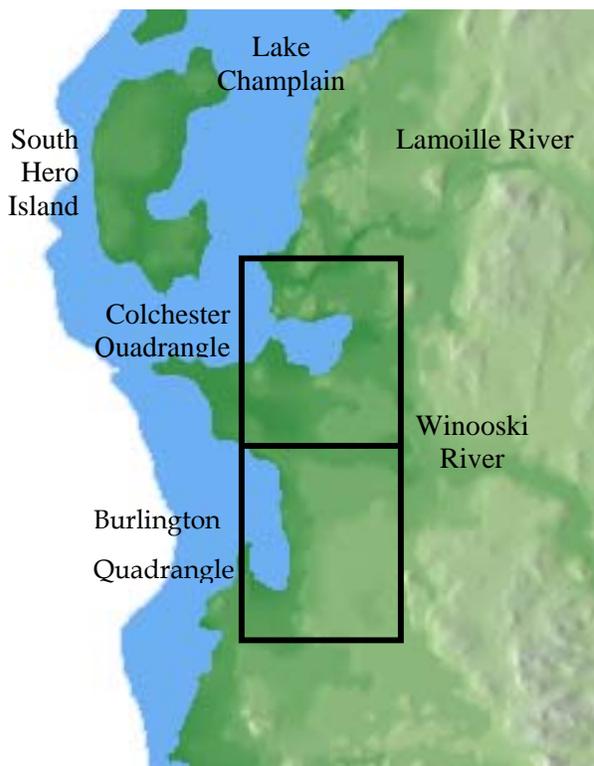


## Glacial Geology of the Burlington and Colchester 7.5' Quadrangles, Northern Vermont

Stephen F. Wright  
Department of Geology  
University of Vermont  
Burlington, Vermont 05405

### Introduction

Surficial materials are the unconsolidated materials at earth's surface. They include sand and gravel, mud and swamp materials; all materials that aren't solid bedrock or ledge. In most places these unconsolidated materials (dirt!) are far more commonly exposed at the surface than are rocks. In the Burlington area rocky areas are limited to some spectacular exposures along the lakeshore and the Winooski River in addition to many small outcrops scattered across the higher ground. In most of New England almost all of the surficial materials mantling the bedrock were deposited either directly by glacial ice or in lakes or streams that existed adjacent to the glacier. A map showing the distribution of surficial materials is therefore a record of both the glacial and post-glacial processes that have affected an area. This short report outlines the distribution of surficial materials and glacial features in the greater Burlington area (Fig. 1) and my interpretation of the glacial and post-glacial processes responsible for



**Figure 1:** Location of the Burlington and Colchester 7.5-minute Quadrangles, northwestern Vermont, within the lowlands of the Champlain Valley, bordering Lake Champlain. The modern delta of the Lamoille River is located in the northwestern corner of the Colchester Quadrangle. The Burlington

Intervale, a broad alluvial valley cut by the Winooski River angles ESE to WNW across the top of the Burlington Quadrangle and the bottom of the Colchester Quadrangle.

those materials and features. Surficial geologic maps of both the Colchester and Burlington 7.5' Quadrangle maps were prepared by myself and UVM students Seth Jones, Sarah Fuller, Simon Rupard, and Andrew McKinney. The Burlington and Colchester topographic maps encompass the greater Burlington area extending north-south from Milton to Shelburne and west-east from the Lake Champlain shoreline almost to Williston. Copies of these maps can be ordered from the Vermont Geological Survey.

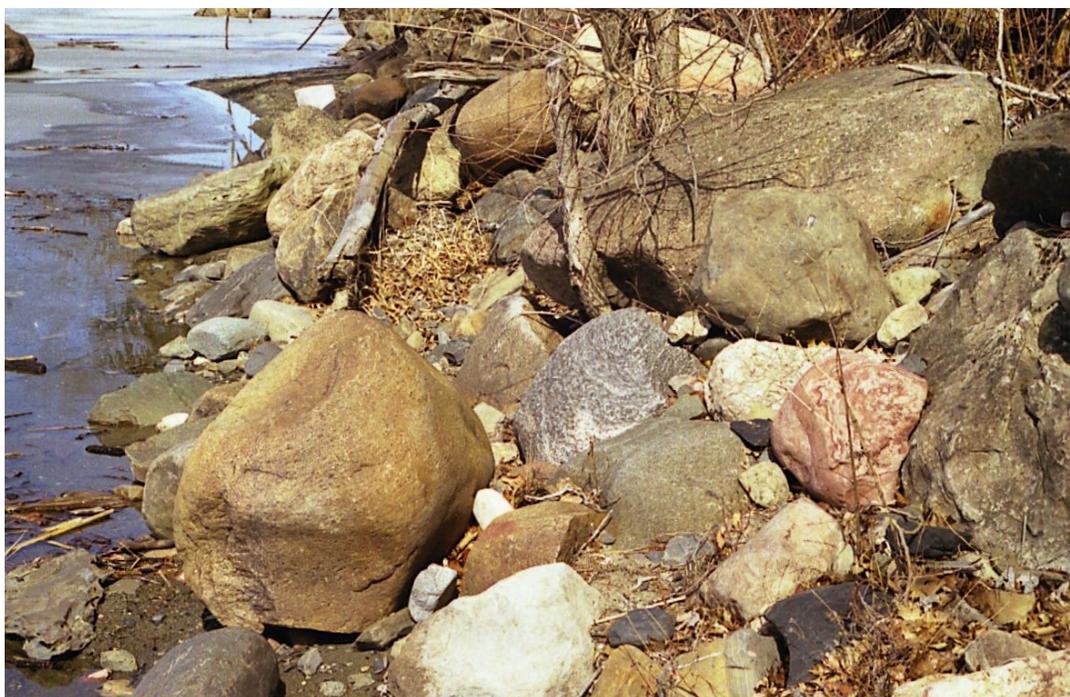
### **The Laurentide Ice Sheet**

The Laurentide Ice Sheet was the most recent of perhaps 20 or 30 different ice sheets that originated in northern Canada and spread across much of northeastern and north-central parts of North America like a thin, cold pancake almost 3,000 km in diameter. With few exceptions, the surficial materials underlying most of New England are all directly or indirectly a result of this last big glacier. At its farthest extent, the Laurentide Ice Sheet reached as far south and east as Long Island, Cape Cod, and several hundred kilometers beyond the present coast line of Maine. If you were at Cape Cod approximately 23,000 years ago and walked up onto the ice sheet you could have walked northwest up a gently inclined ice surface that quickly became thick enough to completely bury all of the New England Mountains between Cape Cod and western Vermont. By the time you were standing over Burlington, there was over 2.5 km of ice between your feet and the ground surface far below and nothing in sight except an immense expanse of ice sloping so gently to the southeast that you'd think the surface was level. If you continued to the center of the ice sheet, over what is now the eastern part of Hudson Bay, you would be standing on almost 4 km of ice.

Beneath this big glacier the ice in some places flowed directly on rock, but in most areas there was a mixture of rocks, sand, silt, and clay (glacial till) that separated the ice from the underlying bedrock. This rock till or "hard pan" occurs in the Burlington area, most commonly near places where bedrock ledges are exposed, but also along stream channels or along the Lake Champlain shoreline where the overlying glacial sediments have been eroded away (Fig. 2). It is common to find large boulders of "foreign" rocks (glacial erratics), rocks not native to the Champlain valley that have been transported here by the glacier. The most distinctive of these are the coarse-grained metamorphic rocks from the Laurentian Mountains of Québec.

As the ice moved at speeds of 10's of centimeters to a few meters per day, it also churned, sheared, and dragged the till beneath it over the underlying bedrock. This crude "sandpaper" smoothed the

underlying bedrock into rounded, whale-back like forms and left a myriad of scratch marks on the rock surface – glacial striations. Striations created by sand grains are short and very fine, while long, deep grooves were made by large hard rocks. In the Burlington area the oldest striations and grooves are aligned from N30°W to S30°E. Inspection of striated surfaces shows the striations moving over surfaces that are not only level or down-hill, but uphill as well. In particular, if one looks in the direction the ice was flowing from Burlington (towards S30°E) you'll notice that the glacier was heading obliquely towards the Green Mountains, Lincoln Mountain specifically. Northwest to southeast trending striations occurring along the crest of the Green Mountains indicate that the Laurentide Ice Sheet flowed with impunity up and over the mountains on its slow journey to southeastern New England.



**Figure 2:** Glacial erratics eroded from till along the shore of Lake Champlain near “Camp Norfleet” in the Colchester Quadrangle. High-grade Grenville-age gneisses, originating from the Laurentian Mountains north of Montréal, Québec, occur with the more common local lower Paleozoic sandstones and carbonates. The most common erratics are small pieces of the Iberville shale, but these don’t survive long in the beach zone.

### **Retreat of the Laurentide Ice Sheet in the Champlain Valley**

Indirect measurements of past temperatures indicate that after an almost 100,000 year long period of slow cooling the northern hemisphere rapidly warmed beginning about 20,000 years ago. With the warming temperatures, the Laurentide Ice Sheet began to melt faster than it flowed forwards and the edge of the ice sheet began to retreat to the northwest as the glacier also began to thin. The first indication of ice sheet thinning in western Vermont comes from observations of glacial striations. In most parts of

the Champlain Valley a younger set of glacial striations aligned from north to south are superimposed over the older regional northwest to southeast set, indicating that the ice sheet changed direction. This change in direction occurred when the ice was no longer thick enough to flow over the mountains and was now confined by topography, specifically the north-south orientation of the Champlain Valley. This probably occurred sometime between 15,000 and 14,000 years ago. It's appropriate to think of the Champlain Valley being occupied by a tongue of the Laurentide Ice Sheet at this time.

In a few places near where Route 2 crosses the Lamoille River, a still younger set of striations indicate that the glacier shifted direction one more time, this time flowing from northeast to the southwest (Fig. 3). This time it appears that the ice was thin enough to be locally guided by the orientation of old, pre-glacial Lamoille River channels cut into the bedrock.



**Figure 3:** Small “rat tails” of dolostone extend SW from quartz sand grains embedded within the Dunham dolostone on outcrop ~500 m NNW of the Rte 2 bridge over the Lamoille River, east side of road. Rat tails record the latest NE to SW ice flow in the area (see arrow; compass is aligned N-S), formed when the ice sheet was thin enough to be guided NE to SW by bedrock channels cut by the Lamoille River through the dolostone.

If you were on top of the ice sheet at this time the landscape would be more interesting than earlier. No longer a featureless expanse of ice, the glacier sloped first gently and then more steeply to the south ending somewhere near Fort Ticonderoga, while the Green Mountains were visible bordering its eastern side and the Adirondacks bordering the west. The ice tongue in the Champlain Valley also branched into smaller tongues that extended *up* into the Winooski and Lamoille River valleys. To the north the ice sheet was still huge, covering most of Québec and thick enough to mask all the underlying mountains. In the summer months you would also notice lots of water flowing in streams on top of the ice. The streams

were fed by the rapidly melting snow and ice not only from the Champlain Valley ice tongue, but also from anywhere up-glacier (Québec) where melting was occurring. Some of these streams stayed on the ice surface but most plunged down into the bowels of the glacier through funnel like holes called moulins. From there water flowed in tunnels within the glacier eventually reaching the bottom where tunnels carried this glacial melt water south to its terminus. These water-filled tunnels were frequently partially filled with sediment carried by the melt-water. Once the glacier retreated, the stream sediments stand in a sinuous ridge that was once the ice tunnel, a landform called an esker. I have not mapped any eskers in the Burlington and Colchester Quadrangles, but suspect that the dynamics of water flow in the glacier forced water to flow towards the deeper parts of the Champlain valley, areas currently beneath Lake Champlain.

### Glacial Lake Vermont

In the Burlington area and in most of the Champlain valley glacial till (the material deposited beneath the ice sheet) is directly overlain by thinly laminated silt and clay (Fig. 4). There are no soils or indications that streams flowed after the glacier retreated, but instead it appears that as soon as the ice sheet retreated exposing till, that till was immediately blanketed by fine sediment, sediment so small that it requires very fairly quiet water to settle. The finely laminated silt and clay is the direct evidence that a lake occupied the Champlain valley during the time that the ice sheet was retreating northward, down the Champlain valley. This lake is called Lake Vermont or sometimes Glacial Lake Vermont to indicate that it only



existed when the ice sheet was nearby. Lake Vermont formed because the Champlain valley slopes to the north, draining sequentially into the Richeleau River, the St. Lawrence River, and the Gulf of St. Lawrence. The ice sheet in the Champlain Valley blocked that northward drainage creating an ice-dammed lake that drained southward via the Hudson River. Initially the southern end of Lake Vermont may have been south of Albany, New York. Somewhat later, the southern end of the lake was fixed just north of Fort Ann, New York where the valley becomes quite narrow.

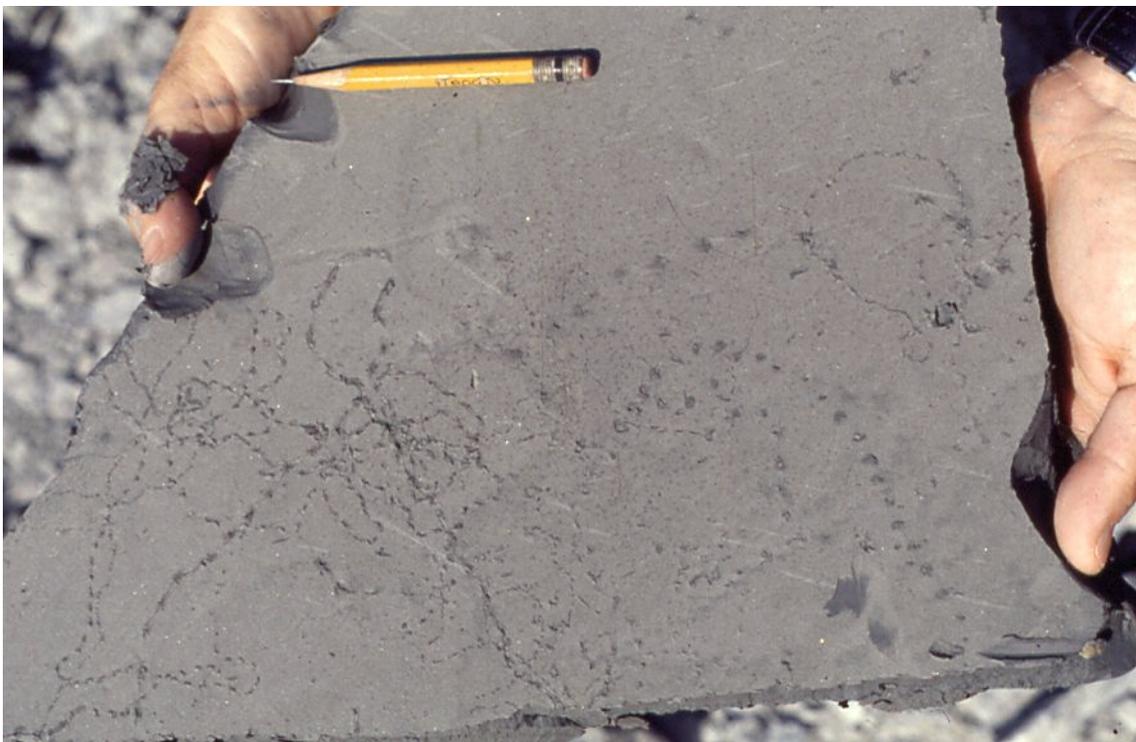
**Figure 4:** Varved Lake Vermont silt and clay deposited directly on glacial till (arrow points to contact) indicating that Glacial Lake Vermont came into existence immediately after the ice sheet retreated, i.e. the ice front was the receding dam holding in the waters of Lake Vermont. Section was

exposed during construction of the Circumferential Highway (Vt 289) approximately 500 m east of its intersection with Vt Rte 15 in Essex. Glacial till rests on bedrock immediately below bottom of picture.

Glacial Lake Vermont grew as the ice sheet retreated northward filling much of the Champlain valley. The Laurentide Ice Sheet retreated past Burlington and Lake Vermont locally began approximately 13,500 years ago. The elevation of the lake surface near Burlington was about 620 ft (189 m) above sea level and its eastern shoreline reached almost to Jericho Center. If you stand along the shore of Lake Champlain and look up, the surface of Lake Vermont was over 500 ft above your head and the deepest parts of the lake exceeded 900 ft. Cobble Hill, Brownell Mountain, and Mt. Philo are high enough to have been small islands in this lake.

Lake Vermont was not a clean lake, but instead contained muddy water. Some of the mud washed off the recently deglaciated and poorly vegetated mountains bordering the lake, but a lot of mud was also pumped into the lake from streams flowing off the melting glacier, especially those streams flowing in tunnels within the ice, near its base. These high-pressure streams were like fire hoses at the front of the glacier spewing cold, dirty water into the lake. If you were able to paddle a boat over where one of these ice tunnels emptied into the lake the water would be boiling! Farther from the front of the glacier, water currents lessened, eventually slowing sufficiently for most of the silt-sized mud to settle to the bottom of the lake. However, it was only during the winter months, when the lake surface iced over and the lake waters became very quiet, that the finest clay-sized mud settled to the bottom. The finely laminated silt-clay sediments deposited in Lake Vermont are therefore yearly layers or varves – the coarser silt layers deposited during the summer and the finer clay layers deposited during the winter.

It is hard to find fossils in Lake Vermont's sediments. Despite its large size, the lake must not have been a very conducive environment for plants or animals. While fossils are rare, it's more common to find footprints and worm tracks made by animals that lived in the lake, but whose remains aren't preserved (Fig. 5).



**Figure 5:** Tracks of several different types of insects/ animals are visible on this bedding plane of silt split from varved silt/clay deposited in Glacial Lake Vermont. Section of varved silt/clay was exposed during construction of the Circumferential Highway in Essex, near its junction with Vt Rte 15.

Sometimes one finds pebbles and even large rocks embedded within Lake Vermont's varved silt/clay layers. They appear to be out of place in an environment where only mud settled to the lake bottom most of the time. These rocks are the modern day equivalent to dropping an anchor over the side of a boat, but forgetting to attach a rope. Within Lake Vermont, the boats were icebergs and the anchors were pieces of rock entrained within the ice called dropstones. When glaciers end in standing bodies of water (lakes or oceans) they calve, a process where blocks of ice break off the glacier creating icebergs. As these icebergs melt, they can release sediment anywhere in the lake that wind and currents take the iceberg.

Lake Vermont continued to grow in size as the ice sheet retreated farther and farther north, well up into Québec. Lake Vermont ended catastrophically when the glacial ice dam that was preventing its water from flowing north failed. This dam failure occurred near Warwick, Québec approximately 12,000 years ago. The failure of the dam allowed a huge volume of fresh water (hundreds of cubic kilometers) to roar out into the Atlantic Ocean through the Gulf of St. Lawrence. In the Burlington area the water level fell almost 100 m (~300 ft) within a matter of hours or days at most exposing huge areas that were formally under the muddy water of Lake Vermont. However, there is ample evidence that a large part of the Champlain Valley remained underwater after Lake Vermont drained.

### **Champlain Sea**

At low elevations within the Champlain valley the rhythmically laminated silt/clay sediments deposited in Lake Vermont are overlain by massive grey silt and clay. The character of these younger sediments is very different and they contain fossils. The common fossils are small clams, but the beluga whale fossil, currently housed at the Perkins Geology Museum at the University of Vermont, was also found in these sediments. The fossils are not extinct so we can observe the modern environments these animals live in and then imply that a similar environment existed here. What is universally true about these fossils is that they are marine, implying that the Champlain Valley was occupied by salt water after Lake Vermont drained. This body of salt water is called the Champlain Sea and extended across low lying parts of northern New York State, Ontario, and Québec merging with the open Atlantic Ocean through the Gulf of St. Lawrence. The modern equivalents of these fossils live in cold, northern coastal settings, often where the Atlantic Ocean is significantly diluted by fresh water. The Champlain Sea must also have been a cold, less-than-fully-marine body of salt water where one could paddle to the still-calving ice front, albeit far north of Vermont by now.

In Burlington, the Champlain sea surface was at ~320 ft (97 m) above current sea level, 300 feet lower than Lake Vermont. Evidence for this comes from the huge deltas built by the Winooski and Lamoille Rivers as they flowed into the sea. The Burlington airport is built on a portion of this delta, as is St. Michaels College. The higher parts of the UVM campus and University Hospital were an island bordered by a beach facing the open sea to the west and inundated by braided streams flowing across the delta surface to the east. The Champlain Sea was a much smaller body of water than Lake Vermont and extensive areas that were once the muddy bottom of Lake Vermont were now left high and dry.

How is it that areas now as high as the Burlington airport were once at sea level? The only way to add significant volumes of water to the oceans and raise sea level is to melt the ice caps. That indeed was happening as the Laurentide Ice Sheet retreated to the north, but at the time the Champlain Sea existed there was still considerably more water tied up in the world's ice sheets than there is today. If anything, sea level should have been lower and Burlington even farther from the open ocean than it is today. The other way to change sea level is to change the elevation of the land surface relative to the sea – to make the land surface sink or rise. There is much evidence indicating that the land surface sank (lost elevation) in response to the weight of the Laurentide Ice Sheet, a process referred to as isostatic depression. The effect is similar to watching a canoe sink progressively lower in the water as it's loaded with people and supplies. As the canoe sinks, water quickly moves off to the side. The earth behaves in a similar way, only the fluid that moves is very thick and slow-moving and the Laurentide Ice sheet was a very big,

fully-laden canoe. The analogy is more appropriate if you think of throwing your canoe into a lake filled with molasses, and even more appropriate if you think of that molasses lake being cold so the molasses is particularly thick and slow-moving. Now when the canoe launched and loaded it sits high for awhile before slowly sinking as the molasses moves out of the way. And similarly, when the canoe is unloaded the boat stays depressed and only slowly rises as the molasses slowly moves back under the canoe. This last model is most appropriate for the Champlain valley after the ice sheet retreated to the north. The ice melted much faster than the fluid part of the earth's mantle could flow back allowing the land surface to remain depressed more than 100 m below its preglacial level for thousands of years after the ice left.

When the land surface did begin to rise, it did so relatively slowly. Locally, evidence for this comes from the many sand-covered, beach and river terraces (approximately level land surfaces) that the cities of Burlington and Winooski are built on. The land surface in much of this area resembles a series of stair steps. While the land surface slowly rose, large infrequent storms probably eroded these distinctive steps into receding shoreline of the Champlain Sea. The Champlain Sea ended when the land surface at what is now the northern end of Lake Champlain rose (isostatically rebounded) to sea level cutting off circulation with the Atlantic Ocean. Evidence suggests that this occurred approximately 10,000 years ago implying that within the Champlain valley the Champlain Sea lasted about 2,000 years.

It is the coincidence of the Champlain Sea, the Winooski River, and the Lamoille River that is responsible for most of the glacial materials and landforms in the Burlington area, primarily sandy terraces. Each of these rivers produced large deltas where their waters slowed when entering the sea, allowing the sand and gravel being transported by the rivers to be deposited. In addition to the sand and gravel deposited in the delta proper, huge plumes of fine sand, silt, and clay were propelled out over the denser salt water. The fine sand settled out in a broad 5–10 km wide apron around the Winooski and Lamoille River deltas. Areas between these two deltas, e.g. Colchester, were receiving sediment from both deltas. The average size of sediment deposited in the Champlain Sea gradually became finer and finer (silt and clay sized sediment vs. sand) farther and farther away from the deltas. In most places Champlain Sea "clay" is actually a mixture of mostly silt with some clay and some very fine sand.

Another dynamic aspect of these deltas is that they grew with time, extending farther and farther into the sea. If you were at the present Lake Champlain shoreline when the Champlain Sea first formed, you would have been in about 200 ft of water thick with clay and silt. Over the 2,000-year history of the sea, the Winooski river delta grew larger and larger and progressively closer. At first only the largest floods brought fine sand out that far into the sea. As the delta grew, the rain of sand would have been more and more common until sand was the only sediment deposited.. It is therefore quite common in the

Burlington area to find deeper water grey silt and clay overlain by fine sand deposited by the approaching delta. The fine sand is, in turn, overlain by coarser sand and pebble gravel deposited by newly formed streams flowing towards Lake Champlain.

As noted earlier, the end of the Champlain Sea was not marked by a catastrophic flood, but by the gradual “rebounding” of the land surface to its former, pre-glacial level. When water levels in the Champlain Sea began to lower, the Winooski and Lamoille Rivers responded by eroding channels down into the delta sediments, redepositing them farther out into the shrinking Champlain Sea. It’s important to note that the delta sediments were thick enough in most places to completely bury both bedrock and older pre-glacial river channels cut through the bedrock. Therefore, when the Winooski and Lamoille Rivers began to cut new channels, the location of these channels was controlled by both chance and the topography of the delta surface, not the underlying bedrock topography. Inevitably, the rivers’ new channels sometimes coincided with their old channels, but sometimes did not. In these areas the rivers cut new bedrock channels, a spectacular example of which is the Winooski Gorge where the 1-2 km wide Winooski River valley narrows to less than 50 m as it cuts across the Shelburne marble (Fig. 6). The river channel here is truly a canyon and proceeds across numerous rapids and waterfalls before it finally approaches lake level below the Salmon Hole. The Lamoille River similarly is following a new bedrock channel between the waterfalls in Milton at the outlet of the Arrowhead Mountain Reservoir and lake level. The implication of this history is that old Winooski and Lamoille River channels exist, but are buried out-of-sight by glacial sediments. One of these channels extends from just east of the Winooski Gorge, under the village of Colchester, and eventually enters Lake Champlain at Mallets Bay. Some water wells drilled in this old channel extend through more than 100 m of glacial materials before reaching bedrock.

### **Modern Setting**

In the 10,000 years since the Champlain Sea left the Champlain valley and Lake Champlain came into existence, the principal surficial materials deposited in the area are these same glacial materials eroded and redeposited by small and large streams, waves and currents in Lake Champlain and smaller ponds, wind, and most recently people. The broad Winooski river valley upstream of the Winooski Gorge and the Intervale were both once filled with sediments that have been eroded and transported into Lake Champlain. In other words, the flat terraces that Burlington’s New North End is built on used to extend across the Intervale to Colchester. All of that material has been removed during the last 10,000 years as the Winooski River builds a new delta into Lake Champlain. Similarly, to the north, the modern delta of the Lamoille River, visible at the Sand Bar, is testament to the erosion of materials from the entire Lamoille River drainage basin (Fig. 7).



**Figure 6:** Beginning of the Winooski Gorge looking down and east from the Lime Kiln Bridge. The flood plain of the Winooski River immediately up river is almost 1 km wide where the river occupies its old pre-glacial channel. Here the channel funnels down to a width of less than 50 m as the river cuts a new Holocene channel through the Shelburne marble.

While we know that it took 10,000 years for the surficial materials that once filled the Lamoille and Winooski River valleys to erode, one should not think that the erosion rate was constant over the last 10,000 years. There are many observations indicating that large, rare, catastrophic events (e.g. very large floods, hurricanes) are responsible for doing most of the erosion that we see and that most of the time in most places erosion rates may be relatively slow. New evidence indicates that erosion rates may have gone through cycles when erosion was relatively faster and slower during the last 10,000 years implying that the frequency of these rare catastrophic events responsible for most erosion has also been cyclical. Nevertheless, as impressive as the Intervale and broad valleys of the Winooski and Lamoille Rivers are, the rate at which material is eroded and redistributed by rivers, lakes, and wind is probably equaled or exceeded now by the rate at which people move and redistribute surficial materials, principally for construction and agriculture.



**Figure 7:** View of part of the modern Lamoille River delta looking west, showing mixture of old channels, alluvium, and swamp that constitute the delta and similar areas along both the Lamoille and Winooski Rivers. Abandoned distributary channel of the Lamoille River is in the foreground. Route 2 is built on fill used to raise the roadbed above the delta surface. Lines of trees commonly grow on levees built parallel to older distributary channels that are slightly raised above the water table.

### **Acknowledgments**

Research supported by the Vermont Geological Survey, Dept. of Environmental Conservation and the U.S. Geological Survey, National Cooperative Mapping Program, under assistance Award No. 98HQAG2068.

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.