SUBSURFACE GEOLOGY OF THE FINGER LAKES REGION

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INTRODUCTION

The Finger Lakes of central New York State (Fig. 1) have long been recognized as the product of continental glaciation. In 1868 Louis Agassiz spoke of the "glacial heritage" of the region (Coates, 1968) and since then numerous glacial geomorphic investigations have been undertaken (Mullins et al., 1989). However, most previous studies dealt with surficial features and because of this relatively little was known about the subsurface Quaternary geology of these world renown lakes.

That the Finger Lakes are deeply scoured and infilled by thick sediment sequences was known from bathymetric surveys of the lakes completed in the late 1800's (Bloomfield, 1978), a drill record of 1,080' (329 m) of unconsolidated sediment at Watkins Glen (Tarr, 1904), and the publication of a line drawing of one seismic reflection profile from Seneca Lake (Woodrow et al., 1969). This paucity of subsurface geologic data has been a major void in our knowledge and understanding of the geologic history of the Finger Lakes. Many questions remained unresolved including the most fundamental -- "When and by what processes were the great Finger Lakes troughs eroded?" (Bloom, 1984, p. 61). Based on the one seismic reflection profile from Seneca Lake, Bloom (1984) noted that bedrock beneath the lake floor was more V-shaped like that of a river valley rather than the expected U-shaped glacial trough, and that there had been multiple erosional and depositional events. He concluded that more comprehensive seismic reflection surveys of the Finger Lakes "might reveal a barely suspected missing chapter in the history of the Finger Lakes region" (Bloom, 1984, p. 61).

During the summer of 1984 we initiated a seismic reflection investigation of the Finger Lakes with a pilot study of the northern half of Seneca Lake (Stephens, 1986) supported by a "starter" grant from Syracuse University. Preliminary results were very encouraging and revealed a detailed stratigraphy of a thick sediment fill. These preliminary data formed the basis of a National Science Foundation grant for a comprehensive seismic reflection study of all eleven Finger Lakes which was carried out during the summers of 1986 and 1987 (Mullins and Hinchey, 1989). The scientific objectives of this study were three-fold: (1) the provincial question of the origin and evolution of the Finger Lakes; (2) evaluation of the processes of deglaciation along the southern margin of the Laurentide ice sheet; and (3) to use the thick sediment sequence beneath the lakes as a record of continental environmental (paleo-limnology/paleoclimatology) change.

In order to fully realize these scientific objectives it was also necessary to extend our lake-based seismic surveys to adjacent on-land areas

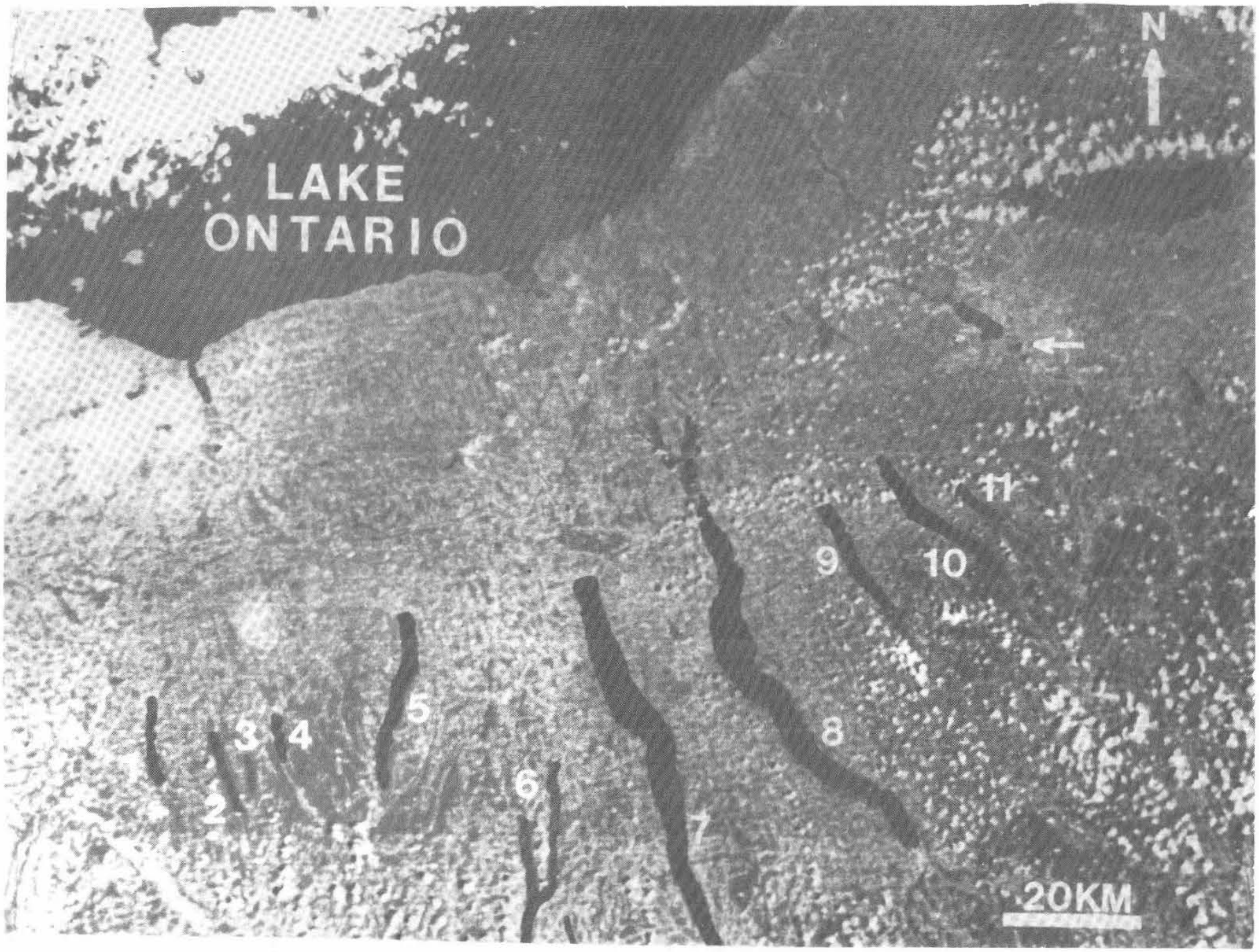

Fig. 1 - Satellite photograph of the Finger Lakes region. Numbers correspond to lakes: (1) Conesus; (2) Hemlock; (3) Canadice; (4) Honeoye; (5) Canandaigua; (6) Keuka; (7) Seneca; (8) Cayuga; (9) Owasco; (10) Skaneateles; (11) Otisco. Arrow points to city of Syracuse.

and to "ground truth" these geophysical data with subsurface geologic samples. Phase II of our investigation was also supported by NSF, and on-land multichannel seismic reflection profiles were obtained during the summers of 1988 and 1990. In July 1990 we also recovered a 120 m (400') drillcore from the dry valley south of Canandaigua Lake, north of the village of Naples, N.Y. These new drillcore samples, which are presently being dated and analyzed, compliment 26 piston cores (up to 5 m long) collected from Seneca and Cayuga Lakes. Previous subsurface geologic information on Quaternary deposits beneath the Finger Lakes was limited to stratigraphic descriptions of water wells at Ithaca (Tarr, 1904) and short cores recovered from southern Cayuga Lake (Ludlam, 1967) and northern Seneca Lake (Woodrow et al., 1969).

The purpose of this field trip is to provide a new and unique perspective on the Quaternary geology of the Finger Lakes -- the shallow subsurface. Following a brief tour of surficial features, we will embark on a comprehensive overview of the subsurface Quaternary geology of the eastern Finger Lakes (Skaneateles, Owasco, Cayuga, Seneca, Keuka, and Canandaigua) as well as Tully Valley (a "dry Finger Lake") and Montezuma wetlands (a glacial meltwater system). We have planned 12 stops over a 1½ day period to examine and discuss seismic reflection, gravity, and drillcore data at acquisition sites. This non-traditional field trip has no outcrop stops so leave your shovels but bring your imagination!

SURFICIAL GEOLOGY

The surficial geology of the Finger Lakes region has recently been compiled by Muller and Cadwell (1986; Fig. 2). Much of the upland area in the Finger Lakes region is covered by relatively thin till. However, a series of low-relief, chevroned, recessional till moraines also occur on the uplands in the central and southern regions of the lakes. At the north end of the lakes, recessional till moraines become more continuous in an east-west direction (Fig. 2).

North of the Finger Lakes is an extensive field of drumlins and meltwater channels which extend to Lake Ontario. Glaciolacustrine and swamp deposits selectively infill north-south oriented channels whereas an east-west system of channels is largely filled by outwash.

South of the lakes, and confined to the valleys, are well-developed kame moraines, collectively known as the Valley Heads moraine. These moraines are not connected over the uplands and consist principally of water-laid stratified drift. Based on regional correlations, Fullerton (1986) suggests that the Valley Heads moraines were deposited between 12.95 and 14.1 ka. If correct, Valley Heads deposition correlates with a pulse of rapid melting of the Laurentide ice sheet centered at 13.5 ka as recognized in the oxygen isotope record of North Atlantic and Gulf of Mexico deep-sea sediments (Ruddiman, 1987). To the south of the Valley Heads is a well-developed, arcuate system of outwash-filled valleys that likely served as meltwater channels during deglaciation.

There are relatively few radiocarbon dates available from the Finger Lakes region. Many of those reported (summarized by Muller and Cadwell, 1986) are "dead" dates >35 ka suggesting pre-late Wisconsin glacial deposits. Based on these dates Bloom (1986) has suggested that the valleys around Ithaca, and

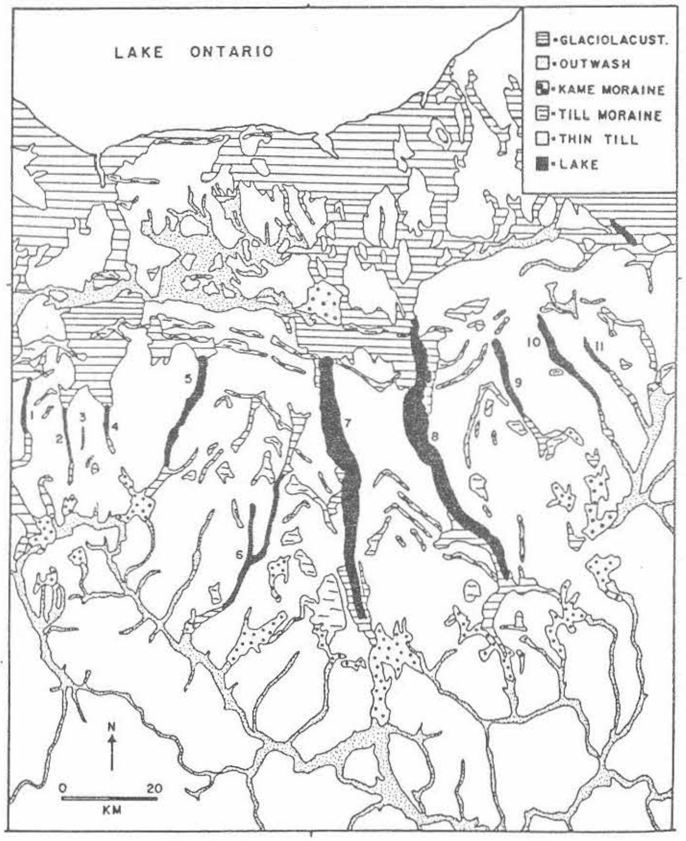

Fig. 2 - Surficial geologic map of the Finger Lakes region. Lakes are numbered as in Figure 1. Note Valley Heads ("kame moraine") at south end of lakes. Chevroned till moraines on uplands between lakes; outwash channels to the south. Simplified from Muller and Cadwell (1986).

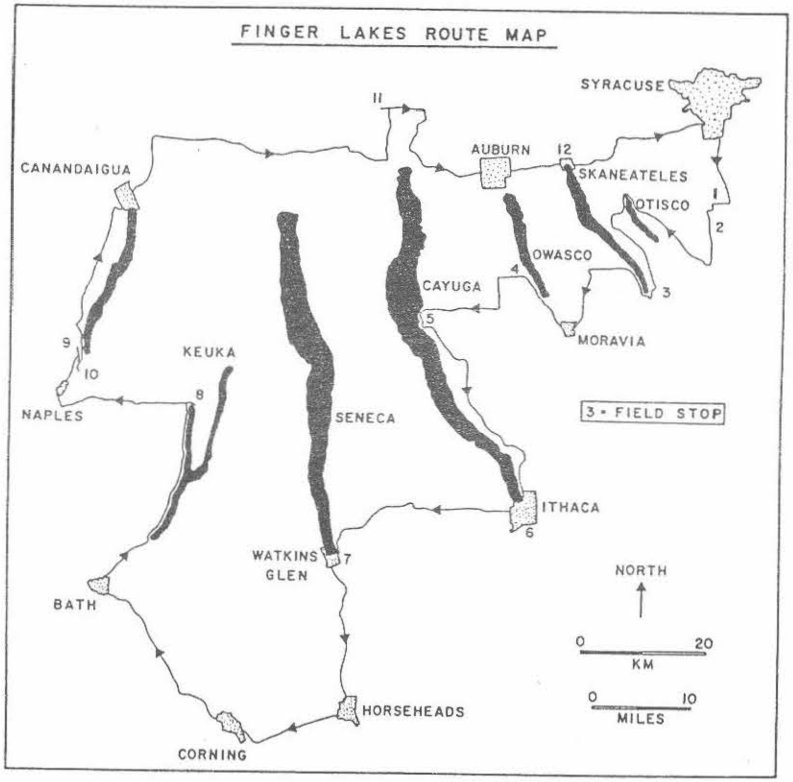

Fig. 3 - Field trip route map with stop locations numbered with text.

presumably the other Finger Lakes valleys, were excavated "prior to two ice ages ago" (p. 263), well before the late Wisconsin.

FIELD TRIP STOPS

This trip will depart from the Heroy Geology Laboratory on the campus of Syracuse University. From Syracuse we will head south to Tully Valley and then across the southern margin of the eastern Finger Lakes to Keuka Lake with an overnight stay in Bath, N.Y. (Fig. 3). From Bath we will head northwest to Naples, N.Y. and Canandaigua Lake, then north and east to Montezuma Wetlands. A final stop for wrap-up discussion will be made at the north end of Skaneateles Lake before returning to Syracuse in the early afternoon (Fig. 3). The purpose, significance, and relevant data for each stop will be briefly described followed by a complete road log.

STOP 1: OVERVIEW OF A "DRY" FINGER LAKE

This brief stop at the dead end of Amidon Road provides (weather permitting) an outstanding south-directed view of Tully Valley, a "dry" Finger Lake valley. Clearly visible are the steep glacially-eroded bedrock walls of the valley and its relatively flat, sediment-filled floor which produced an overall U-shape profile. To the south is the Valley Heads moraine at Tully which completely fills the valley but does not extend over adjacent upland divides. The primary purpose of this stop is to give you a view of a "Finger Lake" without the water!

During late Wisconsin deglaciation glacial meltwaters ponded in this valley to form a proglacial lake more than 183 m (600') deep (Hand and Muller, 1972). The valley floor has an elevation today of about 152 m (500') and Bare Mountain on the west side of the valley crests at about 457 m (1500') which means that the valley was filled to about 60% capacity by this proglacial lake or about to the level we are standing (351 m, 1150').

As the ice receded to the north up contiguous Onondaga Trough east-west outlets were progressively exposed and the proglacial meltwaters in Tully Valley began to drain into the Mohawk through the Syracuse meltwater channels (Hand and Muller, 1972). Hand (1978) suggests that the outflow of water from Tully Valley occurred in a series of catastrophic flood events which ultimately led to the "dry Finger Lake" valley we see today. Since the draining of Tully Valley some 12 ka ago, post-glacial alluvium has washed into the valley, with the large alluvial fan at the mouth of the Rattlesnake Gulf being the most prominent.

From the vantage point of this overview stop we will drive down into this "dry Finger Lake" to examine subsurface data from the floor of Tully Valley.

STOP 2: THE FLOOR OF TULLY VALLEY

At this stop along Otisco Road you are now standing at the bottom of what once was a Finger Lake as deep as modern day Seneca Lake. How far below the valley floor does bedrock extend? How thick are the sediments beneath the valley floor and what is their geologic nature? To address these simple questions we have collected preliminary multichannel seismic reflection and gravity data which have been integrated with available drillhole information.

A gravity transect across Webster Road, 2.5 km north of our current location, suggests a total sediment fill of about 134 m (440′) with bedrock eroded to within 30 m (100′) of sealevel (Fig. 4). Sediment thickness of at least 117 m (385′) has been confirmed there by a drillhole that did not reach bedrock (Fig. 4).

A multichannel (6-fold) weight-drop seismic reflection profile shot across Otisco Road reveals a high-amplitude reflector interpreted as bedrock at a maximum of 0.13 sec. of two-way travel time (Fig. 5). Calculation of true depth to bedrock is dependent upon the compressional wave velocity of overlying sediment. Based on wide-angle reflection experiments conducted in the Finger Lakes (Mullins and Hinchey, 1989) as well as seismic refraction data from southern Tully Valley (Faltyn, 1957) unconsolidated sediments beneath the Finger Lake valleys have a P-wave velocity in the range of 1.5-2.2 km/sec. Using this range of velocities, maximum subsurface depth to bedrock beneath Otisco Road is on the order of 98-130 m (321-4262′). If one accepts the higher range of velocities (2.0 km/sec.) there is good agreement between the seismic (130 m) and gravity (134 m) data. Both sets of data show a relatively flat bedrock floor beneath the axial portion of Tully Valley. Total bedrock erosion, as measured from the top of adjacent divides to bedrock beneath Tully Valley, has been on the order of 540 m (1770′).

The seismic reflection data also suggest that there are three major stratigraphic sequences beneath Tully Valley (Fig. 5). The youngest sequence is characterized by discontinuous, high-frequency reflections and thickens to the west toward the alluvial fan at the mouth of Rattlesnake Gulf where it is as much as 60-80 m (197-262′) thick. We interpret this sequence as post-glacial alluvial in-fill. The middle stratigraphic unit is largely "transparent" or reflection-free indicating massive sediment which we interpret as glaciolacustrine muds, that are as much as 53-70 m (174-230′) thick. The top of this middle unit is undulatory which may be a consequence of loading by the overlying alluvial fill. The lowermost stratigraphic sequence beneath Tully Valley is also transparent and is characterized by a discontinuous, high-amplitude reflection at its top. This oldest sequence is relatively thin (19-25 m; 62-82′) and is interpreted as a coarse-grained facies.

Our inferences on depth to bedrock and stratigraphic nature of the sediment fill beneath Tully Valley based on geophysical data are supported by available drillhole data. Getchell (1983) reported the gross stratigraphy of nine drillholes located in the southern end of Tully Valley (Fig. 6). Eight of the nine wells penetrated three major stratigraphic units: (1) an upper gravel/clayey gravel unit up to 24 m (80′) thick; (2) a middle clay sequence 99-134 m (325-440′) thick; and, (3) a basal gravel/sandy gravel unit at least 17 m (55′) thick. The one well (WL-6) that did not penetrate the basal gravel unit reached shale bedrock at a subsurface depth of 142 m (465′) which is at an elevation of 72 m (235′) above sea level.

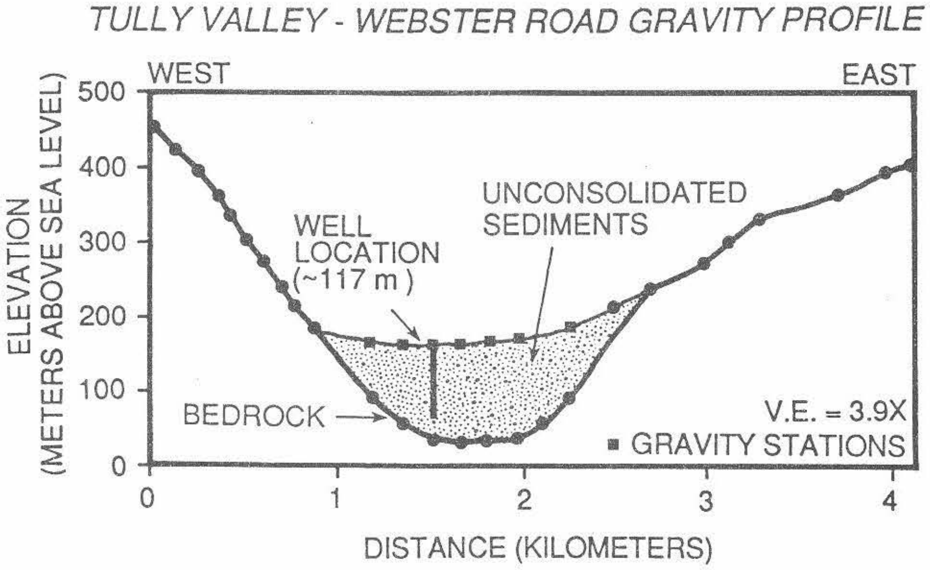

Fig. 4 - Cross-section of bedrock morphology and sediment fill of Tully Valley along Webster Road based on gravity data. Upland data points are based on topography.

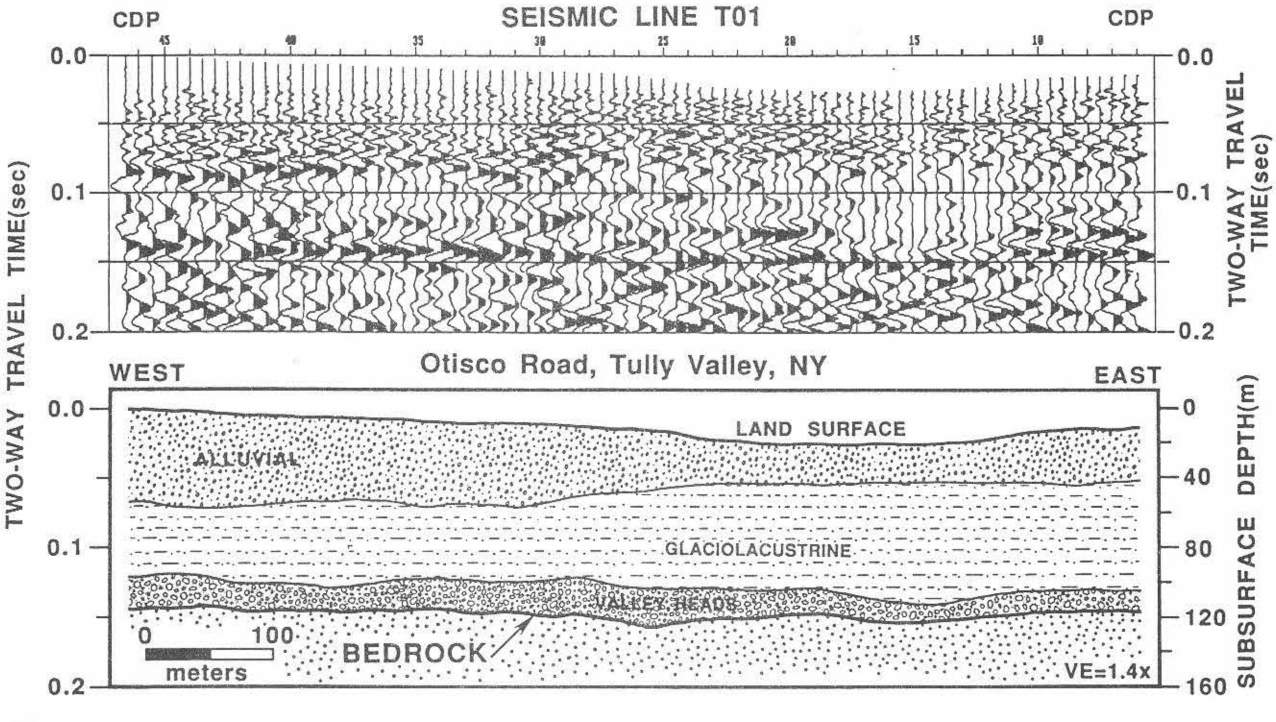

Fig. 5 - Weight-drop, multichannel (6-fold) seismic reflection profile (top) and line drawing interpretation across Tully Valley along Otisco Road. Subsurface stratigraphy based on well data (see Figure 6). Subsurface depth scale assumes a P-wave velocity of 1.6 km/sec.

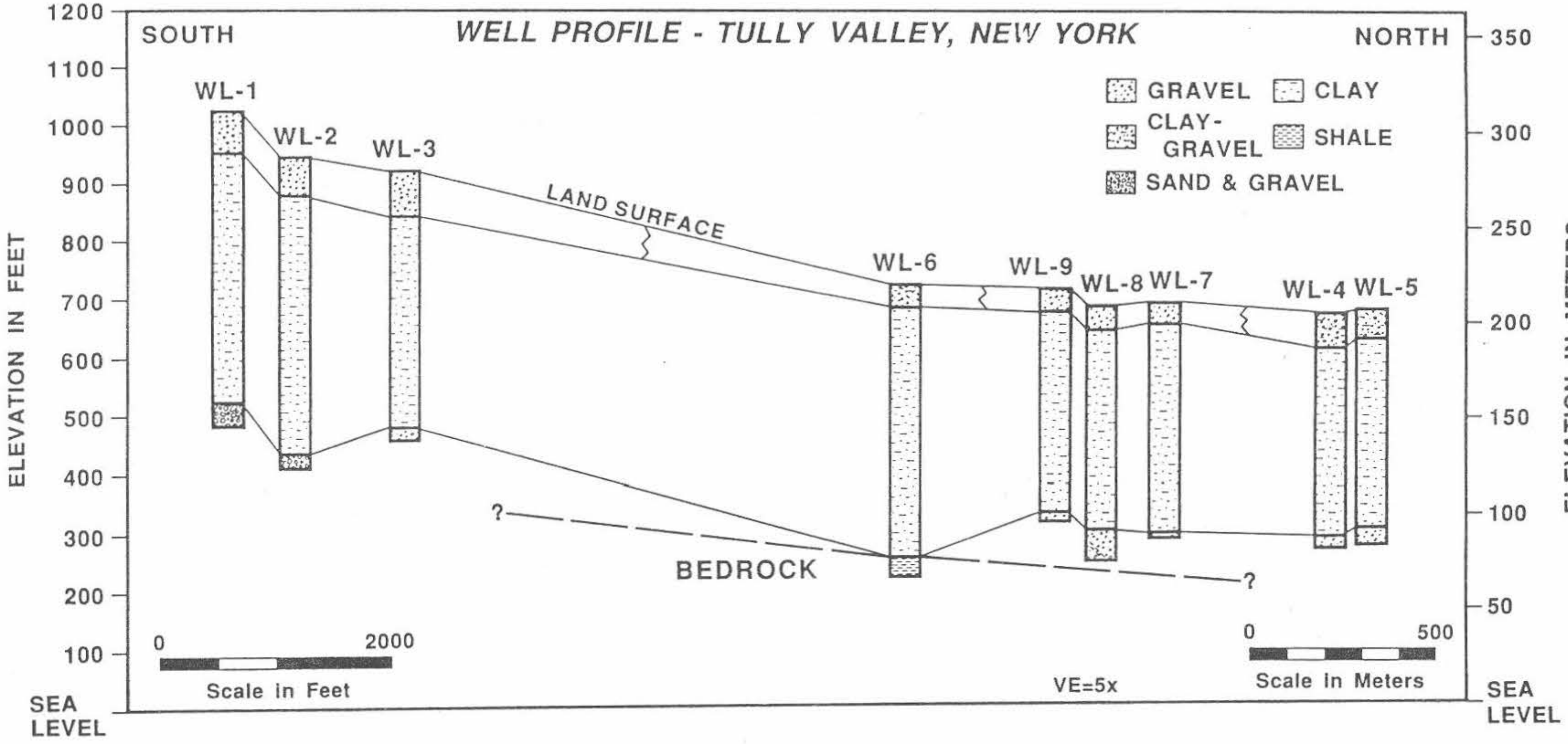

Fig. 6 - Schematic descriptions of south-north transect of wells in southern Tully Valley, based on reports in Getchell (1983). Wells are in their proper relative positions both laterally and with respect to elevation.

Combined, the subsurface geophysical and drillhole data reveal a deeply scoured trough beneath Tully Valley with bedrock rising to the south, which is consistent with reflection data from the Finger Lakes (Mullins and Hinchey, 1989). The data also indicate a relatively simple infill stratigraphy of washed subglacial (?) sands and gravel at the base overlain by glaciolacustrine muds which in turn are capped by coarse-grained alluvial gravels and clayey gravels. Although there is no chronostratigraphic control available, the gross lithostratigraphy beneath Tully Valley argues for a single overall infill sequence.

As we leave Otisco Road we will drive south along Tully Valley and then up the Valley Heads moraine which crests at an elevation of about 366 m (1200') which is some 213 m (700') above the floor of the adjacent valley. Gravel pit exposures here reveal washed sands and gravel that are crudely stratified. The Valley Heads deposits argue for an extended ice marginal environment here with large volumes of coarse-grained debris, both local and exotic, pumped through Tully Valley about 13-14 ka. The thickness of sediment beneath the Valley Heads moraine at Tully and the adjacent outwash plain has yet to be resolved, but is certainly an important question. Durham (1958) suggested that the position of the Valley Heads moraine was controlled by a pre-glacial drainage divide based on a well record at Little York which encountered bedrock at a subsurface depth of only 67 m (220'). However, it is not known whether or not this well, at an elevation of 354 m (1160'), was located along the valley axis. Preliminary gravity data obtained along Little York Road by Steve Wanzer, suggest that bedrock may be considerably deeper than that suggested by Durham (1958). This topic will be part of Steve's master's thesis, and hopefully he will have more definitive results by the time of our field trip.

From the Valley Heads moraine at Tully we will head northwest and drive around the north end of Otisco Lake (the easternmost Finger Lake), and then south to our next stop at the south end of Skaneateles Lake. When leaving the Valley Heads we will be able to see its contact with the bedrock wall of Tully Valley and observe that the moraine does not extend up and over the divide. At the northeast corner of Otisco Lake we will also pass by a hanging delta at Amber some 61 m (200') above the modern lake level of Otisco Lake, attesting to higher glacial lake levels.

Otisco Lake today is relatively shallow (maximum depth of 21 m or 69') and eutrophic which greatly limited our ability to collect seismic reflection data due to gas-saturated sediment (Hinchey, 1986). However, "windows" of seismic data indicate at least 83 m of sediment beneath Otisco Lake (Hinchey, 1986). As we drive around the north end of Otisco Lake we will (weather permitting) have an excellent view down the axis of the lake and Otisco Valley. The steep, U-shaped valley wall on the west side of the valley has a slope of about 35°. From Otisco Lake we will drive over the divide to Skaneateles Lake. Bedrock outcrops along the road attest to the relative paucity of glacial erosion and deposition on the uplands compared to the adjacent valleys.

STOP 3: SOUTH END OF SKANEATELES LAKE

This stop, high above the lake at the Onondaga-Cortland county line, provides a spectacular north-view of one of the most scenic Finger Lakes --

Skaneateles. We are standing at an elevation of 506 m (1660') which is slightly lower than the surrounding top of the plateau at about 579 m (1900'), but well above lake level which is at 263 m (863'). As you look to the north, it is quite apparent that the southern end of Skaneateles Lake is much more deeply incised than it is to the north. Also visible are three "points" along the west shore of the lake which represent post-glacial stream deltas that have built into Skaneateles Lake as higher glacial lake levels receded. The overall morphology of the Skaneateles Lake basin is similar to that observed in Tully Valley except that the valley is partially filled with water.

Maximum water depth in Skaneateles Lake is 90 m (295') which occurs at about the north-south midpoint of the lake. Seismic reflection data indicate that bedrock is relatively shallow beneath the north end of the lake but deepens toward the central portion of the lake where maximum erosion down to about sealevel has produced a closed rock basin (Fig. 7). Bedrock gradually rises toward the south end of the lake producing an overall spoon-shaped longitudinal profile which is typical of the Finger Lakes (Fig. 7; Mullins and Hinchey, 1989). Crossing lines indicate broad, U-shaped bedrock profiles at the north end of the lake which become progressively more incised and V-shaped toward the south (Fig. 8), which is also typical of the Finger Lakes (Mullins and Hinchey, 1989). Total erosion of bedrock, from the top of the plateau to the maximum extent of bedrock beneath the lake, has been on the order of 580 m (1900').

Maximum sediment thickness beneath Skaneateles Lake is on the order of 170 m (Mullins and Hinchey, 1989) with most of the sediment in the southern half of the lake basin (Figs. 7 and 8). The most regionally significant feature of the stratigraphy beneath Skaneateles is onlap at the south end of the lake of transparent to highly reflective sediments onto a southward thickening wedge characterized by a hummocky chaotic seismic facies (Fig. 9). The younger package of sediment is interpreted as largely northerly-derived glaciolacustrine deposits. The older chaotic wedge that thickens to the south, projects to on-land outcrops of Valley Heads. If Fullerton's (1986) correlation of Valley Heads at 13-14 ka is correct, this onlap at the south end of Skaneateles Lake implies that the sediment fill beneath the lake is all less than 14 ka, or of late Wisconsin to Holocene age. If older glacial sequences were deposited in Skaneateles valley they have been effectively removed by late Wisconsin glaciation.

Using this onlap relationship (14 ka) and a maximum sediment thickness of 170 m for Skaneateles Lake, we calculate an <u>average</u> rate of sediment accumulation of 12.1 m/1000 years. However, drilling south of Canandaigua Lake (see Stop #10) suggests that the post-glacial section is quite thin relative to the total thickness of sediment-fill which is consistent with our seismic stratigraphic interpretations. If 90% of the sediment fill beneath Skaneateles Lake was deposited over a 2 ka period between 12 and 14 ka, accumulation rates may have been as high as 77 m/1000 years. If correct, these calculations suggest that large volumes of sediment were rapidly deposited in the Skaneateles Lake basin during deglaciation.

A second stratigraphic feature of significance occurs at about the north-south midpoint of Skaneateles Lake. Here, a series of stacked, transparent wedges, each up to 15 m thick, occur (Fig. 10). These wedges pinch-out to the south over a horizontal distance of 3-4 km and are interbedded with highly

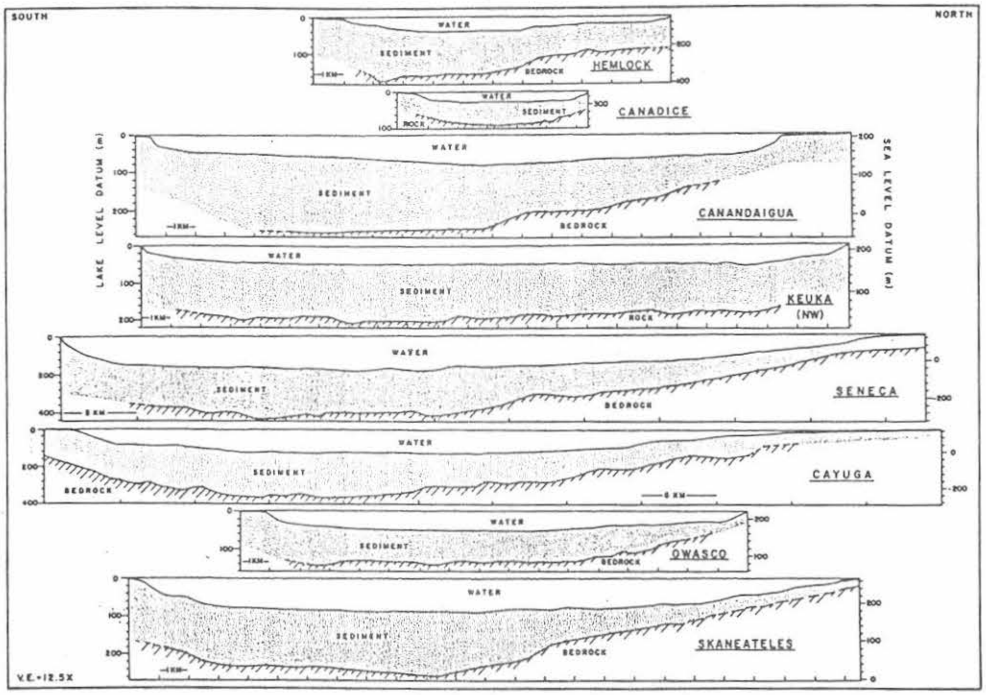

Fig. 7 - Schematic, longitudinal (N-S) bedrock and sediment-fill profiles of the Finger Lakes relative to both sea-level (right) and lake-level (left). Profiles based on reflection data collected from each lake. Scales for Seneca and Cayuga differ from other lakes; from Mullins and Hinchey (1989).

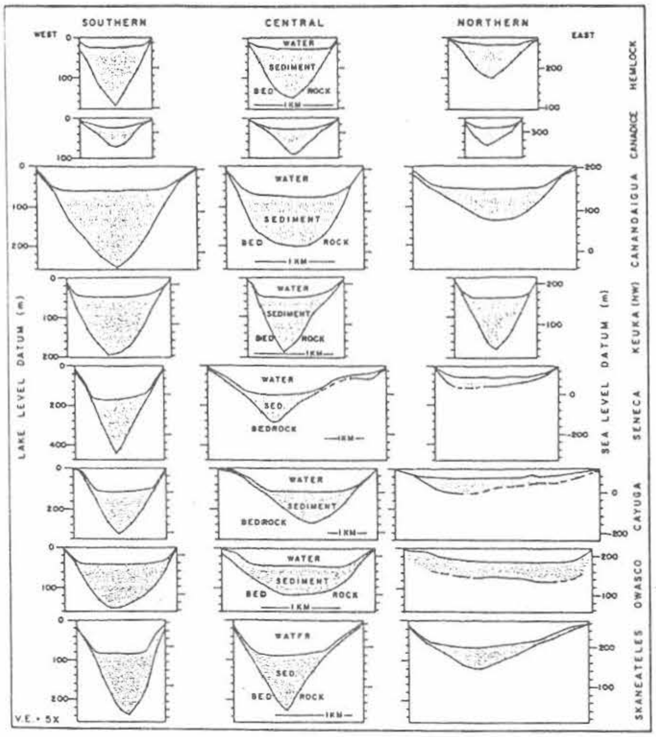

Fig. 8 - Schematic, transverse (E-W) profiles of bedrock and sediment-fill for the northern, central, and southern portions of the Finger Lakes relative to both sea-level (right) and lake level (left). Separate scales for Seneca and Cayuga Lakes; from Mullins and Hinchey (1989).

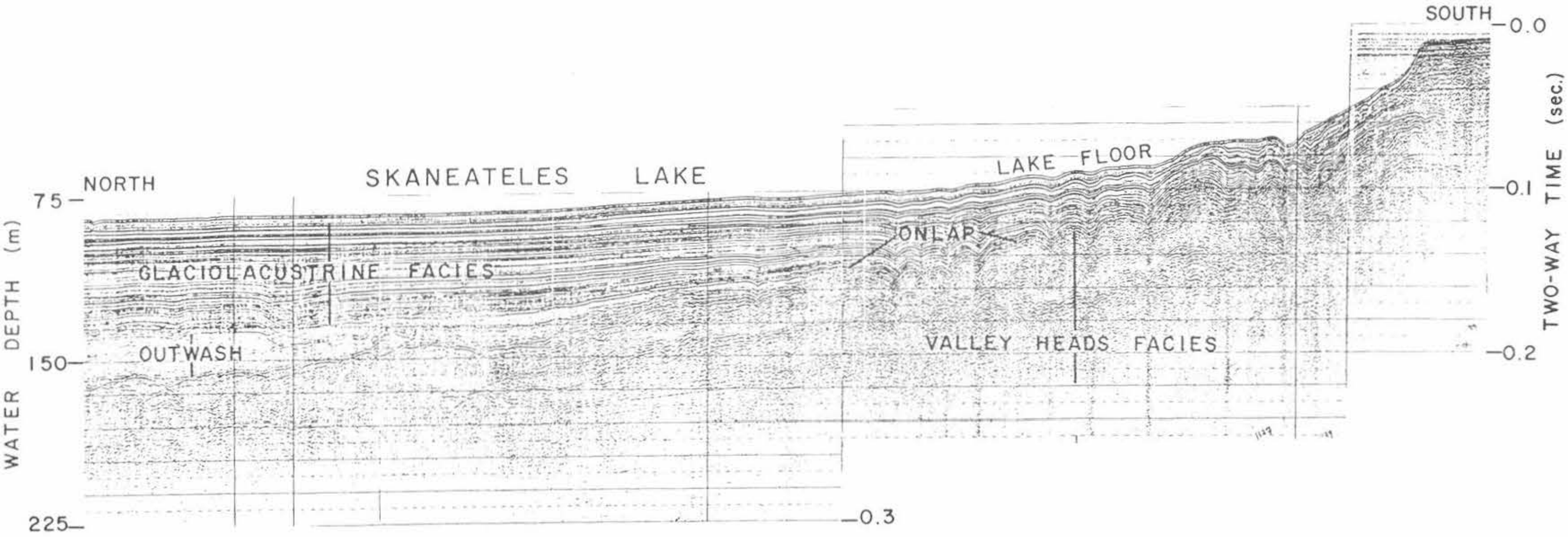

Fig. 9 - Southern portion of axial reflection profile from Skaneateles Lake illustrating onlap of glacio-lacustrine facies onto chaotic Valley Heads facies which thickens to the south. Water depth scale assumes a velocity of 1.5 km/sec.

reflective units interpreted as glaciolacustrine deposits (Fig. 10). Longitudinal (N-S) profiles (Fig. 10) indicate irregular tops with large diffractions. The seismically transparent (reflection-free) nature of these wedges indicates that they consist of massive sediment.

One interpretation is that these wedges represent "inflow events" deposited rapidly, issuing perhaps from a subglacial conduit; in essence a rapid pulse of massive debris. An alternative interpretation is that these wedges represent "till-tongues" similar to those described by King et al. (1991). Unfortunately, no samples from the wedges are available to resolve which (if either) interpretation is correct. However, Ed Hinchey promises to be on hand during the field trip to defend our view that these wedges represent sudden inflow events.

Regardless of the interpretation of these wedges, they suggest the presence of an ice margin that was either grounded or pinned here, where there is a break in the bedrock slope. North of these wedges total sediment thickness thins appreciably, consisting of a thin, highly-reflective (glaciolacustrine?) unit overlying a thin, chaotic (subglacial?) sequence. These stratigraphic relationships suggest that the ice margin in Skaneateles valley retreated rapidly (by calving?) to the north from its Valley Heads position to the lake's midpoint where it stabilized and issued large volumes of sediment into a proglacial lake.

From our overview of Skaneateles Lake we will drive down into the valley and around the south end of the lake. This will give you a good opportunity to get a "feel" for how deeply (and steeply) incised the south end of Skaneateles Lake is into bedrock of the surrounding Appalachian Plateau. As we cross the valley floor at the south end of Skaneateles Lake keep in mind that bedrock extends about 150 m (~500') beneath the surface. We will then drive up the west wall of Skaneateles Lake, over the divide to Owasco valley and through the village of Moravia to our next stop overlooking Owasco Lake at Ensnore.

STOP 4: OWASCO LAKE

This stop near the intersection of Ensnore Road and State Route 38 provides a good north-oriented overview of Owasco Lake. Elevation here is 323 m (1058') which is about half way between lake level at 217 m (711') and the crest of the upland divide at 402 m (1320') just to our west (Fig. 14).

Maximum water depth beneath Owasco Lake is 52 m (170'). Like the other Finger Lakes, it has steep walls and a relatively flat floor. Bedrock beneath the lake extends down to an elevation of ~80 m (262') above sea-level. Total erosion, from the top of the divide here at Ensnore to the bottom of bedrock beneath the lake, has been on the order of 320 m (1050').

Total sediment thickness beneath Owasco Lake is on the order of 100 m (328'; Figs. 7 and 8). The stratigraphy beneath the lake is particularly well-defined by our seismic reflection data. A basal, seismically chaotic sequence which thickens to the south, is overlain by a highly reflective unit (Fig. 12). We infer a single coarse-grained, subglacial sequence overlain by proglacial and post-glacial lacustrine deposits.

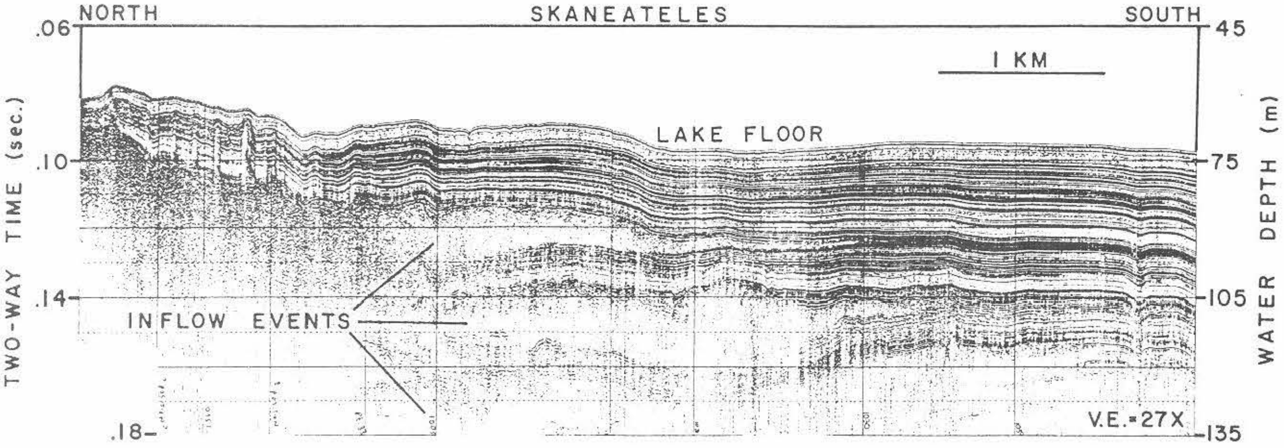

Fig. 10 - Central portion of axial reflection profile from Skaneateles Lake illustrating transparent wedges of sediment that are interpreted here as "inflow events" from a subglacial conduit into a proglacial lake.

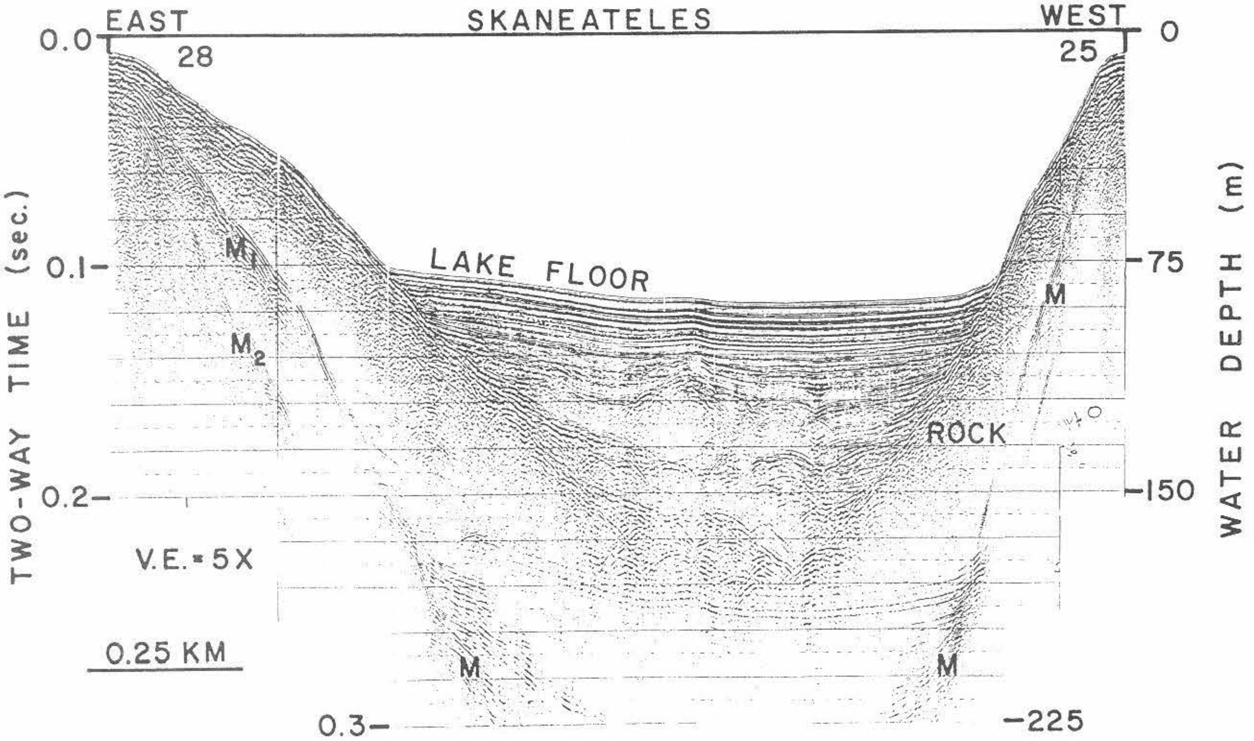

Fig. 11 - Transverse reflection profile from central Skaneateles Lake illustrating stacked wedges of debris with large diffractions at their tops. Note bedrock reflection and overlying highly-reflective sequence; M = multiple reflection.

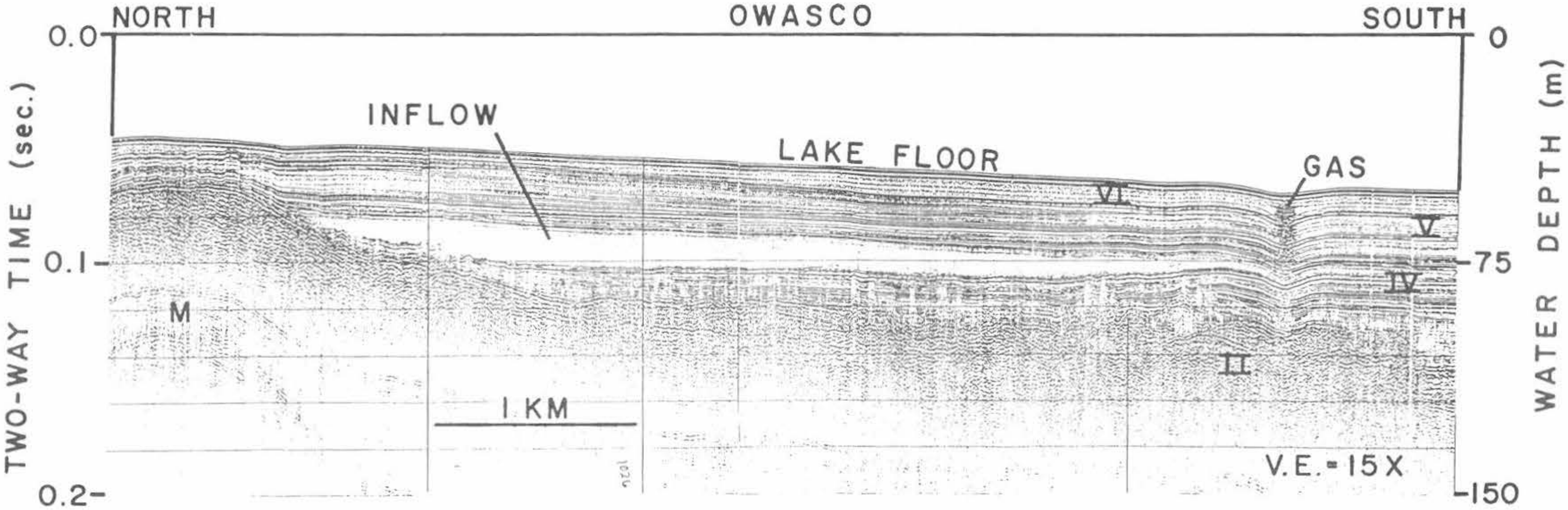

Fig. 12 - Central portion of axial reflection profile from Owasco Lake illustrating transparent sediment wedge interpreted as an inflow deposit. Roman numerals refer to depositional sequences; M = multiple.

In the northern third of Owasco Lake, an axial ridge is buried beneath the highly reflective lacustrine sequence (Fig. 13). This ridge, with up to 20 m (66') of relief, is sinuous and can be traced over a lateral distance of at least 5 km. We interpret this buried ridge as an esker which implies the past presence of a large subglacial meltwater conduit along the axis of northern Owasco Lake. Such an ice tunnel may have been responsible for the supply of coarse subglacial debris to the basal chaotic sequence beneath Owasco.

Another significant stratigraphic feature of the sediment-fill beneath Owasco Lake is a remarkably transparent (reflection-free) wedge of sediment in the northern half of the basin (Fig. 12). The transparent nature of this deposit indicates massive sediment which is interbedded with highly reflective glaciolacustrine sequences. Underlying units reveal only slight erosion and the top of this transparent unit is smooth. The wedge is up to 15 m (50') thick in the north and pinches out to zero thickness near the north-south midpoint of the lake. Transverse reflection profiles (Fig. 14) indicate that the wedge onlaps both the east and west bedrock walls of the lake. Although no subsurface samples are available, we interpret this transparent wedge as a subaqueous outwash fan of massive sand or silt, perhaps analogous to the deposits described by Rust and Romanelli (1973) near Ottawa. If this wedge represents in essence an "inflow event," it further argues in favor of the role of subglacial meltwater in the transport of debris to the southern margin of the Laurentide Ice Sheet, similar to the suggestion by Gustavson and Boothroyd (1987).

From our overlook of Owasco Lake we will head west over the divide toward Cayuga Lake. Just prior to entering the village of Poplar Ridge, we will cross one of the "chevron" till moraines mapped by Muller and Cadwell (1986). Radiocarbon analysis of wood overlying the south end of this till moraine yielded a date of 11,410 ±410 years (Muller and Cadwell, 1986).

STOP 5: CAYUGA LAKE

This stop is located at Long Point State Park at about the midpoint (east shore) of Cayuga Lake, just south of the village of Aurora. Cayuga Lake is one of the two largest Finger Lakes extending north-south for a distance of about 60 km with a maximum width of about 5 km. It has a maximum water depth of 132 m (433') located about two-thirds of the length of the lake form its north end. At this point of maximum water depth, the lake bottom is 15 m (51') below sea-level. Off Long Point maximum water depth is 100 m (361'). Lake level is at 116 m (382') which is the lowest elevation of all the Finger Lakes.

We have collected more than 150 km of high-resolution uniboom seismic reflection data from Cayuga Lake which have been correlated with 11 piston cores (Fig. 15). Bedrock beneath Cayuga Lake has been eroded as much as 358 m (1174') below lake level, which means that bedrock extends as much as 242 m (794') below sea-level!

A north-south schematic (Fig. 16) illustrates the overall "spoon-shaped" longitudinal profile of Cayuga Lake. Note that the maximum extent of erosion extends down to the Onondaga Limestone and appears to follow its southward dip

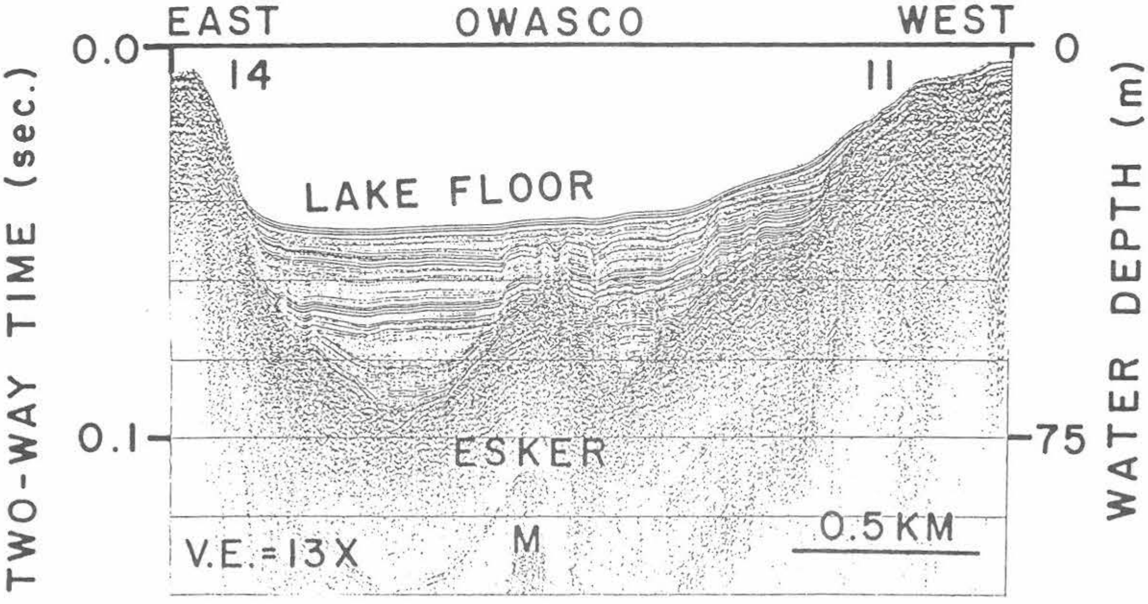

Fig. 13 - Transverse reflection profile across the northern portion of Owasco Lake illustrating buried, subsurface ridge interpreted here as an esker. Note small compactional "faults" at its crest; M = multiple.

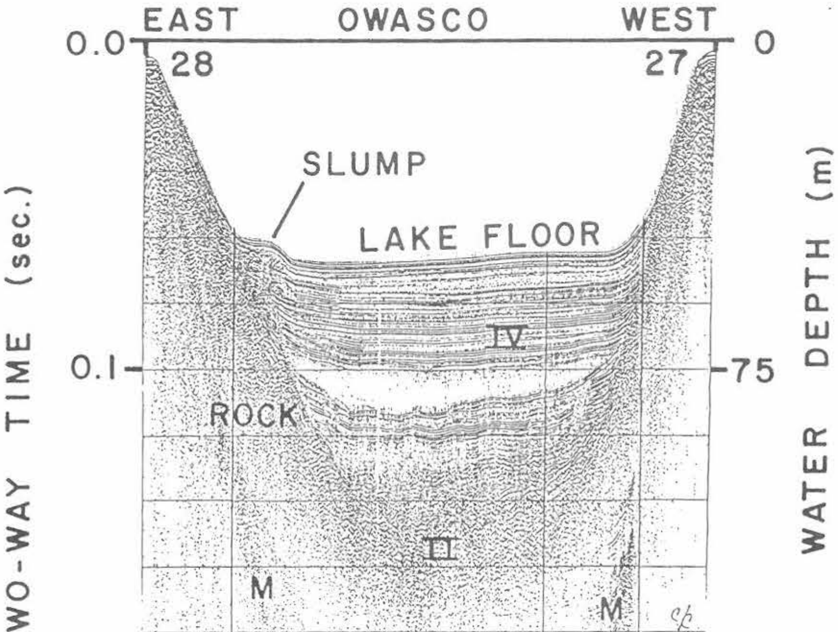

Fig. 14 - Transverse reflection profile across the central portion of Owasco Lake illustrating (in cross-section) transparent sediment wedge. Note onlap onto bedrock walls and small surficial slump on lake floor.

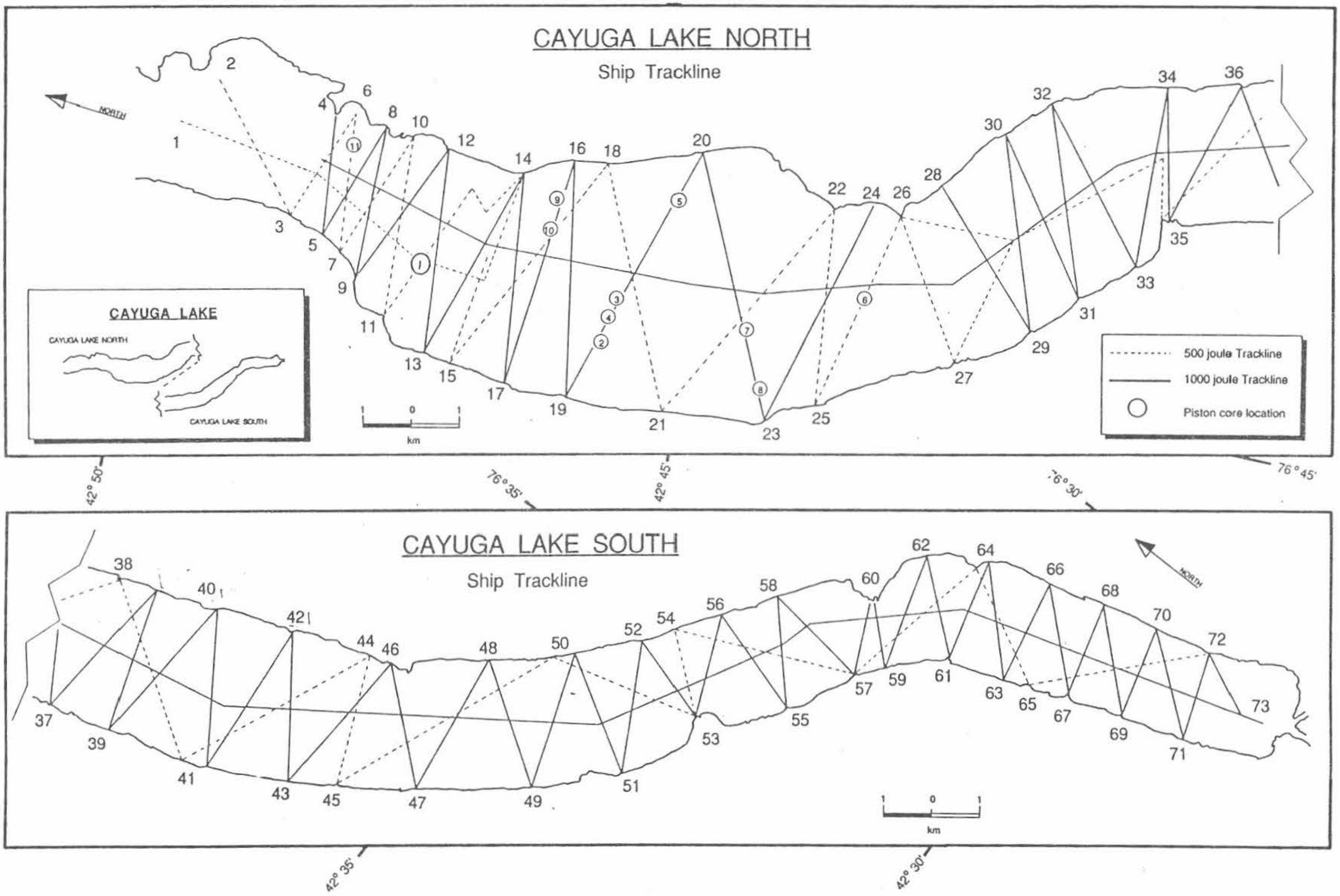

Fig. 15 - Geophysical trackline map for Cayuga Lake. Data spacing is typical of that collected for all Finger Lakes. Also shown are locations of piston cores.

before rising up through Hamilton Group shales at the south end of the lake. East-west schematics (Fig. 17) illustrate the broad, shallow form of the bedrock basin at the north end of the lake which becomes more narrow, and deeply incised to the south.

Maximum sediment fill beneath Cayuga Lake is 226 m (741') which occurs in the southern half of the lake basin. We have divided this fill into six seismically-defined depositional sequences: (I) The oldest sequence occurs only in the axial southern half of the lake basin where it is as much as 100 m (328') thick. This unit is characterized by a chaotic seismic facies and an irregular, hummocky upper surface which projects to Valley Heads outcrops south of the lake; (II) Sequence II is present throughout the lake basin and is up to 135 m (443') thick. It is characterized by a distinct north to south change in acoustic facies from chaotic to transparent (Figs. 18 and 19). A piston core (#10) located at the crest of an esker-like ridge along the top of sequence II (Fig. 18) recovered less than a meter of fine-grained rhythmites with dropstones before bottoming in clast-supported gravels (Fig. 20); (III) This sequence occurs throughout the lake basin as a transparent (reflection-free) unit up to 59 m (194') thick. At the north end of the lake this sequence is diapiric where it intrudes vertically up to 20 m (66'). Although unsampled, the massive, diapiric nature of this sequence suggests rapidly deposited muds; (IV) Sequence IV is a package of high-frequency, parallel reflections (Fig. 18) in which individual reflectors can be traced for 10's km along the length of the lake basin. It has a rather uniform thickness of about 30 m (98') except at the north end where it is more than 60 m (197') thick. Piston cores from lake floor outcrops of this sequence, recovered fine-grained, centimeter-scale rhythmites with occasional dropstones that were deposited in a proglacial lake; (V) This sequence records a "turning point" in the history of Cayuga Lake. It is thickest (>30 m; 98') at the south end of the lake basin as well as off major "points" such as Myers Point and Sheldrake Point; and, it is not present at the north end of the lake. This sequence heralds the beginning of northward drainage and lateral sediment input to Cayuga Lake that likely accompanied the lowering of proglacial lake levels and erosion of regional, upland gorges as ice withdrew from Cayuga Valley (Fairchild, 1934a); (VI) Sequence VI is a low-amplitude to transparent seismic unit that is variable in thickness (8-19 m; 26-62') throughout the lake basin. Piston cores have recovered fine-grained organic-rich sediments from this sequence (Fig. 20), some of which are "banded" and were perhaps deposited by turbidity currents (Ludlam, 1967).

After lunch at Long Point State Park we will head south to Buttermilk Falls State Park near the south end of Cayuga Lake at Ithaca.

STOP 6: SOUTH END OF CAYUGA LAKE

The purpose of this stop at scenic Buttermilk Falls State Park is to examine and discuss land-based, seismic reflection data (acquired from Cayuga valley across from the Park) that have been integrated with results from 13 wells reported by Tarr (1904). The bedrock reflection extends as much as 0.19 sec. of two-way travel time beneath the valley (Fig. 21). Using a range of interval velocities from 1.5 to 2.0 km/sec., <u>maximum</u> depth to bedrock here is 143 m (467') to 190 m (623'). Tarr (1904) reported a salt well along the western margin of Cayuga valley at Ithaca, that encountered bedrock at 131 m

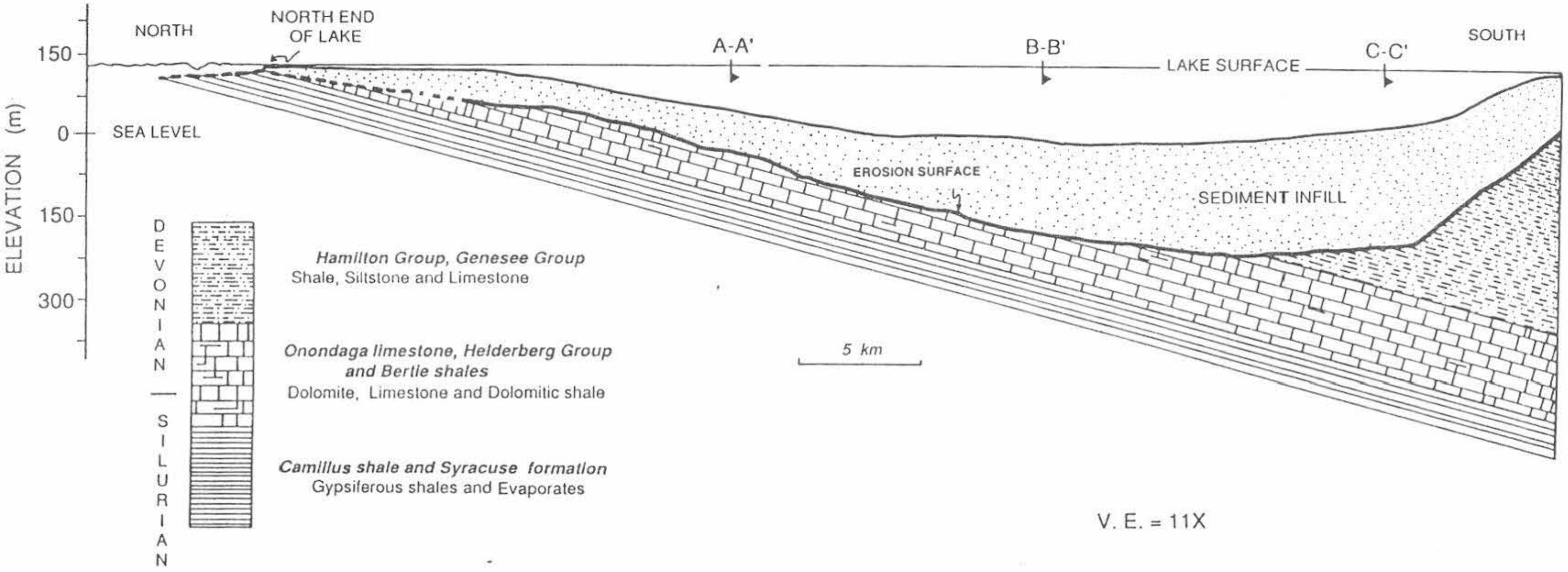

Fig. 16 - Schematic axial (N-S) profile of bedrock geology and sediment-fill for Cayuga Lake. Crossing profiles A-A', B-B', and C-C' illustrated in Figure 17.

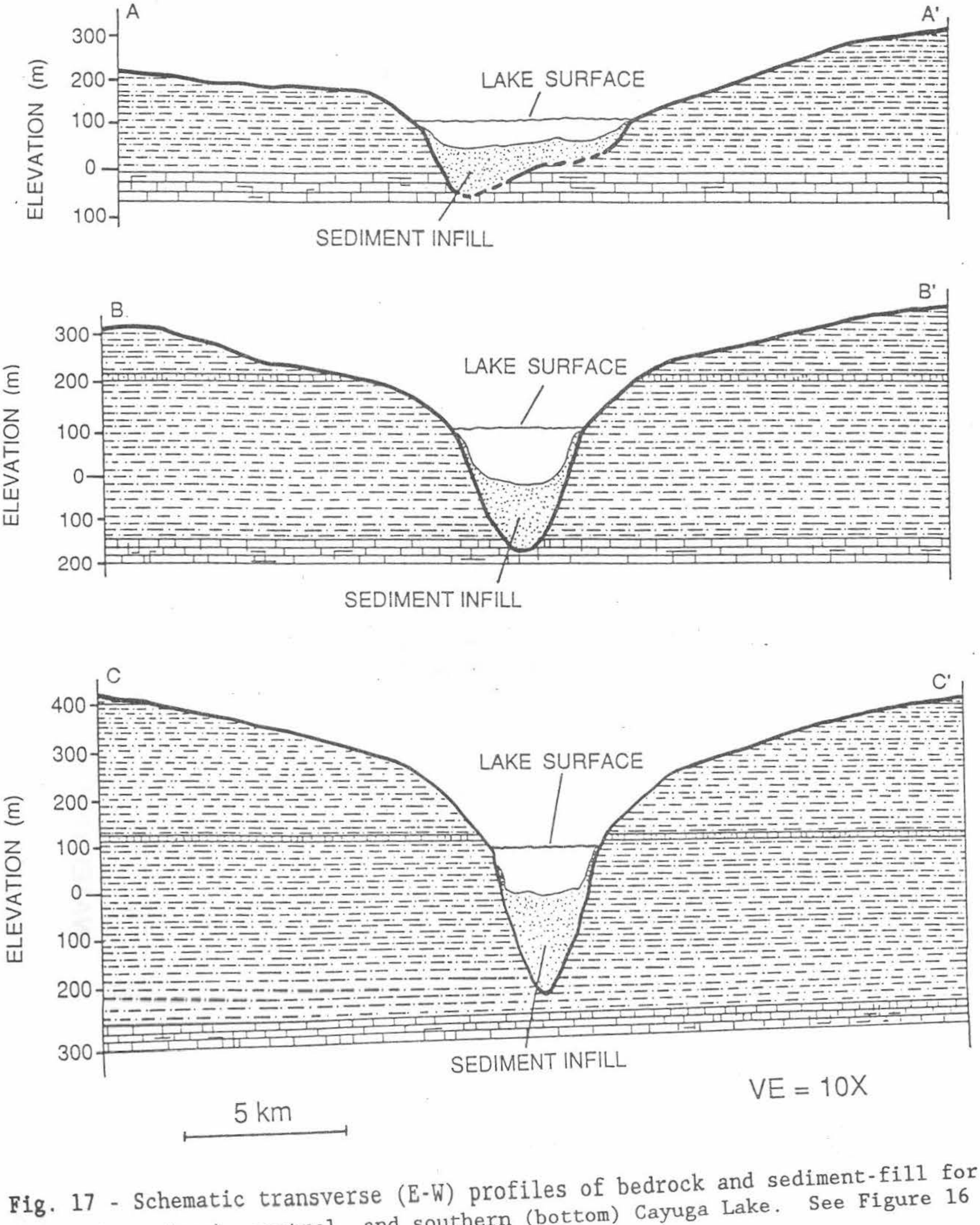

Fig. 17 - Schematic transverse (E-W) profiles of bedrock and sediment-fill for northern (top), central, and southern (bottom) Cayuga Lake. See Figure 16 for locations and legend.

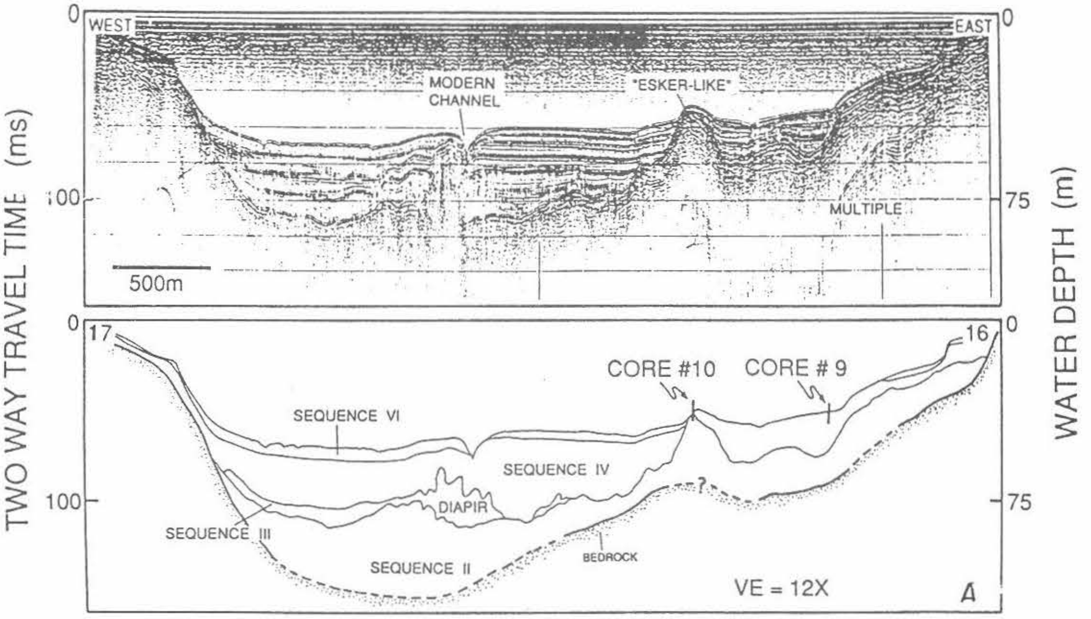

Fig. 18 - Transverse seismic reflection profile (top) and line-drawing interpretation (bottom) across the northern portion (16-17, Fig. 15) of Cayuga Lake. Note depositional sequences and location of piston cores.

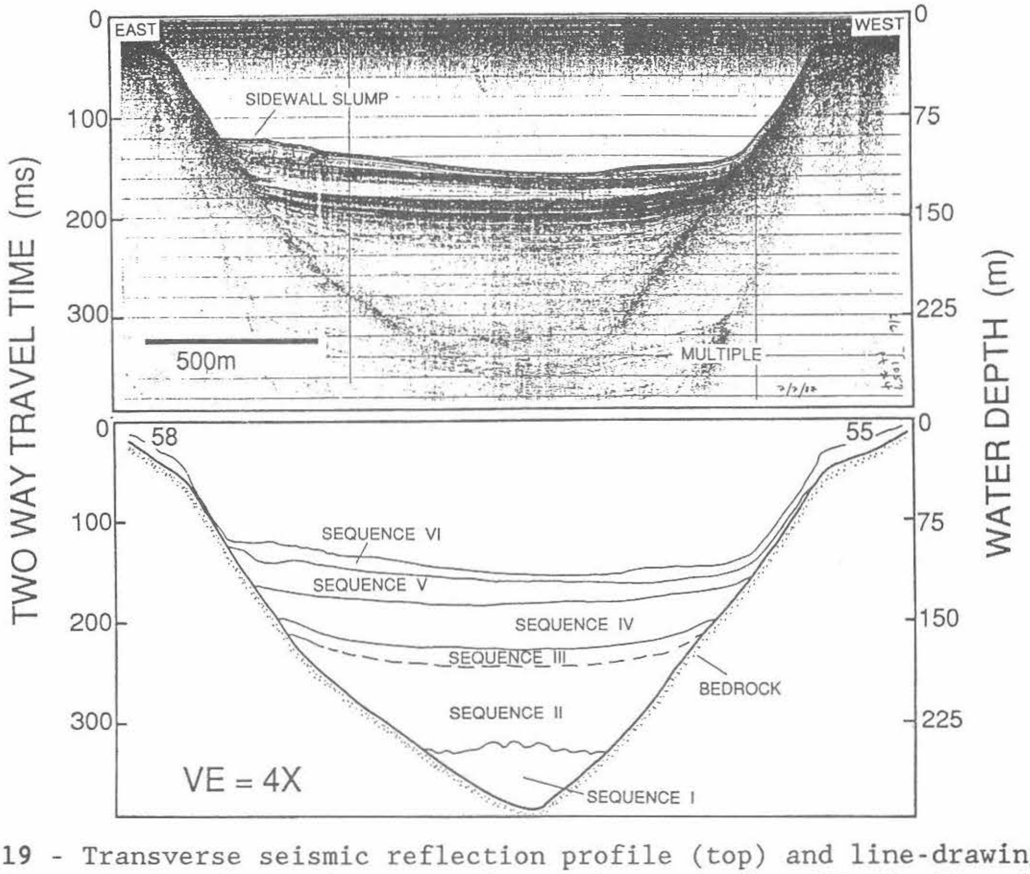

Fig. 19 - Transverse seismic reflection profile (top) and line-drawing interpretation (bottom) across the southern portion (55-58, Fig. 15) of Cayuga Lake.

which provides a minimum value for depth to bedrock because of its western location. Maximum sediment thickness beneath Ithaca is probably on the order of 166 m (545').

Our land-based seismic reflection profile (which is of lower resolution than our lake data) also reveals four major stratigraphic units beneath the valley: (1) an upper transparent (reflection-free) unit up to 20 m (66') thick (assuming an interval velocity of 1.5 km/sec.); (2) a high-frequency unit about 19 m (62') thick; (3) a sequence, bound by high-amplitude reflections, up to 28 m (92') thick (assuming a velocity of 1.6 km/sec.), and, (4) a basal unit characterized by discontinuous high-amplitude reflections up to 85 m (279') thick (assuming a velocity of 1.7 km/sec.).

The stratigraphy of Tarr's (1904) 13 wells, all located along the western margin of the valley, is schematically illustrated in Figure 22. The upper layer in these wells is predominantly fine-grained massive clay (up to 18 m or 60' thick) with fragments of mollusks, plants, and wood, including logs. Beneath these organic-rich clays is a series of sand and gravel layers 6-21 m (20-70') thick. According to Tarr (1904), the sands are well-washed and the gravels well-rounded. Plant fragments, mollusks and logs also occur in these coarser beds.

In all wells, these coarser deposits are underlain by "a great thickness of clay" devoid of mollusk fragments (Tarr, 1904). There are also minor coarser units within this clay layer including scratched, angular pebbles. The base of this clay layer is irregular, occurring at subsurface depths between 61 m (200') and 85 m (280') in the 13 wells (Tarr, 1904).

Beneath this clay layer is a heterogenous, coarse-grained unit from which artesian water flowed (up to 300,000 gallons/day!) in many of the wells. The total thickness of this basal coarse-grained unit is not known as 11 of the 13 wells bottomed in it. Tarr (1904) describes this coarse basal unit as consisting of variable sediment ranging from washed sand and gravel, to till, to "quicksand."

Tarr (1904) interpreted all these subsurface sequences as late Wisconsinian -- "Neither here nor in the other well that reached rock, nor, in fact, in any of the wells, was any older drift encountered. All the materials are such as might have been brought by the last ice advance, or deposited since the ice-sheet melted away." His view of the heterogenous basal coarse layer was that it is morainic; a subsurface extension of the nearby Valley Heads. We concur with Tarr's interpretation and our seismic data suggest that this basal Valley Heads facies extends to bedrock and is more than 100 m (328') thick. We correlate this unit with seismic sequence I beneath Cayuga Lake.

The middle clay layer with scratched angular stones, is interpreted by both Tarr and us as a proglacial lacustrine sequence, perhaps with dropstones which would suggest the presence of icebergs. We correlate this proglacial clay layer with seismic sequence IV beneath the lake. The overlying washed sands and gravels appear to be a fluvial/alluvial or shallow lacustrine facies, that likely records a drop in lake level and drainage reversal as ice receded from the north end of Cayuga Lake (seismic sequence V; Mullins and Hinchey, 1989). The succeeding organic-rich clays at the top of the section

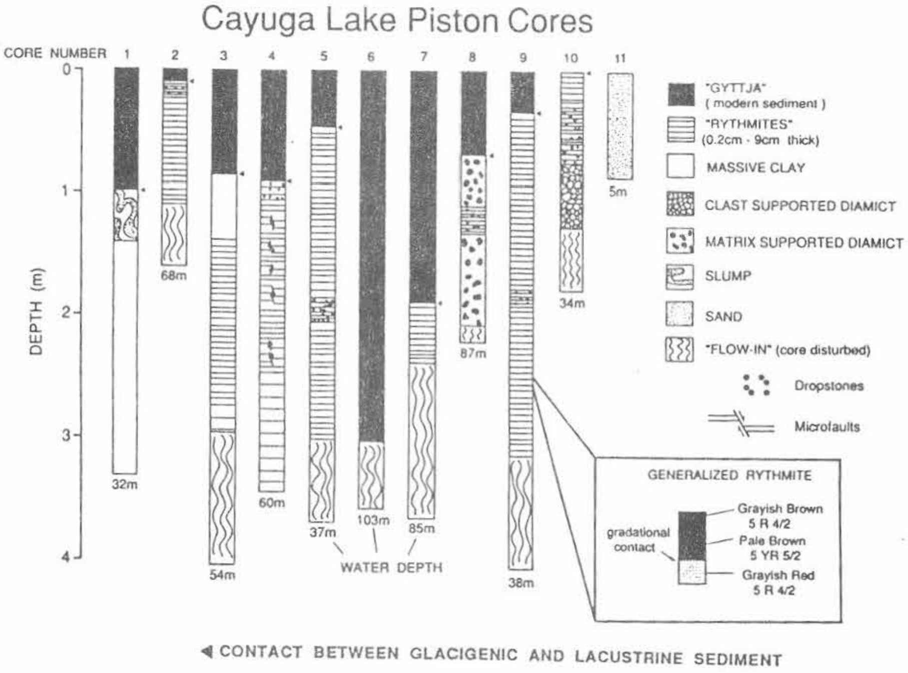

Fig. 20 - Schematic description of piston cores recovered from northern Cayuga Lake; see Figure 15 for locations.

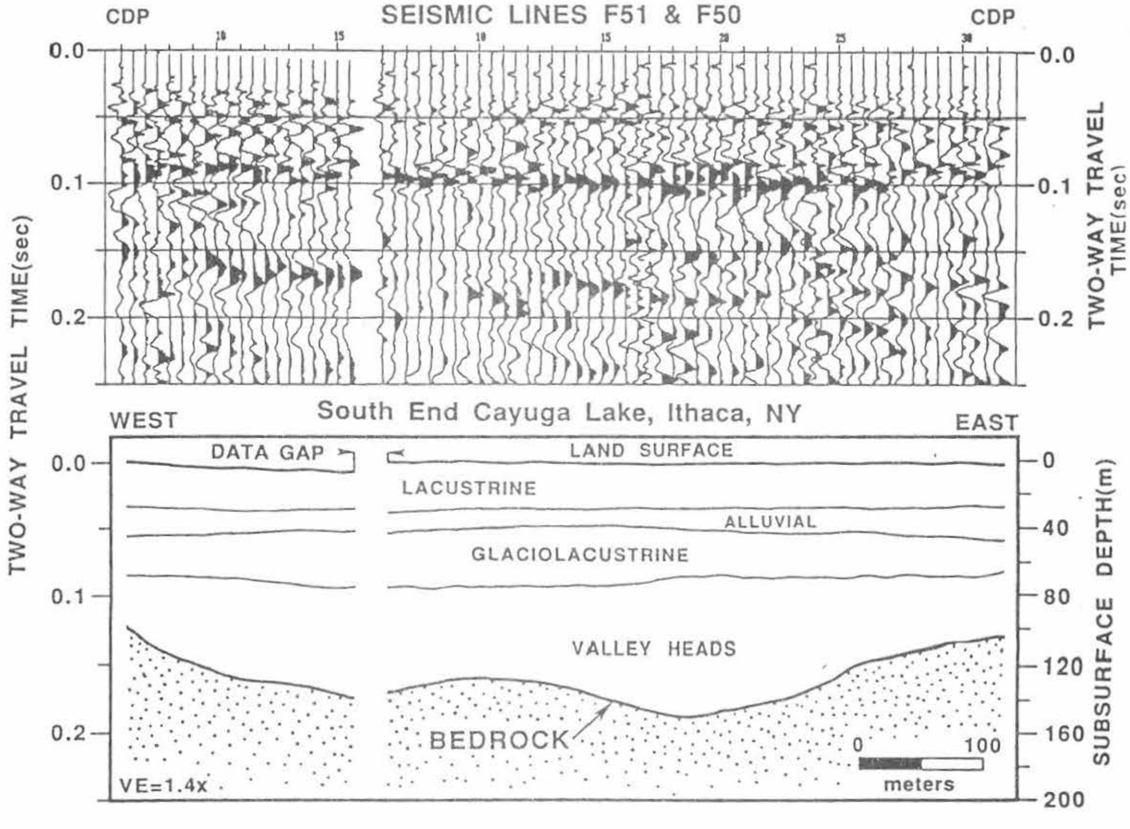

Fig. 21 - Weight-drop reflection profile (top) and line-drawing interpretation (bottom) across Cayuga valley south of Ithaca across from Buttermilk Falls State Park. Numbers across top indicate CDP shot points, subsurface depth scale assumes a velocity of 1.6 km/sec.

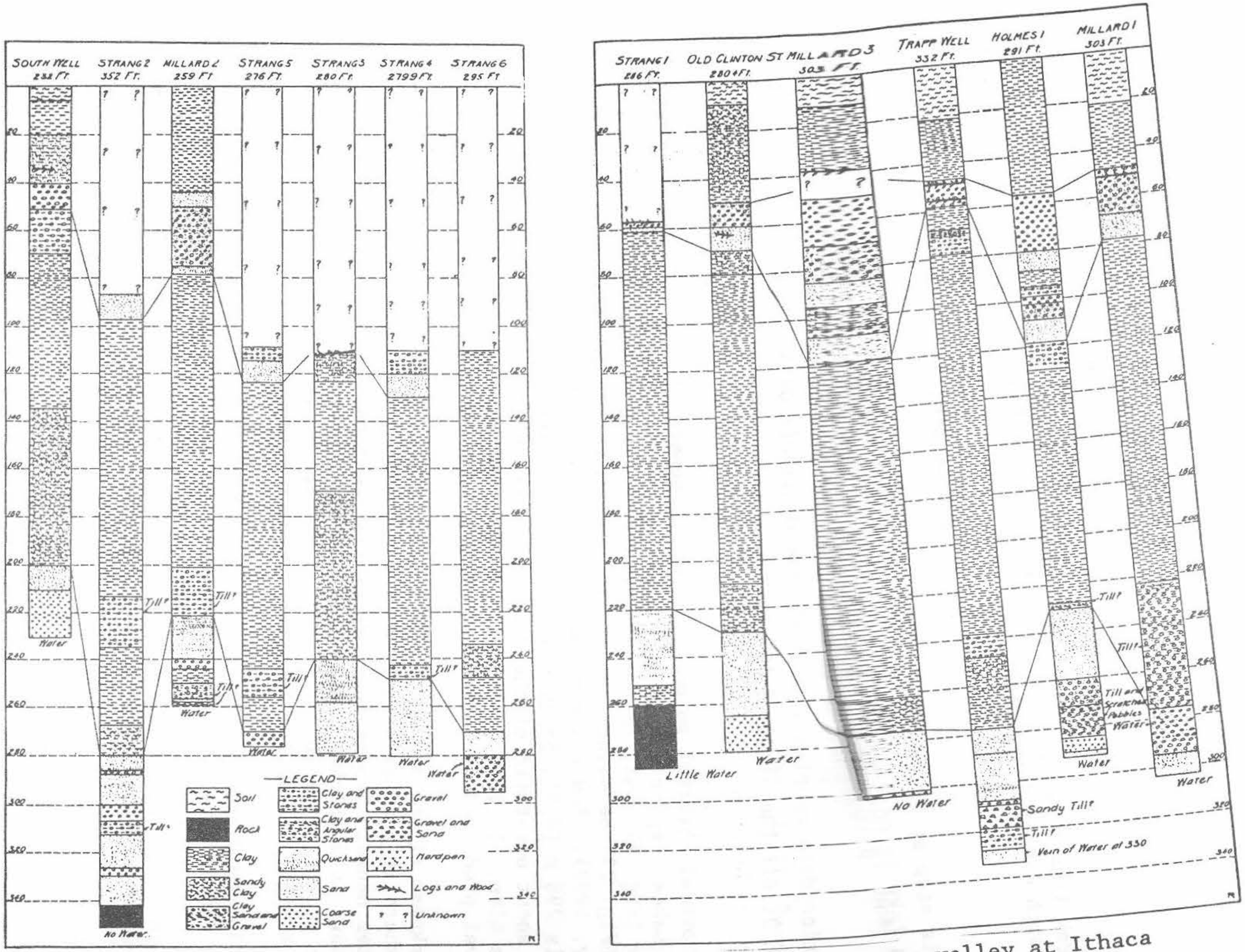

Fig. 22 - Schematic descriptions of well records from Cayuga valley at Ithaca arranged along north-south (left) and east-west (right) transects. Taken from Tarr (1904).

are likely a post-glacial lacustrine facies that records the flooding of the south end of Cayuga valley in response to differential isostatic rebound at the north end of the lake (Tarr, 1904). Since this flooding event, only a thin (8-12 m; 26-39′) unit of organic-rich muds has accumulated in Cayuga Lake (seismic sequence VI).

Based on these correlations between our lacustrine seismic reflection data, land-based profile, and Tarr's well data, we have been able to "groundtruth" four of the six seismic stratigraphic sequences beneath Cayuga Lake (sequences I, IV, V, and VI). Sequences II and III pinchout at the south end of Cayuga Lake and do not extend to Tarr's wells.

From Ithaca we will head west across the upland divide to Watkins Glen at the south end of Seneca Lake.

STOP 7: SENECA LAKE

This stop at Warren Clute Memorial (Lakeside) Park near the south end of Seneca Lake is designed to examine both our lake-based and land-based seismic reflection data coupled with available drillhole data. Seneca Lake is the deepest of all the Finger Lakes having a maximum water depth of 186 m (610′) (in the southern half of the lake) which is 50 m (165′) below sea level.

The overall bedrock morphology beneath Seneca Lake is similar to the other Finger Lakes: spoon-shaped and deepening to the south in longitudinal (N-S) profile (Fig. 7); and, in transverse profile (E-W), broad and shallow in the north (Fig. 23) becoming more deeply incised to the south (Fig. 8; Mullins and Hinchey, 1989). Bedrock extends as much as 434 m (1423′) below lake level which is 298 m (978′) below sea level! This maximum depth of bedrock erosion occurs about one-third of the distance to the north end of the lake from Watkins Glen. It is only slightly deeper than the 257 m (842′) depth below sea level predicted by Fairchild (1934b).

Thickness of the sediment-fill beneath Seneca Lake increases from north to south where it reaches a maximum of 270 m (886′). Seismic stratigraphic sequences beneath Seneca Lake are similar to those beneath Cayuga Lake except that there is a thicker transparent unit (sequence III). However, stratigraphic sequences could not be traced completely to the south end of the lake due to a highly irregular lake floor near the south end.

Similar to Owasco Lake an apparent esker is buried in the subsurface beneath Seneca Lake. A ridge, with up to 35 m (115′) of relief, occurs at the base of the axial thalweg of northern Seneca Lake (Fig. 24). This ridge can be traced from line to line for several kilometers. We interpret this sinuous ridge as an esker which, if correct, further implies the presence of subglacial meltwater conduits during early stages of erosion and infill of the Finger Lakes.

A "half-valley" (east side) multichannel profile collected on-land between Watkins Glen and Montour Falls, further documents large scale erosion and thick sediment fill beneath Seneca valley (Fig. 25). The bedrock reflection here is quite distinct and extends at least 0.28 seconds of two-way travel time into the subsurface. Again, using a range of P-wave velocities of 1.5-2.0 km/sec., bedrock extends as much as 210-280 m (689-918′) beneath the

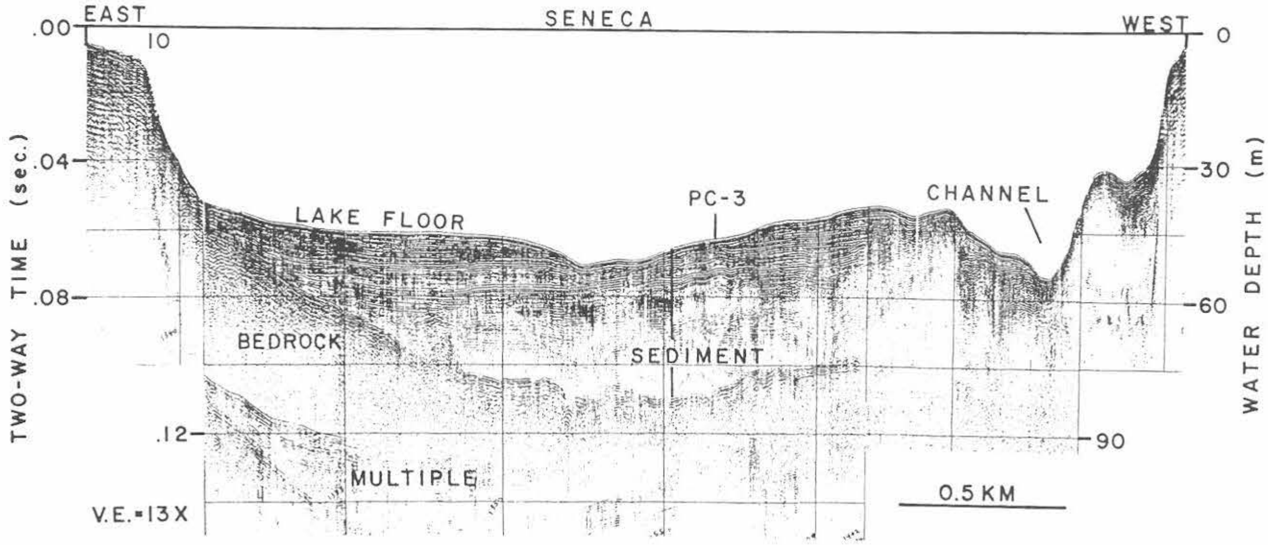

Fig. 23 - Transverse reflection profile from northern Seneca Lake illustrating broad U-shaped bedrock surface and thin (~30 m; 98′) sediment-fill. Piston core (PC)-3 recovered glaciolacustrine rhythmites.

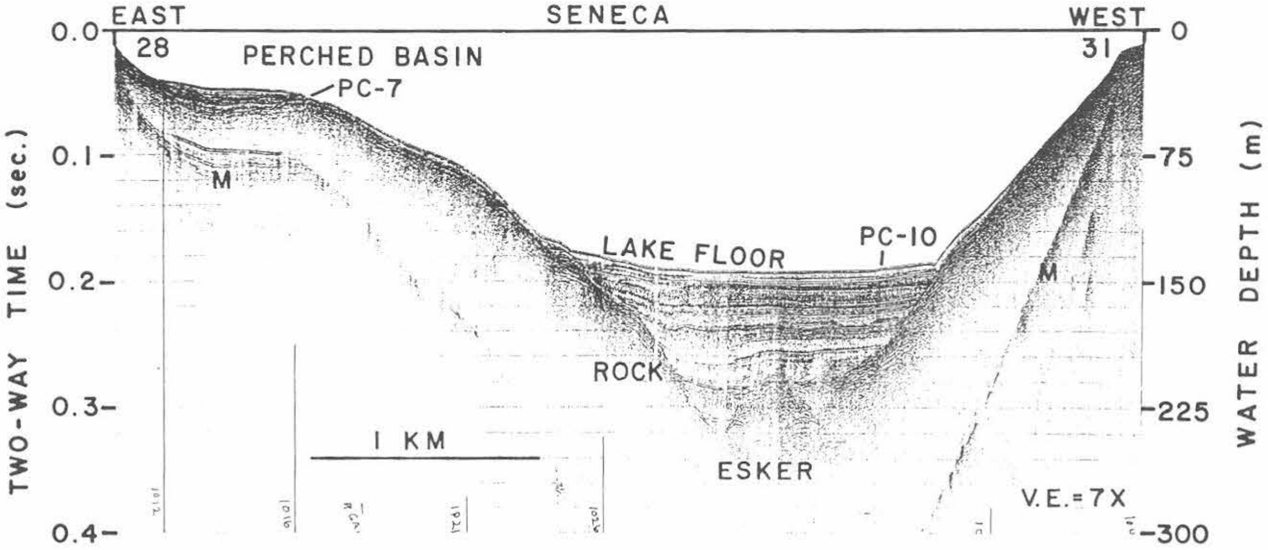

Fig. 24 - Transverse seismic reflection profile from central Seneca Lake illustrating asymmetric bedrock surface, ~90 (295′) of sediment-fill, and buried ridge in axial thalweg interpreted as an esker; M = multiple.

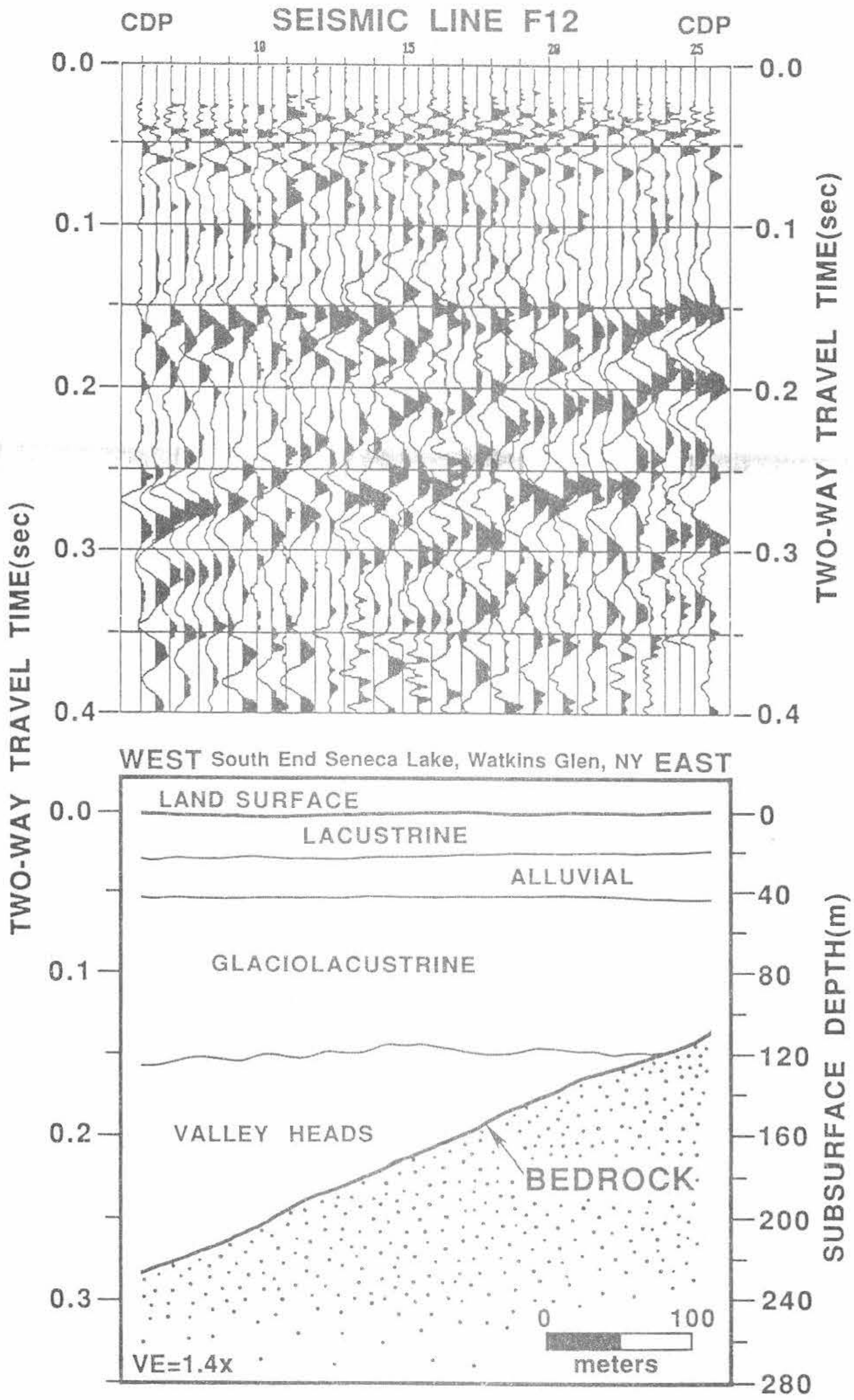

Fig. 25 - Weight-drop, multichannel reflection profile collected from the eastern half of dry valley south of Seneca Lake between Watkins Glen and Montour Falls (top) and line-drawing interpretation (bottom). Note distinct bedrock and Valley Heads reflections as well as three overlying stratigraphic units. Subsurface depth scale assumes a velocity of 1.6 km/sec.

valley floor. The higher end of these possibilities is very compatible with a well drilled at the power station at the south end of Seneca Lake (just to the west of our stop at Lakeside Park) which reached bedrock at 281 m (922') (Wendy McPherson, USGS Ithaca, personal communication, 1991). Thus, bedrock at the south end of Seneca Lake extends only about 145 m (476') below sea level compared to 298 m (978') below sea level further north, indicating that bedrock is rising to the south.

Our on-land profile reveals four major stratigraphic units above bedrock: (1) an upper transparent sequence about 20 m (66') thick; (2) a unit characterized by high-frequency reflections about 23 m (76') thick; (3) a largely transparent sequence with discontinuous high-amplitude reflections about 81 m (265') thick; and, (4) a basal, seismically chaotic high-amplitude sequence that is about 108 m (354') thick. By analogy with Tarr's (1904) well data from Ithaca as well as our own drill records south of Canandaigua Lake (stop #10) we interpret the basal chaotic sequence as Valley Heads equivalent; the overlying transparent unit as proglacial lake clays; the overlying high-frequency unit as fluvial/alluvial sands and gravels deposited as glacial lake levels dropped; and, the upper transparent unit as post-glacial lake muds deposited when the south end of the valley was flooded by isostatic rebound to the north. Again, it is our interpretation that there is only a single large infill sequence beneath the Finger Lakes.

From Watkins Glen we will head south to Horseheads passing through one of the largest Valley Heads deposits in the Finger Lakes region. Outcrops indicate that the Valley Heads here consist of water-laid, stratified sands and gravel. Near Horseheads the hummocky topography of the Valley Heads will give way to a more smooth outwash plain. From Horseheads we will drive west-northwest through Corning and then on to Bath where we will spend the evening. If it is still light, this drive will take us along a broad continuous valley along the Southern Tier Expressway which likely served as a channel for meltwater flow from the western Finger Lakes into the Susquehanna drainage system.

STOP 8: KEUKA LAKE (DAY TWO)

From our overnight stay in Bath, N.Y. we will head north to Hammondsport and then up along the west shore of Keuka Lake to our next stop at the north end of the west branch of Keuka Lake. Bath is located on an outwash plain just south of Valley Heads fill. Soon after leaving Bath you will be able to see hummocky terrain typical of the Valley Heads. We will then drop down to the dry lake floor on which the village of Hammondsport is located.

Keuka Lake is an anomalous Finger Lake in many regards. Most obvious is its two branches that converge to the south at Bluff Point (Figs. 1 and 2) which strongly suggests a southward directed, preglacial drainage system. Second, there are a number of circular to elliptical closed bathymetric depressions on the floor of both branches of Keuka Lake. Third, there is little north-south variation in the depth to bedrock beneath the northwest branch of the lake (Figs. 7 and 8). And, fourth, Keuka Lake valley is the only non-through valley of the Finger Lakes.

Maximum water depth beneath Keuka Lake is 58 m (190') which occurs in a closed depression near the junction of the Lake's two branches. Bedrock has been eroded as much as 200 m (656') below lake level which is 18 m (59') above sea level. Total sediment thickness is rather uniform beneath the west branch with a maximum of about 160 m (525').

Our axial (longitudinal, N-S) reflection profiles clearly define the east branch of Keuka Lake as a hanging tributary valley to the west branch (Fig. 26). Depth to bedrock beneath the east branch is significantly shallower and there is a distinct bedrock high or "sill" where the east branch joins the more deeply scoured west branch.

Axial profiles from the northwest branch of Keuka Lake indicate that the closed bathymetric depressions on the lake floor are remnants of ice-meltout features (Fig. 27). Reflectors beneath these depressions are displaced downwards suggesting post-depositional collapse and chaotic patterns suggest mass wasting (Fig. 27). These meltout features may be analogous to "dead-ice sinks" described by Fleisher (1986) who noticed that they occur preferentially in non-through valleys. He suggested that stagnant ice conditions develop in non-through valleys because of glacial thinning and detachment at headward divides which are not present in through valleys (Fleisher, 1986). The discovery of ice-meltout features beneath Keuka Lake suggests a component of downwasting here during deglaciation unlike the other Finger Lakes where ice retreat appears to have been more rapid, perhaps by calving.

Despite this evidence for downwasting, the seismic stratigraphy beneath Keuka Lake at its southern end is typical of the other Finger Lakes (Fig. 28). A lower chaotic unit (sequence II) is overlain by a very transparent (reflection-free) sequence (III) which in turn is overlain by a highly reflective unit (IV) derived from the north. Sequence V, which is also highly reflective, thickens to the south and contains southerly-derived mass-movement deposits; and, sequence VI is a relatively low-amplitude facies that probably represents contemporary (post-glacial) lacustrine sedimentation.

From our overlook of the northwest branch of Keuka Lake we will drive west through Italy Valley to the village of Naples passing over Valley Heads fill and then to the south end of Canandaigua Lake.

STOP 9: CANANDAIGUA LAKE

This overlook stop provides a spectacular north-view of Canandaigua Lake -- "the chosen place." Bathymetric data reveal a symmetrical "tub-shaped" lake basin with a maximum water depth of 84 m (276') near its north-south midpoint. Bedrock has been eroded as much as 261 m (856') below lake level which is 51 m (168') below sea-level (Figs. 7 and 8). Total erosion, from the top of the adjacent divides to the top bedrock beneath the lake, has been on the order of 630 m (2068'). An on-land seismic reflection profile across Valley Heads along Eel Pot Road south of Naples, suggests that although bedrock does rise to the south there may be as much as 250 m (820') of Valley Heads fill (Fig. 29).

Maximum sediment thickness beneath Canandaigua Lake is 202 m (663') which occurs in the southern half of the lake basin. Similar to the other Finger

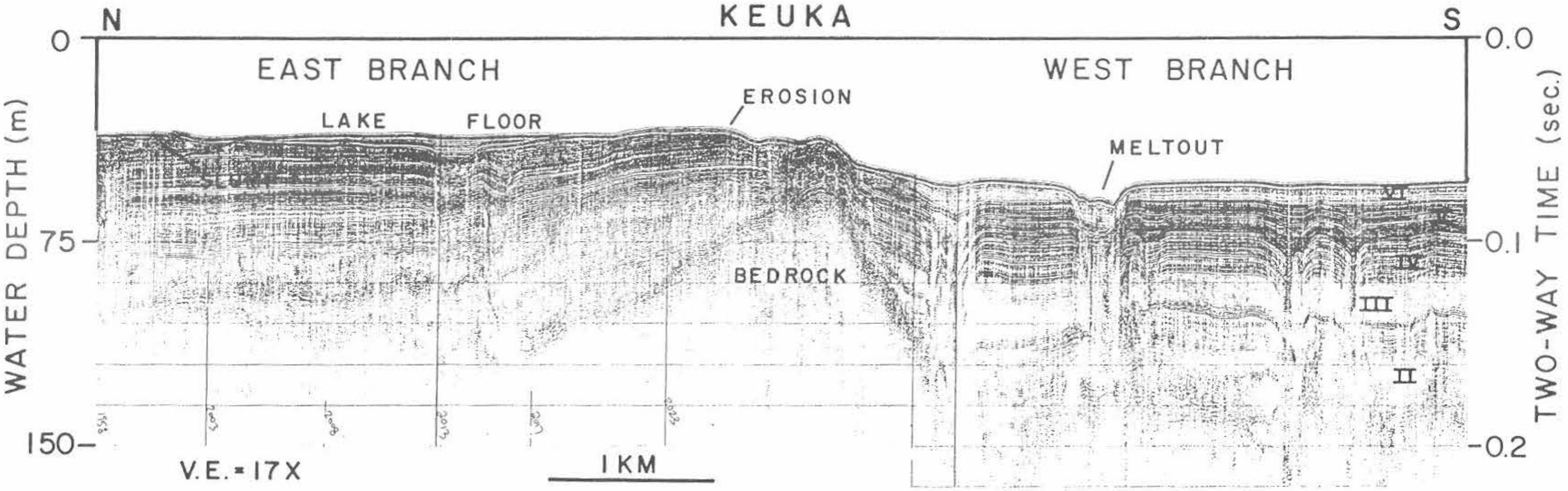

Fig. 26 - Portion of axial reflection profile from Keuka Lake illustrating bedrock "high" (sill) at juncture of east (hanging valley) and west branches near Bluff Point.

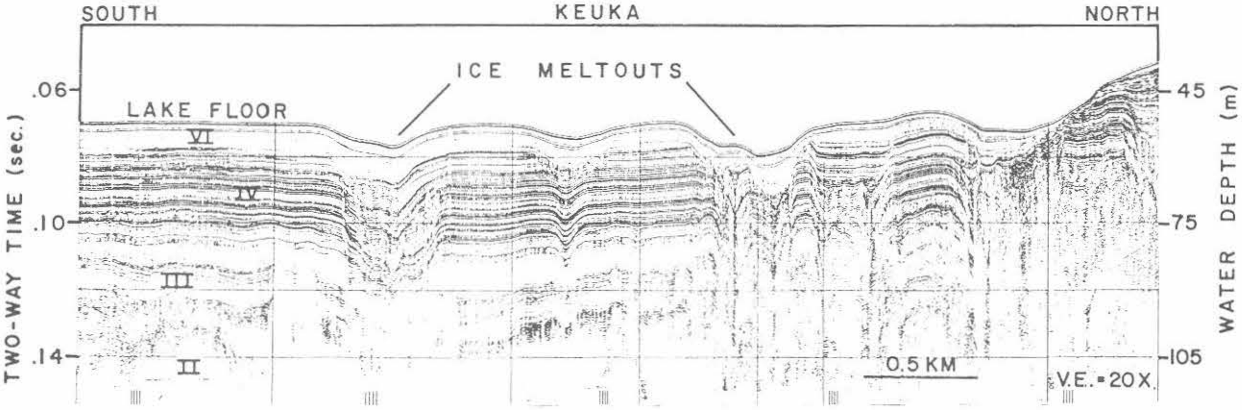

Fig. 27 - Northern end of axial reflection profile from the west branch of Keuka Lake illustrating ice-meltout features ("dead-ice sinks") that produce closed bathymetric depressions on lake floor.

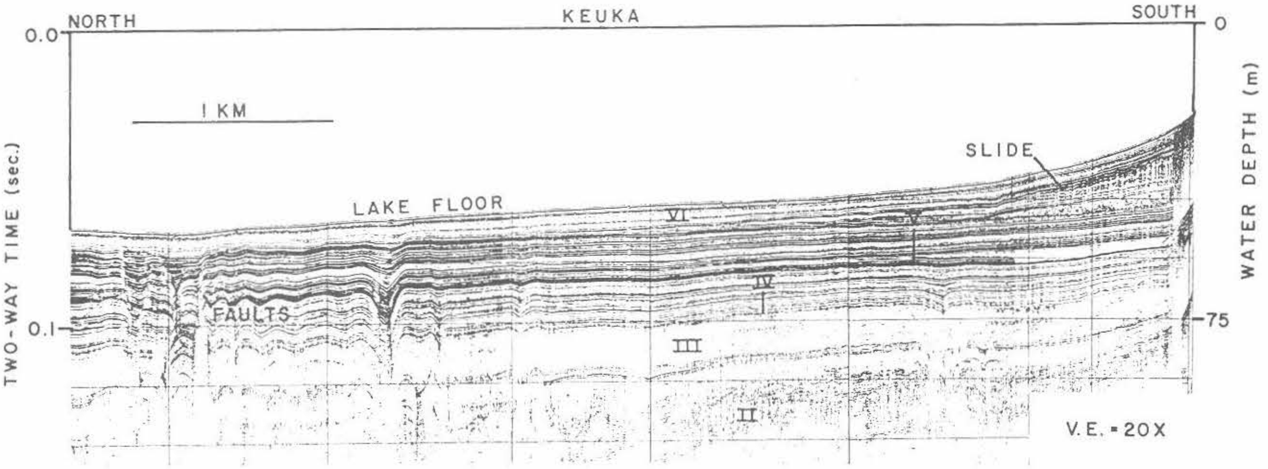

Fig. 28 - Portion of axial reflection profile from the southern end of Keuka Lake near Hammondsport illustrating seismically defined depositional sequences. Note mass flow deposits to south, and small subsidence faults to north.

Lakes we recognize six seismically-defined depositional sequences beneath Canandaigua Lake; however, there are some significant differences. Most notable is sequence III -- a transparent (reflection-free) facies -- which on our axial line (Fig. 30) occupies a restricted, "scooped-out" depression near the center of the lake. These massive fine-grained (?) sediments are up to 60 m (197') thick, and are overlain by highly reflective sequences which onlap bedrock valley walls (Fig. 31).

Another difference is that collectively, sequences IV-VI (highly reflective facies) thicken to the south implying a largely southerly derived source for these deposits. We have noticed a similar relationship in other Finger Lakes only for sequences V and VI which we have related to a lowering of glacial lake levels and a drainage reversal which accompanied complete ice withdrawal from the Finger Lake valleys. In the case of Canandaigua Lake, these data suggest that sediment input from the south end of the lake began sooner than in the other lakes. This may have been due to the fact that there are multiple valleys, which may have been ice-free at the time, that drain into the south end of Canandaigua Lake.

All seismic stratigraphic sequences beneath Canandaigua Lake, with the exception of sequence III, can be traced to the south end of the lake. These sequences do <u>not</u> pinchout here but appear to continue beneath the wetland and dry lake valley to the south. In fact, this is why we decided to locate our drillcore to the south Canandaigua Lake. Figure 29 schematically illustrates the projection of seismic stratigraphic sequences beneath Canandaigua Lake to our drillsite ~3 km to the south along Parrish Flat Road.

STOP 10: PARRISH FLAT ROAD (DRILLCORE RESULTS)

Parrish Flat Road, which cuts across the dry valley just south of Canandaigua Lake, provides a unique accessible location to correlate (as directly as possible) our lake-based seismic reflection data with drillcore samples. Between the drillsite and Canandaigua Lake (3 km to the north) are the High Tor wetlands; directly to the east is a large alluvial fan at the mouth of Conklin Gully; and 3 km to the south, Valley Heads deposits begin to crop out near the village of Naples.

A multichannel reflection profile collected along Parrish Flat Road in 1988 indicated that bedrock extends as much as 0.22 seconds of two-way travel time beneath the valley floor (Fig. 32). Using an interval velocity of 1.5 km/sec., there is about 165 m (540') of sediment fill above bedrock here. This profile also suggested the presence of four stratigraphic units: (1) a thin, upper transparent unit about 11 m (37') thick, underlain by (2) a thin (~10 m, 33' thick) high frequency sequence that thickens to east toward the alluvial fan; (3) a thick (~94 m, 308') unit with discontinuous high-amplitude reflections; and, (4) a basal unit, about 50 m (165') thick, beneath an irregular, high-amplitude reflector (Fig. 32).

Drillcore samples were recovered in July 1990 at two sites along Parrish Flat Road: site 1 extended 120 m (400') into the subsurface; and site 2, located 168 m (550') to the west, extended only 12 m (40') into the subsurface (Fig. 33). Although composite core recovery was only ~40%, vertical stratigraphic continuity was extended with the use of downhole geophysical

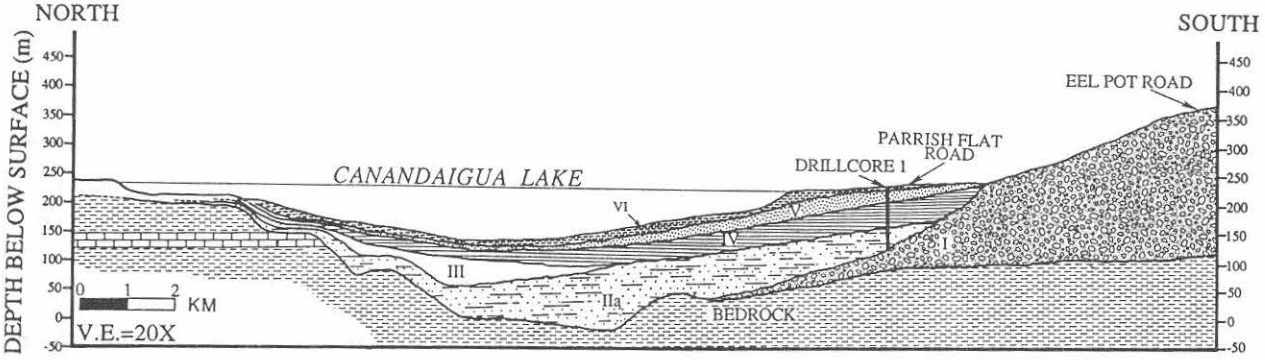

Fig. 29 - Schematic axial (N-S) profile of bedrock and stratigraphy of sediment-fill beneath Canandaigua Lake and dry valley to south. Note depositional sequences and location of drillcore. Vertical scale relative to sea-level; horizontal scale in km.

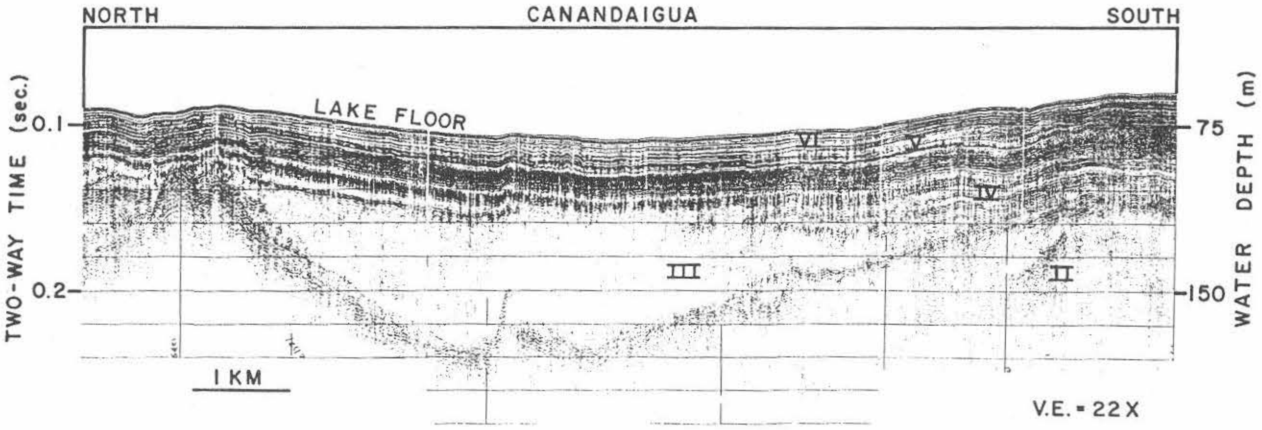

Fig. 30 - Central portion of axial reflection profile from Canandaigua Lake illustrating seismically transparent sequence III.

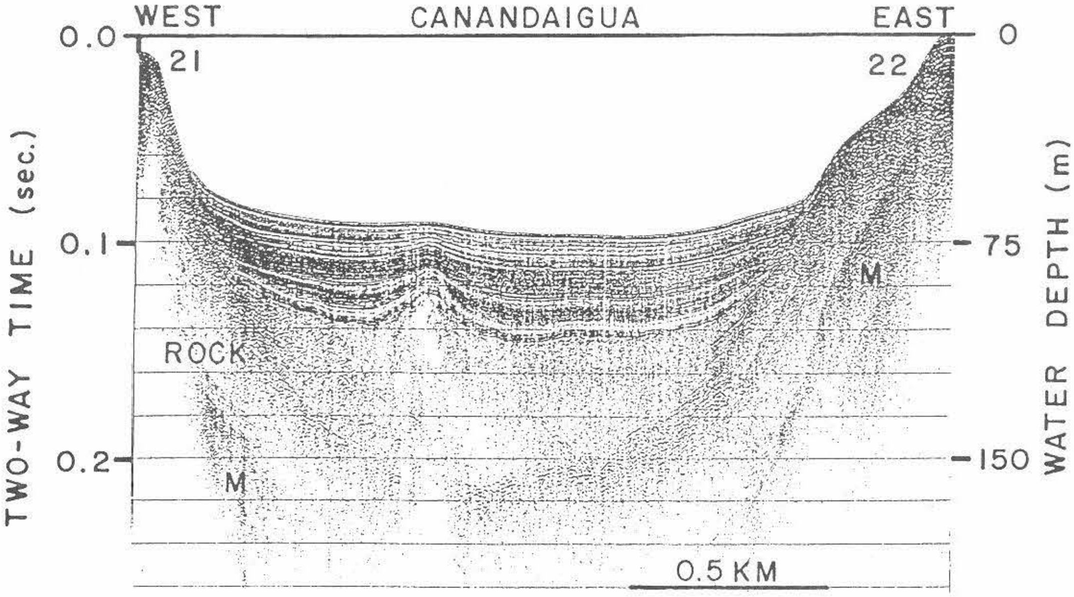

Fig. 31 - Transverse reflection profile from the central portion of Canandaigua Lake

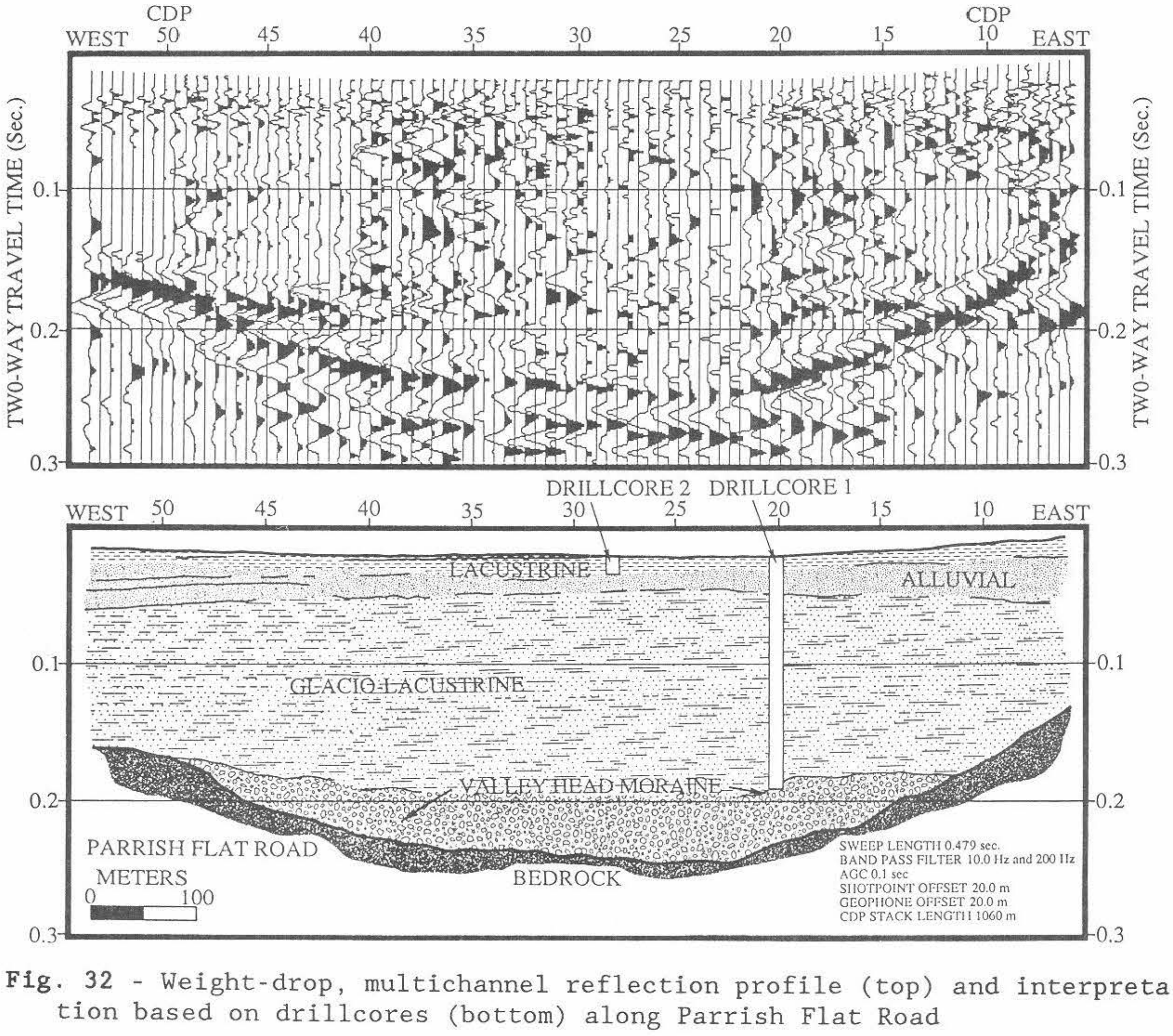

Fig. 32 - Weight-drop, multichannel reflection profile (top) and interpretation based on drillcores (bottom) along Parrish Flat Road (gamma ray and resistivity) logs (Fig. 33). Data from a vertical seismic profile shot at the deeper drillhole indicate that P-wave velocities in the upper 100 m (328') of section are all less than 1.6 km/sec. (Fig. 34) indicating undercompacted materials.

Based on physical stratigraphy, we recognize five distinct stratigraphic sequences in the Canandaigua drillcore: (1) an upper unit (12 m, 39' thick) of cyclic sequences of peat and lake clays; (2) a coarsening-upward, washed sand and gravel unit (containing artesian water) that is 14 m (46') thick; (3) a rhythmically bedded silt and sand sequence plus interbeds of massive clay with dropstones that is 60 m (197') thick; (4) a massive clay unit devoid of dropstones that is 23 m (75') thick; and (5) and basal coarse sand and gravel unit that would not support open-hole drilling (Fig. 33). Although bedrock was not reached in this drillcore, a gas well located in the center of the valley about 3 km to the south, did encounter bedrock at a subsurface depth of 143 m (470'). The age of these deposits has not yet been determined; however, ten peat samples from the upper 12 m (39') have been sent off for radiocarbon analysis and one sample of massive clay from 109 (358') has been sent off for thermoluminescence dating. Hopefully results will be in hand by the time of the field trip.

Our stratigraphic results from the Canandaigua drillcore are strikingly similar to those reported by Tarr (1904) from Ithaca (Cayuga Lake) as well as available drillcore data from Tully Valley (Fig. 6). Basically, a basal sand and gravel unit is overlain by a thick sequence of fine-grained, organic-poor sediment which in turn is capped by sands and gravels that grade up into organic-rich lake clays. We interpret this stratigraphy as a single infill sequence resulting from the last glaciation. The basal sands and gravels are interpreted as part of the Valley Heads fill (13-14 ka); the thick, organic-lean clay sequence is interpreted as glaciolacustrine facies; the upper sands and gravels as prograding alluvial valley fill that formed as glacial lake levels dropped; and, the uppermost organic-rich sequence as post-glacial swamp and lacustrine deposits. The cyclic nature of these youngest sequences suggest that lake levels have fluctuated periodically in Canandaigua Lake, and perhaps the other Finger Lakes, during postglacial time. Much more detailed study of these upper cyclic sequences is currently underway as part of Rob Wellner's doctoral dissertation.

From Parrish Flat Road we will drive north along the western margin of Canandaigua Lake to the city of Canandaigua. Toward the north end of the lake you will begin to notice drumlins which will be very common as we drive east along the New York State Thruway to our next stop at Montezuma wetlands north of Cayuga Lake.

STOP 11: MONTEZUMA CHANNELS

Montezuma National Wildlife Refuge is one of the largest freshwater wetlands in New York State. The wetlands actually occupy a southward directed, dendritic system of channels that funnel into the north end of Cayuga Lake, which has the lowest lake level (116 m, 382'). That these channels are relict, is evidenced by the fact that modern outlet drainage from Cayuga Lake is to the north.

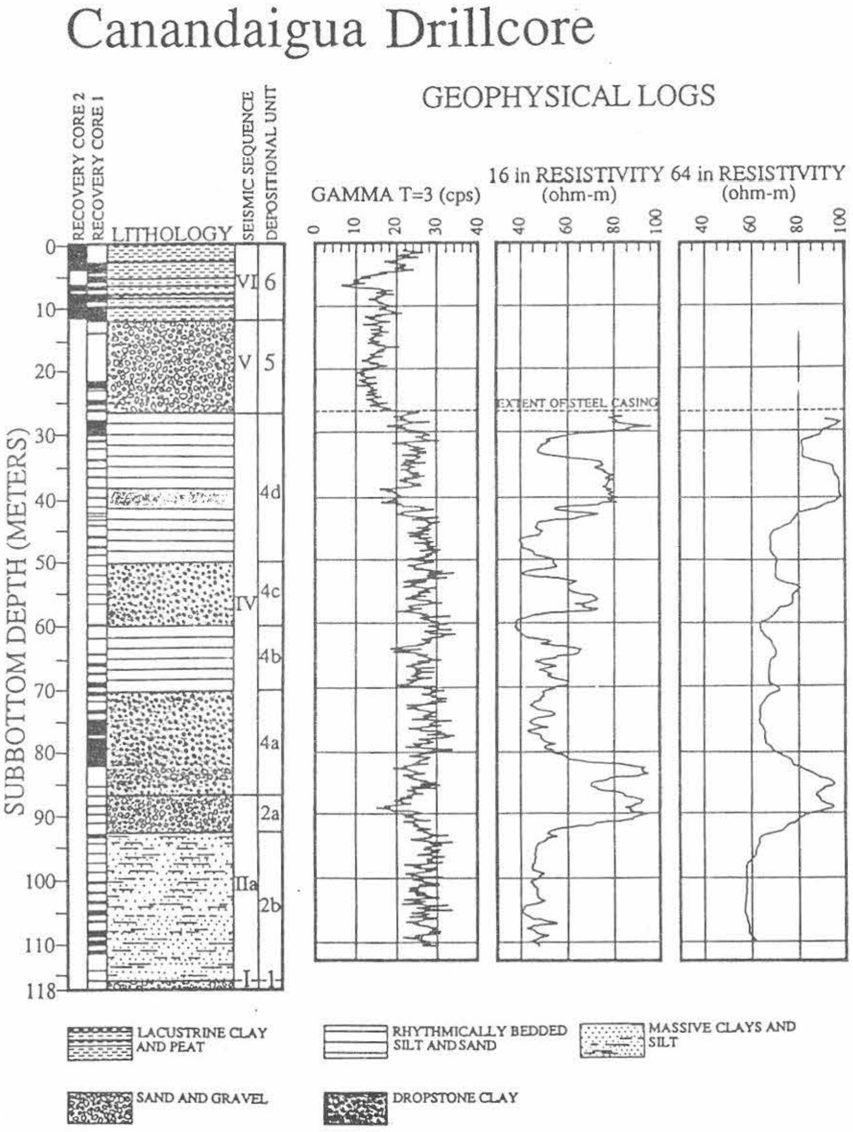

Fig. 33 - Schematic illustration of lithostratigraphy recovered at Canandaigua drillcores (left) and downhole geophysical logs (right).

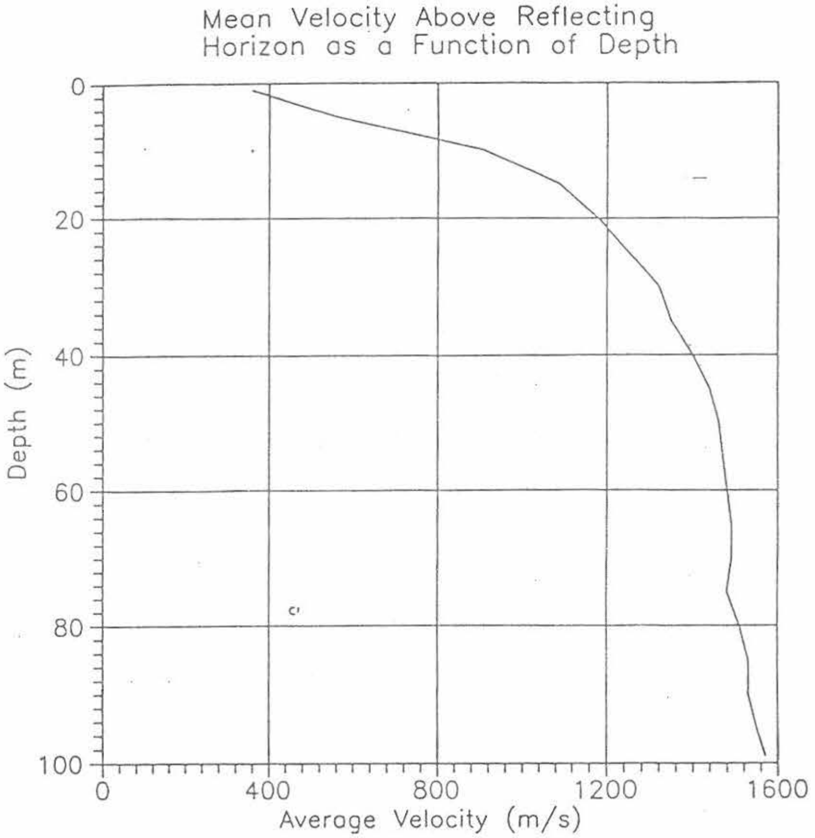

Fig. 34 - Curve of compressional wave velocity versus depth for Canandaigua drillsite along Parrish Flat Road. Data based on vertical seismic profile (VSP) shot down drillhole.

The Montezuma channel system is unusually broad (up to 5 km) for having a north-south length of only ~25 km. The channels are quite distinct on satellite images of the Finger Lakes and have been mapped largely as swamp deposits by Muller and Cadwell (1986). The channels occur within a very well-developed drumlin field but are neither drumlinized nor do they appear to truncate drumlins. The geologic significance of the Montezuma channels has been largely overlooked in previous regional analysis.

In order to better understand the subsurface geology of the Montezuma channels, we have collected about 12 km of on-land, multichannel seismic reflection profiles that have been integrated with available well data. A profile acquired at our stop along Armitage Road reveals a thalweg along the western edge of this eastern branch of the channel system (Fig. 35). Bedrock here extends as much as 40 m (131') beneath the surface of the channel or 78 m (257') above sea level. Maximum depth to bedrock beneath the channels, based on well records, is 55 m (180').

Two well records are available from Armitage Road. One well along the eastern margin of the channel penetrated about 30 m (98') of clay on top of shale before bottoming in limestone at 38 m (125'). The second well, located in the channel's thalweg, bottomed in sand without reaching bedrock (Fig. 35). Facies analysis of our reflection data suggest that the sands are restricted to the channel's thalweg (Fig. 35).

The postglacial pollen record of the Montezuma channels has been investigated via a 12 m core recovered from Crusoe Lake located about 8 km north of Armitage Road (Cox and Lewis, 1965). This core retrieved about 6 m (20') of organic-rich gytta overlying 5 m (16') of clay (Fig. 36). Two radiocarbon dates from 5.0 m (16') and 1.3 m (4') below the lake floor yielded ages of 6,850 ±150 and 3,200 ±100 years, respectively (Cox and Lewis, 1965). Pollen data (Fig. 36) indicate that a spruce-pine-fir forest dominated the region prior to 6,850 years ago. The first deciduous forests (dominated by hemlock and oak) developed about 6,500 years ago during a time when the climate here may have been warmer and more moist than today (Cox and Lewis, 1965). Between about 3,000 and 2,000 years ago, beech replaced much of the hemlock suggesting a decrease in available moisture. During the past 2,000 years, the pollen record (Fig. 36) suggests a decrease in temperature and an increase of available moisture (Cox and Lewis, 1965). These authors also suggest that a large lake, of which Crusoe is a remnant, may have persisted in Montezuma Marsh until about 700 A.D.

We also collected a "sledge-hammer" multichannel seismic reflection profile across the drumlin we are standing on (Fig. 37). Results suggest that there are about 18 m (58') of unconsolidated sediment beneath the crest of the drumlin. The bedrock reflection is quite distinct and indicates a "high" with about 6 m (18') of relief. Although these results are from only one of thousands of drumlins in the area, they do suggest that the drumlins here may be controlled by relief on an eroded bedrock surface.

What is the origin of the Montezuma channels? The facts are that it is a southward-directed, dendritic system with a maximum length to width ratio of about 5:1; it is a broad, shallow system filled with up to 55 m (180') of

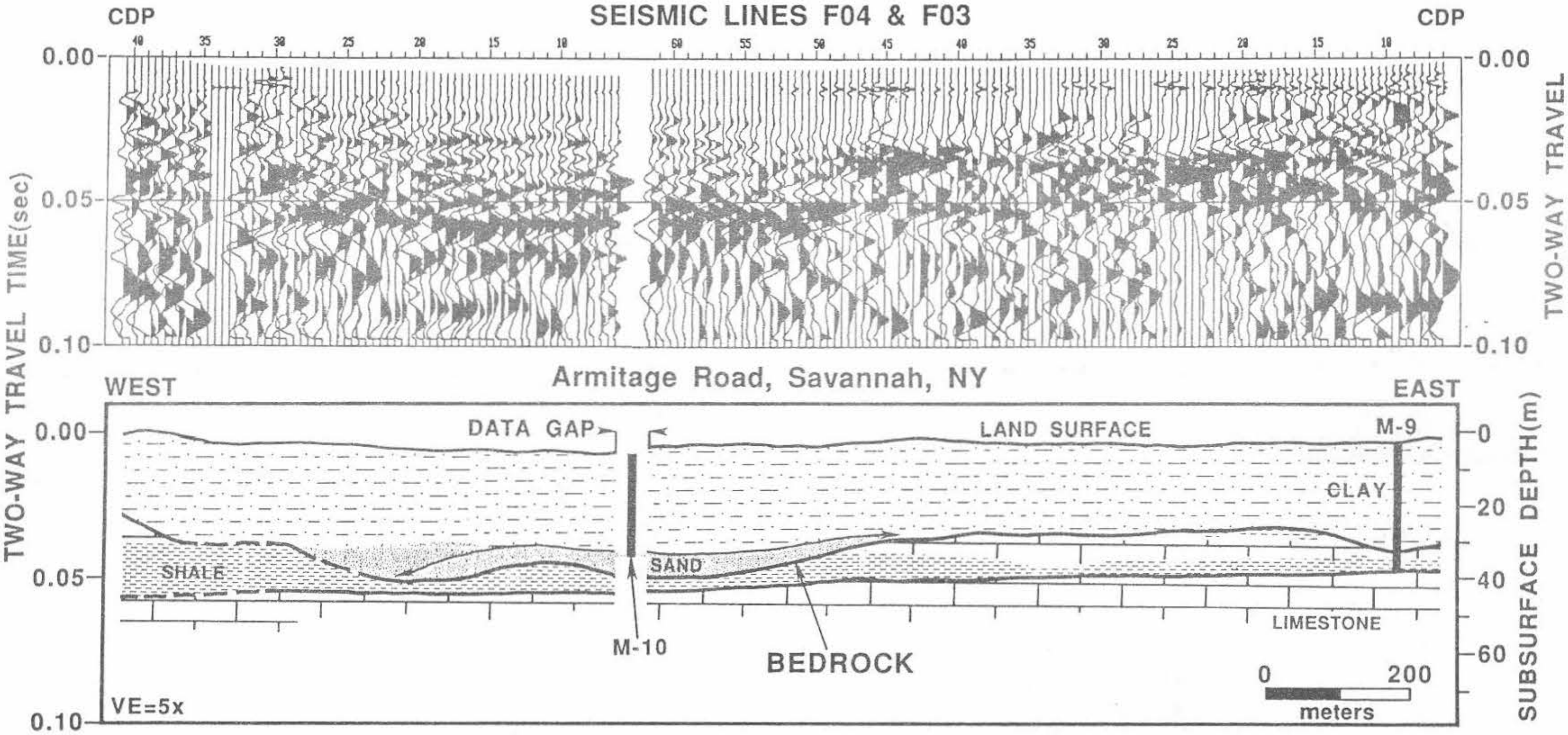

Fig. 35 - Weight-drop, multichannel reflection profile (top) and line-drawing interpretation (bottom) of west branch of Montezuma channels along Armitage Road. Well records confirm subsurface lithologies. Note thalweg along western reach of channel.

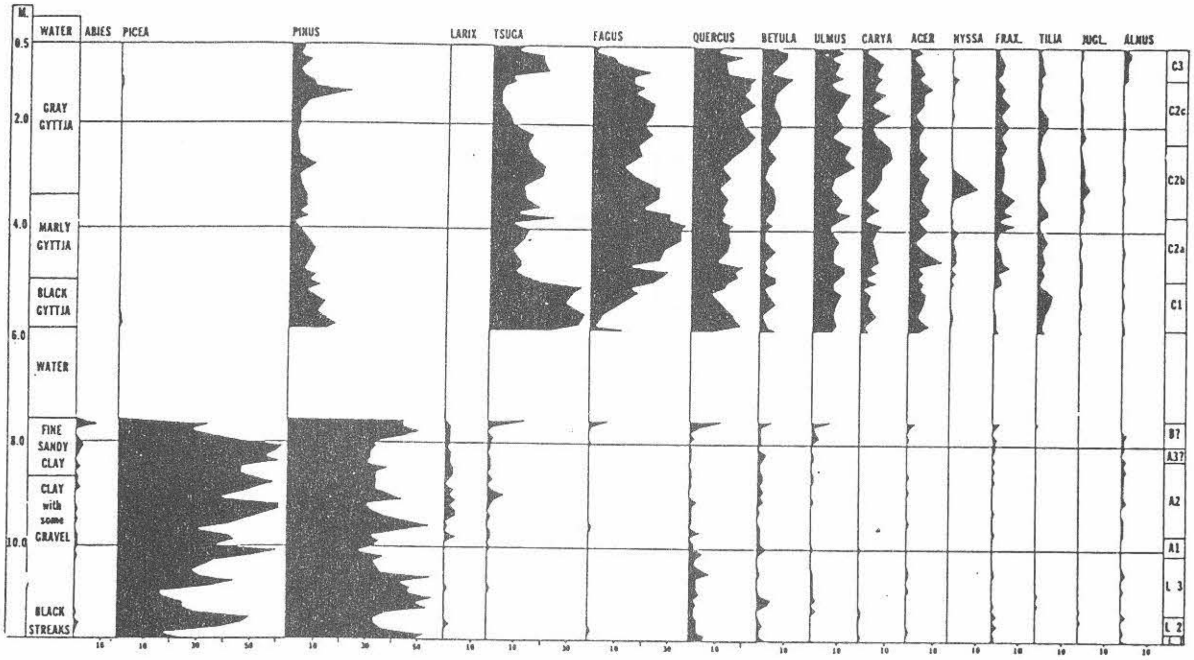

Fig. 36 - Pollen diagram for a core recovered from Crusoe Lake in the Montezuma channels. Gross stratigraphy at left; pollen zones at right; from Cox and Lewis (1965).

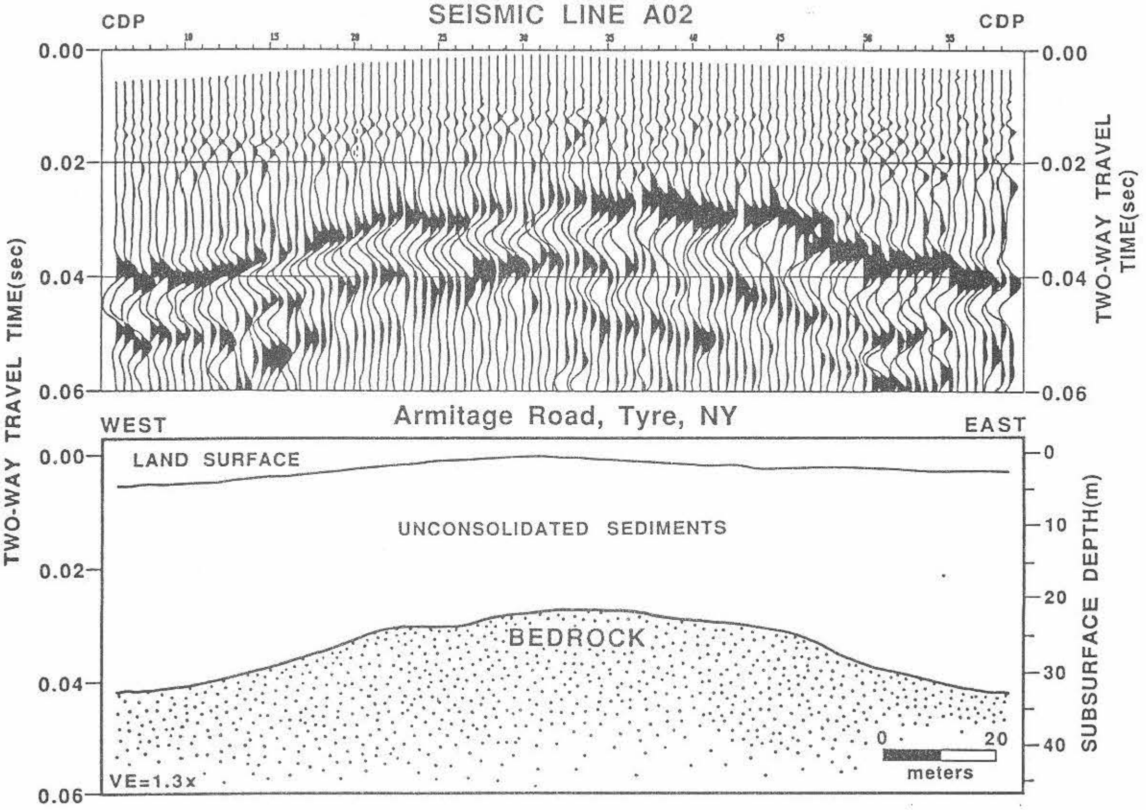

Fig. 37 - "Sledge-hammer" multichannel reflection profile across drumlin along east margin of west branch of Montezuma channels. Note bedrock "high" beneath drumlin. Depth scale assumes a P-wave velocity of 1.55 km/sec.

sediment; basal coarse-grained sediments are overlain by lake clays; and, the entire system feeds into the north end of Cayuga Lake despite the fact that contemporary outlet drainage is to the north.

One interpretation is that these channels represent subaerial proglacial drainage from a stabilized ice margin north of the channels. However, there is little direct evidence for a stabilized ice-margin here (Muller and Cadwell, 1986) and the dendritic pattern is inconsistent with proglacial streams which are typically braided. Also, a proglacial stream origin would require subaerial conditions followed by a sublacustrine environment.

An alternative hypothesis is that the Montezuma channels were carved by subglacial meltwaters that were funneled into the Cayuga Lake valley. A dendritic pattern has been theoretically predicted for subglacial drainage systems (Fig. 38) which Boulton and Hindmarsh (1987) argue are required to drain excess water during stable subglacial deformation to form drumlins. A subglacial origin for these channels would also allow for direct evolution of environments from subglacial fluvial to glaciolacustrine and then lacustrine (without an intervening subaerial stage) as the ice sheet retreated. Muller and Cadwell's (1986) surficial geologic map of the Finger Lakes (Fig. 2) indicates the presence of a similar, but less well-developed, channel at the north end of Seneca Lake which has an esker-like ridge along its northern axial thalweg.

From our stop on Armitage Road along the western branch of the Montezuma channels, we will head east and drive across the eastern branch of the channels where you can get a good "feel" for the width of these channels. We will then drive south to Route 20 and then east to our last stop at Skaneateles which will take us across the southern edge of the Weedsport drumlin field.

STOP 12: NORTH END OF SKANEATELES LAKE (WRAP-UP DISCUSSION)

This scenic stop at the north end of Skaneateles Lake is designed to provide us with an opportunity to collectively discuss the subsurface geophysical/geologic data we have examined during the past day and a half, and its implications for the origin and evolution of the Finger Lakes. These data document the large scale erosion (up to 298 m; 978' below sea-level) and infill (up to 270 m; 886') of the Finger Lake valleys (Mullins and Hinchey, 1989) including a thick Valley Heads sequence. Seismic stratigraphic relationships indicate that the sediment-fill beneath the Finger Lakes post-dates deposition of Valley Heads at 13-14 ka. Thus, timing of the erosion of the Finger Lakes can only loosely be constrained as sometime between the Devonian and 13-14 ka! If pre-late Wisconsin sediments were deposited beneath the Finger Lake valleys they have been removed by subsequent erosion. This implies that the Finger Lakes were at least deepened by late Wisconsin glaciation.

Hughes' (1987) model of Laurentide Ice Sheet deglaciation for 14 ka (Fig. 39) suggests that ice streamed into the Finger Lakes region from the St. Lawrence Lowlands/Ontario Basin as the ice sheet began to collapse. Based on our subsurface data integrated with Muller and Cadwell's (1986) surficial map, we suggest a highly digitate ice margin in the Finger Lakes region with streams of more rapidly flowing ice moving down the Finger Lake valleys

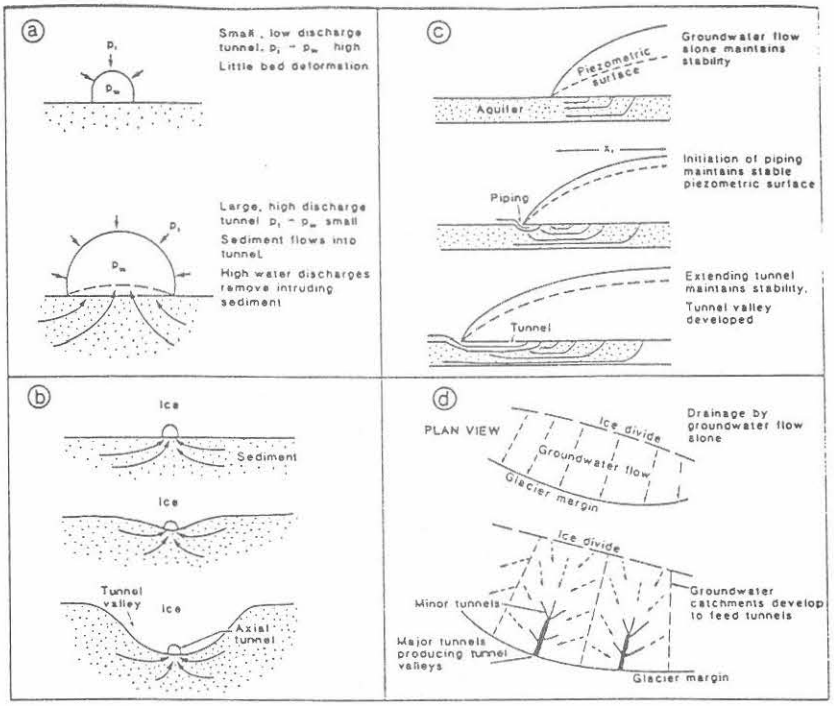

Fig. 38 - Schematic, conceptual models for discharge of subglacial meltwater and formation of tunnel valleys beneath temperate ice sheets. Predicted subglacial drainage system is illustrated in "D". From Bouldon and Hindmarch (1987).

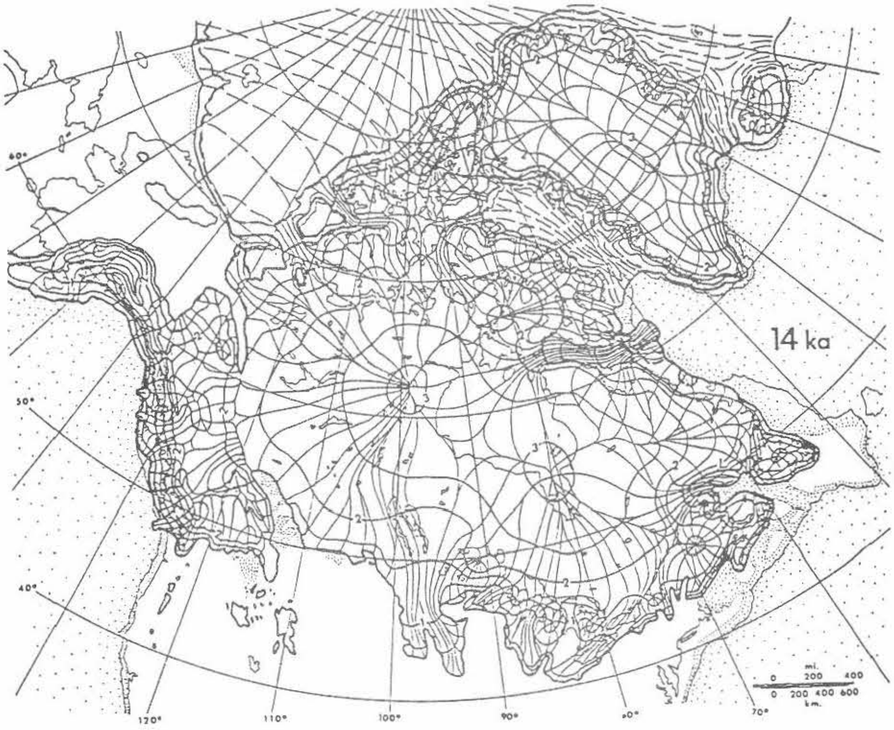

Fig. 39 - Reconstruction of Laurentide Ice Sheet at 14 ka (from Hughes, 1987). Note ice domes over James Bay and southeastern Canada with converging flow lines along St. Lawrence lowlands that extrude into Finger Lakes region.

(Fig. 40). At this time (13-14 ka) large volumes of coarse-grained debris were being pumped subglacially down through the Finger Lake valleys, perhaps by channelized subglacial meltwaters, and ultimately deposited as the Valley Heads moraines. An alternative interpretation for this stage is that an ice dome developed in the Lake Ontario basin and that rapid ice flow through the Finger Lake valleys was in the form of outlet glaciers which may have also been accompanied by channelized subglacial meltwater (Ridky and Bindshadler, 1990).

As the ice margin began to pull-off its Valley Heads position channelized subglacial meltwaters continued to pump large volumes of finer-grained debris into the Finger Lakes valleys as subaqueous outwash (sequence II; Fig. 41). In this regard we agree with Gustavson and Boothroyd (1987) that subglacial streams (rather than "dirt machines") were the primary source of glacio-fluvial and glaciolacustrine sediment along the southern margin of the Laurentide Ice Sheet.

Once ice margins had retreated to the north end of the Finger Lake valleys, classical proglacial lacustrine sedimentation continued to fill the valleys which is recorded on our reflection profiles as highly-reflective sequence IV. At this time, with the north ends of the valleys dammed by ice, lake levels were considerably higher than today. However, as soon as ice retreated from the north ends of the valleys, lake levels dropped rapidly and a drainage reversal (from south- to north-directed) occurred (Mullins and Hinchey, 1989). This event is recorded on our profiles by sequence V which thickens to the south in all the lake basins. When lake levels dropped, highstand deltas were left hanging on valley walls and numerous gorges were eroded as local base level was dramatically lowered (Fig. 41).

After the ice completely withdrew from the Finger Lakes region ~12 ka (Hughes, 1987), differential isostatic rebound in the north resulted in the flooding of the south ends of the Finger Lakes valleys as evidenced by lake clays overlying fluvial/alluvial sands and gravels in drill cores. Subsequent to this flooding event, post-glacial drainage from the south has partially filled the southern ends of the Finger Lake valleys, while accumulating a thin, transparent "blanket" of sediment beneath the lakes.

The most recent chapter in the natural history of the Finger Lakes is recorded in the cyclic sequence of peats and lake clays recovered in the Canandaigua drillcore. There are about six of these cycles that overlay fluvial/alluvial sands and gravels. Do these cycles represent climatically-driven lake level fluctuations or post-glacial rebound oscillations? Whatever their cause, the fact that there are about six cycle in the post-glacial (<~12 ka) section suggests that they have a periodicity on the order of 2 ka. Our working hypothesis is that they were climatically driven and may record an environmental record of wet and dry cycles for the Finger Lakes region during the past 12 ka. We continue to work on these cyclic sequences and should have more definitive results in the near future.

We hope that you have not only enjoyed this unique field trip but that you have also gained a better appreciation of the "unseen" geology beneath the Finger Lake valleys. If we are to fully comprehend the Quaternary geologic history of regions such as the Finger Lakes it will be necessary to record subsurface as well as surficial geology. We hope that our integrated

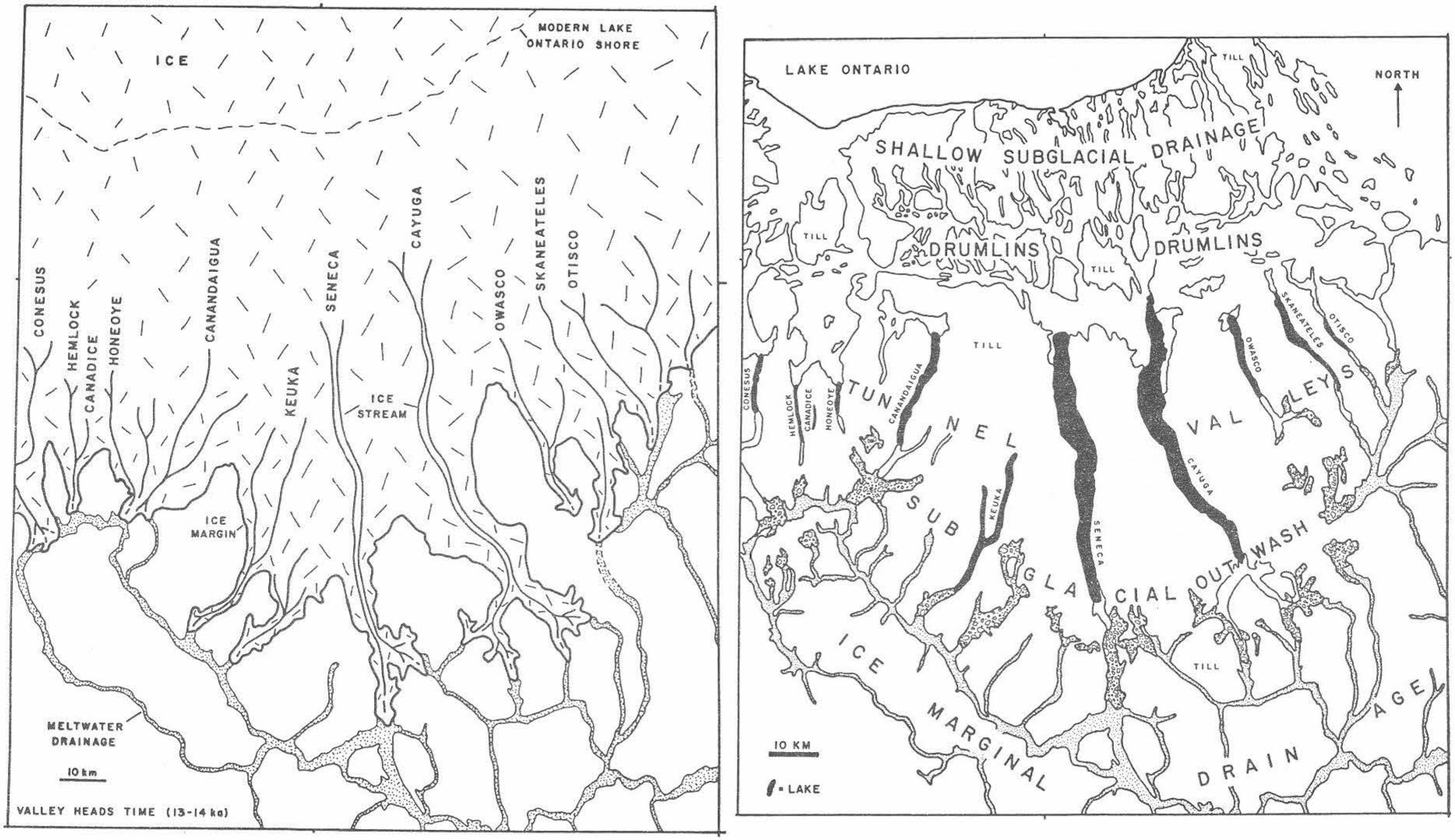

Fig. 40 - (Left) Schematic reconstruction of southern margin of Laurentide Ice Sheet in Finger Lakes region at Valley Heads time (13-14 ka). (Right) Regional interpretation of major glacial features in Finger Lakes region.

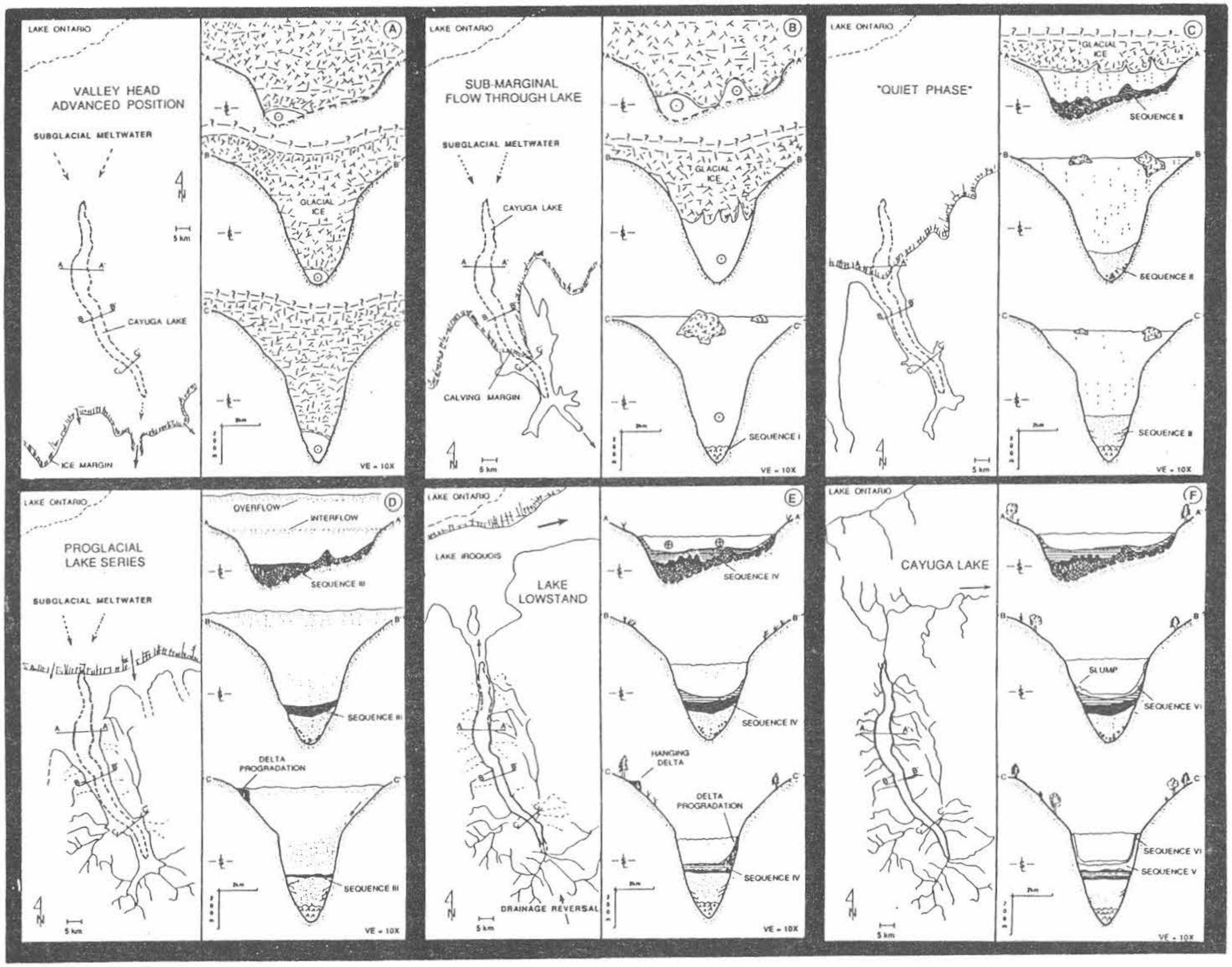

Fig. 41 - Schematic, sequential illustration of sediment infill history for the Finger Lakes based on seismic stratigraphic data from Cayuga Lake (E. Hinchey, in prep.).

subsurface geophysical and geological approach has revealed at least a part of the "barely suspected missing chapter in the history of the Finger Lakes" alluded to by Bloom (1984).

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ROAD LOG

SUBSURFACE GEOLOGY OF FINGER LAKES

Total Miles	Miles from Last Point	Route Description
0.0	0.0	Depart Heroy Geology Lab on the campus of Syracuse University. Turn left at light on to University Avenue.
0.2	0.2	Turn right at light on to Irving Avenue.
0.7	0.5	Turn left at Harrison Street.
0.9	0.2	Turn left on to I-81 south. Drive south along east margin of Onondaga Trough toward Cortland.
12.1	11.2	Exit 15 - Lafayette. Note jointed bedrock along off-ramp.
12.2	0.1	Turn left on to Route 20 west.
13.0	0.8	Turn right on to Webb Road.
13.5	0.5	Turn left on to Amidon Road.
14.1	0.6	<u>STOP #1</u> - dead end of Amidon Road - overview of Tully Valley. Turn around; return east on Amidon Road.
14.7	0.6	Turn right on Webb Road.
15.2	0.5	Turn right on Route 20 west.
16.3	1.1	Turn right on Route 11A.
16.5	0.2	Turn right on Route 11A south.
17.3	0.8	Turn right on Webster Road.
18.0	0.7	Turn left on Tully Farms Road - head south.
19.7	1.7	<u>STOP #2</u> - Otisco Road. After stop, continue south on Tully Farms Road down Tully Valley and up Valley Heads.
23.6	3.9	Turn right on Route 80. Note contact between Valley Heads moraine and bedrock of valley wall as you head west.
28.3	4.7	Bear left on to Oak Hill Road.
33.1	4.8	Turn right on Otisco Valley Road. Pass through town of Amber. Amber hanging delta 1.6 miles from turn.
35.4	2.3	Turn left on Route 174 at north end of Otisco lake. Forest Home Hotel, 1.1 miles from turn, provides view down Otisco valley.

Total Miles	Miles from Last Point	Route Description
38.6	3.2	Turn left at stop sign. Continue on Route 174 to Borodino.
39.8	1.2	Turn left on Route 41. Head south.
47.8	8.0	<u>STOP #3</u> - Picnic area. Overlook of Skaneateles Lake. After stop, return to Route 41 and head <u>north</u>.
47.9	0.1	Turn left on secondary road at Onondaga-Cortland County line. Head down to Skaneateles Valley.
49.4	1.5	Turn right at stop sign on East Lake Road.
49.6	0.2	Turn left on Glenheaven Road. Drive around south end of Skaneateles Lake. Note bedrock outcrops along west valley wall.
55.6	6.0	Head straight across intersection with Route 41A. Drive west on New Hope Road.
56.6	1.0	Continue straight (west) on Burdock Road.
57.6	1.0	Turn left on Route 38A (Dutch Hollow Road). Head south to Moravia to end of Route 38A.
64.6	7.0	Head north (straight) on Route 38.
71.5	6.9	<u>STOP #4</u> - Turn right on to Ensnore Road - Owasco Lake overview. After stop cross Route 38 and head west on Center Road to Scipio Center.
74.2	2.7	Turn left on Route 34. Head south to Venice Center.
77.3	3.1	Turn right on Poplar Ridge Road. Head toward Poplar Ridge. Cross "chevron moraine" just east of Poplar Ridge.
80.5	3.2	At Poplar Ridge cross Route 34B. Continue straight (west) on Poplar Ridge Road.
84.9	4.4	Turn left on Route 90. Head south.
85.0	0.1	Bear right on to Lake Road.
86.6	.16	<u>STOP #5</u> - Turn right in to Long Point State Park on Cayuga Lake - LUNCH. After stop return to Lake Road and turn right.
88.0	1.4	Turn right on Route 90. Head south.
93.1	5.1	Turn right on Route 34B at King Ferry. Head south toward Ithaca.

Total Miles	Miles from Last Point	Route Description
105.1	12.0	Turn right on Route 34. Continue south to Ithaca.
110.6	5.5	Turn right on Route 34 south where it joins Route 13. Continue south through Ithaca. Stay on Routes 13/34.
114.4	3.8	STOP #6 - Turn left into Buttermilk Falls State Park. After stop, leave Park and turn left on Routes 13/34.
114.9	0.5	Turn right on Route 13A. Head north toward Cayuga Lake.
116.9	2.0	Turn left on Route 79 west toward Watkins Glen. (**CAUTION**: World's most complex intersection!)
131.8	14.9	Turn left at stop sign. Continue west on Route 79 to Watkins Glen. Note kame deposits in quarry across road.
134.0	7.2	STOP #7 - Turn right into Warren Clute Memorial (Lakeside) Park. After stop, leave Park, turn right, continue west on Route 79 into village of Watkins Glen.
139.8	0.8	Turn left on Route 14 (N. Franklin Street). Head south toward Horseheads. Note infilled lake valley to left as you head south from Watkins Glen.
155.2	15.4	Turn right at light. Route 14 south to Route 17.
156.6	1.4	Turn right on Route 17 west (Southern Tier Expressway). Head toward Corning. Drive will take you along proglacial meltwater channel.
166.6	10.0	Exit 47. Continue west on Route 17 west toward Jamestown. Pass through city of Corning.
190.8	24.2	Exit 38. Bath, N.Y. Turn right on Route 54 north.
190.9	0.1	Turn right at light. OVERNIGHT STAY at Super 8 Motel. In morning depart motel and head north on Route 54.
191.7	0.8	Left at light. Continue north on Route 54. Drive will take you across Valley Heads and down to dry lake floor.

Total Miles	Miles from Last Point	Route Description
198.6	6.9	Turn left on Route 54A into village of Hammondsport.
199.2	0.6	Continue straight at stop sign.
199.8	0.6	Go to next stop sign and turn right.
199.9	0.1	Bear left on Route 54A north. Drive along west shore of Keuka Lake to Branchport.
213.8	13.9	Turn right at blinking light in Branchport on Route 54A toward Penn Yan.
214.8	1.0	<u>STOP #8</u> - Turn right into overlook at north end of northwest branch of Keuka Lake. After stop, leave overlook and turn <u>left</u> on Route 54A and return to Branchport.
215.8	1.0	Head straight at blinking light on Italy Hill Road. Head west towards Naples.
220.8	5.0	Turn right on Italy Turnpike. Continue west to Naples.
223.9	3.1	Yield sign. Continue straight toward Naples.
229.5	5.6	Turn right on Route 53 north. Drive down Valley Heads.
230.7	1.2	End Route 53. Continue straight on Route 21 north through village of Naples.
232.5	1.8	Bear left on County Road 12 north. Head up hill.
233.9	1.4	There will be a brief stop to overlook drillsite along Parrish Flat Road in valley.
235.6	1.7	<u>STOP #9</u> - Turn right into private parking area. Overlook of Canandaigua Lake. After stop, turn left and return south along County Road 12.
236.0	0.4	Turn left on Griesa Hill Road. Head down hill.
237.2	1.2	Turn right on Route 21 south.
237.5	0.3	Turn left on Parrish Flat Road east.
238.0	0.5	<u>STOP #10</u> - Drillsite in field near intersection DEC-owned old railroad bed and Parrish Flat Road. After stop, return to west on Parrish Flat Road.

Total Miles	Miles from Last Point	Route Description
238.5	0.5	Turn right on Route 21. Drive north to city of Canandaigua along west shore of Canandaigua Lake.
243.0	4.5	Bear right. Continue north on Route 21 toward Canandaigua.
255.8	12.8	Turn right. Continue north on Route 21.
256.2	0.4	Turn right (east) at light on Routes 21 north and 20 east to city of Canandaigua.
257.9	1.7	Turn left at light on route 21 north (Also Route 332).
258.9	1.0	Turn right on Route 21 north. Head toward New York State Thruway.
266.2	7.3	Turn left on to New York State Thruway (I-90). Head east toward Albany.
285.9	19.7	Exit 41. Waterloo/Clyde. Pay toll.
286.4	0.5	Turn right on Rouge 414 south.
286.7	0.3	Turn left at light on Route 318 east toward Auburn.
290.9	4.2	Turn left on Routes 20/5 east.
291.0	0.1	Turn left on Route 89 north.
293.7	2.7	Cross over New York State Thruway. Look to right (east) across Montezuma channel. Continue north on Route 89.
296.4	2.7	Turn left at stop sign on Armitage Road at Wayne County line. Head west.
297.0	0.6	STOP #11 - Drumlin along east side of west branch of Montezuma Channels. After stop, turn around and head east on Armitage Road.
297.6	0.6	Continue straight at stop sign. Head east on Route 89 north.
298.9	1.3	Turn right on Route 31. Head east toward Syracuse.
301.1	2.2	Turn right on Route 90 south.
301.8	0.7	Turn right at blinking light. Continue south on Route 90. Note drumlins.
305.6	3.8	Turn left on Routes 20/5 east. Head to Auburn.
315.6	10.0	Turn right. Continue on Route 20 east.

Total Miles	Miles from Last Point	Route Description
315.7	0.1	Turn left. Continue on Route 20 east to Skaneateles.
322.5	6.8	STOP #12 - Park at north end of Skaneateles Lake. After stop continue east on Route 20 through village of Skaneateles.
324.5	2.0	Turn left on Route 175 toward Syracuse.
329.5	5.0	Turn right. Continue on Route 175 east toward Syracuse.
337.7	8.2	Head straight through traffic lights. Head east on Route 173 (W. Seneca Turnpike).
339.6	1.9	Turn left at light on Route 11 north.
340.7	1.1	Turn right toward I-81 north.
340.8	0.1	Turn left on to on-ramp for I-81 north.
342.4	1.6	Exit 18. Harrison and Adams Streets.
342.6	0.2	Turn right at end of off-ramp on E. Adams Street.
342.8	0.2	Turn right on top of hill on Irving Avenue.
343.0	0.2	Turn left at light on University Place.
343.1	0.1	Turn right at light on Crouse Drive. Return to Heroy Geology Lab on the campus Syracuse University.

-- END OF TRIP --