Trip A-1

GLACIAL AND ENVIRONMENTAL GEOLOGY OF THE ONONDAGA TROUGH, CENTRAL NEW YORK

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INTRODUCTION

The Onondaga Trough valley is a vestige of the glacial history of central New York. The trough extends from the outlet of Onondaga Lake southward, through and south of the City of Syracuse, to and beyond the Valley Heads Moraine at Tully, N.Y. Geologic and hydrologic research focused on the Onondaga Trough has been ongoing for several decades through numerous academic institutions such as State University of New York at Cortland and Syracuse [School of Environmental Science and Forestry (ESF)], Syracuse University, Hamilton College, and Colgate University (among others). In addition, the USGS, in co-operation with USEPA-Region 2, Onondaga County, the Onondaga Lake Partnership, and the Onondaga Environmental Institute, has conducted studies of the Onondaga Trough valley during the last two decades. On-going surficial and bedrock mapping associated with the USGS STATEMAP program have helped to construct a stratigraphic framework that has been used in the development of numerical ground-water-flow and brine-migration models. These models are being used to support central New York's major urban hydrogeology challenge – improving the water quality of Onondaga Lake (purportedly one of the most polluted lakes in the country) and fostering the urban renewal of the adjacent area. Participants on this NYSGA trip will see how glacial geology and hydrology, and engineering geology interact.

ROADSIDE STOPS OVERVIEW

This fieldtrip will be a 10-year retrospective assessment of activities that have occurred since the 1997 NYSGA 69th Annual Meeting at Hamilton College. This 2007 fieldtrip is co-authored by a number of individuals who are familiar with their subject area and each will provide a summary of their work in the following pages. The field-trip stops will commence at the Village of Homer well field (Stop 1), and then progress northward in the Onondaga Trough valley, with stops at the Tully Lakes area (kettle lakes) situated on the Valley Heads Moraine (Stop 2) where the headwaters of West Branch of Tioughnioga Creek (Susquehanna River Basin) will be viewed and its hydrogeology discussed, then further north over the Tully Moraine and down into the Onondaga Creek valley where the unique Tully Valley mudboils will be visited (Stop 3). The remaining two stops will be around Onondaga Lake in Syracuse. An introduction to the Onondaga Lake setting will take place at the Inner Harbor (Stop 4). Discussions will center on the interaction of glacial geology, engineering, anthropogenic contamination of nearshore and in-lake environments, and the brine-filled aquifer. We may also discuss urban redevelopment of shoreline areas, the unique hydrology of the Onondaga Lake Outlet. We'll then hear about the impact of wastebed deposits from the Solvay Process, the associated chemical wastes from the Allied Corporation, now Honeywell Corporation, and the current clean-up plan for Onondaga Lake while standing atop of these massive wastebeds (Stop 5).

Disclaimer

All of the field sites described in the guidebook article and road log are on private property. As such, it is imperative that we respect the rights and wishes of these land owners. Please do not visit these sites on your own, as it may jeopardize future field-trip opportunities. Over the past 15 years it has become increasingly difficult to maintain our access agreements to these sites as individuals and even groups of people have entered these properties without obtaining land-owner permission. We strive to maintain good relations with the land owners and do not want the inappropriate actions of a few to ruin the educational opportunities for many others who wish to enter these areas. The USGS can, and does act as the 'gate keeper' for the property owners and we would be happy to facilitate your future access to these sites. Please contact Bill Kappel for any questions as to access for you and your classes.

HYDROGEOLOGY OF THE ONONDAGA TROUGH

[This section prepared by W.M. Kappel, T.S. Miller, and D.L. Pair]

Onondaga Trough (Valley) Geologic Data Collection and Analyses

The primary sources of geologic data that contributes to our understanding of the Onondaga Trough (Figs. 1 and 2) are logs of test holes drilled at construction sites throughout the trough for buildings, roads, bridges, public utilities, and other projects. Many of these projects are concentrated in the urban area of Syracuse and along major highways. Test holes outside Syracuse are scant and the data are generally less detailed because only limited geologic data are required for most small-scale construction in rural areas. Test-hole logs (descriptions of materials penetrated) provide data on stratigraphy (layering of the glacial sediment), soil properties (permeability, compactness, texture, color), and ground-water levels encountered during drilling.

Information in rural areas was obtained mainly from local ground-water studies and from well records collected through the New York State Department of Environmental Conservation (NYSDEC) well permitting program established in 2000. Additional stratigraphic data for the valley-fill deposits were obtained from 12 deep test holes drilled for USGS investigations conducted between 2000 and 2004 in the central and northern parts of the Onondaga Trough (Fig. 2) and from wells drilled for the salt-dissolution operation on the backside of the Valley Heads moraine near Tully, N.Y.

A listing of USGS reports (including website addresses for these reports) is included as Appendix 1, while a bibliography of cited references is provided at the end of each of this fieldtrip. The USGS reports supplement the information contained herein and should be in-hand while reading the following sections or referenced during the field trip as the report figures (and colors) provide much greater detail.

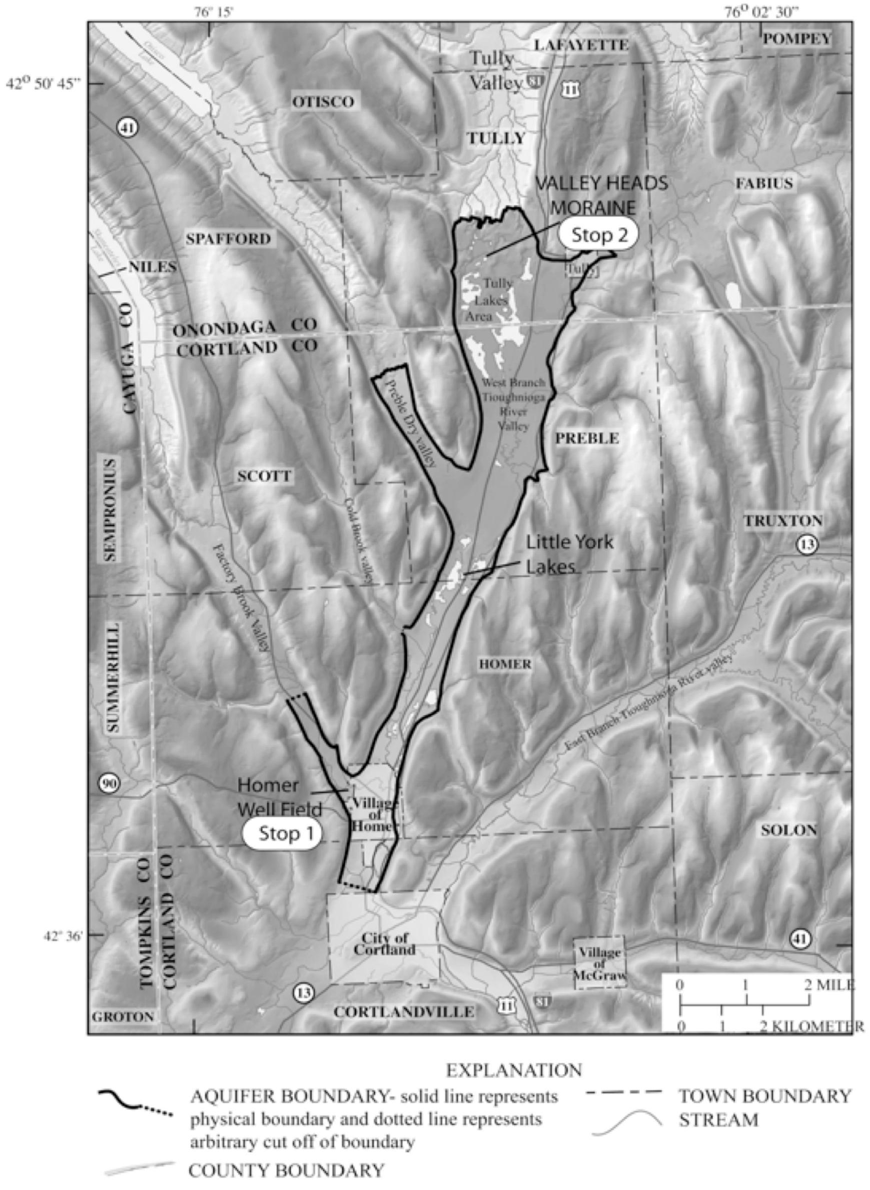


FIGURE 1—The southern part of the Onondaga Trough – West Branch of Tioughnioga Creek valley showing the aquifer boundary for the West Branch ground-water-flow model and location of key features.

Geologic Overview of the Onondaga Trough

The geologic section shown in Figure 3 is along the thalweg (deepest part) of the trough with hills projected in the background and depicts the general southward dip of the sedimentary bedrock units (40 to 50 feet per mile). The unconsolidated deposit geologic section shown in figure 4 is a longitudinal transect roughly following the axis of Onondaga Trough and extends from the Onondaga Lake outlet to and just south of the Valley Heads (Tully) Moraine. If the reader is interested in viewing more geologic sections, there are seventeen sections shown in the paper by Kappel and Miller (2005) that depict unconsolidated materials in the Onondaga trough and its tributary valleys. These sections were constructed to depict the configuration of the bedrock surface below the valley floor, as well as the generalized stratigraphy of the glacial deposits that overlie bedrock.

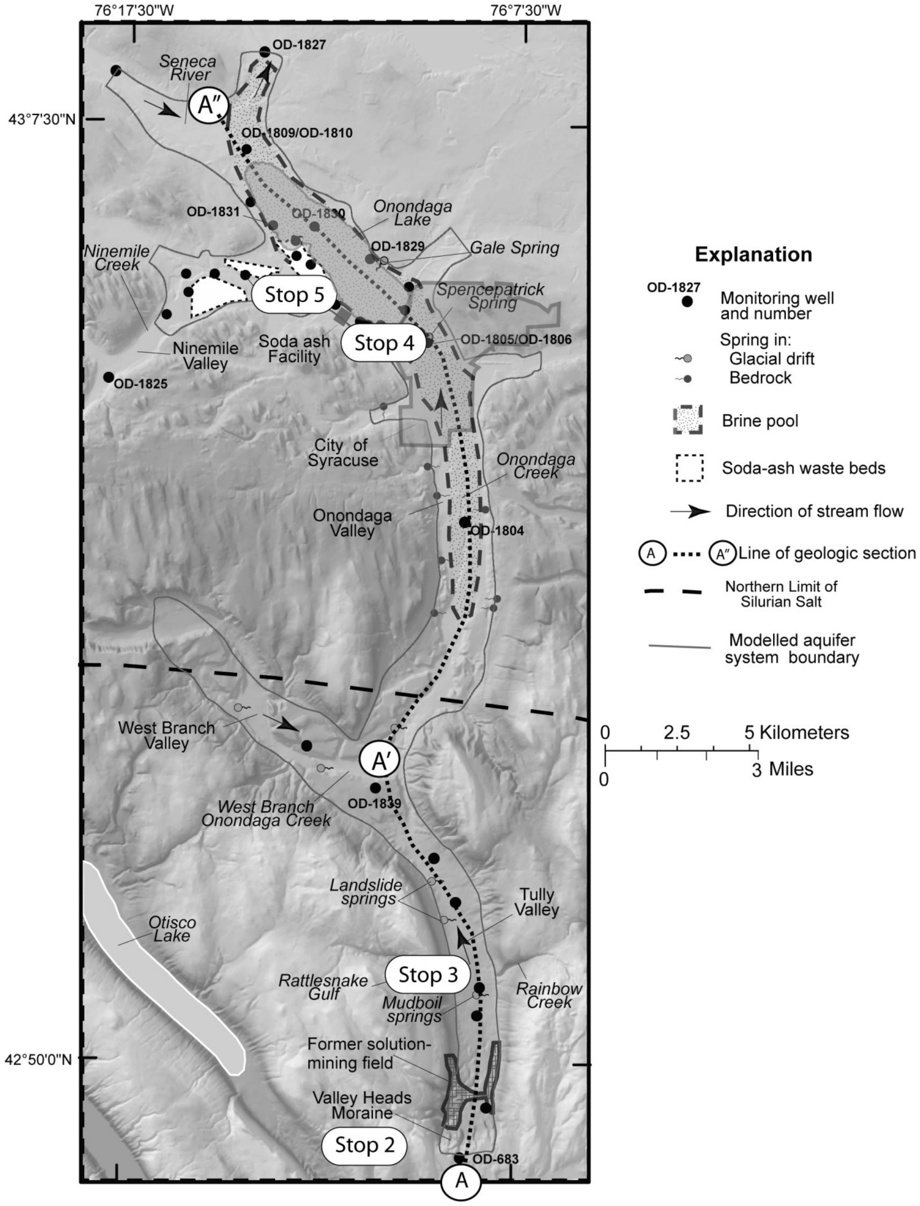


FIGURE 2—Geographic features of the central and northern Onondaga Trough including physical and man-made features, location of wells and borings, springs, the soda-ash facility and associated wastebeds, and location of the brine pool in the valley-fill sediments.

Additional products from the USGS study of the central and northern sections of the Onondaga trough (Tully Valley and Onondaga Valley) included geographic information system (GIS) based shaded-relief maps of (1) the land surface in the Syracuse area (fig. 1 in Kappel and Miller, 2005) and (2) the underlying bedrock surface in the Onondaga Trough (figs. 2 through 4 in Kappel and Miller, 2005). The elevation of bedrock surface map was generated by interpolating elevation data from test-hole logs and other data sources, and subtracting these values from the Digital Elevation Model (DEM). The resulting dataset was directly applied to the ground-water-flow model to generate elevation grids of the bedrock surface that established the hydrogeologic framework for model simulations of ground-water flow and brine migration in the Onondaga Valley unconsolidated aquifer.

The shaded-relief map in figure 2 of Kappel and Miller (2005) depicts an oblique "birds-eye-view" of the bedrock floor of the Onondaga Trough as if all the glacial sediments have been removed from the valley. However, there were little data available on bedrock elevation in the upland areas surrounding the Onondaga Creek, Otisco Lake, and Butternut Creek Valleys therefore, the land outside the Onondaga Trough represents land surface elevation, not bedrock elevation. A contoured representation of the elevation of bedrock surface in the Onondaga Trough is shown in figure 4 of Kappel and Miller (2005). The bedrock-surface elevations range from about -25 ft below mean sea in the deepest part of the trough (under the southern end of Onondaga Lake and the city of Syracuse) to greater than 550 feet along the edges of the trough. The bedrock elevations are greater than 1,400 feet along ridge tops on either side of the trough, but upland elevations higher than 550 feet are not depicted in that figure.

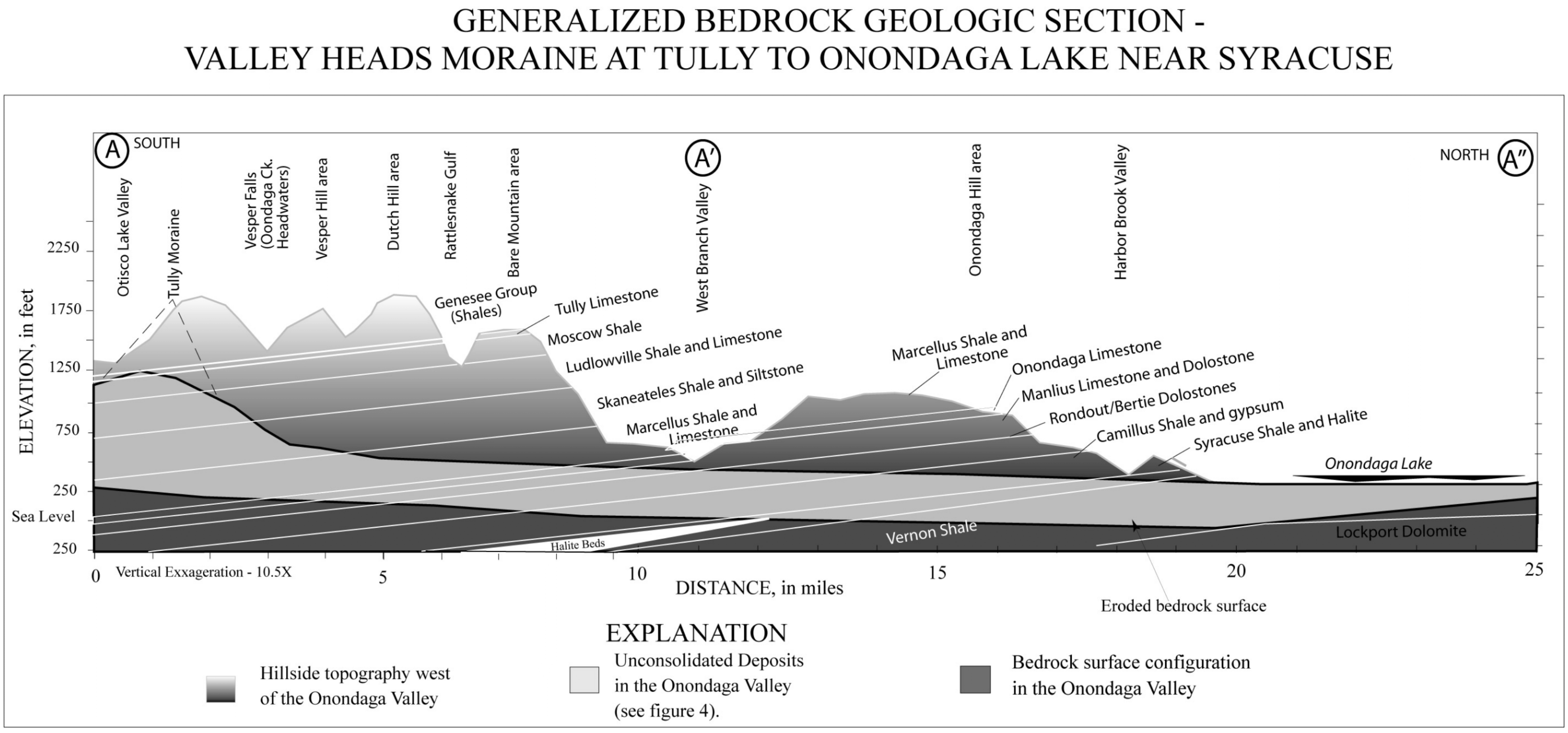
The bedrock floor of the trough rises southward from just south of Syracuse to at least Little York Lake in the West Branch Tioughnioga River valley (fig. 1). The bedrock floor levels out between Little York Lake and Cortland. The bedrock floor also rises to the north under Onondaga Lake (Fig. 2). The thickness of unconsolidated valley-fill deposits along the thalweg of the Onondaga Trough, from Onondaga Lake to the Tully Moraine, averages 420 feet, but near the moraine it exceeds 800 feet (Kappel and Miller, 2003). Valley-fill deposits in the southern part of the Onondaga Trough, in the West Branch valley of Tioughnioga Creek, range from 350 feet to the north, closer to the moraine, and thin to about 250 feet thick to the south, near Cortland.

Bedrock Stratigraphy

Sedimentary rock units of Silurian and Devonian age gently dip 40 to 50 feet per mile to the south (Fig. 3) Halite units (salt) are probably exposed in the floor of the trough and thicken to the south (Fig. 3). Bedrock units in central New York appear as east-west trending bands, therefore the older (Silurian aged) units underlie the lowlands north of Syracuse, whereas the younger (Devonian aged) units underlie the southern part of the trough and form the hills bordering the trough (Fig. 3). The stratigraphic column (Fig. 5) summarizes the characteristics of the bedrock sequence from the Upper Silurian through Middle Devonian time period, and includes the group and formation names, the lithology, and relative thicknesses of the bedrock units.

Unconsolidated Stratigraphy of the Onondaga Trough

Geologic sections along and across the Onondaga Trough and some tributary valleys (fig. 7 and sections A-A' through Q-Q' in Kappel and Miller, 2005) were constructed using records from hundreds of test-hole logs drilled in the greater Syracuse area. These sections were assembled from data sources that span more than 50 years of varied drilling techniques and sediment descriptions. The geologic interpretation of driller and consultant logs have been modified and many times simplified, to conform to the New York State Geological Survey's lithologic characterization of glacial sediments (Pair, 1998a, b). The simplified longitudinal geologic section of unconsolidated sediments along the Onondaga Trough from Tully, N.Y. to the Onondaga Lake outlet is shown in Figure 4. This section depicts the layering of sediments deposited generally from south to north during the recession of the glacial ice from this part of New York (from 12,000 to 14,000 radiocarbon years ago). This period of recession included pauses and brief readvances of the ice margin in the Onondaga Trough.



GENERALIZED BEDROCK GEOLOGIC SECTION -
VALLEY HEADS MORAINE AT TULLY TO ONONDAGA LAKE NEAR SYRACUSE

FIGURE 3—Geologic section along the thalweg of the Onondaga trough valley from the Valley Heads moraine to the Onondaga Lake outlet showing the generalized bedrock stratigraphic sequence.

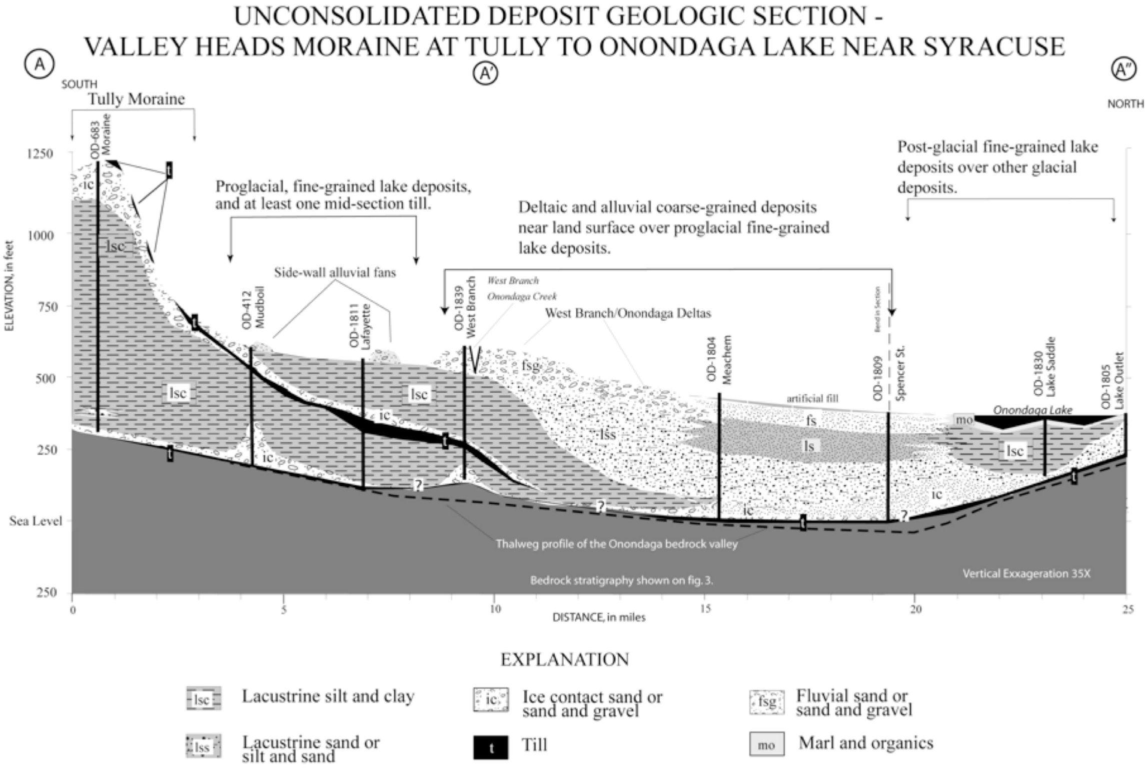


FIGURE 4—Geologic section along the thalweg of the Onondaga trough valley from the Tully Moraine to the Onondaga Lake outlet, showing the generalized layering of unconsolidated sediment in the valley-fill deposits.

Glacial History and Hydrogeology of the Valley Heads Moraine at Tully

The Valley Heads Moraine at Tully, N.Y. forms part of the largest end-moraine complex in central New York and forms the present surface-water divide between drainages that flow north to St. Lawrence River and drainage that flow south to Susquehanna River. The ice in the Onondaga trough came to its standstill position just west of Tully, N.Y. at about 17,000 Cal BP years ago (Ridge, 2003) where it formed the segment of the Valley Heads Moraine shown in figures 3 and 4. The surface-water divide is just south of New York State Route 80 where it crosses the moraine. The surface-water divide doesn't correspond to the ground-water divide as it is generally further to the south, and its position changes seasonally according to local ground-water conditions (Kappel and others, 2001).

The melting of the ice front and the glacial retreat northward from the Valley Heads Moraine resulted in the formation of a proglacial lake between the retreating ice front and the Valley Heads Moraine. Initially, this lake drained to the south through an outlet channel(s) across the Valley Heads Moraine, but as the ice front retreated northward, toward present-day Syracuse, successive outlet channels with progressively lower elevations were exposed along the east side of the valley about 10 miles to the north (Hand, 1978), and sequentially lowered the lake levels. As the ice retreated from the Tully valley segment, large amounts of coarse-grained sediment (sand and gravel) were transported southward through subglacial tunnels; some was probably deposited within ice tunnels as sinuous esker ridges, and the remainder was disgorged into the proglacial lake as subaquatic fans. The finer-grained sediment (fine sand, silt, and clay) was carried out into the lake where it settled to form lake-bottom deposits that buried the older, coarser-grained subglacial sediment. When the Valley Heads ice retreated past Syracuse (about 15 miles north of Tully), the lake drained entirely and glacial deposition in the trough ceased.

STRATIGRAPHIC COLUMN OF BEDROCK UNITS IN THE ONONDAGA TROUGH VALLEY

	Age, in millions of years	GROUP	FORMATION Member	LITHOLGY	THICK-NESS
DEVONIAN	374 Middle		TULLY	Limestone	30
		HAMILTON	MOSCOW Windom	Shale and sandstone	180
			LUDLOWVILLE Portland Point ls. Owasco Spafford Ivy Point Otisco Centerfield ls.	Shale and limestone	10 1-3 25 50-60 160-180 30
			SKANEATELES Butternut Pompey Delphi Station Mottville	Shale and Siltsone	100-200 60 100 45
			MARCELLUS Cardiff Chittenango Cherry Valley Union Springs	Black Shale and limestone	185-200 100 3 13-15
			ONONDAGA Seneca Moorehouse Nedrow Edgecliff	Limestone, grey,with some cherty layers and one or more bentonite layers	27 24 14 12
	387 Lower	TRISTATES	ORISKANY	Sandstone, white	0-5
		HELDERBERG	MANLIUS Pools Brook Jamesville Clarks Reservation Elmwood Olney	Limestone and Dolostone, grey/brown	5 16 15 12 40
			RONDOUT Chrysler	Dolostone	50
SILURIAN	408 Upper		COBLESKILL	Limestone	25
		BERTIE	Oxbow Forge Hollow Fiddler s Green	Mostly Dolostone with Gypsum layers	9 55 30
		SALINA	CAMILLUS	Shale, tr. Gypsum, some Dolomite	250
			SYRACUSE	Shale, Halite and tr. Gypsum, black	275
			VERNON	Shale, Gypsum - green/red	500-600
	421	LOCKPORT	LOCKPORT	Dolomite, Grey	120-140

FIGURE 5—Stratigraphic column of bedrock found below and surrounding the central and northern sections of the Onondaga trough

At Tully, N.Y., large amounts of sediment accumulated at the ice front as a result of the meltout of englacial material that had been eroded and transported from the bedrock valley floor and walls. In addition, subglacial meltwater discharging from conduits at the base of the ice disgorged sediment as subaqueous fans at the ice front. Meltwater that flowed on top of the ice transported supraglacial material to the ice front in channels on or within the disintegrating ice front. A hummocky landscape developed at the ice margin as large amounts of sediment were deposited on the disintegrating ice to form kame, kettle, and glacial karst features. Kame mounds and ridges of glacial drift (mixed glacial sediments) formed across the Valley Heads Moraine; the drift generally consists mostly of coarse-grained sediment (sand and gravel) that settled to the land surface as the ice melted. Kettle hollows sometimes formed between kame mounds as a result of the melting of buried ice masses that became separated from the retreating ice front. Glacial karst formed in areas of relatively thick glacial debris that covered and insulated residual ice masses. Internal drainage networks may then have developed beneath these masses and these drainage conduits slowly enlarged to the point that the overlying ice collapsed to form depressions and sinuous chains of craterlike depressions. Green and Tully Lakes together have a sinuous form that may reflect a former collapsed meltwater conduit(s) (see fig. 4, Kappel and Miller, 2003).

Two deep test wells (well OD-685, 560 feet deep; well OD-683, 830 feet deep, (fig. 5, Kappel and Miller, 2003) were drilled by the USGS on the Valley Heads Moraine and over the deepest part of the valley. Neither well reached bedrock, although the deeper well (OD-683) probably ends close to bedrock. The other well (OD-685) penetrated 135 feet of kame-moraine deposits (sand and gravel) overlying 30 feet of deltaic sand, which is underlain by 240 feet of glaciolacustrine sediments (fine sand, silt, and clay) interbedded with till, and then by 160 feet of silty sand and gravel. This silty sand and gravel unit may be part of a buried moraine of pre-Valley Heads origin, or it may represent an early-Valley Heads standstill position. The thick lacustrine unit between the Valley Heads Moraine and the underlying and presumably older moraine indicates the presence of a lake in the Tully Trough before the Valley Heads readvance. The lake apparently continued to exist or redeveloped, as indicated by fine-grained sediment that buries this early moraine as well as the older coarse deposits north and south of the moraine. Whether the 160-foot thick silty sand and gravel sequence extends to bedrock and continues within the subglacial deposits of sand and gravel (as shown in figure 5, Kappel and Miller, 2003) is uncertain.

Well OD 683 (see fig. 5, Kappel and Miller, 2003) was drilled to 830 ft and did not reach bedrock. The well penetrated, in descending order, 7 feet of till, 118 feet of kame moraine (mostly sand and gravel), 600 feet of fine-grained lacustrine sediment (fine sand, silt, and clay), 40 feet of sand and gravel, another 60 feet of fine-grained lacustrine sediment, and 3 ft of very coarse gravel which may be part of a subaquatic (buried) fan or moraine. Test hole data are insufficient to reveal the extent of the hypothesized buried fan or moraine, and do not indicate whether these deposits extend to bedrock, as implied by figure 5 of Kappel and Miller (2003).

The complex stratigraphy of the moraine results in an aquifer system with multiple-aquifer units. The surficial kame-moraine deposits (ice-contact and collapsed outwash) forms an extensive unconfined sand and gravel aquifer (70 to 120 feet thick) that is underlain by a thick sequence of fine-grained glaciolacustrine deposits that, in turn, confine one or more deep sand and gravel aquifers (presumably subglacial conduit deposits and subaquatic fans) of highly variable thickness (15 to 150 feet thick), that may be discontinuous. The moraine also contains large kettle lakes, such as Song, Crooked, Green, and Tully lakes (see fig. 4, Kappel and Miller, 2003). The water levels in some of the kettle lakes represent the local water table, whereas, the water level in others appear to be perched (Kappel and others, 2001). The bottoms of these perched lakes and ponds are probably lined with poorly-permeable sediment and decayed organic material (muck) and(or) till that impedes the downward movement of lake water.

The kame sand and gravel aquifer at the moraine is connected to the surficial outwash sand-and-gravel aquifer in the West Branch Tioughnioga River valley. Both aquifers typically yield 10 to 50 gallons per minute to open-ended domestic wells. The water quality is generally good, although the water is hard, as would be expected from the large limestone content within the gravel (Ku, and others, 1975, fig. 22; Denny and Lyford, 1963, pl. 3).

Ground water in the northern part of the kame sand and gravel aquifer flows northward and discharges from springs along the north side of the moraine. Some of the springs are perennial, including the springs along Route 11A which are used for a small public-water-supply system for residents in the Tully Valley, whereas others flow only during the wet season. Some domestic wells at the crest of the moraine are completed in a sand and gravel layer, about 15 feet thick that apparently is a thin lens within the upper part of the glaciolacustrine unit (see fig. 5, Kappel and Miller, 2003). Ground water in this unit probably also discharges to the springs along the northwestern side of the moraine (see fig. 4, Kappel and Miller, 2003).

Two domestic wells on the crest of the moraine, each about 400 feet deep (OD-675 in the east central part of the moraine and OD-674 on the western side), were drilled through the surficial kame moraine and the lacustrine deposits and completed in the thin basal aquifer that overlies bedrock. Water from the confined aquifer is typically turbid, moderately mineralized, and similar to water in the shale—with a hydrogen sulfide odor and enough iron to cause staining. The surficial sand and gravel aquifer near the crest of the moraine is thinly saturated because springs on the north side of the moraine drain much of the water from this aquifer. USGS test well OD-683, near the intersection of NYS Route 80 and Gatehouse Road (see fig. 4, Kappel and Miller, 2003), penetrated an unconfined sand and gravel aquifer between depths of 10 and 85 feet, and a thin sand-and-gravel aquifer (lens?) between 107 and 118 feet which was confined within the upper part of the glaciolacustrine unit. Both aquifers yield more than 10 gallons per minute to domestic wells. Underlying the thick confining unit are two confined sand and gravel aquifers between depths of 730 and 770 feet and 827 and 830 feet. Refusal was encountered at depth 830 feet, but a well could only be installed in the aquifer at 730 feet. The driller estimated the yield from the 730 foot deep aquifer at several hundred gallons per minute (gpm). It is uncertain whether the well finished in this aquifer is connected to the basal confined aquifer in the West Branch Tioughnioga Creek valley and that found in the Tully valley.

The Tully Valley Mudboils

The Tully Valley mudboils are volcanolike cones of fine sand and silt that range from several inches to several feet high and from several inches to more than 30 feet in diameter. Active mudboils are dynamic ebb-and-flow features that can erupt and form a large cone in several days, then cease flowing, or they may discharge continuously for several years. Mudboils have been observed in the Tully Valley in Onondaga County, in central New York, since the late 1890's but probably have existed since the last proglacial lake drained from the valley. Mudboils have continuously discharged sediment-laden (turbid) water into nearby Onondaga Creek at least since the early 1950's. The discharge of sediment causes gradual land-surface subsidence that, in the past, necessitated rerouting a major petroleum pipeline and a buried telephone cable, and caused two road bridges to collapse. The water discharged from mudboils can be either fresh or brackish (salty).

Mudboil activity was first reported in the Syracuse (New York) Post Standard, in a short article dated October 19, 1899:

> "***Tully Valley—A Miniature Volcano—*** *Few people are aware of the existence of a volcano in this town. It is a small one, to be sure, but very interesting. In the 20-rod gorge where the crossroad leads by the Tully Valley grist mill the hard highway bed has been rising foot after foot till the apex of a cone which has been booming has broken open and quicksand and water flow down the miniature mountain sides. It is an ever increasing cone obliterating wagon tracks as soon as crossed. The nearby bluff is slowly sinking. Probably the highway must sometime be changed on account of the sand and water volcano, unless it ceases its eruption."*

This newspaper article accurately describes Tully Valley mudboils and presages the collapse of the Otisco Road bridge 92 years later in 1991. The article indicates that land subsidence occurred nearby, but gives no indication that Onondaga Creek was turbid; this was either an oversight by the reporter or was not a concern.

Flow from a mudboil is driven by artesian pressure that forces water and sediment upward from two confined sand and gravel aquifers through a 60-foot-thick layer of dense silt and clay at land surface. The artesian pressure within the aquifers can lift water 20 feet above land surface along most of the valley floor and 30 feet above land surface near Onondaga Creek. The source of the artesian pressure is surface water entering the ground-water system along the valley walls — primarily at the southern end of the valley at the Valley Heads Moraine and from the alluvial fans at the mouth of Rattlesnake Gulf and Rainbow Creeks. Additional water may also enter the mudboil aquifers from the Tully brinefield area in the southern part of the valley where former solution mining of halite deposits has led to fracturing of bedrock and land-surface subsidence in the brine-mining area.

The flow of water from the mudboils changes seasonally in response to changes in artesian pressure in the two aquifers. In the spring, when ground-water recharge is greatest, the mudboils in the main mudboil/depression area (MDA) (see fig. 3, Kappel and McPherson, 1998) can discharge 400 gpm or more. As recharge to aquifers declines during the summer, artesian pressure in the aquifers also declines, and flow from mudboils typically decreases to 200 gpm or less. The rate of mudboil flow does not change in response to individual rainstorms but does respond to seasonal variations in precipitation and resulting changes in hydrostatic pressure within the mudboil aquifers.

Suspended-sediment discharged from the MDA to Onondaga Creek has been measured from October 1991 to present (September, 2007). The daily average suspended sediment load in the 1993 water year was approximately 30 tons per day (tons/d). Most of the suspended sediment is very fine clay and silt with a small fraction of very fine sand. Chemical analyses of mudboil discharge in the MDA indicate that the source of water can be either the confined fresher-water aquifer or an underlying brackish-water (salty) aquifer (Fig 4). Chloride concentrations in the upper, freshwater aquifer range from 37 to 430 milligrams per liter (mg/L) and from 2,000 to 7,100 mg/L in the lower, brackish-water aquifer. The difference in chloride concentration between these two aquifers is due partly to the greater density of the saltwater, which causes the brackish water to concentrate in the lower aquifer. Remedial efforts near the Tully Valley mudboils during the late 1990's included: (1) diverting flow from the tributary that feeds the MDA to an adjacent tributary; (2) installing depressurizing wells at several locations around the MDA and along Onondaga Creek to decrease the artesian pressure; and (3) constructing a dam and sediment-settling impoundment to detain mudboil sediment that would normally discharge to Onondaga Creek.

Surface-Water Diversion.—Flow from the upper 0.7 square miles of the mudboil tributary drainage was diverted south to an adjacent tributary drainage in June 1992. This diversion reduced total annual surface water inflow to the MDA by about two-thirds, which, in turn, reduced sediment loading to Onondaga Creek by half — from about 30 tons/d before diversion to about 15 tons/d thereafter.

Aquifer Depressurizing Wells.—Depressurizing wells were installed near the collapsed Otisco Road bridge during the winter of 1992-93 in an effort to reduce artesian pressures in the upper aquifer and subsequently slow nearby mudboil activity. The wells were drilled to the base of the fresher-water upper aquifer, and 10-foot-long well screens were installed to allow artesian-pressured water to flow out of the well while holding the fine-grained sand and silt in place.

These wells initially had a combined discharge of about 25 gpm of sediment-free water and have modestly reduced artesian pressure in the freshwater aquifer by about 1 pound per square inch, or about 2.5 feet of hydraulic head in the late 1990's. Currently these wells discharge about 15 gpm. While nearby mudboil activity has not increased since they were drilled, and no new mudboils have developed, these wells only influence the artesian pressure within about 100 feet of the well and do not preclude new mudboil activity in the area. Eight additional wells were installed in the aquifers underlying the MDA and Onondaga Creek in the summer of 1996 to further reduce artesian pressure and slow mudboil activity. Total ground-water discharge from all wells averaged about 350 gpm in 1997, but today that flow is averages only about 180 gpm. The chemical quality of water discharging from these wells varies with the position of the well in relation to the MDA and has varied over time. Most of the flows from depressurizing wells screened in the upper aquifer around and downgradient from the MDA are slightly brackish to salty, indicating that water from the lower basal aquifer is migrating upward into the base of the upper, fresher-water aquifer. The salinity of water upgradient (south) of the MDA is generally low. Water quality measurements between 1997 and today indicate a slow but steady increase in conductivity (salinity) in the discharged water. Discharge from individual wells ranged from less than 5 to as much as 100 gpm, depending on (1) the well location within the aquifer unit, (2) the aquifer material, and (3) the time of year In the 10 years of operation of these free-flowing wells, the flow rates have diminished even with well redevelopment in 2005. The decrease in flow is probably caused by the clogging of the fine-grained mudboil aquifer outside the well screen, and outside the influence of well-redevelopment techniques.

Impoundment Dam.—A temporary dam was constructed at the outlet of the MDA (see fig. 3, Kappel and McPherson, 1998) in July 1993 to reduce the average daily load of sediment discharging to Onondaga Creek. The impounded water covered several mudboils and allowed most of the silt and sand to settle out before flowing to Onondaga Creek. Also, the weight of water over active mudboils, and the additional weight of sediment settling on the mudboils likely decreased mudboil discharge. The impoundment, in conjunction with the depressurizing wells, has slowed mudboil activity in the MDA, and slowed land subsidence in this area as well. The impoundment reduced the average daily load of sediment discharged from the MDA to Onondaga Creek, from 15 tons/d in 1992 to about 1.5 tons/d during water years 1993 and 1994, but by 1995, the entire impounded area was filled with sediment. Consequently, sediment loading to Onondaga Creek increased from 1.8 tons/d in water year 1995 to 2.8 tons/d in water year 1996. The dam was reconstructed to allow the outflow elevation to be raised in the summer of 1996 and has kept the discharge of sediment from the MDA to

Onondaga Creek in the range of 1 ton/d or less until about 2004. At that point mudboil activity within the MDA had filled the impoundment with sediment. In the summer of 2005 a ‘moat’ was dug around the MDA to allow any mudboil-generated sediment to settle out prior to the water being discharged from the MDA. While this process did reduce mudboil sediment loads to less than a half ton/d, dredging of the moat will be required on a semi-annual basis to maintain any sediment-retention capability.

Future Remedial Activities.—Based on the past 10-years of remedial activity and monitoring at the main mudboil depression area, the results of these efforts have been mixed. While sediment loading has been reduced by more than 95 percent, the cost of operation and maintenance at the MDA cannot be sustained into the future due to diminishing sources of funding. Rather than treat the sediment problem at the discharge area, it has been proposed that reducing the amount of water which enters the aquifers which are hydraulically connected to the mudboils might be a better, longer-term solution to reduce mudboil sediment loading to Onondaga Creek.

A series of pilot projects have been proposed by the Onondaga Lake Partnership to be implemented in the Tully brinefield area as access to this area is fairly uncomplicated and the landowner has granted permission to implement these activities. One stream (Emerson Gulf) looses about 500 gal/min at the edge of the valley wall where numerous bedrock fractures, related to nearby sinkhole subsidence, are present. (See the Sunday Fieldtrip “B1” for further information.) A 300-foot long section of stream channel will be lined to prevent surface water infiltration. On the east side of the Tully valley, in one of the larger sinkholes, the outlet of the sinkhole will be lowered to remove as much water as possible and route it to the surface water stream course. Supplemental pumping of water from the sinkhole will also be attempted using wind- and solar-powered pumps to test the efficacy moving water to the surface-water system and further reducing the amount of water which enters the ground water system from surface- and ground-water sources which enter this sinkhole. Water levels in this sinkhole generally change by 10 to 15 feet in a normal year, with less water-level change in wet years. If these pilot projects can be shown to be successful, additional remedial activities could be implemented on the alluvial fans of Rattlesnake and Rainbow Creeks, as well as elsewhere near the brinefield. It is not the objective of these remedial activities to stop all mudboil activity, but to return it to the semi-seasonal activity noted in the late 1800’s.

EXCAVATIONS IN AND AROUND ONONDAGA LAKE

[This section prepared by J. P. Stewart and C. W. Dickhut]

The firm of John P. Stopen Engineering has designed several large and deep excavations in the sediments surrounding Onondaga Lake in the last seven years. This section describes the special considerations that the local geology poses for this type of work and is illustrated by case histories.

The area around Onondaga Lake is a deep bedrock trough filled with glacial and soft recent sediments. The groundwater level is shallow with quality that ranges from fresh to highly saline. These conditions are often challenging for the deep excavations required for civil works.

A significant construction problem for excavations is managing groundwater. The deeper porous glacial deposits are confined below less permeable lacustrine soils, and often require differing dewatering considerations, as illustrated by the following case histories.

Case History 1 (Saline Groundwater in Porous Soil)

A below-grade pump station was constructed in 1930 in the lowland area of Syracuse on the south side of Kirkpatrick Street and on the banks of Onondaga Creek. The pump station was replaced around 1975 with a larger, deeper and more modern facility. The pump station was constructed where the porous glacial outwash sands are thick and have no cover of lacustrine sediments. The area had natural artesian salt brine springs and salt was produced commercially throughout the area in the 1800’s. During that century, over 10 million cubic yards of salt were extracted from brine wells.

The 1975 construction required a major excavation dewatering effort to lower the water table 15 to 20 ft next to Onondaga Creek. Thousands of gallons per minute (gpm) were pumped from the deep dewatering wells installed inside the excavation. With that volume of water, the effluent was checked for suspended solids by burning off the water and weighing the residue. Oddly enough, these tests showed significant solids in the essentially clear discharge. It was uncertain if significant fines were being removed from the ground that could presage a collapse. Consequently, the job was shut down for several months.

The job did not resume until it was determined that the groundwater had significant dissolved salt content. The solids in the dewatering discharge were not suspended solids, but dissolved solids that posed no threat for ground settlement or collapse.

After construction of the pump station addition began in 2002, the USGS drilled an exploratory boring within a few hundred feet of the site. The 6-inch-diameter vibro-sonic core boring retrieved a continuous sampling of the valley fill and the bedrock below (Kappel, personal communication, 2003). Figure 6 shows a log of the boring and Figure 7 shows a geologic cross-section through the valley at the pump station. Of particular interest is the salt content of the pore fluid that shows salt content increasing with depth, but also that the salt content of the deep soil is more than 4 times that of sea water.

Project borings and old test borings showed that the site was underlain by about 15 ft of old fill. The water table was about 10 ft below grade. The natural soils consisted of sands and gravels to depths of more than 60 ft. The USGS boring indicated that the deeper soils had seams with greater sand and silt content than the shallower soils.

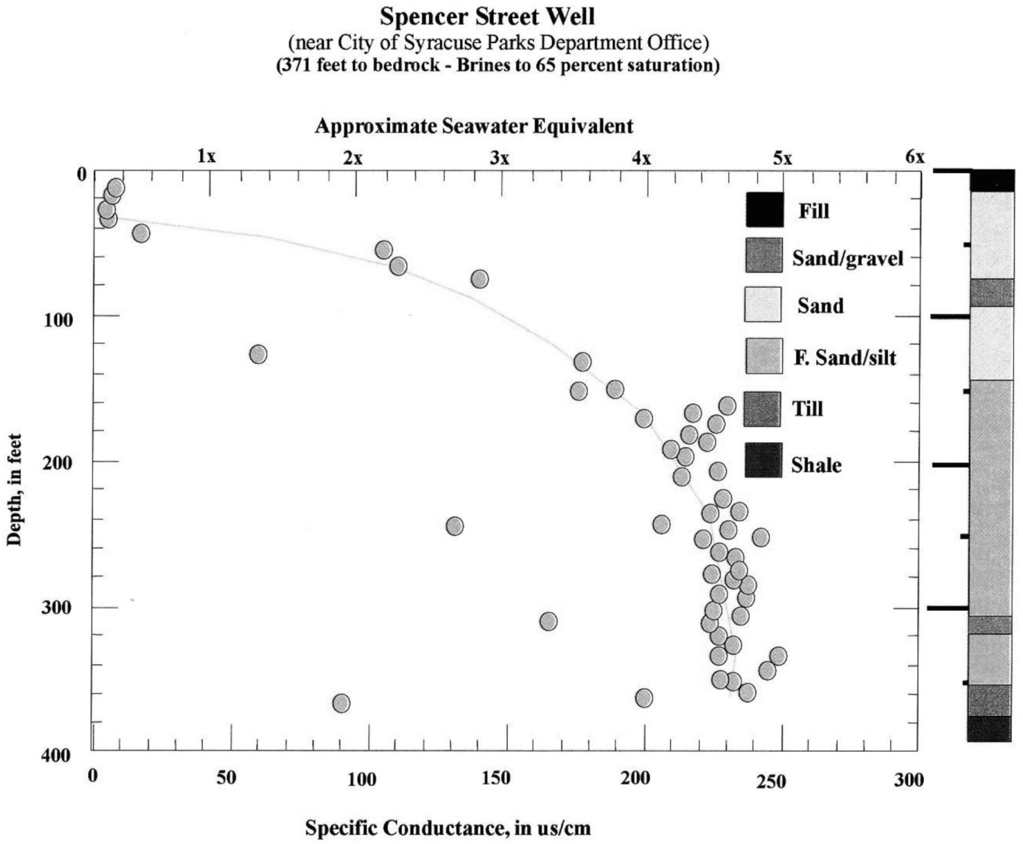


FIGURE 6—Salt Concentration versus Depth near the Kirkpatrick Street site. (Kappel, 2005)

The project required excavation to about 35 ft depth and about 25 ft below the water table. The soils consisted of deep permeable soil that was most likely hydraulically connected to the adjacent creek and could not be easily cutoff with sheetpiling or a cut off wall.

To evaluate the required dewatering effort, a pump test was performed in a test well installed next to the pump station as shown in Figure 8. Back evaluation of the pump test (Continental Placer, 2002) indicated that dewatering efforts could require 10,000 to 15,000 gpm.

Removal of the estimated volume of groundwater had several undesirable effects, including the cost of pumping and the practicality of installing enough well capacity in the limited project area. Furthermore, it was uncertain if contamination on the site to the south might be drawn in.

The dewatering posed a significant environmental concern because the salt content was several times that of sea water. Scientists studying the lake during the 3-day pump test detected a significant spike in chlorides. Since the construction would require about 2 months of pumping at about 10 times the test rate, the dewatering was not acceptable. The owner subsequently issued a change order to construct the excavation without dewatering in excess of 100 gpm.

The most practical way to conform to the dewatering limits was to seal the excavation bottom and sides by jet grouting before beginning excavation. The seal needed to be thick enough to resist the buoyancy of the open excavation that would extend below the water table by about 20 ft. Relying on the existing structure to resist the uplift was not considered reliable because it was eccentrically located next to the excavation and it needed its own weight to resist its own buoyancy. It was viewed prudent to limit the risk of shifting the structure that might occur if load was transferred to it. As a consequence, the bottom seal needed to be stable without contribution from the surrounding structure. Evaluation showed the most economical seal would be attained with a 10-ft-thick bottom seal supplemented with 18 60-kip pressure-grouted ground anchors.

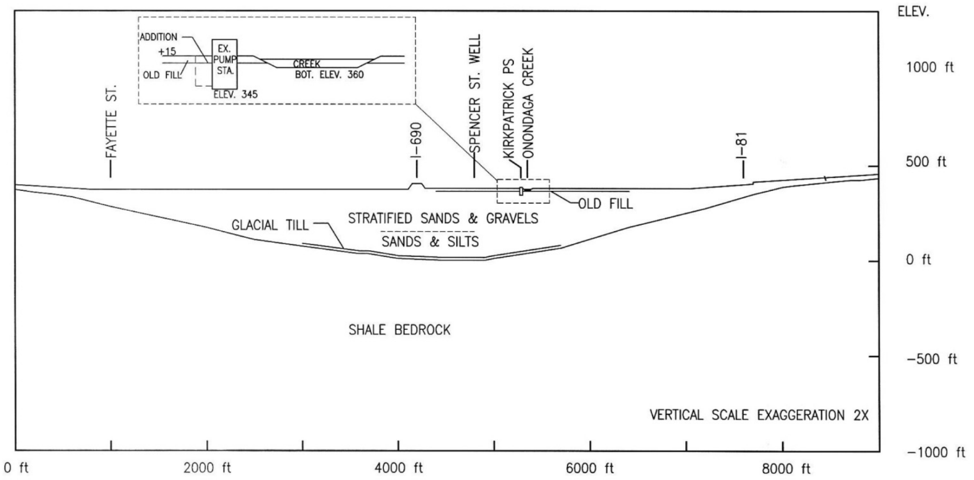
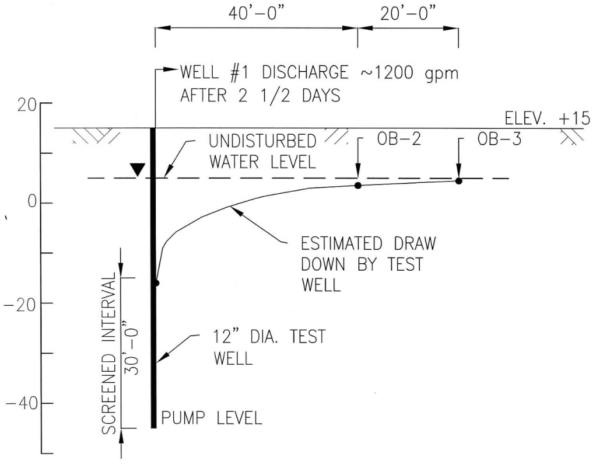


FIGURE 7—Geologic section at the Kirkpatrick Street pump station.



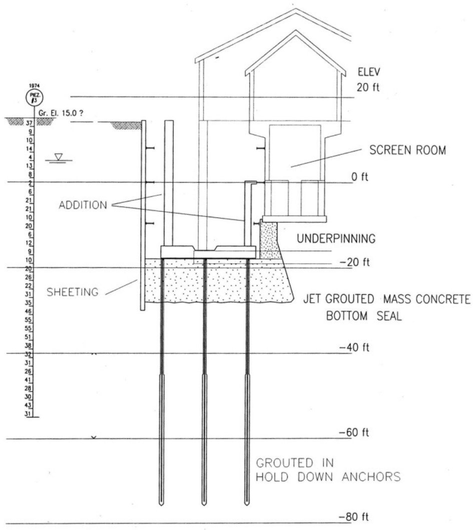


FIGURE 8—Results of aquifer test at Kirkpatrick St.

FIGURE 9—Excavation cross section with down-hole anchors and bottom seal

The first step of construction was to drive interlocked hot-rolled steel sheetpiling on the edges of the excavation that were accessible. Sheeting extended to the bottom of the proposed bottom seal. The next step was to construct a few jet grout test columns to confirm proper procedures and equipment were implemented for the site. The test columns were cored and demonstrated the grout was of good quality. The cores showed thin silty layers and significant proportion of large pieces of gravel and small cobbles. The third step consisted of underpinning the existing structure by jet grouting. Concurrently, jet grout columns were installed to construct the bottom seal, as shown in Figure 9.

After constructing the underpinning and bottom seal by jet grout columns, the fourth step was to install the ground anchors. Ground anchors were drilled from the ground surface through the bottom seal and approximately 30 ft below the bottom seal. After the last anchors were installed, excavation began inside the sheeting and bracing was installed. The work was completed and no movement of the existing structure was detected. The maximum dewatering effort was about 20 gpm and well within the requirements set by the Owner. Most of the water entered the excavation in one localized leak in the side seal between the sheeting and the jet grout. It is likely that the sheeting flexed under the earth pressure loads and separated slightly from the jet grout mass. Nevertheless the leakage was essentially insignificant.

Case History 2 (Thick Lacustrine Sediments Over Porous Glacial Sand)

A second deep excavation closer to Onondaga Lake was constructed about one year later to a similar depth. The site was in an area where the lacustrine soil overlying the glacial sands and gravel was much thicker than for Case History 1. There was a shallow groundwater table with about 10 ft of old fill overlying about 160 ft of interlayered soft clayey silt and loose sandy silt that overlaid the glacial sands.

Even though this excavation was of similar depth and over 250 times larger, the dewatering volume was several orders of magnitude less than would have been required for Case History 1 without the grout seal. As a consequence, the excavation was dewatered by confining the excavation within interlocked steel sheetpiling and pumping from widely-spaced well points around the perimeter. The structure was supported on steel H-piles driven to bear deep in the glacial sands almost 300 ft below the ground surface.

FIGURE 10—Excavation photograph of Case History #2

Case History 3 (Thin Lacustrine Sediments Over Porous Glacial Sand)

A third deep excavation was constructed near the north end of the lake in an area of shallow groundwater and where about 30 ft of low permeability lacustrine clayey silt and silty sand lie over more porous glacial sand. An excavation for a pump station in the 1960’s was apparently constructed to a depth of about 20 ft with limited dewatering, although no records were available to confirm.

FIGURE 11—Case History #3 photographs. A) Construction of hold-down anchors. B) Inside excavation.

Pumping test results indicated that the excavation could be dewatered only if the deep sands were depressurized by pumping several thousand gpm from deep wells. Dewatering at this rate posed risks to a nearby gas transmission line and existing structures. It was subsequently decided to construct a bottom seal inside interlocked steel sheetpiling before making the excavation.

The bottom seal was constructed by jet grouting a 10-ft-thick plug of soilcrete and installing 48 hold down anchors that extended about 70 ft below grade. After completing the bottom seal by jet grouting and installing the hold down anchors, the excavation was completed by dewatering inside at a rate of less than 2 gpm.

These case histories describe how the local geology influences dewatering efforts required to construct civil works in the Onondaga Lakefront area.

REMEDIATION AND ENGINEERING CHALLENGES AT ONONDAGA LAKE

[This section prepared by G. Swenson and T. Johnson]

This portion of the trip is focused on the geology and hydrogeology of the western side of Onondaga Lake and the Ninemile Creek Valley (Figure 12). Due to the complexities associated with this system, various remediation and engineering challenges have been encountered as part of the ongoing cleanup efforts conducted by Honeywell adjacent to Onondaga Lake. A summary of these topics are presented below and will be discussed in more detail during the field program.

Geology of Onondaga Lake and the Ninemile Creek Valley

The geology of Onondaga Lake and the Ninemile Creek Valley is dominated by unconsolidated deposits associated with glaciofluvial and glaciolacustrine deposition. Onondaga Lake occupies a glacial trough through the Silurian shales and evaporites. The Ninemile Creek valley also occupies a bedrock low developed by fluvial and glacial activity. The overburden deposits associated with Onondaga Lake are represented by the following sequence beginning at the top of bedrock (Figure 13):

- till;
- ice contact basal sand and gravel layer;
- glaciolacustrine silt and fine sand layer – this layer is relatively massive and tends to have a coarser texture toward the lake outlet;
- glaciolacustrine and lacustrine silt and clay layer – this layer tends to be thicker toward southern end of lake;
- lacustrine marl - some of these deposits have been dated between 5,000 – 7,000 years B.P. (Kappel 2006); and

- recent fill/settling basins along shore and lake sediments and in-lake waste materials.

The overburden deposits associated with the Ninemile Creek Valley are represented by the following sequence beginning at the top of bedrock (Figure 14):

- glaciofluvial and deltaic deposits of sand and gravel, sand, and silt, which are generally coarser in texture to the southwest and become finer in texture near Onondaga Lake;
- recent fluvial and floodplain deposits of sand, silt and clay;
- recent deltaic deposits; and
- fill/settling basins.

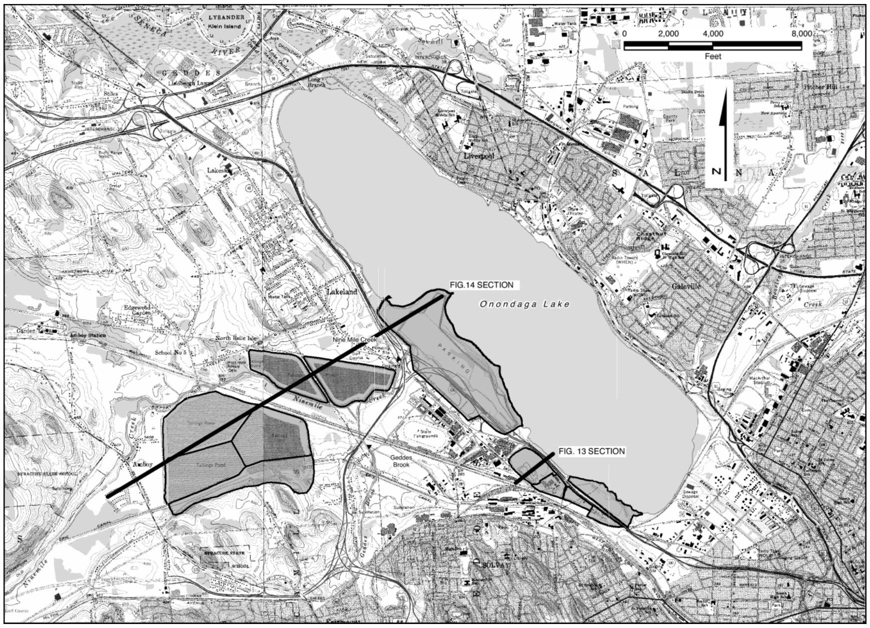


FIGURE 12—Location of settling basins and cross sections.

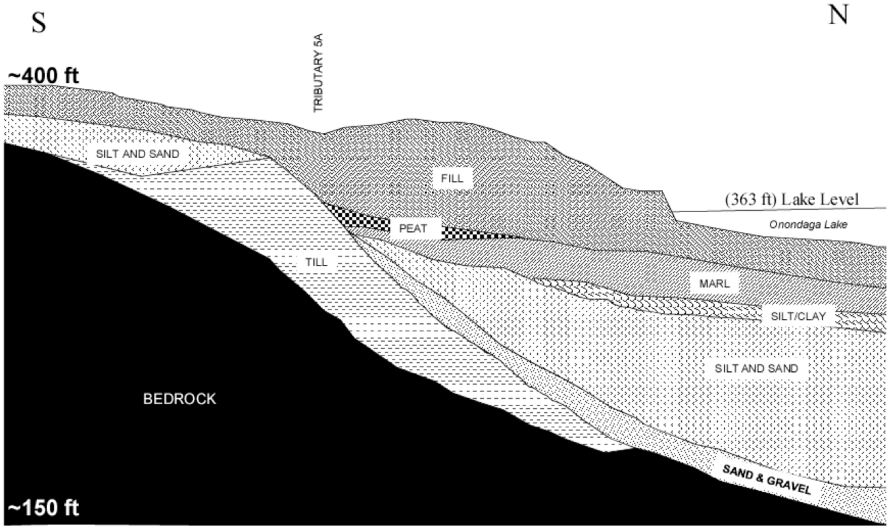


FIGURE 13—Representative cross section of the Willis/Semet site

The deposits in Ninemile Creek Valley reflect fluvial and deltaic deposition. These materials merge with the Onondaga Lake sequence to reflect fluvial discharge to historic Lake Iroquois. Much of the unconsolidated deposits under Onondaga Lake reflect the more recent lacustrine deposition of the sediments associated with glaciofluvial discharges to the lake.

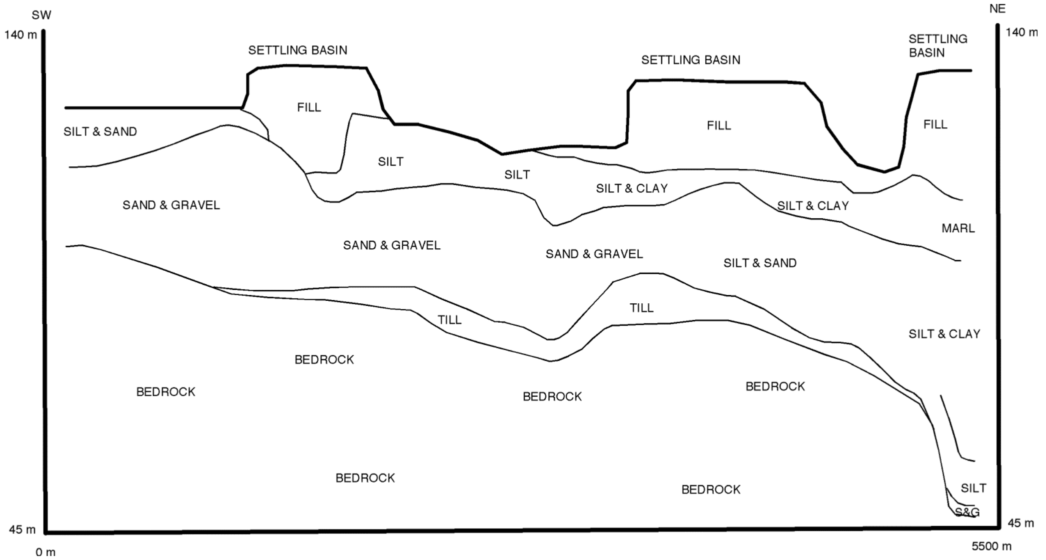


FIGURE 14—*General Ninemile Creek cross section.*

Groundwater of Onondaga Lake and the Ninemile Creek Valley

Background.—Groundwater associated with the Onondaga Lake and Ninemile Creek Valley consists of three principle types of water: naturally occurring halite brine, fresh water, and a leachate associated with the settling basins. The halite brine saturates the overburden deposits under the lake and has a density of up to 1.16 g/cm^3, chloride concentrations over 120,000 mg/l, and halite saturations of up to 80%. The halite brine was formed over 16,000 years ago (Yager and others, 2007) and is confined by the silt and clay layer present beneath the lake. Discharge of the brine through the silt and clay confining layer to Onondaga Lake is limited, estimated to be very low (Effler 1996) (Kappel, 2006). Some discharge also occurs through the shallow units along the shore of the lake, where the confining layer pinches out, and historic discharges initiated the Syracuse salt industry in the late 1700's (Kappel, 2000).

Leachate associated with the settling basins is present in both the shallow and deep overburden deposits. This leachate has a calcium, sodium, chloride composition and is differentiated from the halite brine by the higher percentage of calcium. The density of this leachate can measure up to 1.06 g/cm3. During active use of the settling basins during the 1900's, high volumes of process water were discharged to the settling basins. Currently, recharge of the settling basins only occurs via precipitation.

Groundwater Flow.—Characterization of groundwater flow in the vicinity of Onondaga Lake is complicated by the presence of the dense halite brine and the leachate. In general, the regional direction of groundwater flow is toward Onondaga Lake. Because of the presence of the dense brine and leachate, which the fresh water can not displace, much of the fresh water is forced to discharge to streams surrounding the lake, such as Ninemile Creek. However, there is small amount of localized fresh water discharge to the lake through the shallow sediments.

The distribution and flow of the settling basin leachate is governed by historic settling basin operations and the interaction with native brines and fresh water. The current hypothesis is that historic loading of the settling basins resulted in a dense plume of leachate that migrated downward to the basal sand and gravel unit displacing the halite brine along the lakeshore. Once the settling basin loading ceased, the deep leachate plume remained trapped beneath the confining layer along with the halite brine. Current leachate created by natural recharge to the settling basins discharges to the lake and streams though the shallow deposits.

Due to the complexities associated with evaluating groundwater flow with multiple densities, a groundwater model was developed to support multiple evaluations. This model uses the USGS code SEAWAT 2000 (Langevin et al. 2003) to simulate the movement of the fresh and dense groundwater in the Ninemile Creek Valley and around Onondaga Lake. This model is currently being used to evaluate groundwater flow and various evaluations associated with the remediation of Onondaga Lake and associated Honeywell sites.

Remediation and Engineering Challenges.—Historic industrial practices, in addition to geologic and hydrogeologic conditions around Onondaga Lake, present a variety of remediation and engineering challenges. Much of the overburden deposits around Onondaga Lake are low density. Weight of hammer or low blow counts are common when using conventional soil boring sampling techniques. These low density materials present several construction challenges for buildings and other structures. For example, Carousel Mall was designed to "float" on the soft sediments. The proposed expansion of the mall and the Interstate 690 bridge to the east of this area are using piles driven to depths of 30 m or more to provide an engineering base for construction.

As part of the remediation program for several sites adjacent to Onondaga Lake, Interim Remedial Measures (IRMs) are being implemented to stop the flow of contaminated groundwater and DNAPL to Onondaga Lake. The IRMs will consist of a sheet pile barrier wall and groundwater collection trench with wick drains to capture and pump the water to a treatment plant on the Willis Avenue site. DNAPL recovery wells will also be installed along the shoreline to extract this material from behind the barrier wall. The sheet pile wall will be keyed into the silt/clay layer approximately 25-45 ft below the surface, which is a confining layer to groundwater flow. The low density soils, presence of the silt/clay confining layer, potential need for lake dredging near the wall, and the close proximity of Interstate 690 and utilities present multiple geotechnical design challenges for the construction of the wall and trench.

A portion of the IRMs noted above are focused on the deeper sand and gravel units. The groundwater in the deep zone does not appear to be migrating to Onondaga Lake, however, leachate and other organic constituents in the deep basal sand and gravel layer may require some type of remediation. The deep unit is highly permeable and is under artesian conditions (up to 10 ft above lake level) due to the presence of the silt/clay confining layer. Design of a remedy for this unit is complicated since recovery wells in the deep unit could produce high volumes of water and potentially cause preferential migration of the brines in this unit.

Discharges to Onondaga Lake from historic industrial practices have resulted in sediments and other deposits on the bottom of the lake that will require remediation. Isolation capping has been selected by the NYSDEC as a key component of the remedy for the impacted sediments within the lake. In some areas of the lake, the isolation cap will consist of 1-2 m of sand carefully placed over the soft sediments. Stability of these sediments is a key component of the ongoing design evaluations for the remedy. The amount of groundwater upwelling through the shallow sediments and ultimately into the isolation cap is also a critical portion of the design. The low upwelling velocities are difficult to measure and therefore multiple methods are being used to document this information. Data is currently being collected as part of ongoing pre-design investigation activities on the lake to evaluate stability and groundwater upwelling estimates.

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APPENDIX

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ROAD LOG FOR TRIP -1

GLACIAL AND ENVIRONMENTAL GEOLOGY OF THE ONONDAGA TROUGH, CENTRAL NEW YORK

All of the field sites described in the road log are on private property. As such, it is imperative that we respect the rights and wishes of these land owners. Please do not visit these sites on your own, as it may jeopardize future field-trip opportunities. Over the past 15 years it has become increasingly difficult to maintain our access agreements to these sites as individuals and even groups of people have entered these properties without obtaining land-owner permission. We strive to maintain good relations with the land owners and do not want the inappropriate actions of a few to ruin the educational opportunities for many others who wish to enter these areas. The USGS can, and does act as the 'point of contact' for the property owners and we would be happy to facilitate your future access to these sites. Please contact Bill Kappel for any questions as to access for you and your classes.

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Start at parking lot north of Old Main building on SUNY Cortland campus. From parking lot turn left (E) on Gerhart Dr., Yield sign turn left (N) onto Graham Ave. At bottom of hill (traffic light) turn left (W) onto Groton Ave, (Route 222).
1.1	1.1	CORTLAND CAMPUS TO NYS-ROUTE 281. At intersection with NYS-Route 281, turn right (N) and proceed through the outskirts of Homer. Once past the Homer High School, and crossing NYS-Route 90, on your left is the Homer waterworks about 0.7 mi from Rte. 90. Turn left into waterworks
4.4	3.3	ROUTE 281 TO HOMER WELLFIELD

STOP 1. HOMER WATERWORKS—SITE OF HANGING VALLEY ENTERING THE SOUTHERN END OF THE ONONDAGA TROUGH

At this location the Village of Homer has two municipal supply wells (75 and 83 ft deep) that tap an unconfined outwash sand and gravel aquifer that yield 500 to greater than 1,000 gal/min of potable water. Seismic refraction was used to determine the depth to bedrock within the Factory Brook valley where the water works are located. About 1 mi up-valley from the well field the depth to bedrock was only about 110 ft (elevation. of 1,110 ft) – a subsequent test well ground-truthed the seismic data. These results indicated that the Factory Brook V. is a hanging valley to the W. Br. Tioughnioga River V. where the elevation of bedrock in the center of the valley is at about 900 ft or 200 ft deeper than the Factory Brook Valley. We believe the Homer wells are at the lip of the hanging valley and starting at Rt 281 (a stone throws away) the buried valley wall plunges down into the very southern extent of the Onondaga Trough.

Leave waterworks and turn left, back on to Route 281 (N). Follow Route 281 North, cross over I-81 near Preble, NY, and continue to the intersection with Route 80 just past the Tully exit of I-81. *As you travel this route, you are moving in and across the southern end of the Onondaga Trough. The bridge crossing of Route 281 at I-81 is the location of geologic section B-B' (Fig. 6, Kappel and Miller, 2003). The intersection of NYS-Route 80 and I-81 is the location of geologic section A-A' of figure 6, cited above.*

At the intersection of Route 281 and I-81, take a left (under I-81) and on the other side of the overpass, take an immediate left on to Lake Road (S). Stay on Lake Road and follow it around the southern end of Green Lake *(this is **not** Green Lake State Park*). As you round the bend, the Village of Tully swimming area is on your right and a gravel parking area is on your left. Pull off into the gravel parking lot –carefully

16.6	12.2	HOMER WELLFIELD TO NYS-ROUTE 80 AT TULLY I-81 INTERCHANGE
17.6	1.0	TULLY I-81 INTERCHANGE TO LAKE RD. AND GREEN LAKE

STOP 2. TULLY/VALLEY HEADS MORAINE AT GREEN LAKE

At this location we are on the Valleys Heads Moraine at Tully. This moraine 'plugs' the Onondaga Trough. The term 'trough' stems from a definition by W.M. Davis – *"Along a number of valleys it is possible to pass from one drainage system to the other through open valleys in which the present divides are determined not by rock, but by drift deposits"*. Although Tarr (1905) provided the definition, the term "through valley" is attributed to W.M. Davis, who coined the phrase during the discussion of Tarr's paper at the 1904 Geological Society meeting (Tarr, 1905, p. 233). The moraine forms the surface water divide between St. Lawrence and Susquehanna River Basins.

The location of the Valley Heads Moraine in central New York was thought to closely coincide with a preglacial bedrock divide. However, the study of the moraine has shown that during the last glacial episode, there is no bedrock ridge or high point high beneath the moraine. Rather, the trough continues a gradual slope upward starting near Syracuse, goes beneath the moraine, and continues south for several more miles to about Homer where it eventually flattens out and then begins to slope southward in the Tioughnioga River valley.

The surface-water/ground-water interaction in the Tully Lakes area is very complex and the surface-water divide often does not coincide with the ground-water divide. Ground water generally flows from the edges of the valley toward the center, where it discharges to lakes, ponds, wetlands, springs, and the West Branch Tioughnioga River. Most ground water north of the ground-water divide discharges to springs at an elevation of about 1,125 feet on the northern slope of the moraine; the rest flows northward as underflow to deeper zones of valley-fill deposits in Tully/Onondaga Creek valley. Ground water south of the divide flows southward eventually entering the Tioughnioga River.

A round of synoptic water-level measurements indicated that water levels in the western Tully Lakes are generally above those in the surrounding aquifer; therefore, water seeps from the lakes to the aquifer most of the time. In contrast, the eastern lakes generally receive water from the aquifer. Green Lake commonly receives ground-water flow along its east side and discharges to the aquifer along its west side—while at the same time surface water drains southward out of the lake through a channel at the south end and empties into Tully Lake. Tully Lake receives ground-water flow from all sides during the spring recharge conditions; then, as water levels decline from summer through early winter, it discharges to the aquifer along its southern edge.

Leave Stop 2 and turn left (W) back on to Lake Road and follow the road to a 'T' intersection. Bear to the right which will be Gatehouse Road. Follow Gatehouse until you come to another 'T-like' intersection and bear off to the right (N) – this is Gatehouse Road North. *As you travel north you will see several kettle-hole ponds and lakes on both sides of the road. These ponds were linked in the late 1890's to become the water supply for the Tully brinefield (solution brine mining).* At the

		stop sign you will intersect with Route 80 again. *See geologic section F-F' (Kappel, Miller, 2005) for the unconsolidated stratigraphic section of this area.*
19.8	2.2	LAKE RD.GRAVEL PIT TO NYS-ROUTE 80
		Proceed north across Route 80 ***(***BE VERY CAREFUL – cars zip along Route 80 and there is limited sight-distance***)***. After you have safely crossed Route 80 you are now on Tully Farms Road, headed down the north side of the Tully (Valley Heads) Moraine. *Note the steepness of the road, the many springs about half way down the back side of the Moraine.*
		Continue North on Tully Farms Road. *The road has been affected by subsidence where it crosses Onondaga Creek, due to brine mining*. As you pass through a dog-leg in the road, and through the middle of a farm (*watch for loose cows, cats, kids, and farm machinery)* you will go up a slight incline (*Rattlesnake Gulf alluvial fan*) to the intersection with Otisco Road. *See geologic section E-E' (Kappel, Miller, 2005) for the unconsolidated stratigraphic section of this area.*
		At this intersection, turn right (E) and follow the road to the dead end. *Again be careful of small kids in the cluster of houses, and when you park, do so to the south side of the road, and do not block the vehicle turn-around area on the right*.
24.1	4.3	NYS ROUTE 80 TO OTISCO ROAD – DEAD END

STOP 3. TULLY VALLEY MUDBOILS

At the parking area you can view several different features. Going around the barrier, and walking toward what used to be the bridge over Onondaga Creek you will see the remains of the foundation for the bridge. The downstream side wing walls a tipped back to the south and have dropped about a foot. The upstream wingwalls are just at or under the water surface. The mudboil was located about 30 feet upstream of the former bridge.

Adjacent to Otisco Road on the south side was a formerly active mudboil area (circa 1970's). The only vegetation present now is water-tolerant grassy species and willow trees. The road way experienced minor subsidence.

Walking back up Otisco Road (W) and on your left there will be a red-pipe farm gate. Walk around the gate (watch for poison ivy) and proceed south, down the farm lane. Where the field on the left ends at the tree line, continue south about 300 feet along the farm lane, and there will be a spur road on your left, that drops off the lane (SE) to the Rogue mudboil area. A former depressurizing well is now marked by a mudboil 'pool' and you should be able to note subsidence cracks as you come down this roadway. Walk around the large pond (former mudboil, now diked) where you should find a 6-inch PVC pipe discharging into the pond from another depressurizing well. This well and surrounding area has subsided about 3+ feet. With extreme caution you should be able to walk across the volcano-like cone of the mudboil sediments at the base of this well. Note the fine-grained nature of these sediments, and if you lightly tap these sediments with your foot, you might get them to liquefy. *DO NOT OVERDO THIS LIQUIFACTION!* Back in the woods are other mudboils – *BE VERY CAREFUL IF YOU DECIDE TO TAKE THIS WALK IN THE WOODS, THE MUDBOILS ARE QUICKSAND-LIKE.*

The main mudboil area (MDA) is further south down the farm lane, but the area is covered with phragmities so it is difficult to see into the MDA. If you venture in that direction, there is a moat around the MDA, and if you carefully walk on the dike you can find some active mudboils in the southwest quadrant, and associated land subsidence further uphill. At the outlet of the MDA there is a Parshall flume with associated discharge measuring equipment.

Once you have safely returned to Otisco Road and your vehicle, head back to Tully Farms Road (W) and at the intersection turn right (N) and take Tully Farms Road until it intersects with US Route 20. *As you travel down Tully Farms Road (passing Nichols Road on your right) you will travel through the remains of the 1993 landslide area. This is not a scheduled stop, but if you pull off the by the white cinderblock house, you can see the results of the landslide. Please refer to Wieczorek and others, 1998; Pair and others, 2000 for further information on this slide. Please do not walk into this slide area without permission or venture into the tumble-down house – the house is unsafe and both are private property!*

27.4 3.3 OTISCO ROAD DEAD-END TO US ROUTE 20

At Route 20 you have two options – if you would like to see an overview of the Tully Valley, the directions follow. If you want to continue the 'official' tour route, skip the following VALLEY OVERVIEW section and follow the CONTINUATION directions.

SIDE TRIP FOR VALLEY OVERVIEW

At the intersection of Tully Farms Road and Route 20, take a right on Route 20 (E), (***Careful! Dangerous intersection – cars moving quickly and you have limited sight distance***) proceed up the hill, driving toward I-81. Near the top of the hill take a left hand turn on to Webb Road (~1.7 miles) – careful, as it is almost a U-turn onto Webb and Route 20 traffic is moving quickly. Follow Webb for ~0.4 miles then turn left on to Amidon Road. Follow Amidon Road until it bends to the right (uphill) and turns into Summer Ridge Road. Take the road to the top and then park on the edge of the road where it takes a right-hand turn. Get out and look to the south and see a panorama of the southern Onondaga Trough --the Tully Valley, Tully Moraine in the distance, and Song Mountain ski area in the far distance. Follow the reverse route back down to Tully Farms Road at Route 20 – take a right on to Tully Farms Road Extension (N) from Route 20.

0.0 *3.2* SIDE TRIP -- ROUTE 20 TO TULLY VALLEY OVERVIEW AREA

CONTINUATION OF FIELDTRIP
See geologic section D-D' in Kappel, Miller, 2005 for the unconsolidated stratigraphic section near US Route 20

Drive across Route 20 (***Careful! Dangerous intersection – cars moving quickly and you have limited sight distance***). Follow the Extension Road north to the intersection with NYS-Route 11A. Take a left on to Route 11A (N) and on your left after a few miles will be the Onondaga Creek flood control dam. *See geologic section I-I' (Kappel, Miller, 2005) for the unconsolidated stratigraphic section of this area. This is near the intersection of the main and West Branch valleys of Onondaga Creek. The high bluffs to the west side of the dam are over the thalweg of the bedrock valley, and these bluffs are fluvial deposits discharged from the West Branch valley when the ice front was still located further to the north during the* *development of the Syracuse Channels (Hand, 1978).* If you stop here, you can see the spillway for the dam cut into the local limestone bedrock and the coarse sand and gravel of the fluvial deposits. This dam is on Onondaga Nation property, so don't wander and don't stay too long as the Onondagas are protective of their land and don't like the dam being here.

Continue North on Route 11A, through the Onondaga Nation for and at the 'T' intersection with US Route 11, take a right and go east toward I-81. Just under I-81, take an immediate left for the entrance ramp for I-81 North.

37.7	7.1	ROUTE 20 TO I-81 INTERCHANGE AT NEDROW
44.4	6.7	I-81 AT NEDROW TO I-690 WEST INTERCHANGE

Follow I-81 North to the intersection with I-690 West [~6.7 mi]– this can be a difficult right lane merge with another entrance ramp to I-81—that is, you will move over one lane to the right to get into the I-690 West lane (toward Baldwinsville). Follow this lane and then merge on to I-690 West – right hand merge. Go past the West St. exit and then again move right to get off at Geddes Street. At the foot of the exit ramp, take a right and drive to the traffic light intersection with Kirkpatrick Street. At this light, take a right onto Kirkpatrick St. (NE) and cross Van Rensselaer St. Just ahead, on the left is the parking lot for the Inner Harbor amphitheater (do not cross the bridge over Onondaga Creek). Turn left, park, and go over the knoll to the Inner Harbors tent structure (white sail-like roof).

46.7	1.8	I-690 WEST TO INNER HARBOR

STOP 4. THE SYRACUSE INNER HARBOR – FUTURE COMMERCIAL AND RESIDENTIAL REDEVELOPMENT OF THE FORMER OIL CITY AREA – ENGINEERING GEOLOGY

The Inner Harbor is at the southern end of extensive urban redevelopment for the greater Syracuse area. The expanse of land and water surrounding the Inner Harbor site is slated for massive construction in the near future as is the intervening area northeastward toward the Carousel Mall (green topped buildings) with the development of an expanded Carousel Mall, the potential development of DestiNY USA, and the supporting infrastructure. Discussions here will center around the difficulties and innovations needed to cope with the glacial sediments and salty water that underlie this entire area.

Leave the parking lot and turn right (SW) and back down Kirkpatrick St. to the traffic light. Go straight (a slight right turn) ahead on Spencer Street to the Bear Street traffic light. Just ahead on the left is the on-ramp for I-690 West, get on I-690 (there is a lot of construction on I-690 in 2007) and the next exit is for State Fair Blvd. Exit right, but at the end of the ramp do not follow the road under I-690; go straight ahead and up on toward the Wastebed Parking lot. There is a gate that is normally locked but will be open for the fieldtrip. Those that follow can park off to the side of the road and walk out on the wastebeds, but again this is private property – you'll need permission to do so or go there when the State Fair is ongoing. *There are plans to develop the area with a walking trail as the wastebeds and associated wastes in the lake are to be remediated which we will hear about at Stop 5.*

48.8	2.6	INNER HARBOR TO WASTE BEDS

STOP 5. THE WASTEBED DEPOSITS ADJACENT TO ONONDAGA LAKE AND THE REMEDIATION OF GROUNDWATER, IN-LAKE WASTE DEPOSITS, AND OTHER ENGINEERING CHALLENGES

This portion of the trip is focused on the geology and hydrogeology of the western side of Onondaga Lake and the Ninemile Creek Valley. Meeting on top of one of the wastebeds gives a view of the lake, and allows one to see where various remedial activities are and will occur in the future. Due to the complexities associated with this hydrogeologic system, various remediation and engineering challenges have been encountered as part of the ongoing cleanup efforts conducted by Honeywell adjacent to Onondaga Lake. A summary of these topics are presented and discussed in more detail during the field program.

To return to Cortland follow the signs to Route I-690 East (presently there is a detour back toward the State Fairgrounds) and follow I-690 east and watch for the I-81 South (Binghamton) exit ramp. (This is another kamikaze entrance ramp) As you leave I-690 (right exit off of I-690) and approach I-81 you will need to get over to the left lane of I-81 as it narrows to one lane temporarily – watch for traffic entering from behind, and then join I-81 South (two lanes). Travel south on I-81 back to the Homer exit. Exit at Homer, and at the 'T' (NYS-Route 281) intersection, turn left on to Route 281 South. Follow 281 until it intersects with Route 222 – get in left hand turning lane at the light. Turn left on to 222 (Groton Road) and go to Graham Road, then up the hill to the Cortland Campus

84.8	36.0	WASTEBEDS TO CORTLAND CAMPUS

END OF FIELD TRIP