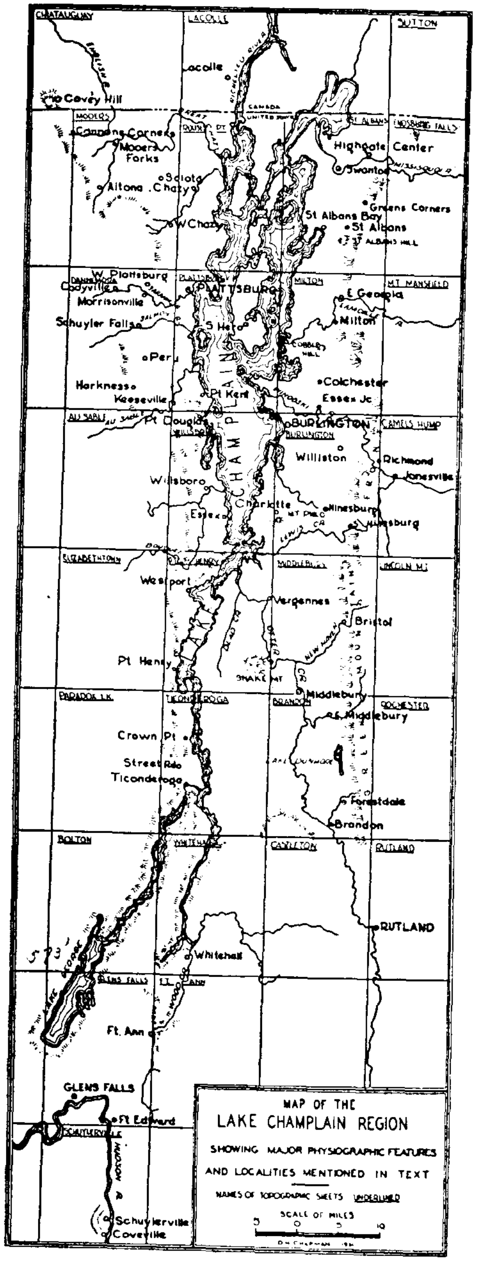

Fig. 9. Map of the Lake Champlain region, showing the major physiographic features and localities mentioned in the text.

Late-Glacial and Post-glacial History of the Champlain Valley [1]

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ABSTRACT

Precise levelling of the elevated shore features on both sides of the Champlain valley shows clearly two stages of glacial Lake Vermont, while, later, the sea flooded the valley southward from the St. Lawrence estuary only as far as Whitehall, N. Y. Thus New England was never cut off as an island in the late-glacial sea. Parallelism of the three major water planes in the valley shows that there was a long period of stability which ended soon after the marine water invaded the valley. This period of stability during the life history of Lake Vermont corresponds to stability in the Great Lakes region during Algonquin time while the period of tilting initiated soon after the marine invasion corresponds to tilting in late Algonquin time. Isobases drawn across the area are in harmony with those already drawn for northeastern North America.

INTRODUCTION

Lake Champlain,[2] occupying the bottom of a preglacial trough[3] between the Adirondack Mountains of New York and the Green Mountains of Vermont, is a very long and narrow body of water, exceeding a width of ten miles only in the latitude of Burlington, Vt. The level of the lake is held at 92.5 feet above the sea by the threshold across which the Richelieu River carries the outlet waters north to the St. Lawrence. Southward there are two narrow passes into the Hudson Valley; one at the southern tip of Lake George (573 feet) and a much lower one several miles north of Fort Edward, N. Y. (147 feet). North of Ticonderoga, the lake is bordered by clay lowlands, continuous with those of the St. Lawrence. These low rolling clay plains are much broader on the Vermont side of the valley and here they are interrupted by occasional hard rock hills rising out of them like islands out of the sea.

During the "Great Ice Age," the climate of North America, together with that of the rest of the world, grew colder. Ice accumulated over parts of Canada and, nourished by continuous snowfalls, spread southward over northern United States. When the ice-sheet reached maximum size, it extended southward along the Atlantic Coast as far as Long Island, and buried

1 The original article has been considerably changed by Professor Chapman in order to adapt it to this Report. It appeared in the American Journal of Science, vol. 34 (1937) and is reproduced by courtesy of this Journal.

2 The lake is 107 miles in maximum length and it extends five miles into Canada. The maximum width is ten miles, this at about the latitude of Burlington. The lake is about 92.5 feet above mean sea level.

There are some eighty islands, of which Grand Isle, North Hero, Isle La Motte, and Valcour are the largest.

The area of the lake is, in New York, 151 square miles; in Vermont, 322; in Canada, 17; total, 490 square miles. The combined areas of the twelve largest islands is 55 square miles, leaving the water surface, 435 square miles. (U. S. Coast & Geodetic Survey data.)

The deepest channel of Champlain runs a sinuous course, first between the New York shore and Isle La Motte and Grand Isle, then nearer the middle of the lake to Split Rock and Thompson's Point, south of which, it trends more towards the New York side as far as the latitude of Port Henry, beyond which it continues south through the narrow part of the lake and up East Bay to Poultney River. The deepest sounding, 399 feet, is a little over two miles north of Split Rock Point.

3 In pre-glacial times a river must have run through this trough, probably southward.

the highest mountain tops of New England. Even Mt. Washington, in New Hampshire, highest peak in northeastern United States, was covered.

Less than 100,000 years ago, when the climate began to ameliorate, the ice began to melt. Not only did it shrink northward, but it also melted down from the top so that great lobes of ice lay in the deeper valleys long after the hill tops were bare. Such a great lobe occupied the Hudson-Champlain valley in late glacial time. Northward, it merged with the great flat dome of the ice-sheet itself, stretching off in a monotonous ice-plateau toward northern Canada.

It has been long recognized that as this lobe of the Pleistocene ice-sheet receded north through the Champlain Valley, an open body of water grew northward with it, finally occupying most of the valley between the Adirondacks and the Green Mountains. The discussion that follows describes the events that transpired in the Champlain Valley during the retreat of the ice, and later. Such questions as whether the water in the valley then was entirely or only for part of the time marine, what outlets there were for any bodies of fresh water, from which direction the invasion of marine waters came, whether post-glacial tilting of the entire region was occurring during the recession of the ice—all had to be answered before the story could be told. In order to interpret the history of the Champlain Valley properly, the physiographic features related to this history of the Valley first have to be understood.

ASSEMBLY AND INTERPRETATION OF DATA

As the ice which had buried New England so completely, began to melt away, the mud, sand and other débris which had been frozen solidly into the glacier were left behind or were washed out by melt-water streams and covered the valley bottoms. There were other features, too, left behind either by the glacier or indirectly as a result of glaciation, which today give us a clue to the physical conditions during ice recession. A complete classification of such glacial features would include four categories: (1) glacial, (2) glaciofluvial, (3) glaciolacustrine, and (4) glaciomarine. Only those features which aid directly in the unravelling of the late-glacial and post-glacial history of the Champlain Valley itself are discussed fully here.

(1) GLACIAL

(a) *Glacial striae:* Scratches made in rock surfaces by rocks and pebbles, held solidly in the glacier's icy grasp as it moved slowly forward across rock outcrops, are common. Plotting of such striae show that the ice moved southward through the valley.

(b) *Moraines:* "Glacial dump piles," deposited directly by the ice as it melted, but without any redistributions by melt-water. They are patchy in character and their importance in the present discussion is slight.

(c) *Drumlins:* There are only a few good drumlins in the valley.

(2) GLACIOFLUVIAL

(a) *Outwsah plains:* Sand and gravel, washed out by the ice by melt-water, were deposited as broad, flat, alluvial plains. A feature of this sort may

terminate abruptly where it was built against the ice, forming a steep "ice-contact" slope which indicates the position of an ice front.

(b) *Eskers:* These are numerous in some of the tributary valleys.

(c) *Kames:* Humocky hills of gravel and sand accumulate wherever the material melted from the ice could not spread out freely because of ice obstructions. They are common in the Champlain Valley. Some very excellent ones occur about four and one-half miles north of Enosburg Falls, Vt.

(d) *Kame Terraces:* Composed of gravel and sand, often poorly sorted and mixed with till, with their surfaces pitted with kettles. These features were developed where drainage from the highlands coalesced with thaw-water from the ice in the depression between ice lobe and valley wall. Flowing down-valley parallel to the edge of the ice, these waters resorted old morainal material into a more or less evenly graded stream bed, one side of which was a valley wall, the other the ice. Much additional glaciofluvial material was added by melt-water. When the ice melted, the invalley portion of the stream bed slumped, resulting in long, spectacular benches which have sometimes been mistaken for wave-built terraces. Fairchild (8) so mistook the South Hinesburg kame terrace, southeast of Burlington, Vt. Since kame terraces were formed by water flowing rapidly down a relatively steep gradient, above standing water level, they allow a minimum estimate of the height of standing water at a given place and time.

(3) GLACIOLACUSTRINE AND GLACIOMARINE

Whether the features listed below were formed in marine or in fresh water must be determined by criteria other than form and shape for a delta or a beach, built into marine water, has the same appearance as one built along the shore of a lake, such as the one occupying the Champlain Valley. Hence these two categories may be discussed together.

(a) *Varved clays:* Seasonally banded, or "varved" sediments are found in the valley but have not been examined or correlated by the author.

(b) *Marine clays* can be identified by their content of marine fossils.

(c) *Beaches:* Wave-heaped ridges of sand and gravel, are found in greatest numbers on the less exposed western slope of the valley. The altitude of the crest of each beach was measured with a fourteen-inch Wye level, though the water surface was probably a few feet lower. In each measurement of beach crests, a variation of several feet in the maximum crest height of any particular beach seemed reasonable, since a vertical range of five to seven feet can easily be explained as a result of the work of a single storm. Extreme seasonal variations of water level are known at present to exceed ten feet. Possible temporary plugging of the earlier, narrow outlet southward at Fort Ann by floating icebergs might explain a vertical range of as much as 25 or 30 feet. Thus it is not

a, b, c, d above: See The Great Ice Age in Vermont.

necessary to invoke a change of outlet, or permanent change of water level, for every beach of a given vertical series. The northerly component of the wind which seems probable if the glacial anticyclone[1] (17) were here still in effect during the waning stages of the ice-sheet, is betrayed by the prevailing southerly developed hooks on many series such as at Peru, N. Y.

(d) *Wave-cut and wave-built terraces:* Though found occasionally on the New York side, these are most numerous in Vermont. The waves did not beat long enough on the shore to erode the bedrock, and even the glacial till was barely modified into rude terraces with boulders strewn over their surfaces. Since the brow of such features varies in altitude, the base of each cliff was measured, though it is recognized that the water stood a few feet lower.

Conditions favoring the formation of beaches and terraces vary so much that one cannot expect that they will be developed along the entire strand line, and gaps of several miles without shore markers are common (Profiles, Figures 12 and 13). North and south of such gaps, and on the opposite side of the valley, however, abundant shore features have been located, thus substantiating the water levels. On the other hand, the interpretation of water levels with gaps of many miles without substantiating features on one side of the valley or the other, must remain in question.

(e) *Normal deltas,* built by streams flowing into the earlier standing water bodies in the Champlain Valley were used in this study, but in the profiles (Figures 12 and 13), a symbol had to be employed which could be expanded to show the variation in altitude of the relatively flat surface of the delta itself.

(f) *Proglacial deltas* were built against the ice edge, into standing water. An ice-contact slope reveals the exact position of the ice front during the time that each feature was being built.

(g) *Kettles,* while not glacial deposits, are mentioned in this connection because they have been used in an attempt to state the maximum level of standing water in a valley. The argument is that had standing water rested in the valley to a height above the surface in which they were found, the holes must have been filled with detritus. Since ice may persist a great many hundreds, or even thousands of years, beneath gravel and sand before melting, the presence of unfilled kettleholes gives no real clue as to the height of water in the valley.

PREVIOUS WORK

While early mention of the problems in the Champlain Valley was made by Emmons (6), C. H. Hitchcock, E. Hitchcock and others (16), and Upham (24), it was Baldwin (3) who first definitely recognized two series of elevated shore features on the New York side of the valley, only Woodworth (25, 26), Fairchild (7, 8, 9, 10, 11, 12, 13) and Merwin (20) based their conclusions on extensive field studies. The method of plotting field data has been essentially the same in each study, including the present one. The altitude of each shore feature (beach, terrace, or delta) is plotted on a north-south profile of the valley. When all data are represented on such a profile, the features fall on inclined lines, which mark the uplifted and tilted surfaces of former bodies of water in the valley (Figures 12 and 13). The present study is the first to employ such water planes from both sides of the valley.

[1] The presence of the vast ice-sheet had its modifying effect on the normal westerly winds with their cyclones and anti-cyclones, producing anti-cyclonic winds that blew off the ice. The effect is present today in Greenland and Antarctica.

Woodworth (26) constructed three such tilted water planes, namely, Coveville and Fort Edward stages of Lake Vermont, and the Upper Marine Plane, which sloped toward the south at an approximate rate of four feet per mile. Fairchild believed the beaches were the result of wave action in a narrow strait extending from New York to Montreal. He drew but one plane, representing the maximum submergence, by connecting the highest beaches in each vertical series (13). He considered the lower beaches as waning stages of the marine invasion. His single water plane does not have a uniform tilt, but slopes more steeply near the Canadian boundry. Merwin's (20) work was limited to an area north of Middlebury, Vt., where he recognized five water planes, the highest having the steepest tilt rate (5.9 feet per mile). The present interpretation more closely follows that of Woodworth than Fairchild, but there are certain important respects in which this interpretation differs from all previous ones.

SUMMARY OF LATE-GLACIAL EVENTS IN THE CHAMPLAIN VALLEY

The Hudson-Champlain Valley during the wastage of the ice was occupied by a great ice lobe fed from the north, while the surrounding highlands were more or less free of ice. As the ice front receded a body of water, expanding northward in the valley, followed it so that the nose of the lobe was continually bathed in water. Varved clay in the Champlain Valley is in itself proof that this water was fresh at least for part of the time. Further proof of the existence of fresh water is described in this paper.

While the Champlain Valley itself was still entirely occupied by its great ice lobe, a body of water called "Lake Albany" (26, p. 175) lay against the ice front in the Hudson Valley. During the later stages of Lake Albany, when the ice front stood north of Schuylerville, gentle uplift of the region was taking place (5). Gradually great portions of the Hudson Valley south of Schuylerville emerged from beneath the waters of Lake Albany until the falling water uncovered an obstacle to its further recession in a rock ledge at Coveville, three miles south of Schuylerville, which held back the water north of this point to form a new glacial lake: "Lake Vermont." During the recession of the ice in the Champlain Valley, Lake Vermont grew to great size and for a while continued to make use of the outlet at Coveville. Later, a lower stage of the same lake had a more northerly outlet.

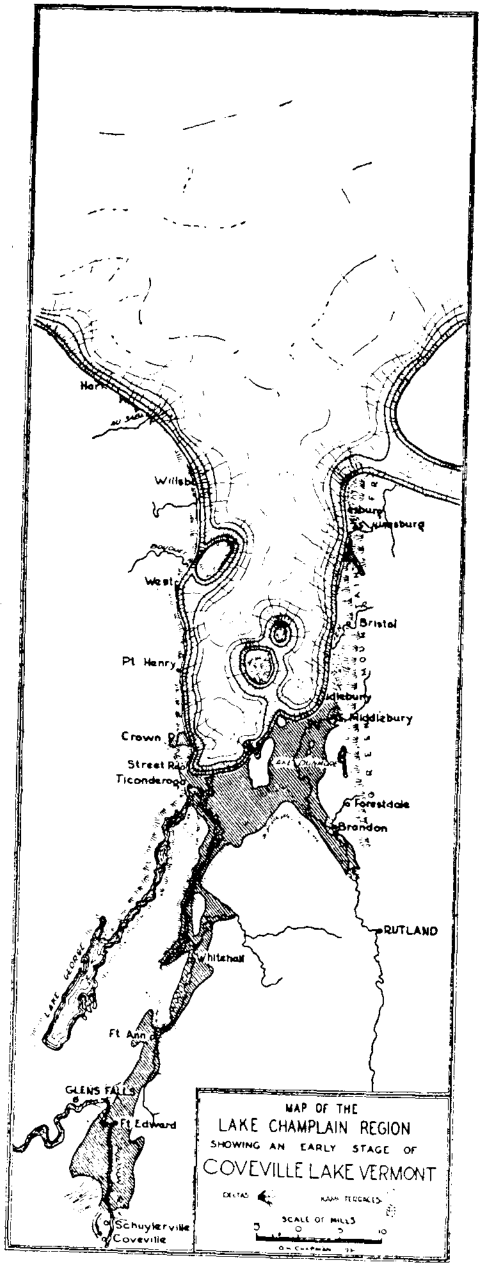


Fig. 10. Coveville Lake Vermont.

COVEVILLE LAKE VERMONT
(Figure 10)

As may be seen from the profiles (Figures 12 and 13), the elevated shore features in the Champlain Valley fall on a series of planes, rising to the north. The uppermost plane may be traced from near Ticonderoga, N. Y., and Brandon, Vt., where the altitude is about 450 feet, northward to Plattsburg, N. Y., and Milton, Vt., where the altitude is about 700 feet. This plane is believed to mark the earliest stage of Lake Vermont and, when projected southward, it leads directly to an abandoned channel of the Hudson River fifteen miles south of the city of Glens Falls, N. Y., and two miles west of Schuylerville. This channel, the "Coveville Outlet," has been described by Woodworth (26, pp. 196-7), and more recently discussed by Fairchild (10, pp. 10-11) and Stoller (23). At Coveville, where the southern end of this channel overhangs the Hudson River by more than a hundred feet, is a rock ledge which acted as the controlling threshold for the waters during the Coveville stage of Lake Vermont.

Whether or not Lake Vermont extended northward as far as the Champlain Valley at the time of its birth cannot be said, but surely before long the ice withdrew across the Hudson-Champlain divide near Fort Edward and the lake history of the Champlain Valley began (Figure 11).

Gentle uplift and tilting, which was going on during the final stages of Lake Albany (5) possibly continued for a while as Lake Vermont grew northward into the Champlain Valley, for there are a few scattered deltas and at least one set of indistinct beaches above the true Coveville plane as far north as Bristol, Vt. Woodworth (26, p. 193) described some such features in New York, which he correlated with an earlier Quaker Springs stage of Lake Vermont, and Barker (4) has more recently described similar features near Crown Point, N. Y. The best of these structures are plotted on the profiles (Figures 12 and 13). On account of the meager development of these features in the Champlain Valley, the present writer inclines toward the view that many of these features at high levels were formed in local lakes or by water liberated from such local lakes escaping around mountain spurs, and he does not feel justified in recognizing the existence of a pre-Coveville stage of the glacial lake history of the Champlain Valley.

MAIN COVEVILLE STAGE

Since the lake grew wider and wider as the ice front withdrew, the reach of the waves lengthened and hence the northern beaches and terraces are better developed. On the New York shore, the waves reworked the coarse material of the kame terrace at Sawyer Hill, three miles north of Ticonderoga, into a terrace (468 feet).[1] A still more perfectly developed terrace, whose surface is covered with assorted cobble, lies at 448 feet on the east slope of the same hill, running through the small cemetery west of the road.[2] This altitude

[1] All altitudes given in this paper were precisely determined by Wye-level, unless otherwise indicated.
[2] As nearly as could be ascertained from Fairchild's description, this is the "shelf-bar" (13, p. 43).

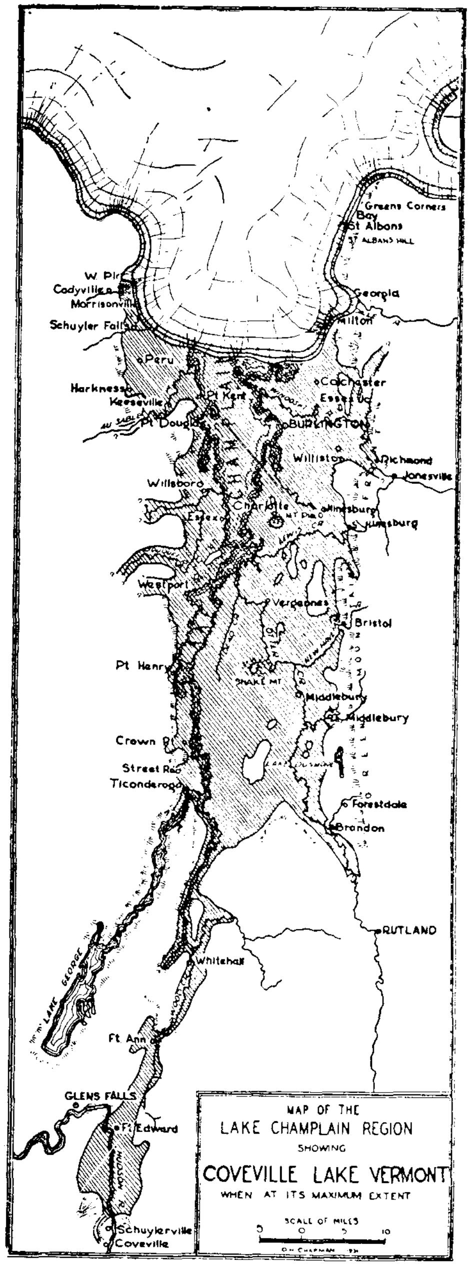
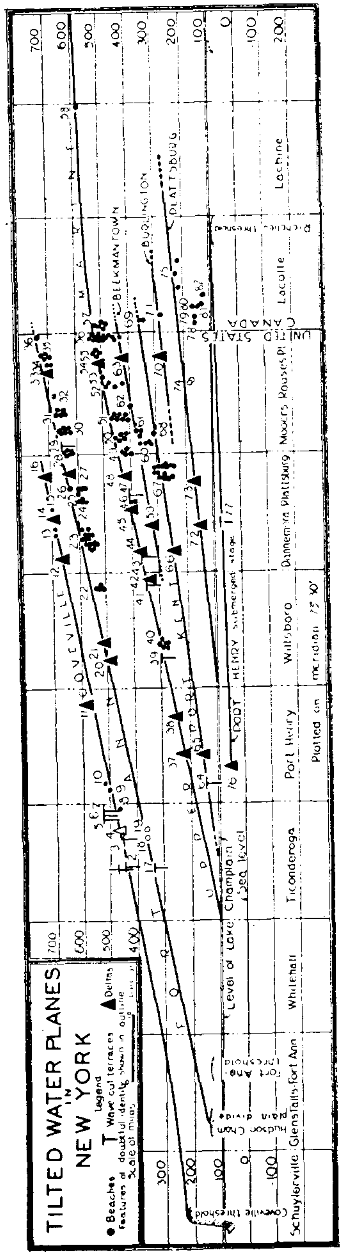


Fig. 11. Coveville Lake Vermont at its maximum extent.



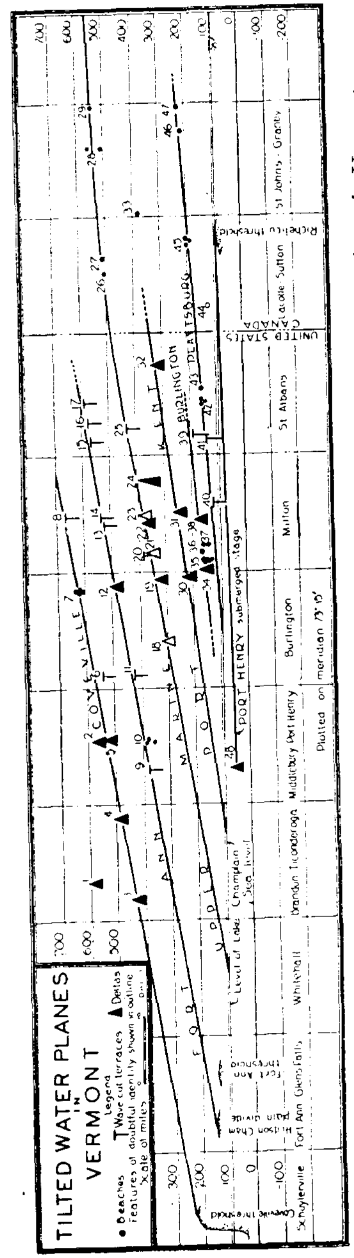


Fig. 12 (*above*): Tilted water planes in New York. Fig. 13 (*below*): Tilted water planes in Vermont.

places this feature on the Coveville plane. Coveville features in the vicinity of Crown Point village have been described by Barker (4). The beaches described by Woodworth (26, Plate 16), near Port Henry village, fall directly onto the plane as does the Elizabethtown, N. Y., delta of the Bouquet River. The Coveville delta of the Little Ausable River, a mile west of Harkness, at an altitude of 660-665 feet (barometer), is pictured by Fairchild (13, Plate 14).

Two miles west of Peru Village is Clark School. Two Coveville beaches, with an altitude of 685 feet, lie across the first east-west road south of this building, where the road turns southwest at a point one mile west of the schoolhouse; other Coveville features can be seen on the profile (Figure 12). The delta that the Salmon River built into Lake Vermont during the Coveville stage may be observed at the foot of Terry and Burnt Hills near Peasleville. Two and one-half miles west-northwest of Schuyler Falls, just west of the four corners, with an altitude of 677 feet, lies a splendidly developed beach (696 feet).

The Saranac River built a fine series of deltas into Lake Vermont and finally into the sea; the highest of these is conspicuous on the Dannemora topographic map one mile east of Cadyville village. Its level, gravelly surface at 729 feet (barometer) is interrupted by a series of shallow, partially filled kettleholes.

In the vicinity of Middlebury and Brandon, Vt., before the Champlain ice lobe had melted away sufficiently to open the valley for Lake Vermont, streams made their way down the slopes of the Green Mountains, encountered the ice, turned south, and continued their escape along the margin of the ice lobe. Melt-water from the ice constantly swelled their size. Sometimes temporary lakes and pools were formed where the mountain wall pressed hard against the ice; elsewhere the streams flowed rapidly through channels bordered on one side by the ice and on the other by the hill slopes. Everywhere the water was muddy with its heavy load of glacial débris. As this material was dropped, a graded valley floor was built, which was left as a kame terrace after the ice melted.

Thus did the New Haven, Middlebury and Neshobe Rivers behave during the early lake history of the valley. Water from the New Haven valley east of Bristol, dammed for awhile in the deep trench east of Hogback Mountain, escaped south along the base of South Mountain. The gravel and sand along the road between New Haven Mills and East Middlebury, at "The Cobble"; north and south of Dow Pond, and at East Middlebury village were deposited in this fashion. Likewise the Middlebury River, escaping south at the west base of Bryant Mountain, is responsible for the coarse gravels near there. Later, when the water dropped to a lower level (but still above the level of Lake Vermont), it escaped around the hill farther west, and scoured narrow terraces out of the gravels which had been deposited earlier. Other similar kame terraces are found near Fernville, a mile east of Leicester, and from Forestdale south toward Rutland.

Before the entire Brandon area was free of ice, the ice front may have blocked Otter Creek Valley from Forestdale to Government Hill, near Sudbury, and a local glacial lake may have been impounded in that valley south of Brandon. When the ice melted from the north slope of Government Hill, the waters escaped west and south into Lake Vermont. In doing so, the escaping water scoured the till-covered hills northeast of Sudbury, producing rude terraces that have been mistaken for wave-cut features.

Finally, however, the ice melted and Lake Vermont spread over the Middlebury-Brandon area. Otter Creek valley was still flooded to a point several miles south of Brandon. Waves of Lake Vermont washed against the hill slopes west of Lake Dunmore, while Snake Mountain and the hills between Salisbury and Shoreham stood out as islands, completely surrounded by lake waters. Every stream was now free to build a delta into Lake Vermont, according to its size and load. The Neshobe River reached the edge of Lake Vermont where Brandon village now stands, and the flat, sandy plain (430 feet, barometer), on which the town is built represents the surface of the delta of that stream. North of the town, the valley of Otter Creek was still under 100 feet of water and only the finest muds were carried out this far. Meanwhile, the Middlebury River was entering the lake at East Middlebury and here again a flat, sandy, plain (480 feet, barometer) marks the surface of its delta. Gravel knolls and sandy hills at a higher elevation, both north and south of the river valley, are but part of the great kame terrace mentioned above.

Similarly around Burlington, before the waters of Lake Vermont had spread thus far north, rivers deposited sand and gravel along the margin of the ice lobe which still stood against the slopes of the Green Mountains. Tributary streams, and outlet waters from temporary, ice-dammed lakes in the hills, built huge kame terraces, similar to the ones found farther south. One such is the conspicuous terrace at South Hinesburg, seventeen miles southeast of Burlington, previously interpreted as a delta of Hollow Brook (20, p. 119; 8, p. 24). North of this "delta" for some distance there is an accumulation which Fairchild described as "storm bars" and other shore features. But the agreement in height of all these features, as well as the similar southward-dipping beds of coarse gravel and sand, leads the author to interpret them as parts of a huge kame terrace, formed when the drainage escaped from glacial Lake Winooski around the shoulder of Yantz Hill and southward along the mountain front toward the open waters of Lake Vermont.

Eventually, however, the ice dam melted from the mouth of the Winooski valley, and the water dropped to the level of Lake Vermont. By this time the ice had melted from over the Burlington vicinity and the open water of Lake Vermont spread east to the mountain slopes. Then, and not until then, did the Coveville features in the Burlington vicinity began to be shaped by shore agents and streams. The level of Lake Vermont during the Coveville stage at Burlington was about 640 feet, or 545 feet above present lake level. Thus, even the hills east of the city were submerged, and the site of the village of Williston lay 140 feet below lake level. The valley of the Winooski River west of Richmond had not at that time been excavated and the river entered the lake at a point east of that village. The exact position of the delta is impossible to determine because, later, the water level dropped and the material was redistributed, forming the sand plains at lower levels east and north of the city of Burlington.

However, North Williston Hill stood out as a small island during this phase of lake history. On the east slope of this hill there is a set of beaches and the highest water level marker is at 641 feet, but the "sloping bar" (8, p. 25), and other "bar-like" features, as well as the "prominent cliff and terrace," are not wave formed.

Some of the sharp, isolated hills south of Burlington also stood out of Lake Vermont as islands. Mt. Philo and Pease Mountain in the town of Charlotte were thus surrounded by the lake. On Mt. Philo there is considerable evidence of wave work. Although Fairchild (8, p. 26) thought that wave work had extended up to his "summit plane" at 640 feet, there really is no good evidence of standing water against the slopes of this hill above 540 feet, where a terrace is cut by the waves into the till mantle at the second horseshoe curve in the road ascending to the summit (Figure 15).

North of the Winooski Valley the shoreline of Lake Vermont lay against the higher hills in the towns of Essex, Westford and Milton. The valley of Browns River was flooded by nearly 200 feet of water and Brigham Hill stood out as an irregular island rising to nearly 400 feet above lake level. Another, smaller island, was Cobble Hill (Figure 16), in the town of Milton. There are no wave-formed features at the height of the Coveville water plane, since the slope at this critical height (670 feet) is entirely too steep. Nor are there many other well-developed shore features in the immediate vicinity. However, one and one-half miles southeast of Milton village, the surface of a fine terrace is strewn with cobble. Its continuity for over one-half mile and its breadth of over 100 feet make it one of the finest wave-cut features in Vermont. Since the altitude of the base of the cliff above this feature (666-668 feet) varies only a very few feet in its entire length, there seems to be good reason for considering this as a wave-carved, rather than an ice-marginal, terrace. Careful search along the slopes of hills north of Milton brought to light no further features belonging on the Coveville water plane.

The shoreline of the Coveville stage of Lake Vermont cannot be traced northward into the St. Lawrence and from there to the sea, as might certainly be expected were the features so far described marine, as Fairchild held. In fact, the Coveville features do not even reach the northern end of the Champlain Valley. The Cadyville delta near Plattsburg, N. Y., and the Milton terrace in Vermont are the most northerly features on this plane. Apparently, when the ice front stood in the latitude of Plattsburg and Milton, this stage of Lake Vermont came to an abrupt end. This occurred when the Hudson gorge near Schuylerville was re-excavated and the water in the valley fell to a lower level. This level was determined by a new, more northerly threshold near Fort Ann, N. Y. Hence the following stage of Lake Vermont has been called the "Fort Ann stage." Although Lake Vermont during this time had essentially the same outlet as Woodworth's "Fort Edward" stage, different beaches have been correlated with this outlet and the lake therefore had a slightly different outline.

After the uplift, which may have been going on during the initial stages of Lake Vermont, had ceased, there was no differential uplift of the land until the ice had completely disappeared from the area and the marine waters had taken possession. The stability of the land during this long period is proved by the single set of shore features (*i.e.*, not a series of wide vertical range) everywhere developed by the Coveville and Fort Ann stages of Lake Vermont. Examples of this are found in the narrow vertical range of the Upper Peru beaches in New York, the flat, rather than sloping tops of the deltas in New York and Vermont, and by the single, rather than multiple development of terraces at Mt. Philo, Cobble Hill, and Milton.

LAKE VERMONT: FORT ANN STAGE

(Figure 14)

Below the shore features of the Coveville stage, another group, as shown on the profiles (Figures 12 and 13), fall onto a plane which, like the Coveville, rises northward. From south of Ticonderoga, N. Y., and near Bristol, Vt., where its altitude is about 390 feet, the plane rises to 749 feet in the International Boundary in New York and 591 feet in Vermont. When projected southward, this plane is directed toward the present day divide between the Hudson and Champlain drainage, several miles north of Fort Edward, N. Y.

THE FORT ANN OUTLET

The present divide between the Lake Champlain Valley and that of the Hudson River lies three miles northeast of the city of Fort Edward, N. Y., in the center of a broad, flat valley partially filled with clays and silts. Here there does not appear to be the slightest suggestion of current action such as one might expect to find at a threshold which controlled the waters for a glacial lake such as Lake Vermont. It is apparent that this divide itself was not the actual controlling point for the water in the Champlain Valley during this stage of lake history, as proposed by Woodworth. For the actual point of control, one must go to the gorge which lies northeast of the village of Fort Ann. Through this narrow gorge the outlet waters for Lake Vermont during this stage rushed, and it is here that current action is to be found.

Various authors have mentioned this gorge (3, p. 178; 27, p. 674; 26, p. 198; 10, p. 10) but only Chadwick (5, p. 914) stated that the actual sill of Lake Vermont was here, nor did he describe any evidence of current action. There seems to be no question that this gorge acted as a stream channel, constricting the outlet waters of Lake Vermont during the Fort Ann stage and forcing them into great velocities.

The evidence for this statement, found by the present writer, rests in the presence of a great number of potholes, some quite large in size, in at least three river channels within the larger gorge which converge at the narrowest

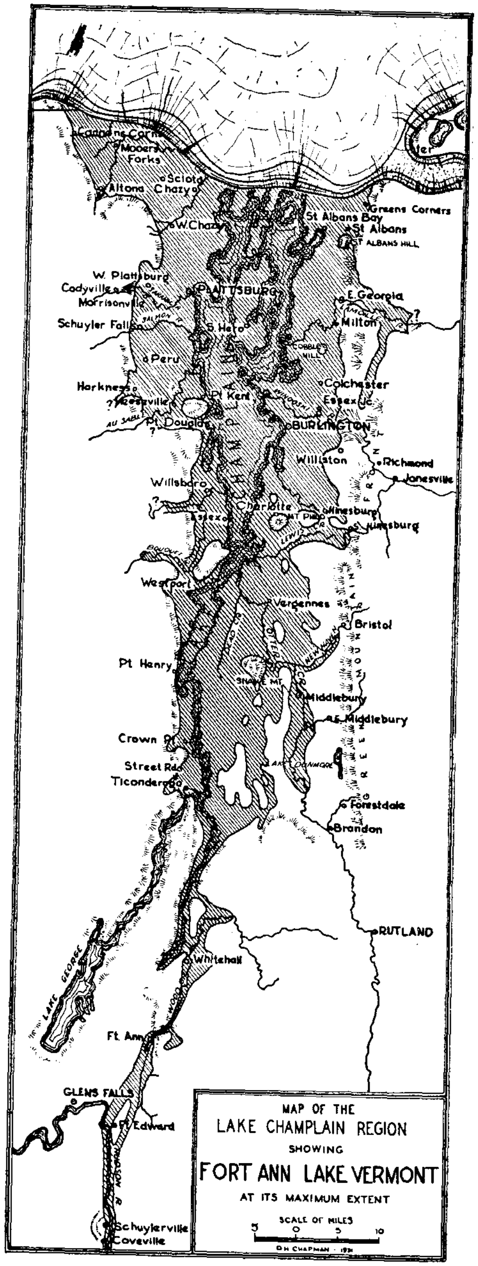


Fig. 14. Fort Ann Lake Vermont at its maximum extent.

part of the valley; and in several outcrops of hard crystalline rock which have been fluted and polished by swift stream action. There are many fine potholes, all within the limits of the three main tributary river channels, and all below 160 feet, the level at which water flowed through the valley. Each rôche moutonnée is typically glaciated above the 160-foot limit as if not touched by direct current action since the retreat of the ice. Furthermore, had the potholes been of glacial origin, they would have been buried deeply beneath marine clay and silt, if the gorge from the first had been submerged beneath 200-300 feet of water, as Fairchild argued. Their freshness, and indeed their very presence, proves that their formation was the very last step in the moulding of the floor of this gorge.

MAIN FORT ANN STAGE

The Fort Ann gorge outlasted the stay of the ice in the Champlain Valley, the ice wasting away to the north until the ice front probably stood not much farther south than the Canadian border (Figure 14). Lake Vermont during the Fort Ann or Fort Ann-Lake Vermont stage was not only longer and wider than it had been during the Coveville stage, but it also had a longer life, for some of the strongest features in the valley were formed during this period.

There is a fine terrace on the Street Road, three miles north of Ticonderoga, at 332 feet, which fits well onto the Fort Ann water plane, and there are other features in the Crown Point embayment which fall near this plane (4). The valley of the North Branch of the Bouquet River contains two tributary deltas built into Lake Vermont during this stage: one near Bouquet village and another one and one-half miles north of the village of Reber. The Port Douglas beach ridge (26, p. 168-169) does not constitute an entirely satisfactory summit determination because the summit of the hill is so nearly on the water plane and the hill itself is much too high to be completely wave heaped.

One of the best series of raised beaches in the Champlain Valley occurs on the hill slopes at the base of the Adirondack Mountain front three miles west of Peru, N. Y., where the slope was favorable for their maximum development. They were mentioned briefly by Fairchild (13, p. 47), and were taken as a type example for special study by the present author because of their unsual strength and continuity. Nowhere else in the Champlain Valley did it seem practicable to ascertain the actual tilt of a single continuous beach. In addition to traverses made up the slope of the hill in five places, a longitudinal traverse of the 561-575-foot beach was completed. From this study the slope was determined to be 5.6 feet per mile, which checks very closely with the five-feet-per-mile tilt rate of the Fort Ann water plane as drawn on the profile (Figure 12).

Two miles northwest of Schuyler Falls is another excellent series of beaches, the highest of which lies at 596 feet (barometer) or about twenty feet too low for the Fort Ann plane as drawn. This may represent a true sag in the water plane occurring when uplift took place. Another equally strong beach lies a mile and a quarter west of Beckwith School (600 feet). Two miles southwest of Morrisonville occurs another well developed series of beaches, reaching up to the Fort Ann water plane. The Saranac River, during this stage, built a wide delta of sand, conspicuous on the Dannemora topographic map, northwest of Morrisonville at 630 feet (barometer), and its abrupt foreslope may be observed clearly from the highway on the east.

A morainic spur two miles north of West Plattsburg carries some of the most conspicuous beach ridges in this region (25, pp. 35-36; 13, p. 50). As the summit of this ridge lies at the altitude of the Fort Ann water plane (highest beach 645 feet, barometer), this series does not constitute an entirely satisfactory summit determination, but no higher beaches are found on the slopes west of here.

Three-quarters of a mile southwest of the three corners at West Beekmantown is another morainic ridge. Close examination of this hill showed that the summit is covered with a mantle of till, entirely unmodified by any wave action, and a rude terrace at 650 feet is the highest feature on the hill that can be considered as wave-formed. Though Woodworth mapped the upper portion of this hill as moraine (25, p. 34), Fairchild (13, p. 51) described and mapped wave action to its summit (700 feet).

At Shelter's Corners, two miles north-northwest of West Beekmantown, beaches may be observed on the eastward sloping hill up to, but not above, 665 feet, which is exactly on the Fort Ann plane. Above this, there are many short, discontinuous kame ridges, which have little significance as water level markers.

North of Shelters Corners, on the Mooers quadrangle, there are numerous shore features which fall onto the Fort Ann plane (Profile, Figure 12). Since these features have nearly all been described by Woodworth (25), they need not be discussed in detail here, but they are plotted on the profile. The northernmost feature yet to be correlated with the Fort Ann stage is a beach at the three corners, two and one-half miles north of Cannon's Corners and a mile south of the International Boundary (749 feet). Woodworth considered all these features to belong to the Coveville stage, rather than to his Fort Edward (Fort Ann) stage, and he correlated with these features in the Mooers area certain other shore features on the Dannemora quadrangle, which unquestionably do belong to the Coveville stage of Lake Vermont. Thus in drawing such a plane with a low angle of tilt, Woodworth correlated definite Coveville features south of Cadyville with features north of that point that are in all probability Fort Ann. That he had difficulty in explaining the height of the Cadyville delta (much too high for his Coveville plane) (26, pp. 160, 171), and that all the Dannemora features fail to reach his Coveville plane as drawn with a low angle of tilt, make the present interpretation the more logical; for with the steeper tilt rate, as drawn by the present author, the Dannemora features, including the Cadyville delta, fall on the Coveville plane.

The northeastern corner of the Adirondack highlands is Covey Hill, less than a mile north of the International Boundary, in Quebec. One investigator (13, p. 55) described wave-cut "cliffs" and terraces up to 740 feet, but these terraces are very rude and all other writers (14, p. 120; 26, p. 162), including the present one, regard these terraces as marks of marginal ice streams.

During the last phases of the Coveville stage of Lake Vermont, discharge of waters from the Lake Ontario basin took place through Covey Gulf (13, 26) and along the eastern flank of the Adirondacks. Much kamic material was strewn by these waters during this time as far south as Peru, N. Y. Later, as the ice withdrew from the northern flank of Covey Hill, the water from Lake Iroquois debouched around Covey Hill into Lake Fort Ann, and it was at this time that the terraces on Covey Hill were shaped.

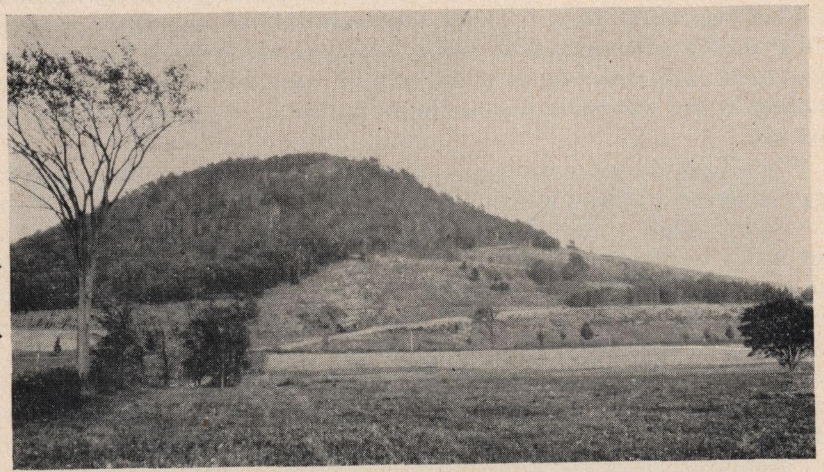


Fig. 15. Mount Philo, Charlotte, showing Coveville ("C") and Fort Ann ("FA") wave-cut terraces. Altitude of Coveville terrace, 540 feet; Fort Ann terrace, 431 feet.

THE FORT ANN STAGE IN VERMONT

When the level of Lake Vermont fell to the Fort Ann stage, the Otter Creek valley in the vicinity of Brandon, Vt., was brought above water level. Otter Creek flowed into Lake Vermont near Salisbury Station, eight miles northwest of Brandon, and the flat bottom of the Otter Creek valley there may represent the surface of the stream deposits during this stage. At Middlebury, only the lower part of the village was below water, and the site of Middlebury College campus had already emerged. Snake Mountain, west of Middlebury, stood out prominently as a high, rocky island in the lake; it is one of the largest of the rock-islands which rise through the Champlain clays. A terrace on the west slope of this mountain (386 feet, barometer) falls on the Fort Ann water plane, but lacks continuity and may not be wave-formed. Other nearby terraces which appear to be wave-cut when viewed from a distance are definitely not formed in this fashion. Buck Mountain, two and a half miles south of Vergennes, carries two sandy beaches on its northwest flank (390 feet), barometer.

Mt. Philo (Figure 15), thirteen miles south of Burlington, is a conspicuous landmark in the northern part of the valley. Its summit, rising to 968 feet from the clay-covered plains below, protruded above the surface of Lake Vermont as an island. It is composed of well-jointed, red Lower-Cambrian quartzite (the Monkton quartzite), and glacial plucking has produced steep slopes which are precipitious on the west, where Fairchild described a "wave-cut cliff" (8, p. 26). The rock cliffs here are on too large a scale, however, and not appropriate to the amount of work that could be done on the shores of a relatively short-lived glacial lake. Below the Coveville terrace described earlier, a more pronounced wave-cut bench (431 feet) correlates exactly with the Fort Ann water plane. Thirty feet broad, it can be traced for nearly a mile along the western flank of the hill (Figure 15). Pease Hill and Jones Hill, nearby, also were islands at this stage in lake history, but the slopes were too steep where the waves were at work so that no terraces or beaches were produced.

When Lake Vermont dropped to the Fort Ann level, the Winooski River began to dissect the sand and gravel which it had deposited during the earlier (Coveville) stage. This material was swept westward, downstream, until quiet water was reached. Here it was spread out in a broad, flat sand plain that gradually was built up to Fort Ann lake level. The surface of this new, lower, delta rises to a little over 500 feet near its apex at Williston, and parts of the old, flat surface can be discerned near North Williston, around Saxon Hill and east of Essex Junction. Later when the water in the valley dropped to sea level, this delta in turn was dissected, resulting in the high mesa-like sand and gravel terrace, remnants which are so conspicuous in the valley near Williston. The material of the delta is all quite fine, and the broad, flat surface stretched westward until it merged imperceptibly with the clay lake bottom, without pronounced foreset. The absence of a foreset may be the result of the small grain-size of the material, the shallow depth of the lake here, or the flat character of the lake floor. Similar deltas, without appreciable "brows," were occasionally built into the shallow ice-dammed lakes in the Great Lakes basin. One such delta is that of the Huron River, near Ypsilanti, Mich. (22).

Like Mt. Philo, Cobble Hill (Figure 16), three miles south of Milton village, was an island in Lake Vermont during the Fort Ann stage. Circular in shape, steep-sided, its summit stood at least 330 feet above lake waters. Waves removed quantities of till from the west side of the hill, and current swept it around to the sheltered eastern side where it was deposited in quiet water, building up one of the most conspicuous water-level markers in the entire Champlain Valley. Spectacular in appearance when viewed from the southeast, a shelf-like collar, twenty feet wide, runs almost completely around the hill. Recent road-building operations have revealed the material to be coarse, well-rounded gravel and sand. The surface of the terrace stands at 527 feet on the east, but gradually rises toward the exposed western side. Across the flooded Mallett Creek valley, east of Cobble Hill, the waves of the lake likewise pounded against the hill slopes of Georgia Mountain. A terrace (537 feet) was soon formed there, too, and it can be traced with only minor interruptions for almost a mile, southeast of Milton village. The surface is strewn with cobbles, washed

from the till by the waves, and bedrock has been exposed, though not attacked, at the base of the cliff.

The deep Lamoille Valley was the site of an ice-dammed lake, much like Lake Winooski, whose outlet was south from Fairfax, past Westford, into the Winooski valley near Essex Center. The gorge of the Lamoille River at East Georgia was still plugged with ice and escape of the local lake waters through this gorge was impossible until the Champlain ice lobe began to melt away from the western face of Georgia Mountain. Even after the ice did melt away here and the water in the Lamoille Valley dropped to the level of Lake Vermont, the valley was flooded to a depth of 200 feet, and the delta which the Lamoille River then built into Lake Vermont probably was situated far east of Fairfax. Later excavation of the sand and gravel in the Lamoille Valley,

Fig. 16. Cobble Hill, Milton, looking northwest. Note the wave-built terrace, formed during Fort Ann stage. Altitude, 527 feet.

however, has removed such a large proportion of the valley fill that the exact location of the delta remains in doubt. Arrowhead Mountain, north of Milton village, like Cobble Hill, was an island in Lake Vermont, but careful search has not yet revealed any evidence of the attack of waves on the slopes of this hill. A cliff on the west side might be mistaken for a wave-cut cliff, but it is too large to have been formed in this fashion. Talus blocks which cover the bench below may possibly conceal other evidence of the work of shore agents.

Long before the ice front receded as far north as St. Albans, the Coveville stage of Lake Vermont came to an end and the lake dropped to the Fort Ann level. It was thus not until this stage of lake history that any shore features were developed in the area around St. Albans. The shoreline of Lake Vermont then lay along the west flank of the Green Mountains, at about 570 feet, running northeastward, from two miles east of Georgia Center along the base of Bellevue Hill, to the vicinity of Sheldon Springs Village. St. Albans Hill was an island while Aldis Hill, in St. Albans City, was a promontory along the shoreline. Waves broke with full force on the west slope of St. Albans Hill producing here, where the lake was widest, one of the best wave-cut terraces in the Champlain Valley. Its width is greater than thirty feet at its narrowest point and increases northward into a beach which hooks eastward around the north end of the hill. A well-developed wave-cut cliff rises above the terrace and the altitude of the base of the cliff (570 feet) places this feature on the Fort Ann water plane.

Fig. 17. Wave-cut terrace, east of Green's Corners, Swanton.

In similar fashion, waves broke on the western slopes of Aldis Hill, within the city limits of St. Albans, forming a terrace (580 feet) east of High Street, behind the Warner's Children's Home. Post-glacial talus accumulation has considerably modified the cliff and terrace.

Another rather well-developed, wave-cut terrace occurs east of the Green's Corners Station of the Missisquoi Branch of the Central Vermont Railroad (Figure 17). Fifty feet broad and more than a half-mile long, the terrace surface is gravelly and covered with beach cobbles. At the base of the cliff (591 feet) there is a suggestion of wave abrasion on some of the bedrock.

From Green's Corners into Canada, the hills are composed of a rapidly weathering black slate, so that it is not surprising that features of wave origin are lacking on their slopes.

During the last few years of the Fort Ann stage of Lake Vermont, as pointed out above, the waters from Lake Iroquois escaped around Covey Hill into the Champlain Valley. For a short time thereafter, Lake Vermont must have been confluent with Lake Frontenac around Covey Hill, but this condition could not have lasted long.

When the ice front had retreated to some point north of the Canadian border (2, p. 137), the waters of Lake Vermont began to soak through the low marginal portions of the ice lobe into the *marine* waters which were simultaneously creeping up the St. Lawrence valley as the ice evacuated that section. That the water from Lake Vermont did not find an outlet marginal to the ice along the Green Mountain front north of St. Albans is indicated by the absence of marginal channels. It is believed that the escape of Lake Vermont waters was almost wholly over, through, and under rotting ice masses which represented what was left of the Lake Champlain lobe. Lack of evidence of standing water above the marine limit (475 feet) in the Missisquoi valley makes this hypothesis even more plausible. Antevs has suggested (1, p. 66) that a part of the ice-sheet over southern Quebec and Gaspé was isolated from the main ice mass to the northwest and that the marine waters gained entrance between these masses.

That the water in the Champlain Valley stood at successively lower and lower positions during the escape of Lake Vermont, is indicated by the great series of beaches at and below (but not above) the Fort Ann limit in northern New York (Figure 12). Undoubtedly many of these features were formed suddenly during some unusually violent storm, and hence each beach need not represent a halt in the lowering waters. There is a marked difference discovered in comparing the transition between Coveville and Fort Ann with that between Fort Ann and the marine invasion, for in the former case few beaches are found, while in the latter the transition is well marked. The former probably took place suddenly; the latter represents a longer period of time.

MARINE INVASION OF THE CHAMPLAIN VALLEY, FORMING THE CHAMPLAIN SEA [1]

After the ice withdrew from the limits of the area, sea level waters flooded the valley (Figure 18), to a relatively shallow depth. The Champlain estuary was a part of the larger St. Lawrence estuary, but it probably did not reach as far south as Whitehall, and certainly no farther. For if a water plane is drawn through the highest marine beach, it plunges under the surface of the present-day Lake Champlain seventeen miles south to Ticonderoga, and intersects the floor of the lake two miles north of Whitehall. *Hence, marine waters never could have invaded the Champlain Valley from the south, and sea level waters never could have cut New England off as an island by invading the Hudson-Champlain lowland from New York to Montreal in one continuous estuary.* Furthermore, a water plane drawn as the one described above is the highest possible marine water plane, for:

1. All marine shells so far found in the valley (21, 26) fall below the upper marine plane as here established.
2. The highest water plane which can be traced out of the Champlain Valley into the St. Lawrence and from there to the sea obviously represents the marine

[1] See The Great Ice Age in Vermont, p. 46.

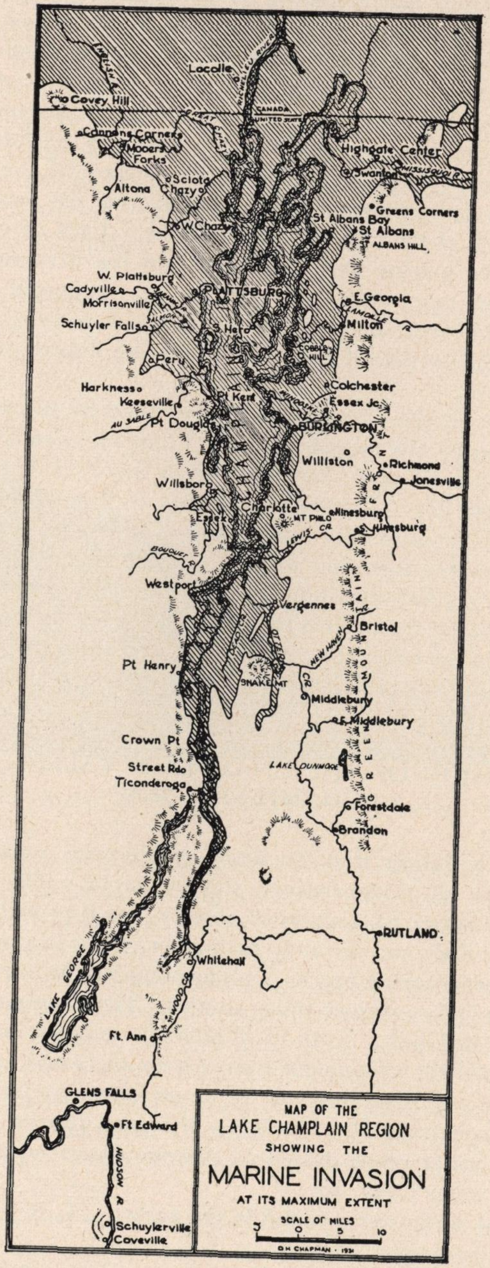


Fig. 18. Map of the Lake Champlain region, showing maximum extent of the marine invasion.

limit. A 440-450-foot terrace in St. Albans correlates with beaches in southern Quebec at Dunham, Cowansville, Granby, and Roxton (14, pp. 120-121), which is the highest series of beaches which Goldthwait has traced along the St. Lawrence valley to the sea. Though the beaches at 525 feet at Covey Hill can be traced into the Ontario basin, this does not necessarily establish the marine origin of them, as it is conceivable that lakes in the Champlain and Ontario basins were confluent.

It is not surprising that no features are to be found on the Upper Marine plane near the southern end of the valley. The estuary was very narrow and tides probably caused a considerable fluctuation in water level (20, p. 120) and under these conditions shore features could not develop. The delta of Mullen Brook, four miles north of Port Henry, is the southernmost feature yet found on this plane in New York (240 feet, barometer). The flat-topped sand plain at the Westport village race track probably represents the material brought down by a small brook (270 feet, barometer). Many features are to be found on the Upper Marine plane north of Split Rock Mountain as shown on the profile (Figure 12). An important one is the delta (Figure 12) of the Saranac River (425 feet, barometer) at Morrisonville. On the Mooers quadrangle there are many features, all mapped by Woodworth (25) but almost all of these fall above his Upper Marine plane, since his plane was directed toward a limit of 450 feet at Covey Hill, rather than toward the true upper limit of 525 feet.

A clearly defined summit determination for the upper Marine water plane was made on a series of beaches on the road running due west, one and one-half miles west of West Chazy. The highest beach, just east of a deserted farmhouse, has an altitude of 467 feet directly on the water plane.

A beach near the International Boundary, north of the west branch of the English River, has an altitude of 539 feet, somewhat higher than the marine limit at Covey Hill a few miles farther north. This discrepancy is possibly more apparent than real and may be due to the variation in the datum of the surveys on either side of the International Boundary. The best summit determination in the Covey Hill region was obtained from a series of beaches on the road a quarter of a mile east of Covey Post Office. Woodworth (25, p. 45) recorded the highest beach here at 450 feet, but this determination is much too low, for Goldthwait (14, p. 124) obtained a precise altitude of 523 feet on this uppermost beach. Fairchild (13, plate 8) described beaches west of Covey Hill which fall on this Upper Marine plane.

When the waters of Lake Vermont fell to sea level and the sea spread southward from Canada, forming the Champlain Sea, the shoreline on the Vermont side of the valley no longer lay against the base of the Green Mountains. Particularly in the southern portion of the estuary, some of the flat, clay-covered valley floor was exposed. The approximate marine shoreline can be plotted on topographic maps by projecting the Upper Marine plane southward from northern Vermont, where it is better known, but there are no recognized shore features south of the Burlington quadrangle. Near Middlebury and Vergennes, the Otter Creek valley was now exposed as far downstream as the village of Weybridge. Here Otter Creek must have emptied into the sea-level waters while, near the stream's mouth, Snake and Buck Mountains rose like bastions. To the west, the low, clay-covered plains in Addison, Panton and Ferrisburg were submerged and silt and clay, sifting down through the quiet marine waters, continued to accumulate here. Northeast of Ferrisburg village, Shellhouse Mountain rose steeply along the shore of the marine estuary, but no good shore feature was discovered on its slopes.

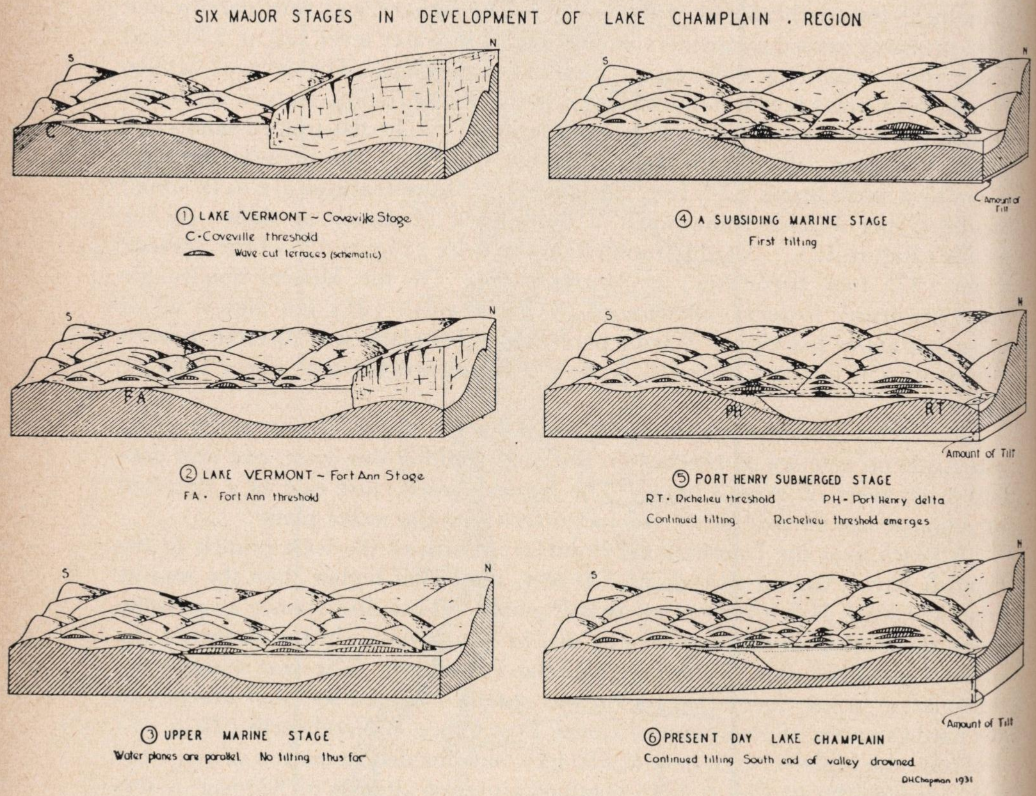


Fig. 19. Block diagram showing the six major stages in the development of the Lake Champlain region.

About two miles southeast of Shelburne Falls, east of the highway bridge, the La Platte River is bordered by flat-topped, gravel-covered terraces. The altitude (300 feet, barometer) places these features on the Upper Marine plane, and they may represent remnants of a marine delta. Sections in the gravelly material reveal delta-like topset and westward-dipping foreset beds.

As soon as the water in the Champlain valley dropped to the Upper Marine level, the Winooski River began to build a new, lower, delta east of Burlington (Plate VI). The broad, sandy, plains of the older Fort Ann delta must have

stood high and dry, more than one hunderd feet above sea level. Here was an ample supply of fine gravel, sand and silt, which the Winooski River began immediately to erode. A gorge of considerable depth was quickly cut while the eroded material, carried farther westward, was spread out along the shore of the new marine estuary. The red quartzite ridge, on which much of the upper part of Burlington is built, now for the first time stood above water level, while the shallow bay east of the ridge slowly filled up with sand and silt, until a broad, flat sandy plain was produced at sea level. From an apex near Essex Junction (345 feet) the sandy material was spread fan-wise, northwest as far as Colchester, west to the campus of the University of Vermont, and south to the valley of Potash Brook. Later, when the land rose, the Winooski River eroded away a great deal of this delta but even today enough of it remains so that its size and surface slope are well known. The best remnants of the delta can be seen at Essex Junction, along the Williston Turnpike, east of the University campus, and particularly in the vast flat sand plains which stretch uninterruptedly north and west of Fort Ethan Allen. As in the Fort Ann delta, there is no abrupt foreset, although there is a difference in the altitude of the two deltas.

The elevations which determine the "water planes" on figures 12 and 13 were accurately determined. Reference to Figure 13 shows that the elevation of Lake Coveville, in the Burlington region, was a little over 600 feet above sea level, while the elevation of Lake Fort Ann was about 500 feet. No tilting of the region took place from early Coveville time until the marine invasion occurred (Figure 19).

The elevation of the entrance to Williams Hall, University of Vermont, is practically 370 feet above sea level and the crest of Mary Fletcher Hospital hill is about the same. The greatest elevation is at the base of the water tower, near Redstone Dormitory, 381 feet. Consequently, during the Coveville stage, the entrance to Williams Hall and the summit of hospital hill must have been about 230 feet under water, while the Redstone grounds were ten feet nearer the surface. During the Fort Ann stage, these points were submerged 130 and 120 feet, respectively.

When excavations for the foundations of the University buildings were made it was seen that the material consisted of a rather thin layer of sand underlain by very compact blue clay containing glacial erratics, some very large, especially in the Waterman excavations. This "hard pan" material is so compact that none of the buildings has settled at all, while the seismograph pier, east of the Fleming Museum, is so stable that the instruments faithfully record the various phases of earthquakes even from the most remote parts of the earth. The hard pan represents glacial deposits and the sediments laid down in the Coveville and Fort Ann stages.

During the "marine stage" Vermont rose differentially: the northern part, most; the southern portion, least. As the Champlain Sea gradually gave way to Lake Champlain, the lake level sank intermittently, with several "still-stands" during which parallel benches were cut into its shore. It was along these benches that several of the north-south running streets of Burlington were built.

As the lake lowered, the Winooski River, flowing out from the mountains, began to cut a channel across its delta (Plate VI) and, as it cut more deeply, it "discovered" several rock ridges athwart its course. Concentrating its energy the river excavated the falls at Essex Junction and Winooski. The gorges across which the twin bridges are built, in Winooski, were falls at first but, since the rock here is easily-erodible limestone, the falls have been cut down and vertical-walled canyons have resulted. Physiographers call a stream with such a "discovering" history a superimposed, or superposed, river.

E. C. Jacobs.

While the Winooski River was building its delta at Burlington, the Lamoille River built a similar one into the sea at Milton. The marine shoreline ran from the vicinity of Fort Ethan Allen northward along the base of the hills east of Colchester. There is a gravel terrace (355 feet), a quarter of a mile northeast of Colchester station, that may represent the delta of a small brook built into the marine water, while nearby there is a terrace which may be wave built. The Lamoille delta, however, is the largest and best shore feature in this vicinity. Emerging from its gorge at East Georgia village, the Lamoille River entered the sea here. Eroding vast quantities of sand and silt from river terraces farther east, it spread out this material in the shape of a great fan, with apex at East Georgia. The sand plains are very little modified by subsequent erosion and completely surround Arrowhead Mountain, reaching northwest as far as Georgia Plains, west beyond Checkerberry village and south to Cobble Hill. Many of the rocky hills along Malletts Bay remained islands in the sea, but were apparently little modified by wave attack.

The Upper Marine shoreline extended diagonally across the St. Albans quadrangle from a point south of St. Albans Hill to the hill slopes northeast of Greens Corners. No very good shore features developed during this time, except that in the southern portion of the city of St. Albans, two blocks southeast of the High School, there is a terrace (400 feet barometer) that may be of marine origin. City construction and grading have largely obliterated the feature but it was probably formed at this time by shore agents. A delta of the Missisquoi River, similar to those described for the Winooski and the Lamoille, was not discovered, but its absence is undoubtedly explained by the fact that this valley was plugged by ice until after the marine waters gained entrance.

Goldthwait (1913) described the highest marine limit northeast of the Champlain Valley in the St. Lawrence lowlands and the beaches that he studied correlate well with the Upper Marine plane (Figure 13).

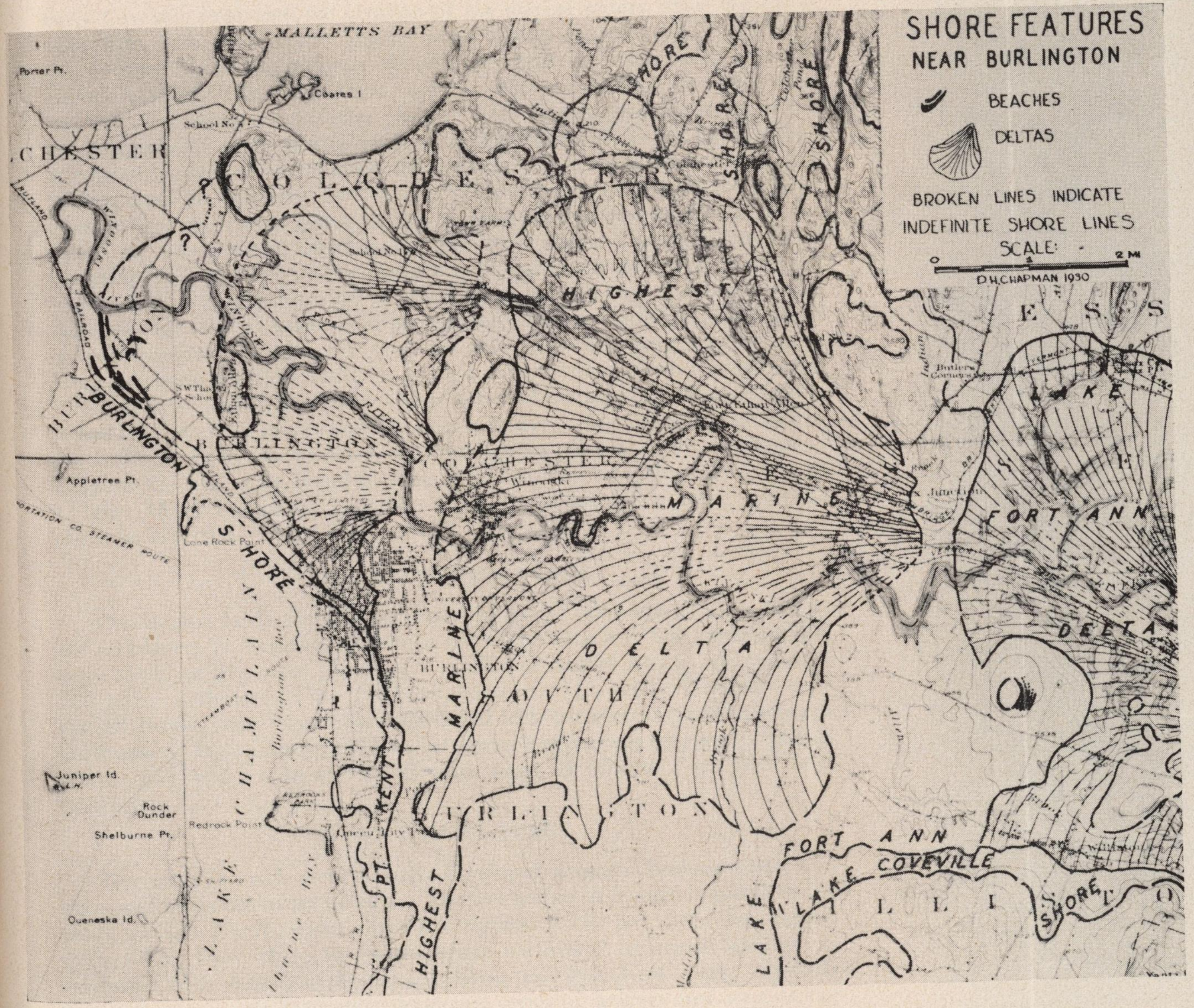


Plate VI. Burlington region, showing extent of the old (fossil) deltas.

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SUBSIDING MARINE STAGES

It has previously been stated that there was no tilting of the region from early Coveville time until the invasion of the marine waters, since the Coveville, Fort Ann, and Upper Marine water planes are parallel. Soon after the entrance of the sea, however, the northern portion of the valley began to rise more rapidly than the southern, and this process continued for a long time, but was intermittent in character (Figure 19). Heretofore, the study of the subsiding phases of the marine invasion in the Champlain Valley has not been attempted because of the number and confusion of beaches below the Upper Marine limit in northern New York. Not every beach below the Upper Marine limit represents a halt in the receding marine waters, for an extraordinarily strong storm might easily pile up a beach in a short time at a favorable locality, while nearby the effects of that particular storm might not be left at all. Where a number of beach series seem to have a common upper limit, through which a tilted water plane may be drawn, and where deltas occur at corresponding altitudes, it is assumed that they were formed at the same time, indicating a halt in uplift for at least a short time. Such a relationship is found in at least five instances and, while advancing the following correlation, the writer recognizes that it is only tentative. The following five stages are deduced from the evidence at hand. Four of the stages represented (Figure 12) are to be found in New York, and at least three in Vermont (Figure 13). The oldest (highest) have tilt angles which are greater, as might be expected.

1. BEEKMANTOWN STAGE

This stage is fairly strongly developed in New York north of Peru village, but no beaches in Vermont have been correlated with it. The principal features found on this water plane are: A delta of Arnold Brook, one and one-half miles northeast of Peru (320 feet, barometer); a series of beaches near Farrell Brook, near West Chazy (360-380 feet, barometer); a strong beach northwest of West Chazy (400 feet, barometer) which was mapped by Woodworth (25), and a sand and gravel plain south of Mooers Fork (425 feet, barometer).

2. PORT KENT STAGE

This stage is much more strongly developed than the Beekmantown, and the upper limits are better defined. The southernmost feature is found as far south as Port Henry, where there is a terrace at 150 feet, near the railroad station (26, Plate 16). In regular order northward, principal features on this plane are: A delta of the Ausable River near Port Kent village (240-250 feet, barometer); an excellently developed series of beaches just west of the city limits of Plattsburg (highest beach 310 feet, barometer), ending in a splendid series of hooks just north of the Morrisonville Pike; a beach one and one-half miles south of West Chazy (320 feet, barometer), showing great continuity, and a series of beaches (340-350 feet) on the north slope of Covey

Hill. In Vermont, scraps of a delta at Burlington (225 feet, barometer), a scrap of the Lamoille delta south of West Milton (260 feet, barometer), and the broad delta of the Missisquoi in the vicinity of Highgate Center (320 feet, barometer) are the major features belonging to this stage.

3. BURLINGTON STAGE

In New York proper this stage is not easily recognized, but a beach at Hemmingford, Province of Quebec (280 feet, barometer), and a delta of the Great Chazy at Mooers Forks (300 feet, barometer) have tentatively been correlated with this stage.

In Vermont, the Winooski delta of this stage (Plate VI) is found on both sides of the present mouth of the stream at an altitude not much above lake level. More definite water level markers are available nearby in a series of beaches crossing the road leading to Starr Farm, two or three miles northwest of the city of Burlington. These beaches, the highest of which has an altitude of 163-165 feet (and a single beach above at 172), though not extremely strong, are sandy, have great continuity and a horizontal crest line. Similar beaches are found a few miles farther north, near Porter Point. The Lamoille delta (150-170 feet, barometer) and a terrace at 185 feet, barometer, on the gentle hill slopes west of St. Albans hill probably also belong to this stage.

4. PLATTSBURG STAGE

The shoreline of this stage is submerged south of the latitude of Westport, N. Y. The principal features correlated are: A delta of the Little Ausable (150 feet, barometer) south of Plattsburg, the delta of the Saranac (170 feet, barometer) at Plattsburg Barracks and parade grounds, beaches east of the main highway north of Chazy village (180 feet, barometer), and a strong beach (220-225 feet, barometer) between Barrington and Sherrington, Province of Quebec. *In Vermont,* on South Hero Island, a terrace (120 feet, barometer) overlooking Sawyers Bay, terraces east of St. Albans Bay on the mainland (140 feet, barometer), two strongly developed beaches two and one-half miles southwest of Swanton Junction (159 feet, barometer), and a good series of beaches three miles southwest of Swanton Village (157 feet, barometer), all seem to have been formed at this time.

A few beaches around the northern end of Lake Champlain, in Canada, have also been correlated with this stage, and are all plotted on the profile (Figure 12). There are other beaches at a lower altitude, also represented on the profile, which have so far not been correlated with any stage.

5. PORT HENRY (SUBMERGED) STAGE

Differential uplift brought the northern end of the valley out of water more rapidly than the southern. Emergence must have been taking place, nevertheless, throughout the entire length of the valley. Streams at the southern end cut down into the weak delta and lake bottom materials of earlier stages. But there finally came a time, as the land rose, when the rocky Richelieu threshold in southern Quebec, just north of the International Boundary, began to act as a barrier for the sea waters. Once out of water, the Richelieu region barred the marine water from entering the valley, and at the same time held back a portion of the old estuary to form the new, *fresh water Lake Champlain,* with outlet toward the north (Figure 19). The level of the water in the valley stood constant for a long period just as the sea was being excluded for the last time. During this critical period, a large stream flowed north along a course marked today by the deepest part of the present lake between Whitehall and Port Henry, and cut a meandering channel well displayed on the Government Lake Charts. This stream reached standing water level five miles northeast of Port Henry and dropped its load to build the "Port Henry delta." Peet (21, pp. 466-8) mentioned this submerged river channel and delta, but made no attempt to correlate it with the history of the Champlain Valley. Contour lines drawn on the lake floor, and cross-sections of this feature show that it has a typical deltaic shape, with flat top and a foreset slope of but four degrees. This feature is not simply a pre-existing configuration of the lake bottom, for the steepest portion of the shore is opposite the flat, shallow, delta-like portion of the lake floor, while the deeper portions of the lake are opposite the low, flat, clay shores. The delta, then, was built into water at sea-level during a transition stage, beginning just before the salt water body was established. This stage may have lasted a long time, as would be indicated by the large bulk of material making up the supposed delta. Terraces south of Plattsburg (18) visible now only at times of extremely low water, may belong to this same phase of lowest level in the valley.

PRESENT-DAY LAKE CHAMPLAIN

Further tilting of the land upward at the north caused over-flooding of the Champlain waters toward the south end of the valley (Figure 19). Former deltas, such as the one near Port Henry, were submerged, and old river channels filled up with detrital material. The valleys near the south end of the lake were drowned. The Port Henry delta is under sixty feet of water; the Plattsburg terraces are under twenty to thirty feet; Otter Creek and other streams south of Middlebury have wide, swampy valleys and the mouths of all valleys are characteristically trumpet-shaped.

Whether tilting is going on at present is not known. It is interesting, however, to note that a tilt of but four-tenths of a foot per mile would be necessary to make the water of Lake Champlain once again flow south cross the Fort Ann divide into the Hudson valley. This amount is one-half that which has taken place since the exclusion of marine waters, and but one-tenth of that which has taken place since the first invasion of the marine waters.

CONCLUSIONS

The most important conclusions of the present work are that:

1. Marine waters invaded the Champlain Valley from the north during late-glacial time, but sea-level water never reached as far south as the Hudson valley and hence New England never was cut off as an island in a late-glacial sea.

2. Previous to the marine invasion, an ice-dammed lake, "Lake Vermont," existed in the valley, and two stages of the lake can be detected.

3. During the life history of Lake Vermont, from a time shortly after the beginning of the Coveville stage, up to and including the time when marine waters first entered from the north, the Champlain Valley was stable, as proved by the parallelism between the Coveville, Fort Ann and Upper Marine water planes.

4. The life history of Lake Vermont correlates with the stability noted by Leverett and Taylor (19) in the Great Lakes region during Algonquin time. If we place the period of stability in the Champlain Valley equal to Taylor's first period of stability during the Kirkfield (Fenellon Falls) stage of Lake Algonquin, then the tilting registered at Glens Falls is the last phase of the Post-Whittlesey tilt, which, according to Taylor, immediately preceded the opening of the Kirkfield outlet. This is just at the time of the beginning of the life history of Lake Iroquois in the Ontario basin. Thus, the life history of Lake Vermont correlates with the stability in the Great Lakes region during Algonquin time. Stability continued even after Lake Iroquois escaped around Covey Hill, and Lake Frontenac was confluent with the Fort Ann stage of Lake Vermont, which is what Taylor implies in his diagram (19, plate XXI, p. 410).

5. The tilting of the Coveville, Fort Ann and Upper Marine planes was accomplished during the tilting of late Algonquin time (19) and Taylor's second period of stability may possibly be expressed in the long life of the submerged Port Henry delta.

6. *Amount and Direction of Tilt in the Champlain Region.* That the features of the New York shore lie at an altitude somewhat higher than features belonging to the same stage and at the same latitude on the Vermont side indicates that the direction of maximum tilt is not due north-south but rather south-southeast and thus the isobases[1] (Figure 20), when drawn on the tilted water planes of Lake Vermont, run from east-northeast to west-southwest. The trend of the isobases as drawn on the tilted surface of the Fort Ann stage of Lake Vermont (Figure 11) are in agreement with those drawn by Taylor (19) in the Great Lakes region and by Goldthwait (15) in New England and the St. Lawrence valley. The apparent flattening of the marine plane north of the International Boundary (Figures 12 and 13) is due to the fact that features in the St. Lawrence valley far east of the Champlain Valley are plotted. North of the boundary, then, the profile runs nearly parallel with the isobases, and the true amount of tilt does not appear.

[1] Isobases are imaginary lines drawn through points that have been elevated to the same extent.

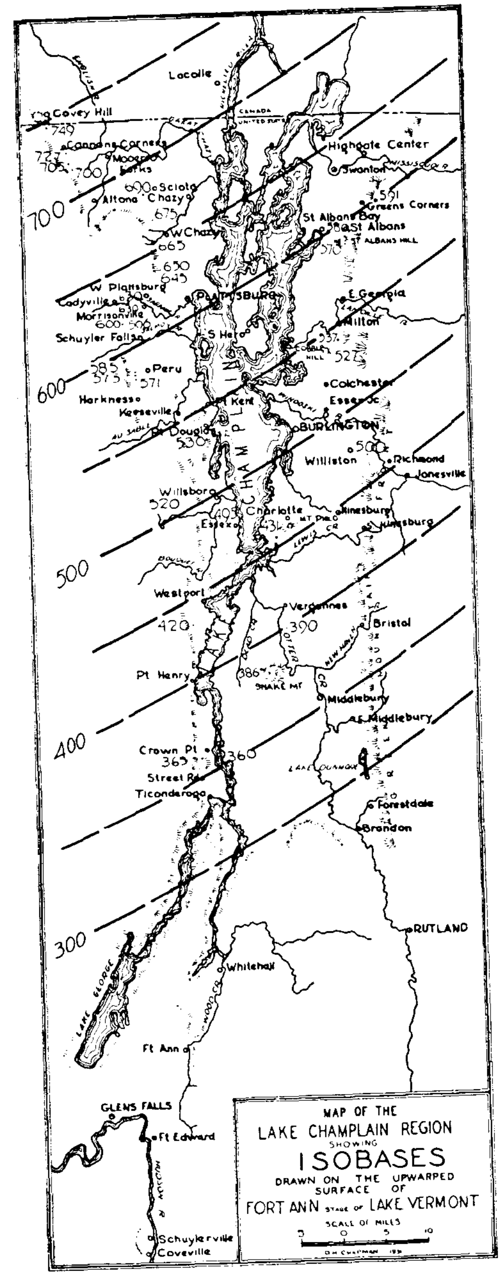

Fig. 20. Map of the Lake Champlain region showing isobases drawn on the upwarped surface of the Fort Ann stage of Lake Vermont.

FEATURES IN NEW YORK

(Figure 12)

Coveville Features

1. Terrace on Sawyer Hill, 468′
2. Terrace of Sawyer Hill, 448′
3. Sugar Hill terrace, 450′
4. Crown Point Center delta, 480′
5. Buck Mt. Boulder pavement, 520′
6. Breed's Hill terrace, 520′
7. Russell Street Rd. Terrace, 520′
8. Bulwagga Mt. beach, 460′
9. Port Henry beach, 500′
10. Port Henry beach, 510′
11. Elizabethtown delta, 600′
12. Harkness delta, 600′
13. Peru beaches, 685′, 697′
14. Salmon R. delta, 690′
15. Schuyler Falls beach, 696′
16. Cadyville delta, 729′

Fort Ann Features

17. Terrace, on Sawyer Hill (Street Road), 332′
18. Sugar Hill beach, 360′
19. Beach, 360′
20. Boquet village delta, 490′
21. Reber village delta, 520′
22. Port Douglas beaches, 530′
23. Peru beaches, 530-590′
24. Schuyler Falls beach, 596′
25. Beckwith School beach, 600′
26. Morrisonville beaches, 630′
27. Morrisonville delta, 630′
28. W. Beekmantown beaches, 645′
29. W. Beekmantown terraces, 650′
30. Shelter's Corners beaches, 665′
31. Cobblestone Hill beaches, 675′
32. Pine Ridge beach, 680′
33. Deer Brook delta, 700′
34. Deer Pond beaches, 705′
35. Cannon's Corners beaches, 727′
36. Cannon's Corners Road beach, 749′

Upper Marine Features

37. Mullen Brook delta, 240′
38. Westport delta, 270′
39. Essex terrace, 300′
40. Essex beaches, 305′
41. Port Douglas terrace, 350′
42. Port Douglas delta, 360′
43. Ausable terrace, 370′
44. Ausable delta, 380′
45. Schuyler Falls delta, 400′
46. Schuyler Falls beaches, 398′
47. Schuyler Falls terrace, 405′
48. Morrisonville delta, 425′
49. W. Beekmantown beaches, 430′
50. W. Beekmantown beaches, 452′
51. W. Chazy beaches, 467′
52. Sciota beaches, 486′
53. Wood Falls beach, 500′
54. North Branch delta, 515′
55. Cannon's Corners beaches, 539′
56. English River beaches, 539′
57. Covey Hill beaches, 523′
58. Mt. Royal beach, 574′

Beekmantown Features

59. Arnold Brook delta, 320′
60. W. Beekmantown beaches, 360′
61. Farrel Brook beaches, 380′
62. W. Chazy beach, 400′
63. Moores Forks delta, 425′

Port Kent Features

64. Port Henry terrace, 150′
65. Mullen Brook delta, 160′
66. Port Kent delta, 250′
67. Plattsburg beaches, 310′
68. W. Chazy beach, 320′
69. Covey Hill beaches, 350′

Burlington Features

70. Mooers Forks delta, 300′
71. Henmimgton beach, 280′

Plattsburg Features

72. Little Ausable delta, 150′
73. Saranac delta, 170′
74. Chazy beaches, 180′
75. Sherrington beach, 220′

Port Henry Features

76. Port Henry, submerged delta, 50′
77. Valcour Is., submerged terrace, 82′

Uncorrelated Features

78. Miranda beach, 155′
79. Clarenceville beach, 150′
80. Hecks Corners beach, 160′
81. Phillipsburg beach, 130′
82. Venice beach, 130′

FEATURES IN VERMONT

(Figure 13)

Coveville Features

1. Forestdale delta, 600′
2. Bristol delta, 570′
3. Brandon delta, 430′
4. E. Middlebury delta, 480′
5. Bristol delta, 520′
6. Mt. Philo terrac, 540′
7. N. Williston Hill beaches, 641′
8. Milton terrace, 667′

Fort Ann Features

9. Snake Mt. terrace, 386′
10. Buck Mt. beaches, 390′
11. Mt. Philo terrace, 431′
12. Winooski delta, 500′
13. Cobble Hill terrace, 527′
14. Milton terrace, 537′
15. St. Albans Hill terrace, 570′
16. Aldis Hill terrace, 580′
17. Green's Corners terrace, 591′

Upper Marine Features

18. Shelburne Falls delta, 300′
19. Winooski delta, 340′
20. Colchester Station terrace, 385′
21. Colchester Station delta, 355′
22. Milton delta, 360′
23. Milton delta, 380′
24. E. Georgia delta, 395′
25. St. Albans terrace, 440′
26. Dunham beach, 509′
27. Cowansville beach, 519′
28. Granby beaches, 516′, 560′
29. Roxton beach, 552′

Port Kent Features

30. Burlington delta, 225′
31. W. Milton delta, 260′
32. Highgate Creek delta, 320′
33. Adamsville beach, 390′

Burlington Features

34. Burlington delta, 160′
35. Starr Farm beaches, 165′
36. Bayside beach, 169′
37. Porter Point beach, 160′
38. Lamoille delta, 170′
39. St. Albans Hill terrace, 185′

Plattsburg Features

40. Sawyer's Bay terrace, 120′
41. St. Albans terrace, 140′
42. Swanton Junction beaches, 159′
43. Swanton Village beaches, 157′
44. Phillipsburg beach, 130′
45. St. Sabin beach, 200′
46. Abbottsford beach, 215′
47. Montreal beach, 225′

Port Henry Features

48. Port Henry, submerged delta, 50′

THE FUTURE OF LAKE CHAMPLAIN

Lakes are temporary features of the landscape, formed by the disruption of old drainage systems: for example, glacial damming which accounts for most, if not all, of the Vermont lakes; and differential rise of the land together with the existence of rocky barriers, in the case of Lake Champlain.

Professor Salisbury, of the University of Chicago, said "Rivers are the mortal enemies of lakes," for eventually they will fill them up. So, the many streams flowing into Lake Champlain are depositing their sediments, which are being impounded, and, in the ages to come, the lake will once more become a river, with the present streams forming its tributaries. Chapman has stated (p. 77) that an increased tilting of the lake basin of only four-tenths of an inch per mile would cause its waters again to flow south across the Fort Ann divide into the Hudson River; therefore, in the remote future, perhaps the "Champlain River" will become a tributary of the Hudson.

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