SURFICIAL GEOLOGY OF THE MIDDLEBURY 15' QUADRANGLE, VERMONT

by

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(A Report to the State Geologist of Vermont)

INTRODUCTION

Location

The Middlebury quadrangle, covering an area of approximately 215 square miles, is defined by latitudes 44° 00' and 44°15' north and longitudes 73°00' and 73°15' west in west-central Vermont (Fig. 1). The area lies within Addison County and contains the principal villages of Middlebury, part of Vergennes, Monkton, and Bristol.

Physiographic and Geologic Setting

The eastern one third of the Middlebury quadrangle lies within the Green Mountain physiographic province and the remainder within the Champlain Lowlands. The contact between these areas is sharply defined by precipitus, west-facing slopes of Hogback and South Mountains; these stand with relief of over 1,100 feet above the Champlain Lowlands province to the west.

Green Mountains

Parts of the Green Mountains area included east of Middlebury are underlain by Precambrian crystalline rocks with Ripton Peak reaching 2,513 feet; however, the predominant formation forming the northern portion and western flank of the mountains is the very resistant, Cheshire Quartzite of Cambrian age (see geologic/trend map fig. 2). Topography here is generally smooth but of high relief as typical of New England's crystalline terrain. Peaks reaching to 1500 or 2000 feet are common. The steep western flank of South Mountain and precipitous topography of Hogback Mountain to the north results from the tight, north-south trending Hogback and South Mountain Anticlines. The valley of Lewis Creek and Beaver Brook to the east, occupies the lowland of Starksboto Syncline (Cady, 1945).

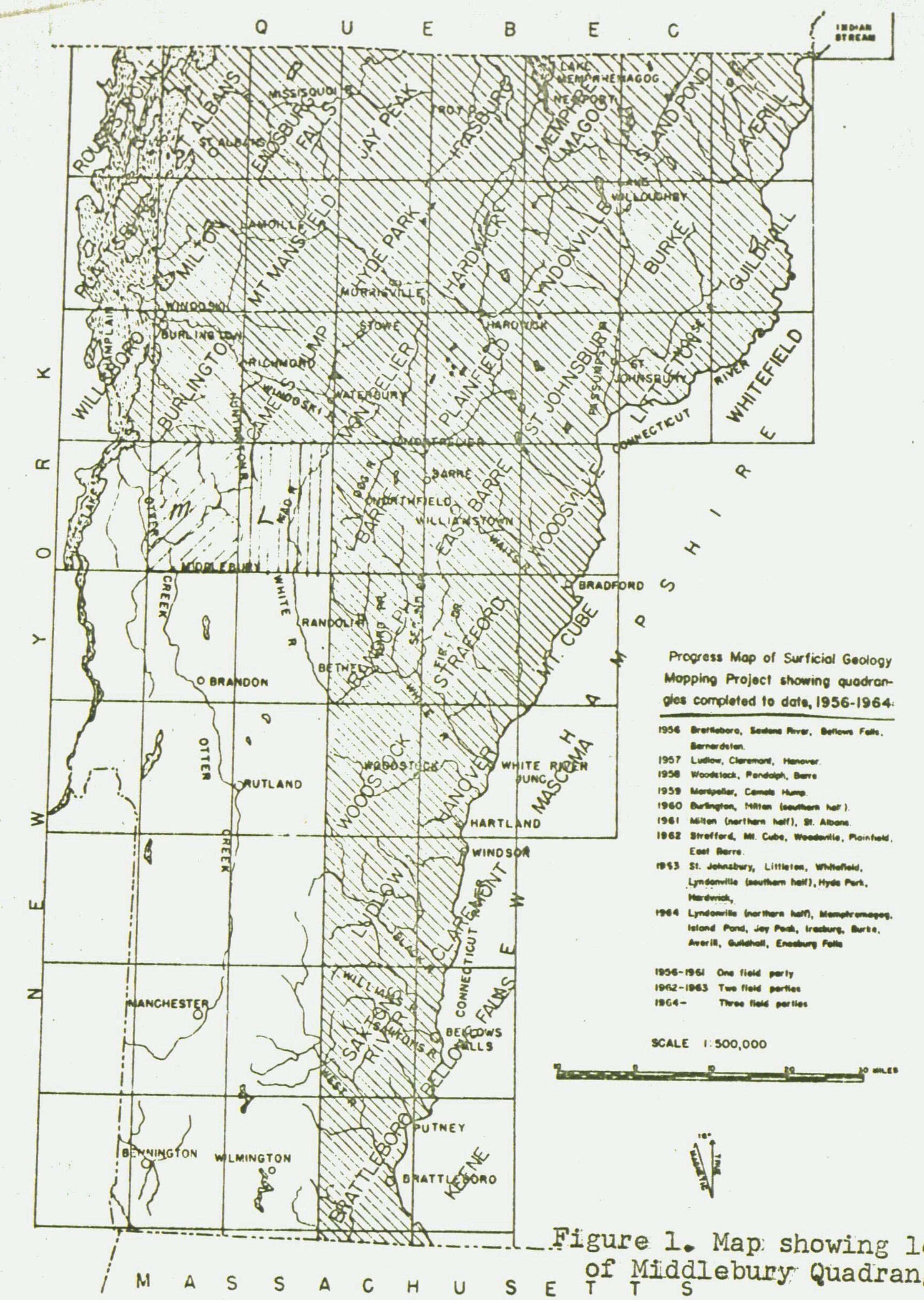

Figure 1. Map showing location of Middlebury Quadrangle (M).

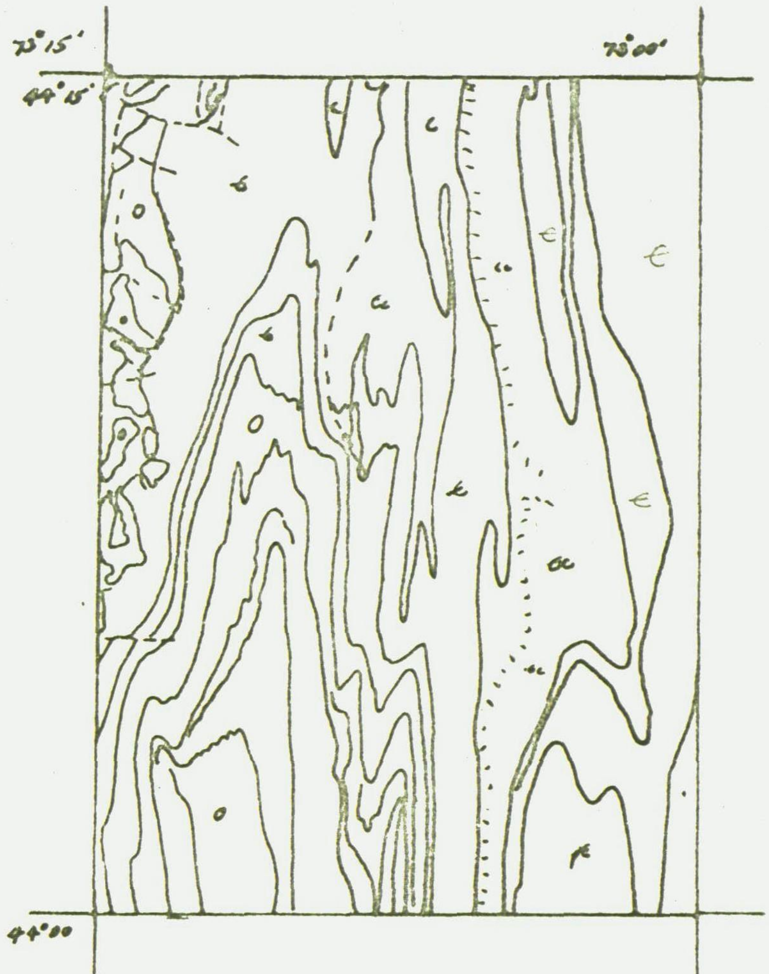

Figure 2. Geologic / trend map of the Middlebury 15' Quadrangle. Hashures line west edge of Green Mountains. Є – Cambrian, O – Ordovician, pЄ – Precambrian, Єc – Cambrian Cheshire Quartzite formation. Map grossly simplified after Doll (1961).

Champlain Lowland

Within the Champlain Lowland, hogback and questa form outliers of Cheshire Quartzite at East Monkton, and respectively of the red Monkton Quartzite at Shellhouse and Buck Mountains, form resistant high areas; however, most of the Lowland area here is underlain by less resistant Cambrian or Ordovician limestones, marbles, or dolostones forming a streamlined topography below the 600 foot contour. These rocks occur with a large and complex down-fold, the Middlebury Synclinorium, which plunges southward from the latitude of Monkton and embraces the structure between Snake Mountain on the west limb and the Green Mountain front on the east limb (Fig. 2). The major structural controls for Pleistocene glaciation in both provinces was generally north-south or a few degrees in either direction.

The Quadrangle is drained by the New Haven River which leads from the mountains at Bristol and joins the west-flowing Otter Creek north of Middlebury. The northern portion of the area is less well drained as evidenced by four large swamps occupying lithologically weak belts, and two major lakes; Winnona and Cedar Lakes (respectively Bristol and Monkton Ponds according to the older, 1903, Middlebury sheet).

Acknowledgements and Nature of Investigations

The fieldwork for this report was undertaken over a period of about seven weeks during the summer of 1965. The writer was ably assisted by James Lehmann and on several occasions received expert guidance in the field from Doctors David P. Steward, Paul MacClintock, Charles G. Doll, and Gordon Connally.

Field mapping was undertaken on the 7 and 1/2 minute sheets and reduced to the 15 minute quadrangle for final copy. Aerial photographs of the Soil Conservation Service at Middlebury were briefly consulted. Soil information and some equipment made available by the Conservation Service at Middlebury is gratefully acknowledged.

Drs. Roland Illick and Brewster Baldwin of Middlebury College helped the writer obtain a student report on the glacial geology of a portion of Addison County. This report, by Miss Susan Hanson, was of initial value in locating some interesting exposures.

Previous Work

The bedrock geology is well displayed in the Centennial geologic map of Vermont (Doll, 1961) and descriptions of the rock strata and their geologic structure as well as more detailed geologic maps can be found in reports by W. M. Cady (1945) and C. W. Welby (1961). A general background of glaciation of Vermont is given by D. P. Stewart (1961). This reference also includes an exhaustive list of references pertaining to the deposits above the bedrock and the glaciation of Vermont. References regarding Pleistocene lacustrine and marine deposits in the area are frequently made in this report to work by Donald H. Chapman (1937 and 1942).

PLEISTOCENE GLACIATION

During the Pleistocene, glaciers advanced south from Canada several times into New England and then, about 12,000 years ago (See Stewart and MacClintock, 1964; also Schafer and Hartshorn, 1965) retreated leaving the glacially sculptured terrain partially blanketed by glacial and glaciofluvial deposits. During the last major recession from Vermont, large proglacial lakes (Lake Vermont) with levels up to 500 feet above the present level of Lake Champlain (100 feet approximately) persisted beyond the glacier front for probably hundreds of years, and thus deposits left by the glacier and glacial streams over the whole quadrangle were overtopped by lake silts and clays in large tracts of the Lowlands area. In addition, as the glacier front receded and the St. Lawrence Valley became ice-free, Lake Vermont drained and the sea invaded the lower part of this region. Marine waters of this "Champlain Sea" persisted for a short duration until the land had risen in response to glacier unloading.

GLACIAL SCULPTURE

General

As ice, through several advances, moved south through the Green Mountains, the massive granitic and quartzitic rocks cropping out here were smoothed off forming a somewhat rounded and frequently streamlined "mammillated surface." In areas of high relief and in mountain valleys with north-south orientation, scouring and rounding was probably most pronounced. The U-shaped valley leading from near Bristol to Starksboro is probably a good example of reshaping by glaciation. Where east-west jointing is frequent, quarrying at southern ends of ridges to form roche moutonee is evident. Hogback Mountain near Bristol and also the present form of the peak adjacent to the Middlebury Water Works 1.5 mi East of The Cobble may be partly due to this mechanism. The materials derived from such erosion are now noticeable in the ice-contact deposits along the valley sides.

Within the Lowlands, glacial streamlining is even more apparent as the weak, but homogenous limestones, dolostones and marbles were stripped of soil and abraded to form the present low, pimpled topography. Many of these hillls might appear to be readily described as drumlinoid, or roches moutonnes, or even as rocdrumlins.[1] However, close examination and relations to geologic maps indicate that their orientation, if not their shape, is nearly always structurally controlled. Such north-south glacially scoured hogbacks or questas are particularly prominent in the Middlebury-Weybridge area.

Striations and Grooves

The direction of grooves and striations formed by subglacial erosion of ice-born rocks is plotted on the overlay accompanying this report. Glacial striations are very common on freshly exposed limestone, marble, or dolostone surfaces and were particularly prominent in dolostones of the Monkton Quartzite. However, striations were rarely found in quartzite outcrops. Apparently abrasion of the massive and resistant quartzite allowed only very shallow or poorly defined marks, if at all, and they were not readily preserved.

[1]Bedrock hills composed of readily erodible material where scour is favored and quarrying minimized (See Muller, 1963).

Particularly well striated, grooved, and polished surfaces were examined on the Shelburn marbles at quarries off Foot Street Road, 2.5 miles southeast of Middlebury (fig. 3) and 2 miles due north of New Haven Junction. Road cuts in the Chipman limestones off U.S. Rt. 7 at New Haven River and at Vergennes respectively were well defined. It is probable that many of the North-South striking striae in the Lowlands were formed and preserved from early in the latest ice advance when ice was thin and structurally controlled. In addition, the path of the ice or subglacial cutting tools shifted direction within a very short distance. For example, southeast of Middlebury, individual grooves could be traced over the freshly exposed Shelburn marbles through angular change of as much as 30° in a distance of 200 feet. In this area where relief is absent and structural control was probably weak, the shift in striae may better be ascribed to subglacial rolling or sliding of the cutting tools or to shearing and change in direction of basal ice.

It may be concluded from the striae and grooves examined that the last ice over the Middlebury Quadrangle advanced from the north and northwest, perhaps covering most of the Lowlands before surmounting the mountains and merging with any ice masses already there. In a few locations very faint northeasterly striae suggest that at some time previously, ice advanced from that direction. No northeasterly striae or grooves were discovered in the mountains probably because of increased erosion and post glacial weathering in this rugged area.

Unstratified Drift

Till (T)

Unstratified and poorly sorted deposits laid down from basal ice during an advance (lodgement till) and let down from within or from the surface of melting ice on recession (ablation till) are shown by the symbol T on the map. These deposits are generally devoid of depositional (morainal) form. Samples and till fabrics are located on the map overlay.

Till of the Green Mountains

Within the mountains, the "till" is of ablation origin, frequently sorted, and noncompacted. Except for its general lack of stratification, such deposits could easily be considered glaciofluvial origin. Such sorting is to be expected in mountainous areas as glacial erosion is predominant over deposition because of the low efficiency and resistance offered to flow and the eroded materials are moved by glacial streams with steep gradients. Therefore, lodgment tills are uncommon and the general glacial cover is thin. Also, in a topographically high and rugged area, downwasting and stagnation or more realistic occurrences during recession than is calving, and even, northerly recession of the ice sheet margins. Therefore, it is to be expected that slipping and sliding of the already partially sorted "ablation" deposits off ice blocks as well as action by wind, and plentiful glacial meltwater would cause sorting and removal of clay and silt to a large degree.

Deposition of such well-sorted tills have been observed in the coastal mountains of Antarctic and Greenland by the writer.

Till of the Champlain Lowlands

Both ablation deposits, and the better compacted lodgement tills are mapped in this region; however, because of the younger blanketing lacustrine deposits, exposures are generally limited to: (1) elevations above about 450 to 550 feet; (2) areas adjacent to bedrock exposures; and (3) on slopes of several degrees inclination. In the latter regions lacustrine deposition has either been slight due to subaquous currents, or the clays or sands thin and have been removed after emergence.

Ablation and lodgement tills of the lowland are variable in composition. In general, the tills are much more poorly sorted than those of the mountains, are more calcareous, and contain more fines than their counterparts to the east, although they are generally not real "boulder clays." In some sections examined such as at Weybridge Hill and at little Otter Creek due north of New Haven, the overriding and incorporation of glaciolacustrine or glaciofluvial sediments by the readvancing ice has caused either a very clayey till or a very sandy till. Till composed of over 50% cobbles or boulders is found south of Buck Mountain and at Weybridge Hill exposures. These localities lie in the lee of high outcrops of Monkton Quartzite. Partially because of the interbedding of weak dolostone, this formation was more easily eroded than other quartzite formations and forms the predominant lithology of course fragments in most tills west of the mountain front.

The somewhat permeable nature of the tills was utilized to map contacts with the bouldery lake clays. The latter are much less permeable and show very hummocky fine textured drainage topography as compared to the tills (fig. 4).

Till Fabric

It has been demonstrated on many occasions that the long and angular stones are carried on, within, or at the base of a glacier parallel to ice movement and are usually deposited through lodgement and on some occasions by ablation with this orientation.

Stones which are somewhat rounded in two dimensions although long in another may be rolled or pushed so as to be deposited normal to glacier flow direction. Weighted mean orientations for such till fabric abservations on 50 to 150 measurements per sample are plotted on the map overlay in an attempt to define orientation for last glacier movement and to differentiate previous glacial advances by their orientation.

Considerable caution must be taken in interpreting individual fabric samples as:

1. Many lodgement tills may have been deposited where the ice front was near. Thus, with thin ice, movement may be strongly deflected by minor basal topography and not reflect overall movement direction.
2. Basal flow of ice in a thick ice sheet may be retarded and does not always closely duplicate direction of faster, near-surface flow.
3. Stress in ice base may be reflected in orientation of long stones and may be oblique to glacier flow at bedrock cliffs or topographically rugged areas.
4. Post depositional movement in stones is to be expected within the surface active layer and on slopes.
5. Measurements in very stoney tills are difficult to make. The orientation of small stones is usually governed by the shape and orientation of the larger adjacent stones; in addition, frictional and interference of freemovement is more probable for adjacent pebbles than for long pebbles in finer materials.

Figure 3. View of striated marble surface at quarry southeast of Middlebury behind Frambors Farm. Brunton alined on straie with 35 degree strike (NE) which is crossed by predominant northwest straie. Looking northeast.

Figure 5. Surface of small kame terrace at 1500 feet between South Starksboro corners and Norton Hill in the Green Mountains. Terrace stands in valley between two spurs. Looking northeast.

Figure 6. Gravels of Bristol kame terrace. Looking north in pit off U.S. 116 below Bristol Airport.

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Figure 4. Portion of Middlebury 7&1/2' Quadrangle south of New Haven Junction showing even contours of till-covered areas contrasted to scalloped contours of areas underlain by lake clay.

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Topographic Form

With one possible exception, tills are apparently thinner over the Lowlands than in the mountains and lack significant depositional form. Their thickness in most cases can probably be measured in a few tens of feet. The thickest till measured was about 15 feet thick. With a general lack of depositional form, no moraines were mapped nor were any linear concentrations of glacial drift delineating a glacial advance or stillstand discovered. The lack of morainal form is undoubtedly due to the fact that deposition occurred in Lake Vermont which followed the glacier front northward during recession. In the Lowland and valley areas, where the till is the thickest, and where one would most expect hummocky, morainal topography, wave action, and lacustrine deposition has altered the depositional form of the tills or smoothed out the topography by deposition of lake sands, silts, or clays. Such subdued topography is common in other areas which bore Pleistocene lakes, such as in the Erie and Ontario Lowlands of New York state.

Chipman Hill

This two-peaked connical hill rises more than 400 feet above the north-eastern corner of the village of Middlebury. Along its eastern margin, it appears composed of kame gravels with sandwiched till lenses, but burrow pits on the western side reveal a good till. Surface observations and augering in other localities suggest that till is probably predominant over outwash. Bedrock outcrops are limited to its northern and southeasterly margins. One may be tempted to call it a rock-cored drumlin as limestone hogbacks of the Chipman Formation strike into its northern end; however, the orientation of the summits and streamlined form parallels this strike and does not parallel the 165° trend of nearby striations and its own till fabric. Thus, the thickness and importance of glacier flow in its shape is yet questionable and must await more intensive subsurface investigation.

Stratified Drift

Because of Lake Vermont, glaciofluvial deposits are generally absent from elevations below 500 feet but ice contact stratified drift is plentiful in the mountain valleys and along the mountain front where down-wasting and stagnation provided plentiful meltwater and debris.

Ice Contact Stratified Drift

Kame Terraces (KT)

Kame Terraces are the most widespread glaciofluvial deposits in the quadrangle. Many isolated terraces occur in small tributary valleys up to elevations of 1,800 feet (fig. 5). Although small, these terraces help illustrate the important down-wasting of the ice sheet that must have occurred in the Green Mountains. More extensive kame terrace deposits occur at the quadrangle boundaries within the New Haven River valley and the creek east of Starksboro village. These deposits nearly blanket the whole valley and merge into valley train (outwash) deposits with paired terraces adjacent to the river and creek respectively.

The most extensive and best terraced deposits line the valley of Lewis Creek near Starksboro and those which rim the mountain front at Bristol and south to the village of East Middlebury. The latter terrace surface is more than a mile wide at Bristol, 1/2 mile wide at The Cobble, and rises in thickness to as much as 200 feet above the adjacent lowlands. The width of the terraces and also the presence or absence of kettle holes in these surfaces of both areas appear to be correlated with the bedrock outliers adjacent to the main valley walls. Examples of kettle areas are listed below:

2 and 5 mi. south of Starksboro

2 mi. south of Bristol

At The Cobble where two kettles are over 40 feet deep

5 mi. south of The Cobble

Examination of present glaciers in Antarctica and Greenland suggest that the bedrock outliers may localize fracturing of ice with widening of the glacier to valley wall fosse and therefore to allow early deposition of outwash and morainal deposits. The outliers may also cause local ice to stagnate, prevent movement of part of the surrounding glacier ice, and thus kettle holes are to be expected.

The sand and gravel deposits of these terraces show the typical irregular lithology, particle size, bedding and slumped structures characteristic of ice contact features (fig. 6 and 7). They generally lack till lenses and except at Bristol, well sorted lacustrine clay beds are sparse and limited to a few inches

Figure 7. Sand of Bristol kame deposits adjacent to Bristol village dump.

Figure 8. Coarse kame gravels southeast of New Haven Mills along bank of Little Notch Road Creek.

in thickness, if present at all. Thus, although much of deposition shows the typical forests of lacustrian bedding, the lakes were short-lived. Huge rounded boulders as large as 10 feet in diameter are plentiful in the larger terrace at Bristol and opposite creek notches in the cliffs to the east (fig.8). It is mainly these boulders high in the Bristol Airport portion of the terrace and within sand and in gravel more than a mile from the mountain front that seem to preclude a deltaic origin for this deposit. The texture and structure of the Bristol kame terrace as revealed in more than 25 gravel pits suggest that both glacier marginal and streams eminating directly from the adjacent cliffs were instrumental in its formation. The latter streams were probably fed by stagnating, down wasting ice masses in the mountains above. The Pleistocene, New Haven River was probably as instrumental as any creek in deposition, flowing south from Bristol down the slope of the glacier and adjacent mountain scarp.

The surface and outer margins of the kame terrace at the town of Bristol has been flattened and mantled with lacustrian sands, silts, and varved clays. In addition, portions of the Starksboro kame terrace east and west of Lewis Creek have been leveled or otherwise altered by lacustrian action up to an elevation of 690 to 700 feet. Because of poor exposures,lacustrian sands were not distinguished from kame sands in these areas. The wave action at Rockfille would seem to have been a very local ice marginal lake; however, extensive lacustrian silts and contorted varved and laminated clays and silts overlie the Bristol Terrace and gravel appears to have been washed off the surface to be deposited in steeply dipping beds (fig. 9 and 10) at the outer margin enhancing the terrace's deltaic appearance.

A few narrow kame terraces, not destroyed by lacustrine action, are found west of the Green Mountains.

Drainage Displacement by Kame Terraces

It is not unlikely that much stream derangement has gone on since pre-Pleistocene time in this area. One of the more obvious diversions occurs in the northeast quarter of the Quadrangle where the headwaters of Lewis Creek and one of its tributaries near the village of Starksboro have been diverted from their southward courses by the presence of ice and by later drift deposition, thus producing the typical barbed intersections. Reversal of drainage directions are not so clear elsewhere but diversions of a lesser degree are common along the kame terrace south of Bristol.

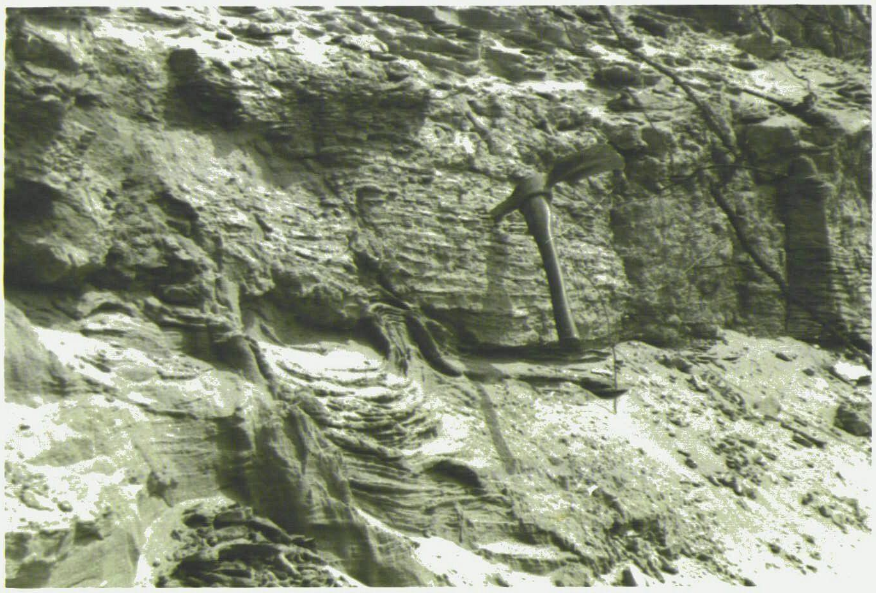


Figure 9. Varved clay and laminated silts over deformed varved clay in upper portion of pit adjacent to Bristol village dump. These calys and silts overlie steeply dipping (west) beds as pictured below. Clay and silt may be deposits of Coveville stage of Lake Vermont. Elevation of about 550 feet.

Figure 10. Sand and gravel beds dipping west off west edge of Bristol Kame Terrace. Such beds overlie typical ace-contact material and may have been formed by wave action of Coveville stage waters acting on the kame terrace. Looking southwest.

Kame Moraine (KM)

A few hummocky gravel deposits of less than a thousand square feet area and lacking a simple conical shape occur associated with the eskers and in the Chipman Hill drift deposit.

Kames and Crevass Fillings (K,$\hat{\wedge}$)

Three prominent ridges of stratified sand and gravel about 1000 feet long and with relief of 60 to 70 feet were mapped one to two miles south of Starksboro Village. These had very fine sorting,medium to fine gravel and predominant sand texture, and a rough arching of bedding to either side of the ridge. Their origin appears to be related to elongate bedrock outcrops which occur at the northern ends of each ridge (fig.10A).

Eskers ($\wedge\wedge\wedge$)

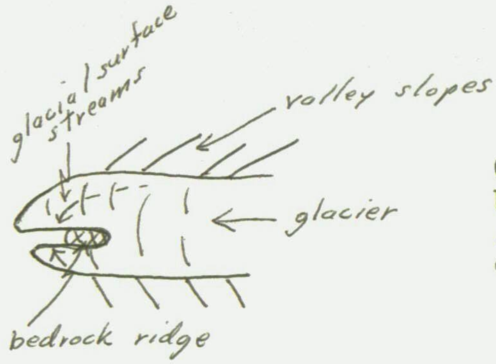
Two chains of well defined eskerine ridges, each about one mile in length slope along north and south running creeks on opposite sides of a drainage divide between Bristol and East Monkton. Each chain consists of 700 to 1500 foot segments 50 to 75 feet wide and with 20 to 30 feet of relief. The southern chain strikes into narrow bedrock ridges at its higher end and both ridges in turn strike into small irregular kame moraines at their lower ends. These data suggest that the ridges may have been deposited at the base of thin glacier ice. The direction of flow of the stream which deposited the north-sloping esker has not been proven.

The surface of the eskers to a depth of about 3 feet is very bouldery and till-like which may result from deposition of ablation moraine during down-wasting of the ice mass. Exploratory borings for kaolin and also gravel pit operations have revealed well stratified sand and gravel below these surface layers.

Outwash (OW)

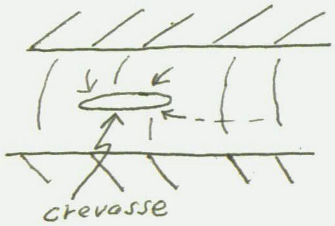
Few outwash deposits are recognized in the Middlebury Quadrangle. Where gravel valley fills appear well documented or ice contact structures are conspicuously absent, outwash has been mapped. The largest such area of valley train deposits may be that above Starksboro Village and the adjacent

A.



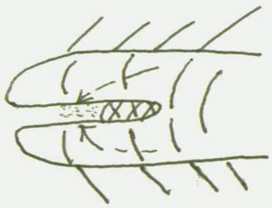
Glacial advance over and around bedrock ridge, with deposition of glacier stream deposits in crevasse or re-entrant.

B.



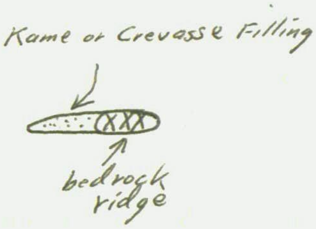
Thickening of ice but crevasse over bedrock ridge preserved for time and filled with glacial stream deposits before eventual complete burial by thickening of the glacier.

C.



Down-wasting and recession of glacier with local melting around ridge causes re-entrant and crevasse? to lee of bedrock which is subsequently filled by glacial stream deposits.

D



End result of process above.

Figure 10A. Sketchs to suggest a possible mechanism for formation of gravel ridges to lee (south side) of bedrock ridges. Such forms are common in the Starksboro Village area but occur elsewhere in the Middlebury quadrangle.

Baldwin Pond. Here, while ice occupied the area of Baldwin Pond, meltwater from the valley above built outwash against this ice, resulting in the present 1440 foot, steep, ice-contact slope. A 20 foot deep kettle hole within the surface of this valley train deposit also helps attest to the stagnant ice hypothesis of the mountains.

In the L-shaped valley intersection of Alden Brook and the North Branch of Middlebury River (SE part of Quadrangle) is a flat outwash terrace more than 1500 feet wide. Very sandy till/kame moraine occupies adjacent uplands. These deposits, in addition to the fact that Alden Brook now appears to be underfit, indicate that this portion of the valleys may be ice marginal in origin.

Glaciolacustrine and Marine Deposits

General

In mapping an attempt was made to distinguish the following units: bouldery lake or marine clay (varved or not varved), silty lake or marine clay (varved or not varved), lake sand,marine sand, pebbly lake and pebbly marine sand, lacustrine beach and marine beach gravels, delta sand and gravel. The symbol WT was used on areas of till which appeared to suggest removal of fines by wave action. Some of the possible errors of interpretation are considered under separate headings; however, particular trouble was encountered in the area adjacent to and 2 to 3 miles north of State Rt. #17 between New Haven and Bristol. Here because of variance in the proglacial lake elevations or in outwash streams, lacustrine sand, silt, and clay are interbedded with individual units frequently less than a foot in thickness. Because of only moderate post glacial direction, one encounters in this region a very rapid and irregular change from sand to silt to clay at the surface. It, therefore, may be more realistic to have shown this area as underlain by "shallow lacustrine bottom sediment."

Bouldery Lake clay (BC and VBC) and Silty Lake Clay (STC)

Lacustrine clay from a few inches to more than 30 feet thick blankets the largest part of the Lowlands area. Here, wide areas of surface and road or stream-cuts show no boulders, the STC or VSTC symbols (fig. 11) were used;

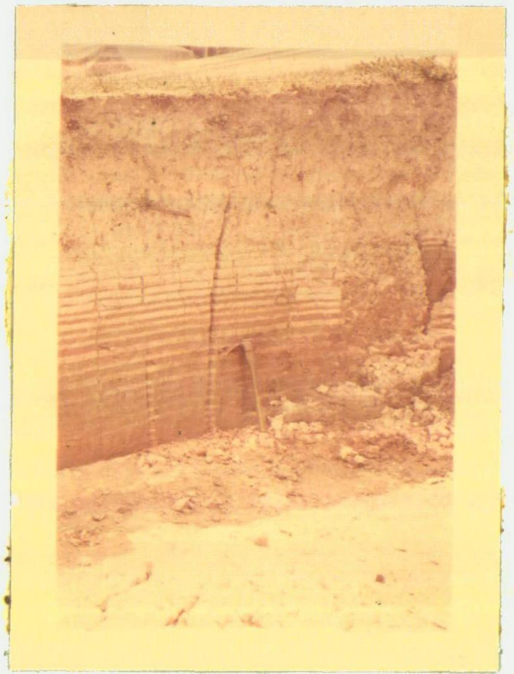


Figure 11. Varved lake clay at intersection southwest corner of Winona Lake (Bristol Pond). Note dark summer layers thin toward top suggesting retreat of glacial climate (warming).

Figure 12. Slumped outer bank of Otter Creek northwest of Weybridge Center.

however, in this quadrangle, most of the surfaces and cuts in the clays reveal boulders, cobbles, or pebbles at irregular intervals but frequently spaced from 5 to 50 feet.

More than half of the vertical cuts in these deposits show that the bouldery clays are varved. The best instance of this fact was noted in excavations made at the sight of the newly erected cash register plant south of Middlebury. In cuts made by steamshovel or back hoe, the surface clays are frequently smeared and varves are only revealed when several inches of clay are cut away by hand. Where no varves were observed in the section, the fine clay, lacked apparent sand or usually small pebbles but may contain boulders at intervals of several feet. Such deposits can be observed in the dump due east of north Vergennes, 1/2 mile east of Mud Creek.

There are several probable origins for the boulders in the clays, some of which may be:

1. Ice-rafting.

   Objections arise when boulders are so widely spread and not largely localized; however, this is the most probable origin for thick deposits of bouldery clay in the Middlebury Quadrangle.

2. Overriding of clean lake clay by glacier producing bouldery clay.

   Evidence for ice is shown at the Weybridge Hill cut and at Little Otter Creek cuts, north of New Haven. Here, varved clays are overlain by tills containing randomly oriented varved clay blocks and boulders. However, these tills did not consist of clean clay with scattered stones and were clearly tills and mapped as such. With poor surface exposure, such deposits might have been mapped as lake clays.

3. Thin covering of lacustrine and marine clays over bouldery till; either as a result of thin deposition or post glacial erosion.

   Such an origin is confirmed in many gullies where drainage has reduced clay thickness and may explain some of the other areas where deposition was slight.

4. Boulders are brought up from till into clays by frost action.

   This is a probable mechanism for many areas observed, where drainage is poor and clays are thin.

5. Where clays were deposited on or near slopes, they may contain scattered stones which were moved from high slopes by current action or mass wasting.

   On the hillslopes between Mt. Fuller and Cedar Lake (Monkton Pond) is very bouldery clay which may have been formed in such a manner.

6. Sands and pebbles may be easily moved by streams on a glacier and in lake bottom adjacent to melting ice front by bottom currents. Thus two groups of particles are separated. When the glacier retreats and boulders are scattered at the top of the outwash, lake clays may settle around them.

   Such a mechanism might only explain the presence of boulders in the basal parts of clay sequences and is probably not a major mechanism.

Marine clay has been definitely located only at the northeast corner of the quadrangle. Here marine pelecypods (probably all of genus Macoma) are abundant in blue clays exposed in road cuts of U.S. Rt. 7 adjacent to Lewis Creek. The elevation is approximately 180 to 200 feet above sea level.

Engineering Aspects of the Clay Deposits

The extremely low permeability of the clay deposits is apparent in the numerous gullies, clay flows, and slumps seen in the quadrangle. Basement flooding at times of high runoff is only one of the many hazards of such deposits. Below and north northwest of Weybridge Hill several large slump blocks have been produced at a sharp meander bend of Otter Creek (fig. 12). Such blocks appear to be a result of several processes: (1) removal of lateral support by migration of Otter Creek at its bend; (2) lubrication of vertical joints in the lake clays comprising the concave bank; and (3) possible surcharging by presence of paved road near the free face of the creek channel.

Sand and Pebbly Sand (LS, PS or MS, MPS)

Large and thick deposits of lacustrine sand and pebbly sand occur in abundance opposite the kame terrace at Bristol. Several other localities south along the same deposit and in the vicinity of New Haven were mapped but they are thin and usually interbedded with silts and clays. The deposits near Bristol frequently show some cut and fill structures which are particularly well exposed in the commercial sand pits off Plank Road near Bristol village (fig. 13). The origin of this deposit as well as those farther south along the terrace and those near Starksboro may be ascribed to the wave erosion of the kame terraces.

Pebbly marine sand mapped in the vicinity of Lewis Creek in the northeast corner of the quadrangle is more than 8 to 10 feet thick at its eastern end and thickens several feet to the west along the creek. In a few exposures near U. S. Rt. 7, beds dip westward up to 20° and small bits of charcoal were found in the deposits to 5 feet below the surface. The beds are interpreted as marine because they overlie the marine clay. Had these beds been thicker they might have been mapped as marine deltaic deposits. These sands are now more than 90 feet above the present Creek level which would appear to preclude very recent flood origin. However, the possibility remains that these are early post-glacial deposits of Lewis Creek before it cut down to its present level.

A smaller deposit but of similar topographic situation is mapped west of the village of Weybridge along Otter Creek. As in the Lewis Creek deposits, this would be a likely spot for a marine embayment. Considering measured glacial rebound (isostatic recovery) in this area as 4 to 6 feet/mile, this deposit is below or at the Marine Limit of Chapman (1937). Likewise, it could have been mapped as a marine deltaic sand; exposures are poor and do not preclude a fluvial origin.

Deltaic Sand and Gravel (DSG)

A large dissected fan of coarse gravel has been mapped at the village of Starksboro. It is probably a result of deposition by melt waters carried from the valley east of the Village into a local, ice marginal lake (the Quaker Springs stage of Lake Vermont of Stewart, 1961).

Figure 13. Well-bedded sand of lacustrine origin overlain by very fine sand and silt (darker color). Sand pit off Plank Road naar Bristol.

Beach Grave, Washed Till, and Other Indicators of Lake and Marine Strandlines. (BG, WT, and BGM)

For unprejudicial study, the reader should refer to Table 1 which shows pertinent elevations and location of all strandline features in the Middlebury Quadrangle. Features of unquestionable lake or marine origin and importance in determining strandlevels of major glacial lakes are indicated on the Map Overlay. The discussion below is directed to correlation of strandline features to those discussed by Chapman (1937) or Stewart (1961).

Lake Vermont

Quaker Springs Stage (highest postulated stage)

A shore terrace at 695 feet .5 miles east of Rockville off State Rt. 116 has already been described by Stewart (1961). This has been correlated with strandline features in the Burlington Quadrangle to the north and therefore to Stewart's highest and earliest Quaker Springs stage of Lake Vermont. A possible wave-cut terrace is plotted east of Starksboro and a cobbly terrace and possible beach gravel has been mapped at 650 feet, 1.5 miles west of Winona Lake. However, there is not other evidence in this area to support this as an extensive Lake Vermont level. No lake clays nor lacustrine sands other than deposits in kame terraces were definitely proven above 580 feet in the quadrangle. Deposits would be expected in the Lowland area if such a lake existed for any length of time comparable to Coveville or Ft. Ann stages of Chapman. The presence of large unfilled depressions such as the very large kettle holes (see p. 9) at 540 feet at the Cobble and at 590 feet 1.5 miles south of Bristol on the Kame Terrace do not disprove the presence of a higher lake level but because of their size and number may be considered evidence against such a level. As noted by Chapman (1937, p. 91) "since ice may persist a great many hundreds, or even thousands of years beneath gravel and sand before melting, the presence of unfilled kettle holes gives no real clue as to the height of water."

Table. Strandline Features of the Middlebury 15' Quadrangle.

Pertanent Elevations (for strandlevels) Reliability	Brief Description of Feature	Location of Feature	Possible Correlation with Chapman, 1937 or 1942. Stewart, 1961.
690-700' good	Wave-cut terrace and weak cliff; faces west; on kame terrace	1/2 mi. E. of Rockville; east side of Lewis Cr.	Quaker Springs ???
680-690' fair	Wave-cut terrace and weak scarp; faces west; on kame terrace	1/10 mi E. of Starksboro; N. side Baldwin Pond Rd.	Quaker Springs ???
650' fair-poor	Wave-cut bench and beach ridge with WT above to 680'; angular qtzite; 50' wide, 1/4 mi. long; faces West	1&1/2 mi. due W. of S. end Winona L. (Bristol Pond), off N-S road to Vt. Kaolin pits.	Quaker Springs ???
610' poor-fair	Gravel beach with bottom at 580'; till above and below; faces east; might be ice-contact deposit.	East-facing hill, 1.4 mi. due W. of Monkton village.	??
560-580' good	Wave-cut terrace on Bristol Kame Terrace; Beach and bottom sed. go from (possibly) 568 to 510 at Terrace margins. Airport at 577'.	Village of Bristol and at Bristol Airport.	Coveville
570-595' excellent	Beach ridge; 3/4 mi. long; LS and BC below ridge.	Forms semicircle around SE. end of ridge opposite Winnona L. (Bristol Pond) off Monkton Rd.	Coveville
515-520' fair-good	Wave built bar - terrace; 50' wide, 1/2 mi. long (NOT MAPPED)	3 mi. NW of Bristol Rock on W. side of road, 1.75 mi. N. of Plank Rd. & 1 mi. W. of Monkton Rd.	Coveville

Strandline Features (continued)

420-440' fair-poor	Silt and clay bar? juts out from Bristol kame terrace base. (NOT MAPPED)	Bristol gravel pit of Rt. 116, 1/5 mi. N. of Rt. 17.	Above the Ft. Ann
390-400' fair-good	Beach ridge, bar?; poorly exposed and(MAPPED AS LS).	NW foot of Buck Mtn.	Ft. Ann
405-410' poor	Wave-cut bench and beach	3/4 mi. W. of Greenwood Cem. near junction of Rts. 17 & 116.	Ft. Ann
475'(top) good	Gravel beach and low scarp; some WT above and BC below at 430'	N. Central Monkton 7&1/2', adj. to Collins Cem., 1.4 mi. E. of Shell-house Mtn. Pk.	Above the Ft. Ann
390-400' excellent	Beach ridge with WT above to 450' and possible cut bench.	1/ to 2 mi. long, near The Ledge at Cornwall; .4 - 2 mi. N. of Rt. 125	Ft. Ann (slightly above)
250-270' excellent	Very well-developed and apparent beach ridge of gravel; traced 2 mi. via WT from N. Edge Mid. Quad. BC below & WT/BC above ridge.	Between East Slang Cr. at Quaker Cem. to Lewis Cr., NW corner Midd. 15', E. and adj. to Rt. 7	Upper Marine Limit
200' (top) good	PMS - beach or delta sand or alluv. on fossil-bearing clay; 8' thick.	Rt. 7 at Lewis Cr. intersection	Port Kent?
180' very good	Beach ridge adj. to Lewis Cr.	S. side Lewis Dr., W. of Rt. 7	Port Kent?
200' (top) good-fair	Beach or delta on Otter Cr. at both sides of cr.; contains some clay lenses; no shells	Both sides Otter Cr. at Weybridge	Upper Marine

However, surface permafrost would not persist for many years beneath lake waters, nor would shallowly buried glacier ice. In addition, more than about 10 to 15 feet of loose gravel would probably have to cover a 40 foot ice cube to prevent it from floating in the postulated ice.

Coveville Lake Stage

Two Coveville strandlines were plotted by Chapman (1937, p. 118-119) in this quadrangle. These were both at the Bristol "Delta" (Chapman recognized it as a kame terrace); one at 520, and the other at 570 feet. The unusually flat terrace surface now occupied by Bristol Airport (577') and part of the town itself is probably due to wave washing and may represent the upper Coveville stage limit. The wave action has also probably produced the silts and sand beds which dip off the margin at angles from 25 to 2 degrees and overlie bouldery ice-contact deposits. The most interesting pit is just north of the Bristol town dump (figs. 9 and 10).

An excellent beach more than .75 mile long encircles the southeast end of a ridge west of Winnona Lake with its top from 580 to 595 feet. A few hundred feet to the south a 50 foot wide wave-built terrace, at 520 feet, is cut into medium lacustrine sand and likewise can probably be correlated with the Coveville stage.

Fort Ann Lake Stage

Chapman (1937, p. 110) mentions sandy beaches at 390 feet on the northwest flank of Buck Mountain south of Vergennes. However, the writer found only one sandy area of a few hundred square feet area overgrown with small trees in this location. Possible washed till is found here up to 420 feet on the mountain flanks and bouldery lakeclay to about 530 feet. However, a good beach at 475 feet 1.4 miles eash of Shellhouse Mountain Peak in the northwest part of the quadrangle and an excellent beach ridge at 390 to 400 feet extends for two miles along The Ledge at Cornwall west of the village of Middlebury. The latter has only 2 to 3 feet of relief but is well formed and a few hundred feet south of the beach the strand is delineated by washed till and a wave-cut bench. Boulder concentrations, probably resulting from wave washed tills occur from 350 to 400 feet and are probably related to this lake stage.

Champlain Sea

Upper Marine Limit

The most clearly defined beach ridge in this quadrangle occurs northwest of Shellhouse Mountain off U.S. Rt. 7. Here it stretches from East Slang Creek more than 1.5 miles north where it merges into a line of washed till at Lewis Creek. The ridge has an upper elevation of 270 feet. Although no marine fossils were found here, this ridge is correlated with the Upper Marine Limit by projection of fossiliferous marine beaches from the Burlington Quadrangle (see Stewart, 1961, p. 110-111). Since marine clays are found at 200 feet elevation below, along Rt. 7, it is realistic that the shore of the lake in which those clays were deposited might be as much as 70 feet above this point, in this case a lateral distance of about 1000 feet. This 275 foot strandlevel is projected south at 5 feet/mile (consistent with average isostatic tilting of this region) to include the sand and gravel deposits on Otter Creek at 200 feet.

Pebbly sand overlying the marine clays at Lewis Creek may be related to the Upper Marine Limit or possibly to the later and lower Beekmantown or Port Kent Marine stages. A small beach ridge at 180 feet off Lewis Creek and west of Rt. 7 may be correlated with the Port Kent beaches in Vermont.

The position of some boulder concentrations in till are undoubtedly a result of wave washing; however, many such concentrations were found at the foot of slopes where they might likely be results of mass movement, or occur, in areas of poor drainage where they may result from frost-heaving. In most cases they occurred over broad zones with indistinct upper limits and were of little use in determining former strand levels.

Interpretation and Correlation of Some Stratigraphic Sections

Although till sections are plotted on the map overlay, observations at four areas where till was found associated with lacustrine deposits may be of stratigraphic interest for future correlation outside the Middlebury Quadrangle.

1) Little Otter Creek, North of New Haven

A composite section composed of a 60 foot cut made by Little Otter Creek and two adjacent road cuts here revealed the following section:

Bouldery Clay with stratified lenses of silt and sand; showed rapid facies change to clay or till. 2-10'

Till, clay rich, with stones of striated pink dolomite, purple and white quartzite, and included blocks of varved clay; weighted mean fabric: in stream cut was 4W in road cuts was 6W and 35W. 3-10'

Varved clay in place. 1-3'

Till, brown, bouldery, lodgement, with "chippy" texture; contains largely rounded cobbles of purple quartzite and striated pink (Swanton?) dolostones; weighted mean fabrics at stream cut were 35E and 19E. 14'

Pebbly, poorly stratified pebbly sand and interbedded "chippy" till; these deposits have flowed in adjacent areas and are extremely contorted in such places. to 15' revealed above scree.

If the fabrics are truly representative of ice source direction, it is quite probable that the Burlington Till of Stewart and MacClintock (1964) is the upper and the Shelburn till the lower, there having been a lake following Shelburn time. However, because of precipitous cliffs, slides, and poor exposures, little is known about the thin tills and interbedded sands at the base except that they probably reflect a minor oscillation of the ice front during Shelburn or earlier times. The concept of an oscillating ice front may also account for the interbedding of tills and lacustrine deposits elsewhere and the alternation of clay and sand in this whole area as manifested in surface cuts.

2) Weybridge Hill Cut, Off State Rt. 23

At this location a 25 foot section of till and lacustrine deposits has been exposed on the side of Weybridge Hill. The section is as follows:

Till? cobbly with deformed varved clays; highly weathered with many crumbly stones; weighted mean fabric is 21E and in adjacent but similar looking till? was 14E; strongly resembles top NW till at Little Otter Creek. 10-15'

Clay, varved, undisturbed. 1-2'

Till, very, very, very cobbly and bouldery; composed of Monkton Quartzite stones; weighted mean fabric is 27E; rapid facies change in few feet to sands and cobbly stratified sands. 15' ±

The upper till here strongly resembles that at Little OtterCreek but in two places it gives a northeast fabric. If this fabric is representative of its source, we have the evidence in the varved lake clays of a pre-Shelburn Lake.

3) Little Otter Creek, Intersection 3.5 miles Northeast of Vergennes

Two "northwest" tills are here separated by lacustrine, pebbly sands as follows:

Clay, bouldery varved. 1-2'

Till, ablation, rich in Monkton Quartzite stones and pink Swanton dolostone; weighted mean fabric 36W. 3-10'

Lacustrine silts and sands, some varved or laminated, all poorly stratified and with scattered till-like patches. 5-10'

Till, as above; weighted mean fabric 14W. 3' exposed

Apparently "Burlington" tills may be interbedded with lake deposits revealing minor glacier fluctuation during retreat.

4) Plank Road and U.S. Rt. 7 at Vergennes

An abandoned gravel pit revealed the following section:

Bouldery lake clay 5'

Till, sandy ablation, showing few 8' x 3-5' boulders at upper part, (boulder pavement?) a facility or cleavage oblique to horizon and

and contacts (fig. 14) and cut by a frost wedge cast or sand wedge; contains wood 5' below till surface which is not apparently related to root system (Spec. 143A); weighted mean fabric 6E (random). 15'

Pebbly sand with some clay, poorly stratified and deformed. 10' exposed

The frost wedge cast or sand wedge (frost cracks may be filled originally with sand rather than meltwater or snow) did not extend through the lake clays above. It may have thus formed before the lake clays. Since permafrost cannot exist for more than a few years (if this?) below lakes and probably not below temperate ice caps there may have been no lake water over this area immediately following the last ice retreat. Should other frost wedge casts be found in similar positions such implications might bear more weight.

Conclusions With Regard to Pleistocene

History

1. Glacial striae indicate that the last ice to cover the Middlebury Quadrangle advanced from the north or northwest. At a few locations, weak northeasterly trending striae adjacent to, or beneath the northwest striae, suggest an earlier advance from the northeast.

2. Most of the fabrics of surface lodgement tills also suggest a northwest origin for the last glacial advance. Evidence from fabrics of a second till below the surface might support a northeast origin for the next to last ice advance in the area.

3. No moraines are evident in the Middlebury Quadrangle. Interbedded tills and lacustrine deposits suggest that there was probably an active and oscillating ice front in the Lowland area during glacial retreat from the Shelburn and from the Burlington advances. However, in the Green Mountains ablation caused downwasting and separation of ice masses from the active front of the continental ice sheet.

Figure 14. Stratigraphic section in gravel pit at intersection of Rt. 7 and Plank Rd. at Vergennes. Arrows show contact of lower till (note jointing oblique to horizon) with overlying Bouldery Lake Clay. Note sand wedge or ice-wedge cast in till where pick is. Margins are granules and small pebbles and more highly stained while main wedge is limonitic-stained sand.

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4. During ice retreat from this area and subsequently from the adjacent Burlington Quadrangle, the active snout of the glacier apparently furnished through calving many debris-laden icebergs which deposited most of the boulders now found in the lake clays of these quadrangles.

5. Strandline features suggest that:

a. There was no widespread proglacial lake level above 570 to 590 feet in the Middlebury Quadrangle, i.e., no Quaker Springs as defined by Stewart (1961).

b. The Coveville stage is as described by Chapman (1937) and Stewart (1961).

c. The Fort Ann stage of Lake Vermont reached about 390 - 400 feet at the latitude of Middlebury and, therefore, would have covered the village and been at the flanks of College Hill.

d. The strandline of the Upper Marine Limit through projection and inference is probably at 275 feet at the north end and at 200 feet at the southern end of the quadrangle. However, definite marine deposits are only found up to 200 feet and only at the north edge of the area.

e. Sand deposits on marine clays at 200 feet and at 180 feet adjacent to Lewis Creek may be correlated with Chapman's Beekmantown or Port Kent, Marine stages.

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