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91st ANNUAL MEETING OF THE  
**New York State Geological Association**  
2019

**FIELD  
TRIP  
GUIDE**



HOBART AND WILLIAM SMITH COLLEGES



HOSTED BY THE

**NYS Council of Professional Geologists**

AND

**Hobart and William Smith Colleges**

# **NYS GEOLOGICAL ASSOCIATION**

**91<sup>st</sup> ANNUAL MEETING**

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**Guidebook for Fieldtrips**  
**New York's Finger Lake Region**  
**October 5-6, 2019**

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hosted by

**NYS Council of Professional Geologists**

and

**Hobart and William Smith Colleges**

All field trip guides are available for free download by following this link: [www.nysga-online.net](http://www.nysga-online.net)

The front cover photo credits are clockwise from top left:

- Zurich Bog Topographic sketch map of the Zurich Bog wetland complex. Redrawn from the USGS 7.5 minute quadrangle Sodus, NY (2016)
- LiDAR Hillshade of the Valley Heads area, US Dept. of the Interior, USGS
- Eurypetid Photo by Stephen M. Mayer
- Tully Valley Mudboil, US Dept. of the Interior, USGS
- Taughannock Falls, Photo by R.M. Ross, Annotations by Don Haas
- The *William Scandling*, courtesy of HWS

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# **Welcome to HWS Colleges**

**David Kendrick,**

**Dept of Geoscience, Hobart & Wm Smith Colleges**

The Hobart & William Smith Colleges Department of Geoscience welcomes the geoscientific community to the 91st Annual Meeting of the New York State Geological Association in 2019. We are proud to host NYSGA this year and look forward to sharing the spectacular landscapes of the Finger Lakes with you. The Geoscience Department at HWS traces its roots to a sedimentologist/stratigrapher and a meteorologist/oceanographer, who established our program with a strong interdisciplinary character; this interdisciplinary nature runs as strong as ever through our department today. Our faculty expertise includes sedimentology and stratigraphy, meteorology and climate science, paleontology, paleobotany, limnology, geochemistry, and more. The field trip offerings this year echo that broad, interdisciplinary approach to investigating this region and the world. Finally, we are also pleased to share the beautiful HWS campus with you; its location overlooking Seneca Lake is hard to beat. Welcome and we hope you enjoy the 91<sup>st</sup> NYSGA.

# Welcome to the 91st Annual Meeting

## Gene Florentino, NYSCPG President

This is New York State Council of Professional Geologist's (NYSCPG's) first time co-hosting this great NYSGA event. NYSCPG's main goal in co-hosting this event is to emphasize our Mission in serving the community, especially Geoscience students and academia-

As per our mission statement, NYSCPG is the principal organization of professional geologists responsible for the advancement of the competent and ethical practice of geology in New York State. NYSCPG's primary goals, on behalf of its members, are to strengthen and advance the application of geological sciences as a profession by providing leadership, advocacy, and education to promote the protection of public health, safety, and welfare, and the balanced protection of the environment.

From my personal experience, both being a former student in geology and now working in the profession, it is a very rewarding experience - I hope you enjoy your studies and the profession as much as I do. Enjoy this weekend's field trips. Hope to see you working in our profession upon your graduation!

## Cheryl Neary, NYSGA President (2019)

### NYSCPG, Immediate Past-President

I would like to take this opportunity to welcome you to the 91<sup>st</sup> Annual Meeting of the NYSGA held in another of New York State's geographical region. Per the Finger Lakes Regional Tourism Council:

“The Finger Lakes Region of New York State is a 9,000 square mile, four-season playground, set against a backdrop of Mother Nature's best work - from waterfalls and gorges to thick, cool woods to rolling hills to miles of spectacular shoreline on 11 glacial lakes and one Great Lake. No matter what you like to do, you'll find it in abundance in the Finger Lakes.”

Hosting this years' NYSGA has brought back many fond memories of attending my first NYSGA at Vassar in 1976, followed by my involvement in 1977 in collating the 49<sup>th</sup> Annual Meeting guidebook, when my college – SUNY Oneonta -hosted the event! Over the years I have attended many more of the annual meetings – each time struggling to determine which of the field trips I should participate in, with each one chosen a rewarding experience. Each year that I have attended one of the annual meetings, I have gained more knowledge of the geological field, as well as the profession. Each annual meeting provides you with technical information and professional networking opportunities.

I hope you continue to support this annual event – as faculty and students - of all ages. acquiring knowledge and skills through your experience as a participant.

## **NYSCPG Mission**

The New York State Council of Professional Geologists (NYSCPG) is the principal organization of professional geologists responsible for the advancement of the competent and ethical practice of geology in New York State. NYSCPG's primary missions, on behalf of its members, are to strengthen and advance the application of geological sciences as a profession by providing leadership, advocacy, and education to promote the protection of public health, safety, and welfare, and the balanced protection of the environment.

## **NYSCPG Services**

The focus at NYSCPG is three fold: 1) Promote the competent practice of professional geology by adhering to sound ethical, scientific, and geologic principles; 2) Monitor and offer professional reviews and opinions regarding pending legislation and research New York State and local laws and regulations as they pertain to or may affect the practice of geology in New York State; 3) Monitor and offer professional reviews and opinions regarding current laws and regulations and pending legislation so that sensible and practical measures are incorporated to protect public health, safety, and welfare and promote the balanced protection of the environment; and, 4) Encourage stewardship for the profession of applied geology.

### ***What do we do?***

- Strengthen the role and importance of the professional practice of geology in the State of New York;
- Advocate and promote professional geologists across the many geologically-related sub-disciplines and practice areas;
- Facilitate continuing education, awareness, and training to our members; and,
- Provide career development, networking opportunities, and other benefits to professionals and students dedicated to the learning, application, and advancement of geological sciences.

### ***How do we do it?***

NYSCPG aims to represent the interests of professional geologists and students over a variety of practice disciplines. NYSCPG will advance the science of geology, and its related fields, by encouraging education, training, and awareness through meetings, exchange of information, and providing a common voice on behalf its members. The dues paid by its members allow NYSCPG to advance and promote the profession of geology through building public appreciation for how professional geologists contribute to protection of public health, safety, and welfare, and the balanced protection of the environment.

### ***Who do we serve?***

NYSCPG's leadership team represents not only its members, but also advocates for all NYS-licensed professional geologists, and individuals on the path to a NYS professional geologist license. NYSCPG will fulfill members' needs with a wide range of useful services (e.g. career development, education, networking opportunities) enabling them to be more effective in their career through advocacy, continuing education, training, and outreach.

# New York State Council of Professional Geologists (NYSCPG) FACTSHEET



*Catskill Mountains, NY*

**NYSCPG Mission Statement:** The New York State Council of Professional Geologists (NYSCPG) is the principal organization of professional geologists responsible for the advancement of the competent and ethical practice of geology in New York State. NYSCPG's primary missions, on behalf of its members, are to strengthen and advance the application of geological sciences as a profession by providing leadership, advocacy, and education to promote the protection of public health, safety, and welfare, and the balanced protection of the environment.

[nyscpge.wildapricot.org](http://nyscpge.wildapricot.org)

January 2019



### **§7204-a. Definition of the profession of geology**

The practice of the profession of geology is defined as performing professional service such as researching, investigating, consulting and geological mapping, describing the natural processes that act upon the earth's materials, predicting the probable occurrence of natural resources, predicting and locating natural or human-induced phenomena which may be useful or hazardous to humankind and recognizing, determining and evaluating geological factors, and the inspection and performance of geological work and the responsible supervision thereof in furtherance of the health, safety and welfare of the public; provided, however, that geological mapping shall not include the practice of land surveying as defined in section seventy-two hundred three of this article.

### **§7204-b. Practice of geology and the use of title "professional geologist"**

Only a person licensed or otherwise authorized under this article shall practice geology or use the title "professional geologist".

\* Effective March 1, 2019

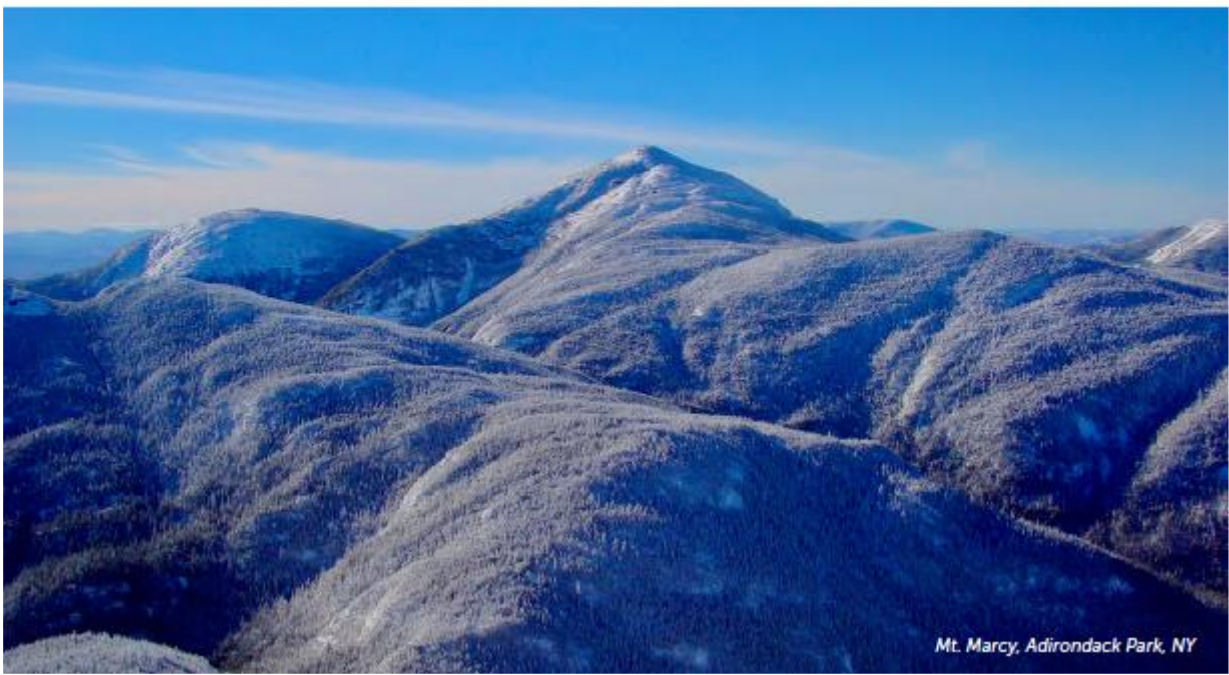
### **\*§7210. Certificates of authorization**

All business entities legally permitted to provide professional geology services in New York State are required to obtain a "Certificate of Authorization to Provide Professional Geology Services in New York State" from the State Education Department according to section 7210 of Education Law.

Individual licensees, who are legally permitted to practice geology in New York State, can obtain a "Certificate of Authorization" according to section 7210 of New York State Education Law, however, they are not required to do so.

### **§6509 Definitions of professional misconduct/§6512 Unauthorized practice a crime**

The laws of the State are clear in regard to unauthorized practice. Section 6512.1 of the Education Law makes it a class E felony for anyone not authorized to practice who practices or offers to practice or holds themselves out as being able to practice professional geology. Section 6509 of the Education Law defines professional misconduct as, among other things, permitting, aiding or abetting



Mt. Marcy, Adirondack Park, NY

an unlicensed person to perform activities requiring a license; and, section 6512.2 of the Education Law makes it a class E felony for anyone, including a public official, to knowingly aid or abet three or more unlicensed persons to practice a profession requiring a license.

**Pathway to Licensure**

To be licensed as a professional geologist in New York State you must:

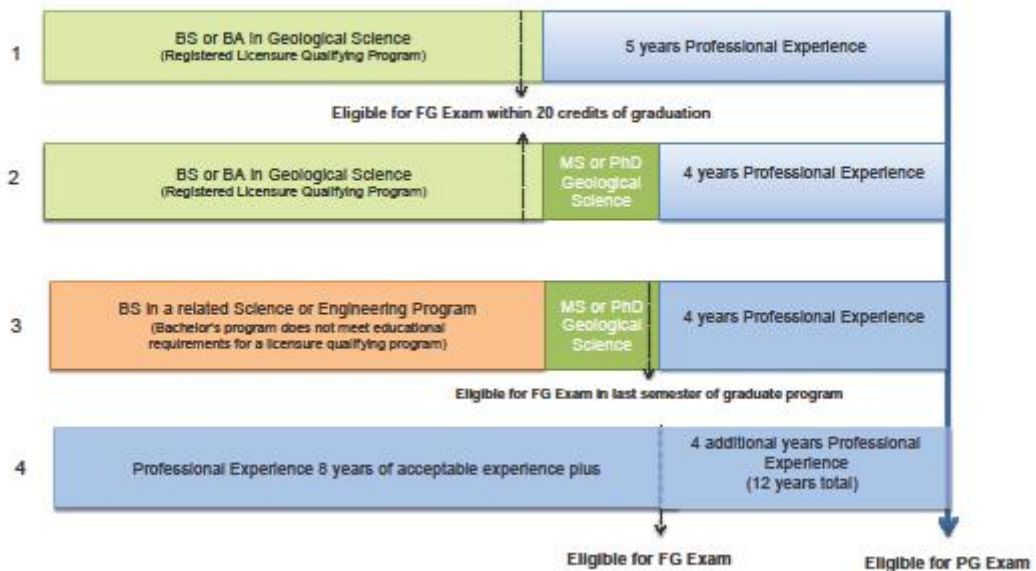
- Be of good moral character;
- Be at least 21 years of age; and
- Meet education, examination, and experience requirements.
- Submit an application for licensure and the other forms indicated, along with the appropriate fee, to the Office of the Professions at the address specified on each form.

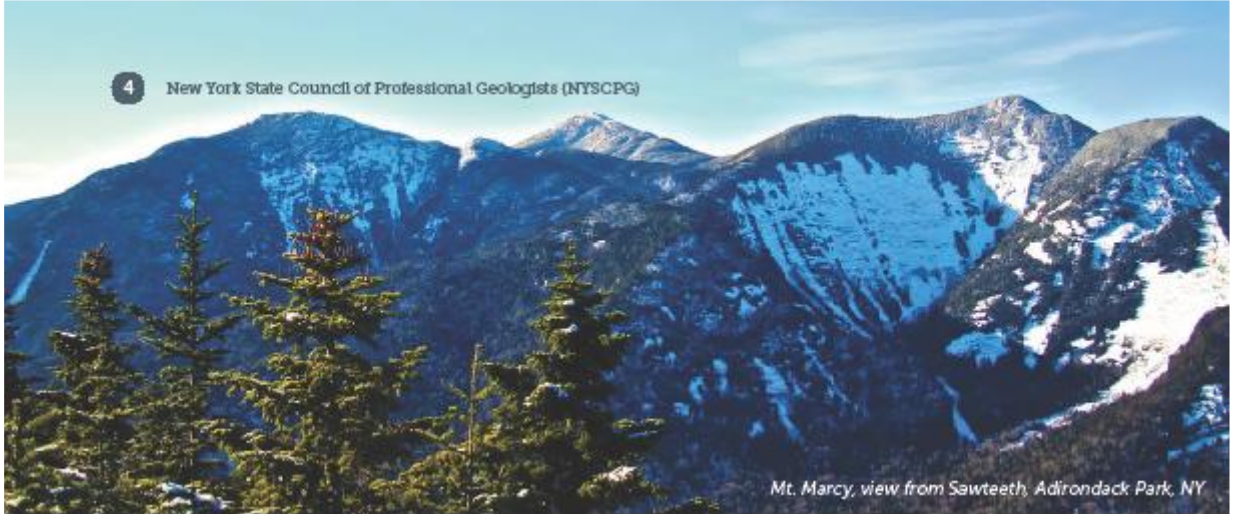
The specific requirements for licensure are contained in Title 8, Article 145, section 7206(b) of New York’s Education Law and Part 68 of the Commissioner’s Regulations (<http://www.op.nysed.gov/prof/geo/geolic.htm>).



Helderberg Escarpment, NY

**Education and Experience Requirements for Professional Geology Licensure**





Mt. Marcy, view from Sawteeth, Adirondack Park, NY

## What is NYSCPG and how can I benefit as a member?

### NYSCPG Services

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[nyscouncilpg@gmail.com](mailto:nyscouncilpg@gmail.com)  
[nyscp.org.wildapricot.org](http://nyscp.org.wildapricot.org)

## **BIOGRAPHIES**

### **Gene Florentino, Speaker**

Gene Florentino has a MS degree in Geology from the University of Akron, OH; and a BS degree in Geology from the State College of NY at Oneonta. He is also a licensed Professional Geologist in NY and PA. He is currently President of the New York State Council of Professional Geologists (NYSCPG) and has been on the Board of Directors for over 16 years. Mr. Florentino was also President of the Buffalo Association of Professional Geologists (BAPG) in 1999, and served on their Board for several years. After studying for several months in 2017, Mr. Florentino earned a Project Management Professional (PMP) credential from the Project Management Institute. After achieving this recognition, he felt after 33 years it was time to sit for the National Association of State Boards of Geology (ASBOG) Fundamentals of Geology and Practice of Geology exams. Passing both of those exams was the major milestone of his career! In his spare time, Mr. Florentino was a Project Manager/Practicing Geologist at Ecology and Environment in Buffalo for over 30 years and now has a similar position with GHD Services in Niagara Falls.

### **David Kendrick | Dept of Geoscience | Hobart & Wm Smith Colleges**

By geological standards of time, David Kendrick was born and grew up in Indiana, earned a B.S. in Geology and Geophysics from Yale and a Ph.D. in Geological Sciences from Harvard, studied rocks and fossils in places like Utah, Montana, Jamaica, the Bahamas, New York, Australia, Sweden, and the Netherlands, and became an Associate Professor of Geoscience at Hobart & Wm Smith Colleges, all in the blink of an eye.

### **Field Trip A1:**

**Dan Karig** came to Cornell in 1973 and taught there for 25 years. His research interests began in structural geology and marine tectonics, mostly related to island arc systems. He then worked on the experimental deformation and mechanical behavior of soft sediments. After retirement he became interested in the glacial geology of the local area, where field work has led him to a number of controversial conclusions.

**Bryan Isacks**, from 1954 to 1971 did his undergraduate - graduate study at Columbia University and a post-doc at the Lamont-Doherty Earth Institute. He then joined the newly re-constituted Department of Geological Science in 1971. His research interests changed over the years from earthquake seismology and tectonics of subduction zones in the SW Pacific to topographic expressions of tectonics and glaciation in the South American Andes. Retiring in 2008, he became fascinated with the topographic expressions of glaciation in central New York, particularly features revealed by the new LIDAR high resolution digital elevation models.

### **Field Trip A2:**

**Stephen Mayer.** I received my BS in geology from SUNY Oneonta in 1985 and my MS in geology in 1989 with specialization in Stratigraphy and Paleontology. I studied the Jaycox Shale Member,

uppermost Ludlowville Formation, Hamilton Group using key fossil beds to correlate the unit from about Lake Erie shoreline thru Finger Lakes to Skaneateles Lake. I studied the paleoecology of these fossil assemblages as well.

Since then I focused on the overlying Lowermost Moscow Formation, the transition from the Tichenor Member thru Deep Run Shale Member subdividing the latter and correlating these beds in a like wish fashion. Past 4 years I have concentrated on Eurypterid bearing horizons in NY studying taphonomy and paleoecology of these chelicerates.

### **Field Trip A3:**

#### **John D. Halfman**

John D. Halfman, Professor of Limnology and Hydrogeochemistry, teaches in the Department of Geoscience and Environmental Studies Program at Hobart and William Smith Colleges. He is also intimately linked with creation and development of the Finger Lakes Institute at the Colleges, accumulating over \$10 million dollars in funding from state, federal and private foundation sources since its inception in 2004. He has recently taught the following courses: GEO-186 Introductory Hydrogeology, GEO-210 Environmental Hydrology, GEO-330 Limnology, ENV-200 Environmental Science, and ENV-203 Fundamentals of GIS.

Building on Lake Superior and East African Rift Lake paleoclimatic research before coming to HWS, his current research interests focus on water quality issues in the Finger Lakes. The projects include: (1) water quality variability between the Finger Lakes and potential drivers for the observed variability; (2) nutrient sources and nutrient loads within selected Finger Lake watersheds; (3) nearshore nutrient dynamics and potential drivers for the recent nearshore blue green algae blooms, (4) spectral signatures of algal blooms and their surface concentrations, and especially blue green algae concentrations as observed by Unmanned Aerial Vehicles (UAVs – aka drones); and, (5) potential remediation efforts to mitigate blue green algae blooms in nearshore regions.

#### **David Finkelstein**

David Finkelstein earned his Ph.D. from the University of Illinois at Urbana-Champaign and M.S. and B.S. degrees from the UMass Amherst and works in variety of scholarly disciplines focused around geochemistry and limnology. Among his recent research interests are comparing modern ancient lacustrine systems, analyzing controls on the chemical evolution of till-derived waters, characterizing the intersection of organic and aqueous geochemistry in the evolution of ponds to lake systems, and exploring microbial life on the edge of hydration in lakes, seeps and hot spring. Professor Finkelstein joined the HWS faculty in 2013.

## **Field Trip A4:**

**Nan Crystal Arens** is Professor of Geoscience at Hobart & William Smith Colleges. She earned a B.Sc. in Earth Science from Penn State University and an M.Sc. in Geology also from Penn State. Her Ph.D. is in Organismal Biology from Harvard with specialization in paleobotany and palynology. She served as a faculty member at the University of California, Berkeley and curator of fossil plants at the University of California Museum of Paleontology before coming to HWS in 2001. Her research focuses on the environmental factors that force macroevolutionary and ecological change. In the last several years she has also begun investigating the role education plays in student's understanding of contemporary climate change.

## **Field Trip A5:**

**William (Bill) Kappel** earned both undergraduate and graduate degrees from Penn State. He has worked as a hydrologist for the U.S. Forest Service in Missouri and Wisconsin. For over 35 years he has studied the hydrogeology of upstate New York with the U.S. Geological Survey in the New York Water Science Center. At present he is a hydrogeologist emeritus with the New York Water Science Center at Ithaca, NY.

Past investigations include the Onondaga Trough, studying the movement of natural brine to Onondaga Lake at Syracuse, NY; study of mudboil (mud-volcano) activity in the Onondaga Creek Valley; study of landslides in upstate New York – in relation to glacial lake clays; aquifer studies in central and western New York, and carbonate and evaporite karst ‘challenges’ throughout New York. He has also coordinated USGS water-resource information and study efforts related to shale-gas development in New York and with other Water Science Centers across the Marcellus ‘Play’ - West Virginia to New York.

## **Field Trip B1:**

**Robert Ross** is the Associate Director for Outreach at the Paleontological Research Institution (PRI) and is adjunct faculty in the Cornell Department of Earth and Atmospheric Sciences. He received his Bachelors degree in Geological Sciences from Case Western Reserve University (1984) and his Ph.D. in Earth and Planetary Sciences from Harvard University (1990). Ross took a post-doctoral fellowship in paleoclimatology at the University of Kiel (Germany) (1990-1992) and was on the Faculty of Sciences at Shizuoka University (Japan) (1992-1997). Ross's research has included the diversity and biography of tropical marine organisms, carbon cycling associated with coastal upwelling, and science education. He has been at PRI since 1997, where he has been involved in a wide variety of education and exhibits in Earth science, paleontology, evolution, and climate change.

**NYSGA bios for Ross et al article**

**Warren Allmon** is the Director of the Paleontological Research Institution (PRI) and the Hunter R. Rawlings III Professor of Paleontology in the Department of Earth and Atmospheric Sciences at Cornell University. He earned his bachelor's degree in Earth Sciences from Dartmouth College (1982) and his PhD in Earth and Planetary sciences from Harvard University (1988). For four years, Allmon was assistant professor of geology at the University of South Florida, Tampa, and in 1992 he became director of PRI, where he has been instrumental in rejuvenating the institution's internationally known fossil collections; starting its local, regional, and national programs in earth science education; and planning and fundraising for PRI and its Museum of the Earth and Cayuga Nature Center. Allmon's major research interest is macroevolution and paleoecology, particularly using Cenozoic marine gastropods.

**Don Haas** is Director of Teacher Programs at the Paleontological Research Institution (PRI). He received a BS in Physics from SUNY Geneseo (1985), an MS in Earth Science Education from SUNY Cortland (1990), and a PhD in Science Education from Michigan State University (2000). He has 10 years experience as an Earth science teacher, and has taught in education departments at Kalamazoo College, Cornell University, and Colgate University before joining PRI in 2008. Haas played an active role in the development of the Next Generation Science Standards (NGSS), served as Chair of the Geological Society of America's Geoscience Education Division, was President of the National Association of Geoscience Teachers, and was on the New York State Science Leadership Team for the NGSS. Don's work focuses on effective teaching of societally significant issues such as climate change and energy and on the use of technology-rich place-based approaches to teach Earth systems.

**Jonathan Hendricks** is Director of Science Communication at the Paleontological Research Institution (PRI) and is adjunct faculty in the Department of Earth and Atmospheric Sciences at Cornell University. Hendricks received his BS in Geology & Geophysics and Zoology from the University of Wisconsin-Madison (1999) and a PhD in Geological Sciences from Cornell University (2005). He was a post-doctoral researcher at the University of Kansas (2005-2008) and was on the faculty of the Department of Geology at San Jose State University (2008-2016). Besides managing PRI's publications, he is also active in paleobiological research on the evolutionary history of cone snails and in outreach activities associated with the National Science Foundation-supported Digital Atlas of Ancient Life project ([www.digitalatlasofancientlife.org](http://www.digitalatlasofancientlife.org)). His recent Digital Atlas projects include founding the Digital Encyclopedia of Ancient Life (an online, open access paleontology textbook), developing an online virtual teaching collection of 3D fossils, and creating an online field guide to fossils from the Cretaceous of the U.S. Western Interior region.

## Trip A1 a

# A REVISED HISTORY OF LATE QUATERNARY GLACIATION IN THE CAYUGA BASIN

DAN KARIG AND BRYAN ISACKS

*Dept of Earth and Atmospheric Sciences, Cornell University*

## INTRODUCTION

The glacial history of the Cayuga Basin has yet to be completely understood and has recently become controversial. The current story is basically that of Tarr (Williams et al., 1909) and Fairchild (1934), with minor updates from von Engel (1961), Muller (e.g. Muller and Cadwell, 1986), Bloom (2018) and Mullins (e.g. Mullins et al, 1996). For the last glacial stage, this is a story of ice retreating from the Last Glacial Maximum (LGM) into the Ontario basin, re-advancing to the Valley Heads moraine and then retreating again, leading to a series of proglacial lakes trapped between the ice front on the north and higher topography to the south. With the assumption that the ice sheet was an impermeable barrier to flow northward and the dearth of chronologic control, this model was logical, given that the simplest model that fits the available data is to be preferred.

Research over the past decade or so has generated data that requires the modification of this paradigm, in some cases significantly. The most radical modification is northward subglacial drainage during the Mackinaw Interstade, requiring the rejection of the existence of the large proglacial lakes Ithaca, Newberry and Hall in the Cayuga Trough (Karig and Miller, 2017; submitted). Other different interpretations are the nature of the Valley Heads re-advance and the extent of ice retreat during the Erie Interstade. These modifications were largely due to the availability of Lidar imagery, scientific drilling, and seismic profiling, but also to field studies that relied more on pitting and coring than had earlier studies. This paper reviews as much of the glacial history of the Cayuga basin as is available but is largely devoted to the history since the LGM because this advance overrode and largely destroyed the evidence of earlier glaciations.

### General Quaternary Glaciation

Ice began to build up in North America about 2.7 ma ago (Haug, et al., 2004) but reached the Cayuga basin a significant time later. Although there is no explicit evidence for when this arrival occurred, there is indirect evidence that there were many ice advances to and through the area prior to the LGM. It is clear that such penetration occurred during Wisconsin and preceding Illinoian stages and, because several advances of similar extents occurred in the mid-West, there were almost certainly several such major advances through central New York. Evidence for multiple advances includes the contrast in the shape of the topography along



the north flank of the Appalachian Plateau, which lies near Ithaca, with that further south. The northern flank of the plateau is marked by linear or arrowhead shaped ridges (Karig, 2015) that have a dominantly N-S trend. The topography shows little of the presumed pre-Quaternary dendritic drainage patterns. Those dendritic patterns remain clearly evident in the topography farther south, where topographic evidence of massive glacial sculpting is not apparent. The video playing and available online at Ithaca's Museum of the Earth (Isacks, 2013) shows that the assembly of Valley Heads Moraines is the approximate boundary between the remarkably different topographies. This difference reflects multiple ice advances into the northern flank of the plateau but far fewer into its interior because ice sheets would have to have thickened markedly to generate the necessary southward surface slope to drive the ice far into or beyond the plateau.

It has been recognized since the work of Tarr (Williams et al., 1909) that glacial erosion in the Cayuga and other troughs has been much greater than that on the uplands. Modern concepts would lead to identification of the troughs as sites of small ice streams, where ice flow was far faster than over the interfluves. The relative lack of glacial erosion on the uplands (e.g. Williams et al., 1909, Muller, 1965) is probably due to thinner and slower moving ice and possibly even to cold based ice in those settings.

Not only was glaciation variable with respect to location within the basin but almost certainly also differed during the various glacial stages. Several lines of evidence suggest that erosion and trough deepening was greater during the Illinoian Stage than during the Wisconsin. The most explicit evidence is the subsurface geometry of the Sixmile Trough, a major glacial trough tributary to the Cayuga Trough. Cross sections of this trough (Karig, 2015, Fig. 4 of field trip guide) show the Illinoian glacial trough (the inner glacial trough of Karig (2015)) deeply incised into an older glacial trough (outer glacial trough) but there is no additional bedrock excavation during the Wisconsin Stage. A large amount of bedrock appears to have been eroded between the pre-glacial topography and the creation of the outer glacial trough but there is no evidence concerning the number of glacial advances that moved through the valley during this interval. The combination of surface, well and seismic data from Cayuga Inlet valley strongly indicate the existence of a thick section of pre-Late Wisconsin sediment there, which precludes any Late Wisconsin bedrock erosion there. Combined with the lack of pre-Late Wisconsin deposits beneath Lake Cayuga (Mullins et al, 1996) this suggests the removal of only that material in the deeper part of the Cayuga Trough. A possible reason for the lack of Late Wisconsin

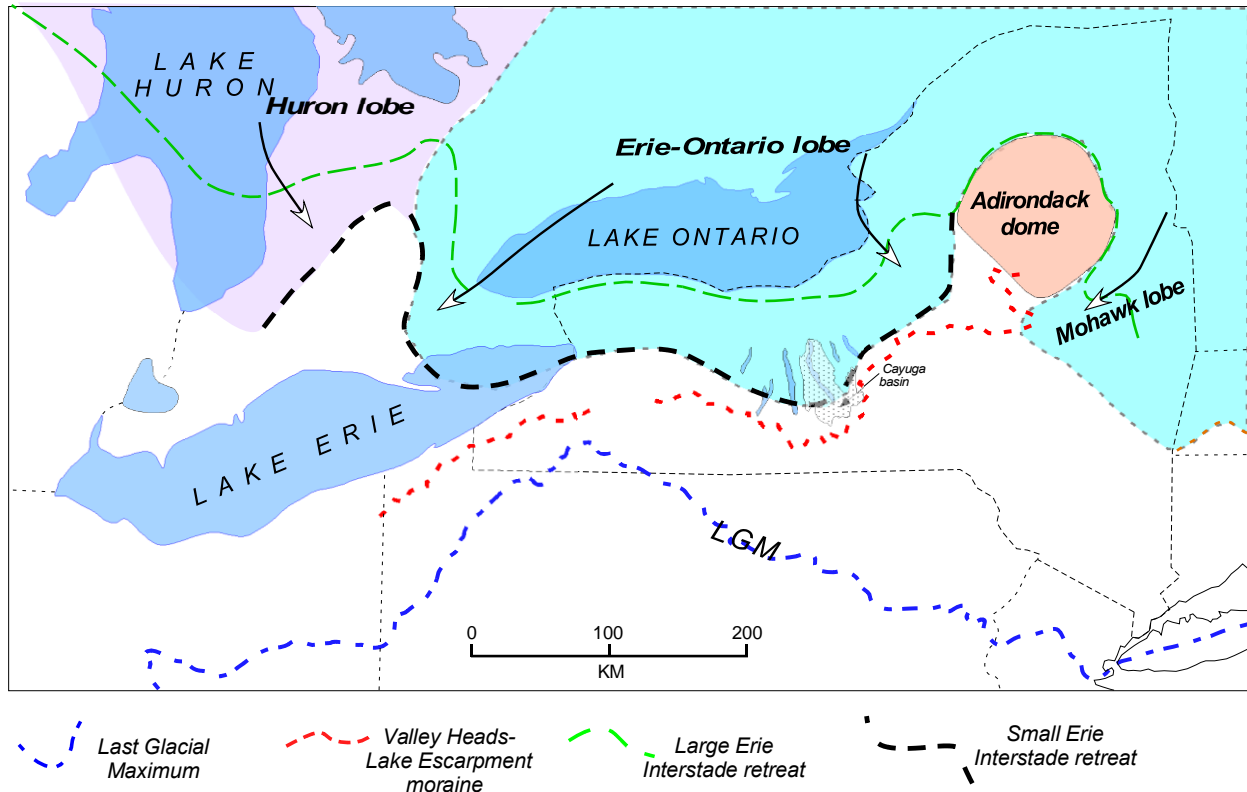


Figure 1. Regional setting of the Cayuga basin and major ice front positions since the LGM.

bedrock erosion is that glacial striae show that ice movement in the Cayuga basin during that advance was southwest to south-southwest (Williams et al, 1909; Denny and Lyford, 1963), strongly oblique to the trend of the Cayuga Trough. Although ice covered the entire area, this obliquity could have led to the reduction in speed of ice flow in the trough, restricting erosion.

Each glacial stage was complex, with secondary advances and retreats. There were several ice advances that reached the Appalachian Plateau margin during the Wisconsin Stage (Tarr, 1905; Kozlowski, 2014; Karig and Miller, 2013) and one can safely assume that the situation was similar for earlier stages. This line of reasoning leads to the conclusion that there were on the order of a dozen ice advances that reached the Cayuga basin, but only the history of those during the last, Wisconsin Stage, is sufficiently preserved to be described in any detail.

#### LGM to Erie Interstade

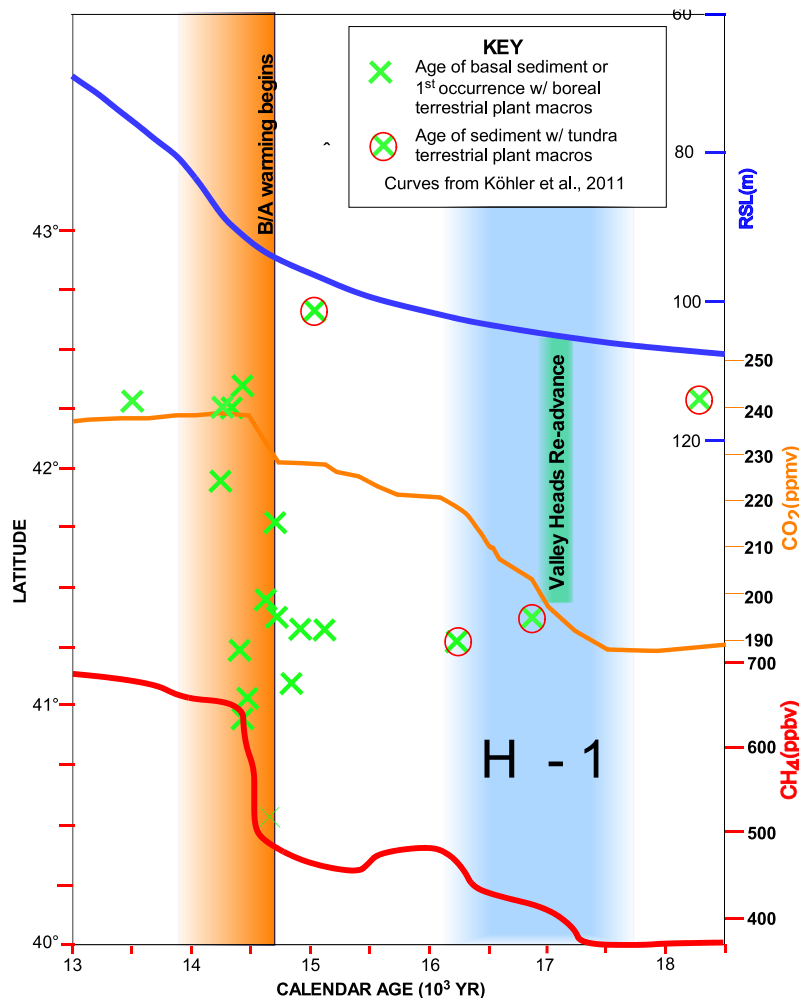
The LGM is dated as approximately 25 ka ago (this and all dates in this paper are in calibrated radiocarbon or calendar years) (e.g. Corbett et al., 2017; Stokes, 2017 and references therein), when the ice margin reached northeastern Pennsylvania and northern New Jersey (Fig 1). The ice thickness in the area of the Cayuga basin at that time has been estimated as about 1.5 km (Peltier, 2004), but with a relief of about 500m between the base of the Cayuga trough and the surrounding uplands, the ice thickness over the trough was probably 2 km or more.

The preserved evidence of the ice movement in the Cayuga basin to and from the LGM terminal moraine is dominantly the Olean Till. Over at least the central and southern sections of the Cayuga basin the Olean till is characterized by a blue-gray silty clay matrix, with a variable clast content. This suggests that the till consists largely of reworked older lacustrine sediment from the trough. Of the valleys of the Cayuga basin this till is best exposed in the Sixmile trough where post-glacial fluvial erosion has incised through the Quaternary section and along the edges of the Cayuga Inlet Valley, between Erie Interstade lacustrine deposits and bedrock. In those areas the clasts in this till have a high percentage of exotic lithologies and are often quite well-rounded. Along the Sixmile trough there are a number of rafts of highly deformed lacustrine silts and clays within the lower part of the till, which supports the interpretation that the till in this region was derived from a proglacial lake that lay in front of the advancing ice. This is consistent with the apparent lack of Olean till beneath Cayuga lake (Mullins et al, 1996) and under the northern section of Cayuga inlet Valley (Tarr, 1904). Decreasing southward glacial erosion led to an increase in Olean till thickness to the south where exposures in the Sixmile trough (Karig, 2015) and seismic profiles in Cayuga Inlet Valley (Figs. 11 and 12 of field trip guide) indicate thicknesses of several tens of meters along the valley axes.

In the uplands of the Appalachian Plateau portion of the Cayuga basin the Olean till is very thin, with only angular clasts of local lithologies. This contrast in clast character led originally to the idea that there were two tills (e.g. MacClintock and Apfel, 1944); Olean with local clasts and Binghamton with exotic clasts, representing advances of different ages, but Moss and Ritter (1962) later showed that the clast difference represented different ice flow trajectories during the same period. The more rounded exotic clasts were derived from clastic deposits moved south along the troughs by older glacial advances and by interglacial fluvial processes.

Except for the Olean till there is very little glacial record of the ice front retreat from the LGM, through the Nissouri Stade, to that of the peak of Erie Interstade, which was at least as far north as the vicinity of Ithaca, but it was apparently slow. If the beginning of the ice front re-advance, which marked the peak of the Erie Interstade occurred about 18,000 years ago (e.g. Dyke, 2004) this withdrawal took about 7000 years. Several lines of evidence indicate that the climate remained very cold during this period.  $^{18}\text{O}$  and dust data from Greenland ice cores (Rasmussen et al, 2014) show a continuous, very slow warming over this interval. Radiocarbon ages from bog and kettle bottom cores in New York have not shown the expected northward decrease, but instead have an almost uniform grouping around 14ka (Fig. 2).

This result was interpreted to reflect permafrost conditions over the newly exposed region (Karig and Peteet, 2015), which kept buried ice masses from melting until after the sharp rise in temperature at 14.7 ka (Rasmussen et al, 2014), when melting of the permafrost and buried ice probably occurred over the entire



area. Although recognized in neighboring regions, permafrost conditions have not yet been recognized in the Cayuga basin, but have been reported from the period following retreat from the LGM in Pennsylvania (Merritts et al., 2014), New Jersey (French, et. al., 2009) and Connecticut (Stone and Ashley, 1992). The only possible example of such conditions reported in the Cayuga basin are the cirque-like “coves” in the headwaters of streams south of the Valley Heads front, which were interpreted as the result of periglacial solifluction by Bloom (2018). It is quite possible that a more serious search would lead to more discoveries of permafrost conditions in the Cayuga basin.

Fig. 2. Plot of basal sediment ages in bogs and kettles and in proglacial lakes in New York as a function of latitude (from Karig and Peteet, 2015). Most sites older than 14.7 ka reflect a tundra environment, whereas all younger sites reflect boreal conditions. There is a slight northward younging of this transition.

The first direct evidence of the ice retreat from the LGM in the Cayuga basin are lakes that were trapped between the retreating ice and local drainage divides. The largest of these was one in the Cayuga Trough, north of the drainage divide between Susquehanna and Ontario watersheds. Lacustrine clays, silts and fine sands are recognized from south of the present drainage divide northward, thickening to more than 100m near Ithaca, where they end against a bedrock sill (Fig. 11 of the field trip guide). Redeposited (slump) units within this sequence contain a tundra floral assemblage that has been dated as 18.4 ka, indicating its Erie Interstade age as well as reflecting a very cold climate at that time. Smaller Erie Interstade lakes existed in the Sixmile-Willseyville trough and in Fall Creek Valley.

This long slow ice front retreat was ended by the readvance to the Valley Heads ice front. (Fig. 1). Based on a beach deposit along the north shore of Lake Erie, which was at such a low elevation as to require drainage down the Mohawk Valley, it has generally been assumed that the ice front at the beginning of the re-advance had retreated into the Ontario basin (e.g. Dreimanis, 1958; Mörner and Dreimanis, 1973; Ridge, 1991, 1997). However, the evidence from the Cayuga basin indicates that the ice front at the peak of the Erie Interstade retreated no further north than the vicinity of Ithaca. None of the Erie lacustrine deposits that occupy the three major tributaries to the south end of Cayuga Lake extends even to that lake (Karig and Ridge; 2015). Moreover, from that area northward, a single Late Wisconsin till represents the period from the Nissouri Stade to the Port Bruce Stade (Muller, 1957; Kozlowski, 2014; Karig, 2015).

### Port Bruce Stade

The Port Bruce Stade is effectively defined in the Cayuga basin by the Valley Heads re-advance, which has generally been described as having resulted in a thick, valley choking deposit of glacial drift or kame moraine (Muller and Cadwell, 1986) in most glacial troughs of central New York. The Valley Heads re-advance in the Cayuga basin clearly does not fit that description. Instead, it is a thin carapace of a till overlain by a kame and kettle unit, both of which overlie older Quaternary deposits, the age and character of which are largely unknown (Fig. 11 of the field trip guide). The Valley Heads front is usually marked by an outwash head rather than by a moraine, although a kame end moraine does occur in the Cayuga Inlet Valley. The predominant components of the Valley Heads system are the outwash plains, which can reach 30 m in thickness, and the valley trains into which the outwash plains trend. These coarse fluvial clastics are dominated by exotic lithologies, especially near the base of those units. To the north of the outwash heads or end moraines are extensive valley floor hummocky terranes, termed kame moraine by Muller and Cadwell, 1986). The character of these in the different troughs of the Cayuga basin varies in details such as drainage direction and clast character, but all appear to be quite thin.

The Valley Heads front in Cayuga Inlet Valley is relatively unusual in being marked by an end moraine instead of an outwash head. Moreover, the hummocky terrane to the north has two easily distinguishable sections, representing two very different environments. Immediately behind the end moraine is a section characterized by extensive, irregular wetlands and intermediary uplands composed of silt and fine sand. This regime drained south as shown by proglacial channels and by a kame terrace along the east side of valley (Fig. 10 of the field trip guide). Coring in one of these wetlands recovered a tundra flora, which is yet to be dated, but indicates a colder and most probably older environment than that of the rest of the hummocky terrane. A working hypothesis is that the wetlands here occupy small proglacial lakes that succeeded supraglacial lakes, the fills of which are the fine-grained uplands, which developed after meltout and topographic inversion. The larger portion of the hummocky terrane in Cayuga Inlet Valley, to the north, slopes and drains north and is occupied by a more classic kame and kettle terrane.

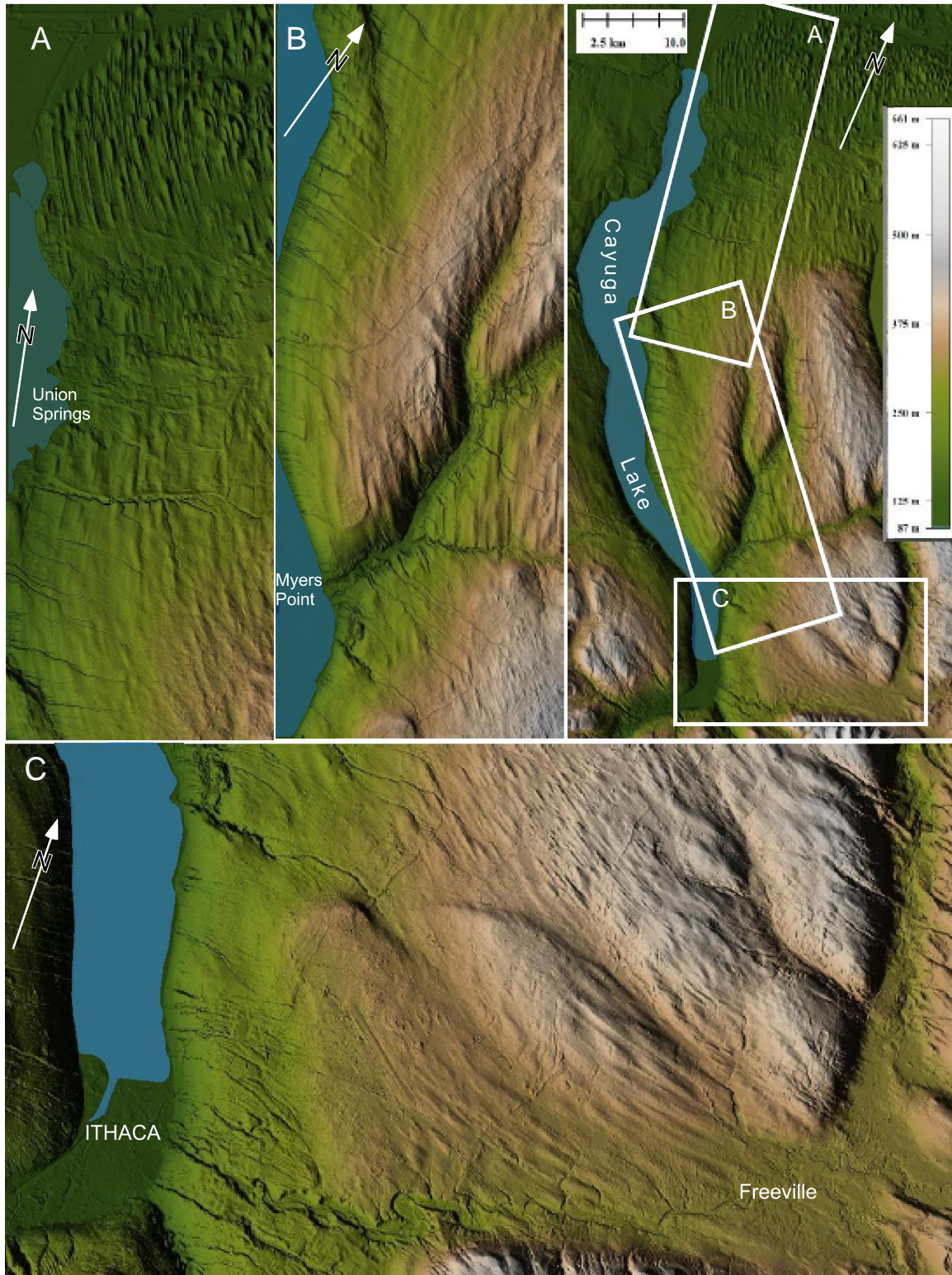


Fig. 3. Lidar hillshade montage from north of Cayuga Lake to the Fall Creek valley, showing the transition from drumlins in the north to MSG's in the south. These lineations are thought to mark the flow directions of ice during the Port Bruce Stade.

The chronology of the Valley Heads readvance is not well constrained and will undoubtedly prove complex because it involves a number of ice front oscillations. In the Cayuga basin and elsewhere in central New York the event began with an “advanced Valley Heads” phase (Muller,1964) during which the ice front advanced several km south of the location of the outwash fronts and moraines that marked a later, more stable Valley Heads front. There are no age constraints for the Valley Heads readvance in the Cayuga basin but extrapolations from western New York (Muller and Calkin,1993) and from the Mohawk Valley (Ridge, 2003) indicate that it peaked about 17ka ago.

The Valley Heads readvance is recorded by a till that lies on the surface in the uplands and in the Sixmile trough and below a kame and kettle unit in the northern section of the Cayuga Inlet valley. Closer to the Valley Heads front there are multiple tills and interbedded glacial deposits reflecting the ice front oscillation. Where this till is exposed it has a silty clay matrix, with very few clasts, and shows almost no internal deformational structure. In the uplands the surface of this till is patterned by drumlins in the north and by megaflutes further south (Fig. 3). These lineations generally parallel the Cayuga trough but swing eastward into the Fall Creek Valley, where the Valley Heads front has a more N-S orientation. These lineations seem to have been initiated during the Valley Heads readvance and show not only the direction of the ice movement but also indicate a high ice velocity during that advance (e.g. Briner, 2007). This suggests that the Valley Heads was basically a large-scale surge rather than representing a period of cooling, for which there is no climatic cooling signal at that time in the Greenland ice cores (Rasmussen et al., 2014).

If the Erie Interstade ice retreat was no further than the south end of Cayuga Lake, the readvance to the Valley Heads position in the Cayuga basin was only 20-30km (Fig. 1), rather than the generally assumed distance of 100 km or more (e.g. Ridge, 1997). However, the ice front oscillations mean that total southward movement of ice to the north of these oscillations was much greater than 20-30 km. The general Valley Heads readvance was followed by a phase of ice stagnation, which is manifested by the kame and kettle terrane in the Willseyville trough, by the proglacial lakes in the Cayuga Inlet Valley and by an area of kame and kettle terrane and eskers at the eastern prolongation of the Fall Creek Valley.

#### Brooktondale Readvance and Northward Subglacial Drainage

This period of general ice stagnation that followed the Valley Heads re-advance was punctuated by very minor re-advances, some marked by push moraines. One of the larger of these re-advances was of at least several km and was marked by a moraine that can be traced semi-continuously from the Sixmile-Willseyville trough into the Cayuga trough (Fig.4). This event has been termed the Brooktondale re-advance (Karig, 2015) and was interpreted to be correlative with the Hatfield event in the Connecticut Valley (Ridge et al, 2012) and the Little Falls advance in the Mohawk Valley (Ridge, 1992), which occurred about 16.3 ka, during the transition from the Port Bruce Stade to the Mackinaw Interstade. This would indicate that the period of general stagnation following the Valley Heads readvance was of the order of 700 years.

The Brooktondale re-advance marks a radical change in mode of deglaciation in the Cayuga basin. During the period between the Valley Heads and Brooktondale re-advances, drainage was southward. Following the Brooktondale re-advance drainage became northward, into the ice front (Karig,2015; Karig and Miller, 2018). Although this surprising and very controversial conclusion was first reached in the Harford-Dryden area (Miller,1993), and later in the Sixmile-Willseyville trough (Karig,2015), it was even more conclusively documented in the Cayuga Inlet Valley.

Evidence of drainage into the ice in the Sixmile trough after the Brooktondale readvance came first from recognition of an ice marginal channel that lies inside and parallel to the Brooktondale moraine but then turns clockwise (NW) and dissects the Brooktondale delta (Fig. 7 of field trip guide). This geometry demands that the channel would have fed surface water into the ice. Subsequently another channel, north of and erosionally truncated by the post-glacial Sixmile Creek was recognized as paralleling the Brooktondale moraine in that area and also feeding water from the upper Sixmile Creek drainage into the ice (Karig, 2015). Finally, a well-defined ice marginal channel along the southwest side of the Sixmile trough can be seen to have broken through the lateral moraine and fed water into and below the ice as a sub-glacial chute (Karig, 2015).

Transport of sediment in the Sixmile trough would have been under the ice and is probably the reason why there are no kames or kettles along this section of Sixmile Valley. It is also possible that erosion along this subglacial stream created the bedrock gorges in sections of the valley where degradation through the underlying till didn't follow the older, interglacial channels.

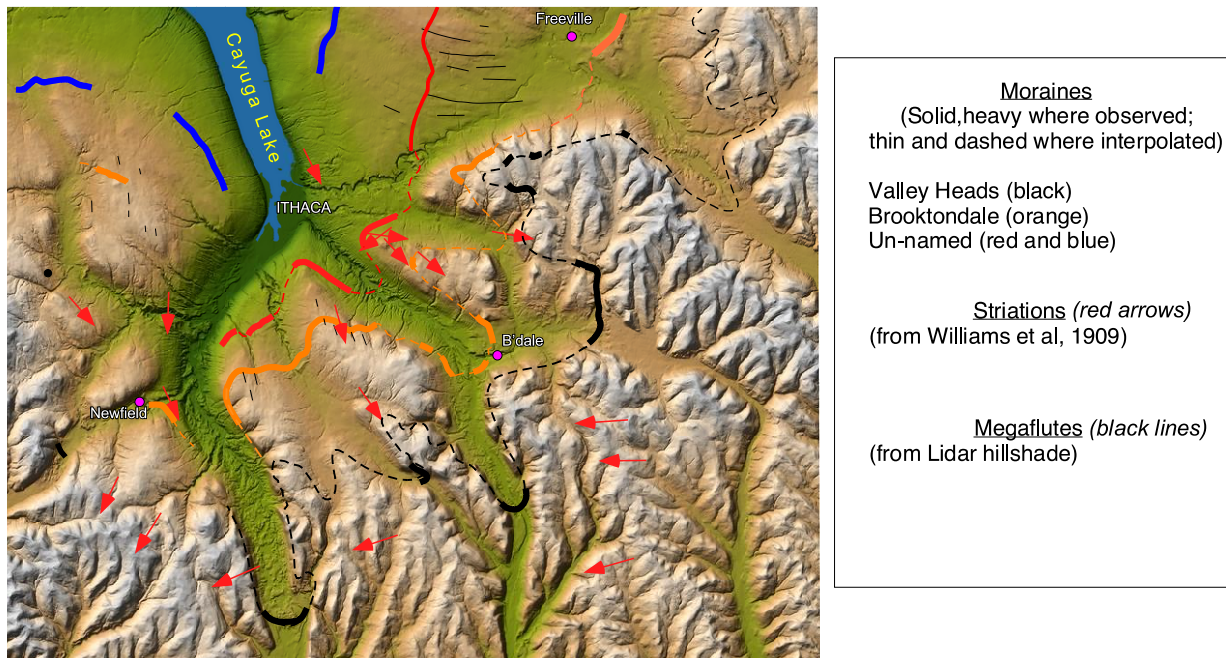


Fig.

4. Moraines around the south end of Cayuga Lake. Striae south of the Valley Heads readvance show that Nissouri ice advanced southwesterly whereas striae and megafaults show that the Valley Heads ice moved generally along the valleys.



Northward subglacial drainage in the Cayuga Inlet Valley during the Mackinaw Interstade is strongly supported by field evidence, but with different characteristics than in the Sixmile trough. The southern section of the valley drained south, but the northern section, which is a more normal kame and kettle terrane, drains north (Fig.11 of field trip guide). This terrane is characterized by scattered ovoid kettles and flat-topped kames consisting of coarse clastics. The kames are largely constructed of cobble-sized clasts with a largely exotic provenance at the south but northward the clasts become finer, to gravel and sand sized and the composition becomes dominated by local lithologies. Because this section of the valley slopes northward, and because the kames reflect a surficial fluvial drainage, it must be concluded that this drainage was into the ice here as well as in the Sixmile trough. The boundary between the two sections in Cayuga Inlet valley seems to be coincident with the extension of the Brooktondale moraine into that valley, which supports the initiation of sub-glacial drainage here, as well as in the Sixmile trough just after the Brooktondale re-advance.

Further support for northward sub-glacial drainage came from recent multichannel seismic reflection profiles at the southern end of Cayuga Lake (Scholz, 2006; Commercial profile released to the first author, 2016) and from re-interpretation of data from water wells in the Ithaca area (Tarr, 1904). Earlier single channel seismic profiles in Cayuga Lake (Mullins et al, 1996) clearly elucidated the shallow sub-bottom Quaternary sediment section beneath the lake but these were much less successful in outlining the deeper section. Where Mullins et al. (1996) interpreted a southward thickening wedge of Valley Heads till at the south end of the lake, the multichannel profiles identify a sub-aqueous fan, sourced from the south (Fig. 5). Because this fan was the earliest post-Valley Heads deposit in the lake, at a time when the ice front was still to the south, this fan must have been a grounding line feature at the contact between the ice and a subglacial lake in the Cayuga trough. Karig and Miller (2018) have correlated this fan with the near-basal thick clastic unit in the deep water wells, described by Tarr (1904) as morainal till, but which does not resemble the kame sediments that are exposed not far to the south. It is most likely that this fan consists of sediment carried down the sub-glacial channel in the Sixmile trough and deposited at the grounding line, where the water velocity dropped after exiting the channel.

The obvious question arises as to where the water that drained into the ice front in the Cayuga trough went. The simplest answer is that it was a form of marginal drainage that penetrated deep

into the ice sheet but exited in the Mohawk Valley (Fig. 6), where the ice front at that time was at a lower elevation than at the entry points (Ridge, 1992). This solution is defended in greater

detail by Karig and Miller (2019, submitted) but it should be noted here that the maximum elevation along the drainage path up the Cayuga trough and eastward along the east branch of the Montezuma channels would have been less than 100m, after removal of post-glacial rebound. When the northward drainage changed from subglacial to proglacial as the ice front retreated, the proglacial lake level couldn't have been any higher than the maximum along the drainage path, which would have precluded the existence of the high-level proglacial lakes Ithaca, Newberry and Hall in the Cayuga trough, as postulated by the Fairchild (1934) model.

## Integration of Local and Regional Observations

Another question is how the ice front advances and retreats, as determined by regional information, fits the deglaciation scenario in the Cayuga basin. The retreat that defines the Mackinaw Interstade is thought to have peaked about 16.0 ka ago (Barnett, 1992; Mickelson and Colgan, 2003) with the ice front in the Ontario basin lowlands (Eyles, et al, 2011; Lewis and Todd, 2019). Such an ice front retreat would have led to drainage of the Cayuga trough through the Mohawk Valley, quite likely through the Syracuse channels, as suggested by Fairchild (1934). This retreat should or could have led to Fairchild's (1934) Cayuga 1, between his falling and rising Vanuxem Waters. The end of northward subglacial drainage would thus have had to end before the peak of the Mackinaw retreat. The elevation of the lake surface in the Cayuga Trough could well have stayed about constant, controlled by the bedrock high near Weedsport, during the Mackinaw Interstade retreat, rising slowly and slightly due to glacial rebound associated with the ice retreat. The northward ice retreat during the Mackinaw Interstade was halted and reversed by an ice re-advance of at least several 10's of km during the Port Huron Stage, which been described as a double advance with ages between 15.25 and 14.6 ka cal (Mickelson and Socha, 2017). The Port Huron re-advance in the

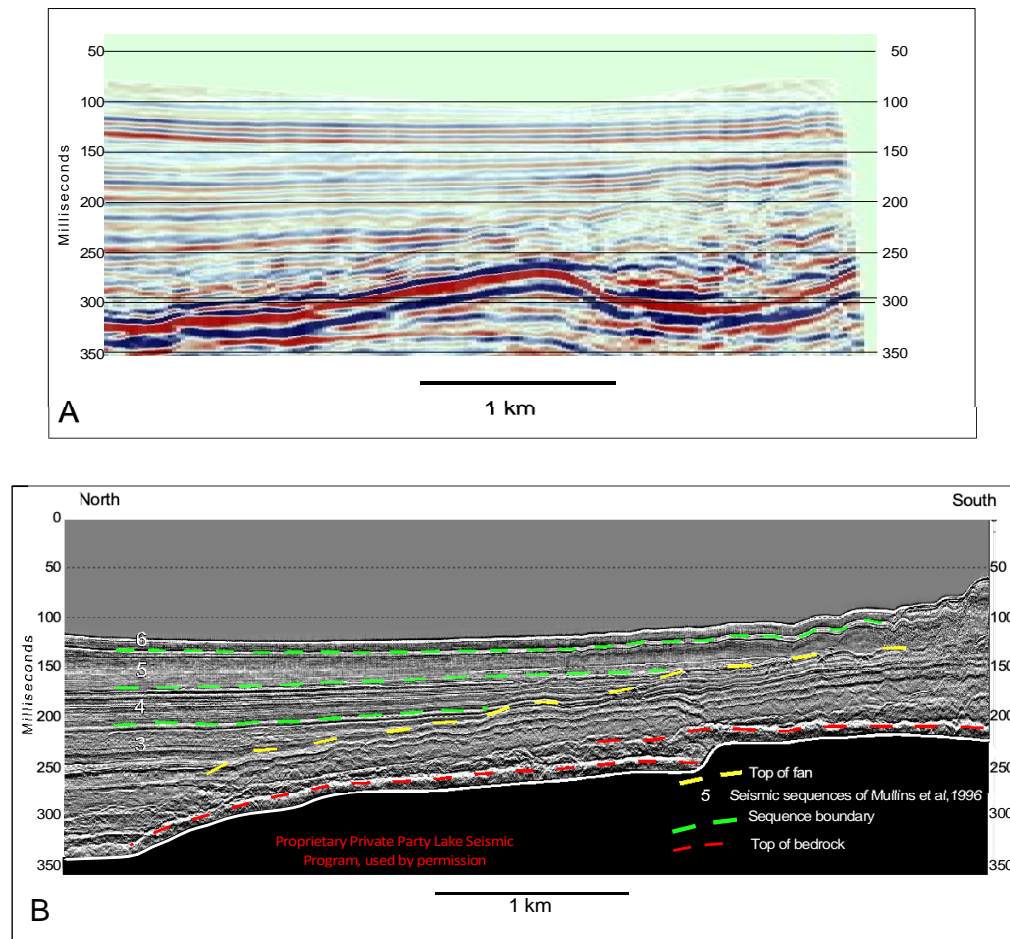


Fig. 5. Multichannel seismic reflection profiles along the axis of Cayuga Lake near its south end, showing a subaqueous fan sourced from the south. Profile A from Scholz (2006) and Profile B from a proprietary source, released to the first author. Seismic sequences from Mullins et al (1996) superimposed on Profile B.

Cayuga trough is suggested to have been back to the Mapleton moraine, just north of Aurora (Kozlowski et al., 2018). This moraine has an age of 15.1 ka, which places it well within the Port Huron age range. The rapid warmup at MWP 1 at 14.7 ka (Rasmussen et al., 2014) followed the advance associated with the Port Huron Stade and led to the Two Creeks Interstade which peaked between 13.8 and 13.5 ka. (Rech et al., 2012 and references cited therein). Proglacial Lake Iroquois formed during this time as ice retreated across the Ontario basin. Recent estimates indicate that Lake Iroquois, as defined by drainage down the Mohawk Valley, existed from 14.5 to 13 ka years ago (Anderson and Lewis, 2012; Lewis and Anderson, in press).

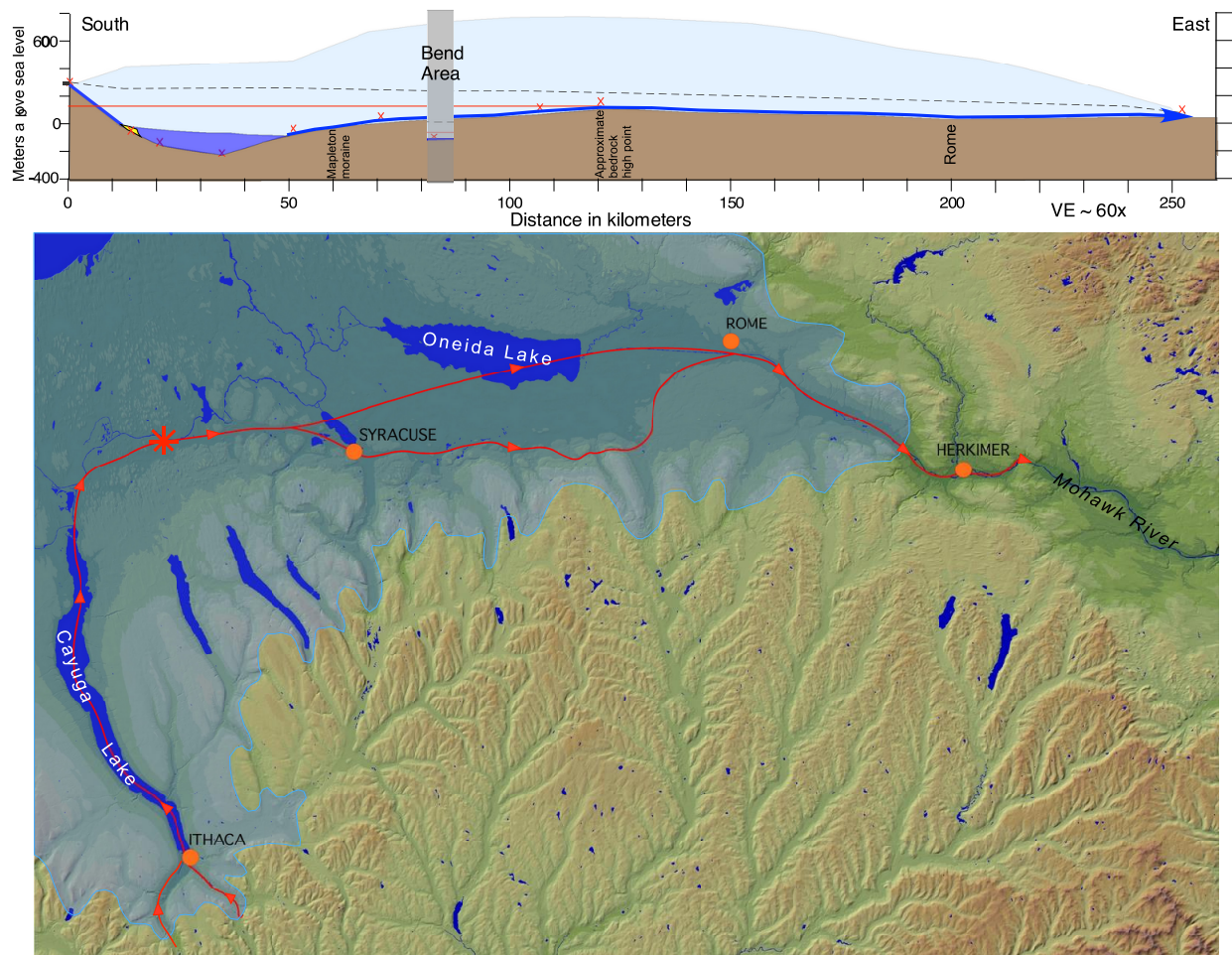


Fig. 6. Possible subglacial drainage paths during the Mackinaw Interstade (from Karig and Miller, submitted) and semi-quantitative profile along that path. Dashed line is the hydraulic surface along that path and red line is the level of proglacial lakes following ice retreat from subglacial lake stage. Drainage through a subglacial Lake Ontario is also possible.

This regional ice front history could well explain a number of features observed in the Cayuga basin. The Port Huron re-advance should have led to the flooding of the Cayuga trough to an elevation around Ithaca of almost 250m. This would explain the coarsening upward, post-till sequence in the lower Sixmile Trough (Karig, 2015) that occurs to about that elevation. In this area are several flat-topped erosional remnants of a sequence that begins with “finely laminated lake clays” (Rich and Filmer (1915) or fine sand (Karig, 2015) that coarsens upward to gravel and cobbles. The surface slopes of most individual erosional remnants of this sequence, as well as its overall slope, are 0.04 to 0.05, much steeper than that of the present Sixmile Creek ( $\pm 0.01$ ). This coarsening upward sequence is most likely the result of an advanced proglacial lake and the steeply sloping surface records a subsequent rapid lake level decrease. Both correlate nicely with a Port Huron readvance into the Cayuga trough followed by a rapid ice front retreat after the 14.7 ka warmup that led to the Two Creeks Interstade and to the formation of Lake Iroquois.

Flooding in the Cayuga trough to an elevation of about 250m correlates fairly well with Fairchild’s (1934) Lake Warren elevation at Ithaca of 242m, although Kozlowski et al. (2014) associate Lake Warren with the Waterloo moraine, which is north of the Mapleton moraine. Nevertheless, a proglacial lake blocked by an ice front along the Mapleton moraine would have had a suitable elevation to account for the lacustrine/deltaic sequence in Sixmile Creek. The deltas in Coy Glen (e.g. von Engeln, 1961), along Taughannock Creek (Kneupfer and Hensler, 2000), and at the mouth of Buttermilk Creek in Inlet Valley (Williams et al., 1909) very likely also formed during and following his period. Deltaic foresets are documented below elevations of about 240m, but sand and gravel deposits occur to elevations of at least 310m. These higher occurrences, which could well represent inwash and supraglacial fans, need further study.

The assumption of an approximate age of 15 ka for the peak of the Port Huron readvance in the Cayuga trough and the establishment of the Lake Iroquois water level at 14.5 ka leads to a rapid fall in lake level from that of Lake Warren to that of Lake Iroquois, which extended down the Cayuga trough almost to Ithaca where its surface elevation is now about 100m (extrapolated from Pair and Rodrigues, 1993). Such a rapid fall in lake level would explain the steeply sloping surface of the lacustrine/deltaic sequence in the Sixmile Valley and would have caused a large-scale drop in the local erosional base level, which should have been recorded in the deglaciation history. This record may be the coarse clastic unit that overlies the lacustrine section in the Cayuga Inlet Valley (Tarr, 1904; Lawson, 1977), which was associated by Tarr (1904) and Mullins et al., (1996) with some period of base level lowering. Tarr (1904) describes this unit as having a large number of logs and small mollusks and interpreted it as a stream or beach deposit. His well sections also show that the base of the unit varies in elevation among the wells by up to 25m. A similar variation in basal elevation of that contact was noted in recent boreholes just west of the junction of Sixmile valley with Cayuga Inlet Valley (Karig, 2015). Such a variable contact geometry suggests stream channel incision, resulting in an erosional disconformity between the coarse clastic unit and the underlying lacustrine sequence.

This coarse clastic unit was correlated by Mullins et al. (1996) with their seismic sequence 5, which would be a finer grained offshore facies, lying conformably on seismic sequence 4. Mullins et al. (1996) interpreted

seismic sequence 5 as a “response to a drop in lake level” resulting from drainage reversal when the ice front retreated to the north end of Cayuga Valley, opening lake outlets to the north. They inferred that this drop in lake level was associated with the Syracuse channels (e.g. Hand, 1978), although these channels were probably used during several periods (Sissons, 1960).

The question is whether this coarse clastic unit was deposited during the base level drop between the Port Huron re-advance and the establishment of Lake Iroquois or following the base level drop when the Lake Iroquois surface fell during the shift in outlet from the Mohawk Valley to glacial Lake Vermont (e.g. Pair and Rodrigues, 1993; Donnelly et al., 2004; Rayburn et al., 2005). The Port Huron/Iroquois drop was of the order of 250m and should certainly have resulted in enhanced sediment transport. On the other hand, the post Lake Iroquois drop of more than 100m (e.g. Anderson and Lewis, 2012) did not extend to the Cayuga trough because of sills along the Seneca River, which isolated that trough from the Ontario basin. Clearly identified sills at Jack’s Reef and Howland Island had elevations prior to canal engineering 5 to 6m higher than at present (William Kappel, USGS, Ithaca, NY, 2018, pers. comm.) and were less than 10m lower than the Lake Iroquois strand line elevation in that area (Bird and Kozlowski, 2014). Possible additional upstream sills would further reduce this difference, but, in any case, the base level drop in the Cayuga Trough following the outlet shift in Lake Iroquois was minor and would favor the association of the coarse clastics to the drop prior to the establishment of Lake Iroquois.

Differential isostatic uplift of the northern end of the Cayuga trough led to progressive southward transgression of the Cayuga Lake shoreline and to deposition of paludal and lacustrine organic silt and clay, which Mullins et al. (1996) correlated with their seismic sequence 6. Decreasing isostatic tilting and continuing sedimentation into Cayuga Lake from the south has caused southerly migration of the south shore to cease and even to reverse. This period, representing modern Cayuga Lake, spans most or all of the Holocene (e.g. Mullins, 1998).

A serious question remains concerning the chronology of the post Valley Heads deglaciation in the Cayuga basin. The demise of Lake Iroquois, the last of the proglacial lakes in the Cayuga trough, is dated at about 13 ka (Lewis and Anderson, in press). Mullins et al. (1996) concluded from radiocarbon ages of bulk samples of organic sediments at the south ends of several Finger Lakes, which were assumed to postdate the proglacial lakes, that the end of those lakes occurred at or before 15.6 ka. This is a great discrepancy with the 13 ka date of Lewis and Anderson (in press). Evidence detailed by Karig and Miller (submitted) demonstrates that bulk sample ages obtained by Mullins (1998) are about 2000 years older than wood ages from almost exactly the same location and the same depths. As has been clearly reported in the literature (e.g. Peteet et al., 2013, and references therein), radiocarbon ages from bulk sediment samples, as well as from aquatic plant samples are too old, often much too old. There is a desperate need for well-chosen and carefully dated material from all units within the Cayuga basin.

## Conclusions

There are as yet no conclusions concerning the deglaciation of the Cayuga basin. The iconoclastic views presented above must be tested, not only in this basin but in other Finger Lakes basins of central New York. We would point out that recent studies in the Cayuga basin, using techniques not employed during the former studies and recognizing the behavior of modern ice sheets, resulted in no end of surprises-and that is continuing. We predict that studies similar to ours will produce equally surprising results in the other basins.

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## Trip A1 b

### FIELD GUIDE AND ROAD LOG

The objectives of this field trip are to visit some of the critical sites that led to the conclusion that there was northward subglacial drainage in the Cayuga basin during the Mackinaw Interstade as well as to show some sites that have not been on previous field trips. The trip officially begins at the Judd Falls (East Hill) shopping center parking lot in Ithaca.



Fig. 1. Field Trip Route with Stops

The route to East Hill Plaza finishes along the Cayuga Trough, which follows a pre-glacial river valley that was oriented close to an ice flow line from the Laurentide ice sheet center. This trough was excavated by numerous ice advances—at least 4—but undoubtedly many more over the past 2 my. The Illinoian advance(s) seem(s) to have caused major glacial erosion in the trough, whereas the Wisconsin stage glaciation probably caused very little. Instead, it mostly cleaned out older Quaternary trough fill and deposited clay-rich till to the south.

Miles from last point	Cumulative mileage	Route description
0.00	0.00	Board bus at SW corner of the Judd Falls shopping center
1.34	1.34	Turn left through gate to Ithaca water supply dam (needs to be unlocked; with permission only)
0.26	1.60	STOP 1. 60' Dam, post glacial gorge, Interglacial gorge; Inner glacial trough

From the Judd Falls starting point we will go SE on Slaterville Rd (Rte 79) to the gate to the City reservoir and (with permission) go down the reservoir road to the 60' dam

**(STOP 1).** The dam was constructed in a post-glacial gorge of Sixmile Creek. The very narrow width at base of the gorge supports its creation during a single erosional cycle, but the present rate of erosion in the gorge wouldn't be sufficient for that creation. There must have been a period of much higher flow earlier, but how and why? I'm hoping for some ideas from the group, but I have an iconoclastic one.

The reservoir is in a very wide section of the valley, part of the large, probably Sangamon interglacial gorge, called the 600' gorge (Fig. 2). Its location at the dam site is just beyond the "rock island" that forms the south abutment to the dam. This interglacial gorge has been re-excavated downstream by the post-glacial Sixmile Creek except opposite the 30' dam (in another post-glacial gorge). Even further downstream another gorge (the interstadial 200' gorge) has been incised into the base of the 600' gorge and Van Natta's dam was built in a site where another post-glacial gorge formed outside this 200' gorge. The 600' gorge can be followed upstream in the subsurface using well and seismic data at least as far as Brooktondale. The entire gorge has a gradient much lower than the present stream gradient (Fig. 3).

A few feet above the 60' dam is a flattish bedrock surface. This is the base of the inner glacial trough, which was probably eroded by an Illinoian ice advance or advances. This bedrock surface has a U-shaped cross-section, the steep upper edge of which will be seen at stop 2 (Fig. 4). The gradient of this glacial trough is very similar to that of the interglacial gorge. This trough is filled by late Wisconsin till, and very locally by mid-Wisconsin deposits.

Miles from last point	Cumulative mileage	Route description
0.26	1.86	Return to St. Hwy 79, lock gate and turn right.
0.55	2.41	Turn right onto Burns Rd
0.91	3.32	STOP 2. East Hill Rec Way. Park along right side of road. Walk about 1/4 mile to RR fill over a trib to Sixmile Creek. Lip of inner glacial trough, Mid Wisconsin sediments.

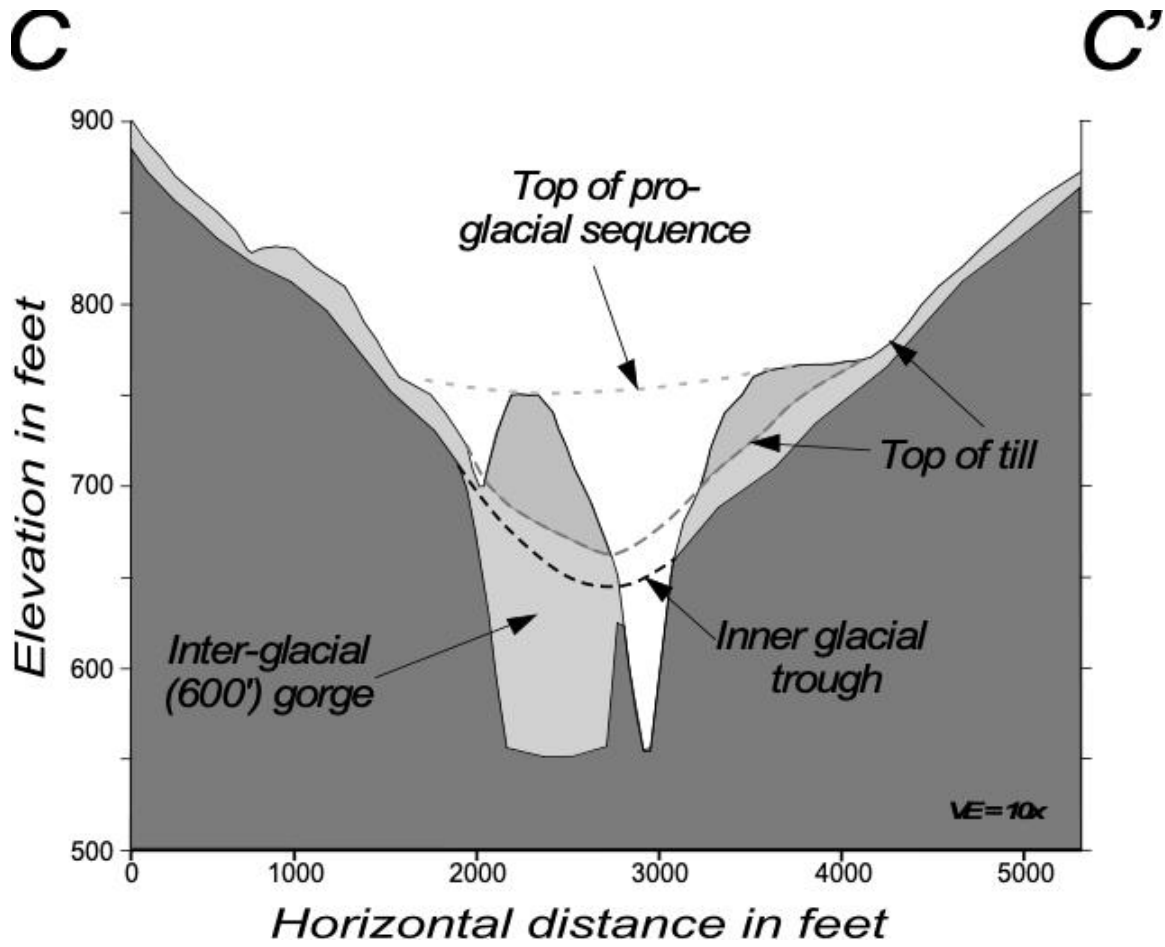


Fig. 2. Geologic section at 30' dam, but similar to that at 60' dam

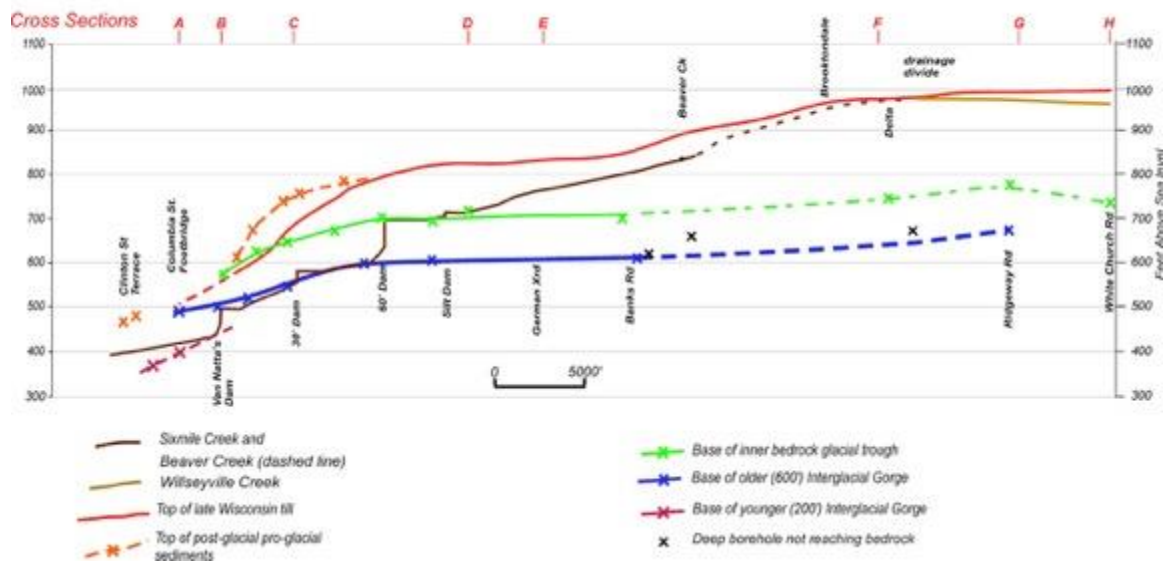


Fig. 3. Longitudinal section along the Sixmile-Willseyville Trough

Go back out the access road to Rte 76 (Slaterville Rd), turn right and and turn right again onto Burns Rd. Drive up the hill a parking spot along the right side of the road (**STOP 3**). An old RR grade, which is now the South Hill Recreation Way, meets Burns Rd at this point. Disembark and walk several hundred yards down the Rec Way to the large fill across a tributary to Sixmile Creek. Here we are on the bedrock lip marking the boundary between the inner and outer glacial troughs. The inner glacial trough is covered with mid-Wisconsin sediments just downstream of the gully crossing. Only a thin till covers a gently sloping bedrock above the lip.

Miles from last point	Cumulative mileage	Route description
0.21	3.53	Continue on Burns Rd to Coddington Rd and turn left
1.12	4.65	<b>Stop 3</b> (brief). View of Outer glacial trough and nature of Sixmile trough

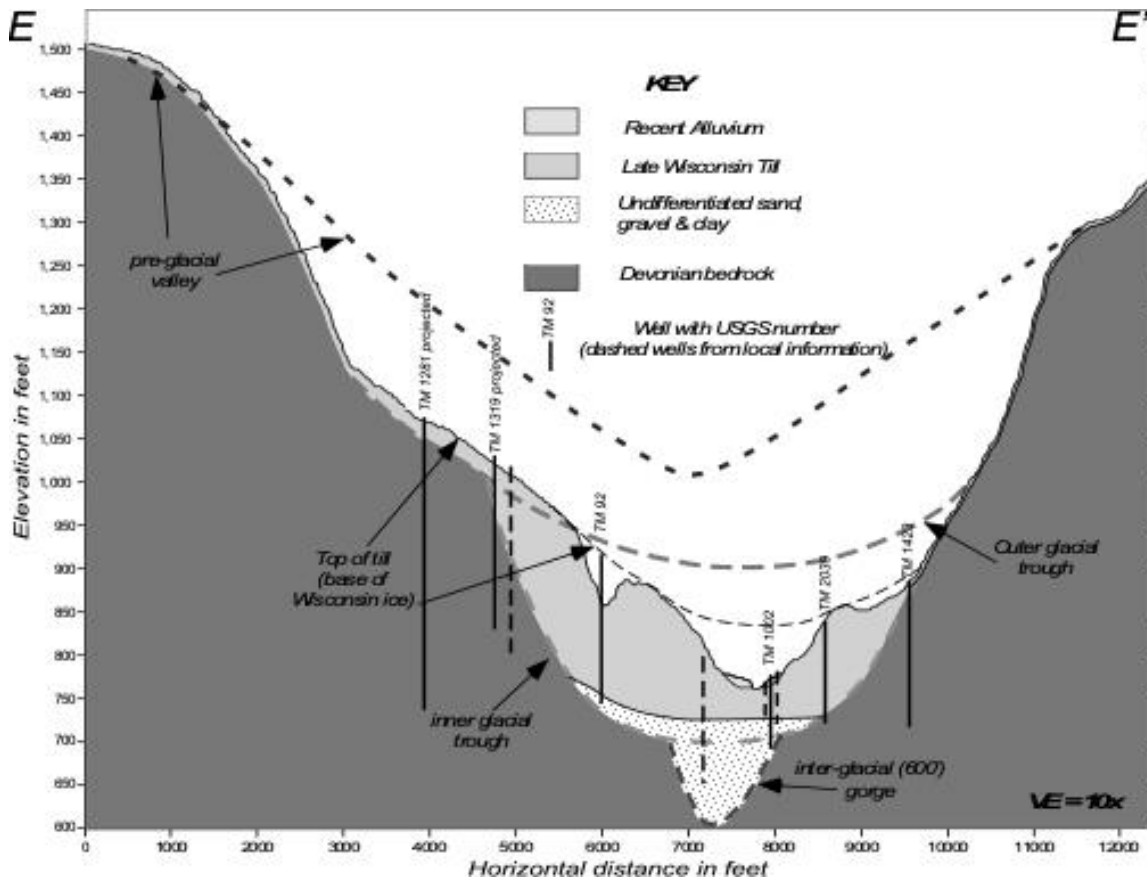


Fig. 4. Geologic Section across the Sixmile Trough at German Crossroad



Return to the vehicles and continue up Burns Rd and turn left (southeast) along Coddington Rd to point where there are open fields on both right and left and before reaching the large farmhouse on left. **STOP 3.**

Here we can look up upper Sixmile Valley to the left. Upper Sixmile is a subsidiary glacial valley that “hangs” above the main Sixmile-Willseyville trough, which lies straight ahead and curves to the right (south). We are parked on the outer glacial trough (Fig. 4) and the smooth concave upward shape can clearly be seen. Bedrock is basically parallel to the surface with a thin cover of Late Wisconsin till. There are no kettles or kames along the Sixmile trough, in sharp contrast to what we will see along the Willseyville trough. Above the steep upper slope of the outer glacial trough the topography is much flatter and more subdued and has been interpreted as pre-glacial with only very mild modification by glacial erosion even though late Wisconsin ice was quite thick even there. Several reasons for this lack of erosion can be suggested, including a thinner ice cover, slower ice movement and cold-based ice.

Miles from last point	Cumulative mileage	Route description
1.49	6.14	Continue on Coddington Rd and turn left on Middaugh Rd
0.27	6.41	Continue straight onto (dirt) Beaver Brook Rd. No sign here
0.56	6.97	Continue on Beaver Brook Rd and stop in front of Gravel pit office ( <b>Stop 4</b> ) Discussion of Brooktondale delta

Continue east on Coddington Road to Middaugh Rd and turn left (north). Go down Middaugh to where it turns 90° left-and go straight. This is Beaver Creek Road, although there is no sign. Continue down Beaver Creek Rd, across Beaver Creek and up to the dirt road junction in front of the University Sand and Gravel Co office (a trailer). **STOP 4.** In front of us is the Brooktondale delta, where foreset beds could formerly be seen on the west-facing quarry headwall (Fig. 5).



*Fig. 5. Foresets in the Brooktondale Delta*

Before gravel extraction removed most of this delta it had a surface elevation ranging from about 1020' at its eastern head to about 1010' at its outer, western margin. The delta was interpreted by Tarr and von Engeln to have formed in an early proglacial Lake Brookton and continued to develop into the larger Lake Ithaca, with an outlet through the Willseyville channel at 980'. This interpretation cannot be correct because one or more tills occur within the deltaic sequence (Fig. 6) and the delta is overlain by yet another till, which marks a post Valley Heads re-advance. The delta fed sediment into an ephemeral lake that formed at the junction of the two arms of the glacier, which still occupied the Sixmile trough. This re-advance is marked by a very well-preserved moraine, which I've named the Brooktondale re-advance, the moraine for which can be easily traced into Cayuga Inlet Valley (Fig. 4 of preceding article).

Miles from last point	Cumulative mileage	Route description
0.38	7.35	Drive east from pit office on Valley Rd to Brooktondale Rd and turn right
0.43	7.78	Drive east on Brooktondale Rd and turn right onto White Church Rd.
0.27	8.05	Drive south and west along White Church Rd to Bald Hill Rd and turn left
0.22	8.27	Drive along Bald Hill Rd to <b>STOP 5</b> . We will discuss the ice margin channel here and then walk to the Brooktondale moraine and look at the head of the channel that led into the ice front at that time



*Fig. 6. Till within foresets of the Brooktondale delta*

Follow the directions above to the first hard left turn along Bald Hill Rd This is where a large and long known “ice margin” channel swings around the nose of Bald Hill. It isn’t truly an ice margin channel because the outer side is a till moraine, which appears to mark a segment of the Brooktondale readvance moraine. The channel here is a linear pond because the downstream end is blocked by an alluvial fan that emanates from a small drainage, but the channel continues southward and can be followed into the kame and kettle terrane south of the delta. We’ll walk a short distance south along this moraine, crossing the present outlet to the pond where bedrock is often exposed. We’ll stop where we can overlook the head of the enigmatic channels that start “inside” the moraine and swing almost 180° clockwise and cut through the delta. Gravel removal has destroyed the evidence of some of this path but aerial photographs taken before gravel mining began clearly show that the channel crosses the delta (Fig. 7)

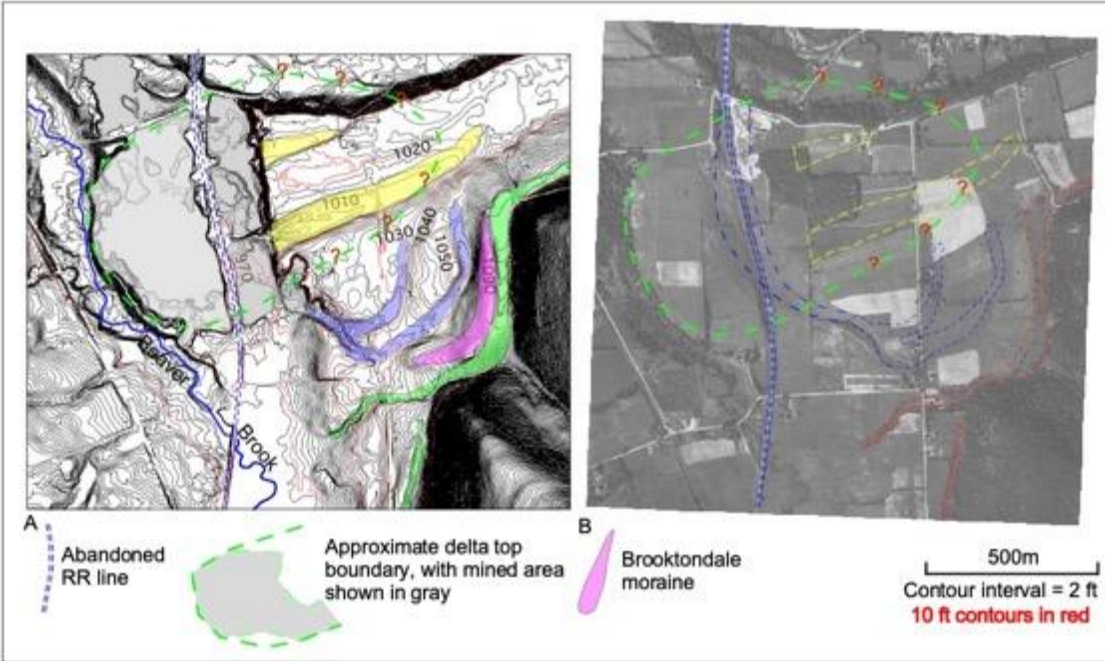


Fig. 7. A. Lidar 2' contour topographic map of the area around the Brooktondale delta. The Lidar topography shows an ice margin channel (red) that debouches into the kettle kame terrane, two fluvial channels (yellow) that fed the delta and the enigmatic channel pair (blue) that begins on the till slope and swings clockwise more than 90° as it approaches the excavated area of the delta. B. 1936 aerial photograph, taken immediately after the railroad line was abandoned and before gravel mining, showing that the enigmatic channel continued across the delta and into the ice front. This channel is more clearly defined on a stereographic pair of photographs but can be observed by the cut along the railroad line as it crosses the southwestern side of the channel.

Miles from last point	Cumulative mileage	Route description
0.22	8.49	Return down Bald Hill Rd to White Church Rd and turn left
1.78	10.27	Drive west along White Church Rd and turn right onto Belle School Rd..
0.26	10.53	Drive north on Belle School Rd to <b>STOP 6</b> (brief). Discuss the 980' Lake Ithaca spillway and the Willseyville channel.

Go back to White Church Rd. and turn left (south), noticing the irregular surface of the trough. This reflects the many kettles and kames along this section of the trough. The road is built on a degraded kame terrace. Turn right (west) on Belle School Rd and briefly **STOP 6** at the bottom, where the old RR line crosses. We are in the Willseyville channel, an outlet from the lake into which the delta was built. Tarr and von Engel identified it as the outflow to a proglacial Lake Ithaca at 980'. However, the 980' elevation is that of a recent alluvial fan that enters the trough from the west here and also created the present drainage divide. A series of hand driven cores along the channel showed that its high point is well to the south and at an elevation of about 965' or less. The typical aspect of the channel cannot be seen from roads crossing the valley because all these were built on alluvial fans-for obvious reasons. Access to the channel is very difficult except where sections of the RR line have been cleared as trails (e.g. Fig. 8). The channel was more likely the result of one or more glacial lake outburst floods (GLOFs) from Lake Brookton.

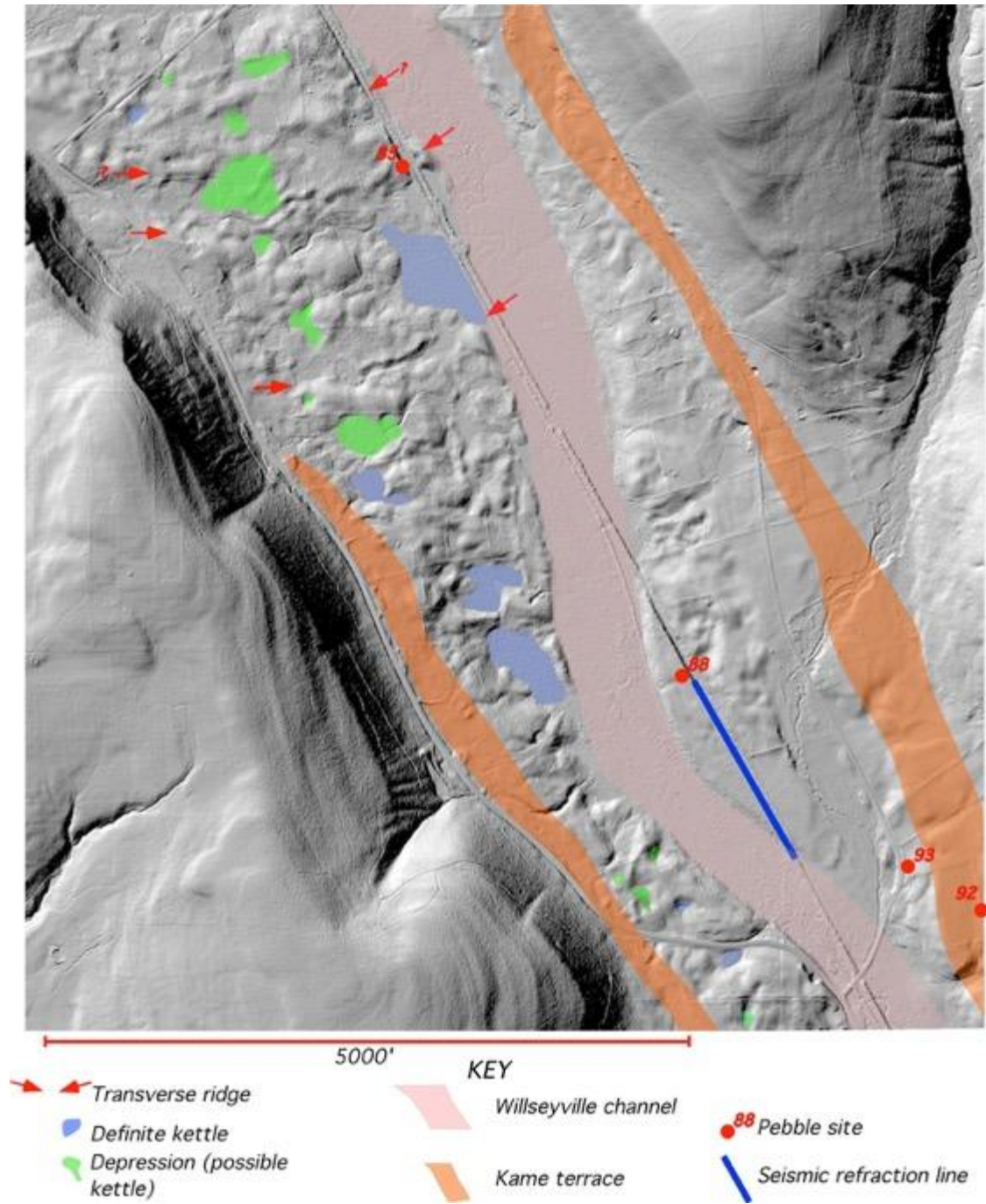


Fig. 8. Willseyville channel and kettle kame terrane

Miles from last point	Cumulative mileage	Route description
0.60	11.13	Continue north on Belle School Rd to Coddington Rd and turn left
0.39	11.52	Drive south along Coddington Rd to <b>STOP 7</b> for a brief look at truncated spurs that mark the original drainage divide of this through valley

Continue along Belle School Rd to Coddington Rd and turn left (south). **Stop 7** is just north of Ridgeway Rd. This section of the Willseyville Trough is flanked by two very well-developed truncated spurs, which mark the pre-glacial drainage divide. Repeated ice flow over the drainage divide cleaved the ends of ridges forming the divide and eroded it from an elevation about 1600' to about 700', which is the bedrock elevation established by a seismic refraction line along the railway line in the center of the valley (Fig. 8). This one of the best developed "through valleys" in the region.

Miles from last point	Cumulative mileage	Route description
2.44	13.96	Continue south along Coddington Rd to the junction with White Church Rd and continue on Coddington Rd
0.82	14.78	Continue south along Coddington Rd to <b>STOP 8</b> , the entrance to the Sultana gravel pit. Distances within the pit complex are not calculated. Here we will look into the pit to see it's internal framework. We'll then walk across the outwash plain and look into the Willseyville channel

Two large kettles just past the junction of Coddington and White Church roads are located just behind (north) of the Valley Heads head of outwash. No end moraine is seen here but one may be buried in the thick outwash to the south. Continue on Coddington Rd past the intersection with White Church Rd to the entrance to the Sultana gravel pit. Note the remarkable flatness of the outwash plain. Enter - with permission.

**STOP 8.** The gravel pit exposes about 80' of outwash (sand to cobble size) and also a till, which is seen on the north face of the quarry (Fig. 9). This till represents an ice front oscillation before its longer pause at the head of outwash location. The Willseyville channel here is near the east side of the valley floor and is deeply incised into the outwash. Incision decreases southward until the channel merges with the outwash valley train.



*Fig. 9. North wall of the Sultana Gravel Pit showing till within outwash*

<b>Miles from last point</b>	<b>Cumulative mileage</b>	<b>Route description</b>
1.08	15.86	Continue south along Coddington Rd to junction with Willseyville Rd and turn right.
0.31	16.17	Continue the short distance to St. Hwy 96 and turn right
6.57	22.74	Drive north along Hwy 96 to Bald Hill Rd in the Village of Danby
0.50	23.24	Go southwest on Bald Hill Rd to Jennings Pond (Buttermilk State Park). We'll have lunch there. Also rest rooms.

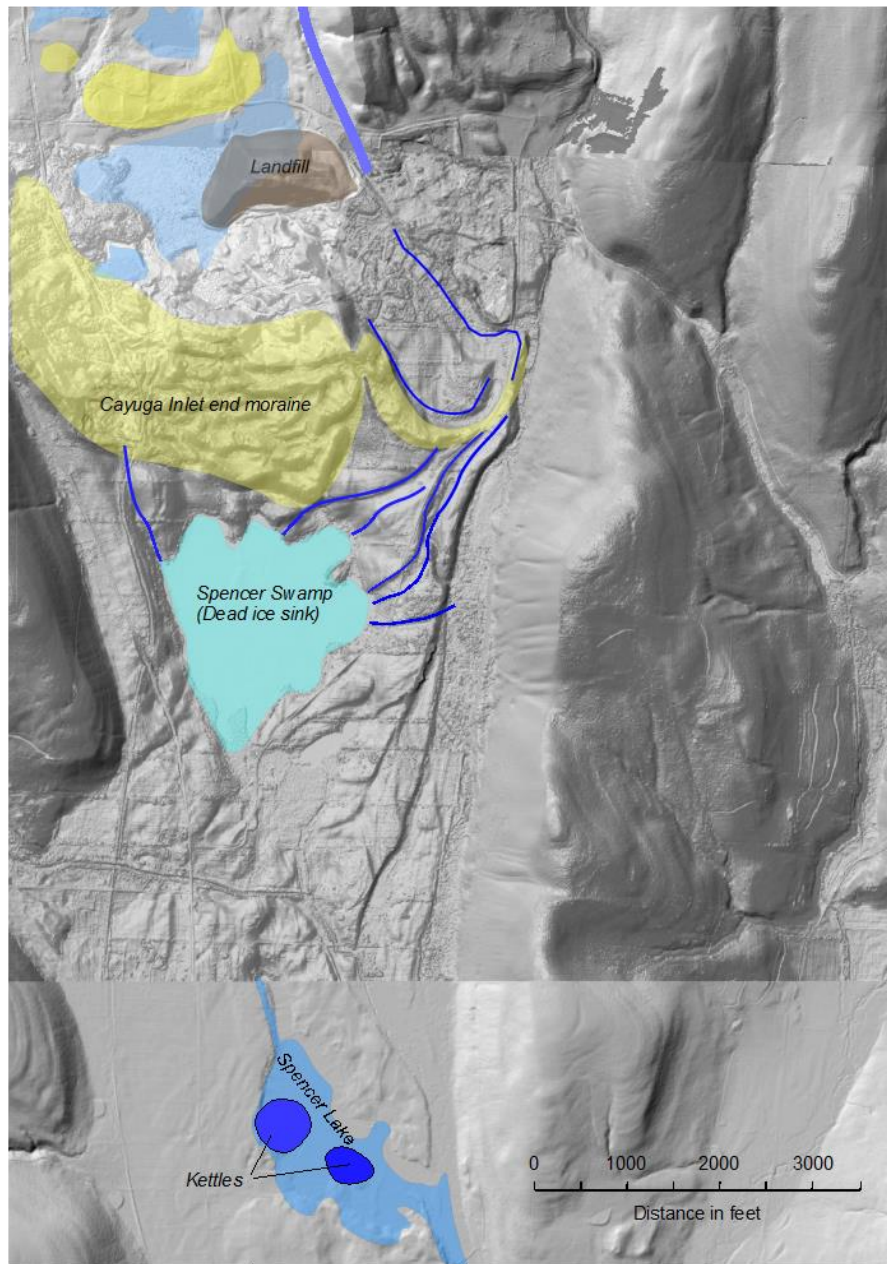
Continue south on Coddington Rd. This section can be termed a valley train-an extension of outwash. Go to the T junction with Willseyville Rd and turn right (north). At the junction with 96B bear right (north). Follow 96B north into Danby and turn left on Bald Hill Rd, and left again into Jennings Pond S.P. We will have lunch there (also toilet facilities).

After lunch we will return to Danby (96B), turn right (south) and go to Michigan Hollow Rd. (next road) and follow it south, down Michigan Hollow to Hillview Rd, where we enter the Cayuga Trough, one of the largest and the lowest of the Finger Lakes glacial Troughs. Michigan Hollow was a glacial overflow route but also contained a short-lived pro-glacial lake.

Miles from last point	Cumulative mileage	Route description
0.50	23.74	Go back on Bald Hill Rd to Danby (Rte 96) and turn right
0.21	23.95	Drive south on Rte 96 to Michigan Hollow Rd and turn right.
5.10	29.05	Follow Michigan Hollow Rd (mostly dirt) to Hillview Rd and turn right
0.68	29.73	Go west on Hillview Rd to the 90° turn to the north (right) <b>STOP 10</b> . Here we'll discuss the local wetlands and nature of the end moraine

**STOP 10.** A short detour to the right on Hillview road will show us a very-well preserved kame terrace that is shown with Lidar topography to slope southward and documents glacial outflow in that direction, at least initially (Fig. 10). The topography in this area is grossly flat with a very large percentage of depressions, largely water filled. This southern section of the Cayuga Inlet Valley differs from the more northerly kame and kettle terrane in having these larger and irregular shaped wetlands as well as having uplands that consist mostly of clay and silt rather than cobbles. Coring in the wetland just to our south recovered a tundra flora dominated by *Dryas integrifolia*, very different from the boreal flora in kettles to the north. We don't yet have reliable ages on the *Dryas* leaves but it appears that the wetlands represent small proglacial lakes that succeeded supraglacial lakes that left the silt/clay deposits after meltout and topographic inversion. At least one recessional moraine crosses this area, just north of our stop, and there may be more further north.





*Fig. 10 Lidar hillshade of the Valley Heads area*

9

Driving back south on Michigan Hollow Rd we cross a number of glacial outflow channels that empty into Spencer Swamp, a nearly valley-wide depression, termed by Jay Fleischer a dead-ice sink (Fig. 10). This represents a large tract of ice that stagnated when the active ice front jumped north to the location of the end moraine Coring in the Spencer Swamp recovered a section of tan marl beneath peat, with a basal  $^{14}\text{C}$  age of 12.35ka, which was initially surprisingly young. It is now realized that almost all bog bottom ages in central New York are about this old and (I think) represent a melt out following the marked warmup associated with MWP-1.

**Stop 11** at the southern edge of Spencer Swamp. Here we will discuss the Advanced Valley Heads phase, which in Inlet Valley extended at least to Spencer Lake, a dammed group of at least 2 kettles. The Valley heads re-advance in general correlates in time with Heinrich Event H-1 and may represent a “purge” in a binge-purge sequence thought by some to be responsible for H events.

In the distance, north of Spencer Swamp, is the main end moraine of the Valley Heads re-advance. The outwash plain is not as smooth as that in the Willseyville Trough, with a number of low hills. These are kames from the Advanced Valley Heads phase.

Miles from last point	Cumulative mileage	Route description
0.68	30.41	Go back (east) on Hillview Rd to Michigan Hollow Rd and turn right
2.09	32.50	Follow Michigan Hollow Rd to Rtes 34/ 96. Few pauses along way to point out things
8.70	41.20	Follow Rtes 34/96 north to Shelter Valley Rd and turn left. Few things pointed out on the way.
0.87	42.07	Go to end of Shelter Valley Rd and turn left on South Rd. Go to end and park. With permission we'll walk several hundred yards to a huge exposure of Erie lacustrine sediments ,which overlie till over bedrock (a nice waterfall) <b>STOP 11</b>

Continue on Michigan Hollow Rd to Hwy 34/96 and turn north. The road passes the end moraine (ridge behind the trees) through an outwash channel (sort of a kame terrace) and skirts a section of Inlet Valley full of kettles and kames. Several kettles are seen in the vicinity of the Lindsay-Parsons Preserve of the Finger lakes Land Trust, but there are many more off the road.

Somewhat past the wide spot in the road called West Danby the road crosses Inlet Creek several times. Along the creek here a terrace has developed which increases in width downstream (northward). By the time the road reaches Shelter Valley Rd, where we turn left, this terrace occupies nearly the entire valley floor. I speculate that this terrace started to develop when the local erosional base level fell, which would have occurred when there was a significant drop in the level of proglacial lakes in the Cayuga trough. The largest such drop, in my scheme of things, would have been from that of Lake Warren to that of Lake Iroquois (>800'). The earlier association of this drop with the drainage of Lake Iroquois cannot be valid because Cayuga Lake formed at this time behind several sills, which resulted in a base level drop of 30' or less.

The base level drop caused not only stream degradation but construction of a delta/flood plain assemblage at the south end of proto Cayuga Lake manifested in the seismic data as seismic sequences 5 and 6 of Mullins et al (1996) and in Cayuga Inlet Valley as the organic silt and clay and underlying gravel in wells.

**Stop 12.** Park at the end of Shelter Valley Rd and walk several 100's of ft to the base of the falls at the bedrock edge of the glacial trough. Bedrock is covered by a thin till most probable of Nissouri (Late Wisconsin max) age. This till lies below a very thick lacustrine section of an Erie Interstade pro-glacial lake that had not been recognized as such until my fieldwork.

The lacustrine sediments here are strongly deformed, especially in the lower part of the section because of slumping down the steep Erie proglacial lake slope (effectively the bedrock trough flank). Higher in the section thin slump units are interbedded with thinly, and well bedded strata. Although pro-glacial lake sediments are notoriously free of plant material, the thin slump units have plant macro "fossils", which denote an herbaceous tundra environment. We are having problems with dating these plants, but one *Dryas integrifolia* sample gave a <sup>14</sup>C age of 15.2 ka, documenting the Erie Interstade age of the proglacial lake. This lacustrine section is overlain by a thin Valley Heads till, which is covered by kame and kettle deposits.

These lacustrine clays and fine sands are observed in many places below the terrace gravels in the valley floor and in a number of large exposures at the edge of the valley. They were also penetrated in water wells and are shown on the seismic section run along Shelter valley Rd (Figs. 11 and 12). This seismic section shows that there is a thick till and probably even older lacustrine strata beneath that till. The subsurface data now available in Cayuga Inlet Valley shows that the Valley Heads deposits are only very small fraction of the total Quaternary section in the valley (Fig. 11). These data also show that there is a bedrock sill just south of Ithaca which separates very different Quaternary stratigraphic sections. To the south there is a thick pre-Valley Heads section, whereas to the north the entire Quaternary section is post Valley Heads.

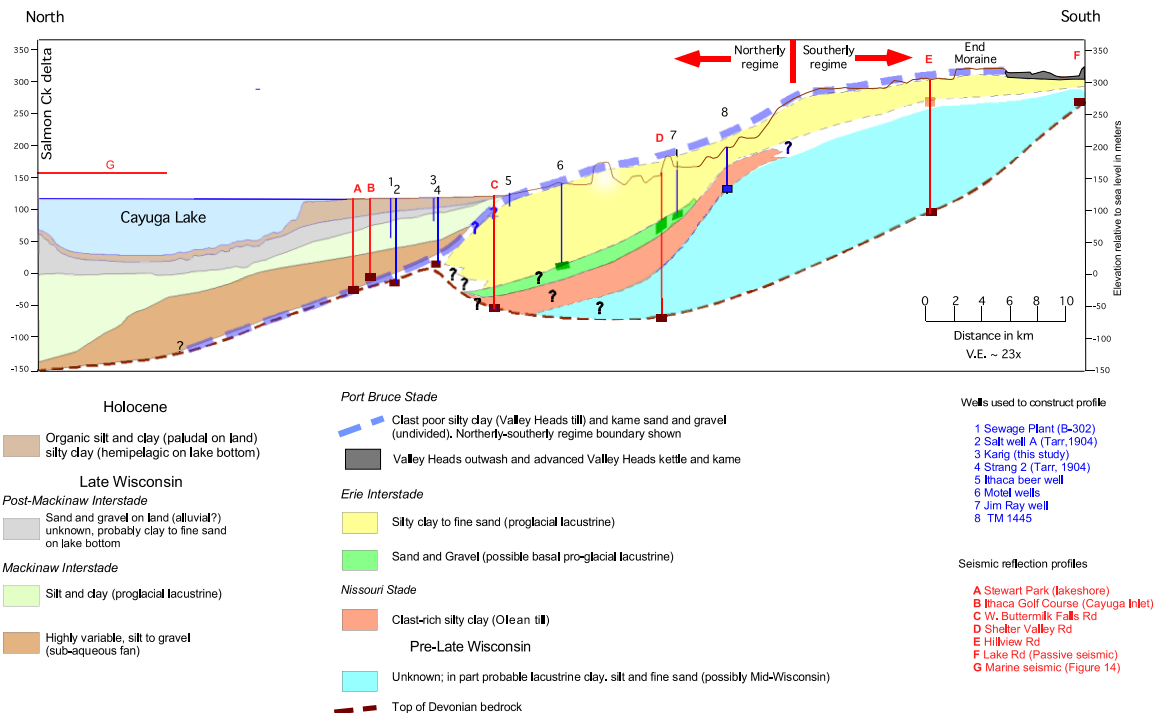


Fig. 11. Composite geological section along Cayuga Inlet Valley

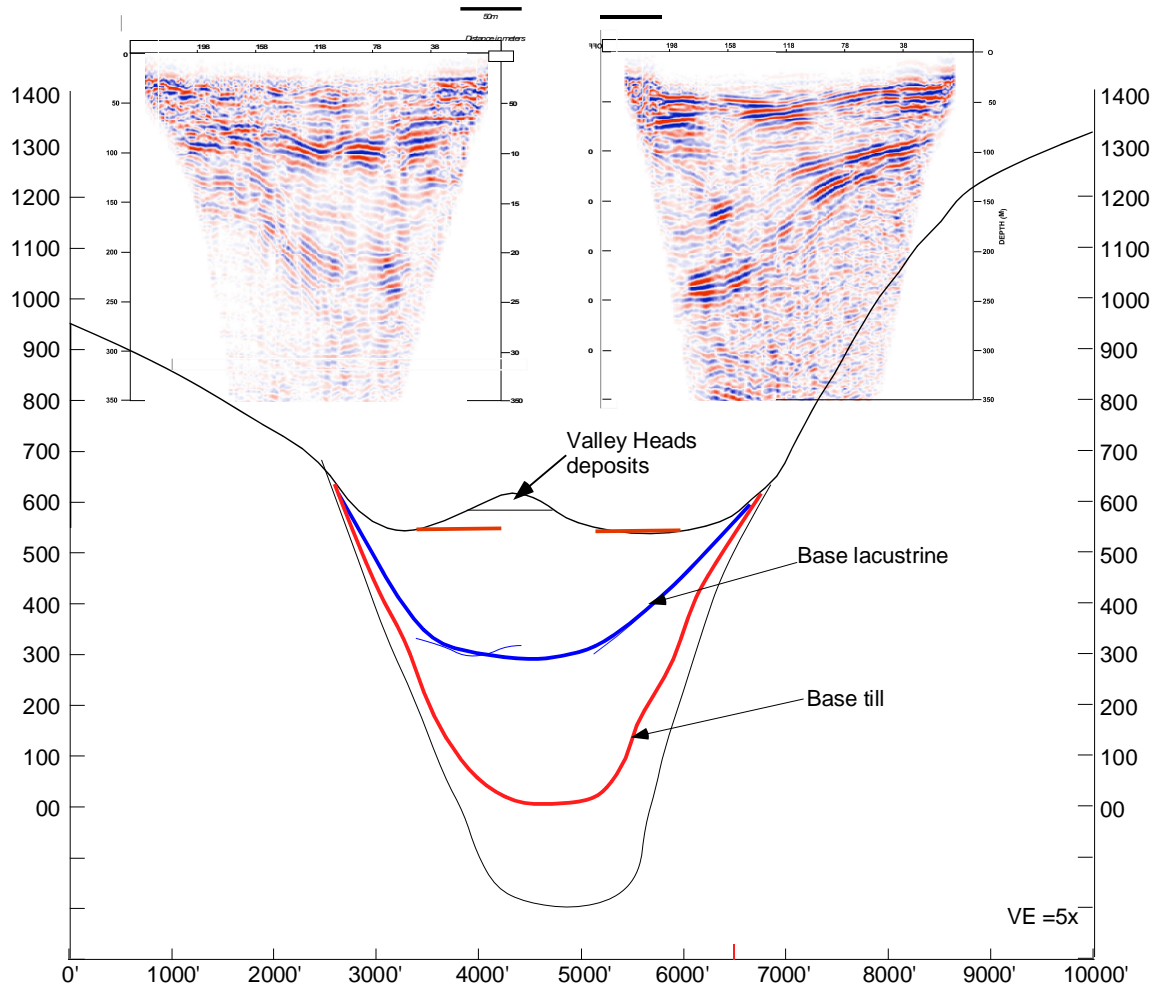


Fig. 12. 64 channel seismic reflection depth section along Shelter valley Rd

<b>Miles from last point</b>	<b>Cumulative mileage</b>	<b>Route description</b>
0.87	42.94	Go back (east) on Shelter Valley Rd to Rtes 34/96 and turn left (north)
0.70	43.64	Drive north on Rte 34/96 to Blakeslee Hill Rd and turn right
2.10	45.74	Follow Blakeslee Hill Rd, past Townline Rd, where the road name becomes W. Jersey Hill Rd, to West King Rd and turn left.
0.51	46.25	Drive north on W. King Rd to Yaple Rd and turn right
0.65	46.90	Follow Yaple Rd to Comfort Rd and turn left
0.73	47.63	Follow Comfort Rd to Rte 96B and turn right
0.30	47.63	Follow Rte 96B south and turn left on Nelson Rd
0.65	48.28	Drive east on Nelson Rd to Ridgecrest Rd and turn left
0.95	49.23	Drive north on Ridgecrest Rd and turn right on E. King Rd.
0.96	50.19	Drive east on E. King Rd and turn right on Coddington Rd
0.15	50.34	Drive east on Coddington Rd and turn left on Burns Rd.
1.11	51.45	Drive north on Burns Rd. to Rte 79 and turn left
0.86	52.31	Drive northwest on Rte 79 and turn slightly right on Pine Tree Rd
0.98	53.29	Drive north on Pine Tree Rd to the Traffic light-and the parking lot is just to the north

## Trip A2

# Paleoecology and Taphonomy of Some Eurypterid-Bearing Horizons in the Finger Lakes Region of New York State

STEPHEN M. MAYER

*5475 East Lake Road, Romulus, NY 14541, USA*

## INTRODUCTION

The Upper Silurian Bertie Group in western and central New York State is famous for its eurypterid (Arthropoda: Chelicerata) *Lagerstätten*. From the earliest recognition of the genus *Eurypterus* by American zoologist James Ellsworth DeKay (1825), studies have concentrated on eurypterid growth and variation (see Andrews et al., 1974; Cuggy, 1994). More recent works have focused on ecdysis (Tetlie et al., 2008), and mating (Braddy, 2001; Vrazo and Braddy, 2011), as well as trace fossils and taphonomy (Vrazo et al., 2014, 2016, 2017, and Vrazo and Cieurca, 2018). Recurrent taphonomic patterns are recognized regardless of species with various hypotheses proposed to explain these occurrences. The purpose of this investigation is to provide an overview of the preservation patterns observed in the fossil record. The contortion of *Eurypterus remipes* and *Erieopterus microphthalmus* exuviae collected from different Finger Lake sites, as well as specimens held in the Samuel J. Cieurca Eurypterid Collection at Yale Peabody Museum of Natural History are interpreted to be the result of flexure of eurypterid exoskeletons by submarine paleocurrents. The present contribution and accompanying field guide review the facies and geological settings of the Bertie Group with an emphasis on eurypterid-bearing horizons in west central New York as well as a discussion of specific aspects of the preservation of these fossils.

## PALEOGEOGRAPHY AND PALEOENVIRONMENTAL SETTINGS

Silurian stratigraphy and paleoenvironmental conditions of western and central New York State have been studied extensively by Rickard (1969, 1975), Cieurca (1973), Belak (1980), Hamell and Cieurca (1986), Brett et al. (1990a, 1990b), Brett et al. (1994), and Cieurca (2013), among others. Siliciclastic muds and carbonates were deposited in the northern Appalachian Basin within a subtropical climatic belt approximately 20-25 degrees south latitude (Van der Voo, 1988; Witzke 1990). During the late Silurian Ludlow and Pridoli Epochs, about 408-419 mya, climatic conditions were very arid and circulation within the basin became restricted (Rickard,

1969) allowing micritic waterlimes, typically with laminated bedding, as well as mudstones and evaporites of the Salina and Bertie Groups to accumulate (Fig. 1). Intermittent subaerial exposure and evaporation resulted in hypersaline lagoonal to tidal flat environments indicated by desiccation cracks and salt hoppers. Ciorca and Hamell (1994) interpreted these facies to represent uppermost intertidal zones to lowermost sabkha. These strata often contain a low diversity of fossils, but microbialites (stromatolites and thrombolites) appear to be common (Ciorca, 2013). Eurypterids typically occur in these predominantly hypersaline peritidal, often ephemeral environments, in association with euryhaline taxa including gastropods, ostracods, leperditians, nautiloids, and rare lingulid brachiopods. Additionally, *Cooksonia*, one of the earliest known terrestrial vascular plants, sporadically grew on estuarine muds and other damp, low-lying habitats. Vrazo et al. (2014) have recognized that eurypterid-bearing horizons typically are subjacent to beds exhibiting evidence of subaerial exposure and have suggested that salt hoppers found in association with eurypterids formed as the result of post-burial processes. These stratigraphic and paleoecological conditions are also readily apparent at the study sites.

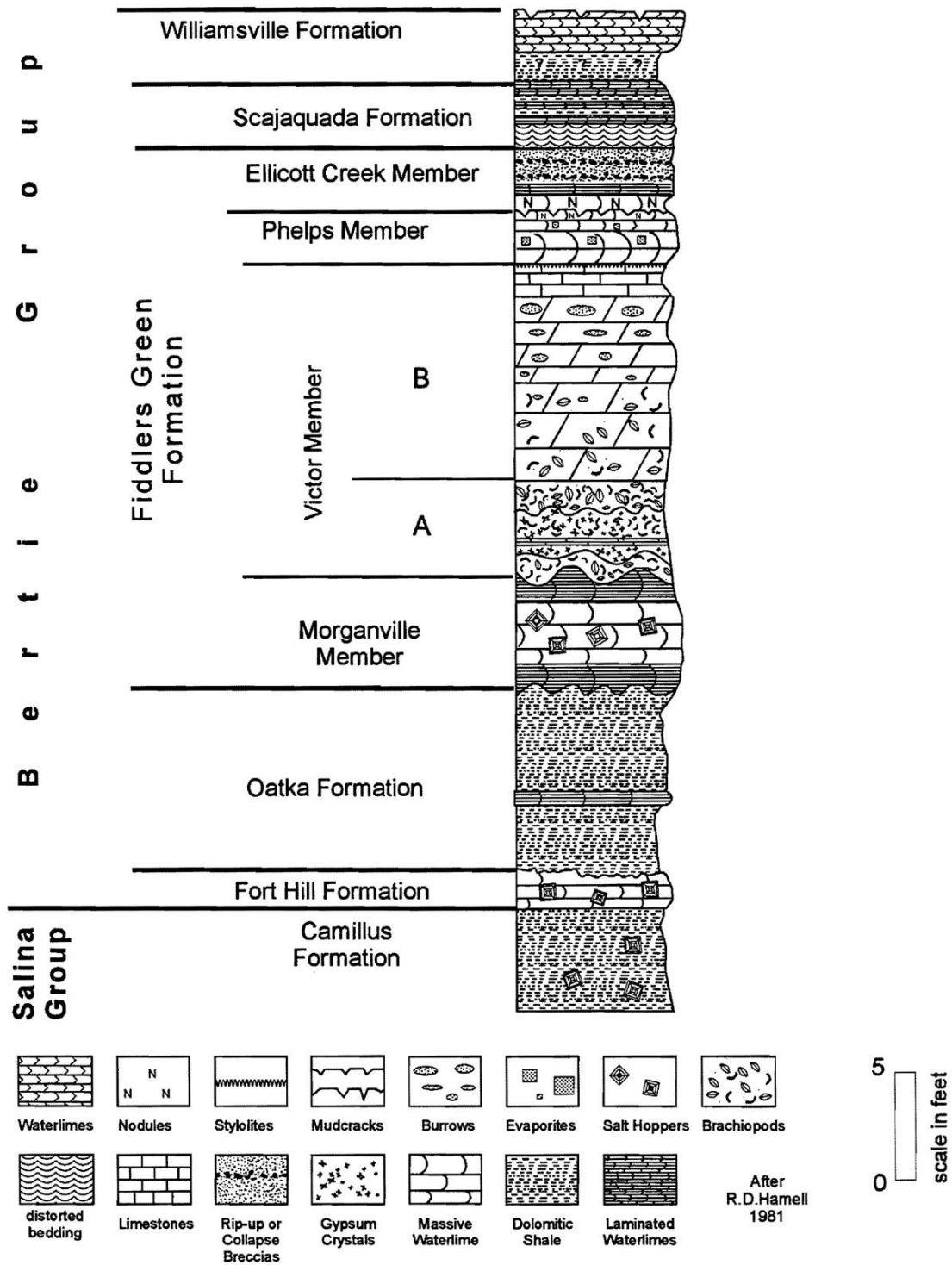


Figure 1. Stratigraphic column for Upper Salina and Bertie Groups in western and central New York State, from Hamell and Cieurca (1986). Vertical scale bar = 5 ft. (1.5 m).

## UPPER SILURIAN STRATIGRAPHY



The Bertie Group in western and central New York was originally named by Chapman (1864) for the strata consisting of massive dolostones and waterlimes of the Niagara peninsula of Ontario Canada. Subsequently, Fisher (1960) placed these units into the Oatka through Williamsville Formations of the Bertie Group. Ciarca (1994) further redefined the Bertie to include all of the eurypterid-bearing waterlimes overlying the Salina Group. These units included the Fort Hill Waterlime at the base through the Oatka, Fiddlers Green, Scajaquada, and Williamsville Formations as well as the overlying Akron Dolostone and Moran Corner Waterlime at the top. This sequence is erosionally overstepped by the sediments of either the Lower Devonian Manlius Formation or Middle Devonian Onondaga Limestone. The following is a brief description of the Bertie units. Additional information can be found in Ciarca (1994, 2010).

**Fort Hill Waterlime Formation-** This *Eurypterus* bearing unit is approximately 2 ft. (0.6 m) thick and is characterized by fine-grained stromatolitic, dolomitized mud with abundant salt hoppers, indicating a hypersaline nearshore environment.

**Oatka Formation** – This unit consists of about 8.5 ft. (2.6 m) of unfossiliferous, thinly bedded dolostones and dolomitic shales. Some bedding surfaces are covered by relict halite casts.

### **Fiddlers Green Formation**

**Morganville Member** – This member is the lowermost waterlime of the Fiddlers Green. The unit consists of 4-10 ft. (1.2-3.0 m) of massive bedded, laminated waterlime or fine-grained dolostone with conchoidal fractures and rare eurypterids.

**Victor Member** – The Victor Member comprises approximately 15 ft. (4.5 m) of massive dolostone beds, which are further subdivided into A, B, and C submembers (Hamell, 1961) containing a fauna of abundant brachiopods, ostracods as well as *Eurypterus* sp. Ciarca and Hamell (1994) have interpreted this facies to constitute a deep water, more offshore, hypersaline subtidal environment. Small thrombolitic buildups are common. The uppermost C submember grades upward into the overlying Phelps Member waterlime.

**Phelps Member** – The Phelps Member is approximately 3 ft. (1 m) to 5 ft. (1.5 m) thick and can be subdivided into a cyclic sequence of eurypterid-bearing, tabular, laminated waterlimes interbedded with layers altogether lacking fossils. Typically, microbialites of irregular shapes and sizes are associated with the eurypterid fauna and Ciarca (2013) has suggested that they resemble rip-up clasts.

The strata records minor sea level transgressions that periodically flooded restricted lagoons freshening the otherwise hypersaline sea water allowing eurypterids and other euryhaline fauna to migrate shoreward alternating with retreating seas increasing salinity to the point that organisms could not readily live in these environments. Continued shallowing resulted in subaerial exposure and conditions favorable to the formation of mudcracks and salt and/or gypsum crystals. When seas subsequently flooded these surfaces again, sediments became jumbled. Older layers containing buried eurypterid remains, along with the microbialites were diagenetically altered. Early stage evaporite precipitates within the sediments were subsequently dissolved forming salt hopper or gypsum molds. These early diagenetic salts may have aided in preservation of associated buried eurypterids. Vrazo et al. (2014, 2016, 2017) observed similar facies in the Upper Silurian Tonoloway Formation of Pennsylvania and proposed a model, which suggests that these transgressive-regressive cycles supported eurypterid habitats as well as the formation of eurypterid *Lagerstätten*.

**Ellicott Creek Breccia Member** – The uppermost unit of the Fiddlers Green Formation consists of about 3 ft. (1 m) of brecciated waterlime, which possibly formed as a result of a Late Silurian earthquake shocks (Cieurca, 2010). This unit is unique in that only two different *Eurypterus* species have been observed and are concentrated in channels formed between adjacent stromatolites. Salt hoppers are widespread throughout the unit.

**Scajaquada Formation** – This unit consists of approximately 3 ft. (1 m) of thinly bedded, medium dark gray argillaceous dolostones and dolomitic shales. The unit grades eastward into the Forge Hollow Formation in central and eastern New York where it is about 40-50 ft. (12-15 m) thick (Cieurca, 2010). The interval is nearly barren with rare eurypterids confined to a basal waterlime. Chert nodules are scattered within some intervals, and may have replaced earlier evaporite salts. Gypsum nodules may have been replaced by chalcedony that recrystallized to chert; small cubic salt crystals molds, up to 1 cm, occur on slabs of slightly shiny, pale reddish gray dolostone near Phelps, New York. Minor deformed beds occur within the member and may have formed as a result of Silurian earthquakes or tsunamis (Cieurca, 2010).

**Williamsville Formation** – The Williamsville consists of about 3 ft (1 m) thick light gray, slightly argillaceous waterlime. Together with the Phelps Member in western and central New York, the Williamsville has yielded hundreds of eurypterids especially from the region around Buffalo, New York and the Niagara Peninsula. This unit contains several extremely hard, thinly laminated intervals with a diverse fauna including nautiloids, gastropods, horseshoe crabs, and many species of eurypterids, as well as moderately common *Inocaulis* algae and rare *Cooksonia*.

**Akron Formation** – This massive vuggy and slightly cherty dolostone, up to 5 m thick, contains a poorly preserved marine fauna including stromatoporoid sponges, small rugose corals, brachiopods as well as

gastropods. This unit is erosionally overstepped by Early and Middle Devonian sediments. Cuirca (2010) reports an absence of eurypterids.

**Moran Corner Formation** - A waterlime of very localized extent that probably was a very thin unit with only this small erosional remnant remaining. Rare eurypterids and the typical associated hypersaline faunas occur within this interval. It ends the depositional cycles of the Upper Silurian.

## LOWER DEVONIAN STRATIGRAPHY

**Chrysler and Manlius Formations** – Lack of diagnostic zonal fossils in the basal beds, comprising the Helderberg Group in New York, has led to much confusion in the placement of the Silurian-Devonian boundary. The Manlius Formation, in Onondaga County in the vicinity of Syracuse, NY has been placed in both periods (see Berdan, 1964). Cuirca (1994) arbitrarily placed the boundary based on the occurrence, or lack of, different species of eurypterids within the uppermost beds of the Chrysler Formation. Specifically *Erieopterus microphthalmus* replaced the *Eurypterus sp.*, which may reflect a transition in depositional environments. Most recently the S-D boundary has been placed within the Green Vedder Member, which was formerly considered as part of the Thacher Member, of the Manlius Formation (Wilson et al., 2011). These units overlie the Late Silurian Chrysler limestone and are subjacent to the Early Lochovian (Early Devonian) Olney Member, Manlius Formation.

## FIELD LOCALITIES

**Locations:** The Fiddlers Green Formation extends from southern Ontario, Canada across the Finger Lakes to Herkimer, New York. The Fiddlers Green comprises dolomitic and chemically precipitated limestones of the Morganville Member at the base overlain by the Victor, Phelps and Ellicott Creek Breccia Members, respectively. Field collecting was conducted at four sites in the Finger Lakes region; however, the Ellicott Creek Breccia was not examined in this study.

At Phelps, the New York State Thruway (Interstate-90) passes through a roadcut (Fig. 2) characterized by gently sloping to near vertical sides exposing waterlimes of the Phelps Member and dolostones of the Victor Member. The New York State Thruway permitted access to this highly restricted outcrop to aid in this study of the lithology and paleoecology of these units. Here, the NYS Thruway only permitted surface collecting of rock samples which were further split in the laboratory in order not to miss critical information. This site represents the type locality for the Phelps Member of the Fiddlers Green Formation (Cuirca, 1973), which contains a eurypterid fauna with some fossils displaying highly contorted body postures.

The Phelps and Victor Members were further examined at an outcrop along McBurney Road in close proximity to the roadcut along the Thruway at Phelps. Eurypterids as well as other fossils were strikingly absent in the Phelps Member at this locality. In addition, the Morganville, Victor and Phelps Members were also collected at Cayuga Junction, along the east side of Cayuga Lake.



Figure 2. Type section of Phelps Member, Phelps, New York.

Field sampling was conducted at Split Rock Quarry, southwest of Syracuse, from the Lower Devonian Olney Member. *Erieopterus microphthalmus* was concentrated in localized very thin calcareous bands in association with more normal marine fauna (Cieurca, 1978) including abundant brachiopods and bivalves.

Sampling eurypterids and associated fauna from four different localities ensured that contortion patterns were not limited to one eurypterid horizon but instead occurred throughout the fossil record. Confirming these observations further were data supplemented by specimens held in the Samuel J. Cieurca Eurypterid Collection at the Yale Peabody Museum of Natural History. Taken all together, eurypterid habitation, population and preservation was defined.

## RESULTS AND OBSERVATIONS

Field collecting for three years at Phelps yielded many eurypterid fossils including common *Eurypterus remipes* exuviae; however, complete *Eurypterus remipes* were scarce. Moreover, very rare *Dolichopterus macrocheirus* and pterygotid remains were found associated with the *E. remipes*, but these fossils were limited only to widely scattered parts.

The smallest *Eurypterus* specimen was just over 15 mm from prosoma to telson, while the largest specimen measured 13 cm. Due to the scarcity of complete exoskeletons, a more useful parameter may be the size of the prosoma. However, this in itself has certain limitations because the head is only one part of the eurypterid body. Tollerton (1989) noted the prosoma unquestionably could become deformed and distorted before and after burial and these affected samples were not measured. Based on 61 complete, or nearly complete, carapaces, height by width measurements ranged from 4 mm x 5 mm to 60 mm x 75 mm respectively, so clearly there were both immature and some large adults living in this environment. A size-frequency distribution graph (Fig. 3) gave a mode of 17 mm with most specimens falling within approximately 15 to 25 mm. The Phelps population was found to be similar to the distribution reported by Vrazo et al. (2014) for the Upper Silurian Tonoloway Formation in the central Appalachian Basin of Pennsylvania.

At Cayuga Junction, *Eurypterus remipes* occurred less frequently than at Phelps. Fossils were well preserved but due to a small sample size, even after combining them with fossils held at the Peabody Museum, only 15 carapaces were measured in all. With a ratio of 1:4 respectively, (Cayuga Junction to Phelps), it is difficult to determine a representative size-frequency distribution (Fig. 3).

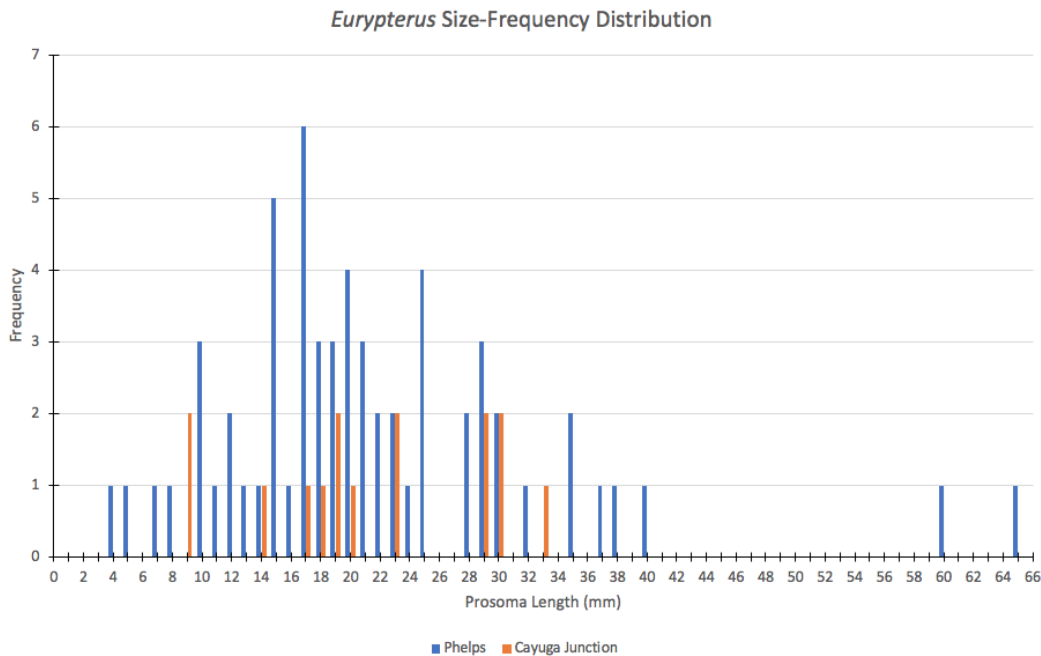


Figure 3. Size-frequency distribution of *Eurypterus remipes* carapaces from the Phelps Member at Phelps and Cayuga Junction, Finger Lakes region, New York.

## DISCUSSION

**Paleoecology:** Eurypterids are an extinct group of chelicerate arthropods with the majority of fossil specimens interpreted as being “cast exuviae (cuticle) from the frequent molting (ecdysis) of growing individuals” (Clarke and Rudemann, 1912; Braddy et al., 1995; Batt 1999; Tetlie et al., 2008, and Vrazo et al., 2014). Vrazo and Braddy (2011) have proposed an idea referred to as the “mass-mate-spawn-molt” hypothesis of eurypterid paleoecology. The interpretation is that males and females would have amassed in shallow water, possibly a lagoon, to mate similar to the modern-day horseshoe crab *Limulus polyphemus*. After mating, males left the area and returned to deeper water, whereas the females remained to spawn and subsequently molt before migrating back to deeper water. After their eggs hatched, eurypterid larvae and juveniles remained in these breeding grounds until they matured and then migrated basinward. Of course, the males molted as well but the researchers found a greater abundance of female exuviae at the different study sites.

The results from very thorough field collecting at Phelps showed a predominance of very small disarticulated and fragmentary body parts, as well as tiny specimens (Fig. 4A, B). The interpreted sequence of events in the ecdysis and disarticulation of *Eurypterus* (Tetlie et al., 2008) generates partial specimens with the prosoma remaining as the last intact tagma (Vrazo and Braddy, 2011). Moreover, these observations can be directly related to the mass-molt-mate-spawn hypothesis and it would be expected that a large number of juvenile and growing individuals would be found in a nearshore environment and Phelps appears to record one of these breeding grounds.



Figure 4 A) Partially disarticulated *Eurypterus remipes* with prosoma attached to the preabdomen.

B) Larval stage of *Eurypterus remipes* lacking appendages and telson. Note the tiny size of these immature specimens, Phelps Member, Phelps, New York.

McCoy and Brandt (2009) and Brandt and McCoy (2014) studied extant scorpions comparing their molts as well as carcasses to recurrent patterns observed in fossil scorpions in an attempt to distinguish the exuviae from the remains of dead animals for a more accurate assessment of the fossil record. They concluded that the position of the chelicerae, the position of the walking legs, the straightness or curvature of body plan, the presence or absence of telescoping thoracic segments as well as the position of the pedipalps were significant criteria and were directly applicable in differentiating molts from carcasses in the extinct eurypterids.

One complexity in determining the paleoecological record at Phelps, New York stems from the extensive disarticulation of the exoskeletons as well as poor preservation of many of the fossils. Commonly found disarticulated eurypterid elements include the prosoma, tergites and sternites, walking and swimming appendages as well as the telson. McCoy and Brandt (2009) experimented with modern scorpion molts and carcasses and concluded that there were no statistically significant differences in the length of time for their entire disarticulation. Their experiments further suggested that the molts were just as strong as the carcasses in water and dry conditions. Extrapolating these results to the abundant disarticulated exuviae compared to the paucity of intact fossil eurypterids at Phelps, it is very difficult to determine which are molts and which are the carcasses of dead animals. Thus, scattered parts could certainly be from the decomposition of decaying carcasses as well as from the disarticulation of the eurypterid exoskeleton after ecdysis and the few nearly complete fossils could either be molts or the remains of the eurypterids after death.

Discrete eurypterid instar classifications (i.e. molt stages) have been based on measurements and morphologies (Hunt and Chapman, 2001). Since the morphology of the eurypterid body plan changes little with growth, several different categories have been assigned (Clarke and Rudemann, 1912; Andrews et al., 1974; and Tollerton, 1992). In this study, Vrazo and Braddy's (2011) stages were utilized. The divisions are based on prosomal (carapace) length which gives a good approximation of the total length of the eurypterid. The stages are larval 0-14 mm, juvenile 15-30 mm and adult >30 mm.

Size-frequency distribution of carapaces from the Phelps site (Fig. 3) suggests that this locality may represent a eurypterid nursery with the greatest proportion of individuals being larvae (12) and juveniles (41) living among adults (8). No distinction could be made to determine if the larger eurypterids were male or female due to the disarticulated nature of most fossils but the Vrazo and Braddy (2011) "mass-mate-spawn-molt" hypothesis predicts that larger specimens were probably mostly molts of female individuals that had not yet returned to open marine water. Regardless, if the fossil was from a molt or a carcass, the great abundance of small body parts and small individuals may represent a growing population of *Eurypterus remipes* with many individuals having reached the juvenile stage.

The biofacies of the Phelps Member at Phelps, along the Thruway, is strikingly different from the faunal characteristics of the McBurney Road site, only 0.45 miles (0.72 Km) away, where eurypterids were

conspicuously absent. It is certainly possible that eventually some fossils may be found, but in this study none were discovered or available in collections. Possibly the precise horizons yielding specimens are missing or poorly exposed at this locality. Alternatively, there may have been differences in oxygen levels, salinity and/or substrate in the paleoenvironment, which prohibited eurypterids from inhabiting this area.

Moreover, at Cayuga Junction, 19.77 miles (31.82 Km) away from Phelps, it is difficult to determine to what extent the biofacies differed, if at all, due to the limited sample size. Size-frequency distribution data of carapaces showed larvae (3), juveniles (11) and adults (1), but quantitatively the individuals appear, on average, larger than those from Phelps due to the lack of very immature sizes. Although these data suggest that juveniles comprise the bulk of the population, further collecting is necessary to ascertain a clearer interpretation of the paleoenvironment.

**Taphonomy:** By comparing recurrent taphonomic patterns in scorpions and eurypterids, McCoy and Brandt (2009) and Brandt and McCoy (2014) explained some contortions in these arthropods and they reported various body orientations taken on during ecdysis. However, the manner in which the exuviae come to rest on the seafloor after exuviation but prior to disarticulation and fragmentation is not well studied and nothing less than remarkable considering the nature of the exoskeleton. Contortion of the intact exuviae or carcasses includes flexure, or flexed, twisted postures, of the exoskeleton by some external environmental factors, which affected the final resting position. Slow moving paleocurrents, wave ripples and tides that came into restricted lagoons (see Vrazo et al., 2014 for further discussion) created a wide variety of skeletal flexures.

Measurements were taken of the degree of curvature of the metasoma and telson in relation to the prosoma and mesosoma. This was done by drawing an axis through the center of the prosoma and mesosoma and a second axis through the telson in the direction the telson is pointing. Then the angle was measured between the two axes resulting in the degree of body curvature.

Fossil contortions can be categorized from 1) the most commonly occurring orientation, with bodies non-contorted, 2) bodies contorted commonly up to 90°, 3) U-shaped flexure with metasoma and telson parallel to the pre-abdomen and prosoma, and 4) rarely with the opisthosoma and telson flipped above or below the pre-abdomen of the body and forward of the prosoma. Various contortion patterns are illustrated in Figure 5. These pre-burial resting positions contrast with later distortion of some exoskeletons (Fig. 6) that were buried edgewise by sediments and subsequently compacted and crushed.

Figure 5. →



A) *Eurypterus remipes* displaying extreme contortion of  $180^{\circ}$  with the opisthosoma and telson bent under the ventral side and above the prosoma.

B) Same as A but with carapace and mesosoma flipped over to show opisthosoma.

C) *Eurypterus remipes* with metasoma and telson bent  $50^{\circ}$  from pre-abdomen (YPM IP 213385).

D). *Eurypterus remipes* approaching U-shape body posture with metasoma and telson twisted  $126^{\circ}$  in relation to the prosoma and mesosoma (YPM IP 210717).

E) *Erieopterus sp.* with metasoma and telson bent  $65^{\circ}$  from pre-abdomen (YPM IP 206794).

F) *Erieopterus sp.* with metasoma and telson bent  $41^{\circ}$  from pre-abdomen(YPM IP 206815).

Specimens A-C are from Phelps Member, Phelps, New York State Thruway;

Specimen D is from Phelps Member, Passage Gulf, Herkimer County immediately east of the study area; Specimens E-F are from Split Rock Quarry, Olney Member, Onondaga County.

Specimens C-F courtesy of the Yale Peabody Museum of Natural History, Division of Invertebrate Paleontology. Images courtesy of Jessica Utrup (Yale Peabody Museum of Natural History).

Figure 6.→

*Eurypterus remipes* distorted edgewise with prosoma obliterated and right swimming arm and paddle elongated as well as parallel to body, from float, suspected Victor Member, Cayuga Junction.



A



B



C



D



E



F

Figure 5.



Figure 6.

During the time that the eurypterids inhabited the lagoons and nearshore environments many became contorted, although countless others laid flat and straight on the substrate possibly aligned with their long axes parallel to the current. Moreover, the scarcity of complete, intact eurypterids in these facies as exemplified at Phelps suggests that bacterial decay and paleocurrents acted on the shed exuviae and carcasses causing extensive disarticulation of the exoskeletons. These fragmentary fossils along with moderately common microbial mats (see microbialite structures of Ciurca, 2013) typically occur in the center of conchoidal dish-like depressions in certain layers. These dishes are actually scalloped fractures that develop during weathering probably owing to differential freezing-thawing cycles or pressure release but are influenced by the inhomogeneity of the embedded features.

The microbial mats may have also had an influence on the contortion of the eurypterid exuviae and carcasses. Different types of orientation are interpreted as resulting from lodging of the slightly heavier prosoma and mesosoma into the sediment and/or possibly attached to sticky microbial mats while the lighter metasoma and telson rotated around as currents pushed the exoskeleton down current. Alternatively, the contortion could have resulted from the telson initially becoming stuck into the sediment and/or microbial mats and the entire body would have been pushed in a down current direction. In certain cases, the telson may have become stuck in the substrate and there was sufficient current to cause the rest of the body to be pushed over and flopped down on top of the opisthosoma and telson (Figs. 5 A & B). In this case, the body appears to have fragmented near the midpoint without completely disarticulating the exoskeleton. The specimens in Figures 5 C-F also clearly demonstrate that paleocurrents acted upon the exuviae and carcasses by twisting the eurypterid into these contortion postures.

## SUMMARY

New research focused on the paleoecology and taphonomy of eurypterid-bearing horizons within the Upper Silurian Fiddlers Green Formation as well as the Lower Devonian Olney Member in the Finger Lakes region of New York State. Field studies concentrated on the large eurypterid sample from the Phelps Member at the Thruway roadcut near Phelps and comparable horizons from Cayuga Junction. Additionally, eurypterids were examined at Split Rock Quarry, southwest of Syracuse, New York.

Despite strong disarticulation and fragmentation of almost all fossil specimens coupled with the complication in determining eurypterid exuviae from carcasses at Phelps, size-frequency distribution evidence suggests that this area may have been both a breeding ground and nursery for *Eurypterus*. Size-frequency histogram was also compiled for Cayuga Junction, but interpretations must be cautionary due to the limited sample size. Large numbers of fragmentary, tiny, larvae to juvenile sized body parts, whether from molts or carcasses, appear to comprise most of the Phelps fossil record. Although it is very difficult to assess the population, clearly larvae and juveniles lived among adult eurypterids at both sites.

*Eurypterus remipes* and *Erieopterus microphthalmus* exuviae and carcasses were affected by currents, which produced a variety of contorted patterns. Examining two different species that lived in different localities, as well as different time periods, demonstrated that contorted postures were not limited to *Eurypterus*. These recurring taphonomic patterns may be in the form of minimal to significant bending and twisting of the opisthosoma and telson in relation to the rest of the body. In more severe cases the opisthosoma and telson may flip over the prosoma or oppositely the prosoma and mesosoma may flip over the metasoma and telson. A common theme in these cases of flexure is the anchorage of heavier or more projecting parts of the exoskeleton to the muddy sediment and/or sticky microbial mats on the lagoon bottom while the rest of the exoskeleton pivoted freely about this point or further fragmented prior to sediment burial.

## ACKNOWLEDGEMENTS

I would like to thank the New York State Thruway Authority for giving me access to the highway road cut in Phelps. Although it was a very tedious process securing the necessary Liability Insurance needed by the Thruway, the Wayne County Gem and Mineral Club patiently worked with me and provided the required insurance. This proved to be a key locality to further research of eurypterid paleoecology and taphonomy.

I would like to extend my sincere appreciation to Susan Butts for granting access to the Samuel J. Cieurca Eurypterid Collection at the Yale Peabody Museum of Natural History and Jessica Utrup for eagerly assisting my search through thousands of fossils and photographing key specimens.

I would also like to thank my wife, Tammy Mayer, for her unending support while she assisted in measuring fossils, compiling data and listening to my ideas.

Further thanks go to Emily Underwood at Hobart and William Smith Colleges for her assistance in using Excel to construct the size-frequency distribution diagram and Nikki Gottshall Chase for assisting at field localities.

#### DEDICATION

Dr. Carlton Brett of the Department of Geology, University of Cincinnati was a professor of mine whose support was fundamental in the completion of my graduate program many years ago. Thirty years later, he is still an important mentor to me. Our continued contact through the years has made geology that much more interesting. Dr. Brett continues to make important suggestions and provide thoughtful criticism for the preparation of this manuscript. Contributing his unbelievable knowledge of paleontology and stratigraphy coupled with his insight into research projects, this study evolved from simply collecting eurypterids in the field to better understanding the paleoecology and taphonomy of this fascinating group of fossils. It is to this extent that words, more than just a transparent "Thank You", are not enough. Therefore, I would like to dedicate this manuscript to him as his support was invaluable for its completion.

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## REVISITING SOME CLASSIC EURYPTERID LOCALITIES

### ROAD LOG AND STOP DESCRIPTIONS

Meeting Point: Hobart and William Smith Colleges

Meeting Point Coordinates: 42.860<sup>0</sup> N, -76.985<sup>0</sup> W

Meeting Time: 8:30 AM

Cumulative Miles	Incremental Miles	Route Description
0	0	Leave Hobart and William Smith Colleges
		Turn left from Pulteney Street onto Routes 5 & 20 W
1.3	1.3	Turn right onto Pre-Emption Rd., County Rd. 6 N
7.5	6.2	Turn left onto Rt. 96 W
10.8	3.3	Turn right onto Newark Street, Rt. 88 N
11.5	0.7	Proceed north under NYS Thruway
11.6	0.1	Turn left onto McBurney Rd., park vehicle in 500 ft.

#### STOP 1: McBurney Road cut – Phelps and Victor Members

Location Coordinates: (42.973<sup>0</sup> N, -77.078<sup>0</sup> W)

An outcrop only one-half mile away from the Phelps type section will provide the first stop. Here the Phelps Member lies at the top of the embankment overlying the Victor Member of the Fiddlers Green Formation. The upper submember of the Victor is a dark gray, thin to medium bedded, argillaceous dolostone, which lacks normal marine fossils. Thickly bedded Phelps layers have eroded from above and slid downslope forming large float blocks at the base adjacent to McBurney Road. Weathered blocks are light beige to tan,

however, when the very hard and dense limestone is broken along a fresh surface, the micritic waterlime is medium gray, laminated and displays a distinctive conchoidal fracture.

Fossils are scarce to absent at this site possibly indicating a subtidal to intertidal depositional environment. This contrasts with a common eurypterid fauna associated with pervasive laminated bedding and mudcracks at the Phelps type section, which indicates a supratidal to lowermost sabkhal depositional zone (Ciorca and Hamell, 1994). Moreover, the contact between the Victor and Phelps is moderately gradational and conformable possibly indicating that sedimentation was steady but the depositional environment was transitioning from a deeper water marine environment to a shallow lagoonal environment.

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11.7	0.1	Return back to Rt. 88 S
12.1	0.4	Park behind Phelps Town Court

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## Stop 2: Restricted Access – New York State Thruway – Phelps Member Type Section

Location Coordinates: (42.969<sup>0</sup> N, -77.071<sup>0</sup> W, mileposts 331.73 – 331.88)

Although this locality along the Thruway (I-90) provided the bulk of the fossil material used in this study, access to this road cut requires special permission from the New York State Thruway Authority. Liability insurance in the amount of \$1,000,000, along with other documents are needed before the Authority will grant a permit enforcing certain rules and regulations. Therefore, it would not be practical or possible for everyone to obtain the necessary documentation to get a permit. Moreover, the Thruway Authority will not allow a large group to visit the site as they believe it would be a significant safety risk to everyone. Only a brief description of the cut will be given here for those who wish to drive by it on the Thruway.

Seen from the Thruway, the Victor Member consists of thin to medium bedded dolostones approximately 7-8 feet from the road level upwards and forms the steep sides of the cut. The contact is gradational and conformable with the overlying Phelps Member. Extensive weathering of the Phelps waterlimes have resulted in rock talus strewn across most inclined surfaces but upon closer inspection discrete bedding is recognizable. There are at least two horizons, midway and towards the top of the roadcut, containing eurypterids and associated fauna interbedded with intervals lacking fossils. Moreover, microbialites, desiccation cracks, and relict halite structures are found throughout the stratigraphic section.

Post-depositional tectonic stresses produced stylolites (pressure solution features) which are commonly parallel to the bedding throughout the section. They are characterized by an irregular and interlocking teeth-like projections where one side fits into their counterpart on the other side. These slickensides were presumably formed diagenetically by differential movement as the rock is pushed laterally under the force of compression. These surfaces are often coated with a carbonaceous residue (anthraxolite) which has been concentrated by solution of the carbonate rock.

Near the top of the outcrop, perfectly circular as well as irregular shaped chert nodules are prevalent (Fig. 7) but the manner in which they formed is problematical. Cephalopods do occur in the Phelps Member and some other parts of the Bertie Group and these rounded nodules may be the chambers of broken nautiloids. However, this seems unlikely since the nodules are relatively common. Alternatively, they could be chalcedony chert formed by replacement of gypsum nodules, although they are not expected to be so perfectly circular.

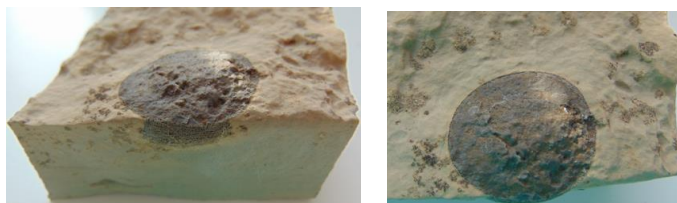


Figure 7. Chert nodule ( 2 cm diameter) from the upper beds of the Phelps Member, Phelps, NYS Thruway.

12.4	0.3	Turn left onto Rt. 96 E
17.4	5.0	Proceed east on Rt. 96, take clover leaf to Rt. 14 N
17.8	0.4	Turn right onto Rt. 318 E
28.7	10.9	Proceed east, then turn left onto Routes 5 & 20 E
30.8	2.1	Turn right onto NY Rt. 90
37.6	6.8	Turn right onto Fire Lane 14 (opposite Kelley Marine)
37.7	0.1	park vehicles in 1000 ft.

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Stop 3: Cayuga Junction

Location Coordinates: (42.871<sup>0</sup>N, -76.700<sup>0</sup>W)

Cayuga Junction was once the place where the Lehigh Valley railroad diverged into north and south routes along the east side of Cayuga Lake. Today, Fire lane 14 follows the abandoned rail line. Partial sections of each member of the Fiddlers Green Formation are exposed, although their contacts are obscured by overburden. The uppermost Phelps Member is intermittently visible on the north side of the gravel road and the Victor Member forms a steep gradient leading into a ravine south of the road. The Phelps and Victor Members exhibit similar lithologies to the waterlimes and dolostones observed at the Phelps type section. The strata contain the typical *Eurypterus remipes* fauna along with widely scattered *Lingula sp.* brachiopods. Cieurca and Hamell (1994) have additionally reported the occurrence of the athyrid brachiopod *Whitfieldella* in the Victor Member. At the base of the slope forming the floor of a small creek, the underlying Morganville Member is present (Cieurca, 1973). This unit has been traced from western New York eastward to Cayuga Junction. This waterlime also bears a *Eurypterus* fauna.

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37.8	0.1	Return to NY Rt. 90 S
38.7	0.9	Turn left onto Rt. 326
40.1	1.4	Bare left, stay on Rt. 326

45.1	5.0	Turn right onto West Genesee St. (stay on Rt.326)
46.7	1.6	Turn left onto Veteran's Memorial Pkwy (stay on Rt.326)
47.4	0.7	Turn right onto Routes 5 & 20 E
49.2	1.8	Stay on Rt. 5
65.2	16.0	Stay straight, merge onto Rt. 174, W Genesee St., Auburn, NY
66.4	1.2	Turn right onto Rt. 98, W Genesee Street
68.2	1.8	Turn left into McDonald's

This is a Lunch/Restroom stop

69.2	1.0	Continue on W Genesee Street and turn right onto Whedon Rd
69.7	0.5	Turn left onto Semloh Drive
70.1	0.4	Turn right onto Whedon Rd.
70.5	0.4	Turn left onto Onondaga Blvd, park and walk to barricade.

#### Stop 4: Split Rock Quarry

Location Coordinates: (43.027<sup>0</sup> N, -76.238<sup>0</sup> W)

The fourth stop is an abandoned quarry southwest of Syracuse near the hamlet of Split Rock in the town of Onondaga, NY. Split Rock Quarry is both historically significant as well as geologically important.

In the late nineteenth century, the site was an active limestone quarry (Fig. 8) but with the advent of World War I, it had become the Semet-Solvay munitions factory. About a quarter of the TNT used by American soldiers in the war was produced there. On July 2, 1918, a fire broke out, followed by one of the worst explosions in the history of New York killing 50 people and injuring dozens more (Syracuse Post-Standard, 1918). By the end of the year, any remaining buildings were scrapped leaving only the original stone crusher behind (Figs. 9, 10).



Figure 8. Limestone quarry 1889.      Figure 9. Original stone crusher on left with munitions buildings.



Figure 10. Devastation after horrific explosion. Today some people claim the locality is haunted.

The Split Rock stone crusher was originally built against the vertical rock wall comprising the Upper Silurian Chrysler Formation. Approximately 10 ft (3 m) below the top of the Chrysler dolostones, Ciurca (1978, 1994) has observed the abrupt appearance of the eurypterid *Erieopterus microphthalmus*. Moreover, *Eurypterus*, so characteristic of the Bertie Lagerstätten, is absent stratigraphically above this level.

These strata are overlain by the Olney Member of the Manlius Formation. The Olney limestone forms a distinct shelf-like ledge on top of the Chrysler dolostones. This surface may be partly due to differential erosion but also may be a relic from the early quarrying days of the region. Furthermore, Split Rock is the type locality for the Olney. At the base, the Olney is an argillaceous limestone, which weathers into very dark gray thin sheets. These beds are gradationally overlain by massive, light gray, thickly bedded limestone with abundant brachiopods. Approximately 2 meters (6.5 ft.) below a widespread layer of mud cracks of the overlying Elmwood Member, Czurca (1978) described the occurrence of *Erieopterus microphthalmus* (Fig. 11) in conjunction with the prolific spiriferid brachiopod *Howellella vanuxemi*. Deposition of these sedimentary units stopped with an abrupt change in the environment into the oolitic limestone of the Clarke Reservation Member. However, this and higher units of the Manlius Formation are locally removed by an erosional unconformity between the Lower Devonian and the carbonates of the Middle Devonian Onondaga Limestone.

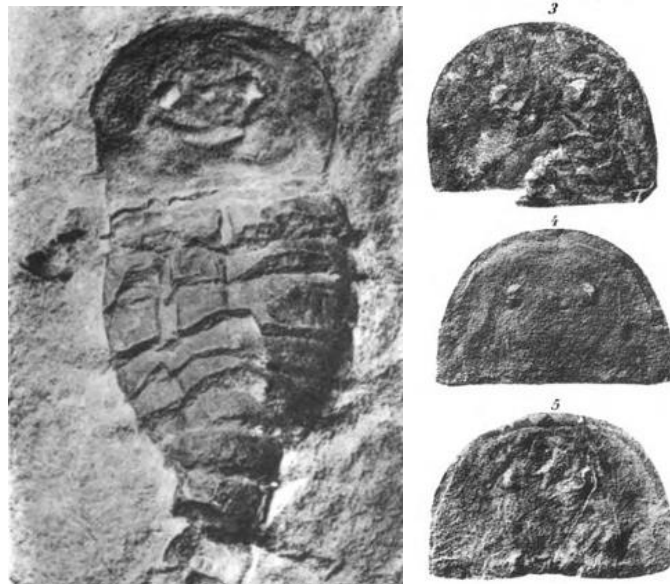


Figure 11. *Erieopterus microphthalmus* showing different outlines of the prosoma from Clarke and Rudemann (1912).

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End of Trip: Return to Hobart and William Smith Colleges.



## TRIP A3

# HOBART & WILLIAM SMITH (HWS) RESEARCH VESSEL TRIP

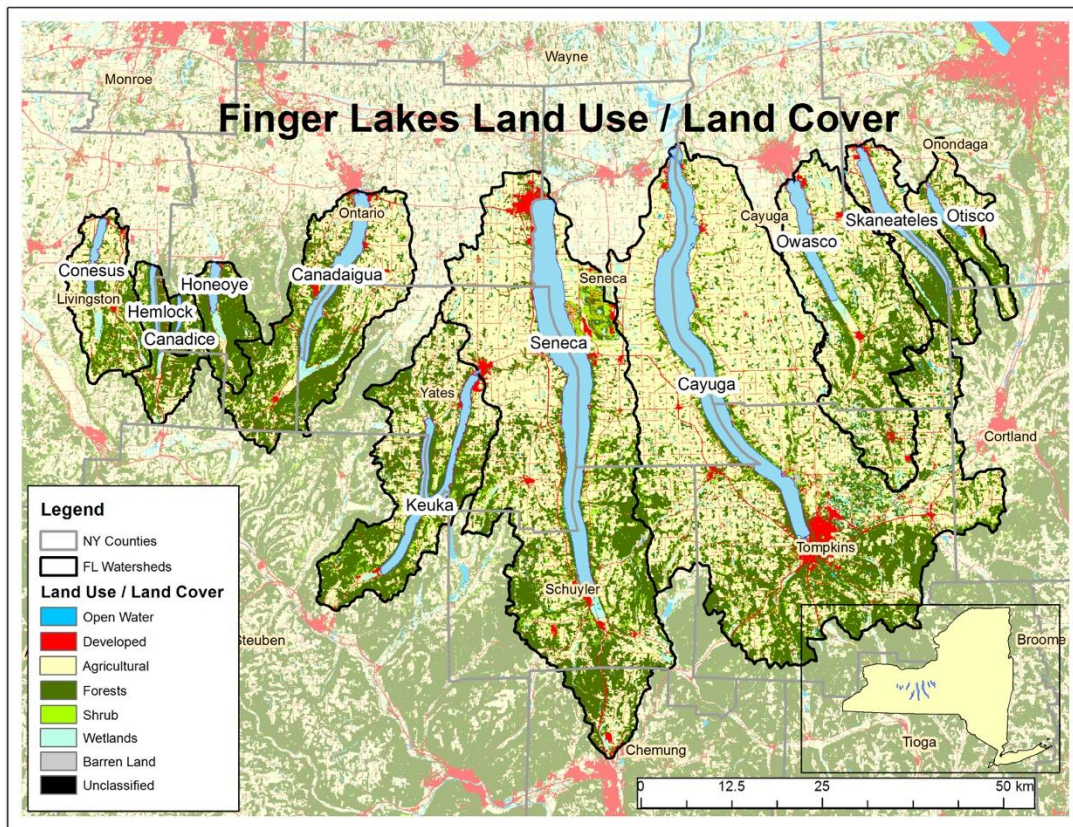
**JOHN D. HALFMAN & DAVID FINKELSTEIN**

Department of Geoscience, Hobart and William Smith Colleges, Geneva, NY 14456

## INTRODUCTION

The purpose of this cruise aboard the Hobart and William Smith Colleges' 65-ft research vessel the *William Scandling* is to investigate the chloride geochemistry and zebra/quagga mussel distributions in Seneca Lake, and how they relate to water quality and the ecology of the lake, and discuss their implications. Our field trip, i.e., cruise, aboard the *William Scandling*, will focus on water quality measurements and surface sediment samples in the northern part of the lake. We will advance Mike Wing's and Bill Ahrnbraak's understanding for the high chloride concentrations in Seneca Lake in comparison to the other Finger Lakes (Wing et al., 1995; Ahrnsbrak, 1974). Finally, we will discuss the impact zebra and quagga mussels and nutrient loading have had on the ecology of the lake, especially on how it may relate to the recent outbreak of blue green algae blooms and their associated toxins.

The Finger Lakes of central New York State consist of 11 elongated, north-south trending basins just south of Lake Ontario (Fig. 1). The basins were scoured into the northern edge of the Appalachian Plateau by glacial scour and glacial meltwaters under the retreating ice sheet (Coates, 1968, 1974; Mullins and Hinchey, 1989; Mullins et al., 1996). The bedrock underlying Seneca Lake is primarily Devonian shales (Hamilton Group in the northern end of the lake), and lesser amounts of sandstones and carbonates that gently dip to the south-southwest. Silurian carbonates, shales and most importantly evaporites (mostly halite) are found below the Devonian section.



*Fig. 1. The Finger Lakes of central and western New York. This fieldtrip explores the chloride chemistry, and the zebra/quagga mussel density in the lake, and the impact of both on the water quality and ecology of Seneca Lake.*

Seneca Lake is the largest (by volume) and deepest of the Finger Lakes (Fig. 1, Table 1). Only Cayuga Lake immediately to the east of Seneca is longer (61 km) and almost as deep (132 m). The other basins are smaller, ranging in length from 5 to 32 km and maximum water depth from 9 to 84 m. The present-day lake drains to the north-northeast through the Seneca River (New York State Cayuga-Seneca Barge Canal). Its large volume influences its large residence time of 18 years, 2 to 10 times larger than the smaller neighboring Finger Lakes (Callinan, 2001). Seneca Lake is mesotrophic (moderate productivity, sandwiched between oligotrophic and eutrophic systems). Annual mean, surface/bottom water algae and nutrients concentrations using 2018 data are: chlorophyll-a 4.8/0.4  $\mu\text{g/L}$ , Secchi disc depth 3.3 m, total suspended solids 2.0/0.6  $\text{mg/L}$ , total phosphate 18.5/13.2  $\mu\text{g/L}$ , soluble reactive phosphate 1.8/2.4  $\text{mg/L}$ , nitrate 0.1/0.2  $\text{mg/L}$ , and dissolved silica 220/420  $\mu\text{g/L}$ . Algal growth in the lake is phosphorus limited, diatoms occasionally limited by limited silica. The trophic state for Seneca Lake is in between the oligotrophic (low productivity) Skaneateles, Keuka and Canandaigua Lakes, and the eutrophic (high productivity) Honeoye, Conesus and Otisco Lakes. Seneca, unlike its neighbors rarely freezes in the winter. Instead it is a warm monomictic lake that thermally stratifies each May through November and is isothermal and thus overturns, i.e., the entire water column vertically mixes, all winter (Hawley and Halfman, 2018).

Seneca Lake is classified as a Class AA water resource by the New York State Department of Environmental Conservation (NYS DEC), except for a few locations along the mid-eastern shore (<http://www.dec.ny.gov/regs/4592.html>; Callinan, 2001; Halfman et al., 2012). The lake supplies drinking water to approximately 100,000 people through municipal and private systems. The lake, the rural countryside and internationally known wineries in the watershed drive the tourism industry that provides a major portion of the economy for the region. Thus, water quality of the lake is a concern to many.

**Table 1. Seneca Lake Statistics (Bloomfield, 1978)**

Length	57 km
Maximum Width	5.2 km
Surface Elevation	136 m above mean sea level
Water Volume	15.54 km <sup>3</sup>
Surface Area	175 km <sup>2</sup>
Maximum Water Depth	186 m
Water Residence Time	18-20 years

### **SENECA LAKE CHLORIDE CONCENTRATIONS (AFTER HALFMAN, 2014)**

Berg (1963) and Schaffner and Oglesby (1978) noted that chloride concentrations were significantly larger in Seneca Lake, and to a lesser extent in Cayuga Lake, than the other Finger Lakes (Fig. 2). Mass balance, steady state arguments by Wing et al. (1995) indicated that the elevated chloride concentrations required an extra source of chloride beyond the measured fluvial fluxes to the lake. They expanded and substantiated arguments by Berg (1963) and Ahrnsbrak (1974), and hypothesized that the extra source of chloride originated from the Silurian beds of commercial grade rock salt (Halite) some 450 to 600 m below the lake's surface. Measured concentration gradients in the sediment pore waters indicated that chloride diffuses into the lake from the lake floor, perhaps from the Silurian evaporites below. Seismic reflection profiles revealed an extensive thickness of glacial till that filled half of the basin down to the bedrock floor under Seneca Lake. The bedrock floor is deep enough to intersect the Silurian beds of rock salt (Mullins and Hinchey, 1989, and Mullins et al., 1996). The most likely location for this intersection is not well defined, but projected to be located under the northern portion of the lake based on a uniform 1° southerly dip of the bedrock and the depth profile of the basin's bedrock floor. Wing et al. (1995) hypothesized that this connection provided an avenue for brine to migrate from these rock salt beds into these two lakes, and not the other Finger Lakes.

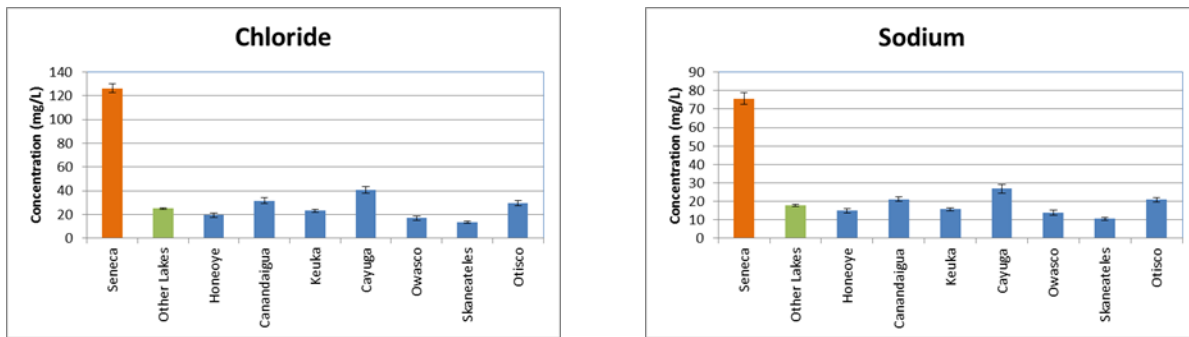


Fig. 2. Mean chloride (left) and sodium (right) concentrations in various Finger Lakes (Halfman, 2014).

Halfman et al. (2006) expanded the salinity investigation of Seneca Lake to include all of the major ions: chloride, sulfate, sodium, potassium, calcium and magnesium (Fig. 2). No horizontal spatial-scale trends in major ion concentrations were observed in the well-mixed lake. Vertically, the epilimnion (surface waters) was slightly less saline than the hypolimnion (bottom water). Mass-balance calculations assuming steady state conditions subdivided the major ions into three populations. Chloride, sodium, and to a lesser extent sulfate, were up to four times greater in the lake than the streams ( $\text{Cl}^-$  140 vs. 33 mg/L,  $\text{Na}^+$  80 vs. 20 mg/L,  $\text{SO}_4^{2-}$  40 vs. 30 mg/L, respectively). Thus, these ions required another source to attain the concentration detected in the lake. Conversely, calcium and magnesium were more concentrated in the streams than the lake and required a mechanism to remove a portion of these ions from the lake ( $\text{Ca}^{2+}$  60 vs. 42 mg/L,  $\text{Mg}^{2+}$  17 vs. 11 mg/L, respectively). Finally, the fluvial flux of potassium was at equilibrium with the lake. The mean molar ratio of chloride and sodium for all the analyses was nearly 1:1, suggesting a common Halite ( $\text{NaCl}$ ) source for these two ions. All of these observations were consistent with a substantial groundwater source to explain the elevated concentration detected in the modern lake.

Steady-state conditions are critical, if Seneca Lake is to remain a potable drinking water supply. The EPA's total dissolved salt (TDS) drinking water advisory concentration is 500 mg/L, and 250 mg/L for chloride (EPA 822-S-12-001, 2012). The drinking water advisory concentration for sodium is between 30 and 60 mg/L, and the threshold is lowered to 20 mg/L for those on low-salt diets (<500 mg/day) and newborn infants (EPA 822-R-03-006, 2003). NYS DEC regulations use the 250 mg/L limit for chloride and 20 mg/L for sodium as drinking water guidelines (<http://www.dec.ny.gov/regs/4590.html>). Thus, any increase in the current chloride (122/128 mg/L, surface/bottom) and/or sodium concentrations (75/79 mg/L) for the lake would be a concern, as sodium already exceeds its 20 mg/L drinking advisory limit. Here, we borrow heavily from Halfman (2014) to update the major ion hydrogeochemistry of Seneca Lake focusing on the conductivity (salinity) and historical chloride data collected since the earlier publications.

Salinity profiles and chloride data collected over the past two decades refute the steady state conditions (Halfman 2014). Sea-Bird SBE-25 conductivity (salinity), temperature and depth (CTD) profiles collected weekly from April through November each year since the early 1990s revealed a systematic seasonal decrease in epilimnetic (surface water) salinities by approximately 50  $\mu\text{S}/\text{cm}$  (~20 mg/L) each year during the stratified summer seasons. Fig. 3 plots CTD profiles from 2018, a typical year. During each year, uniform concentrations with water depth are detected during the isothermal spring. With the onset of thermal stratification, the epilimnion salinity decreased through the summer season. This concentration difference

would dissipate during the breakdown of the thermal stratification to isothermal conditions in the fall. The epilimnetic decrease in salinity during summer stratification is interpreted to reflect the dilution of the epilimnion by less saline rainfall and surface runoff. The seasonal decrease is consistent with adding ~50 cm of rain to the lake. Subsequent mixing due to the late fall through early spring overturn yields a salinity somewhere between the end of summer epilimnion and hypolimnetic concentrations (Fig. 4). It is proportionally closer to the hypolimnetic salinity because the hypolimnion is approximately twice as large as the typical epilimnion (~10 vs 5 km<sup>3</sup>, respectively).

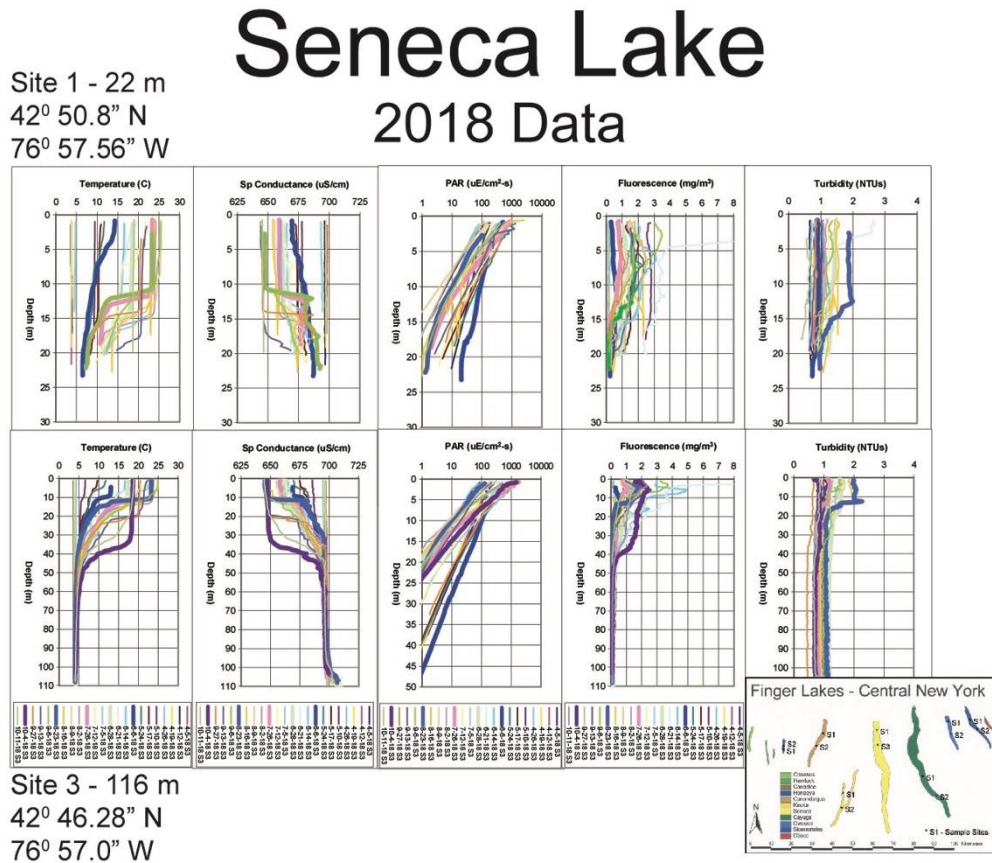


Fig. 3. Weekly CTD profiles from two sites in Seneca Lake collected during 2018. Note the decreasing epilimnetic salinities and nearly constant hypolimnetic salinities through the stratified summer season.

In contrast, the CTD profiles did not reveal a significant increase in salinity in the hypolimnion (bottom waters) of the lake during the summer stratified period (Figs. 3 & 4). A significant increase would be expected if the sediments provided a substantial flux of salt to the lake. Its absence indicates that a lake floor source for the chloride has not been substantial over the past two decades. Thus, the observed multiyear epilimnetic decrease and hypolimnetic uniformity is counter to a significant source of salts from the lake floor.

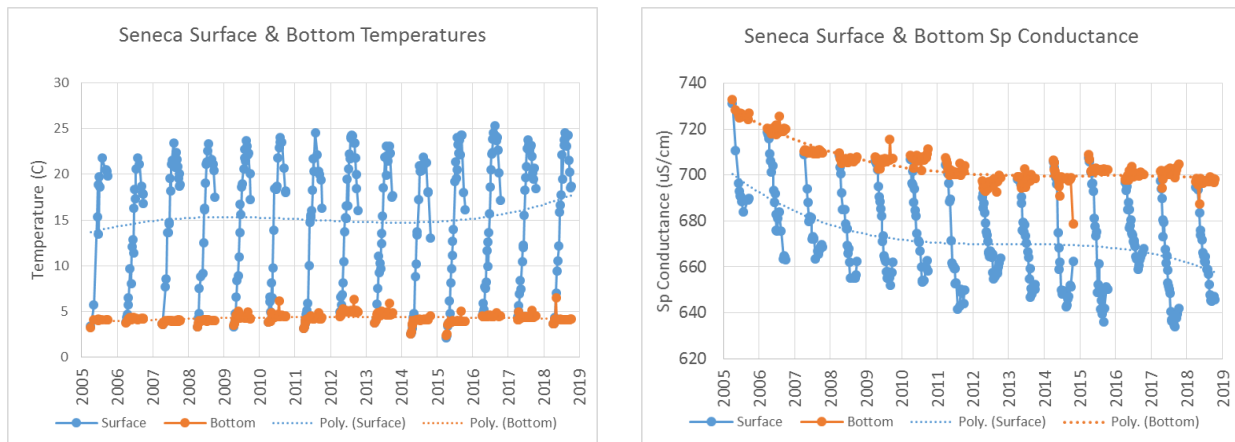
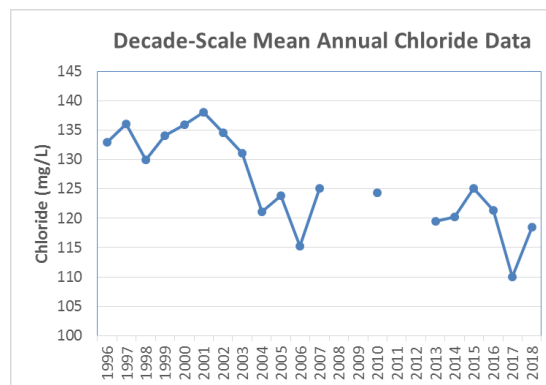


Fig. 4. Mean epilimnetic and hypolimnetic CTD temperatures (left) and salinities (upper right) since 2005 (Halfman, 2014 and unpublished data). Chloride concentration data confirm a declining trend since 1992 (lower right).



The decade-scale chloride ion data reveal decreasing chloride (and sodium) concentrations from 1992 to today as well (Fig. 4). Annual mean chloride concentrations remained between 130 and 140 mg/L from 1992 to 2001, rose to 150 mg/L in 2002 and decreased since to 125 mg/L in 2013 with a noticeable dip to 117 mg/L in 2006. The annual mean epilimnetic CTD specific conductance data also consistently decreased from 698  $\mu\text{S}/\text{cm}$  in 2005 to 672  $\mu\text{S}/\text{cm}$  in 2014. This decrease does not correlate to changes in rainfall, changes in chloride concentrations in streams (thus changes in road salt runoff), changes in the flow out the outlet, and changes in chloride wastes dumped into Seneca Lake from the salt mines in Watkins Glen over this two-decade time period (Halfman, 2014). It suggests that chloride in Seneca Lake is not in steady-state.

Century-scale chloride concentrations for Seneca, Cayuga, Hemlock, Canadice, and Skaneateles Lakes reveal two trends (Fig. 5). These data are reproduced with permissions from the Hemlock Water Quality Laboratory for the City of Rochester, Oneonta County Water Authority for the City of Syracuse, and Glenn Jolly, USGS, Reston (Jolly, 2005, Jolly, 2006, Jolly, 2012, Sukerfort & Halfman, 2005, 2006, Sukerfort et al., 2006). The chloride concentrations measured from Hemlock, Canadice and Skaneateles Lakes reveal two periods of time when the chloride concentration noticeably increased from under  $\sim 10$  mg/L to  $\sim 15$  in the 1960s and again to  $\sim 30$  mg/L in the 1990s. These concentration trends are typical of basins influenced by rising road salt applications throughout northeastern US. They are also in steady state with the fluvial inputs (Halfman, 2014).

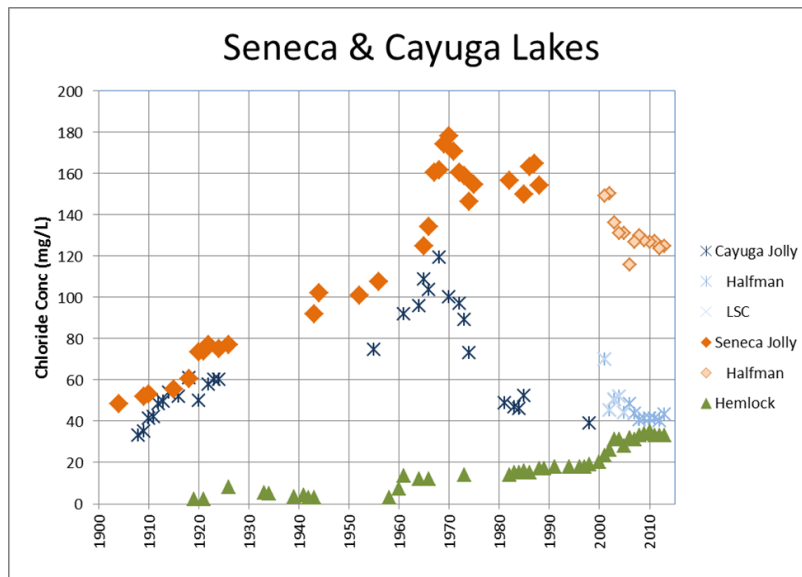


Fig. 5. Century-scale, annual mean, chloride concentrations in Seneca, Cayuga and Hemlock Lakes (Halfman 2014). The concentration trend in Hemlock parallels those measured in Canadice and Skaneateles Lakes.

Century-scale chloride concentrations in Seneca and Cayuga Lakes were consistently larger (up to 200 mg/L) and follow a different temporal trend. In Seneca, and to a lesser extent in Cayuga Lake, chloride concentrations steadily increased from 40 mg/L in the early 1900s to a pronounced peak starting at 1965 that lasted for 5 to 10 years. Chloride concentrations declined afterwards, the decreasing trend is consistent with the decade-scale data. Some scatter is observed in the raw data, especially during the 1965 to 1975 concentration peak, but the century-scale trend is unique from records elsewhere in the region. The decline since 1975 is notable because it declined in both lakes despite likely increased fluvial inputs of chloride from road salt runoff over time.

In the Cayuga Lake watershed, Effler et al. (1989) showed that the decrease in chloride concentrations since the 1965 to 1975 peak is consistent with an abrupt decrease in salt mine wastes input into the lake in the 1960s, and subsequent freshening of the lake since. Currently, the lake is near equilibrium with the entering fluvial and mine waste fluxes. The 1970s timing corresponds with a major change in the disposal methods for salt tailings from the Cargill Rock-Salt Plant in the Cayuga watershed. This change significantly decreased chloride disposal into the lake. Now, chloride concentrations in Cayuga Lake are similar to the saltier members of other Finger Lakes, and suggest that the chloride in Cayuga Lake reached equilibrium from its 1960s slug and has now returned to steady-state conditions as predicted by Effler. It also implies that mining practices probably controlled the pre-1960 elevated chloride concentrations. Thus, Cayuga Lake may never have received any groundwater inputs over the past century.

In the Seneca Lake watershed, chloride concentrations were modeled using a non-steady state, mass balance approach to determine the input of chloride required to attain to historical chloride concentrations (Fig. 16, Halfman et al., 2012). The model assumed a constant inflow of water ( $863 \times 10^6 \text{ m}^3/\text{yr}$ ), a constant evaporation rate ( $103 \times 10^6 \text{ m}^3/\text{yr}$ ) and a constant surface water outflow ( $760 \times 10^6 \text{ m}^3/\text{yr}$ ) as before. It also

assumed an initial input of chloride (30,000 mtons/yr) to attain an assumed pre-1900 chloride concentration of 40 mg/L in the lake. The model could not differentiate one chloride source from another due to a lack of information. Rather it lumped all sources together into one to determine the total quantity of chloride, in units of the initial input (30,000 mton/yr), that must be added to, or removed from, the lake to mimic the concentration distribution over time.

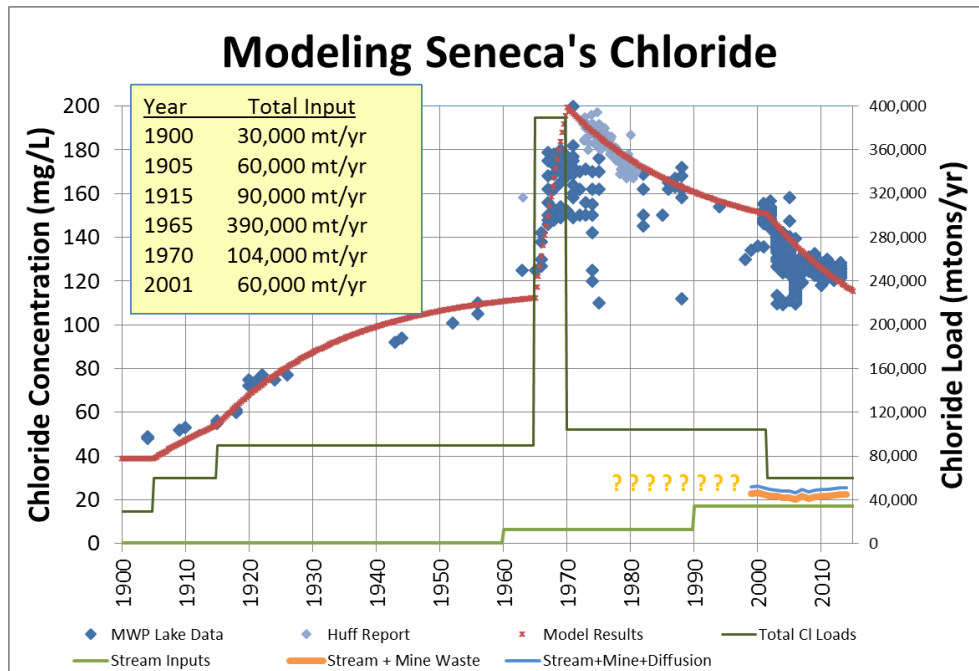


Fig. 6. Modeling chloride inputs to attain Seneca’s chloride concentrations over the past century (Halfman 2014). The green line depicts the total annual load of chloride required to “match” the historical concentrations in the lake. Note the huge spike of chloride that must enter the lake in the late 1960s to balance the observed concentrations in the lake at that time.

Some intriguing generalizations are possible from this model. Today’s concentration is currently close to equilibrium concentrations with the current inputs from the streams and solution salt mines in Watkins Glen. More importantly, the decrease in concentration from the 1960s and 1970s reflects the time required to naturally flush out the chloride from the lake due to its 18-year residence time. The concentrations in the early 1900s were presumably from inputs of chloride from streams and mine wastes. Assuming similar stream and lake concentrations detected in the historical records for Fall Creek and Hemlock, Canadice and Skaneateles Lakes, the amount of mine wastes must have been larger in the early 1900s to attain the lake’s chloride concentration. Mine discharge data are unavailable to confirm this possibility.

Finally, chloride inputs peaked significantly in the 1960 and 1970s. The peak required approximately 400,000 metric tons of salt to be added to the lake for five years. The source is not completely understood. Brine pool leaks, injection of saline wastes into leaky fractured bedrock (carbonates, sandstones and shales), dust from piles of rock salt and other issues at the abandoned hard-rock Morton-Himrod mine located in the Plum Point subwatershed partially influenced the 1965 to 1975 chloride peak detected in the lake. Unfortunately, those inputs do not explain the entire peak in chloride inputs. It is suspected that the input of salt wastes from the



salt mines in Watkins Glen were significantly larger at this time, and only decreased after the mid-1970s when regulations by the EPA and NYS-DEC through the Clean Water Act forced a reduced in the tonnage of mine wastes discharged into Seneca Lake. Data are not publicly available to answer this question. We use this dataset to model the time required (multiple residence times) to flush of a “pollutant” from a lake in various courses at HWS.

## ZEBRA/QUAGGA MUSSELS IN SENECA LAKE

The lake floor benthic community is dominated by the invasive zebra/quagga mussels (*Dreissena polymorpha*, and *D. rostriformis bugensis*, respectively), with lesser amounts of diporia and various other clams, midges and worms (Halfman et al., 2012). Zebra mussels were first detected in the lake in 1992, and soon afterwards they were firmly established on suitable substrates throughout the lake. Quagga mussels were first detected in 2001. Both mussels originated from Eastern Europe to the Great Lakes and probably travelled through the Erie Canal and the Seneca River to Seneca Lake.

Unfortunately, only a few studies investigated the density of zebra and quagga mussels in Seneca Lake. Lake wide investigations in 2002, in 2007, and a third duplicated a N-S, mid-lake transect in 2001 and 2011 (Shelley et al., 2003; Zhu, unpublished data; Dittman, unpublished data, Halfman et al., 2012, Halfman unpublished data, Fig. 7). In each study, lake-floor densities (individuals/m<sup>2</sup>) were determined for live zebra and quagga mussels. Spatially, zebra mussels preferred the shallow water, less than 40 meters depth, whereas quagga mussels preferred the shallow water depths but were also recovered from deeper depths, some from depths of 160 m. Both mussel populations declined in water depths shallower than 5 m, presumably from significant wave action stirring up the lake floor sediments and substrate. Temporally, zebra mussel populations between 10 and 40 m declined since 2002 and were rarely detected since 2011. Presumably, quagga mussels out competed the zebra mussel for this ecological niche. If found in recent years, zebra mussels are attached to a hard substrate, like a monitoring buoy, mooring ball, anchor line, piling or dock, as quagga mussels dominate the populations in the sediments. The population of quagga mussels at 10 to 40 m depths declined from 2002 but the total population probably increased if deeper depths are included in the tally.

Zebra and quagga mussels are filter-feeding organisms. They remove particles from the water column. Each zebra mussels processes up to one liter of water per day. Some particles are consumed as food, whereas nonfood and “yucky” particles are combined with mucus and are deposited on lake floors as pseudofeces. They therefore effectively remove plankton from the water column, and increase lake clarity over time. The increased clarity allows sunlight to penetrate deeper, enabling growth of submerged macrophytes at deeper depths. These plants, when decaying, wash up on shorelines, and foul beaches and cause other water quality problems. The filtering of open water algae and deposition of feces in the nearshore sediments effectively transports the major source of phosphorus, the limiting nutrient in the lake, from algae in open pelagic waters to the sediments, macrophytes and other organisms in shallow water locations (Hecky et al., 2004).

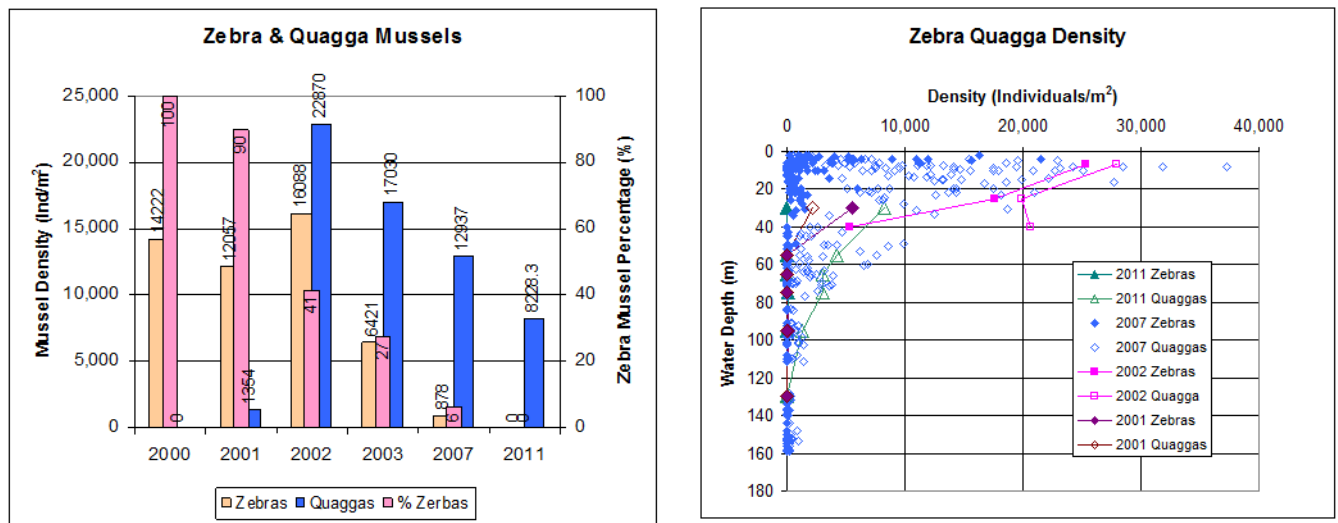


Fig. 7. Zebra and quagga mussel populations from 10 to 40 meters (left) and depth distributions (right) over the past decade. The 2001 to 2011 data exhibited a significant increase in quagga mussel densities at depths deeper than 40 m (D Dittman, unpublished data, not shown here).

Similar processes are inferred from basic Secchi disc depths and other limnological data collected from Seneca Lake. Secchi disk data since 1990 reveal two major temporal trends (Fig. 8). From 1992 through 1997, annual average Secchi disc depths were progressive deeper from 3 or 4 meters in the early 1990s to 7 to 8 meters by the end of 1997. Similar trends were detected in the Seneca River, the outlet to Seneca Lake over the same time frame (Effler et al., 1996). Subsequently, mean annual Secchi disc depths during the stratified season in Seneca Lake have shallowed up to 2 to 5 meters by 2018. Interestingly, the isothermal Secchi disc depths have deepened, up to 20+ meters, in the past decade. Presumably light limited algae during the isothermal winter months result in scarce food supplies for and perhaps regulate the mussel populations. Consistent changes were observed in chlorophyll-a data (Halfman et al., 2012 & Halfman unpublished data).

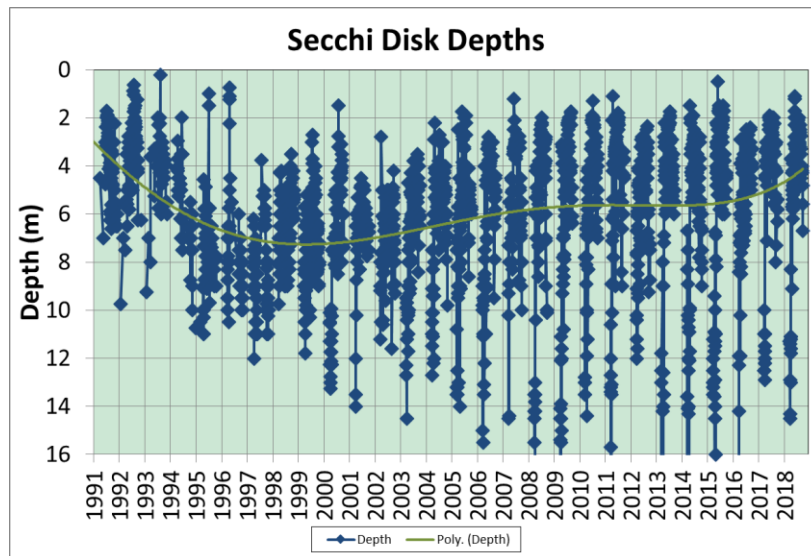


Fig. 8. Weekly Secchi disc depths from four sites in the northern end of Seneca Lake. The green line is a fifth order polynomial through the raw data.

The 1992 through 1997 trend is consistent with increased grazing by the growing population of filter-feeding zebra mussels in the early 1990s (Halfman et al., 2001; Halfman and Franklin, 2008) and consistent with findings elsewhere (e.g., Strayer, 2010). The trend reversed after the initial major die off of zebra mussels in 1998. The die off and associated bacterial decomposition of the mussel biomass released the previously sequestered nutrients back into the water column during 1998 and 1999, as reflected in increasing TP, N, SRP and algal concentrations and decreasing Secchi disc depths. The lake became progressively more impaired since, as shown by shallower Secchi dish depths and larger chlorophyll concentrations (Halfman et al., 2010, Halfman et al., 2012 & Halfman unpublished data).

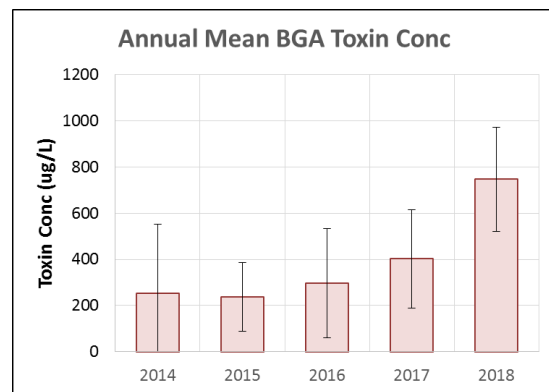
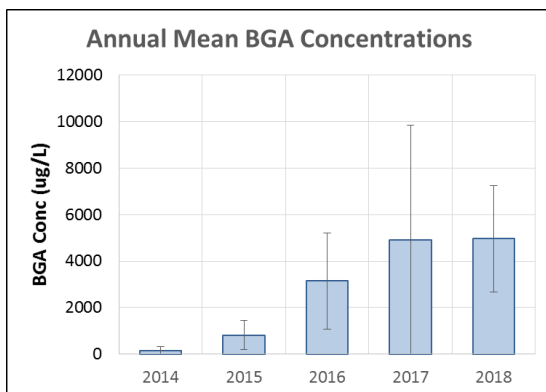
Various factors may have contributed to the decline in water quality over the past decade. First, the available but sparse mussel density data suggest that both zebra and quagga mussel populations declined since 2002 (B Zhu, unpublished data; D. Dittman, unpublished data; Shelley et al., 2003). Zebra mussels posted the largest decline, from 100% to 0% of the total mussel population between 10 and 40 meters of water from 2000 to 2011. Thus, the mussel impact on and reduction of the algal populations probably decreased as well. Unfortunately, these conclusions are speculative at this time because the data were collected from a variety of water depths and site locations, and mussel densities are depth and site sensitive and the surveys excluded water depths greater than 40 m where large populations of quagga are suspected to exist. Second, nutrient loading could have stimulated algal growth and decreased Secchi disc depths. Stream hydrogeochemistry data and preliminary basin-wide phosphorus budgets highlight a nutrient loading issue (Halfman et al., 2012).

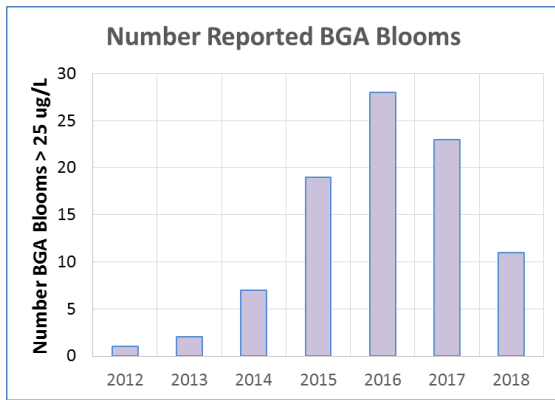
Evidence from several Finger Lakes watersheds studies linked nutrient loading to water quality degradation (e.g., Halfman et al., 2008; Makarewicz et al., 2009; Effler et al., 2010; Halfman et al., 2012; UFI et al., 2014; Halfman et al., 2016; Halfman 2016; Halfman, 2017). For example, annual mean SRP concentrations in the Seneca Lake watershed are consistently 10 to 100 times larger in tributaries draining the watershed than in the lake, indicative of a nutrient loading problem. Estimated inputs typically exceed outputs by 45 metric tons of phosphorus each year, about a third of the total amount of phosphorus in the lake (Halfman et al., 2012). The

phosphorus sources to Seneca Lake are multifaceted and included: runoff from agricultural fields, municipal wastewater treatment facilities, soil, road ditch and stream bank erosion, construction activities, lakeshore septic systems, and atmospheric deposition. More research is required to quantify the contributions from each source.

Research in the Owasco watershed highlights the importance of precipitation events on nutrient loads (Halfman et al., 2018a). Event vs. base flow measurements at Dutch Hollow Brook, an agricultural-intense subwatershed, revealed that over 90 percent of the nutrient and sediment loads were transported during precipitation-induced runoff events as compared to base flow inputs, especially in the spring season (e.g., Halfman et al., 2018). Annual nutrient and sediment loads positively correlate to precipitation totals as well, especially precipitation totals during the spring months ( $r^2 = 0.8$ , Halfman et al., 2018). Thus, rainfall events and runoff from agricultural areas are significant to the delivery of nutrient and sediments to the lake.

The recent rise in BGA blooms and their associated toxins, with toxin concentrations occasionally above MCL thresholds in many Finger Lakes, is disturbing (R. Gorney and S Kishbaugh, NYSDEC, 2018, Fig. 9). To date BGA blooms have been detected in every Finger Lake. The most disturbing aspect is that BGA blooms were detected in some very oligotrophic (Canandaigua, Skaneateles) and mesotrophic (Cayuga, Owasco, Otisco, and Seneca) lakes as well as the expected eutrophic (Honeoye) systems. Data from Owasco Lake and bloom histories for all the Finger Lakes are shown below (Fig. 9). Perhaps the pervasive nutrient loading issues combined with the nearshore shunt by the invasive mussels have contributed to the recent rise in blue green algae blooms (Halfman et al., 2018b). More research is required to conform this hypothesis.





Lake	'12	'13	'14	'15	'16	'17	'18
Conesus			Confirmed	Confirmed	Confirmed	Confirmed	Confirmed
Hemlock						Confirmed	Confirmed
Canadice						Confirmed	
Honeoye	Confirmed	High Toxin	Confirmed	High Toxin	Confirmed	Confirmed	Confirmed
Canandaigua				High Toxin	Confirmed	High Toxin	High Toxin
Keuka						High Toxin	High Toxin
Seneca				Confirmed	High Toxin	High Toxin	High Toxin
Cayuga			Suspicious		Confirmed	High Toxin	High Toxin
Owasco		High Toxin	High Toxin	High Toxin	High Toxin	High Toxin	High Toxin
Skaneateles						High Toxin	High Toxin
Otisco				Suspicious		Confirmed	Confirmed

Suspicious: Light Blue  
 Confirmed: Blue  
 High Toxin: Red

Fig. 9. Annual mean ( $\pm 1\sigma$ ) blue green algae (left top) and toxin (right top) concentrations and the number of conformed blooms (bottom left) reported in Owasco Lake (HABs Shoreline Surveillance volunteers and the Owasco Lake Watershed Inspector's office). The number of Finger Lakes with reported blue green algae blooms since 2012 (bottom right, by permission DEC).

## ***WILLIAM SCANDLING***

The *William Scandling* (formerly the *H-WS Explorer*) is a 65-ft long, steel hulled, single screw, 200 hp diesel powered vessel built in 1954 for the United States Navy. Hobart and William Smith Colleges acquired the vessel in 1976 after it had also been used in, e.g., the lobster and fishing industries. The vessel is documented “Oceanographic” by the United States Coast Guard and meets all of the standards applicable to such a vessel. In 1989, major renovations resulted in the construction of a 20 by 10 ft laboratory on the main deck to complement the growing list of standard oceanographic/limnologic equipment including multiple Sea Bird CTD’s (Conductivity, Temperature, Dissolved Oxygen, pH, Turbidity and Depth sensors), EdgeTech (EG&G) X-Star high-resolution seismic reflection system, EdgeTech sidescan sonar, piston and box corers, computers, flume hood, weather station and other equipment. The pilot house has a full complement of safety, navigation and communication equipment including up-to-date radar, satellite navigation, marine radio-telephone, cellular phone and other equipment. Most importantly, the vessel is operated by a licensed captain and mate. It provides a safe, well-equipped platform useful under most weather conditions experienced on Seneca Lake.



## **CRUISE LOG**

This field trip starts and stops dockside aboard the *William Scandling*, and investigates the water chemistry and surface sediment character at a number of locations in the northern portion of the lake. No specific “Road Log” is required.

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## Trip A4

# ECOLOGY AND GEOMORPHOLOGY OF ZURICH BOG

NAN CRYSTAL ARENS

*Department of Geoscience, Hobart & William Smith Colleges, Geneva, NY 14456*

## INTRODUCTION

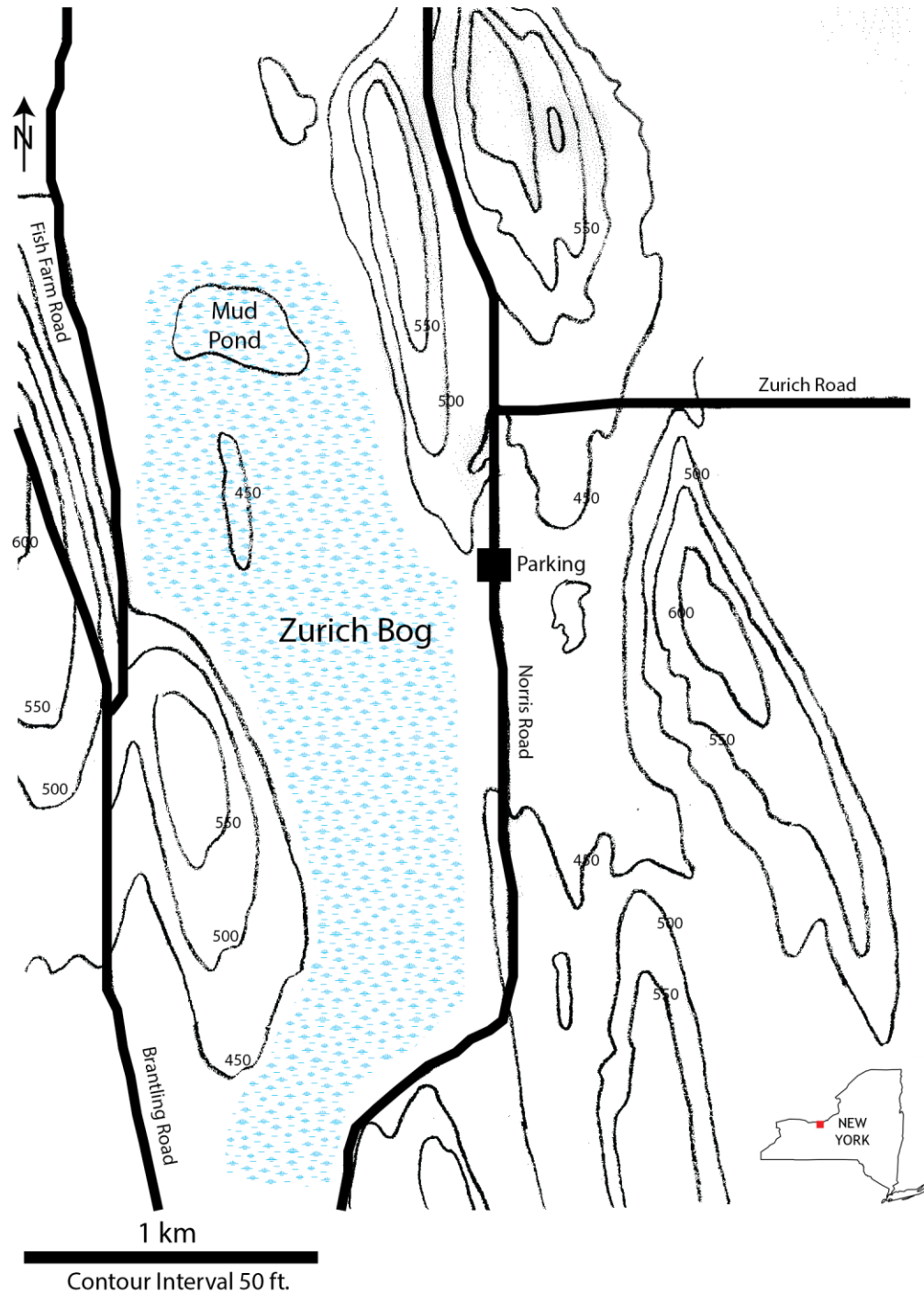
Zurich Bog is an approximately 650-acre wetland complex located in the Wayne County, New York town of Arcadia (Fig. 1). Four hundred fourteen acres of the site are owned and managed by the Bergen Swamp Society, a private non-profit organization that conserves five wetland preserves in western New York State. The Zurich Bog preserve is designated a U.S. Department of the Interior National Natural History Landmark. Access to and research in Zurich Bog requires a permit from the Bergen Swamp Society ([www.bergenswamp.org](http://www.bergenswamp.org)). The land is managed as a conservation, education and research site and is not used for recreation.

The Zurich wetland complex is situated in the Erie-Ontario lowlands, nestled between two tall drumlins (greater than 600 ft. elevation, nearly 200 ft. above the bog surface) that form a natural basin in which the wetland developed. Coring in the bog by several groups documented clay-rich layered marl underlying the peat. These marls are interpreted as sediments from Glacial Lake Iroquois (T. Curtin personal communication, 2019). Low permeability in this clay marl may have contributed to the retention of water in the wetland complex. A smaller drumlin (approximately 450 ft. elevation, Fig. 1) creates a topographic high—an “island” of mineral soil—within the preserve that offers additional substrate diversity and enhances the plant species richness of the site. The wetland complex is underlain by bedrock of the Lockport Formation, Middle Silurian-age dolostones with some limestone and halite, preserved as macroscopic euhedral crystals in some places. Bedrock is not visible in the preserve although glacial till and abundant erratics are visible on the drumlin island.

The Zurich wetland complex is a persistent wetland, with the water table remaining near the surface throughout the year, except in conditions of extreme regional drought. Following the nomenclature used by Johnson (1985), the Zurich wetland complex can be divided into four distinct zones based on substrate characteristics and hydrology. Marshes and swamps are characterized by mineral substrate, though their high water table commonly yields organic-rich soils. Marshes are characterized primarily by herbaceous vegetation and swamps are dominated by woody vegetation with an herbaceous understory. In contrast to wetlands developed on mineral soils, Johnson (1985) distinguished peatlands, which have entirely organic soils. Within peatlands, Johnson (1985) distinguished bogs and fens based on their water source. Bogs are ombrotrophic—fed almost entirely by rainwater. In contrast, fens are fed primarily by groundwater. This

contrast renders bogs oligotrophic (nutrient poor) and generally acidic. Fens have significantly higher nutrient content (eutrophic) due to the influence of groundwater percolating through mineral bedrock. Fens like those at Zurich Bog, which received groundwater from carbonate bedrock, can be rich in  $\text{Ca}^{++}$  and  $\text{Mg}^{++}$  and neutral to alkaline in pH due to the buffering influence of bedrock. These hydrologic contrasts control the vegetation associations on bogs and fens as plant species seek preferred substrates across the landscape. This feature of wetland ecology is well-illustrated at Zurich Bog.

The Zurich wetland complex is of considerable biological—particularly botanical—interest because its diversity of ecotypes leads to an unusually high diversity of plant species, including some listed as threatened and endangered by New York State and the U.S. Department of Interior Endangered Species Act. The wetland also contains a mixture of cool-climate early Holocene plants and those typical of the hypsothermal assemblage in the region. The persistence of cool-climate plants in this site further enhances species richness. A resident turtle, *Clyptemys muhlenbergii* (bog turtle), is also listed as threatened or endangered by both state and federal agencies.

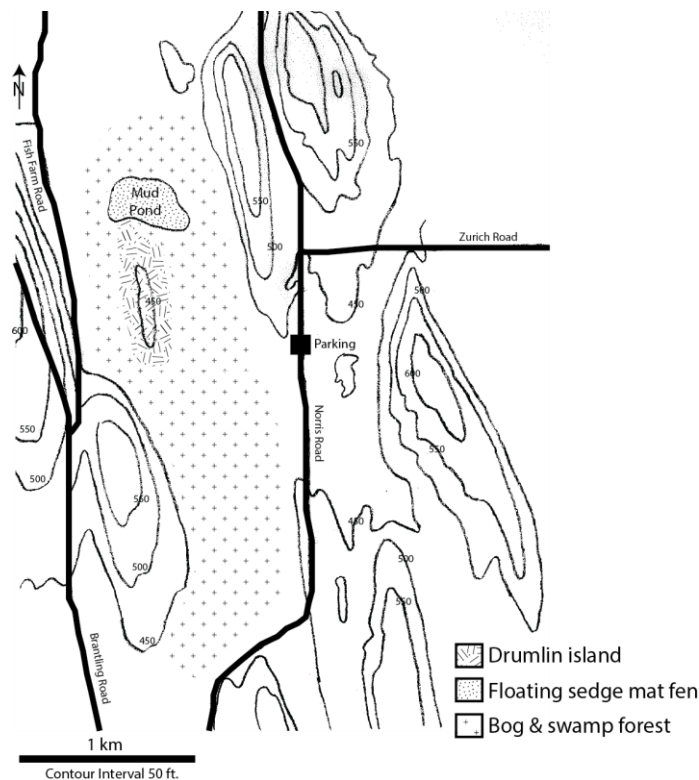


**Figure 1:** Topographic sketch map of the Zurich Bog wetland complex. Redrawn from the USGS 7.5 minute quadrangle Sodus, NY (2016).

## Hydrology and Geochemistry

Wetlands, like the Zurich complex, are important components of watershed hydrology. They can absorb tremendous amounts of water during extreme rainfall events or rapid snow melt, making them vital to flood control. Goodwin (1931) estimated that the upper 20–50 cm of a bog may be up to 10% pore space, allowing for significant uptake of water. He measured a 7–12 cm rise in water table associated with a 1 cm rainfall event in an English fen (Goodwin, 1931). Conversely, bogs and fens release water slowly during precipitation deficit. Farmers to the north of the Zurich wetland complex have created irrigation channels to irrigate crops during the late summer and autumn drought.

The Zurich wetland complex can be divided in three main zones (Fig. 2): 1) drumlin island dominated by well-drained mineral soils derived from weathering of glacial till; 2) fen characterized by a floating sedge mat with a small area of open water in Mud Pond<sup>1</sup>; and 3) the *Sphagnum*-dominated bog and associated forested swamp.



**Figure 2:** Distribution of hydrogeochemical zones within the Zurich Bog wetland. The Drumlin islands is characterized by well-drained mineral soils. The fen is a ground-water fed quaking bog. The bog and swamp zones are ombrotrophic peatlands with a variety of vegetation.

### Floating Sedge Mat Fen

This section of the wetland complex is characterized by a dynamic combination of open water and a floating sedge mat (quaking bog) that supports other vegetation including shrubs and small trees. Over the last several decades, the area of open water has generally declined as the sedge mat and the other species it supports extend toward the interior of Mud Pond. Today, little open water is visible most years. The sedge

<sup>1</sup> In recent years, there has been little or no open water in Mud Pond. The pond's entire surface is covered in floating sedge mat.

mat overlays a zone of poorly consolidated, saturated peat that extends to depths of tens of meters. Groundwater flow is from the southwest to northeast in the fen (Halfman, 1999; Flusche, 2000), where water then mixes with flow derived from the *Sphagnum*-dominated bog. A piezometer field installed in the sedge mat fen during the late 1990s found very low and variable vertical flow that fluctuated seasonally. Low precipitation in 1999, the primary monitoring season, showed net infiltration (Flusche, 2000), which might be due to slow recharge and the resulting dropping of the groundwater table in response to drought.

Fen water is primarily derived from groundwater and is neutral to alkaline (pH = 6.6–7.3, Flusche, 2000) due to the influence of carbonates in the surrounding glacial till, which is derived from underlying carbonate bedrock. Ca<sup>++</sup> dominates the fen water (39–110 ± 3 ppm, Flusche, 2000). Mg<sup>++</sup> (9–26 ppm ± 1) and Cl<sup>-</sup> (26–84 ± 1 ppm) are also high, likely due to the halite-rich Lockport dolostone that underlays the region and from which the local till is derived. Nitrate and ammonia are low. Ion concentrations follow the pattern of flow from high in the southwestern part of the fen, where groundwater enters the system, to lower in the northeastern, where mixing with low-ion water from the *Sphagnum* bog dilutes ion concentrations (Flusche, 2000).

#### *Sphagnum*-Dominated Bog

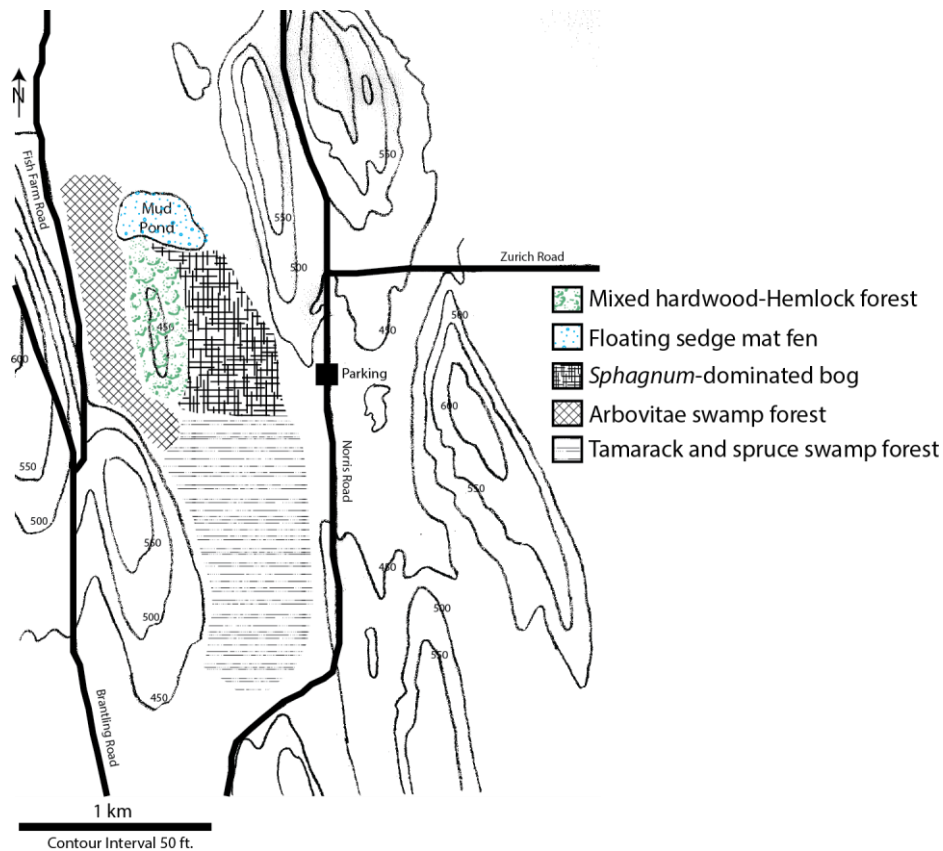
Bogs receive their water exclusively from precipitation (Johnson 1985). This yields low pH (typically < 4.5) due, in part, to the low pH of source water (Gorham et al., 1985). In the case of the Zurich complex, isolation from airborne ion sources such as dust and air pollution limit further buffering. Biomass in the bog is dominated by several species of *Sphagnum* moss native to the northeast. Dominant *Sphagnum* further lowers pH by a combination of organic acids released by the living plants, uptake of buffering ions as micronutrients, and the activity of sulfur-metabolizing bacteria, which are both decomposers and commensals within the bog microbiome (Clymo, 1964). Bog water is also low in sulfate, nitrate and ammonia due to low input and rapid plant uptake of these macronutrients (Gorham et al., 1985). This nutrient poor environment provides a refuge for plants with limited nutrient needs (e.g., orchids like the prairie fringed orchid *Platanthera leucophaea*) and for charismatic carnivorous plants like sundews (e.g., *Drosera intermedia* and *D. rotundifolia*) and the purple pitcherplant (*Sarracenia purpurea*).

Water flow in bogs is generally through the upper, high-porosity layers of the peat, with deeper layers believed to be largely impermeable due to the loss of pore space during peat compression (Johnson, 1985). Siegel and Glaser (1987) challenged this notion with higher than expected  $K_{\text{horizontal}}/K_{\text{vertical}}$  ratios in some Minnesota bogs. Although similar measurements have not been taken in the Zurich bog, geochemical measurements suggest mixing of low and high cation waters primarily at the surface (Flusche, 2000).

## ECOLOGY AND BOTANY

This region is part of the Eastern Lake Section of the Central Lowland Floristic Province. Within the Zurich wetland complex, the hydrology of wetlands generally determines the distribution of plant and animal species. Bogs tend to harbor plants tolerant of low-nutrient conditions and saturated substrates. In contrast, fens will be dominated by species that can compete more successfully in higher-nutrient environments.

Several vegetation zones have been recognized in the Zurich wetland (Fig. 3): 1) mixed-hardwood and Hemlock (*Tsuga canadensis*) forest developed on the exposed drumlin island; 2) floating sedge mat fen; 3) *Sphagnum*-dominated bog; 4) *Arbovitae*-dominated swamp; and 5) Tamarack (*Larix laricina*) and black spruce (*Picea mariana*) swamp (Stauffer and Moosavi, 1991). While the drumlin and fen vegetation zones correspond directly to their hydrological counterparts described above, the ombrotrophic bog can be subdivided according to its successional status. In the northeast, ombrotrophic bogs begin with a *Sphagnum*-dominated association and, through time, succeed to shrub and tree-dominated assemblages that differ in species composition. In space, shrubs and trees enter the bog from its edges and successional assemblages develop in concentric zones (Dachnowski, 1912). Proga (1982) documented this concentric pattern in a series of vegetation transects across the bog.



**Figure 3:** Distribution of vegetation zones within the Zurich Bog wetland. Vegetation parallels the distribution of hydrological zones with the additional overprint of successional status in the ombrotrophic peatlands. Redrawn and updated from Stauffer and Moosavi (1991).

### Mixed Hardwood-Hemlock Assemblage

The mineral soils of the preserve's island drumlin are characterized by a mixed age stand of Eastern Hemlock (*Tsuga canadensis*). Although dominated by Hemlock, other hardwood species including mature red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), black cherry (*Prunus serotina*), red oak (*Quercus rubra*), beech (*Fagus grandifolia*), white pine (*Pinus strobus*), and tulip tree (*Liriodendron tulipifera*) can be found. Botanical enthusiasts have reported seedlings of American elm (*Ulmus americana*) within this small patch of forest. Understory herbs include false solomon's seal (*Smilacina racemose*), Indian cucumber (*Medeola virginiana*)

and several species of trillium (e.g., *Trillium grandiflorum* and *T. erectum*). In low-lying wet areas, grape fern (*Botrychium virginianum*) dominates.

An interesting component of this vegetation is the mixed-age nature of the Hemlock stand. Whilst most hardwoods are fully mature with little regeneration, the Hemlock component includes stems of all age classes. To my knowledge, the Hemlocks of Zurich Bog have not been cored for age determination, but stem size suggests that some trees may be several hundred years old, perhaps predating European settlement of the area. This raises the interesting question of how this stand escaped clear-cutting during the colonization period. It seems likely that despite the value of both Hemlock and the other hardwoods as building and cabinetry species, the difficulty of traversing the bog made logging of this tiny patch or forest impractical. Furthermore, Hemlock is highly fire intolerant. Consequently, Hemlock stands are relatively rare in the Ontario Lowlands, where indigenous people historically managed forests with fire. The regenerating Hemlock stand may persist on Zurich's drumlin island because it was further protected from fire by the surrounding wetland. Although indigenous people used *Sphagnum* and other bog species for many purposes, there were few native plant resources on the drumlin island that were not present in more accessible parts of the surrounding landscape. Thus, the drumlin island might have served as a refuge for Hemlock.

#### Floating Sedge Fen

Floating fens, also known as quaking bogs, are relatively rare. They form during pond succession in which the drop off into the pond is too steep to allow vegetation to gradually build peat inward from the edges. They also require the high-nutrient fen environment to support sedges. To form the floating fen, a dense mat of sedge (e.g., *Scirpus* spp.) forms over poorly consolidated waterlogged peat. Such mats are generally 10–20 cm thick and dense enough to support an adult's weight. At Zurich Bog, the quaking bog is a delight to visitors who enjoy the "waterbed" sensation of walking across the fen.

Although tolerant of the wetland's saturated substrates, *Scirpus* and associated species like *Eleocharis* spp. and twig-rush (*Cladium mariscoides*) require high nutrient levels. Therefore, they are restricted to the fen. At the boundary between mineral soil and the fen (known as the lagg), nutrient loving plants such as cattail (*Typha angustifolia*) dominate. Lagg plants do not form the dense, weight-supporting mat characteristic of the fen itself and this is the spot where a misstep may cause visitors to sample the underlying peat! Within the last two decades, the lagg zone at Zurich Bog has been invaded by aggressive non-natives such as the common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*). Over time, the sedge mat has been colonized by water willow (*Decodon verticillatus*) that moves in from the margins. The sedge mat hosts abundant purple pitcherplant (*Sarracenia purpurea*), bog twayblade (*Liparis loeselii*), bladderworts, and club moss. The precise species composition, particularly for rare species, varies considerably over time likely due to changing hydrological and nutrient conditions. For example, bogbean has been reported within the fen association in the past but was absent during surveys in the mid-1980s (Stauffer and Moosavi, 1991). Whether this can be considered an extirpation or simply the waxing and waning of the distribution within the preserve is not known.

#### Sphagnum Bog

The *Sphagnum*-dominated bog is characterized by a peat substrate with low pH and very low nutrient conditions. This dramatically restricts the suite of vascular plants that can colonize this zone. Carnivorous plants capable of harvesting nitrogen from animal sources are common in this part of the preserve. Sundews (*Drosera intermedia* and *D. rotundifolia*) produce sticky liquid on the tips of hairs to capture small flying

insects. The purple pitcherplant (*Sarracenia purpurea*) captures insects and small vertebrates in a fluid-filled pitcher laced with digestive enzymes. A variety of orchids, including the threatened prairie white fringed orchid (*Platanthera praeclara*) are abundant.

Today, the edges of the *Sphagnum*-dominated bog are protected by a dense stand of highbush blueberry (*Vaccinium corymbosum*) and black huckleberry (*Gaylussacia baccata*). While tolerant of the low nutrient, acid soils, these species do not tolerate waterlogged substrates and thus cling to the edge of the zone.

The composition of the shrub component of the *Sphagnum* bog has changed significantly through time as a consequence of human activity. Between 1876 and 1900, bog peat was hand cut for florist's moss. This stripped vegetation to a depth of about one meter and removed living *Sphagnum* and other vascular plants. Following this disturbance, leatherleaf (*Chamaedaphne calyculata*) colonized the bog and became the dominant shrub. Peat harvest resumed from 1940 to 1943. Leatherleaf did not return in abundance at that site and the current association of highbush blueberry, huckleberry and black chokeberry (*Aronia melanocarpa*) colonized. Furthermore, the small white lady's slipper (*Cypripedium candidum*), ram's head lady's slipper (*C. arietinum*), and linear-leaf sundew (*Drosera linearis*) have not been reported in the bog between 1939 and 1982.

#### Swamp Associations

Two swamp forest associations are recognized within the preserve (Stauffer and Moosavi, 1991): one dominated by arborvitae (*Thuja occidentalis*, also known as northern white cedar) occurs to the west of the drumlin island, and the other dominated by black spruce (*Picea mariana*) and tamarack (*Larix laricina*) is found to the south and east. Both represent advanced successional stages in the bog ecotype. There is no clear evidence to explain the differences in species dominance in these swamps. It seems likely that priority of colonization determined the dominant trees and shrubs in these two areas.

#### Dynamic Vegetation

Any description of the Zurich wetland complex vegetation will necessarily be transient. Like all wetlands, the Zurich complex is in a state of succession that has transformed it from post-glacial ponds with substantial open water, through fen, bog and swamp forest associations. Over time, forest associations will dominate the whole preserve. Of course, human activity may reset the successional clock as it did when peat was harvested in the early 20<sup>th</sup> Century.

The nature of this natural succession calls managers to reflect on the goals of preservation. Is our goal to preserve the natural change in ecological systems, which may eventually lead to the extirpation or extinction of rare and cherished species? Alternatively, do we manage to maintain a particular snapshot of succession with a particular suite of species and associations? And if the latter, which moment in time do we choose to preserve? These questions become increasingly relevant as we enter a period of rapid climate change in which patterns of temperature and precipitation will change the hydrology and temperature range for this region in ways that may drift outside the preferences of some species that thrive in the reserve today.

## VEGETATION HISTORY AND CLIMATE

No palynological reconstructions of the Zurich Bog vegetation have been published. However, post-glacial succession likely progressed as in other areas in the region. Early colonizers were likely grasses and sedges



along with low-bush willow (*Salix*), alder (*Alnus*) and birch (*Betula*) (Maenza-Gmelch, 1997). This association was followed by cold-tolerant pine, spruce and fir forests. At Zurich Bog today, *Picea mariana* is a relic of this association. Other cool-climate relics include tamarack (*Larix laricina*) found in the swamp association, and leatherleaf (*Chamaedaphne calyculata*), Labrador tea (*Ledum groenlandicum*) and cranberry (*Vaccinium oxycoccus*) found in the *Sphagnum*-dominated bog at the edges of the fen. The presence of these cool-climate relics with other woody species associated with warmer winters (e.g., red maple, American beech, white pine and tulip tree) speak to the vegetation crossroad preserved by Zurich Bog. This mixture of warm- and cool-climate plants enhances species richness in this small area, as does the diversity of substrate types present in the preserve.

In contemporary discussions of climate change, wetlands play an outsized role for their relatively small area. By preserving plant biomass as peat, bogs and fens sequester carbon (Lamers et al., 1999). In addition, wetlands may release methane resulting from anaerobic microbial activity in peat. Whiting and Chanton (2001) report that wetlands have a net carbon sequestration effect. However, the greater infrared absorptivity of methane compared to CO<sub>2</sub> reduced the greenhouse gain due to carbon sequestration. They concluded that temperate wetlands like Zurich Bog have a small attenuating effect on greenhouse warming (Whiting and Chanton, 2001). This, coupled with the biological diversity and aesthetic beauty of wetlands like Zurich Bog provide ample reason to prioritize their preservation.

## FIELD TRIP GUIDE

Field trip meeting point: Parking area of the Zurich Bog preserve 43° 08' 45.7"N, 77° 02' 53.77"W

Parking is limited to four vehicles.

We will proceed on foot into the reserve following established trail and boardwalk through the mixed hardwood association to the *Sphagnum*-dominated bog, Hemlock forest on the drumlin island, and onto the floating sedge mat fen. We will return by the same route.

Water-proof boots are recommended on the fen. Please stay on the established boardwalk and trail through the *Sphagnum* bog to prevent damage to delicate herbaceous plants.

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## Trip A5

# Return to the Tully Valley – the Continuing Environmental Impacts of Natural- and Anthropogenic-Induced Change

**William M. Kappel (Emeritus Scientist)**

*U.S. Geological Survey, 30 Brown, Road, Ithaca, NY 14850*

*Email: [wkappel@usgs.gov](mailto:wkappel@usgs.gov)*

The Tully Valley is the southern extent of the greater Onondaga Trough valley of central New York. A large amount of research has occurred in the valley focusing on the effects of mudboil (mud volcano) discharges on the quality and ecology of Onondaga Creek. Very active land-surface subsidence features are also present, related to 1.) mudboils, 2.) landslides which have occurred in the Tully Valley, most recently in 1993, and reoccurring within two major tributary valleys – Rainbow Creek on the east side of the Tully Valley and Rattlesnake Creek (Fall Creek) on the west side and 3.) brine mining in the southern extent of the valley along its lower east and west valley walls from the 1890s through the 1980s. Removal of halite beds 1,200 to 1,400 feet below land surface have resulted in induced land-surface subsidence within these two brine-mined areas.

The relationship between the brine-mining-induced subsidence and changes in mudboil activity noted in the 1950s is of concern to the Onondaga Nation and local, State, and other water-resource agencies. The reduction of mudboil activity is the ultimate goal—to reduce the discharge of sediment-laden and increasingly-salty water to Onondaga Creek which affects the ecology of the Creek from the active mudboil area down to Onondaga Lake at Syracuse.

### **ROADSIDE STOPS OVERVIEW**

This fieldtrip will visit three areas:

1. The Tully Valley Mudboils along the floor of the valley
2. The 1993 landslide area on the western valley wall, north of the mudboil area

-Lunch break-

3. The former Brine Field area – eastern valley wall

Discussions at each location will center on the continuing changes seen in areas 1 and 2, and the interrelationship between the brine field areas and the down-gradient mudboil area as currently understood. Dependent on arrival of fieldtrip participants from Hobart-William Smith, we will break from the fieldtrip, likely after the 1993 landslide site and travel up and over the Tully Moraine for a lunch and “pit stop”. Dependent on your tastes there is a fast food restaurant (Burger King), or a gas station deli (Circle K) at the Tully interchange at I-81 or you can bring your own. We will allow about an hour for you to replenish yourself before heading back into the valley to visit the eastern brine field area.

## Disclaimer

All field sites to be visited 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 site on our own, as it may jeopardize future field-trip opportunities. Over the past several decades it has become difficult to maintain our access agreements as individuals and even groups of people enter these properties without land-owner permission. We continue to maintain good relations with the land owners and do not want inappropriate actions of a few to ruin the educational opportunities for future visitors who wish to visit these areas. The USGS is one 'gatekeeper' for the property owners and we would be happy to facilitate your future educational access to these sites. Please contact USGS (Bill Kappel) for any questions of access.

Secondly, in order to have access you must fill out waivers of liability (hold harmless agreements) required by the respective land owners. These forms will be made available to you prior to the fieldtrip and will need to be completely filled-out, signed, and turned in at the first fieldtrip site.

## RESEARCH OVERVIEW

This fieldtrip will be a retrospective assessment of activities which have occurred since 2007 at the NYSGA 79<sup>th</sup> annual meeting at the State University of New York at Cortland, and the earlier fieldtrip in 1997 at the NYSGA 69<sup>th</sup> annual meeting at Hamilton College – Clinton, New York. The two fieldtrips that occurred in 2007 are summarized in the fieldtrip guidebook for the 79<sup>th</sup> annual meeting (Fieldtrips A-1 and B-1) and the supporting documentation from that guidebook will not be reproduced here as it can be found on the NYSGA website –

[http://www.nysga-online.net/wp-content/uploads/2018/09/2007\\_bookmarked.pdf](http://www.nysga-online.net/wp-content/uploads/2018/09/2007_bookmarked.pdf)

The 1997 guidebook (fieldtrip A8) can be found on the NYSGA website –

[http://www.nysga-online.net/wp-content/uploads/2018/09/1997\\_bookmarked.pdf](http://www.nysga-online.net/wp-content/uploads/2018/09/1997_bookmarked.pdf)

**Mudboil area** – Background information on the Tully Valley hydrogeology and the mechanics of the mudboils can be found in the following USGS publications and associated links:

Kappel, W.M., Sherwood, D.A., and Johnston, W.H., 1996, Hydrogeology of the Tully Valley and characterization of mudboil activity, Onondaga County, New York, U.S. Geological Survey Water-Resources Investigations Report 96-4043, 71 p. <http://ny.water.usgs.gov/pubs/wri/wri964043/>

Kappel, W.M. and McPherson, W.S., 1998, Remediation of mudboil discharges in the Tully Valley of Central New York, U.S. Geological Survey Fact Sheet FS 143-97, 4 p. <http://ny.water.usgs.gov/pubs/fs/fs14397/>

Kappel, W.M., Miller, T.S., and Hetcher, K.K., 2001, Hydrogeology of the Tully Lakes area in southern Onondaga and northern Cortland Counties, New York, U.S. Geological Survey Water-Resources Investigations Report 01-4166, 16 p. <http://ny.water.usgs.gov/pubs/wri/wri014166/>

Kappel, W.M. and Miller, T.S., 2003, Hydrogeology of the Tully Trough -- Southern Onondaga County and Northern Cortland County, New York, U.S. Geological Survey Water-Resources Investigations Report 03-4112, 16 p. <http://ny.water.usgs.gov/pubs/wri/wri034112/>

Kappel, W.M. and Miller, T.S., 2005, Hydrogeology of the Valley-Fill Aquifer in the Onondaga Trough, Onondaga County, New York, U.S. Geological Survey Scientific Investigations Report 2005-5007, 13 p. <http://ny.water.usgs.gov/pubs/wri/sir055007/>

Kappel, W.M., 2009, Remediation of Mudboil Discharges in the Tully Valley of Central New York: U.S. Geological Survey Open File Report 2009-1173, 8p. <http://pubs.usgs.gov/of/2009/1173/>

Kappel, W.M., 2014, The hydrogeology of the Tully Valley, Onondaga County, New York—An overview of research, 1992–2012: U.S. Geological Survey Open-File Report 2014–1076, 28 p., plus 3 appendixes <http://dx.doi.org/10.3133/ofr20141076>

**Landslide areas in and near the Tully Valley** - Background information on landslide research in the Tully Valley can be found in the following USGS publications and associated links:

Wieczorek, G.F., Negusse, Dawit, and Kappel, W.M., 1998. Landslide hazards in glacial lake clays-Tully Valley, New York <http://pubs.er.usgs.gov/pubs/fs/fs01398>

Pair, D.L., Kappel, W.M., and Walker, M.S., 2000, History of landslides at the base of Bare Mountain, Tully Valley, Onondaga County, New York, U.S. Geological Survey Fact Sheet FS 0190-99, 6 p. <http://ny.water.usgs.gov/pubs/fs/fs19099/>

Tamulonis, K.L., Kappel, W.M., and Shaw, S.B., 2009, Causes and movement of landslides at Rainbow Creek and Rattlesnake Gulf in the Tully Valley, Onondaga County, New York: U.S. Geological Survey Scientific Investigations Report 2009–5114, 18 p. <http://pubs.usgs.gov/sir/2009/5114/>

Tamulonis, K.L., and Kappel, W.M., 2009, Dendrogeomorphic assessment of the Rattlesnake Gulf landslide in the Tully Valley, Onondaga County, New York: U.S. Geological Survey Scientific Investigations Report 2009–5134, 14 p. <http://pubs.usgs.gov/sir/2009/5134/>

**Land-surface subsidence** – Background information on hydrogeologic effects related to brine mining in the Tully Valley can be found in the following USGS publications and associated links: (see also reports in the Mudboil section)

Yanosky, T.M. and Kappel, W.M., 1997, Tree rings record 100 years of hydrologic change within a wetland. U.S. Geological Survey Fact Sheet FS 0057-97, 4 p. <http://ny.water.usgs.gov/pubs/fs/fs05797/>

Hackett, W.R., Gleason, G.C., Kappel, W.M., 2009, Land-surface subsidence and open bedrock fractures in the Tully Valley, Onondaga County, New York: U.S. Geological Survey Open-File Report 1188, 16 p. <http://pubs.usgs.gov/of/2009/1188/>

Hayhurst, Brett, and Kappel, W.M., 2013, Natural Heat Storage in a Brine-Filled Solar Pond in the Tully Valley of Central New York: U.S. Geological Survey Open-File Report 2013–1266, 14 p., <http://pubs.usgs.gov/of/2013/1266/>

**Other Tully and Onondaga Valley reports of interest:** Background information on hydrogeology, groundwater and surface water modelling, and other USGS-related research can be found in the following publications and associated links:

McKenna, J.E., Chiotti, T.L., and Kappel, W.M., 1999, Ecological status of Onondaga Creek in Tully Valley, New York -- Summer 1998, U.S. Geological Survey Fact Sheet FS 141-99, 6 p. <http://ny.water.usgs.gov/pubs/fs/fs14199/>

Kappel, W.M., 2000, Salt production in Syracuse, New York ("The Salt City") and the hydrogeology of the Onondaga Creek Valley, U.S. Geological Survey Fact Sheet FS 139-00, 8 p. <http://ny.water.usgs.gov/pubs/fs/fs13900/>

Kappel, W.M., and Teece, M.A., 2007, Paleoenvironmental Assessment and Deglacial Chronology of the Onondaga Trough, Onondaga County, New York: U.S. Geological Survey Open-File Report 2007-1060, 12 p. <http://pubs.usgs.gov/of/2007/1060/>

Yager, R.M., Kappel, W.M., and Plummer, L.N., 2007, Origin of halite brine in the Onondaga Trough near Syracuse, New York State, USA: modeling geochemistry and variable-density flow: Hydrogeology Journal – online. <http://www.springerlink.com/content/008m772313n73413/>

Yager, R.M., Kappel, W.M., and Plummer, L.N., 2007, Halite brine in the Onondaga Trough near Syracuse NY: Characterization and simulation of variable-density flow: U.S. Geological Survey Scientific Investigations Report 2007-5058. <http://pubs.usgs.gov/sir/2007/5058>

Kappel, W.M. and Yager, R.M., 2008, Ground-water-flow modeling of a freshwater and brine-filled aquifer in the Onondaga Trough, Onondaga County, New York--A summary of findings: U.S. Geological Survey Open-File Report 2007-1409, 12 p. <http://pubs.usgs.gov/of/2007/1409>

Coon, W.F. and Reddy, J.E., 2008, Hydrologic and water-quality characterization and modeling of the Onondaga Lake basin, Onondaga County, New York: U.S. Geological Survey Scientific Investigations Report 2008-5013, 88 p. <http://pubs.usgs.gov/sir/2008/5013/>

Coon, W.F., 2008, Simulation of streamflow and selected water-quality constituents through a model of the Onondaga Lake basin, Onondaga County, NY--A guide to model application: U.S. Geological Survey Open-File Report 2008-1188, 27 p., online only. <http://pubs.usgs.gov/of/2008/1188/>

Coon, W.F., Hayhurst, B.A., Kappel, W.M., Eckhardt, D.A.V., and Szabo, C.O., 2009, [Water-quality characterization of surface water in the Onondaga Lake basin, Onondaga County, New York, 2005-08](#): U.S. Geological Survey Scientific Investigations Report 2009-5246, 68 p. <http://pubs.usgs.gov/sir/2009/5246/>

Coon, W.F., 2011, Improvement in precipitation-runoff model simulations by recalibration with basin-specific data, and subsequent model applications, Onondaga Lake Basin, Onondaga County, New York: U.S. Geological Survey Scientific Investigations Report 2011-5203, 37 p. <http://pubs.usgs.gov/sir/2011/5203/>

## Trip B1

# PALEONTOLOGICAL RESEARCH INSTITUTION'S MUSEUM OF THE EARTH AND TAUGHANNOCK STATE PARK AS TEACHING RESOURCES

ROBERT M. ROSS

*Paleontological Research Institution, Ithaca, NY 14850*

DON HAAS

*Paleontological Research Institution, Ithaca, NY 14850*

JONATHAN R. HENDRICKS

*Paleontological Research Institution, Ithaca, NY 14850*

WARREN D. ALLMON

*Paleontological Research Institution, Ithaca, NY 14850*

## INTRODUCTION

A central goal of geoscience education, at both the secondary and college levels, is to help students understand how we know about geologic history, and to be able to interpret for themselves how particular places and organisms came to look the way they do through past geological and biological processes. Visits to the Paleontological Research Institution's Museum of the Earth and to Taughannock State Park, both located near Ithaca, New York, can be used as complementary experiences with any audience – the general public, K-12 students, and college students – to address the geological history of New York State and to show how we know about that history. PRI's research collections of fossils are fundamental to the development of our knowledge of the events that shaped Taughannock Park's strata and those collections are sources for most of the specimens used to tell the story of the history of the Earth and its life at the Museum of the Earth.

## PALEONTOLOGICAL RESEARCH INSTITUTION & ITS MUSEUM OF THE EARTH

### What is PRI?

The Paleontological Research Institution is a natural history museum with programs in research, specimen collections, publications, and public education. PRI cares for a collection of more than 7 million specimens (one of the 10 largest collections in the U.S.), and publishes *Bulletins of American Paleontology*, the oldest continuously published paleontological journal in the Western Hemisphere, begun in 1895. PRI is a national leader in the development of informal Earth and environmental science education resources for educators and the general public. PRI opened the Museum of the Earth, an 18,000 square foot education and exhibits facility, in 2003. In 2013, PRI absorbed the nearby Cayuga Nature Center, a 100-acre site and historic lodge focused on environmental education about the Cayuga Lake Basin, and Smith Woods, a 32-acre old-growth forest.

PRI was founded in 1932 by Cornell Professor of Geology, Gilbert Harris (1865-1952), who was unsatisfied with the University's commitment to support the extensive collections, libraries, and journals that he had built over the course of his career (Allmon, 2004b, 2007). PRI remains separate from, but is formally affiliated with, Cornell University, and works closely with numerous University departments in research, teaching, and public outreach.

Though colloquially most people think of museums as locations with public exhibits, for most of its history, PRI was a museum in a narrower sense, a large scientific research collection with few displays and little public outreach. PRI's public education program was invented in 1992, necessitating the need for significant space for public exhibits and education programs. The Museum of the Earth was built to serve this need. The exhibits in the Museum tell the story of the history of the Earth and its life, focusing especially on New York State and, more broadly, the Northeastern U.S., the home of most Museum visitors.

### PRI Research Collection

The PRI Research Collection contains representatives of most major groups of organisms from many parts of the world over the Phanerozoic, but like all museums it has particular strengths for which it is known. PRI's major strengths are Cenozoic marine mollusks of the Western Hemisphere and Paleozoic marine invertebrates of New York State, and the collection also includes outstanding collections of Recent mollusks, and Cenozoic benthic foraminifera of the U.S. Coastal Plains and Caribbean, as well as more than 15,000 type and figured specimens. Parts of the collection are available online ([www.priweb.org/index.php/collections](http://www.priweb.org/index.php/collections)).

The history of PRI and its collections are reviewed in *The First 75 Years: A History of the Paleontological Research Institution* (Allmon, 2007). The PRI Research Collection had its start when Cornell's founder Ezra Cornell and first President Andrew Dixon White purchased for Cornell the fossil collection of Colonel Ezekiel Jewett (1791-1877), one of the largest collections in the nation at the time. Gilbert Harris and his students added large quantities of Cenozoic mollusks, especially from the U. S. Gulf and Atlantic coastal plains, but also the Caribbean and Central and northern South America.

Harris founded his own journal, *Bulletins of American Paleontology* (1895), and printed it himself on his own press (Figure 1). Because many new species were named in the early issues of the *Bulletins*, numerous type specimens were also added to the collections.





Figure 1: Gilbert Harris' original 1895 printing press, restored and on exhibit in the lobby of the Museum of the Earth.

The fossil collections were housed in McGraw Hall, where Cornell had a museum of natural history. That museum displayed fossils and plaster casts of large fossil skeletons (several of which are on display at the Museum of the Earth; see below), as well as displays of modern mammals, birds, and other specimens.

As Harris prepared to retire, he got into a bitter spat with the University over future care for the research collections, leading him to found the Paleontological Research Institution in part to help insure these paleontological materials would be conserved. He constructed a two-story cinderblock building and on June 28, 1932 laid the cornerstone with family, students, and colleagues. He took about half the Cornell collections with him, including most of the type specimens.

In 1952, Katherine Palmer took over as Director of PRI. She had received her PhD under Harris in 1926 and continued her research with him in the first two decades of PRI's existence. The PRI collections continued to grow under Katherine Palmer, and in October 1966 the current Tudor-style stone PRI building on Ithaca's West Hill, now known as Palmer Hall, was purchased.

In 1995-1996, PRI took over responsibility for all of the modern mollusks and remaining nonbotanical fossils from Cornell University. These fossils included those that Harris had not taken in 1932, as well as many added by later faculty and students. These included many important specimens from the original Jewett collection, as well as those collected by John Wells (1907-1994) during his long career as a Cornell professor. Collections acquired from other organizations over the past 25 years include those from Syracuse University, SUNY Buffalo, SUNY Binghamton, SUNY Fredonia, University of Rochester, Purdue University, University of North Carolina Wilmington, University of Delaware, Rutgers University, Tulane University, Alfred University, and Wells College.

Also in the mid-1990s, the Cornell University malacology collection was moved to PRI on long-term loan. These Cornell collections came particularly from two 19th century shell collections: the Newcomb Collection (collected 1845-1874) and the Maury Collection (collected 1880-1900). The Newcomb Collection was purchased from Albany physician Wesley Newcomb (1808-1892) in 1868 by Ezra Cornell, shortly after founding Cornell University (1865). At the time, the Newcomb Collection was

considered one of the best modern mollusk collections in North America. The collection was formally transferred to PRI in 2018.

A major new direction of growth of the PRI Research Collection is in the field of conservation paleobiology (Dietl and Flessa 2011, 2017; Dietl et al., 2015; Dietl 2016), which applies geohistorical data (primarily from the relatively recent fossil record) and approaches to the conservation and restoration of biological diversity and ecosystem services—the benefits people obtain from natural systems. These collections provide vital and at times irreplaceable information and research opportunities in this rapidly developing field (Dietl et al., 2019).

### Teaching using the Museum

In addition to their role in research—including as the basis for published undergraduate and graduate research projects by students from Cornell and other colleges and universities—specimens from the PRI collection are also the basis for the permanent exhibits at the Museum of the Earth. The Museum displays about 650 specimens from the research collections in the permanent exhibits in order to tell the story of the history of the Earth and its life, and dozens more are used in changing special exhibits. Such exhibits provide resources that are not easily replicated in classrooms or in printed or online materials (e.g., Allmon et al., 2012). The exhibits contain almost exclusively authentic specimens; those that are casts are identified as such and are used only when essential to fulfill the narrative of the exhibits. The Museum specimens on display are more diverse, of higher quality, and historically more significant than those that would be found in even the best teaching collections. In the Museum of the Earth, complementary ways of enjoying the exhibits, such as original artwork, information on the history of specimens, and tailor-made videos are associated with many of the specimens on display.

Before the Museum of the Earth, PRI staff provided science outreach via open houses in the collections in order to explain to the general public the work of PRI and of natural history museums generally. With modern collections standards and a much larger public profile, PRI now gives behind-the-scenes tours only occasionally for modest-sized groups of college students and teachers. Such tours help educators and future scientists understand the nature of museum collections, why they are important, and what sort of care is necessary. Exhibits at the Museum of the Earth provide a way to share specimens and their stories more effectively and at a vastly greater scale than is feasible through a collections tour alone.

### Digital Atlas of Ancient Life

Recently, PRI has begun a project to share specimens from both the research collections and on exhibit at the Museum of the Earth in an all new way: online in three dimensions. PRI's Digital Atlas of Ancient Life project (<https://www.digitalatlasofancientlife.org/>) is creating a host of new online resources to help teachers, their students, and members of the public (especially avocational paleontologists) identify fossils and learn about the history of life. In addition to online field guides to fossils (see Hendricks et al., 2015), an open access college-level “textbook” about paleontology (the Digital Encyclopedia of Ancient Life: <https://www.digitalatlasofancientlife.org/learn/>), and online virtual versions of previous Museum of the Earth temporary exhibits (e.g., Living Fossils;

<https://www.digitalatlasofancientlife.org/vc/living-fossils/>), the Digital Atlas project is also creating 3D models of PRI specimens and museum exhibits using a technique called photogrammetry. To date, over 480 interactive 3D models have been created and posted to the Digital Atlas project Sketchfab page (<https://sketchfab.com/DigitalAtlasOfAncientLife/models>). In turn, these models are being incorporated into online Virtual Collections (<https://www.digitalatlasofancientlife.org/vc/>) organized around themes, ranging from taxonomic groupings (e.g., brachiopods or trilobites; Figure 2), to differing styles of fossil preservation, to overviews of fossil faunas, including Devonian fossils from New York State. Some of the large wall exhibits on display at the Museum of the Earth have also been scanned and added to these virtual collections (Figure 3).

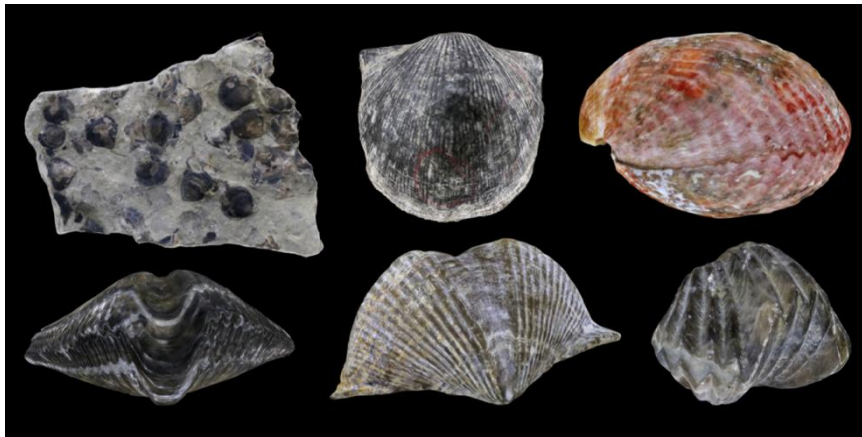


Figure 2: Some of the fossil and modern brachiopod specimens from the PRI collections that have been incorporated into the online Virtual Collection. Explore the virtual collection of brachiopod specimens at: <https://www.digitalatlasofancientlife.org/vc/brachiopoda/>.



Figure 3: Interactive 3D model of the Devonian “Life in an ancient sea” display at the Museum of the Earth (explore this model at: <https://sketchfab.com/3d-models/new-yorks-devonian-sealife-349b0f22f8d843dfb4730ebe1091f972>).

The scanned fossils that comprise the Virtual Collections represent most major groups of macrofossils and scans of modern specimens are also included for comparison. The vast majority of these are specimens that are otherwise generally unavailable for teaching purposes, either because they are “behind the scenes” in the research collections, or because they are under glass in the public exhibits. Most were selected for 3D photogrammetry because they either represent a key component of ancient biodiversity, or because they show exceptional preservation of certain features (many of which are digitally annotated), making them especially useful for teaching paleontology. 3D models of fossil specimens are not better than the real thing, but they have a place in modern teaching environments, allowing educators who teach online to bring fossils into their online classrooms, permitting students to study at home, and facilitating discussions about fossils in classrooms that lack physical specimen collections. Even when physical specimen collections are available in classrooms, virtual specimens—when projected on a display at the front of a classroom—allow fine features of specimens to be viewed at large size, making them a useful supplement to traditional teaching specimen collections, particularly in large classroom settings.

### History and Approach of the Museum of the Earth

Although PRI was chartered by the State of New York in 1936 as an educational organization, PRI had relatively little in the way of public outreach for most of its history. Harris himself was an inspiring teacher of advanced students, but otherwise had little interest in education. When PRI moved into its current facilities, Katherine Palmer created what she called a “mini-museum: in a room on the north end of the building that is now collections working space, and she occasionally met K-12 classes in this space in the 1970s.

When Allmon arrived as Director at PRI in 1992, part of his directive and intention was to make PRI’s collections an educational resource to the broader community, which was first manifested in outreach to the public and local school and community groups. The idea to build a new museum building had been floated informally in the early 1990s by Ray Van Houtte, a PRI Board member with significant influence in the Ithaca community (Allmon, 2007), and was taken up enthusiastically by Allmon. During the mid- and late 1990s initial funds were raised, feasibility studies made, consultants hired, and focus groups held. In 1999 the New York architecture firm Weiss/Manfredi began work on designing the new building. Jeff Kennedy Associates of Boston was hired to coordinate design of the exhibits. The Museum opened in September 2003 and has since received national and international media attention, including several architectural awards.

The exhibits in the main exhibit hall are built around four “major messages”:

- (1) the Earth is a set of interconnected systems (atmosphere, hydrosphere, lithosphere, biosphere);
- (2) paleontology/Earth science is not something only for professional scientists; it is accessible to everyone, and you (the visitor) can do it yourself;
- (3) humans have a major impact on the Earth; and
- (4) the Earth has a history.

These four main messages remain central to all of the Museum’s exhibits and programs.

The exhibits were designed following a set of conceptual guidelines:

- (1) the specimens are paramount and should be used to illustrate ideas whenever possible;
- (2) exhibits should have multiple points of intellectual access — not everything need be accessible to everyone, but each and every visitor, regardless of age or background, should be able to take away something of value from almost every exhibit;
- (3) exhibits should strive for a middle path between the classical specimen-rich approach of the best traditional natural history museum with the hands-on dynamism of the best interactive science center; and
- (4) exhibits should emphasize how we know, as well as what we know.

The Museum welcomes around 30,000 visitors annually, including classes from pre-K to 12 and area colleges and universities, regularly including Cornell University, Ithaca College, Wells College, SUNY Cortland, SUNY Potsdam, Colgate University, Syracuse University, Elmira College, Hobart & William Smith Colleges, and several community colleges (Allmon et al., 2012). In addition to serving classes in biology and geology, classes also visit to consider topics such as exhibit design and public communication of science. PRI also provides workshops to educators, especially secondary school science teachers, on topics connected to the Museum exhibits, fieldwork experiences, climate and energy, and others.

### Layout of the Museum

The Museum building was designed to avoid architectural conflict with the adjacent historic stone building (Palmer Hall) to the north. Much of the structure is built into the slope of the land, implicitly reflecting its function as an Earth museum, providing additional vertical height without rising above Palmer Hall, and adding energy efficiency associated with stable below-ground temperatures.

The Museum is split into two wings, the above-ground space between them echoing Ithaca's famous gorges. The space is oriented at the same perpendicular angle to Cayuga Lake as nearby streams. Entering the lobby is thus metaphorically entering a gorge.

The lobby and admission desk are in the east wing known as the "Park Education Hall," which also contains the Museum store, a ramp down to the main level, the 2500 square foot BorgWarner gallery for changing exhibits under a hanging modern whale skeleton, and the Museum classroom (Figure 4). The "exhibits wing" to the west contains the permanent exhibits. A passageway that connects the two wings contains a working Preparation Laboratory on display to the public, a small theater, and an exhibit on anthropogenic climate change (under re-design as of this writing). The climate change exhibit, *Dynamic Climate*, will cover both the science of climate change and mitigation strategies.

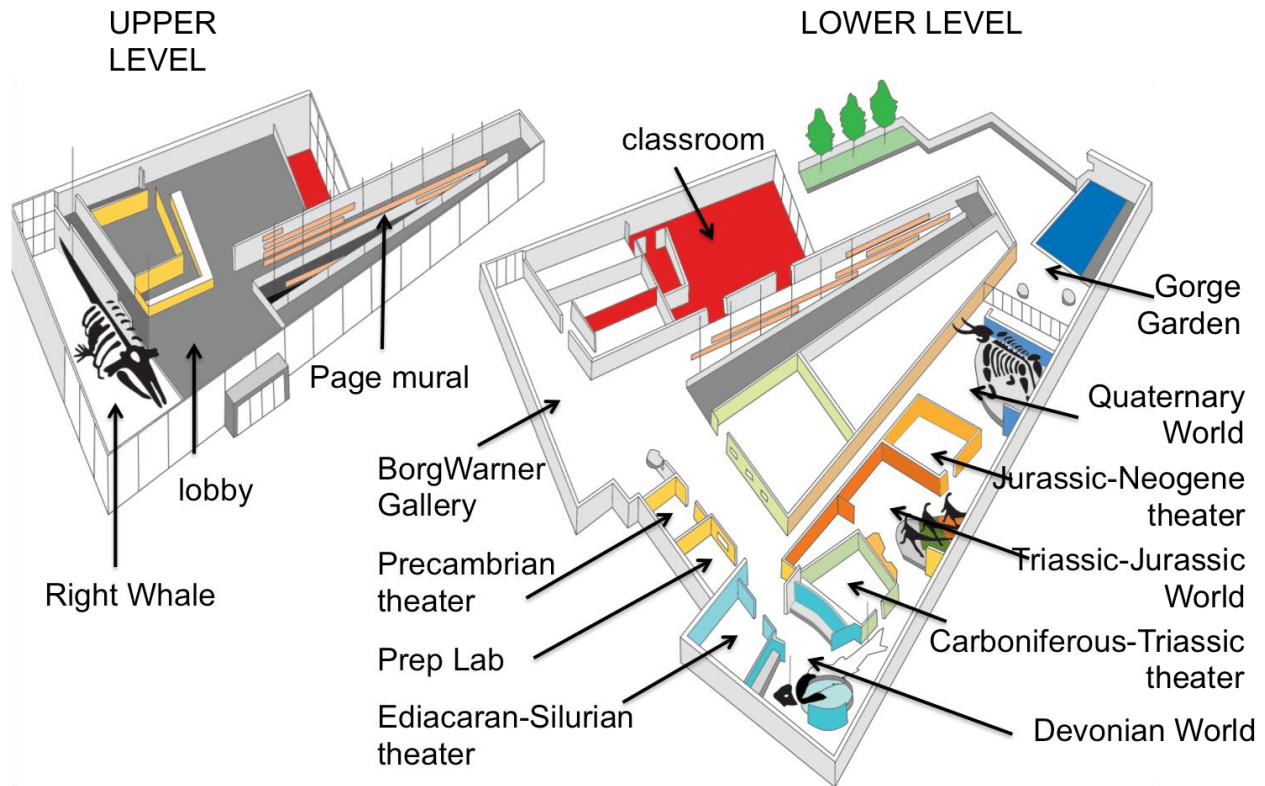


Figure 4: Layout of the Museum of the Earth.

The permanent exhibition, “Journey through Time,” is organized as a chronological walk through the history of Earth and its life. The exhibits emphasize the fossils and geology of the northeastern United States, the home of most of the Museum’s visitors, but are global in scope. Most of the specimens on permanent exhibit in the museum are invertebrates, reflecting both the strengths of the PRI research collections and the fossil faunas of the northeastern US.

Behind the Museum is the “Gorge garden,” a small water feature with plants native to local gorges and glacial erratic boulder excavated on-site during Museum construction, which is visited primarily in warm weather months.

**North Atlantic right whale #2030:** The skeleton on display in the lobby, visible through the large glass windows when approaching the Museum, is a North Atlantic right whale (Figure 5). The whale epitomizes major themes of the Museum education, including evolution, interactions between Earth and life, and humanity’s relationship with nature. Visitors, some of whom assume the skeleton is a fossil, are surprised to learn that the 44-foot long skeleton was salvaged in 1999 by PRI staff at Cape May in New Jersey, after the animal had died tragically tangled in fishing gear. North Atlantic right whales are critically endangered, with only about 400 surviving individuals. The skeleton is therefore an opportunity to highlight conservation. The story of the whale is told in detail in the book *A Leviathan of Our Own* (Allmon, 2004a).



Figure 5: The skeleton of North Atlantic right whale #2030 hanging in the lobby of the Museum of the Earth.

***Rock of Ages Sands of Time* mural:** Barbara Page's *Rock of Ages Sands of Time* mural of the history of life (Page and Allmon, 2001) is a 500-foot long work of art on display along the ramp from the lobby to the exhibit halls (Figure 6). PRI commissioned Page to create the mural, which took her more than 7 years to complete. It contains 544 11-by-11-inch masonite tiles (one for each of the last 544 million years of Earth history) on which are painted images of fossils from each of interval of time. Walking down the ramp transports the visitors back through time, from the present to the start of the Cambrian. The images of fossils on the tiles represent actual specimens and are depicted life-size, and in some cases in 3-D relief. Walking along the mural from bottom to top one can recognize the origin of new taxa, major extinctions, and trends in the history of life. The mural is a unique combination of realistic scientific illustration and impressionistic interpretation.

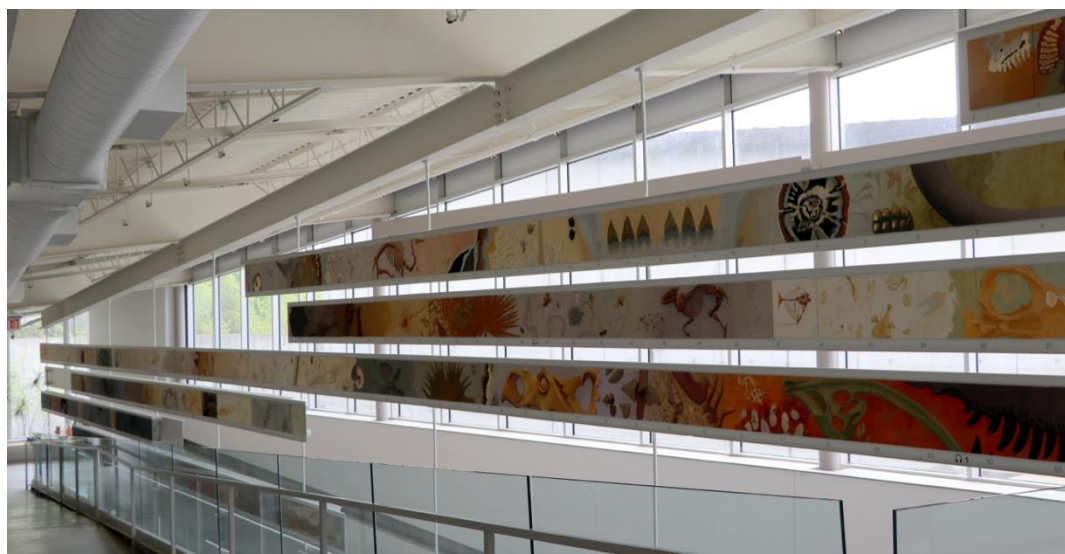


Figure 6: Barbara Page’s mural “Rock of Ages. Sands of Time” lines the ramp connecting the upper and lower levels of the Museum.

**The BorgWarner gallery:** The area under the whale is used for a series of special exhibits, two or occasionally three per year, that attract new audiences and encourage return visits from local audiences. Recent examples have included evolution and diversity of skulls, the evolution and fossil record of “living fossils,” and the evolution and global diversity of bees. Some of the exhibits are rented from other institutions, but most have been developed, designed, and built by PRI staff. Some of our exhibits have been in collaboration with colleagues with NSF grants who are doing outreach (“Broader Impacts” in NSF parlance) through a Museum of the Earth exhibit (such as the bee exhibit, with Cornell entomologist Bryan Danforth). Such exhibits often include a teacher workshop and public programs. Starting in 2019, these exhibits have been accompanied by an online exhibit that lives on after the exhibit has been removed (e.g., the exhibit “Survivors: Up Close with Living Fossils” is available at <https://www.digitalatlasofancientlife.org/ve/living-fossils/>). Spaces near the classroom are used for smaller exhibits highlighting PRI research and collections (such as conservation paleobiology), Earth science events in the news (e.g., volcanoes), or the theme of our annual Darwin Days celebration (e.g., hominin evolution).

**Preparation laboratory:** The visual “Prep lab” contains standard paleontological equipment for removing matrix from fossils, such as air abrasion equipment, microscopes, and a lab hood for chemicals such as for gluing specimens (Figure 7). The lab is staffed entirely by volunteers, who are trained by a paid staff member. We try to have preparators working in the space on high traffic days such as Saturdays. We offer a one-credit class for Cornell students in the prep lab. Because PRI’s collection does not contain many large vertebrate specimens, we have made arrangements with other natural history museums to borrow their unprepared specimens. For the past few years, for example, we have benefitted from an arrangement with the Carnegie Museum of Natural History in Pittsburgh, which has loaned us many unprepared dinosaur specimens, still in plaster jackets after more than a century. The specimens are opened, prepared, and then returned to the Carnegie.



Figure 7: The Museum’s prep lab is both a functioning lab space supporting staff research (left) and also an interactive exhibit for the public (right).



***Journey through Time and the permanent exhibits:*** *Journey through Time* is the name of the primary exhibit experience at the Museum, covering the 4.5 billion year history of Earth and its life. It begins in a theater in the passageway between the two wings of the Museum and occupies the main exhibit hall.

Philosophically, the experience begins with the limestone block directly across from the bottom of the ramp (Figure 8). The block contains numerous silicified rugose corals weathering from the rock. The rock is the outcome of a complicated set of processes involving biosphere, lithosphere, atmosphere, and hydrosphere – the product of the interaction of Earth systems. It illustrates the approach taken in *Journey through Time*, which was to relate the history of the Earth as a system – the exhibits integrate all aspects of the Earth system rather than separating them into different areas. The Museum uses fossils to tell much of the Earth system story, given PRI's strengths in collections and expertise, but one can also extract stories of changing seas, climates, and continents throughout (Allmon and Ross, 2004).



Figure 8: Devonian limestone block with fossil corals from Honeoye, NY.

The first element of the journey is a theater showing a short film that tells the story of the origin of the Earth and its life, and covers most of the Precambrian. This is the only specimen-less part of the journey. A panel outside the next theater introduces the interrelatedness of all life, and contains two specimens of Precambrian stromatolites.

*Journey through Time* is organized such that, in principle, one can follow a variety of threads throughout the exhibit using consistent layouts and iconography. Just as with the natural world, it's possible to experience the Journey through the lens of climate change, biodiversity, presence of lagerstätten, local research, New York fossils, and many more.

- In the main hall, there are three “object” theaters, rooms with large numbers of specimens and a video summarizing the temporal span of the theater, and three “worlds,” large open areas representing smaller intervals of time (Devonian marine, late Triassic-early Jurassic rift valley, and Quaternary glacial) that are relatively well-represented by the rock record of the northeastern U.S.
- Each theater and world contains a summary diagram that shows the position of that display relative to the Phanerozoic (Figure 9). The sign contains simplified plots of biodiversity, sea level, and global temperature, with images of changing positions of the continents.
- In each theater time runs clockwise (a wall or two per geologic period). The “worlds” represent smaller units of geologic time, and are mostly not organized temporally.

- Phylogenies of major fossil groups are found throughout the exhibits.
- Look for thin black panels with skull and crossbones; these represent each of the five major mass extinctions. There is one in each of the object theaters and in the Devonian and Triassic-Jurassic worlds. Interpretations of dominant causes of these extinctions have changed somewhat in the years since these panels were written.
- Themes that run through the exhibits are “exceptional preservation,” “trace fossils,” and “research at Cornell,” and small icons throughout the exhibits communicate these ideas.
- “Postcards” integrated into the labels through the exhibits highlight important sites such as the Ediacara, Burgess Shale, and Solnhofen Limestone.
- The short films in all four of the theaters were produced specifically for the Museum and feature the mellifluous voice of Frank Rhodes, beloved former Cornell President and conodont paleontologist.
- Four large background murals in the three worlds were commissioned from Doug Henderson, a paleoartist best known for his work on dinosaurs.

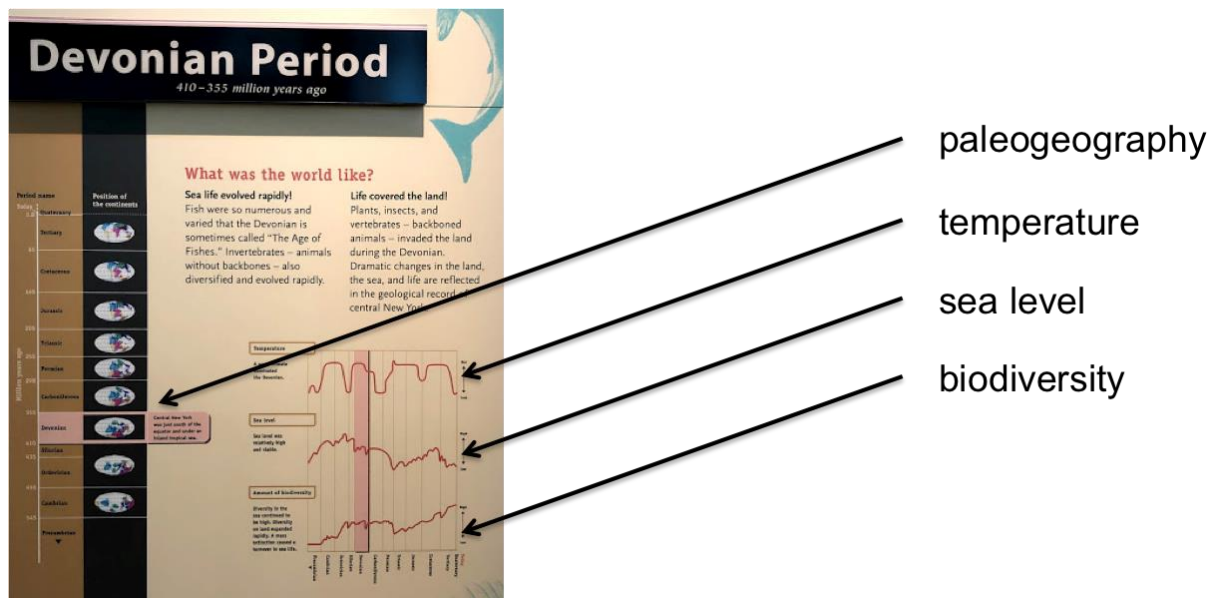


Figure 9: Example of the sign greeting visitors entering the “Devonian World” part of the permanent exhibit. The same series of graphics are present at the entry to each theater and “world.”

Journey through Time Exhibition components

**The main exhibit hall, introduction to fossils, and the Cambrian explosion wall:** The main exhibit gallery contains most of *Journey through Time*, focusing on the Phanerozoic. Visitors encounter a large graphic that introduces Cambrian diversification of animal life and an adjoining case explains the nature of fossils as the basis for our understanding. A second case explains “exceptional preservation.”

**Ediacaran-to-Silurian object theater:** This space contains a rich set of Paleozoic invertebrates. Notable specimens of particular value in teaching include the following:

- Several specimens and casts from Ediacara in Australia.

- Specimens from the Burgess Shale, acquired in a trade made by Gilbert Harris with Charles Walcott at the Smithsonian in the 1920s. A set of lights set obliquely highlights the carbonaceous films. Also present are three pieces of Chengjiang shale (from China), among the only legally collected such specimens on public display in the U.S. (Figure 10).
- Two large slabs from the Cambrian of Wisconsin, featuring the enigmatic (possibly molluscan) trace fossil *Climactinites* (Figure 10) and a large medusoid.



Figure 10: The “Cambrian wall” in the first “object theater,” featuring Ediacara, Burgess Shale, *Climactinites*, and other specimens.

- The world’s largest complete eurypterid specimen, a 1.25 m long *Acutiramus macrophthalmus* from Late Silurian of Herkimer County, NY.
- A block of Silurian salt from the nearby Cargill salt mine, which extends under much of the south end of Cayuga Lake.

**Devonian World:** The Devonian World tells the story of life and major evolutionary events and on the geology – the process of plate tectonics — that explains the distribution of Devonian age rocks in the Northeastern US.

On the left side as one enters the hall is a display of the sort of marine invertebrates (Figure 3) that are common in the Appalachian basin, especially New York State. The wall was inspired in part by the biodiversity wall of the American Museum of Natural History. Note that there are modern representatives and model reconstructions of several invertebrates that may be difficult for students to interpret.

The *Dunkleosteus* head shield hanging from the ceiling (Figure 11) is a cast of a specimen at the Cleveland Museum of Natural History. The *Dunkleosteus* hangs in front of a Doug Henderson mural and above a diverse set of Devonian fish fossils to represent the concept that the Devonian is the “Age of Fishes.”



Figure 11: The “Age of Fishes” island in the Devonian world.

The Life on Land exhibit is also in front of a Doug Henderson mural, intended to convey a sense of the shoreline somewhere near the position of the Gilboa forest in the Catskill Mountains of New York, which would have been not far from Acadian orogeny. Specimens here include casts of early tetrapods *Sauripterus*, *Acanthostega*, and *Tiktaalik*.

Visitors often wonder how it is that marine organisms are found in Upstate New York; thus, plate tectonics is introduced here. The exhibit includes rocks from a series of tectonic contexts across New England, and also a short film featuring Cornell faculty who were involved in the early discoveries of the plate tectonics revolution, including Bryan Isacks and the late Jack Bird. There is a working drum seismograph; a seismogram of a recent earthquake in the news is always on display. The seismograph is connected to a digital seismometer behind the Museum, station “PRNY” of the Lamont-Doherty Cooperative Seismographic Network; you can get real-time and past data at [https://www.ldeo.columbia.edu/cgi-bin/LCSN/WebSeis/24hr\\_heli.pl](https://www.ldeo.columbia.edu/cgi-bin/LCSN/WebSeis/24hr_heli.pl) (select station PRNY at the bottom and click the “submit” button).

One of the most popular areas in the Museum is Fossil Lab (Figure 12), located in the back corner of the Devonian World. At this interactive lab bench, visitors of all ages can collect their own Devonian fossil to take home (supplied from outcrops in the Ithaca area) and identify it with the help of Museum docents (mostly volunteers).



Figure 12: Fossil Lab in the Devonian World area of the Museum.

**Carboniferous-to-Triassic object theater:** This theater focuses on Carboniferous coal swamp forests, the diversification of major tetrapod groups, dominant marine invertebrates, and the Permian-Triassic extinction.

The Carboniferous exhibit contains an extensive set of coal plant fossils, as well as models of lycopods, horsetails, and the enormous dragonfly-like insect *Meganeura* by Terry Chase Studios.

This theater contains casts and reconstructions of skulls that represent early diversification of vertebrates, including a large amphibian (*Mastodonsaurus*), therapsids (the pelycosaur *Dimetrodon*, gorgonopsid *Broomisaurus*, and cynodont *Thrinaxodon*), and early dinosaurs *Eoraptor* and *Herrerasaurus*, plus skulls of a modern alligator and opossum for comparison.

**Late Triassic/Early Jurassic World:** The most significant Mesozoic deposits in the Northeast, and the only ones in New York State, are the Newark Supergroup rift valley deposits, which are the focus of the Late Triassic/Early Jurassic World. The Museum does not focus on dinosaurs, but the Triassic-Jurassic area contains most of the Museum's dinosaur displays. An adjoining DinoZone area contains books and hands-on dinosaur-related activities for pre-K-age children and their caregivers.

A Henderson mural shows part of the Newark Rift Valley in the area near what is now central Connecticut (Figure 13). Notice that the end-Triassic extinction cuts through the middle of the mural: the left side shows a diversity of late Triassic reptile groups, while the right side shows only dinosaurs. *Coelophysis* shows up on both sides. The platform under the mural contains rocks and fossils from the Newark Rift basins, including a large section from the Triassic-Jurassic boundary collected in Reading, Pennsylvania and pieces of brownstown from buildings in New York City.



Figure 13: Exhibit of life and geology in the Connecticut and Hudson valleys during the Late Triassic and Early Jurassic.

The exhibit that most catches visitors' attention is "Steggy," a lifesize model of *Stegosaurus* (Figure 14). Not originally part of the permanent exhibits, Steggy came to PRI from the Smithsonian's National Museum of Natural History in 2014 when their fossil halls closed for major renovations (this exhibit reopened in June 2019; Gramling, 2019). This life-size restoration of the iconic Jurassic armored dinosaur was commissioned by the Smithsonian for the 1904 World's Fair in St. Louis; in 1905 it was moved to the museum in Washington, D.C., where it had been seen by countless millions of visitors. It is made of paper mache and had to be cut into three pieces to get it through doors at the Smithsonian, transported, and brought into the Museum of the Earth. Professional art conservators reassembled and repainted it, and it was installed in front of a mural painted by Ithaca artist Mary Beth Inhken representing the biota of the Morrison Formation of Colorado and Wyoming, from which *Stegosaurus* is best known.



Figure 14: *Stegosaurus* model built by the Milwaukee Papier Mache Works, commissioned by the Smithsonian Institution for the World's Fair in 1904.

As is true for most dinosaur taxa, Recent interpretations of *Stegosaurus* are slightly different than those of the early 1900s, with a more agile posture and legs more underneath the body. The idea that scientific interpretations and reconstructions of ancient life change through time is also the theme of another exhibit in this area, which features three models of the small theropod dinosaur *Coelophysis*, sometimes referred to as “New York State’s only dinosaur” because prints resembling its feet have been found in Rockland County, New York (Fisher, 1981) (Figure 15). These life-sized restorations reflect what paleontologists have thought *Coelophysis* looked like at different times, from the early 1960s to the 1990s. Exhibit panels ask visitor to consider why such changes of scientific view may have happened. Along the edge of the platform holding the *Coelophysis* sculptures is a case with an actual theropod footprint specimen from Rockland County. This story of *Coelophysis* led to its use in the PRI logo, its identity as a PRI mascot (“Cecil”), and the focus on *Coelophysis* in the sculptures and Newark Rift Valley mural. (In addition, a bronze cast of a *Coelophysis* stands in the plaza outside the Museum.)



Figure 15: *Coelophysis* sculptures made by three artists in three different decades (from top to bottom, approximately 1960, 1985, 1990) and cast of a *Coelophysis* skeleton mounted to the wall.

A large model that one may overlook (or underlook) is a life-size *Quetzalcoatlus*, a pterosaur and one of the largest known flying creatures, also acquired from the Smithsonian in 2014 (Figure 16). It hangs from the ceiling, peering over the top of the fourth and final theater.

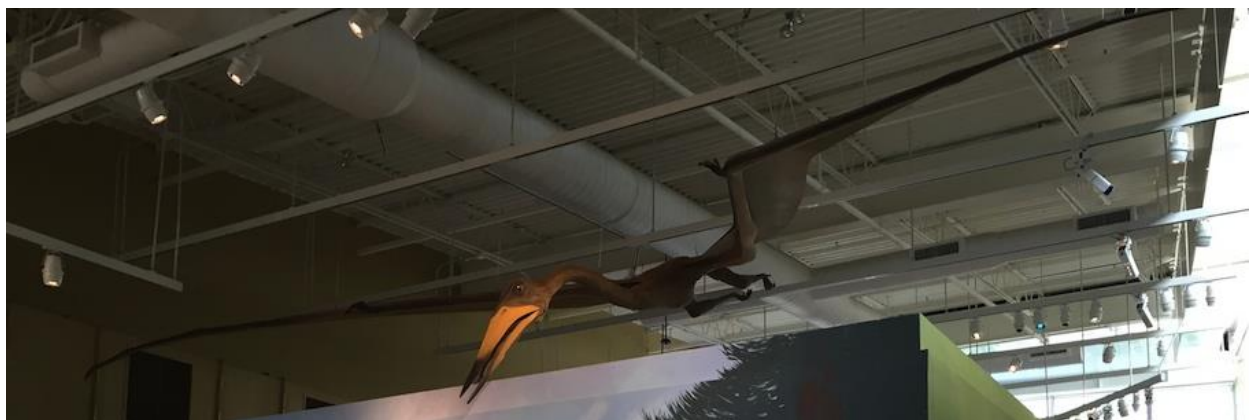


Figure 16: Life-size *Quetzalcoatlus* model, originally on display in the Smithsonian Museum of Natural history.



**Jurassic-to-Neogene object theater:** Much of what the public hears about paleontology in the news – dinosaurs, large marine reptiles and pterosaurs, origin of birds, end-Cretaceous extinction, and diversification of mammals — took place in the interval of time represented in this space, which contains representations of all of these, together with marine invertebrates (particularly ammonites) and the first flowering plants and associated diversification of insects.

Two of the marine reptiles on display, a plesiosaur and ichthyosaur (Figure 17), are casts of famous specimens from Europe purchased by Cornell in the late 1800s from Ward's Natural Science Establishment of Rochester, New York (see Davidson, 2008). Numerous casts purchased from Wards were once on display in Cornell's Natural History Museum in McGraw Hall, and were an important teaching resource. Sadly, most disappeared from Cornell long ago, and these two are among the very few that survived.

Other notable exhibits include (Figure 17):

- a case with Solnhofen fossils (casts and real specimens);
- a very large heteromorph ammonite (*Diplomoceras maximum*) from Seymour Island, Antarctica;
- a cast of a *Tyrannosaurus rex* skull from the Museum of the Rockies in Bozeman, Montana;
- a block from the Cretaceous-Paleogene boundary in the Raton Basin in New Mexico;
- casts of two *Archaeopteryx* specimens and the related small theropod dinosaur *Compsognathus*.



Figure 17: Back half of Jurassic-to-Neogene theater, including: casts of *Ichthyosaurus communis*, *Plesiosaurus hawkinsi*, and jaws of *Mosasaurus hoffmanni*; heteromorph ammonite from Antarctica (foreground center); *Tyrannosaurus rex* skull; and *Archaeopteryx* casts.

**Quaternary World:** The last part of the Museum’s permanent exhibits, the Quaternary World, focuses broadly on climate change, through the lens of megafauna, coral reefs, and glaciers. The original centerpiece of this area is the Hyde Park mastodon, but newer components include two 500-gallon coral reef aquaria and a walk-in glacier. There is also a display summarizing climate change through the Phanerozoic eon. In a tunnel leading through and out of the glacier, the exhibit covers the influence of current climate change on glaciers.

In 2000 PRI was invited to look for mastodon remains in a pond in Hyde Park, NY, where several bones had been revealed during dredging of the pond. Once the rest of the skeleton was found, it became evident that the it was one of the best preserved mastodon skeletons ever found -- the “Hyde Park mastodon” had evidently died in the pond before bones had become scattered and weathered. It was excavated by PRI staff and volunteers in early Fall 2000. The Discovery Channel made a one-hour documentary film of the find (“Mastodon in Your Back Yard”); two brief clips are in the exhibit. The original skeleton is on display (Figure 18), held in place by a metal armature. Because of the weight and fragility of the tusks, they were replaced with fiberglass replicas; one of the original tusks is on the floor of the platform. Behind the skeleton is another Doug Henderson mural showing the Hudson Valley at the time the mastodon was alive, around 13,500 years ago.



Figure 18: Hyde Park mastodon skeleton and white spruce trunk.

The pond contained a rich sedimentological and paleontological record beyond the skeleton itself, and the excavation became a major research project on the late Pleistocene paleoecology at the site. PRI published a volume of this research by PRI staff, students, and specialists at other organizations (e.g., Allmon and Nester, 2008). For many years PRI ran a citizen science project, the Mastodon Matrix Project, in which school and community groups received sediment from which participants were requested to extract and return fossils in order to more fully inventory the fossil record of the site (Ross et al., 2003, 2008).

The coral reef tanks were added in 2013. They are unusual in contrasting Caribbean from Indo-Pacific reefs, which vary greatly in their taxonomic composition and diversity. The tanks were created from live corals that had been collected with permits by Cornell coral biologist Drew Harvell, who was studying them to better understand the influence of stresses such as climate change and disease on coral health.

Though disparate in topic, all of the exhibits in the Quaternary world are climate-related. Glaciers respond to climate change at high latitudes, and reefs are impacted at low latitudes; mastodons were influenced and perhaps at least in part driven extinct by changing climates. The adjoining glacier exhibit (Figure 19) is intended to help visitors ponder both the influence of the presence, influence, and disappearance of past glaciers from the Upstate New York area, and the current disappearance of glaciers globally from anthropogenic climate change.



Figure 19: Glacier exhibition with walk-through ice cave in Quaternary World area.

Other notable components of Quaternary world include:

- The white spruce trunk mounted to the wall behind the mastodon. The trunk was found at roughly the same stratigraphic level as the mastodon. It is now in three pieces and shrunken after drying, but when found was whole and at full girth in its water-logged state.
- The video “Glacial Ice sculpted New York’s Finger Lakes Region,” which plays inside the tunnel, just past the glacier. It was made for the exhibit in 2014 by Professor Bryan Isacks of Cornell Earth and Atmospheric Sciences. It is available on PRI’s YouTube channel at <https://www.youtube.com/channel/UCaP3mwxlJuVRPK1s9FX4iLg/videos>.

**PRI “gardens” and other outdoor specimens:** Local erratics are found at the base of the glacier model and nearby in the Gorge garden area behind the main hall. Another is the large rock just in front of the Museum of the Earth sign on Route 96, which was on land west of Trumansburg.

Large rocks along the plaza as one approaches the Museum entrance include, for example, Onondaga limestone with chert-replaced corals, granitic gneiss from the Adirondacks, sandstone with glacial striations, and (under and behind the bronze *Coelophysis*) Jurassic brownstone from Middletown, Connecticut (Figure 20).



Figure 20: A block of Jurassic sandstone obtained from the last operating brownstone quarry in Portland, Connecticut.

#### Using the Museum and nearby resources for teaching

School groups use the Museum in many different ways and combinations, which may include one or more of the following (see Allmon et al., 2012):

1. allow students to explore on their own, without any particular structure;
2. give the students an assignment, which may include open-ended questions of analysis, documentation of Earth history through images and information about specimens, or requests to find and document specific specimens (which might be designed as a game, such as finding clues toward completing a puzzle);
3. teachers give students a tour or hire a PRI educator to provide a tour, sometimes with a specific theme emphasized;

4. hire a PRI educator to provide a presentation on local geology and paleontology (or other related topics); or
5. combine the Museum visit with another experience such as visiting PRI's other public venue, the Cayuga Nature Center, or Taughannock Falls State Park, explored further below.

**Cayuga Nature Center:** The Cayuga Nature Center (CNC), PRI's second public venue, is about four miles (6.4 km) northeast of the Museum of the Earth on Route 89, about 2.5 miles (4.0 km) south of the entrance to Taughannock Park. In its landscape, streams, forests and fauna, it is possible to explore dimensions of current Earth and environmental sciences that complement natural history experiences available in exhibits and programs at the Museum of the Earth (Allmon and Ross, 2011). In the lodge are exhibits on the Cayuga Lake Basin, including ecology, climate change, faunas, and soils. A live animal collection (mostly vertebrates) contains evolutionary trees and an introductory exhibit on constructing phylogenies. Two 600-gallon aquaria feature fishes of Cayuga Lake from the present and before the arrival of Europeans in the late eighteenth century, and have additional interpretation on the natural history of the Finger Lakes. The CNC property includes a creek that cuts through the Genesee and Sherburne Formations. The modest-sized Denison Waterfall can be observed from a trail or from the top of a 6-story "treehouse" built next to the creek.

## TAUGHANNOCK STATE PARK

### Taughannock Gorge Geology Brief Overview

Taughannock Gorge has been a tourist attraction since the 1800s and outdoor natural laboratory for teaching geology. Taughannock Falls, the 65.5 m (215 foot) high drop of Taughannock Creek, is the primary attraction. The Falls is well complemented by steep gorge walls exposing over 100 m of strata (Genesee Group), the flat easy "Gorge Trail" along the Creek, a broad flat walkable creek bed (Tully Limestone), a "Lower Falls" (about 5 m high), and a delta at the mouth of the creek that is home to State Park public facilities. The gorge offers numerous features of interest for teaching Earth science to audiences from novice to expert.

For the context of this paper we have listed below only some of the general characteristics of Taughannock gorge that might be addressed with groups of students. An excellent overview of the geology of the Finger Lakes region can be found in *Gorges History* (2018). Related summary works of various lengths on or including Central New York geology and paleontology include Wilson (2014), Sang et al. (2013), Allmon and Ross (2008), Ansley (2000), and Linsley (1994).

Between the start of the Gorge Trail and the top of the cliffs at Taughannock Falls, Taughannock Creek cuts through a sequence of several hundred meters of strata, from the Middle Devonian Moscow Formation to the Upper Devonian Renwick Formation (Figures 21, 22).

FORMATION	GROUP	STAGE
Renwick	Genesee	Frasnian
Sherburne		
Genesee		Givetian
Tully	Tully	
Moscow	Hamilton	

Figure 21 (right): Simplified stratigraphic section of Taughannock Park, based on Zambito et al. (2012).

The Tully Limestone forms the floor of the streambed of much of the stream. The first easy entry from the Gorge Trail onto the streambed is about a third of a kilometer from the trailhead; a flatter, wider access trail occurs at about half a kilometer. At Taughannock Park the Tully does not contain obvious fossils, but the unit is correlative with units formed during the Taghanic biocrises, a half-million year interval of turnover that precedes the eventual Frasnian-Famnenian extinction (Zambito et al., 2012).

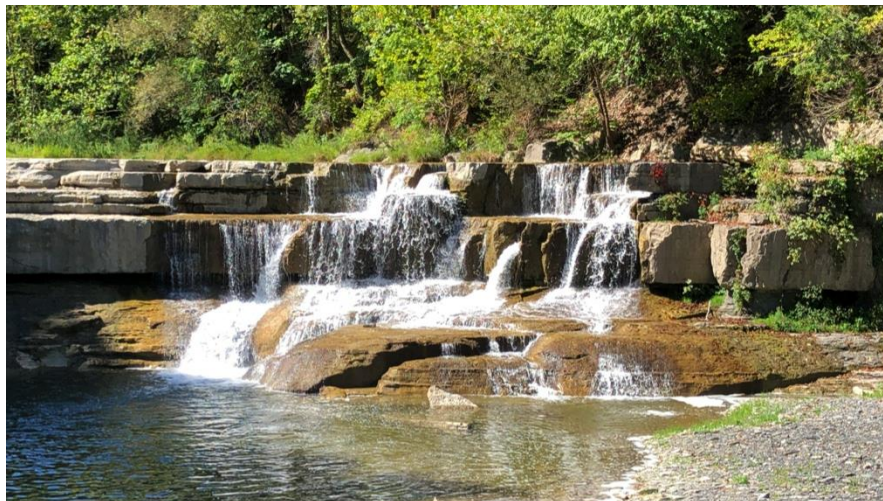


Figure 22: Lower Taughannock Falls, flowing over the Tully Limestone, and, below it, the Moscow Formation.

Solution pits cover the surface of the limestone (Figure 23). The numerous en echelon parallel vertical joints running through the Tully differ in shape from the smooth joints characteristic of those in clastic units through Central New York and in other units at Taughannock (see Engelder et al., 1987; Engelder et al., 2009).



Figure 23: Left: Bedding plane with solution pits of the Tully Limestone exposed in the bed of Taughannock Creek above Lower Taughannock Falls. Right: A weathered exposure of the Geneseo Shale on the south side of Taughannock Gorge.

Along the slope above the streambed is black shale of the Geneseo Formation. The shale is easily accessed on the side of the south side of the trail (away from the stream) starting several hundred meters from the trailhead (Figure 23). There are no macrofossils. Further up the streambed the upper part of the Tully becomes muddier and more finely bedded, associated with the deepening event leading to deposition of the Geneseo. The Tully-Geneseo contact is beneath the surface of the Falls plunge pool, with the Geneseo exposed in the streambed in the 200 m closest to the Falls.

Evidence of rock falls can be seen at numerous points along the trail, where it is possible to see blocks from higher in the section. Just past a 90 degree bend (“Big Bend”) in the creek is a stretch of rock wall without vegetation where past rock falls have taken place, including one in July 2016 in which the NYS Park Service used hydraulic jacks to push over a pillar of rock that was about to topple on its own.

Taughannock Falls is reputed to be the highest freefalling waterfall east of the Mississippi. It is about 10 m higher than Niagara Falls. The plunge pool beneath the falls is about 9 m deep. The strata exposed along the cliff behind the Falls are the Geneseo, Sherburne, and Renwick Formations.

The caprock for the falls is a resistant siltstone bed within the Sherburne Formation, which overlies the weaker Geneseo. Further up Taughannock Creek, above Taughannock Falls, are outcrops of the overlying Ithaca Formation (deWitt and Colton 1978, Zambito pers. comm. 2019).

Jointing is well developed, and weathering occurs especially through large blocks that weather along joint and bedding surfaces. Over a century of photographs of the waterfall and cliff walls allow observation of rate and nature of weathering (see Figure 25 below).

Taughannock Falls and strata can also be viewed from from the Falls Overlook, on the north side of the gorge, which can be reached on Taughannock Park Road off Route 89. Here you can see from a different perspective the V-shaped notch of the stream and shape of the “amphitheater” of the gorge (Figure 24) around the Falls.



Figure 24: The view from Taughannock Falls Overlook.

The gorge is one of dozens in the Finger Lakes. The strata at the top of Taughannock are roughly correlative with the strata near the bottom of other well-known gorges around the southern end of Cayuga Lake.

### Using Taughannock Park for Teaching

Taughannock Gorge, like all places, is the product of a complex set of processes that have occurred over many different time scales. Taughannock is an ideal setting for teaching because it has both an interesting variety of sedimentary rocks and paleoenvironments, as well as interesting topography. The geology has been the subject of numerous research publications over the years on topics ranging from stratigraphy to the formation of gorges to the formation of vertical joint systems in Central New York, providing a rich literature. The site is an excellent location for students to try to weave together geological history to make sense of why the Park and region look as they do.

Events that impact the landscape and stratigraphy are tied to geological events at either end of the timescale, from Precambrian boulders (glacial erratics) to Quaternary landforms to modern processes. While sediments were deposited that became the strata we see at Taughannock, the first forests and tetrapods were evolving, and the end-Devonian extinction took place within the time represented in the cliff walks at Taughannock. The rocks at Taughannock were deeply buried in the late Paleozoic when the joints that cut through these rocks were formed (e.g., Engelder et al., 1987). These other major events may not be seen in local rocks, but they can be explored in the Museum of the Earth (and in the research collections of PRI).

More generally, there is, of course, no one place where all of geologic history can be seen – we rely on different bits of history we find in different places. Museum research collections and exhibits bring



specimens from many of those places together. The Museum of the Earth can in this way be used as a tool to help students provide context for the observations they make at Taughannock – what was happening to life in the Devonian, and what was happening before and after the strata at Taughannock were deposited?

**Taughannock Falls and Virtual Fieldwork:** How can students compile their disparate observations, at Taughannock and elsewhere, and how might a teacher revisit places such as Taughannock and the Museum within the context of their classrooms? New inexpensive technologies allow both teachers and students of any background to document their fieldwork experiences visually and with digital data that augment traditional field techniques.

Virtual Fieldwork Experiences (VFEs) are typically multimedia representations of actual field sites that can be used to extend experiences in the field, or, in a limited way, to replace them (Duggan-Haas, 2015; Duggan-Haas and Kissel, 2016; Duggan-Haas and Ross, 2017; Granshaw and Duggan-Haas, 2012; Kissel et al., 2013; Ross et al., 2007). Ideally, VFEs catalyze field experiences by motivating users to seek to visit field sites in person. Aspects of VFEs can also be used in the field to effectively travel through time, to shift perspective, and to aid in seeing details. The advent of smartphones and tablets have greatly expanded possibilities.

In a very real sense, VFEs offer a modern spin on ancient practices. Cave paintings are arguably a form of VFEs, and if you add stories told in front of those paintings, especially with sound effects, you have a multimedia experience that allows sharing experiences distant in time and space. The array of available media types has grown throughout human history and is now stunning in scope.

We have compiled an annotated list of apps and other technological tools useful for capturing and sharing aspects of field sites as part of the Eastern Pacific Invertebrate Communities of the Cenozoic (EPICC) project here: <https://epiccvfe.berkeley.edu/for-educators/technical-tools-of-real-and-virtual-fieldwork-for-scientific-inquiry/>.

A few examples of such technology applied to VFEs follow, using Taughannock Falls as an example.

**Travel in Time Using Historic Imagery:** While electronics are not required to show historic imagery, the capability to carry thousands of images in your pocket extends the realm of possibilities for using images in the field. The images in Figure 25, show Taughannock in 1888 paired with a more recent image. When sharing imagery in the field, whether printed or electronic, it is often helpful to hold up the image so it aligns with your view in the field. For example, hold the picture of Taughannock in 1888 up so it blocks your view of the falls and move the image in and out of the view to study the changes.

It is relatively simple to create animated gifs combining images using free online services. An animation of these two images, slightly cropped to align them, is available here: <https://imgur.com/gallery/9MMqMHC>.



Figure 25. Taughannock Falls on May 26, 1888 (top, photo by E. M. Chamot and featured on the cover of von Engeln's 1961 book) and March 12, 2008 (bottom, photo by Rick Allmendinger). Notice the projecting crest in the top photo, which broke off "[s]ometime before 1892" according to von Engeln (1961). These images and caption are from Figure 6.5 of Bloom, 2018, available at an online image gallery for the book: <https://www.priweb.org/index.php/publications/special-publications/pubs-bloom-gallery>.)



This particular pair of images not only travels across more than a century, it also shows the appearance in different seasons. Taughannock's flow varies tremendously throughout the year and both images above show higher than normal flow. Contrast the volume of water in these images with the flow shown in Figure 26, below.

**Using Skitch to Annotate Photos:** Skitch (<https://evernote.com/products/skitch>) allows for simple annotation of photos and maps in the field. It is also helpful for field instruction. Rather than pointing to some feature on a distant cliff face, for example, the instructor can snap a picture, label it in Skitch and show the phone to students to guide their eyes (Figure 26). For iPhone and Android. *Free*.



Figure 26. A photo of Taughannock Falls with some annotations added using Skitch (photo by RM Ross; annotations by Don Haas).

**Create an Immersive Panorama Using Google Street View:** Google Street View is both a feature in Google Maps and a free standalone app that allows users to create their own Street View Panoramas on their smartphones or tablets. (<https://www.google.com/streetview/>). As with any imaging technology, this too can be used to show changes over time. Figure 27, below, shows a screengrab of Street View Panorama taken in September 2017 and shows an area with a recent rock fall.

Google Cardboard, is an inexpensive Virtual Reality (VR) headset that allows users to view Street View Panoramas in 3D. More information is available here: <https://vr.google.com/cardboard/>. These viewers can also be used for 3D models, like those hosted on Sketchfab.com. At this writing, there are not models from Taughannock, but the Digital Atlas of Ancient Life includes hundreds of fossil models. The Museum of the Earth's "Life in an ancient sea" exhibit – a wall of Devonian Fossils – is available as a 3D model here: <https://skfb.ly/6NvpV>. It may be viewed as an interactive 3D model on a computer screen or with a VR headset for a more immersive effect (as is the case with Street View Panoramas).



Figure 27. A screen grab of a Google Street View Panorama showing a fresh rock face after a 2017 rock fall. The full panorama is here: <https://goo.gl/maps/G91WCJ2jVEoMqHS2A>.

**Technology to access and record geologic information:** ROCKD, a free app developed by the University of Wisconsin Macrostrat Lab with support from the National Science Foundation, allows you to access key geologic facts about your location and record your observations.

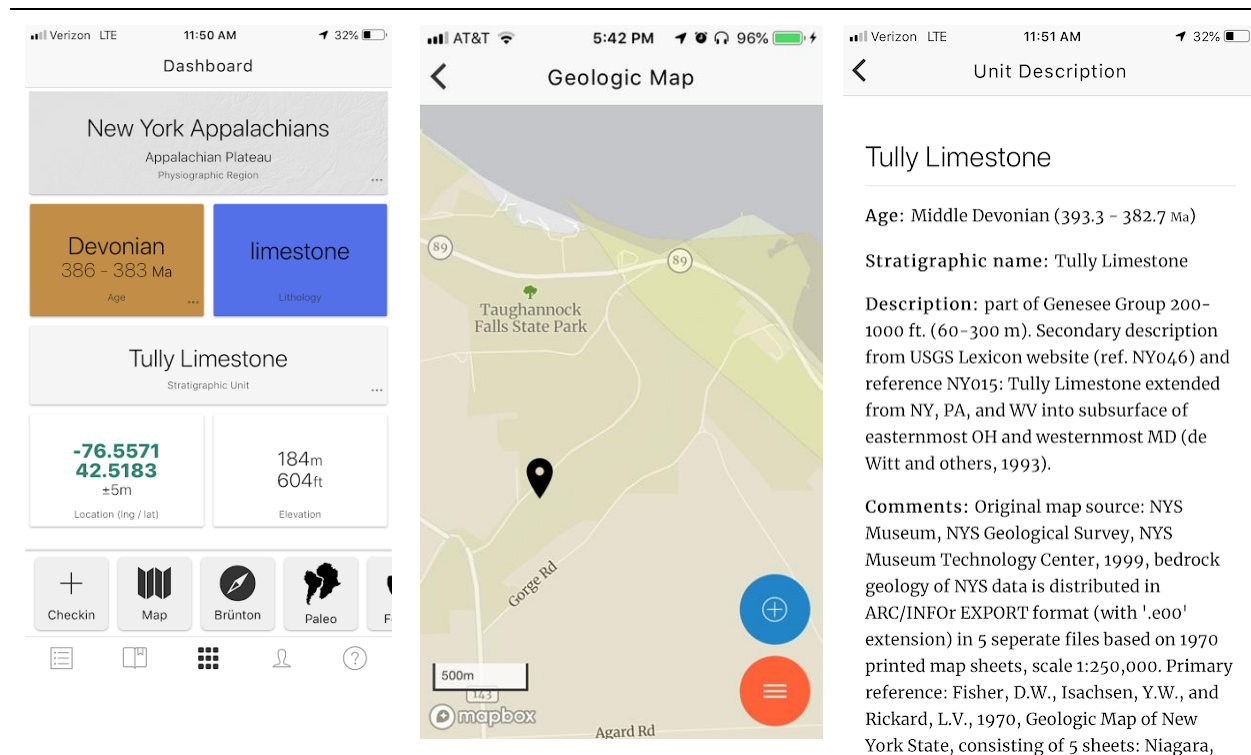


Figure 28. Screenshots from the ROCKD app. The Dashboard automatically shows a basic description of the rock beneath you. The detailed description, excerpted in the third frame is several pages long and includes links to references.

In addition to viewing geologic maps of your location (see screengrabs of the app in Figure 28), ROCKD allows you to search for any locale, includes a virtual Brunton compass, allows you to view paleogeographic maps, and has a check-in feature that allows you to record your observations and site visits. It is available at: <https://rockd.org/>.

## SUMMARY

Perhaps all geoscience educators would agree that learning Earth system science and history is best accomplished with authentic field experiences and specimens. We are, however, inevitably limited in our capacity to share such experiences with our students on a regular basis, given travel and collections resources that are typically available. Effective Earth science teaching mirrors in some respects doing Earth science research: it combines compelling questions and exploration of real-world settings (scientific fieldwork), using associated objects (research collections) and data (including digital imagery). By combining occasional visits to field sites (such as Taughannock Park) and to museums (such as PRI and its Museum of the Earth), accessing 3-D digital teaching collections made from collections specimens (such as on the Digital Atlas of Ancient Life), and developing virtual fieldwork experiences made for and by students, we add to our opportunities to teach in ways that reflect the richness of doing science.

## ROAD LOG

Meeting Point = STOP1: Paleontological Research Institution, 1259 Trumansburg Road (Rt 96), Ithaca, NY

Meeting Time: Sunday, October 6<sup>th</sup>, 2019, 8:30 AM

Location Coordinates: 42.465790, -76.538103

We will meet in the lobby of PRI's Museum of the Earth. There is parking available in the parking lots in front of the Museum.

We will tour the exhibits of the Museum of the Earth and the research collections of the Paleontological Research Institution. We will be at PRI about 2 hours.

STOP 2: Taughannock Park, 1740 Taughannock Boulevard (Rt 89), Trumansburg, NY

Location Coordinates: 42.545242, -76.598511

Taughannock Park is a 6.6 mile (10.6 km) drive from PRI.

Meet in the parking lot on the west side of the road, adjacent to the start of the Gorge Trail.

We will walk the Gorge Trail to Taughannock Falls and back, a total of about 2 miles (3.2 km), which will take about 2 hours.

STOP 2a: Taughannock Falls Overlook and Visitors Center, Taughannock Park Road

Location Coordinates: 42.538821, -76.608126

We will drive 0.6 miles (1.0 km) from the Taughannock Park parking lot to the Falls Overlook parking lot. This stop will be brief.

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