# LATE GLACIAL WATER BODIES IN THE CHAMPLAIN AND ST. LAWRENCE LOWLANDS AND THEIR PALEOCLIMATIC IMPLICATIONS

By

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## INTRODUCTION

The late glacial legacy of the Champlain and St. Lawrence Lowlands and northeastern Adirondack Upland region (Figures 1 and 2) is recorded in the deposits and landforms associated with proglacial and marine water bodies that formed during deglaciation. The largest and most persistent proglacial lake in the region was Lake Vermont, which occupied the central Champlain Lowland and was dammed at its northern margin by the receding ice front (Chapman, 1937; Connally and Sirkin, 1969, 1973; Parrott and Stone, 1972; Wagner, 1972; Denny, 1974; DeSimone and LaFleur, 1985, 1986). Lake Vermont expanded northward until ice receded north of the St. Lawrence Lowland and allowed marine water to inundate the isostatically depressed St. Lawrence and Champlain Lowlands, thus forming the Champlain Sea (Chapman, 1937; Occhietti et al., 2001). Deglaciation of the region postdates deglaciation in the upper Hudson Valley (ca. 13.2 $^{14}$C ka B.P.; Connally and Sirkin, 1971) and was completed prior to the Champlain Sea marine incursion (ca. 12.0 $^{14}$C ka B.P. to 11.5 $^{14}$C ka B.P.; Clark and Karrow, 1984; Fulton et al., 1987; Anderson, 1988; Rodriguez, 1988; Occhietti et al., 2001).

The chronology of lake phases in the Lake Champlain basin provides insight into the style and timing of Late Wisconsinan deglaciation, but may also provide information that is relevant to global paleoclimate studies. Broecker et al. (1989) discussed the possibility that freshwater drainage from proglacial lakes within continental North America during the last deglaciation affected North Atlantic ocean circulation and thereby altered global climate. The Champlain Lowland occupied a strategic position during the Late Quaternary deglaciation of the northeastern United States. The north-south trending lowland served both as a source of cold meltwater and as a corridor for the transmission of proglacial lake discharges from the Great Lakes Region to the North Atlantic. The region is also located at the juncture of two freshwater discharge routes. Discharges from Lake Vermont in the Champlain Valley and proglacial lakes in the eastern and central Great Lakes basin were initially routed southward through the Hudson Valley. Ice recession eventually opened the lower St. Lawrence Valley allowing proglacial lakes in the Champlain Valley and Great Lakes basin to drain northeastward to the Gulf of St. Lawrence. The Champlain Valley region is thus a key for recognizing when and where large freshwater discharge events entered the North Atlantic.

On this trip we shall discuss the preliminary results of our on-going investigations of the geomorphic and stratigraphic record of the late glacial water bodies in the Champlain Lowland and the significance of meltwater outflow and throughflow from the lowland to the North Atlantic during deglaciation.

### Previous Investigations

Woodworth (1905a, 1905b) was one of the first to study the late glacial freshwater and marine water bodies in the Champlain Lowland. Chapman (1937) later conducted an extensive study of the shoreline deposits and landforms in the region. Chapman recognized that Lake Albany formed in the Hudson Valley when the Champlain Valley was still occupied by ice, and that with retreat of the ice there were two main lake stages that occupied the Champlain Valley before the drop to the marine-phase Champlain Sea. He used hand levelling to determine the elevations of strandline and deltaic features from the first and higher "Coveville" phase, and the later "Fort Ann" phase, as well as lower marine shorelines within the basin.

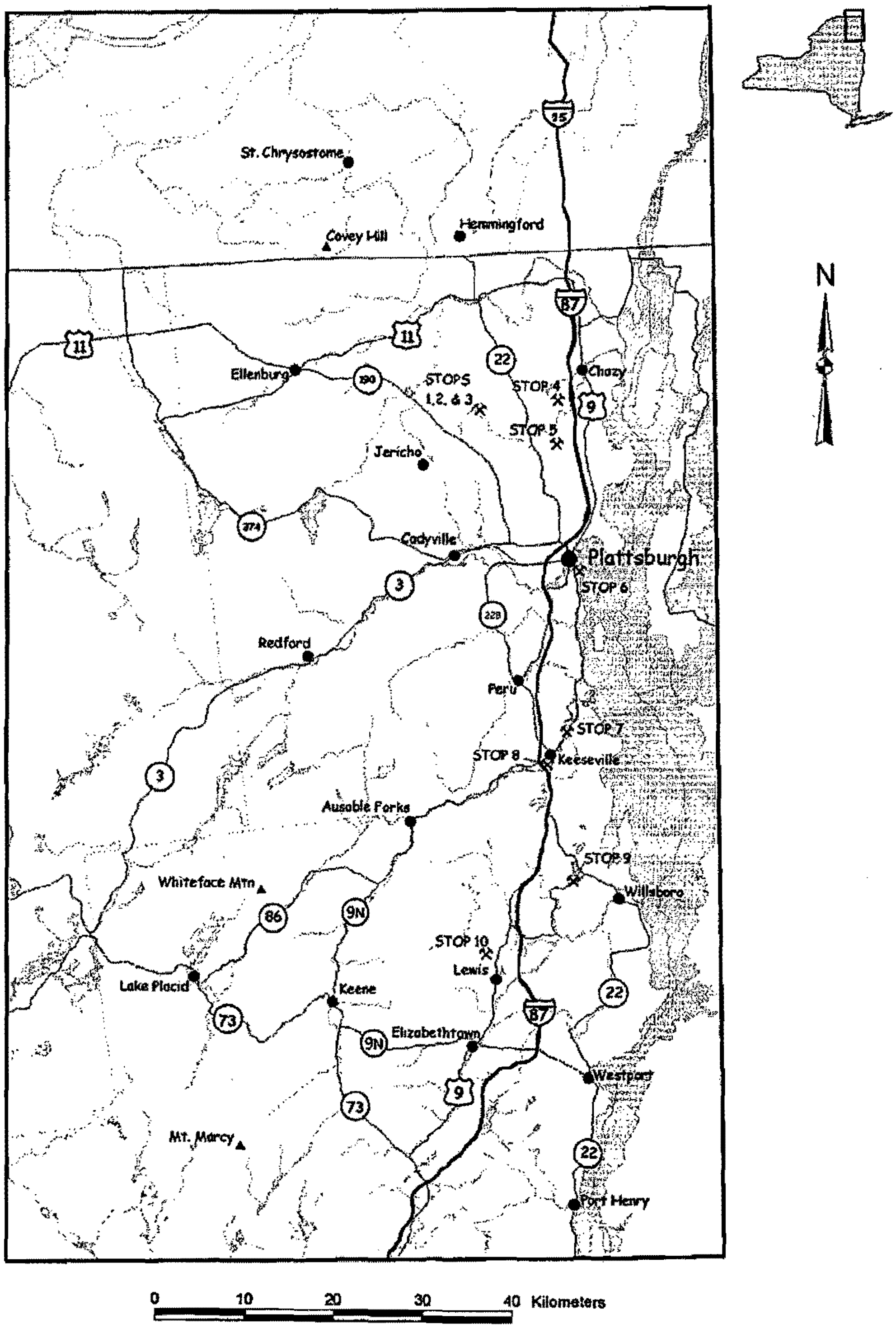

Figure 1. Location map of the northeastern Adirondack Upland and northwestern Champlain Lowland showing the locations of field trip stops.

Chapman (1937) suggested that a rock ledge at Coveville, New York controlled the Coveville lake threshold, and that the lake later dropped to the Fort Ann level when it broke through a barrier at the Hudson Gorge near Schuylerville, New York. He put the Fort Ann threshold at a topographic constriction near Fort Ann, New York, and developed isobases from the Fort Ann shoreline elevations that depict a linear deformation gradient of about 0.95 m/km to the north-northwest.

Connally and Sirkin (1969) suggested that what had, by the late 1960s, been recognized in the upper Hudson Valley as three levels of Lake Albany, and in the Champlain Valley as three separate levels of Lake Vermont, were actually four levels of the same lake. They referred to these (from oldest to youngest) as Lake Albany, Lake Quaker Springs, Lake Coveville, and Lake Vermont. According to Connally and Sirkin (1969), Lake Albany was mostly confined to the Hudson River Valley, and Lake Quaker Springs extended into the Champlain Valley as far north as Ticonderoga, New York and Brandon, Vermont. Their Lake Coveville extended from the Hudson River Valley as far north as Willsboro, New York/Burlington, Vermont, and their Lake Vermont (Chapman's [1937] Fort Ann phase) extended almost to the Canadian border, but was too low to extend into the Hudson River Valley to the south. Connally and Sirkin (1973) describe the relationships of these lakes with the ice margins in detail and speculated about possible outlets. They refer to a "dam" that held back both Lake Albany and Lake Quaker Springs, but which was eventually breached as the water level dropped to Lake Coveville. They put the Fort Ann threshold near Whitehall, New York, with water draining southward to the Hudson River via Wood Creek (now the Hudson-Champlain barge canal), which corresponds to Chapman's (1937) threshold at Fort Ann.

Wagner (1972) and Parrott and Stone (1972) used topographic maps to locate and determine elevations for presumed shoreline features in Vermont. Like Chapman (1937), they emphasized large features such as deltas and kame surfaces. The internal structures of these features, however, are rarely exposed, making it difficult to determine accurate paleo-water level elevations from them. Denny (1967, 1974) traced the Lake Coveville shoreline northward to the Saranac River Valley near Plattsburgh. He also mapped the highest levels for Lake Fort Ann and the Champlain Sea.

DeSimone and LaFleur (1985, 1986) mapped ice margin, lacustrine and fluvial features in the northern Hudson River Valley and the southernmost extent of the Champlain Valley. They identified Lake Albany, Lake Quaker Springs, Lake Coveville, three Lake Fort Ann levels, and suggested that there may have been a "lower Lake Albany" for a short period of time. DeSimone and LaFleur (1985, 1986) did not discuss outlets for Lake Albany or Lake Quaker Springs, as they concentrated on describing meltwater flowing into these lakes and not out of them. They did, however, propose channels at Fort Edward (now Hudson-Champlain barge canal), Durkeetown, and Winchell as Coveville and Fort Ann outlets.

Wall and LaFleur (1995) recognized the lower Lake Albany (which they called "Albany II") and three Fort Ann levels of DeSimone and LaFleur (1985, 1986), and listed elevations of these strandlines at three locations in the Hudson Valley. They examined discharge from the Mohawk River Valley into the Hudson River Valley lakes in detail, but also did not consider ultimate discharge from the Hudson Valley. An important observation from the work of Wall and LaFleur (1995), as well as several of the other earlier investigators, is a suggestion that both Lakes Coveville and Fort Ann were more fluvial in nature south of the Champlain Valley. This change in character between the Champlain Valley and Hudson Valley suggests a constriction between the two.

The breakout of Lake Iroquois through an outlet near Covey Hill, Quebec rerouted Ontario Basin meltwater, which had been draining into the Hudson Valley via the Mohawk River, to the Hudson River through the Champlain Valley. Lake Fort Ann eventually became confluent with the proglacial lakes in the St. Lawrence and Ontario lowlands after ice retreated from the northern slope of Covey Hill (Figures 3A-C; Clark and Karrow, 1984; Pair et al., 1988; Pair and Rodrigues, 1993). The portion of the confluent Lake Fort Ann in the St. Lawrence Lowland has been referred to by the names Lake Belleville, Lake St. Lawrence, and Lake Candona. The reader is referred to Pair and Rodrigues (1993) for a discussion of these names. Finally, ice retreat to the east allowed the proglacial lakes to drain and marine water to invade the isostatically depressed St. Lawrence and Champlain Valleys.

### Physiography

The St. Lawrence and Champlain Lowlands form a broad, contiguous lowland region that is underlain by Cambrian and Ordovician sedimentary rocks (Figure 2). The central portions of the lowlands are underlain by relatively thick glacial, lacustrine and marine deposits and are characterized by low to moderate local relief (generally less than 100 meters). Local relief along the northern margin of the St. Lawrence Lowland and northwestern margin of the Champlain Lowland, in the St. Lawrence Hills subdivision of Cressey (1977), ranges up to a few hundred meters. This subdivision is primarily underlain by the Cambrian Potsdam Sandstone and includes the area around Covey Hill, P.Q. and the "Flat Rocks" in Clinton County, New York.

The Adirondack Upland is a dome-shaped upland region primarily underlain by high-grade PreCambrian metamorphic rocks. The highest summit elevations in the Adirondack Mountain Peaks subdivision (Cressey, 1977) are greater than 1500 meters and local relief commonly exceeds 600 meters. Summit elevations in the Adirondack Low Mountains subdivision generally range between 600 and 900 meters but local relief is generally less than 300 meters (Cressey, 1977).

Drainage patterns within the study area are influenced by regional geology. The principal streams in the region, including the Chateaugay, Chazy, Saranac, AuSable and Boquet rivers, represent the northeastern portion of a radial drainage pattern developed in the Adirondack Upland. The St. Lawrence River and Lake Champlain are part of the tangential master stream network that developed in the lowlands surrounding the Adirondack Upland (Ruedemann, 1931; Morisawa, 1985).

## GLACIAL DEPOSITS AND LANDFORMS

### Ice-Flow Indicators

The direction of Late Wisconsinan ice movement in the Champlain Lowland and northeastern Adirondack Mountain region is inferred from striated bedrock exposures, till-pebble fabrics, roche moutonees, drumlins, moraines, and compositional trends in tills (Ogilvie, 1902; Alling, 1916, 1918, 1919, 1920; Miller, 1926; Kemp and Alling, 1925; MacClintock and Stewart, 1965; Denny, 1974; Craft, 1976; Gurrieri and Musiker, 1990). Two predominant directions of flow are indicated in the published literature, a southerly flow that presumably relates to Late Wisconsinan overriding of the Adirondack Upland by the Laurentide Ice Sheet and a late-glacial flow pattern that was strongly controlled by local physiography. In most instances striation orientation reflects the last ice movement in the region. Kemp and Alling (1925) and Craft (1976) suggested that local alpine glaciers might have contributed to late-glacial ice flow in parts of the Adirondack Uplands.

### Meltwater Channels

The morphology and continuity of meltwater channels and channel systems in the region reflect the magnitude and duration of meltwater discharge, the location of meltwater flow relative to the glacier margin, and the composition and structure of the substratum into which the channels are cut.

Small to medium size channels that are sub parallel to the contours of hill slopes often occur as anastomosing channel systems that are cut into surficial deposits or, less commonly, bedrock. Individual channels range from about 0.1 to 1.0 km long, 10 to 150 meters wide, and 1 to 20 meters deep but the channel systems often occur in belts 0.5 to 2 km wide and several kilometers in lateral extent. Good examples of these channel systems occur near Chateaugay (MacClintock and Stewart, 1965; Denny, 1974; Pair and Rodrigues, 1993), along the northwestern margin of the Champlain Lowland between Jericho and Cadyville and between Cadyville and Peru (Denny, 1974), and north and west of Smith Hill near Lewis. The distal ends of many channels or channel systems open onto fluvial or deltaic sandplains that are graded to bedrock thresholds or proglacial impoundments.

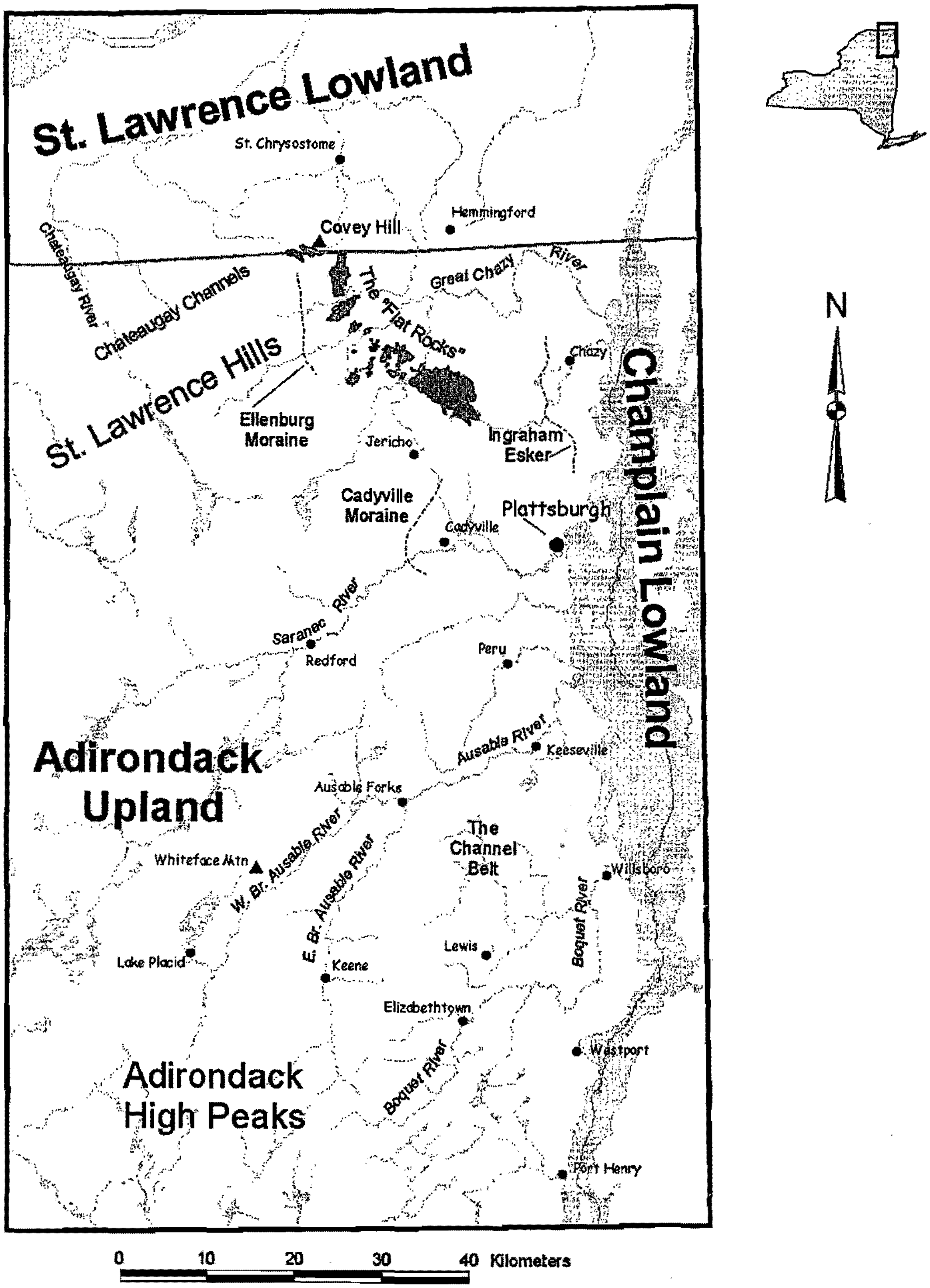

Figure 2. Physiographic regions and geological features of the northeastern Adirondack Upland and northwestern Champlain Lowland region.

Larger and more extensive channels and channel systems cut into bedrock that originate at cols on drainage divides were probably cut by meltwater outflow from proglacial lakes (Alling, 1916, 1918, 1919, 1920; Kemp and Alling, 1925; Miller, 1926; Denny, 1974; Diemer and Franzi, 1988). The outflow channels, presently abandoned or occupied by underfit streams, may attain depths greater than 30 meters and can often be traced more than two kilometers. Bedrock thresholds at the outflow channel heads provided base level control for glaciolacustrine and glaciofluvial sedimentation in the source basin. The elevations of outlet thresholds on drainage divides in Adirondack valleys generally decrease down valley, a distribution that is consistent with the systematic recession of active, valley-bound continental ice lobes (Diemer and Franzi, 1988).

The most extensive outflow channel system is found in the "Channel Belt" (Kemp and Alling, 1925) between Ausable Forks and Lewis (Figure 2). Individual channels may contain deep, circular to ovate plunge basins that are presently occupied by small ponds or swampy depressions. The Channel Belt network heads at the South Gulf and The Gulf outflow channels, on the divide between the Ausable and Boquet drainage basins and was probably cut by the combined erosional effect of outflow and ice-marginal meltwater drainage. Other well-developed bedrock channel systems occur in Wilmington Notch (Diemer and Franzi, 1988), between Redford and AuSable Forks (Miller, 1926; Denny, 1974), and south of The Gulf near Covey Hill (MacClintock and Stewart, 1965; Denny, 1974).

### Rock Pavements

Rock pavements, large areas of exposed bedrock, are commonly associated with meltwater channels and channel systems. The largest rock pavements in the region are the sandstone pavements known locally as “Flat Rocks” in Clinton County (Figure 2). The Flat Rocks comprise a discontinuous, 5-kilometer wide belt of sandstone pavements that extend approximately 30 km southeastward into the Champlain Valley from Covey Hill, P.Q. The pavements are believed to have been created by the erosional effects of catastrophic floods from the drainage of glacial Lake Iroquois and younger post-Iroquois proglacial lakes in the St. Lawrence Lowland (Woodworth, 1905a, 1905b; Chapman, 1937; Coleman, 1937; Denny, 1974; Clark and Karrow, 1984; Muller and Prest, 1985; Pair et al., 1988; Pair and Rodrigues, 1993; Franzi and Adams, 1993, 1999). Outflow from the breakout proglacial lakes in the St. Lawrence Lowland was initially directed southeastward along the ice margin where it crossed the English, North Branch and Great Chazy watersheds before eventually emptying into Lake Vermont. The sandstone pavements generally occur on the drainage divides between watersheds where flood scour was greatest and the exposed surfaces were not subsequently covered (Denny, 1974). Smaller sandstone pavements occur south of Cadyville on the divide between the Saranac and Salmon rivers where they are associated with outflow channels from proglacial lakes in the Saranac Valley (Denny, 1974).

### Diamictons

Diamictons deposited by glacial (till) and nonglacial processes have been recognized in the Champlain Lowland and northeastern Adirondack Mountain region. Subglacial lodgement or meltout till (Dreimanis, 1976; Lawson, 1979) typically consists of massive to crudely stratified, gray to reddish brown, clast-rich diamicton. The texture and composition of till deposits in the region are variable and reflect local provenance (Denny, 1974; Craft, 1976). Massive, over-consolidated till deposits typically form the basal glacial unit in the Champlain Lowland where they often observed overlying striated bedrock. Till occurs primarily as a discontinuous (1 to 3 meters) veneer over bedrock on hill slopes and upland areas.

Nonglacial diamictons consist primarily of intercalated diamicton and stratified deposits. The diamictons occur as lenticular to planar beds that range from a few centimeters to a few meters thick. Individual beds consist of massive to crudely graded, light gray, clast-rich, sandy diamicton. The lateral continuity of individual diamicton beds ranges from a few decimeters to tens of meters. Stratified interbeds range from thin, discontinuous sand, silt and clay lamina to massive, planar bedded, and cross-stratified sand and gravel beds about a meter thick. The bedded diamicton facies is commonly associated with proglacial lake and ice-marginal deposits and landforms. A greater relative proportion, thickness, and continuity of diamicton to stratified beds are generally associated with ice-proximal or valley-side environments.

### Stratified Deposits

Stratified deposits are associated with fluvial, glaciofluvial, subaqueous outwash fan, deltaic, beach, lacustrine, and marine environments. The texture and structure of these deposits is variable and depends on the nature and energy conditions at the site of deposition. Fine-grained sediment, typically associated with low-energy glaciolacustrine and marine environments, include turbidites, pelagic laminites, and varves. Lacustrine deposits of Adirondack provenance are generally less calcareous and coarser grained than those of Champlain Valley provenance (Diemer and Franzi, 1988).

Deltas and beaches provide important evidence for reconstructing the extent of former proglacial lake and marine shorelines. Deltas commonly occur as gently sloping sandplains at the mouths of tributary valleys. The deposits generally grade upward from ripple cross-laminated to planar bedded, fine to medium sand to planar bedded and trough cross-stratified, poorly sorted, coarse sand and gravel (Diemer and Franzi, 1988). The deltas may have been fed by meteoric streams from deglaciated upland areas, ice-marginal or proglacial meltwater streams, or by outflow streams from proglacial lakes in adjacent valleys. Large lacustrine delta plains, deposited primarily by meteoric streams, are commonly found where major rivers entered Lake Vermont. Multiple delta terraces attest to the regrading of inflowing streams as proglacial lake levels dropped.

The Ingraham esker in Clinton County (Figure 2) is a 17 km long, roughly north-south trending, sinuous ridge composed primarily of stratified sand and gravel (Woodworth 1905a, 1905b; Denny, 1972, 1974; Diemer, 1988). The ridge ranges from 100 to 300 meters wide and rises 3 to 10 meters above the surrounding terrain (Diemer, 1988). The esker deposits are interbedded with fine-grained lacustrine deposits, including varved clays, and discordantly overlain by fossiferous gravel, sand, and fine grained marine deposits (Woodworth 1905a, 1905b; Denny, 1972, 1974; Diemer, 1988). Denny (1972, 1974) believed that the ridge formed as an esker in a subglacial tunnel and that its present low relief was due to reworking of the esker deposits by waves and currents in Lake Vermont and the Champlain Sea. Diemer (1988) conducted a detailed sedimentological study of the esker deposits and concluded that the ridge is composed primarily of subaqueous fan deposits. He suggested that the present relief of the esker might be more a primary consequence of subaqueous fan deposition than later resedimentation.

### Moraines

Denny (1974) mapped and described several recessional moraine deposits in the northeastern Champlain Lowland. The largest and most extensive moraines in the region are located in the Saranac Valley near Cadyville and in the Great Chazy River Valley near Ellenburg Depot (Figure 2). The Cadyville Moraine consists of a north-trending belt of linear till ridges and knolls and kame sand and gravel bodies that spans the Saranac Valley. The ridges are typically composed of pebbly, sandy till with interbedded sand and gravel (Denny, 1974). Local relief between ridge crest and adjacent swale ranges between a few meters to approximately 20 meters and ridge crests are commonly spaced 60 to 260 meters apart. The length of individual ridges typically ranges from a few hundred meters to about 0.5 km (Denny, 1974). The swales that Denny described in northern part of the moraine are part of a meltwater channel system that extends from Cadyville northward to Jericho (described above). Small sand bodies at the southern end of the channel system may represent small deltas built into proglacial lakes in the Saranac Valley. The southern portion of the Cadyville Moraine terminates against the northeastern flank of Burnt Hill. The rock pavements and channel system south of the moraine were probably formed by outflow from proglacial lakes in the Saranac Valley at the time the moraine was built.

The Ellenburg Moraine consists of a single north-trending ridge that ranges between 300 and 500 meters wide and rises 25 to 30 meters above the surrounding terrain (Denny, 1974). The moraine is composed of sand, gravel and diamicton that are commonly deformed and offset by normal faults, primarily on its eastern flank. Diamicton interbeds are generally massive to crudely stratified and range between a few decimeters to a few meters in thickness (Denny, 1974; Franzi et al., 1993). The moraine rises to the north where it intersects a low-relief, east-trending recessional moraine north of Clinton Mills (Denny, 1974). Denny (1974) considered a small segment of recessional moraine south of Miner Lake to be contemporaneous with the Ellenburg Moraine.

## LATE WISCONSINAN STRATIGRAPHY AND GLACIAL, LACUSTRINE, AND MARINE HISTORY IN THE CHAMPLAIN LOWLAND

### Proglacial Lake and Marine Water Bodies in the Champlain Lowland

Late glacial ice flow and deglacial sedimentary environments in the Champlain Lowland and northeastern Adirondack Mountain region were influenced by regional physiography. Deglacial drawdown of ice into the Champlain and St. Lawrence Lowlands caused thinning of the ice sheet in upland areas and lobation of the ice front. The Champlain Lobe blocked northward drainage in the lowland and created proglacial Lake Vermont, which drained southward into the Hudson River drainage basin. Lake Vermont expanded with northward recession of the Champlain Lobe.

The names Lake Vermont and Champlain Sea refer to all freshwater and marine phases or levels, respectively, in the Champlain Lowland. The highest phase of glacial Lake Vermont is the Coveville Phase of Chapman (1937), which we shall refer to as Lake Coveville. Denny (1967, 1974) traced the Lake Coveville shoreline northward to the Saranac River near Plattsburgh. Our investigations indicate that Lake Coveville probably extended to Cobblestone Hill and Altona Flat Rock, approximately 12 km farther north than mapped by Denny (1967, 1970). We recognize two lake levels between Lake Coveville and highest marine level, which we refer to as Upper and Lower Lake Fort Ann. The elevations of the lowest two freshwater levels in the St. Lawrence and Ontario lowlands, Belleville and Trenton, (Pair et al., 1988; Pair and Rodrigues, 1993) lie close to the projected elevations of Upper and Lower Lake Fort Ann, which suggests that the Belleville-Upper Lake Fort Ann and Trenton-Lower Lake Fort Ann wader bodies were confluent and controlled by Lake Vermont thresholds.

We have observed that in most cases, the Lower Lake Fort Ann deltas at the mouths of the AuSable and Saranac rivers are notable exceptions, the Lower Fort Ann features are poorly represented in the Champlain Lowland. Because of this, and the fact that both Fort Ann levels occur in the Lake Ontario Basin, we conclude that the Lower Fort Ann level was relatively short lived. Chapman's (1937) Fort Ann shoreline data points are primarily Upper Fort Ann features, however his proposed Fort Ann outlet threshold corresponds to the Lower Fort Ann level. Denny's (1967, 1970) shorelines also correspond to the Upper Lake Fort Ann shoreline.

### Stratigraphy

Stratigraphic sections at Plattsburgh Air Force Base Marina, Keeseville Industrial Park and along the Salmon River in South Plattsburgh and Rae Brook in Beekmantown contain complete or nearly records of late glacial, lacustrine, and marine events in the Champlain Lowland. Two of these exposures, the Plattsburgh Air Force Base and Keeseville Industrial Park sections, will be visited as part of this field trip. The stratigraphy of an exposure along Town Line Brook near Burlington (Bierman et al., 1999) is similar to the Plattsburgh Air Force Base and Salmon River sections, however a measured section is not available. Three key stratigraphic marker horizons are observed in these stratigraphic sections; the contacts between bedrock and diamicton (till), diamicton (till) and lacustrine deposits, and lacustrine and marine deposits. The freshwater proglacial lake and marine laminites and rhythmites at these locations have distinctive sedimentology and fossil assemblages that are consistent with similar deposits in other parts of the Champlain Lowland (Hunt and Rathburn, 1988) and the St. Lawrence Lowland (Rodrigues, 1988; Pair et al., 1988; Pair and Rodrigues, 1993). Ostracodes have been recovered from both lacustrine and marine sediment in the basin (Hunt and Rathburn, 1988; Cronin, 1977, 1979, 1981) and provide biostratigraphic information. Terrestrial pollen and plant macro-fossils have also been recovered from lacustrine and marine sediment in one of the study area exposures (Rayburn et al., 2002), which should provide biostratigraphic information, as well as material for $^{14}$C dating. We have identified other potentially significant stratigraphic markers in our preliminary investigations including an abrupt change in sediment texture and bedding at the Keeseville section corresponding to a drop in proglacial lake level and a thick (~0.5 meter) sand layer in the lacustrine rhythmites at the Plattsburgh Air Force Base exposure, which may correspond to a large sediment influx into the basin. Finally, a unique bed of red clay has been identified at the same stratigraphic position at the Plattsburgh Air Force Base and Salmon River exposures (Rayburn et al., 2002), which is similar in nature and stratigraphic position to a red clay bed observed in cores taken north of Montreal, Canada (Jan Aylsworth, pers. comm.).

Glacial lacustrine and marine sediments observed and sampled from exposures at the former Plattsburgh Air Force Base bluff and the bank of the Salmon River have shown that there is good correlation between sites, and that there is sufficient terrestrial pollen and plant macrofossil preservation to produce a paleoecological study during the time of the lacustrine to marine transition, as well as viable AMS $^{14}$C ages (Rayburn et al., 2002). The till-lacustrine contact has been observed at Keeseville and Rae Brook, NY. Based on these exposures, we have estimated the ice retreat rate through the study area was about 0.45 km/year. Late marine sands cap the Air Force Base bluff, Salmon River and Rae Brook sites, indicating that they contain a complete post-glacial lacustrine and early marine record. The sediment sequences at the Air Force Base and Rae Brook are about 15 meters and 9 meters thick, respectively. Observed couplet thickness at these locations ranges from about 2mm to 5 cm.

A 4.57 meter-long core was obtained from Long Pond, between Willsboro and Keeseville (Stop 9, Figure 1), in March 2002. Long Pond was flooded by Lake Coveville immediately following ice recession from its valley. Proglacial lake water receded from the Long Pond valley when water level in the Champlain Lowland dropped to the Lake Fort Ann level thus creating an early version of modern Long Pond. The Lake Coveville to Lake Fort Ann drainage event may be recorded in the core by a contact between rhythmically laminated glacial lacustrine silty clay and lacustrine fine sand and silt. A wood sample collected 1 cm above this contact yielded a date of 10.9 ± 76 $^{14}$C ka B.P. (Wk -10957).

**Cobblestone Hill Ice Margin**

Cobblestone Hill forms a conspicuous, elongate ridge on the northern flank of Cold Brook at the southeastern margin of Altona Flat Rock where the ice-marginal breakout flood river from Lake Iroquois entered glacial Lake Vermont. The ridge is more than 15 meters high, 500 m wide, and 2.5 kilometers long and is composed of angular boulders, almost exclusively Potsdam Sandstone, that range from 0.5 to about 3 meters in diameter. The average size of surface boulders decreases to the southeast. The position of the ice-front at the time of the breakout is marked by large kettle holes on the northern flank of Cobblestone Hill. The ice front extended northwestward toward Covey Hill where it corresponds closely to ice-front position No.11 of Denny (1974) (Figure 3).

The Cobblestone Hill deposits occur in crude terraces at elevations of approximately 230 m and 205 m, which lie close to the projected water planes of glacial lakes Coveville and Fort Ann (Chapman, 1937; Denny, 1967, 1970). The highest deposits on Cobblestone Hill correspond to similar deposits at Bear Hollow, approximately 1 km south across the present valley of the Little Chazy River. We believe that these data indicate that the ice front lay along the northern flank of Cobblestone Hill as the Lake Iroquois breakout began. The flood discharge initially deposited large boulders of Potsdam Sandstone, most of which were quarried locally from the sandstone pavements, into Lake Coveville. Glacial Lake Vermont dropped during the later stages of the breakout flood and the lower portions of Cobblestone Hill boulder deposit were graded to the Lake Fort Ann level. It is possible that the large influx of floodwater from the Lake Iroquois breakout overwhelmed whatever dam was impounding Lake Coveville and initiated erosion of the outlet to the Upper Fort Ann threshold. We have also observed that the southern extent of the Ingraham Esker, which extends 27-km northward from Beekmantown to Champlain (Figure), lies close to the reconstructed ice margin at the time when the ice front stood at Cobblestone Hill. We believe that it is also possible that the 30-meter drop in lake level between lakes Coveville and Fort Ann steepened the hydraulic gradients of meltwater within the ice mass and initiated the formation of the Ingraham Esker tunnel system. Cobble and gravel terraces on the northeast flank of Cobblestone Hill represent beach ridges formed in Lake Vermont (Woodworth, 1905a; Chapman, 1937; Denny, 1974) following retreat of the ice from the Cobblestone Hill ice margin.

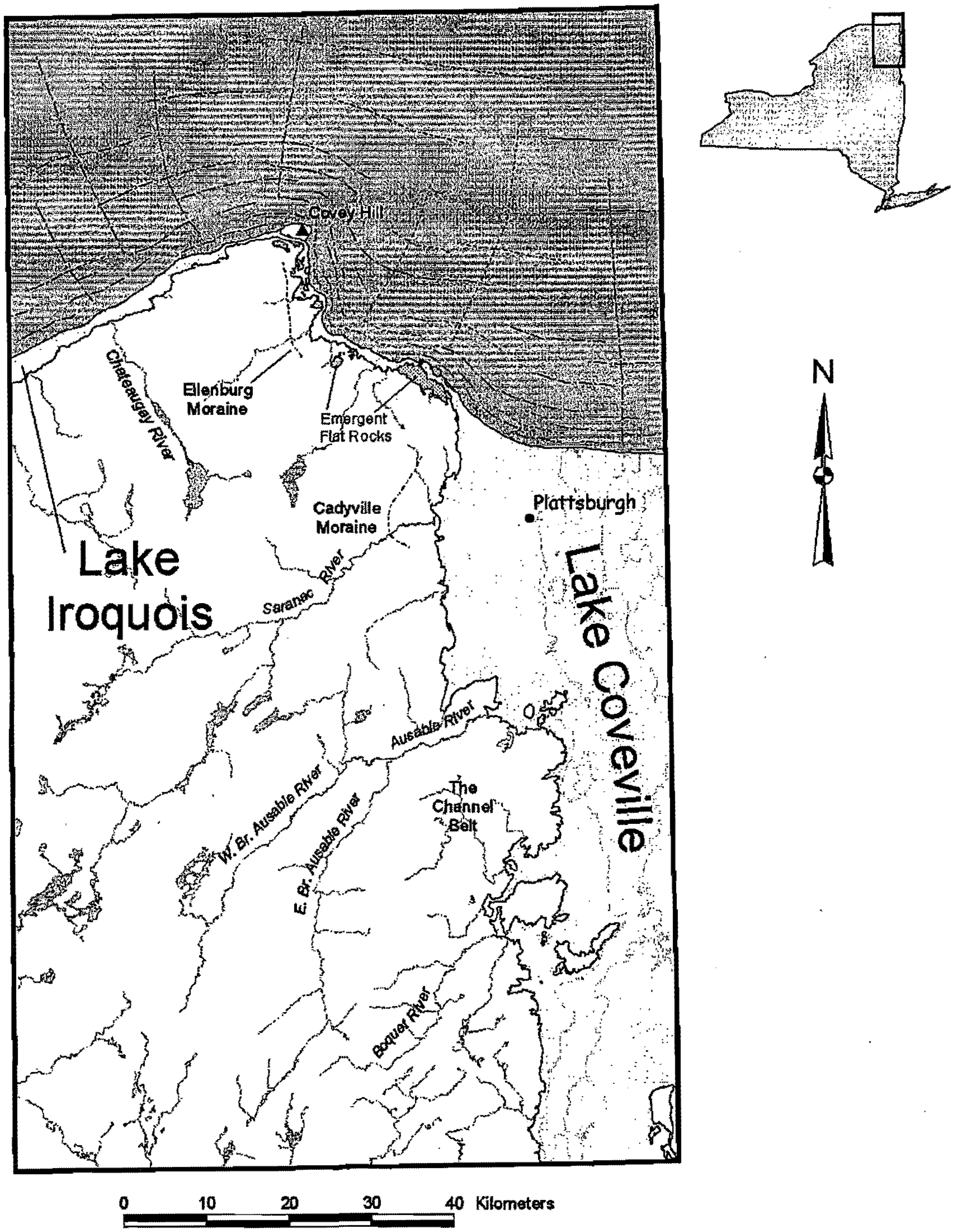

Figure 3. Map of the Champlain Lowland depicting the Cobblestone Hill ice margin and the breakout of glacial Lake Iroquois near Covey Hill.

## PALEOCLIMATIC IMPLICATIONS

Ocean/atmosphere general circulation model (GCM) experiments by Rahmstorf (1995, 2000) predict that moderate changes in the flux of freshwater input into the North Atlantic, perhaps less than 0.06 Sv (1 Sv = $10^6$ $m^3$ $s^{-1}$), can lead to disequilibria in the North Atlantic Deep Water (NADW) circulation, producing substantial changes in regional climate, such as the Younger Dryas event (Broecker et al., 1989). Recent efforts to model freshwater drainage from the North American continent during the last deglaciation by Licciardi et al. (1999) and Marshall and Clarke (1999) estimated that flow changes into the North Atlantic during deglaciation were approximately the same magnitude as those necessary, according to climate models, to affect NADW production. There were three major routes for freshwater discharge into the North Atlantic during the last deglaciation; through the Hudson Strait via Hudson Bay, through the St. Lawrence River, and through the Hudson River. While Licciardi et al. (1999) model recognize all three drainage routes, they acknowledge that the actual duration of southward drainage through the Hudson River is not well constrained. The Marshall and Clarke (1999) model does not have sufficient resolution to distinguish between discharges through the St. Lawrence River and the Hudson River paths (Marshall, pers. comm.).

The northern end of the Lake Champlain Basin is located at the junction of two of these three drainage routes. During the interval between the retreat of the ice margin from the northern slopes of the Adirondack mountains, and deglaciation of the lower St. Lawrence River Valley, all meltwater from the Great Lakes, St. Lawrence Lowland, and Champlain Valley regions that entered the North Atlantic had to pass through the Hudson River Valley via Glacial Lake Vermont in the Champlain Valley (Clark and Karrow, 1984; Pair et al., 1988; Pair and Rodrigues, 1993). When ice margin retreat opened the drainage route through the lower St. Lawrence Valley the southern Lake Vermont outlet was abandoned, and all freshwater drainage from the Great Lakes, St. Lawrence Lowland, and Champlain Valley was re-routed from the Hudson River Valley to the Gulf of St. Lawrence via the Champlain Sea (Clark and Karrow, 1984; Pair et al., 1988; Pair and Rodrigues, 1993).

We estimate that the drop from the Coveville to the Upper Fort Ann level released about 108 $km^3$ of water (Rayburn et al., 2001). The exposure at Keeseville Industrial Park indicates that this transition occurred within one-half varve year. We have therefore concluded that the discharge from this event was between 0.011 and 0.045 Sv, based on a one to four month event (Rayburn et al., 2001, Rayburn et al., in review). This discharge, about the smallest of the large freshwater discharge events, would have entered the North Atlantic through the Hudson Valley. We estimate the freshwater discharge that entered the North Atlantic through the St. Lawrence Valley during the lacustrine/marine transition was at least four times as large (Rayburn et al., 2002; Rayburn et al., in review). Estimates for water volume change between the Upper and Lower Fort Ann levels, the Main and Frontenac levels of Lake Iroquois, and the Frontenac and Upper Fort Ann levels in the Lake Ontario Basin are currently underway.

Our mapping has indicated that there were three large discharge events associated with transitions within the basin 1) the Coveville to Upper Fort Ann level transition, 2) the Upper Fort Ann to Lower Fort Ann level transition, and 3) the Lower Fort Ann to Champlain Sea level transition. Three other large scale discharge events that passed through the basin have also been recognized 1) the transition from the Main Lake Iroquois to Frontenac level which discharged through an outlet at Covey Hill and entered Lake Vermont at Altona Flat Rock, 2) the confluence of Lake Frontenac and Lake Vermont (the water in Lake Frontenac was roughly 110m higher than the water in the Lake Vermont before the confluence), and 3) at least one large discharge event from Lake Agassiz that was directed to the region through the Great Lakes (Clayton, 1983; Teller, 1987).

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## ROAD LOG

| Miles Between Points | Cum. Mileage | Description |
|---|---|---|
| 0.0 | 0.0 | Assemble at the west parking lot of Hudson Hall on the SUNY Plattsburgh campus. Leave the lot and turn right (west) onto Broad Street. |
| 0.2 | 0.2 | Turn right (north) at the second traffic light onto Prospect Street. Continue north on Prospect until it ends at a traffic light on Tom Miller Road. |
| 0.8 | 1.0 | Turn left (west) onto Tom Miller Road and proceed across the I-87 overpass to the traffic light at Quarry Road. |
| 0.2 | 1.2 | Turn right (north) onto Quarry Road and proceed north to the traffic light at the Cadyville Expressway (Rte 374). |
| 0.9 | 2.1 | Quarry Road ends at Cadyville Expressway intersection. Continue straight (north) through the intersection onto Rte 22. |
| 2.7 | 4.8 | The Rae Brook exposure lies on the east side of the small stream valley to your right. The base of the section consists of dark gray, calcareous diamicton (till). The diamicton is overlain by 1.0 to 1.3 meters of thinly laminated rhythmites, which are in turn overlain by marine clays. The faunal assemblages described by Cronin (1977, 1979, 1981) represent the late glacial transition from lacustrine to marine environments in the Champlain and St. Lawrence Lowlands approximately 11.6 to 12.0 $^{14}$C ka. B.P. The bottom water temperatures and salinities at this time probably ranged from –2°C to 10°C and 0 to 18 ppt, respectively (Franzi and Cronin, 1988).<br>Continue north on Rte. 22 to the blinking traffic light at Beekmantown Four Corners. |
| 1.5 | 6.3 | Turn left (west) onto O'Neil Road. O'Neil Road bears right at 0.4 miles from the Rte 22 intersection. Continue north on O'Neil Road until it ends at the West Church Street intersection in Chazy. |
| 4.0 | 10.3 | Turn left (west) onto West Church Street. |
| 0.8 | 11.1 | Turn right (north) onto Barnaby Road. Barnaby Road crosses the Little Chazy River 0.1 miles north of the West Church Street intersection. |
| 0.5 | 11.6 | Denny (1970, 1974) mapped low-relief marine beach ridges on the right (east) of Barnaby Road. The hummocky topography for the next 0.5 miles was mapped by Denny (1974) as recessional moraine. |
| 0.4 | 12.0 | Continue straight (north) on Barnaby Road past the Slosson Road intersection. |
| 0.1 | 12.1 | Barnaby Road and the pavement end at this point. Continue straight (north) on Blaine Road. Blaine Road makes a sharp left turn at 0.9 miles. Continue west on Blaine Road. |
| 1.1 | 13.2 | Blaine Road makes a sharp right turn at the gate to the entrance to the Altona Flat Rock property owned by the William H. Miner Agricultural Research Institute. Leave Blaine Road and continue straight (west) through the gate. It is a good idea to open the gate before completing this step.<br>The Altona Flat Rock access road rises onto the northeastern flank of Cobblestone Hill. |
| 0.1 | 13.3 | Park at a clearing near a sharp turn in the access road. |

**STOP 1. COBBLESTONE HILL BEACHES.** (20 minutes) The beaches at this location were first described by Woodworth (1905a) and later by Denny (1974). The deposits consist predominantly of moderately rounded to well rounded, cobble gravel in multiple, low relief ridges or terraces that extend along the northern and eastern flanks of Cobblestone Hill at elevations between 206 and 175 meters above sea level. The highest ridges lie near the projected highest shoreline of the Upper Lake Fort Ann. Individual ridgess are typically 1 to 2 meters high and 10 to 20 meters wide, and often extend laterally for more than 400 meters (Denny, 1974). The gravel is almost exclusively composed of Potsdam Sandstone that was presumably derived from the alluvial cobble to boulder gravel that composes Cobblestone Hill.

The large (0.2 to 1.4 meter diameter), angular boulders that comprise the core of Cobblestone Hill can be seen along the road a short distance above the highest beach ridge. The boulders of Cobblestone Hill represent material washed into Lake Vermont from the sandstone pavements by ice-marginal streams from the breakout of glacial Lake Iroquois (Woodworth, 1905a; Denny, 1974; Clark and Karrow, 1984; Pair et al., 1988). Reworking of these alluvial deposits by wave action with relatively little longshore transport probably formed the beach deposits (Denny, 1974).

| Miles Between Points | Cum. Mileage | Description |
|---|---|---|
| | 13.3 | Continue up the access road and turn right at the fork just past the highest beach ridge. |
| 0.1 | 13.4 | Bear right and onto a concrete road (Scarpit Road) at Miner Dam. The Scarpit Road presents many hazards, especially for those driving it for the first time. Please drive slowly and cautiously. The road lies on the southwest flank of Cobblestone Hill following the abandoned shoreline of the former reservoir behind Miner Dam.<br>Miner Dam was part of a failed hydroelectric project initiated by William Miner in 1910 (Gooley, 1980). By the time of its completion in March, 1913, the concrete dam, known locally as the "Million-Dollar Dam", had a maximum height of over 10 meters and stretched more than 700 meters across the Little Chazy River valley. The design capacity of the reservoir was more than 3.5 million cubic meters.<br>The inadequate flow of the Little Chazy River and ground water seepage through Cobblestone Hill, which formed the eastern flank of the reservoir, proved to be major design flaws for the project. A 10 to 15 cm layer of concrete grout was spread over more than 100,000 $m^2$ along the flank of Cobblestone Hill (the Scarpit) to mitigate the seepage loss. A deep trench was excavated at the base of Cobblestone Hill behind the dam for the purpose of pouring a grout curtain to the underlying sandstone and thereby, presumably, sealing the northeastern flank of the reservoir. The dam and generating station were completed in 1913 but it took almost two years to fill the reservoir to capacity. The grouting effort was partially successful and the power generating plant began operation on January 21, 1915, more than four years from the beginning of the project (Gooley, 1980). The power plant produced electricity intermittently for seven years before mechanical problems forced the abandonment of the project.<br>Construction of a second dam, the Skeleton Dam (Gooley, 1980), approximately 1.5 km upstream was begun in 1920 to provide supplemental flow to the main impoundment. The Skeleton Dam project, however, ended with the failure of the Miner Dam generating station and was never completed. |
| 0.5 | 13.9 | Park near the Scarpit weather station. |

**STOP 2. COBBLESTONE HILL ICE MARGINAL DEPOSITS.** (40 minutes) The Cobblestone Hill boulder deposits occur at two distinct elevations at this location. The upper level lies between 225 and 232 meters above sea level and may correspond to cobble and boulder deposits at a similar elevation near Bear Hollow, on the southwestern side of the Little Chazy River valley. The elevation of these deposits is close to projected elevation of the Coveville Stage if the Coveville shoreline is extended northward from where Chapman (1937) and Denny (1974) mapped the northernmost Coveville shoreline deposits in the Saranac River valley, assuming a northward isobase gradient of approximately1.2 m/km. The lower level lies between 206 and 215 meters above sea level and corresponds to the boulder deposits observed at Stop 1. The lower level boulder deposits lie close to the elevation of the Upper Lake Fort Ann high stand shoreline (Chapman, 1937; Denny, 1970, 1974).

The northeastern flank of Cobblestone Hill contains several large depressions that we interpret to be kettle holes. The northeastern ends of the kettles rise onto a broad terrace composed of beach deposits (Denny, 1970, 1974) at elevations between 201 and 204 meters above sea level. These beach deposits correspond closely to the elevation of Lower Lake Fort Ann.

We believe that these data indicate that the ice margin stood at Cobblestone Hill at the time of the Lake Iroquois breakout and that proglacial water levels in the Champlain Lowland dropped during deposition of the Cobblestone Hill boulder deposits deposition of the Cobblestone Hill boulder deposits.

| Miles Between Points | Cum. Mileage | Description |
|---|---|---|
| | 13.9 | Return to the vehicles and continue northwest on the Scarpit Road. |
| 0.3 | 14.2 | Note the outcrop of Potsdam Sandstone on your left. The largest boulders on Cobblestone Hill have long dimensions that exceed 3m. |
| 0.2 | 14.4 | The Scarpit Road makes a sharp right turn and the concrete pavement ends. The road emerges onto Altona Flat Rock within 30 meters of the turn. The transition from the northern hardwood forest on Cobblestone Hill to the jack pine barrens on Altona Flat Rock is abrupt at this location. |
| 0.1 | 14.5 | Park at the USGS observation well. |

**STOP 3. ALTONA FLAT ROCK SANDSTONE PAVEMENT AND JACK PINE BARRENS.** (20 minutes) The large areas of sandstone pavement provide habitat for some of the largest jack pine (*Pinus banksiana*) barrens in the eastern United States (Woehr, 1980; Reschke, 1990). Jack pine is a relatively short-lived (<150 years), shade-intolerant, boreal species that maintains communities on the sandstone pavements because of its adaptations to fire and ability to survive in an area with thin (or absent), nutrient-poor soils.

A large proportion of the pine barrens in northeastern New York are owned by a few public and private sector organizations. The William H. Miner Agricultural Research Institute is the largest landowner of pine barrens with almost 1000 ha (hectares) of jack and pitch pine barrens on Altona Flat Rock. New York State owns an additional 600 ha of the Altona Flat Rock barrens, approximately 100 ha of the Gadway barrens and 200 ha of pine barrens at The Gulf near Covey Hill. The Adirondack Nature Conservancy owns 222 ha of the Gadway jack pine barrens at Blackman Rock.

Plattsburgh State University and the William H. Miner Agricultural Research Institute have collaborated in research and teaching initiatives in the Altona Flat Rock pine barrens for more than 30 years. The hydrogeological equipment and instrumentation at Stops 2 and 3 are part of the Ecosystem Studies Field Laboratory (ESFL), a field station dedicated to undergraduate teaching and research in geology and environmental science. The field site offers an excellent geological, hydrological and ecological setting for illustrating the interdependence of natural processes and the effects of human activities on natural ecosystems. For the past three years the ESFL site has been the focus of the Plattsburgh Research Experiences for Undergraduates program, which is funded by the National Science Foundation and the William H. Miner Agricultural Research Institute. The reader is referred to Franzi and Adams (1993, 1999) for a more detailed description of the Altona Flat Rock pine barrens and the Ecosystem Studies Field Laboratory Project.

| Miles Between Points | Cum. Mileage | Description |
|---|---|---|
| | 14.5 | Turn back onto the Scarpit Road and proceed back toward Miner Dam. |
| 1.1 | 15.6 | Bear left at the end of the Scarpit Road at Miner Dam and continue toward the gate at the entrance to the property. |
| 0.1 | 15.7 | Continue straight through the gate onto Blaine Road and continue to Slosson Road. |
| 1.2 | 16.9 | Turn left (east) onto Slosson Road. Please drive cautiously and watch for children and farm animals as you pass the Parker Farm at 17.1 miles. |
| 0.3 | 17.2 | A marine beach ridge can be seen in the field on the right (south) near the intersection with Vassar Rd. Continue east on Slosson Road to the intersection with Rte. 22. |
| 1.5 | 18.7 | Continue straight (east) on Slosson Road across the Rte. 22 intersection to the Rte. 348 intersection. |
| 1.5 | 20.2 | Continue straight (east) on Slosson Road across the Rte. 348 intersection to the Ashley Road intersection. |
| 0.7 | 20.9 | Turn left (north) onto Ashley Road. |
| 0.5 | 21.4 | Turn right (east) into the Kalvaitis gravel pit. |

**STOP 4. INGRAHAM ESKER AT THE KALVAITIS GRAVEL PIT.** (40 minutes). The Ingraham Esker is one of the most conspicuous glacial landforms in the northern Champlain Lowland. This pit contains esker fan deposits, such as described by Diemer (1988), and deposits resedimented by wave action in the Champlain Sea as described by Denny (1972, 1974). Most of the pit is cut into proximal to medial subaqueous fan gravel and sand. The resedimented deposits consist primarily of fossiliferous gravel that occur as dipping bedsets on the western flank of the esker. Individual beds are several centimeters to a few decimeters thick and are laterally continuous for several meters.

| Miles Between Points | Cum. Mileage | Description |
|---|---|---|
| | 21.4 | Leave the gravel pit and turn left (south) onto Ashley Road. |
| 0.5 | 21.9 | Turn left (east) onto Slosson Road. |
| 0.5 | 22.4 | Turn right onto Esker Road. A gravel pit containing esker tunnel and proximal subaqueous fan gravel and sand can be seen on the right (west) side of the road at 22.5 miles. |
| 0.8 | 23.2 | Park beside the road near the head scarp of a gravel pit. |

**STOP 5. INGRAHAM ESKER AT ESKER ROAD.** (10 minutes) This location is the "West Pit" section of Diemer (1988). Most of the sediment consists of coarse-grained channel fill deposits. These deposits generally occur lenticular beds that are meters thick, tens of meters wide and may be traceable for tens of meters in the flow direction (Diemer, 1988). Marine reworking of the esker deposits at this location is restricted to a thin layer (1 to 2 meter) of interbedded sand and gravel near the top of the pit.

| Miles Between Points | Cum. Mileage | Description |
|---|---|---|
| | 23.2 | Continue south on Esker Road to the Stratton Hill Road intersection. |
| 1.2 | 24.4 | Turn left (east) onto Stratton Hill Road and cross the I-87 overpass. The esker was removed in the I-87 corridor but the ridge can be seen on the right (south) side of Stratton Hill Road east of I-87. |
| 0.2 | 24.6 | Stratton Hill Road makes a sharp right turn at the stop sign. Turn right (south) and continue on Stratton Hill Road. |
| 0.9 | 25.5 | Turn right (south) onto Rte. 9. The esker ridge parallels Rte. 9 on the right-hand (east) side of the road. The ridge crosses the Rte 9 at 26.2 miles and continues its southward trend on the left-hand (west) side of the road. |
| 6.2 | 31.7 | Enter the City of Plattsburgh on Rte. 9. Continue south. |
| 0.9 | 32.6 | Continue straight through the lights at the intersections of Tom Miller Road and Sailly Avenue near the Georgia-Pacific Paper Mill. |
| 0.2 | 32.8 | Turn left (south) onto Miller Street. |
| 0.5 | 33.3 | Turn left (east) at the end of Miller Street and proceed to the stop sign at City Hall Place near the MacDonough Monument. Turn right (south) onto City Hall Place. |
| 0.2 | 33.5 | Turn right (east) at the stop sign onto Bridge Street and cross over the Saranac River. |
| 0.1 | 33.6 | Turn right (south) at the traffic light onto Peru Street. |
| 0.1 | 33.7 | Continue Straight (south) through the first traffic light and turn left (east) onto Hamilton Street at the second. |
| 0.1 | 33.8 | Continue straight (east) through the MacDonough Street intersection. |
| 0.1 | 33.9 | Turn right (south) onto Club Street and enter the former Plattsburgh Air Force Base. Club Street becomes US Oval West and continues south past the former officers quarters. |
| 0.9 | 34.8 | Continue straight (south) at the stop sign onto Ohio Avenue East. |
| 0.2 | 35.0 | Turn left (east) on the marina access road. |
| 0.1 | 35.1 | Cross the railroad overpass to the parking lot. |

**STOP 6. PLATTSBURGH AIR FORCE BASE MARINA SECTION AND LUNCH STOP.** (80 minutes) The bluffs along the shore of Lake Champlain extend for more than 1 km north from the former Plattsburgh Air Force Base marina. The bluffs probably contain a complete late glacial stratigraphic section, however, no single location contains all of the stratigraphic units. A massive gray diamicton lies at the base of the glacial section. The diamicton is exposed at the north end of the bluffs where it overlies striated bedrock. The upper contact is not exposed.

The base of the section near the marina consists of more than 3 m of dark gray clayey rhythmites, which were probably deposited as varves in glacial Lake Vermont. The rhythmites occur as clay and silty clay couplets that range from a few centimeters thick in the lower part of the section to thin couplets that rarely exceed a few millimeters in thickness near the top of the unit. Soft-sediment deformation structures are common. Rock and sediment clasts are distributed throughout the unit as individual clasts and in discrete layers along bedding planes. A deformed bed of medium sand that is 0 to 0.2 m thick occurs near the base of the exposed section. The lateral extent of this unit is not known. A thick reddish brown clay lamina occurs near the top of the rhythmite unit. This lamina is similar in nature and stratigraphic position to a red clay bed observed in cores taken north of Montreal, Canada (Jan Aylsworth, pers. comm.).

The rhythmites are conformably overlain by 1.5 to 2.0 m of laminated to thinly bedded, fossiliferous marine mud. The mud facies coarsens upward to horizontally bedded silt and fine sand. The silt and sand unit is approximately 7 m thick and the unit coarsens upward. Individual beds range from a few centimeters to a decimeter or two thick and are generally normally graded. These deposits probably record the incursion and gradual regression of the Champlain Sea in the region.

| Miles Between Points | Cum. Mileage | Description |
|---|---|---|
| | 35.1 | Turn back across the railroad overpass to Ohio Avenue East. |
| 0.1 | 35.2 | Turn right (north) onto Ohio Avenue East. |
| 0.2 | 35.4 | Turn left (west) onto New York Road and exit the Former Air Force Base. |
| 0.1 | 35.5 | Turn left (south) at the light onto Rte 9. Continue south on Rte. 9 to Keeseville. The road passes Clinton County Community College at 37.6 miles, crosses the Salmon River at 39.2 miles, and crosses the AuSable River at 44.2 miles. |
| 9.1 | 44.6 | The road rises onto a marine delta deposit built by the AuSable River into the Champlain Sea. The upper surface of the delta is at an elevation of about 70 meters above sea level. |
| 1.1 | 45.7 | The road rises onto a higher (elevation = 106 m) marine delta. |
| 1.0 | 46.7 | Cross the AuSable River at AuSable Chasm and turn right into the parking lot on the south end of the bridge. |

**STOP 7. AUSABLE CHASM DISCUSSION AND PHOTO OP.** (15 minutes) AuSable Chasm is one of the most unique scenic spots in the Champlain Lowland. The AuSable River has carved a spectacular gorge that exposes a 135 m thickness of the Keeseville Member of the Potsdam Sandstone. The AuSable River also cuts through the upper marine delta noted in the road log, and thus, the cutting of the chasm postdates the Champlain Sea interval.

| Miles Between Points | Cum. Mileage | Description |
|---|---|---|
| | 46.7 | Continue south on Rte. 9. |
| 1.5 | 48.2 | Turn left at the traffic light and follow Rtes. 9 and 22 south. The road crosses the AuSable River and then bears right (south) into the village of Keeseville. |
| 0.4 | 48.6 | Rte. 9 rises out of the AuSable River Valley and onto the surface of a delta that was built into Lower Lake Fort Ann. The delta surface elevation is approximately 156 meters above sea level. |
| 0.9 | 49.5 | Turn right (west) onto Augur Lake Road. |

| Miles Between Points | Cum. Mileage | Description |
|---|---|---|
| 0.2 | 49.7 | Turn right (north) onto Industrial Park Road |
| 0.3 | 50.0 | Park beside the road. |

**STOP 8. KEESEVILLE INDUSTRIAL PARK EXPOSURE.** (40 minutes) The Keeseville Industrial Park section is exposed in a landslide scar on the south bank of the AuSable River. The river is deeply incised into a deltaic terrace graded to Lower Lake Fort Ann. The surface elevation of the delta surface is approximately 155 m.

A massive to crudely bedded, dark gray diamicton forms the base of the section. The diamicton is overlain by approximately 2 m of rhythmically laminated silt and clay couplets. Clay laminae are generally 1 cm or less thick and the silt laminae or beds range from about 0.5 to 4 cm thick. The silt beds are commonly internally laminated. The rhythmite section contains about 67 couplets. The rhythmite section is conformably overlain by approximately 7 m of deltaic silt and sand that coarsen upward to sand and gravel.

The sediments at Keeseville Industrial Park record ice recession from the AuSable Valley. The basal diamicton is interpreted to be a till and thus represents ice cover. The rhythmites are probably varves and thus record inundation of the lower AuSable Valley by proglacial Lake Coveville. Assuming that the entire varve sequence represents proglacial Lake Coveville and the overlying silt and sand record the drop of proglacial lake level to Upper Lake Fort Ann, then Coveville occupied the lower AuSable Valley for approximately 67 varve years before proglacial lake levels dropped to the Upper Lake Fort Ann level. The ice front may have receded about 30 km north to the Cobblestone Hill Ice margin over this time interval at an average retreat rate of approximately 0.45 km/yr.

| Miles Between Points | Cum. Mileage | Description |
|---|---|---|
|  | 50.0 | Follow Industrial Park Road back to Augur Lake Road. |
| 0.3 | 50.3 | Turn left (east) onto Augur Lake Road. |
| 0.2 | 50.5 | Turn left (north) onto Rte. 9 and proceed back toward Keeseville. |
| 0.9 | 51.4 | Turn left (east) at the base of the hill onto Clinton Street. |
| 1.5 | 52.9 | Turn right (south) onto Highlands Road. Highlands Road offers spectacular views of Lake Champlain. Burlington, Vermont lies directly across the lake at this point and is visible on a clear day. |
| 2.1 | 55.0 | A series of marine terraces lie to the left (east) side of the road. |
| 0.3 | 55.3 | A prominent Upper Lake Fort Ann sand and gravel spit parallels the right (west) side of the road. Chapman (1937) identified this feature and measured its surface elevation as 161 meters above sea level. |
| 5.8 | 61.1 | Turn left (south) onto Rte. 22. Long Pond is on the right (west) side of the road at 61.6 miles. |
| 1.6 | 62.7 | Turn right (west) onto Reber Road North. |
| 0.6 | 63.3 | Pull off the side of the road adjacent to Long Pond. |

**STOP 9. LONG POND CORE.** (40 minutes) The Long Pond basin was a deep embayment in Lake Coveville. The drop to the Upper Lake Fort Ann level, however, left proglacial water levels in the Champlain Lowland below the threshold of Long Pond. The bottom sediment of Long Pond was vibracored in March, 2002. Wood obtained 1 cm above a horizon that may represent the drainage of Lake Coveville at this site yielded a date of 10.9 ± 76 $^{14}$C ka B.P. (Wk - 10957). These discussions will continue at the Pok-O-MacCready Outdoor Education Center 0.5 miles (63.8 miles) west of this location where a portion of the Long Pond Core will be displayed.

| Miles Between Points | Cum. Mileage | Description |
|---|---|---|
| | 63.8 | Continue west on Reber Road. |
| 5.1 | 68.9 | Turn right (west) onto Deerhead Road. |
| 1.7 | 70.6 | The Deerhead Road traverses an Upper Lake Fort Ann delta built by the North Branch of the Boquet River. |
| 1.0 | 71.6 | The road rises to the top of a large Lake Coveville delta, known locally as "The Plains". The "The Plains" delta was built by North Branch flow that was augmented in its early stages by outflow from proglacial lakes in the AuSable River basin to the west via the "Channel Belt" (Kemp and Alling, 1925; Diemer and Franzi, 1988). |
| 0.6 | 72.2 | Deerhead Road crosses over I-87. There is a good view of "The Plains" delta to the right (south). Continue west on the Deerhead Road to the Rte 9 intersection. |
| 0.9 | 73.1 | Turn left (south) onto Rte.9 and proceed to the intersection with Pulsifer Road. |
| 2.7 | 75.8 | Turn right (west) onto Pulsifer Road. The road makes a sharp right 0.3 miles from the intersection. Stay on Pulsifer Road. |
| 0.6 | 76.4 | Turn left (west) and proceed through the gate to the NYCO wollastonite quarry at Oak Hill. The road crosses a series of channeled kame terraces and eventually rises to the quarry. Park well off the haul road. |

**OPTIONAL STOP 10. NYCO WOLLASTONITE QUARRY.** (40 minutes) The quarry operators have excavated deeply into ice-marginal stratified drift and diamicton on the flank of Oak Hill. The composition, stratification and texture of these deposits is highly variable. The stratified sediment probably represents sedimentation by ice-marginal streams flowing from the "Channel Belt" (Kemp and Alling, 1925) and local impoundments. The diamicton are probably till or sediment flow deposits.

| Miles Between Points | Cum. Mileage | Description |
|---|---|---|
| | 76.4 | Return to the gate at the entrance to the quarry and turn right (south) onto Pulsifer Road. |
| 0.6 | 77.0 | Turn right (south) at stop sign onto Route 9. |
| 1.0 | 78.0 | Turn left (east) onto County Route 12 and proceed to I-87. |
| 1.6 | 79.6 | Turn right (south) onto the I-87 access ramp and proceed to the NEIGC-NYSGA conference center in Lake George. |

End of Road Log