OPEN-FILE REPORT NO. X-5.

Glacial Geology of Hardwick and Hyde Park Quadrangles

By Paul MacClintock

Chapter I. Introduction.

These two adjacent quadrangles lie in North central Vermont and comprise together some 425 square miles of rolling upland topography with 600 - 800 foot valleys cut below it and many low mountains rising above it. The Lamoille River and its tributaries drain the central and southern parts while the Barton and the Black river drain the northern part into Lake Memphremagog. The area is traversed by a freight railroad in Lamoille valley and by numerous paved and well-kept gravel roads through agricultural and pasture country studded with woodland tracts. The main cities are Morrisville and Hardwick, each of 2000 population. Greensboro, on Caspian Lake is an old and well-known summer resort.

This survey was of 2 1/2 months duration during summer of 1963 with Marvin Saines as the efficient and helpful field assistant. Frequent discussions with D. P. Stewart were most fruitful.

Chapter II. Topography of Hardwick and Hyde Park Quadrangles

The topography of the two quadrangles has been produced by fluvial erosion during many millions of years. It has been modified slightly by a few feet of glacial erosion here and there to round off hills and round out somewhat the valleys lying parallel with the ice movement, and also by deposition of a few feet of glacial till over the area with gravel kames and kame terraces in some valleys. The fluvial erosion has produced gently rolling uplands below which streams have cut 600 to 800 foot-deep valleys, and above which hard-rock hills and mountains rise 1000 feet or more. The upland roughly-level surface has long been thought of as an uplifted and dissected peneplain with monadnocks standing above it. However, more recent work (Meyerhoff and Hubble, 1928, Hack, 1960, Flint, 1963) is returning to the simple concept of the early workers, that the present topography is the response to the erodability of the different rocks; leaving the less erodable ones standing high while the more erodable ones are worn down.

The erodability of the rocks depends both on the lithology (mineral make-up of the rock) and on its structure. Rocks made of durable minerals such as quartz, garnet, stauralite orthoclase, ~~and~~ sericite, and muscovite mica withstand weathering and fluvial erosion, whereas rocks composed of softer, others, more soluable, and more quickly disintegrated by weathering, such as calcite, biotite and plagioclase yield more rapidly to erosion. Likewise the structure of the rock plays a significant role in many instances. Massive rocks such as granite and granitic gneisses withstand erosion and stand as mountains whereas conspicuously jointed and foliated rocks are more erodable. Furthermore schists where foliation is highly inclined erode faster than where the foliation is horizontal. Christman 1951, 1960, attributes the height of Mount Mansfield (3600 ft.) and Camels Hump (3400 ft.) to the fact that they lie on the axis of the Green Mountain anticlinorium and the schistosity is horizontal. This principle is expanded and convincingly documented by Flint 1963 for an area of similar metamorphic terrain in Connecticut.

<u>Hardwick Quadrangle</u>. Bedrock from the 1961 state geological map (C.G. Doll

(C. G. Doll, 1961)

1. The eastern half of the quadrangle is underlain by the Barton River member of the Waits River formation (Dwb) It is composed of interbedded siliceous crystalline limestone and sericite-quartz-clorite-phillite and diopside limestone and cordiorite hornfels at the contact with granitic dikes and sills. It is intruded by many masses of gray granitic rocks, to stand as 1500 foot upland with hills rising to 2500 feet.

2. In the center of the quadrangle the north-south depression of Alder Brook-Black River valley is underlain by the Ayers Cliff limestone member of the Waits River formation (Dwa). It is siliceous crystalline limestone containing thin beds of slate and phillite. The foliation is almost vertical and the formation has been eroded down to the deep depression.

3. The western part of the area is for the most part underlain by the Moretown member of the Missisquoi formation (Omm). It is quartzite and quartz plagioclase granulite in layers 1/8 to several inches thick separated by pinstripe phillites. This formation makes rolling upland about 1500 feet in altitude rising toward the west.

4. In the northwestern corner of the quadrangle the northeast-southwest Lowell Mountains are composed largely of the Umbrella Hill member of the Missisquoi formation(Qmu), a quartz-pebble phillitic conglomerate, and partly of the Stowe formation (O€s) of quartz-sericite-chlorite phillite and phillitic graywacke schist containing abundant segregations of granular white quartz. The Lowell Mountains rise to 2600 feet to form one of the conspicuous features of the landscape.

Hyde Park Quadrangle.

Bedrock

The rocks of the Hyde Park Quadrangle are also formations of the metasediments having also northeast-southwest strike.

1. The formation in the eastern part of the quadrangle is the Stowe formation (O€s), composed of quartz-sericite-muscovite-chlorite phillite porphyroblasts of albite, garnet and phillitic graywacke. It stands as hills along the eastern part of the quadrangle culminating in ~~Elmar~~ Elmore Mountain (2600 feet) in the south eastern corner; Umbrella Hill and Bean Mountain (2200 ft.) in the Middle part; and Hadley Mountain (2400 ft.) in the northeast corner.

2. Through the middle of the area spreads the Hazens Notch formation of the Camels Hump group (€h). It is interbeded carbonaceous quartz-sericite-albite-chlorite schist which grades into quartzite and gneiss. On the north side of Lamoille River its tributary the Gihon River has eroded into this latter formation to make a four-mile-wide lowland area of about 600 to 800 feet in elevation northward to North Hyde Park. Elsewhere it stands as mountains such as Butternut Mt. (2700 ft.) and Leaway Mt. (2700 ft.) South of the Lamoille its surface rises to Whiteface Mt., (3716 ft.) which is composed of the Underhill formation of the Camels Hump group (€u); a quartz-sericite-albite-chlorite-biotite schist containing abundant lenticular segregations of granular white quartz. Ryder Brook, a southern tributary of the Lamoille, has eroded an area of lowland about 600 to 700 ft. altitude southward from Morrisville, on the Lamoille, to its low divide at 750 feet into the Stowe Valley lowland.

Streams

The smaller streams and tributaries are what is known as subsequent streams occupying valleys which they have excavated into the more erodible rocks. On the other hand the main river of the region the Lamoille rises at the regional divide between the Connecticut River drainage and the Lake Champlain drainage and flows westward across the strike of all the formations as well as the Green Mountains and empties into Lake Champlain. Since no structural phenomena, such as faults, folds, erodable beds, have been found along its course, the cross-cutting has long been attributed to superposition, i.e. it acquired its present course on a pre-existing surface which could either have been a mantle of sediments now eroded away, or on the surface a westward-tilted peneplain.

Upon rejuvination the river cut its way down athwart the structure. It also may be that some intricate folding within the Green Mountain anticlinorium, or the great thrust plates on East side of the Champlain lowland, now gone during the thousands of feet of deep erosion of the region, resulted in conditions for superposition. Tributary streams have cut subsequent valleys parallel with the strike of the bed rock formations and structures.

Hardwick Quadrangle
~~Glaciation~~

There have been four separate ice movements across the Hardwick Quadrangle. It is not known but that all of them were parts of the last, (Wisconsin) ~~s~~tage of glaciation. Evidence for this is seen along the valley of Stannard Brook east of Greensboro Bend in the southeastern part of the quadrangle, where exposures display four superposed sheets of till separated by alluvial gravels and lake sediments, these latter deposited during ice-free episodes. There are six exposures altogether of the drift sheets; five of them in stannard Brook valley itself and the sixth in nearby Lamoille valley (Fig. 60) Map of Exposures

Stratigraphy

(Table 1)

A table summarizes the stratigraphy of the glacial deposits in the area. The lowest (earliest) till, (till "A"), has fabric maximum about N.30°-35°W. The second till, (till "B'), has fabric with maximum about N.55°W. The third till (till "C") shows maximum N.25°E.,whereas the topmost fill,(till "D") found at section No. 2 has fabric maximum N. 25°-30°W. It is seen, therefore, that the first ice crossed from NW to SE. Then ensued

Till Fabrics (29), (31) (32) etc.

(30) (33) (36) (38) (39)

(34) (35) (37)

an ice-free episode during which streams deposited the alluvial gravel before the lowlands were flooded by a lake in which laminated silt and clay was deposited. Then followed an ice invasion again from the Northwest and the deposition of till "B", also with a Northwest fabric.

A significant change in glaciation then occurred for the ice that had deposited till "B" must have waned entirely out of the region to make way for a new invasion, this time from the northeast because till "C" has fabric with maximum from the Northeast. This invasion from the Northeast overran much of northern Vermont, as shown by striae and till deposits. Just south of the village of Shelburne near Burlington, two till-sheets are found, one above the other. The lower till has fabric maxim from Northeast; the upper one from the Northwest. This exposure was described by Stewart, 1962, and the lower drift named the Shelburne till and the upper drift the Burlington till. It is concluded that the two ice invasions found in the Hardwick Quadrangle are the Shelburne and the Burlington. And lastly with the waning of this Northeast ice came an invasion again from the Northwest. This last ice invasion overran much of Northwestern Vermont and deposited till in the Burlington area where it has been named the Burlington till.

Shelburne glaciation

The many glacial striae from the Northeast, as seen plotted on the map, are the result of Shelburne glaciation. There are also deposits of till with Northeast fabric maxima that are likewise of Shelburne age. A big exposure of this till is seen in the undercut valley bluff of Wild Branch two miles Northeast of North Wolcott. This exposure shows 8 feet of horizontally bedded fine sandy lake gravel on 10 feet of oxidized buff till, on 72 feet of bluish slate-gray, calcareous, dense basal till with Northeast fabric maximum N 50-60°E. Other smaller exposures of this blue-gray basal till are seen a mile farther north, and two miles further north both on the west side of the river and under locustrine gravels. Another occurrence of Shelburne drift is found in the southeastern part of the quadrangle where it forms a belt of frontal moraine. This is part of an extension moraine which extends north and northeastward to the Canadian border near Newport, and southward across the northeast corner of the Plainfield quadrangle, southward through western part of St. Johnsbury quadrangle, touching the corner of East Barre quadrangle at Goose Green and on South into the Strafford quadrangle. The Moraine where it crosses the Hardwick Quadrangle is largely composed of ablation till of loose sandy texture, lacking in silt and clay constituants and has local bedrock as its most abundant rock constituants. This till, contrary to some published statements, does have a good till fabric. A road cut 1 3/4 miles southwest of Greensboro along the road to Greensboro Bend, 35 feet high shows till fabric with maximum at N 25°E. The topography hereabouts is very steep, nob-and-kettle frontal moraine. Other exposures of Northeast fabric in the moraine, are seen 1/2 miles northeast of East Greensboro,1 mile Northeast of East Hardwick, and at 1/4 mile north of Waldon Heights, and at Goose Green in E. Barre Quadrangle.

Burlington Glaciation

Most of the surface drift of the quadrangle has a northwest fabric. At no place was it actually seen to lie on bedrock with Northeast striae, but at many places it is adjacent to and surrounded by such exposures. It therefore is thought to be younger in age than the Shelburne. Likewise at three places northwest striae are seen to cross older Northeast striae. (a) 1 mile south of South Albany, (b) 1/2 mile N.E. of Greensboro, and (c) 3 miles northeast of Greensboro on road to Four Corners, just off the map. (Fig. 00) Photograph of older N.E. crossed by younger N.W. striae

The location of exposures where till fabrics were measured are plotted in the map, and the fabrics shown in figures 00 (1) to ~~00~~ (4). Most of the exposures seen are of basal till, but ablation till with northwest fabric is found in some places such as (a) 1 mile southwest of Hardwick Street and 1 mile N.E. of East Hardwick, (b) 1 mile SW of Craftsbury, (c) 1 mile North of Craftsbury Common, (d) 1 1/2 mile west of Craftsbury Common, (e) 1 mile NW of North Wolcott. These are on or near the upland surface rather than down in vallies. Kames and ~~kames' areas~~ kamed terraces are scattered at various places over the area. Two good sized kame terrace patches yield gravel high on the east valley slope of Alder Brook two and three miles north of Hardwick and a small esker lies along the west shore of Hardwick Lake two miles Northwest of Hardwick. Kame terraces capped by lacustrene gravel strew the valley of the Lamoille, the valley of Wild Branch as well as the northern part of Black River Valley.

← insert p 13a, 13b.

Hyde Park Quadrangle

~~Glaciation~~

Shelburne Glaciation

Shelburne ice may probably have crossed the Hyde Park Quadrangle since it is known to northeast as well as at Shelburne to the southwest, but no record has thus far been found except on one rock ledge in the extreme southeast corner of the quadrangle where one N.10°E. streation is seen along with others N. 30° W and N. 10°W. The exposure is on the east side of Elmore Mountain which is the northern end of Worcester Mountain range which has NW striae on its west side and NE striae on its east. The Worcester Mountains mark the eastern extremity of Burlington drift.

Burlington Drift.

With the exception of the striae mentioned above, all striae thus far found are from the northwest; N. 30°W. to N. 60°W. (see map). Likewise the several till fabrics measured are from the northwest. (Figs 00-00). At one exposure 3 miles north

Caspian Lake

Caspian Lake lies on the upland 6 miles north-northeast of Hardwick. It is a mile and a half long in N-S direction by a mile wide. Birch Point on the East and Burlington Point on the West constrict its northern part to half a mile. Its water level is maintained at 1400 feet by a low dam and spillway constructed by the Vermont State Water Conservation Board. This agency has surveyed the lake and made the bathometric map. (Fig. 00) It shows the depth in feet to have maximum of 144 in southern part and 119 in the northern. Two shoals of bedrock, 800 feet east of Burlington Point rise to within 3 feet of the surface. These shoals are composed of phyllitic schist members of Waites River formation with northeast foliation normal to the region. The two points mentioned are likewise composed of the regional bedrock, however several smaller points in the northern part are made of granite intrusion rock.

The lake is fed at the north by Cemetary Brook, Tate Brook, and Porter Brook, and drained at the southeast by Greensboro Brook into Lamoille River.

The origin of the lake is obviously glacial modification of fluvial topography;i.e., glacial shaping and locally deepening a river valley or valleys. The valley system was also choked and dammed by deposits of glacial drift. There is evidence that such damming held the lake waters, at one time, up to 1460 foot level, i.e., 60 feet above present level. The evidence consists of a deposit of laminated lake silts on top of till on the low divide between Porter Brook and Wright Brook north of North Side Road two miles North-Northwest of Greensboro. The drift dam may well have been at the south end, subsequently cut down to bedrock by the Greensboro Brook outlet.

of Hyde Park and 1 1/2 miles southeast of North Hyde Park till with fabric maximum of N. 57°W. lies on bedrock striated N. 55° W., demonstrating the dependability of till fabric to give ice movement direction. These occurrances therefore were all made by the Burlington invasion. The margin of the Burlington drift, as mentioned above lies along the west base of the Worcester Mountains and swings around north end of Elmore Mountain, and a mile south of Lamoille River as far east as Greensboro Bend.

Till. Most of the till of the area is seen as thin, patchy and discontinuous strewn over the upland bed rock hills. Many rounded glaciated ledges of rock project through the drift. Slightly thicker till, up to a dozen feet or more is found in the lower places of the bedrock. A small end moraine, of till, about 50 feet high, 300 to 400 feet wide and 11/2 miles long is seen at the north end of Elmore Mountain. It is composed of buff colored calcareous basal till with northwest fabric (Fig. 24) and good bumpy morained topography. It curves down the valley slope from 1100 feet altitude at its southwestern end down to the 850 foot level at its northeastern end where it is overlain by a kame terrace of Lamlille valley. The northern margin of the kame terrace is covered by the pebbly sand 800 foot lake terrace.

Gravel

Lamoille valley and its tributaries contain patches of kame terrace. (1) As mentioned above, one such is seen on south side of Lamoille valley at Elmore Pond Brook with pitted top at about 860 feet in altitude. Coarse gravel with boulders shows it to be of ice-contact origin.(2) Directly north across the valley is a large 1 1/2 mile kame terrace between Green River and Redman Brook and extending from the valley wall at the south northward two miles to Garfield at the north. Its southern part has been overlain with lacustrine sands and its top is strewn with beach gravel northward for a mile, but beyond that, northward, the kame terrace gravel with many striking kettle holes lies uncovered. A continuation of this kame terrace swings eastward for about a mile across the upper part of the Green River valley, to make a large patch of pittal kame terrace on the Eastern side of this valley. The fact that this pittal ice-contact gravel does not project above the lake sediments of the area shows that the buried ice blocks responsible for the pitts persisted till after the lake episode before melting out. (3) Farther west in Rider Brook valley a patch of Kame terrace is seen in a large gravel pit a mile southwest of Morrisville where Ryder book has eroded off lake sediments to expose the ice-contact gravel. Likewise, 1 1/2 miles to the south, eroision of lake sediments has laid bare a large kame of ice-contact gravel containing striated and rounded boulders up to 4 feet in diameter.(4) A goodly patch of flat-topped kame terrace gravel lies on the northwest slope of Elmore Mountain at 1080 feet elevation two miles southeast of Morrisville. The gravel line also contains large striated boulders and striated bobbles as well as large mass of incorporated dense blue-gray till 5 x 15 x 10 feet in size. The presence of the numerous striated stones as well as the mass of till attest to ice-contact conditions. (Fig. 00) (5) a large kame mass is being excavated for gravel just south of Johnson, and (6) another Kame terrace is yielding gravel to the railway 2 1/2 miles west of Johnson. The 600 foot flat top of this

this latter gravel mass is composed of pebbly sand lake deposits which in places ~~drops~~ drapes down the northern ice-contact face of the kame terrace, suggesting lake deposition ~~of~~ as the ice block in the valley melted out. (7) Goodly ~~particles~~ patches of kame terraces are found in Gibson River Valley 1/2, 2, and 3 miles north of North Hyde Park. In Wild Branch valley kames are found along its western side (8) the largest ~~recess~~ mass of kames and kame terraces is found in the area of Eden Mills ~~kn~~ the northeastern part of the quadrangle where kame terraces surround Lake Eden and South Pond, where the gravel area assumes the volume and topography of a kame moraine. This same type of deposit is also found 6 miles to the south and two miles eas of Garfield along the east margin of the quadrangle and extending into the Hardwick, area. (9) Two miles southeast of North Hyde Park a NE-SW kame ridge 1/2 mile long of frontal origin, is being ~~more~~ used extensively for road gravel.

Chapter IV

Late Glacial Lakes

Lakes of Hardwick and Hyde Park Quadrangles

Lake sediment of beach gravel, pebbly sand, sand, silt, silty clay and clay in many places overlie the glacial till and ice-contact gravel deposits. Most of this lake material is fine-grained and incoherent. It is easily eroded by streams and slope wash. It also found itself on slopes and in the drainage-ways of the bedrock and drift topography. Also since it lay bare to erosion without benefit of vegetation cover it has suffered extensive postglacial erosion which swept it out of the major valleys to leave only patches along the valley walls and flat-topped terraces in protected places and in tributary valleys. In many places hills of drift and bedrock have been exhumed by eroding off the blanket of lake sediment. Flat-topped terraces of lake sands and silt at intermediate levels show that lake surfaces stood at these levels long enough to produce these water-plane features.

However, shoreline deposits of the lakes composed of beach gravel in bars, spits, beach ridges, delta beds and gravel-capped shore terraces were not so easily eroded and have persisted with notable freshness in many widely-scattered places and attest to the lake levels at these places. Altitudes are those to today, not the altitude at which the feature was originally made.

Shoreline features

1250'-1270' 1/2 mile southeast of East Hardwick. A Gravel pit of kame gravel and ablation till capped by 2-3 feet horizontal fine beach gravel. On top of pit is beach ridge 10 feet high of fine beach gravel which extends 1/2 mile to northeast. The top of the ridge rises to 1250'-1265' where the highway crosses it.

1270' 1/2 mile north of South Walden (Plainfield Quadrangle) shoreline terrace of uniform beach gravel.

1260' 4 1/2 miles west southwest of Morrisville, south of Meadow Brook, road corner 3/4 miles southwest of Mud City. Excavation shows small beach grave 3 1/2 feet over 3 feet of stratified lake silt and sand, making a flat topped ridge 300 yards long by 50 yards wide, dissected by postglacial gullies on its north flank. This is good proof of lake shore at this elevation.

1275' 1/2 mile southwest of Mud City and 4 1/2 miles west of Morrisville stands a good shore terrace, 1/4 mile long northeast-southwest, of beach gravel, pebbly sand and lake silt.

1275' 1/2 mile southeast of Eden Mills, lies a small gravel delta with top of foreset beds at 1275'.

1220' 4 miles north northwest of Wolcott, on the west slope of Wild Branch valley, are two gravel pits of beach gravel in a beach ridge rising above a pebbly sand lake-shore terrace.

1150' 2 miles north northeast of North Wolcott is found beach gravel in gentle beach ridge 1/2 mile long northeast-southwest.

1150'-1160' Four miles west of Morrisville at Mud City School is a curving beach around the southeast base of Coper Hill and joining with an area of kame terrace at the north.

1180'-1200' One and three quarters miles southwest of Craftsbury Common, making the divide between Black River valley and Wild Branch of Lamoille River, is a deposit of lake silt about 100 feet thick lying on what seems to be kame moraine and ablation till.

1175' One half mile east of Garfield lies an area of pebbly sand surmounted by a gravel spit extending toward the east from a sea cliff of bedrock with wave washed boulders at its base. The spit is about 10 feet high, 80 feet wide and about 1/4 mile long with crest at 1175±5 feet. In the pebbly sand flat lies a good undrained depression with lake silt in its bottom, which shows that a burried ice block lasted till the lake had fallen below this level.

1160' One and one half miles southeast of North Hyde Park occurs a very pronounced well-shaped beach ridge 10-15 feet high and 100 feet wide extending about 3/4 mile north-south, composed of small to medium sized beach gravel.

1100' Three miles east of Hyde Park, a mile east of Cleveland Corners is a shoreline terrace about 200 feet wide and about 1/2 mile long north and south. It is flat on top dissected by several postglacial gullies. It is composed of horizontally-bedded sand and well-sorted fine gravel as seen in a large pit.

1100'-1120' Four miles east of Hyde Park is a large terrace with flat top a square mile in area. It is capped by uniform-sized well-rounded and sorted, horizontally stratified beach gravel which lies on foreset delta bedding dipping southward as seen in gravel pit beside the highway. The south slope of the terrace is composed of sand and pebbly sand, now dissected by postglacial streams; Rodman Brook on the west side and two others with permanent flow, and many intermittent gullies. Between Rodman Brook and the next brook to the east, the interfluve stands at 900 feet as a flat-topped area covered with well-sorted beach gravel. In the bottom of the ravine next east of Rodman Brook, at 850 feet, erosion has uncovered kame gravel. At the northward edge of the summit plain, capped by beach gravel, appears a 1/2 square mile area of well-pitted kame terrace of coarse gravel with top surface at 1120 feet. The large topographic feature here is, therefore, a kame terrace surmounted and buried by a deltaic deposit, probably made by the late glacial Green River drainage into a late glacial lake standing at what is now about 1100 feet in altitude.

1040' - 1100' One and a half miles northwest of Eden, along White Branch Brook, a deltaic mass of fine gravel projects out into, and constricts, the valley. At its eastern end a pit exposes 50+ feet of well-bedded fine gravel with foreset bedding dipping southward, the full height of face of the pit, demonstrating lake water level of about 1040 foot elevation. The topographic feature, however, rises westward to become a large flat-topped pebbly sand area at 1100-1120 foot elevation. It is interpreted as a delta built at the shore of the 1100 foot lake.

1100' Three miles north northwest of Wolcott at 1100 feet is a beach ridge about 10 feet high and 3/10 mile long. A gravel pit exposes well sorted horizontally-bedded beach gravel containing no large stones.

1100' Between Hardwick and East Hardwick the Lamoille valley contains an extensive pebbly sand and silt lake terrace at 1100 feet. This terrace level also extends southeastward up the tributary valley of Haynesville Brook, in the Plainfield Quadrangle, as far as South Walden. The surface of the terrace rises in the Lamoille valley northeast of East Hardwick to 1154 feet at Greensboro Bend. Here a new well at the school house, drilled by Mr. Bennedini, shows the composition of the terrace in the following log:

0 - 9 ft. top soil and alluvium

9 - 70 lake silt, blue clay

70 - 106 clay, blue gray

106 - 110 coarse gravel, under artesian pressure to make well flow at 100 gallons per minute.

1100 ft. The Wild Branch valley upstream from North Wolcott contains significant evidence of lake history. The upper tributaries of Wild Branch descend, from headwaters at 2000 feet in the Lowell Mountains, through rocky little valleys, down to the 1100 foot contour where the valley acquires a flat bottom. The stream has in several places cut five, or six-foot gullies into this flat to expose horizontally bedded fine beach gravel and sand lying on blue gray till. The stream is at grade on this gently-sloping surface throughout a distance of four miles down to the 1000 foot contour at Branch School where it descends more rapidly into the valley it has cut for itself below the plain. Remnants of this plain are seen as terraces on both sides of the valley almost down to North Wolcott. Midway along the stretch of the plain, a mile north of the Branch School, the eastern valley slope is made of a deposit of lake silt, noted previously, of a 1200 foot lake. This deposit of lake silt has been dissected by a dozen or more small conspicuous gullies, 20 to 30 feet deep, which die out completely at the 1080 foot contour of the valley flat here. The absence of alluvial fans at the lower ends of the gullies shows that they were contemporaneous with and flowed into an 1100 foot lake where waves and currents swept away the sediment of the gully-forming streams. The 1100 foot sandy shore-line deposit, 1/2 mile due north of North Wolcott, is dissected by little gullies which can be recognized even on the topographic map.

1060' One half mile east of Eden lies a patch of beach gravel in the valley of Dark Branch Brook.

1050' One and one half miles west of Craftsbury Common on the west side of Black River valley is a deposit of varved laminated lake silt about 150 feet above the valley bottom at this place.

Lower Lake Levels

900+ feet. During the lake episode of the region, the lake level must have dropped first to a stillstand at about 900 foot altitude as shown by benches at this level. One such is the mile-long flat-topped terrace of lake sediment at this altitude in the northern part of Hardwick village. Also two miles to the north at, the base of the east valley wall of Alder Brook valley, is another mile-long terrace of lake sediment at just about the 900 foot level. Also between Little Elego Pond and Elego Pond a narrow strip of terrace along the west side of the valley is at about the 900 foot level. Still farther north, the headward part of the north-flowing Black River contains extensive terrace remnants of pebbly lake sand at about this level. At Craftsbury, a gravel pit in northern part of town, exposes 5 feet of beach sand and gravel above 10 feet of dense lake clay covering kame gravel. The shore of the lake here must have been at the present altitude of 940 feet. From Craftsbury north of

Albany the valley has a flatish floor about 1/2 mile wide strewn with remnants of low kame terraces and lake sediment dissected into low terraces now at about the 900 to 920 foot elevation. Well records, (Personal communication; Mr. Belucci of Back and Belucci Construction Company, Barre, Vermont to Stone, J.C., 1953) show, in this part of the Black River valley, a thickness of lake clay between 70 and 100 feet. The top 10 feet of this deposit, where seen in low bluffs above river level consists of light and dark brown varved clay (Stone, J.C., 1953 plate 47) with layers from a fraction up to 2 inches thick.

800 feet Terraces at the 800 foot level are conspicuous along the Lamoille and its tributaries from Hardwick to Morrisville. A broad 800 foot level is seen on south side of the river 1 1/2 miles west of Hardwick Lake. A second good terrace of the same level occurs a mile farther west on the north side. This terrace is composed of horizontally bedded uniform small gravelly sand capped by horizontal lake sand as exposed in the extensive Mier Gravel pit. This material is attributed to lacustrine deposition in shallow water and shows the lake level to have stood here long

enough to have cut benches in sandy and silty deposits and also to have strewn wave and current deposits at this level. At one place in the pit deltaic bedding of 12 foot amplitude dips westward. Four other small gravel terrace remnants are seen on the north valley wall as far as Walcott where the village cemetery, on one such gravel terrace, is a conspicuous feature in the landscape. Two large gravel terraces lie between Walcott and Wild Branch. Each containing a big gravel pit. The western terrace is a half mile long and almost a half mile wide and contains an undrained depression in its top more than 20 feet deep to show the former presence of a burried ice block. Herwin, H.E. (1908) reports in this terrace deposit forest delta bedding dipping valleyward toward the south. On the north side of the Lamoille in the Hyde Park Quadrangle good 800 foot terraces of pebbly sand capped by beach gravel are found as far west as Morrisville. From here westward through Hyde Park and Johnson to the west edge of the Quadrangle the extensive lake sediment deposits have been dissected to lower levels except for an 800 foot shoreline deposit along Foot Brook. This deposit, exposed in a large pit, is composed of horizontally-bedded pebbly sand shore terrace material now dissected down to underlying kame terrace gravel by post glacial erosion into valleyward-trending interfluves.

Morrisville beach-gravel terraces

The terrace levels at Morrisville illuminate the late glacial events of the lake history. The village of Morrisville stands on a terrace of 670 feet altitude 40 feet above the floodplain of Lamoille River. This terrace is capped by small, uniform sized beach gravel. Above this 670 foot level, toward the east, rises a second gravel-capped terrace at 720 feet where the high school foundation excavation penetrated 15 feet of horizontally-bedded uniform fine gravel. A 15 foot-high wave-eroded scarp behind the school house rises to about 740 feet. South, across the postglacial ravine, is a large flat-topped terrace remnant, 1/2 x 1 mile in extent rising from about 750 feet at the north to 790 feet at the south. It is also capped by beach gravel which displays shallow-water topography of spits, bars and low wave cliffs well seen on the fairways of the golf club. Gravel pits at the south edge of this terrace expose 10-15 feet of horizontally-bedded fine, clean gravel with pebbles 1-1 1/2 inches in size; rarely 2 inches, and no cobbles or boulders, lying on clean sharp sand with cross-bedding of 1 foot amplitude. In the foundation excavation for the hospital here, they encountered 15 feet of this same type of gravel lying on 10-15 feet of sand which lies on dense blue lake silty clay. It therefore becomes evident that all these terraces of the Morrisville area are part of the shore phenomena of the 800 foot lake which has been notched as the water level fell from 800 to 720 and then to 670 feet, and that the beach gravel was reworked and strewn at these different levels.

The village of Hyde Park, two miles away, on the north side of Lamoille River is likewise on a 670 foot beach gravel-covered terrace which probably had somewhat the same history.

Late Glacial Lakes

<u>Origin</u>. Since the early work on the beaches of the Great Lakes, and the Baltic Lakes these beaches have been observed and mapped as rising toward the centers of glacial radiation, and isobases have been drawn between points of equal rise. It has been inferred that the load of ice pressed down the crust and allowed it to rise as, and after the load was relieved when the ice melted. This matter is discussed in innumerable articles and books. One of the most extensive is that by R. A.Daly (1934) in which he not only presents data on the depressed area but also discusses the evidence for a "superelevated marginal belt" which was produced by the outward translation of crustal material from under the depressed area as well as elastic uplift, (Daly p. 129). This marginal bulge subsided with the melting of the glacier and return of material to the central area. Recently John Frye (1963) has had calculated for the region of Illinois that the bulge there could have been as much as ~~200~~ two to five hundred feet depending on the width of the bulged area.

If similarity with Scandinavia may be assumed for North America we would have had the marginal bulge about 800 miles out from the center of the depression; which would place it somewhere across central Vermont and the south end of Lake Champlain.

The late glacial lakes in the valleys of Northern Vermont then are the result of both the downwarping northward of the land and also the upbulging of the terrain across which their outlets must have flowed.

The synchronization of these two processes was doubtless very complex in detail and has resulted in the multiplicity of the lake levels which the present detailed survey has shown. Earlier workers with limited time, transporation, and lack of accurate topographic maps, lumped the lake levels into a few generalized episodes such as Glacial Lake Memphremagog (Hitchcock, 1906), and Lake Lamoille, (Merwin 1908). These are major shoreline features at 1000 feet at Barre and Plainfield on the Winooski, and at 1100 feet at Morristown and Hardwick on the Lamoille, but since all the valleys contain lake sediments as well as scattered remnants of shoreline deposits it seems premature at this time to attempt to write the detailed history of the lake levels.

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Till Fabrics

(1) Till, LakeviewInn, Greensboro

(2) Barr Hill Road, 1 mi. NNE of Greensboro

(3) 1 Mile ENE of Greensboro

(4) 1/4 mi. NE of Hartwell Pond NE corner Hardwick Quadrangle

(5) 1/4 mi. east of East Albany

(6) Barrow pit of "North Side" Road, Greensboro

(7) Road corner of North-Side Road and Hazen Road, Greensboro

(8) Road cut 2 mi. north of Barre

(9) Gunners Brook 1 1/2 mi. North of Barre

(10) Ablation Till, 1/2 mi. North of East Greensboro

(11) 1/2 mi. N.W. of Stannard, dense buff till on upland

(12) Ablation till, 1 3/4 mi. southeast of Greensboro

(13) Till, dense, 1 1/4 S.E. of Greensboro

(14) Compact basal till, 1/4 mi. N.W. Waldon Heights, Plainfield Q. F.M. Topography

(15) Dense silty basal till, 1 mi. N.E. of Hardwick

(16) Dense buff till, 3/4 mi. S.E. of East Hardwick, road cut at bottom of hill

(17) Till, silty, buff gray basal till, S.E. edge of East Hardwick, road cut

Till Fabrics

(18) Ablation till, Buff, Uplands, 3/4 mi. N.W. of North Wolcott

(19) Till at Junction Route 15 and 16, east of Hardwick

(20) Till, 3.1 mi. S.S.W. of Wolcott road cut on Upland

(21) Ablation till, 2 mi. west of Craftsbury Common

(22) Blue-Gray Basal till, Wild Branch, 2 miles N.E. of North Wolcott

(23) Buff till, Road cut 1 mile south of Hardwick Street

(24) Till, basalt, silty, in small moraine

(25) Ablation till, Road cut, 1 1/4 mi. S.S.W. of Craftsbury

(26) Till, 1 1/2 mi. S.E. of North Hyde Park

(27) Dark buff calcarious basal till, Road cut 1/5 mile south of Four Corners Lyndenville Quad.

(28) Till, 1 mi. N.E. of Morrisville

(29) Till "A", Section 3 Stannard Brook

(30) Till "B", Section 3, Stannard Brook

(31) Till "A", Section 1, Stannard Brook

(32) Till "A", Section 2, Stannard Brook

(33) Till "B", Section 2, Stannard Brook

(34) Till "C", Section 2, Stannard Brook

Till Fabrics

(35) Till, "C", Section 3, Stannard Brook

(36) Till "B", Section 6, Stannard Brook. (1 1/2 N. Greensboro Bend)

(37) Till "C", ablation till, Section 6, Stannard Brook. 1 1/2 mi. n. Greensboro Bend

(38) Till "B", Section 5, Stannard Brook

(39) Till "B", Section 1, Stannard Brook

(40) Ablation till, Goose Green Cemetary, Plainf~~boro~~field Quad.

(41) Till, basal, on 36' lake sand east edge of Goose Green, Plain~~sboro~~field Quad.

Table I

Episodes	Section #1	Section #2	Section #3	Section #4	Section #5	Section #6
Glaciation From N.W.		Till "D" Fabric N 25-30° W		Lake Sediment		
Glaciation From N.E.		Till "C" Fabric N 30° E	Till "C" ablation Fabric N 30° E		Lake Sediment	Till "C", ablation Fabric N 25° E
Ice-Free Lake Sediment	Lake sand beach gravel				Beach Gravel	
Glaciation From N.W.	Till "B" Fabric N 55° W	Till "B" Fabric N 50° W	Till "B" Fabric N 50° W Many Quartz pebbles in bottom	Till	Till "B" Calcareous clayey Fabric 60° W	Till "B". Calcareous sandy Fabric N 55° W
Ice-Free Lake Sediment	Lake clay	Lake clay and silt	Lake sediment	Lake Sediment	Lake clay Dense gray-buff Non-Calcareous	Lake Silts & sands Varves Non-Calcareous.
Ice-Free alluvial Gravel Oxidized		Gravel brown many quartz pebbles	Gravel brown Quartz pebbles		Gravel, brown Quartz pebbles	Gravel, fluvial, brown non-calcareous Quartz pebbles
Glaciation From N.W	Till "A" Fabric N 35° W	Till "A" Fabric N 35° W	Till "A" dense, buff fabric N 35° W		Decayed Bedrock	Slump with Seepage on ? Till "A" ?
Weathering	Decayed Bedrock	River level	River level			

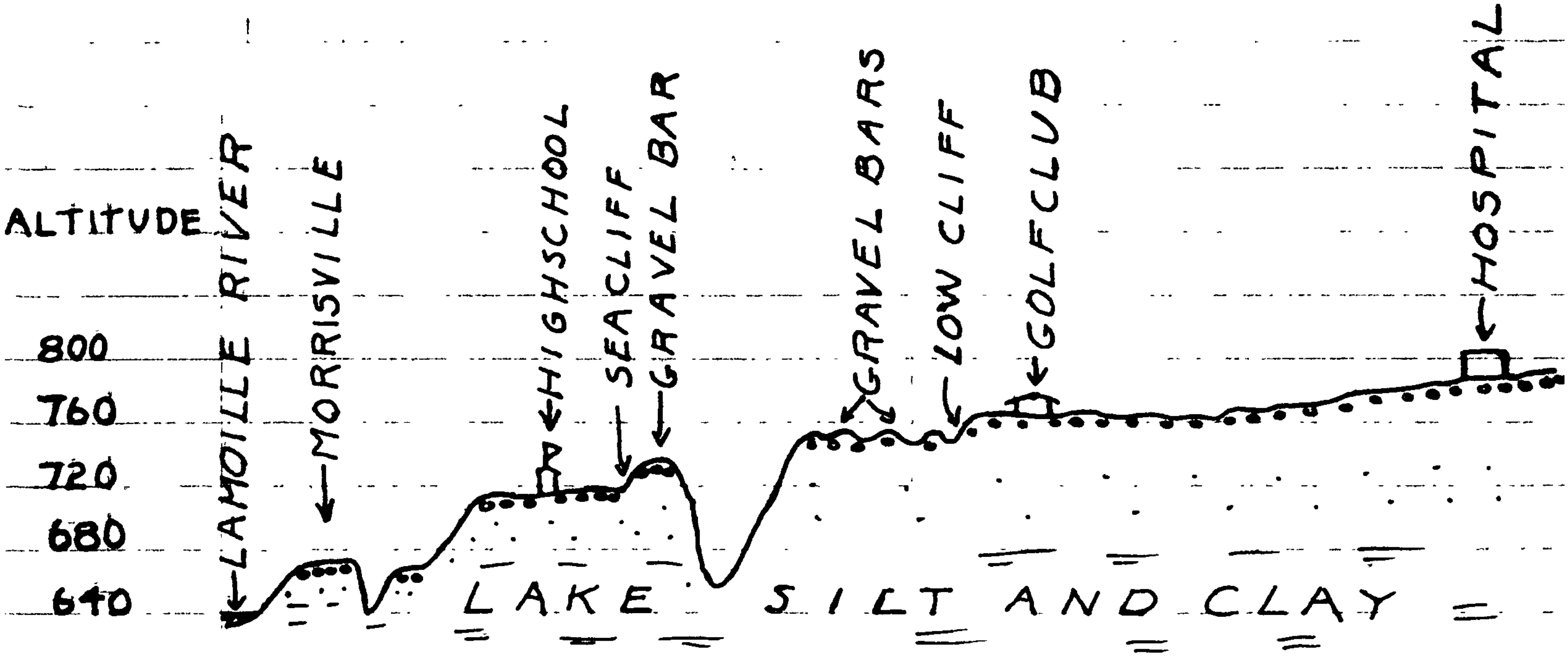
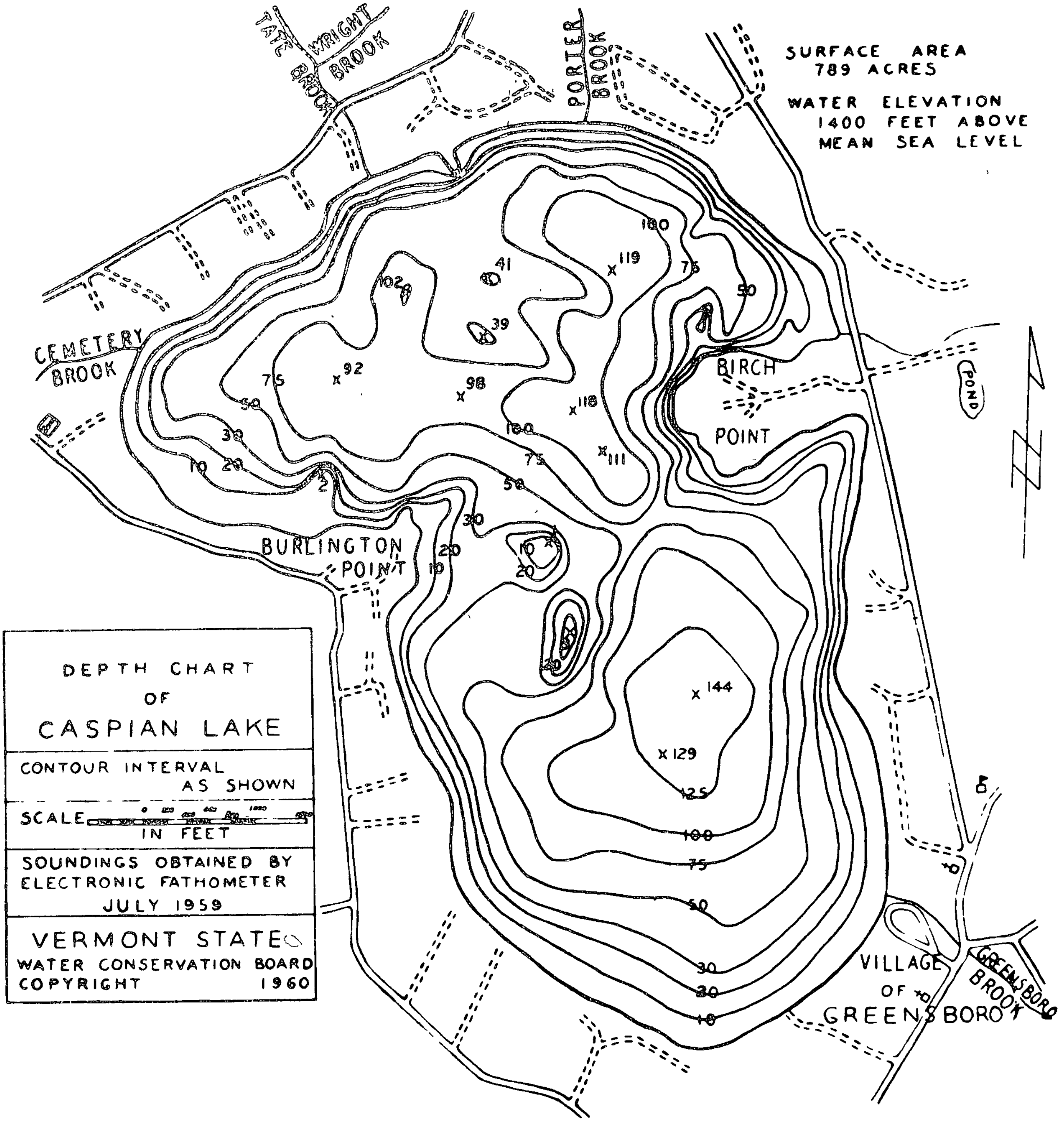
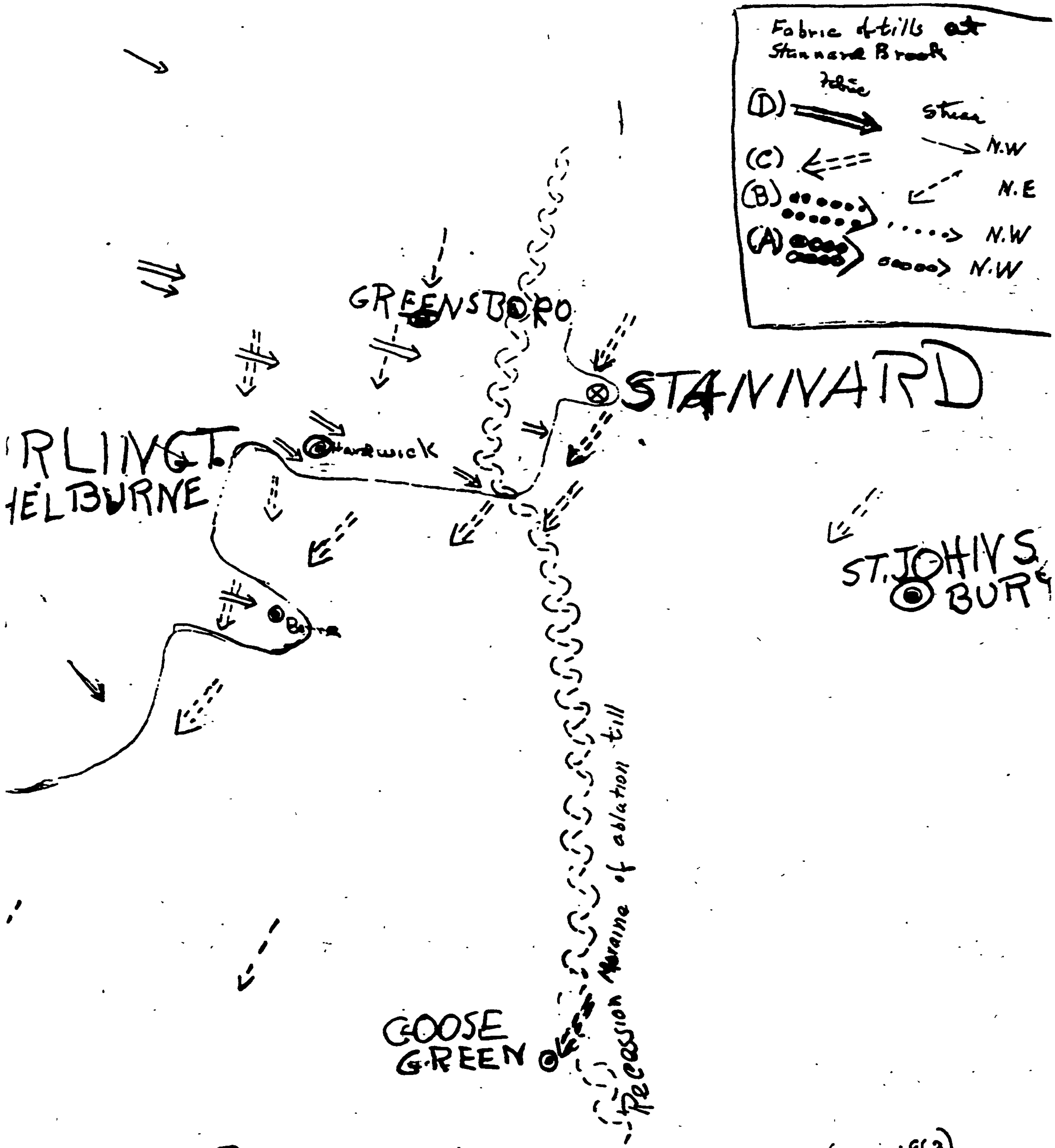


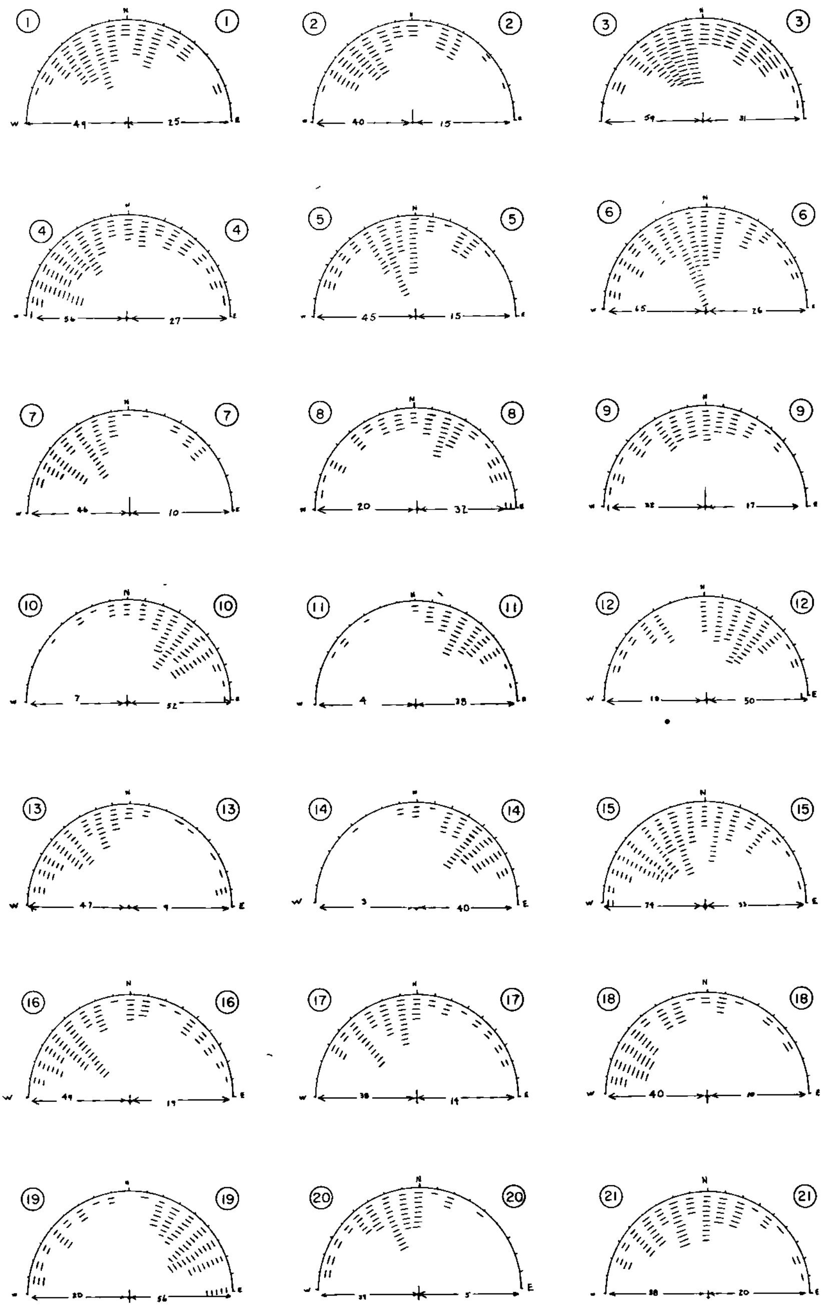
Fig. 66. Diagram of Gravel-capped terrace levels at Morrisville Vt. Section about a mile long.

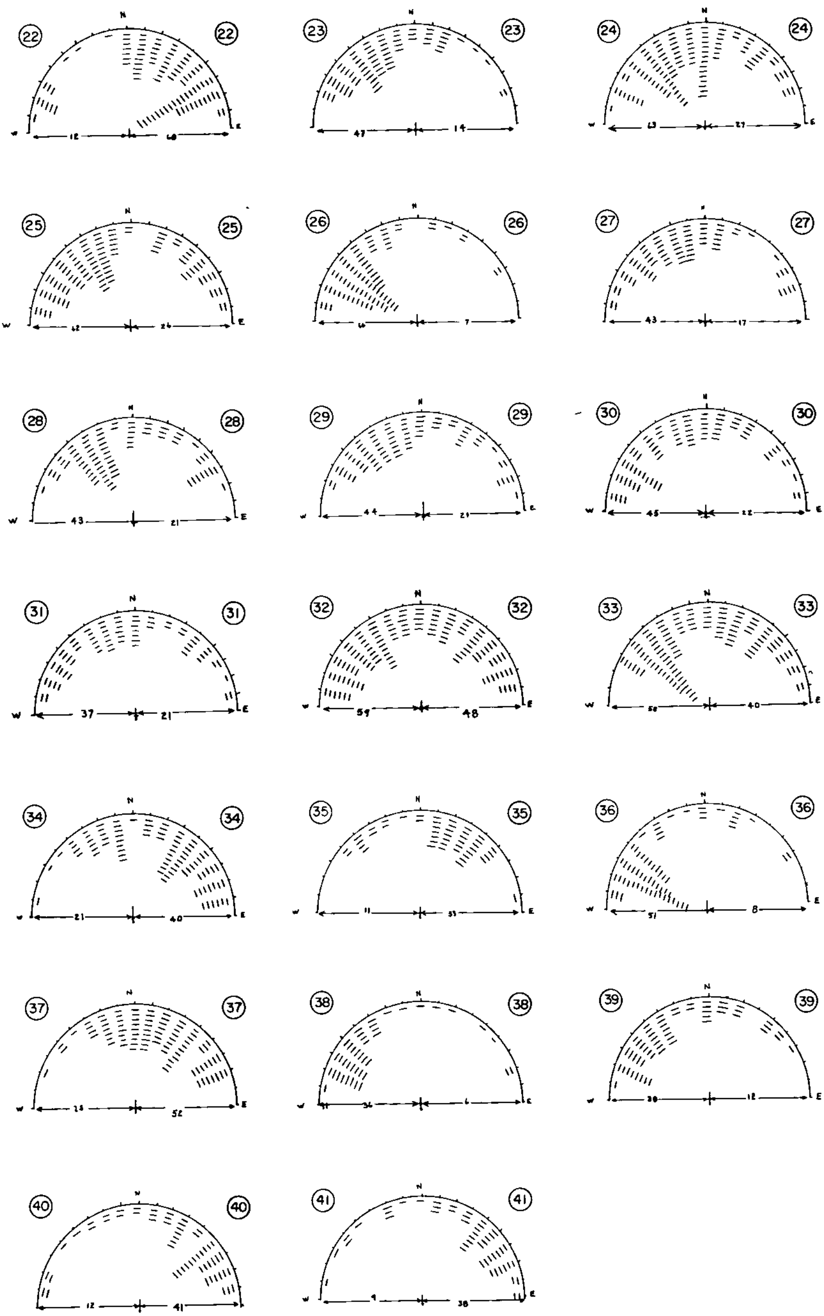


The chart above is reproduced with the permission of the Vermont State Water Conservation Board. Eventually copies of this chart will be made available to the general public, the Board planning to issue them in reports covering the entire State but as yet funds to do so have not been allocated.



liminary Diagrammatic Distribution (as of 1963)
of Ice Lobes in Northern Vermont
compatable with Stannard Brook Section





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