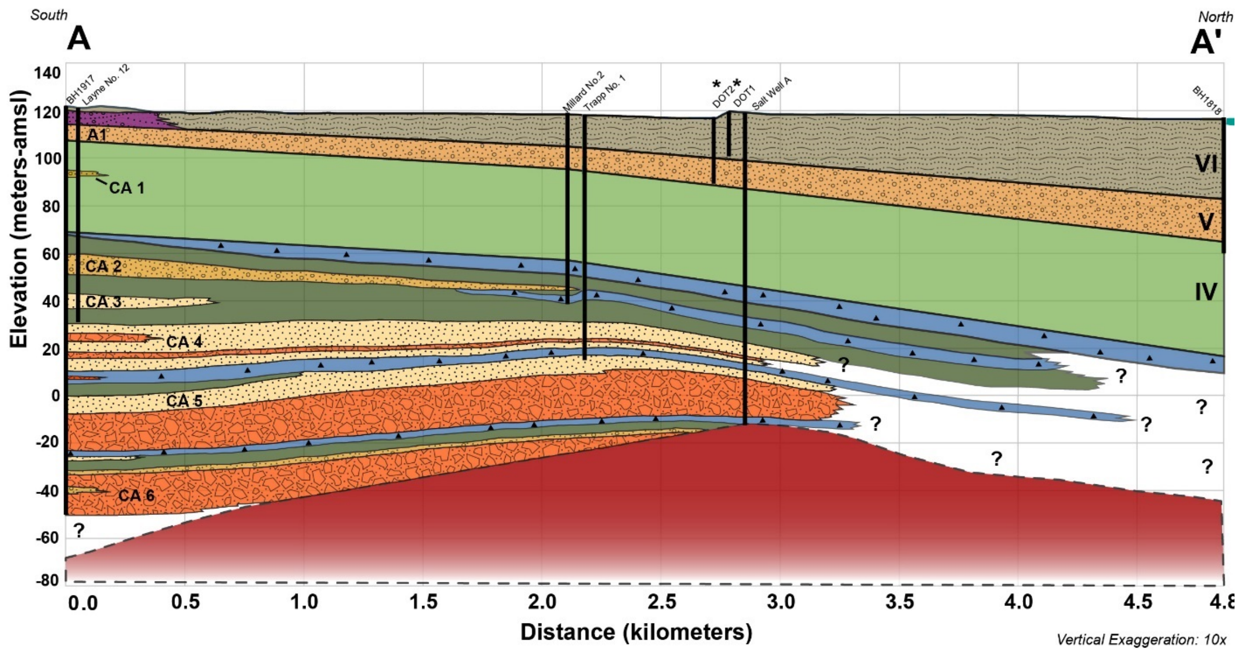
Glacial Stratigraphic Framework of the Cayuga Inlet Valley and Ithaca Delta Plain. Ithaca West 7.5 minute quadrangle, Tompkins County, New York



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BACKGROUND: The New York State Geological and Natural History Survey was established by the New York State Legislature in 1836. Geological research has been conducted continuously since then and has remained an important component of the State Cabinet of Natural History, established in 1842 and later renamed the New York State Museum in 1870. The New York State Geological Survey (NYSGS) is a bureau of the State Museum in the State Education Department.

MISSION: The mission of the NYSGS is to conduct geologic research, evaluate mineral resources and geologic hazards of the State of New York, and make the data and advice derived from that research available to State agencies, the educational community, and the public for the health, safety, and economic welfare of the citizens of the State. Responsibilities of the NYSGS include maintaining a comprehensive inventory of the geologic resources, conducting research into the characteristics of, and processes operating in, the earth's crust, and making the resulting geologic knowledge readily available. The guiding principles require that the work of the NYSGS be synoptic and comprehensive throughout the State, be applicable to addressing the geologically related issues facing the citizens of the State and be assembled in useable formats. Descriptions of various aspects of the State's geology are presented in the Museum Bulletin, Memoir, Map & Chart, Miscellaneous Publications, and Circular series publications. Ongoing research projects are summarized annually in open-file reports such as the one you are about to read.

Introduction

The geology of the Finger Lakes region in central New York State has captivated the attention of both amateur naturalists and trained scientists for more than a century. As part of an ongoing investigation by the New York State Museum (NYSM) to investigate the Pleistocene geology of Tompkins County, deep continuous drill cores have been collected. Thanks to cooperative funding agreements (cooperative agreement G18AC00215) administered by the United States Geological Survey, unprecedented deep stratigraphic resolution of the Cayuga Inlet Valley and Ithaca delta plain (figure 1) has been made possible. The purpose of the coring investigation was to obtain a continuous stratigraphic record of thick (up to 171 m) Pleistocene deposits buried at the south end of the Cayuga Basin. The geologic framework discussed in this publication is the product of geologic survey exploratory borehole BH1818 completed on September 28th, 2018 and borehole BH1917 completed on December 4th, 2019. This report accompanies an oversized plate illustration known as New York State Museum Map & Chart Series 132. This chart is available for free download from the New York State Museum web site.

Previously the surficial geology of the Ithaca East and Ithaca West 7 ½ minute USGS quadrangles (figure 2) located in Tompkins County New York were mapped by the New York State Geological Survey (NYSGS), a bureau of the NYSM during the summer of 2019 and 2018, respectively. This mapping, completed at a scale of 1:24,000 was accomplished as cooperative mapping project for the STATEMAP element of the National Cooperative Geologic Mapping Program. This technical report describes the methods, stratigraphy (including aquifer units) and correlation to the seismic sequences of Mullins et al. (1996).

Geologic Setting and Previous Work

Tompkins County is home to 102,000 residents and is centered at the south end of Cayuga Lake, the second largest and deepest of the Finger Lakes in south-central New York. The county is 1,274 square kilometers (492 Mi^2) in area and represents an eclectic blend of small-scale innovative industry, colleges, universities and rural charm highlighted by more than 550 farms. Located approximately 62 km (38 miles) northwest of Binghamton, NY, the City of Ithaca serves as the County Seat and home to Ithaca College and Cornell University. This bustling city of 30,000 full time residents is the nexus of activity and includes eight of the fourteen major highways that form the major transportation corridors for the County.

The city is located on a delta plain in the Cayuga trough, a through valley with numerous glens and waterfalls along the uplands to the east and west that rise onto the Allegheny Plateau. The uplands have a predominantly streamlined elongate appearance of smooth, gently rolling slopes. Southward the uplands become more rolling and dissected. Massive valley blocking deposits more than 700 feet thick comprise the Valley Heads Moraine systems that form the drainage divide between the Ontario Basin and Susquehanna Basin.

R.S. Tarr was an early researcher who investigated the glacial origins of the Cayuga Basin (1894). He described stratigraphy from local water wells (1904), moraines (1905a) and hanging deltas (1905b) deposited in elevated proglacial basins. Subsequent studies from Maury (1908),Von Englen (1929) and Karrow et al., (2009) investigated faunal evidence from deposits and landforms of a proposed interglacial period in the Finger Lakes. Schmidt (1947, 1996) interpreted Middle Wisconsin lacustrine deposits in Sixmile Creek. Karig and Miller (2013) added additional radiocarbon ages and stratigraphic data and suggested a Middle Wisconsin Ice advance entered the Sixmile Creek Valley. The most widely accepted analysis by Muller and Calkin, (1993) and Ridge (2003) proposes that during the Port Bruce phase (~17,000 calendar yrs. B.P.) of glaciation, the Ontario Lobe of the Laurentide Ice Sheet advanced southward in central New York and deposited large sequences of sediment to form part or all of the Valley Heads Moraine at the southern end of the Finger Lakes. As ice retreat began from this position, all drainage ponded in front of the ice until it could escape through outlets. Thus, extensive, deep, proglacial lakes developed and coalesced into a series of high elevation (300m- (984 ft--amsl) lake levels centered on the Cayuga Trough. When ice retreated far enough to the north, the flooded Finger Lake valleys drained along the ice margin through progressively lower spillways (Fairchild, 1934: Kozlowski et al., 2016; 2018). A series of much larger proglacial lakes occupied the Ontario Basin during the Late Quaternary; the latest of which was glacial Lake Iroquois (Bird and Kozlowski, 2016). During the main phase of glacial Lake Iroquois this extensive proglacial lake extended within the Cayuga Basin north of present-day Ithaca connecting the Finger Lake basins to the Ontario Basin, thus integrally connecting the surficial deposits and hydrogeology to Lake Ontario.

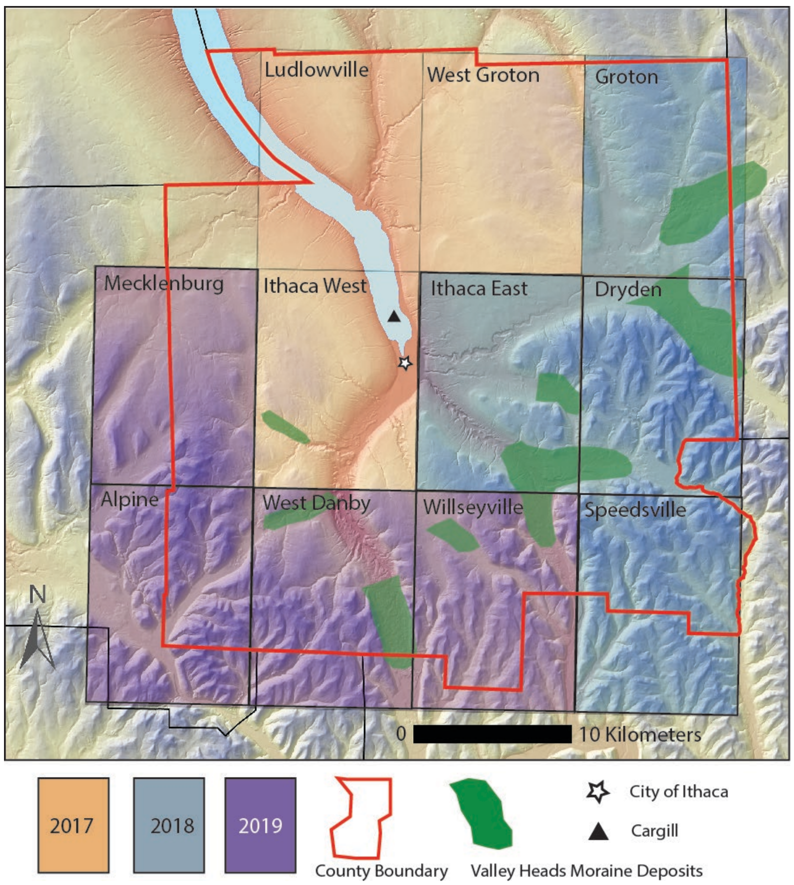

Figure 1. Tompkins County Project with locations of maps completed or in progress from 2017-2020.

The surficial geology is complex and quite variable (figure 2) but does exhibit predictable patterns on the landscape. Upland areas are usually composed of diamicton or deposits of sand and gravel. Low lying areas usually are characterized by finer-grained sand, silt, and clay as well as organic rich deposits and thick lacustrine deposits. Sand and gravel deposits associated with uplands are likely the products of fans at retreating or stalled ice margins, lag deposits of high energy meltwater events or wave action in proglacial lake; or as deposits originating in subglacial tunnels (eskers).

Methods

Although, previous investigations have examined glacial landforms and deposits exposed in quarries, stream cuts and road cuts, the deeper stratigraphy of the inlet valley and delta plain has not been systematically explored with scientific coring. Most previous subsurface stratigraphic information comes from seismic studies (Mullins et. al., 1996) and water well logs (Lawson, 1977) often drilled with rotary methods. Such methods are well suited for the efficient completion of water wells. However, the tri-cone drill bit by design crushes, grinds and pulverizes sediment, rendering it as a uniform aggregation of coarse sand sized particles. Crucial details on grain-size, bedding, and structure are limited if not completely absent. In addition, the drilling process destroys delicate plant and wood macrofossils present that could be vital to estimating ages of glacial formations in the geologic framework.

The New York Geological Survey (NYSGS) initiated deep stratigraphic investigations utilizing PQ-size (8.5 cm diameter) soil coring as part of the Tompkins County mapping project. The cores were retrieved using a Christensen quad latch wireline coring system. The coring system consists of an inner tube and bearing that keeps the internal core barrel stationary while the drill string and 12.7 cm coring bit progress through the sediment. The bottom of the dual tube core barrel may be interchanged with various punch shoes selected to match the lithology of the interval. Softer soils such as clays and silts require a longer nose punch shoe that extends 10 cm ahead of the coring bit. Sand formations may require a shorter punch shoe extending 2.5-5 cm ahead of the coring bit. Indurated till units, coarse gravel, cobbles and or boulders require use of a short punch shoe recessed inside the coring bit to avoid being destroyed. Complex, rapidly changing lithologies typical of glacial deposits require constant attention from the driller and frequent changing of punch shoes to maximize sample recovery with minimal disturbance.

Results

Previous field mapping by the NYSGS in the uplands near Buttermilk Falls State Park revealed complex stratigraphy (figure 3) within the well-developed bedrock gorge system. In April of 2018, D. E. Karig (Cornell geology emeritus) directed A.L. Kozlowski of the NYSM/NYSGS to a four-meter-tall exposure containing fine-grained silt and clay in a deeply eroded bedrock meander in the Upper Buttermilk Falls portion of the park. The silt and clay unit was overlain by two meters of alluvium that extended about a half meter above the stream level and occurred at an elevation of about 293 meters (961 ft)-amsl, 150 meters above the present-day surface elevation of Cayuga Lake. The clay-silt unit clearly represents a slack water deposit, most likely lake sediment from a high elevation (~ 300 m (984 ft) -amsl) proglacial lake phase. Upon detailed inspection a piece of wood was observed protruding from the compact clay-silt unit. With minor excavation it became apparent that the stick was in fact a branch connected to a log (figures 4 and 5). A half meter section of the log was extracted from the sediment and the remainder was left *insitu*.

The trunk wood retrieved was identified as a spruce tree and a radiocarbon age of >54,000 years (calibrated) was obtained on the exceptionally preserved specimen. Such an age is at the upper limit of AMS radiocarbon dating and simply indicates it is older than the date returned. In addition, the specimen was deformed and was elliptical in shape indicating that it had been compressed by a massive force. We interpret the specimen to have been buried, preserved under near anoxic conditions, and then overridden by an advancing glacier. Thus, the specimens and clay may likely represent a preserved remnant of a high elevation interglacial lake deposit. Alternatively, the log and wood could have been reworked and re-deposited during a Late Wisconsin proglacial phase.

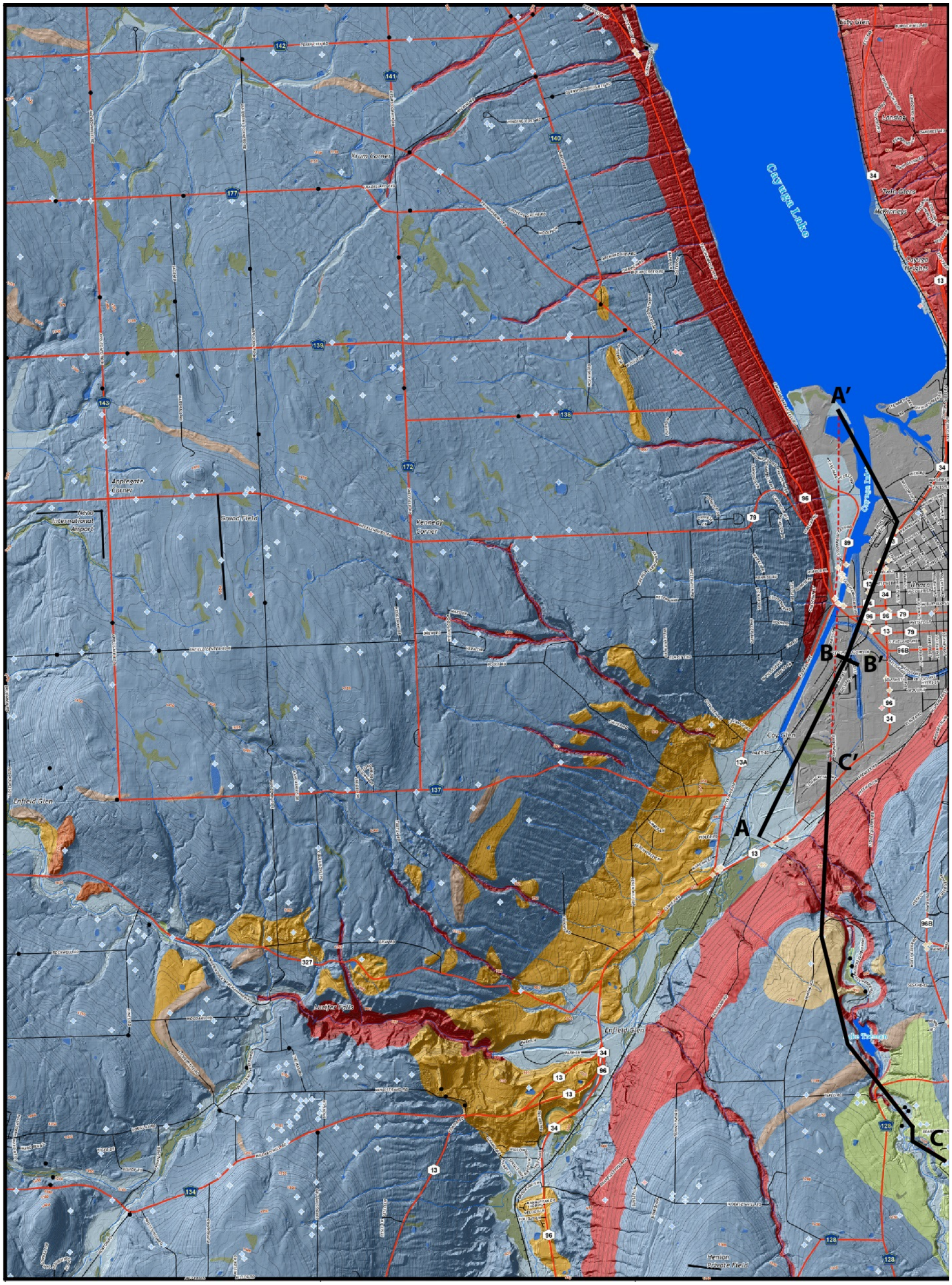

Figure 2. Surficial Geology Map - the Ithaca West Quadrangle. Legend and cross section locations including C to C' on the following page, other cross sections on Map and Chart 132.

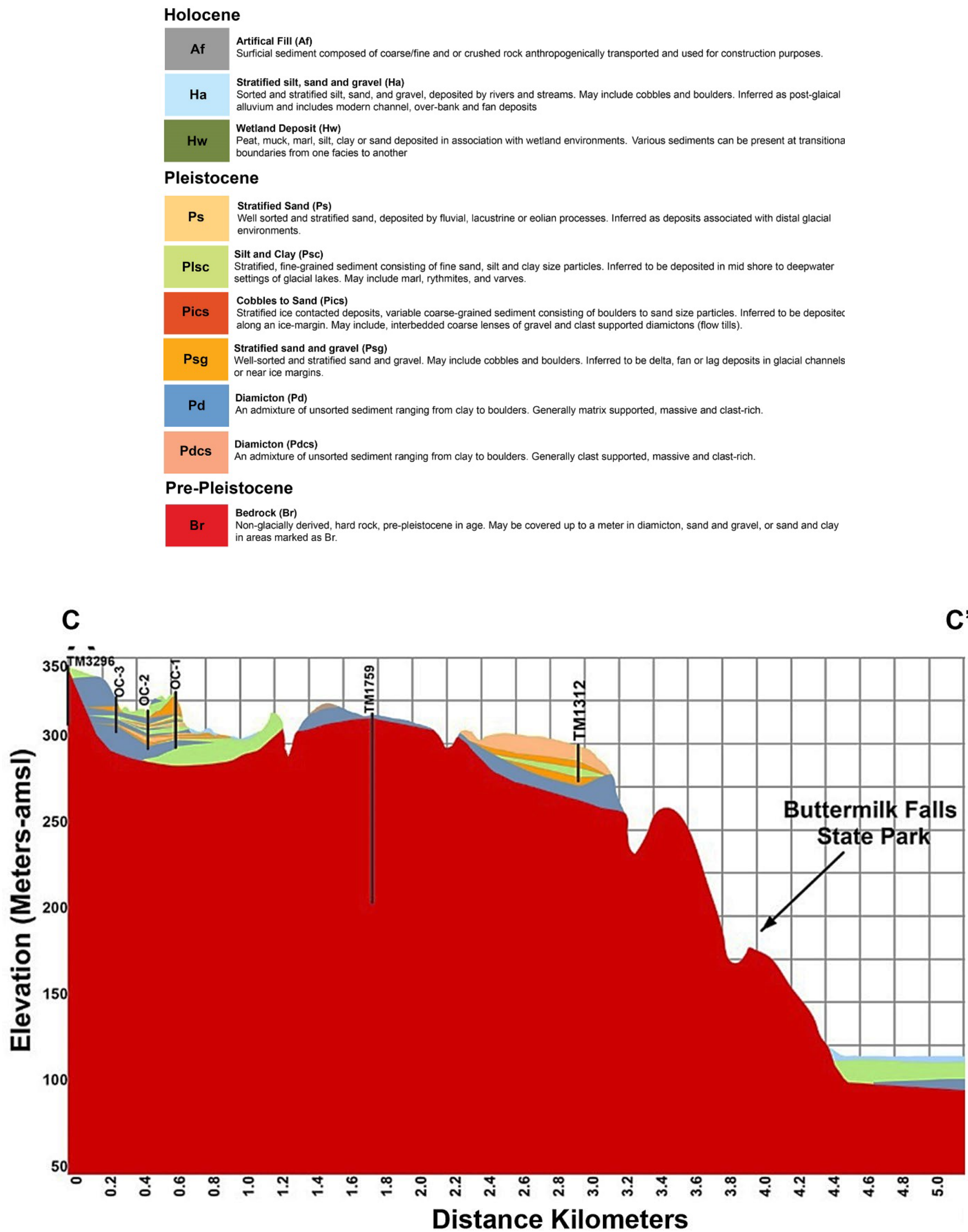

Figure 3. Map legend and geologic cross section C to C'. Note complex stratigraphy in uplands above Buttermilk Falls State Park in the Ithaca West Quadrangle.

Figure 4. Compact gray lake clay deposit at Upper Buttermilk Falls Gorge.

Figure 5. Deformed spruce logs >54,000 years old (calibrated age) retrieved from upper Buttermilk Falls.

Mullins et. al., (1996) utilized marine seismic techniques to explore and characterize the bedrock valley geometry and deposits within the Finger Lakes. The results of their study led to the formulation of three principal interpretations: 1) the basins are all carved into Devonian bedrock (figure 6), 2) the erosional efficiency of the major ice advance (presumed MIS2, Nissouri Phase) removed any and all preexisting deposits from within the basins, and 3) that the thick succession of deposits designated as seismic sequences I-VI are the product of the last glaciation (last 25,000 years).

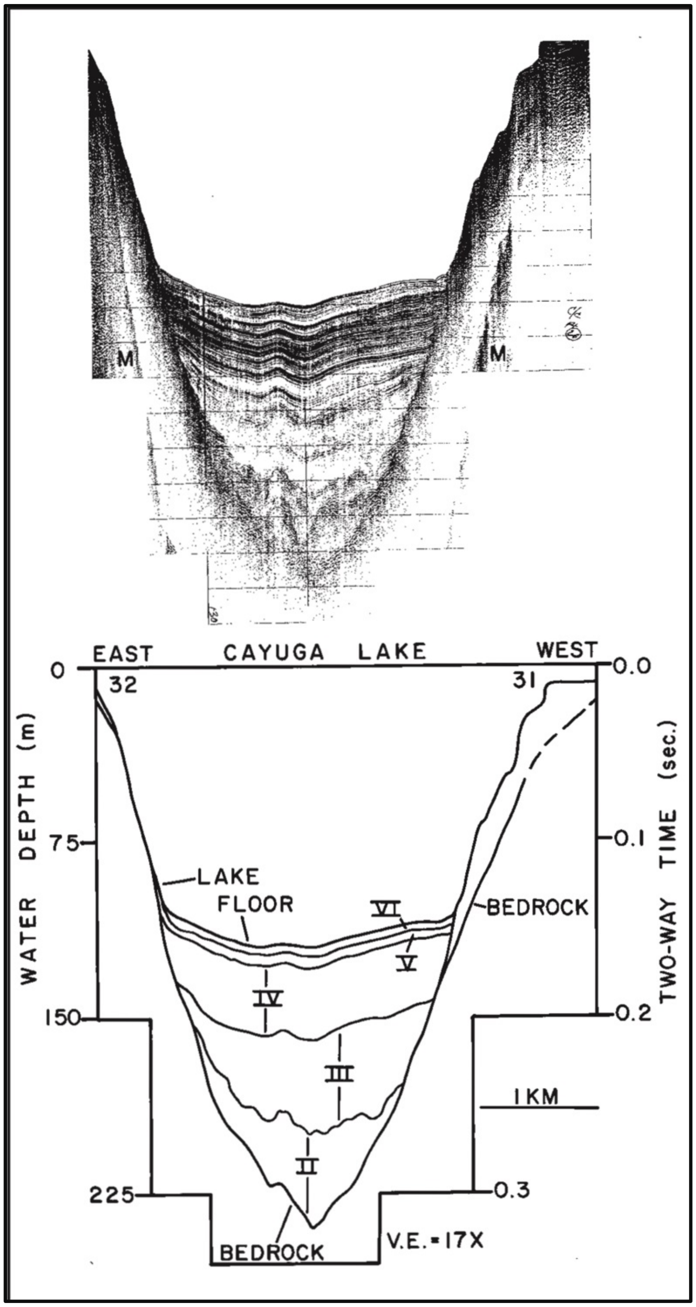

Figure 6. Seismic stratigraphic sequences developed by Mullins et. al., 1996 for Finger Lakes Basins in central New York.

Mullins et. al., (1996) confirmed stratigraphy with one 119 m (390 ft) core collected at the south end of Canandaigua Lake near Naples, NY, 75 kilometers northwest of Ithaca. No additional deep cores (>100 m) have been collected to constrain the seismic interpretations elsewhere in the Finger Lakes Basins. As we began surficial geologic mapping for Tompkins County it became obvious early on that existing, high quality, subsurface geologic data in the Inlet Valley and Ithaca Delta Plain is very limited. Further, the information that is available seldom exceeds depths of 91 m (300 ft); most records do not exceed 46 m (150 feet) in depth and the quality of geologic descriptions is highly variable. In order to accurately characterize the geologic framework and verify the seismic stratigraphy previously defined we collected a 56-meter (185 ft) deep continuous wireline core (NYSGS BH1818) at the Allen H. Treman Park State Marine Park on the southern end of Cayuga Lake (see accompanying Plate to this report).

In October of 2019 we collected a second continuous wireline core (NYSGS BH1917) at the end of West Buttermilk Falls Road at the State Park Boundary, adjacent to Buttermilk Falls Creek and Cayuga Inlet Stream (See accompanying plate on Map and Chart 132). This core was located 5.3 kilometers south of the BH1818 and penetrated multiple lithologic formations to a depth of 171 m (560 ft) without reaching bedrock. To our knowledge core BH1917 represents the deepest continuously cored stratigraphic test hole of Pleistocene sediments collected within the Finger Lakes Basins.

In addition to the continuous cores collected specifically for this study, we utilized lithostratigraphic information from six historic water wells installed over a horizontal distance of 300 meters along the delta plain in Ithaca for water supply during a typhoid epidemic in 1903. The stratigraphic information was obtained from United States Geological Survey Water Supply Paper No. 110, Plate V. (Whitney, 1906) and Tarr (1904) also described the stratigraphy of the artesian wells in context to the glacial geologic history.

Stratigraphic Framework

This study utilizes the two continuous boreholes (BH1818 and BH1917) completed by the NYSGS as anchor points to critically analyze the glacial stratigraphy. Several researchers (Tarr, 1904, Fairchild 1932, and Lawson 1977) have recognized that bedrock within the center of the trough was deeply scoured. In fact, only a handful of wells have penetrated the thick sediment package and encountered bedrock. Of these, the Salt Well A described by Tarr (1904) is the most commonly cited. Unfortunately, no detailed lithostratigraphic information of the glacial drift was recorded (Lawson, 1977) but the depth to rock was reported at 132 meters (430 ft). The location of Salt Well A can be seen on cross section A to A' on the Chart 132 that accompanies this report. Similarly, Mullins et. al., (1996) reported deep bedrock from seismic investigations in the south end of Cayuga Lake and more recently an undergraduate seismic study completed by May (2019) on the delta plain surface near the Inlet Creek indicated bedrock was likely deeper than 180 meters.

The objective of BH1917 was to continuously core to the bedrock surface and provide high quality lithostratigraphic information and confirm actual depth to bedrock in the Cayuga Trough south of the City of Ithaca. Despite a concerted effort on the part of NYSGS and their contracted driller, coring conditions became too difficult and coring efforts had to be abandoned at a depth of 171 meters (560 feet). Although, the bedrock objective was not achieved the resulting stratigraphic data obtained from BH1917 provides excellent resolution upon which to evaluate the Pleistocene deposits.

Upon first evaluation of cross section A to A' on Map & Chart No. 132 it is apparent that the surface lithostratigraphic units display a high degree of lateral continuity. The delta surface consists primarily of sand, silt and clay. Early reports describe several areas as muck, many of which are now leveled and filled within the City of Ithaca. This upper surface most likely represents a stabilized Holocene lake level and aggradation from stream inflow. Lacustrine sedimentation consisting of topsets may have occurred as a transgressive response to isostatic adjustment north of Cayuga Lake as the Ontario Lobe receded (Tarr, 1904). We correlate this surface and sediment to sequence VI of Mullins et al (1996). The next stratum dominated by sand and gravel facies is correlated to seismic Sequence V (Mullins et al., 1996). Historic wells described by Whitney (1904) and Tarr (1904) and integrated into this study as cross section B to B' suggest interstratification and greater lithologic variability is present. Tarr (1904) reported numerous logs, plant vegetation and mollusks were encountered in the construction of the wells. The geometry of the bottom contact as drawn in the construction of cross section B to B' resembles that of channels that appear to have been cut and filled. Further, several of the well descriptions describe clay with gravel, a term often used in drillers descriptions to describe till deposited by glaciers. However, based on the observed lithologies in from boreholes 1818 and 1917 no over-consolidated deposits resembling till were encountered in this interval . Instead, poorly sorted beds of silt, sand and gravel were recovered in BH1818 and these deposits appear to be turbidity type deposits. The sequence V correlative in BH1818 also displays well-bedded sections of sand and gravel with varying degrees of sorting and with angular intra-bed contacts. Based on the sedimentology of BH 1818 and the channel forms in cross section B to B' it is our interpretation that sequence V most likely represents clastic dominated deltaic deposits, possibly foresets. The resulting channel forms may be relict features from channel avulsion in the distributary channels to the delta. Such an interpretation might also explain the numerous reports of buried logs, vegetation and mollusks described in the early stratigraphic reports of Tarr (1904) and Whitney (1904).

The upper clastic unit correlating to Sequence V terminates abruptly into a finer-grained red and brown silt-clay unit that displays fine laminations and rhythmically bedded silt and clay that may be varves. The varved clays and laminations are very soft, and a 10 cm (four-inch) punch shoe was used to facilitate coring and avoid drill induced deformation to the core. Much of this unit and many of the silt–fine sand beds are easily fluidized upon recovery; no signs of deformation were observed in this interval to suggest the sediments had experienced compaction from glaciation. In borehole 1818 the contact between overlying sand facies and clay-silt facies occurred at 51 meters below ground surface at the Treman Marine Park and at a depth of 12 meters in borehole 1917. In Buttermilk Falls the clay-silt unit was 31 meters thick; to the north this unit is inferred to be as thick as 66 meters. By far this lithofacies is the most distinct and traceable subsurface unit forming a key stratigraphic marker. This unit is correlative to Sequence IV of Mullins et al. (1996). While BH1917 fully penetrated the sequence IV clays, borehole 1818 did not and terminated 5 meters into this stratigraphic unit. The thickness of sequence IV on the north end of cross section A to A' is estimated based on the inferred thickness reported from the Mullins et. al., (1996) seismic analysis and the uniformity in thickness observed between the Tarr (1904) wells and BH1917. It is worth noting that Mullins et al. (1996) hypothesized that sequence IV thinned at the south end of Cayuga Lake but the exploration cores from this study indicate that sequence IV deposits extend well into the Inlet Valley as would be expected if they were the result of deposition in high-elevation (>300 m (984 ft)-amsl) proglacial lakes.

The stratigraphic succession illustrated in cross section A to A' of Chart 132 agrees well with the seismic sequences IV-VI proposed by Mullins et al. (1996). In addition, Mullins et. al. (1996) described reflections from seismic sequence III underlying Sequence IV to indicate that this unit is a massive finer-grained deposit that has no internal structure and appear to be acoustically transparent. Sequence III was not sampled in Mullins et. al., (1996) study but he hypothesized the deposits in this sequence formed as a result of high rates of sediment accumulation. Kozlowski et. al., (2009) while mapping at the north end of Cayuga Lake in the adjacent Montezuma Wetlands, completed an exploration core and encountered a 21 meter thick unit of massive, cohesionless (flowing), well-sorted medium sand extending from 28 to 49 meters depth that would seem to correlate to seismic sequence III as described by Mullins et. al. (1996). Yet, no material consistent with flowing sands such as sequence III was encountered by borehole BH1917 or reported in any of the historic wells under the sequence IV lake sediments at the south end of Cayuga Lake. Instead, a dense, gray-brown to olive color, clast-rich, matrix-supported diamicton unit with a sharp contact appears directly under sequence IV. We interpret this indurated stratum as a till unit. In BH1917 this unit was less than half a meter thick but historic wells further north suggest the unit is more than two meters thick. If the sequence IV lake clays represent deposition during a high elevation proglacial lake phase when ice blocked the northern end of the basin then the underlying till unit most likely corresponds to till deposited by a previous glacial advance. According to proposed regional correlations (Muller & Calkin, 1993; Karrow et. al., 2000; Ridge, 2003; 2012) this till should be the Port Bruce Phase or Valley Heads till equivalent. Mullins et. al., (1996) reported that seismic sequence II in Skaneateles Lake to the east had possible till tongues produced by oscillating ice margins, and perhaps that interpretation is applicable here. However, if that is the case then the underlying deposits under the till should be seismic sequence I associated with the kame-moraine gravel lithologies associated with the Valley Heads Moraine and it is not. Instead BH1917 reveals that below the thin diamicton unit is a sharp erosional contact 52 meters below ground surface (70m- (229 ft)- amsl) below which a highly deformed, dense and indurated clay-silt unit >8 meters thick is present. This lithostratigraphic unit is interpreted as lake sediment that has been overridden by the glacier that deposited the overlying till. If not for the presence of the recovered thin till in BH1917 separating sequence IV clays and the subtill clays the two clay units would occur as a disconformable contact. In September of 1971 a rotary water well driller completing an exploration borehole (Layne well No. 12) for the Town of Ithaca near BH1917 (this study) included all three of these lithofacies as one clay unit. Several of the historic wells of Tarr (1904) and Whitney (1904) to the north also indicate that the same clay and fine-grained sediments are present below the till unit. Based on regional events proposed (Muller & Calkin, 1993; Karrow et. al., 2000 and Ridge, 2003; 2012) the dense, indurated and deformed lake sediment below the till most likely represents the Erie Interstade, or Erie Phase, a brief period of ice withdrawal (~18,000 calendar Yr B.P.) from the southern end of the Finger Lakes. As the age of the uppermost subtill clays are not known at this time they are illustrated here as Pleistocene lake clays (forest green color) on cross section A to A’ on Chart 132.

Within the Pleistocene clays (Erie Phase?) in BH1917 at an elevation between 70 and 30 meters (amsl) are two interbeds of sand and gravel and a lower bed of sand that are confined aquifer units. The upper sand and gravel unit is traceable for slightly more than two kilometers north to the Millard No. 2 well (Tarr,1904; and Whitney,1904). The historic wells in this location also record a second diamicton underlying the sand unit at about 40 meters elevation (amsl) that was interpreted as till (Tarr, 1904). This second till unit was not observed in BH1917 and may have been eroded or perhaps the second till unit represents a slight oscillation of a former ice margin.

Below the uppermost Pleistocene clays, at an elevation of approximately 30 meters (131 ft- amsl), is a 20-meter-thick sand and gravel dominated lithostratigraphic unit. The unit is bedded and contains interbeds ranging from well-sorted medium to coarse sand to coarse poorly sorted gravel and cobbles inferred to be ice contact units. The highly porous and granular nature of this sedimentary unit makes it a natural reservoir for groundwater. On cross section A to A' of Chart 132 this unit is labeled as confined aquifer number four. This unit was penetrated by the Trapp No.1 well (Whitney, 1906) and included in discussions of historic artesian wells.

The granular facies of confined aquifer unit number four observed in BH1917 abruptly terminates at an elevation of 11 meters (36 ft-amsl) with an underlying indurated and matrix supported till unit. The second till unit observed in BH1917 is slightly more than two meters in thickness whereas the same inferred till unit is less than 2 meters thick as reported in the Trapp No.2 well (Whitney, 1906) two kilometers to the north. This till, if it is as continuous as drawn on cross section A to A' (Chart 132) would serve as another important stratigraphic reference. The till unit represents another ice advance south of Cayuga Lake. If the upper till unit represents the Port Bruce advance and if the second till unit is in sequential order (no erosion of intermediate till units) then this unit by correlation should represent the Nissouri Phase ice advance in south central New York State. This advance is equivalent to the Marine Isotope Stage 2 (MIS 2) advance that extended to the late glacial maximum (LGM). It is worth noting that upon examination of cross section A to A' (Chart 132) the granular facies and clay units above the second till unit (11 to 35 meters elevation) form a continuing fining-up sequence or recessional sequence of till, outwash, proglacial lake sediments.

Below the presumed Nissouri Phase till (a depth of 117 m) from an elevation of 5 to -18 meters (16 to -59 ft--amsl) is another stratigraphic package of sediments that coarsen with depth. In BH1917 a three-meter-thick silt-clay unit overlies a four-meter sand dominant unit that grades into coarse gravel and cobbles of presumed ice contact origin. The Trapp No. 1 well penetrates the sand facies and is the last unit from BH1917 that can be correlated with the historic well data (Whitney 1904). The combined sand and coarse gravel facies appear on cross section A to A' Chart 132 as confined aquifer unit number five. The coarse gravel unit terminates at a third till unit at an elevation of -18 meters (-59 ft amsl). Clearly, this thin till predates the second till. Following the same earlier assumptions that significant erosion by glacial activity has not removed intermediate tills and that sequential order is maintained, then the lowest till unit is presumed to be pre-late Wisconsin or Middle Wisconsin in age (MIS 3). Radiocarbon dates ranging from 26,000-48,000 yr cal yr BP (calibrated) from varved lake sediment in Sixmile Creek (Schmidt, 1947; Karig and Miller, 2013) have yielded Middle Wisconsin ages. Other locations in the Finger Lakes have also reported Middle Wisconsin glacial deposits (Young and Burr, 2006; Kozlowski et. al., 2014). As was the case above, the stratigraphic progression of till, outwash and then lake sediments bracketing confined aquifer unit five is consistent with a recessional sequence that represents a Middle-Wisconsin or older event in the southern Finger Lakes.

Beneath the lowermost till unit encountered in BH1917 is yet another silt-clay lake sequence. Because the depth of this unit is below the extent of any of the historic water wells described by Tarr (1904) or Whitney (1906) we can only presume lateral continuity exists as is suggested by seismic sequences from within the basins (Mullins et al. 1996). Given this caveat, we have extended the lowermost Pleistocene Lake unit to the southern edge of the bedrock divide constrained by the recorded depth of salt well A. As was the case in the confined aquifer package number five the lowermost lake clays transition to coarser sediments below, beginning with a meter-thick unit of bedded sand and gravel. Beneath this unit is another unit dominated with coarse gravel, cobbles and boulders that was nearly identical to inferred ice contact deposits above. Exploration coring in this lowermost unit was exceptionally difficult and the coarse nature of the geologic material and groundwater conditions lead to the decision to halt further coring in BH1917. Based on the recovered material we know that this lowermost unit is at least 15 meters thick and forms another confined aquifer unit labeled as confining aquifer number six. Based on the depositional patterns of the overlying stratigraphic packages observed while completing BH1917 we predict that another till unit might occur at some unknown depth below an elevation of -50 meters (-164 ft--amsl). Actual depth to bedrock remains unverified.

In the process of completing exploration BH 1818 and 1917 with continuous wireline coring, numerous samples of wood, plant macrofossils and shells were recovered from stratigraphic intervals ranging from a few meters to 162 meters in depth. These materials are currently being examined and selected for their suitability to have AMS radiocarbon dating analyses performed. In addition, several sand units from deep stratigraphy were sampled for optical stimulated luminescence (OSL) dating. The results of these chronological methods will be published at a later date as results are received. It is our hope that the chronological data will confirm the stratigraphic model presented here or provide further data to revise the proposed chronostratigraphic framework.

Aquifer Conditions and Potential

As mentioned throughout this report several aquifers were encountered in the process of completing exploration boreholes 1818 and 1917 in this study. No flowing artesian conditions were encountered during the completion of exploration coring of BH1818. However, a confined aquifer is present in the sequence V sand and gravel facies that could be developed for water supply considerations. Borehole 1818 terminated with sequence IV clays, an aquitard of substantial thickness.

The hydrostratigraphic framework of the glacial deposits cored in BH1917 is more diverse and complex. First, it is worth noting that the Ithaca Delta Plain has a long history of flowing artesian wells (Tarr, 1904; Whitney, 1906). Prior to 1902 a well was constructed near the west side of the city to a depth of 85 meters (280 feet) in gravel produced artesian conditions flowing several feet above ground surface with a flow rate of 300,000 gallons per day. The knowledge of such flowing wells was the principle motivation for construction of the 13 wells to provide groundwater as a replacement for surface water during the typhoid epidemic of 1903. Lower rainfall amounts, drought, increased demand, decreasing well yields, and an unsuccessful groundwater exploration study (Layne study of 1971) in the mid-1960's resulted in the construction of a new surface water intake at Bolton Point on Cayuga Lake with a new water treatment facility. Several of the Layne wells in the 1971 study reported flowing artesian conditions present but yields were probably considered too low for a municipal source. Layne well number 12 was completed to a depth of 91 meters (300 feet) about 61 meters east of BH1917 on West Buttermilk Falls Road.

Due to the fluvial and alluvial setting of BH1917 deposits correlative to sequence V in BH1818 are near surface and occur as an unconfined or possibly semi-confined aquifer system with the water table at stream level of the Cayuga Inlet . As coring progressed into the Sequence IV lake clays a small confined aquifer was encountered (CA1 on cross section A to A' Chart 132) that produced flowing conditions of about 2 gallons per minute and a static head of about 1 meter above ground surface. After coring through 50 meters of sequence IV and the inferred Erie Phase clays, 61 meters (200 feet) of steel casing was set and cemented with a flow diverter on standby to shut in any high-volume flowing conditions encountered. Immediately, below the casing a second confined aquifer and then a third confined aquifer were encountered. The use of weighted mud at 9.0lbs/gallon easily suppressed the moderate artesian conditions present. Continued coring encountered a fourth confined aquifer system that we estimate to be moderate to highly productive. Although no hydrogeologic testing was performed on confined aquifer number 4 on one occasion artesian pressure ejected several dozen gallons of 9.0lb/ gallon mud into the portable mud pit overnight while drilling operations had ceased. Assuming a depth of 328 ft and with an average diameter of a 5.5 inch borehole would equate to a volume of 424 gallons of drilling mud. Utilizing a 9.0lb drilling mud for this volume would equate to a static force of 3,816 lbs of confining of weight. Divided by an area of 20 square inches at the bottom of the borehole yields a hydrostatic pressure of 191pounds per square inch (psi). The artesian pressure was enough to lift this weight of mud a few feet before the borehole collapsed and back filled the borehole. These calculations should serve to provide a crude calculation of artesian pressure present in confined aquifer number 4. With the steel casing and weighted muds increased to 10 lbs/gallon, flowing conditions were suppressed, and continued coring could progress. It is interesting to note the Layne well number 12 appears to have stopped only a few meters short of this aquifer during the 1971 study.

As coring penetrated the second deep till unit (inferred Nissouri Phase) a fifth confined aquifer unit was encountered. This aquifer appears to be a prolific groundwater resource by our estimates and contains an abundance of large coarse gravel and cobbles many of which were exotic (erratic) lithologies such as granite and gneiss. As a testament to the coarse nature of the gravel/cobble lithologies encountered we provide this example. The first coring bit installed new at the initiation of BH1917 lasted for 128 meters (420 feet) of coring before wearing out. At this point the drill string was tripped out of the borehole and a new coring bit was installed and coring resumed. Within 4.6 meters of resuming coring, penetration became greatly diminished and we considered that perhaps a cobble had become lodged in the core bit and was preventing the cutting teeth from making contact with the gravel and cobbles in the formation. Thus, in this scenario we thought we were trying to push a cobble through the gravel formation. The drill string was again tripped out and upon inspection, no cobble was found to be plugging the core bit opening; instead the core bit was fully worn with all the cutting teeth worn to a level of the previous bit and had to be discarded. At this point, a ~15 cm (5-7/8th inch) diameter tricone bit was installed to advance through the remaining gravel in confined aquifer unit five.

Once coring progressed through the lowermost confining unit of till and lake clay, a sixth confined aquifer system was encountered. Of all the aquifers encountered in this stratigraphic investigation, it is our impression that this lowermost aquifer has the most potential to serve as a major water supply for the town of Ithaca and perhaps a larger regional area. We make this statement on the basis of the observation that we were still experiencing episodic intervals of slight artesian push despite the added volume of 10 lb/gallon mud. More specifically and as an example, at a depth of 525 feet using an average diameter of five and half inches for the borehole the weighted mud would yield a counterforce equivalent to ~6,250 lbs, equating to 313 psi of confining pressure. The use of weighted mud worked exceptionally well to stabilize and suppress artesian flow in the five confining aquifers encountered above the lowermost gravel aquifer. However, coring proved very difficult in these coarse deposits and on multiple occasions the basal gravel unit was so porous that the weighted mud began to infiltrate the lowermost formation rather than return as circulation to the surface. Eventually, the coring slowed to rates of penetration of only 2 meters per day and ultimately it was decided to abandon efforts to continue coring in these difficult materials. Once coring ceased the borehole was plugged with cement in accordance to NYDEC standards, a staff member from the Division of Mineral Resources Office reviewed and approved all plugging procedures and inspected the borehole upon completion.

All of the lower aquifers encountered in BH1917 are believed to be artesian and without the counterforce of the weighted mud would most likely lead to flowing artesian wells. That said, confined aquifers four and five would almost certainly flow above grade but would appear as high volume, low to moderate pressure flowing wells. The sixth lowermost confined aquifer may have tremendous potential as a groundwater resource. While we did not conduct any hydrogeologic testing of this unit, it is the estimate of the both the driller and the project geologist that the lower aquifer would easily produce 500 gallons per minute and perhaps 1000 gallons a minute or more. With a proper well-field design this aquifer might possibly serve as a municipal supply of groundwater. In order to test this hypothesis we would recommend a well-designed hydrogeological pump test and installation of monitoring wells to evaluate draw down and calculate actual hydrogeologic aquifer properties.

Lastly, a word of caution. With the recognition that artesian flowing conditions were possible, and the anticipated depth of coring expected to exceed 152 meters (500 feet) the State Museum- Geological Survey coordinated and sought guidance from New York State Department of Environmental Conservation (NYSDEC) Division of Mineral Resources for suggestions and recommended criteria to incorporate steel casing and flow diverters as a precaution to isolate and control artesian conditions present. In addition, the NYSGS hired a drilling contractor specializing in wireline coring of Pleistocene soils and with expertise in weighted drilling mud and use of steel casing to combat flowing artesian conditions if encountered. If further hydrogeological testing proceeds it is our recommendation that similar planning and precautions be taken.

Societal Relevance and Recommendations for further study

The focus of this stratigraphic study was to provide greater stratigraphic resolution to the complex and thick Pleistocene deposits in the Inlet Valley and Ithaca Delta Plain. The study was designed to align with the Natural History Mission of the State Museum and provide greater clarity and understanding of Ice Age events in the southern Finger Lakes region. The study also dovetails with State Geologic Survey Mission and that of the United States Geological Survey National Cooperative Mapping Program to map geologic frameworks and collect data that is both relevant and beneficial to society.

While the present water supply is derived from surface water from Cayuga Lake, a new threat has emerged to such surface water resources in the form of harmful algal blooms (HAB's). While the cause of HAB's is the focus of much study, HAB's continue to remain problematic for water treatment facilities. Presently, the City of Auburn located at the north end of adjacent Owasco Lake is facing the same challenges to its drinking water supply and HAB's continue to adversely affect water quality. Unlike surface water, groundwater is not subject to the development of HAB's and thus if found in sufficient quantities and suitable quality it can possibly serve as an alternate or supplemental water resource for times of intense HAB development. The aquifers defined by this detailed stratigraphic coring study serve as an example that continued mapping and coring activity of the State Museum-Geological Survey in Tompkins County is providing valuable information. To further refine and characterize the geologic framework. We recommend additional coring and detailed geologic mapping throughout the county as resources permit.

Conclusions

The Stratigraphic framework investigated in this study further illustrates the complex glacial history that impacted the Finger Lakes region of central New York. Through detailed core drilling and incorporation of previous studies it is clear that the buried deposits in the Inlet Valley to Cayuga Lake and subsequent construction of the Ithaca Delta Plain record at least three cycles of glaciation. It is also quite possible that deeper deposits beyond the reach of coring completed in this study would provide direct evidence of the Illinoian- (MIS 6) glaciation, and perhaps earlier glaciations. Pending chronologic data from boreholes 1818 and 1917 will help solidify the geologic interpretations presented in Chart 132. Further, this study reveals that multiple deeply buried artesian aquifers are present and could likely serve as municipal water supplies to the Town of Ithaca.

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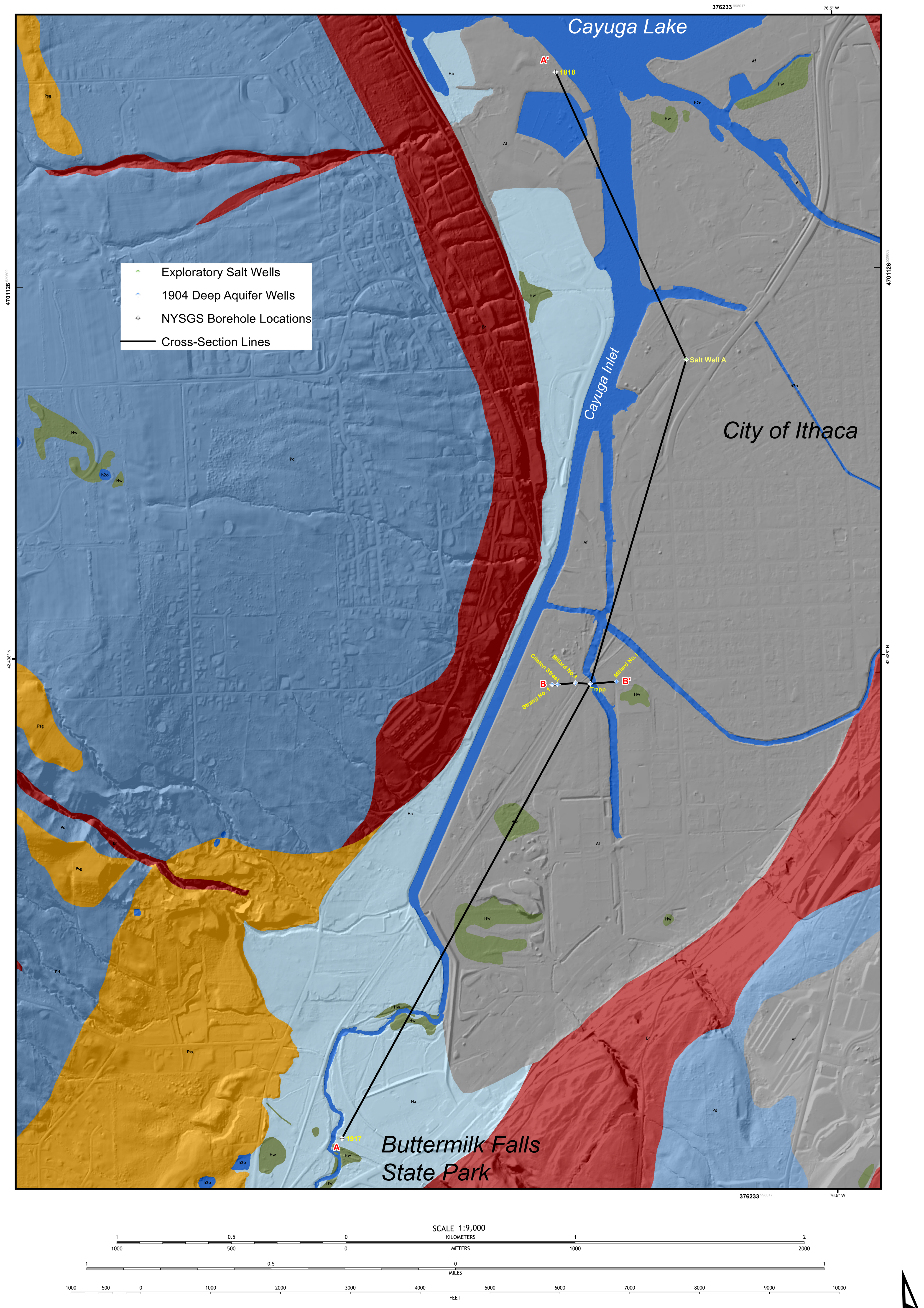
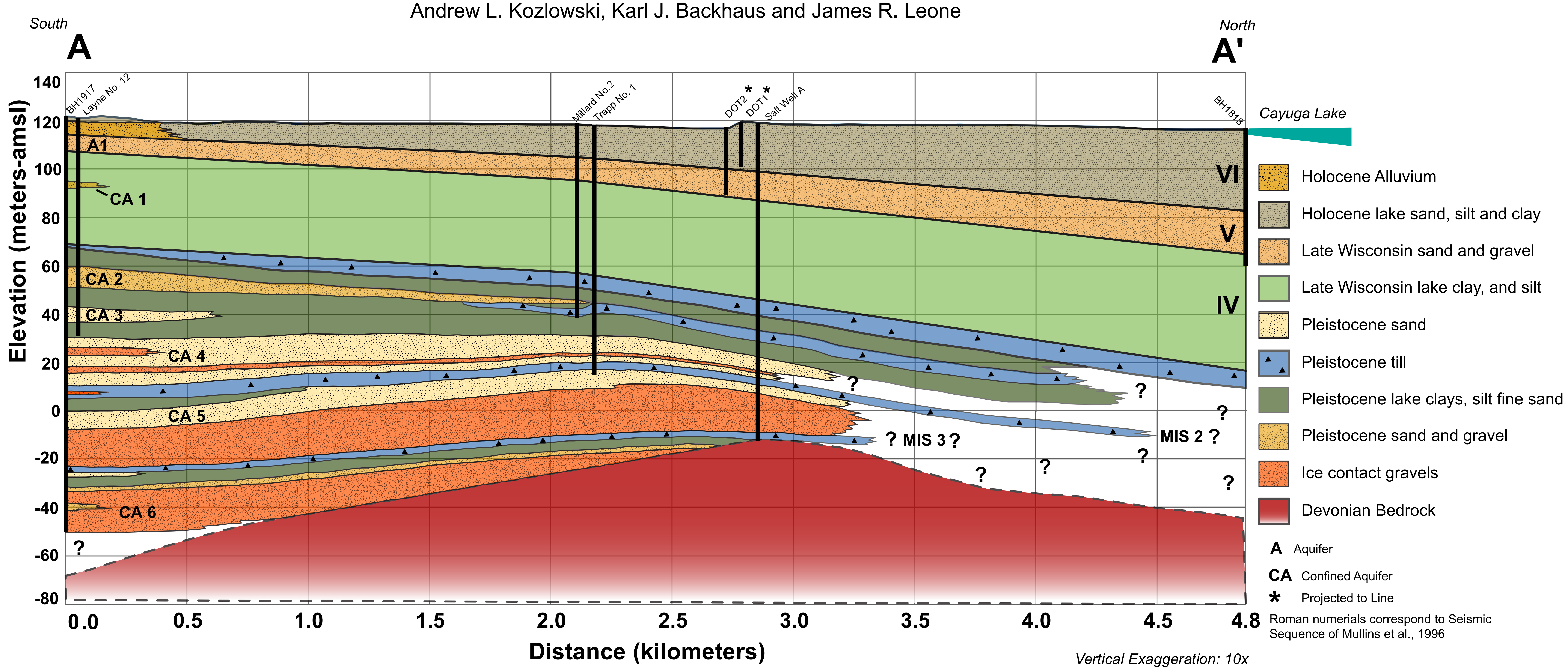
Glacial Stratigraphic Framework of the Cayuga Inlet Valley and Ithaca Delta Plain

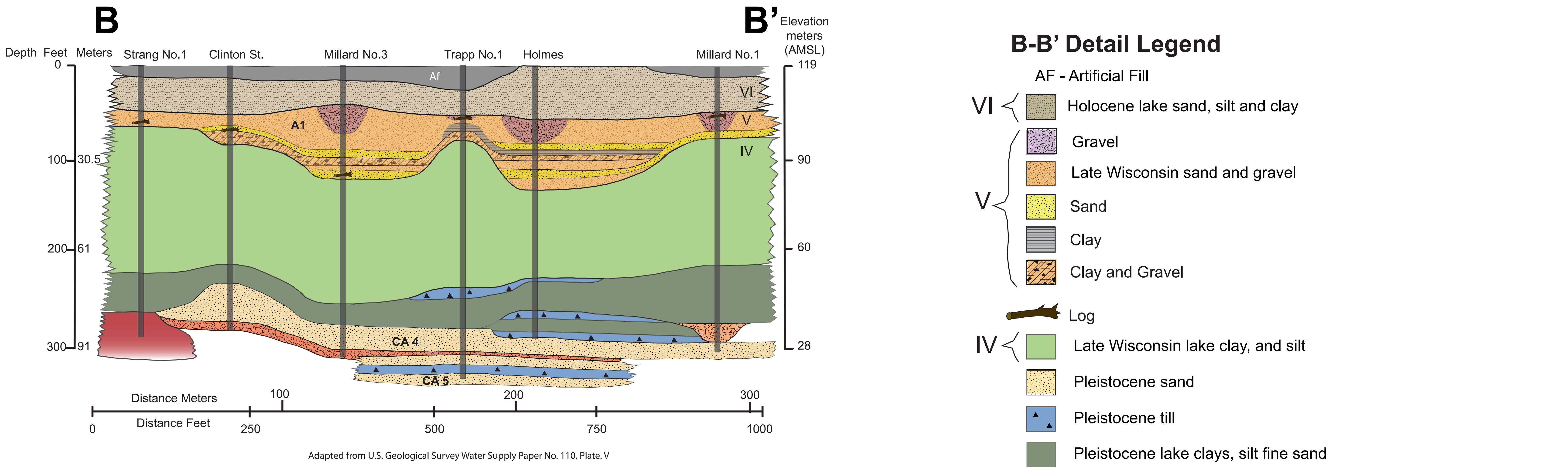
Ithaca West Quadrangle,Town of Ithaca, Tompkins County, New York

Andrew L. Kozlowski, Karl J. Backhaus and James R. Leone



Overview Map of the Cayuga Inlet Basin Cross-Sections A-A' and B-B', Tompkins County, New York





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For Details, See Technical Report NYSGS 01-20

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