REPORT OF PROGRESS: 1964

THE PLEISTOCENE GEOLOGY OF THE ENOSBURG FALLS QUADRANGLE, VERMONT

William F. Cannon

From a low, gently undulating plain blanketed by marine clays, in the northwest, the topography of the Enosburg Falls Quadrangle grades to the south and east into a piedmont region characterized by till covered uplands with valleys containing abundant lacustrine and glacio-fluvial deposits. Within this area at least two stages of Lake Vermont are manifested.

A westward extension of the Green Mountains, termed the Cold Hollow Mountains, extends into the extreme southeastern portion of the quadrangle. Peaked Mountain and Shattuck Mountain form prominent peaks in this area. Although the only glacial deposit in this area is a thin discontinuous till sheet, several abandoned stream gorges high on the slopes of Shattuck Mountain present a unique and interesting problem.

The Missisquoi River and its tributaries constitute the principal drainage of the area. The Missisquoi flows essentially from east to west and is a superimposed stream, transecting the major bedrock structure.

Glaciation

The current study has utilized two indicators showing the direction of glacial movement, namely the trend of glacial striae and grooves on exposed bedrock surfaces and till fabrics as indicated by pebble orientation.

Striae and grooves are extremely abundant and the trends of these were found to have a range of directions from due north to N85°W. By far the most common values, however, occur in the range of N5°W to N40°W with a trend toward more northerly directions in the lowlands in the extreme west and an increasing westward component in the east. From these data it appears that the last ice to cross the region advanced from the northwest but was deflected toward a more north-south flow by the topographic control of the Champlain Lowland and the Green Mountain front. This ice advance was undoubtedly the Burlington glaciation earlier described by Stewart (1960).

Till fabric data were not as conclusive as were those derived from striae. Due to the gently sloping low topography and the thin and discontinuous nature of the till sheet, suitable exposures for fabric studies were rare. Such studies were made at six localities within the quadrangle. At two localities, one near the village of Sheldon and the other along the Missisquoi River two miles west of Enosburg Falls village, the till displayed no discernable fabric.

At two other localities, both in the vicinity of Lake Carmi State Park, the till displayed a northeast fabric. At only two localities, those being one mile north of Berkshire village and one mile south of west Enosburg village, was the fabric of the till found to parallel the general northwest trend of the striae.

Evidence of Fluctuating Ice Margins During Retreat

Several phenomena noted in the northern half of the quadrangle suggest minor readvances of the Burlington ice front. Tongues of ice apparently extended down the major valleys for a period of time after the main ice mass had retreated from the area and in some cases readvanced into formerly deglaciated valleys. The direction of movement of these ice tongues was controlled by the trend of the valleys and was not necessarily parallel to the flow of the main ice mass.

The best evidence for this was found one mile south of West Enosburg village along the Branch Brook. At this locality a one foot thick layer of till occurs within a sand terrace formed while the waters of Lake Vermont occupied the valley. The till overlies a layer of uncompacted and well-sorted sand. The sand shows considerable distortion and disruption of bedding in a two-foot zone immediately below the till. The remainder of the sand, however, shows no indication of overridding by ice. The till is, in turn, overlain by an evenly bedded sand which appears lithologically identical to that underlying the till. The till

contains numerous inclusions and layers of sand but the overall poorly sorted nature of the deposit, an abundance of striated cobbles and pebbles and a well-developed fabric substantiate a glacial origin for the material. At this exposure, approximately 20 feet of lake sand can be seen below the till and judging from the terrace configuration, the total thickness may be much greater; perhaps as much as 75-100 feet.

From this it is evident that the valley was ice free for a significant period of time before ice readvanced and deposited the till.

Another example of similar phenomenon is indicated near the village of Sheldon Springs. Striae trending nearly east-west and lake sediment which appears to be overridden indicate that ice reinvaded the Missisquoi Valley after a period of lacustrine deposition. One half mile southeast of the village, a small sand pit exposes an extremely compacted sand with occassional layers of clay. In some parts of the pit the bedding is disrupted to a point that the clay layers are traceable for only a few inches. The clay is frequently compressed into clayey sandy masses an inch or less in diameter. The writer is able to suggest no reasonable mechanism other than overriding by ice to produce these structures. It should be pointed out that the sand body discussed here occurs at approximately the same elevation as the Missisquoi marine delta but the conclusion that this material is of marine origin,

and that ice advanced into the area after marine sedimentation, seems unjustified. Thus, the sand in question is considered to be of lacustrine origin despite its proximity to proven marine sediments.

At two localities in this area, striae trending N85°W were observed. At one of these localities in the village of Sheldon Springs, these striae can be seen to intersect a groove trending N25°W which is parallel to the major striation direction in this area. In this instance, the N85°W striae are clearly younger than the striae produced by the major Burlington glaciation.

Dennis (1964) mentions a sand pit at Greens Corners (on eastern portion of St. Albans quad.) which "reveals recumbent folding due to a moving ice mass". In a brief reconnaissance of this area, however, the writer was able to find pits only in kame terraces. Although structures, including recumbent folds, were present in these pits they are more likely due to ice contact slump than to moving ice.

A final case where active valley ice seems likely is in the Lake Carmi valley. Lake Carmi occupies a depression in a broad glacial trough trending north-northeast. The sides of the trough are covered with a nearly continuous layer of till but no lacustrine deposits were found although the elevation of much of the valley sides is below the supposed level of Lake Vermont. The till was fabriced at two closely spaced localities near the Lake Carmi State Park and both fabrics indicated a direction of ice movement of

N35°E which is nearly identical to the valley trend and varies considerably from the northwest to southeast movement of the main Burlington ice. The possibility that this till is a product of an earlier glaciation from the northeast cannot be overlooked. Stewart (1960) described a till with northeast fabric occurring beneath the Burlington till and more recently similar exposures have been found at several localities in the northern portion of the state. In this instance, however, two factors point to the conclusionathat the till in question is a product of a tongue of valley ice during the Burlington glaciation. First, the till occurs at the surface and is not covered by deposits of a later glaciation. Secondly, the till occurs on an exposed slope facing toward the northwest and, if it were older than the Burlington glaciation, it would most likely have been eroded by the southeastward advance of the Burlington ice. It is the opinion of the writer, therefore, that the Lake Carmi valley contained active ice for a period of time after the surrounding uplands were ice free.

Glacio-fluvial Deposits

Throughout the Enosburg Falls quadrangle, glacio-fluvial deposits in the form of kames, kame terraces and eskers are abundant.

In the vicinity of Bakersfield, several prominent kame terraces occur along The Branch valley and in the upper

reaches of Bogue Branch valley. South of East Franklin, two large kame masses protrude above the surrounding lake sediments and the area east of Fairfield Pond is occupied by an extensive kame deposit in which kame and kettle topography is unusually well developed.

A nearly continuous esker with a general north-south trend is traceable for over one and one half miles in the area immediately northwest of Bakersfield. A small esker was also noted approximately two miles north northeast of Enosburg Falls village.

The most prominent glacio-fluvial deposit, however, is a kame moraine extending in a north-south direction from the northeastern outskirts of Enosburg Falls village to East Franklin village. Some of the kamic swells rise as much as 200 feet above the surrounding topography and appear to be composed entirely of glacio-fluvial gravel and sand. The extent of the gravel is probably considerably greater than is indicated by the surface expression of the kames since the lower areas of this region are blanketed by lacustrine sand.

Lacustrine Sequence

Deposits of both the Coveville and Fort Ann stages of Lake Vermont are found within the quadrangle.

A well-developed series of beaches and one delta define a gently sloping water plane which rises from 710 feet (aneroid) in the extreme southwest portion of the quadrangle

to 740 feet (aneroid) in the vicinity of West Enosburg. This is believed to represent the Coveville stage.

A single beach at an elevation of 600 feet (aneroid) near West Enosburg is the only definite indication of the Fort Ann stage observed in this region. These elevations are in approximate agreement with the isobases proposed by Chapman (1942).

The following table summarizes the elevation and locations of features believed to indicate lacustrine water planes.

Coveville Features

Delta one half mile south of Soule School	Top of delta at 710'
Gravel bar at Herrick School	Top of bar at 740'
Gravel beach in village of Bordoville	Top of terrace at 740'
Gravel beach one mile north of Bordoville	Top of terrace at 740'
Gravel beach on south side of Bogue Branch Valley	Top of terrace at 740'
Gravel beach 1/2 mile WSW of Enosburg Center	Top of terrace at 700' Top of wave washed - till at 720'

Fort Ann Features

Gravel beach on south of Bogue Branch valley	Top of terrace at 600'

2¼ miles S.E. WEST ENOSBURG

These features are all found in the southern portion of the quadrangle and no definite shore features were observed north of the Missisquoi River. With the exception of sand

bodies associated with the extensive kames in Berkshire Township and one small body of sand in the Lake Carmi valley, no evidence of lacustrine deposition was found above an elevation of 440 feet north of and in the Missisquoi Valley. This level is far lower than any recognized level of Lake Vermont.

Chapman (1942) states that no evidence of Lake Vermont is found in the Champlain Valley north of the Missisquoi Valley and concludes that the Lake waters were able to drain around the ice front by the time that it had receded to this vicinity. The writer agrees that no evidence of Lake Vermont is found north of the Missisquoi River in the Champlain lowland, but silt and clay terraces of the Missisquoi Valley and southern portion of the Lake Carmi valley are interpreted as a product of a stage of Lake Vermont, since this material appears to be unconformably overlain by marine sediments at several localities along the river.

Two interpretations of these sediments are possible. First, they may be a product of the Fort Ann stage and represent only a short period of deposition, the Lake draining before sediments could accumulate to the proposed 600 foot level of the Fort Ann Stage. Since no shore features have been found in the vicinity, it is impossible to determine the lake level. Most of the deposits are silt and clay and appear to be the result of deep water accumulation. The terrace levels are, therefore, not necessarily

indicative of the true lake level.

An alternate hypothesis is that these sediments were deposited in a lower level lake which existed after the Fort Ann stage. It is an interesting observation that the 440-foot level closely corresponds to the elevation of the divide in the Lake Carmi valley. Silty clay and sand fills the valley to 440 feet south of the divide but no evidence of lacustrine deposits have been observed north of the divide. This suggests that this divide may have controlled the level of the lake into which these sediments were deposited and the outlet for the lake was through the Lake Carmi and Pike River valleys. It is not intended to suggest, however, that this drainage was a major outlet of Lake Vermont for there does not seem to be any adequate drainage way to the north or east which could result in the ultimate drainage of Lake Vermont to this level. The Pike River flows to the west and enters Missisquoi Bay north of the international boundary.

Marine History

A widespread erosion surface developed on deposits of Lake Vermont throughout the Missisquoi Valley is marked by deposits of fluvial gravel and channeled and rilled lake terraces and is partially blanketed by marine sediments. It is apparent, therefore, that this area was subjected to a period of subaerial erosion after the final drainage of Lake Vermont and prior to the Champlain Sea marine invasion.

The uppermost deposits of marine origin are found at an elevation of 500 feet and are represented by a sand beach and dune area on the hill one half mile east of East Highgate and a gravel beach two miles north northeast of East Highgate.

During this time the Missisquoi River was depositing a large sand delta in Sheldon Springs-East Highgate area and much of the northwestern portion of the quadrangle was being blanketed by clays and silts.

The recession of the sea is marked by one poorly developed beach one mile west of Franklin at an elevation of approximately 400 feet.

The Shettuck Mountain Channels

In the notch between Peaked Mountain and Shettuck Mountain and on the north slopes of Shettuck mountain are several deeply cut channels which are apparently the product of meltwater erosion. These channels are cut 50' to 75' into the bedrock, vary in width from to 5' to 50' or more and are marked by an abundance of exceptionally large potholes. The portions of the channels with the steeper gradients seem to have been formed almost exclusively by pothole drilling since partial potholes are present in the entire height of the valley walls. In some instances where adjacent potholes have coalesced, the channels are widest at the bottom and narrower toward the top. In all cases, the channels are now either completely dry or contai

only minor streams. The meltwater origin of the channels seems clear but the drainage history of the area remains puzzling.

The time alloted for the present survey did not allow a complete reconnaisance of the area and a detailed mapping of all features but the following discussion presents the details that have been observed.

What appears to be the main channel begins abruptly on the north slope of Shattuck Mountain at an elevation of approximately 1300 feet. Within a few yards of its origin the channel is roughly 20' wide and 10' to 20' deep. This appears to be the point at which a meltwater stream flowed from the ice and began erosion of the bedrock. From this point, the channel extends north northeast for several hundred yards and then bifurcates into three branches. Two of these rejoin within 100 yards and continue in a southeasterly direction down the eastern flank of the mountain. The channels are marked by several extraordinarily large potholes. The third branch which appears to have been the main drainage way continues to the north as a steep-sided, flat-bottomed and relatively broad valley. Saddle Pond, shown on the Enosburg Falls topographic Sheet, occupies a portion of this valley and is held in by a debris dam where talus and organic material has partially filled the channel in an unusually narrow restriction. This pond is intermittent and is able to completely drain through the dam in dry seasons. Slightly north west of Saddle Pond, this channel

joins another short but deeply cut channel with a markedly discordant juncture. From this point the channel turns westward and the last evidence of meltwater erosion is found a few hundred yards east of Waterville Road along the present stream valley containing the headwaters of The Branch.

It is obvious that these channels are not the product of normal subaerial erosion. The unusual drainage pattern with bifurcating channels ultimately flowing in opposite directions, discordant valley junctures and the large volume of water needed to sculpture these features indicate meltwater erosion. The northward gradient of some portions of the channels suggest that the erosion may have been, at least in part, subglacial.

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OPEN-FILE REPORT NO. 1964-2.

PLEISTOCENE GEOLOGY OF THE VERMONT PORTION OF THE AVERILL AND GUILDHALL QUADRANGLES

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The Averill and Guidhall quadrangles lie in the extreme northeastern corner of the state. This mountainous region is a westward extension of the White Mountain uplift. The bedrock consists of intensely deformed eugeosynclinal sediments intruded by several granitic plutons.

Nearly the entire area lies in the Connecticut River drainage bastin. Only Averill Creek is the extreme northwestern corner of the area is a part of the Memphre magog drainage basin.

Glaciation

Much of the uplands of the area is blanketed by till. This till can be divided into two textural categories. Most of the till is a compacted basal till whose lithology varies markedly according to the type of the underlying bedrock. Some areas, however, especially in the northern portion of the Averill quadrangle, contain extensive deposits of an uncompacted, sandy ablation till.

The direction of ice movement during the last glaciation is not entirely clear. Two till fabrics in the northern portion of the Averill quadrangle and two in the southern portion of the Guild all quadrangle indicate a flow from the

northeast which is in accordance with evidence from other areas to the south and west. A fabric in basal till along the Connecticut River near Bloomfield, however, indicates a southeasterly flow and two fabrics near the eastern edge of Yellow Bogs on the Averill quadrangle indicate a nearly north-south flow.

Striae are seldom preserved on the bedrock but were observed at two localities by the writer in Yellow Bogs and were found to have a trend of N45°W. Meyers (1964) states that striae observed at several localities throughout the Averill quadrangle were found to have an average trend of N30°W and further states that "A pronounced lineation in the surface alluvium in Yellow Bogs depression is visible in aerial photographs. This lineation is also oriented in a N30°W direction andconsequently thought to be of glacial origin."

Judging solely from evidence found in these quadrangles it is impossible to make a definite statement concerning the direction of flow of the last ice to cross the area.

Lacustrine Deposits

The Connecticut Valley and lower reaches of the Mulhegan Valley contain a thick sequence of lacustrine sand, silt and clay.

It appears that throughout the extent of the Connecticut Valley in this area, sedimentation occurred at sufficiently rapid rate or for a sufficient time for the lake basin to

be nearly filled with sediment, for a layer of fluvial gravel is commonly found capping the lake terraces. This gravel layer should be a reasonably accurate indicator of lake level and is considered as such in following discussions.

These gravel capped lake terraces are occassionaly pitted by ice contact depressions and in shallow exposures are indistinguishable from kame terraces. A sufficient number of exposures revealing the gravel over lake sand have been found, however, to establish the history of lacustrine deposition followed by a fluvial phase. This is particularly well displayed at Brunswick Springs in the Guildhall quadrangle. At this locality, a high bluff along the Connecticut River exposes 75-100 feet of lacustrine silt and fine sand capped by 15-20 feet of gravel with no evidence of an erosion surface between the sand and gravel. Ice contact structures extend throughout the entire exposure of lake sediments and continue through the gravel to the surface resulting in kettle holes. The pond at Brunswick Springs occupies one of these depressions.

It is the writers interpretation that the gravel is a delta-like deposit which built progressively down valley during a shoaling phase of the lake.

Considering this gravel to mark the level of the lake, the water plane thus defined rises from an elevation of 1000 feet at the southern boundary of the Guildhall quadrangle to 1040 feet at Bloomfield, 1060 feet at Colebrook and 1080 feet at the international boundary.

In several areas, but most noticeably immediately north and west of Guildhall village, the Connecticut River has barely begun to dissedt the lake deposits. Well records indicate as much as 125 feet of unconsolidated material above bedrock along the river north of Guildhall and the river displays features such as meander cutoffs, oxbow lakes and a wide floodplain which are typical of an old age stream. A similar channel pattern occurs north of Colebrook but no well data are available. In this area the stream is flowing on varved clay. It appears that the depth of erosion in these areas is controlled by a bedrock sill somewhere downstream which has halted downcutting and caused the river to grade progressivily upstream. If this is the case, the bedrock floor of the valley must slope northward over a considerable portion of the valley and the production of a glacial lake would have required only a moderate amount of isostatic tilting to the north (approximately 2½ feet per mile.)

There is no evidence as to whether or not this lake was contiguous with the lake which occupied the Connecticut Valley south of the Fifteen Mile Falls region.

Glacio-fluvial Deposits

Glacio-fluvial deposits occur intermittently along the Connecticut Valley as Kame terraces. Three prominent eskers were noted in the Guildhall quadrangle, two along Paul Stream and the third along Wheeler Stream. The most extensive area of glacio-fluvial deposits is in Yellow Bogs where a thin blanket of sand and gravel covers several square miles of

the Averill quadrangle.

A Possible Origin of the Yellow Bogs Depression

The Yellow Bogs depression is a topographic low covering approximately 45 square miles of the southwestern portion of the Averill quadrangle, the southeastern portion of the Island Pond quadrangle and the extreme northern portion of the Burke quadrangle.

This depression is unusual in that it is floored by a massive quartz monzonite while the surrounding rim of hills is composed of metasediments. It is not, however, unique. Myers (1964) mentions a similar feature reported in southern Quebec and western Maine and G.M. Boone (personal communication) reports a similar phenomenon in central Maine.

Other granitic rocks in this area such as the quartz syenite of the Monadnock pluton form topographic highs while still others such as the Averill granite appear to have little control of the topography, underlying both highs and lows.

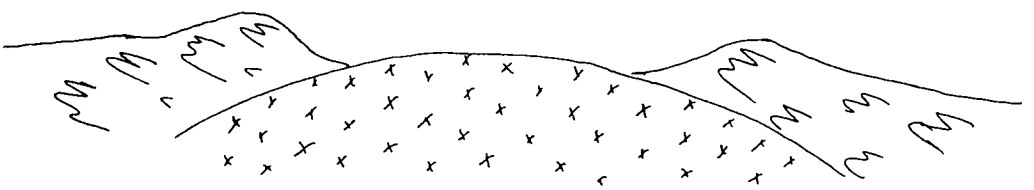
Since granitic rocks can obviously maintain topographic highs in this region, the writer sees no possible explanation of the Yellow Bogs depression through normal weathering and stream erosion or simply by glacial abrasion. The only origin which the writer can suggest is one similar to that indirectly suggested by Myers (1964) of unroofing of the pluton.

The metasediments surrounding the pluton have been drag-

ged upward during intrusion and presumably were also domed over the pluton. Such doming should cause jointing in the metasediment rendering them more susceptible to glacial plucking than the surrounding rocks. The depression could have been formed as the jointed metasediments over the pluton were eroded by glacial plucking while those surrounding the pluton were more resistent. By this mechanism it is not necessary to erode large quantities of the quartz monzonite since the current floor of the depression should be approximately the upper limit of the intrusion.

The following diagram illustrates the suggested mechanism.

Before glaciation, jointed metasediments overlying pluton.



After glaciation, jointed metasediments removed by glacial plucking.

Plant Fossils in the Connecticut Valley

Approximately 500 yards south of Columbia Bridge (Averill quadrangle) varved lake clays outcrop along the western bank of the Connecticut River. These clays contain abundant imprints of leaves which were earlier described by Lougee (1953) who identified birch, poplar and willow leaves and a tundra flora of *Dryas* and heath.

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PLEISTOCENE GEOLOGY OF THE NORTHERN CHAMPLAIN ISLANDS AND ALBURG PENNINSULA, VERMONT

William F. Cannon

The islands of South Hero, North Hero, Isle La Motte and Hog Island and the Alburg penninsula rise gently from the waters of Lake Champlain. The land attains a maximum elevation of 275 feet on South Hero or 180 feet above lake level. The low, rolling topography is blanketed with till and scattered areas of marine clay with locally prominent areas of marine sand and beach gravel.

Glaciation

Although much of the area is blanketed by till, exposures suitable for fabric studies are rare and fabrics were measured at only two localities. These two fabrics have yielded conflicting evidence as to the direction of ice movement.

One fabric measures along a recently excavated channel on the north shore of Cary Bay (North Hero) indicates a direction of flow from N30°W. This is in accord with evidence from surrounding areas of a glacial advance from the northwest which has been referred to as the Burlington glaciation. The second fabric, however, measured on the west side of Isle La Motte indicates a flow from N30°E. The fabric of this till was measured at two closely spaced local-

ities and both localities yielded the same northwest fabric.

Most of the northern Champlain Valley has been glaciated by an ice advance from the northwest but there is also evidence at several localities of an earlier glaciation from the northeast. It is possible that the till on Isle La Motte with a northeast fabric is a product of this earlier glaciation, but no direct proof of this was found.

The till occurs on a hillside sloping toward the northwest and is as much as 15 feet thick. The writer can suggest no reason why an older till should be preserved at this locality. The till is overlain by marine beach gravel with no trace of a younger till between the gravel and the till with the northeast fabric.

An alternate explanation is that the ice advance from the northwest was deflected from its course by the topographic control of Isle La Motte and the lake basin to the west; a phenomenon which does not appear to be common in this region, especially a deflection of 60° as would be required in this case.

The writer can offer no direct evidence as to the true age of this till. It was noted however, that the till is unusually hard and compact which may indicate that it has been overridden by a later ice advance.

Only one set of striae were found in the area, those being on the north end of Hog Island. These were found to trend N25°W.

Marine History

The entire area was covered by the Champlain Sea Marine invasion and marine deposits in the form of clay, sand and gravel blanket much of the surface. The clays are generally restricted to the lower areas of the topography, while bodies of sand and gravel occur throughout the area. The gravel bodies were formed as beach deposits and commonly occur as bars and terraces. The most extensive beach deposits occur on the western side of Isle la Motte where up to 30 feet of gravel is exposed without exposing bedrock.

Fossils are abundant in the gravel and are also locally abundant in clay and sand deposits. The genera noted during the present survey are Saxacava, Macoma, and Mytilus. Several barnacles were also found at one locality on Isle La Motte.

Erwin (1957) suggests that the stunted and thin shelled nature of many of the fossils indicates a lowered temperature and salinity of the sea water due to mixing of large quantities of glacial meltwater with the sea water.

The Pre-Burlington History of the Area

At Robinson Point on the east side of South Hero a wave cut cliff along the present shoreline exposes a brown sandy till overlying lake silt. The silt has highly contorted bedding and the top foot of the deposit is varved with thin layers of black clay alternating with layers of light

brown silt. It appears, therefore, that a lake occupied the Champlain Valley prior to the Burlington glaciation. Whether this lake was dammed by the advance of the Burlington ice, during the retreat of an earlier ice advance, or was a natural lake without an ice dam cannot be determined from this single exposure.

On the west side of Isle La Motte, at a slightly higher elevation, a cross bedded gravel is exposed beneath a till with a northeast fabric (discussed above). This gravel deposit is at least 20 feet thick, is well bedded with beds dipping uniformly at about 30° to the east and contains a few faults which are probably ice contact structures.

If the overlying till is considered to be a product of the Burlington glaciation, the presence of an ice contact gravel body is not in accord with the evidence of lacustrine deposition at Robinson Point. If, on the other hand, the till is considered to be the product of an earlier glaciation, the gravel may indicate the absence of a pro-glacial lake associated with this glaciation.

Dunham Dolomite Erratics

Several boulders of Dunham dolomite have been observed at the surface and along beaches on South Hero. The Dunham formation occurs only to the east of the Champlain Thrust and outcrops only on the Vermont mainland. The presence of these boulders on South Hero indicates a glacial advance with a westerly component of movement at some time in the

glacial history of the area.

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