QUATERNARY DEGLACIATION OF THE CHAMPLAIN VALLEY WITH SPECIFIC EXAMPLES FROM THE AUSABLE RIVER VALLEY

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INTRODUCTION

Deglacial events and paleoenvironments in northeastern New York were influenced by the high relief of the Adirondack Mountains and predominance of north to northeast-draining river valleys (Figure 1). Landforms and sediments within these valleys record sequences of proglacial lakes that existed between the retreating margin of the Laurentide Ice Sheet (LIS) and drainage divides farther south. In general, these proglacial lakes evolved from small headwater impoundments to lowland lakes as the LIS exposed connecting spillways, and each change in lake level caused concomitant changes in tributary stream channels as river systems adjusted to the drop in local base level. Because of the interdependence of these water bodies and the adjacent LIS margin, the chronology of these lakes forms a key record for constraining the timing and style of deglaciation of this area.

In this trip we will examine the field evidence for these lakes and consider the implications of their chronology. In particular, we will focus on the methods used to reconstruct the sequence of proglacial lakes in the Ausable River valley and the constraints that this lake chronology places on a putative interval of post-LIS alpine glaciation in the Adirondacks. These deglacial events and deposits have influenced the evolution of modern drainage patterns, and we will also consider the geomorphology of Ausable Chasm and the nearby Ausable River delta at the shoreline of Lake Champlain as they relate to late Pleistocene and Holocene landscape evolution.

Background

The principal elements of the regional deglacial chronology have been recognized since the early 20th century and are updated and summarized by Rayburn et al. (2005) and Franzi et al. (2007) (Figure 2). Glacial Lake Vermont formed in the Champlain Valley and expanded northward with the receding ice front. Simultaneous ice retreat in the St. Lawrence Valley allowed Glacial Lake Iroquois in the Ontario basin to expand along the northern flank of the Adirondack upland. Chapman (1937) recognized two levels of Lake Vermont, an earlier and higher Coveville level and a later and lower Fort Ann level. Franzi et al. (2002) suggested that the Coveville stage persisted until the ice front retreated into the northern Champlain Lowland and enabled Glacial Lake Iroquois to breakout across the St. Lawrence-Champlain drainage divide at Covey Hill

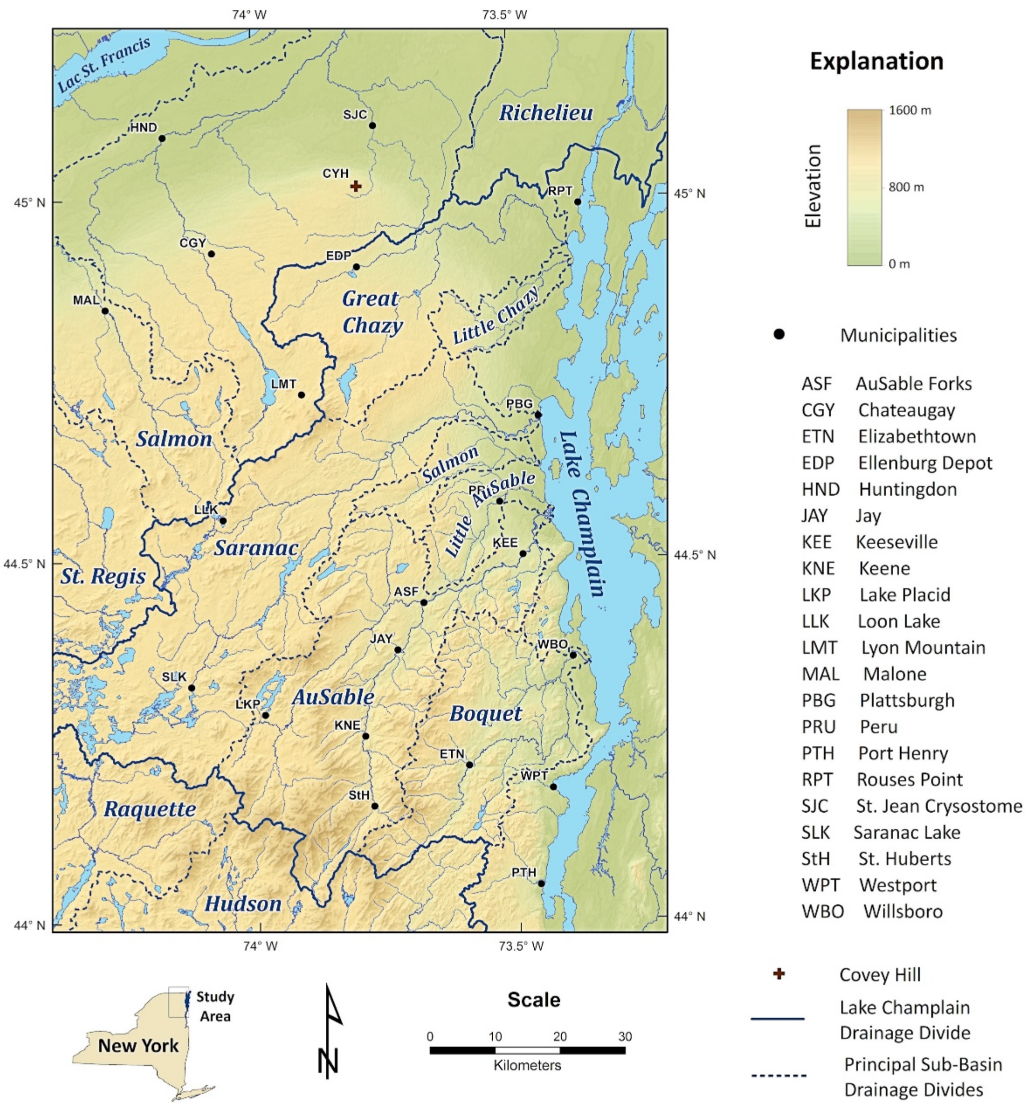

Figure 1. Principal drainage basins in the Adirondack Mountains and Champlain Valley of northeastern New York. The Lake Champlain drainage basin is delimited by a solid blue line.

(Figure 1). This catastrophic outburst released approximately 570 km^3 of water from the Ontario basin (Rayburn et al., 2005) and lowered the water surface in the St. Lawrence Valley to the Frontenac level (Pair et al., 1988). The breakout flood-wave moved south through the Champlain Valley and may have eroded the threshold at the south end of Glacial Lake Vermont, thereby causing the water level drop from the Coveville stage to the Fort Ann stage (Franzi et al. 2002). Ice margin recession from the northern flank of Covey Hill enabled a second breakout flood that released approximately 2500 km^3 of water from the Ontario basin and left proglacial lakes in the St. Lawrence and Champlain valleys fully confluent at the Fort Ann level (Rayburn et al., 2005; Franzi et al., 2007). This freshwater lake remained in the lowlands until ice recession near Quebec opened the St. Lawrence Valley and so allowed free drainage to the Gulf of St. Lawrence. Marine waters intruded into the glacio-isostatically depressed lowlands to form the Champlain Sea, which then slowly freshened over the subsequent millennia as isostatic rebound gradually raised the region to its modern elevation.

Less is known about the sequence of ice-impounded lakes in the headwaters of the Saranac, Ausable, and Boquet river basins (Figure 1). Landforms and sediments of these high-level water bodies have long been recognized (e.g. Alling, 1916, 1918, 1920; Kemp and Alling, 1925; Denny, 1974; Craft, 1976; Diemer and Franzi, 1988; Gurrieri and Musiker, 1990; Franzi, 1992; Barclay, 1993), but their relationships with each other and the retreating ice sheet margin remain poorly resolved.

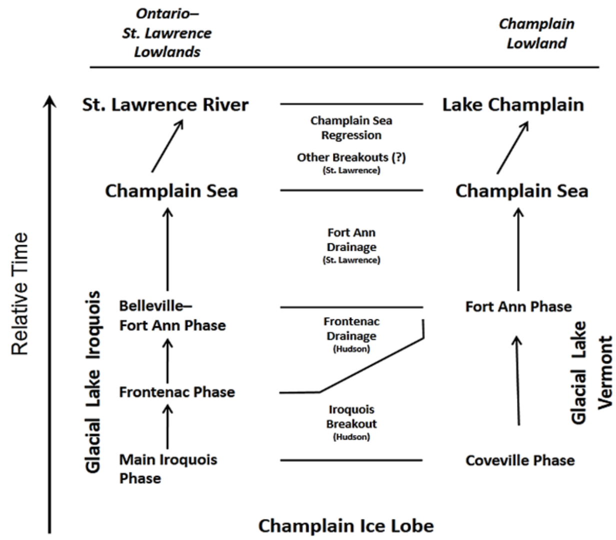

Figure 2. A generalized regional deglacial chronology for the Champlain and St. Lawrence valleys.

A related issue in these headwater valleys is whether or not alpine glaciers developed following retreat of the LIS. Ogilvie (1902), Johnson (1917), and Alling (1918, 1920) all suggested that cirque and/or valley glaciers developed in a few high valleys and deposited moraines that post-dated the regional ice sheet deglaciation. This hypothesis was extended by Craft (1969, 1976, 1979) who interpreted landforms and sediments in multiple valleys as evidence of kilometers-long valley glaciers. However, Fairchild (1913, 1932) considered the evidence for post-LIS alpine glaciers in the Adirondacks to be weak, and Barclay (1993) re-examined landforms and sediments in three valleys and found their interpretation as deposits of local alpine glaciers to be equivocal. The debate over whether or not alpine glaciers existed in the Adirondack High Peaks following LIS retreat from the region mirrors similar debates for and against post-LIS alpine glaciers in other mountain areas of the northeastern United States (e.g. Johnson, 1917; Goldthwait, 1970; Waitt and Davis, 1988; Davis, 1999).

REGIONAL DEGLACIATION

Ice-Margin and Proglacial Lake Correlations

Franzi (1992, unpublished), Franzi et al. (2002), Franzi et al. (2007) and Rayburn et al. (2007) used ice marginal landforms and glacier-profile models (e.g. Shilling and Hollin, 1981; Benn and Hulton, 2010) to map and correlate recessional ice margin positions and their associated proglacial lake phases in the Ausable, Boquet and Saranac valleys. Kranitz et al. (2014) used GIS techniques to extend this analysis into the Chazy, Chateaugay and Salmon basins and proposed correlations to the ice-margin stands of Denny (1974) (Figure 3).

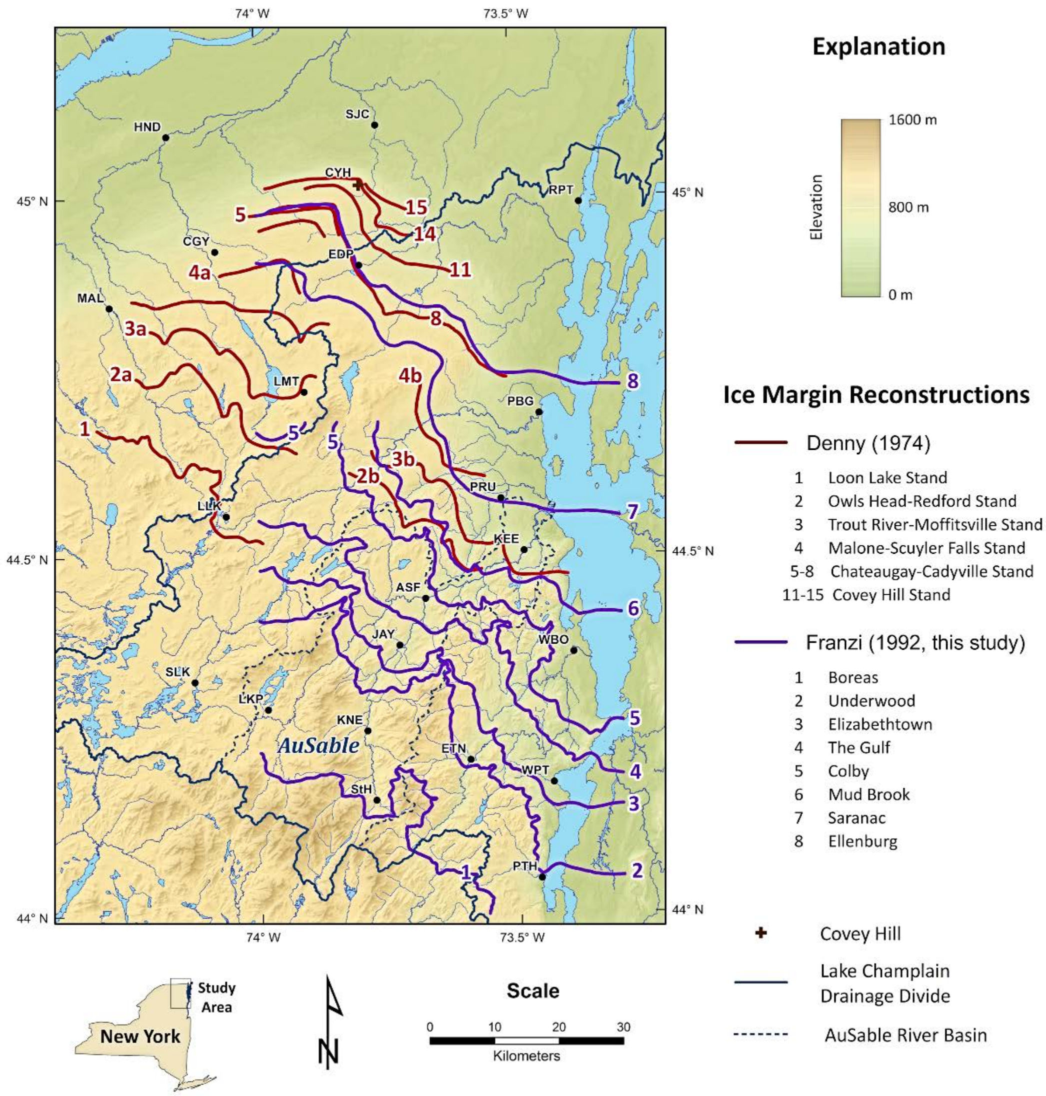

Figure 3. Late Pleistocene ice margin reconstructions from Denny (1974), Franzi (1992, unpublished). Not all of the ice margin stands of Denny (1974) are depicted. Cities and towns are keyed to the explanation in Figure 1.

Shorelines for the regional proglacial lakes Coveville, Fort Ann and Iroquois and the upper marine limit of the Champlain Sea were reconstructed by fitting a topographic trend surface to the surface elevations of shoreline deposits (compiled by Rayburn, 2004) and intersecting those surfaces with a 10-meter digital elevation model (DEM) for northeastern New York region. Adirondack lake shorelines were approximated by projecting a first-order trend surface from the lake outlet elevation at a gradient of 0.8 m/km (Denny, 1974; Franzi, 1992; Rayburn, 2004). The up-valley extent of fluvial-deltaic sandplains in major tributaries to the St. Lawrence and Champlain valleys were determined using an isostatic-rebound-corrected trend surface that projected up-valley at a gradient of 2 to 4 m/km (Boothroyd and Ashley, 1975).

GIS software facilitates regional correlation of glacial deposits and landforms by allowing the user to work easily at different scales and apply simple models to plot shorelines, inwash/outwash and glacier surface profiles. In several instances, the use of ice-surface profile models led to reinterpretation of previously correlated ice-marginal deposits. These techniques generally produce realistic correlations, especially when used in combination with field evidence to correlate well-developed ice-marginal deposits and landforms in adjacent valleys.

Regional Deglacial Chronology

The results correspond well with interpretations presented in previous investigations in the region or provide reasonable alternative explanations. The regional deglacial chronology is summarized in the examples of ice margin and proglacial lake reconstructions presented in Figure 4A-E.

Loon Lake–Elizabethtown (Figure 4A): This ice margin combines the Loon Lake stand of Denny (1974) in the upper Saranac River basin and the Elizabethtown ice margin (Franzi, unpublished; Franzi et al., 2007; Rayburn et al., 2007) in the Ausable, Boquet and Champlain valleys (Figures 3 and 4A). Meltwater outflow in the upper Saranac River basin deposited thick bodies of outwash and drained to the west through the St. Regis River basin (Denny, 1974). Lakes Chapel, Elizabethtown and Hoisington fronted the ice margin in the Ausable and Boquet river basins. These proglacial lakes drained eastward to Lake Coveville (Coveville stage of Lake Vermont) in the Champlain Valley. The ice margin is dated by a musk-ox bone found in prodeltaic mud in Lake Hoisington that yielded a corrected AMS age of 11,280 ± 110 yr. B.P. (AA-4935), which corresponds to 13,438–13,020 calibrated years B.P. (Rayburn et al., 2007).

Malone–Keeseville (Figure 4B): The Malone–Keeseville ice margin roughly follows the Malone–Schuyler Falls stand of Denny (1974) in the St. Lawrence drainage basins between Malone and Lake Chazy and follows ice margin 6 of Franzi (unpublished) in the Saranac, Salmon and Ausable river basins (Figure 3). This interpretation was guided by projecting ice-marginal deposits in the Saranac River valley near Moffitsville into the Chazy Lake valley using the PROFILER ice-surface model (Benn and Houlton, 2010) and if correct means that Malone–Schuyler Falls ice margins 4a and 4b (Figure 3) do not correlate as Denny (1974) suggested.

Ellenburg–Plattsburgh (Figure 4C): This ice margin corresponds with the ice margins 5 and 8 of the Chateaugay–Cadyville stands of Denny (1974) and ice margin 8 of Franzi (unpublished) (Figure 3). Lake Iroquois occupies the St. Lawrence Valley and a smaller proglacial lake occupies the upper North Branch of the Great Chazy River basin at the Ellenburg Moraine. This reconstruction depicts Lake Coveville near its maximum extent in the Champlain Valley. Further ice recession allowed Lake Iroquois to break-out eastward across the St. Lawrence–Champlain drainage divide near Covey Hill, which triggered the transition from the Coveville to the Fort Ann level of glacial Lake Vermont.

Lake Fort Ann (Figure 4D): Lake Fort Ann is depicted at the lower Fort Ann level (Chapman, 1937), at which time the lake had a stable outlet across the Hudson–Champlain drainage divide near Fort Ann.

Champlain Sea (Figure 4E): The Champlain Sea is depicted near the upper marine limit, which occurred shortly after the drainage of Lake Fort Ann.

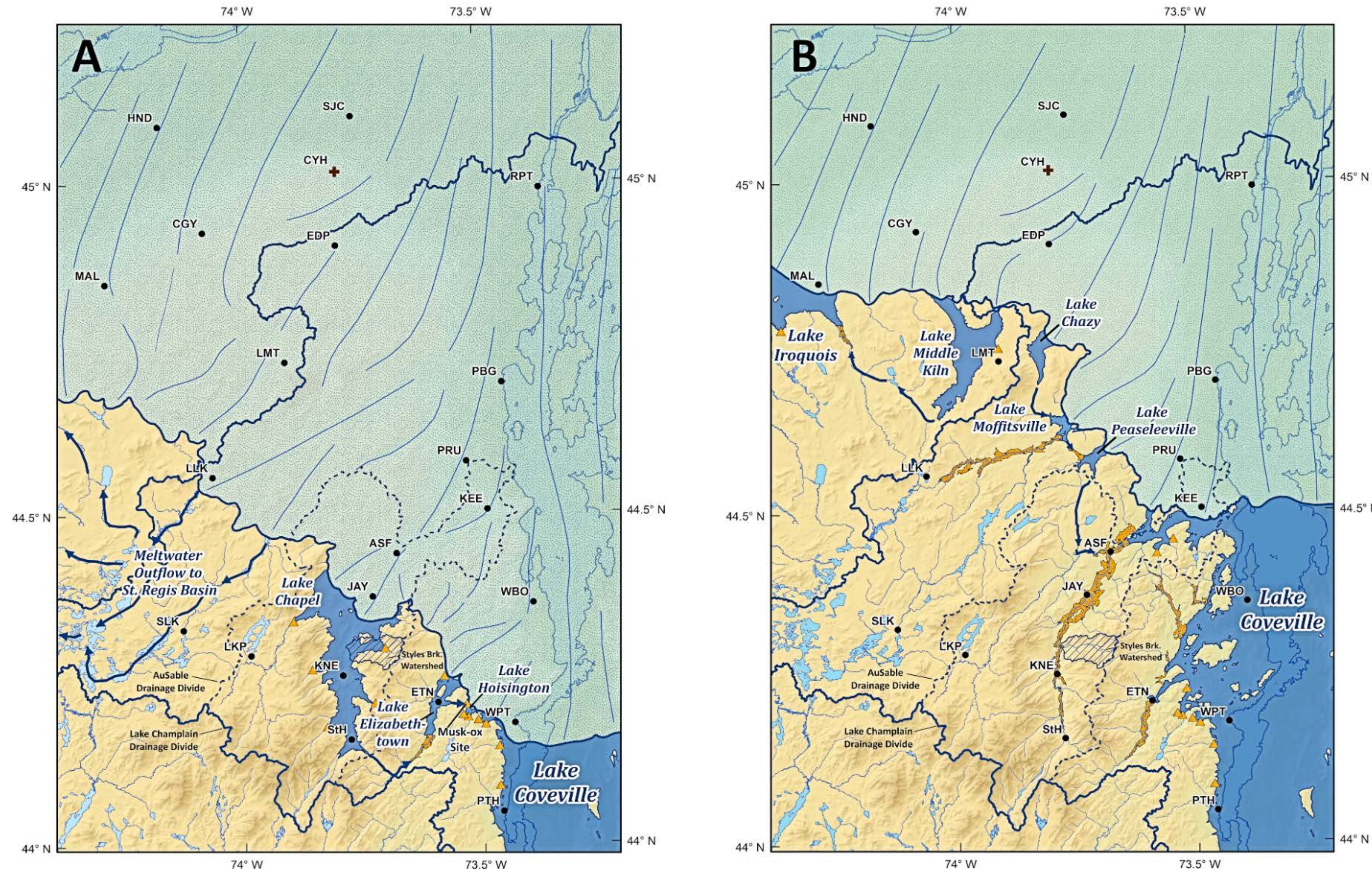

Figure 4. The Loon Lake–Elizabethtown (4A) and Malone–Keeseville (4B) ice margins in the northeastern Adirondack uplands and western Champlain Valley.

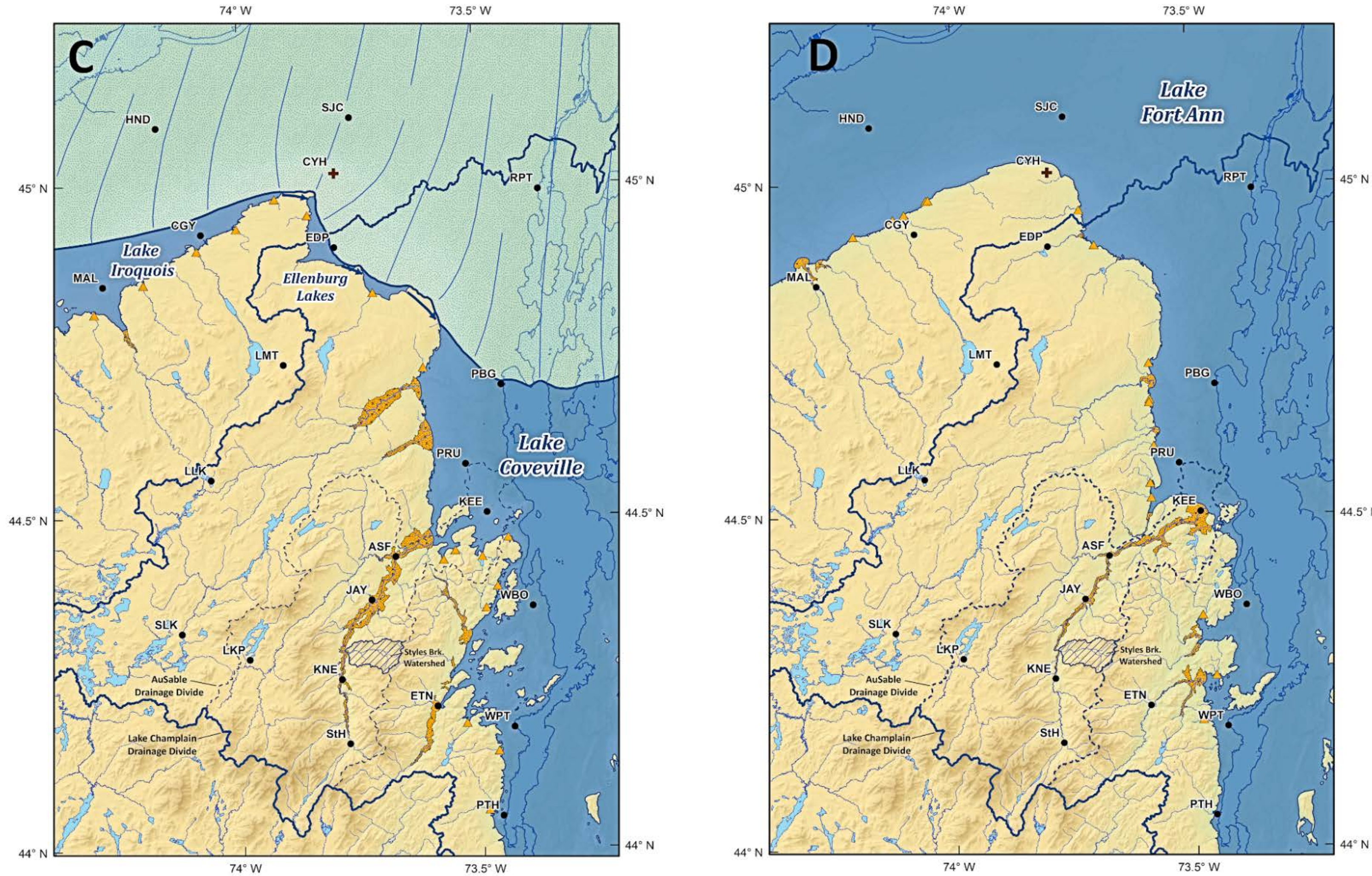

Figure 4 (continued). The Ellenburg–Plattsburgh (4C) ice margin and the lower Fort Ann Phase of proglacial Lake Vermont (4D) in the Champlain and St. Lawrence valleys.

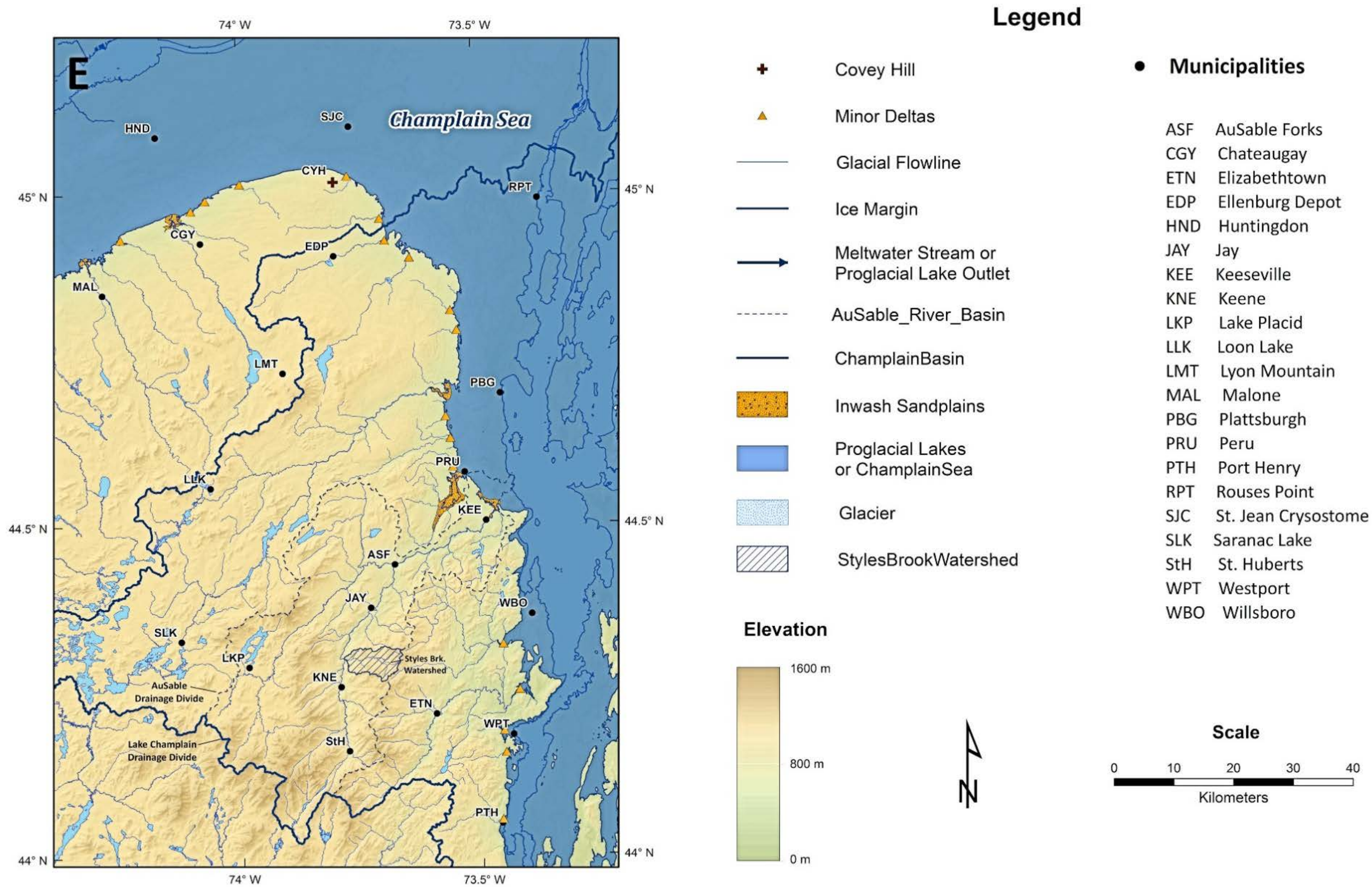

Figure 4 (continued). The Champlain Sea (4E) near the upper-marine limit in the Champlain and St. Lawrence valleys.

Deglaciation in the Ausable Valley

The Ausable River has two principal tributaries, the East and West branches, which originate in the High Peaks south of Lake Placid and Keene Valley (Figure 5). The West Branch Ausable River flows northward from the mountains surrounding South Meadow into the Lake Placid Basin. The river then flows northeastward through Wilmington Notch, where the valley floor drops more than 200 meters in elevation, to its confluence with the East Branch at Au Sable Forks. The East Branch Ausable River is fed by the Ausable Lakes, south of St. Huberts, and flows northward through Keene Valley. Below Au Sable Forks the Ausable River flows northeastward through a broad, gently sloping valley to Keeseville where the river descends approximately 100 meters through Ausable Chasm to its current delta on Lake Champlain.

Deglaciation in the Ausable Valley occurred by the generally synchronous northward recession of active continental ice lobes that blocked local surface drainage and created deep proglacial lakes. These lakes expanded northward with ice recession and drained to lower levels, often by sudden breakout, as lower outlets on the Ausable–Boquet drainage divide were uncovered. The first deglacial chronology for the region was developed by H.L. Alling nearly a century ago (Alling, 1916, 1918, 1920; Kemp and Alling, 1925), although many of the lake stages originally proposed have been abandoned in the light of more recent data or were renamed to reflect the location of their presumed outlets (e.g. Diemer and Franzi, 1988; Franzi, 1992).

Franzi (1992) recognized six proglacial lake stages in the East Branch valley (Figure 6), although this remains a conservative estimate and will likely change as studies in the region continue. The sequence begins with proglacial Lake Boreas in the Ausable Lakes valley south of St. Huberts (Figures 5 and 6), which drained southward across a 615-meter a.s.l. (above sea level) bedrock threshold immediately north of Boreas Pond into the upper Hudson basin (Deimer and Franzi, 1988). Lake Boreas was probably coeval with the proglacial lakes described by Gurrieri and Musiker (1990) near South Meadow in the West Branch Valley. Subsequent lake stages, respectively controlled by cols near Chapel Pond, South Gulf, The Gulf, Colby Mt. and Mud Brook/Trout Pond, occupied portions of both the East Branch and West Branch valleys and drained eastward into the Boquet drainage basin.

The Spruce Hill col (515 meters a.s.l., Figure 5), lies just above the maximum projected shoreline elevation for Lake Chapel, and thus, is not considered to represent an intermediate lake stage between lakes Chapel and South Gulf. Possible westward drainage of proglacial Lake Chapel into the upper West Branch Valley via Wilmington Notch (Alling, 1916; 1918, 1920) is considered unlikely (Diemer and Franzi, 1988). A series of meltwater channels and plunge basins, the latter now occupied by small ponds, on the south side of Wilmington Notch originate above the projected level of Lake Chapel and may record an earlier episode of ice marginal meltwater drainage.

Proglacial lake drainage in the South Meadows area was generally westward (Alling, 1916, 1918, 1920; Gurrieri and Musiker, 1990). However, at least one episode of eastward drainage into Lake Chapel may have occurred via Cascade Lakes col, morphology of which is consistent with that of known outlet channels in the region. This valley originates at a bedrock threshold at 665 meters a.s.l. on the divide between the East and West Branch of the Ausable River, which is nearly the same as the elevation of the Heart Lake threshold which Gurrieri and Musiker (1990) proposed as an outlet for an early South Meadows lake. A deltaic plain immediately south of Owls Head, southwest of Keene (Figure 5), may record outflow from the Cascade Lakes valley when ice in the Keene Valley lay on the north flank of Owls Head. The possible eastward drainage of proglacial lakes in the South Meadows area to the Keene Valley requires simultaneous retreat of continental ice lobes in the East Branch and West Branch valleys.

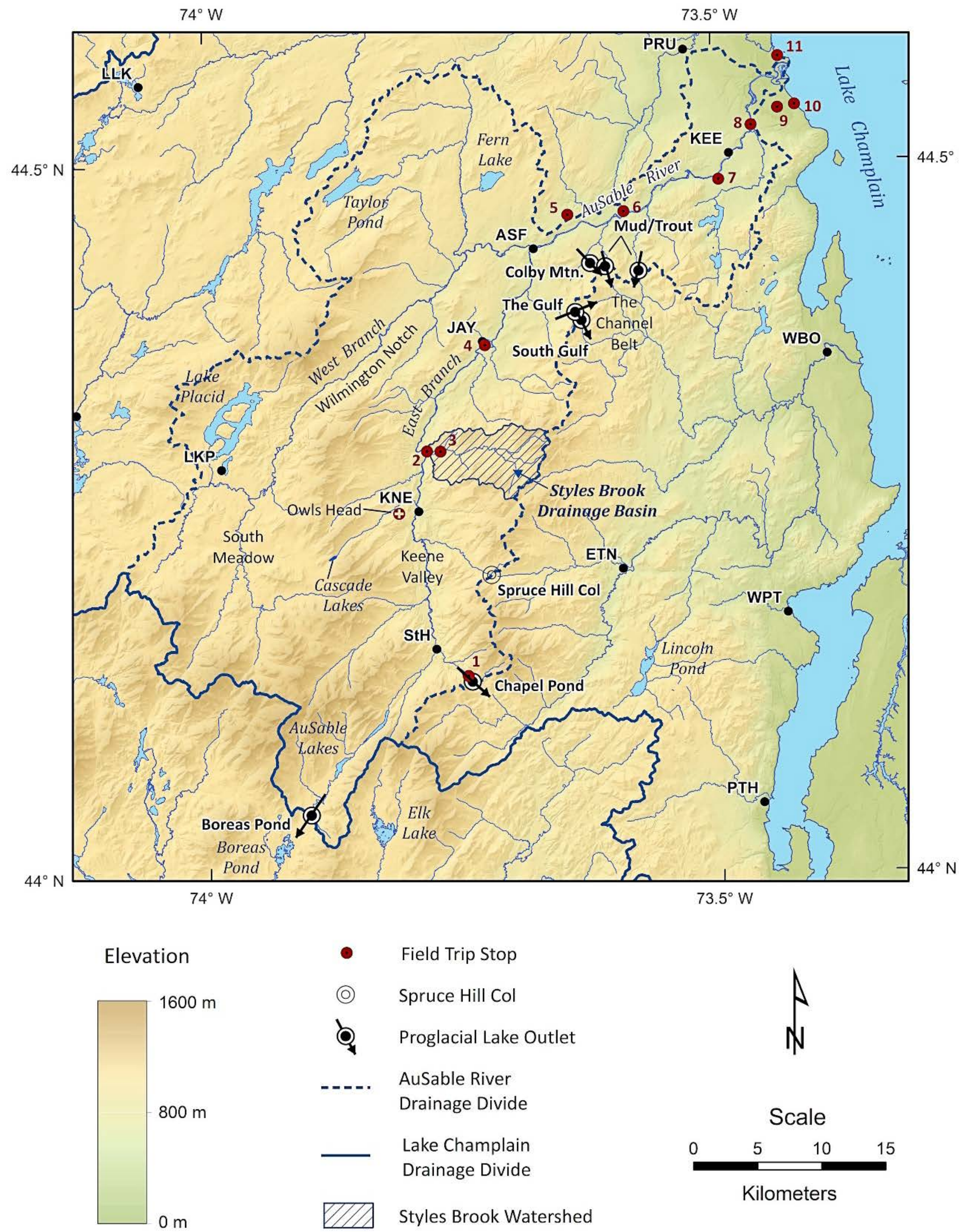

Figure 5. Map of the Ausable River drainage basin, showing the locations of inferred proglacial lake outlets (Franzi, 1992), geographic features and the Styles Brook drainage basin. Cities and towns are keyed to the explanation in Figure 1.

STYLES BROOK VALLEY

Setting and Tropical Storm Irene

Styles Brook is located about 5 km north of Keene and is a major east-bank tributary of the East Branch Ausable River (Figure 5). The basin drains westwards from peaks around 800-1100 meters a.s.l. (Figure 7), which are substantially lower than the highest peaks of the Adirondacks (up to 1629 m) to the south of Keene and Lake Placid. The study area is located along ~2 km of the lower valley where Styles Brook has incised a 20-50 m-deep V-shaped valley during the Holocene into the Pleistocene-age valley fill deposits (Figures 7 and 8). Bedrock is exposed at the downstream end of the study reach and forms a local base level for Holocene fluvial processes in the lower valley.

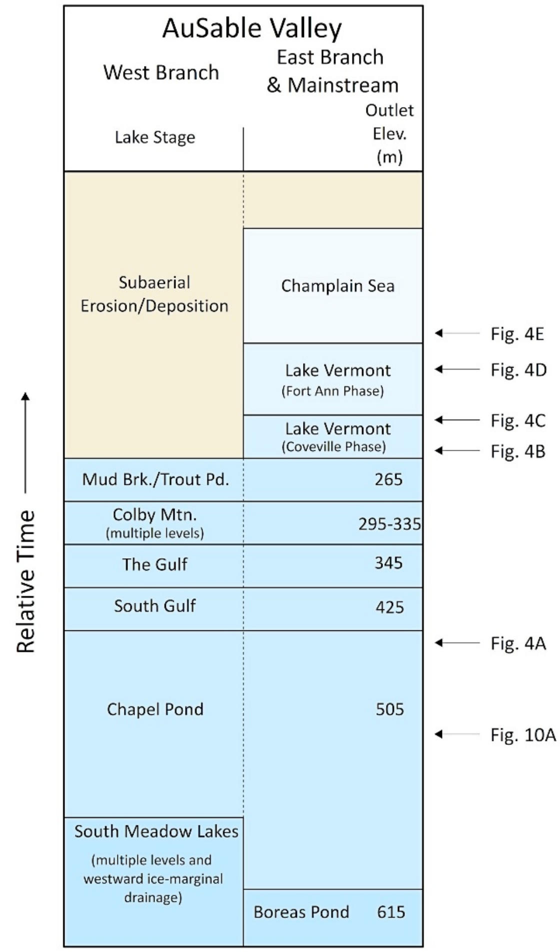

Figure 6. Proglacial lake sequences and outlet elevations in the Ausable Valley (from Franzi, 1992). The approximate time slices for the regional deglacial chronology in figures 4 and 10 are shown to the right of the figure.

This area experienced severe flooding during Tropical Storm Irene in 2011. A total of 161 mm of rainfall was recorded near Jay (Figure 5) in a 17-hour period (E. Romanowicz, unpublished data), although anecdotal evidence from local residents who operated manual rain gauges during the event suggests that total precipitation at Styles Brook may have been considerably higher. The U.S. Geological Survey gauge on the East Branch Ausable River at Au Sable Forks recorded a peak stage of 5.64 m, which was 3.51 m above flood stage and 1.01 m above the previous record stage. Debris strand lines and tree scars indicate that lower Styles Brook rose almost 4 m above its low flow level. This extreme flow washed-out NY Route 9N at the mouth of the basin and caused extensive scouring of the streambed and adjacent bluffs in the study reach.

Fieldwork was done in the study reach in September and October 2011. *In situ* Pleistocene-age sediments were documented along ~2 km of the lower valley where the recent erosion had created exceptionally fresh exposures of the lower bluffs along the bottom of the stream-incised V-shaped valley.

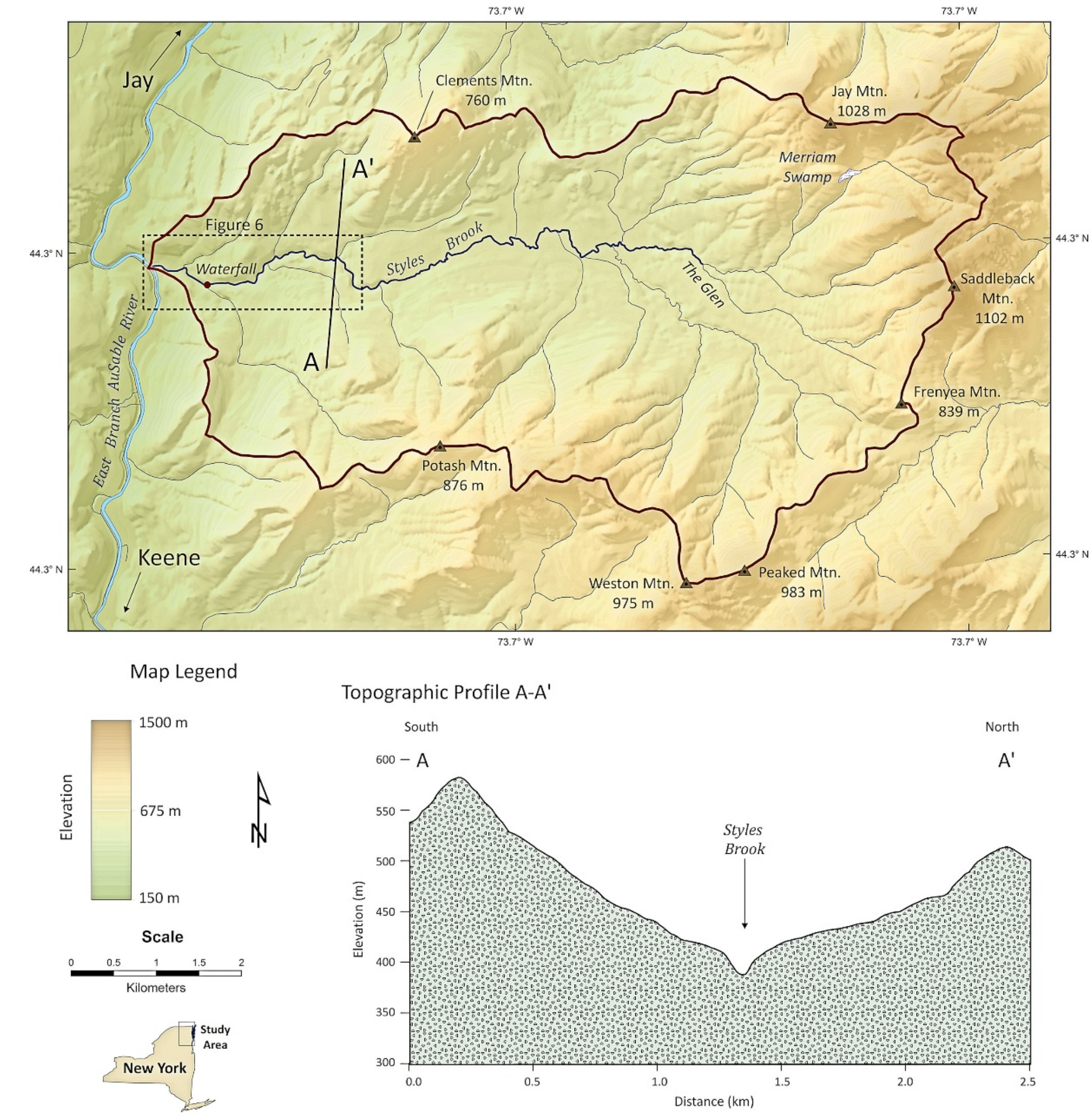

Figure 7. Map of the Styles Brook drainage basin showing the extent of the study area in Figure 8 and a cross sectional topographic profile along line A-A'. Profile has 4 x vertical exaggeration.

Pleistocene Deposits and Ice Margin Reconstruction

Sediments exposed in the study reach included matrix-supported massive diamictons, matrix-supported stratified diamictons, clast-supported diamictons, boulder beds, cobble beds, granule to sandy gravels, ripple cross-bedded and laminated sands and silts, and dropstone-bearing rhythmically bedded sandy silts and clays (Figure 9). Beds were discontinuous along outcrop

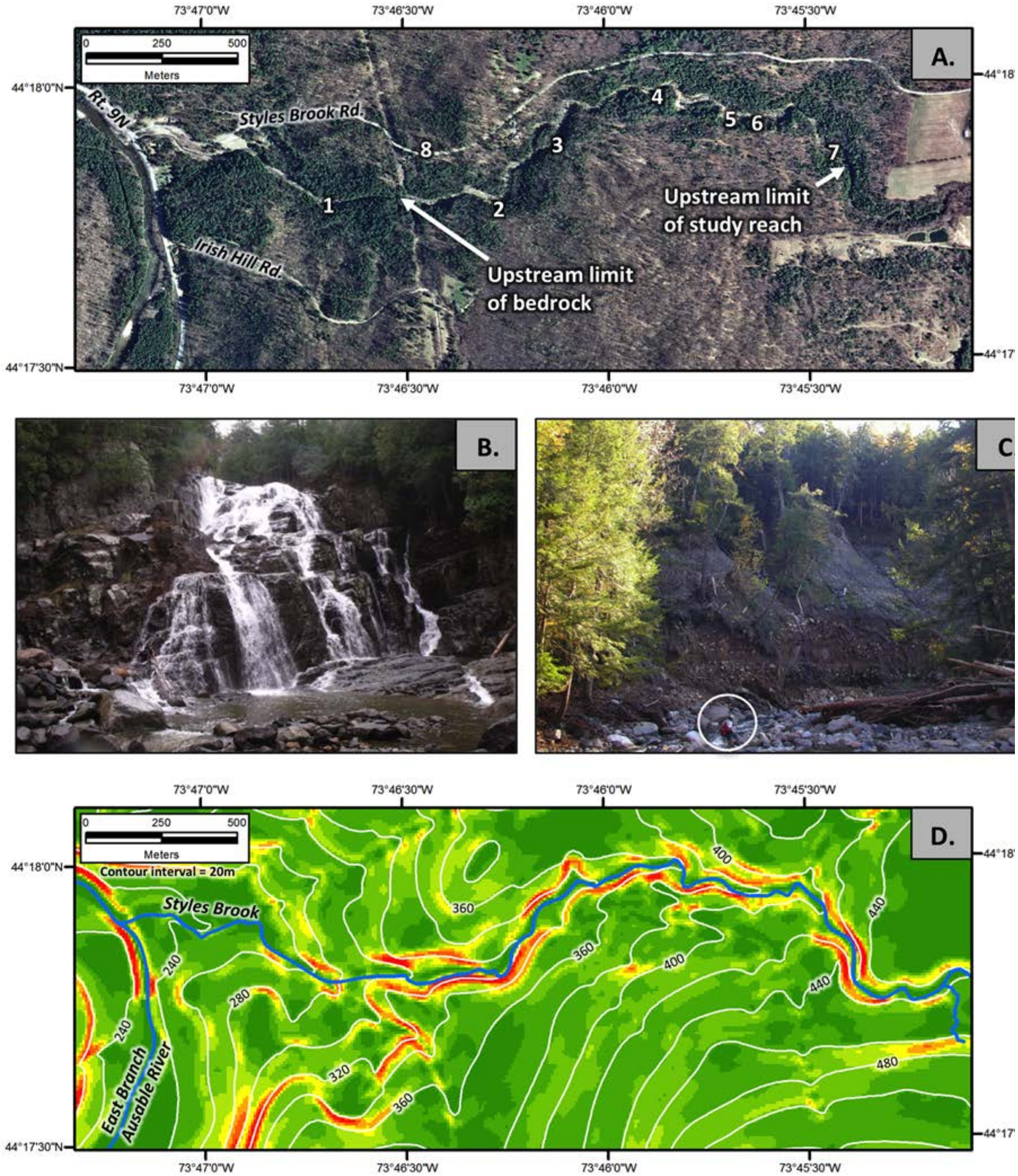

Figure 8. Study area along lower Styles Brook. A) 2013 orthophotograph with site numbers. B) Site 1, waterfall on bedrock. C) Site 2, ~40 m bluff of Pleistocene-age sediments, figure in middle-ground for scale. D) Slope map derived from 10-meter digital elevation model with steepest slopes (35-55°) in red, these steepest slopes adjacent to the channel are the bluffs of Pleistocene-age sediment.

Figure 9. Pleistocene sediments in Styles Brook valley. A) Site 3, laminated silts and sands (Fl) draped over topography of underlying clast-supported boulder bed (Bcm). B) Site 4, clast-supported boulder bed (Bcm) overlain by multiple bedded diamictons (Dms). C) Site 5, deformed clay, silt, and fine sand. D) Site 6, interbedded diamictons (Dms) with 21° dip towards SW. E) Site 6, laminated silts and sands (Fl) overlain by clast-supported boulder bed (Bcm), laminated silts and sands (Fl), and clast-supported diamicton (Dcm). F) Site 6, granule gravel (GRmc) overlain by thinly bedded sands (Sl) and silts (Fl). G) Site 7, silt and clay rhythmites with dropstones.

and generally could be traced laterally for only a few tens of meters. The vertical arrangement of beds was highly variable with fine-grained deposits often interbedded with coarser units (Figure 9E) or draped over the topography of underlying units (Figure 9A). Some fine-grained units were deformed (Figure 9C) and many beds throughout the area showed a dip towards the southwest (Figure 9D). In places, interbedded silts and clays were pervasively sheared and had slickensides at the contact with underlying beds.

We interpret the sediments at sites 2 to 7 (Figure 8A) to have been deposited in a proglacial lake. Finer grained units indicate periods of quiet deposition from the water column while cobble beds and diamictons represent episodic grain flows and subaqueous mass flows along the lake bottom. The deformation of finer units show dewatering and syndepositional movement, and in places this movement was directed towards the southwest down an inferred paleoslope of the lake floor. While some sediment could have originated from an ice-margin to the west or from the headwaters and side slopes of the valley to the east, another source may have been from the low-point on the drainage divide immediately west of Clements Mountain (Figure 7). This saddle on the divide is at the apex of a fan-shaped landform that extends south into the study reach and we infer that the LIS margin stood against the north slope of Clements Mountain and delivered sediment southwards through the saddle while the units at sites 2 to 7 were deposited.

A reconstruction of the LIS margin at the Clements Mountain position is shown in Figure 10. At this time the East Branch Ausable Valley was occupied by proglacial Lake Chapel, which drained southward through the Chapel Pond spillway (505 m) into proglacial Lake Underwood in the Boquet Valley. Clements Mountain was an island in Lake Chapel, which was about 300 meters deep at this time in the area near the modern mouth of Styles Brook valley. This water depth is similar to water depths in front of large lacustrine-calving glaciers in southern Alaska today (e.g. Yakutat Glacier, Trüssel et al., 2013), and so it is likely that the LIS margin in Lake Chapel was similarly calving large tabular icebergs at this time. Clements Mountain and the adjacent ridgeline would have formed a natural pinning point in Lake Chapel for the calving LIS margin, and so it is reasonable to infer that the retreating margin paused at this location during the regional recession.

As the LIS margin subsequently continued to retreat northwards, it uncovered successively lower spillways at South Gulf (425 m) and then The Gulf (345 m). As each spillway opened the lake level in the East Branch Ausable Valley would have dropped in elevation and then stabilized, and lake-marginal streams would have incised through their previous deposits to build new deltas and alluvial plains graded to each new, lower water surface. At Styles Brook the delta for Lake The Gulf is at site 8 (Figure 8A) and has a surface elevation of 346 m. Franzi et al. (2007) suggest retreat rates of about 190 to 440 m/yr for the LIS ice margin in the Champlain Valley during this time; application of these rates to the East Branch Ausable valley gives 45 to 110 years for the ice margin to retreat from the Clements Mountain position to opening of The Gulf spillway (Figure 5).

Implications for a Post-LIS Valley Glacier

Styles Brook is important because it is one of the locations where Craft (1976, 1979) suggested that a local valley glacier formed following retreat of the LIS. Roadwork in 1966 created exposures up to ~10 m high along ~220 m of Styles Brook Road near the junction with Route 9N, and Craft (1976, 1979) interpreted one unit therein as a till. Because this unit was not found on the west side of the East Branch Ausable River, he inferred that the till had been deposited by a

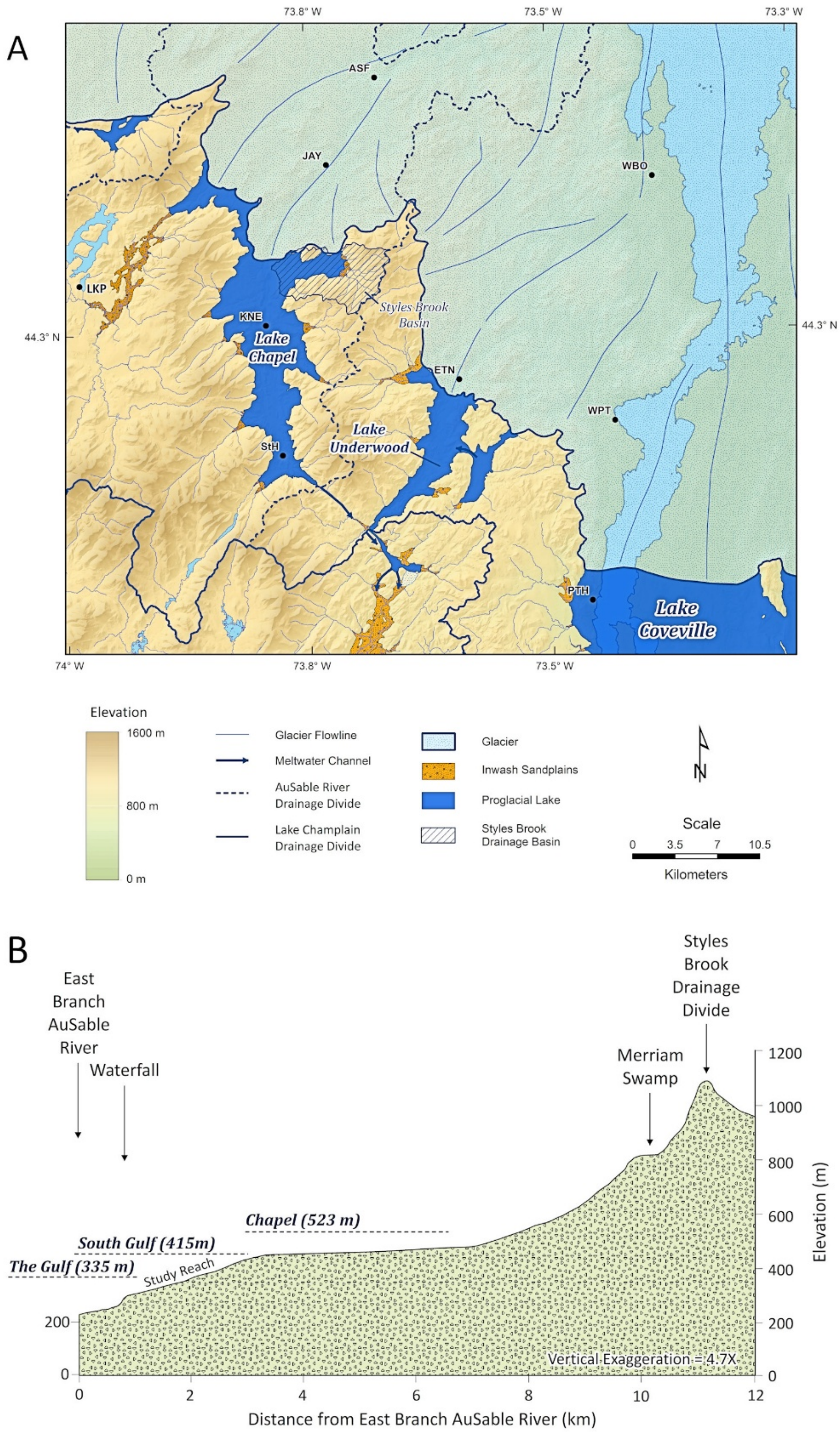

Figure 10. Proglacial lakes at Styles Brook Valley. A) Ice margin reconstruction, Clements Mountain on the north side of Styles Brook Valley is the large island at the ice margin in Glacial Lake Chapel. B) Longitudinal profile of modern Styles Brook valley with projected water levels for lakes in East Branch Ausable River valley.

local valley glacier that extended about 11 km from Jay Mountain and other peaks at the east end of Styles Brook valley (Figure 7).

It is difficult to reconcile this interpretation with our findings. We found proglacial lake deposits in the lowest areas of Styles Brook valley (sites 2 to 7) and these appear to be a conformable sequence up to a proglacial lake delta at the modern land surface (site 8). While arguably there could be a till somewhere within the sediment sequence that we did not observe, the deglacial chronology leaves only decades to perhaps a century for deposition of the proglacial lake sediments and landforms, which is too little time for an 11-km-long valley glacier to form, advance, and retreat in this area. The extant delta at the modern land surface precludes advance of a local valley glacier after drainage of the last proglacial lake. The simplest interpretation is that the sediments and landforms in lower Styles Brook Valley were all deposited close to the LIS margin and in multiple stages of a proglacial lake as the LIS margin retreated, and that no local valley glacier advanced over this site following LIS deglaciation. This conclusion is consistent with the findings of Ackerly (1989), who modeled the putative valley glacier at Styles Brook and found it to be implausible because the ice surface profile projected over the mountains at the head of the valley.

AUSABLE RIVER DELTAS NEAR KEESEVILLE

Evolution of the Champlain Sea Deltas

The principal elements of the following discussion are derived from Denny (1974) who wrote a detailed account of the evolution of the Ausable River delta from the time of the Champlain Sea to its avulsion into its present course.

The Ausable delta at the upper marine limit lies at an elevation of about 107–110 meters a.s.l. and formed a linear delta complex with smaller streams to the northwest (Figure 11A). The Ausable River's upper marine delta lies on top of the Cambrian Potsdam Formation at Ausable Chasm (Field Trip Stop 8), and thus, its construction must predate the cutting of the gorge. Forced regression caused by postglacial isostatic rebound led to incision of the deltaic deposits and underlying bedrock and successive regrading of the delta complex to falling baselevel. The pattern of regrading was interrupted by the exhumation of a bedrock sill (Point A on Figure 11A, see also Figure 28 in Denny (1974)), which inhibited further downcutting and led to the development of a broad floodplain and an elongated meander bend on the Ausable River between the sill and the emerging Ausable Chasm. Incision continued in response to falling baselevel below the sill and the Wickham Marsh basin began to form by vertical and lateral erosion of the deltaic sediments by the Ausable River and its lowermost tributaries. At some point in the process isostatic uplift raised a bedrock sill at St. Jean sur Richelieu in southern Quebec above sea level and the water body in the Champlain Valley transitioned from the saline Champlain Sea to modern freshwater Lake Champlain.

The Ausable River established its present course by channel avulsion near Point B on Figure 11A. Most likely, the avulsion was by a combination of cutbank erosion on the meander near Point A and headward erosion, perhaps enhanced by spring sapping, of gullies in the Dry Mill Valley (Figure 11A). Eventually the low divide composed of older deltaic sediment between the meander bend and Dry Mill valley near Point A was breached, the Ausable River rapidly established its present course and the channel above Wickham Marsh was abandoned (Figure 11B).

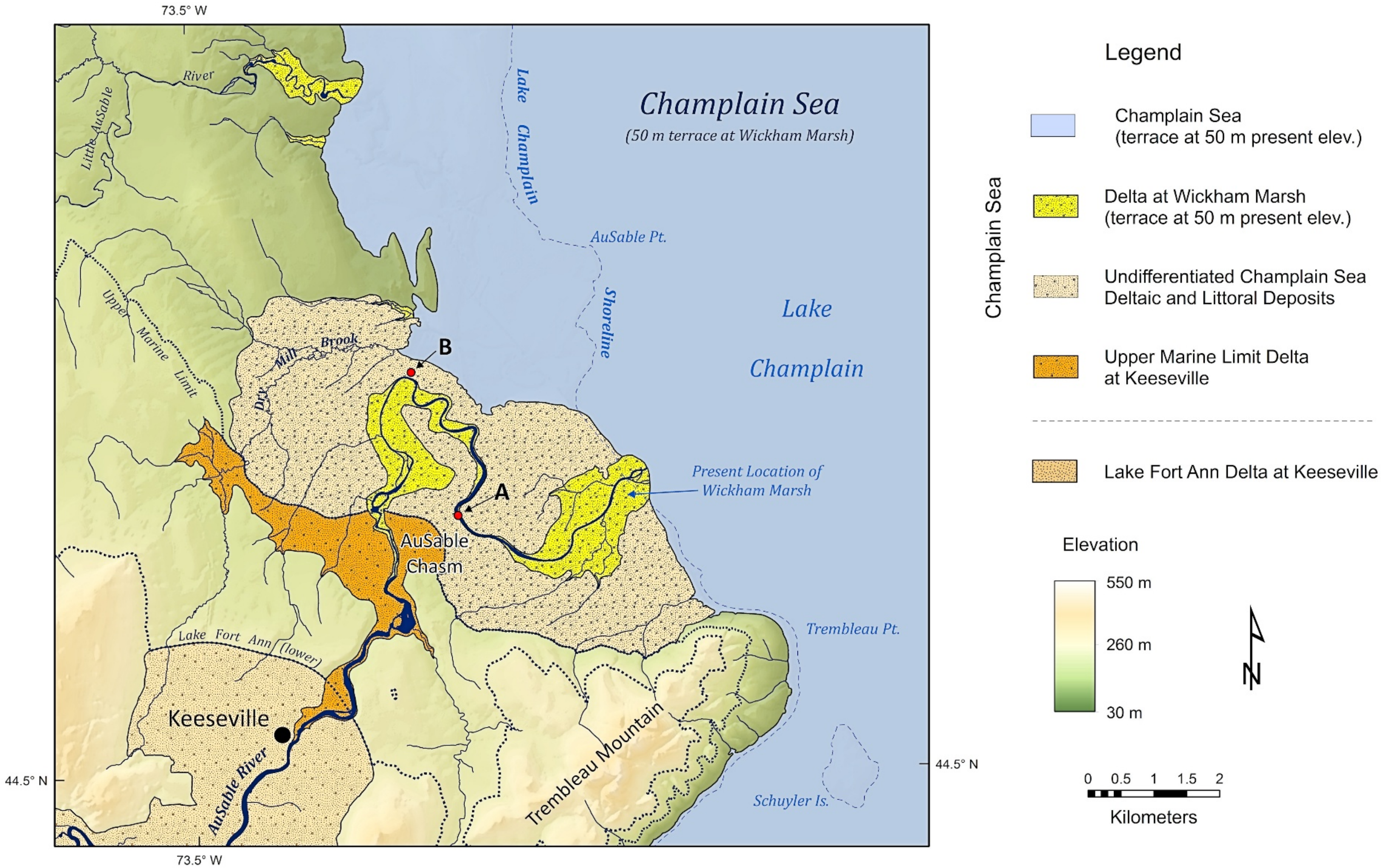

Figure 11A. Map of the Lake Fort Ann and Champlain Sea delta complex at the mouth of the Ausable River near Keeseville (after Denny, 1974). The marine shoreline is drawn at the margin of a deltaic terrace at a present elevation of 50 meters a.s.l. Points A and B are explained in the text.

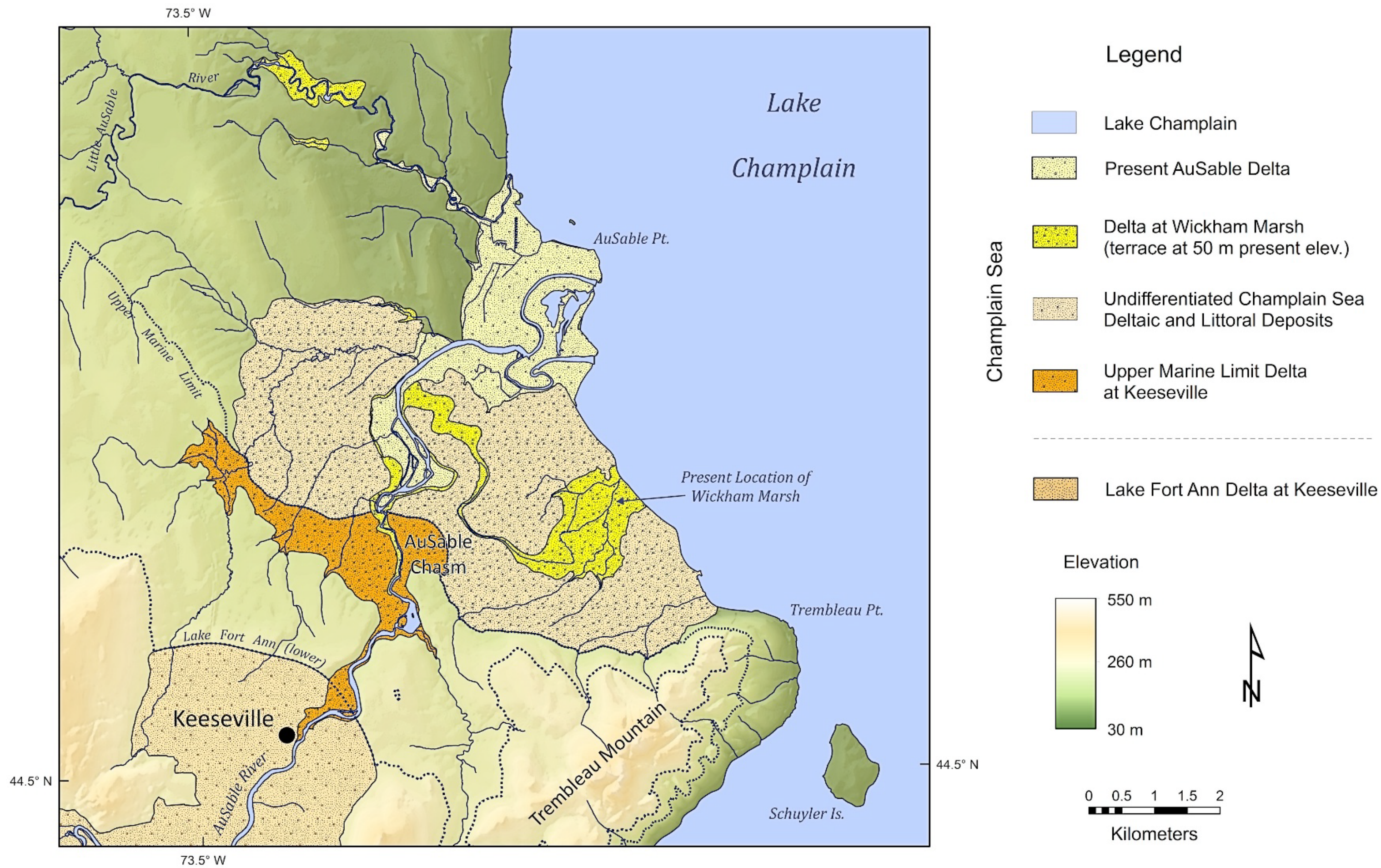

Figure 11B. Map of the modern shoreline of Lake Champlain showing the Lake Fort Ann and Champlain Sea delta complex at the mouth of the Ausable River near Keeseville (after Denny, 1974).

FIELD GUIDE AND ROAD LOG

Meeting Point: Comfort Inn and Suites, 411 West Cornelia Street (NY Route 3).

Alternate Meeting Point: Intersection of US Route 9 and NY Route 73 in New Russia, NY (west of Exit 30 on Interstate 87). Please inform the field trip leaders if you plan to meet the group at this location.

Meeting Point Coordinates: 44.696° N, 73.488° W

Alternative Meeting Point Coordinates: 44.106° N, 73.694° W

Meeting Time: 8:00 AM (approximately 8:45 AM at the alternative meeting point in New Russia)

Distance in miles (km)		
Cumu-lative	Point to Point	Route Description
0.0 (0.0)	0.0 (0.0)	Assemble in the northeastern parking lot of the Comfort Inn and Suites. Leave parking lot, turn left at the entrance and proceed toward Cornelia Street (NY Route 3). Turn left onto Cornelia Street and proceed west for 0.4 miles to the I-87 on-ramp.
0.4 (0.6)	0.4 (0.6)	Intersection I-87 (Northway) and West Cornelia Street; Turn left onto the entrance ramp and follow the signs to I-87 South. Proceed southward on I-87 to Exit 30 in North Hudson, NY (48.5 miles).
48.9 (78.7)	48.5 (78.0)	Intersection I-87 and US 9. Turn right on US Route 9 and proceed west about 2.2 mi (3.5 km) to the intersection with NY Route 73.
51.1 (82.2)	2.2 (3.5)	Intersection of US 9 and NY 73. Bear left onto NY Route 73 and proceed west for approximately 0.2 mi (0.3 km) to arrive at the alternate meeting point, located at a turn-off on the south side of the road.
51.3 (82.5)	0.2 (0.3)	Alternate Meeting Point. Continue west on NY 73 after the group assembles at this stop.
54.9 (88.3)	3.6 (5.8)	Turn left into the Chapel Pond parking area on the south side of NY 73. Stop 1: Chapel Pond.

STOP 1: Chapel Pond, Keene Valley, NY

Location Coordinates: (44.141° N, 73.747° W)

Chapel Pond Pass (elev. 505 meters a.s.l.) served as the outlet for proglacial Lake Chapel. We shall use this scenic spot to present a brief summary of the field trip, regional geography and deglacial lake chronology of the Ausable Valley.

Distance in miles (km)		
Cumu-lative	Point to Point	Route Description
54.9 (88.3)		Return to the vehicles and continue west on NY 73 through the villages of St. Huberts and Keene Valley.
62.2 (100.1)	7.3 (11.7)	Intersection with NY 9N. Continue north on NY 73 and 9N to Keene. The road leading to Norton Cemetery on the right is underlain by reddish brown varved clay that was deposited in proglacial lakes in the East Branch valley.
64.2 (103.3)	2.0 (3.2)	NY Routes 73 and 9N separate in the village of Keene. Follow NY 9N north to Styles Brook.
67.2 (108.1)	3.0 (4.8)	Intersection of NY 9N and Styles Brook Road. Turn right onto Styles Brook Road and proceed east to Stop 2.
67.3 (108.3)	0.1 (0.2)	Stop 2: Styles Brook Mouth, Jay, NY

STOP 2: Styles Brook Mouth, Jay, NY

Location Coordinates: (44.299 ^{o} N, 73.785 ^{o} W)

We shall stop briefly near the mouth of Styles Brook to discuss Tropical Storm Irene, the damaged it caused, the restoration efforts and natural recovery of the fluvial system. We may also use this opportunity to consolidate vehicles to reduce parking congestion at the next stop.

Distance in miles (km)		
Cumu-lative	Point to Point	Route Description
67.3 (108.3)		Return to the vehicles and continue east on Styles Brook Road for 0.8 mi (1.3 km). Park well off the road for Stop 3.
68.1 (109.6)	0.8 (1.3)	Stop 3: Styles Brook Valley bottom.

STOP 3: Styles Brook Valley Bottom, Jay, NY

Location Coordinates: (44.299 ^{o} N, 73.771 ^{o} W)

We will access the Styles Brook study area via a trail that crosses private property. Time constraints prevent us from viewing the entire study reach but the flood damage and late Pleistocene sediment exposures at this location are typical.

Distance in miles (km) Cumu-lative	Point to Point	Route Description
68.1 (109.6)		Return to the vehicles and return west to NY 9N, approximately 0.9 mi (1.4 km).
69.0 (111.0)	0.9 (1.4)	Intersection of Styles Brook Road and NY 9N. Turn right on NY 9N and travel north for 6.7 mi (10.8 km) to the village of Jay. The town is built on a stream terrace that is graded to the lower Lake Fort Ann delta at Keeseville.
75.7 (121.8)	6.7 (10.8)	Intersection of NY 9N and County Route 82. Turn right onto County Route 82 for 0.6 mi (1.0 km) to Glen Hill/Mill Hill Road.
76.3 (122.8)	0.6 (1.0)	Turn sharply right onto Glen Hill/Mill Hill Road and proceed to the parking lot at the covered bridge in Jay.
76.5 (123.1)	0.2 (0.3)	Stop 4: Jay Covered Bridge, discussions and lunch.

STOP 4: Jay Covered Bridge, Jay, NY; Discussions and Lunch Stop

Location Coordinates: (44.373^{o} N, 73.727^{o} W)

The covered bridge in Jay lies adjacent to a knickpoint formed by a metanorthosite outcrop in the East Branch channel. We shall take advantage of this scenic location to enjoy lunch and discuss our paleogeographic reconstructions and implications of Styles Brook stratigraphy and landforms for alpine glaciation.

Distance in miles (km) Cumu-lative	Point to Point	Route Description
76.5 (123.1)		Return to the vehicles and return to NY 9N via Glen Hill/Mill Hill Road and County Route 82 (approximately 0.8 mi (1.3 km)).
77.3 (124.4)	0.8 (1.3)	Intersection of County Route 82 and NY 9N. Turn right on NY 9N and travel northeast 5.9 mi (9.5 km) to the Village of Au Sable Forks.
83.2 (133.9)	5.9 (9.5)	Intersection of NY 9N (Main Street), West Ausable Road, and North Main Street. Continue through the traffic light to North Main Street.
83.4 (134.2)	0.2 (0.3)	Intersection of North Main Street, Silver Lake Road, Palmer Street and Golf Course Road. Continue northeast on Golf Course Road.
85.3 (137.2)	1.9 (3.1)	Intersection of Golf Course Road and Dry Bridge Road. Bear slightly right onto Dry Bridge (no stop in this direction) for 0.2 mi. (0.3 km).
85.5 (137.6)	0.2 (0.3)	Park on the roadside near the intersection of Dry Bridge and Buck Hill roads. Stop 5: Clintonville Pine Barren.

STOP 5: Clintonville Pine Barren, Clintonville, NY

Location Coordinates: (44.464° N, 73.643° W)

The Clintonville pine barren is situated on a large deltaic sandplain built by the Ausable and Little Ausable rivers into an embayment of glacial Lake Coveville in the lower Ausable Valley (Figures 4B and 4C). The Little Ausable River was originally a tributary of the Ausable River but the lowering of glacial Lake Vermont water level to the Fort Ann stage initiated downcutting into the Coveville delta deposits and resulted in its diversion across the Ausable drainage divide to its present course (Figure 4D). The Clintonville pine barren is a fire-dependent ecosystem, consisting primarily of pitch pine with an understory of heath plants that has adapted to the low nutrient and drought-prone soils of the deltaic sandplain.

Distance in miles (km)

Cumu-lative	Point to Point	Route Description
85.5 (137.6)		Return to the vehicles and continue east on Dry Bridge Road for 2.9 mi (4.7 km) to the intersection with Clintonville Road.
88.4 (142.2)	2.9 (4.7)	Intersection of Dry Bridge and Clintonville roads. Take a sharp right onto Clintonville Road and travel south 1.2 mi (1.9 km) to NY 9N.
89.6 (144.2)	1.2 (1.9)	Intersection of Clintonville Road and NY 9N. Carefully turn left at the stop sign and immediately enter a small gravel pit on left, adjacent to NY 9N. Stop 6: Clintonville Stream Terrace Deposits.

STOP 6: Clintonville Stream Terrace Deposits, Clintonville, NY

Location Coordinates: (44.466° N, 73.587° W)

The upper portion of the north face of this small gravel pit exposes about 4m of medium to thickly bedded pebble gravel, sand and minor silt that is part of a stream terrace graded to the lower glacial Lake Fort Ann delta at Keeseville. Individual beds range from about 0.1 to 1.0 meters thick and are traceable for several meters across the exposure. The middle approximately 2–3 meters of the section contains a remarkable set of climbing dunes, the upper and lower bedding surfaces of which dip gently upvalley.

The stream terrace gravel and sand disconformably overlies a discontinuous (0.0–0.7 m thick) layer of reddish brown rhythmically laminated silt and clay (varves). The undisturbed clay section is inaccessible but estimates from photographs indicate that it contains at least 20 silt-clay couplets. The west wall of the pit is oriented perpendicular to the paleocurrent and parallel to the valley slope. The rhythmite section in this exposure is thicker (up to a meter thick) and contains soft sediment deformation and slump structures. The rhythmites are draped over 5–6m of sandy, light brownish gray diamicton. The sandy texture of the diamicton is typical of surface till deposits in the region but is markedly dissimilar to the silty, dark gray diamictons observed in exposures at Styles Brook.

Distance in miles (km)		
Cumu-lative	Point to Point	Route Description
89.6 (144.2)		Return to the vehicles and travel east on NY 9N for 0.2 mi (0.3 km) to the intersection with Lower Road.
89.8 (144.5)	0.2 (0.3)	Turn right onto Lower Road for 0.4 mi (0.6 km) to the bridge across the Ausable River.
90.2 (145.1)	0.4 (0.6)	Turn right onto the bridge and cross the Ausable River (0.1 mi, 0.2 km) to the Dugway Road and Burke Road Intersection.
90.3 (145.3)	0.1 (0.2)	Turn left onto Dugway Road and travel 4.6 mi (7.4 km) east to the intersection with Augur Lake Road.
94.9 (152.7)	4.6 (7.4)	Augur Lake Road Intersection. Turn left onto Augur Lake Road and travel east for 0.2 mi (0.3 km) to Stop 7.
95.1 (153.0)	0.2 (0.3)	Stop 7: Lake Vermont Lacustrine and Deltaic Deposits, Keeseville, NY.

STOP 7: Lake Vermont Lacustrine and Deltaic Deposits, Keeseville, NY.

Location Coordinates: (44.487^{o} N, 73.493^{o} W)

This exposure lies along the south bank of the Ausable River approximately 0.5 mi upstream (south) of the Keeseville Industrial Park (KIP) section that was described by Diemer and Franzi (1988), Franzi et al. (2002) and Franzi et al. (2007) and contains a similar record of lacustrine and deltaic sedimentation. The basal portion of the section consists of approximately 3 meters of dark gray silt and clay rhythmites that probably record pro-deltaic varved clay sedimentation in the Coveville phase of Lake Vermont. Water depth here at this time exceeded 80 meters. Deltaic sedimentation at this site began following the glacial Lake Iroquois breakout when glacial Lake Vermont was lowered to the Fort Ann level. The ice front would have receded about 30 km north to the Cobblestone Hill ice margin over this time interval at an average retreat rate of approximately 0.44 km/yr (Franzi et al., 2007). The locus of deltaic sedimentation shifted nearly 10 km downvalley (eastward) during the breakout (Figures 4C to 4D) from the Coveville-level Clintonville delta at approximately 205 meters a.s.l. to the lower Fort Ann-level delta in Keeseville at approximately 155 meters a.s.l.

The deltaic section at this site exposes approximately 10 meters of lower to middle delta slope foreset and bottomset beds. Excellent examples of ripple-drift cross lamination are commonly exposed.

Distance in miles (km) Cumu-lative	Point to Point	Route Description
95.1 (153.0)		Return to the vehicles and continue east on Augur Lake Road for 0.5 mi (0.8 km) over the Adirondack Northway (I-87) to the intersection of US Route 9.
95.6 (153.8)	0.5 (0.8)	Intersection of Augur Lake Road and US 9. Turn left and proceed north for 1.3 mi (2.1 km) through the village of Keeseville to the stoplight at the intersection of US 9 and NY 9N.
96.9 (155.9)	1.3 (2.1)	Intersection of US 9 and NY 9N. Turn right and travel north on US 9 (North Ausable Street) for 1.5 mi (2.4 km) to Stop 8: Ausable Chasm.
98.4 (158.3)	1.5 (2.4)	Stop 8: Ausable Chasm.

STOP 8: Ausable Chasm, Keeseville, NY.

Location Coordinates: (44.525° N, 73.462° W)

Ausable Chasm is a post-glacial gorge cut deeply into the Cambrian-aged Keeseville Member or, to a lesser extent, the Ausable Member of the Potsdam Formation. Landing et al. (2007) note three items of interest in the Cambrian section; 1. the occurrence of scyphomedusae impressions 2. siliciclastic microbial structures and 3. a low-diversity suite of trace fossils. These features are typically restricted to medium to fine grained quartz arenites and rare mudstones in the exposures immediately upstream from the US 9 bridge over the chasm, which are interpreted to represent shallow to emergent littoral sand flat facies (Landing et al., 2007). The scyphomedusae impressions from these outcrops were recently described by Hagadorn and Belt (2008). The outcrops also contain extensive horizontal trackways of *Climactichnites* and *Protichnites* (Landing et al., 2007).

A delta complex built by the Ausable and several smaller streams to the northwest overlie the Potsdam sandstones at this location (Figure 4E) (Denny, 1974; Franzi et al., 2007). Forced regression of the Champlain Sea shoreline accompanied isostatic uplift of the region causing the Ausable River to cut through the unconsolidated deltaic sediments and the underlying Potsdam Formation. Incision through the bedrock was probably accomplished by a combination of gradual incision and knickpoint migration and was influenced by the well-developed joint system in the sandstone, resulting in a rectangular channel pattern through the chasm.

Distance in miles (km)		
Cumu-lative	Point to Point	Route Description
98.4 (158.3)		Return to the vehicles and follow the signage to exit the Ausable Chasm parking lot to NY Route 373.
98.7 (158.8)	0.3 (0.5)	Intersection of exit road and NY 373. Turn left and proceed northwest on NY 373 for 0.2 mi (0.3 km) to the intersection with US 9.
98.9 (159.1)	0.2 (0.3)	Intersection of NY 373 and US 9. Turn right and proceed northeast for 0.8 mi (1.3 km) to the intersection with Giddings Road.
99.7 (160.4)	0.8 (1.3)	Intersection of US 9 and Giddings Road. Turn right and proceed east on Giddings Road for 1.0 mi (1.6 km) to Stop 9.
100.7 (162.0)	1.0 (1.6)	Stop 9: Spring Sapping Channels in Champlain Sea Deltaic Deposits.

STOP 9: Spring Sapping Channels in Champlain Sea Deltaic Deposits.

Location Coordinates: (44.538° N, 73.432° W)

Spring sapping channels like the two at this site are commonplace in the deltaic deposits surrounding Wickham Marsh. In 1985 the heads of these channels were located several tens of meters farther downstream and their headcuts stood 2 meters high with slight to moderate spring flow near their bases. Since then, the channel heads have migrated headward and the height of the headcuts decreased. We shall discuss the significance of spring sapping as a channel-forming process in the Champlain Sea deltaic deposits and its possible role in the channel avulsion that led to the abandonment of the Wickham Marsh delta lobes and the creation of the modern Ausable delta in Lake Champlain (Figures 11A and 11B).

Distance in miles (km)		
Cumu-lative	Point to Point	Route Description
100.7 (162.0)		Return to the vehicles and travel eastward for 0.8 mi (1.3 km) on Giddings Road to Wickham Marsh.
101.5 (163.3)	0.8 (1.3)	Stop 10: Wickham Marsh.

STOP 10: Wickham Marsh.

Location Coordinates: (44.540° N, 73.419° W)

Wickham Marsh is a bayhead wetland on Lake Champlain that is separated from the main waterbody by a barrier beach, although nearly all of the beach is presently buried by a railroad embankment. The marsh's basin was cut as the Ausable River and smaller tributaries adjusted to falling baselevel during the latest stages of the Champlain Sea (Figures 11A and 11B) and possibly early Lake Champlain (Denny, 1974). Spring sapping might have contributed to the development of the tributary stream networks. The lowest deltaic terrace presently lies about 4 meters below the level of Lake Champlain and represents the last deltaic surface formed before the avulsion of the Ausable River to its present course.

Distance in miles (km) Cumu-lative	Point to Point	Route Description
101.5 (163.3)		Return to the vehicles and backtrack southwest for 1.8 mi (2.9 km) on Giddings Road to US 9.
103.3 (166.2)	1.8 (2.9)	Intersection of Giddings Road and US 9. Turn right on US 9 and head north for 3.2 mi (5.1 km) to the Ausable Point State Park entrance.
106.5 (171.4)	3.2 (5.1)	Turn right into Ausable Point State Park on Ausable Point Road. Proceed 0.9 mi (1.4 km) to the parking lot at Stop 11: Ausable Delta on Lake Champlain.
107.4 (172.8)	0.9 (1.4)	Stop 11. Ausable Delta on Lake Champlain.

STOP 11: Ausable Delta on Lake Champlain.

Location Coordinates: (44.571° N, 73.429° W)

This scenic spot provides an opportunity to conclude the trip on the modern Ausable delta and summarize the deglacial history of the region.

Distance in miles (km) Cumu-lative	Point to Point	Route Description
107.4 (172.8)		Return to the vehicles and backtrack northwest for 0.9 mi (1.4 km) on Ausable Point Road to US 9.
108.3 (174.3)	0.9 (1.4)	Intersection of Ausable Point Road and US 9. Turn left and proceed south on US 9 for 0.5 mi (0.8 km) to Bear Swamp Road.
108.8 (175.1)	0.5 (0.8)	Turn right onto Bear Swamp and head west for 2.8 mi (4.5 km) toward the intersection of Bear Swamp Road and I-87.
111.6 (179.6)	2.8 (4.5)	Intersection of Bear Swamp Road and I-87. Turn right onto the northbound entrance ramp of I-87 and proceed 7.7 mi (12.4 km) to Exit 37.
119.3 (192.0)	7.7 (12.4)	Take Exit 37 and follow the signage to the Comfort Inn and Suites.
		END OF ROAD LOG

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