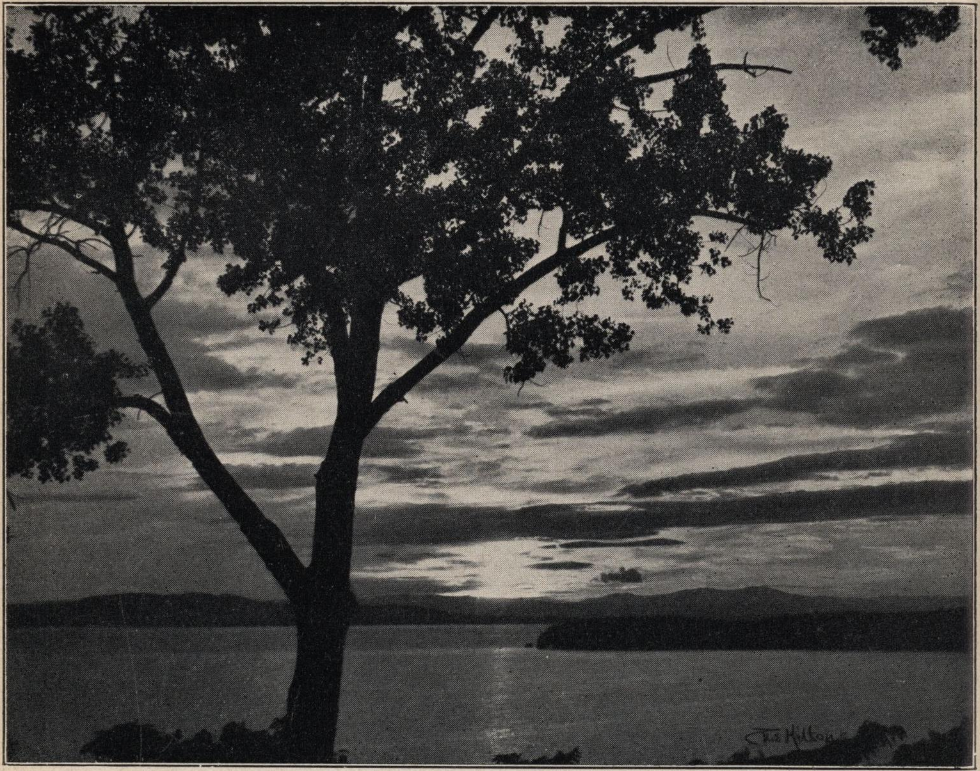

"E'en the sunset's golden glow,
Given back from Mansfield's brow,
Makes thy face still fairer now,
Ever fair Champlain."

REPORT

OF THE

STATE GEOLOGIST

ON THE

MINERAL INDUSTRIES AND GEOLOGY

OF

VERMONT

1941 - 1942

TWENTY - THIRD OF THIS SERIES

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State Geologist

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STATE OF VERMONT
OFFICE OF STATE GEOLOGIST
BURLINGTON

To the Board of Conservation and Development,
Montpelier, Vermont,

Gentlemen: I herewith present my biennial Report, as State Geologist, for 1941-42.

In this Report I have given a full account of the rehabilitation of the Orange County copper mines, now in progress, and have presented, as fully as the many scattered records will allow, the story of their long and famous history. The reopening of the mines, which will soon occur, will constitute Vermont's most important geological contribution to the war effort.

The present condition of the State's mineral industries is briefly given and results of the long quest for other economic minerals are recorded.

Part II is devoted to the physiography, or geomorphology, of the State and is designed to acquaint the public, and especially the school children, with some of the surficial features of Vermont.

Professor Doll presents an account of his studies of an ancient river valley in West Charleston. The writer gives a general account of the glacial features of the State, together with illustrations which will help in the recognition of these features. Such an account has not hitherto appeared in the reports of former State Geologists. The article will serve as an introduction to the article which follows.

In this concluding article, Professor Chapman, of the University of New Hampshire, has partly rewritten his paper which appeared in the *American Journal of Science,* in 1937, in order to emphasize the glacial phenomena in the Vermont Lowland during the evolution of Lake Champlain.

Besides preparing this bulletin I have attended to the unusually large correspondence, and laboratory work, connected with this office and have advised with various people and firms on their geological problems.

Respectfully submitted,
Elbridge C. Jacobs,
State Geologist.

Fleming Museum,
University of Vermont,
December, 1942.

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MINERAL INDUSTRIES

Reopening of the Vermont Copper Mines

ELBRIDGE C. JACOBS

The outstanding event of geological interest in Vermont at the present time is the reopening, by the Vermont Copper Company, Incorporated, of the Elizabeth Mine, near South Strafford, Orange County. Furthermore the company is giving attention to the Ely and Pike Hill mines, north of the Elizabeth, and to minor prospects which also occur along the copper-bearing belt extending north and south over a known distance of approximately twenty miles, with a view to their rehabilitation. This enterprise was undertaken for the patriotic purpose of increasing our country's sorely needed supply of copper. In this time of "all out" war the task of bringing a long-idle mine into production, with its attendant selection of an efficient scientific personnel, procurement of priorities for the necessary materials, the giving of contracts and the coördination of the whole effort, is a formidable one. To this task Mr. George A. Ellis, ex-Governor Stanley C. Wilson, and their associates have given unsparingly of their time and efforts.

Activities along the copper belt date back as far as 1793 when the outcrop of the Elizabeth ore body was first discovered, followed in 1821 by the finding of the Ely lode in Vershire and, in 1866, of the Pike Hill deposits in the northern part in Corinth.

The Ely mine, in the central part of this belt, was the largest producer of copper and was the scene of many early events of historical and economic interest. It was here, and to a lesser extent at the Elizabeth mine, that copper production held the lead in the United States until the Michigan copper mines with their rich ores, and later the Montana deposits, gained precedence during the latter part of the last century. The significant feature of the Ely occurrence was that the ore was mined continuously to a depth of 3,400 feet along the gently-pitching orebody, or to a vertical depth of about 1,500 feet below the surface. It is worthy of note that at the Eustis mine, located just across the border from Vermont, in Canada, and possibly along the extension of the Vermont copper belt, a somewhat similar deposit of copper ore was mined down to a vertical depth of 5,240 feet. At the Elizabeth and Pike Hill mines, however, mining operations have been carried to vertical depths of only a few hundred feet.

These facts and other characteristics of the type of mineralization represented has led to the belief by engineers of the Company that the present exploration in progress at the Elizabeth Mine, and now being planned at other localities, may result in much deeper mining, particularly in view of the modern methods of mining that are being adopted and supervised by skilled operators who have been brought from leading mining districts of the western states.

Several attempts have been made to reopen these mines since they were abandoned some forty years ago, but these in all cases have led to failure with the collapse in the price of copper, largely because of the small scale of the operations and the use of makeshift and inadequate equipment, as well as the lack of cooperative interest in keeping a potential industry alive in the State in times of adversity.

In the early days of production the extraction of the copper was possible only by roasting the raw ore, after hand picking or cobbing, and subsequently smelting the roasted product. Since that time revolutionary improvements have been made not only in mining methods (from hand to machine drilling, for example), but also in mechanized transportation, while the entire milling of copper ores has been radically changed by the introduction of selective flotation for the mechanical concentration of the copper mineral (chalcopyrite) intimately associated with barren iron sulphides (pyrrhotite) and silicates which constitute the ore as mined. In more recent years this flotation treatment has been further improved to make it possible cheaply to separate the copper-bearing minerals in the form of a high-grade concentrate, containing 25 to 30 percent copper, that can be shipped to smelters and refineries in the New York area for the final extraction of the copper.

The present Vermont Copper Co., Inc., was organized with private capital in April, 1942, to make a systematic, thorough study of the Vermont copper belt and to develop and equip meritorious sections of it. This company has acquired full ownership of the three areas which had been the principal producers of copper in the past.

While the primary motive for this undertaking was to supply copper for the war needs, it was desired in addition to do something of real constructive value for the State by reviving an old industry in a manner which would have a reasonable chance of becoming a permanent asset. The officers are: J. V. W. Reynders, of New York City, Chairman of the Board; George A. Ellis of New York City and Bennington, Vermont, President; Stanley C. Wilson, of Chelsea, Vermont, and A. E. de Villermont of New York City, Vice-Presidents; Edward A. Ellis of Castleton, Vermont, Treasurer. The capital stock of the company is $500,000: 4,000 shares of $100 preferred and 10,000 shares of $10 common.

Preliminary geological investigations were carried on early in the spring of 1942 by Mr. H. M. Kingsbury, Mining Geologist of the American Smelting and Refining Company, who was loaned to the Vermont Copper Company for the purpose. While a student at Harvard Mr. Kingsbury first became acquainted with the Elizabeth Mine in 1909, as a member of that University's mining school summer camp. Since then he has been primarily responsible for the explorations of widely scattered and now well-known copper and precious metal deposits in many countries, including Russia, Africa, India and New Guinea.

After extensive investigations last summer, both underground and on the surface, by Government experts, a contract was entered into by which the Vermont Copper Company agreed to re-equip the mines and to produce and deliver to the Federal Government 16,500,000 pounds of copper.

Messrs. R. S. Cannon and L. W. Currier, representing the U. S. Geological Survey and Mr. J. E. Bell, representing the U. S. Bureau of Mines, made early visits to the district and, in co-operation with Mr. Kingsbury, made recommendations to their respective departments to assist in the study and testing of the district. Plane-table mapping was conducted during the fall by field parties of the U. S. Geological Survey under the direction of Mr. W. S. White, while aerial photographs were made in October by the Topographical Branch. These studies are being carried through the winter months and will be continued next summer.

In addition Prof. Charles G. Doll, of the Geological Department of the University of Vermont, assisted by Mr. Carl Lucarini, also of the University, spent a part of last summer in making a study of the structural geology of the region and will resume the work in 1943.

The U. S. Bureau of Mines has recently established a new Northeastern District, with headquarters at Hanover, New Hampshire. Mr. J. H. Bardill is in charge of this office as District Engineer. The Bureau of Mines is taking an active part in exploratory work in the region and Mr. Bell, the Bureau's Project Engineer, assisted by a crew of samplers, is supervising an extensive diamond drilling and sampling campaign. The drilling is being done by the Pennsylvania Drilling Company, who have had three crews at work at the South Strafford mines and will continue this work through the winter. It is also planned to make geophysical examinations of the copper belt in order to discover possible new ore bodies.

Before the contract with the government was made, the company began early last spring and continued through the summer the preliminary arrangements to reopen the Elizabeth mine where easily accessible ore reserves were known to exist. The caved portion of the timbered entrance to the main haulage adit into the mine was cleared and the old mill building was torn down to make way for modern mine and mill structures. (Plate I.) The sites for these buildings were cleared of timber and excavations started. A large amount of planning was necessary to accommodate the personnel required for construction and operation. Houses remaining on the property and suitable dwellings in the vicinity of the mine were acquired and extensive repairs made to render these habitable through the cold winter months. It is expected that around 125 men will be employed when the mine is producing. Additional accommodations and a boarding house near the mine are to be provided. A new electric power line was required and a right of way for the construction of this line, seven miles in length, was obtained to connect the mine with the Central Vermont Public Service Corporation's nearest source of power at Union Village. This right of way has been cleared and the new line is now in the course of construction and should be completed by the end of January. The line will furnish about 1,200 kw. but is being constructed for 4,000 kw.

Plate I. Conditions at the Elizabeth Mine, January, 1943. *Above,* new buildings under construction. *Below,* the adit entrance to the workings in Copperas Hill.

to provide for possible future expansion. The voltage on this line is to be 33,000, but will be stepped down at the mine sub-station to 2,200 and 440 volts for the electric motors and to 110 volts for lighting at the mill plant and in the mine.

Early in October engineers under the direction of Mr. J. W. Thompson, of the Galigher Co. in Salt Lake City, Utah, arrived to design and commence construction of mine and mill buildings, make the necessary arrangements for tailings disposal and for the water supply which will be pumped from the Ompompanoosuc River, three-quarters of a mile distant. Mr. J. A. Norden, also from Utah, has been engaged as General Manager for the Company and has taken charge of equipping, unwatering and putting the mine into condition for the delivery of 500 tons of ore daily to the mill. This has required the retimbering of the entrance section of the adit and the enlarging of this adit to accommodate the increased 36-inch-gauge track and larger ore trains for electric haulage than were used during previous smaller scale operations. H. M. Kingsbury, as Consulting Mining Geologist, has been retained in charge of exploration and geological studies of the district.

A new office, 30 by 31 feet; together with a warehouse, 30 by 59 feet; machine shop, 30 by 30 feet; compressor building, 30 by 60 feet; and change house for the miners, 64 by 50 feet, are nearing completion and mill construction is now well underway. (Plate I.) It is planned to have both the mine and mill ready for production early in the spring of 1943.

The mill, which will have a daily capacity of 500 tons, is being built on the hill slope about 650 feet north from the mine entrance. The mill will include separate structures: the crusher, flotation, thickener and filter buildings, and assay and mill superintendent's office. In general the mill operation will consist of primary and secondary crushing to reduce the ore to about one-half inch size. This crushed ore will then be elevated by conveyor belt to a fine-ore storage bin at the head of the flotation building in which will be installed a new Marcy ball mill and Aikens type classifier. The product from this fine-grinding unit will pass through conditioning cells and then into Agitair scavenger, rougher, and cleaner cells from which the copper concentrate will go to a thickening-tank and thence to an Oliver-filter. From the Oliver-filter the copper concentrate, containing about 10 percent moisture, will go to the concentrate bin from which it can be loaded by gravity into trucks for shipment twelve miles to the railroad station at Pompanoosuc and from there transshipped by the Boston and Maine Railroad to the New York area for smelting and refining.

When in operation the mill will produce from fifty to sixty tons of copper concentrate daily, containing 25 to 30 percent copper. At the present time the road and bridges between the mine and the Pompanoosuc station are being improved by the State, through a grant of $75,000 given by the Federal Aid for Roads, to permit the use of trucks to carry loads of from ten to twenty tons.

The U. S. Bureau of Mines,[1] as the result of examinations made by its expert, Mr. James E. Bell, concludes that:

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[1] The Elizabeth Mine, Orange County, Vermont; War Minerals Report No. 2, Bureau of Mines (November, 1942).

1. The Elizabeth Mine can produce copper at the annual rate of 6,000,000 pounds, starting early in 1943.
2. Because of urgent war requirements for additional copper, prompt resumption of operations should be expedited through financial aid and other assistance from the Federal Government.
3. Additional prospecting by diamond drilling is warranted.

HISTORICAL SKETCH OF THE COPPER MINES

Unfortunately the copper industry in Vermont produced no historian and so what records there are are fragmentary and more or less inaccurate. W. H. Weed, formerly of the U. S. Geological Survey, wrote two articles[1] about the mines and to these frequent reference has been made. Mr. James Tyson, Jr., of South Strafford, has contributed valuable information concerning the Elizabeth Mining Company which he incorporated; Mrs. Ethel C. Harding, of Vershire, has kindly consulted the town records as they concern the Ely Mine; while Prof. Evan Thomas, of Burlington, who held a pastorate in Vershire Center from 1880 to 1889, has given the writer details of happenings at Copperfield during a part of its varied history. Ex-Governor Wilson, and Mr. H. M. Kingsbury of the Vermont Copper Company have made contributions and criticisms which are invaluable. This historical matter has proved so intriguing to the writer that he has been impelled to present it, with the thought that readers may find much of interest in this phase of Vermont history.

THE MINE AT VERSHIRE

This working was best known as the Ely Mine and was the largest and most famous of the group. It lies in the southeast corner of Vershire, near the now abandoned mining village of Copperfield.

Weed states that the ore was discovered here in 1821 by farmers who were attracted by the oxidized appearance of the outcroppings. Explorations led to the formation of the Farmers Copper Company, who opened up a body of good ore and smelted it in a crude furnace. Operations were carried on with more or less success and interruptions.

This company was apparently succeeded by the Vershire Copper Mines which was owned by Henry Barnard, J. I. Bicknell, J. E. Smith, Samuel Mitchell, Fulton Cutting, and L. L. Lombard. Later, The Vermont Copper Mining Company was chartered by the Legislature and organized in 1853 by this same group. The capital stock of this company was $500,000: 100,000 shares at $5 par value. Of these, 96,000 shares were issued to the six organizers and the remaining 4,000 shares were sold at par to provide working capital. The company used uneconomical apparatus in the development and operation of the mine and apparently made but little money.

The name of Smith Ely, of New York City, first appears as a stockholder in the records of 1863. In 1864 he held 2,588 shares of stock and was elected president in 1865. The affairs of the company were not prosperous and Ely was able to pick up the shares of most of his associates at bargain prices, while he acquired an extensive acreage around the original holdings of the company. A keen business man, he soon brought the property into a condition of fame and prosperity. The Ely Mine, as it came to be called, became practically a family affair. During one year of his régime a dividend of $100,000 (20 percent of the par value of the stock) was paid, while salaries to himself and other members of his family were for those days, large. It is said that at one time Smith Ely was offered $1,250,000 for the property but refused it.

Many stories are told of the palmy days of this mining camp: of the great prosperity of Copperfield, as the mining village was called (the name still appears on the Strafford topographical quadrangle), and its several hundred inhabitants, of the desert condition of the region, caused by sulphur dioxide fumes from the roasting beds; of the changing of the name of the township to Ely, in 1880, owing to the efforts of the picturesque E. Ely Goddard (a grandson of Smith Ely) who represented the town in the Legislature, drove his coach-and-four and entertained lavishly; of the three-day "Ely war," in 1883, when the miners rioted because of over due wages and the militia was called out to restore order. The crash came on July 3, 1883 and the company became bankrupt.

To go back somewhat, Smith Ely, in 1882, had deeded the property, with the exception of the company store, to E. Ely Goddard and F. M. Cazin who therefore were the owners when the enterprise collapsed. In September, 1883, Judge Samuel L. Gleason was appointed receiver and the next year the Court ordered the property sold at auction. F. M. Cazin bid it in for $36,000, but assigned his interests, in 1888, to Otto K. Krause, of New York City, who proceeded to rehabilitate the mine. The plant was remodeled and a 100-ton concentrator was installed at a cost of $53,000. In spite of the large investments and considerable production the enterprise was short lived, the plant was shut down in 1892, and the Vermont Copper Mining Company, as it continued legally to be called, again went into receivership.

On December 8, 1899, George Westinghouse, of electrical fame, bought the property and expended a large amount of money in experimenting with new methods of ore treatment but without success. In January, 1917, the property passed to Agnes P. Bennett. It was transferred, indirectly, to the Vermont Copper Company in April, 1942.

At some time after the Westinghouse occupation, owing to the heavy taxes imposed by over zealous assessors, the plant was demolished, the miners' houses removed or torn down, and the village of Copperfield ceased to exist.

During the first world war H. W. Bennett formed a company called the Ely Associates, who built a flotation mill in 1918 and worked over the Ely dumps. The mill was operated for ten months and, during this time, worked over about 19,000 tons of dump material, which averaged 1.34 percent copper; recovery was 67 percent.[1] Due to various circumstances, including a poorly-

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[1] Notes on the Copper Mines of Vermont; Bull. 225 U. S. G. S. (1904) and The Copper Deposits of the Appalachian States; Bull. 455 U. S. G. S. (1911).

[1] War Minerals Report 2.

designed mill, the use of second-hand machinery, and the inaccurate sampling of the dumps, the company soon ceased operations and another chapter in the long history of the mine closed.

PRODUCTION

According to Weed, the average composition of the Copperfield ore was: copper, 3.31%; iron, 30.39%; sulphur, 14.71%; insoluble matter, 36.57%.

The same writer gives the production of the mine, under its various owners, as follows:

Copper ore shipped.	1854-1860	3,270 tons
	1861	1,812 tons
	1863	1,430 tons
	1865	1,430 tons
	Total	7,942 tons

Metallic copper produced in 1870, 943,465 pounds.
Amount of pig copper produced from 1872 to 1882, 25,000,000 pounds.
Copper produced in 1890, 7,500,000 pounds.

Assuming an average of 3 percent copper in the "Copper ore shipped," we get a total of over 33,400,000 pounds of copper produced by the Copperfield mine.

THE ORE

The ore at Copperfield is chalcopyrite ($CuFeS_2$, sulphide of copper and iron) disseminated in pyrrhotite (Fe_7S_8, one of the sulphides of iron) and containing some pyrite (FeS_2) sphalerite (ZnS, sulphide of zinc) and from 0.44 to 1.28 Troy ounces of silver per ton.

Again quoting Weed, the ore bodies consisted of several overlapping lenses, "en echelon," with their long axes "striking," or extending, north and south, "pitching," or slanting downward to the north at an angle of about 25 degrees with the surface, and "dipping," or sloping, about 24 degrees easterly. These lenses averaged 100 feet in horizontal extent, 10 feet in thickness, and from 100 to 300 feet along the "dip." The total depth is unknown, but the inclined shaft, which was probably driven parallel to the "pitch," was 3,400 feet long. This would give the vertical depth of the end of the shaft below the surface of 1,580 feet.

DEVELOPMENT

The upper lens was opened by an inclined stope,[1] sunk in the ore and worked by the underhand-stoping method. The stope was 3,386 feet long; the average width, about 100 feet; average height, about 10 feet. When one lens pinched out, a "winze"[1] was sunk to the top of the underlying lens which was then opened up and mined. This happened four or five times in the history of the mine. Further details are lacking.

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[1] See p. 15.

REDUCTION WORKS

In smelting sulphide ores a large part of the sulphur must be eliminated. This was done in the old days by burning (roasting) the ore in heaps or within rectangular walls, open on top, called stalls. Of course the roasting increased the copper content of the ore—and killed the vegetation in the immediate vicinity of the roast-beds, giving the "desert condition" mentioned above. The roasted ore was then smelted to a "first matte" (a double sulphide of copper and iron). This first matte was then presumably reroasted, further to increase the copper content, and again smelted to impure, "black-copper" which was then ready for the refinery. Details of these processes as carried on at Copperfield are fragmentary but Weed states that the ore was first smelted in twenty-four-brick "reverberatory"[1] furnaces, of a type that was developed at Copperfield and was called the Vershire furnace. Later, water-jacketed blast furnaces[2] were employed in place of the reverberatories.

In 1901, while visiting the mines and smelting works at Freiberg, Saxony, the writer met a metallurgist who, many years before, had been employed at Copperfield during the Ely régime. He talked interestingly of the old days at the Ely smelter.

Plate II, taken from the 1901-02 Report of the State Geologist, Prof. George H. Perkins, gives an interesting view of the smelter buildings as they existed during the prosperous days of the Ely mine.

THE CORINTH MINES

This old group of mines lies in Corinth Township, some eleven miles north of Copperfield, on a continuation of the mineralized belt, with the same character of ore but in a more gneissose country rock. The ore bodies make up a series of lenses which lie at different depths "en echelon." The group includes:

1. THE UNION MINE

Again quoting Weed: "The Union mine was first opened in 1866. Production from then up to 1881, inclusive, amounted to 31,504 tons of ore, averaging about 9 percent of copper." (Whether the ore was that rich or was sorted, or "cobbed" to bring up the copper content is not stated.) In 1878 the property was bought by Smith Ely, who shipped the ore to the Copperfield smelter. In 1879 and 1880 a total of 5,712,604 pounds of "fines," carrying 2.7 to 4.5 percent of copper were so shipped. In 1879 the first Vermont Copper Company was organized by the same interests, and mining and shipping were continued till 1889.

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[1] A reverberatory furnace consists of a long, narrow basin or hearth, separated from the combustion chamber, at one end, by a low partition, called the fire-bridge, and ending in a chimney at the other end. The roof of the hearth pitches downward towards the chimney so as to concentrate the heat. A sea of flame, from the long-flaming coal, passes across ("reverberates") the ore, spread upon the hearth and mixed with such fluxes as may be needed, and smelts it to matte by radiated heat.

[2] A blast furnace, generally speaking, is an upright cylinder, constricted at its lower end to form the crucible, which is water-jacketed. Above the crucible a blast of air is driven through several radial openings, called tuyères intensifies the combustion of the fuel and by its reducing action, the copper, iron, and sulphur contents of the ore form a "matte." Ore, fluxes, and coke, in proper proportions, are mixed and fed into the upper part of the furnace, which is kept full, while the resulting matte and slag collect in the crucible: the matte above and the slag below. These products are drawn off at intervals and the matte is further treated.

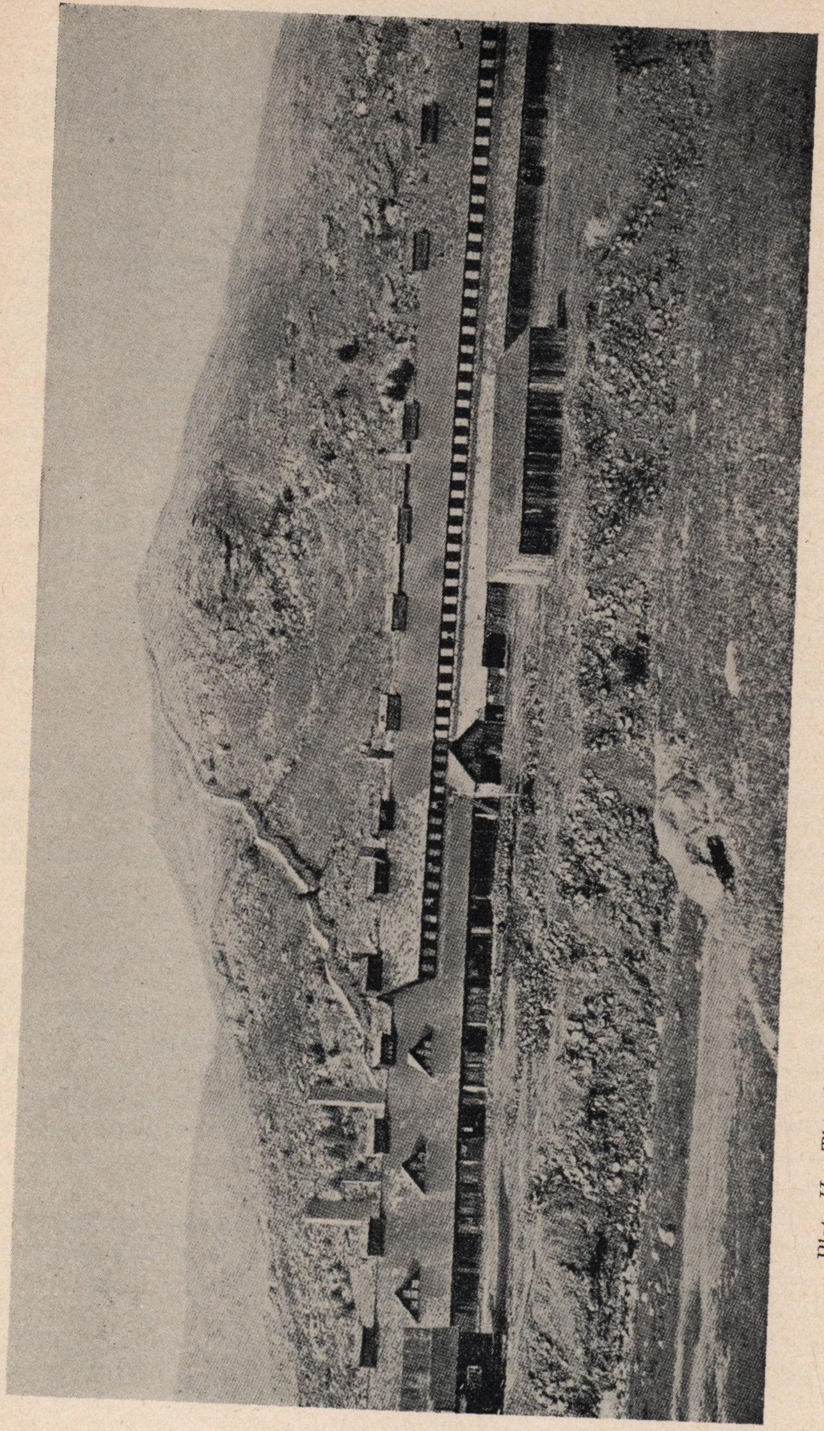

Plate II. The old Ely smelter building at Copperfield. The Ely Mine entrance is near the top of the hill, *From The Vermonter.*

DEVELOPMENT

Weed states that the property was developed by an inclined shaft 900 feet long, or 766 feet below the adit level. Down to a depth of 300 feet four overlapping ore lenses (or shoots), were worked by winzes sunk from the main lens. Selected ore showed 8.15 percent of copper, 0.3 ounces of silver per ton, and a trace of gold. The lenses had a north-south direction ("strike"), sloped ("dipped") 30 degrees easterly, and had an average thickness of eight feet.

2. THE CUPRUM AND EUREKA MINES [1]

The ore bodies of these mines lie south of the Union; the Cuprum, near the summit of Pike Hill. Nothing seems to be known about the beginnings of the Cuprum but in 1860 it was taken over by the Corinth Copper Company who sunk an inclined shaft in the ore body and opened it up to the north and south. An adit,[2] 1,000 feet long, was driven at the lower level to intercept the lode and this, when found, was called the Eureka mine (*Eureka,* Greek for "I have found it"). The adit met the upper (Cuprum) lens near its lower end, where it was pinching out, and, this proving discouraging, very little work was done on it, chief attention being given to the thicker part of the lens. This was worked intermittently till 1889. Weed states that selected samples of the ore contained 19.65 percent copper and 0.76 ounce of silver per ton.

In 1904 Knox and Allen, mining engineers of New York City, acquired the property for private interests and started further development work. This showed that there was another lens lying in line with the strike of the Cuprum but about twenty feet below it. This new lens was opened up and a body of high-grade ore discovered. The combined length of the two bodies proved to be about 900 feet. A third lens was subsequently found below the second.

Mining operations were started on a large scale in both the Cuprum and Eureka lodes. The high-grade ore was hand sorted (cobbed) and shipped to New York smelters, while the lower grades were stored for future mill treatment.

The Pike Hill Mines Company[3] was incorporated in 1906, with James G. Pirie, president; Ernest M. Bowen, vice-president; and Harry G. Hunter, general manager.

The company's freehold included the Union, Cuprum, and Eureka properties, aggregating 215 acres, together with the mineral rights of an additional 185 acres. The equipment included hydroelectric power, compressor, coarse crushers, Hardinge mill, a 100-ton flotation plant, Oliver-filter, etc.

PRODUCTION

Production in 1905 was 131,911 pounds of copper; in 1906, 304,377 pounds of copper and 1,698 ounces of silver; in 1907, 425,367 pounds of copper and 2,292 ounces of silver.

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[1] E. C. Jacobs: Copper Mining in Vermont; 10th Rep. Vt. State Geologist (1915-16).
[2] See p. 15.
[3] From the Mines Handbook, vol. 18, part 1 (1931).

For reasons not stated the company was inactive from November, 1907, till October, 1915. Then experiments with the Wood flotation process were carried on. In 1916 Mr. Hunter informed the writer that the experimental runs were satisfactory and that this type of concentration would be adopted. The Handbook states that the flotation plant was completed in 1917. Production in the following year was 509,654 pounds of copper and 2,056 ounces of silver. Presumably this resulted from the shipment of the concentrates to a smelter.

The mines were closed early in 1919 owing, no doubt, to the fall in copper prices with the end of the year.

As far as the writer is informed the Corinth mines have been idle ever since. They were purchased by the present Vermont Copper Company in 1942.

MINING OPERATIONS AT SOUTH STRAFFORD

These mines form the most southerly group on the mineralized belt, already noted, and are situated in Copperas Hill,[1] one and one-half miles south of South Strafford village and about seven miles south by east of Copperfield.

The ore which, like that of the northern deposits, consists of chalcopyrite disseminated in pyrrhotite, was first used for the manufacture of copperas ($FeSO_4 \cdot 7H_2O$, hydrous iron sulphate), in 1793. It was mined in the open cut at the south end of the great ore body which was later to be worked for copper. This open cut, some 1,200 feet long, was known as the Foster-Cleveland property and, from its ore, copperas was manufactured and shipped by teams to Boston for many years.

On June 9, 1830, Isaac Tyson, Jr., bought the mineral rights north of the open cut and began mining operations. From then to 1883 the ore was heap-roasted and smelted for copper in reverberatory furnaces. It is said that seven smelters were built at different times and some 250,000 tons of ore were treated.[2]

In about 1881 James W. Tyson, Sr. (then president of the Tyson Mining Company of Baltimore, Md.), acquired the property in fee and incorporated the Elizabeth Mining Company (named for his wife). Being refused entrance to his mine through the Foster-Cleveland land, he sank a shaft near the southern end of his property and mined the ore, which was "cobbed," or selected, to bring the copper content up to 4 or 5 percent, and shipped to smelters in Connecticut. Later, under the management of his son, James W. Tyson, Jr., two water-jacketed furnaces were erected to produce copper matte and this was refined in a reverberatory furnace to "black copper" of 96 to 98 percent purity.

In about 1885, after the failure of the French Syndicate, which had apparently maintained an artificial price for the red metal, copper dropped to eight cents a pound and maintained a low level for many years. The company failed, James W. Tyson, Jr., was appointed receiver and, in 1907, he sold the Elizabeth

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[1] There is another Copperas Hill, in Shrewsbury, Rutland County, where copperas was once manufactured from the iron pyrite deposits there.

[2] Taken from Sidney A. Mewhirter's Report to the National Copper Corporation (1930).

Mine to August Heckscher of New York City. Heckscher also acquired the Foster-Cleveland and other properties in the neighborhood. He started operations under the name of The Strafford Mining Company but later discarded that designation and incorporated the Anhama Realty Company (named for his wife and daughter). Mr. Heckscher built the dam on the White River, below Sharon Station, and a power plant and lines to carry the electricity nine miles over the ridges to the mine, but these were destroyed by the flood of 1927. At one time, Heckscher was experimenting with an electric process of smelting, one which had been successfully used by the New Jersey Zinc Company, but for some reason it was not a success.

During the period of the Heckscher activity, according to Mewhirter, "Pyritic smelting was tried[1] in a 300-ton blast furnace, but this was destroyed by fire in 1909, a few months after being blown in. Another blast furnace, of 200 tons capacity, was built the same year and operated for two weeks, when the main flue collapsed and smelting operations were again discontinued. A branch railroad was also projected at this time."

"More systematic underground development was started during this period, including about 9,000 feet of diamond drilling to prove the continuity of the ore body. But after the last smelter failure the property remained idle until 1916, except for some diamond drilling in 1912-13." "In 1916 pyritic smelting was again attempted, under the direction of (Professor) G. A. Guess, of Toronto. After a thirty-six-hour run a spout failed and operations came to an abrupt stop. Since there was no spare spout on hand smelting was not resumed and this marked the end of attempts to smelt this ore."

"In 1916-18 (during the first world war) some diamond drilling was done and, in the latter year, the old magnetic separation plant was remodeled into a 100-ton flotation plant by the General Engineering Company. A six-foot by 22-inch Hardinge mill, Door Classifier and Callow cells (rougher and cleaner) were installed. The plant operated with this equipment till April, 1919, when a second unit was added to raise the capacity to 200 tons a day. (Mr. N. O. Lawton was the mining engineer during this period.) Considering the status of differential flotation at this time, the results were very satisfactory, but the drop in copper prices after the war caused the property to be shut down."

"After remaining idle till 1925 the property was leased to The American Metal Company, of Vermont, who added a 16-cell Minerals-separation machine to the equipment. About 20,000 tons of ore were mined and 1,756 tons of 18 percent copper concentrates were shipped during a six-months run. Again the drop in copper prices prohibited further profitable production at the existing scale of operations and the company cancelled its lease."

"In 1928[2] the National Copper Corporation was incorporated, with LeRoy M. Gross, of New York City, president; Frederick W. Foote, vice-president; Sidney A. Mewhirter, manager. In the fall of 1928 this company took over

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[1] Pyritic smelting employs the sulphur of the ore as a partial or total fuel and so avoids roasting as a preliminary to ordinary smelting.

[2] The Mines Handbook (1931).

the property on a twenty-year lease. "After remodeling the mill and installing new machinery in the grinding section, operations were started in April, 1929, and continued till June, 1930, when the drop in copper prices (following the business collapse) necessitated a shut-down. The 50,000 tons of ore mined and milled during this period may properly be considered as an experimental test run to determine a basis for permanent operations when copper should recover its normal price. The run also provided a basis for estimating the possibility of sulphuric acid manufacture from the pyrrhotite in the ore."

PRODUCTION

In his report, Mewhirter wrote: "It has been estimated that 330,000 tons of ore have been removed from the Elizabeth-Foster-Cleveland mines since mining operations began in 1793." In a personal communication Mr. Kingsbury reduced this figure to 320,000 tons and stated that this tonnage came mainly from the underground workings of the Elizabeth mine. These 330,000, or 320,000 tons, included about 20,000 tons mined during the American Metal Company's operations on the Elizabeth ore body and 50,000 during the National Copper Company's lease. James Tyson, Jr., is the authority for the statement that the ore mined during his régime did not average more than 3 percent copper. Using his figure the total copper content of the 320,000 tons of ore would amount to 19,200,000 pounds.

As one reads the history of operations on the Elizabeth ore body he is impressed with the many vicissitudes that attended reduction and marketing operations. It would seem that the mine has never had a fair chance to show its commercial possibilities.

THE ORE

Like the Copperfield and Corinth ore bodies, the Strafford lode consists of chalcopyrite disseminated in pyrrhotite, a small amount of zinc, as sphalerite, and silver up to 0.2 Troy ounce per ton. Mewhirter states that 7,000 tons mined during March, 1930, gave the following analysis:

Copper	2.29%
Zinc	0.32%
Iron	36.40%
Sulphur	23.02%

The average copper content of 60,000 tons, mined in 1929-30, was 2.11 percent. He calls attention to the value of the sulphur and iron as sources of sulphuric acid and iron sinter. The ore body is present in the form of great ore shoots, lying concordantly with, or penetrating, the country rock. This country rock is, generally speaking, a quartz-biotite schist, containing also garnet, sillimanite, rutile, pyrrhotite, calcite, and other minerals. The strike of the lenses is northeast; the dip, 60 to 65 degrees easterly; and the pitch, about 25 degrees to the northeast. The Elizabeth lode can be traced for about a mile along the strike.

DEVELOPMENT [1]

The Elizabeth mine has been opened by two shafts,[2] a series of levels, stopes,[3] raises,[4] and an adit,[5] or entrance level.

The shaft which James Tyson, Sr., sank in 1881 was abandoned and an adit (Plate I) was driven from a point near the mill, westward into the mountain side to cut the 'D' level and provide a haulage route for the mine cars. This adit was seven feet by nine feet in section and 1,360 feet long, with an average grade, easterly, of 2.25 degrees. A 28-inch-gauge electric locomotive hauled the loaded mine cars to the ore bins at the mill. The old workings above the 'D' level connected with the Foster-Cleveland open cut and provided additional access to the mine. The 'D,' also called the "225-foot," and "the haulage," level extended 620 feet south of the adit entrance and 230 feet north. The larger part of the ore thus far mined has come from above this level.

"On the 'D' level, 25 feet north of the adit entrance, a 30-degree inclined shaft was sunk 810 feet, to a point of 330 feet vertically below the 'D' level. From this shaft levels were driven at 90 feet (the 'E' level), 220 feet ('G' level), and 310 feet ('H' level) vertically below the haulage level. The 'E' level has been driven 400 feet to the south and 140 feet to the north of the shaft. Raises (or winzes[6]) connect it with the haulage level. The 'G' level has been driven 190 feet south and 290 feet north. In the north section some stoping has been done and 'raises' driven to a sub-level, between the 'E' and 'G.' Since the 'E' level does not extend over the 'G' to the north, no raises connect them. The bottom ('H') level, extends 900 feet north of the shaft ending in a 'face' containing narrow veins of high-grade ore. A horizontal diamond drill hole had been driven 250 feet north into this face. When operations ceased, June, 1930, a raise to connect 'H' level with that next above was being driven, preparatory to stoping operations."

From the south end of the haulage level to the north end of the lowest level the horizontal distance is 1,800 feet.

Some 3,000 feet of diamond drilling was done underground and about 13,000 feet, from the surface, the latter to delimit the ore body.

ORE RESERVES

Mewhirter's Report gives the following estimated tonnage so far developed (blocked out) in the mines: Positively developed (ore "in sight"), 233,000 tons, analyzing 2.7 % copper, 31.60% iron, 18.7% sulphur. Ore estimated as the result of diamond drilling: in the Elizabeth Mine, 530,000 tons, analyzing 2.25% copper, 24.35% iron, 13.50% sulphur; below the Foster-Cleveland open cut, 802,000 tons, showing 1.35% copper, 26.0% iron, 15.0% sulphur. Total

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[1] Most of this information has been taken from Mewhirter's Report.

[2] Shafts, in mining parlance, are openings driven downward, either vertically or slopingly into or near an ore body. Levels run horizontally from the shaft into the ore body at various distances below the surface.

[3] Stopes are step-like excavations driven in the ore for the purpose of mining it; overhand stopes are driven upward; underhand, downward.

[4] Raises are short shafts driven from below, from one level to another, upward.

[5] An adit is a tunnel open at only one end.

[6] A winze is a short shaft connecting levels or driven to the surface for ventilation.

reserves, thus far indicated, 1,565,000 tons, averaging 1.76% copper, 26.25% iron, 15.10%, sulphur.

In April, 1942, the newly incorporated Vermont Copper Company bought the Foster-Cleveland and Elizabeth mines. Extensive drilling operations on Copperas Hill, now in progress, are very satisfactory and the success of the new company seems assured.

ESTABLISHED MINERAL INDUSTRIES

The six basic mineral industries of the State: asbestos, granite, limestone, marble, slate, and talc, have been variously affected by war conditions.

The asbestos industry has been extremely active during the past two years, with the Vermont Asbestos Mines, a division of the Ruberoid Company, running three shifts. Asbestos is an essential war mineral and is in great demand, especially for brake linings and brake blocks for mechanized war equipment, but also in the construction of buildings for the army and navy and in moulding compounds. An enormous tonnage of asbestos-bearing serpentine is being quarried and milled on Belvidere Mountain, while the old Gallagher property, to the east, which was acquired several years ago, is being developed for future use. Vermont is the largest producer of asbestos in the United States.

The granite business is holding up surprisingly well. In 1941, the latest year for which data are available, the industry was, as regards output, better than in 1938, 1939, and 1940. The number of operators remained the same, the number of days worked increased, while the average daily wage increased about 5 percent.

The lime business, judging from the only report that has been received, is operating at about 80 percent of normal, this largely due to conditions in the paper industry which uses a great deal of Vermont lime.

The Vermont Marble Company has gone extensively into war production work and, for this purpose, has reorganized its marble-cutting machinery for the manufacture of machine tools, engine bed-plates, winches, and submarine parts. The company's subsidiary, The White Pigment Corporation, has been extensively developed.

The slate industry is at a low ebb and is operating at only about 10 percent of normal. Most of the quarries are closed. Slate is not a war industry and building restrictions are severe.

The talc companies are operating at 75 or 80 percent of normal. One company reports that about half its product is going into materials for the war effort—paint, paper, roofing, textiles, etc.—while another concern finds a market for its product in the coated-wire and cable industry. The critical condition of the rubber situation has greatly restricted the use of Vermont talc.

Vermont possesses in the Bennington region one of the largest kaolin deposits in the East. It is, unfortunately, contaminated with fine, graphitic matter which, so far, has not yielded to beneficiation. The clay has been used by the General Electric Company for insulator purposes and, by other concerns, for the manufacture of face-brick. When the present bauxite deposits, which are the chief source of aluminum production, are exhausted or depleted, it is probable that kaolin will be used in their place; hence our deposits may be considered reserves for the future.

Mr. Leon Bushey, of Monkton Ridge, continues to produce a small tonnage of kaolin which is largely used by the Rutland Firebrick Company.

THE QUEST FOR NEW SOURCES OF MINERALS

MICA

An extensive search for mica (muscovite) for war purposes has been made but without success; it is doubtful if we have any good deposits in the State.

FELDSPAR

In Grafton Township Mr. A. F. Moriglioni discovered an enormous deposit of feldspar on the land of Mr. O. K. Rounds, which is on the Bartonsville Road, five miles from Chester. This is a pegmatite deposit containing only a small amount of quartz and very little mica. The feldspar is pink and white, with an iron content (the mineral pyrrhotite) of about 1.29 percent, which is too high for ceramic purposes. It might find use for soap powders and other purposes.

POULTRY GRIT

A good deal of poultry grit is used in Vermont and it has been obtained from dealers outside the State: from the Mica Crystal Company, of Warren, N. H., and from dealers in the West. But there is no good reason why the grit cannot be made from Vermont rocks. The Wells-Lamson Quarry Company, of Barre, is now offering a product made from their granite waste.

The Mica Crystal Company of Warren, N. H., is grinding a biotite-mica-gneiss for their grit. Probably an equally good gneiss, which occurs in large quantity along the road from Chester to Grafton, could be used.

QUARTZ

Mr. Frank B. Howard, of Randolph, owns a large deposit of very pure, translucent quartz which has been passed upon by New Haven, Conn., dealers and found acceptable. The only question is the freight rate, and this is a serious one for many Vermont mineral products; for naturally dealers will favor nearby sources of supply unless the more distant sources are of sufficiently superior quality.

QUARTZITE

The Cheshire Quartzite formation, which extends from western Massachusetts up along the Green Mountain front, is a very dense, gray, rock which, cut into blocks of the requisite size, should make an excellent abrasive for Hardinge or other grinding mills. There is an excellent outcrop along the road from East Middlebury to Ripton which could be used for this purpose.

QUARTZ SAND

In places the Cheshire quartzite is found disintegrated into very pure, white sand for which uses should be found: for abrasives, glass making, and other purposes. Swan and Baker, grocers, of East Dorset, own a large deposit of this sand and there are other deposits in the neighborhood.

MANGANESE

The largest deposit of manganese ore ever found in Vermont is that at East Wallingford. The ore consists of iron and manganese minerals occurring in pockets of yellow, gray, and white clay. The ore was worked for its iron contents as early as 1820 and smelted at Troy, N. Y. The Carnegie Steel Company worked the deposit, which became known as the Kinny-Cobble Mine, for manganese in the late 1880s and early 1890s, and shipped probably 20,000 tons. How much ore still remains underground has not been determined but, since the U. S. Geological Survey, which is acquainted with the deposit, has not thought it expedient to investigate the deposit, it is doubtful if it could be successfully rehabilitated.

In South Lincoln there is surface evidence of manganese mineral (probably wad) on the land of Mr. C. C. Hubbell. This deposit was investigated by the U. S. Bureau of Mines, whose report has not been made public. It is of doubtful value. Several other small deposits of manganese minerals have been brought to the writer's attention but have not been investigated. It should be borne in mind that the investigation of an ore deposit is an expensive undertaking so that, in order to be successful, the deposits must be large and rich enough in economic minerals to warrant the outlay.

TALC

In Bridgewater Center, on Freestone Hill, there appears to be an enormous deposit of talc. Surface showings are of low grade, but such deposits generally improve with depth. However, this one is four or five miles up a country road from the highway and is probably too distant from a railroad to have commercial possibilities.

ZINC - LEAD ORES

Sixty-five or seventy years ago a deposit containing galena and sphalerite was mined on Lyon Hill, Leicester; a shaft was sunk some fifty feet deep and an unknown amount of ore was mined. During the summer and fall of 1941 the St. Joseph Lead Company, of New York, did extensive core-drilling from Lyon Hill eastward to the Fay farm. They found good ore but the width of the vein did not warrant further investigations.

IRON ORES

In the first half of the last century a good many small iron ore deposits were worked and the ore smelted in several small, stone furnaces: The Granger Furnace at East Pittsford; Conant's Furnace, in Forestdale, near Brandon; the Tyson Furnace (built by Isaac Tyson who first opened the Elizabeth Copper Mine, at South Strafford) in Ludlow; and the Pittsford Furnace. Some of these old furnaces are still standing and are metallurgical curiosities.

Deposits of iron ore were worked in Stamford, east and west Bennington, Shaftsbury, Manchester, Wallingford, Tinmouth, East Pittsford, Brandon and Forestdale, Plymouth, Cuttingsville, Chittenden, Ludlow, and perhaps in other places. To what extent these deposits were exhausted could not be told except by unwatering the old shafts (and probably retimbering them) and exploring the workings—expensive operations. If Federal aid can be obtained the most promising deposits, notably those at Pittsford and Ludlow, will be examined during the coming field season.

SCHOOL COLLECTIONS OF MINERALS AND ROCKS

The State Geologist has gathered and, with the aid of N. Y. A. students, has prepared some fifty sets (twenty specimens each) of common minerals and rocks, very largely from Vermont sources, for distribution among the high schools and academies of the State. Each set will be accompanied by an explanatory pamphlet. Distribution now awaits suitable boxes with compartments for the specimens, in order that they may not get lost. Such boxes have been promised by the Department of Education but have not been received.

Plate III. Fig. 1 (*above*): General view of locality, looking south. Pensioner Pond lies beyond the rocky barrier in which the gorge has been cut. Fig. 2 (*below*): Exposed face of waterfall in gorge, showing strata dipping steeply to the west. Talus blocks in right foreground.

II

PHYSIOGRAPHY

An Abandoned Valley at West Charleston, Vt.

Charles G. Doll
University of Vermont

INTRODUCTION

Valleys abandoned by their rivers are not uncommon features on a landscape once covered by the huge mass of glacial ice during the last Great Ice Age. Numerous examples have been recorded by geologists from the vast glaciated regions of the world. Among the occurrences are many rivers which were forced from their pre-glacial channels when these became filled with ice or glacial débris. The diversion to a new course has often resulted in the production of a picturesque gorge possessing characteristics of a stream in extreme youth. The youthful characteristics of the stream were carved since the termination of the Glacial Period and, in many cases, have been superposed upon a landscape of an earlier mature cycle of erosion. An interesting occurrence of such a post-glacial gorge and an accompanying pre-glacial valley, is shown by the Clyde River at West Charleston, Vermont (Plate III, Figure 1).

DESCRIPTION OF SITE

A mile south of the village of West Charleston the Clyde River leaves Pensioner Pond situated on a floodplain, to enter a gorge in which it descends eighty-two feet in approximately a quarter of a mile, to a pond below. On its way through the gorge the river courses in a series of rapids to a waterfall, over which it plunges forty feet in several channels (Plate III, Figure 2). The gorge attains its greatest depth of more than 100 feet immediately below the waterfall. It is only a few steps from the motor highway to the overhanging edge of the west wall directly above this place.

The gorge is cut essentially parallel to the trend of the upturned edges of steeply inclined layers of metamorphosed sedimentary rocks consisting of phyllites and crystalline limestones. The trend and inclination of the rock layers, known to the geologist as strike and dip, are N. 2° W. and 70° W., respectively, in the gorge. Thus, the walls of the gorge are the more or less smooth bedding surfaces of the rock layers, since the down-cutting process follows these surfaces in the direction of the steep dip.

In the zone of rapids above the waterfall, the turbulent waters have produced a number of small potholes with round and oval groundplans. The pot-

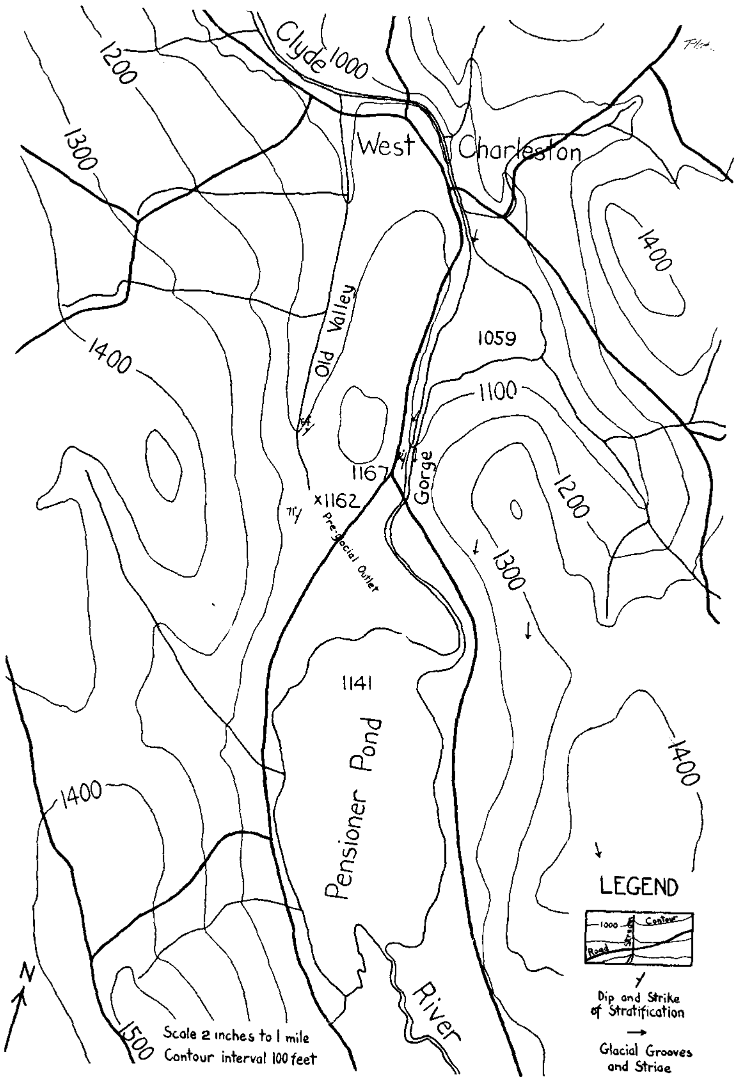

Plate IV. Map of the area discussed.

holes are best developed in the softer limestones in which the largest measures thirty by twenty inches across and two feet deep. The long diameters of those with oval cross section conform to the direction of stream flow. Below the waterfall, the floor of the gorge is strewn with extremely coarse débris, some of the boulders being ten feet long. Much of this cover of loose material was contributed blockwise from the overhanging west wall, chiefly by the action of ordinary weathering. Hence, if potholes are present in this area, they lie hidden with the bedrock.

Directly west of the gorge the land rises to a north-south trending low ridge which is notched in the village by the river where it swings to the west. Bordering this ridge on the west lies a valley possessing characteristics indicative of an earlier development than the gorge (Plate III, Figure 1, Plate IV). That this valley very probably was a former course of the Clyde River in pre-glacial time, is revealed by its physiographic features and position with respect to the present course of the river. In its upper portion this valley falls rather rapidly in step-like fashion, soon reaching a level from which the decline is gradual for the remainder of its length. In this lower portion the valley bottom is flat and wide with flaring sides, features showing a period of erosion antedating that of the gorge. A brook with a normal width of hardly three feet throughout most of its length, occupies the valley at the present time. A wide, shallow depression, running southeasterly, connects the head of the valley with Pensioner Pond.

DRAINAGE HISTORY

Before the advent of the Ice Age the Clyde River flowed leisurely among scenes greatly different from their present aspects. It must be realized, in this connection that the surface of the land stood at a much higher level than at present and that its relief was generally low and rolling, with perhaps an occasional monadnock to give sublimity to the scene. Such modern features as narrow gorges, waterfalls, and lakes, were extremely rare. Hence, it is quite unlikely that Pensioner Pond and, much less, the gorge with its waterfall, were in existence on this ancient landscape of advanced maturity. One can imagine the vastness of tillable acreage on this old land surface replete with immense river floodplains, as compared with its present-day distribution in small patches on hillsides and in restricted valley bottoms. However unfortunate this may seem, it is hardly to be expected that this truly farmers' paradise could remain intact after supporting a thick, impelling ice sheet for the next million years.

During the Ice Age Vermont was as bleak as glacial Greenland is today. Ice covered the ground everywhere, and river erosion was supplanted by that of glacial ice. Slowly but surely the ancient land surface was being remolded, in a great measure, to the scenery of the present time. At length the time came for the giant refrigerator to be defrosted, and a new drainage appeared on the reexposed land as the rivers again began their work. In this drainage derangement the Clyde River at West Charleston was compelled to discover a new course, which has resulted in the formation of the present gorge.

Parallel grooves and striations on the smooth surface of the bedrock bordering both sides of the gorge, not only indicate the former presence here of the ice sheet, but point in the direction of its movement (Plate IV). Moreover, these glacial markings denote the glacial erosion surface below which the Clyde River has subsequently eroded its deep rock channel. Thus may be seen the relationship in time between the Ice Age and the development of the gorge. The gorge is known, therefore, as a post-glacial gorge. An outcrop at the north end of the pond below the gorge is noticeably impressed with glacial grooves measuring six inches in width and two inches deep. Other evidence of glaciation consists in a general distribution of a heterogeneous mixture of boulders in a matrix of clay and sand, called till. The plow often reveals its presence on stony slopes, but on alluvial flats it is much less frequently encountered because of the cover of recent stream deposits.

Fig. 3. A granite erratic.

Not infrequently in the till are cobbles and boulders which show the effects of rubbing and grinding on their faceted and striated surfaces. The enormous sizes of isolated boulders of foreign origin located on the hills and slopes in the vicinity of West Charleston, prove the practically unlimited carrying power of the glacier. An enormous, moss-covered, glacial boulder of granite weighing more than 300 tons, is situated in the woods on the hill immediately southwest of Pensioner Pond (Figure 3). The man in the photograph is six feet tall. A smaller granite boulder stands directly upon the stratified bedrock on the summit of Oliver Hill southwest of West Charleston. No natural agency other than the glacier is capable of transporting boulders of such large dimensions. Some of these "erratics" have traveled great distances and can be traced to their bedrock sources in Canada. A few "erratics" are mingled with the loose rock of local origin near the mouth of the gorge, while several, of which one is distinctly striated, lie upon the surface at the head of the old valley.

The abandonment of the old valley by the Clyde River took place after the glacier retreated to the north, and in consequence of the lower elevation of the new channel upon the site of the present gorge. From this time on the river has been constantly at work cutting the gorge deeper and deeper, the effect of which was to lower the stream level on the plain above to twenty-one feet below the pre-glacial outlet at the head of the old valley (Plate IV). An effect of steam level lowering has been the gradual shrinkage in size of Pensioner Pond. The nature of the deposits, such as sands and clays, and the gradual rise of the lower slopes bordering Pensioner Pond, seem to indicate the existence of a larger body of water which must have extended a considerable distance up the valley for some time after the ice sheet melted back to the north. Pensioner Pond now fills the deepest depression in this old glacial lake basin.

Besides the fashioning of a picturesque landscape, the glacier has left features of utility, among them water power. This serviceable, geologic inheritance is being utilized in the gorge at West Charleston, where hydro-electric power is generated for the surrounding villages and distant places.

It is reported that the gorge was able to accommodate the high water during the Vermont Flood of 1927 and that the hydro-electric power station at the lower end of the gorge survived intact. However, the large expanse of flat upon which Pensioner Pond is located, was covered with water. It may be that a part of the flood waters from this floodplain found a temporary outlet through the old valley, thus creating a two-way channel which relieved the greatly strained capacity of the gorge. It is possible that two courses of the Clyde River existed in these positions in early post-glacial time, and that at some later period the outflow through the old valley was abandoned. Double outlets are extremely rare; a modern occurrence of them, however, is shown by Sneech Pond in the town of Cumberland in northeastern Rhode Island.

The geologic relationship of the river to rock composition and structures at West Charleston, shows clearly why double channels and outlets are scarce. When the river followed the pre-glacial outlet to the old valley, the waters flowed across the strike of hard and soft layers of rock alike, whereas in its present location the river channel has become adjusted to the strike of the intercalated hard and soft rock (Plate IV). This latter parallelism in the strike of the rocks and river channel, permitted an increase in the rate of erosion, as the current now confined its efforts linearly to the compositionally weaker limestones, leaving the harder, projecting siliceous beds to be eroded blockwise along joints and bedding planes by frost and hydraulic action. Thus, by concentrating its erosive power almost wholly on the weaker strata, the Clyde River has made a substantial cut in the bedrock, forming the present gorge. The old valley, once followed by the river, now harbors an insignificant little brook.

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Plate V. Maximum glaciated areas in North America during the Great Ice Age.

The Great Ice Age in Vermont

Elbridge C. Jacobs

The subject of glaciology is one of the most fascinating in the whole field of geology and, moreover, most of its concepts are easily comprehended by the lay reader while illustrative material is seen, in this north country, on every hand. This article represents one more effort on the part of the State Geologist to arouse interest among the citizens of Vermont and elsewhere, and especially among the young people, in the wonderfully varied geology of the State. With this brief story of glaciology in mind they will be the better fitted to read, study, and observe the many glacial phenomena of this region. Furthermore, the article will serve as an introduction to Professor Chapman's brilliant paper on the glacial history of Lake Champlain which follows.

At least three times in the geological history of the earth hundreds of thousands, and even millions, of square miles of its surface have been deeply buried by ice-sheets which, persisting for hundreds of thousands of years, have profoundly modified the land, eroding its bed rock, moving tremendous quantities of unconsolidated rock material, damming up lake basins, deranging old river systems, modifying climates, causing considerable changes in sea and land levels and, on melting, leaving immense quantities of débris in characteristic glacial forms.

The glacial epochs, as they are called, are irregularly spaced as to time, the oldest occurring in the Proterozoic Era roughly a billion years ago, and leaving its evidences in the country north of the Great Lakes, in Australia, South Africa, and other regions.

The second great glaciation occurred in Permo-Carboniferous times, some 230,000,000 years ago, and was especially remarkable for its occurrence in tropical areas of South America, Africa, and in Australia, as well as in regions remote from the equator. In North America this glacial epoch is definitely known only on the coast of Massachusetts (at Squantum, near Boston) but there may be other areas in some of our other states, in Alaska, and Canada.

The latest glacial epoch is called the Pleistocene, or Great Ice Age. Geologists believe that it began about a million years ago and its waning stages are still with us. Plate V[1] shows the area of maximum glaciation in North America during which about 5,920,000 square miles of the continent were covered by the ice-sheet. The Pleistocene also extended over some 1,350,000 square miles of Europe, 5,200,000 square miles of Antarctica, and smaller areas in Asia, New Zealand, and Patagonia, giving a total glaciation for the earth, according to Daly (1), of 12,900,000 square miles, or about 13 percent of the surface of our planet. These maximum areas in the different continents were not necessarily contemporaneous.

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[1] Reproduced from Tarr & Martin's College Physiography by kind permission of the Macmillan Company, New York City.

Today the ice-sheets in Greenland and Antarctica and the smaller ice-caps on Ellesmere and Grinnell lands, in the Arctic, cover about 6,000,000 square miles, so that the Great Ice Age is only approximately half over and the earth is slowly returning to the more genial climes of its normal condition.

In the Pleistocene there were several great areas of ice accumulation of which the two largest are known as the Keewatin and the Labrador ice sheets (Plate V). From these centers the ice, which had accumulated on the relatively low lands of Canada (today about 1,000 feet above sea level) spread out in all directions. In the mountainous and plateau regions of the far west mountain glaciation (see p. 33) first appeared and gradually spread to the plateaus and valleys forming what is called by some writers the Cordilleran-sheet. According to Coleman (2) the Keewatin-sheet covered over 1,500,000 square miles while the Labrador-sheet, which formed later, had an area of some 2,000,000 square miles; these two sheets ultimately coalesced. The Cordilleran glaciation reached an elevation, according to the same writer, of 8,000 feet, for glacial phenomena appear on the mountains up to this elevation. Above this ice-sheet many mountain tops projected as islands, called nunataks. The Labrador sheet covered eastern Canada, New England, New York, and the present Great Lakes region, overriding all our New England mountains, as well as the Adirondacks, and extending for considerable distances into the ocean.

The southern border of the ice sheet, the terminal moraine, is shown on Plate V extending along the southern shore of Long Island, crossing Pennsylvania, and following the courses of the Ohio and Missouri rivers and thence westward to the Pacific coast. It is noted that a large part of Alaska is unglaciated—this because of deficient precipitation.

Geologists estimate that the ice sheet, at maximum, was some 10,000 feet in thickness. It either killed or drove to the south all living things and must have presented a desolate waste if there had been human eyes to see it.

Daly (1) estimates that if all the Pleistocene ice-sheets reached their maximum size simultaneously, the ocean lost about 240 feet of depth, which would have extended the Atlantic coast line considerably to the eastward. On the other hand, should all the ice-sheets of the earth today be melted the ocean would gain about 160 feet in depth and many of our coastal cities would be submerged.

In North America and Europe, owing to climatic fluctuations, there were four advances of the ice-sheet, separated by three interglacial stages. In the United States the sequence, from oldest to youngest, included the first advance, called the Nebraskan, followed by the Aftonian interglacial stage; the second advance, known as the Kansan, followed by the Yarmouth interglacial; the third, of Illinoian advance, followed by the Sangamon interglacial; and the latest, or Wisconsin advance, followed by the Post-Glacial stage, in which we live. It is an interesting speculation whether we are in a fourth interglacial stage and if, say in a few hundred thousand years, another ice-sheet will descend upon the earth.

The interglacial stages were hundreds of thousands of years in duration and in them the ice-sheets were melted back to varying degrees, and animal and plant life again flourished in the formerly ice-ridden areas. In the Yarmouth interglacial, which was the longest in duration, it is thought that the earth was warmer than it is now.

In New England the glaciation belongs very largely to the Wisconsin advance and was a part of the Labrador Ice-Sheet.

With the coming of the Post-Glacial stage the ice-sheet slowly melted ("rotted") and its front retreated northward, where it is found today on borders of Greenland and in Ellesmere and Grinnell lands. Antevs (3) shows that it required 4,100 years for the ice front to retreat from Hartford, Conn., to St. Johnsbury, Vermont, a distance of about 185 miles; this is at the rate of one mile in twenty two years (see p. 39). Daly (1) estimates the time required for the retreat of the ice front from Long Island to the center of dispersion at James Bay (the southern end of Hudson Bay) at about 30,000 years.

It may be mentioned, in passing, that primitive man probably first appeared in the Pleistocene Epoch.

GLACIERS

Glaciers form in those regions where more snow falls in the winter than can be melted in the following summer. With successive snow falls and the effect of moisture the snow assumes a granular texture and is slowly consolidated into ice. The progress can be observed in your back yard, in spring, where the transition from granular snow to solid ice is clearly seen. The granular snow is called the névé.

Ice is a crystalline substance similar in its optical properties to mineral crystals (it crystallizes in the hexagonal system), and glacial motion, caused primarily by gravity, is not that of a viscous substance, like tar, but is a very complicated affair which, like the cause of glacial epochs, need not be gone into here. Glaciers carry, frozen into their bottoms, rock débris from their scouring action and, on their surfaces, enormous amounts of rock wastage of all sizes, including boulders often of huge dimensions, plucked from the rock surfaces in their course, together with soil and vegetable growth. The rock débris, of all sizes, is called *glacial drift*. The glacial ice wastes by evaporation and by melting. Streams of melt-water flow in and under the glacier and the sediments carried and deposited by them give rise to characteristic glacial forms. A glacier acts something like a huge belt conveyor, bringing the rock débris to a position where ice melting is equal to ice "making." Here it forms a temporary *terminal moraine*. Streams from the ice, working over this morainal material, sort it, carrying away the finer material and leaving *outwash plains*. The material under the glacier forms the *ground moraine;* in mountain glaciers *lateral moraines* also form.

Hence a region like Vermont shows many evidences of former glaciation, as will be shown.

Like water-streams glaciers erode and transport, and deposit their loads.

GLACIAL EROSION

The erosive action of glaciers is due to abrasion, and quarrying or plucking. Ice is too soft a substance to erode rock by itself but needs "tools," as rivers do in their erosive action. But, whereas the tools of a stream are sediments carried in the water, the glacial tools are rocks frozen into the under surface of the moving ice—something like the action of a diamond drill with its black diamonds (bort) embedded in the end of the bit, only of course the motion of the ice is not circular but longitudinal. Thus equipped the glacier moves ponderously forward under the action of gravity, smoothing, fashioning, striating, and gouging the rock surfaces below. These smoothed surfaces are very common in this State, projecting above the soil mantle and drift and bearing upon them striations and grooves. Some of these rounded rock surfaces resemble a longitudinal section of a cigar with the tapering end towards the advancing ice (the stoss side) while the butt end (or lee side) is cut off abruptly by the plucking action, to be presently described. These surfaces form asymmetrical rock hills, with their gently sloping stoss slopes and abrupt lee ends. All these rounded rock forms are called *rôches moutonnées,* from the fancied resemblance to a sheep's back.

Striations and grooves are found almost everywhere in Vermont: on the mountain tops and in the lowlands, and their compass courses, or trends, tell us the direction in which the ice was moving. These trends are mostly from west of north to east of south but cross-striae on the same surface, and even east-to-west trending markings, in some places, testify to cross-currents in the ice-sheet. On Mount Mansfield, near the hotel, the smooth rock surface bears striae trending North 37° West, while along the summit ridge other striae trend in the same general direction. But along Hell Brook Trail, which ascends the east side of the mountain from Smugglers Notch, striations are noted trending about north and south. Without doubt all the mountains of the State bear glacial striae. The most astonishing display that the writer has seen is on the summit of Mount Hunger, in the Worcester Range, which shows thousands of such markings. They trend from N. 6° to 24° E. There are said to be similar striated surfaces on the neighboring Burnt Mountain. In East Putney there is a glaciated surface, peering out from under its drift mantle and striated.

Glacial grooves are also numerous. On Isle La Motte the Trenton limestone shows such depressions a foot wide with parallel striae in them: A specimen from here, at the University of Vermont, has such a groove a foot wide, with striae cutting an Ordovician fossil snail (*Macluria magna*).

In the 1861 Geology of Vermont hundreds of striae are listed with trends ranging from N. 70° W. to N. 70° E. The accuracy of these figures is questionable. Glacial grooves are also listed, the largest (in Whiting) is "several feet long"; other dimensions are not given. Another is located along the Missisquoi River, north of Troy: "six inches wide, three feet deep, and three or four rods long," trending southerly.

Besides striations and grooves, "chatter marks" are found. These are horseshoe-like gougings caused by the rasping action of the ice-held tools cutting out rock chips—like those made on wood by a chisel too lightly held. The 1861 Geology locates such "chatters" "along the shore of Lake Champlain," which is delightfully vague.

Glacial quarrying, or *plucking,* by which masses of rocks, often in the form of joint blocks, are loosened and carried away from their parent rock, is due to the prying action of freezing melt-water which has penetrated the joints and fractures of the bedrock. This action may go on beneath the ice-sheet as well as on exposed rock surfaces. Plucking gives rise to *glacial troughs* and *cirques.* Glacial troughs are U-shaped depressions, often of vast cross-section and great length. They usually occupy pre-glacial stream valleys to which they add the U-section. The tortuous courses of the old valleys become straightened out by the snubbing action of the ice-sheet. A good many stream valleys in Vermont show this modifiying action; the Black River Valley, in Coventry, is a case in point.

GLACIAL TROUGHS

The finest glacial trough in Vermont was carved out of the limestone ridge, intruded by granite, which crosses southern Westmore, in Orleans County, from northeast to southwest and forms the divide between the St. Lawrence and the Connecticut River drainages. This great U-shaped cut, trending northwest and southeast, is a striking feature of the region and is visible for many miles; even on a clear day, from Mount Washington. In it lies the upper portion of Lake Willoughby (4), one of the most beautiful bodies of water in the State. This lake is about five miles long and somewhat less than a mile in maximum width. Its surface is 1,170 feet above sea-level, while from its eastern shore Mt. Pisgah rises to 2,761 feet, and from its western border Mt. Hor reaches 2,648 feet. The lake basin, in cross section, increases gradually in depth from the eastern shore to about 200 feet, at one-third the width of the lake, and then descends precipitously forming an inner gorge 250 to 330 feet wide and 96 feet deep, giving the lake a total depth of 296 feet.

Now this trough was probably not carved from a preexisting stream valley but owes its existence wholly to the plucking action of the glacier; for most of the glacial débris is found as a high morainal embankment some distance south of the lake and 130 feet above its surface, while the glacial dam at the northern end of the lake is composed of sand only twenty-seven feet above the lake level. These facts and the deep, inner gorge seem to show that the trough was excavated by the southward movement of the ice-sheet. The outlet of the lake is controlled by a dam; the overflow empties into the Willoughby River, a tributary to the Barton River.

To the west of the lake lies Wheeler Mountain, a granite "boss" glacially smoothed, with a steep escarpment on its eastern border caused by the "snubbing" action of the ice. Several other eminences in the neighborhood show the same effect.

About four and one-half miles to the west, in Barton, Crystal Lake lies in a similar but less spectacular trough. Its surface is 945 feet above sea level. Lake Willoughby is shown partly on the Lyndonville and partly on the Memphremagog topographic quadrangles; Crystal Lake is wholly on the former.

The Averill Lakes, in Essex County, also lie in rocky basins carved out by glacial action.

Fig. 4. The glacial trough near Peacham, Vermont.

There is another large glacial trough in Underhill, Chittenden County, lying between Macomber Mountain and the western spurs of Mt. Mansfield, but there is no lake in it. The glacial trough southeast of Peacham, Caledonia County, is shown on Figure 4. Probably other troughs exist in the State.

SMUGGLERS NOTCH

Smugglers Notch was originally formed by stream action in the great fold (an anticline) which once included Mt. Mansfield and Stirling Mountain; its course is north and south. The highest point in the Notch is 1,803 feet above sea level and forms the divide between the Brewster River, flowing north to the Lamoille, and the West Branch, or Waterbury River, which empties into the Winooski.

The valleys of these rivers are heavily glaciated: great deposits of till are seen along the highway through the Notch. It has already been noted that, along the Hell Brook trail, glacial striae are still to be seen, trending generally north and south; other glacial features may well have been obliterated by the great rock falls from the valley walls. It is clear that a tongue of the ice-sheet passed through the Notch.

A GLACIAL POTHOLE

Ordinary potholes are round or cylindrical excavations in bedrock caused by the swirling motion, or eddys, in streams laden with their "tools" which may consist of sand, gravel, or even boulders of considerable size. The pothole stones are themselves rounded by the abrasion. Such potholes are very common in our streams; one of the best series of such holes is seen along the lower course of the Huntington River in Richmond.

That streams of melt-water, high up in the ice-sheet, produced this type of erosion is shown by the glacial pothole not far from the summit of Burnt Rock Mountain in Fayston, Washington County. This pothole is four feet in diameter, about thirty inches deep, and 2,820 feet above sea level. It is described by Professor Doll (5).

MOUNTAIN OR ALPINE GLACIATION

If mountains are sufficiently lofty to extend above the snow line, glaciers form on their surfaces and move down the valleys, which they modify as stated above. The Alps, Himalayas, Rockies, and many other mountains in various parts of the earth show this type of glaciation.

On such mountains there are formed, by the quarrying action of the ice, snowshoe-shaped depressions with their broad, convex ends towards the mountain crests and their narrower ends extending down the slopes. The upper ends form steep head-walls, often thousands of feet high. Such depressions are called *cirques.* The glaciers, whose quarrying action forms the cirques, are "nourished" by the snow fields above and these must of course be extensive, hence only on large mountain masses are cirques found. Often two cirques form on opposite slopes of a mountain and quarry towards each other, so that often only a narrow ridge of the rock remains. Such a residual ridge is known as an *arête.* If three or more cirques approach one another, a pyramidal erosion remnant remains, often thousands of feet high; this is called a *horn.* The Matterhorn, in Switzerland, is probably the most famous example.

The Presidential Range, in New Hampshire, is today far below the permanent snow line but, during the Pleistocene Epoch, as the ice-sheet approached the range, Alpine glaciation was induced and eight cirques were formed. These are indicated on the Mt. Washington topographic quadrangle. They are in order: Tuckermans Ravine, Huntington Ravine, the Great Gulf, Jefferson Ravine, Madison Gulf, Castle (Gulf), King Ravine, and Bumpus Basin. All except Castle (Gulf) lie east of the Crawford Path-Appalachian Trail. Whether one could consider the ridge along which the trail runs an arête is open to question. Further information concerning New Hampshire glaciation can be found in Professor Goldthwait's valuable book (6). This author states that: "Strongly developed cirques have been reported on Mt. Katahdin, Maine." No cirques exist on the Green Mountains, the explanation being that the crests were not sufficiently high or extensive to furnish adequate snow fields for circation.

Fig. 5. Glacial erratic in Underhill.

TRANSPORTATION

Glaciers gather in their courses and transport enormous amounts of rock material of the most diverse form and size: from great boulders, called *erratics,* to gravel, sand, and clay; the clay may arise also from the decomposition of the feldspathic minerals in the rocks. All this glacial matter, as we find it today, is called *drift* or *till.* In its unmodified state the drift is unsorted, the larger pieces often lying on the finer material.

Glacial erratics, often of enormous size, are found everywhere in a glaciated region. The largest ever discovered is known as the Madison Boulder and lies in the woods in Madison, N. H., about half a mile west of New Hampshire Route No. 13. It measures 83 by 37 by 23 feet and is estimated to weigh 7,650 tons. It is a single block of granite which Goldthwait states was evidently brought by the ice-sheet from the ledges in Albany, N. H., about two miles from its present resting place.

In Vermont erratics are found on every hand, from the mountain tops to the shores of Lake Champlain, and on the islands in the lake. The largest ever reported was found in West Whitingham. The 1861 Geology of Vermont gives the dimensions as 41 feet long, 32 feet wide, and 125 feet in circumference, with an estimated weight of 3,400 tons. It is known as the Vermont Giant; the material is not stated. Another huge erratic, called Rock Raymond, is recorded in the same volume as lying in Stamford. It is 12 feet high, 20 feet long, and 18 feet wide. Others are found in Searsburg, along the Deerfield River, from 6 to 25 feet in diameter, and in the region between Bennington and Brattleboro. Numerous erratics occur on the flanks of Mt. Ascutney.

Probably most of the erratics have been transported only short distances but some have traveled far. Thus, on Mt. Mansfield, east of the summit ridge, the largest boulder, over 30 feet long by about 20 feet high; and another, 21 feet long by 8 feet wide, and 9 feet high, are of Green Mountain gneiss and probably of local origin; but a smaller erratic is composed of syenite which is not found in the Champain valley but probably came from Canada. Unfortunately it was removed, years ago, to the Stowe cemetery as a war memorial.

In Underhill, a few rods south of the summit of the road which leads from the Center to Stevensville, there is a great erratic (Figure 5) 19 by 15 by 10 feet, made up of serpentine studded with shining black octahedral crystals of magnetite and showing on its surface elliptical markings which are characteristic of pillow lava. On the roadside opposite the Shaw cottage there are several others. The nearest sources of this type of igneous rock are on Owls Head and Bear Mountain, near Newport, Vt., some forty miles in an air line to the northeast. Professor Doll describes an erratic on the Clyde River (Figure 3).

Sometimes erratics are so delicately poised that they can be tilted by hand; they are then called balanced rocks. There is one, reported in the Geology of Vermont (1861) in Greensboro, weighing seventy tons. Another boulder here, not balanced, is 41 feet long, 22 feet wide, and 22 feet high.

BOULDER TRAINS

Erratics sometimes form boulder trains, or trails, of the same kind of rock, extending over considerable distances. The largest one in the State is made up of syenite boulders (syenite is quartzless granite) from Mt. Ascutney. From this source it spreads out, fan like, in a widening arc across southern Vermont, western New Hampshire, as far east, according to Goldthwait, as East Jaffrey and Peterboro, and as far south as Bernardston, Mass. Pieces of the syenite are now found in the stone walls along the course of the train. Goldthwait states that this fanning out was probably due to the changing in direction of the glacial flow, and this is borne out by the varying compass directions of the striae and grooves in the bedrock.

In Craftsbury, Vt., there are huge erratics composed of biotite granite containing more or less spherical segregations of biotite, an inch or less in diameter. This is called orbicular granite; prune granite is a local term. Similar erratics have been found in Irasburg and in Stanstead, Quebec. A boulder train is thus suggested but it has not yet been studied.

The most striking formation in northwestern Vermont is the red Monkton quartzite which extends from Snake Mountain, near Middlebury, to Roods Pond, in Milton. Rocks from this formation are easily recognized and have been found to form a boulder train. One of Professor Goldthwait's students has plotted this train and found that it fans out from its source, over an area extending from eastern New York nearly to the Connecticut River.

A smaller train of syenite boulders fans out from Cuttingsville, Rutland County, to the southeast.

DEPOSITION

The extreme southern border of the Pleistocene ice-sheet is marked by ramparts of glacial débris which extend along the southern part of Long Island and thence across the continent as shown in Plate V. They represent the results of the conveyor-belt-action, already referred to, and make up the *terminal moraine*. The material left by the glacier along its course, after it melted, is known as the *ground moraine*. This morainal stuff is seen in boulder-strewn upland pastures and it was in other places before the farmers cleared the land and built stonewalls which became veritable outdoor museums of glacial débris. It has already been seen that the source of the Ascutney boulder train was determined from the material of such walls.

In temporary halting places of the glacier *intermediate moraines* were formed. One crosses the Third Branch of the White River, north of Roxbury, while another is seen in the White River valley near Granville.

LAKES

In Vermont, and of course in other glaciated regions, there are hundreds of lakes, great and small, probably all due to glacial action. They are found in many parts of the State: in the lowlands, St. Catharine, Bomoseen, Dunmore, Carmi, and others; and even on Mt. Mansfield, where the tiny Lake of the Clouds lies about 3,900 feet above sea level and, farther south, Lake Mansfield, a considerably larger body, has an elevation of 1,140 feet. But the Vermont Piedmont, the region east of the Green Mountains, is the lake country *par excellence* of the State, especially that part north of the White River and its tributaries. Here are hundreds of lakes of which the largest are Morey, Fairlee, Willoughby, Crystal, Seymour, Echo, Island Pond, Maidstone, and the Averill Lakes. Of course the largest, Memphremagog, lies only about one-fifth in Vermont.

Some of these bodies of water, such as the Lake of the Clouds, Willoughby Lake, and the Averill Lakes, lie in depressions plucked out of the bedrock and bordered by glacial embankments, while others have resulted from the glacial damming of preexisting valleys. During the last glacial epoch tongues of ice lay in these valleys and around these tongues, and to a lesser extent upon them, the glacial till accumulated. When the ice tongues rotted away melt-water filled the depressions and formed the lakes. Small ponds so formed are called *kettles;* they usually have no outlets. Childs Pond, in Thetford; Gut Pond, in Eden; Roods Pond, in Milton; Colchester Pond; and Small Pond, in Newport, are kettles.

On the melting of the ice-tongue which filled the Connecticut River valley (7), a great lake, 157 miles long, was formed by glacial damming in the narrow gorge of the river near Middletown, Conn., and its extension northward to Lyme, N. H., was made possible by the downwarping which the earth's crust had undergone under the enormous and long continued pressure of the ice cap, "so that the floor of the valley actually sloped northward towards the ice." "The width of this lake in New Hampshire and Vermont was only two or three miles, but in Massachuetts and Connecticut it attained a width of ten or twelve miles." This body of water, which was named for President Edward Hitchcock, the co-author of the Geology of Vermont (1861) endured for about 4,000 years when it was suddenly drained, probably by the failure of the glacial dam near Middletown.

Of more local interest to us is Lake Upham, which formed after the abrupt lowering of Lake Hitchcock, at 90 feet lower elevation. With the continued retreat of the ice-sheet this lake expanded like the branches of a tree to the north, with one branch reaching North Stratford; another up the valley of the Passumpsic River, past Woodsville and St. Johnsbury, and reaching nearly to West Burke; while a third branch reached Randolph where it received the waters of Lake Winooski, near Montpelier. Lake Upham endured for at least 600 years at Hanover and for 1,600 years near Haverhill and Woodsville. Enough of the old shore lines remain in sufficient degree to permit their delineation.

As the ice-sheet withdrew across Vermont the large streams of melt-water issuing from it greatly increased the size of old valleys which, today, are much too large for the streams flowing in them. Such enlarged valleys may be seen from Route 7, on the way from Burlington to Charlotte, and doubtless in other places. The waters formed ancient lakes fragments of whose shore terraces still remain. Some of these occur along Route 2, going out from Burlington; another on the road from Underhill to Underhill Center.

A long glacial lake formed in the valley of the Black River and extended from Plymouth to Cavendish where it was dammed by a ridge extending across the valley and by glacial drift. When the ice in the lake melted the water overflowed the southern end of the ridge and formed a post-glacial gorge, across which, not many years ago, a dam was built for power purposes. Cavendish Village lies on the old lake bottom on the northern side of the valley. During the fateful November third, 1927 (8), the swollen river, held back by the dam, flooded the old valley, while streams coming down from the north burst the storm sewers which had been built east of the village for its protection, carried away the glacial fill, and revealed the old preglacial gorge of the river. On the polished bedrock were seen striae trending N. 45° E., which showed that a tongue of the ice-sheet had moved down the valley. A similar condition was disclosed in the White River Valley, near Gaysville, where it was seen that the river had been driven from its pre-glacial gorge and was flowing in a post-glacial gorge, which had also been dammed, when the 1927 flood occurred.

Several other glacial lakes, long since drained, have been described by Merwin (9), and C. H. Hitchcock (10), while Bigelow (11) gives the evidence for the existence of a former glacial lake in the Barrows Valley of Stowe.

DERANGED DRAINAGE SYSTEMS

In the glaciated areas of the Pleistocene many rivers have changed their courses, some of them reversed in their flow, by the ice-sheet and the rise of the land following its retreat. The post-glacial channels of the Black River, at Cavendish, and the White River, at Gaysville, have already been noted. Hitchcock (12) states that, at one time, the glacial lake in the Stowe valley was high enough to discharge its waters through the Williamstown Gulf into the Connecticut River, whereas the present streams of the Stowe valley flow into the Winooski. The same author believes that Lake Memphremagog, which now discharges into the St. Francis River and thence into the St. Lawrence, once drained through Eligo Pond, in Hardwick, and thence into the Lamoille River. Moreover he claims that the glacial Lamoille was reversed in its flow and emptied into the Winooski and that the latter stream, also reversed in its course, poured through Williamstown Gulf into the White River and thence into the Connecticut. This was due to the ice tongue which "filled up Lake Champlain so high that there was no chance for the waters to discharge except into an eastern outlet." Without doubt many other Vermont streams were similarly diverted.

GLACIO - FLUVIATILE DEPOSITS

DELTAS

Sediment laden streams flowing into quiet water bodies deposit their loads and form deltas. On these deltas characteristic arrangements of the material are noted: the "top set," horizontal; the "fore set," sloping towards the deep water; and the "bottom set," also horizontal. Of these the "fore sets" are by their inclination the most easily recognized on what may be called fossil deltas (deltas high and dry). Gravel banks have been opened up here and there by the road makers and these foreset beds disclosed. Such indications of former lakes have been noted especially in the Barre-Montpelier region.

The great Bristol delta which the New Haven River formed as it entered Glacial Lake Champlain is of notable interest. Other Champlain deltas will be found discussed in Professor Chapman's paper which follows this article. The Quechee delta, near Deweys Mills, in Hartford, one of the best preserved in the State, has been described by Goldthwait (13). Quechee Gulf, a narrow, post-glacial gorge is described in the same paper.

VARVES

Streams of melt-water, flowing from a ground moraine, sort the material, carrying the lighter stuff away and leaving the coarser conglomeration of boulders, gravel, pebbles as an outwash plain. The lighter silt and clay are deposited in lakes and ponds, where the stream velocity is checked, forming alternate strata of light-colored silt and dark, greasy clay. These banded strata are called *varves*. The explanation is that, in the warmer seasons of the year, the coarser material settles to the bottom while the finer stuff is held in suspension (colloidal suspension). During the winter months when the ponds are frozen at the surface and the water beneath is stagnant, this colloidal material settles and forms the dark, greasy layer. Thus a coarser and a finer layer, taken together, are the product of one year's deposition. If a varved deposit is sliced smoothly and a strip of paper is fastened against it the varves can be graphed, the age of the deposit in years, told, and by the width of the varves, something about the prevailing temperature determined. Furthermore de Geer, the Swedish geologist who discovered the phenomenon, found that each varve overlaps its predecessor in the direction of the glacial recession—like the slates on a roof which overlap towards the ridge pole.

There is not found an unbroken succession of varves but, by measuring sets of them in all available places, they can be correlated and a chronological series established. Then the number of double varves between the ends of the series will equal the number of years needed for their deposition. The number of double varves between two points along the line of retreat of the ice-sheet will give the number of years taken by the ice-sheet to retreat from the first point to the second.

The varve method affords the most accurate ice-sheet chronology that we have.

Ernst Antevs (3) has carried on the de Geer method of varve study in many parts of North America; some of his earliest studies were undertaken in New England. He determined an equivalent series of 4,100 double varves between Hartford, Conn., and St. Johnsbury, Vt., which meant that it required 4,100 years for the ice-sheet to retreat between these places, a distance of 185 miles, or an average retreat of 238 feet a year. Similar studies by Lougee and others were used to determine the "life" of Lake Hitchcock, Lake Upham, and other glacial water bodies.

Varved deposits are found in many parts of Vermont; in some places they are the only indications remaining of the former existence.old lakes and ponds. Several brick-making companies use varved clays.

ESKERS, DRUMLINS, KAMES, KAME TERRACES

The process or processes by which these glacio-fluviatile features were formed has largely to be inferred, since the ice-sheets under which they were produced have disappeeard and the ice-caps of the world today conceal those that are probably forming under them.

ESKERS

Eskers are long, low, sinuous ridges, made up of more or less water-sorted morainal material (sand, gravel, and boulders, great and small) extending along the valleys in the general direction of the ice movement. They are seldom over 75 or 100 feet high, a few rods wide and often less than a mile long, although some are *many miles in length.* They look like old railroad embankments except that they are too crooked.

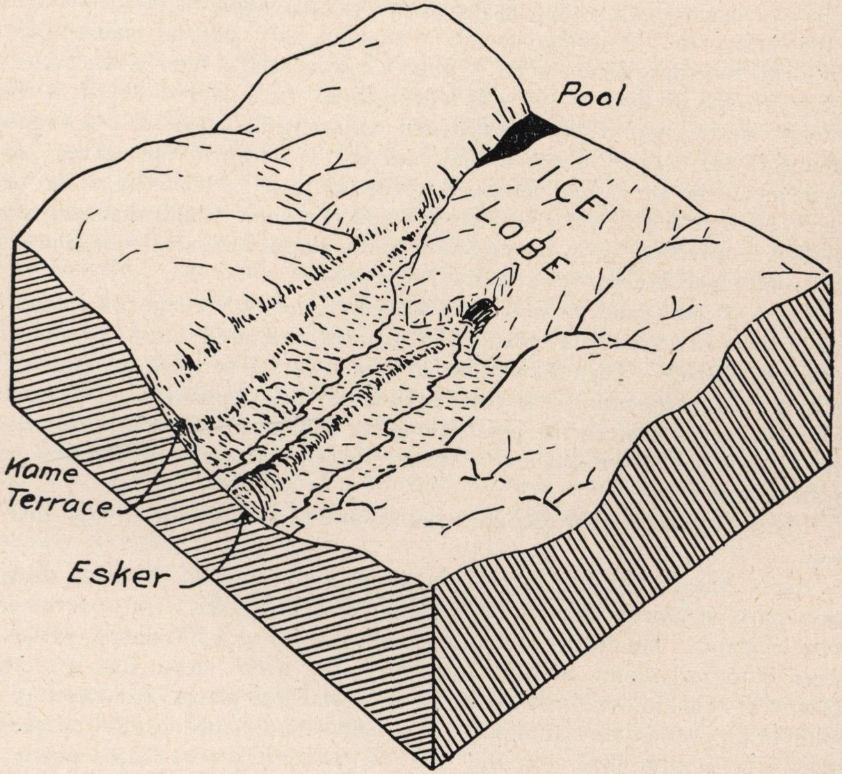

Fig. 6. Block diagram illustrating the way in which eskers and kame terraces are formed during the ice recession.

ORIGIN

The origin of eskers may be explained by an analogy. The Rhone River rises in a glacial trough far up in the Alps Mountains. The glacier itself, whose front forms a huge wall across the valley, is criss-crossed with crevasses and bears on its surface some of the rock débris which it has plucked in its onward movement. In the glacial front there is a large tunnel worn by the melt-water and flowing from this orifice is the stream which forms the very beginning of the Rhone. The Rhone Glacier has retreated about a mile from its farthest advance and strewn along its old bed one sees the outwash plain, or valley train, made up of englaciated material which had worked down through the crevasses and been swept along the tunnel by the rushing stream. This material is more or less water-sorted: the coarser near the source of supply; the finer farther away; the finest, carried in suspension, gives the milky hue to the river all the way along its course to the quiet water of Lake Geneva, where it settles and is forming a delta. All this is of course the work of an Alpine glacier.

Fig. 7. The esker at West Burke.

A similar action must have taken place in the lobes of the continental ice-sheet which lay in our valleys, but with this difference: Towards the end of the glacial epoch, when forward motion had ceased, sub-glacial tunnels entered glacial lakes which bathed the glacier front and the streams carrying englaciated material were checked in their velocity so that their loads were deposited and the tunnels became choked with rock débris, more or less sorted, forming *eskers.* With the final disappearance of the ice the esker remained with its typical serpentine form. The whole picture is admirably shown in Figure 6, reproduced by kind permisson of Professor Goldthwait.

EXAMPLES

On the way down the valley from Lake Willoughby to West Burke the road cuts across a typical esker (Figure 7), a few rods wide, perhaps twenty feet high and of undetermined length. The cross section shows that the esker is made up of sand, gravel, and small boulders.

Another esker is seen by the roadside in Groton along Route U. S. 302. Goldthwait (13) describes an esker at Bridgewater Corners (Woodstock quadrangle) and another in the northwest corner of Plymouth Township, which forms "a peninsula over a quarter of a mile long and only a few hundred feet wide, extending from the north into Woodward Reservoir" (Rutland quadrangle). Richardson (14) describes an esker, a quarter of a mile long, in the northwest part of Coventry, between two small ponds.

The largest known esker in New England extends on either side of the Connecticut River for twenty-four miles, from Windsor, Vt., to Lyme, N. H. It is unbroken save where the river has cut across it.

There are without doubt many eskers in Vermont which should be located. The readers of this article are asked to aid in this interesting quest.

DRUMLINS

These are elongated, oval hills of morainal material, "stream-lined" in current parlance, with their long axes parallel to the direction of the ice movement. They are commonly 50 to 200 feet high and from one-quarter of a mile to one mile long, although many are much larger. Drumlins are made up of compacted, unsorted drift and, unlike eskers and kames, were evidently not deposited by streams of melt-water flowing in or under the ice; rather they seem to represent till that had been passed over and fashiond by the ice-sheet. One gets some such effect by sweeping wet snow with a broom. Drumlins may occur singly or in groups.

ORIGIN

The origin of drumlins is uncertain. Goldthwait (6) describes them as "thick masses of till, plastered on and rubbed down smoothly by the ice-sheet, near the close of the epoch when forward motion was still strong but downward pressure had been reduced by decrease in thickness." W. M. Davis, on the other hand, likens them to sand banks in a river, formed under the ice where the topography favored accumulations of till, which were left when the ice-sheet melted away.

EXAMPLES

Massachusetts has thousands of drumlins, of which the largest forms Corey Hill, in Brookline; Beacon Hill, on which the State House stands, in Boston; and Breeds Hill, on which the Battle of Bunker Hill was fought, in Charlestown. Many island drumlins are found in Boston Harbor.

In New York, between Syracuse and Rochester, there are thousands of drumlins and they are also abundant in eastern Wisconsin, near Fond du Lac. Goldthwait states that drumlins in New Hampshire are most abundant in a wide belt that stretches from near Mount Monadnock, in Jaffrey and Rindge, northeastward to Pittsfield and Barnstead. The New Hampshire quadrangles, Monadnock and Peterboro, show many of these. From the Vermont topographical quadrangles there appear to be drumlins in Berkshire, Grand Isle, North Hero, Alburg, Isle La Motte, Weybridge, Ferrisburg, Panton, Springfield, Pawlet, and Wells; these have not yet been investigated.

KAMES

As one goes about the State he sees hundreds of graceful, grass-covered hills of rounded outline or elongated form. They occur either isolated or in groups. Where they have been cut into for road material it is seen that they are made up of glacial material: in some cases of sand alone; in others, of sand, gravel, and small boulders. The material is generally sorted but not in all cases. They are called *kames*.

ORIGIN

Kames are made up of englaciated material which has been carried downward through the ice-sheet by melt-water flowing through crevasses and have accumulated under stagnant ice—else they would have been destroyed by ice motion. They are, therefore, generally water-sorted. An artificial kame can be formed by pouring sand through a funnel.

Some writers also ascribe them to accumulations formed by débris-laden streams of melt-water which deposit the morainal material as they emerge from the margins of mountain glaciers. They are reported to be in process of formation on the margins of some of the Alaskan glaciers.

EXAMPLES

There is a fine sand kame some fifty feet high, in the eastern part of Brownington, on the country road from the Center to the highway (Figure 8). Other kames occur in the neighborhood. Several low gravel kames are seen just west of Hardwick. In Underhill, north of the road to Underhill village, there are several huge kames. Chipman Hill, in Middlebury, is probably a kame; it rises about 400 feet above the surrounding country. Southeast of it is a smaller one. It will be interesting for readers of this article exactly to locate other kames and report them to the State Geologist.

KAME TERRACES

Ice lobes remained in the valleys long after the ice-sheet had melted away from the higher ground. The glacial débris left behind was carried by streams of melt-water and deposited between the ice tongue and the valley walls. When the tongue finally melted this accumulated débris slumped and formed even-topped kame terraces (Figure 6).

Goldthwait (13) describes a kame terrace where Pinny Hollow Brook joins Hale Hollow Pond, in Plymouth township, and another at Bridgewater Corners, on the south side of the Ottauquechee River. Chapman, in the following article, has much to say about kame terraces in the Champlain

Valley. In the narrow valley of the Winooski River, between Middlesex and Waterbury, kame terraces occur on either side. The Central Vermont Railroad is built on the northern terrace.

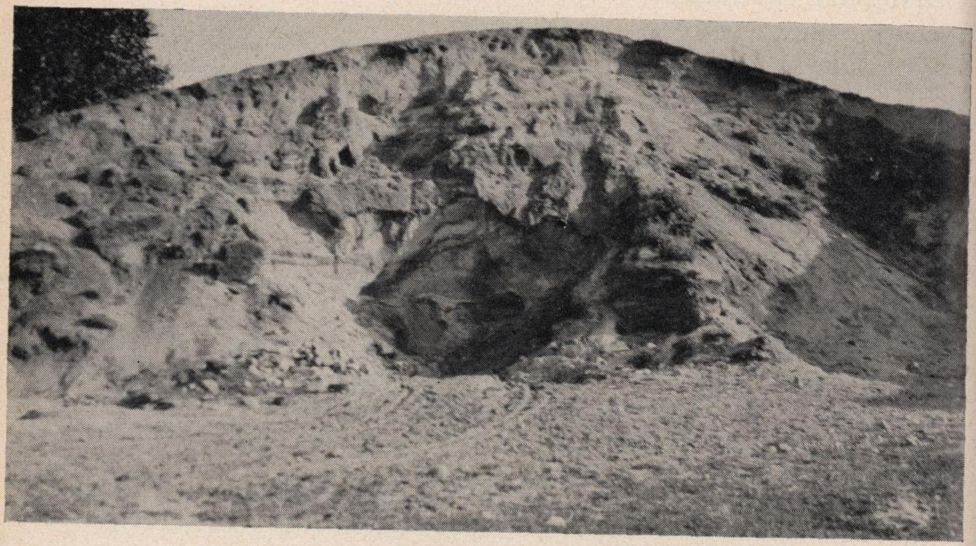

Fig. 8. The sand kame in Browningtion.

THE GREAT LAKES

The glacial history of the Great Lakes is a long and involved one and only a brief outline can be given here. Several excellent books may be consulted by those desiring a fuller discussion. The present outline is based chiefly on Professor Daly's treatise.

Plate 5 shows the lobated, terminal moraine of the Pleistocene ice-sheet which crosses Long Island and Pennsylvania, extends down the course of the Ohio and up the Missouri rivers, thence northward along the eastern borders of the Rocky Mountains where it meets the mountain and piedmont glaciation.

The earth is an elastic body and, under the tremendous load of ice, its surface was depressed for hundreds of feet. As the load was gradually removed by the melting of the ice, the surface slowly rebounded, not steadily but spasmodically, with long still-stands in between. Evidences of this uplift are seen at Battery Park, Burlington, a great sand bank which stands a hundred feet above the present lake level, as well as along the lake shore to the north. Cobble Hill, in Milton, whose summit is now 860 feet above sea level, shows a "bench" at 527 feet, made by the waters of the Champlain Sea; several neighboring hills or mountains have similar benches on their flanks. On the slopes of Mount Royal, Quebec, there are found numerous beaches of shell-bearing sands and gravels, about 600 feet above sea level, which show that this eminence was once at the level of the Champlain Sea. This uplift of the land, therefore, increases from sea level, at New York City to 527 feet, at Cobble Hill, and to about 600 feet at Montreal. Old strand lines along the shores of the Great Lakes furnish further evidences of uplift.

The sites of the Great Lakes, in pre-glacial times, are thought to have been rocky basins which, as Daly puts it, "controlled the set of the glacial currents."

As the ice melted and the ice-sheet retreated to the northeast, great volumes of melt-water were formed which eroded new stream channels or flowed through old ones. The Ohio, Missouri, Illinois, Wabash, and Mississippi rivers received much of this drainage.

With the recession of the ice-sheet small glacial lakes were impounded, the earliest of which was Glacial Lake Maume, which lay just east of Fort Wayne, Ind., and discharged into the Wabash River. As the ice farther receded the southern end of the Lake Michigan basin was exposed and in it another small body of water was formed which is known as Glacial Lake Chicago. This lake found an outlet into the Illinois River and thence into the Mississippi. This outlet, excavated in modern times, now forms the Chicago drainage canal, whose level has to be controlled to prevent a general lowering of the Great Lakes. Meanwhile, Glacial Lake Maumee increased in size as far as Cleveland, on the east, and as far as Imlay, Mich., on the north, where it discovered a new outlet into Lake Chicago.

The ice-sheet continued to retreat to the northeast and Glacial Lake Whittlesey was formed in the modern Lake Erie basin, extending from western Ohio northeastward to Buffalo, N. Y., and from Cleveland, on the south, to Port Huron, Mich., and Toronto, on the north. This lake included the older Lake Maumee. Lake Whittlesey, with the further recession of the ice-sheet, found a lower outlet across western New York and possibly into the Susquehanna River, but a readvance of the ice closed this outlet and forced the drainage back through the old Imlay outlet to Glacial Lake Chicago and the Illinois River. Glacial Lakes Warren and Lundy were later stages of Lake Whittlesey. The former extended into the Finger Lakes region of New York.

The continued retreat of the ice-sheet enlarged Glacial Lake Chicago into the present Lake Michigan and formed Glacial Lake Duluth, in the western half of the Lake Superior basin, which drained through the St. Croix outlet into the Mississippi River. Further recession of the ice-sheet to the northeast gave rise to the giant Glacial Lake Algonquin which included the present lakes Superior, Michigan, and Huron.

Meanwhile the old Glacial Lake Whittlesey had grown from Buffalo to Rome, N. Y., and had become divided into Glacial Lake Erie, and Glacial Lake Iroquois, which was a much larger body of water than the modern Lake Ontario and drained through the Mohawk Valley into the Hudson River valley which, with the retreat of the ice northward, had become an estuary of the Atlantic Ocean.

In regard to the Lake Erie, B. F. Taylor (15), an eminent glacialist, wrote: "After Lake Erie became separated from Lake Ontario it ceased to be a glacial lake, and from that time was entirely independent of the ice-sheet. By the time the separation had been accomplished, following the fall of Lake Lundy, the basin of Lake Erie had probably been brought nearly to its present size. In this time it had two low stages, during which it was not receiving the discharge of the upper lakes. These times were when the Kirkfield and North Bay outlets were active."

To go back somewhat, Glacial Lake Algonquin found an outlet at Kirkfield, Ontario, east of Georgian Bay, through which its waters flowed into Glacial Lake Iroquois and thence into the Atlantic Ocean.

Released of its ice burden the land rose along a hinge line extending northwestward across southwestern Ontario and gradually closed the Kirkfield outlet, forcing the water of Glacial Lake Algonquin to find a new escape in the St. Clair River channel, Lake St. Clair and Lake Erie, at the eastern end of which it spilled over the escarpment between this lake and Lake Ontario and partly excavated the Niagara gorge, forming Niagara Falls, 160 feet high, but the falls, at this time, were seven miles down the river at Lewiston. During the twenty-five or thirty thousand years that have elapsed, the falls have receded up the river to their present position.

Next, the continued withdrawal of the ice-sheet opened a new outlet for the waters of Lake Algonquin through a spillway that followed the course of the present Ottawa River, from North Bay to the *CHAMPLAIN SEA,* a great body of salt water which, in the depressed state of the land in that region, had made its way up the St. Lawrence River, invaded the St. Lawrence Plain and the Lake Ontario basin, and extended into the northern part of the Lake Champlain Valley, as Professor Chapman's paper, following this, will show. According to the older textbooks Glacial Lake Champlain connected with the Hudson estuary and made an island of New England. Chapman shows this theory to be false.

That the Champlain Sea was salt is proved by the multitude of salt water fossil shells that occur along the northern shores of Lake Champlain and by the discovery in the township of Charlotte, in 1849, of the skeleton of a small whale (*Delphinapterus vermontanus*). This skeleton is now in the State Cabinet, in Montpelier. Other fossil whale skeletons have been found in Ontario and Quebec.

With the further recession of the ice-sheet and the rise of the land the Ottawa outlet was abandoned and the present size and drainage of the Great Lakes were established. Many more details and numerous illustrations of the glacial history of the Great Lakes may be obtained from the works cited.

Gutenburg estimates that present tilting of the region between Chicago and the northeastern part of the Great Lakes region is about two-fifths of an inch a year. Other seismologists see in the gradual recovery of the earth's crust from its bowed-down condition during the Great Ice Age a possible explanation for the earthquakes which occur in this northern region from time to time.

Coleman thinks that the ultimate disappearance of the present ice-sheets of the earth may take a million years or more.

The Pleistocene glaciation was the latest great geological event in the earth's history. The glacial forms which have been discussed have suffered only slight erosion and remain practically in the same condition in which they were formed. Bedrock has been but little decomposed and our soils are largely of glacial origin—and so are "sour" and need much limestone "sweetening." If we could compare pre-glacial Vermont with its present topography we would be amazed at the changes that the Great Ice Age wrought: Instead of "ever fair Champlain" there would be the Champlain(?) River with the present western Vermont and eastern New York streams as tributaries; other streams would probably differ in their courses from those which they now take; our beautiful lakes would be missing; the graceful *rôches moutonnées,* eskers, kames, and drumlins (if there are any) would be absent; and, in place of the great mantle of drift with its stony fields, great erratics, and clay banks, we would have—who knows?

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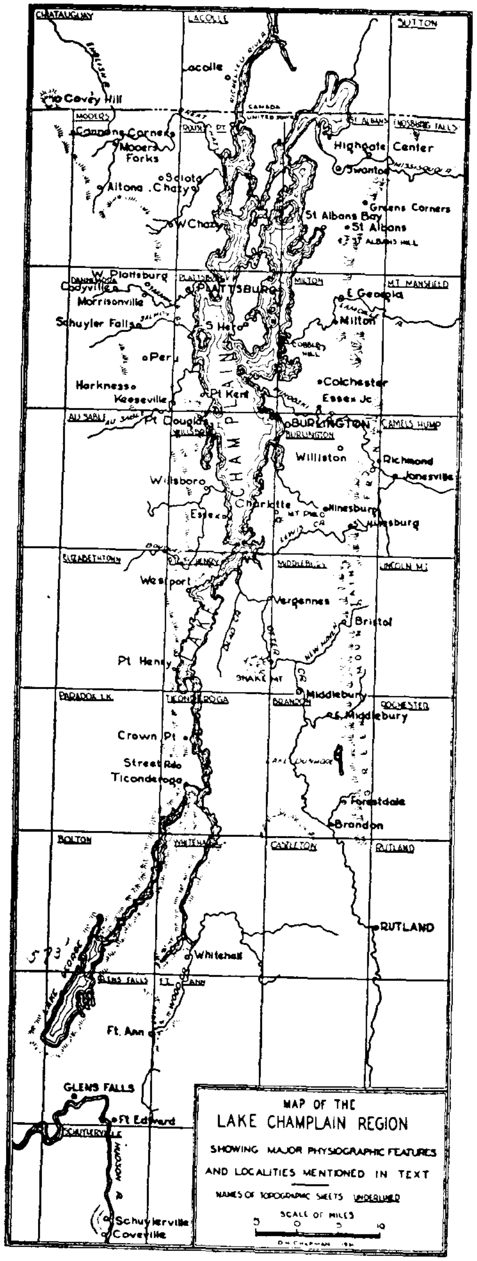

Fig. 9. Map of the Lake Champlain region, showing the major physiographic features and localities mentioned in the text.

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

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[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.

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.

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[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.

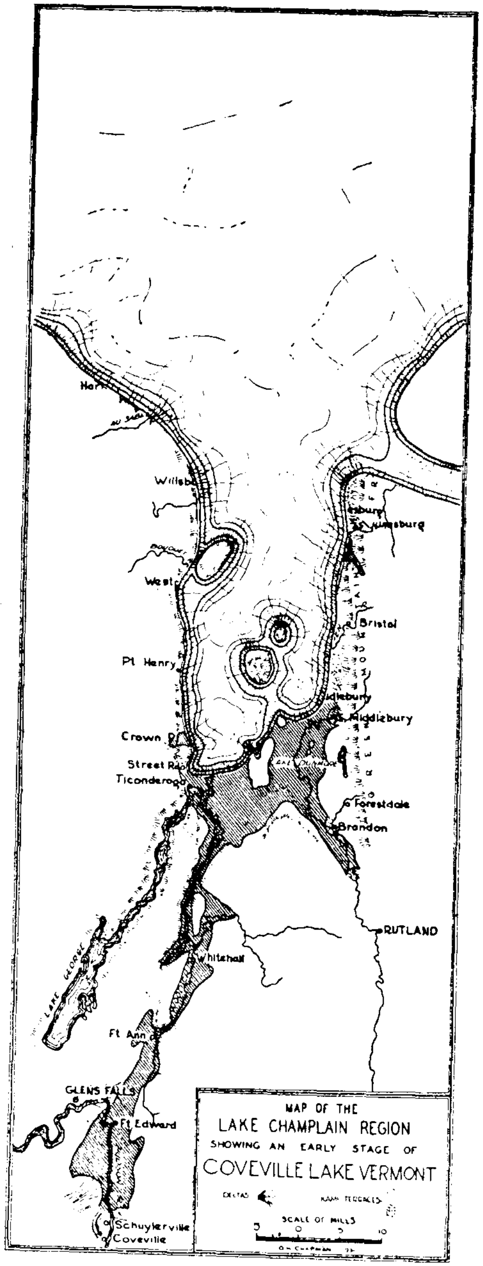

Fig. 10. Coveville Lake Vermont.

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

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[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).

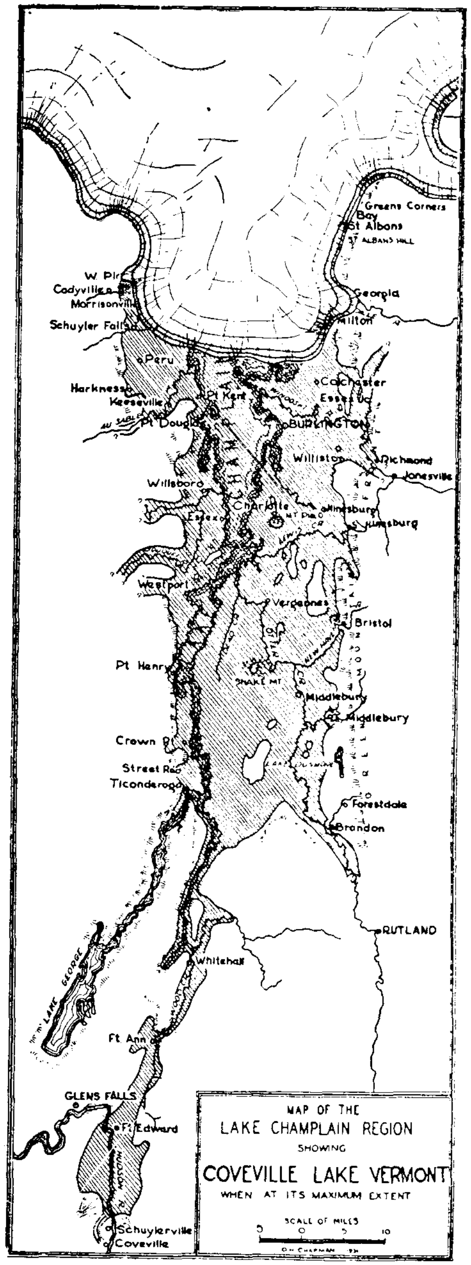
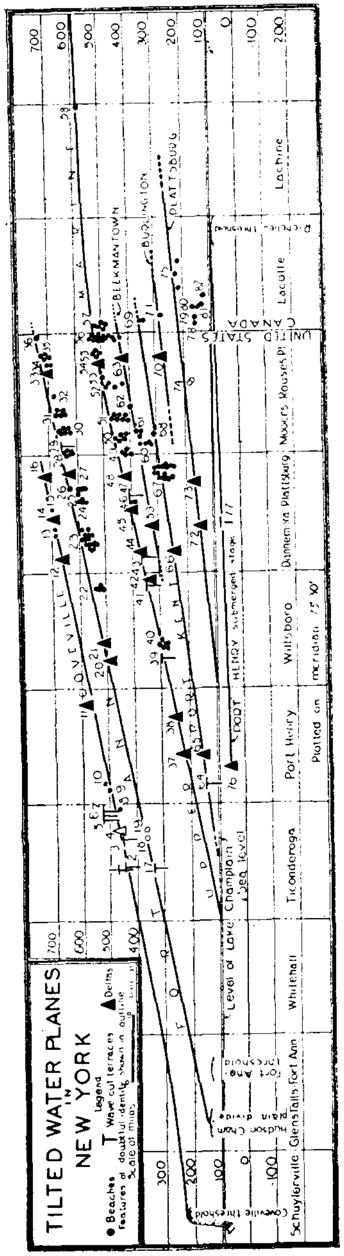


Fig. 11. Coveville Lake Vermont at its maximum extent.



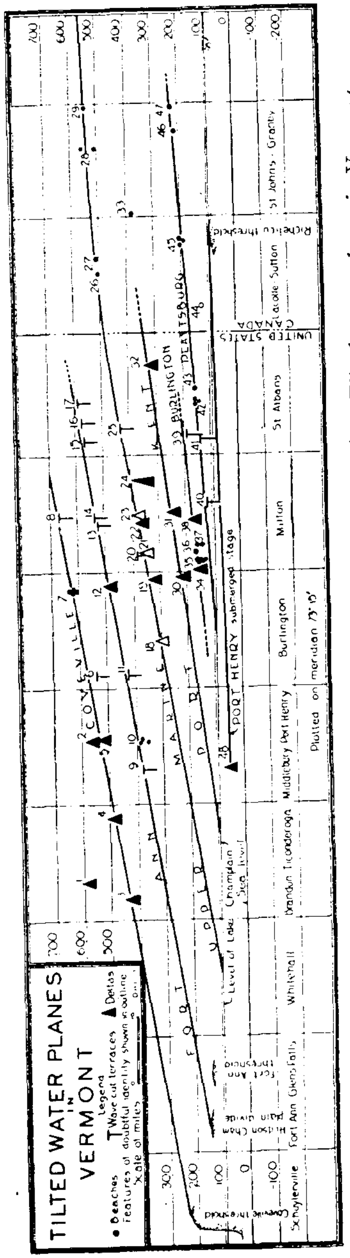


Fig. 12 (*above*): Tilted water planes in New York. Fig. 13 (*below*): Tilted water planes in Vermont.

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

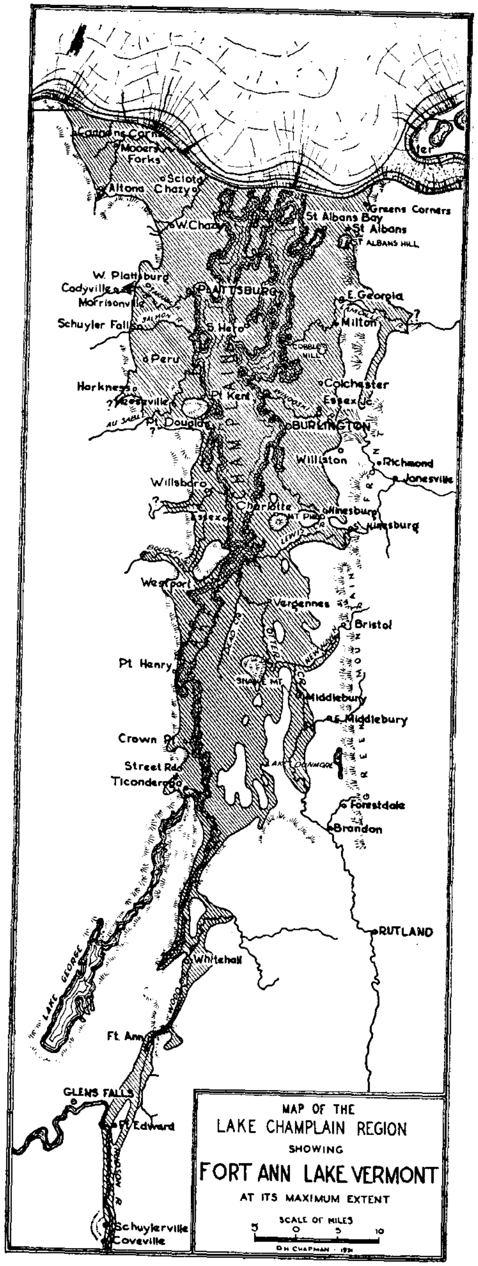


Fig. 14. Fort Ann Lake Vermont at its maximum extent.

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 unusual 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.

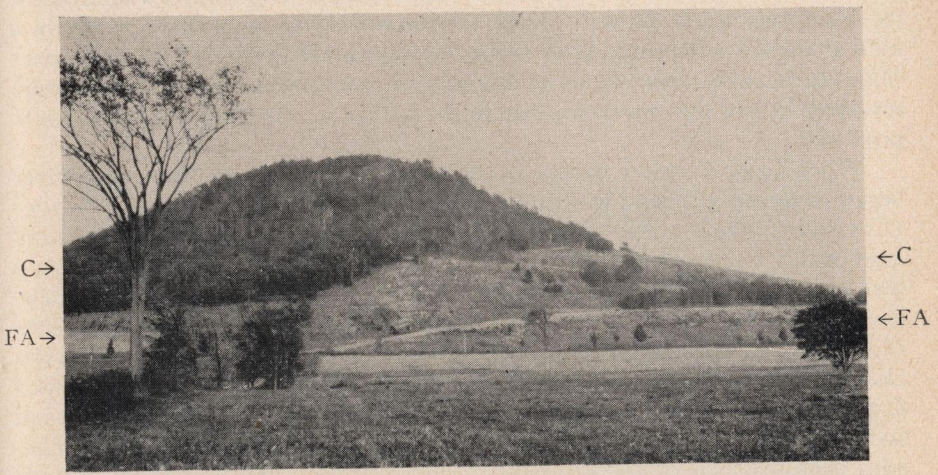


Fig. 15. Mount Philo, Charlotte, showing Coveville ("C") and Fort Ann ("FA") wave-cut terraces. Altitude of Coveville terrace, 540 feet; Fort Ann terrace, 431 feet.

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, 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.

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

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

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

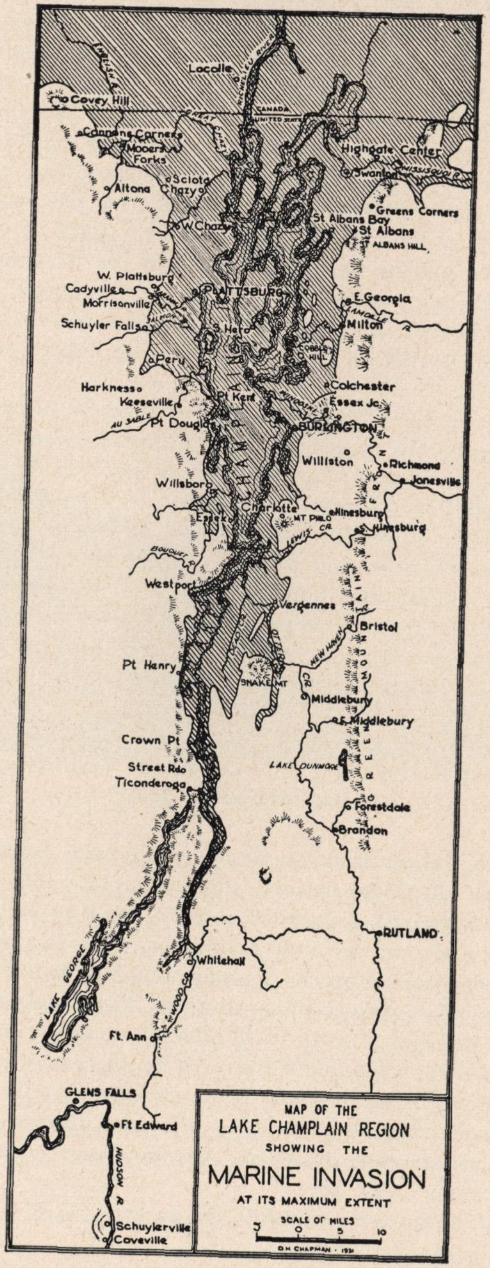

Fig. 18. Map of the Lake Champlain region, showing maximum extent of the marine invasion.

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.

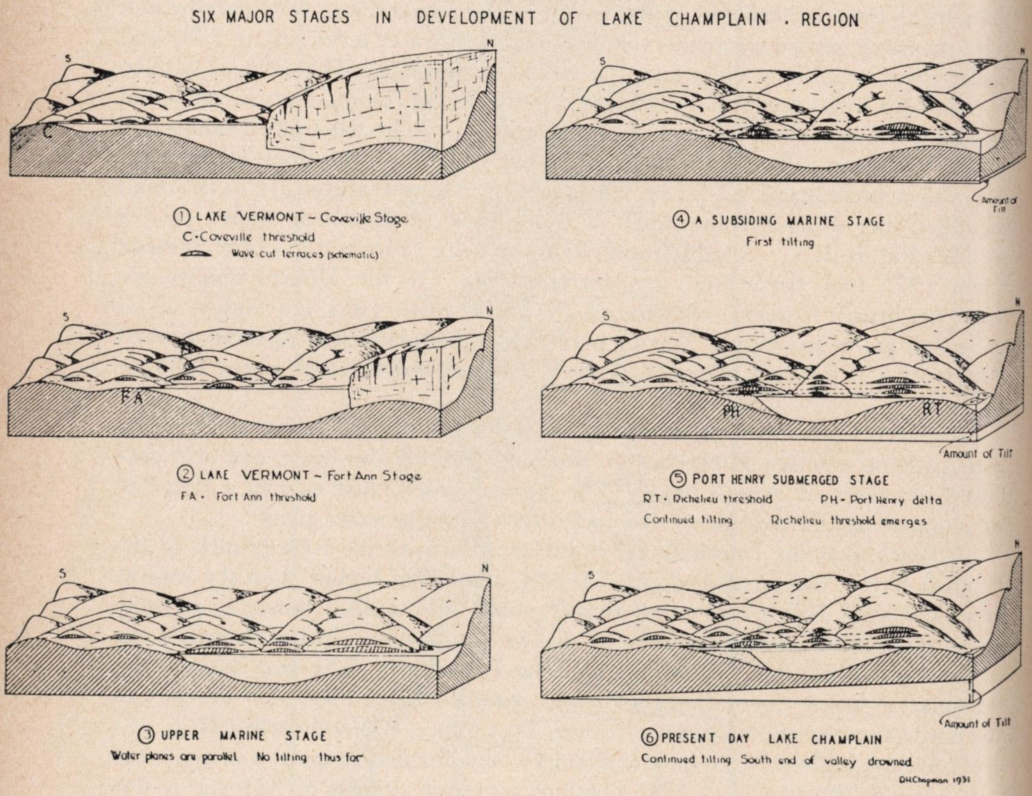

Fig. 19. Block diagram showing the six major stages in the development of the Lake Champlain region.

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).

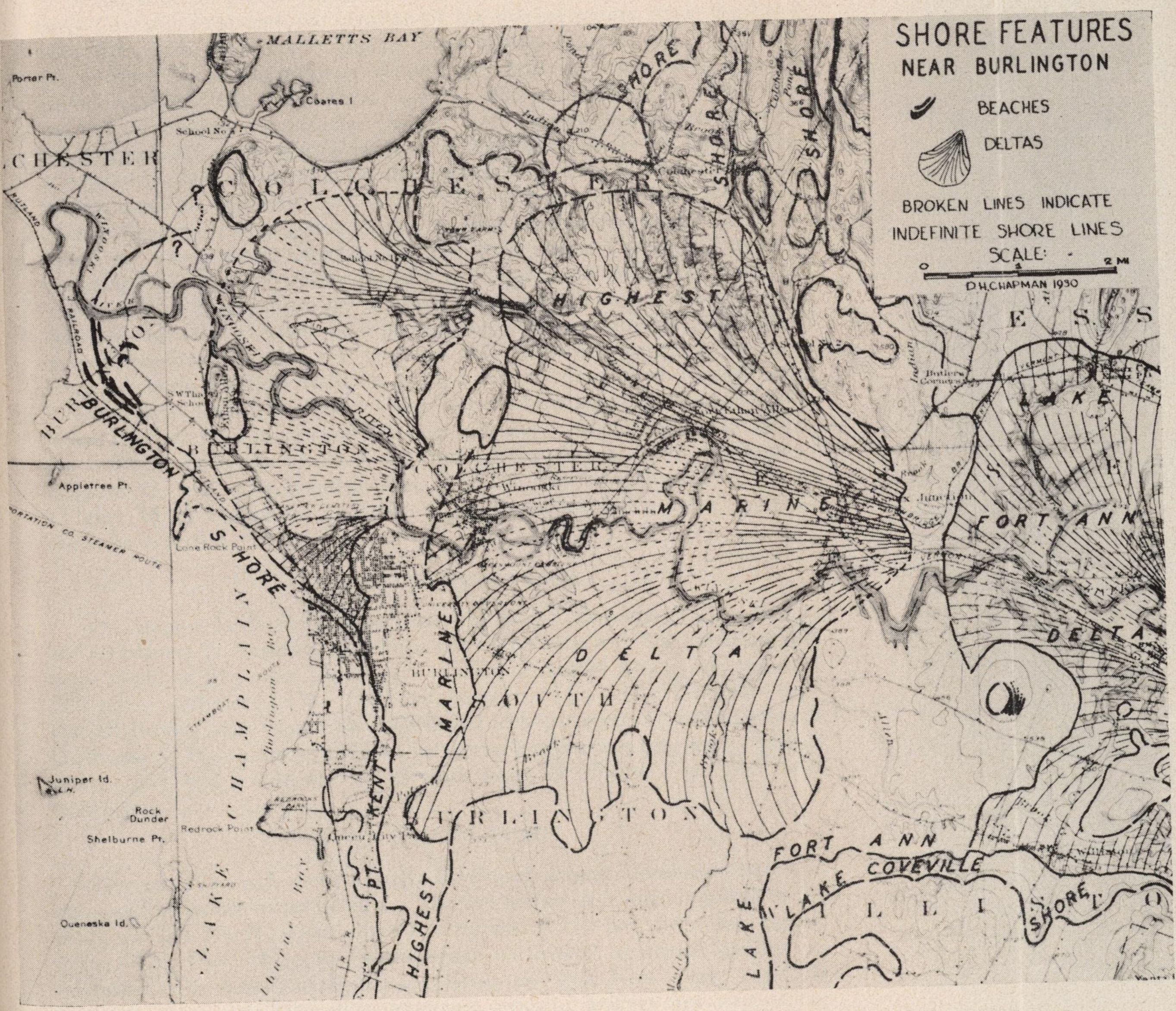

Plate VI. Burlington region, showing extent of the old (fossil) deltas.

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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.

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

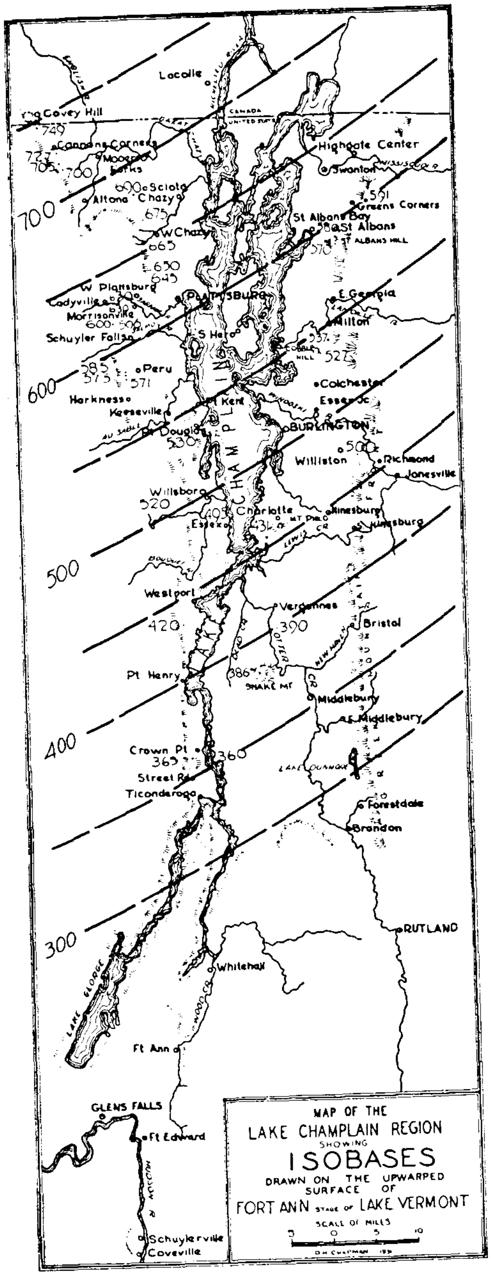

Fig. 20. Map of the Lake Champlain region showing isobases drawn on the upwarped surface of the Fort Ann stage of Lake Vermont.

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, 530'
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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