook east of Greensboro Bend and the sixth was along the west valley wall of the Lamoille River north of Greensboro Bend (Figure 4) (Hardwick and Lyndonville Quadrangles). In five of the sections, a till with northwest fabric (Till A) at the base of the exposures was separated from an overlying till with northwest fabric (Till B) by several feet of fluvial gravel and lacustrine sediment. It was reasoned that the upper till with northwest fabric (Till B) was of Bennington age and that the stream gravel and lake sediment separating it from the lower till (Till A) was probably deposited during an ice-free interval preceding the Bennington glaciation. The basal till (Till A) was accordingly ascribed tentatively to a pre-Bennington glaciation.

The Stannard Brook sections were first discovered and studied near the end of the 1963 field season. Behling (1965) completed a detailed investigation of the sections during the summer of 1964 and failed, ac-

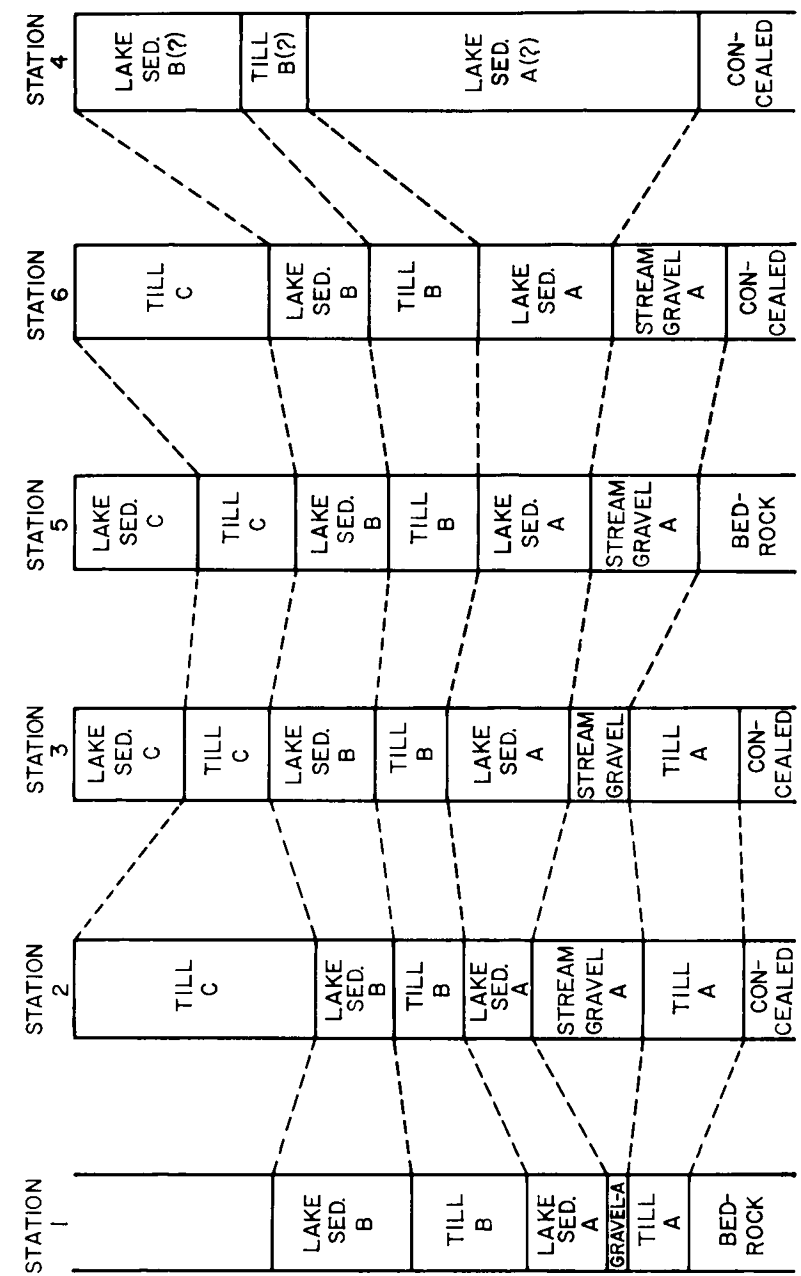
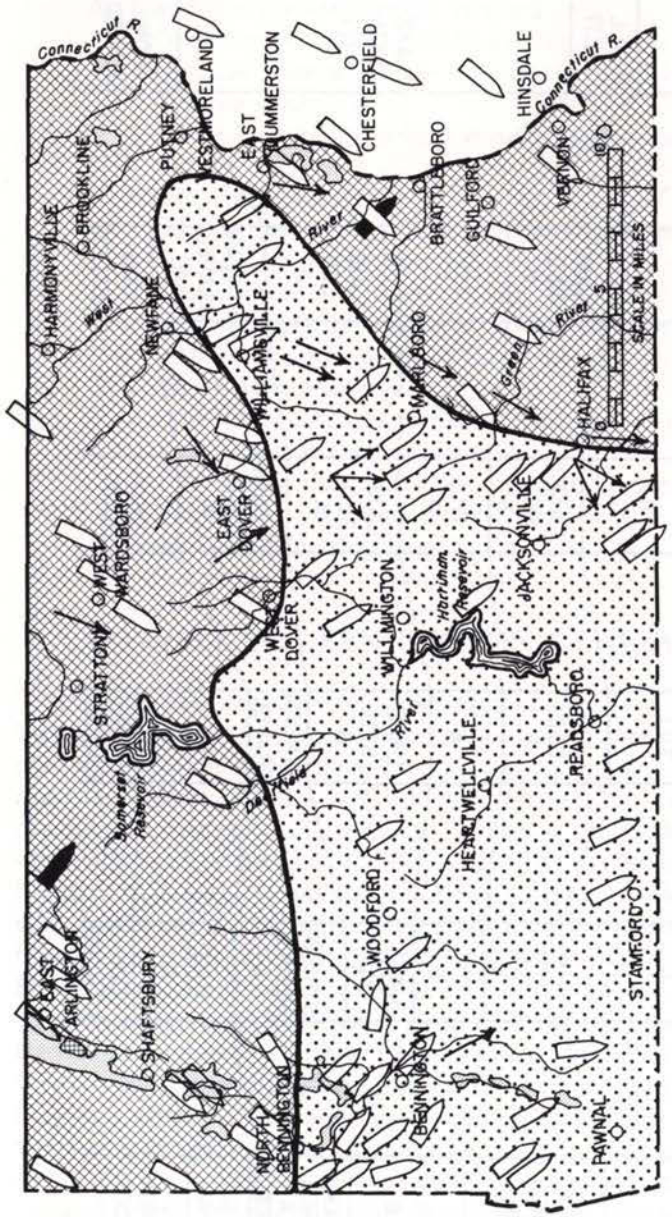


Figure 4 Stratigraphic units of the sections exposed along Stannard Brook.



INDEX MAP SHOWING THE AREA OF BENNINGTON SURFACE TILL AND THE SHELBURNE DRIFT BORDER

SHELBURNE DRIFT
MORAINES OF SHELBURNE DRIFT
BENNINGTON DRIFT
KAME MORAINE
STRIAE
FABRIC OF SURFACE TILL
FABRIC OF SUBSURFACE TILL

Figure 5

cording to his own conclusions, to establish the existence of a till older than the Bennington.

Shilts (1966b) reported two tills with northwest fabric at two different locations in the Wilmington Quadrangle. One of the exposures is a natural stream cut approximately two hundred feet high on the south side of the Rock River immediately to the east of East Dover. The second exposure is in a road cut along the East Branch of the North River three miles southwest of Jacksonville. In each of these exposures, located thirteen miles apart, a lower till with northwest fabric is separated from an upper till with the same fabric orientation by lacustrine sediment measuring ten to fifteen feet in thickness. Each of the tills and the lake sediments have very similar characteristics at the two exposures. If these are indeed two different till sheets of different ice episodes, the lower till may be of pre-Bennington age.

We are, at this writing, in doubt about a pre-Bennington ice episode. To date no method of separating tills of the same fabric orientation has been found that can be used in the region. More research will be necessary to prove or disprove the existence of glacial deposits in Vermont older than the Bennington drift.

THE BENNINGTON GLACIAL STADE

The earliest proven glaciation of Vermont was an invasion of glacial ice across the region from a northwest direction. This glacial episode covered all of Vermont and probably all of New England, including the White Mountains, as postulated by C. H. Hitchcock (1908a, p. 173). The exact time that the Bennington glacier covered Vermont cannot, as yet, be definitely stated, but it is assumed that it was early in the Wisconsin Stage and probably older than the so-called "classical Wisconsin."

The till deposited by the Bennington glacier has been identified in all sections of Vermont except in the northwest part. The northwestern region was covered by the most recent glaciation which also invaded from the northwest. Since the fabric maxima are the *only* means of positive identification, the two tills, deposited by ice from the same general direction, cannot be differentiated unless the till with northeast fabric is in position between them. No exposure showing such a stratigraphic relationship has yet been discovered in the area covered by Burlington drift. Northwest trending striae on the bedrock below Shelburne, however, do indicate Bennington glaciation in that northwest region.

The only section where the Bennington drift is exposed at the surface is a small area in the extreme southern part between Bennington and Brattleboro (Figure 5, Plates VI, VII, VIII, and IX). It is not known at this time whether or not this area was actually covered by the later Shelburne glacier. Evidence, reported by other studies, seems to suggest that the Shelburne may have extended farther south.

The Bennington till is a dense basal till which has been overridden by subsequent glaciation except in the small area where it forms the surface till. The unweathered till is blue-grey to dark grey in color, contains much silt and sand with little clay, and is very compact. Cannon (1964, Figure 5a) analyzed seventeen samples of Bennington till from the north-central part of the state. These analyses generally show 40% to 60% sand, 25% to 50% silt and 5% to 20% clay. In spite of the high sand-low clay ratio, the till is often very hard, almost indurated, due to the combined content of silt and clay. In most exposures, many erratics are found, but the content of local bedrock is most conspicuous and makes up approximately 75% of the fragmental material. The cobbles and boulders are rounded faceted and striated.

The high content of local bedrock is probably most conspicuous in the weathered till inasmuch as chemical weathering is greatly influenced by the fragmental material. The weathered till is usually buff to brown in color, but the depth of weathering and the intensity of decomposition is a function of the porosity, permeability and composition. The top, leached, zone of the till has been removed, but in many exposures much of the oxidized zone is still intact. It seems probable that chemical weathering has continued after the deposition of the overlying till since the most common cover is a thin layer of loosely packed, sandy ablation till.

One section, where the Bennington till is well exposed and was much studied, is north of the White River and between the Connecticut River and the First Branch of the White River. In this region, specifically in the Mt. Cube, Strafford and Hanover quadrangles, the till is exposed almost continuously along the stream valleys, especially along the Ompompanoosuc River and its West Branch. The overlying Shelburne till is very thin, sandy and in some localities it has been completely removed. The older till has a blue-grey color, a sandy-silty texture, is well compacted and contains many cobbles and boulders. The pebbles, cobbles and boulders are composed chiefly of the gneiss, schist and limestone of the Waits River Formation. The till is oxidized up to depths of 25 feet, and the contact between the oxidized and unoxidized zones is so sharp that the possibility of two tills was considered when study first began in this area. The mafic minerals of the gneisses and schists are

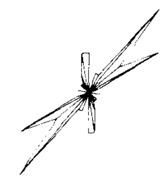


FIGURE 1. BUFF ABLATION TILL FROM THE WHITE RIVER VALLEY THREE MILES WEST OF TOWNSEND.

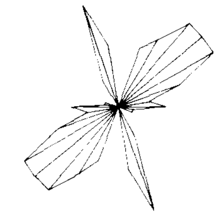


FIGURE 2. BROWN BASAL TILL ONE AND ONE-HALF MILES NORTH OF WILLIAMSVILLE.

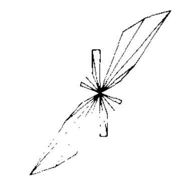


FIGURE 3. GREY BASAL TILL ON THE UPLAND ONE MILE NORTH OF WILLIAMSVILLE.

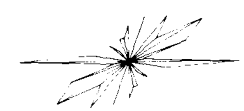


FIGURE 4. BUFF SILTY BASAL TILL ONE MILE SOUTH OF CHESTERFIELD, NEW HAMPSHIRE.

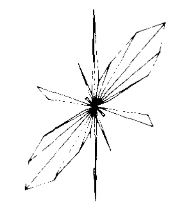


FIGURE 5. LOOSE SANDY ABLATION TILL TWO MILES NORTH-NORTHWEST OF CHESTERFIELD, NEW HAMPSHIRE.

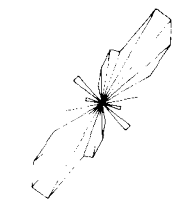


FIGURE 6. DENSE SILTY BASAL TILL ONE-HALF MILE EAST OF WESTMORELAND, NEW HAMPSHIRE.

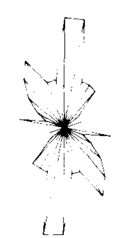


FIGURE 7. SILTY BUFF TILL ALONG STATE ROUTE 9 ONE MILE EAST OF THE CONNECTICUT RIVER AND THREE MILES NORTH OF BRATTLEBORO.

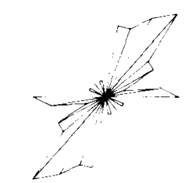


FIGURE 8. TAN SANDY ABLATION TILL FROM THE SOUTH SIDE OF WEST RIVER TWO MILES NORTH-NORTHWEST OF BRATTLEBORO.

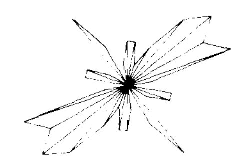


FIGURE 9. SILTY SANDY ABLATION TILL ALONG STATE ROUTE 63 TWO MILES NORTH OF HINSDALE, NEW HAMPSHIRE.

FIGURE 10. DENSE DARK BROWN CLAYEY BASAL TILL FOUR AND ONE-HALF MILES WEST OF GILFORD.

FIGURE 11. COMPACT BASAL TILL IN AN EXCAVATION ONE-HALF MILE WEST OF GILFORD.

FIGURE 12. PEBBLY NON-CALCAREOUS BASAL TILL TWO MILES NORTHEAST OF WESTMORELAND, NEW HAMPSHIRE.

PLATE VI FABRICS OF THE SHELBURNE TILL IN THE BRATTLEBORO REGION.

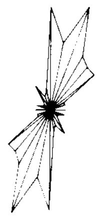


FIGURE 1. GREY SILTY BASAL TILL FROM THE EAST SIDE OF EAST DOVER.

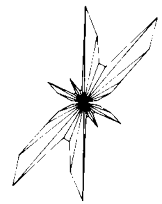


FIGURE 2. DENSE BUFF BASAL TILL THREE MILES NORTHEAST OF EAST DOVER.

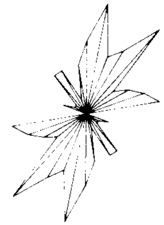


FIGURE 3. ABLATION TILL ALONG STATE ROUTE 100 TWO AND ONE-HALF MILES EAST OF WEST WARDSBORO.

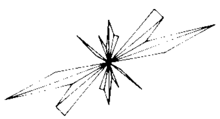


FIGURE 4. DARK GREY DENSE BASAL TILL ONE MILE SOUTH OF WEST WARDSBORO.

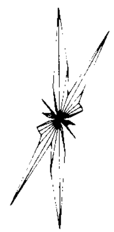


FIGURE 5. ABLATION TILL EXPOSED IN A ROADCUT ONE AND ONE-HALF MILES EAST OF WEST WARDSBORO.

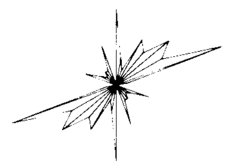


FIGURE 6. TILL EXPOSED IN A ROADCUT ALONG ROUTE 100 ONE MILE NORTH OF WEST DOVER.

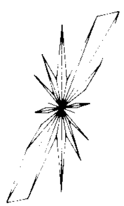


FIGURE 7. LIGHT GREY SANDY TILL ONE MILE WEST OF THE OUTLET OF SOMERSET RESEVOIR FIVE AND ONE-HALF MILES NORTH OF SEARSBURG.

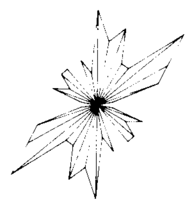


FIGURE 8. DENSE BUFF BASAL TILL FROM WHITE CREEK VALLEY ONE MILE NORTHWEST OF NORTH BENNINGTON.

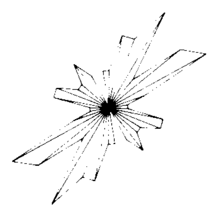


FIGURE 9. BLUE BASAL TILL IN A STREAM BANK ONE AND ONE-HALF MILES NORTHWEST OF NORTH BENNINGTON.

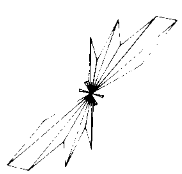


FIGURE 10. BASAL TILL EXPOSED IN AN EXCAVATION ONE AND ONE-HALF MILES NORTH OF NORTH BENNINGTON.

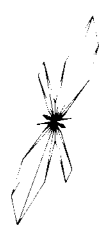


FIGURE 11. YELLOW-BROWN SANDY TILL FROM EAST SIDE OF U.S. ROUTE 7 ONE AND ONE-HALF MILES SOUTH-SOUTHWEST OF SHAFTSBURY.

FIGURE 12. ABLATION TILL EXPOSED ALONG ROARING BRANCH ONE AND ONE-HALF MILES SOUTHEAST OF EAST ARLINGTON.

PLATE VII FABRICS OF THE SHELBURNE TILL ALONG THE TERMINUS IN THE BENNINGTON-WILMINGTON AREA.

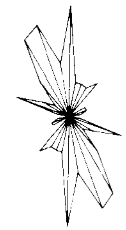


FIGURE 1. DARK GREY DENSE BASAL TILL ONE AND ONE-FOURTH MILES EAST OF EAST DUMMERSTON.

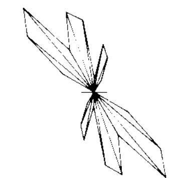


FIGURE 2. BUFF SILTY ABLATION TILL ALONG STATE ROUTE 9 SIX AND ONE-HALF MILES WEST OF BRATTLEBORO.

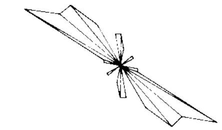


FIGURE 3. DENSE DARK-BROWN CLAYEY TILL ONE-FOURTH MILE NORTH OF HALIFAX.

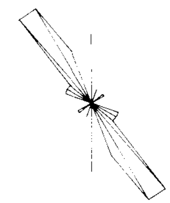


FIGURE 4. DENSE DARK-GREY BASAL TILL ON HAYSTACK MOUNTAIN ROAD TWO MILES NORTH OF WILMINGTON.

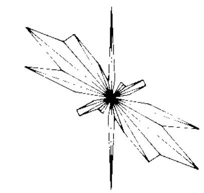


FIGURE 5. GREY ABLATION TILL EXPOSED ALONG STATE ROUTE 5A THREE MILES SOUTH OF JACKSONVILLE.

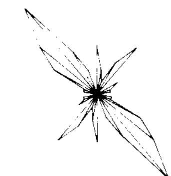


FIGURE 6. SANDY ABLATION TILL ALONG STATE ROUTE 8A FOUR MILES SOUTH OF JACKSONVILLE.

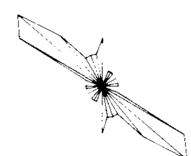


FIGURE 7. SILTY COMPACT GREY TILL ALONG SOMERSET RESEVOIR ROAD TWO MILES NORTH OF SEARSBURG.

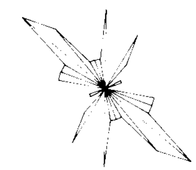


FIGURE 8. BUFF SANDY SILTY TILL FROM THE NORTH SIDE OF STATE ROUTE 9 THREE MILES WEST OF MARLBORO.

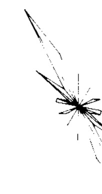


FIGURE 9. BUFF-GREY TILL ALONG STATE ROUTE 100 TWO AND ONE-HALF MILES SOUTH OF WILMINGTON.

PLATE VIII FABRICS OF THE BENNINGTON TILL BEYOND THE SHELBURNE TILL BORDER IN THE WILMINGTON-BRATTLEBORO REGION.

seemingly decomposed to some extent even though the carbonate minerals have not been leached.

One of the most northerly exposures of Bennington Till studied during the survey is located along the Willoughby River two miles east of Orleans (Memphremagog Quadrangle). At this location, twenty-five feet of Bennington till is exposed at stream level. The till is brownish-blue, compact and sandy. It is overlain by laminated, lacustrine silts and clays containing gravel layers with a total thickness that varies between twenty and forty feet. Shelburne ablation till overlies the silts and clays on the east side of the cut and Burlington basal till covers the lake sediments on the west. The Bennington till is also exposed under the Shelburne one and one-half miles south of the Willoughby River cut at Heath School (two and one-half miles southeast of Orleans). Here the brown, sandy Shelburne ablation till lies directly on the compact, blue Bennington.

In the Burke Quadrangle, striae trending N 50° E cross striae trending N 30° W in the valley of King Brook on the east side of East Haven Range. To the south, in this quadrangle, along Sheldon Brook and one and one-fourth miles southwest of East Lyndon, ten feet of Bennington till are exposed at stream level and are covered by forty feet of lacustrine gravel, sand and clay. The top twenty feet of the lacustrine sequence are contorted varved clay. The clay was apparently deformed by the ice that deposited the twenty-five feet of Shelburne till that covers it. One mile upstream fifteen to twenty feet of Bennington till are at stream level and Shelburne till is exposed in the same cut sixty feet above. The slope between the two tills is, however, covered with slump material.

At Stannard Brook (Stewart and MacClintock, 1964, p. 1093), the Bennington till (Till B) is exposed at all of the six exposures with one possible exception (Figure 4). As stated earlier, definite proof of a pre-Bennington drift (Till A) has not been found and it is possible that Till A is also Bennington. At any rate, lake sediment separates the Bennington and Shelburne tills in all sections showing that there had been an ice-free interval as far north as that place. Four miles northeast of Greensboro Bend, in this area, striae trending N 15° E cross striae trending N 35° W.

Bennington till is exposed beneath Shelburne till at several localities in the St. Johnsbury region. Exposures occur along the valley wall of the Moose River east of St. Johnsbury, in the Sleepers River valley north-northwest of St. Johnsbury and along the Water Andric to the southeast. In all exposures in this area, the Bennington is light blue-grey, compact, basal till with no weathering zone or interstadial sediment separating it from the overlying Shelburne till. Three miles north-northeast of Lunenburg (Littleton Quadrangle) in this region striae trending N 25° E cross striae trending N 15° W. Many rock exposures in the area show striae trending northwest, but the till over the bedrock has a definite northeast fabric. It is assumed that the striae were made by the Bennington glacial advance.

In the Woodsville Quadrangle, along Scotch Hollow Road one and one-fourth miles south of Ryegate, the Bennington and Shelburne tills

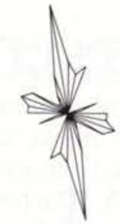


FIGURE 1. DARK BROWN FISSLE TILL SOUTH OF STATE ROUTE 9 THREE AND ONE-HALF MILES WEST OF BENNINGTON.

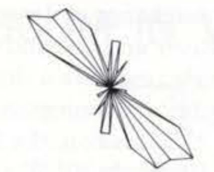


FIGURE 2. BUFF BASAL TILL IN A ROADCUT ONE AND ONE-HALF MILES WEST OF BENNINGTON.

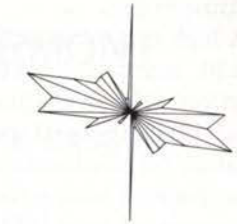


FIGURE 3. GREY-BROWN TILL SOUTH OF OLD BENNINGTON ONE MILE SOUTHWEST OF BENNINGTON.

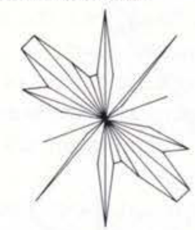


FIGURE 4. BUFF SILTY TILL ALONG U.S. ROUTE 7 FOUR AND ONE-HALF MILES SOUTH OF BENNINGTON.

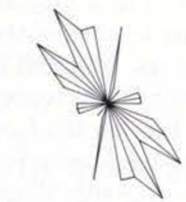


FIGURE 5. DARK TO YELLOW-BROWN TILL THREE AND ONE-HALF MILES NORTHWEST OF POWNAL.

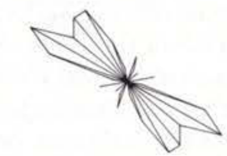


FIGURE 6. DENSE BLUE BASAL TILL FOUR MILES NORTHWEST OF POWNAL.

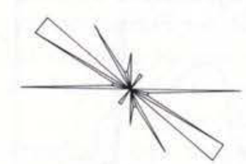


FIGURE 7. BASAL TILL ALONG U.S. ROUTE 7 AT POWNAL CENTER TWO MILES NORTH OF POWNAL.

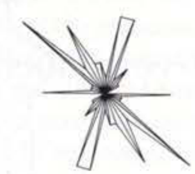


FIGURE 8. SANDY OXIDIZED TILL ON PARK STREET ONE MILE NORTH OF BENNINGTON.

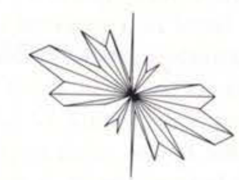


FIGURE 9. LIGHT BROWN SANDY LOOSE TILL AT WHITE CHAPEL TWO MILES NORTH OF BENNINGTON.

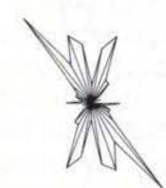


FIGURE 10. OXIDIZED SANDY SILTY TILL NORTH OF STATE ROUTE 9 ONE-FOURTH MILE EAST OF BENNINGTON.

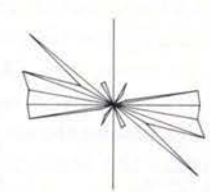


FIGURE 11. BROWN SANDY COMPACT FROM THE WEST SIDE OF WALLOOMSACK RIVER TWO MILES SOUTHEAST OF NORTH BENNINGTON.

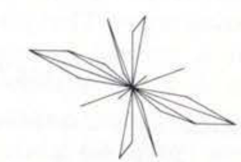


FIGURE 12. YELLOW-BROWN SANDY TILL AT WOODFORD HOLLOW SCHOOL TWO MILES WEST OF WOODFORD.

PLATE IX FABRICS OF THE BENNINGTON TILL BEYOND THE BORDER OF THE SHELBURNE TILL IN THE BENNINGTON AREA.

are separated by five to ten feet of dense, silty clay of supposedly lacustrine origin.

A high exposure for the interchange of Interstate Highway Routes 89 and 91, south of the White River and one and one-half miles due west of Hartford (Hanover Quadrangle) exhibits a dense, blue-grey, calcareous, basal till with northwest fabric (Bennington) under a brown, sandy, ablation till (Shelburne). At this location, the Bennington till lies directly on bedrock with striae N 10° W, N 20° W and N 40° W. The two tills are separated with lake silts and clay containing calcareous concretions and nodules. One mile south of Meriden, New Hampshire, in the same quadrangle, the same sequence is in a fifty-foot high bank, but the lacustrine silts at this location are leached of the carbonate.

North of the White River in the Strafford Quadrangle, just west of a cross-roads named West Norwich on the topographic map, the Shelburne overlies the Bennington, and the top ten feet of the Bennington till is leached of carbonate beneath the calcareous Shelburne.

Two miles south-southwest of South Woodstock (Woodstock Quadrangle) the Bennington till is exposed in a high cut along the highway, and the Shelburne till is exposed above in the woods, along a newer private road. The contact of the two tills was covered, but the Bennington basal till contained large amounts of the Waits River Formation and a definite northwest fabric whereas the Shelburne was an ablation till with northeast fabric. The same two tills are exposed in a high road cut along State Route 12 four miles northwest of Woodstock.

One of the most impressive exposures of Bennington and Shelburne tills is in a new road cut along State Route 30, two and one-half miles northwest of Brattleboro. Fifteen feet of bouldery, very dense Bennington till is exposed at road level. The till is covered with thirty feet of lacustrine silts and clays plus fifteen feet of gravel believed to be of lacustrine origin. Thirty feet of Shelburne till overlies the gravel and it, in turn, is covered by twenty, or more, feet of pebbly sand and gravel.

In all of the sequences described above, the fabric of the tills is the most satisfactory method of identifying them. The Bennington till has a strong northwest fabric, whereas the Shelburne is definitely northeast.

Lake Bascom in the Bennington Region. As the Bennington ice receded from the Bennington region, a lake formed in the Hoosic River valley (Figure 6). Taylor (1903) first noted a lake in this area at an elevation of 1,100 feet which he named Lake Hoosic. Later he (Taylor, 1916) changed the name to Lake Bascom. The present survey has mapped the shore features of this Lake Bascom which have elevations of 1,100 feet

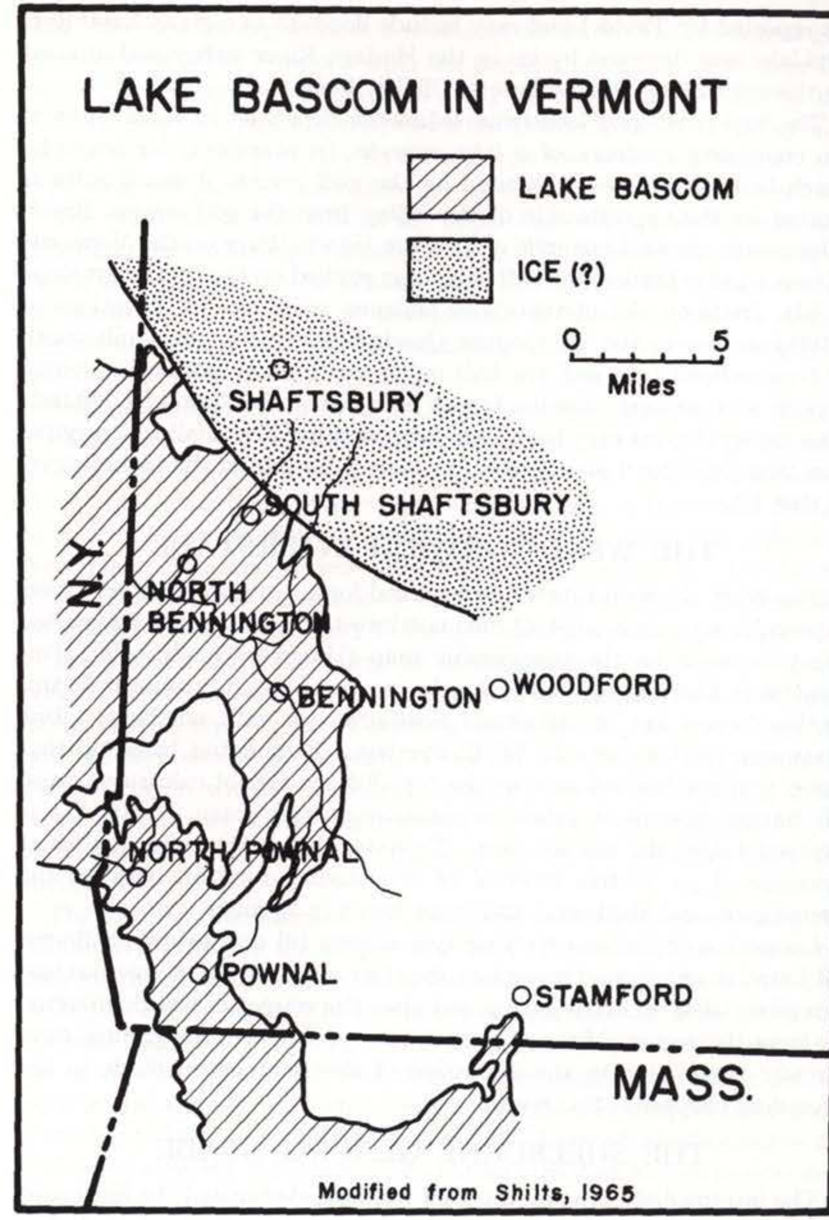


Figure 6

(as reported by Taylor) and may include deposits as high as 1,200 feet. The lake was dammed by ice in the Hudson River valley and drained southward through Massachusetts (Shilts, 1966).

The well-developed lacustrine sediments deposited in Lake Bascom are conclusive evidence of a lake episode. In Stamford, for example, beach features are well exhibited on the golf course. A small delta is located on the opposite side of the valley from the golf course. Beach ridges were mapped one mile east of the Hoosic River on the Vermont-Massachusetts border. A small delta was studied on the southwest slope of Mt. Anthony. All of the above features, with tops at elevations of 1,100 feet, are in the Bennington Quadrangle. One-quarter mile south of Barber Pond (two and one-half miles northeast of Pownal) a deltaic deposit with westerly dipping foreset beds has an elevation of 1,200 feet. This higher deposit may have been formed either in a small ice-marginal lake that preceded Lake Bascom, or it may have been the highest level of that lake.

THE WEST NORWICH INTERSTADE

The West Norwich Interstade is named for a section, described above, exposed in a roadcut one-half mile northwest of a cross-roads designated West Norwich on the topographic map (Hanover Quadrangle). This location is four and one-half miles due south of South Strafford. At this section, seven feet of calcareous Shelburne till with northeast fabric maximum (vector mean N 34° E) overlies a Bennington basal till that has a ten-foot leached zone at the top. Fifteen feet of calcareous basal till having northwest fabric orientation (vector mean N 50° W) is exposed below the leached zone. To date, this is the only significant evidence of an ice-free interval of interstadial duration between the Bennington and Shelburne stades yet found in Vermont.

Lacustrine sediment overlying Bennington till and below Shelburne till found in exposures throughout the state suggests that numerous and extensive lakes occurred during and after the retreat of the Bennington ice from the region. Many of the till-lake, sediment-till sequences have already been noted in the discussion of the Bennington Stade in the preceding chapter of this report.

THE SHELBURNE GLACIAL STADE

The intermediate drift in Vermont has been designated the Shelburne from exposures near the village of Shelburne where it was first studied (Stewart, 1961). The deposits of this glacial episode were made by ice

that traversed the region from a northeast direction. The Shelburne glaciers covered all of Vermont with the possible exception of an area between Bennington and Brattleboro along the southern boundary of the state (Figure 5). The ice moved down the Connecticut River valley into Massachusetts and probably as far south as southern Connecticut, and expanded eastward at least into the western part of New Hampshire.

The existence of two tills in the upper Connecticut Valley was first reported many years ago. Agassiz (1871, p. 557) believed that there were two glacial episodes in the White Mountains of New Hampshire and as far south as the environs of Bethlehem. He believed that the earlier glaciation was a continental ice sheet that was followed by local glaciation originating in the White Mountains. C. H. Hitchcock (1908a, p. 169) noted two or more sets of striae in the Hanover Quadrangle (New Hampshire-Vermont) and correctly identified two till sheets. He proposed a a continental glaciation from the northwest and a "Connecticut Lobe" down the Connecticut River valley with a source in the White Mountains. Hitchcock studied the Bethlehem, Littleton and Lyme regions of New Hampshire and noted numerous striae pointing northeastward. From these studies he extended the White Mountain local glaciation far enough to the southward to include the Hanover Quadrangle.

The position of the Shelburne till in the stratigraphic sequence of this region is based on its occurrence above the Bennington till as described earlier in this report and its position below the Burlington till in the northwestern section of the state. The numerous localities in the northwestern region where the bedrock exhibits northwest trending striae crossing northeast striae confirm that the region was traversed by a glaciation from the northeast followed by an ice invasion from the northwest.

The southern boundary of the Shelburne drift was mapped using the till fabric maxima of the tills in that area (Figure 5). The surface till with northeast fabric north of the boundary is both ablation till and basal till. South of the Shelburne till margin the till with northwest is mostly basal till (Plates VI, VII, VIII, and IX). The area of Bennington surface till is so small that definite conclusions concerning an ice front in this area are somewhat problematic. As we interpret the reports of studies of the glacial drift to the south of Vermont, the Shelburne till is, in our judgment, the surface till in at least part of Massachusetts and Connecticut. It may be, therefore, that the small area along the southern border of Vermont on the crest of the Green Mountains was covered by very thin ice or was surrounded by ice because of the topography or other environmental factors. As will be discussed later, Shilts and Behling (1967, p. 203), who mapped the southwest corner of the state, have a different interpretation of the glacial sequence in that region.

In Vermont, the Shelburne drift is predominantly an ablation till although exposures of basal till have been studied in all parts of the state. In spite of the fact that the surface till is chiefly ablation drift, it has a determinate fabric with a preferred orientation ranging from north-northeast to northeast. In general, the Shelburne till is thin and may be only a veneer covering the surface. The ablation till may be covering an older till or it may lie directly on the bedrock. In only a few places does the ablation till with northeast fabric cover a basal till with the same preferred orientation. As was noted earlier in this report, it is common to find Shelburne ablation till covering Bennington basal till over widely scattered localities of the state.

The most conspicuous characteristics of the Shelburne ablation till are its sandy, loose texture and the high percentage of angular cobbles and boulders composed of the local bedrock. These characteristics of the till lead us to propose that the deposit resulted from the slow down-wasting of stagnant ice. Probably the most common explanation of the sandy, flaggy nature of the drift has been to assume that it was superglacial and therefore an upper unit of a deposit that included a subglacial till deposited by different layers of the same ice sheet. This was the original interpretation by Upham (1891, p. 376) and Chamberlain (1894, p. 521) and a similar explanation was made by Denny (1958, pp. 80–82) in the Canaan area of New Hampshire.

Elson (1960, pp. 5–17) also proposed a superglacial origin for ablation till. But, he also had a place for it as a subglacial deposit. Elson's suggestion that ablation till is formed by the slow, downward melting of stagnant ice with the quiet washing out of the silt and clay is in close agreement with the concepts proposed in this report.

Crosby (1934b, pp. 417–19) studied the Fifteen Mile Falls dam site excavations and the area of the Bethlehem moraine of New Hampshire and reported two tills at several localities. These must be the Shelburne and Bennington tills described in this report. Crosby, however, followed the concepts of a continental glaciation followed by local glaciation from the White Mountains as proposed by Agassiz (1871, p. 554).

Tills in the Athol area of Massachusetts, according to Eschman (1966, p. 5) have a surface unit with loose, sandy texture which this report assumes to be ablation till. His analyses show the material to consist of 3% clay, 13% silt, 40% to 60% sand, 10% to 30% pebbles and about

15% cobbles. Eschman interprets the loose, sandy surface unit to be the top of a single drift sheet, but attributes the loose, sandy texture to various sources of parent rock.

This report contends that the angular cobbles and boulders contained in the ablation till are indicative of a short distance of transport which, of course, is the conclusion that has been made by most investigators. The sandy, loose texture, we believe, is the result of ice stagnation with very slow oozing out of the meltwater. The flow of the meltwater is barely enough to transport colloidal material and very fine silt, but not enough to carry sand and gravel. That is to say, the fines are washed out leaving the coarser material to be deposited by being very slowly and gently let down. The marginal stagnation hypothesis seems valid except that it does not provide a mechanism for the deposition of several frontal moraines, which have been mapped, that are composed of ablation till. The moraines are small and quite scattered but they are definitely frontal deposits. A thin ice sheet seems probable inasmuch as the amount of older till that was removed is much less than that which might be expected, striae of an older ice advance remain on the bedrock over wide areas, and the till deposited is generally thin. This hypothesis credits water activity with the removal of much clay, and in many cases silt, but the water action was not intense enough to destroy the orientation of the fragments, not even the very small pebbles. It is inconceivable that the pebble orientation was made by water currents since the fabrics show a regional continuity that water would not have produced.

Shelburne basal till is not an uncommon occurrence in the state, but compared to the ablation till, it is much less widespread. The basal till is probably most prominent in the St. Johnsbury region, particularly in the Littleton Quadrangle. In this area, compact, tannish-brown to brown basal till with northeast fabric has been studied along U.S. Route 2 of Lower Waterford and one and one-half miles north of Concord. A hard, compact, blue basal till is exposed in the south valley wall of the Moose River one mile east of the intersection of U.S. Route 2 and State Route 18.

In the Burke Quadrangle, thirty feet of grey basal till with northeast fabric is exposed one mile east of East Burke. One of the few exposures noted during the survey showing ablation till, with northeast fabric covering basal till deposited by ice of the same glacial episode, is located one-fourth mile east of East Lyndon. At this exposure, ten feet of Shelburne basal till are covered with approximately one hundred feet of Shelburne ablation till. A dense, dark olive brown basal till with north-

PLATE X. Northwest striae crossing older northeast striae. One-half mile west of The Four Corners (Lyndonville Quadrangle).

east fabric was found exposed in a road cut on the west side of Town Farm Hill two miles east of Halls Lake (Woodsville Quadrangle). A brown, clayey basal Shelburne till was studied at two localities in the northwest corner of the Lyndonville Quadrangle. One of these was in a road cut one and one-fourth miles northwest of West Glover and the other was in a stream cut along Roaring Brook one and one-half miles north-northwest of West Glover. Crossing striae in this area, one-half mile west of The Four Corners, show northwest striae crossing northeast (Plate X).

Two localities of basal till with northeast fabric were noted in the Mt. Mansfield Quadrangle (Connally, 1967a, p. 20). The first is on the west side of Mt. Mansfield, exposed on a cut bank of a tributary of the Brewster River, one mile northeast of Morses Mill, and the second is just to the north of Cloverdale. Shelburne basal till also occurs in the area of Hapgood Pond on the west side of Mad Tom Notch (Wallingford Quadrangle) and in the Wilmington Quadrangle one mile east of East Dover.

The Shelburne till was first identified in the Burlington Quadrangle along the valley wall of a small, unnamed stream one and one-quarter miles south-southwest of Shelburne (Stewart, 1961, p. 102). At this location, the Shelburne till is a very dark grey, almost black, compact, clayey, basal till varying in thickness from three to twelve feet. The till fabric maximum is approximately N 30° E. The dark grey till is covered by eight to fifteen feet of reddish brown, sandy, basal till with a fabric trending north-northwest. Striae on the bedrock under the Shelburne till at this location trend north-northwest and it is assumed that they were made by a pre-Shelburne ice advance, probably the Bennington. Till of similar description is exposed in a high stream cut on the north side of Lewis Creek two and three-quarter miles northeast of North Ferrisburg (Burlington Quadrangle). Twenty to thirty feet of dark grey Shelburne till are exposed at stream level and the overlying light yellowish-brown Burlington till is approximately fifty feet in thickness.

In the Memphremagog Quadrangle, two exposures of silty, buff Burlington till overlying reddish brown Shelburne till were mapped on the east wall of the Barton River valley two and one-half and three and one-half miles south-southeast of Newport. Bedrock exposures showing northwest striae cutting northeast were found three and four miles south of Newport (south of the airport) where striae trending N 30° W cross striae trending N 20° E and N 30° E. At other exposures,

Figure 1. High till bank exposing Shelburne basal till below Burlington basal till of the West Rutland Moraine. North side of U.S. 4, one mile east of West Rutland (Castleton Quadrangle).

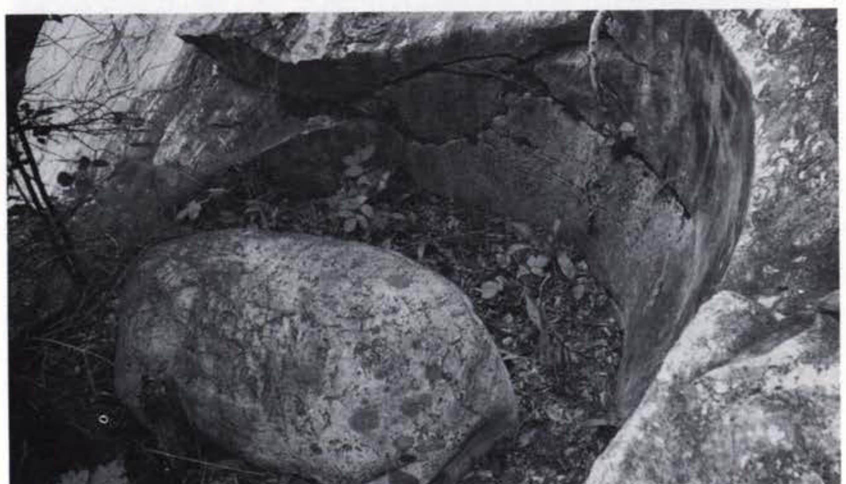


Figure 2. Pothole cut in marble on the east valley wall of Otter Creek one hundred feet above the valley floor. One mile south of Proctor (Castleton Quadrangle).

PLATE XI

two miles northeast of Brownington Center, the crossing striae trend N 35° W (younger) and N 15° E (Figure 17).

In the East Barre Quadrangle, along Jail Brook one mile southeast of the Barre city limits, till with northwest fabric overlies till with northeast fabric in the valley walls on both sides of the stream. On the south side, the two tills are in contact, but on the north side they are separated by over 100 feet of lacustrine silts and clays. Crossing striae in this area were noted at the south end of Berlin Pond (west side) where striae pointing N 15° W and N 30° W cut those that trend N 15° E on several bedrock exposures.

One mile east of Warren (Lincoln Mountain Quadrangle) a dense, blue till with northeast fabric crops out below compact, buff till with northwest fabric. The two tills are separated by ten feet of lacustrine silts. The same two tills are exposed on the north side of Shepard Brook three miles west-southwest of the village of Moretown.

Two miles north of New Haven (Middlebury Quadrangle) a sixty-foot exposure along Little Otter Creek exposes fifteen feet of brown, bouldery Shelburne till (northeast fabric) beneath three to ten feet of clay-rich Burlington till (northwest fabric). Three feet of varved clay separates the two tills, and fifteen feet of pebbly sand and interbedded till lies below the Shelburne till at stream level. Several areas of bedrock exposures with northwest striae crossing northeast are found in the Middlebury Quadrangle. A large area of bedrock was stripped of the overlying till by the Vermont Marble Company two and one-quarter miles southeast of Middlebury. The surface of the rock was highly polished and striae trending northwest covered the entire exposure. Weak, but definite, northeast striae cut by the northwest were found in several places. Crossing striae with the northwest crossing northeast were also recorded three miles north of Middlebury, one mile north of South Starksboro, one-half mile west of New Haven and one mile west-northwest of Monkton.

Till with northwest fabric overlies till with northeast fabric in the Ticonderoga Quadrangle in an exposure along the shore of Lake Champlain, one-half mile southwest of West Bridport. To the east of this exposure in the Brandon Quadrangle striae trending N 15° W cut those pointing N 40° E at Farmingdale and two miles north of Salisbury.

The Shelburne till is exposed in the lower half of a high (over seventy feet) road cut on the north side of U.S. Route 4 one-half mile east of West Rutland (Castleton Quadrangle) (Plate XI, Figure 1). The till at the base of the cut is dark blue to grey buff, very compact and calcareous

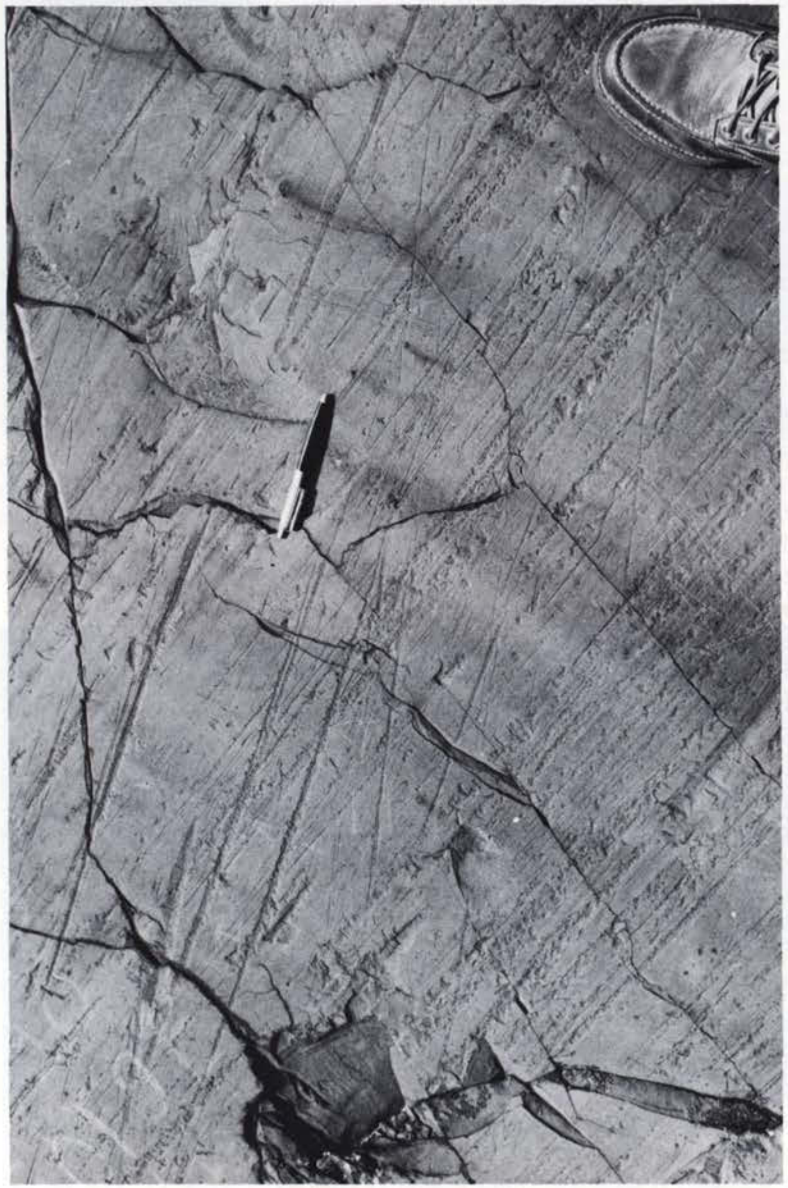


PLATE XII. Northwest striae crossing northeast striae on slate bedrock. Pen points in direction N 10° W. "Ranney Rock," one mile west of Fair Haven (Whitehall Quadrangle).

with a northeast fabric. The till in the top half of the cut is blue-grey, compact and calcareous with a northwest fabric. The upper till is seen, at the top of the cut, to have good morainic topography and to be a part of the terminal moraine of the Burlington drift sheet, as described later. Crossing striae (northwest younger) are exposed on the bedrock at numerous places at the Vermont Marble Company quarries in the vicinity of Florence. The same sequence was noted on bedrock on the east side of Otter Creek one mile northeast of Florence.

A really spectacular exposure of striated bedrock was found on the east side of the Poultney River three-quarters of a mile west of the Fair Haven village limits (Whitehall Quadrangle). This location is immediately north of the bridge where the Sciota Road crosses the river into New York state. The bedrock is slate and apparently a small knoll of rock had been recently uncovered during an exploration for slate. The knoll is covered with glacial striae, grooves and fluting trending both northwest and northeast. That the northwest striae cross the northeast ones here and are therefore younger is distinctly obvious on this single outcrop (Plate XII).

Possibility of Two Northeast Till Sheets

From the above discussion of the Shelburne drift, it is apparent that there are actually two different situations in which the till with northeast fabric orientation occurs which have, generally speaking, two different lithologies. The first of the occurrences is that of the till which forms the surface east and south of the Burlington till and north of the southern margin of the drift sheet lying between Bennington and Brattleboro. In this region, the surface is chiefly the loose, sandy, ablation till. The second situation in which the till with northeast fabric orientation occurs is under the Burlington till in the northwestern part of the state. In this latter region the Shelburne till is a compact, basal till containing a higher percent of silt and clay than the ablation drift.

It has been assumed during the mapping program, and it still is, that the loose, surface till and the basal till under the Burlington, both with northeast fabric orientation, were deposited by the same glacial invasion. This assumption was made inasmuch as no evidence was found that would indicate that they were deposited during different glacial stades. It is equally true, however, that the evidence to prove they are of the same ice episode has not, as yet, been found. In spite of the fact that the discussions in this report assume that both occurrences of the tills with northeast fabric orientation are of the same age, and of an earlier glacial stade than the Burlington, three alternate interpretations that come to mind are noted here.

Alternate Interpretation I. The first alternate interpretation assumes that the surface ablation till is of a younger age than the basal till below the Burlington. The younger till, according to this interpretation, could be of a later glacial stade or perhaps of a readvance of the ice during the same stade that deposited the basal till. In either case, the ablation till is older than the Burlington drift. This interpretation best explains the concept of readvance of the ice to the south in the Connecticut River valley as noted by Flint (1956) and Colton (1968). This problem is discussed in a later chapter on correlation.

Alternate Interpretation II. A second interpretation of the data assumes that the Shelburne surface till is of the same glacial episode as the Burlington till. The till was deposited by an ice invasion from the northeast that spread out from a lobe in the Connecticut Valley. The large area covered by the surface ablation till, it seems to us, would require a separate invasion, from a center to the northeast, contemporaneous with the Burlington invasion from the northwest.

Alternate Interpretation III. The third possible interpretation assumes that the surface till with northeast fabric was deposited by a lobation of the Burlington ice. This is the interpretation of Shilts and Behling (1967) based on evidence found in southwestern Vermont. They believe that the till with northeast fabric was deposited as the Burlington ice thinned to still-active lobes in the major valleys such as the Connecticut Valley, the Champlain Lowland and the Vermont Valley. In the wider valleys, the lobes had ice movement toward both margins producing evidence (fabric, striae, etc.) of northeast to southwest movement along the western edge of the lobe and northwest to southeast movement along the eastern edge. In narrow valleys, such as the Vermont Valley, all movement was parallel to the valley.

Each of the above alternate interpretations separates the two kinds of northeast till into two different glacial stades. It seems to the writers that if the Burlington and the Shelburne surface tills were of the exact same age that interlobate moraines and other features should mark the zone along which they were in contact.

Moraines Composed of Shelburne Till

As has been noted earlier in this report, moraines are not widespread in Vermont. There are scattered over the area of Shelburne drift many

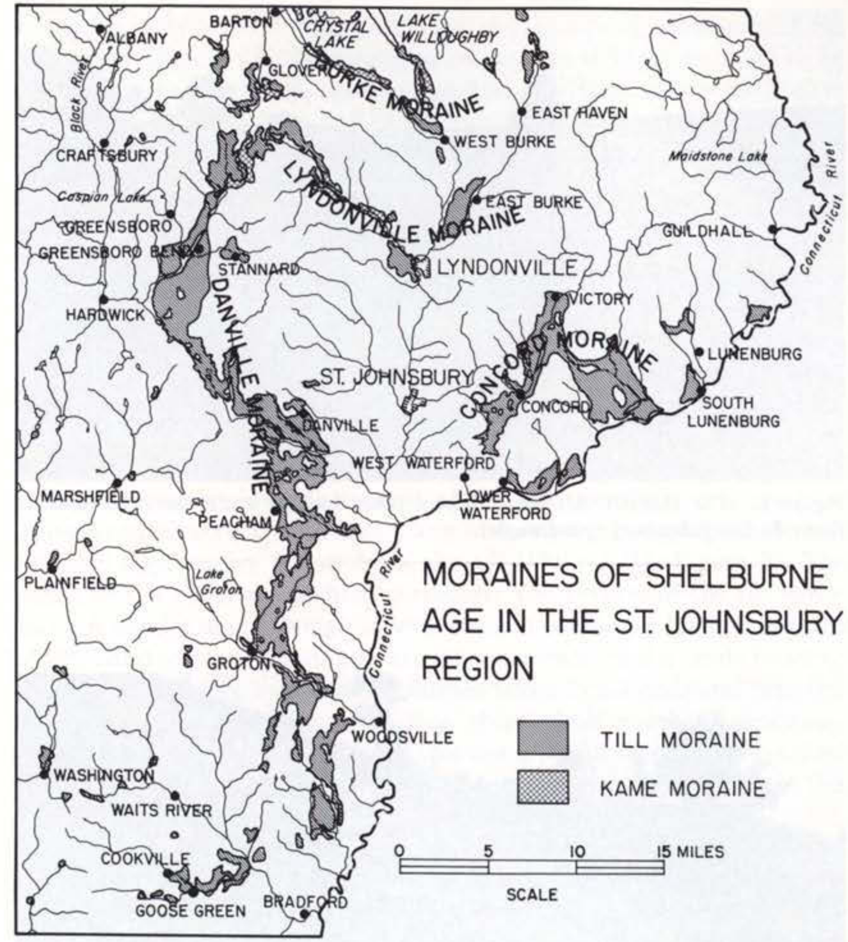


Figure 7

small and insignificant moraines composed of Shelburne ablation till. There are only three regions in which the moraines are of enough significance or size to warrant discussion. These are the St. Johnsbury region in northeastern Vermont, the Rutland section in the west-central region and the Manchester-Bennington area of the southwestern corner of the state.

Moraines of the St. Johnsbury Region. Undoubtedly the most significant moraines composed of till with northeast fabric are those

Figure 1. The Danville Moraine. Picture taken looking south one mile south of Danville (St. Johnsbury Quadrangle).

Figure 2. Shelburne ablation till of the Danville Moraine exposed in a rain-washed road cut at Goose Green (East Barre Quadrangle).

PLATE XIII

located mostly in the triangle formed by Bradford, Barton and St. Johnsbury (Figure 7). The moraines are, at this writing, assumed to be of Shelburne age although another possible correlation will be outlined in the discussion that follows. All of the moraines in this area are composed of till, with the exception of a few kame moraines that are included in the system.

The most westerly of the moraines of this system is an almost continuous till moraine trending north-south and extending northward from the hamlet of Goose Green, seven miles west of Bradford, to Parker Pond, two and one-half miles west of Glover. The moraine, designated the Danville Moraine in this report, is fifty miles long, is generally one-half to four miles wide, and exhibits a conspicuous morainic topography throughout its width and length (Plate XIII, Figure 1). To the writers' knowledge, this is one of the largest and best developed moraines in northern New England. Because the till in the moraine is very sandy and contains fewer boulders than most of the ablation drift, it is used for gravel road construction so that many borrow pits throughout its length afforded opportunity for study of the till (Plate XIII, Figure 2). The fabric of the till is everywhere northeast. The texture of the till varies but it is always sandy though in some areas it contains a high percentage of silt. Sand lenses and stringers are quite common, and a crude bedding is apparent in some sections. Till fabrics taken in till near and between the well-sorted sand concentrations show clear northeast maxima. Apparently the pebble orientation was not affected by the water action that deposited the sand. The moraine has good relief, particularly in the Danville section where it was first studied and named.

A second well-developed moraine in this section of Vermont is called the Concord Moraine in this report. This moraine, with a shape similar to an inverted "V", trends northeast from the north side of Hulburt Hill, one and one-half miles northeast of West Waterford (Littleton Quadrangle), through Concord to the vicinity of Victory (Burke Quadrangle), and then southeastward to the Connecticut River at South Lunenburg (Whitefield Quadrangle). Whether or not this moraine continues eastward into New Hampshire is not known at this time. The Concord Moraine is composed of both basal and ablation till.

A small morainic accumulation trending in an east-west direction along the north side of the Connecticut River east of Lower Waterford may well be a part of the Bethlehem Moraine that has been described by Crosby (1934, p. 415) south of the river in New Hampshire. For this reason, a name is not suggested for this moraine in this report.

A group of small till and kame moraines follow the Miller River valley from south of Sheffield Heights southeastward to Lyndonville and thence northeastward to the north of East Haven (Lyndonville and Burke quadrangles). This moraine is designated the Lyndonville Moraine. Another group, more or less paralleling the first, occupies the Sutton River valley between Willoughby and West Burke and then it turns northeastward to a point south of Burke (Burke Moraine of Figure 7).

The geologic significance of the moraines in the St. Johnsbury region is not definitely known at this time. Two possible interpretations seem plausible. In the first place, these moraines may be recessional moraines of the Shelburne glacier inasmuch as no evidence was found during the survey that would prove them to be otherwise. According to this interpretation, the presence of the moraines in this area, in contrast to the absence of moraines elsewhere, might be explained by the fact that the topography is more subdued. As a result, retreat of the ice occurred rather than stagnation and downward melting. The geological significance of these deposits, if they are recessional features, would be minimal.

A second interpretation of the moraines of this region might be possible. Undoubtedly these are a part of the same morainic system as the Bethlehem Moraine located to the southeast in New Hampshire (Crosby, 1934a, pp. 414–15). The notion that the moraines in the vicinity of Bethlehem, New Hampshire, were terminal moraines of a local ice advance from the White Mountains was, as previously said, first proposed by Agassiz (1871, p. 554). C. H. Hitchcock (1908a, pp. 177–78) extended the White Mountain glaciation past the Hanover Quadrangle and suggested a Connecticut Valley lobe down that valley. Antevs (1922a; 1928), from the study of disturbed varves and interbedded glacial deposits proposed an ice readvance as far south as the mouth of the Passumpsic River, eight miles south of St. Johnsbury. Crosby (1934a, pp. 419–21) studied the Bethlehem Morainic System in New Hampshire and the excavations for the site of the Fifteen Mile Falls Dam (Monroe, New Hampshire) and concluded that the moraines marked the terminus of a local ice readvance. Flint (1953, p. 908) suggests that these deposits mark the border of the Mankato-Port Huron drift sheet.

More recently, data reported from Quebec (Gadd, 1964; McDonald, 1967a), Maine (Borns and Hager, 1962; Borns, 1966) and for other areas of New England (Schafer, 1967) have renewed interest in a possible local ice cap in northwestern Maine and/or the White Mountains. The new evidences concern the fact that C^{14} dates over these areas seemingly cannot be explained by a single ice retreat. Other evidences that seemed

to indicate ice movement into southern Quebec from the south have been disproven by McDonald (1967a).

In spite of the fact that the investigations of the surficial deposits in the St. Johnsbury area, by the recent survey, found no suggestion of an ice readvance or a local glaciation from the White Mountains, it is equally true that the necessary evidence to disprove such an hypothesis was not discovered. This report therefore does not discount the possibility. The fabrics made of the till composing the moraines, the characteristics of the till and all other data collected in this area, however, were comparable to similar data collected from the studies of the Shelburne tills south and west of the moraines.

Shelburne Moraines of the Rutland Region. A second morainic belt that is of relatively large size is located in the Rutland Quadrangle. The moraine is actually a two unit system comprised of a kame moraine to the east and an ablation till moraine immediately to the west of it. The moraine trends in a north-south direction and follows the western slope of the Green Mountains the entire length of the quadrangle. The kame moraine is continuous except for a short distance on the northwest slope of Bald Mountain; it exhibits a well-developed kame and kettle topography, and it drapes the slopes of the mountains to elevations of 1,000 to 1,500 feet. The gravel composing the moraine is very sandy, is relatively thick and numerous gravel pits are located throughout its length. The ablation till moraine, located immediately to the west of the kame moraine, has a more subdued, but very definite, morainic topography. The till composing the moraine, with a typical northeast fabric maximum, is thin, but the surface is strewn with large boulders many of which are striated, faceted, and rounded. North of Rutland the till moraine is less continuous and ends in the vicinity of Chittenden. The two units are collectively designated the Mendon Moraine in this report inasmuch as the village of Mendon is located at the top of the moraine at its contact with the slope of Mendon Mountain.

Moraines of the Manchester-Bennington Region. It is apparent that the last ice that moved down the Vermont Valley, south of East Dorset, did actually recede northward since recessional, cross-valley or loop moraines mark the position of still stands during the ice withdrawal. These moraines are composed predominantly of gravel and include the Manchester Moraine (Manchester Depot-Barnumville section), the Arlington Moraine (south of Arlington) and the Hale Mountain Moraine (north of Shaftsbury) that will subsequently be described under the heading of outwash deposits of Shelburne age (Figure 8). This report assigns a Shel-

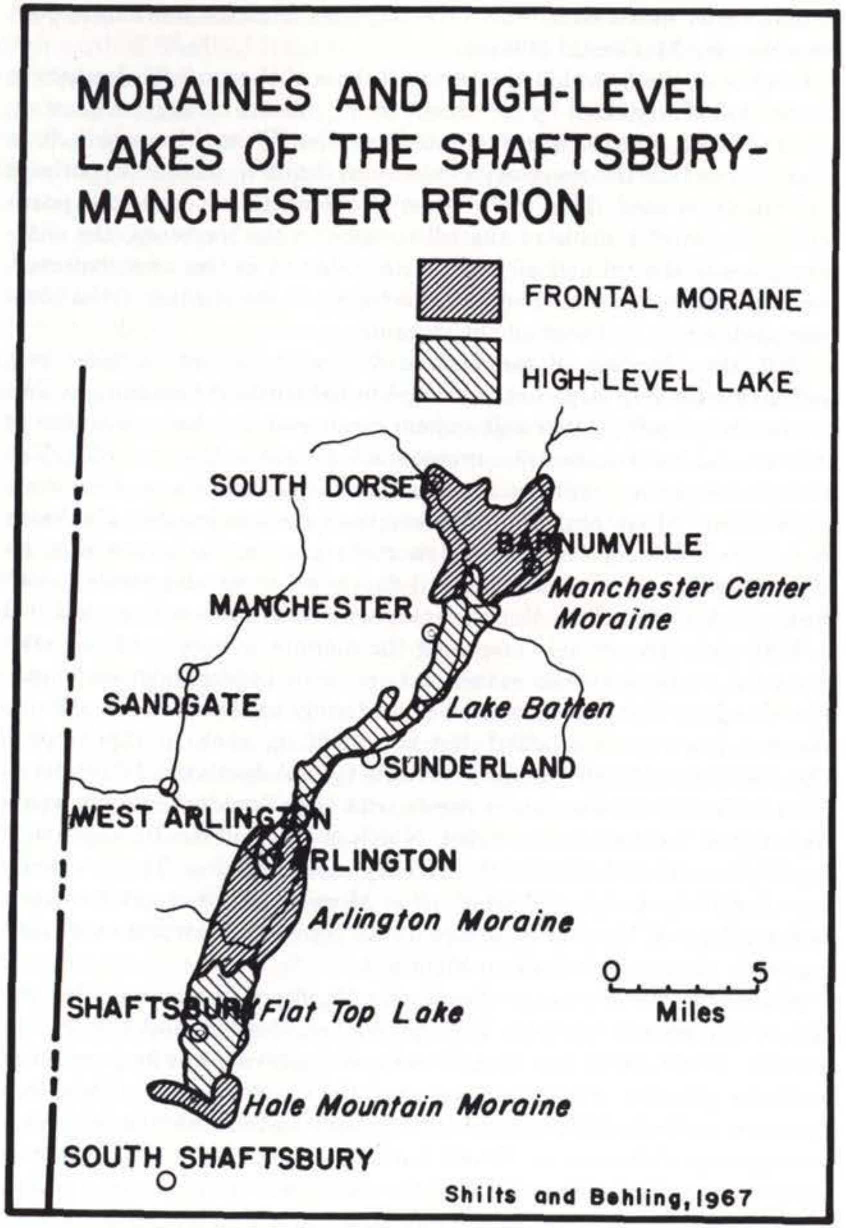


Figure 8

burne age to these moraines. The age of the drift is still an open question, as has already been noted, and there are three other possible interpretations, based on the same data, concerning the glacial stade that deposited the Shelburne drift.

Shilts and Behling (1967), who mapped the southwestern corner of the state (Bennington, Wilmington, Equinox, Pawlet and Londonderry quadrangles), have proposed a different correlation for the moraines of the Manchester-Bennington region. Their interpretation places more emphasis on the source of the rock found in the drift of the Vermont Valley and the influence of the topography on the direction of the ice movement. Briefly stated, their hypothesis contends that there are no indicators in the valley derived from the rocks of the Green Mountains although the fabric of the till is oriented northeast-southwest, approximately the same as the direction of the valley. They therefore conclude that the last ice advance into the valley must have been a Burlington ice lobe that moved down the valley from Rutland. According to Shilts and Behling, the moraines of this section of the valley, therefore, would be correlated with the Burlington Glacial Stade (Behling, 1966; Shilts, 1966; Shilts and Behling, 1967). Their correlation is more in accord with Hypothesis III, already discussed, inasmuch as they believe that the surface till with northeast fabric orientation was deposited by active lobes of ice deflected down the major valleys during the waning stages of Burlington glaciation (Shilts, personal communications).

The southwestern part of Vermont was mapped during the final field season of this survey (1966) and there have been no opportunities for our groups to discuss together, in the field, the conclusions and implications of the region. The adjacent area of New York state has not been studied so that comparisons could not be made.

The writers mapped the Rutland, Castleton and Wallingford quadrangles and the fabric orientation of the till in that area seemed to show that the Burlington ice did not enter the Vermont Valley south of Rutland. We therefore suggest that, if the Burlington glacier did occupy the valley in the Manchester-Bennington section, it could have moved into the region from the Lake St. Catherine depression and the Mettawee-Batten Kill valleys. Behling (personal communication), however, does not believe that the ice moved through these valleys. Shilts and Behling believe that the scattered exposures of till with northwest fabric orientation are Burlington in age and argue that many of the tills with northeast fabric orientation were deposited by the same ice moving parallel to the valley. Their objection to a stadial ice invasion from the northeast is based on the absence of gneissic rock from the Mount Holly complex. This report, therefore, tentatively designates the till in the valley with northwest fabric orientation as Bennington and those with northeast fabric as Shelburne as shown in Figure 6. We do so, nonetheless, with the reservation that the above evidences may prove that a different classification is necessary.

Outwash Deposits of Shelburne Age

Outwash materials deposited during the Shelburne Stade are scattered over the region covered by the Shelburne ice (Plate XV, Figure 2). The outwash deposits are limited to kame gravel contained in terraces, moraines and eskers. Most of the accumulations are small, isolated deposits that are not large or thick enough to be of economic importance with the exception of those located in the southwestern part of the state in or near the Vermont Valley.

Kame Gravel Deposits. Kame terraces and kame moraines are widely scattered over the area covered by the Shelburne drift. Kame moraines are seemingly more numerous than similar deposits of the later (Burlington) ice advance and kame terraces are probably less widespread. The kame deposits of Shelburne age are not as well developed or as massive as those of Burlington age.

The Shelburne kame deposits located in valleys formerly occupied by ice-marginal and post-glacial lakes are more sandy and silty than those in other areas. In addition to the fact that the deposits are, in general, thin and often too sandy, the economic quality of the gravel is also influenced by the kind of rock it contains. As in the case of the ablation till, the gravel contains a high percentage of local bedrock. Inasmuch as most of the bedrock in the area covered by the Shelburne ice is highly metamorphosed, foliated, and contains micaceous and chloritic gneisses and schists, the gravel is composed of soft fragments and does not wear well. In addition, gravel composed of this type of rock weathers easily and is therefore rapidly discolored and decomposed. As a result of the weathering, the gravel becomes even less desirable for highway and construction purposes.

The most widespread and massive kame deposits of Shelburne age are in the Vermont Valley in southwestern Vermont. The valley walls from South Wallingford to South Shaftsbury are draped, more or less continuously, with kame terraces on either or both sides of the valley. The valley floor, in this area, is covered with kame moraine in several sections south of East Dorset. The kame terraces rise high above the valley floor,

two to three hundred feet in most deposits. As already stated, the valley is completely filled with massive moraines, mostly kame, in the Barnumville-Manchester Depot area (Manchester Center Moraine), south of Arlington (Arlington Moraine) and north of Shaftsbury (Hale Mountain Moraine) except where the gravel has been removed by the Batten Kill River (Figure 8). Several small kame (loop) moraines extend across the valley marking positions where the retreating ice was stable for a short period of time. The valley of the West Branch of the Batten Kill is also occupied by kame moraines between Manchester Center and South Dorset.

There is a large reserve of good to excellent quality gravel in the Vermont Valley. The bedrock is durable and, as a result, the gravel wears well. The gravel is sandy in some areas and bouldery in others, but good gravel is usually near. The fact is, gravel is so plentiful in the region that there are very few working pits inasmuch as small pits can be located near where they are needed.

Kame gravel deposits are scattered throughout the Connecticut River valley and its tributaries. The amount of kame gravel in the main valley, however, is much less than it was formerly thought to be, even at the time of the publication of Bulletin 19 (Stewart, 1961). Much of the gravel in the valleys of the Connecticut River and its tributaries in Vermont that was formerly thought to be kame terrace has been reclassified as lacustrine gravel and pebbly sand deposited during the shoaling stage of the Connecticut Valley lakes (Lake Hitchcock). Most of the kame gravel is therefore found along the tributary streams and even here reclassification has diminished the extent of the kame deposits. The most important deposits of the tributary valleys include: the West River valley in the Newfane-Townshend-Jamaica section; the Black River valley north and east of Ludlow; and the White River valley in the Sharon, Bethel and Gaysville sections. Kame moraines are almost nonexistent in the Connecticut River valley except in those areas described below in the discussion of eskers.

The gravel contained in the kame deposits of the Connecticut River and the tributary valleys varies greatly from place to place. In general, the gravel is of low quality due to the high content of sand, caused by slack water conditions during deposition, and the soft, easily weathered metamorphic rock contained in it.

Eskers. Since eskers are of general interest and an excellent source of gravel this section describes some of the more important eskers in the area of Shelburne Drift.

Figure 1. Erosional topography of Lake Hitchcock silts and clays in the Connecticut River valley. West of U.S. Route 5, three miles north of Windsor (Hanover Quadrangle).

Figure 2. Varved and laminated Lake Hitchcock silts and clays that overlie gravel of the Passumpsic Valley Esker. Gravel pit exposure at the southern limits of St. Johnsbury (St. Johnsbury Quadrangle).

PLATE XIV

The Connecticut Valley Eskers. The literature records an esker in the Connecticut River valley twenty-four miles long that supposedly reached from Windsor, Vermont, to Lyme, New Hampshire (Jacobs, 1942, p. 42). The esker, according to Jacobs, is "unbroken save where the river has cut across it." The study of this part of the valley during the survey, however, does not bear out the existence of such a feature. Because of the lack of good roads, Jacobs had to project across gaps that we now know interrupt the continuity.

There is a short esker-like ridge just north of the village of Ascutney, three miles south of Windsor, but there are no gravel deposits between this structure and Hartland except a small kame terrace two miles north of Windsor. There are a few, scattered, small kame moraines between Hartland and North Hartland and no other similar features between North Hartland and the White River at White River Junction. North of the White River a kame moraine extends from near the river northward to the vicinity of Wilder. A ridge of kame gravel that was mapped as an esker by the present survey starts two and one-half miles south of the mouth of the Ompompanoosuc River. It is almost continuous to East Thetford, a distance of seven miles.

Investigations were not carried out on the east side of the Connecticut River during the survey, but contours on the topographic map have been studied and these do not suggest a continuous esker ridge. It seems most likely that the ridge extending southward from East Thetford to south of the Ompompanoosuc is a part of an esker described by Goldthwait, Goldthwait and Goldthwait (1951, p. 38) which they said extended for fourteen miles down the Connecticut River from Lyme to West Lebanon, New Hampshire.

The Passumpsic Valley Esker. The most impressive esker in Vermont is a ridge of gravel extending for twenty-four miles in the Passumpsic River valley. The south end of this feature is two and one-half miles upstream from the mouth of the river and from this point it is almost continuous to East Haven. The esker is on the west side of the river from its southern end to St. Johnsbury where it crosses the river, whence it continues on the east side past Lyndonville and East Burke to the vicinity of Hartwellville. North of Hartwellville, the river has a meandering course and cuts through the esker at several places. State Route 114 follows close to the esker between Lyndonville and East Haven and in some sections the highway follows the crest of the ridge and in other sections the highway crosses over it.

The Passumpsic Valley Esker is highest and most massive in the vi-

Figure 1. Esker in Chandler Brook valley one mile north of West Waterford (Littleton Quadrangle).

Figure 2. Outwash (spillway) gravel exposed in a gravel pit one mile north of West Waterford (Littleton Quadrangle).

PLATE XV

cinity of St. Johnsbury and for approximately three miles north of the village. In this section, however, the ridge is almost buried with lake sediment so that only the higher crests rise above the sediment and are exposed at the surface (Plate XIV, Figure 2). Two good cross-sectional exposures are found in the St. Johnsbury section. One is where the ridge crosses the river at St. Johnsbury and the other is two miles north of the village where the esker is crossed by Roberts Brook.

Many small eskers were mapped during the survey and are shown on the state map. Some of these are: 1) a ridge four and one-half miles long, one mile south of Bennington; 2) an esker in Chandler Brook valley two and one-half miles long (Littleton Quadrangle) (Plate XV, Figure 1); 3) one immediately west of Manchester Center (Equinox Quadrangle); 4) one three miles long trending south from Evansville (Memphremagog Quadrangle); and 5) a ridge two and one-half miles long, one mile west of West Fletcher (Mt. Mansfield Quadrangle).

High-Level Ice-Contact Lakes of Shelburne Age

Deposits made in high-level, ice-contact lakes were mapped during the present survey along the Connecticut River valley and in the southern part of the Vermont Valley. It is postulated that these ice-dammed lakes were in existence during the melting stage of the Shelburne glaciation and were therefore recessional features.

High-Level Lakes of the Connecticut River Valley. There are numerous occurrences of lacustrine sediment deposited in high-level lakes in the valleys of the eastward-flowing tributaries of the Connecticut River. There are also scattered deposits along the Connecticut River that were made in slack water ponds higher than the deposits of Lake Hitchcock. As noted above, it is assumed that these lakes occurred during the final melting stages of the Shelburne ice. It is not believed, however, that the ice actually did recede inasmuch as all of the evidence seems to show that the glacier thinned as it waned to the level of the mountain tops, stagnated between the mountains, and melted down in situ. The stream valleys were therefore the last areas to be free of ice (Stewart, 1961, pp. 47–53). If ice recession did occur, or if a local ice lobe did move down the valley, the high-level lakes and the moraines of the St. Johnsbury region, described earlier, may be related in time.

It was necessary to establish the position of the deposits made during the stability stage (Lake Hitchcock) by plotting the elevations of the tops of the littoral deposits on a longitudinal (north-south) coordinate and constructing a profile of the tilted plane of these sediments (Figure

11). The high-level lakes are thus defined as those lakes that stood higher than the elevation on that plane at the same latitude. Certain shore deposits in the valley occur below the Lake Hitchcock sediment, but these do not conform to any particular profile made by a lower stable lake in spite of the fact that some of them may have been formed during the lowering of the lake. The lower deposits more probably were formed below water level in Lake Hitchcock or they may have been subsequently lowered by erosion.

One of the highest of the lake levels is found in the Brattleboro area. The top of the sediment of Lake Hitchcock is at an elevation of 450 feet at Brattleboro, but a series of lakes are shown by the deposits of the Whetstone Brook valley, west of Brattleboro, to elevations up to 1,000 feet. A well-developed delta to the west of Richardson Mountain, four miles west-northwest of Brattleboro, has a top elevation of 1,000 feet. The delta was apparently formed by Halladay Brook that must have entered an ice-contact lake at that point. Lake gravel on the east side of Richardson Mountain has an elevation of 800 feet. A lake at 600 feet extends up Whetstone and Halladay brooks from West Brattleboro for a distance of two miles. Lake sediment on the west and south sides of the City of Brattleboro is at 500 feet. Another deltaic deposit in this area occurs at 800 feet on a tributary of Broad Brook, two and one-half miles west-southwest of Guilford and beach gravels along another tributary, one mile southeast of Guilford rise to 550 feet. The lake waters in which these sediments were deposited may have existed along the terminus of the Shelburne ice when it stood along the slopes of the mountain west of Brattleboro (Figure 5), but it seems more likely that they were ponded by stagnant ice after the glacier had dissipated.

Lacustrine sediment higher than Lake Hitchcock is also found along the slopes of the Connecticut and West River valleys. The Lake Hitchcock level at the Massachusetts line is 415 feet, but lake sediments just north of the border, in the Vernon area, are in places 500 feet in elevation. Lake gravel along the West River north of Brattleboro, in the vicinity of the country club rises to the 600-foot contour and pebbly sand is commonly 500 to 550 feet upstream in the West Dummerston-Townshend reaches of the river.

The deposits of a most interesting group of high-level lakes occur in the Ludlow and Claremont quadrangles along the valley of the Williams River. The top sediment of Lake Hitchcock in this section rises from 550 feet at Rockingham to 595 feet at Weathersfield Bow. In the valleys of the Middle Branch of the Williams River and its tributary Andover

Branch, west of Chester, the lacustrine sediment has elevations between 1,150 and 1,200 feet. A delta at 1,150 feet is perched on the hill just south of the Chester reservoir, two miles northwest of Chester. Deltaic sediment fills the valleys of Middle and Andover branches to the 1,200-foot contour for three miles upstream from the confluence of the two streams. The main branch of the Williams River contains gravel to 700 feet north of Chester and to 680 feet in the village. The lacustrine gravels are generally above 600 feet downstream from Chester to Brockway Mills, and in one area along what must have been the former valley of Hall Brook, three miles southeast of Chester, the elevations are 750 to 800 feet.

The deposits of high-level lakes occur in the upper reaches of the Ottauquechee River (Woodstock Quadrangle). Lake sediment to 1,100 feet is well formed in the North Branch Valley, two and one-half miles north of Bridgewater Corners and along Broad Brook one mile south of the river. At Bridgewater, lake gravel and a small, sandy delta mark a lake level at 950 to 1,000 feet south of the Ottauquechee. Two miles south of Woodstock, the top of the lake sediment on either side of Kedron Brook is at an elevation of 800 feet. The elevation of the Lake Hitchcock sediment in the Hanover Quadrangle, due east of Woodstock, is 700 feet.

A small delta at 1,000 feet elevation marks a high-level lake in Chandler Brook valley (Littleton Quadrangle). The delta is located three miles north-northeast of West Waterford, and lake sands show the lake extended northeastward through Duck Pond and the south end of Stiles Pond to a point one and one-half miles west of Concord.

High-level lacustrine sand deposits occur along Paul Stream and Granby Stream in the Guildhall Quadrangle. The sands in Granby Stream are 1,400 feet in elevation west of the south end of Maidstone Lake and at 1,200 feet in Paul Stream southwest of Browns Mill.

A lake, or a series of lakes must have occupied the Connecticut River valley north of Guildhall, prior to the Lake Hitchcock stage, inasmuch as lacustrine sands are sixty feet above the Hitchcock level at Guildhall, Brunswick Springs and Bloomfield. The consistent difference in elevation between the higher sediment and the Lake Hitchcock level seems to imply a single lake. The valley widens north of Lunenburg and the lake may have been along the sides of an ice block (or blocks) when the water stood at the high-level.

High-Level Lakes of the Manchester-Bennington Region. When the margin of Shelburne ice stood at or near its terminal position in the Bennington area a large lake developed in essentially the same area as that of

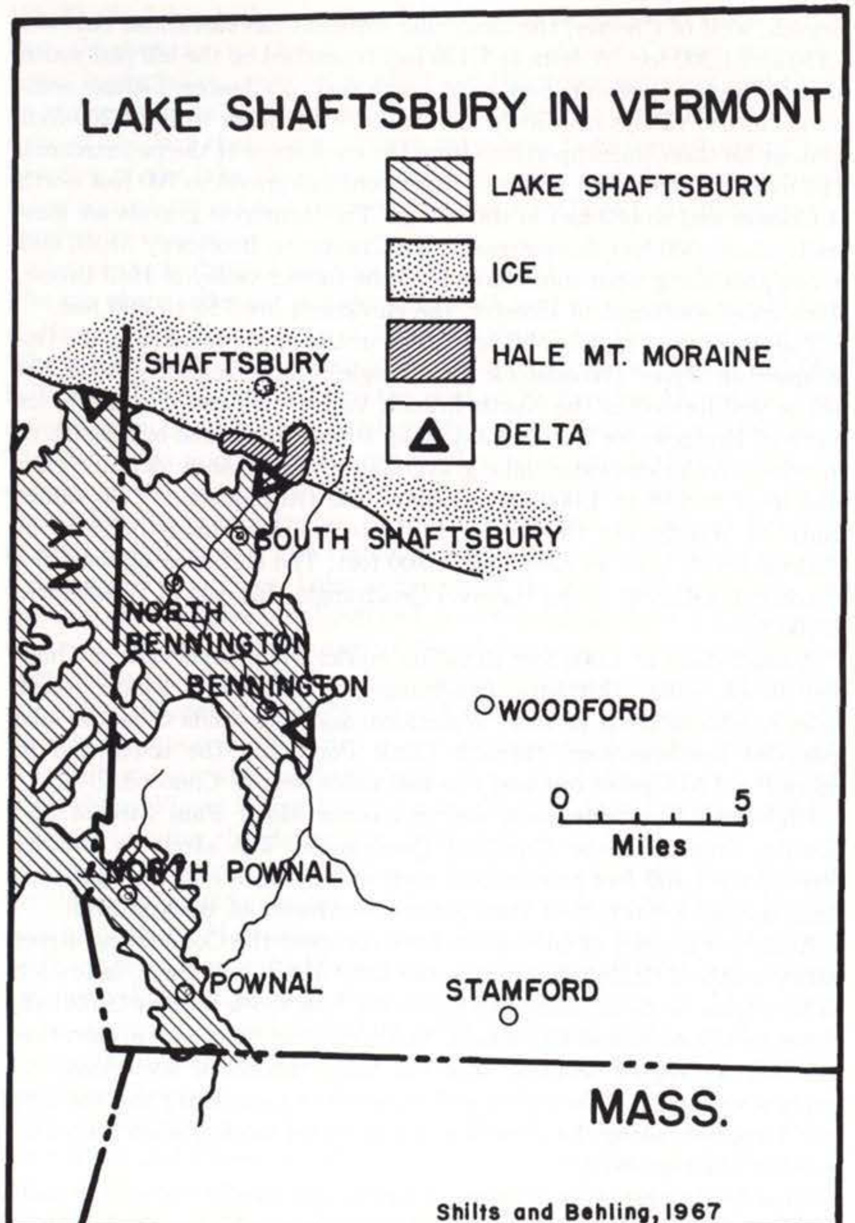


Figure 9

Lake Bascom, but at a lower level, during the retreat of the Bennington glacier. The lake, designated Lake Shaftsbury (Shilts, 1966) with an outlet at Patter Hill, New York, was in existence until the Shelburne ice deposited the Hale Mountain Moraine. The northwest shore of the lake followed a morainic system that extends from Hoosic Falls, New York, northward to the Taconic Mountains and, at its maximum extent, the Hale Mountain Moraine formed the north shore. The strand-line deposits made in Lake Shaftsbury, now at an elevation of 900 feet, are evidence of a lake at that level (Figure 9). After the ice waned from the Hale Mountain Moraine, Lake Shaftsbury drained completely (Shilts, 1966).

As the ice-edge moved back from the Hale Mountain Moraine, lake waters were impounded behind the ice-cored moraine that existed until after the deposition of the Arlington Moraine. The lake that existed between the two moraines (Hale Mountain and Arlington) at an elevation of 1,000 feet, is designated the Flat Top Lake inasmuch as a massive, flat topped, ice-contact delta was built into the lake that now protrudes from the distal margin of the Arlington Moraine (Figure 9).

The Arlington Moraine was ice-cored and acted as the dam for a lake, designated Lake Batten, that occupied the valley from the Arlington Moraine north to the Manchester Moraine (Behling, 1966). The shore deposits of Lake Batten now stand at an elevation of 720 feet (Figure 8).

It has not been established whether or not the Flat Top Lake and Lake Batten were in existence at the same time. The lakes did not exist for a long period of time. The morainic dams were no doubt rapidly eroded as soon as the ice-core had melted.

Eastern Margin of the Shelburne Drift

In an effort to clarify some of the problems involving the Shelburne drift in eastern Vermont, preliminary studies were made of several exposures of the tills east of the Connecticut River in New Hampshire. The Shelburne till was identified, on the basis of till fabric, in a belt five to ten miles wide east of the river (Figure 10). East of this belt the fabrics of the surface till were northwest, indicating the Bennington. The Shelburne drift is commonly found as ground moraine, exposed in borrow pits or road cuts, composed of either basal or ablation till. One mile northeast of Westmoreland, however, the till forms a morainic ridge a mile or more long trending in a north-south direction (Plate XVI, Figure 1). The ridge, over a hundred feet high, has a crest approximately a quarter of a mile wide with a morainic topography of sharp crests and undrained depressions. A one hundred-foot exposure of basal till, made when the road was improved at the south end of the moraine, demonstrates that it is composed of till. A good northeast maximum to the till fabric (vector mean N 28° E) shows it to be Shelburne.

A mile south of Meriden, a sixty-five-foot exposure at the south end of another ridge of till displays twenty-five feet of buff Shelburne ablation till having northeast fabric (vector mean N 19° E) above forty feet of dense Bennington basal till which has northwest fabric maximum (vector mean N 30° W). A ten-foot layer of lake sediment separates the two tills and demonstrates an ice-free interval between the Bennington and Shelburne stades.

Excavations for a shopping center, under construction in 1966, three miles southwest of Claremont, also exposed two tills. A ten-foot deep pit at the north edge of the construction site was dug in dense, buff, calcareous basal till which yields a till fabric with a clear northeast maximum (vector mean N 30° E) indicating that it is Shelburne till. At the south edge of the construction, excavation into a low mound exposed two tills without any clear-cut line of demarcation between them. It was only by making till-fabric analyses that it was found that the lower blue-grey, basal till had a northwest fabric maximum (vector mean N 30° W), whereas the upper buff-colored, basal till had a northeast fabric maximum (vector mean N 39° E). Both tills were found to be calcareous. Oxidation had penetrated through the upper till and two or three feet into the top of the lower till. The upper till is therefore thought to be the Shelburne and the lower to be the Bennington.

Origin of the Northeast Fabric Along the Eastern Margin. Along the eastern edge of an ice lobe, one should expect ice movement from the northwest toward the southeast. Such a movement should produce till fabrics in the drift along this margin with maxima toward the northwest. The northeast fabric orientation, consequently, poses a question about the drift lying between the Connecticut River and the White Mountains. Can the northeast fabric orientation still be used to correlate the Shelburne drift here on the eastern margin as it was done out in the middle of the lobe in central Vermont? Two hypotheses are proposed which might explain the phenomenon and retain the correlation as valid.

Piggy-Back-Ride Hypothesis. The first hypothesis suggests that a northeast fabric was produced to the north in a tectonite of actively moving, debris-laden ice of the Shelburne advance. The tectonite was later sheared up into the stagnant-ice part of the glacier. From here, it was carried bodily in "piggy-back" fashion, on flowing ice below, to the

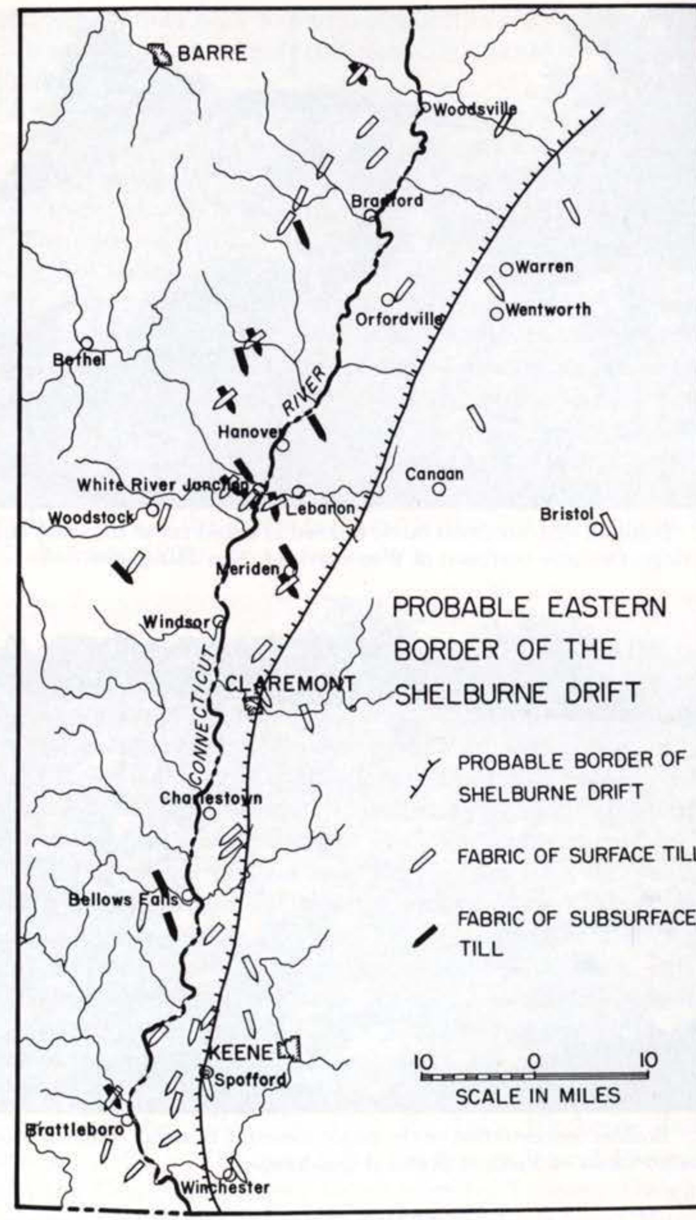


Figure 10

Figure 1. Basal till with northeast fabric exposed in a road cut at the south end of a morainic ridge. One mile northeast of Westmoreland, New Hampshire.

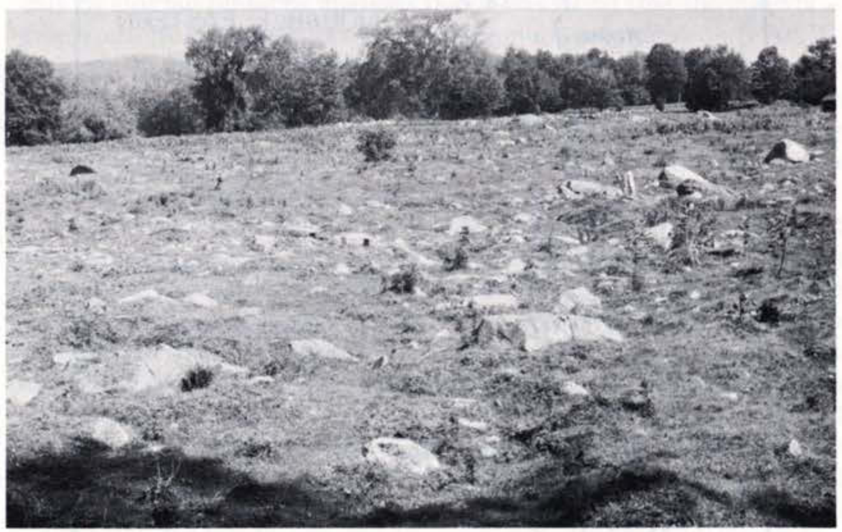


Figure 2. Boulder concentration on the slopes above the Rutland Terminal Moraine. Two miles northeast of Rutland (Rutland Quadrangle).

PLATE XVI

eastern edge of the lobe where final stagnation and down melting slowly let it down on to the ground, still retaining its original northeast fabric orientation.

Marginal Shear Hypothesis. Where ice lobes spread out onto flattish country, ice motion is, of course, outward toward the end and side margins. In this case, the till fabrics do coincide with the movement. But where the margin lies against a valley wall or the foot of a mountain mass, the movement is parallel to, and retarded by, friction along the contact, and shear takes place between the slow moving ice at the edge and the more rapidly moving ice toward the center. This shear could be actual rupture of differential laminar flow within the ice. In either case, debris within the ice would become oriented in the direction of the shearing motion and in that way develop a fabric oriented in the direction of shear. Examples of such motion and its resistant shear are widely recognized in mountain glaciers and are noted in the literature. A recent paper on the Antler Glacier in Alaska describes well the phenomena and produces diagrams and discussion pertinent to the idea (Hashimoto, Shimizu and Nakamura, 1966).

THE LAKE HITCHCOCK INTERSTADE

The most widespread manifestations of an ice-free interstade following the Shelburne glaciation is found in the lacustrine deposits of the Connecticut River valley and its tributaries. The major portion of the lake sediment in these valleys was deposited in a lake that formed during the retreat of the Shelburne ice sheet. The lake, however, remained in the valley long after the glaciers had melted. The lake, or perhaps more correctly the lakes, that occupied the valleys of the Connecticut River system at this particular time has been noted in the literature under several different names, the most familiar undoubtedly being Lake Hitchcock. The designation Lake Hitchcock is used in this report to designate the one major stable lake episode recorded in the sediments on the west side of the Connecticut Valley and the valleys of its eastward flowing tributaries in Vermont. The ice-free interval during which the lake occupied the valleys is called the Lake Hitchcock Interstade.

Emerson (1898, p. 609) stated that the first geological discussions of a lake in the Connecticut River valley were by Timothy Dwight in his *Travels in New England* published in 1822 and by Edward Hitchcock in

1824. The Hitchcock reference was published in 1824, but the paper was read before the American Geological Society at a meeting of that group on September 11, 1822. It therefore seems fitting that this lake should be named in his honor. Since 1822, the sediment of that lake has been the subject of many geological investigations and studies are continuing at the present time. Just when the lake was first named "Hitchcock," and by whom, is not known to the writers.

As described in the older literature, the lake in the Connecticut Valley consisted of a body of water extending from Middletown, Connecticut, northward to Lyme, New Hampshire, a distance of 157 miles, and later the lake expanded to St. Johnsbury, Vermont. The lake formed because the valley was dammed at Middletown by a glacial moraine, presumably, according to this report, deposited by Shelburne ice. The first, and highest of the lake stages was named Lake Hitchcock, and a second lake stage supposedly developed where the lake waters dropped ninety feet. The lower lake was designated Lake Upham (Jacobs, 1942, p. 47; Lougee, 1935, pp. 5–8; Antevs, 1922a).

That a lake, or lakes, occupied the Connecticut River valley in the section that borders Vermont and in the tributary valleys of that state is unquestionable. Lake sediments form the major portion of the unconsolidated detritus in both the master valley and the tributary valleys from the Massachusetts-Vermont border to the international boundary. The lacustrine clastics include varved clay, laminated silts and clays, sand, pebbly sand, gravel from a shoaling lake, beach gravel and deltaic deposits. Many of the exposures, particularly the varved clays and the laminated clays and silts, measure 75 to 100 feet in height above the streams and form precipitous bluffs. Because of the content of clay in the bluffs, slumps and slides are common so that fresh exposures are not difficult to find. The lacustrine sediment in most areas extends down to the bedrock, with till or outwash below the lake sediment being a rare occurrence. In some exposures, till may occur between layers of lacustrine sediment but the lake deposit is in almost all cases found lying directly on the bedrock.

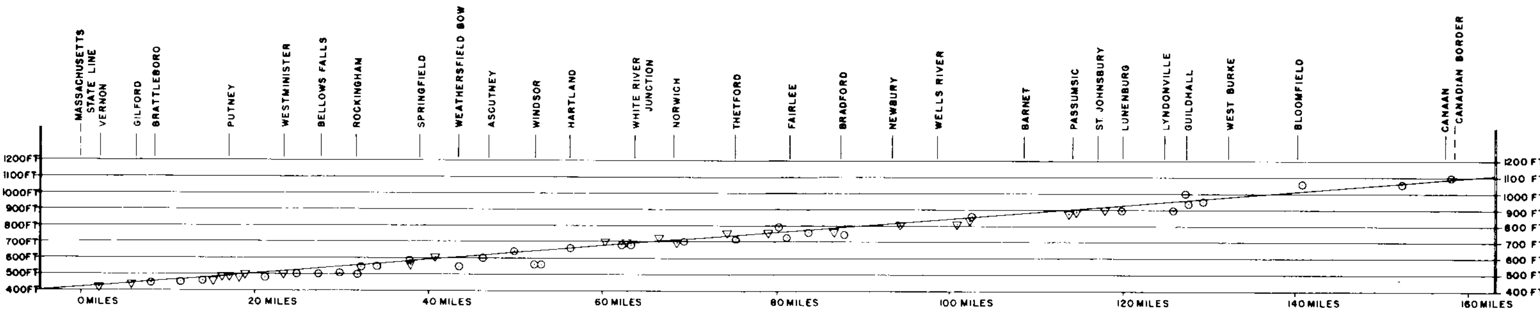
Recent studies of the lake sediment in the Connecticut Valley, south of Vermont, have discounted the concept of a two-stage lake. Jahns and Willard (1942, p. 166) suggested that the lake (Lake Hitchcock) was "a single ponded body of water" that maintained a rather constant level during its existence. A single stable lake is consistent with the conclusions made from the data collected during the present survey of Vermont. No evidence was found that indicated a sudden drop in the lake level (Lake

Upham) north of Lyme, New Hampshire, as was postulated by Antevs (1922a). The conclusions of Antevs and others that the lake extended only as far north as St. Johnsbury was also disproven inasmuch as the lacustrine sediments were mapped all the way up the river to the Canadian border. It is the conclusion of this survey, however, that the lake sediment and the lake history that it records is not as simple as it has been thought to be. There are many exposures showing lake sediment that as yet have not been explained. It seems probable that a pre-Shelburne lake episode occurred in the valley.

This report makes no attempt to develop a so-called "water plane" for any of the lake sediment mapped in Vermont. It is our belief that it is impossible to establish the water level with any assurance at any point along the lake shore. In the case of the Connecticut Valley lakes, it is even more confusing inasmuch as lakes higher than the stable lake were apparently common along the sides and between blocks of stagnant ice as well as upstream from ice-block dams in the tributary valleys. Since the interstadial in which the lakes occurred, much erosion, both atmospheric and fluvial, has lowered, dissected and otherwise modified the deposits (Plate XIV, Figure 1).

It is the intention of this report to note the occurrence and position of the deposits along the valleys and to make conclusions based on these data. The highest point on the most significant deposits will be noted. Most elevations are taken from the contours on the topographic map but some were made with an aneroid altimeter. Time did not allow for more detailed measurements, but more accurate measurements, we believe, would not have given more exact information on the lake levels. The fact that beach gravel deposits, beach ridges, deltas and other similar deposits do occur does not necessarily prove the "water level," especially in glacial lakes, as has been demonstrated in recent studies.

Lake Hitchcock, as already noted, extended up the valley from Middletown, Connecticut, to beyond the Canadian border because the valley had been dammed by stratified drift deposited by the so-called Middletown readvance of Flint (1953, p. 899). According to the results obtained from radio-carbon dates, the lake was in existence for at least 2,300 years (Schafer and Hartshorn, 1965, p. 122). Antevs (1922a), however, insists that his varve counts in the Connecticut Valley show that the retreat from Middletown, Connecticut, to St. Johnsbury, Vermont, required 4,100 years. Inasmuch as the studies made during the Vermont survey indicate ice stagnation, instead of retreat, the varve count of Antevs is seriously questioned.



PROFILE PLOT OF THE LITTORAL SEDIMENTS OF LAKE HITCHCOCK

⊙ GRAVEL, PEBBLY SAND AND SAND DEPOSITS

▽ DELTAIC DEPOSITS

Figure 11

The Lake Hitchcock shore sediment has been tilted by post-glacial uplift and rises from an elevation of 435 feet at the Massachusetts line to 1,101 feet at the Canadian boundary, a north-south distance of 158 miles. The rate of the rise is thus 4.15 feet per mile which is consistent with the 4.2 feet per mile rate reported by Jahns and Willard (1942, p. 274) and the 4 to 4.5 feet per mile calculated by Koteff (1966, p. 113) for the Connecticut Valley sediment in Massachusetts and Connecticut.

The designation "stable lake episode" is used advisedly in reference to Lake Hitchcock. Stability has to be a rather flexible term when used to describe glacial and post-glacial lakes in any region. The usage here is to imply that there was a single lake during the interstade between the Shelburne and Burlington glaciations. Fluctuations in the lake level must have occurred during the time the lake existed while downcutting at the outlet probably caused a gradual lowering of the lake level. No sudden, appreciable changes occurred, however, to initiate a different stage. Uplift of the area did not occur until after the Lake Vermont and Champlain Sea intervals following the Burlington Stade.

The most reliable shore features of the lake consist of deltas built into the lake at the mouths of small tributary streams along the sides of the main valley or up the tributary valleys at the maximum extension of the lake waters. Most of the deltas built into the tributary streams such as the West, Saxton and White rivers, however, have either been removed by subsequent stream erosion or they were covered with lacustrine gravel during the shoaling phase of the lake. It is apparent that much erosion has taken place on most of the deltas and the original top (or apex) of the deposit has been removed. For this reason, there are many deltas whose top elevations are below the tilted plane of Figure 11 inasmuch as the interpretation of the data had to take into account the field study of the deposits and the erosion of the deltaic material. The interpolation, based on field data, placed the lines on Figure 11 twenty feet higher than they would have been if all deposits had been given equal value. When consideration is given to the erosion factor, it is necessary to give major emphasis to a few, higher, better developed and less eroded forms.

The lake level deposits that rank second in importance, insofar as the establishing of a "lake-level" is concerned, are the shoaling gravels of the tributary valleys that were deposited when the arm of the lake extending up the valley was filled with sediment. The large amount of water flowing into the lakes that extended up the tributary streams carried much sediment into the lake. The arm of the lake extending up the White River valley, for example, was long and narrow with fingerlike coves

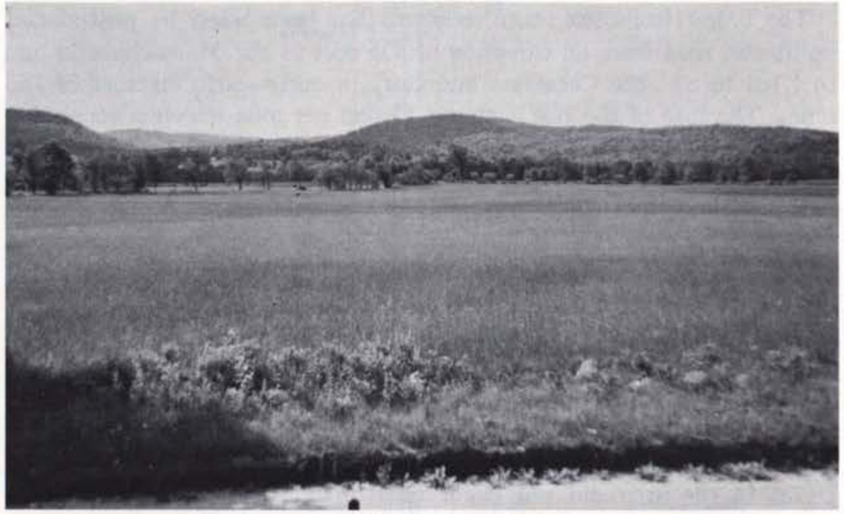


Figure 1. Level surface of the North Springfield delta built into Lake Hitchcock by the Black River. Top elevation 600 feet. One mile west of North Springfield (Ludlow Quadrangle).

Figure 2. Deltaic bedding in the North Springfield Delta. Gravel pit on the south side of the Black River, one mile southeast of North Springfield (Ludlow Quadrangle).

PLATE XVII

extending into the First, Second and Third branches. The large amount of sediment carried into these valleys eventually filled the lake. As the level of the sediment approached the level of the lake waters, the type of sediment changed from silt and clay to sand and pebbly sand and finally to gravel. It is assumed that the tops of such deposits were very close to the lake level.

Beach gravel is not a common occurrence along the shore of Lake Hitchcock. The lake was so long and so narrow in most sections that wave activity was at a minimum. Pebbly sand which, like the shoaling gravel, is assumed to be a deposit made at about lake level marks the shore deposition in some sections. Since wave activity was minimal, there was little erosion along the shore and shore cliffs and eroded terraces are few.

The absence of beach gravel and shore terraces definitely should not be used to erroneously postulate a lake of a short duration. The great thicknesses of bottom sediment, mostly varved clay and laminated silts and clays, indicate a lake that existed for a relatively long time. Regardless of the validity of the varve counts made by Antevs (1922), insofar as ice recession time is concerned, his work definitely shows a large time-span over which one lake existed. Steep bluffs of lake bottom sediment fifty to one hundred feet high are common all along the Connecticut River.

As stated above, a dozen or so deposits were of most importance in determining the stability level of Lake Hitchcock. These include the delta of Broad Brook at Guilford; the deltas of Salmon, Canoe and Mill brooks between Brattleboro and Putney; the combined delta of Morse and Newcomb brooks at Westminster Station; the deltaic complex of Commissary Brook north of the Williams River; the delta of the Black River at North Springfield; the lake gravel, probably part deltaic, of the Ottauquechee River upstream from Quechee Gorge; the delta of Dothan Brook near Norwich; and the deltas of Joe's Brook and the Water Andric southwest of St. Johnsbury.

The village of North Springfield, along the Black River (Ludlow Quadrangle), is situated on one of the largest, most interesting and most important of the deposits listed above. The deposit is a large, flat, sandy and gravelly deltaic complex that is two miles wide and three miles long. Although most of the deposit lies to the west of the Black River, it is obvious that the detritus was deposited almost entirely by that stream. Furthermore, there is the suggestion of a large meander that seemingly occurred in the area now occupied by the delta at the time of deposition.

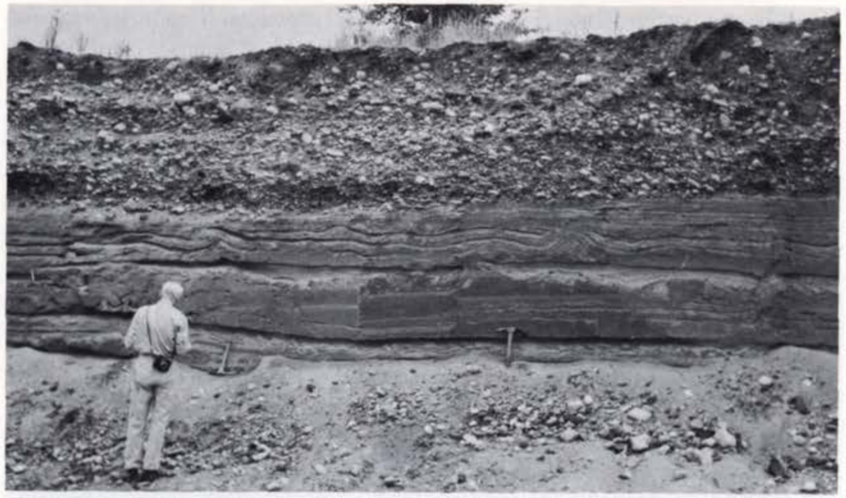


Figure 1. Lacustrine gravel over laminated silts and fine sands in the Ottauquechee River valley. Top elevation 700 feet. Gravel pit exposure one mile west of Quechee (Hanover Quadrangle).

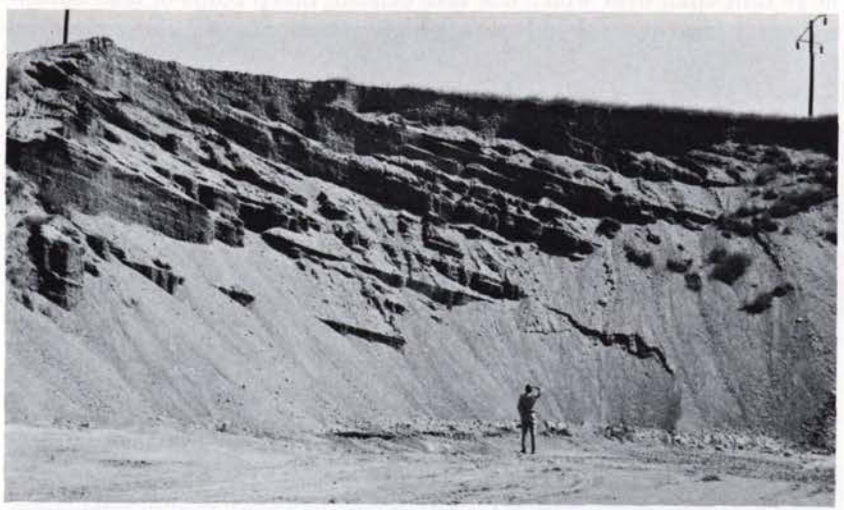


Figure 2. Foreset bedding in the combined deltas of Morse and Newcomb brooks. Exposed in a gravel pit one mile east of Westminster Station (Bellows Falls Quadrangle).

PLATE XVIII

The filling of the meander by deltaic sediment probably accounts for the present course of the stream. The deposit extends upstream in the main branch past Perkinsville to Downers, up the North Branch to Amsden, and southeast from North Springfield (downstream) to Springfield. The top elevation at 600 feet is an accurate estimate of the lake level in this section inasmuch as most of the deposit is protected and has had little erosion (Plate XVII, Figures 1 and 2).

Another deposit of major importance is located in the Ottauquechee River valley that extends from a point two miles southeast of Quechee Gorge upstream past the gorge, Dewey Mills and Quechee to Taftsville. Inasmuch as the lacustrine sediment is here one to one and one-half miles in width, it is assumed that the valley had been widened in preglacial time by stream meandering. It seems probable that the river at one time followed a channel east of the present gorge and since the deposition of the lake sediment it has followed a shallow channel, now abandoned, to the west of the gorge. The thickness of the valley-fill ranges from 100 feet near Taftsville to over 200 feet just north of the gorge. Since the deposition of the lake sediment, the river has cut its present valley down through the deposit but on either side of the valley the deposit is still intact. The surface of the higher parts of the deposit, at an elevation of 700 feet, is lacustrine gravel that is generally ten to twenty feet thick overlying lake sand and silt (Plate XVIII, Figure 1).

The delta of Joe's Brook, three miles west of Passumpsic at an elevation of 890 feet, is small but well developed (St. Johnsbury Quadrangle). This deposit plus the delta of the Water Andric, two miles north of it, at an elevation of 900 feet, establishes the approximate level of Lake Hitchcock in the St. Johnsbury region.

The delta deposits in the southern part of the state are small and many have had considerable erosion. The deltas of Broad Brook at Guilford with an elevation of 450 feet and the small deltas of Salmon Brook at East Dummerston, Canoe and Mill brooks southwest of Putney at 500 feet indicate stability at that level in the Brattleboro region (Brattleboro Quadrangle).

At Westminster Station (Bellows Falls Quadrangle), the combined delta of Morse and Newcomb brooks spreads over the valley floor from an apex up the Morse Brook valley to the village of Westminster Station. A gravel pit in the delta, one mile due west of the village at an elevation of 430 feet exhibits well-developed foreset bedding dipping toward the Connecticut River at an angle of approximately sixty degrees (Plate XVIII, Figure 2). The lake waters extended up the valleys of these

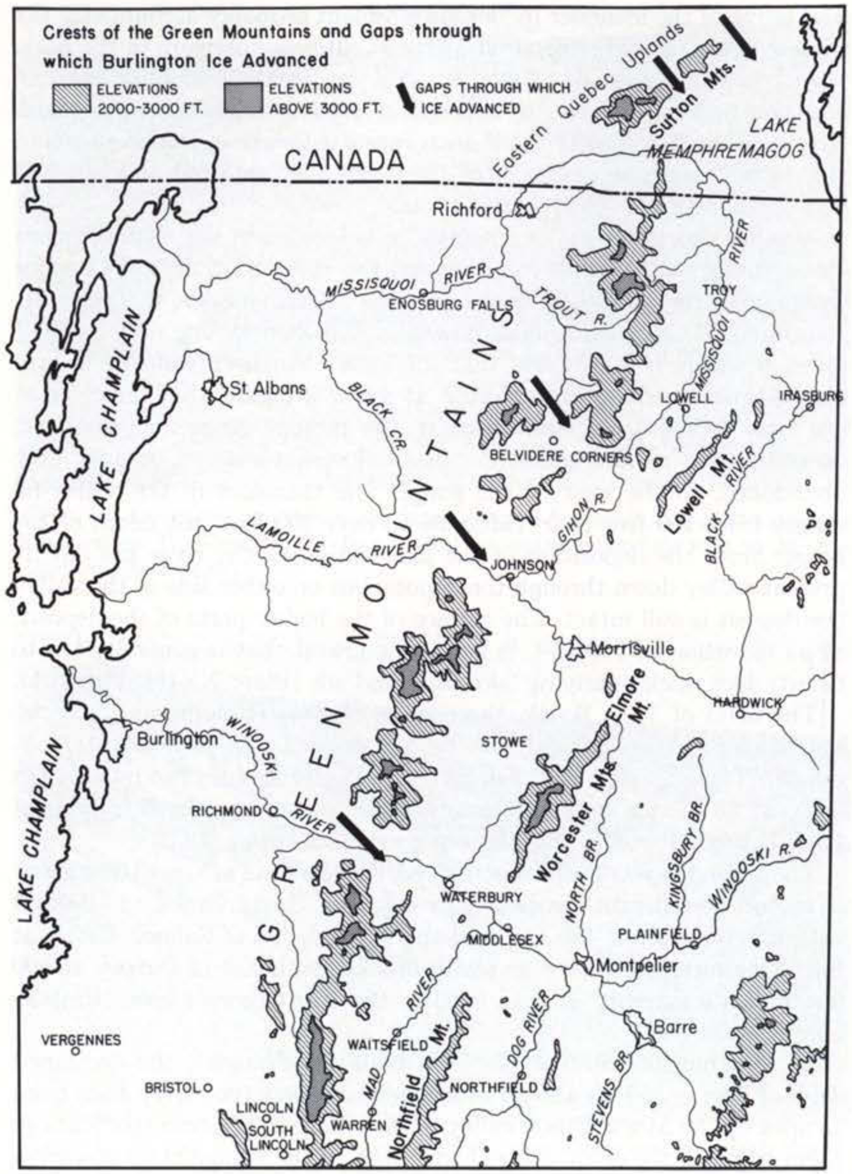


Figure 12

streams, and the delta built up then. Erosion has removed much of the apex area making the top elevation difficult to establish. The gravel is found along the valley to elevations of about 540 feet.

Champlain Lowland

Evidences of a lake following the retreat of a glacier that preceded the Burlington Stade were found at a few localities in the Champlain Lowland. Varved lacustrine sediment was found in the valley of Lewis Creek in the Burlington Quadrangle. The winter varves of this deposit are very dark grey, almost black, and the material resembles no other lake deposit in Vermont. Twenty feet of Burlington till covers the varves and Shelburne till occurs on either side of it. Calkin (1965) reported an exposure along Little Otter Creek two miles north of New Haven with two feet of varved lake clay between the Burlington and Shelburne tills. These deposits have characteristics much like the sediments described by Hansen, Porter, Hall and Hill (1961) in the Glens Falls area of New York. It therefore seems probable that an interstadial lake occupied the Champlain Lowland during the same interval that Lake Hitchcock existed in the Connecticut Valley.

THE BURLINGTON STADE

The third and final ice episode for which there is evidence in Vermont was a glacial invasion that moved into the state from a north-northwest direction and covered the northwestern and north-central regions. The surficial materials of the areas covered by glaciers during this interval include: 1) till and outwash deposited by the ice and the associated meltwater streams; 2) lacustrine sediment deposited in high-level ice-marginal lakes formed during the early stages of glacial waning; 3) the sediment deposited in Lake Vermont during the calving retreat of the glacier in the Champlain Lowland; 4) marine sediment of the sea invasion (Champlain Sea) of the Champlain Lowland that followed deglaciation; and 5) those of post-glacial origin. Because of the geologic significance of these deposits and the geologic activities that caused them, the next four chapters of this report will be devoted to their description and discussion. It should be noted, however, that the first three categories of surficial materials listed above were made by geologic activities that actually occurred during the Burlington Stade.

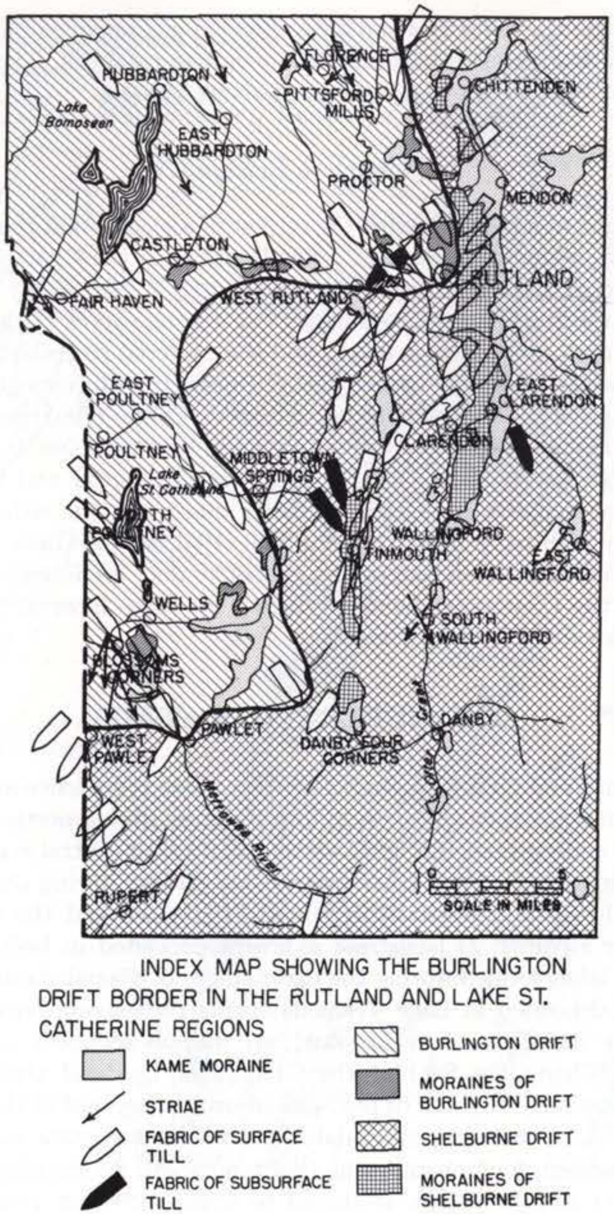
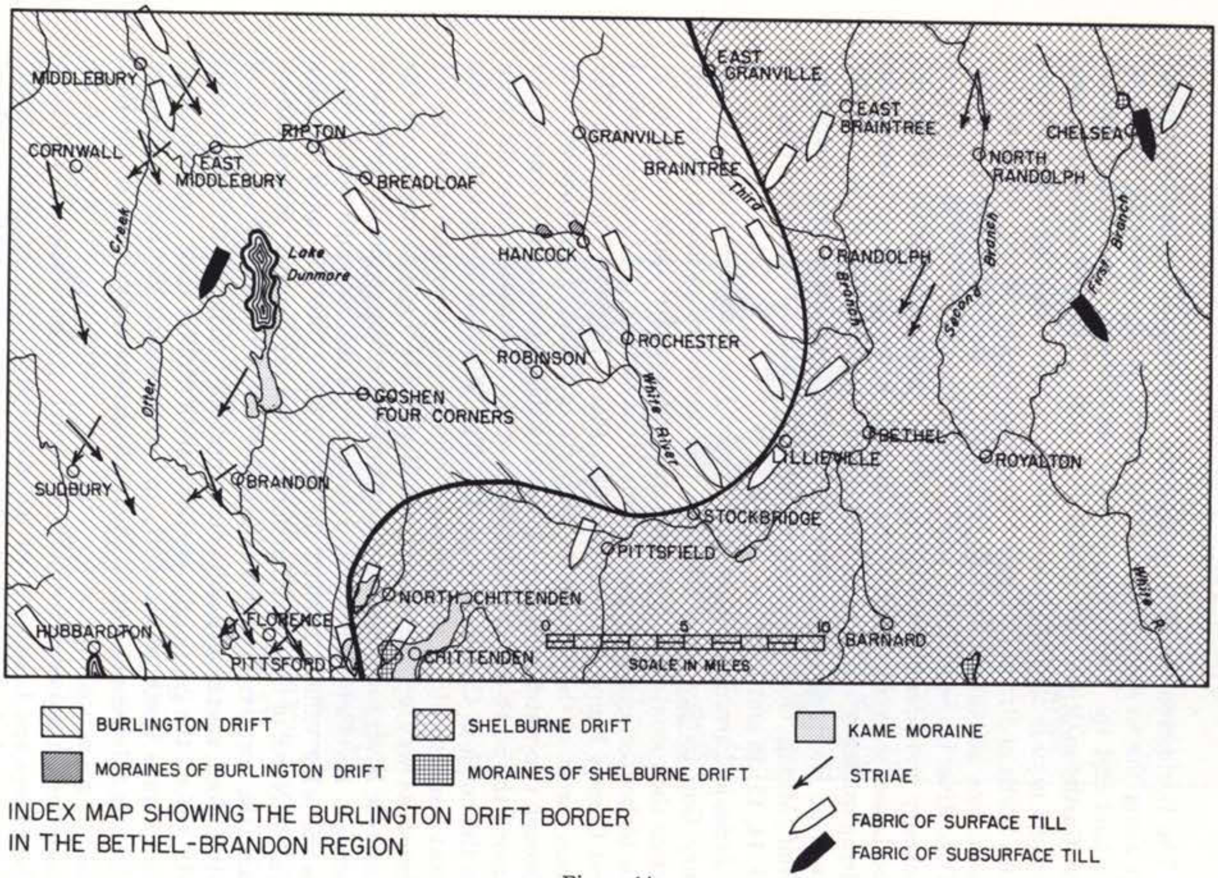


Figure 13

The Extent of the Burlington Glaciation

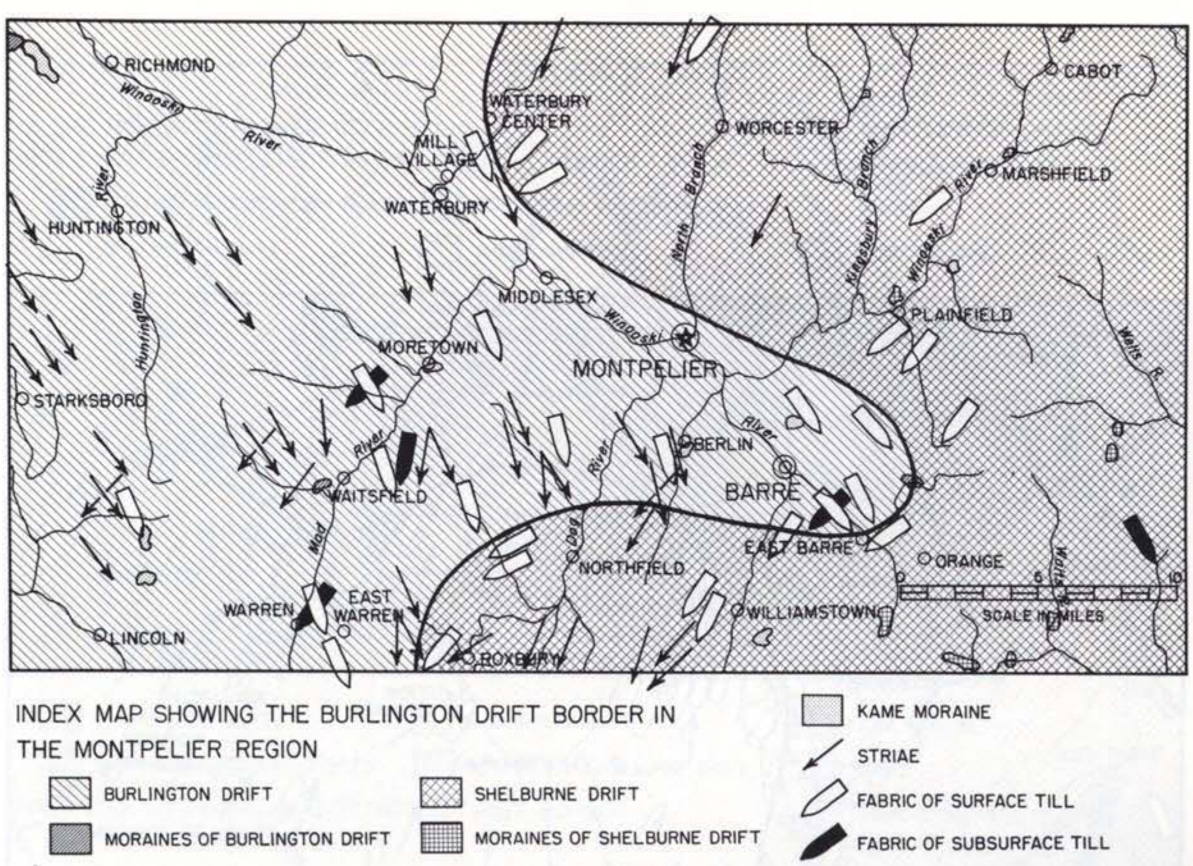
The Burlington ice first invaded the Champlain Lowland and piled up along the western slopes of the Green Mountains as far south as Rutland and the western foothills of the Taconic Mountains between the Castleton River and the Batten Kill. The ice thickened in the lowland until it attained enough height to move over the Green Mountains north of Brandon. The ice moved down the eastern slopes of the mountains and terminated in the valley of the Third Branch of the White River between Bethel and Roxbury, the Dog River valley between Roxbury and Montpelier and the Stowe Valley between the Winooski and Lamoille rivers. North of the Lamoille River the glacier covered the Memphremagog Basin as far east as the upper reaches of the Lamoille River at Hardwick and Glover and to the foothills of the mountains (Bluff, Middle, Gore, Brosseau and Averill) north of Island Pond (Figures 13, 14, 15, 16 and 17).

Striae and erratic boulders on the Green Mountain crests from Middlebury Gap to Jay Peak attest to the northwest-southeast movement across the mountains. Northwest trending striae are quite numerous in the higher sections of the mountains in the vicinity of Mount Mansfield and Camels Hump (Christman, 1959, Plate III; 1961, Plate III). The main thrust of the Burlington ice north of Lincoln Gap, however, was through two water gaps and a low sag in the mountains in Vermont and around the north end of the terminus of the continuous mountain chain to the north in Canada (Figure 12). The Winooski River valley is the most southern of the passage-ways through the mountains and the ice thrust its way up the valley past Barre. The ice also moved up the Lamoille River to Hardwick. A northwest-trending sag in the mountains between Belvidere Corners and Enosburg Falls, although not as deep as the other valleys, allowed the ice to move into the upper Lamoille Valley. North of the Canadian border, a low sag occurs in Sutton Mountain (the northern continuation of the Green Mountains) southwest of Mt. Orford, twenty-five miles north-northeast of Jay Peak. Northeast of Mt. Orford the continuity of the mountain range ends, approximately thirty miles north of Newport, and merges with the Eastern Quebec Uplands (McDonald, 1967a, Figure 2). In the early stages of the Burlington glaciation, as the ice piled up on the western slopes of the mountains, tongues of ice pushed through the gaps and spread out in the valleys and basins east of the mountains. After the glacier crossed the crests of the mountains and covered the region to the east, basal



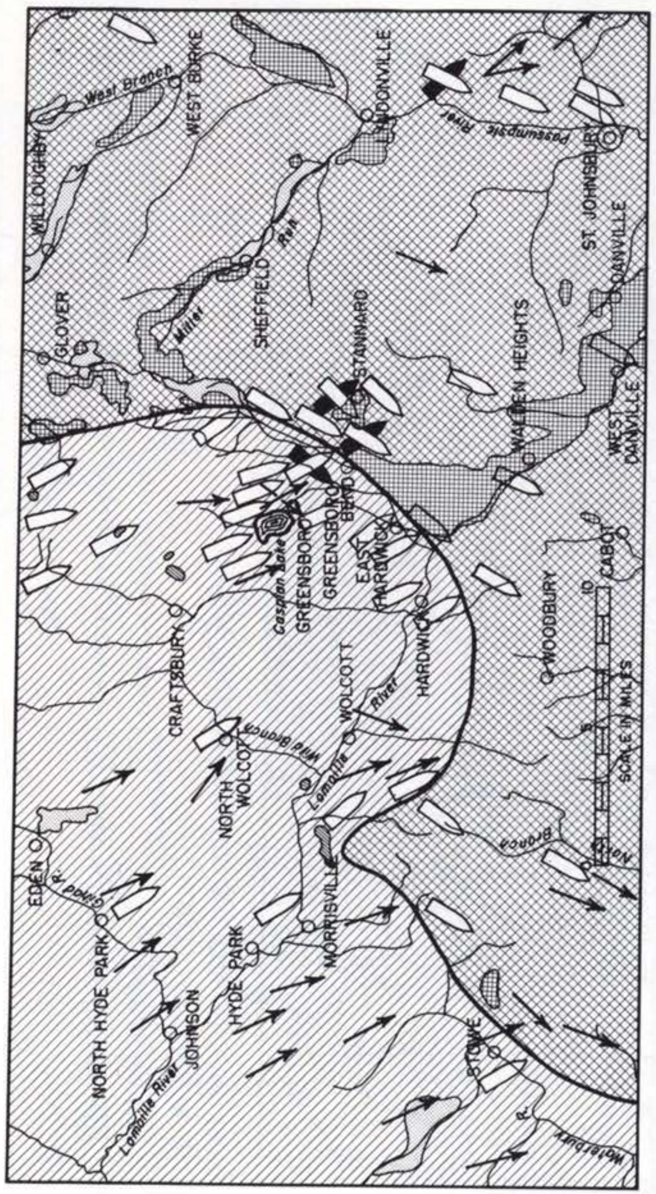
INDEX MAP SHOWING THE BURLINGTON DRIFT BORDER IN THE BETHEL-BRANDON REGION

Figure 14



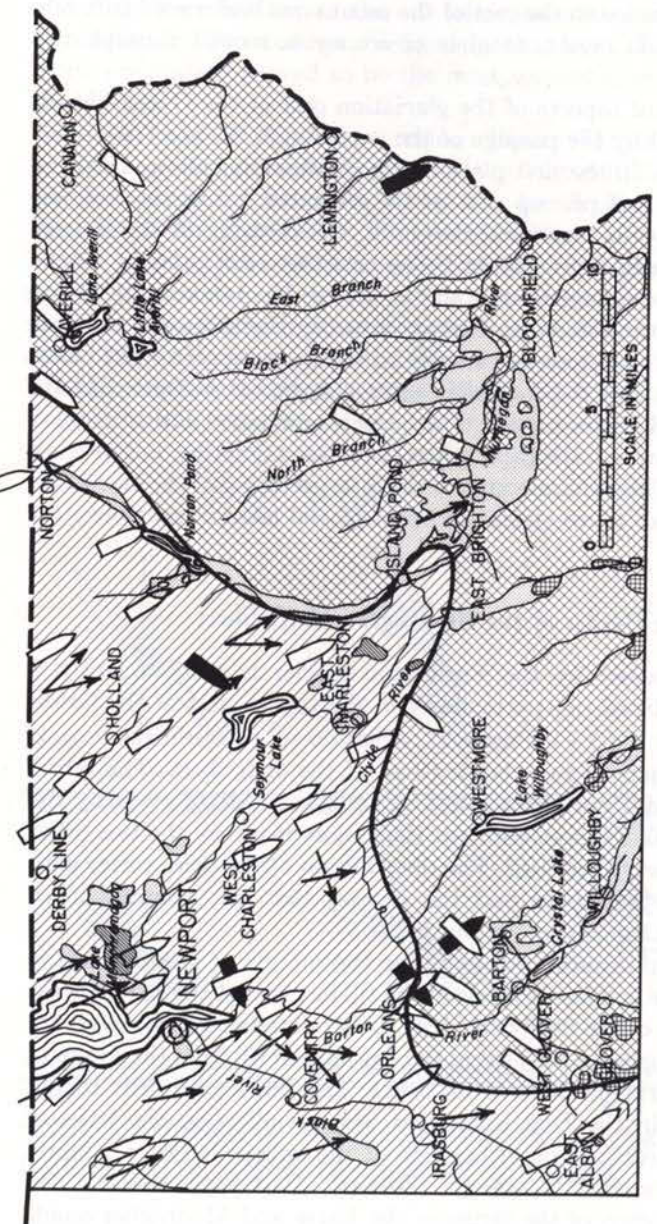
INDEX MAP SHOWING THE BURLINGTON DRIFT BORDER IN THE MONTPELIER REGION

Figure 15



INDEX MAP SHOWING THE BURLINGTON DRIFT BORDER IN THE HARDWICK-MORRISVILLE REGION

Figure 16



INDEX MAP SHOWING THE BURLINGTON DRIFT BORDER IN THE MEMPHREMAGOG REGION

Figure 17

supply currents of the overriding ice sheet moved through the gaps. Still later, when the ice to the east of the mountains had waned to levels below the mountain crests, tongues of ice again moved through the passageways.

Several important aspects of the glaciation east of the Green Mountains are explained by the passage of the ice through the gaps described above (Figure 12). In the first place, these passageways allowed the ice to fill the valleys and pile up east of the mountains thus intensifying the glacial activity in that area. Secondly, the merging of the Sutton Mountain with the Eastern Quebec Uplands to the north gave the southeastward moving ice unrestricted access to the Memphremagog Basin and the region to the east of it. This accounts for the eastward swing of the ice margin at the Canadian border to the vicinity of Averill Lake. A third influence was the fact that after the glacier had reached its maximum and had begun to melt down, the ice remained active in areas where it moved through the gaps, whereas it was stagnating and melting down elsewhere. This is paramount to the interpretation of the lacustrine sediment deposited in pro-glacial and post-glacial lakes in north-central Vermont.

The Border of the Burlington Drift Sheet

The drift deposited by the Burlington glacier is predominantly a sandy, compact, basal till, particularly in the region west of the Green Mountains (Plate XXXVI, Figure 2). Ablation till of Burlington age is more or less restricted to the border area of the drift sheet. The fabric orientation is always north-northwest to northwest. Striae made by the Burlington are much more abundant than those made by the two other ice invasions already described. The distribution of the drift varies with the steepness of the slopes and the erosion that has occurred since deposition on the exposed mountain terrain.

The most useful criterion for mapping the margin of the Burlington drift sheet was the northwest fabric of the till in contrast to the northeast fabric orientation of the Shelburne drift. Other parameters, however, are much more conclusive in the case of the Burlington till than they were in either the Shelburne or Bennington drifts. The Burlington drift border had been noted in the Dog River and Stowe valleys on the basis of differing striae directions on either side of the valleys before till fabric orientation was used in Vermont (Stewart, 1961, pp. 40–41). The original interpretation of the striae in the Barre and Montpelier quad-

rangles has been verified by till fabric studies. Or, perhaps it could be said that the reliability of the till fabric orientation as a basis for till correlation in Vermont was verified in that area. In other areas, till fabric orientation proved to be the most successful method of mapping the border.

In the Lake St. Catherine region (Figure 13), which is the most southerly extent of the Burlington drift in Vermont, the ice invaded the western margin of the state across the low foothills of the Taconic Mountains. Drift deposited by this glaciation extends as far east as Pawlet, Danby Four Corners and Middletown Springs (Pawlet Quadrangle). The margin of the ice in this area is manifested in the massive morainic deposits, both till and kame, south and east of Lake St. Catherine. The moraines are concentrated in the southward extension of the Lake St. Catherine trough between Wells and North Pawlet (Blossoms Corners Moraine) and the stream valleys occupied by Flower, Wells and

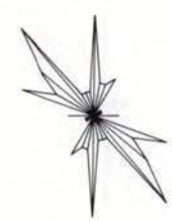


FIGURE 1. BUFF BASAL TILL FROM A FOUNDATION EXCAVATION TWO MILES SOUTHWEST OF POULTNEY.

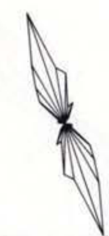


FIGURE 2. SANDY BROWN BASAL TILL ONE MILE WEST-SOUTHWEST OF MIDDLETOWN SPRINGS.

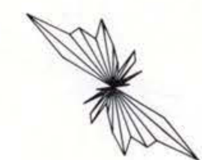


FIGURE 3. BLUE BASAL TILL EXPOSED IN A SLATE QUARRY ONE AND ONE-HALF MILES SOUTH OF SOUTH POULTNEY.

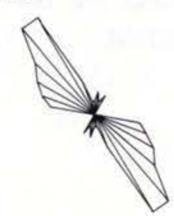


FIGURE 4. SANDY BASAL TILL TWO AND THREE-FOURTHS MILES NORTHWEST OF DANBY FOUR CORNERS.

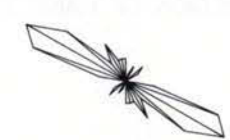


FIGURE 5. SANDY CLAYEY BASAL TILL ONE-FOURTH MILE NORTH OF BLOSSOMS CORNERS.

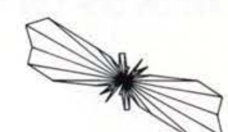


FIGURE 6. DENSE PEBBLY GREY TILL FROM A ROADCUT IN MORAINE ONE MILE SOUTH OF WELLS.

PLATE XIX FABRICS OF THE BURLINGTON TILL ALONG THE DRIFT BORDER IN THE REGION OF LAKE ST. CATHERINE.

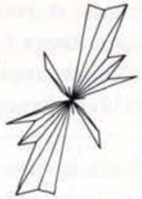


FIGURE 1. SANDY ABLATION TILL FROM NORTH SIDE OF FURNELL HOLLOW TWO AND ONE-HALF MILES NORTHEAST OF EAST POULTNEY.

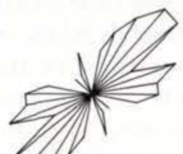


FIGURE 2. DENSE BLUE-GREY SILTY TILL FROM A HIGH ROADCUT ONE MILE EAST OF MIDDLE-TOWN SPRINGS.

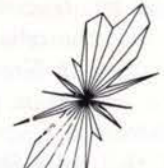


FIGURE 3. SILTY SANDY TILL FROM AN EXCAV-ATION ONE AND ONE-FOURTH MILES SOUTH OF TINMOUTH.

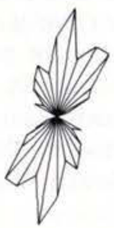


FIGURE 4. SANDY BASAL TILL FROM AN EXCAV-ATION ONE AND ONE-HALF MILES WEST OF DANBY FOUR CORNERS.

FIGURE 5. CALCAREOUS TILL FROM A NEW EX-CAVATION TWO MILES NORTHWEST OF SOUTH DORSET.

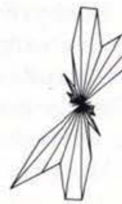


FIGURE 6. SILTY BASAL TILL FROM A ROAD-CUT ONE AND ONE-FOURTH MILES WEST OF SANDGATE.

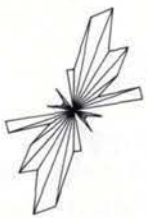


FIGURE 7. BLUE-GREY BASAL TILL FROM THE NORTH BANK OF FLOWER BROOK ONE-FOURTH MILE EAST OF PAWLET.

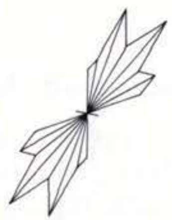


FIGURE 8. BUFF BASAL TILL FROM A THIRTY FOOT HIGHWAY CUT FOUR MILES SOUTH OF WEST PAWLET.

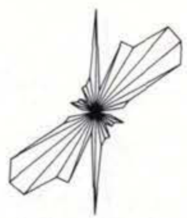


FIGURE 9. DENSE SILTY BLUE TILL ONE AND ONE-FOURTH MILES NORTHWEST OF WEST PAWLET.

PLATE XX FABRICS OF THE SHELBURNE TILL BEYOND THE BURLINGTON DRIFT IN THE REGION OF LAKE ST. CATHERINE.

FIGURE 1. BROWN ABLATION TILL ONE AND ONE-HALF MILES NORTH OF RUTLAND AND ONE MILE EAST OF ROUTE 7.

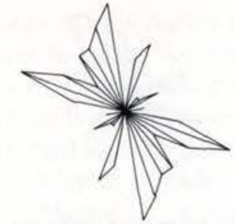


FIGURE 2. BROWN ABLATION TILL FROM AN EXCAVATION IN THE NORTHEAST CORNER OF RUTLAND.

FIGURE 3. BUFF ABLATION TILL ONE AND ONE-FOURTH MILES NORTH OF RUTLAND HOSPITAL.

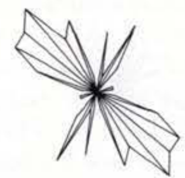


FIGURE 4. TILL IN AN EXCAVATION ON TERMINAL MORAINE ONE MILE SOUTHWEST OF RUTLAND.

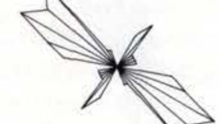


FIGURE 5. BUFF TILL FROM AN EXCAVATION FOR A SCHOOL NEAR THE ARMORY CLOSE TO THE WESTERN EDGE OF RUTLAND.

FIGURE 6. BLUE-GREY TILL EXPOSED IN A HIGH ROADCUT ONE-HALF MILE EAST OF WEST RUTLAND.

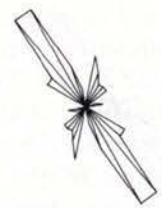


FIGURE 7. DENSE BUFF TILL FROM EXCAVATION ON WEST SIDE OF OTTER CREEK VALLEY THREE MILES SOUTH OF PROCTOR.

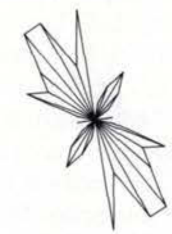


FIGURE 8. SILTY TILL FROM TERMINAL MOR-AINE THREE AND ONE-HALF MILES WEST OF WEST RUTLAND.

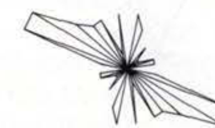


FIGURE 9. TILL EXPOSED IN TERMINAL MOR-AINE ONE-HALF MILE SOUTHWEST OF CENTER RUTLAND.

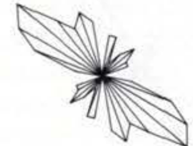


FIGURE 10. DENSE SILTY TILL ONE-HALF MILE NORTHWEST OF CASTLETON CORNERS.

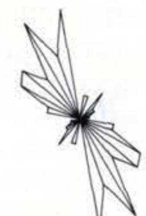


FIGURE 11. UPLAND TILL FROM A ROADCUT ONE MILE NORTHWEST OF EAST HUBBARDTON.

FIGURE 12. BUFF TILL FROM A ROADCUT TWO MILES WEST OF HUBBARDTON.

PLATE XXI FABRICS OF THE BURLINGTON TILL ALONG THE DRIFT BORDER IN THE VICINITY OF RUTLAND.

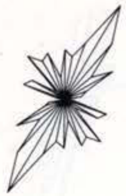


FIGURE 1. COMPACT SANDY TILL TWO MILES SOUTHWEST OF MENDON.

FIGURE 2. BUFF ABLATION TILL FROM A ROADCUT ONE AND ONE-HALF MILES NORTH OF EAST CLARENDON.

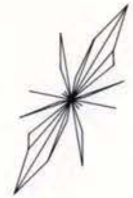


FIGURE 3. UPLAND ABLATION TILL FROM A ROADCUT ALONG ROUTE 140 ONE MILE WEST OF EAST WALLINGFORD.

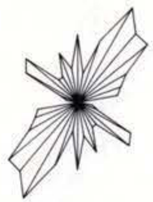


FIGURE 4. BUFF SANDY ABLATION TILL FROM A BORROW PIT NEAR THE SOUTHERN EDGE OF RUTLAND 250 YARDS EAST OF ROUTE 7.

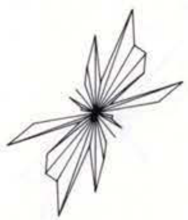


FIGURE 5. BUFF ABLATION TILL FROM A ROADCUT ONE-FOURTH MILE SOUTH OF RUTLAND HOSPITAL.

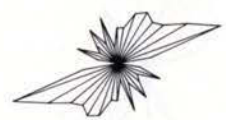


FIGURE 6. BUFF ABLATION TILL FROM AN EXCAVATION ON MORAINE ONE MILE NORTH OF CLARENDON.

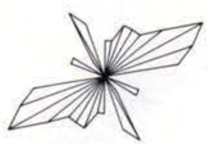


FIGURE 7. BROWN SANDY ABLATION TILL ALONG KILLINGTON ROAD THREE-FOURTHS MILE EAST OF RUTLAND.

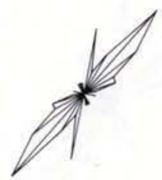


FIGURE 8. UPLAND TILL FROM A ROADCUT ONE AND ONE-HALF MILES SOUTHWEST OF CENTER RUTLAND.

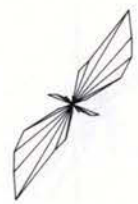


FIGURE 9. BUFF SILTY ABLATION TILL FROM A ROADCUT ONE AND ONE-HALF MILES SOUTH OF WEST RUTLAND.

FIGURE 10. DENSE BUFF TILL FROM A ROADCUT ONE MILE SOUTH OF CHIPPENHOOK.

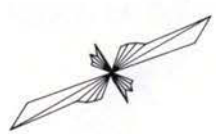


FIGURE 11. BUFF ABLATION TILL FROM A ROADCUT ONE AND ONE-HALF MILES SOUTH-SOUTHWEST OF WEST RUTLAND.

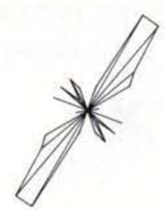


FIGURE 12. DENSE SILTY BASAL TILL FROM A THIRTY-FIVE FOOT TILL BANK NEAR THE NORTHERN EDGE OF IRA.

PLATE XXII FABRICS OF THE SHELBURNE TILL EAST AND SOUTH OF THE BURLINGTON DRIFT IN THE VICINITY OF RUTLAND.

South brooks. The moraines of this region are the most massive, best developed marginal features found in Vermont.

North of Lake St. Catherine the drift border trends northward to the Castleton River valley where it swings eastward through the valley to Rutland and thence northward again along the western foothills of the Green Mountains to the vicinity of Brandon (Figure 14). The margin of the ice is marked in this distance by terminal moraines at Castleton, Birdseye (three miles east of Castleton), West Rutland, and Rutland (Plate XVI, Figure 2; Plate XXIII, Figures 1 and 2). The first three of the moraines (Castleton, Birdseye and West Rutland) are restricted to the Castleton River valley, the Birdseye Moraine being the largest and most massive. The Rutland Moraine, however, extends from the southeastern part of the city northward for a distance of five miles (Plate XXIV, Figure 1). The moraines are, in part, composed of kame gravel, basal till and ablation till. Whereas the Castleton, Birdseye and West Rutland moraines are composed of compact, basal till, plus kame moraine in the case of the Birdseye, the Rutland Moraine is predominantly ablation till (Plate XXIV, Figure 2). Because the physical characteristics of the Burlington and Shelburne tills are so similar the drift border was mapped on the basis of till fabric orientation (Plates XIX, XX, XXI, and XXII). A high road cut (U.S. Route 4) through the West Rutland Moraine exposes Burlington till with Shelburne till below it (Plate XI, Figure 1). Both are very compact basal tills. On the east side of the city of Rutland only four miles from the West Rutland Moraine, however, both the Rutland Moraine and the adjacent Mendon Moraine of Shelburne age are composed of loose, sandy ablation till.

East of Brandon the drift border swings eastward crossing the Green Mountains and crossing the White River valley at Stockbridge. The border follows the river to Bethel and the Third Branch of the White River to the vicinity of Randolph. From data collected thus far, it is assumed that the White River valley east of Stockbridge and the Third Branch south of Randolph were open during the Burlington Stade inasmuch as the ice margin apparently remained a short distance to the north and west of them (Figure 14; Plates XXV and XXVI). The drift border crosses to the east side of the Third Branch just west of Randolph and continues northward on the east side of the Dog River valley (Figures 14 and 15).

In the Montpelier region, the ice moved up the Winooski River valley past Barre but did not cross the Worcester Mountains which lie north of the river. The drift border therefore lies along the western slope of the Worcester Mountains, on the east side of Stowe Valley, and

Figure 1. Morainic topography of the Rutland Terminal Moraine. Two miles northeast of Rutland (Rutland Quadrangle).

Figure 2. Topography of the eastern end of the Birdseye Terminal Moraine. This section of the moraine composed of kame gravel. Esker in upper left. One and one-half miles northwest of West Rutland (Rutland Quadrangle).

PLATE XXIII

swings around the northern end of Elmore Mountain (Figures 15 and 16; Plates XXVII and XXVIII). A very small moraine marks the terminal position of the Burlington glacier around the northern end of Elmore. In spite of its size, however, the Elmore Mountain Moraine is significant inasmuch as moraines of any kind are extremely rare in that region.

The Burlington margin follows closely the upper Lamoille Valley east of Morrisville past Hardwick and Greensboro Bend to the vicinity of Glover (Figure 16; Plates XXIX and XXX). At Orleans the border turns east to Island Pond and thence through the Pherrins River-Norton Pond-Coaticook River valleys to the Canadian border north of Averill Lake (Figure 17; Plates XXXI and XXXII). It is apparent from studies made by McDonald (1967a) and Shilts (personal communications) that the border of the Burlington drift follows closely the international border into New Hampshire. There are no terminal moraines of Burlington age in the Memphremagog Basin.

Outwash Deposits of the Burlington Stade

The outwash deposited by meltwater from the Burlington ice, like that of the Shelburne Stade, is restricted almost entirely to kames, kame terraces and kame moraines. These deposits are scattered all over the area covered by the Burlington glaciation. In general, the kame gravel deposits of this ice episode are more numerous, larger and better developed than those of the preceding ice episodes (Bennington and Shelburne). One exception is the number and size of the eskers, which are fewer and less impressive than those of Shelburne age. The kame gravel of the Burlington Stade, as a rule, is of higher quality than the Shelburne outwash inasmuch as it contains more massive, hard rock and less soft, schistose rock. The rocks of the Champlain Lowland are crystalline, hard quartzites and limestones with a minimum of shale, and little or no foliated metamorphics. The gravel therefore is made up of fragments of durable stone that wears well and is excellent for road building and general construction uses. Not all local areas have an adequate gravel supply, but no area is out of hauling distance of a good source of gravel.

Geologically, however, the significance of the kame moraines are minimal except in the southern end of the Vermont Valley. Whereas many of the Shelburne kame moraines are terminal or recessional deposits, as described earlier, very few of the Burlington outwash accumulations outside the Vermont Valley have geologic significance insofar as the glacial history is concerned.

Hinesburg Kame Terraces. One of the largest, most interesting and

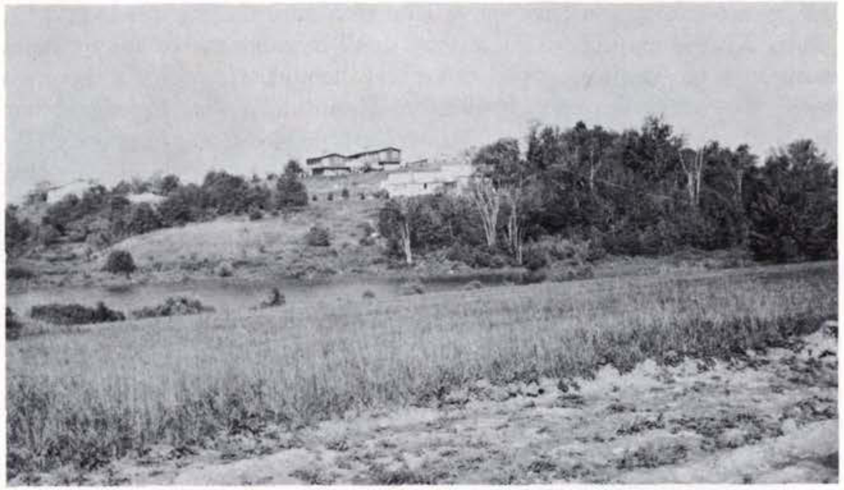


Figure 1. Relief of the Rutland Terminal Moraine just west of Moon Brook on the eastern limits of Rutland (Rutland Quadrangle).

Figure 2. Burlington ablation till of the Rutland Terminal Moraine. Excavation near Moon Brook near the eastern limits of Rutland (Rutland Quadrangle).

PLATE XXIV

most important (economically) of the outwash deposits are the Hinesburg kame terraces located to the southeast of the village of Hinesburg (Burlington Quadrangle). The terraces are about four miles long, average about three-quarters of a mile in width and stand seventy-five to two hundred feet above the lake plane to the west. A gravel pit on the north side of Hollow Brook, during the period of the mapping in that area, exposed a gravel face over one hundred and fifty feet high. The deposit contains a large gravel reserve for the Burlington region and supplies gravel to a wide area.

The origin of the Hinesburg gravel deposits has been confused in the past by the attitude of the bedding on the outer (ice-contact) slope of the terraces. During the interval when Lake Vermont was at its highest (Quaker Springs) stage, the lake level stood just above 700 feet, the approximate elevation of the top of the terraces, and waves carried the sand and gravel out, and over, the ice-contact slope. Gravel pits that penetrate only the wave distributed gravel expose dipping beds that resemble the foreset beds of a deltaic deposit. Gravel pits that extend through the dipping beds, however, expose kame gravel showing ice-contact structures (Plate XXXIII, Figures 1 and 2). The lake level of the Quaker Springs stage is marked by beach gravel at the 700-foot contour on the top of the middle one-third of the terraces.

Buck Hollow Kame Terrace. The Buck Hollow Kame Terrace on the west side of Buck Hollow (Milton Quadrangle), five miles southeast of St. Albans, is a small deposit when compared with the Hinesburg terraces. The quality of the gravel at this location, however, is excellent and for this reason it should be noted. The better part of the deposit, immediately to the west of Buck Hollow, is two and one-half miles long and about one-half mile wide. There is a fairly large reserve of high quality gravel in the deposit.

Kame Gravel of the Enosburg Falls Quadrangle. There are two large areas of kame gravel in the Enosburg Falls Quadrangle. The most southerly of these is a kame terrace along the north-south trending valley of The Branch. The Branch, a tributary of Tyler Branch, heads in the Shattuck Mountains southwest of Bakersfield and flows almost due north to West Enosburg. The valley is almost completely filled with kame terrace gravel from its headwaters, two miles southwest of Bakersfield, northward for a distance of five and one-half miles. A large reserve of good gravel occurs here. The second kame gravel area in this quadrangle is located north of the Missisquoi River and south of Burleson Pond (two miles west of Berkshire). The deposit, mapped as kames, is

FIGURE 1. TILL EXPOSED IN CAMP BROOK VALLEY, THREE AND ONE-HALF MILES WEST-NORTHWEST OF BETHEL.

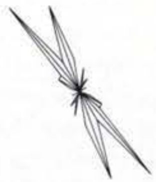


FIGURE 2. GREY TILL IN A ROADCUT IN THE THAYER BROOK VALLEY, TWO MILES WEST OF RANDOLPH.

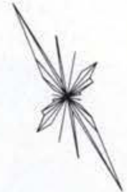


FIGURE 3. GREY BASAL TILL IN A VALLEY ONE MILE NORTH OF PITTSFIELD.

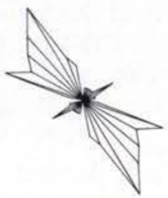


FIGURE 4. GREY CALCAREOUS TILL FROM A ROADCUT ONE AND ONE-HALF MILES EAST-NORTHEAST OF PITTSFIELD.

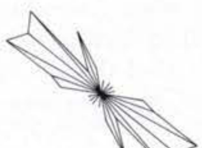


FIGURE 5. TILL FROM A ROADCUT ALONG ROUTE 73 TWO MILES WEST OF ROBINSON, AND TWO AND ONE-HALF MILES EAST OF BRANDON GAP.

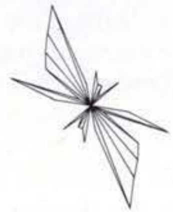


FIGURE 6. BUFF-GREY UPLAND TILL ONE MILE NORTHEAST OF STOCKBRIDGE.

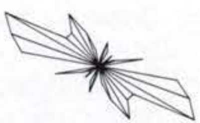


FIGURE 7. BUFF BASAL TILL FROM A HIGH STREAM BANK ONE MILE SOUTHWEST OF ROCHESTER.

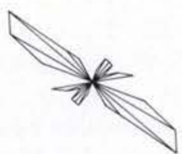


FIGURE 8. BUFF TILL FROM A NEW ROADCUT THREE MILES SOUTH OF GOSHEN FOUR CORNERS.

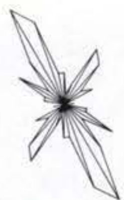


FIGURE 9. TAN-BROWN ABLATION TILL FROM A ROADCUT ONE MILE EAST OF PITTSFORD MILLS.

FIGURE 10. DENSE BLUE-GREY BASAL TILL FROM A HIGH ROADCUT ONE AND ONE-HALF MILES SOUTHEAST OF HANCOCK.

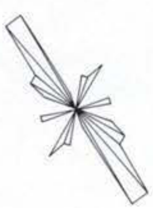


FIGURE 11. UPLAND ABLATION TILL FROM A NEW ROADCUT ONE MILE SOUTH OF BREAD-LOAF.

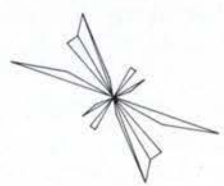


FIGURE 12. UPLAND TILL ONE AND ONE-HALF MILES WEST-NORTHWEST OF GRANVILLE.

PLATE XXV FABRICS OF THE BURLINGTON TILL ALONG THE DRIFT BORDER IN THE RANDOLPH-BRANDON REGION.

FIGURE 1. DARK BROWN BASAL TILL FROM A ROADCUT ONE MILE SOUTHWEST OF EAST BRAINTREE.

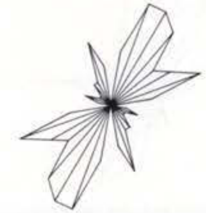


FIGURE 2. BROWN BASAL TILL FROM A ROAD-CUT TWO AND ONE-HALF MILES NORTHWEST OF BETHEL.

FIGURE 3. DENSE BASAL TILL IN A VALLEY AT LILLIEVILLE.

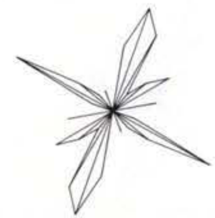


FIGURE 4. DENSE TILL ONE MILE WEST OF OLYMPUS.

FIGURE 5. UPLAND ABLATION TILL FROM A ROADCUT THREE MILES NORTH-NORTHWEST OF RANDOLPH.

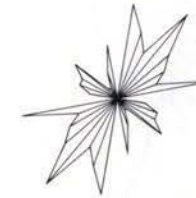


FIGURE 6. SILTY BUFF TILL FROM A ROADCUT ONE MILE WEST OF PITTSFIELD.

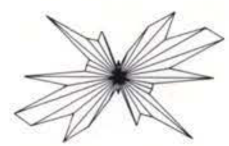


FIGURE 7. TAN SANDY ABLATION TILL FROM A ROADCUT ONE MILE WEST-NORTHWEST OF CHITTENDEN.

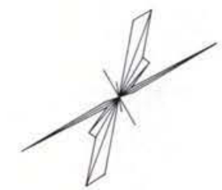


FIGURE 8. BUFF SILTY TILL FROM A ROADCUT ONE MILE WEST OF NORTH CHITTENDEN.

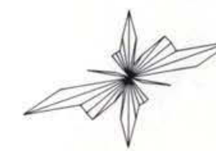


FIGURE 9. ABLATION TILL FOUR MILES NORTH-WEST OF WOODSTOCK.

PLATE XXVI FABRICS OF THE SHELBURNE TILL BEYOND THE BURLINGTON DRIFT IN THE RANDOLPH-BRANDON REGION.

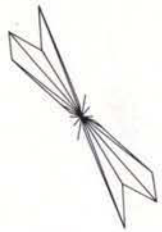


FIGURE I. BROWN CLAYEY BASAL TILL, FROM BORROW PIT ON PERRYS HILL TWO MILES EAST OF MILL VILLAGE, MONTPELIER QUADRANGLE.

FIGURE 2. BROWN-BUFF SANDY BASAL TILL, ONE MILE SOUTHEAST OF MORETOWN COMMON, MONTPELIER QUADRANGLE.

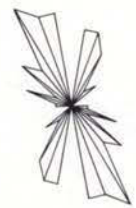


FIGURE 3. GREY-BUFF DENSE BASAL TILL, FROM GUNNERY BROOK TWO MILES NORTH OF BARRE.

FIGURE 4. BROWN AND GREY UPLAND TILL, FOUR MILES NORTHEAST OF BARRE.

FIGURE 5. SANDY BUFF TILL, FROM THE SOUTH SIDE OF JAIL BROOK, ONE-FOURTH MILE NORTHWEST OF EAST BARRE.

FIGURE 6. SILTY-SANDY CALCAREOUS ABLATION TILL FROM HIGH BLUFF ONE-HALF MILE NORTH OF EAST BARRE.

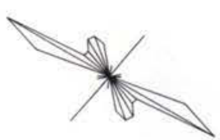


FIGURE 7. DENSE DARK GREY-BUFF UPLAND TILL, ONE MILE WEST OF BERLIN.

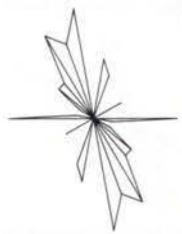


FIGURE 8. BUFF COMPACT BASAL TILL, FROM ROADCUT ONE AND ONE-HALF MILES WEST OF RIVERTON.

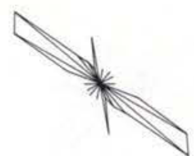


FIGURE 9. TAN SANDY ABLATION TILL, FROM WAITSFIELD GAP ROAD FOUR MILES NORTHWEST OF NORTHFIELD.

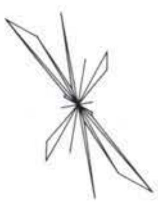


FIGURE 10. DENSE BASAL TILL, FROM A ROADCUT TWO MILES WEST-NORTHWEST OF WAITSFIELD.

FIGURE 11. UPLAND ABLATION TILL, ONE-HALF MILE SOUTHWEST OF EAST WARREN.

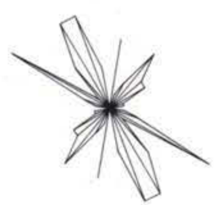


FIGURE 12. BUFF TILL, FROM BANK ALONG FREEMAN BROOK ONE MILE EAST OF WARREN.

PLATE XXVII FABRICS OF THE BURLINGTON TILL ALONG THE DRIFT MARGIN IN THE MONTPELIER REGION.

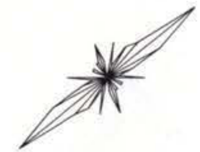


FIGURE I. TAN-BROWN BASAL TILL, FROM AN EXCAVATION TWO MILES SOUTHEAST OF WATERBURY CENTER.

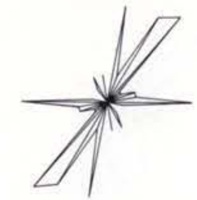


FIGURE 2. BROWN SANDY BASAL TILL, FROM MIDDLESEX NOTCH ROAD THREE MILES EAST OF MILL VILLAGE.

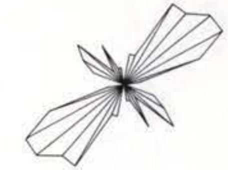


FIGURE 3. BUFF SANDY ABLATION TILL, FROM ROADCUT THREE MILES NORTH-NORTHEAST OF WORCESTER.

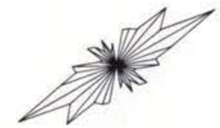


FIGURE 4. BLUE-GREY TILL FROM A BANK ALONG GREAT BROOK ONE AND ONE-HALF MILES SOUTH-SOUTHEAST OF PLAINFIELD.

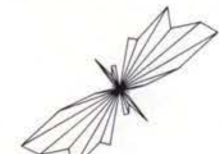


FIGURE 5. SANDY ABLATION TILL, FROM A ROADCUT FIVE MILES NORTH OF ORANGE.

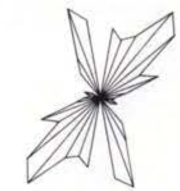


FIGURE 6. SANDY ABLATION TILL, FROM A BLUFF ALONG U.S. ROUTE 302 ONE AND ONE-HALF MILES SOUTHEAST OF BARRE LIMITS.

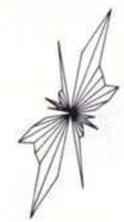


FIGURE 7. GREY-BUFF SILTY BASAL TILL, FROM BANK ONE-FOURTH MILE NORTHEAST OF EAST BARRE.

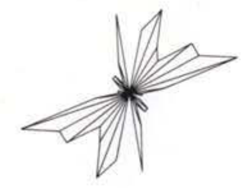


FIGURE 8. DARK GREY TILL, FROM A ROADCUT TWO MILES SOUTHWEST OF MARSHFIELD.

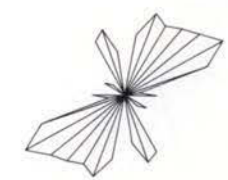


FIGURE 9. DENSE BUFF TILL, FROM A ROADCUT ONE-FOURTH MILE WEST-SOUTHWEST OF WILLIAMSTOWN.

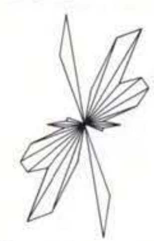


FIGURE 10. TAN SANDY ABLATION TILL, FROM ROADCUT THREE MILES WEST-NORTHWEST OF NORTHFIELD.

FIGURE 11. BROWN SANDY ABLATION TILL, FROM ROADCUT TWO AND ONE-HALF MILES WEST OF NORTHFIELD.

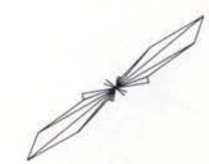


FIGURE 12. BASAL TILL, FROM A ROADCUT ONE AND ONE-FOURTH MILES WEST-SOUTHWEST OF ROXBURY.

PLATE XXVIII FABRICS OF SHELBURNE TILL BEYOND THE BURLINGTON DRIFT BORDER IN THE MONTPELIER REGION.

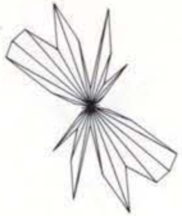


FIGURE 1. BUFF SILTY TILL FROM A ROADCUT ONE MILE NORTHEAST OF HARDWICK.

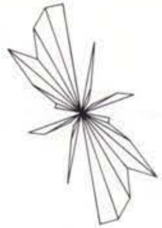


FIGURE 2. ABLATION TILL FROM A ROADCUT ALONG ROUTE 16, FOUR MILES NORTHEAST OF GREENSBORO BEND.

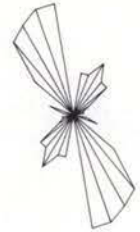


FIGURE 3. GREY-BUFF SILTY TILL FROM A ROADCUT ONE MILE EAST-NORTHEAST OF GREENSBORO.

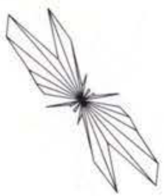


FIGURE 4. DENSE BUFF TILL FROM A ROADCUT ONE AND ONE-HALF MILES SOUTHEAST OF GREENSBORO.

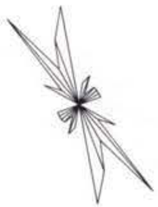


FIGURE 5. BUFF SILTY TILL FROM A ROADCUT AT THE SOUTHEAST EDGE OF EAST HARDWICK.

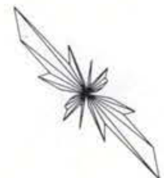


FIGURE 6. GREY COMPACT TILL ONE MILE SOUTHEAST OF EAST HARDWICK.

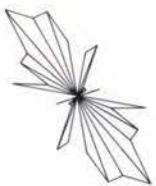


FIGURE 7. BUFF TILL FROM A ROADCUT ONE MILE SOUTH OF HARDWICK.

FIGURE 8. DENSE BUFF TILL FROM A ROADCUT THREE MILES SOUTH-SOUTHWEST OF WALCOTT.

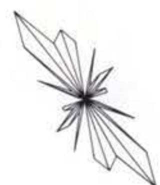


FIGURE 9. BUFF SILTY TILL FROM A ROADCUT IN A SMALL MORAINE ONE MILE NORTH-NORTHWEST OF LAKE ELMORE.

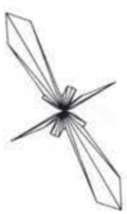


FIGURE 10. DENSE BASAL TILL FROM AN EXCAVATION ONE MILE NORTH OF MORRISVILLE.

FIGURE 11. DENSE TILL OVERLYING BEDROCK WITH NORTHWEST STRIAE ONE AND ONE-HALF MILES SOUTHEAST OF NORTH HYDE PARK.

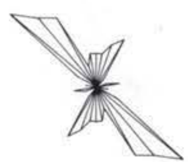


FIGURE 12. TAN SANDY ABLATION TILL FROM A ROADCUT ON HILL SLOPE ONE MILE SOUTH OF STOWE.

PLATE XXIX FABRICS OF THE BURLINGTON TILL ALONG THE DRIFT BORDER IN THE HARDWICK-MORRISVILLE REGION.

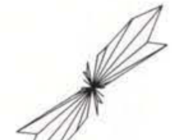


FIGURE 1. ABLATION TILL, FROM BORROW PIT ALONG ROUTE 16 TWO AND ONE-HALF MILES NORTHEAST OF GREENSBORO BEND.

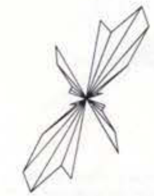


FIGURE 2. SANDY ABLATION TILL, HIGH ROADCUT TWO MILES SOUTHEAST OF GREENSBORO.

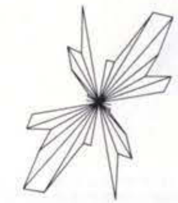


FIGURE 3. ABLATION TILL, FROM STREAM CUT ALONG STANNARD BROOK, ONE MILE WEST OF STANNARD (STEWART AND MACCLINTOCK, 1964, TILL C, STATION 2).

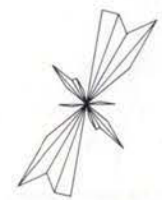


FIGURE 4. ABLATION TILL, FROM STREAM CUT ALONG STANNARD BROOK, ONE AND ONE FOURTH MILES WEST OF STANNARD (STEWART AND MACCLINTOCK, 1954, TILL C, STATION 3).

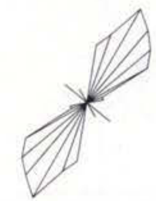


FIGURE 5. ABLATION TILL, FROM UPLAND ROADCUT ONE MILE WEST-NORTHWEST OF STANNARD.

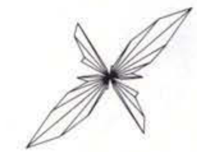


FIGURE 6. BROWN SANDY ABLATION TILL, ONE-HALF MILE SOUTH OF STANNARD.

FIGURE 7. COMPACT BASAL TILL, ONE-HALF MILE NORTHWEST OF WALDON HEIGHTS.

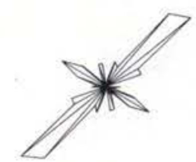


FIGURE 8. TAN SANDY ABLATION TILL, FROM BORROW PIT ONE-HALF MILE NORTHEAST OF WEST DANVILLE.

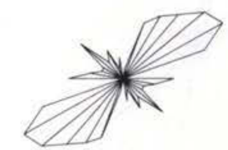


FIGURE 9. BLUE-GREY SILTY TILL, FROM HILLSIDE GULLY TWO MILES EAST OF HARDWICK.

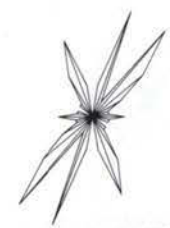


FIGURE 10. SANDY BROWN COMPACT TILL, ROADCUT ALONG ELMORE MOUNTAIN ROAD TWO MILES EAST OF MOSS GLEN FALLS.

FIGURE 11. BROWN SILTY SANDY BASAL TILL, FROM BORROW PIT THREE MILES SOUTH-SOUTHEAST OF ELMORE.

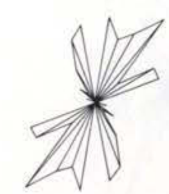


FIGURE 12. SANDY ABLATION TILL, ONE AND ONE-HALF MILES NORTH OF GREENSBORO BEND. (STEWART AND MACCLINTOCK, 1954, TILL C, STATION 6).

PLATE XXX FABRICS OF THE SHELBURNE TILL SOUTH AND EAST OF BURLINGTON DRIFT IN THE HARDWICK-MORRISVILLE REGION.

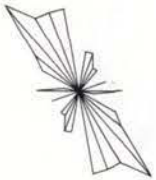


FIGURE 1. BROWN ABLATION TILL FROM A BORROW PIT NORTH OF CANADIAN BORDER ONE MILE NORTHWEST OF NORTON.

FIGURE 2. DARK BROWN SANDY BASAL TILL. FROM ROADCUT FOUR MILES NORTHEAST OF HOLLAND.

FIGURE 3. BROWN SANDY ABLATION TILL FROM A BORROW PIT TWO AND ONE-HALF MILES NORTHWEST OF NORTON POND.

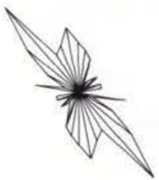


FIGURE 4. BROWN BASAL TILL FROM A ROADCUT ON ROUTE III, FOUR MILES NORTHWEST OF ISLAND POND.

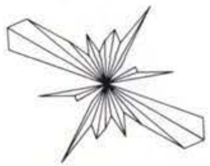


FIGURE 5. LIGHT BROWN SANDY FISSILE TILL. ONE MILE SOUTHWEST OF EAST CHARLESTON.

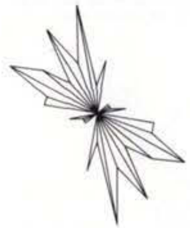


FIGURE 6. LIGHT TAN SANDY ABLATION TILL FROM THE VALLEY WALL OF THE CLYDE RIVER TWO MILES SOUTH OF WEST CHARLESTON.

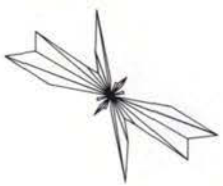


FIGURE 7. DARK BROWN DENSE SILTY TILL FROM ROADCUT ON ROUTE 5A, ONE MILE SOUTH OF PENSIONER POND.

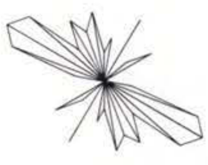


FIGURE 8. DARK BROWN DENSE SILTY TILL ONE MILE WEST-SOUTHWEST OF WEST CHARLESTON.

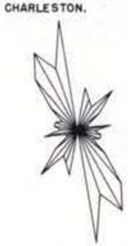


FIGURE 9. BROWN SANDY FISSILE TILL FROM HIGH CUT ON THE NORTH SIDE OF WILLOUGHBY, TWO MILES EAST OF ORLEANS.

FIGURE 10. BROWN CLAYEY BASAL TILL FROM ROADCUT ONE AND ONE-HALF MILE EAST OF IRASBURG.

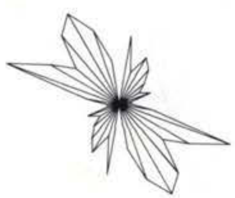


FIGURE 11. GREY-BUFF DENSE TILL FROM ROADCUT TWO MILES SOUTHEAST OF EAST ALBANY.

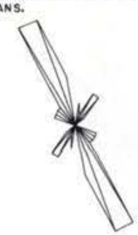


FIGURE 12. DENSE BUFF TILL FROM ROADCUT ONE-FOURTH MILE EAST OF EAST ALBANY.

PLATE XXXI FABRICS OF THE BURLINGTON TILL ALONG THE DRIFT BORDER IN THE MEMPHREMAGOG REGION.

FIGURE 1. BLUE-GRAY BASAL TILL FROM A ROADCUT TWO MILES SOUTH-SOUTHEAST OF EAST CHARLESTOWN.

FIGURE 2. DARK BROWN DENSE CLAYEY BASAL TILL, ALONG ROUTE 114 TWO AND ONE-HALF MILES EAST OF NORTON.

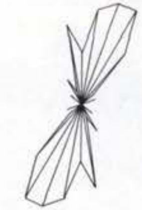


FIGURE 3. OLIVE-BROWN SANDY BASAL TILL, ALONG ROUTE 114 ONE MILE EAST OF AVERILL.

FIGURE 4. COARSE ABLATION TILL, ALONG SCHOOLHOUSE BROOK ROAD THREE MILES SOUTHWEST OF CANAAN.

FIGURE 5. DARK BROWN COMPACT BASAL TILL, FIVE MILES NORTHWEST OF EAST BRIGHTON.

FIGURE 6. SANDY GRAY BASAL TILL, FIVE MILES WEST OF GUILDHALL.

FIGURE 7. GRAY-BROWN SANDY BASAL TILL, ALONG ROUTE 105 ONE AND ONE-HALF MILES EAST OF EAST BRIGHTON.

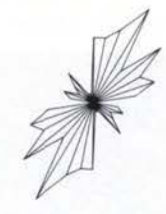


FIGURE 8. LIGHT BROWN SANDY ABLATION TILL, FROM BLUFF ON NORTH SIDE OF WILLOUGHBY RIVER TWO MILES EAST OF ORLEANS.

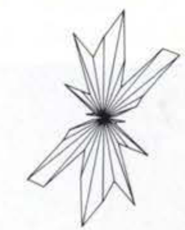


FIGURE 9. BROWN SANDY ABLATION TILL, FROM ROADCUT NEAR HEATH SCHOOL TWO MILES SOUTHEAST OF ORLEANS.

FIGURE 10. BROWN SANDY ABLATION TILL, FROM PIPELINE EXCAVATION AT THE WATER RESEVOIR IN ORLEANS.

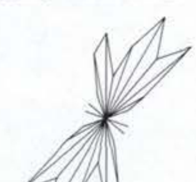


FIGURE 11. BLUE-BROWN BASAL TILL, FROM ROADCUT ONE MILE NORTH-NORTHEAST OF WEST GLOVER.

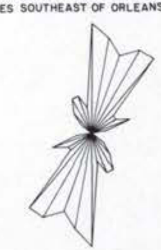


FIGURE 12. BROWN BASAL TILL, FROM ROAD-CUT ONE MILE NORTHWEST OF WEST GLOVER.

PLATE XXXII FABRICS OF THE SHELBURNE TILL SOUTH AND EAST OF THE BURLINGTON DRIFT IN THE MEMPHREMAGOG REGION.

Figure 1. Dipping beds of gravel carried out over the ice-contact slope of the Hinesburg kame terraces by wave activity of the Quaker Springs Lake. Two miles southeast of Hinesburg (Burlington Quadrangle).

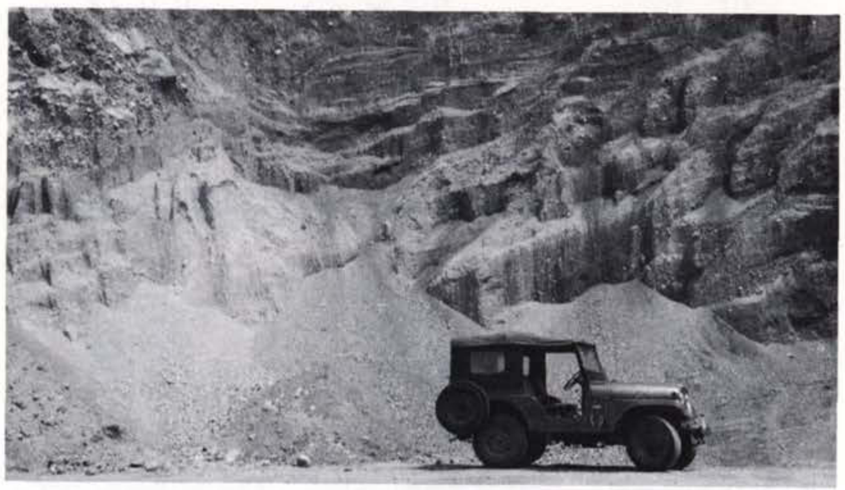


Figure 2. Ice-contact structures of the Hinesburg kame terraces. Exposed in a gravel pit two miles southeast of Hinesburg (Burlington Quadrangle).

PLATE XXXIII

probably a single kame complex with the lower parts of the deposits (the kettles) having been covered by lacustrine sand deposited during the Fort Ann Stage of Lake Vermont. The gravel exposed in gravel pits in the area is of the highest quality.

Black River Kame Complex. A series of kame terraces and kame moraines occupy the Black River valley from a point two and one-half miles south of Albany (Hardwick Quadrangle) northward through Irasburg and Coventry (Irasburg Quadrangle) to the border of the Memphremagog Quadrangle three miles north of Coventry. The outwash gravel, both terrace and moraine, has been partially covered by lacustrine sediment, partially removed by stream erosion and is partially still intact. It is difficult to estimate the total extent of the gravel now in the valley inasmuch as it is concealed in many sections by lake clays, silts and sands. It is also difficult to ascertain the original extent but it seems that this whole section of the valley was completely filled with outwash when the Burlington ice melted from the region. It is apparent that the pre-glacial valley of the Black River between Coventry and Irasburg was abandoned because of the massive kame moraine in the valley and kame terraces on the valley wall. The river probably took its present course during the lake episodes following the retreat of the ice. More discussion of this deposit will follow in the chapter on the lake history of this region.

Kame Deposits of the Newport Region. There are kame deposits in the Newport area some of which seem to be recessional moraines. A small kame moraine with conspicuous relief that may be a recessional feature starts in the southern part of the city of Newport and extends for one and one-half miles in an east-west direction. The gravel in this deposit is of excellent quality. A second kame moraine that seems to be a recessional deposit trends almost due north from the eastern limits of Newport for a distance of three miles. A third kame moraine lies north of Derby Pond, continues to the south between Derby and Salem ponds, and probably includes the kame moraine east of Salem Pond. The village of Derby Line is located on a wide, flat kame terrace that is the southern end of a deposit that extends northward for several miles into Canada. The southern boundary of the terrace is two and one-half miles south of Derby Line. It is two miles wide at the Canadian Border and the stream that forms the international boundary has cut a steep valley over one hundred feet into the terrace.

The Bristol-East Middlebury Kame Terraces. The village of Bristol (Middlebury Quadrangle) is built on a large flat-topped kame terrace that extends north-south for a distance of two miles and has a maximum width of over one mile. Like the Hinesburg kame terraces, this deposit was planed-off by the wave activity of at least one stage of Lake Vermont, creating the flat top, and depositing the inclined beds of lacustrine gravel that cover the outer ice-contact slope. The margins and part of the top of the terrace are veneered with lake bottom sediment. Below the lacustrine sediment, however, high quality kame gravel is exposed in existing gravel pits. The varved clays immediately above the gravel in a pit just east of Bristol are deformed (contorted), but they are covered by undeformed horizontal varved clay and laminated silt (Calkin, 1965). The deformation suggests that the lake covered the terrace soon after its deposition. The contorted varved clay was deposited before ice blocks, deposited contemporaneously with the gravel, had melted.

Beginning just south of the New Haven River at Bristol, and extending continuously to East Middlebury, a kame terrace eleven and one-half miles long follows the western foothills of the Green Mountains. The terraces that rise as much as two hundred feet above the lake plane to the west, according to Calkin (1965), show the irregular lithology, particle size, bedding and slumping structures characteristic of ice contact deposits. The width of the terraces as well as the presence or absence of kettle holes appear to be influenced by the bedrock outliers adjacent to the main valley wall.

Kame Gravel in the Barre Area. It is apparent that a tongue of Burlington ice extended southward from Barre, up the valley of Stevens Brook. Kame gravel almost completely fills the valley from South Barre to Cutter Pond, two miles south of Williamstown. As will be noted later, these deposits prevented the early stages of high-level lakes that occurred in the Winooski Valley from draining southward through Williamstown Gulf. Several gravel pits in the terraces show good quality gravel, and a good reserve of gravel seemingly still remains.

Kame Terraces on the Green Mountain Slopes. An interesting series of kame terraces occur on the slopes of the Green Mountains from south of Huntington Center (Camels Hump Quadrangle) to a point three miles south of South Lincoln (Lincoln Mountain Quadrangle). The terraces have elevations, at the contact with the mountains, ranging from 1,200 to 1,600 feet. They follow (north to south) the headwaters of the Huntington River, Hallock and Beaver Meadow brooks and the New Haven River. There are very few gravel pits in these deposits, and the quality of the gravel could not be ascertained. Such terraces at the headwaters of streams are rather common in that part of the Green Mountains covered by Burlington ice. Considerable reserves of gravel are found, for example, along the headwaters of the Lee River and Mill Brook in the West Bolton-Jericho Center area of the Camels Hump Quadrangle and the headwaters of the Gihon River upstream from North Hyde Park (Hyde Park Quadrangle).

HIGH-LEVEL LAKES OF THE BURLINGTON STADE

When the Burlington glacier piled up in the Champlain Basin along the western slopes of the Green Mountains, all of the drainage ways that normally flow into Lake Champlain were blocked by ice. The drainages remained blocked so long as the ice in the Champlain Lowland remained active and until the ice receded or melted down. As a result, a series of lakes developed in the valleys and basins. The most complicated and significant of these occurred in the north-central part of the state but many lakes were formed all along the ice border.

High-Level Lake of North-Central Vermont

In north-central Vermont, where the Burlington ice crossed the Green Mountains, high-level lakes were in existence from the time the glacier stood at its maximum advance until the Winooski, Lamoille and Missisquoi valleys were freed of ice and the glacier melted back to the north of their courses across the Champlain Lowland. As a result, the water in the valleys and in the Memphremagog Basin ponded and rose to elevations high enough to drain into the Connecticut watershed. The ice in the valleys and basins melted down at different rates inasmuch as the ice continued to feed through low gaps and around the northern end of Sutton Mountain (Figure 12). A series of lakes developed as the ice dissipated and lower and lower outlets were successively freed of ice.

The high-level lake area of north-central Vermont has four basins and valleys that were occupied by independent lakes for at least a part of the interval. The Memphremagog Basin is the largest of the lake areas, and it includes the valleys of the Missisquoi, Black, Barton and Clyde rivers and their tributaries. The second lake basin, at that time, was the Lamoille River valley that was occupied by an independent lake for a short period. The Stowe Valley was a third lake basin, and it, like the Lamoille, was occupied by an independent lake for a short time. The fourth lake basin was the Winooski River valley. The evidence, to be discussed later, seems to show that the lakes in the Memphremagog Basin existed independently and were not connected with the lake to the

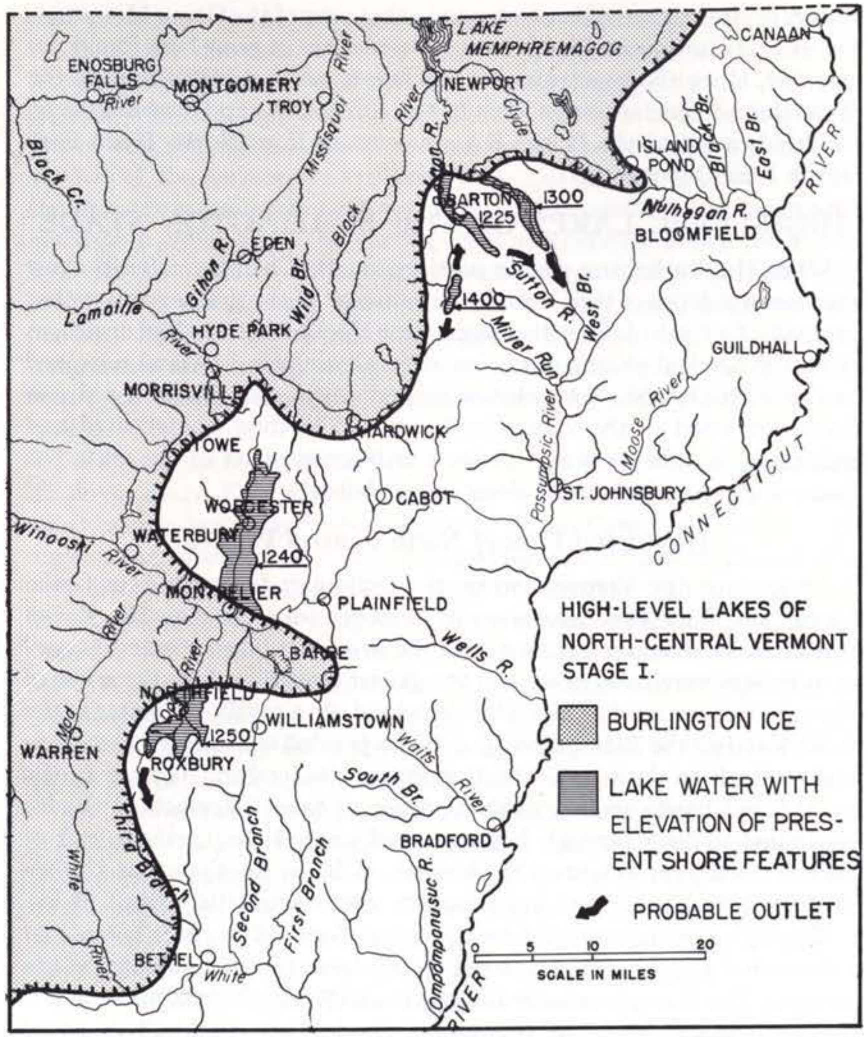


Figure 18

south, except perhaps during the final stages of the lake. The waters of the other basins (valleys), however, did eventually merge, forming a single lake occupying the Lamoille, Stowe and Winooski valleys.

In spite of the fact that independent lakes occurred in the basins, as described above, the lake episodes are so closely associated with the melting of the ice that a discussion of each basin, and the designation of lake stages for each, without the inclusion of the significant changes in the position of the ice, is impossible. It seems more appropriate, therefore, to consider the lakes collectively during each change in the position and influence of the melting glacier. The various positions of the ice, called stages in this report, that allowed significant changes in the lakes are here given major emphasis as shown in Figures 18, 19, 20, 21, and 22. The stages here designated, it should be emphasized, are not independent lake stages. Each successive stage involves a new position (stage) of the diminishing ice and a resulting change in the lake sequence.

The naming of the lakes of this sequence poses a problem inasmuch as several names have been proposed by early investigators (C.H. Hitchcock, 1906, 1907, 1908b; Merwin, 1908; Fairchild, 1916). It seems appropriate that the names suggested by these authorities be retained even though the original usage is no longer valid. Glacial Lake Memphremagog, as suggested by Hitchcock (1908b, p. 641), would designate a series of lakes in the Memphremagog Basin. The usage as proposed here is essentially the same as that originally proposed by Hitchcock. Merwin (1908) proposed the name Lake Mansfield and Fairchild (1916) the name Lake Winooski for a lake in the Lamoille, Stowe and Winooski valleys. The literature is confusing on the usage of these designators inasmuch as it seems that both were used for the same lake in different localities. It is suggested here that the name Lake Winooski is the most appropriate name for the series of independent lakes in the Winooski Valley, Lake Lamoille for the independent lake in the Lamoille Valley, and Stowe Lake for the lake in the Stowe Valley. Lake Morrisville is used in this report to designate the single lake that occupied the Lamoille and Stowe valleys and Lake Mansfield for the lake that occupied the Lamoille, Stowe and Winooski valleys. No effort is made to designate stages (i.e. Memphremagog I, II, etc.) for the various lakes or to propose different names for different levels or different outlets. It is hoped that the description that follows, however, will be complete enough to allow for such subdividing if one wishes to do so.

The Nulhegan River that flows east from Island Pond to the Connecticut River was not dammed by the Burlington ice. The river was a

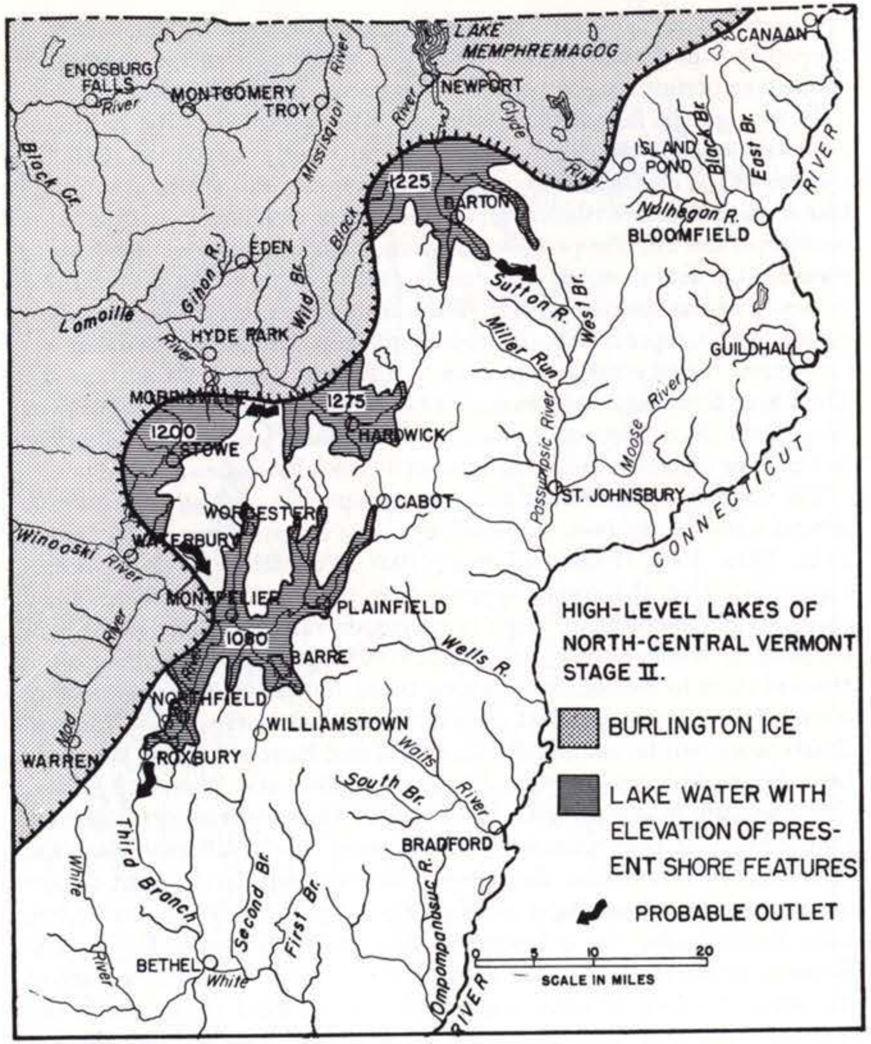


Figure 19

glacial spillway since it carried the water from the melting glaciers in that area. Some of the lakes of the Memphremagog Basin also probably drained via this stream as will be discussed later.

Stage I

When the Burlington ice stood at its maximum advance, and as it began to melt, several small proglacial lakes developed in basins and valleys that were dammed. The position of the ice at this time is designated Stage I (Figure 18).

Memphremagog Basin. Three small lakes of this stage are manifested by the lacustrine sediment in the Memphremagog Basin. The Willoughby River was dammed east of Orleans, and a high-level lake formed in the river valley and the Willoughby lake basin (Memphremagog and Lyndonville quadrangles). The water of this lake rose to the top of the col between the Lake Willoughby basin and the headwaters of the Passumpsic River (elevation 1,300 feet) and drained southward via the Passumpsic to the Connecticut River. The sediments of this lake occur above the present level of Lake Willoughby and northwest of the lake along the valley of the Willoughby River.

The Black River valley was blocked at this time near Barton forming a lake at an elevation of 1,250 feet that drained southeastward through the Sutton River (Lyndonville Quadrangle). The lake extended from Barton through the Crystal lake basin and up the valley of Willoughby Brook to the present site of Bean Pond, one mile southeast of Willoughby.

A third small lake, at an elevation of 1,400 feet, occupied the present divide of the Barton and Lamoille rivers. The valley, now partially occupied by Clark Pond, is blocked at the north by kame moraine in the vicinity of Parish School (one and one-half miles south of Glover). The valley is also blocked at the south by kame moraine in the area of Runaway Pond. The lake differs from the two described above by not having been dammed by ice. Since both the Barton and Lamoille rivers now head in the area formerly occupied by the lake, it is not known whether the lake drained to the north or to the south.

Lamoille and Stowe Valleys. The Lamoille and Stowe valleys were completely filled with ice during Stage I, and no lakes were formed at that time.

Winooski Valley. The Winooski Valley, during Stage I, was filled with ice past Montpelier. Lakes developed in the Dog River valley south of Montpelier and to the north in the valley of North Branch. The lake in

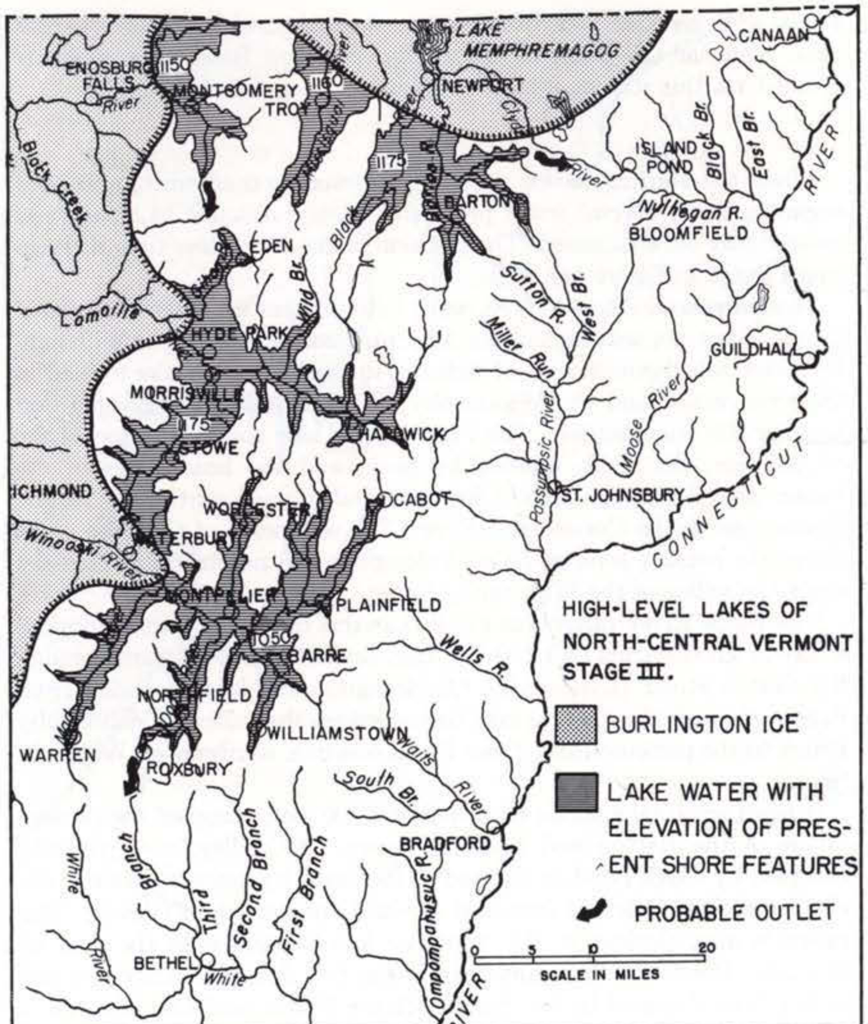


Figure 20

the Dog River valley drained through a col south of Roxbury that, at that time, had an elevation of 1,250 feet. The valley south of Roxbury must have been partially filled with unconsolidated sediment inasmuch as the lake outlet was rapidly lowered. The lake in North Branch Valley had no apparent outlet and the water level no doubt fluctuated with the rate of ice melting. The water probably drained into the Dog River valley through or over the ice dam. The two lakes existed independently until the Winooski Valley was freed of ice east of Montpelier, and the waters of the two valleys merged.

It seems logical to assume that the upper reaches of the Winooski River valley, northeast of Montpelier, were also occupied by a high-level lake during Stage I. The lacustrine sediments in this section of the valley, however, do not bear out this conclusion. There are no lake sediments in the upper part of the valley higher than the level of Lake Winooski that formed in a subsequent stage. A lake in the upper valley is not, therefore, shown on Figure 18 in spite of the fact that we cannot explain its not occurring there.

It should be noted here that former investigators, particularly Fairchild (1916), have suggested that drainage of the lakes in the Winooski Valley was via Stevens Brook and through Williamstown Gulf. The data collected by the present survey, however, show that the valley of Stevens Brook between Barre and the Gulf south of Williamstown was filled with kame gravel and did not act as a lake outlet until a later stage. This in spite of the fact that the present elevation of the divide (920 feet) south of Williamstown is ninety feet lower than the present divide south of Roxbury.

Stage II

At the beginning of Stage II of the wasting away of the ice from central Vermont, as described in this report, the ice had diminished enough in parts of four basins for lakes to begin to occupy them. It is important to note, however, that the ice removal was not the same in all areas. As explained earlier, the ice that invaded the basins came in part from across the mountains and in part through the gaps in the mountains (Figure 19). Whereas the ice in those areas that were fed by glaciers crossing the mountains began to melt down quite rapidly, the ice that moved through the gaps and around the northern end of the Sutton Mountains remained active. As a result, the ice in the Winooski and Lamoille valleys and in the Memphremagog Basin north and east of Newport persisted for a long time.

Memphremagog Basin. When the ice in the Memphremagog Basin began to melt down, melting was mostly concentrated in the Barton area since this section was not affected by ice moving through the gaps. As the ice in the Orleans-Barton region melted back, the waters of the Willoughby and Crystal lake basins combined to form a single lake that drained through the lower outlet southwest of Barton. As long as the lake waters drained across this divide, via the Sutton River, the water level was maintained at about 1,225 feet. Inasmuch as this lake, and the two lakes that preceded it, are mostly restricted to the Willoughby and Crystal lakes depressions, it does not seem that they should be considered early stages of Glacial Lake Memphremagog. No doubt these lakes were the 1,270-, 1,274- and 1,280-foot levels recorded by Hitchcock (1908b, p. 248) but he envisioned a lake at this level covering the Memphremagog Basin. The lake is here designated Lake Barton.

Lamoille Valley. During Stage II, a lake formed in the headwaters of the Lamoille River at an elevation of about 1,275 feet (Hardwick Quadrangle). The lake extended from the vicinity of Wolcott upstream past Hardwick almost to Greensboro Bend. There is no natural drainageway through which this lake could have drained. It is assumed that the lake waters flowed westward between the southern margin of the ice and the northern end of Elmore Mountain (Hyde Park Quadrangle). The lake was in existence only for a short time inasmuch as the water level dropped to the level of the lake in the Stowe Valley as soon as the ice melted down from the slopes of Elmore Mountain. This lake is designated Lake Lamoille. The shore features of Lake Lamoille are well defined in the Hardwick area by pebbly sand and gravel deposits and a well-developed beach one mile south of Hardwick.

Stowe Valley. A lake in the Stowe Valley at an elevation of 1,200 feet was separated from Lake Lamoille by ice that moved up the Lamoille Valley, through the Lamoille Gap, and overlapped the northern slope of Elmore Mountain. The Stowe Lake drained through Middlesex Notch, three miles north-northeast of Middlesex, into the Winooski Valley. The shore features of Stowe Lake are quite well developed since the lake level was maintained and the Middlesex Notch was used for a relatively long time. The ice in the Winooski Valley did not melt back (to the west) far enough to open the southern end of the Stowe Valley for at least another recessional stage. Even after the ice melted in the Lamoille Valley and opened the northern end of Stowe Valley, the lake formed by the combining of the two lakes continued to use the outlet at Middlesex Notch.

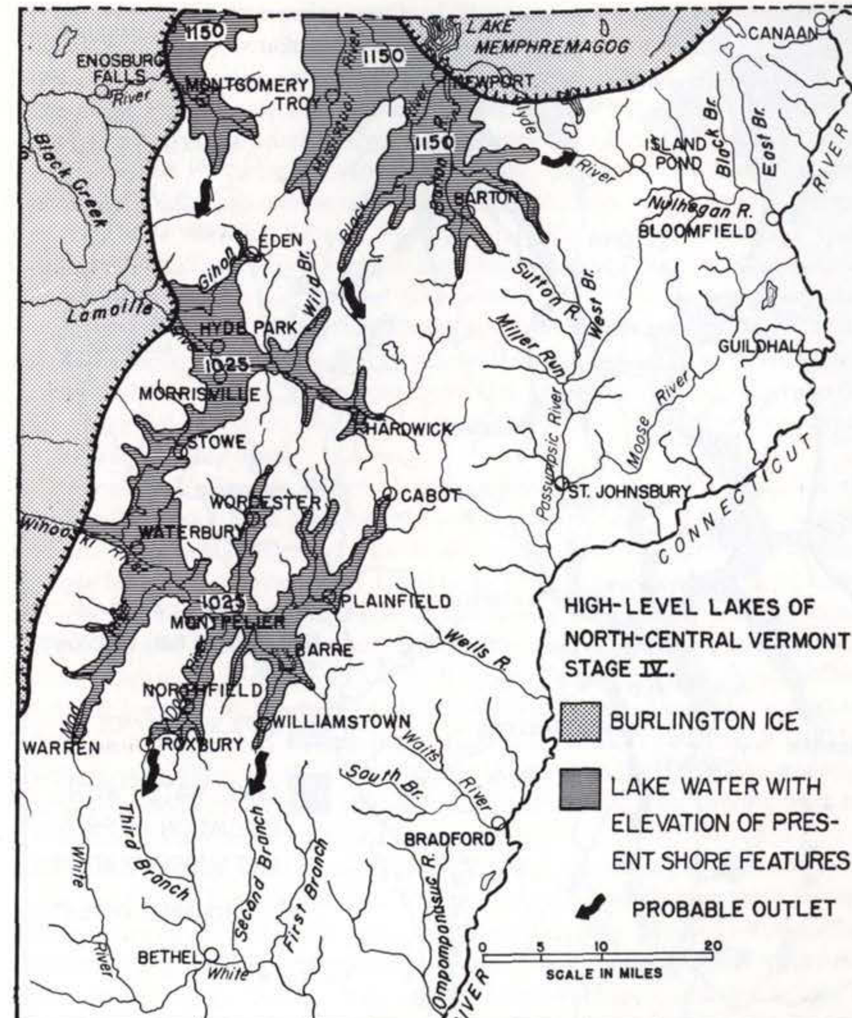


Figure 21

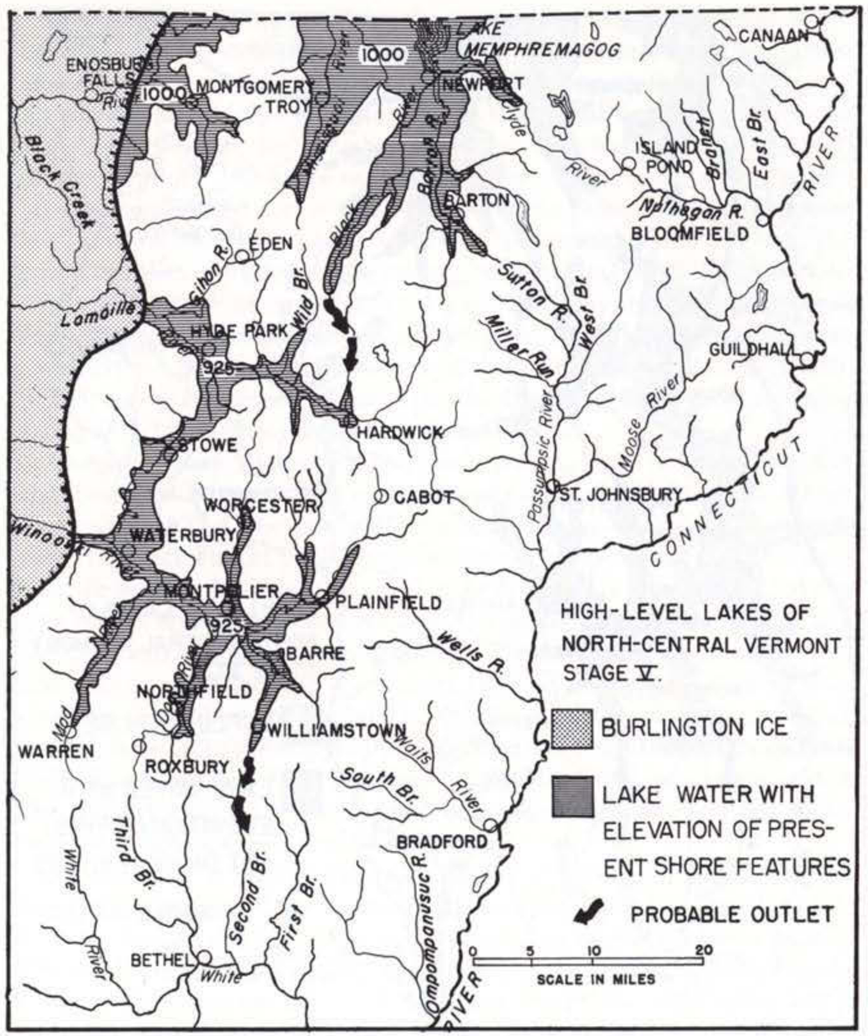


Figure 22

On West Hill, two miles north of Stowe, a large area is covered with beach gravel and beach bars. The highest bar is at an elevation of 1,170 feet. On Sunset Hill, one mile east-southeast of Stowe, another area of beach gravel occurs, and a well-developed bar stands at 1,200 feet. Several patches of beach gravel were mapped on Brush Hill two, three, four and five miles east-northeast of Stowe. The tops of all of these are near the 1,200-foot contour. Pebbly sand and a few sand bars also occur on the west slope of Elmore Mountain (Hyde Park Quadrangle). One mile west of Waterbury Center a large kame terrace (four miles long and one mile wide) in the Barnes Hill-Loomis Hill section laps upon the western foothills of Worcester Mountain. The wave activity of the lake, like the activity at Hinesburg, planed off the top of the terrace and carried the sand and gravel out over the ice-contact slope. High-level, ice marginal lakes are indicated above the Stowe Lake shore to about 1,500 feet in this area.

Winooski Valley. By Stage II, the ice margin in the Winooski Valley had melted back to a position just west of Montpelier. The lake waters of the Winooski, Dog and North Branch valleys combined to form a single lake at an elevation of 1,080 feet. This was the beginning of Lake Winooski. The existence of a lake at this level is manifested in many small deposits, the most important being the deltas. North of Montpelier, along the western side of North Branch Valley, several small deltas started forming at the 1,200-foot level during Stage I and continued to form at a lower level during Stage II (Plate XXXIV, Figure 2). In the Dog River valley, south of Montpelier (Barre Quadrangle), lake gravels, probably deltaic, occur in the valleys of Cox and Union brooks west of Northfield Falls and Northfield respectively.

Lake Winooski drained southward through the outlet at Roxbury and via the Third Branch and the White River to the Connecticut River. The water level was lower than the preceding lake (Stage I) due to the downcutting of the outlet. Apparently the unconsolidated valley-fill was eroded away during Stage I and Lake Winooski drained across a bedrock threshold. The outlet was used by several lake stages and successive lakes were lower because of downcutting of the bedrock divide (Plate XXXIV, Figure 1).

Stage III

At Stage III of the glacial melting in central Vermont the ice had melted back to the Green Mountains in many areas. The influence of the

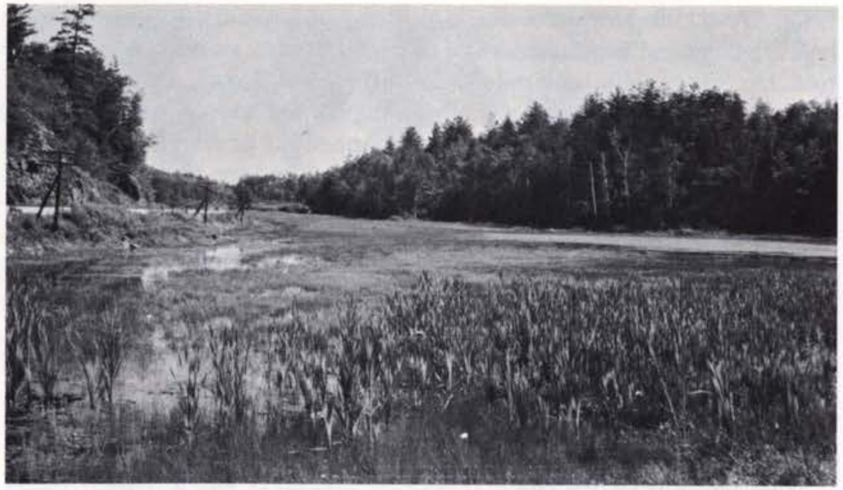


Figure 1. The Roxbury outlet of Lake Winooski (Stages II, III and IV). Present elevation 990 feet. Picture taken looking north, one and one-half miles south of Roxbury (Barre Quadrangle).

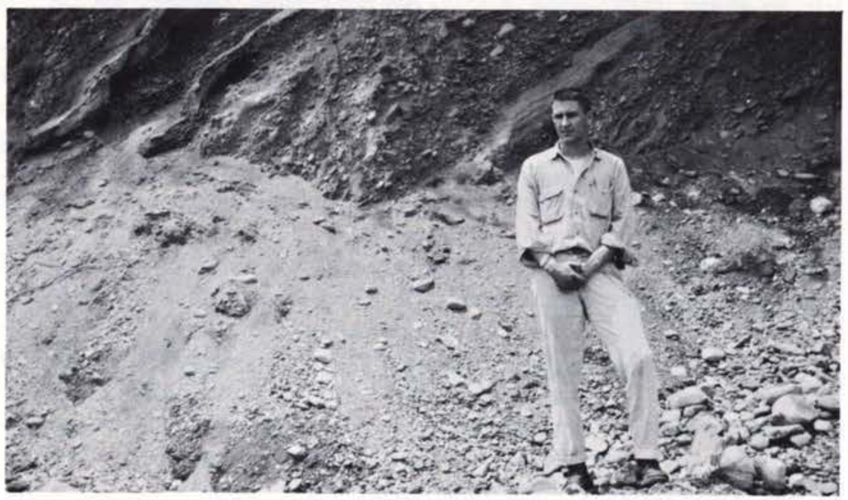


Figure 2. Deltaic bedding in small delta built into Lake Mansfield (Stage IV) on the west side of North Branch River valley by small tributary stream (elevation 1020 feet). One mile west of Wrightsville (Montpelier Quadrangle).

PLATE XXXIV

gaps through the mountains had decreased considerably and ice no longer moved through the sag at Belvidere Corners. The ice margin in the Lamoille Valley stood in the vicinity of Johnson. In the Winooski Valley, however, the ice still persisted and the southern end of the Stowe Valley was still closed. To the north, the ice moving across the Eastern Quebec Uplands (north of Sutton Mountain) into the Memphremagog Basin was still active and the Newport region was still covered (Figure 20).

Memphremagog Basin. Because glacial ice in the Newport region still covered a section of the Missisquoi Valley and the northern end of the divide between the Black and the Missisquoi rivers, three independent lakes were formed in the Memphremagog Basin. The most easterly of these occupied the Barton, Black and Willoughby valleys and the divides between them (Memphremagog and Irasburg quadrangles). The lake drained through a low col four and one-half miles south of West Charleston into the Clyde River. This lake may have used the old Clyde River channel described by Doll (1942, p. 22) at West Charleston for a short time or it may have started the cutting of a new channel. It seems, however, that the Clyde River northwest of West Charleston was ice-covered during this stage inasmuch as there are no lake sediments above 1,000 feet. The outlet south of West Charleston now has an elevation of about 1,170 feet and forms the divide between Nutting Brook and the headwaters of Brownington Branch.

The second lake in the region during this stage filled the headwaters of the Missisquoi River from the vicinity of North Troy southward past Troy and Lowell (Irasburg Quadrangle). The lake level was approximately 1,160 feet. The water must have drained by seepage through the ice, or around the ice margin, into a lake to the west in the same valley.

A third lake formed in the Richford section of the Missisquoi River valley because the valley was blocked by Burlington ice in the vicinity of Enosburg Falls (Enosburg Falls and Jay Peak quadrangles). The lake filled the valley (in Vermont) between East Berkshire and East Richford and probably extended as far west as Enosburg Falls and eastward into Canada before the end of the stage. The lake extended southward into the Trout River valley to a point at least five miles south of Montgomery Center. The elevation (1,160–1,180 feet) of the present divide between the Trout River and the North Branch of the Lamoille River (seven miles south of Montgomery Center) is low enough to have been the outlet of this lake. A problem arises, however, as to where the water drained inasmuch as the lake waters in the Lamoille Valley were at a higher level. It seems, therefore, that the North Branch was covered by ice at this time.

The evidences for three separate lakes instead of a single (connected) lake are two-fold. The shore features of the different lake levels are well developed in the three basins. Small, well exposed deltas at elevations above 1,100 feet are common in the tributary streams that flow into the three valleys. Numerous deposits of beach gravel, beach ridges and pebbly sand also mark the shore zone. The differences in the elevations of the shore deposits in the three valleys would hardly warrant three separate lakes inasmuch as measurements are hardly that accurate. The composition of the lacustrine sediment, however, is significantly different in the three valleys and it is on this basis that the three lakes were identified. Shilts (1965) did a detailed laboratory study of Pleistocene sediment collected in the Memphremagog Basin. The sediment, including both glacial and lacustrine materials, was subjected to a variety of laboratory tests that included X-ray, differential thermal and heavy mineral analyses, pebble counts and minor chemical tests. Shilts concluded (p. 73) that the composition of the sediments indicate independent lakes in these valleys. It is probable, according to Shilts, that the Black and Barton river valleys contained separate lakes during the transition from Stage II to Stage III as outlined in this report.

The Lamoille and Stowe Valleys. By Stage III, the ice margin in the Lamoille Valley had melted back to the vicinity of Johnson, opening the northern end of the Stowe Valley so that the lake waters of the two valleys merged, forming a single lake at an elevation of 1,175 feet (Montpelier, Hyde Park and Hardwick quadrangles). As suggested earlier, this lake is designated Lake Morrisville in this report. The height of the water was determined by the elevation of the Middlesex Notch outlet inasmuch as the southern end of the Stowe Valley was still blocked by ice in the Winooski Valley. Some water may have escaped around the ice margin as the ice slowly melted, but the total drainage was into the Winooski Valley.

Evidences of a lake at this level in the Lamoille Valley offers conclusive proof of the merger of the lake waters in the two valleys. A large fan-shaped deposit of sand, pebbly sand and beach gravel overlaps a kame terrace just north of the Lamoille River and two miles upstream (east) from Morrisville. A beach ridge occurs immediately to the northwest of this deposit. A gravel spit associated with beach gravel was mapped at Garfield, four and one-half miles northeast of Morrisville. Another beach

ridge, three-quarters of a mile long, marks the shore of Lake Morrisville one and one-half miles southeast of North Hyde Park. Four miles west of Morrisville and due east of Mt. Mansfield, beach gravel marks the lake shore along the eastern slope of the Green Mountains. The features, of course, are in addition to those of the Stowe area noted in the discussion of the Stowe Lake of Stage II.

Winooski Valley. Lake Winooski, during Stage III, had expanded to include the valley of Stevens Brook, south of Barre, and the Mad River valley south of Middlesex, and therefore occupied parts of the Montpelier, Barre, East Barre, Plainfield, Camels Hump and Lincoln Mountain quadrangles. This was the greatest extent of Lake Winooski. The outlet of the lake at this stage, we believe, was the col south of Roxbury, but a second outlet is a possibility. In the earlier stages, the valley of Stevens Brook between Barre and Williamstown (Barre Quadrangle) was filled with kame gravel, mostly kame terrace. By Stage III, however, stream erosion had opened the valley and the lake waters expanded down the valley past Williamstown. A large delta was built into the lake at Williamstown attesting to the presence of a lake in the valley (Plate XXXV, Figure 1). The lake could have drained southward through Williamstown Gulf for at least a part of this stage. But, evidence for an outlet at this level is not conclusive. During Stage III, the Roxbury outlet was cut down about twenty-five feet.

The shore features of Lake Winooski at Stage III are probably the best developed of any in north-central Vermont. Numerous small, but well-developed deltas occurring between 1,025 and 1,050 feet in the Dog, Winooski, North Branch and Mad River valleys are the most important of this stage. Deltas and lake gravel, probably of deltaic origin, are found in the Mad River valley south and east of Waitsfield in the valleys of Folsom and High Bridge brooks and an unnamed brook one mile due east of Waitsfield. One mile north of Waitsfield, on the west side of the Mad River, a deposit of lake gravel seems to be a compound delta built into the lake by two or three streams (unnamed) that flow into the Mad River from the west. A well-formed delta, one and one-fourth miles east of Moretown, was built into the lake by a westward flowing stream that now enters the Mad River just north of the village (Plate XXXV, Figure 2). Another delta is located one-half mile north-east of Moretown Common.

The deltas that were built into the lake at the Stage II level in the Winooski, North Branch and Dog River valleys were extended at this lower level.

Stage IV

Two major changes in the configuration of the ice border are conspicuous in Stage IV of the ice removal. In the Memphremagog Basin the ice had melted back from the divides so that a single lake was formed for the first time. To the south, the ice had cleared the southern end of the Stowe Valley so that a single lake existed in the Lamoille, Stowe and Winooski valleys (Figure 21).

Memphremagog Basin. Glacial ice still occupied the northeastern part of the Memphremagog Basin in Vermont during this stage inasmuch as glaciation was still active to the north-northeast. Glacial ice was thus still moving across the Eastern Quebec Lowlands into the northern and eastern sections of the basin. The ice, nevertheless, was gradually melting back along the eastern side of the Green Mountains and northward to the west of Lake Memphremagog. It is apparent, however, that the present Memphremagog lake basin was still filled with ice, and the area east of the lake was covered as far south as the vicinity of Seymour Lake.

The divide between the Missisquoi and the Black rivers was free of ice as was the valley of the Missisquoi, and a single lake was formed in the valleys that had held three separate lakes in the preceding stage. This report contends that, since this was the first lake to spread over the Memphremagog Basin, this lake should be designated the first stage of Glacial Lake Memphremagog. As we understand the original usage of this name by Hitchcock (1907, 1908b), his intent was to connote a single lake covering the basin instead of a series of disconnected, independent lakes. The lake here described would correspond to the 1,060- and 1,070-foot levels noted by Hitchcock.

Hitchcock (1908b) believed that Glacial Lake Memphremagog drained southward to the Lamoille Valley through the present divide at Eligo Pond. This report does not discount this valley as a possible outlet. The absence of high-level lake sediment (above 1,000 feet) in the Eligo Pond and Black River valleys south of Albany, however, seems to prove that the lake did not use this drainageway. If the Eligo Pond-Black River valleys were open at this time (Stage IV), then a single lake may have existed in north-central Vermont that drained southward through the Roxbury outlet. The outlet at Roxbury stood at about 1,025 feet during Stage IV. The Coveville and Fort Ann shorelines have been uplifted 110 to 125 feet higher at the Canadian border than in the Dog River valley, and other lake shores have been uplifted the same amount. Thus a single lake would be a possibility.

A second possible outlet, to the Lamoille Valley, for Glacial Lake Memphremagog is the divide south of Montgomery Center between the Trout River and the North Branch of the Lamoille, mentioned in the discussion of Stage III. This outlet is more likely in Stage IV inasmuch as the ice had melted back enough for the water to drain along the margin. The present elevation of the divide seems a bit too high, but not exceedingly so. A third possible outlet for this lake is through the Clyde River to Island Pond and thence the Nulhegan to the Connecticut River. The divide at Island Pond (present elevation) also seems to be higher than the lake but much depositional material at this locality may have been deposited during or following the existence of the lakes. It is probable that Glacial Lake Memphremagog may have drained through any of these possible outlets at one time or another in the early development. No doubt water began to escape southward through the Black River-Eligo Pond valleys during this stage, and cutting of the present channel between Coventry and Irasburg began. Before the end of Stage IV, this southward channel had been well established and cut down to the level of the lake in Stage V.

Shore deposits at about 1,150 feet, marking the level of Lake Memphremagog at this stage, are widespread and well developed all over the Memphremagog Basin except to the east of Lake Memphremagog. Delta deposits along the Brownington Branch of the Willoughby River at Brownington Center (Memphremagog Quadrangle) were cut by the present stream, but the top of the deposit is preserved at about 1,160 feet. Another small deposit is located two miles to the south-southeast at Heath School. In the Irasburg Quadrangle, a delta along Lamphear Brook two and one-half miles north of Albany is the most southerly deposit at this level in the Black River valley. Several deltas and other sand and gravel deposits were mapped along tributary streams of the Missisquoi south of Troy. These deposits include deltas along Taft Brook, an unnamed brook along Hazens Notch Road, Mineral Springs Brook and one of its tributaries, and lake sand in Burgess Branch. In the Jay Peak Quadrangle, deltas are found on the headwaters of Lucas Brook two miles east-southeast of East Richford, along Black Falls Brook, a tributary of the Trout River, two and one-half miles east-northeast of Montgomery and in the Trout River valley four and one-half miles south of Montgomery Center.

Lamoille, Stowe and Winooski Valleys. During Stage IV the lake waters of the Lamoille, Stowe and Winooski valleys combined to form

Figure 1. Topset and foreset beds of the delta built into Lake Winooski (Stage III) at Williamstown (Barre Quadrangle).

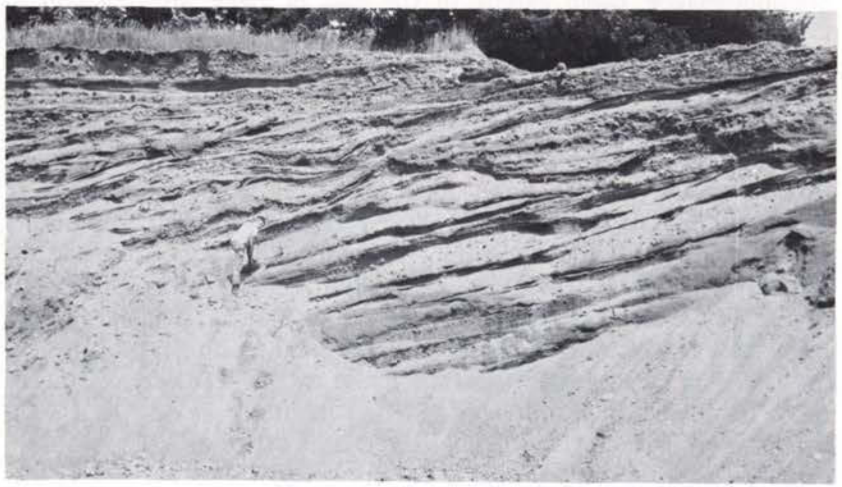


Figure 2. Foreset beds of the delta built into Lake Winooski (Stage III), one and one-fourth miles east of Moretown (Barre Quadrangle).

PLATE XXXV

a single lake at an elevation of approximately 1,025 feet with an outlet at Roxbury. The name Lake Mansfield is used in this report to designate the lake that occupied the three valleys. Figure 21 shows the elevation of the lake to be the same elevation in all valleys. The water, of course, was at a single level, but the present shore features are not now horizontal due to tilting since the recession of the last ice sheet.

The shore features of this stage of Lake Mansfield are well developed and common to all the valleys. The deposits in the Winooski Valley are best developed inasmuch as Lake Winooski was only about twenty-five feet higher than Lake Mansfield. Because the lake level was lowered gradually by downcutting of the outlet, the shore features of the two lakes, particularly the deltas, are more or less continuous deposits and difficult to separate.

Stream erosion was active in the Stevens Brook-Williamstown Gulf valley during this interval. Headward erosion, probably from the south, lowered the divide in this valley. Sometime during Stage IV, the outlet of Lake Mansfield was shifted to this valley. Downcutting of this outlet accounts for the lower level of the lake during the following stage.

Stage V

At the beginning of Stage V, the ice of the Burlington Stade had almost completely melted down in the region of the high-level lakes in Vermont. Two exceptions were that the ice still blocked the drainage to the west through the Green Mountains and glaciation was still active north of Lake Memphremagog (Figure 22). The ice must have occupied the northern part of the Champlain Lowland at least as far south as Vergennes since all of the drainageways to the west were blocked, including the valley between Huntington and Hinesburg, the most southern possible outlet of Lake Mansfield. The ice in the Memphremagog Basin was probably north of the Canadian border at the beginning of this stage but active glaciation must have been taking place on the uplands to the north of the international boundary.

Memphremagog Basin. Glacial Lake Memphremagog dropped to a level of approximately 1,000 feet during this stage due to the opening and downcutting of a channel through the Black River-Eligo Pond valleys. McDonald (1967a, p. 109) notes that drainage of a lake at this level could have been through a col (elevation 1,025) near La Guadeloupe, Quebec. This report contends, however, that the La Guadeloupe col is much too far north (latitude 45° 57′) to have been free of ice at this time. As has already been noted, it seems logical to assume that lake waters began to spill over this divide during Stage IV, cutting the new channel of the Black River (Coventry to Irasburg), and gradually lowering the outlet. Whether or not a pre-glacial valley of a tributary stream or smaller valleys of two tributaries followed the present course of the Black River in this section is not known. The downcutting continued and Glacial Lake Memphremagog was probably lowered to the approximate level of Lake Mansfield during Stage V.

The lacustrine sediment in the Black River south of Orleans and the Clyde River between Newport and West Charleston suggest that these valleys were filled with lake waters for the first time during this stage. Evidences of the 1,000-foot lake level are common in the Derby-Derby Line area.

Lamoille, Stowe and Winooski Valleys. The outlet of Lake Mansfield was obviously through Williamstown Gulf during Stage V. The outlet south of Williamstown was cutting down thus lowering the level of the lake. The deposits of the lake at this level are definite, but shore deposits are not as well developed as in the preceding stages. It is apparent that the water level was lowered gradually during the stage, and therefore stable levels were maintained for short periods only.

Several small deltas, or lake gravel deposits, are found at the 900-925 foot level in the Montpelier and Barre quadrangles. A delta at 900 feet occurs in the North Branch valley two miles north of Worcester. An unnamed tributary stream north of the Winooski River built a delta into the lake two miles west of Montpelier, and lake gravels almost fill Jones Brook valley south of the Winooski Valley. Sandy lake sediment of this lake stage fills the Stowe Valley in the vicinity of Stowe and the Dog River valley south of Northfield.

The End of the High-Level Lakes

The high-level lakes of north-central Vermont ended when the ice in the Champlain Lowland melted back or receded north of the valleys through the Green Mountains, thereby allowing the lake waters of these valleys to lower to the level of Lake Vermont. The different valleys were not opened at the same time, however, for Glacial Lake Memphremagog remained after Lake Mansfield ceased to exist.

The first outlet to the Champlain Lowland to be freed of ice was the valley now occupied by Hollow Brook between South Hinesburg (Burlington Quadrangle) and Huntington (Camels Hump Quadrangle); between the Champlain Lowland and the Huntington River valley. Inasmuch as Lake Mansfield had expanded into the Huntington River

valley south of Bolton before the end of Stage V, the opening of the Hollow Brook valley allowed Lake Mansfield to drop to the level of the Quaker Springs stage of Lake Vermont. Since the divide between the Winooski and Lamoille valleys at Stowe was lower than the level of the Quaker Springs Lake, the lake waters of the Stowe and Lamoille valleys also dropped to the Lake Vermont level.

The Missisquoi River valley through the Green Mountains in the vicinity of East Berkshire (Jay Peak Quadrangle) was blocked for a considerable time after the opening of a drainageway to the west for Lake Mansfield. As a result, the lake waters of the Memphremagog Basin maintained a high level and flowed southward to the Lamoille Valley through the Eligo Pond outlet. The outlet was cut down to about 900 feet and stabilized at that level, where shore features are rather common in the Basin (Plate XXXVII, Figure 1). By the time that the ice in the Champlain Lowland had receded far enough north to open the Missisquoi Valley, Lake Vermont had dropped to the Coveville Stage.

High-Level Lakes of Southern Vermont

Damming of the streams by Burlington ice south of the Winooski Valley but north of Rutland resulted in few lakes inasmuch as the ice crossed the Green Mountains in this area and the streams flowing westward were small with very steep gradients. The White River valley was free of ice during the Burlington Stade, and no damming on the east side of the mountain was possible south of Roxbury.

In the Rutland area, it is reasoned that Otter Creek should have contained a high-level lake south of the terminus of the Burlington ice. Lake sediments, however, are not found above 625 feet in that valley. Obviously the water in this valley had some escape route, possibly around the ice margin or even under the ice, but a definite answer to this problem was not found during the survey.

The Poultney River was dammed by the Burlington ice in the vicinity of East Poultney (Castleton Quadrangle). A lake was thus formed that extended upstream to Middletown Springs (Pawlet Quadrangle). The lake gravel, probably deltaic, at Middletown Springs has an elevation of 900 feet, and deposits downstream, two miles upstream from East Poultney, at 700 feet seem to indicate two different levels for this lake.

The Mettawee River was dammed by ice at Pawlet, and a small lake at about 750 feet elevation formed in the valley between Pawlet and East Dorset.

LAKE VERMONT

When the Burlington glaciation was at its maximum, the Champlain Lowland was completely covered by ice. As melting began, however, lakes were formed beyond the ice margin inasmuch as the only possible drainage was southward through the present divide between Lake Champlain and the Hudson River. Lake waters occupied the Champlain Basin until the Burlington ice melted down or receded northward to the St. Lawrence Lowland thus allowing the drainage to shift to the northeast. When drainage was finally possible through the St. Lawrence River, the lake waters lowered to the level of Lake Champlain. The series of lakes that existed in the Champlain Lowland during the recession of the Burlington glacier is collectively known as Lake Vermont.

Chapman (1937, 1941) made a detailed study of the lacustrine and marine sediments on the Champlain Lowland in Vermont and New York. His reports on the glacial and post-glacial lake and marine histories of this region are accurate and complete. It is not the intention of this report to supersede the findings or the interpretations of this scientific study. We found it to be most helpful and reliable during the mapping program. Inasmuch as the present survey covered the whole Champlain Lowland and all adjacent areas in Vermont, however, certain new data collected are here recorded to add to the work of Chapman. Certain new interpretations, such as a new lake stage, and additional discussion of the deposits of Lake Vermont are also included.

The Calving Retreat of the Burlington Glacier

The few and scattered occurrences of till and a predominance of boulder strewn lake sediment over most areas of the Champlain Lowland indicate a calving retreat of the Burlington ice. Whereas we propose a stagnant zone retreat over the uplands of Vermont, the evidence in the Vermont Valley and the Champlain Lowland suggest an edge retreat. The ice edge melted back against outwash deposits in the Vermont Valley and by calving into lake waters in the Champlain Lowland. Connally (1967), Shilts (1966a) and Behling (1966) cite evidences of ice readvance in the Brandon area and the Vermont Valley, but no other areas exhibited such evidence. Insofar as present knowledge is concerned, the ice may have been stagnated in most areas but calved nonetheless into Lake Vermont. Regardless of whether the ice was active or stagnated, it is apparent that the glacial margin, buoyed up by the waters of Lake Vermont, calved off from the glacier and floated away as icebergs. As the

icebergs melted, the detritus contained in them dropped to the bottom and was incorporated in the lake-bottom sediment as it accumulated there.

The boulder strewn, lake-bottom sediment is very widespread in the Champlain Lowland. The lacustrine material containing the pebbles, cobbles and boulders consists mostly of clay and silty clay. The number of cobbles and boulders contained in the lake sediment is surprisingly large, causing the surface of cultivated land to resemble a till plain. In the Burlington region, in particular, the surface of the clayey lake sediment contains such a large number of boulders that the farmers line the fence rows with them. A good exposure of this material is found along the shore of Lake Champlain near the mouth of Holmes Brook two miles northwest of Charlotte (Willsboro Quadrangle). Here ten to thirty-five feet of varved lake clay are exposed along the lake shore in a vertical cliff one hundred yards long (Plate XXXVI, Figure 1). Numerous boulders, contained in the lake clay, ranging in size up to thirty inches across, were striated and/or faceted, indicating ice erosion (Stewart, 1961, p. 105, Plate XVIII, Figure 2). The extent of the "bouldery lake clay" suggests that the calving retreat extended the entire length (north to south) of the Champlain Lowland in Vermont. Similar boulder strewn lake sediment, indicative of a calving retreat, was reported for the western half of the St. Lawrence Lowland by MacClintock and Stewart (1965, p. 8).

The second significant evidence of a calving retreat of the Burlington glacier is the virtual absence of till over many areas of the Champlain Lowland. Wave activity, of course, was responsible for some removal of till along the shorelines of the different lake stages. The erosion by waves on till shorelines, however, is easily recognized because of the boulder concentrations left after the removal of the finer grain sizes. In many areas, the lake bottom sediment is found to lie directly on the bedrock These sediments were deposited at depths below wave base where removal by any erosive agent would have been impossible. In these areas, the striae on the bedrock, under the lacustrine sediments, are well preserved and fresh showing that fluvial erosion did not take place before the silts and clays were deposited. Till deposits on the lowland are restricted mainly to the foothills of the mountains and the hills standing above the highest lake level or areas where the lake water was not deep enough to permit calving. This suggests that the ice edge was calving both during the advance of the glacier as well as during retreat.

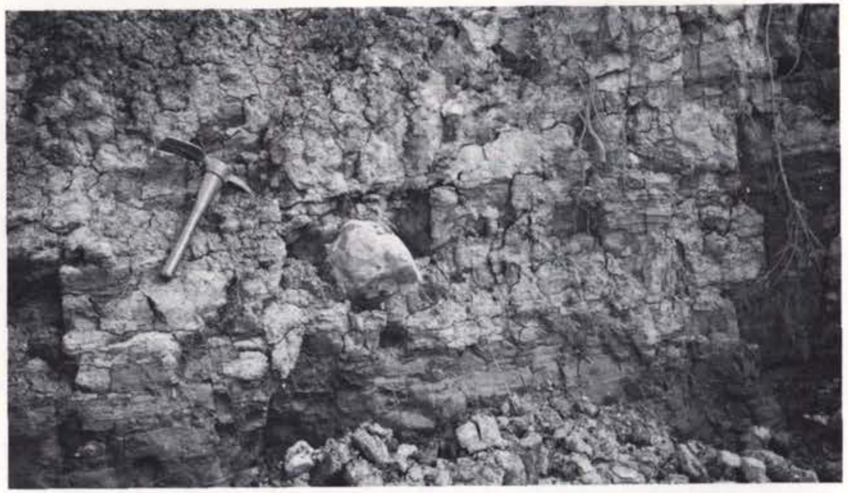


Figure 1. Bouldery, varved, lacustrine clay exposed along the Champlain lake-shore at the mouth of Holmes Brook (Burlington Quadrangle).

Figure 2. Burlington basal till exposed in an excavation at Main and Spear Streets in Burlington (Burlington Quadrangle).

PLATE XXXVI

The Quaker Springs Lake Stage

Chapman (1937, p. 97) noted certain lacustrine deposits in the Champlain Lowland that were above the level of his Coveville lake stage. These deposits he interpreted as having been made in local, high-level lakes that formed along the ice margins as the ice margin waned along the sides of the lowland, but before the glacier had receded enough to form Lake Vermont. Chapman was cognizant of the fact that Woodworth (1905, p. 103) had described shore features in New York which he believed marked an earlier, higher stage than the Coveville. Chapman, however, did not believe that the evidence that he had found in Vermont and New York were conclusive enough to warrant the designation of an earlier than Coveville stage. The present survey has identified a series of higher than Coveville shore phenomena which seem to establish the existence of an earlier, higher stage of Lake Vermont. Inasmuch as Woodworth used the name "Quaker Springs Stage" to designate the lake that he described, this designation already had precedence and was used by Stewart (1961, p. 105) to identify the highest stage of Lake Vermont. The higher shore features are approximately 100 feet above the Coveville shoreline and extend more or less continuously from Lake St. Catherine in the south to the Lamoille River in the north. The shore sediments of this stage are best developed in the Burlington, Milton and Mt. Mansfield quadrangles and upstream in the valleys of the Winooski and Lamoille rivers. In these regions, the shore features are so well developed that they seem to indicate that the Quaker Springs Lake was in existence for an interval as long as the later lake stages.

At Rockville, two-tenths of a mile south of the southern border of the Burlington Quadrangle, a shore terrace was cut into the mountain slope. A beach gravel deposit extends from the base of the wave-cut cliff at an elevation of 695 feet down to the highway (State Route 116) approximately one hundred feet below. Because the mountain slope is here partly covered by till and partly by kame terrace gravel, the wave activity that cut the terrace and deposited the beach left a heavy concentration of large boulders on the surface of the terrace. Several bars and/or spits were built on the terrace more or less normal to the shoreline.

In the vicinity of Hinesburg (Burlington Quadrangle) the lake shore phenomena are at the same level as the flat-topped kame terraces. As described earlier in this report, the wave activity of the Quaker Springs Lake planed off the terraces and carried the sediments out over them depositing a mantle of delta-like foreset beds. The amplitude of the foreset beds is over one hundred feet, down to the base of the ice-contact slope, as seen in exposures of the large gravel pits. At some places, on the tops of the terraces, beach gravel deposits are found and in other sections lacustrine clays and silts show lake waters to have been at that level. The tops of the terraces and the beach gravel deposits have an elevation of 700 feet. Gravel pits penetrating the outer slopes of these terraces show evenly bedded, medium textured gravel dipping away from the flat tops covering kame gravel exhibiting ice-contact structures (Plate XXXIII, Figures 1 and 2). Early investigations of these deposits assumed that the dipping beds were deltaic in origin, but the underlying kame gravel was probably not exposed at that time.

Along Johnny Brook, one-half mile south of Fay's Corners, a lacustrine sequence consisting of lacustrine silts and clays covered by kame gravel was exposed at the time of the mapping. The top of the deposit is at an elevation of 740 feet. These sediments may have been deposited in a local ice-marginal lake since they seem to be above the Quaker Springs level in that area.

The shore sediments of the Quaker Springs Lake are well developed in the Jericho-Underhill region (Camels Hump and Mt. Mansfield quadrangles). A gravel pit on the south side of the Lee River valley, one-half mile north-northeast of Jericho Center, showed ten to fifteen feet of beach gravel. The gravel follows the valley for a distance of two miles and has a top elevation of 725 feet. An extensive deposit of beach gravel and near shore-level sand and gravel occurs south of Browns River along the highway (State Route 15) between Jericho and Riverside. The level valley floor, including the section from which Underhill Flats derives its name, is a deposit made at about water level in a shoaling cove that extended upstream from the lake. Some of the gravel, however, is definitely beach with bars found on the surface, particularly in the vicinity of Jericho. The elevation of the highest bars in this end of the valley are 710 to 725 feet. Lake gravel deposits upstream from Underhill indicate at least one earlier ice-contact lake higher than the Quaker Springs level.

The most northerly deposit of the Quaker Springs Stage in the Champlain Lowland is located on Prospect Hill two miles south-southwest of Fairfax (Milton Quadrangle). On the north slope of the hill, a beach gravel was deposited over the till, and a low, but definite, shore cliff was eroded. The elevation at the top of the gravel and at the base of the cliff is 750 feet. Beach gravel is spread over the slopes for a distance of about four miles.

Evidences of a higher than Coveville lake are found throughout the valleys of the Lamoille, Winooski, North Branch, Dog and Huntington rivers and to a lesser extent along the Mad River. Inasmuch as these valleys were all occupied by one or more lakes during the high-level stages, described in the preceding chapter, it is difficult in many cases to separate the sediment of the upper and lower lake sequences. After the high-level lake dropped to the level of Lake Vermont, the streams rapidly cut down through the unprotected sediment filling the valleys and reworked the easily eroded sands and gravels at the lower lake levels. Shoaling did occur, but the sediment filling the lakes was mostly sand and pebbly sand. Shore features, mostly beach gravel and a few deltaic deposits, do occur, and these are the best indicators of lake levels.

In the Lamoille Valley, the most prominent lake-level markers are the gravel flats composed of beach materials in the vicinity of Morrisville (Hyde Park Quadrangle). The village stands on a gravel terrace at 670 feet (Coveville), forty feet above the floodplain of the Lamoille River. A second gravel-capped terrace, at Morrisville, standing at an elevation of approximately 720 feet, lies to the east of the lower level marking the Quaker Springs in that area. The Morrisville High School stands on the second level. An excavation at the high school, at the time that region was mapped, penetrated fifteen feet of horizontally bedded, uniformly sorted, fine gravel. A wave cut terrace behind the high school rises to 740 feet. To the south, across a post-glacial ravine, the country club, hospital and armory are located on another terrace at about the same level. This terrace, approximately one mile long and one-half mile wide rises from elevation 750 feet at its north end to 790 feet at the south. The flat-topped terrace also displays shallow water topography including spits, bars and low wave cut cliffs which are conspicuous on the fairways of the golf course. Gravel pits at the south edge of the terrace expose ten to fifteen feet of horizontally bedded, fine, clean gravel with pebbles ranging from one inch to one and one-half inches in size, but with no cobbles or boulders, lying on clean, well sorted sand. The foundation excavations for the hospital on the south-central part of the terrace penetrated fifteen feet of the same surface gravel, ten to fifteen of sand, and a dense, blue, silty clay of lacustrine origin.

An 800-foot lake level is also manifested by shore deposits along the Lamoille Valley between Hardwick and Morrisville. This lake level was not noted in the discussion of the high-level lakes inasmuch as it is now believed to be a transitional lake between the higher and lower lake stages. The 800-foot lake shore is marked by a broad, level terrace on the south side of the river one and one-half miles west of Hardwick Lake (Hardwick Quadrangle). A second terrace occurs on the north side of the river one mile to the west. Both terraces are composed of horizontally bedded, uniform, gravelly sand. At one place, in a gravel pit on the second terrace, deltaic bedding with a twelve-foot amplitude and a westward dip is exposed. This lake level is also indicated by four small terraces in the vicinity of Wolcott and two large terraces between Wolcott and Wild Branch. On the Hyde Park Quadrangle, gravel capped terraces at 800 feet altitude are found as far west as Morrisville (Plate III, Figure 1). The deposits west of Morrisville have been dissected to a lower level except along Foot Brook, one and one-half miles northwest of Johnson, where horizontally bedded, pebbly sand, shore terrace material is exposed in a large gravel pit.

Connally (1967) reported the elevations of the lake levels along the Lamoille Valley in the Mt. Mansfield Quadrangle at 840, 740 and 660 feet. It is apparent, therefore, that the lake levels in the valley dropped from a 800–840-foot level to a 720–740-foot level and then to 666–670 feet.

In the Winooski Valley, the Quaker Springs shore phenomena have been much eroded and are not too conspicuous. Good evidence of a lake is found north and south of Montpelier in the North Branch and Dog River valleys. Two miles west-northwest of Montpelier and one mile north of the Winooski River, a delta was deposited by a small unnamed stream. The topset and foreset beds are well developed as was exhibited in a gravel pit during the mapping of the Montpelier Quadrangle. The highest elevation on the flat topset beds is 820 feet. A lower terrace level, which seems to be about the top of the foreset beds, has an elevation of 760 feet.

In the North Branch valley, north of Montpelier, a large flat lacustrine gravel deposit extends one mile upstream and one and one-half miles downstream from the village of Worcester. The deposit averages about one-half mile in width. The sediment was mapped as lake gravel inasmuch as no openings or exposures were found in which the attitude of the bedding could be ascertained. It is believed, nonetheless, that this is the delta of the North Branch that was built into the Quaker Springs Lake. The lacustrine origin of the detritus is unquestionable since the surface layers of the gravel could be studied in two shallow pits located in it. The elevation of the flat surface ranges from 700 feet to almost 780 feet. Two other small deltaic deposits at 700 feet elevation occur downstream from Worcester. These are on the east side of the North

Branch one and one-eighth and one and one-half miles south of Putnamville.

A deposit in the Dog River valley, south of Montpelier, that resembles the deposit at Worcester occupies both sides of the valley between Riverton and Northfield Falls (Barre Quadrangle). The flat-topped, gravel-capped terraces have elevations of 700 to 740 feet. Whereas the deposits at Worcester are definitely believed to be a delta, the Dog River terraces may be either deltaic or shoaling gravel. Pits in the Riverton area show sandy gravel and pebbly sand at the surface grading downward into sand without pebbles at depths of ten to fifteen feet. Two well-developed beach gravel deposits were still intact in the Dog River valley at the time of this survey. One beach, at elevation 700 feet, is on the west side of the valley one mile north of Riverton. The latter deposit, before its removal for road metal, exhibited even-sized, flat pebbles with imbrications overlapping both into and away from the shore.

There is much gravel and sand in the Huntington River valley (Camels Hump Quadrangle) which includes kame, lacustrine and post-glacial fluvial materials. A great amount of erosion, reworking of the sediment and redeposition has taken place in the valley since the Lake Vermont interval. There are, however, a series of sand and gravel terraces, the tops of which have elevations ranging from 700 to 750 feet, that establish the existence and level of the Quaker Springs Lake in the valley. A pebbly sand terrace lies to the south of the river near its mouth, high on the valley wall, one mile south-southwest of Jonesville. Lake sand in the vicinity of Towers School, two miles upstream from Jonesville, seems to indicate two lake levels at altitudes of 720 and 640 feet. Pebbly sand at 700 feet drapes the west side of the valley at Huntington and the east side of the valley along Brush Brook just north of Huntington Center. The Brush Brook deposit is probably deltaic.

The Quaker Springs level is marked in the Mad River valley south of Moretown (Lincoln Mountain Quadrangle) by a wide, pebbly sand terrace on the west side of the river. The terrace extends upstream (southward) from the vicinity of Moretown for a distance of two and one-half miles. Elevations on the inner margins of the terrace, at the contact with the mountain slope, are 725 to 750 feet. A small beach gravel deposit one-fourth mile east of Moretown rises from 700 feet elevation at the outer margin to 800 feet at the contact with the valley wall, indicating a lowering from the 800-foot level to that of the Quaker Springs.

South of the Burlington region, on the Champlain Lowland, the shore phenomena of the Quaker Springs Lake Stage are scattered, not too well developed and, at this writing, still confused with the features of the Coveville Stage. Calkin (1965), who mapped the Middlebury Quadrangle, reports a wave-cut terrace and a weak scarp one-tenth mile east of Starksboro at 680 to 690 feet. A second fairly well developed wave-cut bench and beach ridge were mapped one and one-half miles due west of the south end of Lake Winona (Bristol Pond) at an elevation of 650 feet. These, according to Calkin, are the only evidences, such as they are, of the Quaker Springs Lake in the Middlebury Quadrangle.

In the Brandon Quadrangle, the Forest Dale delta, reported by Chapman (1937, 1942), is probably a Quaker Springs feature at elevation 620 to 640 feet. Chapman interpreted this and other deposits that he found above the Coveville level in the Brandon area to be evidences of local glacial lakes. The local lakes, according to Chapman, occurred along the mountain front before the glacial ice melted from the Champlain Lowland in that region. Several small beach gravel deposits at or near the 600-foot contour occur along the mountain slope between Forest Dale and Pittsford (Castleton Quadrangle). Just north of Pittsford, pebbly lake sand and gravel capping a kame terrace indicate a lake level at 600 feet.

South of Rutland (Rutland Quadrangle), on the west side of Otter Creek valley, four small deltas were mapped with elevations from 580 to 620 feet. The most northern of these is within the southern limits of the city of Rutland. Several abandoned gravel pits were found in the deposit but structures were obscured due to slumping. This deposit at 620 feet is the only one of the four above 600 feet elevation. A second delta at North Clarendon was built into a lake by the Cold River. The third delta, a deposit made by an unnamed tributary of Otter Creek, is located one and one-half miles south of North Clarendon. The fourth deposit is the delta of the Mill River at Clarendon.

Lacustrine gravels around Lake St. Catherine and southward to the vicinity of North Pawlet (Pawlet Quadrangle) have elevations as high as 525 feet. Behling (1966) describes these features as having been made in a local, ice dammed lake which he called Lake Granville. These may, however, be associated with the Quaker Springs Stage. The shoreline of such a lake would follow the foothills of the low Taconics into New York State, and that area was not investigated during this survey.

The drainage of the Quaker Springs Lake had to be southward over the divide between Lake Champlain and the Hudson River. Inasmuch

as this divide is in New York State and was therefore not studied during the present survey, the exact location of the outlet is not known at this time. LaFleur (1965), who has studied the sediments of Lake Albany in the Troy, New York region, has suggested that these deposits seem to show that all three levels of Lake Vermont were controlled by levels of Lake Albany. More recently, Connally (1968) has reported that his data from the Champlain Lowland of New York and Vermont supports LaFleur's conclusion that the Quaker Springs and Coveville lakes were continuous with levels in the Hudson Valley. Connally does not, however, believe that Fort Ann Lake was controlled by a lower level of Lake Albany.

The Coveville Lake Stage

The Coveville Lake was thought to be the highest level of Lake Vermont prior to this survey and the publication of *The Glacial Geology of Vermont* in 1961. Chapman (1937, 1942), as already stated, considered all lake-shore phenomena above the Coveville strand-line to have been formed in local, independent lakes that existed for a short time before the recession of the Burlington glacier. According to Chapman (1937, p. 95) the Coveville was so named because the outlet, according to his interpretations, was through a col at Coveville, New York. The tilted water plane of this lake rises from an elevation of 450 feet near Brandon to an elevation of 700 feet in the vicinity of Milton, the northern limit of the Coveville Lake recorded by Chapman (1937, p. 95).

Data collected during the present survey seems to prove that the Quaker Springs Lake, and not the Coveville, had its northern limit just north of the Lamoille River in the Milton region. Shore features, believed to be those of the Coveville Stage, have been traced to the Canadian border along the Missisquoi River and its tributaries in the Enosburg Falls, Jay Peak and Irasburg quadrangles.

At East Richford (Jay Peak Quadrangle), a delta at the international boundary at an elevation of 740 feet occurs at the mouth of Lucas Brook on the south side of the Missisquoi River. The foreset bedding of this deposit, with amplitudes of thirty feet or more, rest directly on varved clay and laminated silt. One and one-half miles southwest of the East Richford deposit, at Stevens Mills, a delta at the mouth of Mountain Brook has an elevation of approximately 760 feet (Plate XXXVII, Figure 2). The foreset beds of this delta, exposed in a new road cut at the time the quadrangle was mapped, were dipping into the valley with

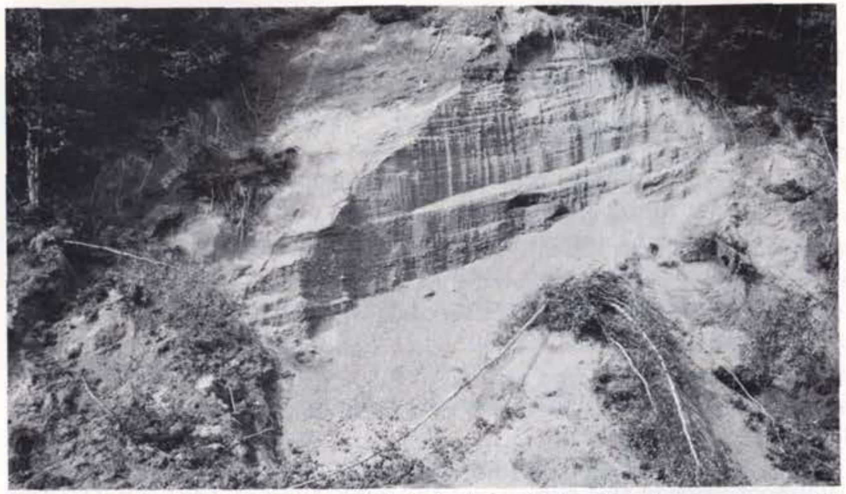


Figure 1. Foreset bedding of a small delta built into Lake Memphremagog, one mile south of Lowell. Top elevation 900 feet (Irasburg Quadrangle).

Figure 2. Delta built into Coveville Stage of Lake Vermont by Mountain Brook at Stevens Mills. Top elevation 760 feet (Jay Peak Quadrangle).

PLATE XXXVII

the toe resting on the ice-contact gravel of a kame terrace in the Missisquoi Valley. Similar deltas occur along the Missisquoi Valley at Richford near the mouth of North Branch and two miles south of Richford where the small stream that drains Guillmettes Pond enters the Missisquoi. A large gravel pit in the North Branch delta exposes foreset bedding with amplitudes of fifty to sixty feet. The top of the foresets is at 640 feet, but the surface of the deposit slopes upward to over 700 feet at the top of the terrace.

Along Alder Brook, a tributary of the Trout River, at South Richford, beach gravel and beach ridges occur at the 760-foot contour. Two miles south of Montgomery Center the South Branch of the Trout River exhibits delta levels with elevations at 720 to 740 feet that were dissected, reworked and redeposited to make a flat delta top at 600 to 625 feet.

At the headwaters of the Missisquoi River in the Irasburg Quadrangle, a pebbly sand terrace extending three miles to the south of North Troy stands at elevations of 720 to 740 feet. Smaller patches of a pebbly sand terrace at the same elevations south of Troy suggest a shoaling lake at that level. Dissection by post-glacial stream erosion has exposed lake clays below the pebbly sand veneer in these areas as well as kame gravel below the lacustrine sediment.

A well-developed series of beaches and one delta define a gently sloping shore strand-line in the Enosburg Falls Quadrangle. The shore features rise from an elevation of 710 feet in the extreme southwestern part of the quadrangle to 740 feet in the vicinity of West Enosburg. Four beach deposits along Tyler Branch, Bogue Branch and The Branch mark the level of a lake south, southeast and east of West Enosburg at an elevation of 740 feet. The deposits in that area include gravel beaches one-half mile west-southwest of Enosburg Center, on the south side of Bogue Branch two miles southeast of West Enosburg, one at Bordoville and another one mile north of Bordoville. A gravel bar was mapped two miles west of Bordoville. In the southwestern part of the quadrangle, a delta built into the lake by the Fairfield River, three and one-half miles upstream (south) from Fairfield, stands at an elevation of 710 feet (Cannon, 1964b).

The above data leads us to conclude that the Coveville lake waters extended as far north as the Missisquoi River and up the Missisquoi River to the Canadian border and beyond. McDonald (1967, p. 110) notes nearshore features occurring at an altitude of 760 feet southeast of Sherbrooke, Quebec, that rise to approximately 860 feet near Windsor. This lake, designated Lake Orford by McDonald, we postulate, is a

Figure 1. Lacustrine silts and very fine sand in twenty foot high terrace one-half mile north of Proctor (Castleton Quadrangle).

Figure 2. Beach gravel on lake silt and sand. Top elevation 551 feet by hand-level. West side of Otter Creek valley, three miles south of Proctor (Castleton Quadrangle).

PLATE XXXVIII

northward continuation of the Coveville Lake.

The present elevations of the shore sediment, noted above, compare favorably with the water planes and isobases established by Chapman (1942, Figures 12 and 20). According to Chapman's isobase map, the Fort Ann level should be near the 600-foot contour at the Canadian border in the Enosburg Falls Quadrangle, and the Coveville shore should be 120 to 140 feet higher than the Fort Ann.

Scattered deposits of beach gravel and pebbly sand, although not as well developed as those along the Missisquoi River, make it possible to trace the shore of the Coveville Lake from the Enosburg Falls Quadrangle to the Lamoille River in the vicinity of Milton. Beach gravel drapes the slopes of Aldis Hill at St. Albans on all sides. The foliage and urban development on this hill, however, make it impossible to establish the top of the lacustrine material. Immediately east of Aldis Hill the beach gravel overlapping the slopes of a hill has a top at the 700-foot contour. Beach gravel on the southwestern slope of Bellevue Hill, two miles south of St. Albans, has an elevation of 680 feet at the contact with the slope. In the northern part of the Milton Quadrangle, a deltaic deposit one mile north of the Lamoille River on the headwater of Beaver Meadow Brook has an elevation of 660 feet.

As noted earlier in this chapter, a terrace level in the village of Morrisville stands at an altitude of 670 feet. The village of Hyde Park, two miles to the west, on the north side of the Lamoille River is located on a beach gravel terrace at the same elevation. Connally (1967), as also noted earlier, reported the Coveville shore features in the Mt. Mansfield Quadrangle at elevations of 640 to 660 feet. Stewart (1961, p. 97) recorded the Coveville beach deposits of the Winooski and Dog River valleys at elevations of 650 to 675 feet.

In the Burlington region, the shore terrace of the Coveville Lake on Mt. Philo at 520 feet and North Williston Hill at 540 feet were noted by Chapman (1942, p. 81). The data collected by the present survey, published by Stewart (1961, pp. 107–8), include a wave-cut terrace north of Monkton Ridge (585 feet), wave-cut terraces at South Hinesburg (600 feet), a beach deposit on the south side of Pease Mountain near Charlotte (545 feet), and beach gravel at Fay's Corners (620 feet).

Calkin (1965) reported that the Coveville shore phenomena in the Middlebury Quadrangle have elevations ranging from 560 to 595 feet. Two of these deposits that are quite well developed mark the lake level in the northern part of the quadrangle. One deposit is a beach ridge three-fourths of a mile long that forms a semicircle around the southeast end of Winona Lake (Bristol Pond). The elevation of the ridge varies from 580 to 595 feet. A few hundred feet to the south a fifty-foot wide wave-built terrace standing at 520 feet is also probably a correlative of the Coveville Stage. The other shore deposits, also noted by Chapman (1937, pp. 118–19) are on the kame terrace at Bristol. The flat-topped terrace on which the village and the airport are located has an elevation of 577 feet which is probably the highest Coveville in that area. Other terraces on the gravel deposit occur at 520 and 570 feet. The gravel beds along the margin of the kame terrace are quite similar to those already described at Hinesburg and Barnes Hill. The wave erosion carried the gravel out over the ice-contact slope forming inclined beds similar to a delta. At Bristol, the beds dip two to twenty-five degrees away from the kame terrace. Here, as at Hinesburg and Barnes Hill, the underlying ice-contact structures of the kame terrace are exposed in gravel pits that penetrate below the lake sediment.

On the west slope of Snake Mountain (Port Henry Quadrangle), one-half mile east of Willmarth School (three miles south of Addison), is a horizontal beach ridge of sand and gravel. The ridge is about ten feet high and fifty to seventy feet wide with a top elevation of 500 feet.

Chapman (1942) reported a Coveville delta at Brandon (Brandon Quadrangle) with an elevation of 430 feet. Connally (personal communications), who mapped the quadrangle during the present survey, however, reported the elevations of the Coveville beach deposits at 540 to 560 feet.

In the Castleton Quadrangle, the lake sands in the Pittsford area have elevations up to 500 feet and lake clay occurs at 495 feet at Hortonville (Plate XXXVIII, Figure 1). A well-developed beach located on the west side of Otter Creek valley, three miles south of Proctor, has a top elevation of 551 feet (Plate XXXVIII, Figure 2).

The Fort Ann Stage

The final stage of Lake Vermont, named the Fort Ann for the gorge near Fort Ann, New York, through which it drained, has a water plane approximately one hundred feet below the Coveville (Chapman, 1942, p. 61). According to Chapman, the water plane of this lake in Vermont, as indicated by strand-line features, rises from 386 feet elevation at Snake Mountain, west of Middlebury, to 591 feet east of Green's Corners Station.

The Fort Ann shore phenomena do not seem to be as well developed in Vermont as the earlier lake stages, and they are also more scattered. The implication seems to be that the Fort Ann Lake was not in existence as long as the two preceding lake stages. The evidences where found are quite definite and conclusive but do not seem to be as prominent. If our interpretation of Chapman's statements is correct, he found the beach deposits and shore terraces, in general, to be better developed on the New York side of Lake Champlain than in Vermont.

In extreme northern Vermont, the Fort Ann features, like those of the Coveville Stage, are best developed in the Missisquoi River valley. In the headwaters of the river in the Irasburg Quadrangle, beach gravel is found at the northeast limit of North Troy at 600 feet elevation and one-half mile to the east at 620 feet. A flat, pebbly sand terrace one mile north of North Troy also stands at an elevation of 600 feet. The delta two miles south of Montgomery Center that was reworked at an elevation of 600 to 625 feet has already been noted in the Jay Peak Quadrangle. A basement excavation in this deposit at the time of this survey showed good beach gravel at 625 feet. Several patches of beach gravel on shoreline terraces were found along the Trout River valley between Montgomery Center and East Berkshire. One of the best developed of these is located one mile northwest of Montgomery Center where fifty feet of small, clean beach gravel lies on twenty-five feet of laminated silt and clay. The beach forms a flat-topped terrace at 600 feet altitude. A single Fort Ann beach was mapped in the Enosburg Falls Quadrangle on the south side of Bogue Branch valley, two and one-fourth miles southeast of West Enosburg. The top of the terrace has an elevation of 600 feet.

From the above statistics we conclude that the present elevation of the Fort Ann strand-line at the Canadian border is about 625 feet. In southeastern Quebec, a lake described by McDonald (1967a, p. 110) has nearshore features that rise from 625 feet southeast of Sherbrooke to 700 feet in the vicinity of Windsor. These seem to be the Fort Ann strand of that region.

Chapman (1942) stated that he found no shore features of Lake Vermont in the Champlain Valley north of the Missisquoi River. He concluded that the lake waters were draining around the ice front by the time it had receded that far to the north. Cannon (1964b), who mapped the Enosburg Falls Quadrangle, agrees that no evidence of the lake was found in the Champlain Lowland north of the river. But, he believes that silt and clay terraces in the southern section of the Lake Carmi valley, as well as those in the Missisquoi Valley, were deposited in Lake Fort Ann.

Chapman (1942, p. 81) has noted the Fort Ann shore features along the slopes of St. Albans Hill (570 feet) and Aldis Hill (580 feet) in the St. Albans Quadrangle as well as the Milton and Cobble Hill terraces (537 feet and 527 feet) in the Milton Quadrangle. The present survey studied the gravel terrace on the slope of Cobble Hill and by aneroid barometer measured the elevation of the top to be 575 feet. Most of the gravel has now been removed for construction and road building purposes. A delta on the headwaters of Malletts Creek, located one mile due east of Milton, has a top elevation of 600 feet. The delta seems to have been reworked down to about 560 feet, and stream dissection has removed a goodly part of the deposit. The original top of the deposit was undoubtedly at the Coveville level. A beach gravel deposit in the southern part of the Milton Quadrangle, one-half mile north of Butlers Corners at an elevation of 580 feet, was reported by Stewart (1961, p. 109).

In the Burlington area, Chapman (1942, p. 81) recorded the Fort Ann level of the Winooski Delta at Richmond at 500 feet elevation and the Mt. Philo terrace at 431 feet. Stewart (1961, p. 109) noted Fort Ann beach gravel on Pease Mountain and Jones Hill, near Charlotte, at elevations of 460 and 465 feet respectively and one-half mile west of North Williston Hill at 525 feet.

In the Middlebury Quadrangle, Calkin (1965) mapped four Fort Ann shore features that establish the strand-line in that area between elevations of 390 to 410 feet. The most northerly of these, that seems to be above the Fort Ann level, is east of the foot of Shellhouse Mountain, two and one-fourth miles west-southwest of Monkton where a gravel beach and low scarp have an elevation of 475 feet. A beach ridge was mapped at the foot of Buck Mountain (northwest side) two and one-half miles south of Vergennes. The elevation of the ridge is 390 to 400 feet. In the central part of the quadrangle, a wave-cut bench and beach are located three-fourths of a mile west of Greenwood Cemetery near the junction of State Routes 17 and 116 west of Bristol. A well-developed beach ridge one mile long near The Ledge at Cornwall, two and one-half miles west of Middlebury, marks the shore of the lake in the southwest corner of the Middlebury Quadrangle. The elevation of the beach ridge is 390 to 400 feet, and the till above it is wave washed to 450 feet.

On the north slope of Snake Mountain (Port Henry Quadrangle), one and one-half miles east of Addison, the Fort Ann shore is manifested by a

beach deposit of sand and gravel at an elevation of 366 feet.

In the Brandon Quadrangle the Fort Ann strand is marked by a ridge of beach gravel over a mile long, one mile northwest of Middlebury Center. The elevation of the top of the deposit is 440 to 450 feet. A small delta one mile northwest of Salisbury at an elevation 450 feet was apparently deposited by the stream flowing out of the Lake Dunmore depression just to the east. A small beach gravel deposit on the west side of Otter Creek valley two miles east of Sudbury also has an elevation of 450 feet. The sandy lake sediment in the Otter Creek valley between Pittsford and Proctor (Castleton Quadrangle) have been terraced from their highest level at 600 feet elevation down to the present floodplain of the stream. A distinctive pebbly sand-capped terrace at 400 to 420 feet seems to be the best marker for the Fort Ann in that area (Plate XXXVIII, Figure 1). The pebbly sand terraces along the Castleton River are at 440 to 460 feet. The village of Fair Haven (Whitehall Quadrangle) stands on a lake plain one by two miles in area at about 360 feet elevation, which appears to be a deltaic mass built into the former lake by the Castleton River.

POST LAKE VERMONT EROSION INTERVAL

After the draining of Lake Vermont due to the recession of the Burlington ice to beyond the St. Lawrence River, the Champlain Lowland, above the level of Lake Champlain, was dry land and subjected to an interval of weathering and fluvial erosion. Prior to 1958 it was assumed that marine waters invaded the St. Lawrence and Champlain lowlands as soon as the St. Lawrence Valley was free of ice. Studies of the lacustrine and marine sediment in the St. Lawrence Lowland, however, have shown that an erosional interval did occur after the deposition of the lake sediment and before the placement of the marine clastics on top of it. The excavations for the St. Lawrence Seaway and Power Project exhibited lacustrine varved clays with the top foot or two oxidized and "fractured" into a sort of a breccia (MacClintock, 1958; MacClintock and Terasmae, 1960; MacClintock and Stewart, 1965). MacClintock and Terasmae (1960, p. 238) interpret these fractures and the oxidation as evidence of weathering and desiccation of the lake clays before the deposition of the overlying marine sediment. The shrinkage caused by the dewatering and drying out of the clays and silts apparently caused the fracturing of the upper layer.

The evidences of erosion following the recession of the Burlington ice and the draining of Lake Vermont are not as spectacular in Vermont as those described above, but certain evidences do exist.

In the Missisquoi River valley, particularly in the Enosburg Falls Quadrangle, the marine sands and pebbly sands deposited during the Champlain Sea interval lie in the bottom of the valley. The valley walls, in this area, are covered by lake bottom sediment, mostly silty clay, to heights of fifty to eighty feet above the marine sands that form the valley floor. It is assumed that the lake bottom sediment filled the valley at the time that the lake waters drained. Stream erosion must have subsequently removed much of the sediment before the invasion of the sea. An erosion surface is also indicated by the fact that the top of the lake sediment, below marine sands, is channeled and rilled with scattered deposits of fluvial gravel in them (Cannon, 1964b).

In some sections of the Champlain Lowland the marine sediments, including clay, silty clay and sand, contain cobbles and boulders. It cannot be assumed that these boulders were ice rafted because the glaciers were north of the St. Lawrence River valley when the Champlain Sea existed. The source of these must have been the till and the boulder strewn lake sediment. Two possible erosive processes could have been responsible for the concentration of the larger fragments. In the first place, the wave erosion by the marine waters during the deposition of the sediment could have winnowed out the boulders. The only other possibility is that erosion during an interval preceding the Champlain Sea left the boulders as a lag concentrate and the marine sediment was deposited over them and washed off later. Some of the finer sediment containing boulders must have been deposited below wave base where wave erosion was unlikely.

In recent years, the interpretation of certain radio-carbon dates has led to the conclusion that the Fort Ann Stage of Lake Vermont, and probably Lake Iroquois, may have existed at the same time as the Champlain Sea (McDonald, 1967a, p. 122). Such an interpretation, radio-carbon dates notwithstanding, seems most improbable to the writers of this report. In Vermont, the deposits of the highest marine limit lie well below those of the lowest Fort Ann, indicating no gradual lowering to the marine stage. The marine sediment with fossil shells overlies varved lake sediment in both the St. Lawrence and Champlain lowlands. All evidence in these regions indicates an erosion interval between the lake and marine episodes.

We conclude, therefore, that the Champlain Lowland was not below sea level at the time that the Burlington ice withdrew. The lowland was invaded by marine waters because of the eustatic rise of the sea. After

the Champlain Sea episode, the land rose out of the water because of isostatic adjustment.

THE CHAMPLAIN SEA INTERVAL

Following the post-Lake Vermont erosion interval, the eustatic rise of the sea caused a slow rise of marine waters into the Champlain Basin to form a body of water, connected with the sea, that has been designated the Champlain Sea. The manifestations of the ocean waters are found in the beach and bottom sediments that are similar to the lacustrine material except that they contain fossil shells of marine invertebrates. The marine estuary extended up the St. Lawrence Valley at least as far west as Ogdensburg in New York State (MacClintock and Stewart, 1965, p. 115) and southward into the Champlain Valley to the approximate vicinity of Whitehall, New York (Chapman, 1937, p. 113).

Chapman (1942, pp. 75–77) believed that there were times of stability during the marine stage that were of sufficient duration for strandlines to develop. He recognized five different shorelines below the upper marine limit which he named, from higher to lower, the Beekmantown, Port Kent, Burlington, Plattsburg and Port Henry stages. Three of these, the Port Kent, Burlington and Plattsburg, he recognized in Vermont. The present survey did not find shore phenomena below the highest marine limit that seemed to establish a "water plane." We believe, therefore, that the withdrawal, as the land rose out of the sea, was slow, but at a constant rate. We also contend that the marine beach deposits at various levels are indicative of such a withdrawal. All of the better developed beach deposits below the marine limit, it seems, were formed in quiet waters that were protected from wave erosion by rock outcrops and other topographic forms. The environmental conditions influenced the location of these deposits rather than a standstill of the marine waters or the land. For this reason, all of the following discussion of the data collected during the present survey concerns only the upper marine limit.

The most northerly of the marine shore features mapped during the survey are in the Enosburg Falls Quadrangle one-half mile east of East Highgate. At this location the upper marine limit is marked at an elevation of 500 feet by a sand beach and dune area. A gravel beach occurs in this same locality and at the same elevation two miles north-northeast of East Highgate. During the marine interval, the Missisquoi River was depositing a large sand delta in the Sheldon Springs-East Highgate area

Figure 1. Sea caves in the Clarendon Springs Formation formed by Champlain Sea waters. Elevation 240 feet. Three-fourths mile southeast of Chimney Corner (Milton Quadrangle).

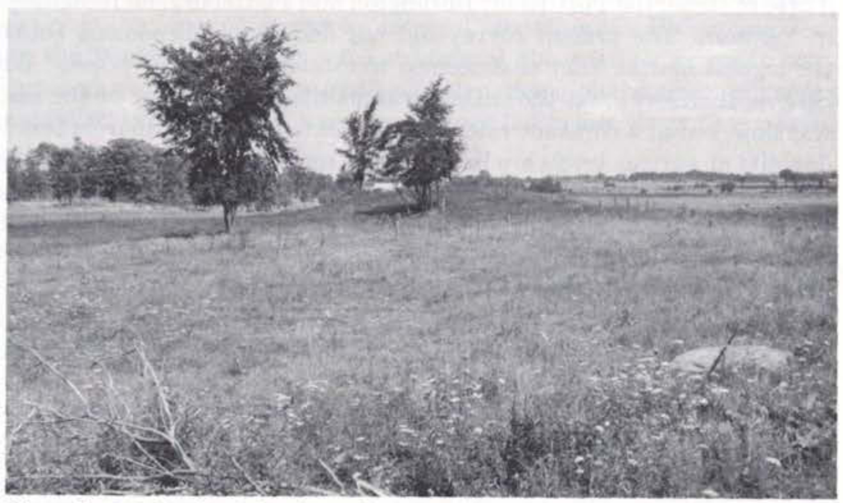


Figure 2. Marine beach bar (gravel). Two miles southwest of Swanton (St. Albans Quadrangle).

PLATE XXXIX

and much of the northwestern portion of the quadrangle was being blanketed by marine silts and clay (Cannon, 1964b).

The highest marine level is indicated in the St. Albans region by a marine beach that extends southward from a point two miles north of the city limits to a point one mile south of Georgia Center, a distance of ten miles (St. Albans and Milton quadrangles). The beach goes through St. Albans on the slopes of the hill just east of Main Street, with elevation on the top of the beach near the southern limits of the city measured at 430 feet. The activity of the waves in this region is manifested by large areas of wave-washed till strewn with huge boulders and of marine beach gravel over the slopes and in low areas. Near Lake Champlain, west of St. Albans, beach bars are common below the 180-foot contour (Plate XXXIX, Figure 2). The delta of the Lamoille River is spread out over a wide plain west of Georgia Station (East Georgia) that extends from West Georgia southward to Cobble Hill and westward to Lake Champlain. Sea caves occur in the Dunham and Clarendon Springs dolomite formations just east of Chimney Corner and southwest of Walnut Ledge (Plate XXXIX, Figure 1). The region between the Missisquoi River (near Swanton) and the Lamoille River (near Milton) undoubtedly has more marine beach deposits and the greatest variety of features formed by marine water action than any other area of Vermont. Chapman (1942) described the deltas at East Georgia, Milton and Colchester Station.

South of Burlington a well-developed shore cliff, with beach gravel at its base in most places, attests to the highest marine limit. The shore cliff, rising above the sands of the Winooski delta, can be traced almost continuously to Shelburne Village. The conspicuous cliff runs parallel to and about a mile east of U.S. Route 7. The elevations on the top of the gravel at the base of the cliff range from 325 to 330 feet. Excavations for a new wing of the De Goesbriand Memorial Hospital in the city of Burlington, near the University of Vermont, were made in a marine beach deposit in 1960. The elevation of the top of the gravel, as near as it was possible to ascertain, was approximately 340 feet. Two miles south of Charlotte (Willsboro Quadrangle) fossiliferous beach gravel covers the top and western side of a ridge to an elevation of 275 feet.

The most clearly defined marine beach ridge in the Middlebury Quadrangle lies to the northwest of Shellhouse Mountain and east of U.S. Route 7. The ridge stretches from East Slang Creek northward for more than a mile and one-half where it merges with a section of wave-washed till. The southern end of the ridge is one and three-quarter

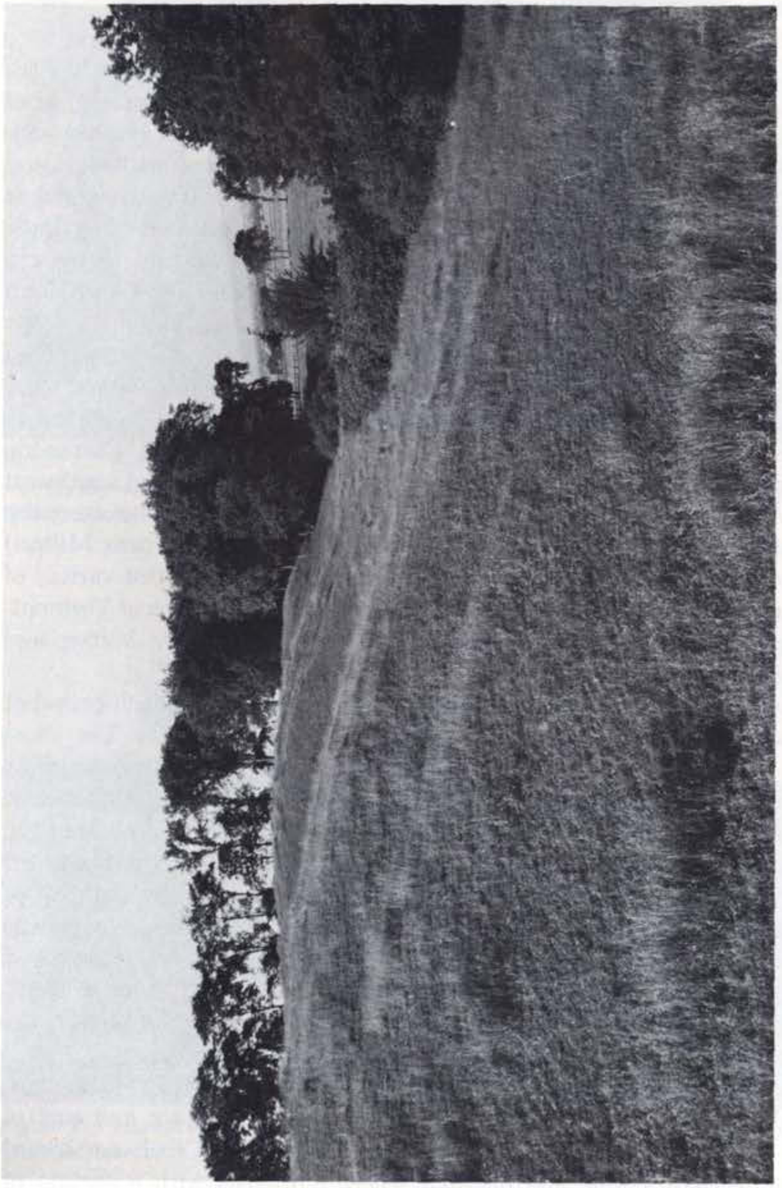


PLATE XL

Sea cliff along the northwest slope of a ridge trending southwest from Vergennes (Port Henry Quadrangle).

miles north-northeast of Ferrisburg. The top elevation is 270 feet (Calkin, 1965).

In the Port Henry Quadrangle, a prominent sea cliff along the northwest slope of a ridge that trends southwest from Vergennes marks the shore in that area (Plate XL). The ridge, composed of bedrock, is capped with twenty to thirty feet of lake sediment at the north and till at the south. The scarp, cut into the lake sediment and till, is dissected by many gullies. The smaller gullies have, at the base of the cliff, horizontally bedded beach sand and gravel instead of alluvial fans. These deposits show that the gullies were formed while waves and currents were transporting the sediment away from their lower ends, thus accurately marking the level of the waves of the Champlain Sea at 247 feet present altitude. One mile south of East Panton the sea cliff is cut into till and makes a bluff forty feet high. This bluff is also dissected by gullies which end, at their lower end, in a horizontal deposit of beach gravel at about 240 feet. One mile south of the mouth of Otter Creek marine fossil shells were found in a sandy beach gravel on top of a hill at elevation 230 feet.

One small beach gravel deposit at an elevation of 220 feet, one and a quarter miles east of West Bridport, is the only beach material mapped in the Ticonderoga Quadrangle. A prominent shore cliff, however, follows the 200-foot contour from the northern border of the quadrangle map almost unbrokenly to West Bridport, a distance of two and one-half miles. Other wave-cut shore terraces occur east of Leonard Bay and the southern end of Stony Cove at the 180-foot contour.

POST-GLACIAL TILTING OF THE LAKE AND SEA SHORELINES

The best evidences of post-glacial uplifts are the tilted shorelines of the lake and marine waters that are found in northern North America. In Vermont, as has already been described, the lacustrine and marine shoreline and nearshore deposits are tilted, to rise gently toward the north. In the Connecticut River valley, as previously noted, the Lake Hitchcock shore features rise to the north 4.15 feet per mile. In the Champlain Lowland both the Lake Vermont and Champlain Sea shorelines rise to the north at the rate of about 3.5 feet per mile. Chapman (1942, p. 78, Figure 2), who studied the shore phenomena on both sides of Lake Champlain, found that the direction of tilting (uplift) is to the north-northwest. On a north-south coordinate, nonetheless, the isobases drawn by him on the Fort Ann strand line, show a rise of approximately four feet per mile. McDonald (1967a, pp. 111–14 and Figures 14 and 15) calculated the tilt of the shore deposits of Glacial Lake Orford, in southeastern Quebec, to be in a northwest direction, rising at a rate of 3.8 feet per mile.

Inasmuch as the shore deposits of all three stages of Lake Vermont and the upper marine limit of the Champlain Sea are parallel to each other, uplift must have begun after the maximum sea invasion. It seems logical to assume that the uplift responsible for the tilting was the same isostatic rise that brought the land up out of the marine waters. MacClintock and Terasmae (1960, p. 238 and Figure 6) have assumed that both land and sea were rising after the Fort Ann Stage. They explain the erosion interval following Lake Vermont as resulting from an isostatic rise of the land that was greater than the eustatic rise of the sea at that time. Since the lake and sea strands are parallel, it would seem that the uplift following the Lake Vermont episodes was a vertical movement rather than a tilting. Perhaps the isostatic rebound of the land had not begun at that time, and the eustatic rise of the sea had to await additional melting of the glaciers before sea level could rise above the level of the St. Lawrence Valley.

CORRELATION OF THE VERMONT PLEISTOCENE

At this writing, the correlation of the Pleistocene events in Vermont with the established stratigraphic sequence of North America is uncertain, since no datable organic remains have been found, and a leached zone between calcareous tills has been found in only one place. This section of this report is therefore limited to a discussion of the possible relationships of the substages of the Wisconsin (Appendix D) and the Pleistocene stratigraphy of adjacent areas of New York, southeastern Quebec and New England. It is assumed, as stated earlier, that the three tills that have been identified in Vermont are Wisconsin in age inasmuch as the leaching and decomposition of the oldest (Bennington) till does not seem to be sufficient to suggest an older age, and radio-carbon dates in New England and Quebec are all less than 60,000 years B.P.

Probable Correlation with the St. Lawrence Lowland and Southeastern Quebec

The two areas adjacent to Vermont where the Pleistocene stratigraphy has been established by detailed study are the St. Lawrence Lowland of New York (MacClintock, 1958; MacClintock and Stewart, 1965) and southeastern Quebec, north of the Vermont border (McDonald, 1967a;

Gadd, 1964a, 1967). It is apparent that the three areas can be combined to produce a framework for possible regional correlation. The tills are discussed in reverse order (younger to older) inasmuch as the correlation of the younger surface tills seems the most probable.

Burlington Till. A surface till with northwest fabric orientation has been mapped and described in the St. Lawrence Lowland as far east as the west shore of Lake Champlain at Rouses Point, New York (MacClintock, 1958, p. 6; MacClintock and Terasmae, 1960, p. 239; MacClintock and Stewart, 1965, p. 6). The sediments of Lake Iroquois (Lake Vermont) and the Champlain Sea overlie the Fort Covington till in the St. Lawrence Lowland as they also do the Burlington drift in the Champlain Lowland. Inasmuch as the lacustrine sediment and/or the marine deposits are now believed to be Two Creeks in age, based on C^{14} dates, the Fort Covington drift has been tentatively correlated with the Port Huron (Mankato) Substage of the Wisconsin Stage (MacClintock and Terasmae, 1960, p. 239; MacClintock and Stewart, 1965, p. 41). There is still debate as to whether Lake Iroquois (Lake Vermont) or the Champlain Sea, or perhaps both, occurred during the Two Creeks Interstadial; but it seems certain, at this writing, that one or the other was of that interval (Broecker and Ferrand, 1963, p. 779; McDonald, 1965a, pp. 60–62).

Because of the similarities of the till, their surface position and their northwest fabric orientation, the Burlington till of Vermont is believed to be of the same glacial stade as the Fort Covington of New York. Assuming that the recent C^{14} dates are correct, the occurrence of the Burlington till below the sediments of Lake Vermont and the Champlain Sea would establish its age as pre-Two Creeks. Whether or not the age is Port Huron (Mankato) cannot be established on this basis, but such a conclusion seems compatible with the known facts.

McDonald, who has done a detailed study of the Pleistocene deposits of southeastern Quebec, immediately north of Vermont, has recorded a surface till with northwest fabric orientation which he calls the Lenoxville. This drift sheet, he says (1967a, p. 95), seems to have reached the entire northern border of Vermont. A minimum date for the deglaciation of southeastern Quebec, obtained by the C^{14} dating of organic lake beds that occur four miles west of Coaticook, is 11,020 ± 330 years B.P. As pointed out by McDonald (p. 96), however, this date was after the beginning of the Champlain Sea episode and when the ice must have been far to the north. It seems convincing that the Burlington till is a correlative of the Lenoxville, and the C^{14} dates seem to support the

Port Huron (Mankato) age. The Highland Front Moraine (Gadd, 1964a, p. 1249), composed of Lenoxville till that may correlate with moraines in New York State, was deposited prior to the Champlain Sea, and radiocarbon dates establish its time of deposition as prior to 12,000 years ago (McDonald, 1967a, p. 107).

Connally (personal communication) reports a C^{14} date of 12,400 years B.P. on peat at the base of a bog resting on outwash in the vicinity of Glens Falls, New York. The outwash below the peat was from the latest glacial advance in that area. The bog is near the outcrop described by Hanson, et al. (1961, p. 1415), where décollement structures in varved clay were reported under till. The deposit, as described, seems to be very much like the Lewis Creek exposure northeast of North Ferrisburg described earlier in this report. The date and the characteristics again seem to suggest correlation with the Burlington glacial episode.

From the above dates, it seems probable that the Burlington ice had melted from Vermont prior to 12,500 years before the present.

Shelburne Till. The Fort Covington drift of the St. Lawrence Lowland is underlain by a till with northeast fabric orientation that is named the Malone (MacClintock, 1958, p. 6; MacClintock and Stewart, 1965, p. 41). The Malone till has been assigned a probable Cary age inasmuch as no evidence of inter-glacial weathering was found, and the weathering of the Malone is the same depth as that of known Cary till to the south and southwest. Whereas the Fort Covington drift extends as far south as the northern slopes of the Adirondacks, the Malone till spreads over the Adirondacks into Pennsylvania and New Jersey (MacClintock, 1958, p. 6).

Since the Shelburne till has a stratigraphic position under the Burlington, similar to that of the Malone below the Port Huron, it is believed to be a correlative of the Malone till. A Cary age is suggested, but admittedly no positive evidence of the correct age is, as yet, available.

McDonald (1967a, pp. 22–23, Figures 4 and 5, Table 2) has described two stratigraphic sections containing three tills that occur along the Ascot River approximately eight miles southeast of Sherbrooke and less than twenty-five miles north of the Vermont border. The bedrock in this area and to the northeast of it is the St. Francis Group whereas the rocks of the Green Mountain anticlinorium lie to the northwest. On the basis of till fabric and the abundance of rocks with Green Mountain lithologies as compared to those of the St. Francis Group, he has established that the lower portion of the till below the Lenoxville, which he calls Till II, was deposited by ice from the northeast. The upper part of

Till II was deposited by ice from the northwest. In between, there is a gradual change upward from a northeast influence to a north and, at the top, a northwest. These data indicate a change in ice-flow direction from the northeast to the northwest during the glacial episode that deposited the till at this place. The intermediate till (Till II) is separated from the overlying Lenoxville by thirty-six feet of lake sediment. This is the same relationship as that between the upper Malone till complex and the Fort Covington till in the cuts for the St. Lawrence Seaway (MacClintock, 1958).

In spite of the fact that no other sections studied by McDonald in southeastern Quebec show similar changes in flow direction, and none have been found in Vermont, the occurrence of this single section must be given consideration. The only logical conclusion that can be made is that glaciers were active from both the northeast and the northwest from different centers of accumulation during that particular glacial stade, but the region was ice-free before Lenoxville time as was true in the St. Lawrence area.

Since it is assumed that the Burlington and Lenoxville tills are correlatives, as discussed above, it seems logical to assume that the Shelburne till should be of the same ice episode as that portion of Till II with northeast fabric orientation. No evidence has been found anywhere in Vermont, however, for a northwest ice advance contemporaneous with the northeast invasion that deposited the Shelburne till.

Bennington Till. The earliest glacial stade recognized in southeastern Quebec is manifested in a one foot layer of till near the base of the Ascot River section (McDonald, 1967a, pp. 25–27). The fabric orientation of the till is northeast but the rock provenance indicates ice movement from the northwest. The importance of this single till layer (Till I), aside from its recording a glacial stade, lies in the fact that it is overlain by leached lake silts bearing plant material. The plant fragments date the interstadial in which the silts were deposited at 41,500 and 54,000 years B.P. (McDonald, 1967b, p. 42). The Bennington till of Vermont has a stratigraphic position similar to Till I of the Ascot River section. But the single till layer, only a foot in thickness, does not provide adequate information for more than a possible correlation.

Conclusions. From the data noted above, we believe that it is quite definitely established that the Burlington till of Vermont was deposited during the same glacial stade as the Fort Covington drift of the St. Lawrence Lowland of New York State and the Lenoxville till of southeastern Quebec. The correlation of the Shelburne till of Vermont with the Malone till of the St. Lawrence Lowland seems very probable. The correlation of the Shelburne with Till II of southeastern Quebec is suggested, but more study is needed to better equate the parameters of the two till sheets. There is no correlative of the Bennington till in the St. Lawrence Lowland and its correlation with the oldest till in the Ascot River section in Quebec, although their stratigraphic position is comparable, is quite problematic.

Correlation with Other Areas of New England

The correlation of the drift sheets in New England, in general, is at this writing somewhat confusing. There have been no studies covering large areas in which the stratigraphic relationships of the drift sheets have been established. Numerous radio-carbon dates have been made on various organic remains over widely scattered regions of the area. Without the stratigraphic relationships, however, the use of the dates has been very confusing, and to date no generally accepted stratigraphic sequence for New England has evolved. Insofar as Vermont is concerned, there have been few studies close enough to the state boundary to be of value. Few studies have been made in which the fabric of the till has been used for identification, and without C^{14} dates for the Vermont episodes, actual correlation is impossible.

The radio-carbon dates recorded thus far in New England seem to indicate three different Pleistocene events, or glacial intervals, that may be related to the stratigraphy of Vermont. Dates on organic materials contained in sediment separating an older and younger till have been reported as 38,000 B.P. in Maine, 40,000 B.P. in Connecticut, and 38,000 B.P. in Massachusetts (Schafer and Hartshorn, 1965, p. 113). Schafer (1967, p. 55), in a summary of the work of many investigations and numerous C^{14} dates, interprets the available data as indicating that the last glaciation of New England reached its maximum extent 19,000–20,000 years ago. Flint (1956), Chute (1959), Kaye (1961), Davis (1965). Colton (1968), and others have noted evidences of an ice readvance that occurred 13,000–14,000 years B.P. The stratigraphy and the dates in New England are much more complex and complicated than the above statements imply, but these data, so simplified, may be used as a basis for consideration.

Many studies, as noted above, in various parts of Connecticut and Massachusetts have noted the occurrences of two tills in the areas that were studied. White (1947) reported two tills, identified on the basis of lithology and stratigraphy, in the Stafford Springs area of Connecticut.

Currier (1941) noted a grey and a lower brown till in his studies in eastern Massachusetts. Judson (1949) and Moss (1943) identified two tills in the Boston area and the Concord Quadrangle of Massachusetts.

Colton (1968), working in the Collinsville Quadrangle of northwestern Connecticut, reported two tills, the older deposited by ice from the north-northwest and the upper till deposited by ice moving from east to west. The later movement, he suggests, may be from an ice readvance down the Connecticut Valley that spread out to the west over the area he mapped. The readvance, postulates Colton, may correlate with the Middletown readvance noted above.

Flint (1961, p. 1687) reported two tills at Lake Chamberlain, northwest of New Haven, Connecticut. The lower till with fabric orientation, rock provenance and striae indicating deposition by ice moving from the north-northwest, has been designated the Lake Chamberlain till. The upper till, with all data indicating a strong northeast movement, was named the Hamden till. The Hamden till is believed to be the surface till throughout the New Haven district.

Without dates for the Vermont till sheets and ice direction data for most of the studies in Connecticut and Massachusetts, correlation to the south is most speculative. Certain possibilities, however, can be suggested.

Bennington Till. It is apparent that an older till lies below a surface till in many areas of New England which could possibly be, in most cases, the same till that lies below the interstadial deposits that have been dated at about 40,000 years (Schafer and Hartshorn, 1965, p. 113). This date is also comparable to that of 41,500 B.P. on the lowest till in the Ascot River section in Quebec (McDonald, 1967b, p. 42). It is therefore postulated here that the Bennington till of Vermont might be of the same glacial interval. Such a date would place this glacial interval in the Farmdale Interstade of the Leighton (1960) classification.

Shelburne Till. If we suppose that the Bennington till may correlate with the oldest till in other parts of New England, it might then be assumed that the Shelburne ice invasion correlates with the surface till that covers much of the region. The last ice invasion in most areas, according to Schafer (1967), reached its maximum about 19,000 to 20,000 years ago. This date would place the glacial interval that deposited the drift at about the Tazewell Substage of Leighton (1933).

Middletown-Cambridge Readvance. The one complicating factor in the above speculations concerning the correlation of the Shelburne till is the glacial readvance of 13,000–14,000 B.P. Inasmuch as this readvance, in the area of Middletown, Connecticut, was in the Connecticut River valley, preceding the Lake Hitchcock Lake Interval, it does not seem possible that such a readvance could have by-passed the Vermont-New Hampshire section of the Connecticut Valley. It also seems, from C^{14} dates in Quebec, that the Burlington glacier may have been covering northwestern Vermont at the same time.

The above statements re-open the question of the surface ablation till with northeast fabric (Shelburne) in central and northeastern Vermont and the basal till with northeast fabric, under the Burlington drift, in the northwestern part of the state. If the Shelburne till in eastern Vermont was deposited by the readvance that terminated in the environs of Middletown, Connecticut, 13,000 to 14,000 years ago, then it may be the same, or of only slightly older, age than Burlington and of later age than the northeast till below the Burlington. This is one of the problems of correlation pointed out by Shilts and Behling (1968) and Shilts (personal communication). It also seems possible that the Middletown readvance could be of the Cary stade, as suggested by Flint (1956, p. 275), and that the Burlington was somewhat later during the Port Huron (Mankato), as proposed for the Fort Covington (MacClintock and Stewart, 1965).

Borns (1963) suggests a Port Huron (Mankato) age for the ice margin that stood near Bangor, Maine. At this writing, we believe that the margin of the Burlington drift trends eastward from the Vermont-Quebec border near Norton, through New Hampshire north of the White Mountains and into Maine, probably to the margin noted by Borns.

APPENDIX A

FIELD DATA AND CALCULATED VECTOR MEAN OF FABRICS OF THE BENNINGTON TILL

WEST	N 4	EAST
17	10	8
11	20	5
11	30	6
10	40	2
2	50	2
2	60	2
1	70	0
4	80	4

Fabric 1. Vector mean N 13 W. Memphremagog Quadrangle. Subsurface till. Two miles east of Orleans.

WEST	N 9	EAST
6	10	5
8	20	3
8	30	7
9	40	8
13	50	4
3	60	0
5	70	1
1	80	0

Fabric 2. Vector mean N 18 W. Memphremagog Quadrangle. Subsurface till. Two miles southeast of Orleans.

WEST	N 2	EAST
4	10	1
10	20	2
14	30	1
7	40	2
3	50	0
3	60	1
2	70	0
0	80	0

Fabric 3. Vector mean N 27 W. Averill Quadrangle. Subsurface till. Three miles south of Lemington.

WEST	N 15	EAST
6	10	11
1	20	0
3	30	0
2	40	1
3	50	0
6	60	2
1	70	0
1	80	2

Fabric 4. Vector mean N 10 W. Averill Quadrangle. Subsurface till. Three miles northwest of Bloomfield.

WEST	N 2	EAST
1	10	1
1	20	1
4	30	0
4	40	1
7	50	1
8	60	0
8	70	2
1	80	0

Fabric 5. Vector mean N 53 W. Hardwick Quadrangle. Subsurface till. Two miles north-northeast of Greensboro Bend.

WEST	N·O	EAST
8	10	7
13	20	9
10	30	3
9	40	4
5	50	0
3	60	0
1	70	2
0	80	0

Fabric 6. Vector mean N 14 W. Hardwick Quadrangle. Subsurface till. One-half mile south of Greensboro.

WEST	N 12	EAST
17	10	6
16	20	3
10	30	2
5	40	2
1	50	0
0	60	0
0	70	3
0	80	1

Fabric 7. Vector mean N 11 W. Lyndonville Quadrangle. Subsurface till. Coles Pond, two and one-half miles south of Stannard.

WEST	N 5	EAST
5	10	7
5	20	8
9	30	4
18	40	8
15	50	4
6	60	4
0	70	3
0	80	2

Fabric 8. Vector mean N 21 W. Lyndonville Quadrangle. Subsurface till. One and one-fourth miles west of Stannard.

WEST	N 5	EAST
6	10	6
6	20	7
11	30	4
8	40	9
8	50	6
6	60	4
8	70	7
6	80	4

Fabric 9. Vector mean N 24 W. Lyndonville Quadrangle. Subsurface till. One and one-fourth miles west of Stannard.

WEST	N 7	EAST
6	10	3
7	20	2
6	30	2
3	40	5
4	50	4
5	60	2
4	70	1
2	80	2

Fabric 10. Vector mean N 17 W. Lyndonville Quadrangle. Subsurface till. One-fourth mile west of Stannard.

WEST	N 5	EAST
7	10	3
8	20	2
8	30	5
8	40	3
6	50	1
5	60	2
2	70	4
0	80	1

Fabric 11. Vector mean N 21 W. Lyndonville Quadrangle. Subsurface till. One and one-half miles west-northwest of Stannard.

WEST	N·O	EAST
2	10	3
2	20	3
7	30	6
7	40	3
6	50	2
5	60	1
8	70	0
1	80	0

Fabric 12. Vector mean N 28 W. Lyndonville Quadrangle. Subsurface till. One mile west of Stannard.

WEST	N 6	EAST
7	10	6
6	20	3
3	30	4
6	40	0
3	50	4
10	60	2
6	70	1
4	80	2

Fabric 13. Vector mean N 28 W. Lyndonville Quadrangle. Subsurface till. One and one-half miles west-northwest of Stannard.

WEST	N·0	EAST
7	10	7
1	20	4
4	30	6
8	40	4
6	50	2
5	60	1
2	70	2
2	80	1

Fabric 14. Burke Quadrangle. Subsurface till. Three and one-half miles east of East Haven.

WEST	N 0	EAST
8	10	3
5	20	6
10	30	1
13	40	5
4	50	6
7	60	4
8	70	3
2	80	5

Fabric 15. Burke Quadrangle. Subsurface till. Two and one-half miles east of East Haven.

WEST	N·0	EAST
15	10	7
12	20	9
12	30	5
9	40	6
6	50	4
2	60	0
2	70	4
1	80	0

Fabric 16. Vector mean N 22 W. Burke Quadrangle. Subsurface till. Two miles east-southeast of East Haven.

WEST	N 2	EAST
0	10	1
4	20	2
6	30	6
17	40	1
9	50	3
4	60	1
7	70	3
1	80	0

Fabric 17. Vector mean N 37 W. Burke Quadrangle. Subsurface till. One-half mile south of East Lyndon.

WEST	N·0	EAST
6	10	2
5	20	3
5	30	8
8	40	7
7	50	4
5	60	3
5	70	3
1	80	3

Fabric 18. Vector mean N 15 W. Burke Quadrangle. Subsurface till. Two miles southeast of Lyndonville.

WEST	N 4	EAST
4	10	10
5	20	0
6	30	0
6	40	1
5	50	3
7	60	0
2	70	1
0	80	0

Fabric 19. Vector mean N 24 W. St. Johnsbury Quadrangle. Subsurface till. Three miles north of Danville.

WEST	N 3	EAST
5	10	4
9	20	0
5	30	1
11	40	0
9	50	4
8	60	0
1	70	0
5	80	0

Fabric 20. Vector mean N 36 W. St. Johnsbury Quadrangle. Subsurface till. Two and one-half miles northwest of Passumpsic.

WEST	N 1	EAST
2	10	3
5	20	2
15	30	5
14	40	1
8	50	1
2	60	0
2	70	0
0	80	0

Fabric 21. Vector mean N 30 W. St. Johnsbury Quadrangle. Subsurface till. Two and one-half miles southeast of North Danville.

WEST	N·0	EAST
2	10	2
5	20	5
5	30	3
8	40	0
13	50	3
8	60	1
1	70	3
1	80	0

Fabric 22. Vector mean N 29 W. St. Johnsbury Quadrangle. Subsurface till. One and one-half miles southeast of North Danville.

WEST	N 10	EAST
15	10	15
16	20	11
15	30	5
5	40	1
3	50	2
3	60	1
1	70	1
0	80	0

Fabric 23. Vector mean N 8 W. Littleton Quadrangle. Subsurface till. One and one-half miles east of St. Johnsbury.

WEST	N 4	EAST
5	10	1
3	20	2
8	30	0
4	40	1
4	50	1
5	60	1
3	70	0
2	80	1

Fabric 24. Vector mean N 33 W. East Barre Quadrangle. Subsurface till. Goose Green, two miles south-southeast of Cookville.

WEST	N·0	EAST
5	10	8
12	20	9
13	30	9
18	40	7
10	50	6
1	60	1
3	70	0
1	80	0

Fabric 25. Vector mean N 15 W. Woodsville Quadrangle. Subsurface till. One and one-half miles south-southeast of South Ryegate.

WEST	N 3	EAST
5	10	1
11	20	2
14	30	1
12	40	0
6	50	0
6	60	0
0	70	0
0	80	0

Fabric 26. Vector mean N 30 W. Woodsville Quadrangle. Subsurface till. One and one-fourth miles northwest of Ryegate.

WEST	N 4	EAST
9	10	3
4	20	4
11	30	4
1	40	2
1	50	1
0	60	0
1	70	0
0	80	0

Fabric 27. Vector mean N 8 W. Woodsville Quadrangle. Subsurface till. Three and one-fourth miles north of East Topsham.

WEST	N 3	EAST
2	10	2
4	20	0
3	30	2
8	40	2
3	50	0
1	60	2
3	70	0
0	80	1

Fabric 28. Vector mean N 28 W. Strafford Quadrangle. Subsurface till. One mile south of South Strafford.

WEST	N 11	EAST
11	10	8
5	20	5
13	30	7
11	40	5
8	50	6
3	60	1
8	70	1
5	80	2

Fabric 29. Vector mean N 17 W. Strafford Quadrangle. Subsurface till. One-fourth mile east of Chelsea.

WEST	N 2	EAST
2	10	0
2	20	0
3	30	1
4	40	2
5	50	0
10	60	0
6	70	1
1	80	0

Fabric 30. Vector mean N 50 W. Strafford Quadrangle. Subsurface till. West Norwich, four and one-half miles south of South Strafford.

WEST	N 6	EAST
1	10	1
8	20	1
1	30	1
9	40	2
8	50	1
5	60	2
1	70	1
1	80	0

Fabric 31. Vector mean N 32 W. Strafford Quadrangle. Subsurface till. One mile east of South Strafford.

WEST	N 5	EAST
1	10	2
8	20	1
4	30	1
2	40	0
2	50	1
2	60	1
2	70	0
3	80	1

Fabric 32. Vector mean N 25 W. Strafford Quadrangle. Subsurface till. One and one-half miles northeast of Tunbridge.

WEST	N 2	EAST
3	10	4
5	20	1
2	30	0
3	40	0
4	50	1
6	60	1
3	70	1
0	80	0

Fabric 33. Vector mean N 32 W. Strafford Quadrangle. Subsurface till. One and one-half miles northeast of Tunbridge.

WEST	N 2	EAST
0	10	4
2	20	2
7	30	0
8	40	1
9	50	5
8	60	4
11	70	8
9	80	8

Fabric 34. Vector mean N 70 W. Strafford Quadrangle. Subsurface till. Two miles east of South Strafford.

WEST	N 4	EAST
2	10	2
8	20	3
9	30	0
8	40	0
5	50	1
1	60	0
3	70	0
0	80	0

Fabric 35. Rumney New Hampshire Quadrangle. State Route 118, eight miles northeast of Warren, New Hampshire.

WEST	N 7	EAST
8	10	4
7	20	2
5	30	1
5	40	2
2	50	1
2	60	0
0	70	1
2	80	1

Fabric 36. Vector mean N 14 W. Rumney New Hampshire Quadrangle. State Route 118, fourteen miles north of Canaan, New Hampshire.

WEST	N·0	EAST
8	10	5
15	20	6
7	30	4
11	40	1
2	50	1
2	60	1
0	70	0
1	80	1

Fabric 37. Vector mean N 17 W. Rutland Quadrangle. Subsurface till. One mile northeast of Killington Peak.

WEST	N·0	EAST
3	10	1
6	20	0
8	30	0
11	40	1
9	50	0
4	60	5
2	70	0
1	80	2

Fabric 38. Vector mean N 41 W. Rutland Quadrangle. Subsurface till. Two and one-half miles southeast of East Clarendon.

WEST	N·0	EAST
2	10	0
3	20	1
8	30	0
6	40	2
6	50	0
7	60	0
1	70	0
3	80	0

Fabric 39. Vector mean N 43 W. Rutland Quadrangle. Subsurface till. Two and one-half miles southeast of East Clarendon.

WEST	N 6	EAST
5	10	2
11	20	0
9	30	4
3	40	1
5	50	0
3	60	1
4	70	1
0	80	0

Fabric 40. Vector mean N 23 W. Woodstock Quadrangle. Subsurface till. Two miles south-southwest of South Woodstock.

WEST	N 3	EAST
2	10	5
4	20	0
3	30	2
4	40	0
11	50	1
10	60	0
17	70	9
7	80	6

Fabric 41. Vector mean N 64 W. Woodstock Quadrangle. Subsurface till. Four miles northwest of Woodstock.

WEST	N 8	EAST
2	10	3
14	20	1
13	30	1
8	40	4
7	50	5
1	60	1
2	70	2
1	80	1

Fabric 42. Vector mean N 22 W. Hanover Quadrangle. Subsurface till. One mile west-northwest of Hartford.

WEST	N·O	EAST
2	10	0
2	20	0
5	30	0
4	40	1
3	50	1
0	60	0
1	70	0
3	80	0

Fabric 43. Vector mean N 40 W. Hanover Quadrangle. Subsurface till. One mile west of Hartford.

WEST	N 9	EAST
5	10	4
1	20	2
7	30	2
1	40	1
9	50	0
2	60	0
4	70	1
1	80	1

Fabric 44. Vector mean N 23 W. Hanover Quadrangle. Subsurface till. One mile west-southwest of White River Junction.

WEST	N 7	EAST
2	10	1
4	20	0
6	30	1
6	40	1
5	50	0
1	60	0
7	70	0
2	80	1

Fabric 45. Vector mean N 35 W. Hanover Quadrangle. Subsurface till. U. S. Route 4, two miles west of Hartford.

WEST	N 4	EAST
3	10	0
0	20	0
2	30	0
5	40	1
2	50	0
5	60	1
2	70	1
2	80	0

Fabric 46. Vector mean N 42 W. Hanover Quadrangle. Subsurface till. One mile northeast of Woodstock.

WEST	N 13	EAST
4	10	4
6	20	1
5	30	0
5	40	3
9	50	1
5	60	0
1	70	0
1	80	2

Fabric 47. Vector mean N 23 W. Hanover New Hampshire Quadrangle. Subsurface till. West Lebanon Airport.

WEST	N 4	EAST
3	10	2
9	20	3
9	30	1
6	40	0
4	50	2
2	60	0
3	70	0
2	80	3

Fabric 48. Vector mean N 28 W. Hanover New Hampshire Quadrangle. Subsurface till. Five miles south-southeast of West Lebanon, New Hampshire.

WEST	N 3	EAST
1	10	3
5	20	0
9	30	0
6	40	2
4	50	0
3	60	0
1	70	0
1	80	0

Fabric 49. Vector mean N 30 W. Hanover New Hampshire Quadrangle. Subsurface till. One mile south of Meriden, New Hampshire.

WEST	N 7	EAST
1	10	0
0	20	1
4	30	1
2	40	4
2	50	0
1	60	0
4	70	1
7	80	1

Fabric 50. Vector mean N 45 W. Hanover New Hampshire Quadrangle. Subsurface till. One mile north-northwest of Lebanon, New Hampshire.

WEST	N·O	EAST
4	10	4
9	20	1
7	30	0
10	40	0
5	50	0
3	60	0
1	70	1
0	80	0

Fabric 51. Vector mean N 33 W. Hanover New Hampshire Quadrangle. Subsurface till. South side of Lebanon, New Hampshire.

WEST	N 1	EAST
1	10	1
3	20	1
10	30	0
8	40	0
3	50	2
3	60	1
3	70	1
0	80	0

Fabric 52. Vector mean N 27 W. Mascoma New Hampshire Quadrangle. Subsurface till. Four miles northeast of Hanover, New Hampshire.

WEST	N 7	EAST
5	10	4
1	20	2
3	30	1
5	40	1
7	50	2
3	60	0
4	70	0
2	80	1

Fabric 53. Vector mean N 27 W. Mascoma New Hampshire Quadrangle. Subsurface till. Interstate 89 interchange east of Lebanon.

WEST	N 4	EAST
8	10	0
7	20	1
9	30	0
14	40	2
3	50	0
1	60	2
4	70	0
2	80	0

Fabric 54. Vector mean N 30 W. Holderness New Hampshire Quadrangle. Surface till. One mile east of Bristol, New Hampshire.

WEST	N·O	EAST
8	10	2
6	20	1
17	30	0
11	40	0
7	50	1
8	60	2
5	70	0
7	80	1

Fabric 55. Vector mean N 41 W. Pawlet Quadrangle. Subsurface till. Three-fourths mile north of Tinmouth.

WEST	N 11	EAST
6	10	8
10	20	5
14	30	6
3	40	3
3	50	3
4	60	1
1	70	1
0	80	1

Fabric 56. Vector mean N 8 W. Pawlet Quadrangle. Subsurface till. Three and one-fourth miles north-northeast of Tinmouth.

WEST	N·O	EAST
1	10	2
3	20	0
4	30	2
4	40	1
5	50	0
10	60	7
7	70	5
11	80	6

Fabric 57. Vector mean N 73 W. Wallingford Quadrangle. Subsurface till. South Wallingford marble quarry.

WEST	N 8	EAST
1	10	1
2	20	0
8	30	1
5	40	1
3	50	0
3	60	1
3	70	0
1	80	0

Fabric 58. Vector mean N 29 W. Claremont New Hampshire Quadrangle. Surface till. Three miles east of Claremont, New Hampshire.

WEST	N 1	EAST
1	10	0
4	20	0
3	30	1
3	40	1
4	50	2
4	60	0
2	70	0
0	80	0

Fabric 59. Vector mean N 34 W. Claremont New Hampshire Quadrangle. Surface till. One mile north of Claremont, New Hampshire.

WEST	N 7	EAST
1	10	4
8	20	1
5	30	4
10	40	1
7	50	1
8	60	0
1	70	0
3	80	0

Fabric 60. Vector mean N 30 W. Claremont New Hampshire Quadrangle. Subsurface till. Three miles southeast of Claremont, New Hampshire.

WEST	N 9	EAST
3	10	5
5	20	7
2	30	1
1	40	3
0	50	2
0	60	4
0	70	0
1	80	1

Fabric 61. Vector mean N 29 W. Sunapee New Hampshire Quadrangle. Surface till. One mile west of Newport, New Hampshire.

WEST	N 7	EAST
1	10	4
4	20	0
4	30	1
8	40	1
11	50	2
8	60	0
12	70	2
4	80	0

Fabric 62. Vector mean N 47 W. Equinox Quadrangle. Subsurface till. One mile east of Kelley Stand.

WEST	N 8	EAST
13	10	8
12	20	6
8	30	4
10	40	8
4	50	2
7	60	0
5	70	1
1	80	1

Fabric 63. Vector mean N 12 W. Equinox Quadrangle. Subsurface till. Two miles east-southeast of South Dorset.

WEST	N·O	EAST
0	10	0
0	20	0
1	30	0
6	40	2
11	50	0
15	60	2
19	70	0
10	80	1

Fabric 64. Vector mean N 64 W. Equinox Quadrangle. Subsurface till. Two and one-half miles south-southwest of Arlington.

WEST	N 12	EAST
10	10	4
11	20	5
3	30	1
4	40	2
1	50	1
3	60	0
0	70	2
0	80	0

Fabric 65. Vector mean N 6 W. Equinox Quadrangle. Subsurface till. One mile south of Manchester.

WEST	N 6	EAST
4	10	5
3	20	3
3	30	4
4	40	6
4	50	3
6	60	2
3	70	0
1	80	1

Fabric 66. Vector mean N 6 W. Equinox Quadrangle. Subsurface till. One mile south of Manchester.

WEST	N 2	EAST
9	10	1
10	20	2
9	30	1
9	40	4
15	50	1
7	60	0
3	70	1
0	80	0

Fabric 67. Vector mean N 33 W. Londonderry Quadrangle. Subsurface till. Jamaica.

WEST	N 5	EAST
4	10	3
4	20	4
6	30	7
2	40	0
6	50	3
3	60	0
2	70	1
3	80	2

Fabric 68. Vector mean N 14 W. Saxtons River Quadrangle. Subsurface till. One mile east of Saxtons River.

WEST	N 7	EAST
4	10	1
12	20	2
8	30	3
11	40	2
6	50	1
2	60	2
4	70	1
1	80	0

Fabric 69. Vector mean N 26 W. Bellows Falls Quadrangle. Subsurface till. Three and one-half miles southwest of North Westminster.

WEST	N 13	EAST
2	10	0
5	20	0
3	30	2
3	40	3
3	50	1
3	60	0
4	70	1
2	80	0

Fabric 70. Vector mean N 20 W. Bellows Falls New Hampshire Quadrangle. Subsurface till. Four miles southeast of Walpole, New Hampshire.

WEST	N 5	EAST
2	10	1
3	20	3
3	30	0
5	40	2
5	50	0
8	60	2
6	70	0
3	80	0

Fabric 71. Vector mean N 42 W. Hoosic Falls New York Quadrangle. Surface till. North outskirts of Hoosic Falls, New York.

WEST	N8	EAST
3	10	4
9	20	3
7	30	2
3	40	1
0	50	0
1	60	0
4	70	1
0	80	2

Fabric 72. Vector mean N 14 W. North Pownal New York Quadrangle. Surface till. Two miles east of Hoosic, New York.

WEST	N 4	EAST
1	10	0
0	20	0
4	30	0
1	40	1
0	50	0
2	60	3
4	70	0
6	80	3

Fabric 73. Vector mean N 68 W. Bennington Quadrangle. Surface till. U. S. Route 7 at Woodford Hollow School.

WEST	N 5	EAST
1	10	5
6	20	4
12	30	1
8	40	0
3	50	1
2	60	0
3	70	0
1	80	1

Fabric 74. Bennington Quadrangle. Surface till. One mile north of Stamford.

WEST	N 2	EAST
1	10	0
1	20	0
4	30	1
0	40	1
6	50	0
6	60	0
1	70	0
1	80	0

Fabric 75. Vector mean N 44 W. Bennington Quadrangle. Surface till. Two miles north-northeast of Pownal.

WEST	N 5	EAST
2	10	2
2	20	0
3	30	0
5	40	5
5	50	1
3	60	0
4	70	3
2	80	0

Fabric 76. Vector mean N 36 W. Bennington Quadrangle. Surface till. Four and one-half miles south of Bennington.

WEST	N 2	EAST
5	10	4
3	20	0
5	30	1
2	40	1
6	50	3
4	60	4
7	70	4
11	80	6

Fabric 77. Vector mean N 68 W. Bennington Quadrangle. Surface till. One mile south of North Bennington.

WEST	N 2	EAST
7	10	5
11	20	1
10	30	3
6	40	1
2	50	0
5	60	2
2	70	0
4	80	0

Fabric 78. Vector mean N 25 W. Hoosic Falls Quadrangle. Subsurface till. Three miles west-southwest of Shaftsbury.

WEST	N 5	EAST
10	10	6
14	20	4
13	30	4
17	40	5
11	50	5
8	60	7
3	70	2
4	80	6

Fabric 79. Vector mean N 26 W. Bennington Quadrangle. Surface till. One and one-half miles northwest of North Bennington.

WEST	N·O	EAST
0	10	0
2	20	0
2	30	2
0	40	1
9	50	0
3	60	0
8	70	1
7	80	7

Fabric 80. Vector mean N 70 W. Bennington Quadrangle. Surface till. Two miles southeast of North Bennington.

WEST	N 3	EAST
1	10	0
5	20	3
4	30	2
6	40	3
3	50	0
7	60	0
8	70	2
5	80	5

Fabric 81. Vector mean N 54 W. Bennington Quadrangle. Surface till. Two miles north of Bennington.

WEST	N 3	EAST
7	10	6
8	20	8
5	30	3
12	40	3
3	50	1
2	60	0
2	70	1
1	80	0

Fabric 82. Vector mean N 14 W. Bennington Quadrangle. Surface till. One-fourth mile east of Bennington.

WEST	N 1	EAST
0	10	1
1	20	0
0	30	2
0	40	1
1	50	2
9	60	3
9	70	3
13	80	5

Fabric 83. Vector mean N 82 W. Bennington Quadrangle. Surface till. Three miles east of Woodford.

WEST	N 1	EAST
0	10	4
4	20	0
1	30	0
0	40	0
2	50	1
4	60	0
6	70	3
3	80	0

Fabric 84. Vector mean N 56 W. Bennington Quadrangle. Surface till. Two miles west of Woodford.

WEST	N 4	EAST
11	10	4
4	20	5
2	30	0
1	40	0
1	50	0
4	60	0
5	70	3
4	80	1

Fabric 85. Vector mean N 20 W. Bennington Quadrangle. Surface till. Three and one-half miles west of Bennington.

WEST	N·O	EAST
1	10	0
3	20	2
6	30	1
6	40	0
5	50	1
8	60	0
6	70	0
1	80	2

Fabric 86. Vector mean N 49 W. Bennington Quadrangle. Surface till. Four miles northwest of Pownal.

WEST	N 2	EAST
5	10	5
5	20	1
7	30	0
3	40	1
6	50	0
4	60	0
3	70	2
0	80	2

Fabric 87. Vector mean N 20 W. Bennington Quadrangle. Surface till. Three and one-half miles northwest of Pownal.

WEST	N 6	EAST
1	10	0
1	20	0
3	30	0
3	40	1
3	50	1
4	60	0
7	70	3
5	80	2

Fabric 88. Vector mean N 58 W. Bennington Quadrangle. Surface till. One mile southwest of Bennington.

WEST	N 3	EAST
1	10	0
0	20	2
1	30	2
2	40	2
6	50	0
5	60	2
7	70	5
5	80	3

Fabric 89. Vector mean N 74 W. Bennington Quadrangle. Surface till. One-half mile east-southeast of Bennington.

WEST	N 4	EAST
2	10	5
2	20	5
5	30	1
2	40	2
7	50	1
1	60	1
1	70	0
1	80	0

Fabric 90. Vector mean N 13 W. Bennington Quadrangle. Surface till. One mile north of Bennington Park Street .

WEST	N 5	EAST
4	10	5
2	20	1
2	30	2
5	40	1
2	50	1
7	60	0
1	70	0
1	80	1

Fabric 91. Vector mean N 22 W. Bennington Quadrangle. Surface till. One mile north of Bennington.

WEST	N·O	EAST
6	10	0
1	20	0
1	30	1
3	40	1
3	50	0
3	60	3
4	70	2
7	80	7

Fabric 92. Vector mean N 73 W. Bennington Quadrangle. Surface till. One mile south of Old Bennington.

WEST	N 5	EAST
2	10	1
5	20	0
5	30	1
7	40	0
3	50	0
6	60	2
4	70	2
3	80	0

Fabric 93. Vector mean N 40 W. North Pownal Quadrangle. Surface till. One mile north of North Pownal.

WEST	N·O	EAST
0	10	2
1	20	1
3	30	0
6	40	1
6	50	0
5	60	0
8	70	2
6	80	0

Fabric 94. Vector mean N 57 W. North Pownal Quadrangle. Surface till. One and one-half miles north of North Pownal.

WEST	N 4	EAST
4	10	5
11	20	0
4	30	0
2	40	0
1	50	0
1	60	3
4	70	1
5	80	5

Fabric 95. Vector mean N 30 W. Hoosic Falls Quadrangle. Surface till. State Route 9, four miles west of Bennington.

WEST	N 3	EAST
7	10	6
8	20	8
5	30	3
12	40	3
3	50	1
2	60	0
2	70	1
1	80	0

Fabric 96. Vector mean N 14 W. Bennington Quadrangle. Surface till. One-fourth mile east of Bennington.

WEST	N 3	EAST
1	10	0
5	20	3
4	30	2
6	40	3
3	50	0
7	60	0
8	70	2
5	80	5

Fabric 97. Vector mean N 54 W. Bennington Quadrangle. Surface till. Two miles north of Bennington.

WEST	N·O	EAST
0	10	0
2	20	0
2	30	2
0	40	1
9	50	0
3	60	0
8	70	1
7	80	7

Fabric 98. Vector mean N 70 W. Bennington Quadrangle. Surface till. Two miles southeast of North Bennington.

WEST	N 10	EAST
10	10	6
14	20	4
13	30	4
17	40	5
11	50	5
8	60	7
3	70	2
4	80	6

Fabric 99. Vector mean N 26 W. Bennington Quadrangle. Surface till. One and one-half miles northwest of North Bennington.

WEST	N·O	EAST
6	10	4
5	20	2
4	30	4
6	40	0
6	50	0
3	60	0
2	70	0
0	80	0

Fabric 100. Bennington Quadrangle. Surface till. Two and one-half miles northeast of Woodford.

WEST	N 4	EAST
2	10	0
5	20	1
3	30	1
5	40	3
2	50	4
6	60	4
9	70	6
7	80	7

Fabric 101. Vector mean N 79 W. Bennington Quadrangle. Surface till. One mile south of North Bennington.

WEST	N 1	EAST
1	10	2
2	20	4
2	30	2
11	40	1
4	50	2
2	60	3
2	70	0
1	80	1

Fabric 102. Vector mean N 31 W. Wilmington Quadrangle. Surface till. One mile southeast of East Dover.

WEST	N 3	EAST
2	10	0
2	20	1
2	30	1
4	40	1
7	50	0
6	60	1
1	70	0
0	80	1

Fabric 103. Vector mean N 40 W. Wilmington Quadrangle. Surface till. Two miles north of Searsburg.

WEST	N 3	EAST
0	10	0
5	20	0
10	30	1
2	40	0
5	50	0
1	60	1
2	70	2
2	80	0

Fabric 104. Vector mean N 36 W. Wilmington Quadrangle. Surface till. Two and one-half miles south of Wilmington.

WEST	N 5	EAST
1	10	1
2	20	0
4	30	1
4	40	1
6	50	1
3	60	2
5	70	2
2	80	1

Fabric 105. Vector mean N 45 W. Wilmington Quadrangle. Surface till. Three miles south of Jacksonville.

WEST	N 4	EAST
0	10	2
2	20	1
4	30	3
9	40	5
6	50	0
4	60	2
1	70	1
1	80	1

Fabric 106. Vector mean N 33 W. Wilmington Quadrangle. Surface till. Four miles south of Jacksonville.

WEST	N 5	EAST
2	10	0
2	20	0
6	30	4
7	40	2
3	50	0
3	60	1
3	70	1
0	80	0

Fabric 107. Vector mean N 29 W. Wilmington Quadrangle. Surface till. Three miles west of Marlboro.

WEST	N 5	EAST
0	10	0
4	20	1
8	30	0
8	40	0
2	50	1
2	60	1
2	70	0
0	80	0

Fabric 108. Vector mean N 31 W. Wilmington Quadrangle. Surface till. Two miles north of Wilmington.

WEST	N-O	EAST
1	10	1
0	20	1
1	30	2
4	40	2
4	50	0
6	60	1
15	70	1
7	80	4

Fabric 109. Vector mean N 70 W. Wilmington Quadrangle. Surface till. One and one-half miles north of West Halifax.

WEST	N 4	EAST
5	10	0
4	20	1
4	30	0
6	40	3
7	50	1
5	60	0
6	70	1
2	80	1

Fabric 110. Vector mean N 40 W. Wilmington Quadrangle. Surface till. Five miles east of Wilmington.

WEST	N 2	EAST
0	10	2
0	20	3
1	30	4
0	40	3
2	50	2
4	60	0
13	70	2
9	80	0

Fabric 111. Vector mean N 79 W. Wilmington Quadrangle. Surface till. One mile southwest of Readsboro.

WEST	N-O	EAST
1	10	1
3	20	2
2	30	0
9	40	1
2	50	0
3	60	0
4	70	0
3	80	0

Fabric 112. Vector mean N 44 W. Wilmington Quadrangle. Surface till. One and one-fourth miles east-southeast of East Dover.

WEST	N 2	EAST
12	10	7
7	20	2
5	30	0
2	40	0
6	50	0
9	60	1
4	70	1
2	80	0

Fabric 113. Vector mean N 27 W. Wilmington Quadrangle. Subsurface till. One and one-fourth miles east-southeast of East Dover.

WEST	N 1	EAST
0	10	0
1	20	0
6	30	3
2	40	1
8	50	0
5	60	1
2	70	0
0	80	1

Fabric 114. Vector mean N 45 W. Wilmington Quadrangle. Subsurface till. One mile southeast of East Dover.

WEST	N 1	EAST
2	10	1
8	20	4
7	30	2
4	40	4
4	50	1
5	60	1
5	70	2
3	80	0

Fabric 115. Vector mean N 34 W. Wilmington Quadrangle. Surface till. Two miles south of Wilmington.

WEST	N-O	EAST
4	10	3
4	20	5
13	30	2
5	40	1
6	50	1
1	60	1
1	70	1
2	80	3

Fabric 116. Vector mean N 26 W. Wilmington Quadrangle. Surface till. Two and one-half miles southeast of Jacksonville.

WEST	N 1	EAST
5	10	5
5	20	6
9	30	0
3	40	2
6	50	3
5	60	2
1	70	0
2	80	1

Fabric 117. Vector mean N 22 W. Wilmington Quadrangle. Subsurface till. Two and one-half miles southeast of Jacksonville.

WEST	N 2	EAST
1	10	3
12	20	3
8	30	2
6	40	0
2	50	1
2	60	0
0	70	0
0	80	0

Fabric 118. Vector mean N 21 W. Wilmington Quadrangle. Surface till. Three-fourths mile south-southeast of West Dover.

WEST	N 2	EAST
1	10	0
7	20	3
4	30	1
9	40	1
5	50	0
4	60	2
5	70	1
1	80	0

Fabric 119. Vector mean N 38 W. Brattleboro Quadrangle. Subsurface till. Three miles northwest of Brattleboro.

WEST	N 2	EAST
2	10	0
0	20	1
3	30	0
5	40	0
5	50	1
7	60	1
1	70	0
1	80	0

Fabric 120. Vector mean N 45 W. Brattleboro Quadrangle. Surface till. One-fourth mile north of Halifax.

WEST	N 6	EAST
7	10	1
4	20	4
9	30	3
7	40	1
3	50	0
0	60	0
0	70	0
1	80	0

Fabric 121. Vector mean N 16 W. Brattleboro Quadrangle. Surface till. Six and one-half miles west of Brattleboro.

WEST	N 12	EAST
6	10	4
11	20	4
10	30	4
5	40	5
2	50	0
3	60	2
6	70	2
1	80	1

Fabric 122. Vector mean N 14 W. Brattleboro Quadrangle. Surface till. One and one-fourth miles east of East Dummerston.

WEST	N 1	EAST
0	10	0
2	20	0
2	30	1
3	40	0
2	50	0
4	60	0
3	70	0
3	80	1

Fabric 123. Vector mean N 53 W. Keene New Hampshire Quadrangle. Surface till. Three miles northwest of Keene, New Hampshire.

WEST	N 25	EAST
7	10	8
8	20	5
6	30	1
7	40	1
2	50	0
1	60	1
4	70	3
0	80	0

Fabric 124. Vector mean N 9 W. Keene New Hampshire Quadrangle. Surface till. One-half mile southwest of Spofford, New Hampshire.

WEST	N 7	EAST
3	10	7
3	20	3
5	30	3
4	40	3
3	50	1
2	60	0
1	70	1
3	80	0

Fabric 125. Keene New Hampshire Quadrangle. Subsurface till. Three miles northeast of Brattleboro.

WEST	N 7	EAST
1	10	3
0	20	2
1	30	0
5	40	0
4	50	2
6	60	0
7	70	1
2	80	0

Fabric 126. Vector mean N 42 W. Keene New Hampshire Quadrangle. Surface till. Northeast limits of Winchester, New Hampshire.

WEST	N 5	EAST
2	10	2
7	20	0
2	30	2
8	40	0
2	50	2
6	60	1
6	70	1
0	80	0

Fabric 127. Vector mean N 34 W. Williamstown Massachusetts Quadrangle. Surface till. Williamstown College campus, Williamstown. Massachusetts.

WEST	N 6	EAST
1	10	6
2	20	1
2	30	1
5	40	1
5	50	1
1	60	0
2	70	2
0	80	0

Fabric 128. Vector mean N 28 W. Northfield Massachusetts Quadrangle. Surface till. One-fourth mile east of Bernardston.

APPENDIX B

FIELD DATA AND CALCULATED VECTOR MEAN OF FABRICS OF THE SHELBURNE TILL

WEST	N 3	EAST
3	10	11
3	20	15
4	30	18
0	40	11
0	50	2
2	60	0
5	70	5
2	80	7

Fabric 1. Vector mean N 27 E. Rouses Point Quadrangle. Subsurface till. Isle La Motte, one-half mile south-southeast of Sandy Point.

WEST	N·0	EAST
3	10	8
0	20	6
1	30	7
2	40	9
0	50	6
1	60	0
0	70	0
2	80	0

Fabric 2. Vector mean N 26 E. Rouses Point Quadrangle. Subsurface till. Isle La Motte, one-half mile south-southeast of Sandy Point.

WEST	N 1	EAST
3	10	2
2	20	6
3	30	6
2	40	8
5	50	7
5	60	6
3	70	4
3	80	1

Fabric 3. Vector mean N 42 E. St. Albans Quadrangle. Subsurface till. Three miles southwest of St. Albans.

WEST	N 1	EAST
3	10	0
0	20	2
0	30	6
0	40	9
1	50	11
1	60	2
3	70	1
2	80	1

Fabric 4. Vector mean N 33 E. Enosburg Falls Quadrangle. Subsurface till. East of Lake Carmi, three miles north of South Franklin.

WEST	N 2	EAST
4	10	9
2	20	8
5	30	7
2	40	11
2	50	7
0	60	1
4	70	6
0	80	5

Fabric 5. Vector mean N 26 E. Enosburg Falls Quadrangle. Subsurface till. Entrance of Lake Carmi State Park, three miles north of South Franklin.

WEST	N 9	EAST
4	10	7
1	20	5
2	30	1
1	40	0
1	50	0
0	60	2
4	70	3
4	80	3

Fabric 6. Vector mean N 3 E. Enosburg Falls Quadrangle. Subsurface till. One-half mile east of Sheldon.

WEST	N 1	EAST
3	10	1
9	20	4
9	30	5
5	40	10
8	50	8
4	60	8
5	70	7
0	80	7

Fabric 7. Vector mean N 22 E. Enosburg Falls Quadrangle. Subsurface till. Three miles west of Enosburg Falls.

WEST	N 4	EAST
1	10	8
2	20	11
4	30	6
2	40	4
1	50	5
0	60	2
1	70	0
1	80	1

Fabric 8. Vector mean N 18 E. Memphremagog Quadrangle. Surface till. Orleans water reservoir.

WEST	N 19	EAST
15	10	17
9	20	16
1	30	4
1	40	3
0	50	0
0	60	0
0	70	0
0	80	1

Fabric 9. Vector mean N 4 E. Memphremagog Quadrangle. Surface till. Two miles south of Orleans.

WEST	N 3	EAST
4	10	1
3	20	4
3	30	11
2	40	15
1	50	10
1	60	4
1	70	5
0	80	2

Fabric 10. Vector mean N 35 E. Memphremagog Quadrangle. Subsurface till. One-half mile east of Tice.

WEST	N 6	EAST
1	10	6
1	20	7
1	30	10
5	40	4
3	50	8
2	60	5
4	70	6
3	80	4

Fabric 11. Vector mean N 37 E. Memphremagog Quadrangle. Surface till. Two miles east of Orleans.

WEST	N 9	EAST
7	10	12
10	20	7
3	30	4
4	40	10
6	50	11
1	60	5
1	70	4
2	80	1

Fabric 12. Vector mean N 13 E. Memphremagog Quadrangle. Surface till. Heath School, two miles southeast of Orleans.

WEST	N 3	EAST
1	10	3
3	20	6
2	30	6
1	40	13
1	50	6
2	60	4
2	70	0
5	80	2

Fabric 13. Vector mean N 35 E. Memphremagog Quadrangle. Surface till. Willoughby River, two miles east of Orleans.

WEST	N·0	EAST
4	10	11
3	20	9
2	30	10
0	40	12
2	50	9
1	60	1
0	70	1
0	80	1

Fabric 14. Vector mean N 25 E. Memphremagog Quadrangle. Subsurface till. Willoughby River, two miles east of Orleans.

WEST	N·0	EAST
3	10	21
7	20	7
0	30	11
0	40	1
1	50	3
0	60	4
4	70	1
0	80	1

Fabric 15. Memphremagog Quadrangle. Subsurface till. Two and one-half miles east-southeast of Derby Line.

WEST	N·0	EAST
4	10	2
0	20	6
1	30	4
2	40	9
1	50	4
2	60	1
1	70	3
1	80	0

Fabric 16. Memphremagog Quadrangle. Subsurface till. Newport airport.

WEST	N·0	EAST
2	10	1
0	20	2
0	30	10
0	40	1
1	50	5
0	60	2
1	70	1
0	80	0

Fabric 17. Vector mean N 31 E. Memphremagog Quadrangle. Subsurface till. Two and one-half miles south-southeast of Newport.

WEST	N·0	EAST
5	10	3
1	20	11
0	30	8
2	40	4
0	50	1
1	60	1
0	70	2
0	80	1

Fabric 18. Memphremagog Quadrangle. Subsurface till. Two miles south-southeast of East Charleston.

WEST	N 1	EAST
1	10	2
1	20	10
1	30	15
0	40	9
0	50	7
2	60	2
0	70	4
2	80	2

Fabric 19. Vector mean N 36 E. Island Pond Quadrangle. Subsurface till. Two miles east-northeast of Morgan Center.

WEST	N 4	EAST
3	10	7
1	20	6
1	30	4
0	40	6
3	50	3
0	60	2
0	70	0
0	80	0

Fabric 20. Vector mean N 18 E. Island Pond Quadrangle. Surface till. North end of Norton Pond.

WEST	N 12	EAST
8	10	14
7	20	5
5	30	5
3	40	8
2	50	0
2	60	1
2	70	0
0	80	0

Fabric 21. Vector mean N 1 E. Island Pond Quadrangle. Surface till. One and one-half miles east of East Brighton.

WEST	N 17	EAST
2	10	16
1	20	8
0	30	2
0	40	0
0	50	0
0	60	1
0	70	0
1	80	0

Fabric 22. Vector mean N 8 E. Island Pond Quadrangle. Surface till. Five miles northwest of East Brighton.

WEST	N·0	EAST
1	10	3
0	20	5
2	30	7
2	40	2
2	50	3
3	60	2
0	70	4
0	80	3

Fabric 23. Vector mean N 32 E. Island Pond Quadrangle. Surface till. One-half mile southeast of East Charleston.

WEST	N 11	EAST
6	10	8
1	20	9
1	30	2
0	40	2
0	50	2
0	60	0
2	70	0
1	80	0

Fabric 24. Vector mean N 8 E. Averill Quadrangle. Surface till. Two and one-half miles east of Norton.

WEST	N 4	EAST
6	10	7
1	20	8
2	30	8
0	40	5
1	50	1
0	60	0
0	70	1
0	80	0

Fabric 25. Vector mean N 15 E. Averill Quadrangle. Surface till. One mile east of Averill.

WEST	N 5	EAST
2	10	14
1	20	8
4	30	9
4	40	8
0	50	4
2	60	8
1	70	5
0	80	4

Fabric 26. Vector mean N 27 E. Averill Quadrangle. Surface till. Three miles southwest of Canaan.

WEST	N·0	EAST
1	10	10
0	20	6
1	30	9
1	40	7
0	50	6
3	60	18
5	70	10
1	80	2

Fabric 27. Vector mean N 43 E. Hardwick Quadrangle. Subsurface till. Two miles northeast of North Wolcott.

WEST	N 1	EAST
0	10	9
0	20	8
7	30	12
5	40	11
2	50	6
2	60	1
2	70	2
0	80	0

Fabric 28. Vector mean N 19 E. Hardwick Quadrangle. Surface till. Two miles southeast of Greensboro.

WEST	N 1	EAST
4	10	6
7	20	3
10	30	5
8	40	4
5	50	3
7	60	2
11	70	3
3	80	1

Fabric 29. Hardwick Quadrangle. Surface till. One mile east of Taylor Swamp.

WEST	N 5	EAST
2	10	1
1	20	6
3	30	7
2	40	8
5	50	10
2	60	11
2	70	8
3	80	0

Fabric 30. Vector mean N 50 E. Hardwick Quadrangle. Surface till. Two miles east of Hardwick.

WEST	N 0	EAST
9	10	11
7	20	19
5	30	12
8	40	12
3	50	6
0	60	7
3	70	3
3	80	7

Fabric 31. Vector mean N 23 E. Lyndonville Quadrangle. Surface till. Stannard Brook, one mile west of Stannard.

WEST	N 2	EAST
1	10	7
2	20	7
2	30	6
4	40	8
2	50	4
0	60	0
0	70	0
0	80	1

Fabric 32. Vector mean N 18 E. Lyndonville Quadrangle. Surface till. Stannard Brook, one and one-fourth miles west of Stannard.

WEST	N 1	EAST
9	10	4
5	20	4
6	30	10
4	40	11
1	50	7
1	60	5
0	70	7
1	80	6

Fabric 33. Vector mean N 29 E. Lyndonville Quadrangle. Surface till. One mile west of Stannard.

WEST	N 3	EAST
0	10	1
1	20	1
6	30	4
5	40	7
3	50	11
3	60	6
0	70	4
1	80	2

Fabric 34. Vector mean N 45 E. Lyndonville Quadrangle. Surface till. One mile south of Stannard.

WEST	N 0	EAST
9	10	4
5	20	4
6	30	10
4	40	11
1	50	7
1	60	5
0	70	7
1	80	6

Fabric 35. Vector mean N 29 E. Lyndonville Quadrangle. Surface till. One mile west of Stannard.

WEST	N 8	EAST
6	10	4
2	20	7
0	30	11
0	40	7
2	50	10
0	60	4
2	70	2
0	80	0

Fabric 36. Vector mean N 26 E. Lyndonville Quadrangle. Surface till. One and one-fourth miles north-northeast of West Glover.

WEST	N 8	EAST
2	10	7
3	20	6
3	30	7
2	40	7
1	50	2
0	60	2
0	70	3
0	80	1

Fabric 37. Vector mean N 17 E. Lyndonville Quadrangle. Surface till. One and one-fourth miles northwest of West Glover.

WEST	N 0	EAST
0	10	4
0	20	5
1	30	9
0	40	7
2	50	6
1	60	5
0	70	1
0	80	1

Fabric 38. Vector mean N 35 E. Lyndonville Quadrangle. Surface till. One mile west-northwest of Stannard.

WEST	N 1	EAST
3	10	4
1	20	5
2	30	9
0	40	12
1	50	8
0	60	10
0	70	2
0	80	1

Fabric 39. Lyndonville Quadrangle. Surface till. Two and one-half miles northeast of Greensboro Bend.

WEST	N 0	EAST
3	10	3
3	20	8
2	30	6
8	40	5
2	50	3
2	60	4
0	70	3
0	80	0

Fabric 40. Burke Quadrangle. Surface till. One mile south-southwest of East Lyndon.

WEST	N 0	EAST
4	10	6
2	20	3
3	30	6
2	40	9
2	50	4
3	60	2
6	70	0
0	80	0

Fabric 41. Vector mean N 18 E. Burke Quadrangle. Surface till. Two miles southeast of Lyndonville.

WEST	N 0	EAST
3	10	4
7	20	12
3	30	6
4	40	5
0	50	3
1	60	4
2	70	4
1	80	2

Fabric 42. Vector mean N 17 E. Burke Quadrangle. Surface till. One mile south of Newark Hollow.

WEST	N 0	EAST
1	10	6
5	20	9
5	30	18
1	40	8
1	50	5
1	60	5
0	70	2
0	80	0

Fabric 43. Vector mean N 11 E. Burke Quadrangle. Surface till. One mile south-southeast of East Lyndon.

WEST	N 0	EAST
4	10	7
3	20	10
0	30	27
0	40	5
0	50	5
0	60	3
0	70	1
0	80	0

Fabric 44. Vector mean N 26 E. Burke Quadrangle. Surface till. One-fourth mile east of East Lyndon.

WEST	N 0	EAST
4	10	3
1	20	15
4	30	7
4	40	10
3	50	3
1	60	6
3	70	4
1	80	0

Fabric 45. Vector mean N 25 E. Burke Quadrangle. Surface till. One mile east of East Burke.

WEST	N 0	EAST
6	10	9
4	20	3
1	30	12
4	40	3
1	50	3
1	60	1
1	70	0
0	80	1

Fabric 46. Vector mean N 22 E. Burke Quadrangle. Surface till. North end of East Haven Range, two and one-half miles east of East Haven.

WEST	N 0	EAST
2	10	4
0	20	11
4	30	9
2	40	7
2	50	4
0	60	0
3	70	1
0	80	0

Fabric 47. Vector mean N 22 E. Burke Quadrangle. Surface till. Two miles east-southeast of East Haven.

WEST	N 0	EAST
2	10	2
2	20	4
2	30	5
1	40	7
0	50	6
1	60	10
1	70	5
1	80	3

Fabric 48. Vector mean N 44 E. Burke Quadrangle. Surface till. One mile east of Gallup Mills.

WEST	N 7	EAST
4	10	8
5	20	13
4	30	12
0	40	7
0	50	7
0	60	2
3	70	1
3	80	3

Fabric 49. Vector mean N 20 E. Guildhall Quadrangle. Surface till. Southwest slope of Harris Mountain, seven and one-half miles west of Guildhall.

WEST	N 2	EAST
4	10	8
0	20	16
0	30	14
0	40	3
0	50	4
4	60	1
3	70	4
0	80	7

Fabric 50. Vector mean N 30 E. Guildhall Quadrangle. Surface till. Five miles west of Guildhall.

WEST	N 4	EAST
5	10	3
3	20	10
5	30	5
1	40	10
1	50	6
1	60	2
1	70	0
0	80	0

Fabric 51. Vector mean N 18 E. Burlington Quadrangle. Subsurface till. One and one-half miles south of Shelburne.

WEST	N 4	EAST
6	10	8
6	20	12
2	30	20
3	40	12
0	50	4
0	60	1
0	70	1
0	80	0

Fabric 52. Vector mean N 19 E. Burlington Quadrangle. Subsurface till. One and one-half miles south of Shelburne.

WEST	N 11	EAST
3	10	6
3	20	7
3	30	9
0	40	4
0	50	2
0	60	0
1	70	0
0	80	1

Fabric 53. Vector mean N 12 E. Burlington Quadrangle. Subsurface till. Two and one-half miles north-east of North Ferrisburg.

WEST	N 5	EAST
3	10	9
5	20	6
2	30	1
2	40	0
0	50	2
2	60	1
0	70	0
1	80	0

Fabric 54. Vector mean N 1 E. Montpelier Quadrangle. Surface till. Three miles south-southeast of Elmore.

WEST	N 6	EAST
2	10	7
0	20	2
2	30	7
1	40	8
0	50	1
0	60	1
0	70	2
1	80	2

Fabric 55. Vector mean N 23 E. Montpelier Quadrangle. Surface till. Three miles east of Mill Village.

WEST	N 3	EAST
1	10	3
3	20	1
1	30	3
1	40	4
0	50	9
1	60	5
1	70	2
0	80	1

Fabric 56. Vector mean N 37 E. Montpelier Quadrangle. Surface till. Two miles southeast of Waterbury Center.

WEST	N 2	EAST
2	10	2
5	20	7
3	30	1
1	40	7
1	50	4
0	60	2
1	70	1
1	80	1

Fabric 57. Vector mean N 19 E. Montpelier Quadrangle. Surface till. Elmore Mountain Road, two miles east of Moss Glen Falls.

WEST	N·O	EAST
1	10	2
1	20	2
3	30	6
1	40	6
4	50	7
3	60	7
2	70	5
0	80	1

Fabric 58. Vector mean N 49 E. Montpelier Quadrangle. Surface till. Three miles north-northeast of Worcester.

WEST	N·O	EAST
1	10	5
4	20	3
6	30	6
1	40	9
2	50	2
0	60	4
0	70	1
1	80	4

Fabric 59. Mt. Mansfield Quadrangle. Subsurface till. One mile northeast of Morses Mill.

WEST	N·O	EAST
1	10	1
2	20	1
1	30	3
6	40	9
8	50	4
0	60	5
2	70	4
0	80	4

Fabric 60. Mt. Mansfield Quadrangle. Subsurface till. One mile east-southeast of North Underhill.

WEST	N·O	EAST
7	10	6
3	20	8
1	30	5
2	40	4
2	50	7
1	60	7
0	70	10
1	80	3

Fabric 61. Vector mean N 28 E. Plainfield Quadrangle. Surface till. Two miles southwest of Marshfield.

WEST	N 13	EAST
6	10	11
3	20	12
8	30	13
5	40	23
8	50	18
9	60	34
4	70	18
5	80	12

Fabric 62. Vector mean N 47 E. Plainfield Quadrangle. Surface till. One and one-half miles south-southeast of Plainfield.

WEST	N·O	EAST
4	10	7
5	20	10
2	30	18
1	40	14
1	50	2
3	60	5
1	70	2
1	80	1

Fabric 63. Vector mean N 23 E. Plainfield Quadrangle. Surface till. One-half mile south-southeast of Plainfield.

WEST	N·O	EAST
2	10	1
0	20	5
0	30	5
1	40	11
0	50	8
0	60	7
0	70	0
0	80	0

Fabric 64. Vector mean N 37 E. Plainfield Quadrangle. Surface till. One-fourth mile northwest of Walden Heights.

WEST	N 3	EAST
5	10	1
5	20	6
2	30	5
1	40	21
7	50	24
11	60	8
7	70	8
1	80	0

Fabric 65. Vector mean N 47 E. St. Johnsbury Quadrangle. Surface till. One-half mile northeast of West Danville.

WEST	N 5	EAST
2	10	4
1	20	6
0	30	1
1	40	2
1	50	2
0	60	3
1	70	3
2	80	0

Fabric 66. Vector mean N 22 E. St. Johnsbury Quadrangle. Surface till. One mile south of Ewells Mill.

WEST	N·O	EAST
6	10	1
5	20	4
1	30	4
1	40	8
5	50	19
1	60	4
1	70	3
0	80	3

Fabric 67. Vector mean N 40 E. St. Johnsbury Quadrangle. Surface till. One-half mile northeast of West Danville.

WEST	N 1	EAST
1	10	5
3	20	2
3	30	7
4	40	12
5	50	14
4	60	6
3	70	5
1	80	0

Fabric 68. Vector mean N 41 E. St. Johnsbury Quadrangle. Surface till. One-half mile north of East Peacham.

WEST	N 2	EAST
2	10	4
3	20	6
1	30	6
0	40	10
0	50	6
1	60	2
0	70	4
0	80	3

Fabric 69. Vector mean N 34 E. Littleton Quadrangle. Surface till. Three and one-half miles west of Concord.

WEST	N 4	EAST
2	10	11
6	20	7
8	30	10
8	40	14
2	50	6
0	60	9
0	70	2
0	80	2

Fabric 70. Vector mean N 20 E. Littleton Quadrangle. Surface till. Three and one-fourth miles west of Concord.

WEST	N 5	EAST
7	10	13
4	20	6
6	30	9
3	40	8
3	50	11
4	60	6
0	70	5
3	80	1

Fabric 71. Vector mean N 21 E. Littleton Quadrangle. Surface till. Two and one-half miles west of Concord.

WEST	N 1	EAST
4	10	4
3	20	3
3	30	11
3	40	15
2	50	21
4	60	8
3	70	6
1	80	4

Fabric 72. Vector mean N 44 E. Littleton Quadrangle. Surface till. Two and one-half miles west-northwest of West Waterford.

WEST	N 3	EAST
3	10	1
6	20	10
5	30	20
9	40	10
2	50	12
0	60	5
2	70	2
0	80	2

Fabric 73. Vector mean N 25 E. Littleton Quadrangle. Surface till. One and one-half miles north of Concord.

WEST	N 3	EAST
3	10	6
4	20	7
7	30	11
3	40	14
8	50	16
1	60	4
0	70	3
0	80	1

Fabric 74. Vector mean N 27 E. Littleton Quadrangle. Surface till. One mile north-northwest of Lower Waterford.

WEST	N 6	EAST
10	10	16
9	20	16
4	30	11
3	40	4
0	50	5
2	60	0
0	70	0
0	80	0

Fabric 75. Vector mean N 8 E. Littleton Quadrangle. Surface till. One mile west of Concord.

WEST	N 6	EAST
7	10	5
6	20	14
5	30	13
7	40	14
4	50	3
4	60	2
5	70	0
2	80	0

Fabric 76. Vector mean N 9 E. Littleton Quadrangle. Surface till. One and one-half miles north of Concord.

WEST	N 1	EAST
6	10	10
0	20	12
0	30	13
2	40	14
1	50	13
3	60	5
0	70	3
3	80	0

Fabric 77. Vector mean N 32 E. Middlebury Quadrangle. Subsurface till. Four and one-half miles north of Bristol.

WEST	N 1	EAST
2	10	3
0	20	2
1	30	11
1	40	10
0	50	6
0	60	3
1	70	6
1	80	3

Fabric 78. Vector mean N 42 E. Middlebury Quadrangle. Subsurface till. Two miles north of New Haven.

WEST	N 5	EAST
3	10	8
5	20	4
6	30	4
2	40	11
2	50	10
2	60	12
3	70	10
11	80	8

Fabric 79. Vector mean N 57 E. Middlebury Quadrangle. Subsurface till. Two miles north of New Haven.

WEST	N 1	EAST
10	10	13
8	20	14
11	30	5
2	40	9
2	50	3
0	60	3
1	70	4
1	80	4

Fabric 80. Vector mean N 10 E. Middlebury Quadrangle. Subsurface till. One mile northeast of Monkton.

WEST	N 11	EAST
7	10	10
9	20	12
7	30	4
5	40	5
2	50	7
2	60	3
3	70	3
4	80	1

Fabric 81. Vector mean N 4 E. Middlebury Quadrangle. Subsurface till. One mile west-southwest of Vergennes.

WEST	N 4	EAST
3	10	3
4	20	8
0	30	14
4	40	7
1	50	8
3	60	10
5	70	8
4	80	8

Fabric 82. Vector mean N 46 E. Middlebury Quadrangle. Subsurface till. Two miles south of Weybridge.

WEST	N·O	EAST
2	10	6
2	20	4
2	30	3
3	40	4
0	50	3
0	60	3
0	70	3
0	80	1

Fabric 83. Vector mean N 20 E. Lincoln Mountain Quadrangle. Subsurface till. One mile northeast of Waitsfield Common.

WEST	N·O	EAST
3	10	2
2	20	5
1	30	2
2	40	4
0	50	2
0	60	11
1	70	5
1	80	5

Fabric 84. Vector mean N 47 E. Lincoln Mountain Quadrangle. Subsurface till. One mile east of Warren.

WEST	N·O	EAST
0	10	1
0	20	1
0	30	1
0	40	5
1	50	10
0	60	8
1	70	3
0	80	3

Fabric 85. Vector mean N 55 E. Lincoln Mountain Quadrangle. Surface till. One and one-fourth miles west-southwest of Roxbury.

WEST	N 4	EAST
6	10	8
9	20	11
8	30	10
0	40	11
2	50	12
3	60	14
0	70	11
0	80	2

Fabric 86. Vector mean N 28 E. Barre Quadrangle. Surface till. One-fourth mile west-southwest of Williamstown.

WEST	N·O	EAST
1	10	0
1	20	4
1	30	7
0	40	6
0	50	5
0	60	3
0	70	2
0	80	1

Fabric 87. Vector mean N 38 E. Barre Quadrangle. Surface till. Two and one-half miles west of Northfield.

WEST	N 2	EAST
6	10	2
4	20	5
0	30	6
0	40	3
0	50	4
0	60	4
1	70	3
1	80	1

Fabric 88. Vector mean N 26 E. Barre Quadrangle. Surface till. Three miles west-northwest of Northfield.

WEST	N·O	EAST
4	10	4
1	20	11
2	30	9
2	40	4
0	50	6
0	60	4
4	70	3
0	80	2

Fabric 89. Vector mean N 28 E. Barre Quadrangle. Surface till. One mile northwest of Williamstown.

WEST	N·O	EAST
2	10	3
2	20	3
2	30	7
1	40	2
1	50	11
0	60	6
2	70	6
2	80	3

Fabric 90. Vector mean N 48 E. East Barre Quadrangle. Surface till. Goose Green, two and one-fourth miles south-southwest of Cookville.

WEST	N·O	EAST
1	10	3
3	20	2
0	30	3
1	40	8
2	50	5
1	60	7
0	70	6
1	80	2

Fabric 91. East Barre Quadrangle. Surface till. Goose Green, two miles south-southwest of Cookville.

WEST	N 2	EAST
4	10	5
4	20	9
2	30	6
4	40	2
0	50	1
4	60	3
1	70	4
1	80	0

Fabric 92. East Barre Quadrangle. Surface till. Two miles north of Barre.

WEST	N 1	EAST
0	10	0
1	20	5
1	30	5
0	40	3
1	50	2
0	60	4
3	70	3
0	80	3

Fabric 93. Vector mean N 47 E. East Barre Quadrangle. Surface till. One mile east of Cookville.

WEST	N 1	EAST
0	10	1
2	20	4
0	30	5
2	40	11
1	50	5
0	60	3
1	70	1
0	80	0

Fabric 94. East Barre Quadrangle. Surface till. One mile southeast of Corinth Corners.

WEST	N 2	EAST
10	10	9
12	20	8
6	30	9
4	40	14
0	50	12
1	60	6
2	70	8
1	80	3

Fabric 95. Vector mean N 20 E. East Barre Quadrangle. Subsurface till. One mile southeast of Barre.

WEST	N 1	EAST
3	10	7
3	20	7
2	30	12
5	40	10
1	50	13
0	60	14
1	70	8
0	80	3

Fabric 96. Vector mean N 38 E. East Barre Quadrangle. Surface till. Five miles north of Orange.

WEST	N·O	EAST
13	10	11
4	20	19
4	30	10
3	40	9
2	50	8
5	60	10
2	70	7
4	80	4

Fabric 97. Vector mean N 25 E. East Barre Quadrangle. Surface till. One-fourth mile northwest of East Barre.

WEST	N·O	EAST
4	10	5
2	20	9
4	30	6
1	40	4
2	50	2
2	60	4
5	70	13
3	80	4

Fabric 98. Vector mean N 20 E. East Barre Quadrangle. Subsurface till. One and one-half miles southeast of Barre.

WEST	N 7	EAST
7	10	4
9	20	5
7	30	6
5	40	7
3	50	6
1	60	5
1	70	5
4	80	8

Fabric 99. Vector mean N 13 E. Woodsville Quadrangle. Surface till. Two miles north of Waits River.

WEST	N 5	EAST
4	10	5
2	20	11
3	30	3
2	40	8
1	50	6
5	60	7
4	70	5
1	80	3

Fabric 100. Vector mean N 31 E. Woodsville Quadrangle. Surface till. One-half mile south of Halls Lake.

WEST	N 3	EAST
5	10	6
2	20	5
0	30	6
0	40	3
1	50	2
6	60	0
12	70	2
1	80	7

Fabric 101. Vector mean N 38 E. Woodsville Quadrangle. Surface till. One and one-half miles west of Boltonville.

WEST	N·O	EAST
5	10	6
3	20	7
0	30	11
3	40	5
4	50	3
1	60	4
3	70	3
0	80	0

Fabric 102. Vector mean N 22 E. Woodsville Quadrangle. Surface till. One and one-half miles west of Boltonville.

WEST	N 6	EAST
10	10	12
6	20	12
3	30	17
0	40	8
5	50	5
7	60	4
15	70	3
1	80	7

Fabric 103. Vector mean N 19 E. Woodsville Quadrangle. Surface till. Combined count of Fabrics 101 and 102 from same location.

WEST	N 5	EAST
3	10	12
0	20	13
4	30	4
3	40	4
1	50	1
1	60	1
1	70	3
0	80	0

Fabric 104. Vector mean N 12 E. Woodsville Quadrangle. Surface till. Town Farm Hill, two miles east of Halls Lake.

WEST	N 7	EAST
6	10	5
3	20	4
2	30	4
3	40	10
0	50	10
1	60	3
1	70	3
5	80	3

Fabric 105. Moosilauke New Hampshire Quadrangle. Surface till. Four and one-half miles east of Swiftwater, New Hampshire.

WEST	N·O	EAST
4	10	7
2	20	6
1	30	4
1	40	8
4	50	5
3	60	4
3	70	3
2	80	7

Fabric 106. Vector mean N 38 E. Rochester Quadrangle. Surface till. One mile west of Pittsfield.

WEST	N·O	EAST
3	10	4
5	20	8
2	30	8
2	40	7
1	50	4
1	60	5
2	70	7
1	80	3

Fabric 107. Vector mean N 31 E. Randolph Quadrangle. Surface till. Two and one-half miles northwest of Bethel.

WEST	N·O	EAST
0	10	1
1	20	1
1	30	4
0	40	10
6	50	9
2	60	14
2	70	14
3	80	1

Fabric 108. Vector mean N 60 E. Randolph Quadrangle. Surface till. One mile southwest of East Braintree.

WEST	N·O	EAST
3	10	10
2	20	4
2	30	5
0	40	1
3	50	1
2	60	0
1	70	3
0	80	0

Fabric 109. Vector mean N 6 E. Randolph Quadrangle. Surface till. Lillieville Brook valley at Lillieville.

WEST	N·O	EAST
0	10	3
1	20	5
0	30	4
1	40	1
2	50	2
5	60	3
1	70	0
0	80	2

Fabric 110. Vector mean N 15 E. Randolph Quadrangle. Surface till. One mile west of Olympus.

WEST	N·O	EAST
3	10	4
9	20	1
1	30	5
2	40	8
1	50	1
0	60	1
0	70	3
0	80	0

Fabric 111. Vector mean N 11 E. Randolph Quadrangle. Surface till. Three miles north-northwest of Randolph.

WEST	N·O	EAST
1	10	3
2	20	5
4	30	4
5	40	2
2	50	2
2	60	2
1	70	0
1	80	0

Fabric 112. Randolph Quadrangle. Surface till. Four miles northwest of Randolph.

WEST	N 2	EAST
0	10	3
0	20	6
3	30	5
2	40	8
1	50	3
0	60	2
1	70	1
0	80	0

Fabric 113. Vector mean N 27 E. Strafford Quadrangle. Surface till. One-fourth mile northwest of West Norwich.

WEST	N 4	EAST
6	10	2
1	20	7
2	30	12
2	40	8
0	50	4
1	60	4
2	70	6
1	80	2

Fabric 114. Vector mean N 31 E. Strafford Quadrangle. Surface till. One mile east of South Strafford.

WEST	N 3	EAST
0	10	1
6	20	3
0	30	5
5	40	7
1	50	7
1	60	2
3	70	4
0	80	2

Fabric 115. Vector mean N 34 E. Strafford Quadrangle. Surface till. One-half mile northwest of West Norwich.

WEST	N 3	EAST
1	10	7
0	20	3
1	30	4
0	40	9
1	50	1
0	60	4
0	70	1
0	80	0

Fabric 116. Vector mean N 27 E. Strafford Quadrangle. Surface till. One and one-half miles east of Chelsea.

WEST	N 6	EAST
2	10	2
0	20	3
0	30	5
1	40	3
0	50	1
0	60	3
0	70	1
0	80	0

Fabric 117. Vector mean N 22 E. Northfield Massachusetts Quadrangle. Surface till. One and one-half miles east of Northfield, Massachusetts.

WEST	N 1	EAST
1	10	6
0	20	5
1	30	9
3	40	7
1	50	2
2	60	4
1	70	0
0	80	0

Fabric 118. Mt. Cube New Hampshire Quadrangle. Surface till. Two miles northeast of Orfordville, New Hampshire.

WEST	N·O	EAST
5	10	6
2	20	6
2	30	6
3	40	4
3	50	0
0	60	2
2	70	0
4	80	0

Fabric 119. Vector mean N 22 E. Whitehall Quadrangle. Subsurface till. Two miles north of Fair Haven.

WEST	N·O	EAST
3	10	7
6	20	9
3	30	6
3	40	7
0	50	8
1	60	5
1	70	4
1	80	1

Fabric 120. Vector mean N 22 E. Whitehall Quadrangle. Subsurface till. One mile northwest of Fair Haven.

WEST	N·O	EAST
6	10	5
5	20	14
5	30	8
6	40	6
1	50	1
3	60	2
2	70	1
0	80	1

Fabric 121. Vector mean N 3 E. Whitehall Quadrangle. Subsurface till. One-fourth mile west of Benson.

WEST	N·O	EAST
3	10	5
3	20	5
4	30	6
2	40	5
7	50	8
2	60	9
2	70	9
3	80	6

Fabric 122. Vector mean N 38 E. Whitehall Quadrangle. Subsurface till. One mile northwest of Fair Haven.

WEST	N·O	EAST
3	10	6
3	20	9
5	30	3
3	40	6
4	50	1
4	60	1
1	70	3
1	80	0

Fabric 123. Vector mean N 2 E. Castleton Quadrangle. Subsurface till. One-half mile east of West Rutland.

WEST	N·O	EAST
1	10	6
1	20	2
1	30	4
0	40	10
0	50	6
0	60	3
0	70	3
1	80	1

Fabric 124. Vector mean N 32 E. Castleton Quadrangle. Surface till. One and one-half miles southwest of Center Rutland.

WEST	N·O	EAST
2	10	1
2	20	1
0	30	3
0	40	6
0	50	3
0	60	3
0	70	2
0	80	0

Fabric 125. Vector mean N 33 E. Castleton Quadrangle. Surface till. Two miles south-southeast of Center Rutland.

WEST	N·O	EAST
6	10	3
3	20	4
4	30	5
2	40	4
0	50	6
2	60	3
0	70	10
0	80	1

Fabric 126. Vector mean N 19 E. Castleton Quadrangle. Surface till. One mile south of Chippenhook.

WEST	N·O	EAST
0	10	0
2	20	2
3	30	9
1	40	9
3	50	5
0	60	4
3	70	0
0	80	1

Fabric 127. Vector mean N 36 E. Castleton Quadrangle. Subsurface till. Northern edge of Ira.

WEST	N·O	EAST
1	10	7
0	20	7
4	30	8
3	40	4
1	50	5
0	60	3
0	70	5
0	80	1

Fabric 128. Vector mean N 23 E. Castleton Quadrangle. Surface till. Two and one-half miles northeast of East Poultney.

WEST	N 1	EAST
0	10	5
0	20	7
0	30	16
1	40	13
1	50	11
3	60	8
4	70	2
0	80	0

Fabric 129. Vector mean N 39 E. Castleton Quadrangle. Surface till. One and one-half miles south of West Rutland.

WEST	N 1	EAST
1	10	7
0	20	7
2	30	10
1	40	11
4	50	6
5	60	6
4	70	7
0	80	3

Fabric 130. Vector mean N 42 E. Castleton Quadrangle. Surface till. One and one-half miles north of East Clarendon.

WEST	N·O	EAST
6	10	9
9	20	15
3	30	10
5	40	8
1	50	2
2	60	4
1	70	0
0	80	1

Fabric 131. Vector mean N 61 E. Castleton Quadrangle. Surface till. One and one-half miles south-southwest of West Rutland.

WEST	N·O	EAST
6	10	9
9	20	15
3	30	10
5	40	8
1	50	2
2	60	4
1	70	0
0	80	1

Fabric 132. Vector mean N 13 E. Rutland Quadrangle. Surface till. South limits of City of Rutland.

WEST	N·O	EAST
1	10	5
0	20	6
2	30	3
0	40	3
0	50	1
0	60	7
0	70	1
0	80	0

Fabric 133. Vector mean N 26 E. Rutland Quadrangle. Surface till. One-half mile west of North Chittenden.

WEST	N 6	EAST
6	10	9
9	20	15
3	30	10
1	40	8
1	50	2
2	60	4
1	70	0
1	80	1

Fabric 134. Vector mean N 13 E. Rutland Quadrangle. Surface till. Southern limits of Rutland, just east of U. S. Route 7.

WEST	N 12	EAST
6	10	5
9	20	11
5	30	19
5	40	16
12	50	16
11	60	10
3	70	8
2	80	7

Fabric 135. Vector mean N 28 E. Rutland Quadrangle. Surface till. Southern limits of Rutland.

WEST	N 6	EAST
2	10	6
8	20	9
3	30	10
7	40	9
4	50	10
5	60	13
7	70	17
3	80	5

Fabric 136. Vector mean N 45 E. Rutland Quadrangle. Surface till. One mile north of Clarendon.

WEST	N 5	EAST
5	10	4
3	20	12
6	30	10
3	40	6
5	50	5
9	60	10
8	70	6
3	80	2

Fabric 137. Vector mean N 38 E. Rutland Quadrangle. Surface till. One mile north of East Clarendon.

WEST	N 2	EAST
4	10	3
3	20	9
1	30	6
3	40	1
0	50	7
0	60	1
1	70	4
3	80	4

Fabric 138. Vector mean N 29 E. Rutland Quadrangle. Surface till. Two miles southwest of Sherburne.

WEST	N 2	EAST
0	10	2
3	20	3
4	30	3
1	40	3
0	50	4
2	60	6
2	70	5
0	80	4

Fabric 139. Vector mean N 48 E. Rutland Quadrangle. Surface till. One mile east of Rutland.

WEST	N 5	EAST
3	10	2
2	20	7
0	30	5
2	40	5
0	50	4
2	60	1
1	70	6
1	80	4

Fabric 140. Vector mean N 33 E. Rutland Quadrangle. Surface till. One-fourth mile south of Rutland Hospital.

WEST	N 9	EAST
4	10	8
9	20	11
8	30	19
10	40	13
2	50	6
7	60	10
8	70	4
1	80	3

Fabric 141. Vector mean N 17 E. Rutland Quadrangle. Surface till. Two miles southwest of Mendon.

WEST	N 2	EAST
1	10	1
6	20	3
5	30	7
6	40	10
8	50	7
4	60	12
4	70	13
4	80	6

Fabric 142. Vector mean N 65 E. Rutland Quadrangle. Surface till. One mile west-northwest of Chittenden.

WEST	N 7	EAST
6	10	3
3	20	10
1	30	9
1	40	7
0	50	2
0	60	2
0	70	1
0	80	0

Fabric 143. Vector mean N 17 E. Woodstock Quadrangle. Surface till. One mile south-southeast of Woodstock.

WEST	N 5	EAST
3	10	3
2	20	1
2	30	2
2	40	4
0	50	4
0	60	4
1	70	8
3	80	5

Fabric 144. Vector mean N 47 E. Woodstock Quadrangle. Surface till. Four miles northwest of Woodstock.

WEST	N 6	EAST
2	10	8
2	20	10
1	30	13
2	40	7
3	50	2
5	60	2
2	70	2
4	80	1

Fabric 145. Vector mean N 20 E. Woodstock Quadrangle. Surface till. Two miles south-southwest of South Woodstock.

WEST	N 2	EAST
2	10	6
2	20	6
0	30	14
0	40	7
1	50	6
0	60	4
0	70	2
1	80	0

Fabric 146. Vector mean N 30 E. Hanover New Hampshire Quadrangle. Surface till. One mile southeast of West Lebanon, New Hampshire.

WEST	N 5	EAST
1	10	4
0	20	2
3	30	8
2	40	11
2	50	3
0	60	10
4	70	6
1	80	2

Fabric 147. Vector mean N 42 E. Hanover Quadrangle. Surface till. One mile west of Hartford.

WEST	N 5	EAST
5	10	4
0	20	6
0	30	6
0	40	5
0	50	2
0	60	1
0	70	0
0	80	0

Fabric 148. Vector mean N 19 E. Hanover New Hampshire Quadrangle. Surface till. One mile south of Meriden, New Hampshire.

WEST	N 15	EAST
5	10	3
4	20	11
4	30	11
2	40	16
3	50	16
3	60	14
4	70	5
2	80	4

Fabric 149. Vector mean N 28 E. Fort Ann Quadrangle. Subsurface till. One and one-fourth miles northwest of West Pawlet.

WEST	N 6	EAST
0	10	2
2	20	3
1	30	4
0	40	5
1	50	5
0	60	2
0	70	4
2	80	3

Fabric 150. Vector mean N 37 E. Pawlet Quadrangle. Surface till. One mile east of Middletown Springs.

WEST	N 7	EAST
3	10	8
4	20	7
0	30	10
1	40	9
4	50	6
2	60	2
1	70	7
4	80	2

Fabric 151. Vector mean N 27 E. Pawlet Quadrangle. Surface till. One and one-fourth miles south of Tinmouth.

WEST	N 2	EAST
0	10	4
5	20	10
2	30	7
3	40	10
6	50	9
3	60	5
3	70	5
1	80	2

Fabric 152. Vector mean N 35 E. Pawlet Quadrangle. Surface till. Two and one-half miles northeast of Rupert.

WEST	N 9	EAST
5	10	12
6	20	7
5	30	9
4	40	9
2	50	5
3	60	4
0	70	1
0	80	0

Fabric 153. Vector mean N 11 E. Pawlet Quadrangle. Surface till. One and one-half miles west of Danby Four Corners.

WEST	N 4	EAST
4	10	10
6	20	8
4	30	7
3	40	5
1	50	2
0	60	2
1	70	0
0	80	1

Fabric 154. Vector mean N 8 E. Pawlet Quadrangle. Surface till. Three-fourths mile north of Tinmouth.

WEST	N 4	EAST
0	10	5
0	20	10
0	30	7
0	40	11
0	50	6
0	60	7
0	70	5
1	80	0

Fabric 155. Vector mean N 36 E. Pawlet Quadrangle. Surface till. Four miles south of West Rupert.

WEST	N 3	EAST
3	10	7
0	20	8
0	30	5
2	40	6
1	50	4
1	60	2
1	70	5
2	80	5

Fabric 156. Vector mean N 34 E. Pawlet Quadrangle. Surface till. One-fourth mile east of Pawlet.

WEST	N·O	EAST
6	10	2
3	20	6
0	30	10
1	40	6
0	50	5
1	60	0
0	70	5
4	80	1

Fabric 157. Vector mean N 34 E. Wallingford Quadrangle. Surface till. One mile west of East Wallingford.

WEST	N 12	EAST
5	10	8
2	20	9
1	30	4
0	40	3
1	50	5
1	60	4
2	70	6
0	80	3

Fabric 158. Vector mean N 21 E. Ludlow Quadrangle. Surface till. Two miles west of Chester.

WEST	N 10	EAST
0	10	1
4	20	8
2	30	5
6	40	8
2	50	7
6	60	10
7	70	4
1	80	4

Fabric 159. Vector mean N 39 E. Claremont New Hampshire Quadrangle. Surface till. Claremont Shopping Center.

WEST	N 4	EAST
2	10	1
2	20	5
2	30	9
1	40	8
0	50	6
1	60	2
1	70	4
0	80	0

Fabric 160. Vector mean N 39 E. Claremont New Hampshire Quadrangle. Surface till. Three miles southwest of Claremont, New Hampshire.

WEST	N 11	EAST
5	10	4
1	20	7
1	30	4
3	40	11
1	50	5
2	60	3
0	70	3
2	80	3

Fabric 161. Vector mean N 23 E. Claremont New Hampshire Quadrangle. Surface till. Three and one-half miles south of Cornish Flat, New Hampshire.

WEST	N 5	EAST
5	10	7
5	20	8
1	30	16
0	40	12
0	50	10
0	60	10
0	70	2
0	80	3

Fabric 162. Vector mean N 31 E. Shushan Quadrangle. Surface till. Three miles west-northwest of Arlington.

WEST	N 2	EAST
1	10	3
3	20	2
1	30	12
0	40	9
6	50	8
2	60	5
0	70	5
0	80	1

Fabric 163. Vector mean N 38 E. Shushan Quadrangle. Surface till. Three miles west of Shaftsbury.

WEST	N 3	EAST
0	10	2
0	20	3
2	30	3
2	40	7
1	50	5
0	60	4
0	70	4
0	80	1

Fabric 164. Vector mean N 39 E. Shushan New York Quadrangle. Surface till. One mile north of Cambridge, New York.

WEST	N 2	EAST
3	10	5
1	20	9
1	30	12
1	40	15
2	50	7
1	60	2
4	70	2
0	80	1

Fabric 165. Vector mean N 31 E. Equinox Quadrangle. Surface till. One and one-half miles southeast of East Arlington.

WEST	N 11	EAST
6	10	11
2	20	7
4	30	9
1	40	12
2	50	6
1	60	0
1	70	0
1	80	1

Fabric 166. Equinox Quadrangle. Surface till. One and one-fourth miles west of Sandgate.

WEST	N 4	EAST
0	10	4
0	20	6
1	30	5
0	40	7
1	50	8
1	60	8
0	70	2
0	80	4

Fabric 167. Vector mean N 40 E. Equinox Quadrangle. Surface till. One and one-fourth miles south of Manchester.

WEST	N·O	EAST
0	10	4
0	20	1
0	30	6
0	40	10
0	50	9
0	60	12
0	70	10
0	80	9

Fabric 168. Vector mean N 54 E. Equinox Quadrangle. Surface till. One and one-fourth miles northwest of MacIntyre.

WEST	N 4	EAST
4	10	1
3	20	3
0	30	4
2	40	4
4	50	6
2	60	4
1	70	8
2	80	4

Fabric 169. Vector mean N 47 E. Equinox Quadrangle. Surface till. One mile south-southeast of Arlington.

WEST	N 3	EAST
2	10	13
1	20	9
3	30	9
4	40	11
1	50	10
1	60	11
1	70	19
3	80	8

Fabric 170. Vector mean N 45 E. Equinox Quadrangle. Surface till. One mile west of Barnumville.

WEST	N·O	EAST
1	10	4
2	20	14
4	30	21
0	40	11
0	50	6
0	60	5
1	70	4
3	80	6

Fabric 171. Vector mean N 36 E. Equinox Quadrangle. Surface till. Two miles northwest of South Dorset.

WEST	N 7	EAST
3	10	11
5	20	10
3	30	15
6	40	10
7	50	5
2	60	11
3	70	8
1	80	5

Fabric 172. Vector mean N 28 E. Equinox Quadrangle. Surface till. Three and one-fourth miles southeast of West Rupert.

WEST	N 10	EAST
11	10	2
9	20	8
3	30	6
2	40	8
1	50	4
0	60	4
2	70	3
3	80	4

Fabric 173. Vector mean N 12 E. Equinox Quadrangle. Surface till. One-half mile west of Arlington.

WEST	N 6	EAST
4	10	9
1	20	5
4	30	6
4	40	9
1	50	3
1	60	4
2	70	5
0	80	6

Fabric 174. Vector mean N 25 E. Londonderry Quadrangle. Surface till. One-half mile east of West Wardsboro.

WEST	N 2	EAST
4	10	4
4	20	5
2	30	12
4	40	9
0	50	1
4	60	3
0	70	2
1	80	2

Fabric 175. Vector mean N 21 E. Londonderry Quadrangle. Surface till. Two miles southwest of Peru.

WEST	N 2	EAST
1	10	1
0	20	6
1	30	8
4	40	10
3	50	8
4	60	8
3	70	5
0	80	1

Fabric 176. Vector mean N 45 E. Londonderry Quadrangle. Surface till. Two miles east of Peru.

WEST	N 1	EAST
0	10	3
1	20	4
0	30	1
0	40	7
0	50	3
0	60	2
1	70	2
0	80	2

Fabric 177. Vector mean N 39 E. Londonderry Quadrangle. Surface till. Two miles east of Bondville.

WEST	N 14	EAST
4	10	6
1	20	3
0	30	11
3	40	4
1	50	3
1	60	3
2	70	3
1	80	1

Fabric 178. Vector mean N 17 E. Londonderry Quadrangle. Surface till. One and one-half miles east of West Wardsboro.

WEST	N 3	EAST
1	10	2
2	20	2
0	30	0
0	40	5
3	50	5
1	60	3
0	70	8
0	80	4

Fabric 179. Vector mean N 51 E. Londonderry Quadrangle. Surface till. One mile south of West Wardsboro.

WEST	N 4	EAST
4	10	0
2	20	2
1	30	2
1	40	11
1	50	4
0	60	8
0	70	1
1	80	0

Fabric 180. Saxtons River Quadrangle. Surface till. Three miles west of Townshend.

WEST	N 17	EAST
5	10	4
5	20	6
1	30	7
2	40	6
1	50	4
3	60	5
3	70	5
2	80	2

Fabric 181. Vector mean N 16 E. Saxtons River Quadrangle. Surface till. Three and one-half miles south-southwest of Saxtons River.

WEST	N 15	EAST
7	10	4
6	20	8
6	30	11
3	40	12
0	50	4
0	60	9
0	70	1
0	80	1

Fabric 182. Vector mean N 17 E. Bellows Falls New Hampshire Quadrangle. Surface till. Two miles east of South Charlestown, New Hampshire.

WEST	N 5	EAST
1	10	1
4	20	0
0	30	3
0	40	2
1	50	4
1	60	9
0	70	5
1	80	1

Fabric 183. Vector mean N 38 E. Bellows Falls New Hampshire Quadrangle. Surface till. Two miles east of South Charlestown, New Hampshire.

WEST	N 3	EAST
3	10	5
1	20	5
2	30	8
1	40	6
1	50	4
1	60	4
1	70	1
0	80	1

Fabric 184. Vector mean N 26 E. Bellows Falls New Hampshire Quadrangle. Surface till. One-half mile southeast of Walpole, New Hampshire.

WEST	N 5	EAST
2	10	6
0	20	10
0	30	13
1	40	9
1	50	16
0	60	7
0	70	7
0	80	9

Fabric 185. Vector mean N 41 E. Hoosic Falls New York Quadrangle. Surface till. Shaftsbury Hollow, near Hoosic Falls, New York.

WEST	N 2	EAST
5	10	4
2	20	4
1	30	3
2	40	4
0	50	2
1	60	5
1	70	4
0	80	4

Fabric 186. Vector mean N 31 E. Hoosic Falls New York Quadrangle. Surface till. White Creek Road, one mile east of New York State Route 22.

WEST	N 6	EAST
2	10	4
3	20	5
0	30	3
3	40	3
3	50	7
2	60	5
3	70	4
1	80	1

Fabric 187. Vector mean N 28 E. Bennington Quadrangle. Surface till. One mile northwest of North Bennington.

WEST	N 10	EAST
3	10	18
10	20	14
8	30	8
2	40	2
0	50	1
1	60	1
2	70	3
1	80	1

Fabric 188. Vector mean N 5 E. Bennington Quadrangle. Surface till. One mile north of Shaftsbury.

WEST	N 4	EAST
2	10	16
3	20	13
2	30	4
0	40	9
2	50	4
1	60	0
2	70	1
0	80	7

Fabric 189. Vector mean N 21 E. Bennington Quadrangle. Surface till. Bennington Airport.

WEST	N 2	EAST
2	10	4
0	20	4
2	30	6
3	40	2
2	50	5
2	60	6
3	70	2
3	80	1

Fabric 190. Vector mean N 38 E. Bennington Quadrangle. Surface till. One mile northwest of North Bennington.

WEST	N·O	EAST
3	10	2
1	20	2
0	30	2
1	40	0
2	50	2
6	60	5
5	70	3
7	80	11

Fabric 191. Vector mean E-W. Bennington Quadrangle. Surface till. One-half mile east-southeast of Bennington.

WEST	N 8	EAST
0	10	6
1	20	7
1	30	2
1	40	1
1	50	1
0	60	1
0	70	0
0	80	0

Fabric 192. Vector mean N 10 E. Bennington Quadrangle. Surface till. ? . Two and one-fourth miles east of Pownal Center.

WEST	N 4	EAST
8	10	3
0	20	7
1	30	3
1	40	5
2	50	8
1	60	8
1	70	4
2	80	1

Fabric 193. Vector mean N 33 E. Bennington Quadrangle. Surface till ? . One and one-half miles northeast of Pownal.

WEST	N 5	EAST
1	10	4
4	20	2
4	30	6
1	40	3
3	50	5
1	60	13
4	70	20
2	80	9

Fabric 194. Vector mean N 60 E. Bennington Quadrangle. Surface till. One and one-half miles east of South Shaftsbury.

WEST	N 1	EAST
1	10	0
0	20	2
1	30	1
0	40	2
0	50	3
1	60	3
9	70	5
9	80	7

Fabric 195. Vector mean N 85 E. Bennington Quadrangle. Surface till ? . Two miles east of Pownal.

WEST	N 8	EAST
0	10	4
1	20	3
1	30	7
2	40	3
1	50	5
1	60	8
2	70	8
0	80	4

Fabric 196. Vector mean N 42 E. Bennington Quadrangle. Surface till ? . Two miles northeast of Pownal.

WEST	N·O	EAST
1	10	8
1	20	6
1	30	7
1	40	2
0	50	1
0	60	1
0	70	1
1	80	0

Fabric 197. Vector mean N 21 E. Bennington Quadrangle. Surface till ? . Two and one-fourth miles east of Pownal Center.

WEST	N 2	EAST
3	10	4
2	20	16
0	30	13
2	40	4
1	50	9
2	60	4
0	70	0
1	80	1

Fabric 198. Vector mean N 27 E. Bennington Quadrangle. Surface till. Bennington Airport.

WEST	N 2	EAST
0	10	2
2	20	4
3	30	4
2	40	6
2	50	2
3	60	5
3	70	6
1	80	2

Fabric 199. Vector mean N 48 E. Bennington Quadrangle. Surface till. One mile northwest of North Bennington.

WEST	N 3	EAST
10	10	10
8	20	18
2	30	14
0	40	8
1	50	2
2	60	1
1	70	1
0	80	3

Fabric 200. Vector mean N 15 E. Bennington Quadrangle. Surface till. One and one-half miles south-southwest of Shaftsbury.

WEST	N·1	EAST
4	10	5
4	20	4
1	30	2
3	40	6
1	50	3
4	60	5
2	70	13
8	80	20

Fabric 201. Vector mean N 72 E. Bennington Quadrangle. Surface till. One and one-half miles east of South Shaftsbury.

WEST	N 5	EAST
1	10	3
1	20	7
1	30	5
0	40	9
0	50	10
0	60	5
1	70	0
1	80	0

Fabric 202. Vector mean N 33 E. Bennington Quadrangle. Surface till. One and one-half miles north of North Bennington.

WEST	N 3	EAST
1	10	1
1	20	3
2	30	2
1	40	6
1	50	1
1	60	3
1	70	5
4	80	0

Fabric 203. Vector mean N 44 E. Wilmington Quadrangle. Surface till. Two and one-half miles north of Wilmington.

WEST	N 2	EAST
0	10	4
1	20	3
1	30	1
0	40	5
0	50	0
1	60	0
0	70	2
2	80	1

Fabric 204. Vector mean N 44 E. Wilmington Quadrangle. Surface till. Two and one-fourth miles north of Wilmington.

WEST	N 15	EAST
3	10	10
2	20	16
4	30	12
0	40	8
1	50	8
1	60	2
2	70	2
0	80	0

Fabric 205. Vector mean N 18 E. Wilmington Quadrangle. Surface till. East side of East Dover.

WEST	N 9	EAST
0	10	3
5	20	2
2	30	6
2	40	5
1	50	8
2	60	6
4	70	14
0	80	1

Fabric 206. Vector mean N 48 E. Wilmington Quadrangle. Surface till. One mile north of West Dover.

WEST	N 1	EAST
5	10	2
2	20	0
1	30	1
2	40	2
3	50	0
4	60	7
3	70	11
5	80	8

Fabric 207. Vector mean N 85 E. Wilmington Quadrangle. Surface till. Two and one-fourth miles north of Somerset.

WEST	N 6	EAST
2	10	2
4	20	7
1	30	8
3	40	4
0	50	2
0	60	0
1	70	1
0	80	2

Fabric 208. Vector mean N 15 E. Wilmington Quadrangle. Surface till. Five and one-half miles north of Searsburg.

WEST	N 7	EAST
1	10	5
1	20	3
2	30	3
1	40	8
1	50	6
3	60	3
2	70	2
1	80	1

Fabric 209. Vector mean N 28 E. Wilmington Quadrangle. Surface till. Three miles northeast of East Dover.

WEST	N 2	EAST
1	10	2
2	20	1
0	30	3
1	40	3
0	50	2
0	60	1
0	70	2
0	80	2

Fabric 210. Vector mean N 30 E. Brattleboro Quadrangle. Surface till. Four and one-half miles west of Guilford.

WEST	N 4	EAST
1	10	4
1	20	4
0	30	5
1	40	6
0	50	3
1	60	3
1	70	1
0	80	3

Fabric 211. Vector mean N 31 E. Brattleboro Quadrangle. Surface till. Two miles north-northwest of Brattleboro.

WEST	N 3	EAST
4	10	0
7	20	4
2	30	5
0	40	7
0	50	7
0	60	7
1	70	4
1	80	2

Fabric 212. Vector mean N 34 E. Brattleboro Quadrangle. Surface till. One and one-half miles north of Williamsville.

WEST	N 7	EAST
1	10	1
2	20	7
1	30	4
0	40	4
0	50	0
1	60	1
0	70	2
1	80	1

Fabric 213. Vector mean N 20 E. Brattleboro Quadrangle. Surface till. One-half mile west of Guilford.

WEST	N 2	EAST
1	10	2
0	20	1
2	30	2
4	40	4
0	50	5
1	60	4
2	70	5
2	80	1

Fabric 214. Vector mean N 52 E. Keene New Hampshire Quadrangle. Surface till. Two miles north of Hinsdale, New Hampshire.

WEST	N 2	EAST
1	10	3
0	20	3
0	30	6
2	40	6
2	50	5
0	60	3
1	70	0
1	80	2

Fabric 215. Vector mean N 35 E. Keene New Hampshire Quadrangle. Surface till. One-half mile east of Westmoreland, New Hampshire.

WEST	N 3	EAST
2	10	0
2	20	4
0	30	0
1	40	5
2	50	3
0	60	7
0	70	5
3	80	1

Fabric 216. Vector mean N 48 E. Keene New Hampshire Quadrangle. Surface till. One mile south of Chesterfield, New Hampshire.

WEST	N 5	EAST
3	10	0
1	20	7
3	30	6
3	40	15
2	50	2
2	60	6
1	70	2
2	80	0

Fabric 217. Vector mean N 28 E. Keene New Hampshire Quadrangle. Surface till. Two miles northeast of Westmoreland, New Hampshire.

WEST	N 8	EAST
1	10	2
4	20	4
0	30	7
1	40	9
1	50	7
0	60	5
5	70	1
4	80	0

Fabric 218. Vector mean N 32 E. Keene New Hampshire Quadrangle. Surface till. Two miles north-northwest of Chesterfield, New Hampshire.

WEST	N 5	EAST
5	10	7
3	20	3
2	30	7
4	40	6
2	50	5
0	60	3
0	70	3
0	80	2

Fabric 219. Brandon Quadrangle. Subsurface till. One mile northwest of Salisbury.

WEST	N 1	EAST
0	10	3
6	20	1
0	30	5
3	40	1
4	50	8
5	60	7
3	70	5
0	80	1

Fabric 220. Ticonderoga Quadrangle. Subsurface till. One-half mile southwest of West Bridport.

WEST	N 1	EAST
4	10	0
0	20	2
1	30	3
0	40	9
2	50	9
0	60	8
0	70	4
0	80	6

Fabric 221. Ticonderoga Quadrangle. Subsurface till. One-half mile southwest of West Bridport.

WEST	N	EAST
	10	
	20	
	30	
	40	
	50	
	60	
	70	
	80	

Fabric 222. Vector mean N 29 E. Middlebury Quadrangle. Subsurface till. Weybridge Hill, one and three-fourths miles south of Weybridge.

APPENDIX C

FIELD DATA AND CALCULATED VECTOR MEAN OF FABRICS OF THE BURLINGTON TILL

WEST	N 4	EAST
8	10	0
14	20	3
16	30	4
11	40	0
6	50	1
6	60	6
6	70	4
0	80	1

Fabric 1. Vector mean N 30 W. Rouses Point Quadrangle. North Hero, one mile northwest of Camp Kenjockety.

WEST	N 12	EAST
25	10	7
16	20	1
18	30	3
4	40	1
2	50	0
1	60	0
11	70	0
3	80	1

Fabric 2. Vector mean N 19 W. Enosburg Falls Quadrangle. One and one-half miles north of Berkshire.

WEST	N 1	EAST
4	10	0
11	20	0
17	30	2
13	40	1
15	50	4
3	60	2
4	70	1
1	80	1

Fabric 3. Vector mean N 37 W. Enosburg Falls Quadrangle. One mile south of West Enosburg.

WEST	N·0	EAST
21	10	4
7	20	3
7	30	0
2	40	1
2	50	0
2	60	0
4	70	0
1	80	0

Fabric 4. Vector mean N 15 W. Jay Peak Quadrangle. One and one-half miles south-southeast of Richford.

WEST	N·0	EAST
8	10	2
7	20	3
12	30	0
6	40	1
4	50	0
4	60	0
3	70	0
3	80	0

Fabric 5. Vector mean N 29 W. Jay Peak Quadrangle. Two and one-half miles south-southwest of Jay Peak.

WEST	N 2	EAST
2	10	4
4	20	1
9	30	1
10	40	2
2	50	2
9	60	1
9	70	2
4	80	1

Fabric 6. Vector mean N 44 W. Irasburg Quadrangle. Four miles north-northeast of Newport Center.

WEST	N·0	EAST
6	10	5
11	20	10
5	30	4
4	40	1
4	50	3
4	60	5
0	70	3
2	80	2

Fabric 7. Vector mean N 4 W. Irasburg Quadrangle. One and one-half miles east of Irasburg.

WEST	N·0	EAST
1	10	0
2	20	2
1	30	3
5	40	1
6	50	0
7	60	2
12	70	2
9	80	1

Fabric 8. Vector mean N 65 W. Irasburg Quadrangle. One mile south Coventry.

WEST	N·0	EAST
3	10	1
8	20	3
8	30	1
19	40	2
9	50	0
3	60	2
4	70	1
3	80	0

Fabric 9. Vector mean N 38 W. Irasburg Quadrangle. Two miles north of Troy.

WEST	N·0	EAST
8	10	4
12	20	3
7	30	3
8	40	1
3	50	0
3	60	2
4	70	3
0	80	0

Fabric 10. Vector mean N 6 W. Irasburg Quadrangle. Two and one-half miles east-northeast of North Troy.

WEST	N·0	EAST
4	10	4
11	20	3
13	30	5
20	40	4
6	50	1
2	60	0
2	70	0
0	80	1

Fabric 11. Vector mean N 26 W. Irasburg Quadrangle. One mile east of Newport Center.

WEST	N·0	EAST
3	10	0
5	20	2
10	30	1
3	40	4
2	50	1
7	60	3
4	70	3
3	80	2

Fabric 12. Vector mean N 37 W. Irasburg Quadrangle. Two and one-half miles east-southeast of Newport Center.

WEST	N 4	EAST
6	10	5
14	20	10
5	30	4
4	40	1
4	50	3
4	60	5
0	70	3
2	80	2

Fabric 13. Vector mean N 50 W. Irasburg Quadrangle. One and one-half miles east of Irasburg.

WEST	N·0	EAST
0	10	0
4	20	0
3	30	2
7	40	0
2	50	0
7	60	0
1	70	3
1	80	1

Fabric 14. Vector mean N 24 W. Memphremagog Quadrangle. One mile west of Derby Center.

WEST	N·0	EAST
6	10	3
6	20	1
10	30	2
5	40	0
1	50	1
1	60	0
2	70	1
0	80	0

Fabric 15. Vector mean N 18 W. Memphremagog Quadrangle. One-half mile west of Derby Center.

WEST	N·0	EAST
8	10	6
4	20	4
7	30	6
8	40	4
4	50	2
3	60	4
3	70	0
1	80	0

Fabric 16. Vector mean N 18 W. Memphremagog Quadrangle. One-half mile west of Derby Center.

WEST	N·0	EAST
9	10	4
18	20	2
8	30	1
8	40	0
1	50	2
0	60	2
0	70	2
0	80	1

Fabric 17. Vector mean N 16 W. Memphremagog Quadrangle. Two miles northeast of Newport.

WEST	N·0	EAST
3	10	1
5	20	0
8	30	0
4	40	1
3	50	1
4	60	1
1	70	0
0	80	0

Fabric 18. Vector mean N 32 W. Memphremagog Quadrangle. Three and one-fourth miles south-southeast of Newport.

WEST	N·0	EAST
4	10	2
11	20	4
17	30	2
4	40	2
3	50	1
3	60	1
4	70	2
0	80	1

Fabric 19. Vector mean N 22 W. Memphremagog Quadrangle. One mile west of Newport.

WEST	N·0	EAST
1	10	6
3	20	1
6	30	1
6	40	3
3	50	5
6	60	3
7	70	1
2	80	1

Fabric 20. Vector mean N 24 W. Memphremagog Quadrangle. One mile west of Derby Center.

WEST	N·0	EAST
8	10	3
7	20	1
7	30	2
9	40	2
8	50	0
3	60	0
2	70	1
0	80	0

Fabric 21. Vector mean N 24 W. Memphremagog Quadrangle. One mile east of Derby Line.

WEST	N 1	EAST
5	10	1
7	20	4
4	30	1
5	40	2
14	50	8
9	60	2
4	70	7
3	80	3

Fabric 22. Vector mean N 52 W. Memphremagog Quadrangle. Two miles east of Orleans.

WEST	N 2	EAST
4	10	8
9	20	4
7	30	7
2	40	3
3	50	4
2	60	0
3	70	1
6	80	2

Fabric 23. Vector mean N 8 W. Memphremagog Quadrangle. Two miles east of Orleans.

WEST	N 9	EAST
21	10	8
12	20	6
16	30	5
12	40	10
6	50	5
2	60	2
4	70	2
4	80	6

Fabric 24. Vector mean N 12 W. Memphremagog Quadrangle. Two miles east of Orleans.

WEST	N 2	EAST
5	10	3
4	20	0
5	30	5
3	40	0
7	50	2
8	60	4
7	70	0
2	80	0

Fabric 25. Vector mean N 40 W. Memphremagog Quadrangle. One mile west-southwest of West Charleston.

WEST	N·1	EAST
7	10	0
4	20	1
2	30	1
3	40	2
8	50	1
7	60	0
9	70	1
5	80	1

Fabric 26. Vector mean N 50 W. Memphremagog Quadrangle. One mile south of Pensioner Pond.

WEST	N 2	EAST
8	10	4
4	20	0
7	30	0
3	40	0
5	50	1
7	60	1
4	70	1
4	80	2

Fabric 27. Vector mean N 38 W. Memphremagog Quadrangle. Two miles south of West Charleston.

WEST	N 4	EAST
3	10	5
5	20	4
3	30	8
5	40	2
9	50	0
10	60	3
9	70	3
0	80	6

Fabric 28. Vector mean N 41 W. Memphremagog Quadrangle. One mile southwest of East Charleston.

WEST	N·1	EAST
3	10	1
5	20	0
8	30	0
4	40	1
3	50	1
4	60	1
1	70	0
0	80	0

Fabric 29. Vector mean N 32 W. Memphremagog Quadrangle. Three and one-fourth miles south-southeast of Newport.

WEST	N 7	EAST
4	10	2
11	20	4
17	30	2
4	40	2
3	50	1
3	60	1
4	70	2
0	80	1

Fabric 30. Vector mean N 22 W. Memphremagog Quadrangle. One mile west of Newport.

WEST	N 3	EAST
6	10	3
7	20	2
4	30	3
11	40	6
8	50	1
10	60	7
6	70	7
7	80	5

Fabric 31. Vector mean N 54 W. Memphremagog Quadrangle. Two and one-half miles east of Derby Line.

WEST	N 9	EAST
5	10	3
3	20	3
13	30	3
6	40	5
8	50	9
5	60	5
3	70	7
7	80	12

Fabric 32. Vector mean N 58 W. Memphremagog Quadrangle. One-fourth mile south of Holland.

WEST	N 7	EAST
9	10	7
5	20	4
5	30	3
6	40	2
5	50	0
3	60	3
7	70	2
4	80	3

Fabric 33. Vector mean N 21 W. Memphremagog Quadrangle. Two and one-half miles west of Derby Center.

WEST	N 7	EAST
4	10	6
7	20	5
6	30	1
15	40	2
9	50	3
5	60	1
2	70	3
6	80	3

Fabric 34. Vector mean N 28 W. Island Pond Quadrangle. Four miles northwest of Island Pond.

WEST	N 7	EAST
10	10	10
7	20	10
7	30	8
6	40	4
3	50	3
8	60	3
1	70	3
4	80	1

Fabric 35. Vector mean N 3 W. Island Pond Quadrangle. South end of Seymour Lake.

WEST	N 13	EAST
20	10	8
12	20	3
12	30	1
5	40	1
2	50	0
4	60	0
2	70	0
2	80	1

Fabric 36. Vector mean N 15 W. Island Pond Quadrangle. Two and one-half miles northwest of Norton Pond.

WEST	N 1	EAST
0	10	2
1	20	0
2	30	1
5	40	4
10	50	2
14	60	1
7	70	1
4	80	1

Fabric 37. Vector mean N 59 W. Island Pond Quadrangle. Four miles northeast of Holland.

WEST	N 7	EAST
20	10	3
17	20	2
6	30	0
2	40	3
1	50	2
1	60	1
1	70	3
2	80	2

Fabric 38. Vector mean N 12 W. Island Pond Quadrangle. One mile south of the Canadian Border at Norton.

WEST	N 3	EAST
5	10	3
5	20	3
5	30	2
8	40	2
4	50	0
3	60	0
0	70	2
1	80	0

Fabric 39. Vector mean N 22 W. One-half mile northwest of Norton north of Canadian border .

WEST	N·0	EAST
8	10	7
10	20	2
9	30	4
15	40	6
11	50	2
2	60	3
7	70	3
1	80	0

Fabric 40. Vector mean N 20 W. Hyde Park Quadrangle. One mile north-northwest of Elmore Lake.

WEST	N·0	EAST
2	10	2
5	20	1
4	30	2
11	40	0
16	50	0
14	60	2
11	70	0
3	80	0

Fabric 41. Vector mean N 51 W. Hyde Park Quadrangle. One and one-half miles southeast of North Hyde Park.

WEST	N 2	EAST
2	10	3
11	20	3
13	30	3
10	40	1
3	50	3
3	60	7
1	70	1
0	80	0

Fabric 42. Vector mean N 19 W. Hyde Park Quadrangle. One mile north of Morrisville.

WEST	N·O	EAST
13	10	5
13	20	5
12	30	7
11	40	5
6	50	5
0	60	2
3	70	1
1	80	1

Fabric 43. Vector mean N 12 W. Hardwick Quadrangle. One mile east-northeast of Greensboro.

WEST	N·O	EAST
7	10	3
16	20	1
16	30	5
3	40	5
3	50	1
3	60	0
3	70	0
0	80	0

Fabric 44. Vector mean N 14 W. Hardwick Quadrangle. One-fourth mile east of East Albany.

WEST	N·O	EAST
5	10	1
8	20	0
12	30	2
4	40	3
10	50	4
5	60	0
2	70	0
0	80	0

Fabric 45. Vector mean N 31 W. Hardwick Quadrangle. Northwest side of Caspian Lake.

WEST	N·O	EAST
3	10	1
5	20	5
9	30	6
9	40	0
6	50	2
7	60	0
1	70	1
0	80	0

Fabric 46. Vector mean N-S. Hardwick Quadrangle. One mile north of Greensboro.

WEST	N 1	EAST
5	10	2
8	20	0
4	30	1
9	40	1
8	50	0
5	60	1
4	70	1
3	80	3

Fabric 47. Vector mean N 38 W. Hardwick Quadrangle. One and one-half miles southeast of Greensboro.

WEST	N·O	EAST
10	10	2
7	20	3
4	30	1
11	40	2
2	50	2
4	60	2
0	70	2
0	80	0

Fabric 48. Vector mean N 13 W. Hardwick Quadrangle. Southeast edge of East Hardwick.

WEST	N·O	EAST
1	10	4
6	20	1
4	30	1
14	40	4
10	50	3
5	60	3
6	70	2
3	80	1

Fabric 49. Vector mean N 40 W. Hardwick Quadrangle. One mile southeast of East Hardwick.

WEST	N·O	EAST
8	10	1
12	20	3
6	30	0
5	40	1
2	50	0
2	60	0
2	70	0
2	80	0

Fabric 50. Vector mean N 21 W. Hardwick Quadrangle. Three miles south-southeast of Wolcott.

WEST	N·O	EAST
4	10	6
10	20	6
4	30	1
7	40	3
7	50	1
2	60	0
4	70	2
0	80	1

Fabric 51. Vector mean N 16 W. Hardwick Quadrangle. Two miles west of Craftsbury Common.

WEST	N·O	EAST
1	10	4
5	20	1
5	30	0
2	40	2
7	50	1
8	60	2
7	70	0
4	80	0

Fabric 52. Vector mean N 46 W. Hardwick Quadrangle. Three-fourths mile northwest of North Wolcott.

WEST	N·O	EAST
5	10	4
8	20	5
8	30	1
10	40	1
6	50	1
6	60	0
3	70	2
6	80	0

Fabric 53. Vector mean N 27 W. Hardwick Quadrangle. One mile south of Hardwick.

WEST	N·O	EAST
1	10	1
1	20	4
4	30	1
1	40	0
11	50	0
13	60	2
17	70	0
3	80	0

Fabric 54. Vector mean N 36 W. Hardwick Quadrangle. Two miles north of Greensboro.

WEST	N·O	EAST
8	10	6
8	20	2
7	30	1
5	40	0
7	50	1
4	60	3
2	70	4
2	80	0

Fabric 55. Vector mean N 24 W. Lyndonville Quadrangle. Four miles northeast of Greensboro Bend.

WEST	N·O	EAST
16	10	10
20	20	2
8	30	6
7	40	3
3	50	1
6	60	2
2	70	2
3	80	0

Fabric 56. Vector mean N 26 W. Hardwick Quadrangle. Three-fourths mile north of Greensboro.

WEST	N 4	EAST
6	10	0
11	20	5
12	30	2
8	40	4
8	50	6
6	60	4
7	70	3
4	80	2

Fabric 57. Vector mean N 27 W. Hardwick Quadrangle. One and one-fourth miles south-southwest of Craftsbury.

WEST	N 2	EAST
8	10	12
14	20	7
8	30	3
12	40	7
12	50	2
11	60	1
5	70	0
2	80	1

Fabric 58. Vector mean N 26 W. Hardwick Quadrangle. One mile northeast of Hardwick.

WEST	N 9	EAST
3	10	3
2	20	6
1	30	3
6	40	2
5	50	3
5	60	0
4	70	1
1	80	1

Fabric 59. Vector mean N 14 W. Port Henry Quadrangle. One mile west of Palmer Corner.

WEST	N 3	EAST
8	10	6
14	20	2
7	30	4
4	40	4
10	50	2
3	60	2
7	70	4
1	80	1

Fabric 60. Vector mean N 18 W. Port Henry Quadrangle. Southwest side of Potash Bay.

WEST	N 6	EAST
3	10	2
4	20	6
7	30	1
8	40	1
6	50	2
2	60	2
1	70	1
2	80	0

Fabric 61. Vector mean N 21 W. Port Henry Quadrangle. Two miles north of Ferrisburg.

WEST	N 3	EAST
5	10	2
2	20	1
5	30	2
10	40	2
12	50	1
7	60	1
8	70	2
3	80	0

Fabric 62. Vector mean N 44 W. Port Henry Quadrangle. One and one-half miles west of Vergennes.

WEST	N 3	EAST
5	10	1
6	20	3
8	30	1
4	40	1
1	50	0
3	60	0
4	70	2
0	80	2

Fabric 63. Vector mean N 26 W. Montpelier Quadrangle. One mile southeast of Moretown Common.

WEST	N 2	EAST
1	10	2
11	20	0
7	30	0
10	40	1
8	50	0
2	60	0
1	70	0
0	80	0

Fabric 64. Vector mean N 32 W. Montpelier Quadrangle. Two miles east of Mill Village.

WEST	N 3	EAST
3	10	3
2	20	4
7	30	5
8	40	1
10	50	0
4	60	0
0	70	1
1	80	2

Fabric 65. Vector mean N 28 W. Montpelier Quadrangle. One mile south of Stowe.

WEST	N 14	EAST
13	10	16
15	20	10
10	30	4
3	40	1
3	50	3
2	60	0
2	70	0
1	80	0

Fabric 66. Vector mean N 6 W. Burlington Quadrangle. Intersection of Main and Spear Streets, Burlington.

WEST	N 18	EAST
16	10	16
23	20	12
10	30	2
1	40	2
2	50	0
0	60	1
0	70	1
0	80	0

Fabric 67. Vector mean N 5 W. Burlington Quadrangle. Muddy Brook, one mile south of Burlington Airport.

WEST	N 4	EAST
16	10	17
11	20	13
9	30	0
6	40	0
2	50	1
1	60	0
1	70	2
1	80	0

Fabric 68. Vector mean N 7 W. Burlington Quadrangle. Three miles southeast of Hinesburg.

WEST	N 2	EAST
3	10	6
2	20	3
7	30	2
11	40	4
8	50	4
8	60	2
1	70	1
6	80	0

Fabric 69. Vector mean N 28 W. Port Henry Quadrangle. One and one-half miles south of Addison.

WEST	N 7	EAST
3	10	4
5	20	3
9	30	1
7	40	1
5	50	0
5	60	0
4	70	0
2	80	0

Fabric 70. Vector mean N 28 W. Port Henry Quadrangle. Two and one-fourth miles east-southeast of Addison.

WEST	N 8	EAST
11	10	7
18	20	4
5	30	6
2	40	4
4	50	2
4	60	4
3	70	3
3	80	0

Fabric 71. Vector mean N 8 W. Middlebury Quadrangle. One and one-half miles north of New Haven.

WEST	N 2	EAST
3	10	7
16	20	4
9	30	4
12	40	5
3	50	2
2	60	3
1	70	4
1	80	1

Fabric 72. Vector mean N 15 W. Middlebury Quadrangle. Two miles north of New Haven.

WEST	N·0	EAST
2	10	1
0	20	0
0	30	2
8	40	0
9	50	0
12	60	0
10	70	1
8	80	1

Fabric 73. Vector mean N 60 W. Middlebury Quadrangle. Two miles north of New Haven.

WEST	N 3	EAST
2	10	1
5	20	0
8	30	0
6	40	2
13	50	0
9	60	1
0	70	2
1	80	1

Fabric 74. Vector mean N 41 W. Middlebury Quadrangle. Three and one-half miles northeast of Vergennes.

WEST	N·1	EAST
11	10	12
11	20	6
6	30	2
7	40	2
11	50	3
7	60	4
6	70	4
3	80	2

Fabric 75. Vector mean N 24 W. Middlebury Quadrangle. One and one-half miles south of North Ferrisburg.

WEST	N17	EAST
9	10	2
9	20	2
8	30	3
5	40	0
2	50	2
0	60	1
1	70	1
0	80	0

Fabric 76. Vector mean N 11 W. Middlebury Quadrangle. Middlebury, east side of Chipman Hill.

WEST	N5	EAST
3	10	2
7	20	1
6	30	2
7	40	3
6	50	4
4	60	0
0	70	0
1	80	0

Fabric 77. Vector mean N 23 W. Middlebury Quadrangle. Two miles east of Ferrisburg.

WEST	N 7	EAST
3	10	1
6	20	2
1	30	0
6	40	0
4	50	1
4	60	0
5	70	1
3	80	1

Fabric 78. Vector mean N 35 W. Middlebury Quadrangle. One mile east of Vergennes.

WEST	N 6	EAST
5	10	6
5	20	3
1	30	3
5	40	2
5	50	3
8	60	2
4	70	3
8	80	2

Fabric 79. Vector mean N 35 W. Middlebury Quadrangle. Two miles west-southwest of New Haven Junction.

WEST	N 2	EAST
3	10	3
10	20	4
7	30	7
10	40	4
12	50	2
10	60	4
15	70	2
4	80	3

Fabric 80. Vector mean N 48 W. Middlebury Quadrangle. Two miles northwest of Bristol.

WEST	N 8	EAST
7	10	2
4	20	3
4	30	1
4	40	1
1	50	0
4	60	1
3	70	2
3	80	1

Fabric 81. Vector mean N 20 W. Middlebury Quadrangle. Three and one-half miles northeast of Vergennes.

WEST	N·0	EAST
3	10	5
7	20	1
7	30	2
4	40	5
1	50	3
8	60	3
2	70	1
1	80	1

Fabric 82. Vector mean N 15 W. Lincoln Mountain Quadrangle. One mile east of Warren.

WEST	N·0	EAST
6	10	3
1	20	0
5	30	4
7	40	3
1	50	0
1	60	0
0	70	0
0	80	1

Fabric 83. Vector mean N 10 W. Lincoln Mountain Quadrangle. One-half mile east-northeast of Waitsfield Common.

WEST	N 4	EAST
12	10	7
4	20	0
5	30	0
10	40	6
4	50	2
2	60	1
4	70	1
3	80	1

Fabric 84. Vector mean N 21 W. Lincoln Mountain Quadrangle. Three-fourths mile northwest of Jerusalem.

WEST	N 6	EAST
5	10	3
5	20	3
3	30	1
6	40	2
5	50	6
4	60	4
8	70	3
4	80	2

Fabric 85. Vector mean N 37 W. Lincoln Mountain Quadrangle. Two miles west-southwest of Moretown.

WEST	N·0	EAST
3	10	2
2	20	1
6	30	1
3	40	3
11	50	2
3	60	2
2	70	1
2	80	0

Fabric 86. Lincoln Mountain Quadrangle. One-half mile southwest of East Warren.

WEST	N 2	EAST
7	10	1
4	20	1
2	30	2
7	40	7
7	50	3
9	60	2
4	70	0
13	80	2

Fabric 87. Vector mean N 54 W. Lincoln Mountain Quadrangle. Two and one-fourth miles west-southwest of Moretown.

WEST	N 10	EAST
6	10	8
4	20	9
6	30	4
7	40	2
3	50	4
2	60	2
7	70	4
4	80	1

Fabric 88. Vector mean N 6 W. Lincoln Mountain Quadrangle. Two and one-fourth miles west-southwest of Moretown.

WEST	N5	EAST
7	10	4
5	20	3
6	30	0
3	40	0
3	50	0
1	60	2
0	70	0
1	80	0

Fabric 89. Vector mean N 15 W. Barre Quadrangle. One and one-half miles north-northwest of Northfield Falls.

WEST	N·1	EAST
4	10	1
1	20	0
2	30	0
3	40	1
9	50	0
8	60	1
3	70	0
0	80	0

Fabric 90. Vector mean N 45 W. Barre Quadrangle. Four miles northwest of Northfield.

WEST	N·1	EAST
3	10	1
4	20	0
4	30	0
3	40	5
3	50	0
11	60	0
7	70	1
0	80	0

Fabric 91. Vector mean N 45 W. Barre Quadrangle. One mile west of Berlin.

WEST	N·1	EAST
6	10	5
6	20	5
7	30	4
3	40	1
4	50	2
1	60	0
3	70	0
1	80	0

Fabric 92. Vector mean N 11 W. East Barre Quadrangle. Two miles north of Barre.

WEST	N·0	EAST
31	10	12
22	20	1
15	30	3
3	40	0
1	50	4
0	60	1
1	70	2
0	80	2

Fabric 93. Vector mean N 10 W. East Barre Quadrangle. One-fourth mile northwest of East Barre.

WEST	N·0	EAST
11	10	9
15	20	3
4	30	3
1	40	9
6	50	3
4	60	5
3	70	0
1	80	0

Fabric 94. Vector mean N 13 W. East Barre Quadrangle. One-half mile north of East Barre.

WEST	N·0	EAST
2	10	3
11	20	4
5	30	3
7	40	1
1	50	0
1	60	2
0	70	4
0	80	1

Fabric 95. East Barre Quadrangle. Four miles northeast of Barre.

WEST	N·0	EAST
5	10	4
8	20	2
8	30	4
7	40	6
5	50	1
1	60	4
2	70	2
1	80	0

Fabric 96. Ticonderoga Quadrangle. One mile west of Orwell.

WEST	N 8	EAST
9	10	0
5	20	4
1	30	0
1	40	1
0	50	1
0	60	0
6	70	1
1	80	0

Fabric 97. Ticonderoga Quadrangle. Two miles south-southwest of Shoreham.

WEST	N·0	EAST
1	10	3
0	20	1
2	30	0
2	40	1
5	50	1
11	60	0
12	70	4
2	80	4

Fabric 98. Ticonderoga Quadrangle. One-half mile southwest of West Bridport.

WEST	N 6	EAST
8	10	9
4	20	7
6	30	5
9	40	3
4	50	2
4	60	3
10	70	4
2	80	6

Fabric 99. Brandon Quadrangle. One and one-half miles southeast of Middlebury.

WEST	N 3	EAST
1	10	3
1	20	3
4	30	2
6	40	2
20	50	0
17	60	5
11	70	6
15	80	4

Fabric 100. Vector mean N 65 W. Brandon Quadrangle. One and one-half miles southeast of Middlebury.

WEST	N·0	EAST
0	10	2
1	20	2
6	30	3
6	40	0
3	50	0
3	60	0
2	70	2
0	80	2

Fabric 101. Vector mean N 32 W. Rochester Quadrangle. One mile south of Breadloaf.

WEST	N·0	EAST
4	10	0
5	20	1
4	30	1
11	40	1
2	50	0
5	60	0
3	70	0
0	80	1

Fabric 102. Vector mean N 37 W. Rochester Quadrangle. One and one-half miles southeast of Hancock.

WEST	N·O	EAST
1	10	0
5	20	0
4	30	2
4	40	2
0	50	0
3	60	2
6	70	1
0	80	0

Fabric 103. Vector mean N 31 W. Rochester Quadrangle. One and one-half miles west-southwest of Granville.

WEST	N·O	EAST
3	10	1
4	20	2
3	30	1
2	40	1
4	50	3
2	60	1
4	70	0
1	80	0

Fabric 104. Vector mean N 21 W. Rochester Quadrangle. One-fourth mile northeast of Breadloaf.

WEST	N·O	EAST
2	10	3
9	20	2
7	30	2
6	40	1
5	50	3
1	60	0
7	70	0
3	80	0

Fabric 105. Vector mean N 32 W. Rochester Quadrangle. One mile northeast of Stockbridge.

WEST	N·O	EAST
3	10	1
4	20	1
9	30	1
7	40	1
6	50	1
5	60	3
7	70	1
1	80	1

Fabric 106. Vector mean N 39 W. Rochester Quadrangle. One and one-half miles east-northeast of Pittsfield.

WEST	N·O	EAST
0	10	0
0	20	1
2	30	2
3	40	2
8	50	2
7	60	1
4	70	2
0	80	3

Fabric 107. Vector mean N 65 W. Rochester Quadrangle. Three miles south of Goshen Four Corners.

WEST	N·O	EAST
2	10	1
4	20	3
7	30	2
5	40	0
5	50	2
12	60	1
11	70	2
9	80	5

Fabric 108. Vector mean N 57 W. Rochester Quadrangle. One mile southwest of Rochester.

WEST	N·O	EAST
2	10	1
5	20	0
2	30	0
8	40	1
7	50	0
8	60	1
4	70	0
3	80	1

Fabric 109. Vector mean N 14 W. Rochester Quadrangle. Two miles west of Robinson.

WEST	N·O	EAST
1	10	2
8	20	0
7	30	1
4	40	0
2	50	0
1	60	0
1	70	1
0	80	0

Fabric 110. Vector mean N 25 W. Randolph Quadrangle. Three and one-half miles west-southwest of Bethel.

WEST	N·O	EAST
4	10	3
11	20	1
4	30	2
13	40	0
3	50	0
3	60	1
1	70	0
0	80	0

Fabric 111. Vector mean N 24 W. Randolph Quadrangle. Two miles west of Randolph.

WEST	N·O	EAST
3	10	4
5	20	3
1	30	4
4	40	3
3	50	3
7	60	4
6	70	2
1	80	0

Fabric 112. Vector mean N 14 W. Whitehall Quadrangle. Two and one-fourth miles east-southeast of Benson.

WEST	N·O	EAST
4	10	4
1	20	3
4	30	0
4	40	2
5	50	1
8	60	1
8	70	2
2	80	2

Fabric 113. Vector mean N 35 W. Castleton Quadrangle. One-half mile southwest of Center Rutland.

WEST	N·O	EAST
7	10	7
11	20	3
4	30	6
16	40	5
5	50	0
6	60	1
1	70	2
0	80	1

Fabric 114. Vector mean N 16 W. Castleton Quadrangle. One-half mile east of West Rutland.

WEST	N·O	EAST
6	10	1
3	20	2
6	30	3
6	40	2
4	50	1
3	60	0
4	70	0
1	80	1

Fabric 115. Vector mean N 30 W. Castleton Quadrangle. Three and one-half miles west of West Rutland.

WEST	N·O	EAST
14	10	3
8	20	3
14	30	0
6	40	4
9	50	2
8	60	2
4	70	1
4	80	1

Fabric 116. Vector mean N 23 W. Castleton Quadrangle. One mile northwest of East Hubbardton.

WEST	N·O	EAST
5	10	7
7	20	3
1	30	2
11	40	3
7	50	2
6	60	2
3	70	0
0	80	0

Fabric 117. Vector mean N 20 W. Castleton Quadrangle. Two miles west of Hubbardton.

WEST	N·O	EAST
4	10	3
5	20	3
4	30	1
6	40	2
8	50	3
7	60	2
6	70	2
2	80	0

Fabric 118. Vector mean N 29 W. Castleton Quadrangle. One-half mile northwest of Castleton Corners.

WEST	N 3	EAST
3	10	1
8	20	2
10	30	6
5	40	5
2	50	2
5	60	3
2	70	0
2	80	1

Fabric 119. Vector mean N 18 W. Castleton Quadrangle. One mile east of Pittsford Mills.

WEST	N·O	EAST
2	10	6
5	20	4
12	30	3
12	40	3
5	50	3
5	60	0
0	70	1
0	80	2

Fabric 120. Vector mean N 21 W. Castleton Quadrangle. Three miles south of Proctor.

WEST	N·O	EAST
1	10	4
5	20	1
4	30	5
7	40	2
6	50	0
6	60	0
4	70	1
1	80	1

Fabric 121. Vector mean N 26 W. Rutland Quadrangle. One mile southwest of Rutland.

WEST	N·O	EAST
0	10	0
1	20	0
1	30	2
6	40	3
5	50	1
6	60	1
4	70	1
3	80	1

Fabric 122. Vector mean N 57 W. Rutland Quadrangle. Near armory on western edge of Rutland.

WEST	N 2	EAST
6	10	3
5	20	4
4	30	0
4	40	1
2	50	1
4	60	2
6	70	0
3	80	1

Fabric 123. Vector mean N 31 W. Rutland Quadrangle. Northeast corner of Rutland.

WEST	N·O	EAST
3	10	0
5	20	2
8	30	2
5	40	0
5	50	2
2	60	1
4	70	0
3	80	0

Fabric 124. Vector mean N 38 W. Rutland Quadrangle. One and one-half miles north of Rutland.

WEST	N 5	EAST
16	10	3
16	20	5
8	30	0
9	40	1
6	50	1
4	60	3
3	70	2
1	80	2

Fabric 125. Vector mean N 22 W. Rutland Quadrangle. One-fourth mile north of Rutland Hospital.

WEST	N 13	EAST
3	10	4
3	20	4
3	30	5
14	40	0
8	50	1
5	60	1
9	70	1
0	80	0

Fabric 126. Vector mean N 27 W. Pawlet Quadrangle. Two miles southeast of Poultney.

WEST	N 3	EAST
3	10	0
3	20	1
6	30	2
3	40	0
11	50	3
16	60	2
14	70	0
4	80	0

Fabric 127. Vector mean N 54 W. Pawlet Quadrangle. One-fourth mile north of Blossoms Corners.

WEST	N 5	EAST
8	10	3
6	20	2
8	30	5
8	40	4
13	50	1
7	60	4
0	70	1
0	80	2

Fabric 128. Vector mean N 25 W. Pawlet Quadrangle. One and one-half miles south of South Poultney.

WEST	N 9	EAST
10	10	3
22	20	4
12	30	1
8	40	0
6	50	0
1	60	0
1	70	0
1	80	0

Fabric 129. Vector mean N 20 W. Pawlet Quadrangle. One mile west-southwest of Middletown Springs.

WEST	N·1	EAST
1	10	2
3	20	1
10	30	2
10	40	4
7	50	4
6	60	9
5	70	2
4	80	6

Fabric 130. Vector mean N 60 W. Pawlet Quadrangle. Two and three-fourths miles northwest of Danby Four Corners.

WEST	N 2	EAST
2	10	1
1	20	1
2	30	0
3	40	2
7	50	1
8	60	2
7	70	1
7	80	2

Fabric 131. Vector mean N 61 W. Pawlet Quadrangle. One mile south of Wells.

WEST	N 8	EAST
20	10	2
20	20	0
7	30	2
4	40	0
1	50	2
0	60	0
3	70	1
0	80	0

Fabric 132. Vector mean N 16 W. Pawlet Quadrangle. One-fourth mile east of Pawlet.

APPENDIX D

Discussion of the Glacial Sequence in North America and New England. Reprinted from *The Glacial Geology of Vermont* (Stewart, 1961)

The Pleistocene Epoch in North America

The Pleistocene Epoch of the Quaternary Period in North America dates from the climatic extreme that allowed the accumulation of snow and ice in such great proportions as to cause the formation of continental glaciers. Paleontological research and the study of marine sediment may, in the near future, supply a more explicit basis for marking the beginning of this glacial age, but at the present time the climatic factor seems to be the most reliable. In respect to the marking of the end of this epoch, it is not yet possible to ascertain that it has indeed come to an end. The last continental glaciers retreated from North America less than 10,000 years ago, and since the interglacial stages were of much longer duration, it is quite possible that the present is merely an interglacial stage of the Great Ice Age or even an interval of deglaciation of the last glacial episode.

Subdivisions of the Pleistocene Epoch

Basically, the Pleistocene Epoch is a four unit interval in geologic history, represented by four episodes of glaciation. It is estimated that the first ice advance, at the beginning of the Nebraskan Stage, started over one million years ago. The Nebraskan was followed by three succeeding glacial maxima which have been named the Kansan, Illinoian and Wisconsin (Table I). During each of these stages, the ice formed far to the north, probably in the mountains of northeastern North America (Flint, 1952), and the ice moved outward in all directions. At one time or another during this short epoch, the whole of the northern and portions of the central regions of the North American continent were covered by continental ice sheets. In the eastern and midwestern sections of the United States the southern limits of the ice invasions extended at least as far south as the islands off the coast of New England, into northern New Jersey and Pennsylvania and to the Ohio and Missouri rivers. Each ice advance was a slow, spreading movement, and after the glaciers had advanced to their terminal positions, the withdrawal was also a generally slow retreat.

After each ice retreat an interval of deglaciation followed during which time the temperatures rose again, and the climate approximated that of

Table I

Subdivisions of the Pleistocene Epoch

	Post Cochrane
Wisconsin Stage	
	Sangamon Interglacial
Illinoian Stage	
	Yarmouth Interglacial
Kansan Stage	
	Aftonian Interglacial
Nebraskan Stage	

the present time. These periods of ice retreat, the interglacial stages, have been designated the Aftonian, Yarmouth, Sangamon, and the interval since the retreat of the last glaciers which this report prefers to call the post-Cochrane (Table I). Although it is true that the ice advances and retreats progressed quite slowly in the ordinary concept of time, geologically speaking the Pleistocene Epoch was a very short span and the glacial history is a record of four ice advances and retreats in very rapid succession.

Subdivisions of the Wisconsin Stage

Due to the recentness of the Wisconsin glacial invasions and because the deposits of this stage have not been overridden by subsequent ice sheets, it has been possible to divide it into several subdivisions. For many years it was believed that this stage was represented by four, and only four, distinct till sheets, and it was therefore subdivided into four substages. These were designated (from oldest to youngest) the Iowan, Tazewell, Cary and Mankato. More recent studies, however, have established the fact that there were more than four maxima (substages) and, at the present time, seven substages are recognized in the Wisconsin stratigraphy (Table II).

The above-mentioned original four substages were proposed by Leighton in 1933. These were well accepted and were in general use shortly after they were proposed. In 1943, however, Thwaites identified a till sheet, which he called the Valders, that he believed to represent a fifth substage. Antevs (1945), however, considered this drift as the same age as Leighton's Mankato. Except for the short period during which there was debate concerning the Mankato and Valders, the Leighton proposal of 1933 was used as the basis for Wisconsin stratigraphic correlation for almost a quarter of a century. In 1950, Leighton and Willman recognized a drift which they believed to be younger than the Iowan and this drift has since been mapped by Shaffer (1956) and is now known as the Farmdale. In 1957, Elson published the results of his studies of the Agassiz Lake basin. In the course of his studies he traced the Valders and the Mankato drifts across the basin and established the fact that they were of different age, the Valders being the younger. The Cochrane was recognized in Canada and described by Karlstrom (1956).

Like the glacial stages, the substages were also separated by times of deglaciation called intervals. These, in general, have not been as well delineated and defined as the interglacial stages. The intervals are usually simply named the Farmdale-Iowan interval for the time between the Farmdale and the Iowan; the Iowan-Tazewell interval between the Iowan and Tazewell substages, etc. (Table II). An exception to this system of naming is the Two Creeks interval between the Mankato and the Valders.

The most significant Wisconsin interstadial so far as this report is concerned, is that separating the Mankato and the Valders, the Two Creeks interval. This particular interval is important because of the forest beds exposed near Manitowac, Wisconsin, which have been dated

Table II

THE SUBDIVISIONS OF THE WISCONSIN STAGE

	Post Cochrane
Cochrane	
	Valders-Cochrane interval
Valders	
	Two Creeks interval
Mankato	
	Cary-Mankato interval
Cary substage	
	Tazewell-Cary interval
Tazewell substage	
	Iowan-Tazewell interval
Iowan substage	
	Farmdale-Iowan interval
Farmdale substage	

by the C_{14} method as 11,400 years before the present. Before the separation of the Mankato and the Valders (Elson, 1957) the Two Creeks interval was believed to separate the Cary and Mankato.

Hough (1959) in his recent compilation of data on the glacial history of the midwest, particularly the Great Lakes region, has proposed three new names for the substages of the Wisconsin. These are: the Shelbyville-Iowan for the Iowan, which he believes may be more correctly correlated with the early Tazewell; the Bloomington for the substage that has been called the Tazewell; and the Port Huron for the Mankato. In spite of the fact that the arguments of Hough may be valid in respect to the Shelbyville-Bloomington Morainic System in Illinois, it seems to the writer that less confusion would result by retaining the terminology of Leighton. It is admitted that the recent change in the stratigraphic positions of the Mankato and the Valders has made the new usage of the terms a bit confusing. The fact remains, however, that the Mankato is still a valid designation.

Radiocarbon Dating

Much of the confusion in regard to the Wisconsin stratigraphy, particularly in the classical midwest, has been brought about by the development of a radiocarbon (C_{14}) method of ascertaining the absolute age of organic materials buried in, or associated with, the glacial deposits. This method was developed by W. F. Libby and was first used about 1937 to date archeological materials. The date determination is on the constant rate at which an organic body loses its radiocarbon (C_{14}) after it ceases to have life. The dating processes and techniques have been developed to the point that the results obtained are now accurate enough (within certain limits) to make this method most useful. The radiocarbon content gives the most accurate dates up to 20,000 years before the present (BP) but is considered by many to be relatively reliable between 20,000 and 35,000 years (BP).

With the development of this dating procedure, it immediately became a tool for use in the establishing of the Pleistocene sequence. In areas where the chronology was already known, for example in the midwest, dates were obtained to establish the absolute, as well as the relative, ages of these deposits in order to set up a basis of correlation by this method. Dates were also made on deposits in areas in which the age relationships were not so well known in an effort to correlate them with the established stratigraphic sequence. As a result, many data have been collected relative to the absolute ages of various deposits containing plant and animal remains associated with the glacial drifts.

As might be expected, confusion resulted from the new method. In the first place, dates obtained in the early days of the application of this method were not always reliable and a wide range of dates was often obtained from the same deposit. With the improvement and further development of the method, and with the improvement of equipment and techniques, these errors have been greatly reduced, and the former criticism based on this factor is no longer valid.

Secondly, dates obtained from deposits in areas where the sequence had been established prior to radiocarbon dating did not always agree with supposed chronology. This meant that either the prior sequence had to be changed or that the dates had to be ignored. Naturally there were some geologists that agreed with the old established stratigraphy whereas others took the radiocarbon dates as fact and immediately set about to formulate a new sequence. This debate is still in progress and at present there are many deposits, the relative ages of which were believed to have been established, that are now in very doubtful positions. It should be pointed out, however, that there are many deposits where the establishing of a date by the radiocarbon method has been most helpful. In these cases, the older stratigraphic units have been given more useful meaning by the dating process.

Probably the most frustrating factor concerning the dating results from the fact that it is impossible to obtain dates unless organic material is available from the deposits. And the discovery of deposits containing buried wood or peat is fortuitous. The organic material, in many instances, occurs in such widely separated areas that the correlation of them is not valid without knowledge of the area between. A more discouraging factor is that in large areas where it has been impossible to do correlation by stratigraphy alone there seems to be no deposits containing organic materials suitable for dating. This is true for the whole St. Lawrence Valley area as well as for most of New England. The one exception to this statement is the recently obtained date for the fossil shells of the Champlain Sea deposits.

The Glacial Sequence in New England

New England was undoubtedly covered by ice sheets before the Wisconsin stage, as evidenced by older drifts to the south and southwest. Drifts, probably as old as the Kansan, are recognized in New Jersey and Pennsylvania, and the logical assumption is that New England was also glaciated at that time. The surface materials on the islands off the coast

of New York and New England (Nantucket, Martha's Vineyard, Fisher, Block and Long islands) have been, at least tentatively, correlated as early Wisconsin, maybe as old as Iowan. The older drifts, beneath the surface on most of these islands, are believed by many to be pre-Wisconsin in age, perhaps even Kansan or older. The early investigations of Veatch (1906), Fuller (1914) and Woodworth and Wigglesworth (1934) lead them to conclude that all four glacial stages were represented by the drifts on the islands. Crosby (1928), Fleming (1935), MacClintock (1934) and Flint (1935), however, have questioned these correlations and have suggested that there may be drifts of only one pre-Wisconsin stage. In the Boston and Cape Cod regions of Massachusetts, and in central Connecticut and Rhode Island, exposures showing two till sheets, one on top of the other, have been found. The lower of the two tills is generally considered to be pre-Wisconsin because of the great depth of the weathered zone formed at the top of the older drift. The correlation of the older drifts is only speculation (Flint, 1957, p. 359) but they serve to show that there are older glacial deposits in New England.

Except for scattered areas such as those above, the glacial surface in New England was deposited by Wisconsin glaciers, and the drifts of earlier stages, assumed to have been present, were removed by subsequent fluvial or glacial erosion. On Long Island, the Ronkonkoma moraine, trending in a northeast direction through Block Island, Martha's Vineyard and Nantucket Island, and the Harbor Hill moraine, traceable northeastward through Fisher Island to Cape Cod, mark the outer margin of a Wisconsin substage. The exact age of these moraines is still under debate but they are presumed by many to be early Wisconsin, possibly Tazewell or Iowan. This ice invasion covered the whole of New England, and the glacial surface material is either of the same age or younger throughout the whole region. Striations, grooves, boulder trains and eskers indicate that the advance or advances crossed the New England states in a south-southeast to southeast direction.

Correlation of the drifts north of Long Island has been most difficult. It has been impossible to apply the same methods of correlation in the northeast that have been employed successfully in the midwestern states. Chiefly because of the irregular topography and the resulting stagnation of the ice, as is explained later in this report, few frontal moraines were deposited north of the coastal areas. The tills in most upland areas are so thin that a study of their characteristics is almost impossible or at least impractical. The valley drift is predominantly glacio-fluvial. The tills that are in the valleys were deposited by ice moving parallel to the valley because the topography had caused a change in the direction of movement.

As yet material recovered suitable for radiocarbon dating north of Hartford, Connecticut, has been too scanty to be of much value, and for the same reason pollen analyses have not been conclusive. It is believed, however, that the tills of northwestern New England are younger than those to the south. It also seems that most geologists would agree that the drift in southern Vermont and New Hampshire is of Cary age or younger and that the Mankato is probably present at least in extreme northern sections of these states. Flint (1945) implied that the drift represented by the moraines on Long Island extends as far north as Hartford, Connecticut, and the assumption has been that these were deposited by pre-Cary ice. It seems, therefore, that at least three substages of the Wisconsin are represented in New England.

A few studies of pollen from peat deposits in New England have been made in recent years, and these have given some very interesting results. One of the most recent pollen studies was made by Ogden (1959, p. 366), and two aspects of his results should be noted here. In the first place, Ogden's location on Martha's Vineyard was beyond the terminal moraine of the Wisconsin ice (Harbor Hill-Charlestown-Buzzards Bay-Sandwich moraines), and the pollen sequence should possibly record the climatic variations of the whole epoch. Secondly, Ogden summarized the previous works of Deevey (1943, 1949, 1951), Leopold (1955, 1956) and Davis (1958) and correlated his results with these earlier studies.

According to Ogden (1959, p. 370–376), three climatic extremes are indicated by the pollen sequence on Martha's Vineyard. This supports the geological point of view stated above. He does not, however, interpret his results as indicative of the same age relationships. Ogden (p. 369) assigned no age to the deposits of the Buzzards Bay (Harbor Hill) moraine, but he dated the drift of the whole of New England north of Durham, Connecticut, as Port Huron (Mankato), and he postulated that the Valders terminus is north of New England in Canada. The implication here seems to be that the drift on the off-shore islands and as far north as Durham, Connecticut, is Cary or older and the remainder of the New England deposits are Mankato. This correlation as already implied, does not agree with the current geological point of view since most geologists doubt that the Mankato drift extends so far to the south.

Although the geological evidence is still quite scanty, many geologists believe that the drift north of Connecticut, at least as far north as Vermont, is Cary in age. Flint (1956), for example, suggested that the

ice advance reaching Middletown, Connecticut, represents the Cary Maximum. It seems that the chief difference between Ogden and Flint lies in their interpretations of radiocarbon dates from deposits near Middletown and Durham, Connecticut. According to Flint, this readvance occurred "before, but not long before, 13,000 years ago," and this, he stated, is in "reasonable agreement" with the Cary of the Midwest. It is apparent that Ogden believed that the dates from Durham agree more favorably with the Mankato. There are geologists who are in more agreement with Ogden than with Flint on these interpretations. MacClintock (1954b) found two tills in the St. Lawrence Valley, and these are correlated tentatively with the Cary and Mankato. At this particular time, it seems inadvisable to try to use the classical midwestern stratigraphy for correlation in New England.

The correlation of the lake episodes of the Connecticut Valley and the Champlain Lowland (and the adjacent areas) is still in a state of confusion. It has been recently established, however, that the marine invasion of the St. Lawrence Valley and the Champlain Basin occurred during the Two Creeks interval and not after the Valders as formerly believed. The writer believes, from the findings of the survey, that the lake episodes of the Champlain Basin (Lake Vermont) followed the last glacial recession in this section and that the lake sequence in the Connecticut Valley may possibly be associated with a different glacial retreat. The results of the work of MacClintock (1958) in the St. Lawrence Valley would definitely support a conclusion that the Valders ice did not extend as far south as New England. These correlations are only tentative, and the evidence will be discussed later in this report.

The glacial drift is generally thin or lacking over the uplands and large areas of bedrock are exposed at the surface. This makes correlation even more difficult since the valley deposits, which are thicker, are only conspicuous as kame terraces banked against the lower slopes of the valley sides.

The discussion of the glacial chronology in North America and New England, in this and the preceding chapters, serves to point out some very significant facts that are helpful to the understanding of the problems of correlation in Vermont. First of all, the glacial stages have been defined in the midwestern area, but the till sheets have not been traced eastward into New England. The correlation of the older drifts in the northwest with the classical stratigraphic sequence has not, as yet, been possible. Secondly, recent radiocarbon dates of deposits in the areas of the classical Wisconsin have been confusing and the proper place of many of the deposits is still in doubt. Thirdly, efforts to correlate the deposits of the last glacial stage with the classical Wisconsin have met with little success in New England. Fourthly, systematic mapping and survey programs have been so limited in extent and detail that data on New England are quite incomplete.

Glacial Advance and Retreat

The most common concepts concerning the advance and retreat of continental glaciers have been formulated in regions of low, relatively level to undulating relief such as is exemplified in the Central Lowlands of the midwest. In most of these areas, the ice, with little obstruction, moved more or less in straight lines to a terminus. Here it maintained a relatively stable front for a period of time during which the forward movement of the glacier and wastage due to melting were approximately equal. It was during this interval that the terminal moraine marking the maximum extent of the glacier was deposited. During retreat, the ice melted back en masse (from top to bottom) by the ablation process, and any stationary periods of quiescence were accordingly marked by recessional moraines. The low relief, with no major irregularity, made possible the deposition of features that now record the recession of the ice.

Glacial Advance over Rugged Topography

As has formerly been noted by Flint (1930) and Goldthwait (1938), the concepts described above cannot be adequately applied in an area of rugged relief such as that found in New England. Many earlier theories concerning the relationships of glacial movement and the terrain proposed that the direction of the ice movement over an area more or less controlled the resulting topography. This misconception was dispelled by Zumberge (1955) from his studies on Isle Royale in Lake Superior and in the Rove area of northern Minnesota. Glacial ice, the writer is convinced, is most sensitive to the irregularities of the surface over which it moves and the ice direction at the base of a glacier may be greatly modified by bold, irregular relief without greatly affecting the general, overall direction of movement of the upper portions. As a result of the studies that have been made of the ice directions across Vermont, the writer here submits an hypothesis dealing specifically with the advance and retreat of continental glaciers over areas of rugged topography.

In Vermont, it is believed that at least one of the ice invasions moved over the state in a southeasterly direction. This ice, of necessity, had to

pile up in order to overtop the Green Mountains that form a north-south barrier the entire length of the state. The ice that crossed the mountains however, was spread over an area of valley and highland topography. Striations show that the basal ice of this glacier moved more or less parallel to larger, well-established lines of drainage, with little or no relationship to the southeasterly movement of the ice mass. It does not seem to the writer that this fact is difficult to understand inasmuch as the thickness of the ice was great enough for pressure to cause independent movement. The ice in the Dog River valley south of Montpelier (elevations 500 to 700 feet), for example, was in a deep ravine between Northfield Mountain on the west (elevations 2000 to 2500 feet) and the higher ground to the east (elevations 1500 to 2400 feet). The basal ice was not greatly influenced by the southeasterly direction of the upper portion of the glacier inasmuch as it was located on the lee side of the Green Mountains (elevations approximately 4000 feet). The weight of the overlying ice, none the less, was great enough to cause movement of the bottom ice which followed the path of least resistance and moved southward through the valley. The ice direction was thus changed from approximately S 40° E to due south. It is apparent that the basal ice followed the course of most of the major lines of drainage in this manner, and for this reason most valleys were scoured and modified into the U-shape so characteristic of those carved also by valley glaciers.

The evidence of this "two-directional" movement of the ice has been on record for over a hundred years. It is the writer's belief that it was this evidence that prompted Hitchcock (1861, p. 66–87) to report two agencies causing striations on the bedrock which he designated a drift direction and a glacier direction. It was not possible, it seems, for him to reconcile diversified movements of the ice and thus he suggested valley glaciers as a second agency since striae along the streams usually parallel the valley. Dana (1871, p. 233–43) also noted and emphasized the fact that the ice moved more or less parallel to the valleys.

It is probable that independent ice movement in the valleys took place in the early stages of the advancing phases of glaciation near the ice margins. During this stage of the advance, pressures were not equalized in all directions since the ice thickened in the direction from which the glaciers invaded. Movement was therefore in the direction of less pressure, in the general direction of the ice margin. After the upper, main body, of the glacier had moved over the area, pressures were stabilized and the devious movement of the basal ice ceased or was greatly reduced.

The writer is convinced that, with certain modifications, this concept of ice advance is compatible with the mechanics of glacial motion described by Demorest (1942, p. 95–100). It can easily be visualized that the surface slopes would be quite irregular as the glacier moved over an area of rugged relief and that obstructions to linear flow would be encountered, particularly by the basal ice, all along the routes of advance.

Deglaciation in Regions of Bold Relief

The effects of irregular surfaces on the advance of a glacier are not as significant, geologically speaking, as the net effect on glacial waning. According to the hypothesis here developed, it is impossible for a moving mass of ice to retreat in an area of rugged relief in the same manner as it would in a plains region.

Flint (1930, p. 56–69) proposed that ice stagnation (en masse) was necessary to explain the glacio-fluvial and glacio-lacustrine deposits in Connecticut. After criticism of certain aspects of his report, and particularly those of Alden (1931, p. 172–74), Flint admitted that he had been somewhat carried away by his new hypothesis. In subsequent writings, however, Flint (1931b, p. 174–76; 1932, p. 152–56) has so revised his original concepts that the emphasis on stagnant ice has been almost completely eliminated. Goldthwait (1938, p. 345–72) strongly supported the stagnant ice hypothesis although he did not suggest how such stagnation might have occurred. He also conceded that the last ice in the Connecticut Valley must have retreated northward as Antevs (1922, p. 65–101) had proposed from varve studies.

The writer agrees that the original hypothesis by Flint was in error in the proposed idea of complete stagnation of the glacier and the uncovering of New England from north to south. It seems, however, that the evidences presented to show that much of the ice was stagnant during the deposition of much material by glacio-fluvial action were, and still are, valid. The condition and position of much of the drift in Vermont seems definitely to indicate stagnant ice as do those in New Hampshire described by Goldthwait (1938, p. 345–57).

This report contends that the upper, major portion of a glacier did recede from south to north in progressive steps, chiefly by ablation thinning, and may have fluctuated or even halted during retreat. The basal ice, however, could not so retreat because it was trapped in the basins and valleys between high divides and here it had to remain. As the upper active ice retreated above the trapped basal portion, pressures may again have been so unbalanced that the basal ice was reactivated. The basal ice therefore may have moved again in the direction of lessened pressure,

away from the direction of the upper ice retreat. It is even possible that movement in the lower portions may have been increased by the fact that it was nourished by the retreating upper mass. In this case, a valley ice lobe might have been active several miles, or even tens of miles, downstream from the margin of the retreating upper ice, providing that the mass of the glacier was still in an upstream segment of the valley.

It is the opinion of the writer that it was in this manner that the glaciers that covered Vermont were gradually thinned by ablation and were reduced to a thickness equal to the heights of the higher elements of the topography. It may be deduced that the valleys were the last to be uncovered. In general, this is true, but not necessarily so since temperature variations between high and low altitudes in some areas may have been great enough to allow valley ice to melt first. Rounded cobbles and boulders on the slopes of the higher areas, particularly in the southeastern part of the state, suggest water transportation down the slope and tend to support the latter possibility. The kame terraces on the slopes of the Green Mountains, particularly in the vicinity of Mt. Mansfield, however, would surely show that the ice in this region melted from the top down.

The above hypothesis is not entirely new for evidence has been cited by several former studies which tends to substantiate the belief that the ice in New England did not retreat in a "normal" manner. The concepts here presented are modifications of, and additions to, those of Flint (1930, p. 56–69; 1931b, p. 174–76; 1932, p. 152–56), Goldthwait (1938, p. 345–57) and Rich (1943, p. 95–100).

APPENDIX E

Vecmac Program Used to Compute Vector Mean

The following explanation of the computer program used to determine the vector mean of the till fabrics was written by R. C. Flemal who, with W. C. Krumbein, set up the program.

VECMAC is a computer program in the FORTRAN II language designed to compute arithmetic, vectorial, and corrected vectorial sample statistics for till fabric data measured in ten degree class intervals, which are numbered one to seventeen beginning from azimuth 85° W passing through north to 85° E. Class midpoints are at 80° W, 70° W, 60°W, etc., to 80° E, and are numbered consecutively from one to seventeen.

Input: Input consists of a control point number and pebble counts for each interval. A single card is used for each sample. The input format is (6XA4, 17I3). The initial six blanks of the data card may be used for a project number. The A4 designation is for the control point (sample number), which is called KONPT in the program. The seventeen fixed-point fields (I3's) contain the pebble count data. Neither control nor master cards are required anywhere before, within, or after the data deck.

Output: Output is produced in a standard form and for each control point consists of: (1) a line histogram of the number of pebbles in each class interval; (2) the total number of pebbles in the sample; (3) arithmetic mean, azimuth, and standard deviation (abbreviated S.D.) taken around the arithmetic mean (XBAR); (4) simple vector (RAW VECTOR) mean, azimuth, standard deviation taken around the vector mean (VEC XBAR), and the vector strength; and (5) the corrected vector mean, azimuth, and standard deviation taken around the corrected vector mean (COR XBAR).

Notes: A rotation of the reference axes is required in this program to bring the axes notation used in the data into accord with standard trigonometric notation. This is done internally, and output notation is the same as that used in the input.

(2) All *azimuths* are measured in the output from north. Thus positive values of azimuth indicate means east of north, and negative values of azimuth indicate means west of north. Azimuths are computed by subtracting 90° from the corresponding mean.

(3) The *corrected vectorial* statistics are computed by multiplying all class intervals by a factor of two before computing the individual statistics. The effect of this operation is to make coincident observations

which are 180° apart, and to make observations which are 180°-*n* apart, where *n* is a small number, part of a single mode. To retain the same reference system with the corrected vector statistics as with the arithmetic and simple vector statistics, the corrected vector statistics are divided by two following their computation and before printout. All corrected vectorial operations are done internally.

(4) Page estimates are approximated by dividing the total number of samples (data cards) by five.

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