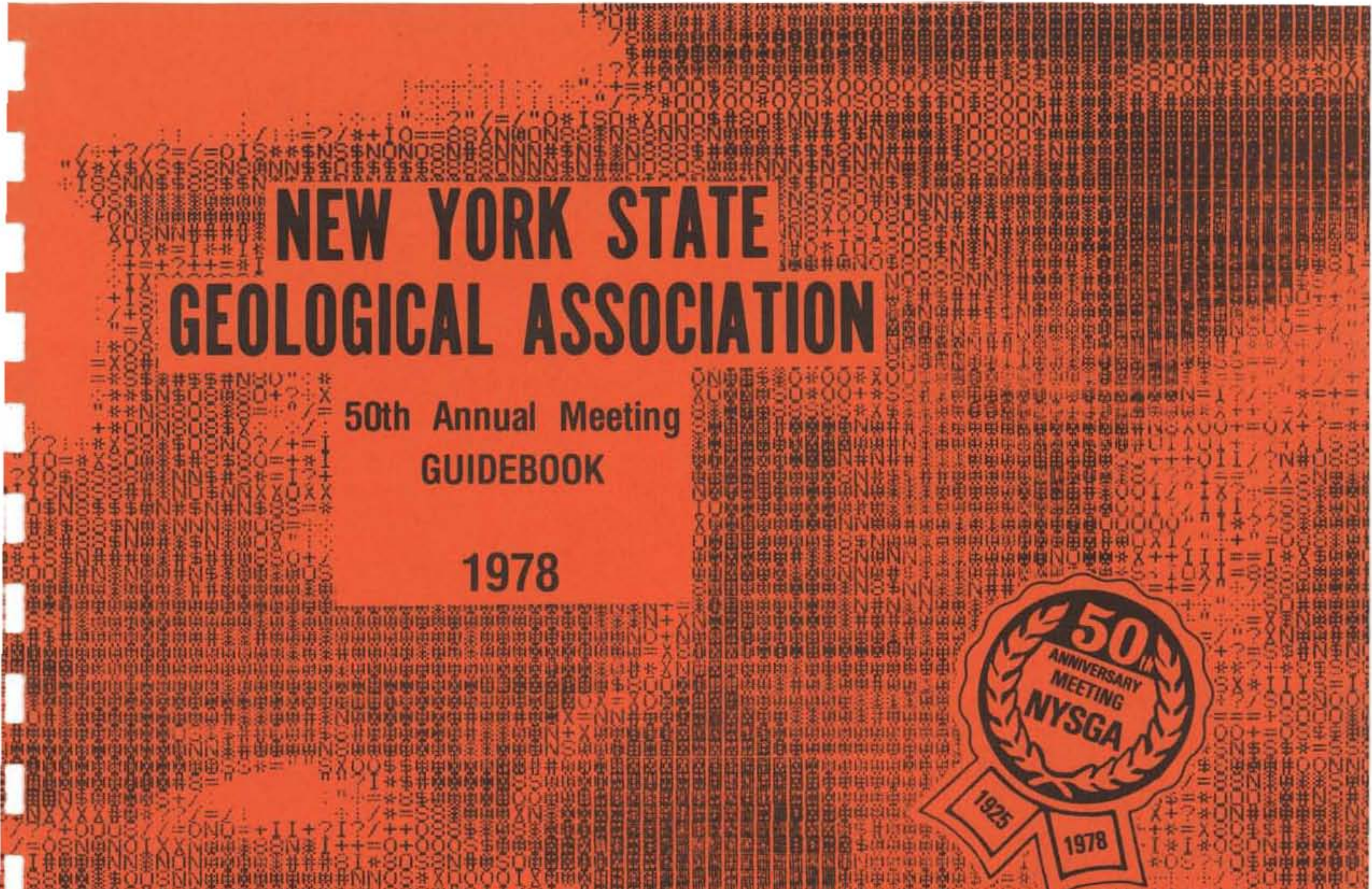

NEW YORK STATE GEOLOGICAL ASSOCIATION

50th Annual Meeting GUIDEBOOK

1978

50th ANNIVERSARY MEETING NYSGA

1925 1978

DEPARTMENT OF GEOLOGY
SYRACUSE

SYRACUSE UNIVERSITY
NEW YORK

NEW YORK STATE GEOLOGICAL ASSOCIATION

GUIDEBOOK

50th Annual Meeting

SYRACUSE, NEW YORK

23-24 September 1978

Daniel F. Merriam, *editor*

Department of Geology

Syracuse University

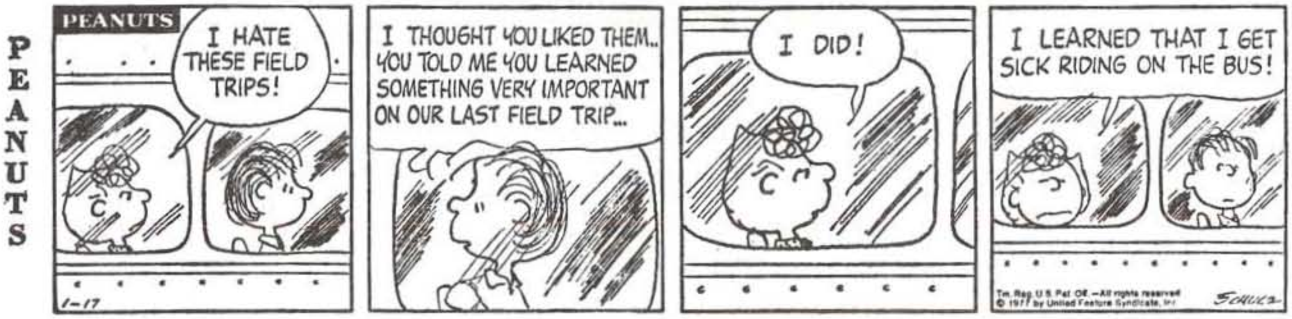

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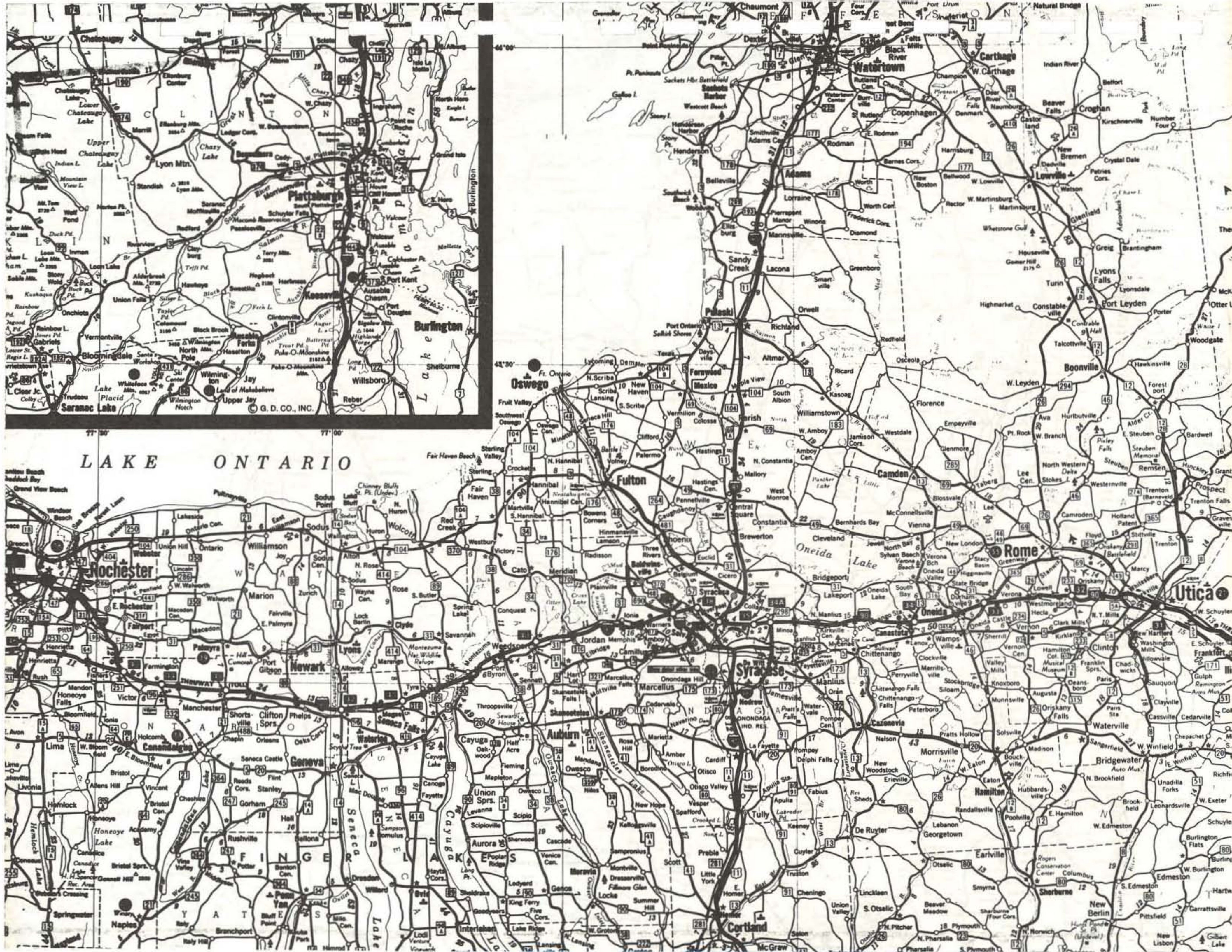
Table of Contents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Hague
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Elizabethtown
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Lake Placid
Saranac Lake
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Cranberry Lake
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Greenwich
Cambridge
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Vergennes
Fair Haven
Middleville
Newport
Poland
Remsen
Forestport
Camden
Lake Champlain
Adirondack

INTRODUCTION

It is appropriate that the Golden Anniversary meeting of the NYSGA be held at Syracuse University. Syracuse has been involved actively in Association activities since the beginning. As secretary, Harry N. Eaton of SU issued the announcement of the first meeting to be held at Hamilton College in April of 1925. He then was president the next year as Syracuse served as host.

In 1937 SU was host for the 13th meeting with Louis W. Ploger president. Again in 1950 Ploger served as president as Syracuse hosted the 22nd annual meeting on the Silver Anniversary of the formation of the Association (1925-1950). John J. Prucha organized the 36th meeting in 1964.

Syracuse is always proud and pleased to host the Association that may be the oldest organized state intercollegiate geological group in the country. The Association has grown considerably in size and stature from that first meeting 53 years ago (see paper by Lowe and Wolff on history of the Association in this volume). There is no record of the number of attendees but the meeting consisted of a few pages of handouts for the one field trip following a previous evening dinner and lecture. This loose organizational arrangement was successful in the early years and continued until 1953 when Kurt E. Lowe was elected first permanent secretary of the Association. The secretaryship provided a stability and continuity needed for the Association and beginning in 1956 guidebooks for each meeting were kept in print for sale. Lowe was followed in office by Philip Hewitt in 1968 (now the office was termed executive secretary), D.F. Merriam in 1972, and Fred Wolff in 1977. The Association affiliated with the American Association of Petroleum Geologists in 1974.

The Association grew in permanency and organization (it now had a constitution) so did the size of the guidebooks. From a few pages in 1925 to 425 pages in 1977. Subject matter was expanded until today the guidebooks provide one of the most important sources of information on the geology of New York State.

The offerings this year are no exception. In addition to writeups and roadlogs for the 17 trips, background papers on selected subjects are included. Of special importance are the two papers on the history of geology in New York by Don Fisher of the NY State Geology Survey and on the history of the Association by Kurt Lowe and Fred Wolff. These contributions undoubtedly will serve as standard references for years to come.

Each of the authors are to be thanked for their contribution. It is their collected efforts that made this publication possible. A different procedure was used this year on preparing the papers for inclusion in the guidebook. Each author was asked to provide finished copy for direct reproduction. Although this method has its problems (but all publication methods do), it allows authors greater flexibility and the possibility to make last minute changes. It also speeds up production time and reduces costs.

Many people have cooperated in putting on this meeting. Janice Potak assisted in typing, editing, and proofreading material for the guidebook and helped in a variety of other ways. Beverley O'Brien and Debby Blose also have assisted in preparing material and making arrangments. All of the faculty and students of the Department of Geology at SU have given considerable time and effort in preparing for the meeting. Credit for success of the meeting goes to the entire Department.

Dewey Hale of the Syracuse Chamber of Commerce provided material and advice in making arrangements. Owen Muir of the Treadway Inn helped with the housing. Elmer Foote of the SU press assisted with the printed material. Many individuals and other Departments at Syracuse University cooperated in the logistical arrangements.

Last but not least Fred Wolff lent his support for the entire year of preparations. This was most appreciated.

So here are the results for the golden anniversary volume. May the next 50 years of the Association be equally successful and rewarding to those involved and interested with the geology of New York State.

D.F. Merriam, President
New York State Geological Association
Department of Geology
Syracuse University
Syracuse, NY 13210

FIELD TRIPS

23 September (SATURDAY)

Trips leave from SU Colvin parking lot of Manley Fieldhouse at 8:30 A.M. There is ample parking space in this area. Note all Saturday field trips are by bus, <u>except</u> A-2 which will meet in Blue Mtn. Lake and A-6 which will meet in Alexandria Bay.

A-1 Structures in lower Paleozoic rocks, northwest Adirondacks: leaders, J.T. Bursnall and Brian Barber, Syracuse University

A-2 Structure and petrology of the central Adirondacks: leaders, G.M. Boone, Syracuse University; Ennis Geraghty, New York State Geological Survey; and J. McClelland, Colgate University

A-3 Lower Hamilton Group paleoecology: leaders, J.C. Brower and O.B. Nye, Syracuse University

A-4 Geomorphology of the southeast Tughill area: leader, E.H. Muller, Syracuse University

A-5 Upper Hamilton group paleoecology: leader, T. Grasso, Monroe Community College

A-6 Paleoenvironments of the Potsdam Sandstone and Theresa Formation, northwestern New York: leader, B.W. Selleck, Colgate University

A-7 Benthic communities in the Ordovician clastics, Tug Hill Region: leaders: D.J. Thomas, SUNY Oswego and P.W. Bretsky, SUNY Stony Brook

A-8 Punctuated aggradational cycles in the Black River-Trenton and Helderberg-Onondaga: a general model of deposition: leaders, E.J. Anderson and P.W. Goodwin, Temple University, and B.W. Cameron, Boston University

A-9 Eurypterid horizons and stratigraphy of the upper Silurian and lower Devonian rocks of central-eastern New York: leader, S.J. Ciurca, Jr., Rochester, New York

A-10 An examination of bottom sediments in Seneca Lake: leader, D.L. Woodrow, Hobart and William Smith Colleges

A-11 Nine Mile Point nuclear site: leader, J.A. Fischer, Dames & Moore

A-12 Geology of the Tully Limestone: leaders, J.M. Cubitt, Syracuse University and P.H. Heckel, University of Iowa

24 September (SUNDAY)

Trips leave from SU Colvin parking lot of Manley Fieldhouse at 8:30 A.M. Note <u>only</u> trips B-2, B-3, and B-5 are by bus, all other trips are by private car.

B-1 (A-3) Lower Hamilton Group paleoecology: leaders, J.C. Brower, and O.B. Nye, Syracuse University

B-2 Syracuse channels: leader, B.M. Hand, Syracuse University

B-3 Valley Heads Moraine in the Syracuse vicinity: leaders, D.E. Andrews and R.J. Jordan, Syracuse University

B-4 (A-8) Punctuated aggradational cycles in the Black River-Trenton and Helderberg-Onondaga: a general model of deposition: leaders, E.J. Anderson and P.W. Goodwin, Temple University; and B.W. Cameron, Boston University

B-5 (A-10) An examination of bottom sediments in Seneca Lake: leader, D.L. Woodrow, Hobart and William Smith Colleges

B-6 Moss Island (an examination and history of the newest National Landmark in the US): leader, H. Muskatt, Utica College

B-7 Upper Devonian biostratigraphy near Cortland: leaders, J.W. Harrington and G. Heaslip, SUNY Cortland

B-8 (A-12) Geology of the Tully Limestone: leaders, J.M. Cubitt, Syracuse University and P.H. Heckel, University of Iowa

LAUDABLE LEGACY -----a synopsis of the titans of geology and paleontology in New York State

Donald W. Fisher, State Paleontologist
Geological Survey, New York State Museum, Albany, New York 12234*

"Not to know the events which happened before one was born,
that is to remain always a child" ..... Cicero

Someone famous once said, "Great minds talk about ideas, average minds talk about events, and small minds talk about people." At the risk of becoming a target for a brusque and unflattering categorization, I shall nevertheless proceed to talk about people, events, and ideas in that order of emphasis. Because people report on events and ideas, it seems to be the most expedient procedure to introduce you to the notable personages who fostered geological and paleontological thought prior to offering an analysis of the events and ideas that have transpired. Tracing almost two centuries of the history and development of geology and paleontology in New York State is no small story. The abridgement that follows focuses on the highlights of that evolution.

Within the designated scope of this overview, it is impossible to acknowledge all those who have made significant contributions toward a better understanding of the sediments, rocks, fossils, geologic processes, depositional environments, geologic structures, and geologic history within the Empire State. Those whom I have chosen to recognize are regarded as having contributed the most toward the elucidation of the geology and paleontology of New York State. Doubtless, a few of you may disagree with some of my choices or omissions. This, of course, is your privilege (and mine!); I offer no apologies for my selection.

Prior to the 1820's, geologists and paleontologists did not exist as such. Instead, those who observed, lectured on, and wrote about geological things usually were physicians, lawyers, theologians, philosophers, or travelers. Customarily, these learned ones also concerned themselves with botany, chemistry, physics, and zoology. Because of their broad interests in natural history, they were labelled "naturalists." Probably the most gifted and versatile of these late 18th century-early 19th century scientists was the physician-lawyer Samuel Latham Mitchill (b. 1764, North Hempstead, Long Island; d. 1831, New York City) (Plate 2). As a youth, he studied medicine with an uncle, Dr. Samuel Latham and, later, with Dr. Samuel Bard in New York City. Mitchill received his Doctor of Medicine from the University of Edinburgh, with honors, in 1786 and it seems likely that he must have come under the "spell" of the famous James Hutton, while there. Mitchill studied law with Robert Yates, Chief Justice of New York.

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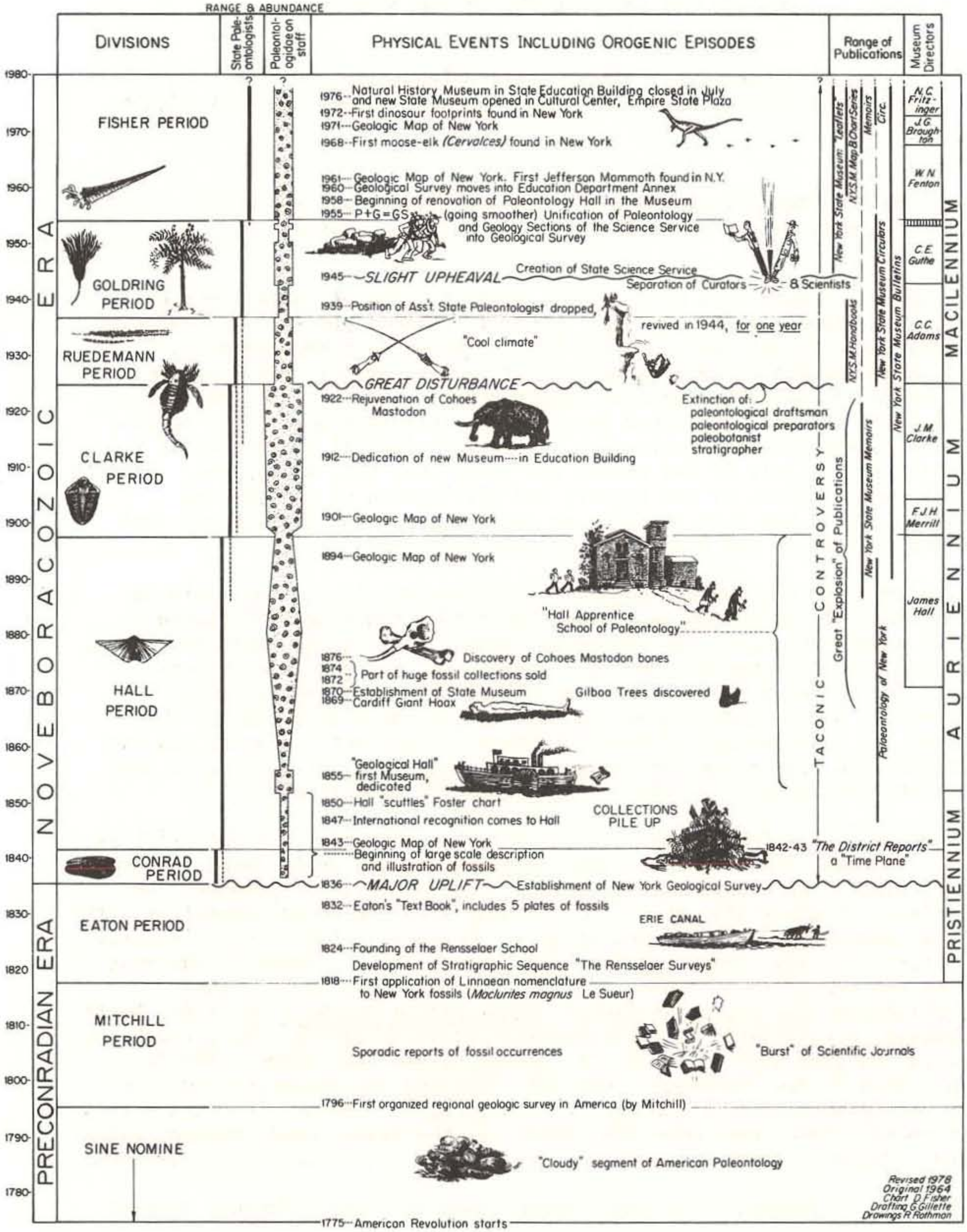


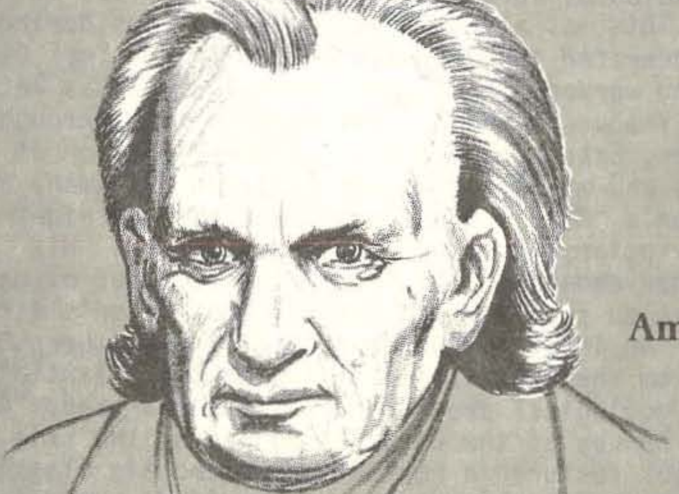
Plate 1. Paleontological time scale for New York State.

Effectively combining the studies of medicine and law, Mitchill served as U.S. Congressman, U.S. Senator, and Professor of Natural History, Chemistry, Agriculture, and Botany at Columbia University. He was instrumental in founding several scientific journals and was a frequent contributor to them. Also, he was a polished orator and poet. Mitchill's reputation as a naturalist was international and served to enhance the scientific stature of the "New Republic." His political acumen was such that Thomas Jefferson referred to Mitchill as the "congressional dictionary." Mitchill was equally at home studying the geology of Niagara or the anatomy of an egg, in offering suggestions on windmill efficiency or deciphering a Babylonian brick, in championing the cause of Fulton and Livingston in promoting steam for navigation or in studying conchology. Truly, Samuel Mitchill was "Mr. Scientist" in young America and had he been an artist, too, he most certainly would have been labelled "America's Leonardo daVinci." On my somewhat whimsical "Paleontological Time Chart" (Plate 1), the "Mitchill Period" begins with the first informal geological survey of New York State (1793-1796)---by Mitchill---and encompasses the beginnings of better recorded, though still a "curiosity" approach to, geological study in New York.

Amos Eaton (b. 1776, New Concord, N.Y.; d. 1842, Troy, N.Y.) (Plate 2) epitomizes the budding of the natural sciences in an emerging nation. Like Mitchill, Amos was a talented youth with a broad spectrum of interests including oratory, blacksmithing, and surveying. After studying law and receiving a B.A. from Williams College, Eaton became a land agent, acting as attorney, rent collector, and all-around supervisor for a Livingston estate near Catskill, N.Y. Eaton's legal career ended abruptly in 1810 when he was wrongfully convicted of forgery and sentenced to life at hard labor----without clemency. This was a most severe penalty considering the supposed crime. While incarcerated in Greenwich Prison in New York City, Eaton learned botany from the warden's son, John Torrey----who was later to distinguish himself as a famous botanist. Pardoned in 1815 through DeWitt Clinton's intervention, Eaton resumed his college education at Yale, studying chemistry, geology, and mineralogy under Benjamin Silliman, and botany under Eli Ives. Eaton's "Manual of Botany" went through eight editions and contained descriptions of 5,267 species of plants. His scientific stature was further enhanced as a travelling lecturer of natural sciences----perhaps the first on such a broad scale. Amos Eaton's first geological contribution was "An index to the geology of the Northern States, with a transverse section from the Catskill Mountains to the Atlantic" (1818). But his best known geological production was the 163-page, "A Geological and Agricultural Survey of the District adjoining the Erie Canal" (1824). The canal book featured a revised and elaborate classification of North American rocks. Four major classes were recognized: Primitive, Transition, Secondary, Superincumbent. These, in turn, were categorized into 25 divisions and 28 subdivisions. None had geographic names, such as are used today. Instead, Eaton's rocks sported names like "Primitive Argillite," "Calciferous Sandrock," "Metalliferous Limerock," "Millstone Grit," "Calciferous Slate," "Cornitiferous Limerock," etc. This new rock nomenclature was a brash innovation and invited harsh criticism. Rocks were correlated by physical description,----now proven to be a dangerous practice. Eaton's failure to use fossils caused some glaring errors of sequential arrangement and correlation. As a result, he correlated the

Plate 2

Samuel L. Mitchill



Amos Eaton

Catskill redbeds (Middle and Late Devonian) with the Queenston redbeds (Late Ordovician) and placed the salt-bearing strata (Late Silurian) above both! Seemingly, he was ignorant of William Smith's classic work on stratigraphy in the British Isles. With T. Romeyn Beck and Lewis C. Beck, Eaton conducted geological surveys of Albany (1820) and Rensselaer (1822) Counties,---the first such detailed county studies in North America. The multitalented Eaton was selected by the patroon Stephen Van Rensselaer as first senior professor at the Rensselaer School (later the Rensselaer Polytechnic Institute). Eaton's highly innovative teaching techniques included students learning by doing via laboratory experiments, field collecting, and practice teaching. All this was a bold departure from the boring, stereotyped method of that day which saw professors formally reading from prepared notes and calling on students to recite from memory. The spirit of camaraderie between Eaton and his students was one not previously developed in the scientific community and was no small point of professional jealousy among the well-known universities of that period. The Rensselaer School, together with a School of Industry operated by William Maclure at New Harmony, Indiana, attracted the best would-be geologists of the early 19th century, and between them produced most of the outstanding geologists of that period. Amos Eaton was also a pioneer in women's rights, openly encouraging young ladies who possessed a scientific bent. Among these were his daughter, Sarah Cady Eaton, his sister-in-law Laura Johnson, Almira Lincoln Phelps (sister of Emma Willard who founded the famous school for girls in Troy), and Mary Lyon, the emancipator. Eaton prepared the first "Geological Textbook" (1830) which sold for $1.50 and included the first colored geological map of New York State. As an educator, he introduced the Bachelor of Natural Science and Bachelor of Civil Engineering degrees. Amos Eaton, this zealot of science, attained the rare achievement of becoming a colossus in two sciences----geology and botany. Between 1817 and 1841, his passionate peddling of science, through more than 4,000 lectures, 12,000 chemistry experiments, and over 17,000 miles of "field-tripping," provided an impetus in natural science at a time when scientific artifacts became more than curiosities of nature. Appropriately, the 1818-1836 interval is termed the "Eatonian Period" in the evolution of geology in New York State (Plate 1).

April 15 is both an infamous and famous day. Infamous because, annually, it is the deadline for payment of Federal and State income taxes. Famous, for April 15, 1836 was a turning point in the development of geological undertaking in New York State because it marked the initiation of state-sponsored geologic study. On that momentous day, Governor William Marcy, an ardent proponent of conservation of the State's poorly known but presumably vast natural resources, signed into law the establishment of the Natural History Surveys of New York. Geologists should be especially indebted to the then-Secretary of State John A. Dix. It was he who so convincingly argued in favor of a geological survey, before the skeptical legislature succumbed to his enthusiasm and appropriated $104,000 for that purpose.

Upon the advice of Eaton and Edward Hitchcock (Professor of Geology at Amherst College, and respected New England geologist), the state was apportioned into four geological districts. Not one, but four State Geologists were appointed with equal authority (and, it was hoped, equal competency!). U.S. Army engineer William W(illiams) Mather (b. 1804, Brooklyn, Conn.; d. 1859, Columbus, Ohio) (Plate 4) was given charge of the First or Eastern District. Rensselaer School Professor of Chemistry (and Albany Medical College Doctor of Obstetrics) Ebenezer Emmons, Sr. (b. 1799, Middlefield, Mass.; d. 1863, Brunswick County, N.C.) (Plate 4) headed the Second or Northern District. Conchologist Timothy A(bbott) Conrad (b. 1803, Trenton, N.J.; d. 1877, Trenton, N.J.) (Plate 4) became chief of the Third or Central District. Paris-trained geologist Lardner Vanuxem (b. 1792, Philadelphia, Penn.; d. 1848, Bristol, Penn.) (Plate 4), the only one with formal training in geology, headed the Fourth or Southern District. Physician and Professor of Chemistry, Botany, Mineralogy, and Zoology Lewis C(aleb) Beck (b. 1798, Schenectady, N.Y.; d. 1853, Albany, N.Y.) (Plate 4) was appointed State Mineralogist. Because the 1836 season's work yielded such a prodigious array of unidentified fossils, and Conrad and Vanuxem were displeased with the boundaries of their respective districts, the survey was reorganized in 1837 with an adjustment in the boundaries of the Third and Fourth Districts (Plate 3) and the appointment of Conrad as Paleontologist. This suited Conrad as he was none-too-fond of field work anyway and he could remain closeted in Albany, studying fossils. Vanuxem was transferred to the Third District, which now had agreeable boundaries, and the young 25-year old James Hall, assistant to Emmons the previous year, was placed in charge of the new Fourth or Western District,---considered a geological "no-man's-land" by the elder staff members. Hall chose his fellow Rensselaer classmates, George Boyd, Ezra Carr, and Eben Horsford, as his field assistants. Together, this quartet of relatively "green" geologists demonstrated to their somewhat condescending colleagues that it was the "wasteland" that would yield the "pearl-in-the-oyster." Each chief geologist had from one to five assistants. The resulting five year foot and horseback fieldwork yielded much unsuspected new information which was summarized in five annual reports and four final, quarto-size, District Reports (1842-1843). These four classics in early American 19th century geology are obligatory reading for all those engaged in geological research in New York State. Beck prepared a final report, "Mineralogy of New York," a methodical and exemplary monograph of 536 pages and 533 woodcuts----all of this accomplished while simultaneously serving as Professor of Medicine at Albany Medical College and Rutgers University. But, alas, there was no final report of the descriptions of the fossils of the State; this was a bitter disappointment. Although "married" to New York's Paleozoic fossils by contract, Conrad had carried on "extramarital affairs" with Tertiary fossils from the Atlantic Coast. Apparently, the task of preparing over 100 plates and describing scores of fossils overwhelmed Conrad. Thus, when Governor Bouck abolished the Survey in 1842, a representative collection of New York's fossils was in hand, but undescribed. Conrad hastily departed without bothering to resign. Mather became active with the growing Ohio Survey. Vanuxem retired to his farm in Pennsylvania. Beck continued research on mineralogy and in medicine and gained an international reputation for his work on pure foods and drugs. This left Emmons and Hall, who remained in Albany, competing to persuade the Legislature to set up funds to collect, study, describe, and publish on the untapped wealth of fossils that occurred in New York strata.

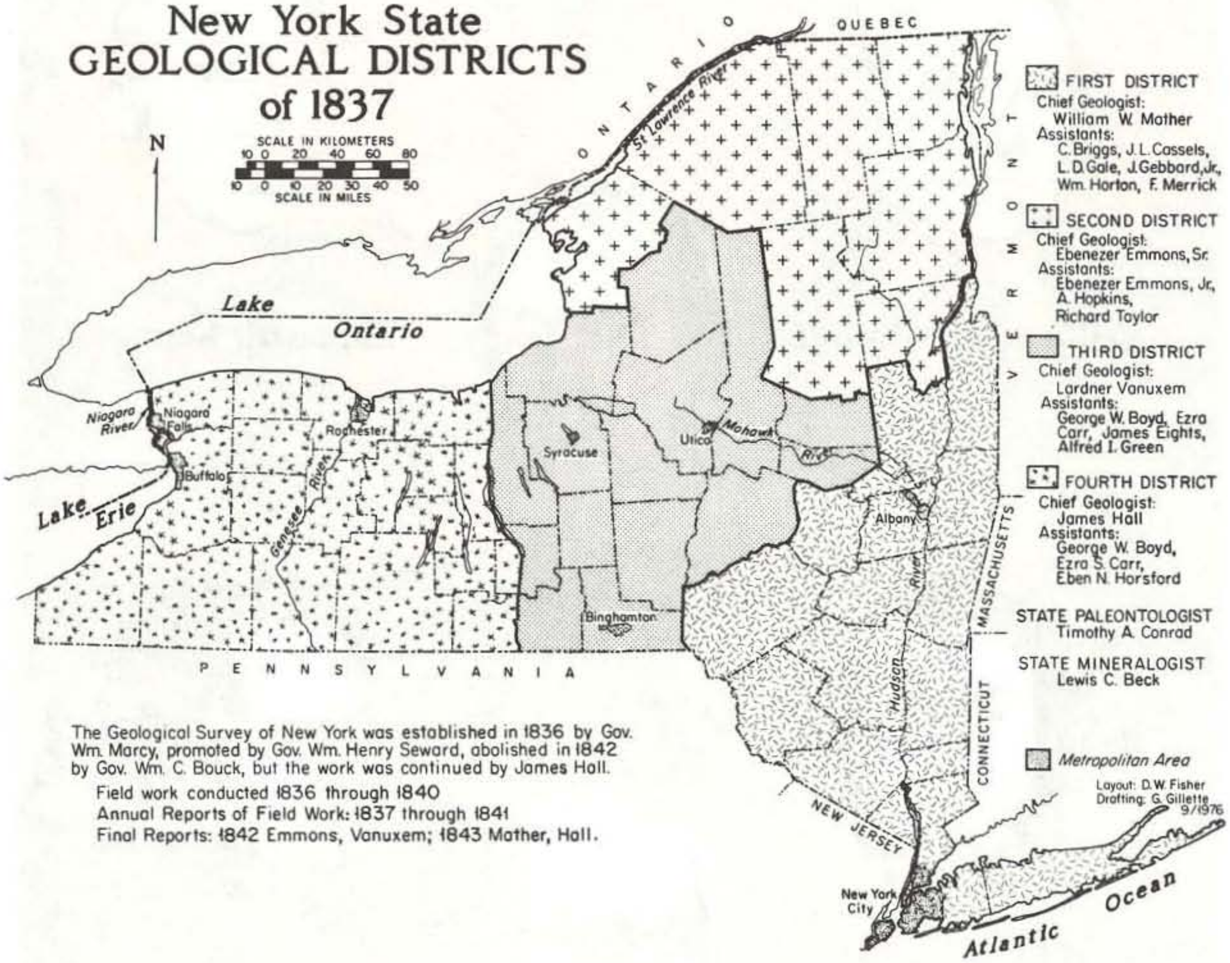
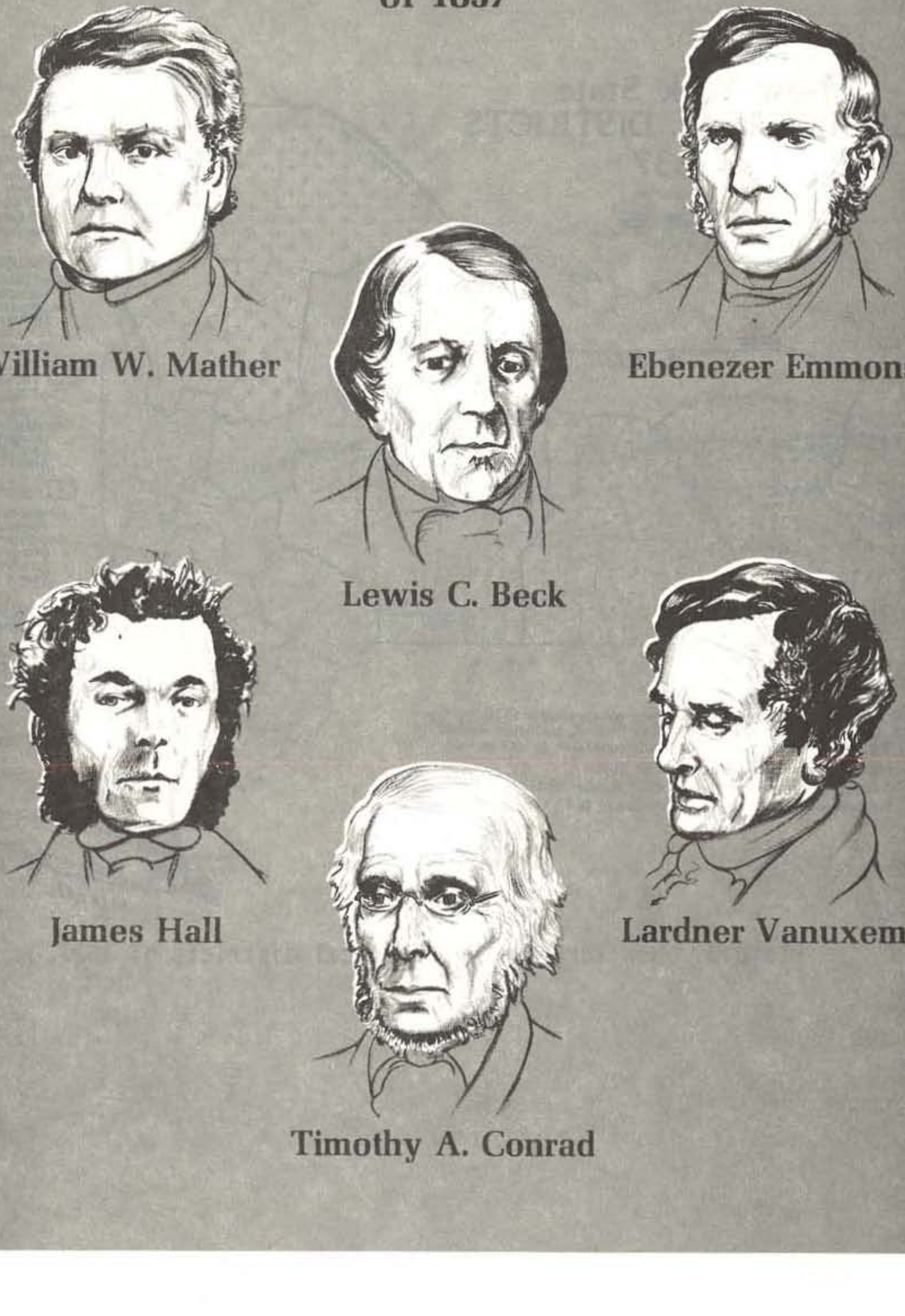


Plate 3. New York State geological districts of 1837.

Plate 4

Principal Staff of the New York Geological Survey of 1837



William W. Mather

Ebenezer Emmons

Lewis C. Beck

James Hall

Lardner Vanuxem

Timothy A. Conrad

The "New York System," the sequence of rocks developed by the District Geologists, would not endure and receive national and international acceptance if it were not fortified by detailed study of its fossils. Either through superior competence, relative youth, or political chicanery, Hall was appointed State Paleontologist by Governor Bouck in 1843. As a conciliatory measure, Emmons was made State Agriculturist but he made the most of this apparently demeaning appointment. He produced five monographs on the Agriculture of New York (soils, fruits, insects, etc.) in which he surreptitiously included his novel notions on the Taconic System of rocks in eastern New York, -- views which were anathema to Hall. Briefly, Emmons believed that the Taconic rocks were older fossil-bearing rocks than any others that were then known in New York (Potsdam). Hall, supported by Mather (who had mapped all of these rocks), the influential James Dwight Dana, and Louis Agassiz (personal friend of Hall) argued that these deformed rocks were nothing more than equivalents of the rocks to the west. The Hall-Emmons discord was widened. In the 1870's and 1880's, discoveries of diagnostic fossils by S(ilas) W(atson) Ford, Troy jeweler and amateur geologist, and William B(uck) Dwight, Professor of Geology at Vassar College, proved that both antagonists were right and wrong! Some rocks in the Taconics are, indeed, older than the Potsdam whereas others are equivalents of those further west. In its original guise, the Taconic Controversy "died a lingering death"; within the last three decades it has been resurrected in a new form in that some geologists have offered different non-conforming structural interpretations for these complexly deformed rocks.

The New York State Geological Survey of 1836-1842, or the Seward Survey (so named because William Henry Seward, later Secretary of State under President Abraham Lincoln, was Governor of New York during most of the Survey's years) left a more impressionable legacy upon American geology than any that preceded or succeeded it. Besides supplying American geology with a nomenclature largely its own (New York System), it demonstrated unequivocally the value of invertebrate fossils for purposes of correlation. The published results (the "Geology of New York") of the Seward Survey attests to the dedication and prodigious efforts of those pioneer geologists (staff of the Survey), ---- traits which modern geologists often fail to appreciate. Within the time span of the history of New York geology, the "Conradian Period" (Plate 1) marks the shortest duration but with the greatest consequence.

The omnipotent reign of James Hall (b. 1811, Hingham, Mass.; d. 1898, Bethlehem, N.H.) spanned 63 years of public service, a tenure that is unmatchable owing to the current mandatory retirement age of 70 under New York State retirement regulations. No other single person exerted as influential a role in the development of paleontology in North America during the 19th century than James Hall. Surely, no one before or since, has been so thoroughly involved with the inception of geologic organizations and government-sponsored geological surveys, nor has exercised such a persuasive influence on his fellow colleagues than did this patriarch of American invertebrate paleontology. Hall's attributes as an astute observer, sagacious scientist, and prolific writer (he authored 302 scientific articles), coupled with his inflexibility of purpose and dynamic personality, made Albany, New York, the "mecca" for aspiring young

Plate 5

State Paleontologists of New York

John M. Clarke
1898 - 1925

Rudolf Ruedemann
1926 - 1937

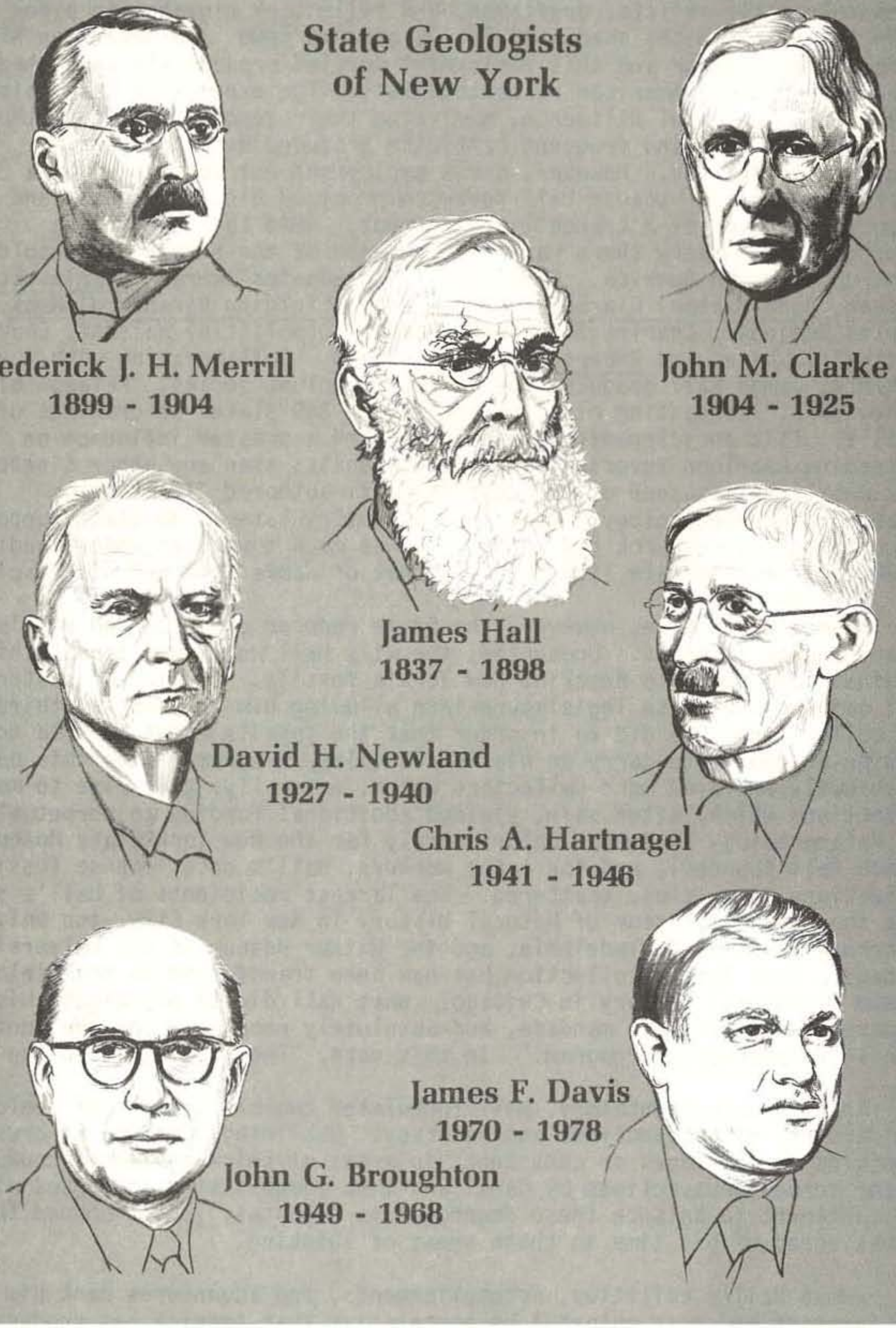
James Hall
1843 - 1898

Winifred Goldring
1938 - 1954

Donald W. Fisher
1955 -

Plate 6

State Geologists of New York



Frederick J. H. Merrill
1899 - 1904

John M. Clarke
1904 - 1925

James Hall
1837 - 1898

David H. Newland
1927 - 1940

Chris A. Hartnagel
1941 - 1946

James F. Davis
1970 - 1978

John G. Broughton
1949 - 1968

paleontologists. In 1857, Hall had constructed (at his own expense) a large brick building (still standing in Lincoln Park, within a "fossils-throw" of the new N.Y. State Museum). To this apprentice school, would-be paleontologists, artists, draftsmen, and collectors migrated in order to learn and labor in the shadow of Hall's growing fame. To have been hired by Hall was an honor and this employment carried credentials unmatched among 19th century American paleontologists. The experience they gained under Hall's watchful diligence, mimicking their teacher's study methods, and receiving free and frequent criticism produced extraordinarily competent scientists. However, one's employment was certain to be a tempestuous tenure because Hall never compromised his high ideals and purposes in favor of a tranquil environment. Amid this continuing atmosphere of anxiety there was produced some of the finest paleontological research in North America. Among Hall's "graduates" were: Charles E(merson) Beecher, John M(ason) Clarke, Orville Derby, Fielding B(radford) Meek, Charles Rominger, Charles Schuchert, Charles D(oolittle) Walcott, Charles A(bithair) White, and Robert P(arr) Whitfield. Collaborating with these students, James Hall produced the 13-quarto volume series, "Palaeontology of New York," consisting of 4,305 pages, and 869 plates of drawings of fossils. This encyclopedic reference exerted a greater influence on succeeding American invertebrate paleontologists than any other single work until the issuance of the current multi-authored "Treatise on Invertebrate Paleontology," more than a century later. No state-supported paleontological research has contributed as much toward an understanding of ancient invertebrate life than has that of James Hall and his disciples.

From time to time, however, the State reduced or suspended Hall's salary and/or expenses. Undaunted, the wily Hall would not forsake his original commitment to describe New York's fossils. In lieu of sustenance, Hall cajoled the State legislature into allowing him to keep two-thirds of his collections. He did so in order that the fossils might be sold to provide an equity to carry on his Palaeontology Program. With this capital, he shrewdly employed more collectors which, naturally, gave rise to more collections which, after sale, yielded additional funding to perpetuate his Palaeontology Project. Unfortunately for the New York State Museum (which Hall founded), and for later workers, Hall's once immense fossil collections were, thus, scattered. The largest recipients of Hall's sales were the American Museum of Natural History in New York City, the University of Pennsylvania at Philadelphia, and the Walker Museum of the University of Chicago. This latter collection has now been transferred to the Field Museum of Natural History in Chicago. What Hall did to promulgate his research was within his mandate, and absolutely necessary for the continuance of his "Palaeontology Program." In this case, "The end justified the means."

Apart from paleontology, Hall formulated two basic ideas of geology, the concepts of geosynclines and isostasy. Outlining his idea of crustal downfolds at the edges of continents in areas of thick sediment accumulation (later termed geosynclines by Dana) and then compensating responses within the continent to balance these downfoldings (isostasy), Hall showed that he was ahead of his time in these areas of thinking.

James Hall's abilities, accomplishments, and adventures rank him as the foremost and most colorful paleontologist that America has produced.

Truly, he was the main catalyst and activator for biostratigraphy, taxonomic paleontology, and paleoecology, fields that he was privileged to observe wax from unpretentious beginnings to assertive sciences.

Although G(rove) K(arl) Gilbert (b. 1843, Rochester, N.Y.; d. 1918, Jackson, Mich.) is best known for his meticulous and sound work with the federal Wheeler and Powell Surveys, his brief career in New York deserves mention. Receiving his bachelor's degree from the University of Rochester at 19, Gilbert associated himself with Henry A. Ward, not only professor at Rochester but founder of the unique institution known as Cosmos Hall,---later to evolve into Ward's Natural Science Establishment, supplier of geological and biological specimens and equipment (and some outstanding zoologists!). Gilbert was responsible for the measurements and comparisons of the famous Cohoes Mastodon skeleton and for its erection in Geological Hall in the old State House in Albany in 1867. This exhibit did much to focus attention and to attract scientists to "Hall's Community" in Albany.

"....he stands today, alone and pre-eminent, the acknowledged master of field technique, the greatest reconnaissance geologist of our time," spoke Douglas Johnson in 1940, then president of the Geological Society of America, when awarding the Penrose Medal, the Society's highest honor, to N(elson) H(oratio) Darton (b. 1865, Brooklyn, N.Y.; d. 1948, Chevy Chase, Md.) (Plate 7). Fifty four years earlier, one month beyond his 21st birthday, Darton was hired by the U.S. Geological Survey as the direct result of his card catalog of references on the geology of New York and vicinity. G.K. Gilbert, then head of the Appalachian Division of the Federal Survey, suggested that Darton expand his card catalog to include the entire Appalachian District. Eventually, 13,330 cards were prepared, covering the area from Maine to Alabama; this later evolved into the exceedingly useful "Bibliography of North American Geology." In 1892, W.J. McGee, chief of the Atlantic Coastal Plain Division of the Survey, sent Darton to New York State to trace the Oneonta strata. While there, it was arranged that young Darton should work with the aging James Hall on a new geologic map of New York State. Darton mapped in the Hudson and Mohawk Valleys and supplied information for other areas of the State where knowledge of the bedrock geology was previously vague. Darton's New York mapping covered 9,350 square miles and often necessitated preparing topographic base maps in the process. Practically all of the compilation and drafting of the 1893 Geologic Map of New York was performed by Darton. But when the map was published, it was both shocking and disappointing to Darton to see only Hall's and McGee's names on the new colored map! Despite this travesty of justice, Darton's contributions to geology are preserved in his 15 articles on New York geology (including two U.S.G.S. Atlas Folios covering southeastern New York). His 50-year career netted him over 200 publications. There is scarcely an area from the Dakotas to Texas and Arizona that was not mapped by the most outstanding field geologist that the U.S. Geological Survey has ever employed.

Eminent stratigraphers inherently possess the compulsory attributes of conciseness, perspicacity, and scrupulosity. Vanuxem, of the Seward Survey, had them and so did Charles S(mith) Prosser (b. 1860, Columbus, Chenango County, N.Y.; d. 1916, Columbus, Ohio) (Plate 7). In 1897, as Professor of Geology at Union College, Schenectady, and with his students

Edgar R. Cumings and William L. Fisher, he mapped the bedrock of the Amsterdam 15-minute quadrangle (N.Y. State Museum Bulletin 34, 1900). This was the first N.Y. State 15-minute quadrangle to be published in color. Prosser continued his stratigraphic and paleontologic work by measuring, in great detail, several thick sections of Middle Devonian strata in Chenango County. His works were among the earliest to pinpoint the horizons of fossils within detailed stratigraphic sections. Prosser early identified some of the Lower Devonian Helderberg limestone facies problems.

Following the death of James Hall, the statutory positions of State Geologist and State Paleontologist were assigned to Frederick J(ames) H(amilton) Merrill and John M(ason) Clarke, respectively. The former had been appointed Director of the State Museum in 1894 to relieve the aging Hall from the bulk of increasing administrative duties; the latter had been a protegé of Hall's since 1882. Merrill (b. 1861; d. 1916) wrote many articles on sediments and rocks in southeastern New York, particularly on the metropolitan New York City area; he was a co-author of the still authoritative New York City Folio of the U.S. Geological Survey Atlas Series. He resigned in 1904 to do consulting in Mexico and the western United States whereupon Clarke assumed the dual titles of State Geologist and State Paleontologist. The ensuing "Clarkian Period" (Plate 1) was the "Golden Age" of geology and paleontology in New York State. Research, both state and university sponsored, was greatly encouraged and generously supported. The result was a plethora of articles covering a broad spectrum of geological topics. It was a transition period in which detail and specialization began to replace generalized studies. Whereas Hall was often crude and tyrannical in his dealings with others, John M(ason) Clarke (b. 1857, Canandaigua, N.Y.; d. 1925, Albany, N.Y.) (Plate 5) was quite opposite. Clarke's firm and persuasive manner was tempered by politeness, quietness, and compromise. Like Hall, Clarke received many lucrative offers to teach at universities and, like his successor New York State Geologists and State Paleontologists, chose to close his lengthy career at the State Museum in Albany. Elected to about 50 scientific societies, Clarke authored (and co-authored) over 300 scientific papers totalling over 10,000 pages; he named some 135 genera and 870 new species of fossils. His areas of specialization included: brachiopods, eurypterids, trilobites, sponges, Naples Fauna, Guelph Fauna, Devonian stratigraphy. During the "Clarkian Period" topographic mapping by the U.S. Geological Survey in New York State achieved 100% coverage on a 1:62,500 basis. The time was now ripe for an intensified program of mapping bedrock distribution and surficial deposits.

In the field of bedrock geology, two tireless and dedicated mappers stand out. W(illiam) J(ohn) Miller (b. 1880, Red Bluff, Calif.; died. 1965, San Diego, Calif.) (Plate 7) mapped ten 15-minute quadrangles between 1907 and 1920 while Professor of Geology at Hamilton College, Clinton, N.Y. and at Smith College, Mt. Holyoke, Mass. These were published in ten N.Y. State Museum Bulletins (1909-1926). Miller's mapping was in and peripheral to the Adirondack Mountains. Considering the complexity of the geology and the relative inaccessibility of the areas mapped, this was, indeed, a monumental effort. Miller's interpretive articles for the layman and geologist, "Geological History of New York State" (1914, 1924) and "The

Plate 7

Outstanding Mappers of New York Geology

Nelson H. Darton

D. Dana Luther

William J. Miller

James H. Stoller

Adirondack Mountains" (1917) were pioneer efforts to popularize the geology of the Empire State. In 1924, Miller left the east and moved to California where he started the Geology Department at the then new University of California; he remained in California for the remainder of his life.

An even larger area was mapped by D. Dana Luther (b. 1840, Naples, N.Y.; d. 1923, Naples, N.Y.) (Plate 7). Luther, a miller by profession, was a self-taught stratigrapher, who joined the State Geological Survey at the age of 51 and performed field mapping until 70. In 1891 a rare opportunity arose to examine in detail the Upper Silurian and Devonian strata of western New York. An exploratory shaft for salt was to be excavated at Livonia, Livingston County. A prism 18 feet square and 1,400 feet deep was dug. Luther logged this shaft in meticulous detail, and his acute observations have proven of great value to this day. During Luther's state tenure he mapped about 24 15-minute quadrangles, of which 18 were published between 1904 and 1914. This concentrated career of geologic mapping is unsurpassed in New York State. Unlike Miller's mapping, Luther's was done in flat-lying sedimentary rocks of western New York, which are relatively easily distinguished and easily accessible. This is not to take away from Luther's prolific production but to compare the complexity of geology and accessibility to outcrop.

In the field of surficial mapping, James H(ough) Stoller (b. 1857, Johnstown, N.Y.; d. 1955, Bamberg, S.C.) (Plate 7), Professor of Geology at Union College, Schenectady, stands out. His mapping of glacial deposits in the Mohawk and Hudson Valleys resulted in completion of the Schenectady (1911), Saratoga (1916), and Cohoes (1920) quadrangles as N.Y. State Museum Bulletins.

Without challenge, the chief elucidator of New York glacial geology was Herman Leroy Fairchild (b. 1850, Montrose, Penn.; d. 1943, Rochester, N.Y.) (Plate 7). From 1888-1920, Fairchild was Professor of Geology at the University of Rochester. His many publications, 104 on New York, concentrate on central and western New York and are primarily concerned with proglacial lake history and meltwater drainage. Six N.Y. State Museum Bulletins were authored by Fairchild, as well as the popular "Geologic Story of the Genesee Valley and Western New York" (1928).

A(madeus) W(illiam) Grabau (b. 1870, Cedarburgh, Wisc.; d. 1946, Peking, China) is conspicuous as author of two of the finest and most cited publications that the N.Y. State Museum has ever published. These are "Guide to the Geology and Palaeontology of Niagara Falls and Vicinity" (1901) and "Geology and Paleontology of the Schoharie Valley" (1906). These were prepared while Grabau was Professor of Geology at Columbia University. Though long out-of-print, they stand as classics on these geologically vital areas. Grabau's fame rests primarily with his 1,200 page "Principles of Stratigraphy," "North American Index Fossils," "Textbook on Geology," and 4-volume work on the Palaeozoic Pulsation Theory. Interestingly, he also authored 18 articles on New York glacial geology. Together with his Niagara Falls guide (intended to supply geological information to visitors at the 1901 Pan American Exposition in Buffalo), Grabau's first five publications reflect the consummation of subjects in which he had become interested while living in Buffalo. Chief among these was his concise and precise "Geology and Palaeontology of Eighteenmile Creek and the Lake Shore sections of Erie County, New York" (1898-1899),---- intended as a handbook for students and amateurs. Grabau's contributions to physical and organic stratigraphy and paleogeography spurred his contemporaries and successors to a period of productive thinking and research along these lines.

Since the "Hallian Period," probably no one has made a more thorough probe of the total faunal content of a single group of sedimentary rocks in New York State than did Percy E(dward) Raymond (b. 1879, New Canaan, Conn.; d. 1952, Cambridge, Mass.). As a student of G(ilbert) D(ennison) Harris of Cornell University, he acquired the fine points of field collecting and learned about N.Y. geology on Harris' famous field trips. Later, he was a graduate student of Charles E(merson) Beecher and an assistant to Charles Schuchert at Yale University. Raymond's indoctrination into the realm of invertebrate paleontology was, indeed, impressive and complete. Between 1905 and 1911, Raymond completed 12 articles on several fossil groups of the Chazy limestones; trilobites were his specialization. So thorough were his studies that, today, the Chazy Group is the best known portion of the New York Ordovician from a faunal standpoint.

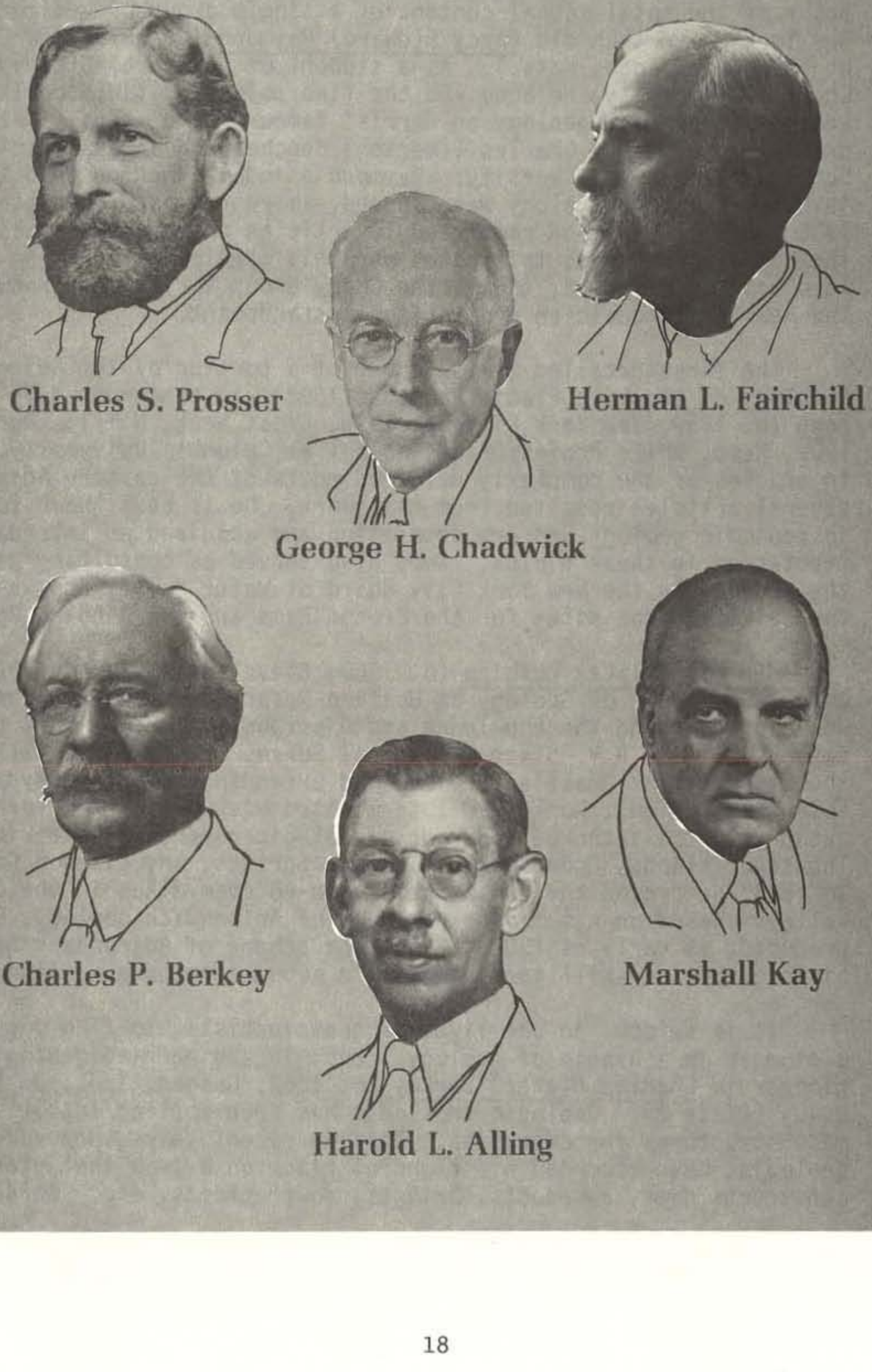
The first detailed geologic map of a portion of the Adirondack Mountains, "Geology of the Lake Placid Region" (1898) was constructed by James F(urman) Kemp (b. 1859, New York City; d. 1926, Great Neck, N.Y.). During 1892-1902, Kemp, while Professor of Geology at Columbia University, was engaged in studies of the complexly deformed rocks of the eastern Adirondacks; several articles resulted from this work. He is best known for investigations in economic geology and ore deposition and acquired an international reputation in these fields. Kemp also served as consulting geologist for the studies by the New York City Board of Water Supply and was responsible for selecting the sites for the Croton Dams and the Ashokan Reservoir.

H(enry) P(latt) Cushing (b. 1860, Cleveland, Ohio; d. 1921, Cleveland, Ohio), Professor of Geology at Western Reserve University, rendered yeoman work in advancing the knowledge and distribution of New York rocks. He was employed by the N.Y. State Geological Survey from 1893 to 1917, spanning the close of the "Hallian Period" and extending into the heyday of the "Clarkian Period"; World War I terminated his work in New York. Cushing authored or co-authored quadrangle geologic reports on the Little Falls, Thousand Islands, Ogdensburg, Saratoga Springs, and Clinton County regions. In 1896, he proved the existence of pre-Potsdam dikes in the Champlain Valley. Based on his broad knowledge of Adirondack geology, Cushing produced, as early as 1902, a coherent scheme of Adirondack geological history that is still consistent with subsequent observations.

It is seldom, in the lives of geoscientists, to find one who has been a pioneer in a branch of geology. But, in engineering geology, such a pioneer is Charles P(eter) Berkey (b. 1867, Goshen, Ind.; d. 1955, Palisade, N.J.) (Plate 8). Geologic knowledge has been applied intuitively to man-made structures for centuries. Only in recent years, however, has the geologist been accorded his rightful place on a team that plans and constructs dams, aqueducts, bridges, power plants, etc. Berkey was foremost

Plate 8

Outstanding Academicians of New York Geology



Charles S. Prosser

Herman L. Fairchild

George H. Chadwick

Charles P. Berkey

Marshall Kay

Harold L. Alling

among those who proved the value of competent geologic advice in the realm of public works construction. For engineering geology, 1903 was a memorable year. It marked the appointment of Berkey as junior instructor in the Department of Geology at Columbia University (where the aforementioned J.F. Kemp was now senior professor) and it was the year that the Board of Water Supply of New York City was contemplating bringing water from the Catskill watershed to service the fast-growing population of the metropolis. Large tunnels were to pass through mountains; access shafts were to have an aggregate depth of almost 15,000 feet; large dams were needed to be built in order to pond reservoirs; tunneled water was to pass under the Hudson River; and 18 miles of distributing tunnel were to be blasted in a network of rock beneath New York City. Because engineers were unable to answer all of the questions which arose, especially those relating to the rocks, this was a situation made to order for an able, enthusiastic young geologist. Berkey tackled the problems unhesitatingly and the splendid Catskill, Delaware, and Croton hydrology systems today are working evidences of his abilities. Following this successful venture, Berkey's expertise was demanded during the construction of the Holland and Lincoln Tunnels, and the George Washington, Whitestone, and Triborough Bridges. During the ensuing 30 years, hardly a major structure in the United States was built without Berkey's advice and visitation. Numbered among his projects are the Boston, Massachusetts water supply, and the Hoover, Shasta, Hungry Horse, Grand Coulee, and Bonneville Dams, as well as those of the Tennessee Valley Authority. As a sidenote, Berkey was chief geologist for the Dr. Roy Chapman Andrews American Museum of Natural History Expeditions of 1922, 1923, and 1925 into central Mongolia. Here, he was co-discoverer of fossilized dinosaur eggs. Charles P. Berkey's engineering geology influence will affect the lives of generations who will not know his name.

Following J.M. Clarke's death in 1925, Rudolf Ruedemann (b. 1864, Georgenthal, Germany; d. 1956, Albany, N.Y.) (Plate 5) became State Paleontologist. Ruedemann had immigrated to America in 1892 and taught in the high school in Lowville, N.Y. Moving to Dolgeville, northeast of Little Falls, Ruedemann found himself surrounded by some of the richest graptolite-bearing shales in the United States. As a consequence, over the years he patiently studied these enigmatic animals and, concurrently, became a specialist in Ordovician stratigraphy. Eventually, he attained the status of America's premier authority on graptolites demonstrating their value as superb index fossils. Among his 163 scientific articles, Ruedemann's State Museum publications on graptolites, cephalopods, eurypterids, the Lorraine Fauna, the geology of the Thousand Islands region, the Saratoga Springs region, the Capital District, and the Catskill area are frequently consulted. It is noteworthy that Ruedemann's geologic interests were not restricted to paleontology and stratigraphy. Taught by the famous Gustav Steinman, Ernst Kalkowsky, Johannes Walther, and Ernst Haeckel, Ruedemann's Ph.D. thesis at the University of Jena concerned contact metamorphism of the Reuth batholith in the Fichtelgebirge. Years later, he applied his Alpine education to the Taconic Mountains and suggested overthrusting (1909) for the emplacement of the Taconic Allochthon. Although he retired in 1937, he continued his work for many years, culminating in the giant Geological Society of America Memoir, "Graptolites of North America" (1947).

The "Ruedemannian Period" (Plate 1) witnessed great advances in stratigraphic knowledge in New York State. One of the principal workers was George H(alcott) Chadwick (b. 1876, Catskill, N.Y.; d. 1953, Selkirk, N.Y.) (Plate 8). Chadwick was an extremely dedicated, hard-working geologist who early in life, became smitten with a love of nature. His knowledge of plants was equal to that of his geology. As Fairchild's student at the University of Rochester, Chadwick inherited an appreciation for the many facets of geology. His bibliography, therefore, covers topics on glacial geology, stratigraphy, and structural geology. Chadwick's primary contributions are (1) recognition and delineation of the complex facies relations within the Devonian Catskill Delta rocks, (2) clarification of Middle Silurian Clinton Group stratigraphy, (3) bedrock mapping in the Canton and Catskill-Kaaterskill Quadrangles, and (4) discovery of a "Large Fault in western New York." This, later named, "Clarendon-Linden structure" has occupied the time and efforts of many recent geologists who are concerned with underground waste disposal, water supply problems, and earthquake studies. Chadwick authored 35 papers on New York geology, of which 13 were on glacial geology and most of the remainder on the Devonian.

Another Rochesterian, Harold L(attimore) Alling (b. 1888, Rochester, N.Y.; d. 1960, Pittsford, N.Y.) (Plate 8) furnished important geologic data in diverse geologic disciplines. Fairchild's stimulating teaching together with the Alling family's annual vacations in the Adirondack Mountains prompted Harold Alling's first geologic paper to deal with glacial lakes and glacial features in the central Adirondacks. Aware that Professor James F. Kemp was investigating Pre-Cambrian rocks in the eastern Adirondacks, Alling managed to get himself assigned as Kemp's field assistant. This developed into a life-long friendship with mutual interest in problems pertaining to Adirondack rocks. Alling made noteworthy discoveries in the fields of igneous, metamorphic, and sedimentary petrology, specifically addressed to feldspars, graphite, and salt. Seven N.Y. State Museum Bulletins were authored or co-authored by him. He was one of the first to write a special textbook on the petrography of igneous rocks. His enthusiasm for photography was an asset in accumulating hundreds of photomicrographs of rocks. Harold Alling, using graphite horizons, was the first to demonstrate that stratigraphy worked in the highly contorted Adirondack metamorphic rocks.

State Geologists David H(ale) Newland (b. 1872, Vienna, N.Y.; d. 1943, Menands, N.Y.) (Plate 6) and C(hris) A(ndrew) Hartnagel (b. 1874, Newark, N.Y.; d. 1962, Slingerlands, N.Y.) (Plate 6) successively followed John M. Clarke. Their contributions were chiefly in the form of issuing reports on the mineral resources of the State. Newland, as an economic geologist, was well aquainted with mineral deposits both in the United States and in some foreign countries. His bulletin on the Adirondack magnetic iron ores (1908) is a model for thoroughness and accuracy of description and soundness of interpretation. It has proved indispensable to succeeding geologists and engineers in their quest for additional economically feasible mineral deposits within the Adirondacks. Hartnagel's interests in geology unfolded as a result of his student-professor relationship with C.S. Prosser at Union College, listening to lectures on geological subjects by State Geologist F.J.H. Merrill, and collecting fossils for State Paleontologist J.M. Clarke. By his own admission, Hartnagel's most rewarding contribution to New York geology was his tracing of the Cobleskill Limestone, in 1902, westward to prove that it was not the extension of the caprock of the Niagara cuesta but, rather, that it lay stratigraphically above the Salina Group. Similar field work with the Oneida Conglomerate and the Shawangunk "grit" caused him to believe that much of the Salina passed laterally into the Shawangunk. In his later years with the State Survey, Hartnagel developed a system of record keeping for oil and gas wells within the State. Through his dealing with other State agencies, the State Geological Survey gained a reputation for being a storehouse of vital geologic information. As with most members of the State Survey, Chris Hartnagel's tenure was long, amounting to 44 years.

Upon the retirement of Ruedemann, Winifred Goldring (b. 1888, Kenwood, N.Y.; d. 1971, Slingerlands, N.Y.) (Plate 5) became State Paleontologist. She began her career at the N.Y. State Museum in 1914 and continued productive and significant work until her retirement in 1954. In the United States, it is with great difficulty that a woman accedes to a high position in science. For her sound work in invertebrate paleontology and paleobotany, the Paleontological Society honored her, in 1949, by electing her its first woman president. Noted especially for her studies on Devonian trees (Gilboa Forest), Late Cambrian algae (Cryptozoans), and Devonian crinoids (sea-lilies), her fields of research mirror her botanical training. Forty-four titles, ranging from Pleistocene salinities of the Champlain Sea to Devonian stratigraphy constitute her bibliography. She is best remembered for her (1) popular type publications, especially the "Handbook of Paleontology for Beginners and Amateurs: Part I--The Fossils and Part II--The Formations, and the "Guide to the Geology of Thacher Park"; (2) publications on Devonian crinoids, chief among which is the memoir, "Devonian Crinoids of New York"; and (3) classic quadrangle studies, "Geology of the Berne Quadrangle," and "Geology of the Coxsackie Quadrangle." The "grandame" of New York State paleontology spread her passion for paleontology among innumerable graduate students and hundreds of theses topics which were suggested and implemented during the period 1930-1950. She was avidly interested in museum exhibition, and the famous restoration of the oldest known Devonian Forest in the old N.Y. State Museum, reproduced in many textbooks, has become her exhibit signature.

No one possessed a more intense zeal for Ordovician stratigraphy than did (George) Marshall Kay (b. 1904, Paisley, Ont.; d. 1974, New York City) (Plate 8). Internationally, he was "Mr. Ordovician," and particularly so for the "Three N's" (Newfoundland, New York, Nevada). Kay's ardor for Ordovician stratigraphy was catching and no one who came in contact with him could resist becoming involved (or embroiled!) in fervent discussions on terminology or correlations. His most notable contributions are concerned with descriptions and correlations of Ordovician strata, history and classification of geosynclines, and their bearing on continental drift and plate tectonics. In New York, his efforts toward unraveling the stratigraphy of the Trenton, Black River, and Chazy Groups are especially cogent. For his prolific publications toward a better insight into the problems of the Ordovician Period, he was awarded the Geological Society of America's highest honor, the Penrose Medal.

Amongst the living, enduring and distinguished contributions on New York geology and paleontology have been made by A.F. Buddington and G. Arthur Cooper, respectively.

A(rthur) F(rancis) Buddington (b. 1890, Wilmington, Del.) (Plate 9), Emeritus Professor of Geology (since 1959), Princeton University, and "Mr. Adirondack Geology," ----- for his extensive geologic mapping, his intensive topical studies of complexly deformed and physically complicated metamorphic rocks, iron ore deposits, and origin of anorthosite. Buddington, and a few of the many students whom he inspired, mapped about 3,500 square miles, or about one-third of the Adirondacks. During World War 2, he conducted the first aeromagnetic survey in the western hemisphere. This resulted in the discovery of 70 new magnetite ore bodies, including the large Benson Mines near Tupper Lake; the others are of lower grade and are held in reserve. Buddington also rediscovered the wollastonite deposit near Willsboro,---the only major economic source of that mineral in the world. Since his retirement he has published over a dozen significant articles and two books on Adirondack petrology, metamorphism, and anorthosite petrogenesis and was a major contributor (and dedicatee) at a recent international symposium on the origin of anorthosite. For his many and significant achievements, he was awarded the Penrose Medal by the Geological Society of America.

G(ustav) Arthur Cooper (b. 1902, College Point, N.Y.) (Plate 9), Chief Paleontologist, U.S. National Museum of Natural History, Smithsonian Institution, and "Mr. Brachiopod," ----- for his detailed paleontologic and stratigraphic studies of the Middle Devonian Hamilton Group and Tully Formation, and for his contributions to the knowledge of Chazy brachiopods. While at Yale University, and under the esteemed Charles Schuchert's guidance, Cooper blossomed as the current foremost specialist on fossil brachiopods, especially those of the Ordovician, Devonian, and Permian Periods. Cooper's brachiopod-taxonomy studies, biostratigraphic investigations, and identification of facies relationships brought clarity to Hamilton and Tully rock-unit correlations. For his notable paleontological accomplishments, Cooper was awarded the Paleontological Society Medal for eminence.

Today, the State Geological Survey and faculties and graduate students at universities and colleges have embarked upon sophisticated and specialized avenues of research dealing with New York's geology. Investigations into the realms of geochemistry, geophysics, seismology, oceanography, paleoecology, and environmental geology have supplemented the traditional areas of petrology, geomorphology, stratigraphy, sedimentology, economic geology, mineralogy, and paleontology. This has been made possible through fascinating new techniques and time-saving tools and equipment, not the least of which has been the incomparable computer. But, let us pause, and take cognizance of the pioneering and basic work of our predecessors, who labored so fervently without benefit of our modern tools and techniques. It was they who paved the way for our refinements of fact and speculation. We salute our titans of geology and paleontology and appreciate our laudible legacy!

Plate 9

Arthur F. Buddington

G. Arthur Cooper

ACKNOWLEDGMENTS

My special thanks go to Carl Dennis Buell, New York State Museum artist, who immeasurably enhanced this article with his skillful sketches of geologists and paleontologists and to Gwyneth Gillette, New York State Museum cartographer, who prepared the "Paleontological Time Scale" and "District Map". Appreciation is also extended to the following for kindly providing photographs of geologists and paleontologists: Smithsonian Institution (Cooper, Darton, Merrill, Prosser); Geology Departments at Columbia University (Berkey, Kay, Kemp), Princeton University (Buddington), University of Rochester (Alling, Fairchild), University of California (Miller); and to Union College Library (Stoller) and Rensselaer Polytechnic Institute (Eaton); Paula Metzler (Hartnagel); John Broughton (himself); James Davis (himself). The remaining pictures used are from my personal collection.

LOOKING BACK OVER HALF A CENTURY:
A BRIEF HISTORY OF THE NEW YORK STATE GEOLOGICAL ASSOCIATION

by

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FOREWORD

It is only fitting and proper to present the review of the Association's first fifty years at this 1978 Golden Anniversary meeting at Syracuse University, which more than any other New York State institution has been linked closely to the development of the Association. The call for the first meeting at Hamilton College (1925) came from the Geology Department of SU which also hosted the meetings of 1926, 1937, 1950 (Silver Anniversary) and 1964, that is at fairly regular intervals of approximately a dozen years.

The permanent record file of the Association served as principal source of information for this account which reflects some uncertainties due to the lack of complete data covering the early years. It was not until the election of a Permanent Secretary in 1953 that such a collection of records could be initiated and carried out with the help of many "old-time" members who donated copies of meeting announcements, field-trip itineraries and other pertinent information from their own files, a fact which was inscribed duly on each contribution. This valuable service to the Association hereby is gratefully acknowledged with particular thanks going to Dr. A. Scott Warthin, Jr., Professor Emeritus of Vassar College who supplied by far the greatest volume of material.

The reader is referred to Tables 1 and 2 accompanying this article for a summary of facts and statistics on the first 50 meetings of the Association.

IN THE BEGINNING
(1925)

On 25 April 1925 a one-page letter addressed to "heads of departments of geology and others interested" was sent from Lyman Hall of Syracuse University, the location of the Geology Department. It contained the following pertinent information (verbatim excerpts are indicated by quotation marks):

Announcement of the "first annual intercollegiate field meeting of

Table 1. New York State Geological Association - 1925 to 1954.

Abbreviations: C - College; ChC - Chamber of Commerce; CCNY - City College of NY; Ed - Editor; Fld - Field; M - Museum; Mtg - Meeting; Nat Sci - Natural Science; NYC - New York City; pp - pages; S - Survey; U - University

Note: Unless otherwise noted, all localities mentioned are in New York State.

Mtg No	Year	Host Institution	Mtg Locality	Dates	Type of Fld Information (# of pp.)	President (*Field Director)	Secretary	Attend-ance
1	1925	Hamilton C	Clinton	5/15-16	Fld Stops (2)	*Nelson C. Dale	Harry N. Eaton	
2	1926	Syracuse U	Syracuse	5/14-15	Fld Stops (3)	*Harry N. Eaton	Harry N. Eaton	
3	1927	Vassar C	Poughkeepsie	5/6-7	Fld Stops (4)	*Thomas M. Hills	Thomas E. Burling	
4	1928	Cornell U	Ithaca	5/11-12	Fld Stops (5)	*Henrich Ries	O.D. von Engeln	
5	1929	St. Lawrence U	Gouverneur	5/17-18	Itinerary (5)	*Chas. A. Hartnagel	Harold L. Alling	198
6	1930	Union C	Schenectady	5/15-17	Itinerary (3)	Edward S. Smith	Harold L. Alling	199
7	1931	Elmira C	Port Henry	5/15-16	Itinerary (8)	Harry N. Eaton	O.D. von Engeln	
8	1932	U of Rochester	Rochester	5/13-14	Itinerary (7)	Harold L. Alling	J.E. Hoffmeister	
9	1933	Columbia U	Newburgh/NYC	5/12-13	Pamphlet (8)	Robert J. Colony	G. Marshall Kay	
10	1934	Colgate U	Hamilton	5/18-19	Itinerary (10)	Harold A. Whitnall	Towner B. Root	
11	1935	Hamilton C	Utica	5/10-11	Itinerary (11)	Nelson C. Dale	John T. Rouse	
12	1936	Penn Geol S	Scranton, PA	5/22-23	Itinerary (12)	Heinrich Ries	Joseph D. Burfoot	
13	1937	Syracuse U	Syracuse	5/14-15	Itinerary (7)	Lawrence W. Ploger	Earl T. Apfel	
14	1938	Buffalo M Nat Sci/U	Buffalo	5/13-15	Magazine (7)	Irving G. Reiman	Wm. P. Alexander	
15	1939	St. Lawrence U	Gouverneur	5/12-13	Itinerary (27)	Robert W. Brown	John S. Brown	
16	1940	ChC Town of Catskill	Catskill	4/26-27	Itinerary (27)	George H. Chadwich	Robert W. Jones	
17	1941	U of Rochester	Rochester	5/9-10	Itinerary (36)	J.E. Hoffmeister	J.E. Hoffmeister	
	1942 through 1945 - No meetings during World War II.							
18	1946	Vassar C	Kingston	5/10-11	Itinerary (6)	Thomas M. Hills	A.S. Warthin Jr.	
19	1947	CCNY	NYC	5/9-10	Itinerary (16)	D.T. O'Connell	Cecil H. Kindle	
20	1948	Hamilton C	Clinton	4/30-5/2	Itinerary (11)	Nelson C. Dale	Robert H. Arndt	
21	1949	Cornell U	Ithaca	5/13-14	Booklet (35)	John W. Wells	W. Storrs Cole	
22	1950	Syracuse U	Syracuse	4/28-30	Booklet (35)	Earl T. Apfel	Earl T. Apfel	247
23	1951	NY State Geol S	Plattsburg	5/18-19	Booklet (42)	John G. Broughton	Survey Staff	
24	1952	Buffalo M Nat Sci/U	Buffalo	5/1-3	Booklet (25)	Edw. J. Buehler	Edw. J. Buehler	
25	1953	St. Lawrence U	Canton	4/30-5/2	Guidebook (21 (Ed J.J. Prucha)	Robert O. Bloomer	Robert O. Bloomer	
26	1954	Vassar C	Poughkeepsie	4/30-5/1	Itinerary (9)	John H. Johnsen	K.E. Lowe (Perm. Secy.)	146

See Table 2 for 1955 through 1978.

Table 2. New York State Geological Association - 1955 to 1978.

Abbreviations:			
	C - College	Mtg - Meeting	SUNY - State University of NY
	CoC - Community College	RPI - Rensselaer Polytechnic Institute	TS - Technical Session
	CCNY - City College of NY	pp - pages	Abst - Abstracts
	CUNY - City University of NY	S - Survey	U - University

Note: All localities mentioned are in New York State.

Mtg No	Year	Host Institution	Mtg Locality	Dates	President	Editor of Guidebook incl Panel Discussions & Symposia	# of pp	TS Abst pp	Permanent (*Executive) Secretary	Attendance
27	1955	Colgate U	Hamilton	5/13-14	John G. Woodruff	Staff	47		K.E. Lowe	251
28	1956	U of Rochester	Rochester	5/4-5/6	William R. Evitt	Staff	123		K.E. Lowe	236
29	1957	NY State Geol S	Wellsville	5/9-12	Wilber H. Young	W.L. Kreidler	66		K.E. Lowe	248
30	1958	CCNY	Peekskill	5/9-11	Kurt E. Lowe	K.E. Lowe	65		K.E. Lowe	267
31	1959	Cornell U	Ithaca	5/8-9	W. Storrs Cole	J.W. Wells	45		K.E. Lowe	278
32	1960	Hamilton C	Clinton	5/13-14	David Hawley	D.B. Potter	68		K.E. Lowe	254
33	1961	RPI	Troy	5/12-13	Joseph Rosenholtz	R.G. LaFleur	100		K.E. Lowe	329
34	1962	Brooklyn C	Port Jervis	5/4-6	Wilbur G. Valentine	W.G. Valentine	90		K.E. Lowe	341
35	1963	SUNY at Binghamton	Binghamton	5/3-4	Donald R. Coates	D.R. Coates	111		K.E. Lowe	357
36	1964	Syracuse U	Syracuse	5/8-10	John J. Prucha	J.J. Prucha	127	26	K.E. Lowe	406
37	1965	Union C	Schenectady	4/30-5/2	Philip C. Hewett	Leo M. Hall	120	7	K.E. Lowe	435
38	1966	SUNY at Buffalo	Niagara Falls	4/29-5/1	Edward J. Buehler	E.J. Buehler	97	32	K.E. Lowe	325
39	1967	SUNY at New Paltz	Newburgh	5/5-7	Russel H. Waines	R.H. Waines	139	10	K.E. Lowe	378
40	1968	Queens C, CUNY	Flushing	5/3-5	Walter S. Newman	R.M. Finks	251	8	P.C. Hewitt	350
41	1969	SUNY at Plattsburg	Plattsburg	5/2-4	Lawrence B. Gillett	S.G. Barnett	163	9	P.C. Hewitt	247
42	1970	SUNY at Cortland	Cortland	5/1-3	W. Graham Heaslip	W.G. Heaslip	141	5	P.C. Hewitt	257
43	1971	SUNY at Potsdam	Potsdam	5/7-8	Neal R. O'Brien	B.B. VanDiver	148	6	P.C. Hewitt	281
44	1972	Colgate U/Utica C	Utica	9/15-17	James McLelland	J. McLelland	277		P.C. Hewitt	276
45	1973	SUNY at Brockport & Monroe CoC	Rochester	9/28-30	Philip C. Hewitt	P.C. Hewitt	177		D.F. Merriam	342
46	1974	SUNY at Fredonia	Fredonia	10/18-20	Olcott Gates	D.N. Peterson	187		D.F. Merriam	321
47	1975	Hofstra U	Hempstead	10/31-11/2	Manfred P. Wolff	M.P. Wolff	327		D.F. Merriam	290
48	1976	Vassar C	Poughkeepsie	10/15-17	John H. Johnsen	J.H. Johnsen	297		D.F. Merriam	288
49	1977	SUNY at Oneonta	Oneonta	9/16-18	P. Jay Fleisher	P.C. Wilson	425		D.F. Merriam	430
50	1978	Syracuse U	Syracuse	9/22-24	Daniel F. Merriam	D.F. Merriam			M.P. Wolff	

*After 1970.

central New York colleges to be held at Clinton and Little Falls, New York on the 15th and 16th of May. "Program by" our field director Dr. N.C. Dale of Hamilton College" to include:

Friday, May 15, 11:00 AM: "Gathering of the clan at Knox Hall, Hamilton College campus" followed by "luncheon at College Commons".

Friday afternoon: Organization of "field parties for the study of the iron ore deposits and Silurian formations in the immediate vicinity of Clinton, possibly extending operations as far as the famous Devonian section at Oriskany Falls"

Friday evening: "Dinner at the Yahnundasis Country Club in the outskirts of Utica, price $1.50 per plate, the exact time to be announced later. A lecture on the geographical and historical significance of the Gorge of the Mohawk River at Little Falls will probably be delivered at this time, the attempt being made to obtain Dr. Albert Perry Brigham of Colgate University as speaker."

Saturday, May 16: "The party will journey to Little Falls either by rail, auto or trolley, where the day will be spent studying preCambrian and early Paleozoic structures and stratigraphy. If time permits, an interesting side trip can be taken to the historic Herkimer homestead near Little Falls."

The director (or secretary) will arrange for "accommodations in Utica hotels, on request". He will also prepare "a section of the Paleozoic of the Oriskany Valley and fossil lists which will be distributed later." The secretary then requests early information on the approximate number from each institution planning to attend luncheon and dinner on Friday.

The letter concludes prophetically: "Trusting that this coming first excursion may be enjoyed by all and that it may be the beginning of annual gatherings of like character for our mutual benefit and the fuller knowledge of our great out-of-door science, I remain faithfully yours

Harry N. Eaton, Secretary"

This is all that has come down to us from that initial meeting more than half a century ago. We are left to speculate on the nature and extent of earlier discussions and communications between geology faculty members of the "central New York colleges" which must have preceded this first "call to meeting". Considering the Association's subsequent history, we can only assume that the program as planned was carried out successfully. We do not know the number of participants, but would guess that it was rather small and probably included mostly faculty members at this early stage.

THE EARLY YEARS
(1926-1941)

The time for "annual gatherings of like character" had indeed arrived.

The 1926 "get-together" at Syracuse University provided a mimeographed program with annotated lists of field stops, a correlation chart and structural data on the East Oriskany quarries. Also, in October of the same year Prof. Harold L. Alling of the University of Rochester mentioned in a letter to Prof. Thomas W. Hills of Vassar College, the host institution for 1927:

"I have been using the name "The New York State Geological Association". How does it strike you?" Professor Hills evidently agreed because the program of the 1927 meeting carried the new name on its masthead where it has appeared ever since.

It is interesting to note that some of the procedures followed at the first two meetings became virtually customs for many years to come. Until 1972 annual meetings continued to be held on a spring weekend between mid-April and the end of May. The preferred scheduling called for arrival at the meeting locality at noon on Friday, just in time for luncheon (occasionally offered by the host free-of-charge) which probably was deemed necessary to supply the energy needed for the afternoon field trip and to tide the participants over until the "official" evening dinner (often featuring an invited guest speaker). A half-day or full-day field trip on Saturday then brought the meeting to a close.

Until World War II forced temporary discontinuance of activities (1942 through 1945), relatively few innovations were made in the conduct of meetings, although the host institution had a completely free hand in planning and organizing their meetings. The first time that the meeting locality differed from that of the host institution was in 1929 (5th meeting) when Gouverneur, New York served as meeting headquarters with St. Lawrence University located at Canton, New York (25 miles distant) acting as host.

The 12th meeting (1936) proved to be unique because it was held at Scranton, Pennsylvania and hosted by the Pennsylvania Geological Survey, the only time that the Association extended its activities beyond the borders of New York State. Participants were also treated to the first detailed itinerary complete with distances in tenths of miles.

A few years later another unusual event occurred when the Chamber of Commerce, representing the town of Catskill, New York and its citizens, hosted the 1940 meeting. The moving spirit behind this invitation was the Association President, George H. Chadwick, a native of Catskill and for many years Professor of Geology at St. Lawrence and Rochester Universities. He was a renowned expert on the geology of the Catskill mountain region with particular emphasis on its Silurian and Devonian stratigraphy and structural features.

Although complete registration rosters are available for only two meetings in these early years (see Table 1), they reveal a remarkably large and varied attendance as shown here.

	1929 (5th Mtg.)		1930 (6th Mtg.)	
Attendance:				
Faculty	25	38 = 19%	30	47 = 24%
Professional Geologists & other adults	13		17	
Students	160	= 81%	152	= 76%
Total Attendance	198		199	
Institutions Represented				
Colleges & Universities	10		21	
Government agencies	2		3	
Industrial organizations	7		1	
Total number of Institutions	19		25	

The large attendance figures are surprising indeed when compared with those of the meetings after 1954 (see Table 2). Furthermore, the well-known student-oriented nature of the Association evidently was established very early. A few faculty members seem to have brought along entire undergraduate geology classes as suggested by student attendance of 52 from St. Lawrence University (1929) and 48 from Rensselaer Polytechnic Institute (1930). Such attendance procedures, however, did not go unnoticed as pointed out by Prof. O.D. von Engeln, the Association secretary, in the preliminary announcement (dated 8 April 1931) for the Port Henry meeting. He concluded his letter with the following paragraph:

> "I may add that there seems to be a general feeling that undergraduates who are not seriously interested and go just for the ride or the diversion from school work should be discouraged from making the trip. Of course, if such an undergraduate owns a car and will furnish the transportation for some of the more seriously inclined students, it would be a bad policy to head him or her off. No doubt these comments will sufficiently give you the idea."

One cannot help wondering just how trip leaders managed the field logistics considering the fact that only one trip was offered at any one time and private cars were the only mode of transportation mentioned. Car caravans of great lengths snaking across hill and dale and raising large clouds of dust must have been a sight to behold!

THE POST-WAR YEARS
(1946-1953)

During World War II no meetings were held from 1942 through 1945. Consequently, meeting No. 17 of 1941 was followed by meeting No. 18 of 1946. T.M. Mills and A.S. Warthin Jr. of Vassar College, who had been chosen to conduct the cancelled 1942 meeting, wrote to the "member institutions" on 21 September 1945 offering to host the "customary two-day meeting next Spring". One paragraph of this letter is worth repeating because it clearly states the original purpose of the Association.

> "At this time we think it in order to restate the primary aim of these meetings. They were originally set up to give the students in the member colleges a chance to see other parts of the State in the field. At some meetings it has seemed to us that the aim was a little obscured, and that the meeting was conducted on more of a professional level, for the benefit of the faculty members attending. With the formation of the North-eastern Section of the G.S.A., the professional interest can perhaps be best taken care of by meetings of that Section, leaving us to care more specifically for the students."

It appears that the Association got back into the "old groove" without difficulty and continued to operate with little change in the pre-War style.

At the Cornell University meeting (No. 21, 1949) buses were used for the first time as exclusive field transportation with the overwhelming approval of the Association (by mail ballot). The cost per person was 75 cents for Friday afternoon and $1.75 for all-day Saturday. And while we are mentioning prices, the cost of the annual dinner was $1.85 and a field lunch went for 75 cents. Who said that there were no "good old days"?

The records of the Silver Anniversary meeting at Syracuse (No. 22, 1950) included a detailed list of registrants permitting the following break-down:

Meeting No. 22, 1950:	Attendance		Institutions represented	
Faculty	40)		Colleges & Universities	19
Professional,	)	Adults		
Government &	20)	24%	Government agencies	5
other geologists	)		& Museums	
Students	187)	76%	Industrial Organizations	1
Total attendance	247		Total number	25

A comparison with the previously cited attendance figures for the 6th meeting of 1930 shows an astoundingly identical ratio of adult/student attendance and total number of institutions represented. Except for a 25 percent increase in total attendance, little had changed indeed in 20 years.

In 1951, the New York State Geological Survey, for the first time, acted as host for the 23rd meeting at Plattsburg in the eastern Adirondacks.

The 25th meeting (1953) at St. Lawrence University probably is best remembered for its singularly cold, wet, and thoroughly uncomfortable field weather. In fact, the City College of N.Y. contingent, starting for home at about noon on Saturday, May 2, had to battle a raging Adirondack blizzard and barely managed to reach food and shelter at Lake Placid by nightfall, with some 15 inches of snow on the ground. But history already had been made at the business meeting of the Association on the preceding evening, May 1. As a result of repeated complaints about lack of coordination and continuity in Association activities (particularly concerning mailing lists) from meeting to meeting, Kurt E. Lowe proposed the election of a Permanent Secretary as the only continuing officer of the Association. The venerable New England Intercollegiate Geologic Conference, active since 1901 and operating successfully with such an officer, was cited as an example. Upon acceptance of the proposal, Kurt Lowe nominated Dr. John G. Broughton, the New York State Geologist, as the logical candidate to fill the new position. But to his surprise, Dr. Lowe himself also was nominated and then elected the first Permanent Secretary, an office he was to hold for 14 years.

AGE OF "THE" SECRETARIES:

The LOWE Epoch - 1954 - 1967

The new Permanent Secretary was facing a future of great uncertainty in the absence of any instructions or guidelines offered by the Association which seemed to say: "You thought of it, now go ahead and do it."

Considering the obviously successful development of the Association since 1925, despite loose operational procedures and a sometimes lack of conformity, the Secretary made two basic commitments (to himself), viz.,

1. to maintain the informal, friendly albeit occasionally "loose" conduct of activities, and

2. to continue fostering the original concept of "student-orientation" at Association meetings and on field trips.

He then proceeded to concentrate on improvements in communication, record keeping, financial responsibility, publications and operational continuity in general, roughly in that order.

On 8 January, 1954 a rather lengthy, 3-part questionnaire was sent to all New York State Institutions listed in the AGI Directory of Geology Departments in the U.S. and Canada and to some out-of-State Colleges and Universities whose representatives had attended Association meetings in the past. New York government agencies and a few professional geologists also were included in this mailing. The excellent (78%) response to this inquiry enabled the fledgling Secretary to prepare summary statistics on all past meetings (1925 - 1953), listing dates, host institutions and meeting localities as well as New York Institutions which had never served as host and regions within the State which had not been visited up to that time.

This information was presented and distributed at the Association business meeting in 1954 (Poughkeepsie) as the First Annual Report of the Permanent Secretary, initiating a procedure which was followed annually until 1972 (Nineteenth Annual Report).

The Second Annual Report of 1955 set the basic pattern of presentation, viz.,

1. Resume of previous year's business meeting;
2. Attendance statistics of previous year's meeting;
3. Mailing Roster Information: Number of institutions and individuals on roster; changes and limitations introduced from time to time;
4. Permanent Record File: Contributions received and records needed;
5. Proposals for Association action at current meeting;
6. Treasury Report: The initial treasury of $69.50 came from registration fees at the 1954 meeting. By May of 1955 the cash balance had shrunk to $6.09. Not until 1959 did the treasury reach a healthy balance of $219.64.

These annual reports then high-lighted significant developments and innovations in Association affairs.

The first "pre-registration with payment" forms introduced at the 1957 (Wellsville) meeting proved so successful that it became standard operating procedure from then on.

Although the first spiral-ring bound field-trip guidebook was prepared for the 1956 (Rochester) meeting, no extra copies for post-meeting distribution were available for either the 1956 or 1957 Guidebooks. The 1958 (Peerskill) meeting, however, provided a sizable stock of guidebooks for post-meeting sale, which was so brisk that the Secretary found himself with the added responsibility of stocking and filling orders for annual guidebooks with the attendant financial headaches. As time went on, out-of-stock items had to be reprinted further increasing the Secretary's work load. But to this day, all 21 guidebooks from 1957 to 1977 are available for purchase.

Starting with the Sixth Annual Report (1959), statistics on guidebook sales and inventory were included. In addition, yearly lists of available guidebooks, their cost and table of contents (as long as this proved feasible) were made available.

The Seventh Annual Report (1960) included the financial statement of the 1959 meeting submitted by the host institution (Cornell U.) to serve as a guide for future hosts. This feature also became a standard report item.

At the 1963 meeting, Dr. John J. Prucha's proposal to include a ½ day Technical Session for the presentation of student papers in the program of the annual meeting was accepted. The first of 8 similar consecutive, annual sessions was held at Syracuse in 1964. Abstracts of papers were printed as part of the guidebook or as separate stapled pamphlets (see Table 2). It should be noted, however, that the Technical Session at Queens College (1968) consisted of two ½ day symposia on problems of regional geology presented entirely by faculty members and professional geologists. For reasons that are not clear, Technical Sessions were dropped from the Association activities after the 1971 (Potsdam) meeting.

A matter of periodic concern was the fluctuation in meeting attendance. Following the low registration figure of 146 (1954), attendance abruptly increased to 251 (1955) and leveled off between 250 and 280 until 1961 (Troy) when it spurted again to 329, starting an unprecedented climb to the peak of 435 in 1965 (Schenectady). The rapid change brought about by the large number of registrants presented serious problems of planning and logistics for smaller host institutions with somewhat limited facilities for food and lodging. Also, the number of simultaneous field trips offered had to be increased sharply to accommodate the large crowd, thus placing additional burden on the departmental staff.

Bus transportation became a "must" for all but a few of the "last-day" field trips. The Secretary, from time to time, reminded faculty members to limit student attendance to graduate students and bona fide undergraduate majors. Students accounted for 52 percent of attendance in 1954, rising to a high of 78 percent in 1957 and then decreasing slowly to 51 percent by 1966. These figures stayed between 39 and 50 percent from 1967 to 1971 (the last year for which such information is available).

At the 1966 meeting at Niagara Falls, the Association surprised the Permanent Secertary with an engraved plaque "in recognition of exceptional contributions in service to the Association since 1953", which was deeply appreciated. Little did the Association or the recipient suspect that the Lowe Epoch had just about run its course. Following a heart attack in the Spring of 1967 (from which he obviously recovered), the first Permanent Secretary had to resign from his somewhat less than permanent post. The Fourteenth Annual Report contained his resignation and outlined orderly procedures for the transfer of records and stock of guidebooks to a new Secretary by September 1967.

The HEWITT Interval - 1968-1972

Philip C. Hewitt of SUNY at Brockport, former Association president (1965), was elected as the second Permanent Secretary with the understanding that "permanence" be replaced by a specific period of service at a later date.

The Annual Reports of the Secretary were continued essentially in the style and format as had been established over the years. After dropping below the 400 mark following the 1965 meeting, attendance ranged between a manageable 250 to 350 from 1968 to 1972. Treasury balances rose beyond the $1000.00 level and reached $3627.45 by 1972. Such funds had become necessary to pay for the ever rising cost of reprinting a growing number of older guidebooks. Also, guidebooks continued to grow in length (see Table 2 for number of pages) with the offering of multiple field trips and a more detailed and sophisticated presentation of data, often using numerous illustrations. The 66 pages of the 1957 (Wellsville) guidebook expanded in 20 years to 425 pages of the 1977

(Oneonta) book.

Secretary Hewitt's particular concern was the Association's tax status (considering the increasing treasury balances) and its potential incorporation to remove legal responsibility from any one individual in the event of an accident on an Association field trip. He soon discovered that the basic requirement was presentation of a formal constitution and bylaws without which the Association had flourished for over 40 years. He promptly convinced his predecessor and friend, Kurt Lowe, to accept the appointment as a Committee of one to draw up the required documents. This was done by simply putting the operating procedures which had become established through routine into the legal form of a constitution and bylaws. Some minor additions and changes were made, particularly limiting the length of the Secretary's term to 6 years and changing his title from Permanent to Executive Secretary.

The new constitution was presented for the Association's approval at the 1970 (Cortland) business meeting. The only provision which caused considerable argument was the proposed exclusion of student from full (voting) membership owing to their transient status. Although this clause gained approval at this (1970) meeting, the Association amended the constitution in 1971 (Potsdam) to grant students the vote on Association affairs at annual business meetings but excluded them from the permanent mailing roster. Another amendment was added to provide for a Board of Directors consisting of the current president, the executive secretary and the two most recent past presidents.

Another major change took place at the 1971 meeting when the scheduled hosts for the 1972 meeting, Colgate U. and Utica C., asked for postponement until the Fall Term because they would not be able to get ready for the usual Spring meeting. There also had been a growing desire to shift meetings to the Fall season even though it would make it more difficult to avoid conflicts with meeting schedules of the New England Intercollegiate Geologic Conference, The Geological Society of America, and other geologic organizations. The dissatisfaction with Spring meetings had developed as a result of changes in College calendars bringing the Spring Term to a close as early as the middle of May. The Association then would have to meet no later than the third week in April when the weather is generally inclement, cold and wet, particularly in upstate New York. The Association agreed to hold its 1972 meeting from September 15 to 17 on a "trial" basis, which promptly became an established procedure (see Table 2).

Hewitt, although elected for a 6-year term, decided understandably that service for 5 years was enough considering the steadily increasing work load in connection with the sale and distribution of guidebooks numbering 15 at the time. He appointed a Committee in 1971 to nominate a new Secretary for election in 1972.

The MERRIAM Stage - 1973-1977

Daniel F. Merriam of Syracuse University was nominated and elected

Executive Secretary at Utica (1972). The Association had arrived at another stage in its development. With the internal functioning of the organization now following a well-established operational routine, the new Secretary could direct his attention to the Association's external relations with the geologic profession, governmental agencies, and concerned public interest groups, a process which his predecessor Hewitt had initiated.

The tax exemption and incorporation quests were pursued actively but faced a seemingly unending series of bureaucratic obstacles and delays. The new constitution and bylaws had to be reviewed and audited, followed by changes in the wording of the documents which then had to be approved by the membership. Actually, the Internal Revenue Service was less troublesome than the New York State Department of Taxation and Finance which had to give its approval before the exemption could become a reality. The official notification of our tax-free status was not received until Merriam's term had expired ......5 years later.

Merriam established contact with the American Association of Petroleum Geologists (AAPG) leading to the affiliation of the NYSGA with AAPG, which was approved by the membership at the 1974 (Fredonia) meeting. The Association now elects 2 representatives and 2 alternates to the house of delegates of AAPG.

The 1974 meeting also was made aware of the threatened destruction of the spectacular potholes on Moss Island at Little Falls by the planned construction of a 4-lane highway bridge to be anchored on the Island. A committee consisting of David Hawley (Hamilton C.), chairman, Ernest H. Muller (Syracuse U.), and Herman S. Muskatt (Utica C.) was appointed to look into the matter and to recommend action by the Association. H. Muskatt, reporting for the Committee at the 1975 (Hempstead) and 1976 (Poughkeepsie) meetings, kept the membership informed of the continuing efforts in support of local organizations to preserve the Island as a "Geologic landmark". Finally, the Committee could report relocation of the bridge and preservation of Moss Island at the 1977 (Oneonta) meeting with justifiable pride in the Association's endeavor in the public interest.

During Merriam's term of office the Annual Reports of the Secretary were replaced by (temporarily, we hope) Minutes of Meetings which gave more detailed information than the "resume" previously supplied. But owing to their preparation soon after the close of the annual meetings, they included only sketchy information on meeting attendance, meeting finances, and similar factual data which had proven so helpful to the authors of this history.

The stock of guidebooks was replenished to meet the rise in demand resulting from advertisements appearing State-wide and in Geotimes. The considerable cost involved is indicated by the drop of the Treasury balance from $4489.85 in 1974 to $614.84 in 1976.

The Committee on Organization, Philip C. Hewitt (SUNY at Brockport), chairman, William D. Romey (St. Lawrence U.), and Robert M. Finks (Queens C.)

had been charged with (1) determining the advisability of a more organized structure of the Association including dues and a full slate of officers; (2) considering the possibility of contracting a central printing service to reduce the cost of reprinting guidebooks; and (3) reviewing existing conditions which might favor the return of the annual meetings to the Spring Term. A questionnaire concerned with these subjects was distributed to all participants at the 1977 meeting and a definitive Committee report is expected in 1978.

Following Hewitt's example, Merriam also anticipated the end of his term of office after 5 (rather than 6) years and charged the Nominating Committee with proposing a candidate for Executive Secretary to be elected at the 1977 meeting.

The WOLFF Future - 1978 - ?

With the election of Manfred P. Wolff of Hofstra University as Executive Secretary and the election of Daniel F. Merriam to the Presidency of the Association for 1978, we have at last reached the present and can look confidently to the future. Fred, as he is known to one and all, took an immediate and firm hold of Association affairs. A new 1978 price list for guidebooks was prepared showing costs of individual copies ranging from $7.00 (1957) to $15.00 (1977) or $210.00 for the entire sequence of 21 (including a second, special guidebook prepared for the 1976 meeting). In order to reduce the cost to libraries, all guidebooks starting with 1956 (Rochester), which is not available in book form, were photographed on microfiche and may be obtained as a complete set of 22 items for $88.00. Individual guidebooks on microfiche range from $2.00 (1957) to $10.00 (1977). A 20 percent discount is provided for all students submitting a student verification form (printed on price list). The reverse side has a "thumb-nail" history of the Association which preceded the present effort.

Fred also is following through on Dan Merriam's suggestion to explore the possibility of affiliating with the National Association of Geology Teachers (NAGT).

We now look forward to the promising future of a stable, well-organized, although "informal" society under the leadership of dedicated "public servants", the Executive Secretaries. We believe that Nelson Dale and Harry Eaton, the founding fathers of the Association would be pleased with the results of their initiative ... 50 years later.

NEW YORK STATE GEOLOGICAL

ASSOCIATION

Department of Geology, Hofstra University
Hempstead, New York 11550

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Annual field trip in the fall; visitors welcome. Information on Association activities and a list of available publications can be obtained from the executive secretary.

A Brief History of the Department of Geology at Syracuse University

by

D.F. Merriam
Department of Geology, Syracuse University, Syracuse, NY

History of the Department of Geology at SU begins with the arrival of Alexander Winchell in January of 1873 as first chancellor and professor of geology, zoology and botany. He was the first to occupy ordained chair 13 (geology, mineralogy and botany) in the new University which had been formed under the sponsorship of the Methodist Church. Winchell actually was second choice after the Rev. Erastus O. Haven (later second chancellor of SU) declined the appointment because of other commitments (Galpin, 1952).

Winchell, born in Duchess County, New York in 1824, had been educated at Wesleyan (graduating in 1847) and had won distinction as professor of geology, zoology and botany at the University of Michigan as well as serving as director of the Michigan Geological Survey. He also had been president of Masonic University at Selma, Alabama, and attracted considerable attention with his book on "Sketches of Creation". The Board of Trustees and Faculty were impressed with his accomplishments and offered him the position; after some consultation with friends and family he accepted.

Winchell however soon became disenchanted with being chancellor. It required an inordinate amount of his time and there was the constant problem of raising money for the fledgling university. He was a "...bold and mighty thinker" but "...a scholastic hermit." "The affairs of men in general or of students out of the class room did not interest him" (Smalley, 1920). So after only two years he resigned as chancellor but remained on the faculty teaching for another 5 years (Table 1). Undoubtedly part of the decision to relinquish his administrative duties was based on domestic affairs as well as distaste for attending petty duties and details, which meant in his words "leaving my intellect to lie fallow" (Galpin, 1952). A year later he accepted a position at Vanderbilt University and divided his time between the two universities until he received a call to return to Michigan.

Winchell was first of all a scientist and scholar. He published almost 100 papers including nine books. A list he kept of his literary compositions numbered 566 (Winchell, 1892). He was cofounder of the Geological Society of America and of The American Geologist. He has been called the "Father of GSA" and served as its third president in 1891.

Winchell was a popular lecturer and was described as "...an effective, if not an eloquent speaker" (Smalley, 1920). He could bridge the gap between science and religion and had the remarkable ability to inspire and impart knowledge to others - "no man since the days of the elder Agassiz has done so much to familiarize the more intelligent portion of our

Table 1 - Heads and Chairmen of Department of Geology - SU

1873-79	Alexander Winchell	Prof. of Geology, Mineralogy and Botany; Prof. of Geology, Zoology and Botany
1879-83	-----	-----
1883-91	Lucien Marcus Underwood	Inst. (later Prof.) of Geology, Botany, and Zoology and in 1889 Prof. of Mineralogy[1]
1891-94	Rev. Charles Wesley Hargitt	Prof. of Biology and Geology
1894-95	-----	-----
1895-96	Edmund Chase Quereau	Prof. of Geology and Mineralogy
1896-1900	-----	-----
1900-31	Thomas Cramer Hopkins	Chm., Dept. of Geology
1906-31	Charles Henry Richardson	Chm., Dept. of Mineralogy
1931-45	George Babcock Cressey	Chm., Dept. of Geology and Geography
1945-58	Earl Taylor Apfel	Chm., Dept. of Geology
1958-63	William Meredith Merrill	Chm., Dept. of Geology
1963-70	John James Prucha	Chm., Dept. of Geology
1970-71	Ernest Hathaway Muller	Interim Chm., Dept. of Geology
1971-	Daniel Francis Merriam	Jessie Page Heroy Prof. & Chm., Dept. of Geology

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[1] This appointment apparently was the beginning of the Department of Mineralogy which administratively was separate from Geology.

Top row (left to right): A. Winchell, L.M. Underwood, T.C. Hopkins
Middle row (left to right): C.H. Richardson, G.B. Cressey, E.T. Apfel
Bottom row (left to right): W.M. Merrill, J.J. Prucha, D.F. Merriam

American communities with the great deductions and the established results of our science" (Orton, van Hise, and White, 1892). In February and March 1876 the University all but suspended activities as Winchell organized a school of geology providing instruction in elementary and advanced geology and in addition delivered 10 lectures on "The Derivative Origin of Species". The following year he repeated his performance with eight popular lectures, "Chapters from the Lifetime of a World". Apparently, he returned to the campus only once after leaving (in 1879) and then to give the J. Dorman Steele lecture in 1888. He died in Ann Arbor in 1891.

The Department has recognized his contributions with the Alexander Winchell Distinguished Lecture series given annually to commemorate his inauguration on 13 February 1873, and the Winchell Distinguished Alumni Awards. Winchell Hall was opened in 1900 as a university dormitory.

The first classes of geology were given in Hall of Languages (HL), although some of them were given in the Myers Block in downtown Syracuse. Room 31 HL was listed as the location on Wednesday and Friday of Winchell's course on geology for seniors during the winter term (13 weeks) of 1875. Geology was required of seniors in the classical curriculum during their third term and of sophomores in the scientific curriculum during their third term.

By the time Winchell left in 1879, geology was an established course in the university. He was replaced by Lucien M. Underwood (instructor and later professor of geology, botany and zoology, and 1889 professor of mineralogy), who had been a student of Winchell's and had just obtained his PhD from SU in 1879. He was followed by the Rev. Charles W. Hargitt, a biologist by training, who was professor of biology and geology from 1891-94. Apparently no geologist was on the faculty in 1894-95 and again from 1896 to 1900 although geology courses were offered. Edmund Chase Quereau was professor of geology and mineralogy from 1895-96. Others during the late 1800's who taught geology were Frank Smalley, who received a masters in geology but a PhD in Latin; Oscar Rogers Whitford, a mineralogist and later with King Gold Mining and Developing Co., and Edward Henry Kraus, a student of German and mineralogy, who later distinguished himself at the University of Michigan.

The first graduate degree in geology was granted in 1876 to Frank Smalley (AM '76). Early PhD's include:

1876	Miles Gaylord Bullock
1879	Frederic William Simonds
1879	Lucien Marcus Underwood
1881	Henry Joseph Rice
1884	Samuel John Sornberger
1887	David Worth Dennis
1888	Nicholas Knight

In 1900 Thomas Cramer Hopkins was appointed professor of geology. Hopkins had been educated at Stanford University and had just received his PhD from the University of Chicago. Previously he had been an instructor in chemistry at DePauw University, assistant state geologist of Arkansas, and assistant professor of geology at Penn State College. He was assisted in mineralogy by Edward Kruas who received his PhD in 1901 from the University of Munich. Kruas left for Michigan in 1904 and was replaced by Charles Henry Richardson (PhD, Dartmouth) in 1906. Richardson rose through the ranks from instructor to professor and Chairman of the Department of Mineralogy by 1909. Burnett Smith (PhD, University of Pennsylvania) was appointed an instructor in 1907.

It was in 1907 that the small three-man department moved to their new quarters on the third floor of Lyman Hall of Natural History (which also housed the Departments of Biology, Zoology, and Forestry). The Geology Department library was moved from HL to Lyman during the term break in early 1908.

Thomas Cramer Hopkins (1861-1935) was an inspirational teacher; he was well liked and respected. Often the Geology Club met at his home located adjacent to the campus. Hopkins had been associated earlier with R.A.F. Penrose (later benefactor of GSA) and F.W. Simonds (PhD, 1879 from SU) working for J.C. Branner (Stanford University) as assistants on the newly established State Geological Survey of Arkansas. His prestige in academics was "rated in part by the number of his published works" (almost 50 titles) and "his wide acquaintence among geologists of the times added significantly to the benefits to be derived from his teaching" (Holmes, 1977). He had a productive professional life considering he did not receive his PhD until he was 39. In 1958 W.B. Heroy endowed scholarships for the outstanding junior and senior majoring in geology in honor of his beloved professor who died in 1935. Since 1959, 27 undergraduate students have received the award.

The Geology Club was founded on 4 November 1905. The first vice president was William Bayard Heroy (PhB, '09) later benefactor and supporter of the Department. The Club was reactivated in the late 1920's and has been active since sponsoring field trips, seminars, and social activities. A professional geology fraternity, Pi Eta Sigma, was founded on 27 November 1915 and was active for about ten years.

The first part of the 1900's was a busy one, although activities were interrupted by two World Wars and seriously curtailed by a major depression. George B. Cressey became chairman of the combined Department of Geology and Geography in 1931. Hopkins and Richardson both retired that year. By 1945 the Department consisted of five faculty members, and some 50 advanced degrees had been awarded. Some of the graduates of this time include A.E. Brainerd (MS, 1912), Florence Huck (AM, 1920), Louis W. Ploger (AM, 1922 and later on the faculty), Chauncey D. Holmes (AM, 1927), Stewart H. Ross (MS, 1928), Louis Wade Currier (PhD, 1930), Samuel S. Goldich (AM, 1930), Marjorie Hooker (AM, 1933), Harry J. Klepser (AM, 1933), Neil A. Miner (AM, 1933), Andrew J. Mozola (MS, 1938), Russell F. Kaiser (MS, 1939), and Robert F. Black (AM, 1942).

The New York State Geological Association had roots in Syracuse. Announcement of the first annual intercollegiate geological field meeting held in central New York (1925) and hosted by Hamilton College was issued by SU's Harry N. Eaton, secretary. Eaton then served as president in 1926 for the 2nd meeting in Syracuse. In addition the 13th (1937), 22nd (1950), 36th (1964), and 50th meetings were held in Syracuse.

After WW II the Department of Geology and Geography was split and George Cressey (PhD in both geology and geography) became chairman of geography and Earl T. Apfel became chairman of the Department of Geology. Apfel was followed by William M. Merrill as chairman in 1958 and John James Prucha in 1963. Ernest H. Muller was interim chairman in 1970-71 and Daniel F. Merriam became the first Jessie Page Heroy professor and chairman in the spring of 1971. The faculty was increased to 6 by 1962, 8 in 1963, 10 by 1970, and 11 by 1971.

Numerous scholarships and awards have been established over the years to honor outstanding students and alumni. In 1961, Chauncey D. Holmes provided for an award for excellence in beginning geology, which is given annually to students with the highest grade in the introductory course and shows the most promise in science. The Newton E. Chute Graduate Award was eatablished in 1975 to be given annually to the graduate student judged outstanding based on scholarship, service to the Department, and professional promise. In 1976 the Faye M. Merriam Scholarship was endowed for a full-time SU undergraduate geology major to be awarded on academic achievement, need, and professional promise. The Marjorie Hooker Award (AM 1933), established in 1977 in support of research, is given annually to the thesis or dissertation proposal judged outstanding by the faculty.

SU Department of Geology Alumni are honored for their achievements each year. The awards are recognized for the alumni contributions to their profession and service to the Department. To date nine awards have been announced and include:

1976:	Louis A. Fernandez (PhD '69) Marjorie Hooker (AM '33) Vincent E. McKelvey (BA '37)
1977:	Samuel S. Goldich (AM '30) Chauncey D. Holmes (AB '25, AM '27) Yngvar W. Isachsen (BA '42)
1978:	Robert F. Black (AM '42) B. Churchill Loveland (BS'16) James R. Slater (MA '17)

In addition to Department awards, on occasion the University confers honorary degrees. Geologists and others associated with the Department have been honored and include: ScD's: E.H. Kraus '20, W.R. Jillson '21, W.F. Libby '57, W.B. Heroy '58, M.K. Hubbert '72, and V.E. McKelvey '75; and honorary LLD's: W.N. Rice '86, L.S. Smith '17, and E.H. Kraus '34.

Each year, since 1972, the Department has hosted a Geochautauqua in the fall. The first one was in conjunction with the Heroy Geology Laboratory dedication in 1972. The topic that year was "The impact of quantification on geology" and the speakers were G.Y. Craig of Edinburgh University, R.A. Reyment of Uppsala University, M.K. Hubbert of the U.S. Geological Survey, W.C. Krumbein of Northwestern University, S.C. Robinson of the Geological Survey of Canada, and J.C. Griffiths of Pennsylvania

State University. Proceedings of the symposium were published in the Syracuse University Geology Contribution (SUGC) series.

The Department initiated the SUGC publication series in 1973 with a paper on "Geology in the Service of Man" by V.E. McKelvey (BA '37). A publication outlet had long been needed for the Department and the new series filled that need. The first publication, which was both timely and relevant, was dedicated to the promotion of geology in the Upstate New York area.

An auspicious event took place in the history of the Department in 1966. William Bayard Heroy (PhB '09) approached the University with an offer to contribute money towards a geology building. Heroy had been supporting the Department through gifts for scholarships, equipment, and research during the previous 10 years. His offer was accepted graciously and the building named in his honor. The building was completed near the end of 1971 and the Department moved between semesters in December of 1971 and January 1972 from their third-floor quarters in Lyman where they had been since 1907 to the spacious new Heroy Geology Laboratory (HGL).

Heroy also endowed a distinguished chair of geology in honor of his first wife Jessie Minerva Page Heroy (PhB '08). D.F. Merriam was the first to occupy the position.

Heroy (1883-1971) was active in many geological organizations and had served them in many capacities (Conselman, 1974). He was cognizant of his education as a factor in his success both as a professional geologist and in business, and as a result he gave generously to his alma mater, Syracuse, to Southern Methodist University, where he spent much time in his later years, and to the Paleontological Research Institution in Ithaca. He gave money to both SU and SMU for buildings to house their geology departments. In recognition of his many accomplishments he received many awards and honorary degrees. He died in 1971.

In 1978 the Department consists of 11 faculty (including vice chancellor J.J. Prucha), 40 graduate students (MS, MA, and PhD) and another 5 completing requirements off campus, and about 55 majors (both BS and BA). The curriculum stresses field work and computer applications including geomathematics. As a medium-sized department with limited resources, all fields are not covered but an all-around basic education is offered at the undergraduate level. Specialization is possible at the graduate level, with either the group concerned with events on the stable interior of the craton or with continental margins. About 1500 students a year enroll in introductory courses where they get an understanding of geology and an appreciation for their environment.

The future at this time looks bright for geology and the Department anticipates an active and exciting time during the remainder of the 20th Century.

ACKNOWLEDGMENTS

I would like to thank the following people for help and information in regard to the Department: Mrs. Virginia Wood (adm. asst. 1956-72), Mrs. Beverley O'Brien (adm. asst. 1972-), Mr. B. Churchill Loveland (BS '16), Dr. Chauncey D. Holmes (AB '25, AM '27), Dr. Stewart H. Ross (MS '28, PhD '51), and Dr. Ernest H. Muller (faculty 1959-).

TO A CAMBRIAN TRILOBITE

Oh thou, great warrior of th'emergent earth,
First conqueror of Neptune's mighty deep,
Reveal the secret of thy early birth,
And where and how and why you came to reap
The fruits of life's emergent evolution,
To conquer all that dared to live. Oh, say
For me the reasons for your dissolution,
What mighty battle ended your life's day.
Although you dwelt in glory for a time,
You were not destined to immortal be.
New types replace the old, for in its prime
This form must cede to that control o'er sea.
So tell--must man, who now is king o'er all,
In prime of life be overthrown and fall?

Barbara Eaton Ferguson, PBK AB
Syracuse, 1949

(from the fieldtrip guide for the NYSGA Silver Anniversary Meeting, Syracuse University, 28-29 April 1950)

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Deformation Structures in Lower Paleozoic Rocks, Northwestern New York

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INTRODUCTION

This field trip is concerned with the nature and origin of some deformation structures within Lower Paleozoic cover to Precambrian basement in the vicinity of Theresa, New York (Fig. 1). Many of the structures suggest localized mobility within the basement that generated instability within the cover rocks - both during and at some time following their deposition.

All of the main stops will be within the Potsdam Sandstone (Upper Cambrian) and the Theresa Formation (Lower Ordovician). A cursory examination of some of the Precambrian gneisses also will be made.

The Potsdam Sandstone in the Theresa area lies with marked angular unconformity on a Precambrian sequence of marble and quartzofeldspathic gneisses. The sub-Potsdam surface in places is rugged with a relief in excess of 70 ft although some of this relief may be due to penecontemporaneous faulting during sedimentation (Stops 2 and 3). The relict topography in part may be due to differential erosion of alternating zones of marble and quartzofeldspathic gneisses because in some areas the marble underlies marked topographic depressions. Where observed, the lowermost Potsdam occurs above an approximately 3-ft thick weathered zone of the basement rocks (Barber, 1977). The Potsdam Sandstone in this area typically consists of a buff to light-gray, thin-bedded to massive, silica-cemented, medium- to fine-grained orthoquartzite; minor amounts of detrital feldspar, mica, and tourmaline occur but rarely exceed 3 percent of the mode. It lacks the pink coloration of the lower parts of the formation in the north (Kirchgasser and Theokritoff, 1971; Selleck, 1978).

The irregular topography on the Precambrian profoundly influenced Potsdam sedimentation. Lowermost Potsdam rocks occur in depressions of the basement surface and these areas are characterized by syndepositional deformation structures. Rapid and large changes in thickness, breccia slides, and minor faulting suggest active faulting during deposition (Stops 2, 3 and 5). At least one of these areas is on strike with NE-trending faults within the basement to the north (R.V. Guzowski, 1977, pers. comm.; Barber, 1977; Buddington, 1934).

The overlying Lower Ordovician Theresa Formation ranges in composition between dolomitic limestone to quartz sandstone, the latter being concentrated in the lower 5 to 10 ft of the formation (Stop 1). Calcite sandstones locally occur within the succession. Typically, the Theresa is thinly bedded and light gray. Convolute lamination is a locally abundant feature.

In the central part of the area (Fig. 1), Theresa limestones outcrop as outliers capping elongate low-amplitude domal folds. These are best

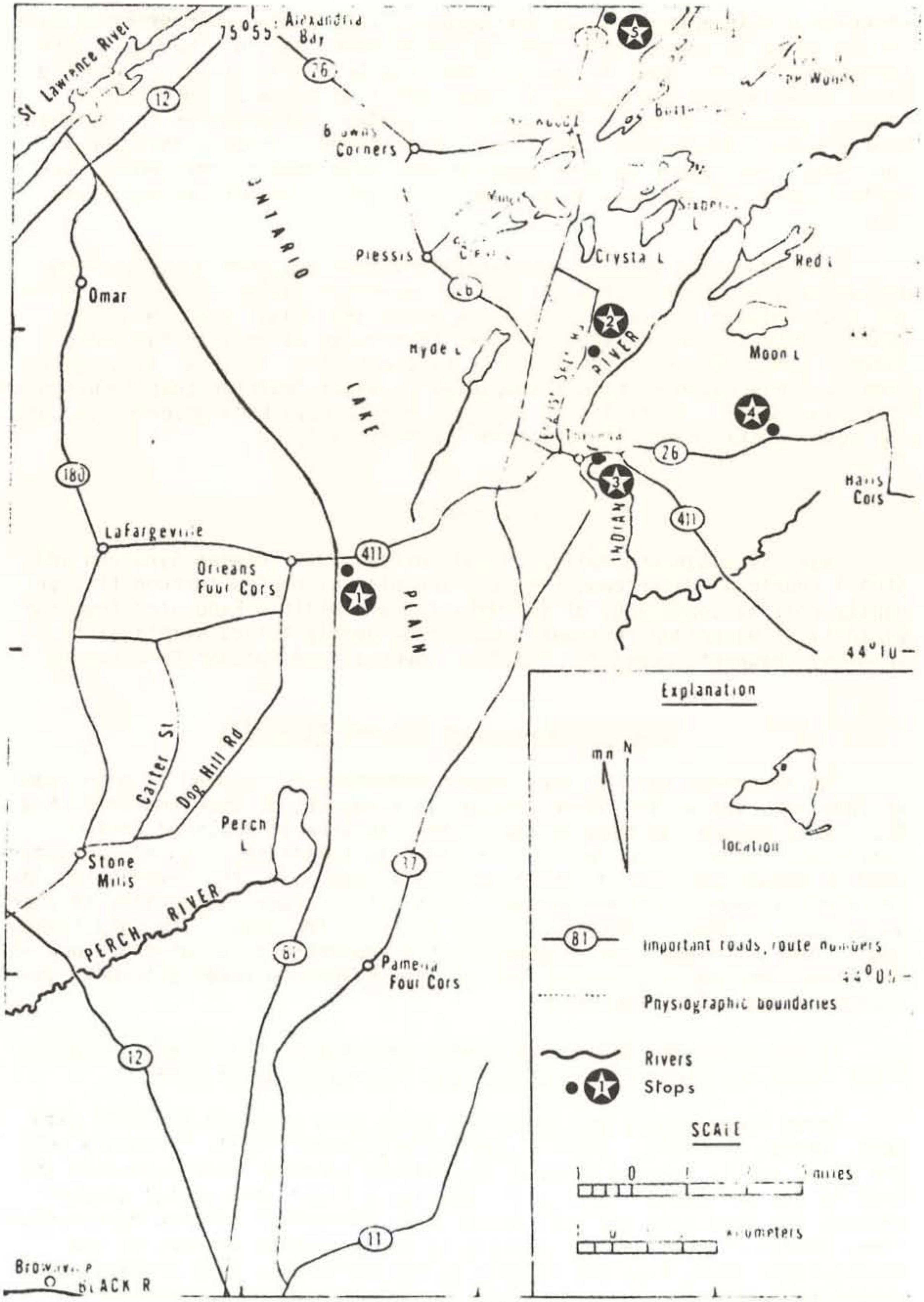

Figure 1. Locality map for Theresa area.

observed within a 3-5 mi wide NNE-trending zone extending from Perch Lake in the south to Butterfield Lake in the northern part of the area. The boundaries of this zone are marked imprecisely by NNE-striking probable fault zones within the basement. The effect of these on the Potsdam-Theresa sequence is seen as instability during sedimentation in the east (see previous discussion) and in post-depositional folding throughout the zone. The latter is particularly well developed in the central and western parts of the zone within the structurally higher Theresa Formation.

Fold-producing post-Ordovician deformation has been described from the succession to the north, in the St. Lawrence Valley (Chadwick, 1915) and post-Potsdam mineralization along veins and joints throughout the region close to the contact with the Precambrian attests to Phanerozoic thermal reactivation of parts of the basement (B.W. Selleck, 1978, pers. comm.). This may have been accompanied by major faulting that deformed the overlying cover. No faults of regional extent have been observed to cut the cover rocks in the Theresa area (Barber, 1977).

FIELD GUIDE

Leave Syracuse and follow US I81 northwards. Between Syracuse and Stop 1 (north of Watertown, Fig. 2), the highway passes through flat or gently rolling topography of the Ontario Lake Plain. Exposures from the vicinity of Watertown northward consist of gently folded strata of the Trenton, Chaumont, Lowville, Pamelia, Theresa, and Potsdam Formations.

Stop 1. Junction Rt I81 and Rt NY 411

The lowermost part of the Theresa Formation is exposed on both sides of this road cut in the hinge zone of an elongate, NE-trending dome (Fig. 2). It is typical of many of the upright to steeply inclined gentle anticlinal folds in the region that occur as relatively high ground separated by broad synclinal or undeformed rock underlying the intervening low and usually poorly drained ground. This 'first order' topography is characteristic of the western and central parts of the area. The fold trends N33°E, and the hinge line plunges NE at approximately 12° at this locality. The interlimb angle is around 160 and no measurable layer thickness variation occurs across the fold.

To the south the hinge-zone widens and extends for at least a mile. Minor folds are present in a relatively flat-lying axial zone.

Three recognizable but dispersed joint sets traverse the fold with mean trends of N74°E, N46°E , and N50°W (Barber, 1977). Probably only the N46°E set is related directly to folding because on rotation of the beds to the horizontal their poles develop a tight zero plunge cluster whereas the remaining two sets become more dispersed. On the northwestern limb, joints of this set dip steeply to the southeast whereas on the southeastern limb, dips are steeply to the northwest; they probably are extensional 'ab' fractures developed during the folding process. The

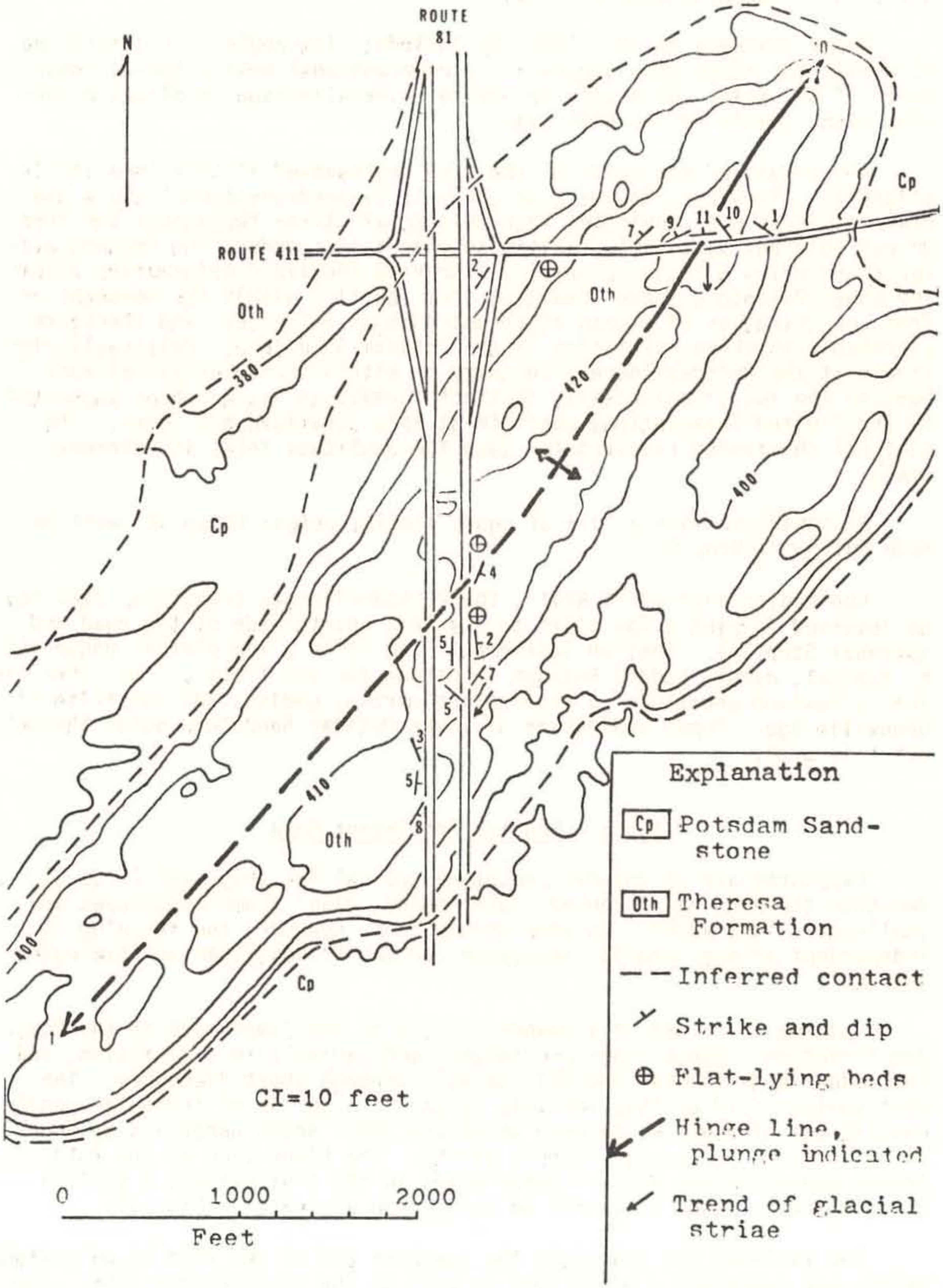

Figure 2. Stop 1 - Generalized structural map.

N74°E and N50°W post-date folding.

Other features at this locality include: low-angle joints striking NE within the hinge zone suggesting a compressional origin for at least parts of the fold; and a calcite-pyrite mineralization in places occurring along joints of the N74°E set.

The origin of the folds of the type represented at this locality is enigmatic. They are, however, unlikely to be syndepositional and a glacial origin is not convincing because glacial striae throughout the area do not hold any systematic relationship to fold trends. The present evidence indicates a tectonic origin, either as localized deformation within the Lower Paleozoic rocks resulting from faulting within the basement or from concentration of strain at abrupt changes in relief, and therefore a probable thickness variation in the Potsdam Sandstone. Relatively high strain at the Potsdam-Theresa boundary or within the transitional zone between the two lithologically distinct formations has not been supported by the limited observations possible at this stratigraphic level. The regional shortening required for such low-amplitude folds is extremely small.

A comparison with a fold of known glacial origin (Stop 5A) will be made following Stop 5.

Continuing east on Rt NY411, the Potsdam-Theresa transition beds may be observed forming a low cliff to the left (north side of the road and optional Stop 1A). English Settlement Road is on a low plateau underlain by typical, evenly bedded Potsdam Sandstone for the first 1.5 mi, then dips into a lowland underlain by alternating marble, gneiss, and quartzite of Grenville age. Domes and basins of lower Potsdam Sandstone occur throughout this area.

Stop 2. English Settlement Road

Exposures are of Potsdam Sandstone typical for this area (Fig. 3). Hematite staining has accented crossbedding, minor slump structures and small-scale lamination. In some occurrences, however, the staining is independent of any internal structure and may be described as 'liesegang banding'.

Bedding is folded in a manner typical of the lower part of the Potsdam Formation. Hinge lines are tenuous and variable in orientation, and individual beds thicken and thin greatly through short distances. The most obvious fold at this locality is one of a series of irregular gentle undulations of bedrock, between which are small areas underlain by Grenville rocks or horizontal Potsdam strata. The hinge-line of the fold trends approxiamtely N40°E. Other folds in the area exhibit a similar trend wherever hinge lines can be determined accurately (Fig. 3).

The railroad cut transects the southern end of the fold at an oblique angle, and expresses a hinge-zone as well as the northwestern limb. The central part of the fold is comprised of horizontally bedded Potsdam and

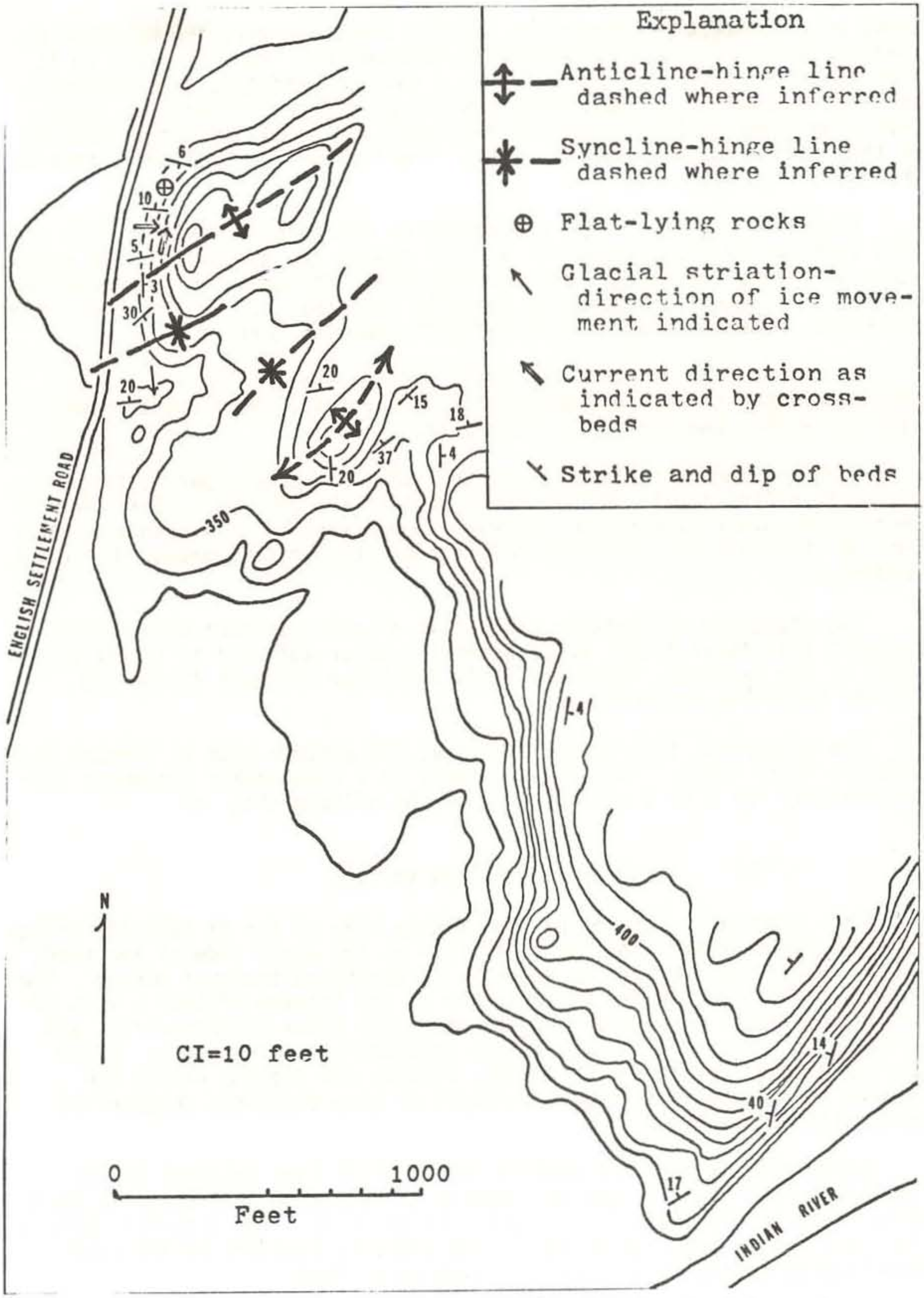

Figure 3. Stop 2 - Structures within Potsdam Sandstone at English Settlement Road.

shows no evidence of deformation. On the limb, however, are a number of features indicative of pre-induration deformation. Approximately 10 ft from the northern end of the outcrop, a massive sandstone layer abruptly deflects downwards and terminates against an adjacent underlying layer. Overlying layers exhibit annealed fractures and lumpy, contorted bedding as they form a flexure over the zone. The flexure has been propagated to the top of the exposure.

Strata to the south, for a distance of approximately 65 ft, form the fold limb, which dips between 5° and 10° toward the northwest. The sandstone is cut by fractures, some of which are differentially weathered normal faults of small displacement (usually less than 0.5 in) that dip to the northwest. Some of these are filled with granular quartz.

On the limb, beds pinch and swell and may change from massive to shaly character through distances of 10 ft or less. Most crossbedded layers are thin and crossbeds are planar.

A major slump structure occurs near the fold crest (partially obscured by a pine tree). At the lower part of the outcrop, a portion of a large slump block is exposed. Poorly layered sandstones within and adjacent to the block are separated by a narrow zone of homogeneous disturbed sandstone.

The abundance of features indicative of soft-sediment deformation suggests that these folds, which generally occur adjacent to topographic highs of the basement, formed by rapid downslope movement during and closely following sedimentation.

The escarpment that crosses NY411 at the western edge of Theresa is a possible fault scarp. This fault extends as a topographic lineament discontinuously for 2 or 3 mi northeast of the village (Fig. 4).

Stop 3. Theresa Village

This outcrop is located on the Theresa side of the Rt NY26-411 bridge over the Indian River. At the cliff face on the south side of the road, Potsdam Sandstone overlies an exposure of weathered basement gneiss. The effects of initial dip are evident here as the Potsdam offlaps a knob of Precambrian rock. Irregular bedding, numerous minor unconformities and evidence of soft-sediment deformation characterize the outcrop. Where the Precambrian core has been eroded, ripples are exposed within the Potsdam that probably formed as a result of slow downslope movement of unconsolidated sediment.

Large slump blocks are exposed in the cliff face adjacent to the sidewalk. Each block is set in a matrix of sandstone that exhibits small-scale contorted laminae or is accented by hematite. The interface between block and matrix tends to be sharp, and suggests slumping of partially consolidated sediments in areas of steep paleoslope.

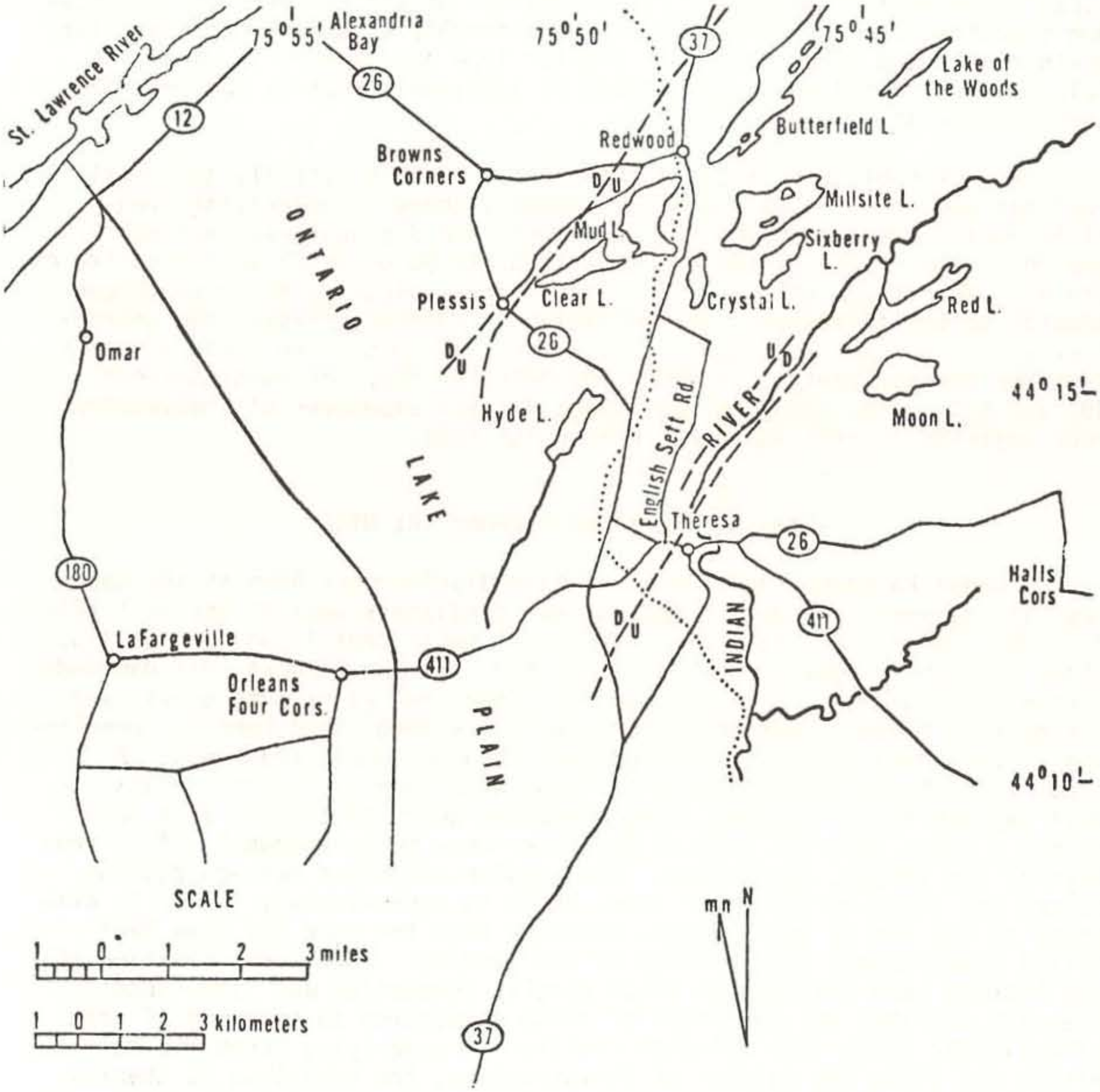

Figure 4. Inferred position of basement faults.

Stop 4. Ritchie's Farm

The high ground behind the farm buildings is comprised of variably bedded, buff-colored, lower Potsdam Sandstone that forms a broad structural basin toward the north. It is typical of all the outliers of Potsdam Sandstone in the region and its relationship to underlying Grenville. Whether this and other basins of similar type are primary is uncertain. Calculations of thickness variations in individual beds is not possible through lack of exposure.

The dominant joint sets in the Potsdam at this locality are nearly vertical and trend N42°W and N81°E, whereas those in underlying Grenville gneiss trend between N42°E and N66°E and dip southeast between 57° and 70°. The strike of these joints tends to be parallel to the strike of the main foliation, whereas dip of these same joints tends to be perpendicular to the foliation. The foliation in coarsely crystalline quartz-biotite-plagioclase (?oligoclase) gneisses, visible a few yards downhill from the Potsdam contact, strikes N68-84°E and dips northwest between 39° and 43°. This trend is consistent for all exposures of Precambrian rock adjacent to this and other nearby outcrops.

Stop 5. North of Redwood, Rt NY37

A major basement fault with relative displacement down to the northwest is inferred to underlie the valley immediately west of the hill (Fig. 4). The hill is comprised of a structural basin containing Potsdam Sandstone similar to that at the previous stop. At the roadcut, Potsdam beds strike N41°E and dip gently southeast. They consist of both evenly and irregularly bedded sandstone containing 'liesegang''type banding, conglomeratic zones and numerous soft sediment deformational structures. A large cone-shaped concretion of the type described by Dietrich (1953) is well exposed in the outcrop. The structure seems to consist of a cone within a cone, with the axis of the inner cone being somewhat offset from that of the larger, outer cone. The angular relations between bedding planes and sides of the outer cone, which is approximately 7-8 ft in diameter at the top of the outcrop, indicate that the cone may have been tilted concurrently with tilting of the bedding. Therefore, rotation of the Potsdam beds followed at least partial compaction and lithification. Dietrich ascribed the formation of these structures to slumping of semi-consolidated sands into solution cavities in underlying Grenville marble. Within and along the margins of the structure, the sandstone is chaotically bedded, and contains numerous healed fractures and small slump blocks. These conical or cylindrical structures occur elsewhere in the area, and although they suggest the importance of soft-sediment deformation, this is the only one that occurs in tilted strata.

Optional Stops (time permitting)

1A Potsdam-Theresa transition beds east of Stop 1.
5A Bedrock deformation of glacial origin. Rt NY12.

Return to Syracuse

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The Structural Framework and Petrology of the Southern Adirondacks

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INTRODUCTION

The area referred to as the southern Adirondacks is shown in Figure 1. Within this region, the Precambrian is bounded approximately by the towns of Lowville and Little Falls on the west and Saratoga Springs and Glens Falls on the east.

Mapping in the southern Adirondacks was done first by Miller (1911, 1916, 1920, 1923), Cushing and Ruedemann (1914), Krieger (1937), and Cannon (1937); more recent investigations were undertaken by Bartholomé (1956), Thompson (1959), Nelson (1968), and Lettney (1969). At approximately the same time Walton (1961) began extensive field studies in the eastern portion of the area (Paradox Lake, etc.), de Waard (1962) began his studies in the west (Little Moose Mt. Syncline). Subsequently de Waard was joined by Romey (de Waard and Romey, 1969).

Separately and together, Walton and de Waard (1963) demonstrated that the Adirondacks are made up of polydeformational structures, the earliest of which consist of isoclinal, recumbent folds. Their elucidation of

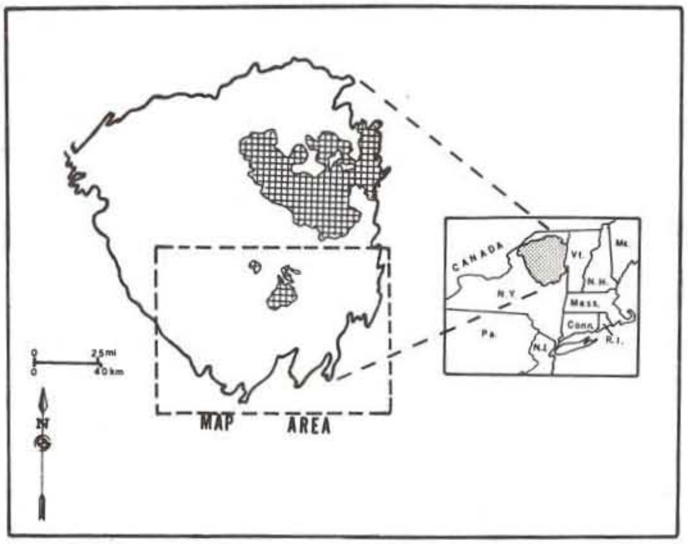

Figure 1. Location of map area. Major anorthosite bodies patterned.

Adirondack geology set the tone for future workers in the area. In this regard one of their most important contributions to the regional picture was that the stratigraphy of the west-central Adirondacks is correlative with that of the eastern Adirondacks.

Beginning in 1967 McLelland (1969, 1972) initiated mapping in the southernmost Adirondacks just to the west of Sacandaga Reservoir. This work was extended subsequently north and east to connect with that of Walton and de Waard. Geraghty (1973) and Farrar (1976) undertook detailed mapping in the eastern half of the North Creek 15' quadrangle. This tied into investigations in the Brandt Lake region by Turner (1971). Recently, Geraghty (1978) completed a detailed study of the structure and petrology in the Blue Mt. Lake area.

The foregoing investigations have increased our knowledge of the southern Adirondacks, and this fieldtrip is designed to show as many examples of the region's structure, lithology, and petrology as time allows.

STRUCTURAL FRAMEWORK OF THE SOUTHERN ADIRONDACKS

The southern Adirondacks (Figs. 2, 3, 4) are underlain by multiply deformed rocks which have been metamorphosed to the granulite facies. The structural framework of the region consists of four unusually large fold sets, F_1-F_4 (Figs. 2, 4). Relative ages have been assigned to these fold sets, but no information exists concerning actual time intervals involved in any phase of the deformation. It is possible that several, or all of the fold sets, are manifestations of a single deformational continuum.

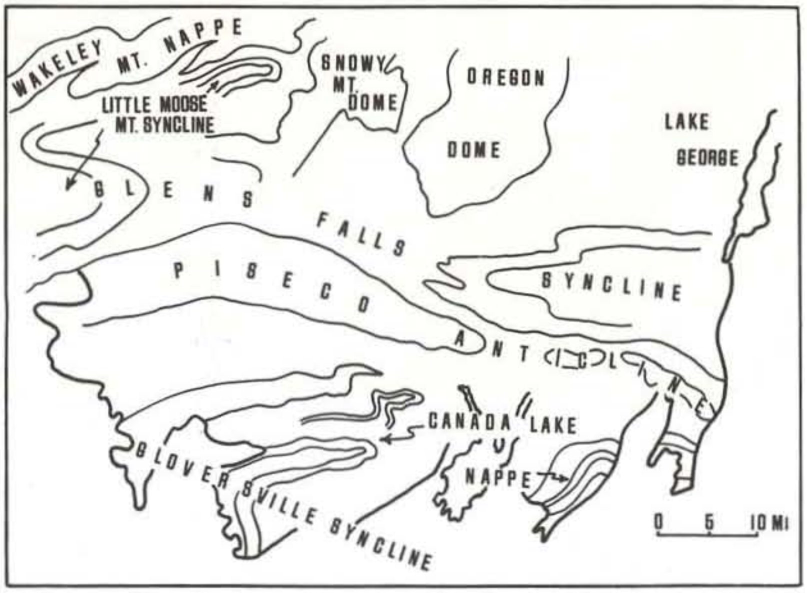

Figure 2. Major structural elements of southern Adirondacks.

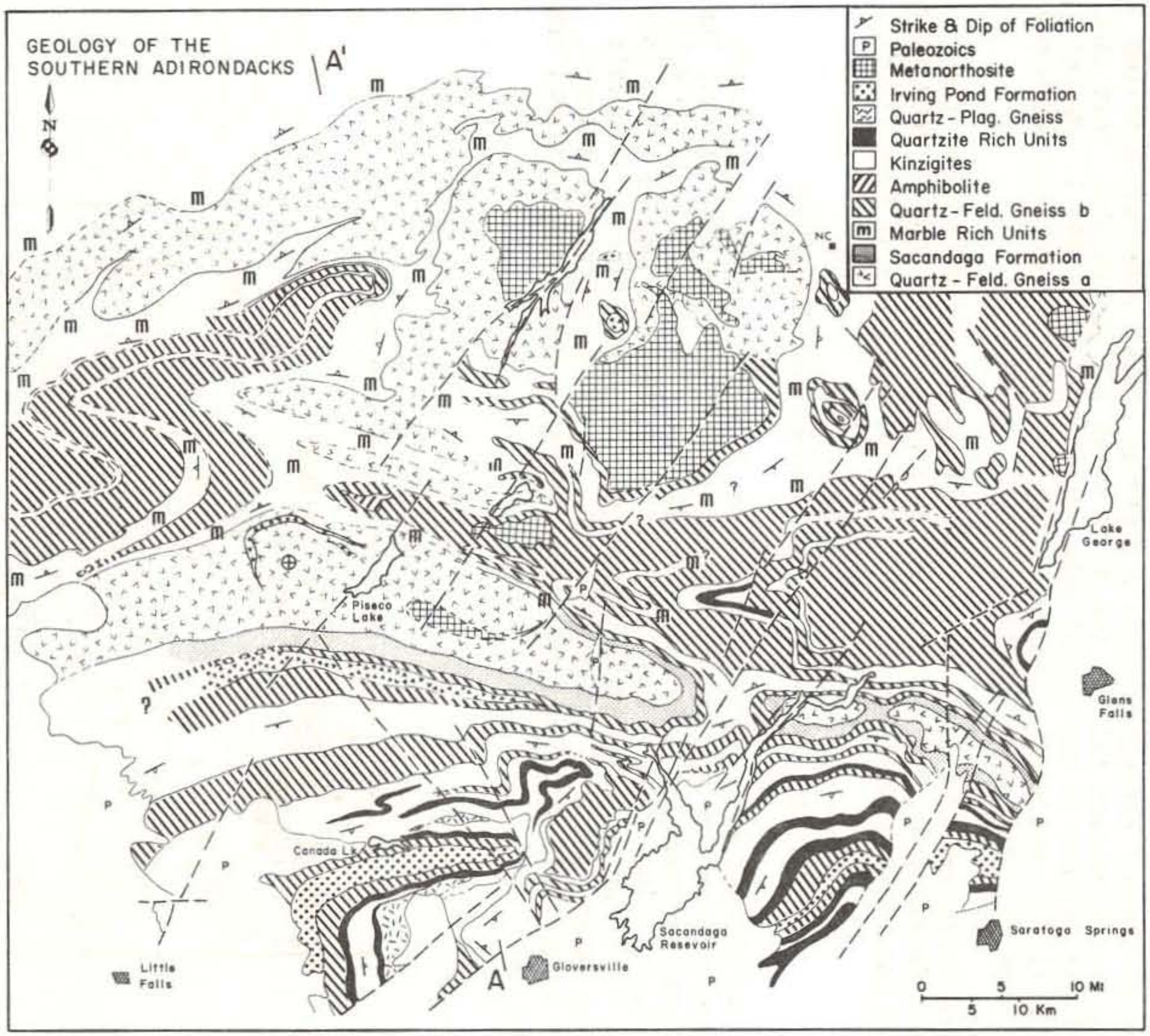

Figure 3. Geologic map of southern Adirondacks.

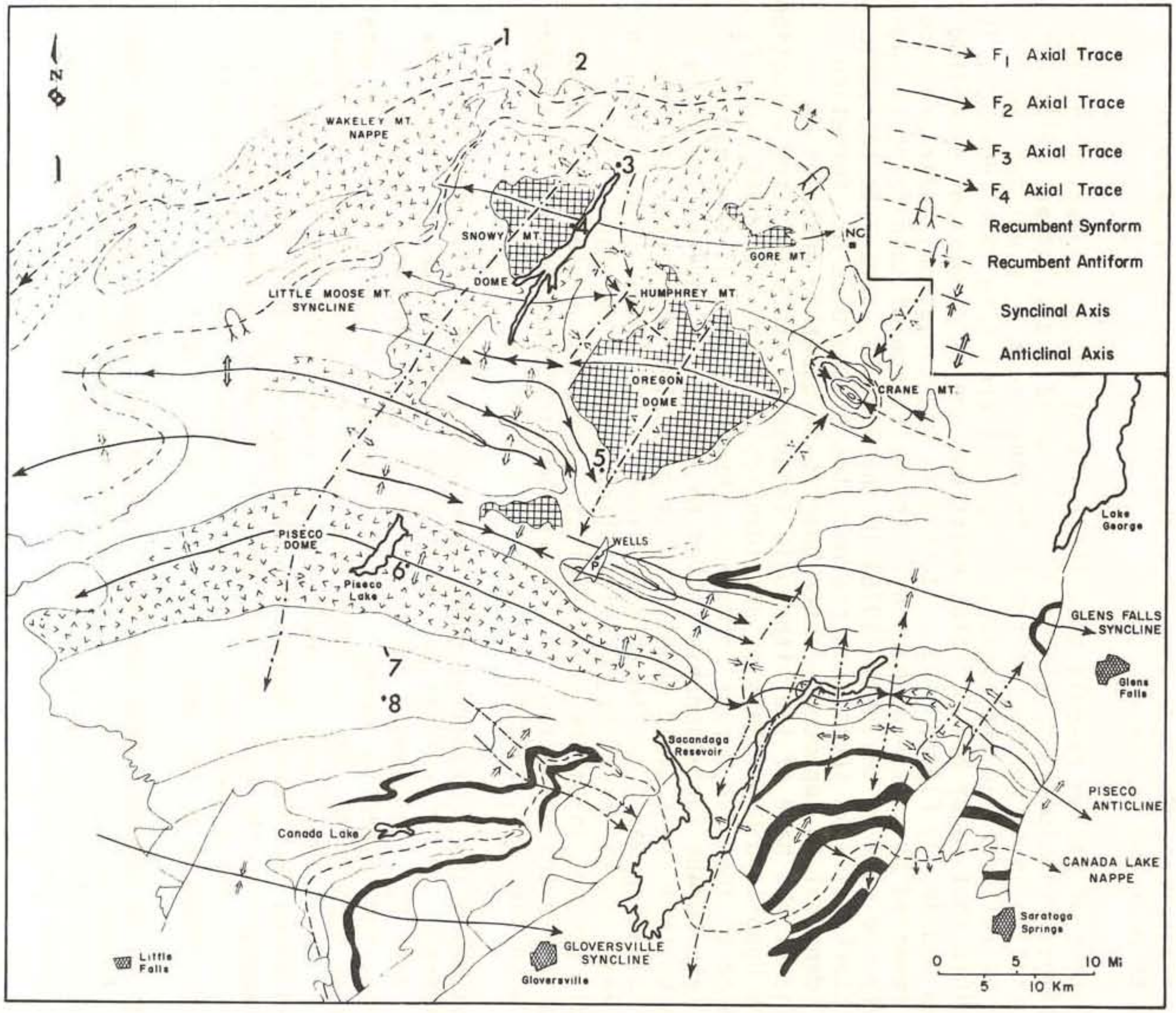

Figure 4. Axial traces of major folds in southern Adirondacks. Field trip stops 1-8 indicated.

The earliest and largest of these folds are recumbent, isoclinal structures (F_1) -- for example Little Moose Mt. Syncline (de Waard, 1962) and Canada Lake Nappe (McLelland, 1969)(Figs. 3 and 4). These isoclines have axes that trend approximately E-W and plunge within 20° of the horizontal. As seen in Figure 4 the axial traces of each of the F_1 folds exceeds 100 km. They are believed to extend across the entire southern Adirondacks. Subsequent useage of the terms "anticline" and "syncline," rather than "antiform" and "synform," is based on correlations with rocks in the Little Moose Mt. Syncline where the stratigraphic sequence is thought to be known (de Waard, 1962).

Close examination reveals that the F_1 folds rotate an earlier foliation defined principally by plates of quartz and feldspar. Although this foliation is suggestive of pre-F_1 folding, such an event does not seem to be reflected in the regional map patterns (Fig. 3). However, it is possible that major pre-F_1 folds exist but are of dimensions exceeding the area bounded by Figure 3. If this is the situation, their presence may be revealed by continued mapping. The existence of such folds is suggested by the work of Geraghty (1978) in the Blue Mt. area. In the vicinity of Stark Hills it seems that charnockites of the Blue Mt. Formation may be identical to supposedly older quartzo-feldspathic gneisses "A" which lie at the base of the lithologic sequence. If this is the situation then the Upper and Lower Marbles are identical and there emerges a pre-F_1 fold cored by the Lake Durant Formation. However, careful examination of the Lake Durant Formation has failed to reveal the internal symmetry implied by this pre-F_1 fold model. It is possible, of course, that the pre-F_1 foliation may not be related directly to folding (e.g. formed in response to thrusting, gravity sliding, etc.; Mattauer, 1975). Currently the origin of the pre-F_1 foliation remains unresolved. In most outcrops the preF_1 foliation cannot be distinguished from that associated with the F_1 folding.

Following the F_1 folding, there developed a relatively open and approximately upright set of F_2 folds (Figs. 3 and 4). These are coaxial with F_1. In general the F_2 folds are overturned slightly to the north, the exception being the Gloversville Syncline with an axial plane that dips 45°N. The F_2 folds have axial traces comparable to those of the F_1 set. The Piseco Anticline and Glens Falls Syncline can be followed along their axial traces for distances exceeding 100 km until they disappear to the east and west beneath Paleozoic cover. The similarity in size and orientation of F_1 and F_2 suggests that both fold sets formed in response to the same force field.

The third regional fold set (F_3) consists of large, upright NNE folds having plunges which differ depending upon the orientation of earlier fold surfaces. The F_3 folds are observed to tighten as one proceeds towards the northeast.

The fourth fold set is open, upright, and trends NW. Within the area these folds are less prevalent than the earlier sets. However, Foose and Carl (1977) have shown that within the NW Adirondacks, northwest-trending folds are widespread and play an important role in the development of basin and dome patterns.

The regional outcrop pattern is distinctive because of the interference between members of these four fold sets (Figs. 3 and 4). For example, the "bent-index-finger" pattern of the Canada Lake Nappe west of Sacandaga Reservoir is due to the superposition of the F_2 Gloversville Syncline on the F_1 fold geometry (Fig. 5). East of the reservoir the reemergence of the core rocks of the Canada Lake Nappe is due to the superposition on F_1 of a large F_3 anticline whose axis passes along the east arm of the reservoir (Fig. 6). The culmination-depression pattern along the Piseco Anticline results from the superposition of F_2 and F_3 folds. The structure of the Piseco Dome is due to the intersection of the Piseco Anticline (F_2) with the Snowy Mt. Anticline (F_3). Farther to the north, Crane Mt. is a classic example of a structural basin formed by the interference of F_1, F_2, and F_3 synclines (Fig. 4 and 7).

DISCUSSION AND SYNTHESIS OF STRUCTURAL RELATIONSHIPS

Over a decade ago Walton and de Waard (1963) proposed that rocks of the anorthosite-charnockite suite comprise a pre-Grenvillian basement on which a coherent "supracrustal" sequence was deposited unconformably. Rocks which would be assigned a basement status in this model are designated as quartzo-feldspathic gneisses, "a" in Figure 3. The basal unit of the overlying "supracrustal" sequence consists of marbles, quartzites, and various calc-silicates. This lowermost unit is followed upward by various quartzo-feldspathic gneisses, marbles, and other metasedimentary sequences shown in Figure 8. Although our own research agrees with the generalized lithologic sequences of de Waard and Walton, two major provisos are necessary and are given here.

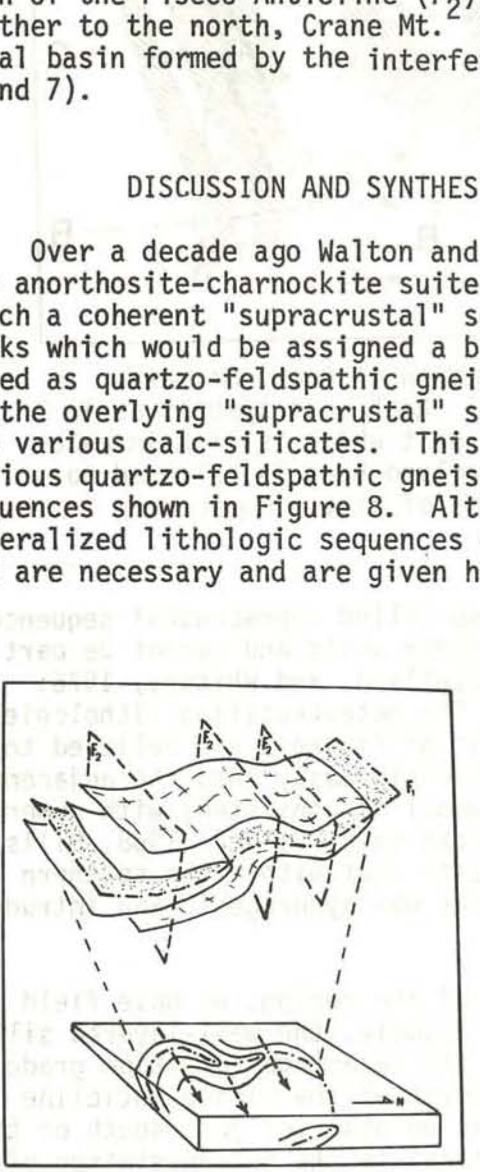

Figure 5. F_1-F_2 fold interference resulting in "bent-index-finger" pattern of Canada Lake Nappe.

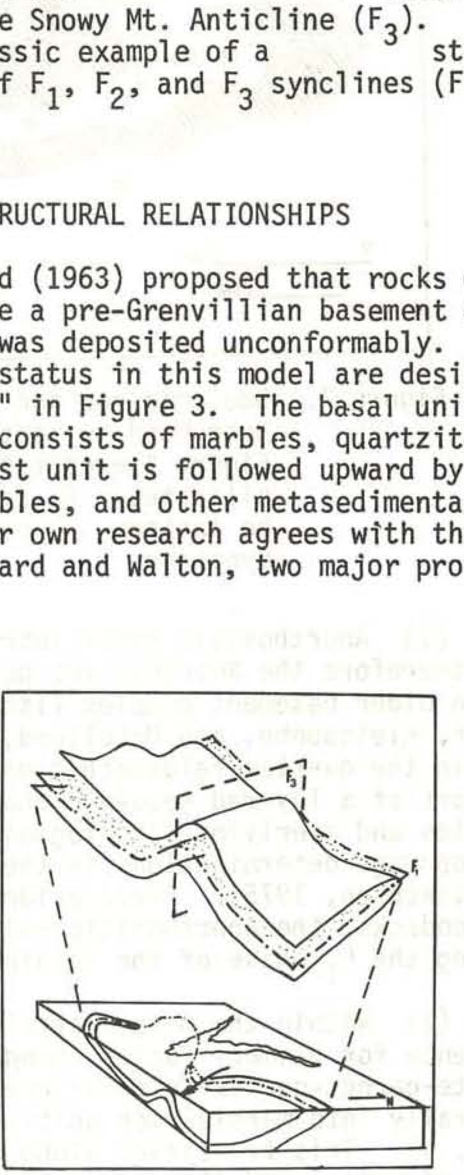

Figure 6. F_1-F_3 fold interference resulting in reemergence of core of Canada Lake Nappe east of Sacandaga reservoir.

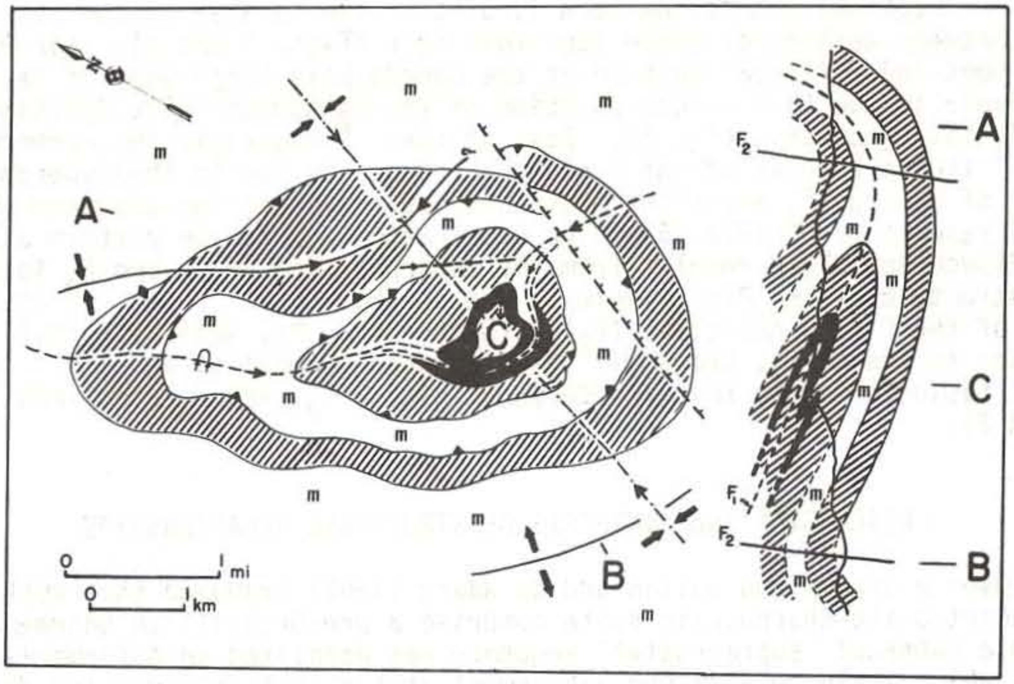

Figure 7. Geologic map and cross section of Crane Mt. area. Note bend in section at c. Rock unit symbols as in Figure 3 except for black unit which is rich in calc-silicates. F_1 synform involved here is believed to be eastern continuation of Little Moose Mt. Syncline.

(1) Anorthositic rocks intrude the so-called supracrustal sequence, and therefore the anorthosites post-date these units and cannot be part of an older basement complex (Isachsen, McLelland, and Whitney, 1976; Husch, Kleinspehn, and McLelland, 1976). The metastratified lithologies within the quartzo-feldspathic gneisses "a" of Figure 3 are believed to be part of a layered sequence that passes continuously into the adjacent marbles and overlying lithologies. This model is consistent with numerous isotope age determinations in the Adirondacks (e.g. Silver, 1968; Hills and Isachsen, 1975). Field evidence suggests that within the southern Adirondacks, the anorthositic suite of rocks was synorogenic and intruded during the F_1 phase of the folding.

(2) Within the metastratified units of the region, we have field evidence for primary facies changes. For example, the well-layered sillimanite-garnet-quartz-feldspar gneisses of the Sacandaga Formation grade laterally into marble-rich units exposed north of the Piseco Anticline (Fig. 3). This transition along strike can be observed just south of the town of Wells, and its recognition is critical to the interpretation of the regional structure. Thus the great thickness of kinzigites (granulite-facies metapelites) south of the Piseco Anticline gives way to the north to thinner units marked by marbles, cal-silicates, and quartzites. We interpret this lithologic change as due to a transition from a locally deep basin in which pelitic rocks were accumulating to a shallow-water shelf sequence dominated by carbonates and quartz sands.

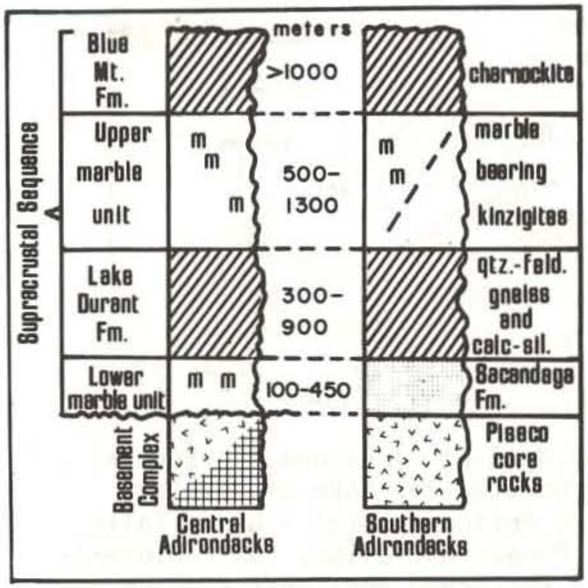

Figure 8. Stratigraphic sections for Little Moose Mt area (central Adirondacks) and Piseco Anticline region (southern Adirondacks). Central Adirondacks data from de Waard (1964a).

Given the foregoing information, it has been possible to map and correlate structures and lithologies on either side of the Piseco Anticline. In the northwest the sequence on the northern flank proceeds without structural discontinuity into the core of the Little Moose Mt. Syncline. There occurs on the southern flank a mirror image of the northwestern lithologic sequence as units are traced towards the core of the Canada Lake Nappe. It follows that the Canada Lake Nappe and Little Moose Mt. Syncline are parts of the same fold (Fig. 9). The amplitude of this fold exceeds 70 km, and it can be followed for at least 150 km along its axial trace. The major F_2 and F_3 folds of the area are exposed through distances of similar magnitude, but their amplitudes are less than those of the F_1 isoclines. The structural framework that emerges is one dominated by exceptionally large folds.

Accepting that the Little Moose Mt. Syncline and Canada Lake Nappe are the same fold, and noting that the fold axis is not horizontal, it follows that the axial trace of the fold must close in space. The axial trace of the Canada Lake Nappe portion of the structure can be followed from west of Gloversville to Saratoga Springs. Therefore, the axial trace of the Little Moose Mt. Syncline also must traverse the Adirondacks to the north. Mapping strongly suggests that the hinge line of this fold passes through North Creek and south through Crane Mt. (Fig. 10). From here the axial trace swings eastward along the north limb of the Glens Falls Syncline and passes under Paleozoic cover in the vicinity of Lake George. This model is depicted schematically in Figure 10 where the southern Adirondacks are shown as underlain largely by the Canada Lake-Little Moose Mt. Syncline. Later folding by F_2 and F_3 events has resulted in regional doming of the F_1 axial surface, and erosion has provided a window through the core of this dome. Note the western extension of the Piseco Anticline beneath the Paleozoic cover. This extension is consistent with aeromagnetics of the area.

Currently attempts are underway to synthesize the structural framework of the entire Adirondacks by extending the elements of the present model to other areas. A preliminary version is shown in Figure 11 and suggests that most Adirondack structure is explicable in terms of the four large fold sets described here.

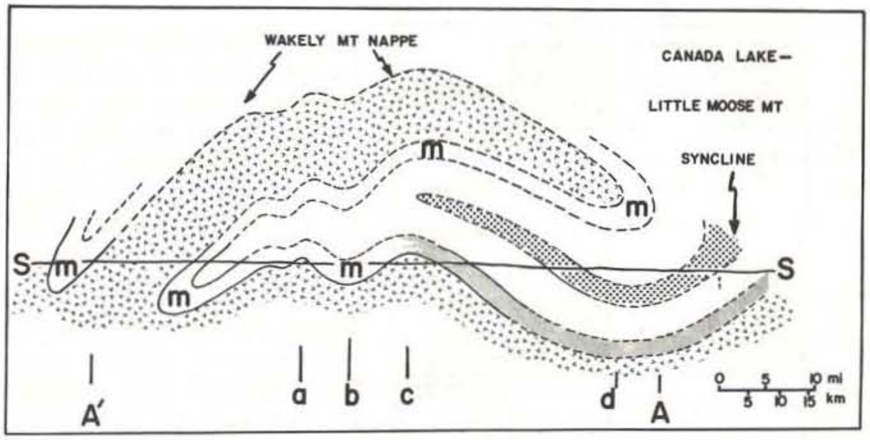

Figure 9. Cross section along A-A' of Figure 2. Several units have been omitted for sake of clarity. (a) - Spruce Lake Anticline, (b) - Glens Falls Syncline, (c) - Piseco Anticline, (d) - Gloversville Syncline. Patterned rock unit symbols as in Figure 3.

METAMORPHISM

Introduction

Metamorphism of rocks in the Adirondack highlands has been investigated extensively for the past fifteen years (see e.g. Buddington, 1963, 1965, 1966; de Waard, 1964a, 1965a, 1965b, 1967, 1969, 1971; Whitney and McLelland, 1973; McLelland and Whitney, 1977; Bohlen and Essene, 1977;

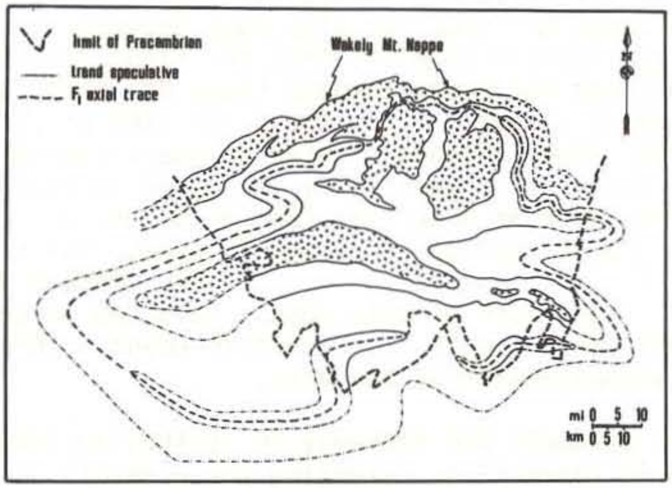

Figure 10. Generalized map showing known and projected axial trace of Canada Lake-Little Moose Mt. Syncline. Heavy dashed line marks Proterozoic-Paleozoic boundary as shown in Figures 1 and 2.

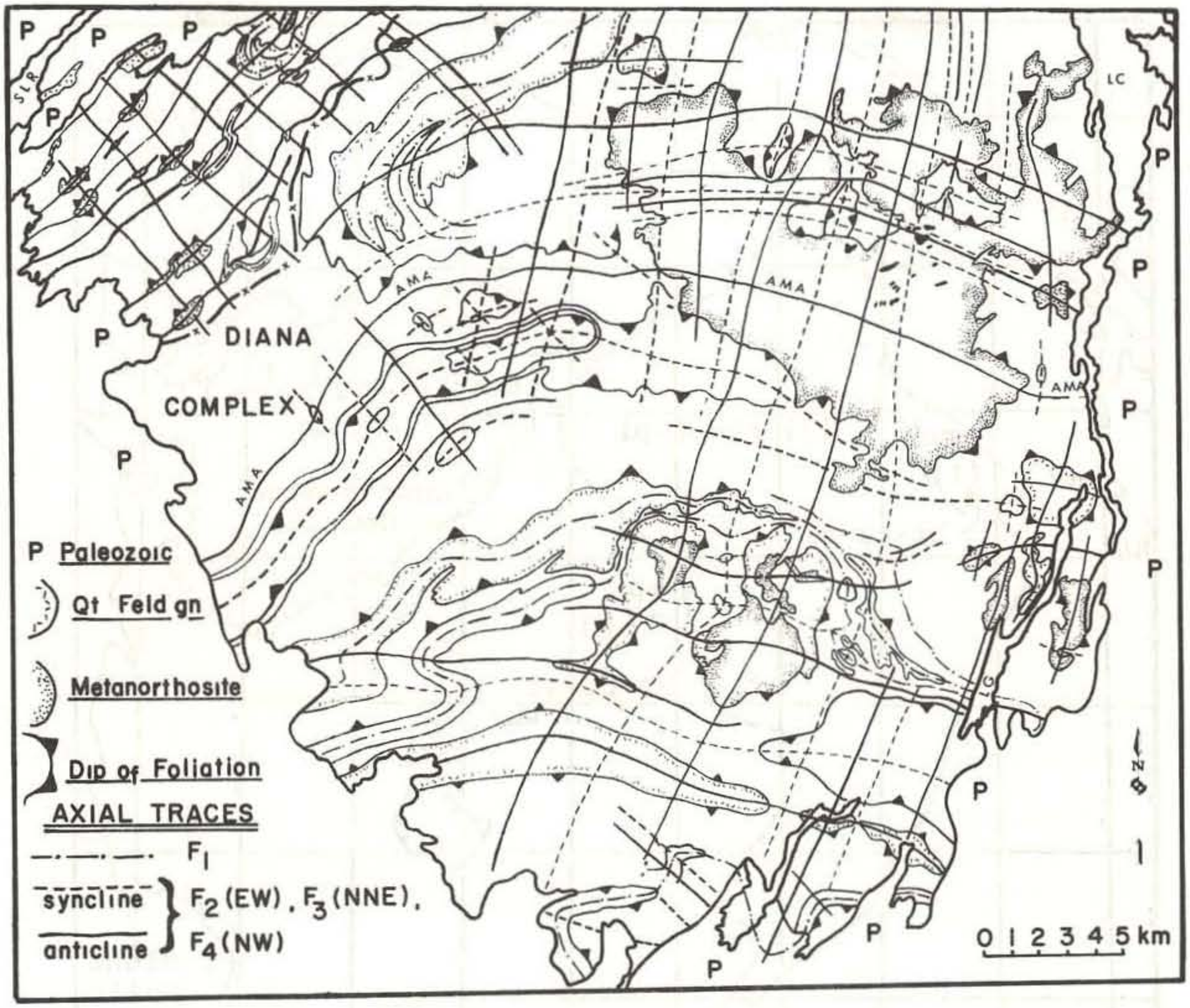

Figure 11. Hypothetical structural framework for Adirondacks. AMA-Arab Mt. Anticline.

Essene and others, 1977; Boone, 1978; Boone and others, in prep.; Valley and Essene, 1976; Jaffe and others, 1977; Stoddard, 1976). Engel and Engel (1962) made an early and fundamental contribution when they delineated in part the orthopyroxene isograd in the northwestern Adirondacks (see Fig. 12). Orthopyroxene is the diagnostic mineral of high-grade metamorphism and its regional stable occurrence with plagioclase and garnet demonstrates that metamorphic conditions of the granulite facies were attained to the east of the orthopyroxene isograd.

de Waard (1971) proposed a three-fold subdivision of the granulite facies in the Adirondack highlands (Fig. 12). The three zones, in order of progressive metamorphism, are the (1) biotite-cordierite-almandite subfacies, (2) hornblende-orthopyroxene-plagioclase subfacies, and (3) hornblende-clinopyroxene-almandite subfacies. de Waard (1971) believed the subfacies represent three stages of increasing granulite-facies metamorphism constituting an Adirondack Type of metamorphic series. All stops

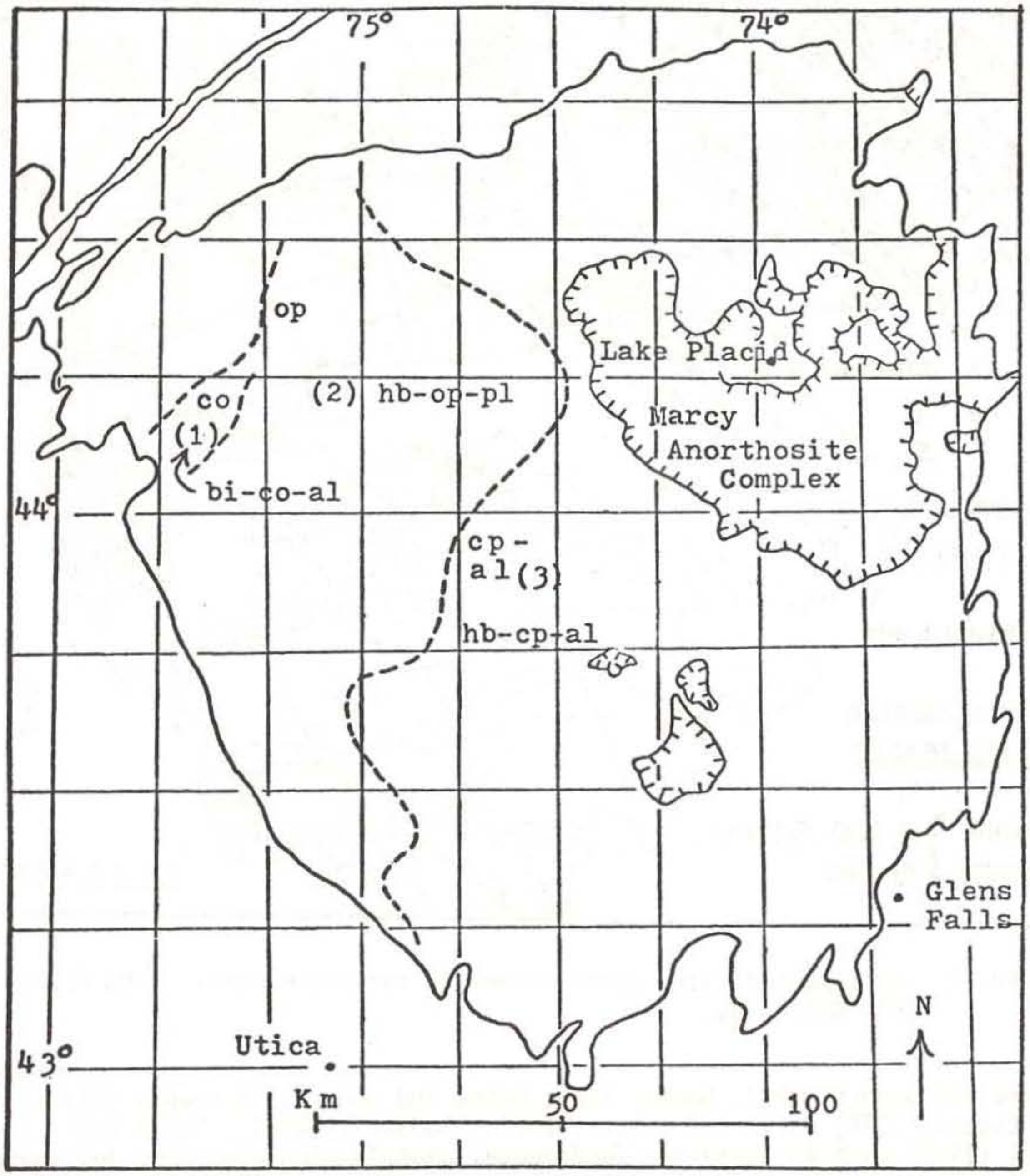

Figure 12. Outline map (modified after de Waard, 1971) of Precambrian terrane of Adirondack Mountains and Northwest Lowlands showing de Waard's proposed subdivision of granulite facies of Adirondack highlands: (1) biotite-cordierite-almandite subfacies, (2) hornblende-orthopyroxene-plagioclase subfacies, and (3) hornblende-clinopyroxene-almandite subfacies. Three isograds are shown; parts of isograds were mapped by de Waard (1971), Engel and Engel (1962), and Buddington (1963). Solid contact is trace of Precambrian-Paleozoic boundary; hatchured contacts delineate boundaries of relatively larger anorthosite complexes.

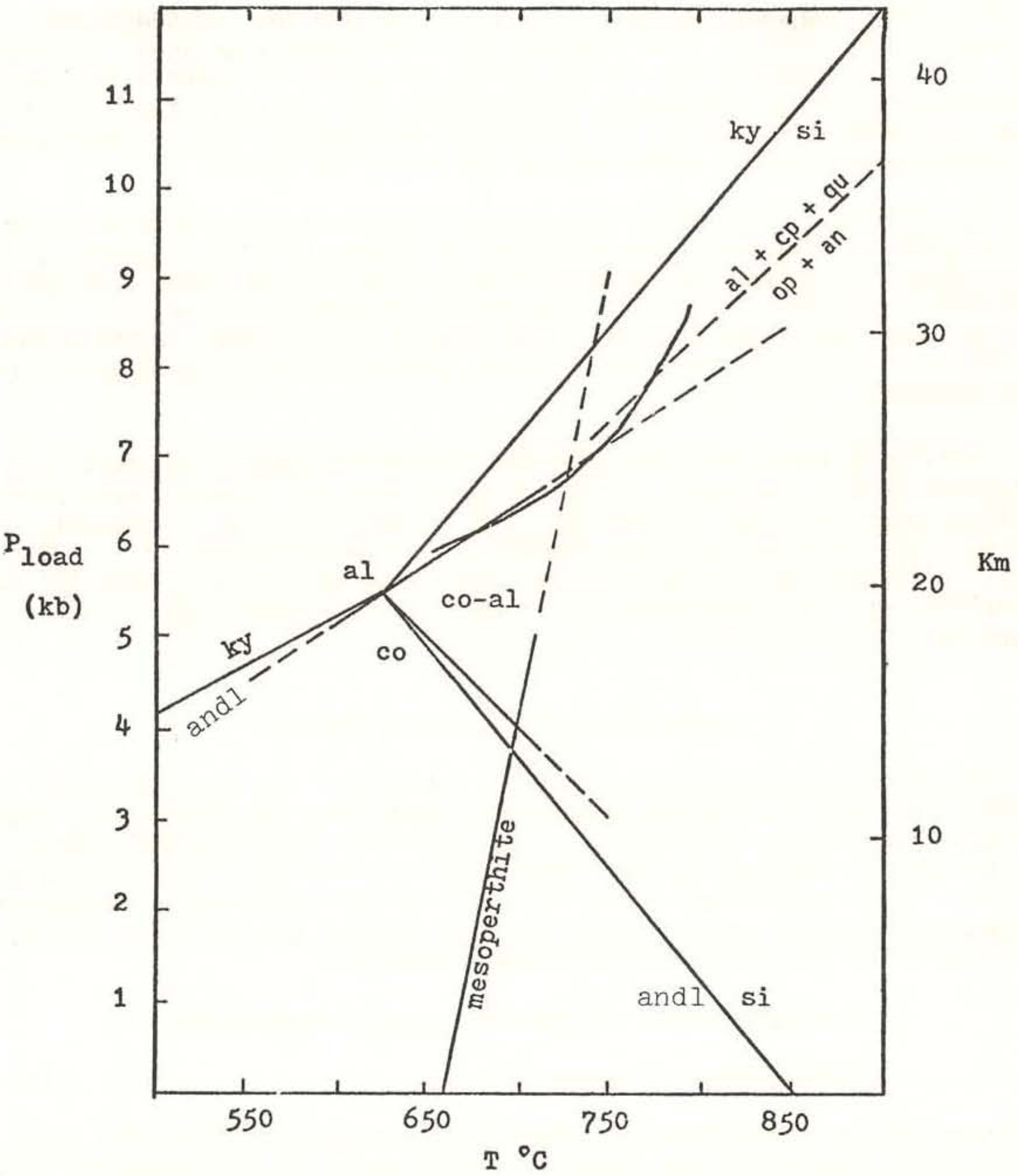

Figure 13. Petrogenetic grid (modified after de Waard, 1969, p. 129) composed of stability boundaries for solid-solid reactions involving anhydrous phases only. Curved line is geothermal gradient representing P_{load}-T conditions of metamorphism favored by de Waard. Grid is based upon following experimentally derived curves: reaction orthopyroxene + plagioclase $\rightleftharpoons$ clinopyroxene + almandite + quartz after Ringwood and Green (1966); triple point of aluminum silicates after Gilbert, Bell, and Richardson (1968) and Holdaway (1968); kyanite-sillimanite boundary after Richardson, Bell, and Gilbert (1968); cordierite and almandite stability fields after Hirschberg and Winkler (1968); and solvus temperature maximum of alkali feldspars after Orville (1963).

on this field trip are located in zone (3), to the east of the garnet-clinopyroxene isograd. This isograd, far from sharply defined, is based upon the first recognition, in the field, of garnet in quartzo-feldspathic (charnockitic) rocks (de Waard, 1971). Thus, all rocks in the field-trip area have been subjected to P-T conditions appropriate for the hornblende-clinopyroxene-almandite subfacies of the granulite facies.

In addition, the area of the biotite-cordierite-almandite subfacies has greater areal extent than exhibited in Figure 12 (P.R. Whitney, 1977, pers. comm.). Cordierite and garnet-bearing pelitic gneisses have been reported by Stoddard (1976) to occur north-northeast of zone (1). It can be inferred from these locations that zone (1) now extends north-northeast, ~parallel to the orthopyroxene isograd, almost to the Precambrian-Paleozoic boundary.

Only rock types that have yielded information about P-T conditions of metamorphism are discussed in the following section. Mineral-name abbreviations used are: al - almandite; andl - andalusite; an - anorthite; bi - biotite; ca - calcite; co - cordierite; cp - clinopyroxene; Kf - K-rich alkali feldspar, chiefly microcline, usually perthitic; ky - kyanite; ma - magnetite; op - orthopyroxene; pf - plagioclase feldspar; qu - quartz; sc - scapolite; si - sillimanite.

Charnockitic and Granitic Gneiss

Hornblende-clinopyroxene-almandite subfacies: de Waard proposed (1964a) that with increasing metamorphic conditions the typomorphic orthopyroxene-plagioclase association of the granulite facies becomes imcompatible and is replaced by the higher density almandite-clinopyroxene association. This replacement marks the start of the hornblende-clinopyroxene-almandite subfacies, and de Waard proposed (1964a) the following reaction to account for the garnet-clinopyroxene formation:

$$\text{6 orthopyroxene + 2 anorthite} \rightleftharpoons \text{clinopyroxene +}$$
$$\text{2 almandite + 2 quartz} \qquad (1)$$

Reaction (1) has a positive P-T slope (see petrogenetic grid, Fig. 13). de Waard (1967) considered two manners in which reaction (1) proceeded to the right. In one instance, the reaction progression may indicate a gradual increase in both T and P_{load} during progressive regional metamorphism in which the central and eastern Adirondacks were subjected to hornblende-clinopyroxene-almandite-subfacies conditions. In the second instance, the reaction may have been produced by a decrease in T with little change in P_{load} during retrogressive metamorphism. However, de Waard (1967) favored the first instance of increasing P_{load} and T for the following reasons: (1) the clinopyroxene-garnet-quartz assemblage has a higher density than the orthopyroxene-anorthite assemblage and represents a reduction in molar volume of ~14 percent, thus favoring higher P_{load}, and (2) cordierite, considered indicative of relatively lower P_{load} (or higher T), is present in pelitic gneisses in the northwestern portion of the highlands, but absent in gneisses of comparable composition to the SE (Fig. 12).

Martignole and Schrijver (1971) contended that reaction (1) proceeds to the right as a consequence of de Waard's second instance: decrease in T with little change in P_{load}. They believe the formation of garnet and clinopyroxene does not represent a reaction due to progressive regional metamorphism, but, rather, represents a retrograde metamorphic reaction during slow cooling at relatively constant P_{load}. They base their interpretation on field and petrographic observations associated with their work in the Morin anorthosite complex of southern Quebec, located ~120 km north of the Adirondack highlands portion of the Grenville Province. In their field area, the garnet-quartz-clinopyroxene assemblage is restricted virtually to norites, ferrogabbros, jotunites, and mangerites that surround the anorthosite mass. Martignole and Schrijver believe this areal restruction suggests the garnet-forming reaction is genetically linked to the anorthosite complex. In addition to de Waard's reaction (1), they propose reaction

$$\text{orthopyroxene + plagioclase} \rightleftharpoons \text{Ca-Fe-Mg garnet + quartz} \quad (2)$$

and imply (1971, p. 700) that reaction

$$\text{orthopyroxene + plagioclase + Fe oxide} \rightleftharpoons \text{garnet +}$$
$$\text{quartz + clinopyroxene} \quad (3)$$

involving reduction of Fe^{3+} from left to right, also was active in the formation of garnet-quartz symplectites.

Rare occurrences of cordierite (Martignole and Schrijver, 1971, p. 701) are present at the immediate contact between the anorthosite complex and supracrustal rocks. Martignole and Schrijver believe this rare occurrence of cordierite precludes using an increase of P_{load}-T near the complex to explain garnet formation as de Waard does for the Adirondack highlands. Their alternative explanation for the association of garnet-quartz symplectites and the anorthosite complex is that the anorthosite completed solidification under high load pressure and retarded regional cooling. This retarded regional cooling permitted reactions (1), (2), and (3) to proceed slowly to the right as retrograde reactions in the "dry" environment of granulite-facies metamorphism. Thus, Martignole and Schrijver contend the highest grade of metamorphism in the Adirondack highlands is preserved as the hornblende-orthopyroxene-plagioclase subfacies, zone 2 in Figure 12. Zone 3 (Fig. 12) is considered by them representative of retrograde metamorphism associated with close spatial relationship to anorthosite complexes.

McLelland and Whitney (1976, 1977) studied the origin of garnet in the anorthosite-charnockite suite of rocks in the Adirondacks. Their analysis of textural and chemical relationships suggests that the onset of the hornblende-clinopyroxene-almandite subfacies of de Waard (1964a) is marked by the following reaction:

$$2\ CaAl_2Si_2O_8 + (6-\alpha)(Fe, Mg)SiO_3 + \alpha Fe\text{-oxide} +$$
$$(\alpha-2)SiO_2 \rightleftharpoons Ca(Fe,Mg)_5Al_4Si_6O_{24} + Ca(Fe,Mg)Si_2O_6 \qquad (4)$$

where α is a function of the distribution of Fe and Mg between the several coexisting ferromagnesian phases. Reaction (4) is a general garnet-forming reaction for saturated rocks. It differs from de Waard's reaction (1) in that (a) quartz is a reactant instead of a product and (b) Fe-oxide is a reactant, as it is for reaction (3) of Martignole and Schrijver. McLelland and Whitney (1977) consider reaction (1) to be a special situation of reaction (4) where there exists, in charnockitic gneiss, a relatively high Mg/(Mg + Fe) ratio. An interesting feature of their study is that most garnet-quartz symplectites are actually garnet-plagioclase symplectites on the basis of microprobe analysis.

P-T Conditions of Metamorphism: de Waard (1969) and Bohlen and Essene (1977) estimated P-T conditions of metamorphism for the Adirondack highlands.

Figure 13 is the petrogenetic grid used by de Waard (1969) in arriving at P_{load}-T conditions of ~ 7.8 kb and 770°C at the garnet-clinopyroxene isograd (see Figure 12). de Waard estimated maximum P_{load}-T conditions to be perhaps ~ 8.3 kb and 800°C to the east of the garnet-clinopyroxene isograd (see de Waard, 1969, for a fuller discussion).

Bohlen and Essene (1977) report that pressure estimates increase from 6 kb at Balmat (northwest Adirondacks, in zone 2 of Fig. 12) to 8 kb in the central Adirondack highlands. Temperature estimates are almost 800°C in the central highlands as determined by plagioclase-orthoclase and ilmenite-magnetite thermometers (see Bohlen and Essene, 1977, for a fuller discussion).

McLelland and Whitney (1977) have estimated equilibrium temperatures for one charnockite from the Adirondack highlands assuming a P_{load} of 7.5 kb. The temperatures range from 610°C by the method of Wood (1974) to 792°C by the method of Wood and Banno (1973). The temperature methods are based on the distribution of Mg and Fe between clinopyroxene, orthopyroxene, and garnet as functions of temperature and pressure.

Metagabbro and Metadiabase

Origin of corona structures: Whitney and McLelland (1973) studied the origin of corona structures in metagabbros of the Adirondack Mountains. In the southern Adirondacks, Area I, two types of coronas are observed: (1) olivine-pyroxene-spinel coronas and (2) oxide-hornblende coronas. In the central and eastern Adirondacks, Area II, two types are also observed: (1) olivine-pyroxene-garnet coronas and (2) oxide-amphibole-garnet coronas.

Whitney and McLelland (1973) propose three partial reactions took place in the formation of olivine-cored coronas in Area I:

$$\text{olivine} \rightleftharpoons \text{orthopyroxene} + (Mg,Fe)^{++} \qquad (a)$$

plagioclase + $(Mg,Fe)^{++}$ + Ca^{++} ⇌ clinopyroxene +
spinel + Na^{+} (b)

plagioclase + $(Mg,Fe)^{++}$ + Na^{+} ⇌ spinel + more
sodic plagioclase + Ca^{++} (c)

Reaction (a) occurs in the inner shell of the corona structure adjacent to olivine. Reaction (b) occurs in the outer shell and reaction (c) occurs in the surrounding plagioclase, giving rise to spinel clouding in plagioclase. Summed together these partial reactions are equivalent to:

olivine + anorthite ⇌ aluminous orthopyroxene +
aluminous clinopyroxene + spinel (5)

Garnet develops in olivine-cored coronas of Area II by the following partial reactions proposed by Whitney and McLelland (1973):

orthopyroxene + Ca^{++} ⇌ clinopyroxene + $(Mg,Fe)^{++}$ (d)

clinopyroxene + spinel + plagioclase + $(Mg,Fe)^{++}$ ⇌
garnet + Ca^{++} + Na^{+} (e)

plagioclase + $(Mg,Fe)^{++}$ + Na^{+} ⇌ spinel + more
sodic plagioclase + Ca^{++} (f)

These partial reactions [(d)-(f)] involve the products of reactions (a)-(c) and (5). Balanced, and generalized to account for aluminous pyroxenes and variable An content of plagioclase, partial reactions (d)-(f) are equivalent to:

orthopyroxene + anorthite + spinel ⇌ garnet (6)

Whitney and McLelland (1973) propose the following net reaction to account for oxide-cored coronas:

olivine + anorthite + albite + ilmenite + diopside +
H_2O ⇌ hornblende + hypersthene + spinel (7)

The garnet shell observed in oxide-amphibole coronas of Area II is believed (Whitney and McLelland, 1973, p. 93) to have formed by a complex reaction consuming hornblende, spinel, and plagioclase, yielding garnet, clinopyroxene (as inclusions in garnet), and a bright red, titaniferous biotite.

P-T Conditions of Corona-Structure Formation: Whitney and McLelland (1973) also have investigated the P-T conditions of corona-structure formation. Reactions (5) and (6) have been studied experimentally by Kushiro and Yoder (1966) and Green and Ringwood (1967), respectively. Figure 14 is modified after Whitney and McLelland (1973, fig. 5, p. 95). They cite several reasons for exercising caution in applying experimental results to natural systems. With those reservations, Whitney and McLelland are able to give a general estimate of P_{load} and T of corona formation. Broken lines A and B in Figure 14 illustrate two possible metamorphic histories for corona-structure formation. For garnet-bearing rocks, both paths must pass through the pyroxene spinel field prior to entering the garnet field. Path A is the prograde-metamorphic path in which gabbro and diabase intruded at shallow depths prior to maximum P-T conditions of metamorphism. Path B is the retrograde metamorphic path in which gabbro intruded at depth and cooled at constant, or increasing, pressure. A path similar to path A is favored for metagabbro of Area I (but at lower pressure

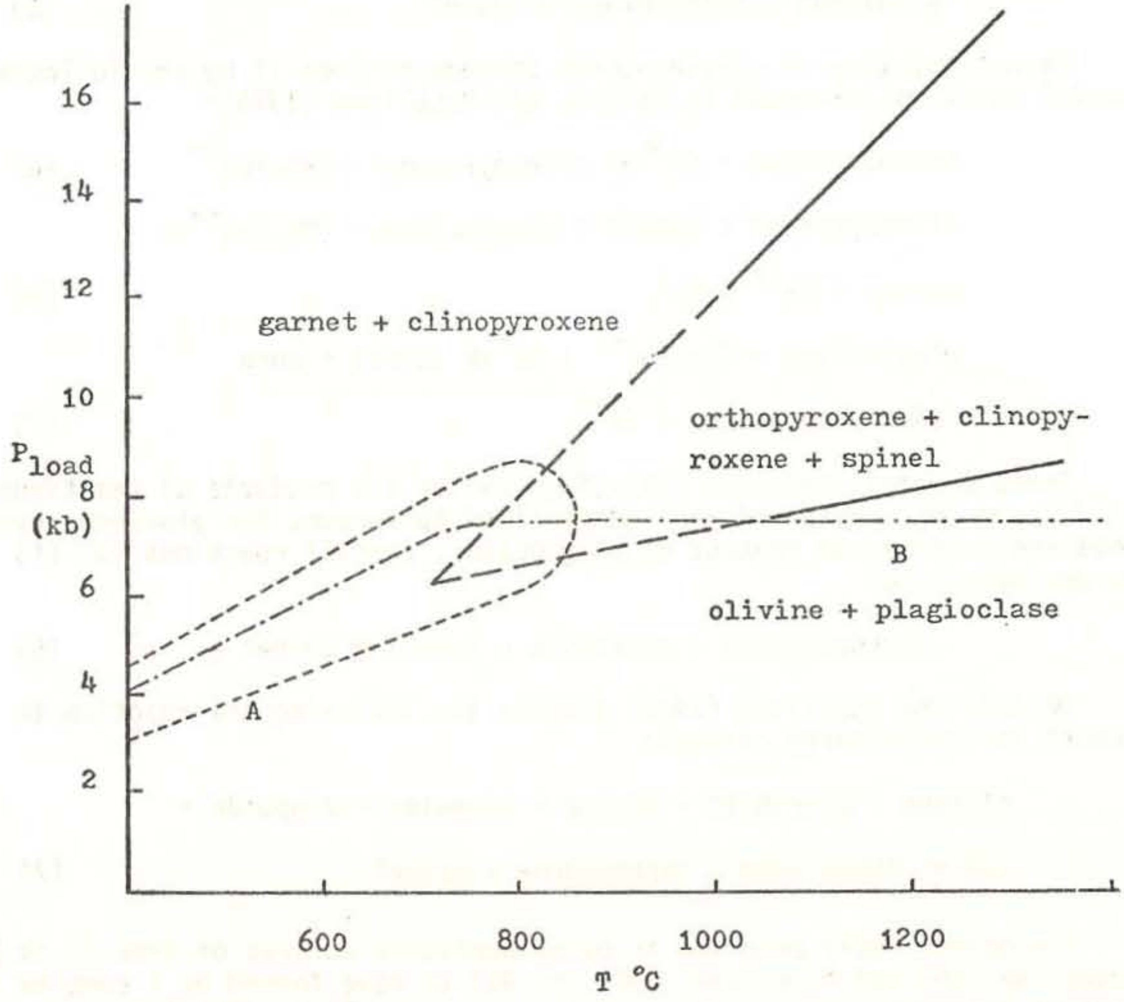

Figure 14. Stability fields of corona-structure mineral assemblages (modified after Whitney and McLelland, 1973, p. 95, fig. 5). Reaction boundaries (solid) are from Kushiro and Yoder (1966); dashed reaction boundaries are extrapolations of their work. A - path for prograde origin of garnet-bearing, olivine-cored coronas. B - path for retrograde origin of garnet-bearing, olivine-cored coronas.

because no garnet formed) whereas path B is favored for metagabbro of Area II, which is in close spatial association with the Marcy anorthosite complex. Regardless of the path followed, minimum pressure of ~ 8 kb and minimum temperature of ~ 800°C were necessary for formation of garnet-bearing coronas (see Whitney and McLelland, 1973, for a complete discussion).

Kyanite - Sillimanite-bearing Aluminous Gneiss

Description: Boone (1978) and Boone and others (in prep.) have determined mineral compositions in sillimanite-rich, quartz-feldspar gneiss at Ledge Mountain. The gneiss is situated in the core of a south-facing, recumbent antiform, and is structurally - if not also stratigraphically - the lowest unit exposed in the central Adirondack highlands (Geraghty, 1978). The gneiss consists predominantly of microcline perthite, plagioclase, quartz, sillimanite, biotite, magnetite, garnet, and minor hercynite. Lenses and alternating layers of sillimanite, magnetite, and quartz with minor garnet and hercynite, make up the remaining 20 to 30 percent of the gneiss in the central part of the mountain. Abundance of these lenses and layers decreases westward toward Route NY 28-30. Only two small patches of kyanite have been found; these occur as relatively coarse-grained, blue crystal aggregates in the feldspathic portions of the gneiss. Pegmatite lenses and discordant bodies abound.

P-T Conditions of Metamorphism: The following relationships are of interest: (1) kyanite-sillimanite; (b) biotite-magnetite-feldspar; (c) Fe/Mg distribution between biotite and garnet; and (d) Ca-contents of garnet and plagioclase. Almandine-hercynite-magnetite-quartz relationships are puzzling, and may not conform to other reaction relationships in the gneiss perhaps owing to low reaction rate. The preponderance of sillimanite effectively argues against the notion that the gneiss equilibrated on the kyanite-sillimanite univariant boundary (or divariant field in Al-Fe). Insofar as kyanite is present, however, the following enquiry was made: Taking into account the Fe^{3+}, F^- and Cl^- contents of biotite, the reaction

$$\text{Biotite } (0.4\,{}^{VI}Fe^{2+}) + \text{Quartz} \rightleftharpoons \text{K-rich feldspar} + \text{Sillimanite} + \text{Magnetite}$$

$$+ H_2O + H_2 + F + Cl, \qquad (8)$$

was examined with reference to the redox equation of Czamanske and Wones (1973) across the temperature range of 650° - 800°C using a range of f_{O_2} compatible with the coexisting impure phases magnetite and hercynite (Turnock and Eugster, 1962). Values of calculated $P_E\ H_2O$ range from 120 bars at approximately 700°C to 600 bars at 770°C. These and volumetric data for the reaction abbreviated in equation (8) were applied to Greenwood's (1961) modification of Thompson's (1955) equation for the projected slope on P_s and T coordinates of a dehydration reaction boundary under steady-state outward diffusion conditions of H_2O with effective H_2O "pressure" less than total pressure. The resulting steep biotite dehydration boundaries are shown in Figure 15; inasmuch as they are nearly parallel to the pressure axis, the values of 695°C and 790°C may be taken as minimum and maximum for the temperature of granulite facies

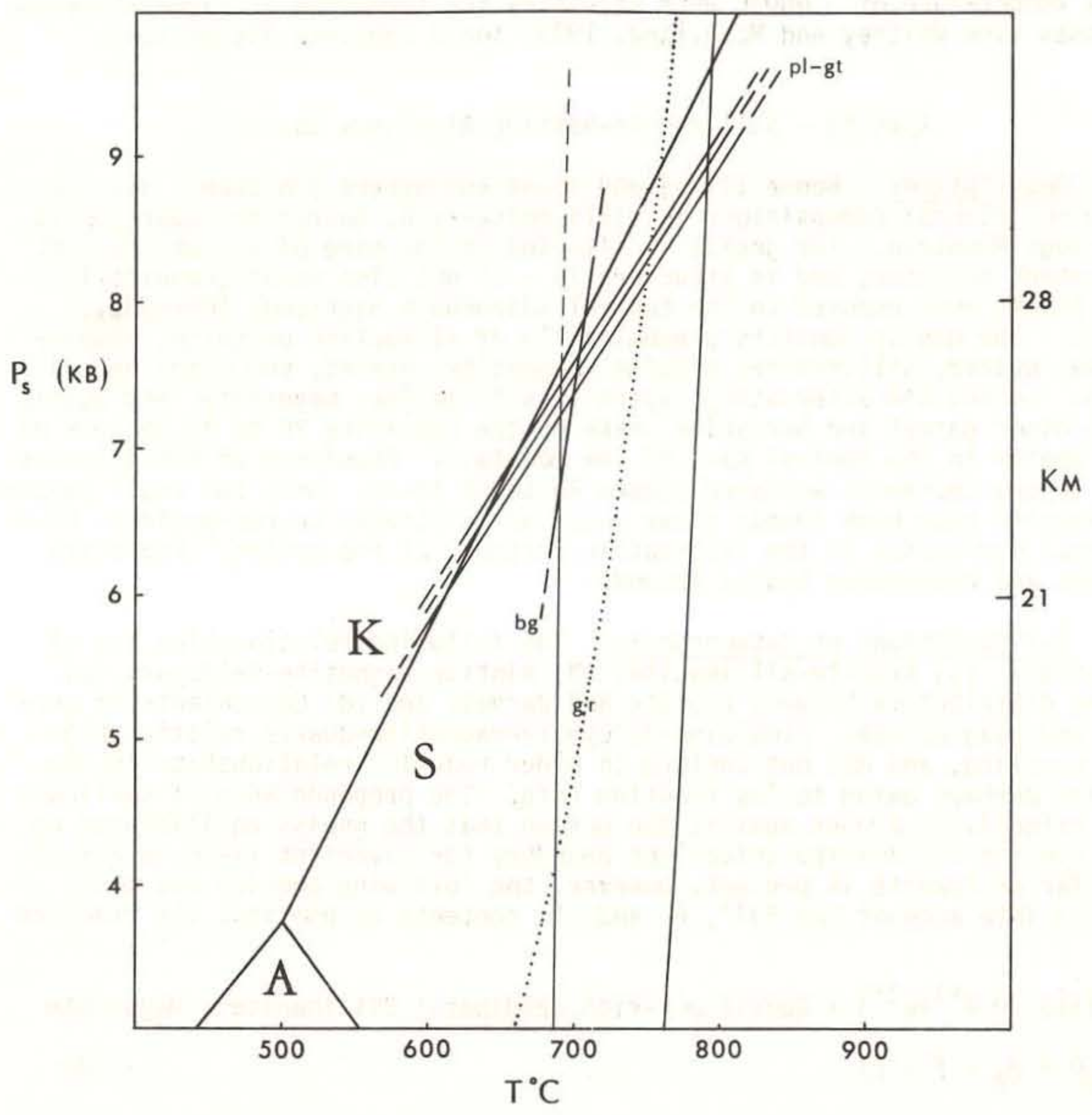

Figure 15. Petrogenic grid for Ledge Mountain aluminous gneiss showing biotite-K-rich feldspar-magnetite redox equilibria at P_EH_2O = 120 bars (left) and 600 bars (right) unlabelled boundaries. bg: biotite-garnet-Al_2SiO_5-Kf Fe/Mg equilibrium at P_EH_2O = 500 bars. pl-gt: Plagioclase-garnet equilibria. gr: muscovite granite solidus at 0.6 wgt. percent H_2O (P_EH_2O=~200 bars) from Huang and Wyllie (1973). Al_2SiO_5 phase boundaries after Holdaway (1971). Intersection of boundaries gr and pl-gt are interpreted as representing upper P_S-T limits for granulite facies metamorphism and anatexis of Ledge Mountain gneiss. Cf. text and road log (stop 2) for additional explanation.

metamorphism. Fe/Mg ratios for garnet, and biotite external to garnet porphyroblasts, when applied to Schmid and Wood's (1976) equation 11, give results shown by curve b-g (Fig. 15) for which P_{EH_2O} = 500 bars. The lack of agreement between curves b-g and P_{EH_2O} = 600 bars for equation (8) (they should be closer) probably is largely due to the lack of direct thermochemical data for the Mg end-member reaction: phlogopite + Sillimanite + quartz $\rightleftharpoons$ pyrope + Kfeldspar + H_2O.

Limiting values for total pressure were sought via the anhydrous mineral reaction relation involving plagioclase and garnet:

$$3 \text{ anorthite} \rightleftharpoons \text{Grossular} + 2\ Al_2SiO_5 + \text{Quartz}. \qquad (9)$$

Based on the estimation of mixing parameters for pairs of garnet end-members (Henson, Schmid, and Wood, 1975; Ganguly and Kennedy, 1974), grossular activity coefficients, (γ_{Gr}^{Gt}), across the above temperature range were taken between 1.23 and 1.37. Values of γ for anorthite in plagioclase were taken from Orville (1972). These and data for X_{An}^{Pl} and X_{Gr}^{Gt} were applied to the van't Hoff equation

$$-10{,}300 + 31.83T - 1.2746(P-1) = -RT\ln\left[\frac{(X_{Gr}^{Gt}\gamma)^3(0.99)^2}{(X_{An}^{Pl}\ \gamma)^3}\right] \qquad (10)$$

to obtain the reaction boundaries collectively labelled Pl-Gt summarized in Figure 15. It can be seen that within the temperature range of interest shown in Figure 15 that the plagioclase-garnet equilibria lie within the sillimanite field of stability. (One which does not is discussed in the trip log under Stop 2.) These intersect the biotite oxidation equilibrium boundaries at approximately 7.3 and 9 kb. Owing to the set of assumptions which lead to the calculation of the biotite equilibrium boundary P_{EH_2O} = 600 bars, the temperatures along this curve are thought to be too high, and therefore the value of P_s = 9 kb, also too high. Some confirmation of this view is that, with reference to the curve for the beginning of melting of aluminous granite (Huang and Wyllie, 1973), labelled gr on Figure 15, it is unlikely that temperatures much above 750°C were maintained during the metamorphism because much of the feldspathic portions of the Ledge Mountain gneiss is of granitic composition, and therefore ought to have been removed largely as anatectic granitic magma. This aspect of the problem presently is under field and analytical investigation by Ellen Metzger of Syracuse. For these reasons, the upper limit of load pressure is taken at approximately 8.2 kb (Table 1). Paths of P-T change are discussed under the heading of Stop 2.

Plagioclase-Scapolite Phase Relations

Phase relations in the systems plagioclase-calcite-halite-scapolite, high albite-halite-marialite, anorthite-calcite-meionite, and anorthite-anhydrite-sulfate meionite have been studied experimentally (Orville, 1975; Newton and Goldsmith, 1975, 1976; Goldsmith, 1976; Goldsmith and Newton,

Table 1. Summary of inferred and calculated P-T conditions of metamorphism for Adirondack highlands.

	T	P_{load}	Source
Charnockitic and granitic gneiss	>770°C<800°C	>7.8<8.3 kb	de Waard (1969)
	>700°C<750°C	~8.0 kb	Bohlen and Essene (1977)
Metagabbro	~800°C	~8.0 kb	Whitney and McLelland (1973)
Kyanite and sillimanite-bearing granulite	695°-770°C	>7.4<8.2 kb	Boone (1978)
Marble	650°-756°C		Geraghty (1978)

1977). Newton and Goldsmith (1976), in all instances, and Orville (1975), in most instances, observed that scapolite is stable in preference to plagioclase, calcite, and halite at high temperatures and pressures. This is in marked contrast to earlier discussions that gave the impression that scapolite is a metamorphic mineral resulting from retrogressive processes (see, e.g., Fyfe and Turner, 1958).

The assemblages plagioclase-calcite-scapolite and plagioclase-scapolite are observed in several thin sections of calc-silicate rock and marble from the mapped area (see Fig. 16). Compositions have been determined by microprobe. In addition, plagioclase compostions were determined optically, using the zone method of Rittman. The compositions of coexisting scapolite and plagioclase are presented graphically in Figure 17.

On the basis of analyzed compositions, it is believed the idealized reaction

$$\text{Albite + anorthite + calcite + halite} \rightleftharpoons \text{scapolite} \qquad (11)$$

took place in samples 116, 130, 215, and 289.

Direct textural evidence that reaction (11) took place is expressed in a thin section of sample 116 by the spatial association of reactants (except for halite) and product of (11). It is inferred that halite was present originally in small amount based on relatively low content of Cl in scapolite of sample 116. Textural evidence for reaction (11) is not as pronounced in other thin sections. Usually, reactants (except for halite) and product coexist in close spatial association without the development of reaction rims or corona structure. Calcite is absent in many samples, indicating that it could have been consumed in reaction (11).

Microprobe analyses were not made for all mineral phases in thin sections containing assemblages plagioclase-calcite-scapolite or plagioclase-scapolite. Thus, it is not possible to analyze in detail whether chemical equilibrium was attained in these rocks. However, it is possible to

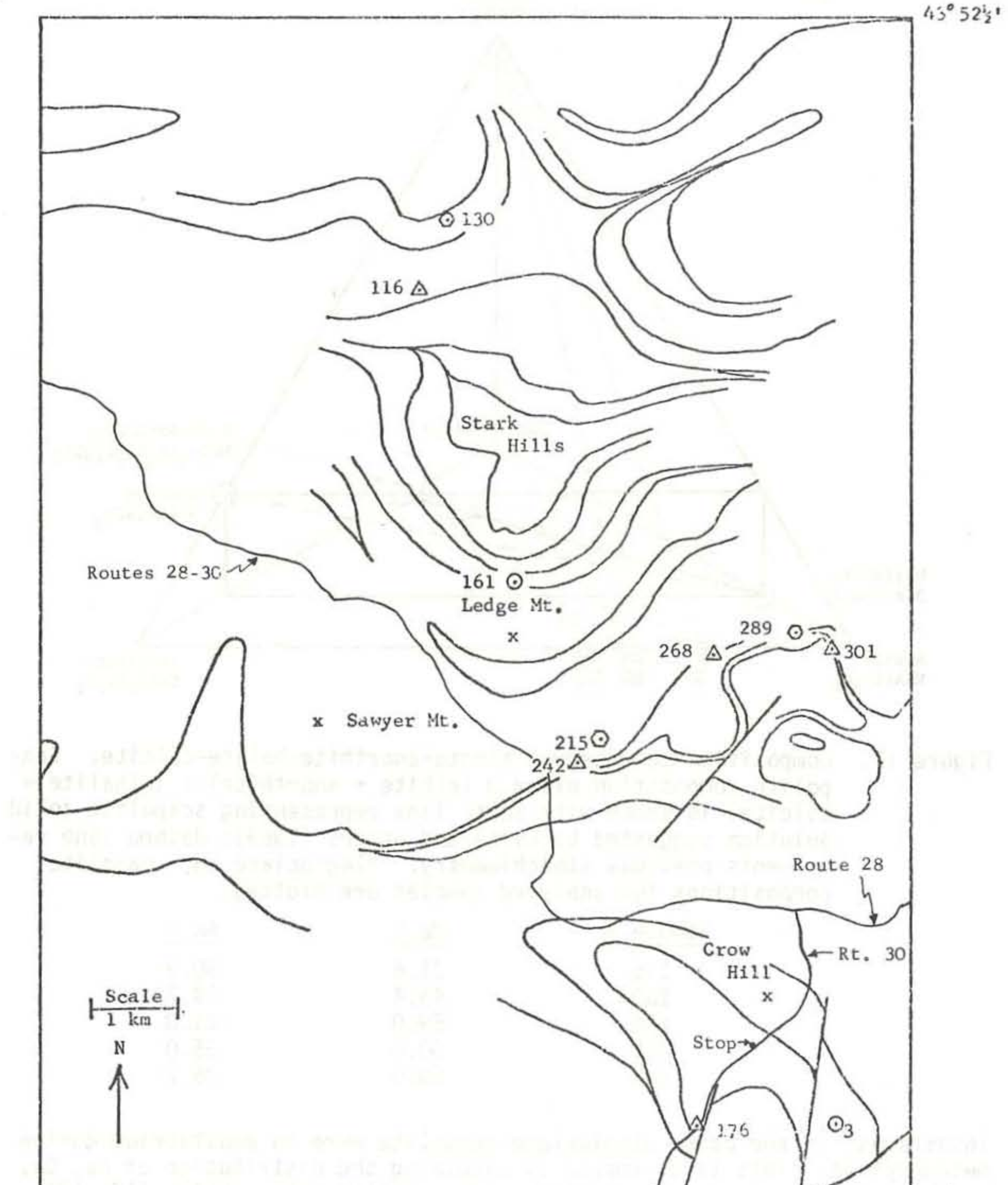

Figure 16. Location of samples used in discussion of plagioclase-scapolite phase relations (Δ - assemblage sc-ph-ca, ⬡ - assemblage (sc-pf) and in calcite-dolomite geothermometry ⊙). Map is SE ¼ of Blue Mountain 15' quadrangle; contacts between major rock units are shown for reference.

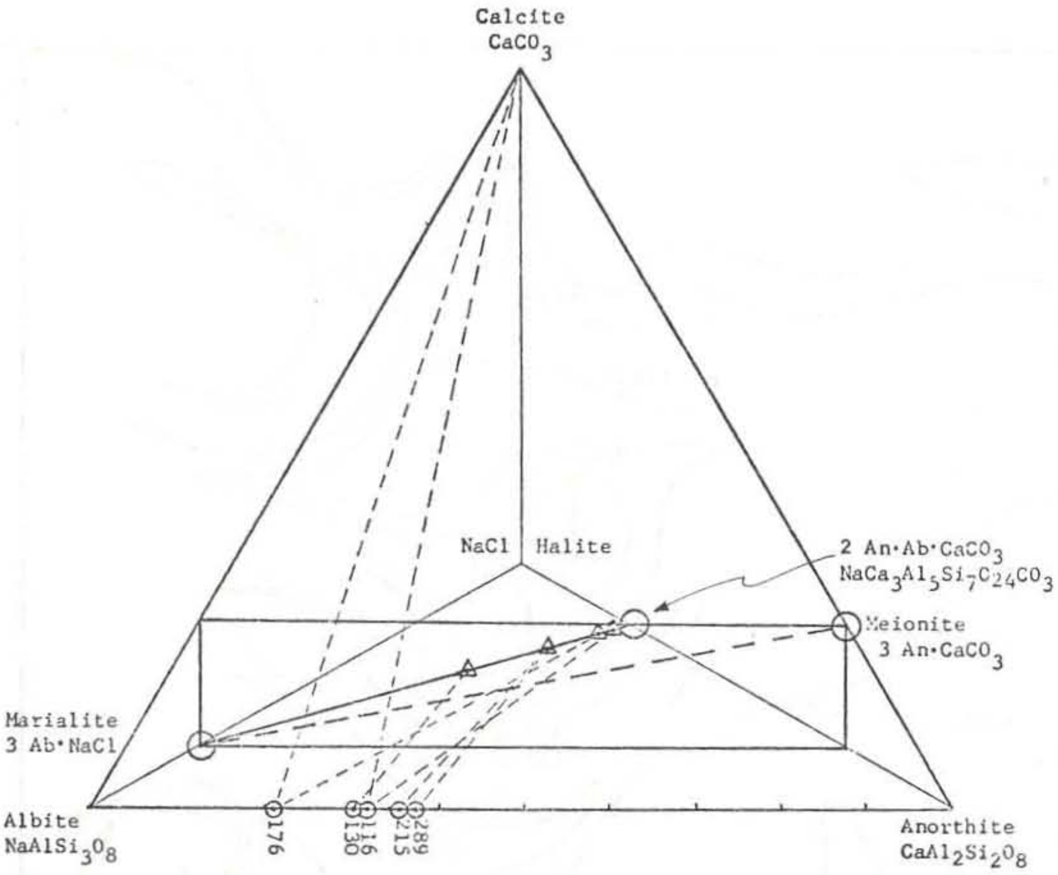

Figure 17. Composition tetrahedron albite-anorthite-halite-calcite. Scapolite composition plane 3 (albite + anorthite) : 1 (halite + calcite) is shown with solid line representing scapolite solid solution suggested by Evans and others (1969); dashed line represents previous stoichiometry. Plagioclase and scapolite compositions for analyzed samples are plotted.

Sample #	Me %	An %
116	71.6	30.9
130	45.4	29.7
176	69.0	21.0
215	60.0	35.0
189	60.0	36.7

investigate if the pairs plagioclase-scapolite were in equilibrium during metamorphism. This is attempted by examining the distribution of Na, Ca, and Al among coexisting plagioclase and scapolite from samples 116, 130, 215, and 289 (see Fig. 18). Unfortunately, only four distribution points are plotted and the clustering of points does not allow a distribution curve to be drawn. Equilibrium is suggested if the distribution curve is a straight line or smooth curve as defined by the distribution points. However, excluding data from sample 116 and using data from 130, 215, and 289, a straight line passing through or near these three samples and through the origin could be constructed for all three distribution diagrams.

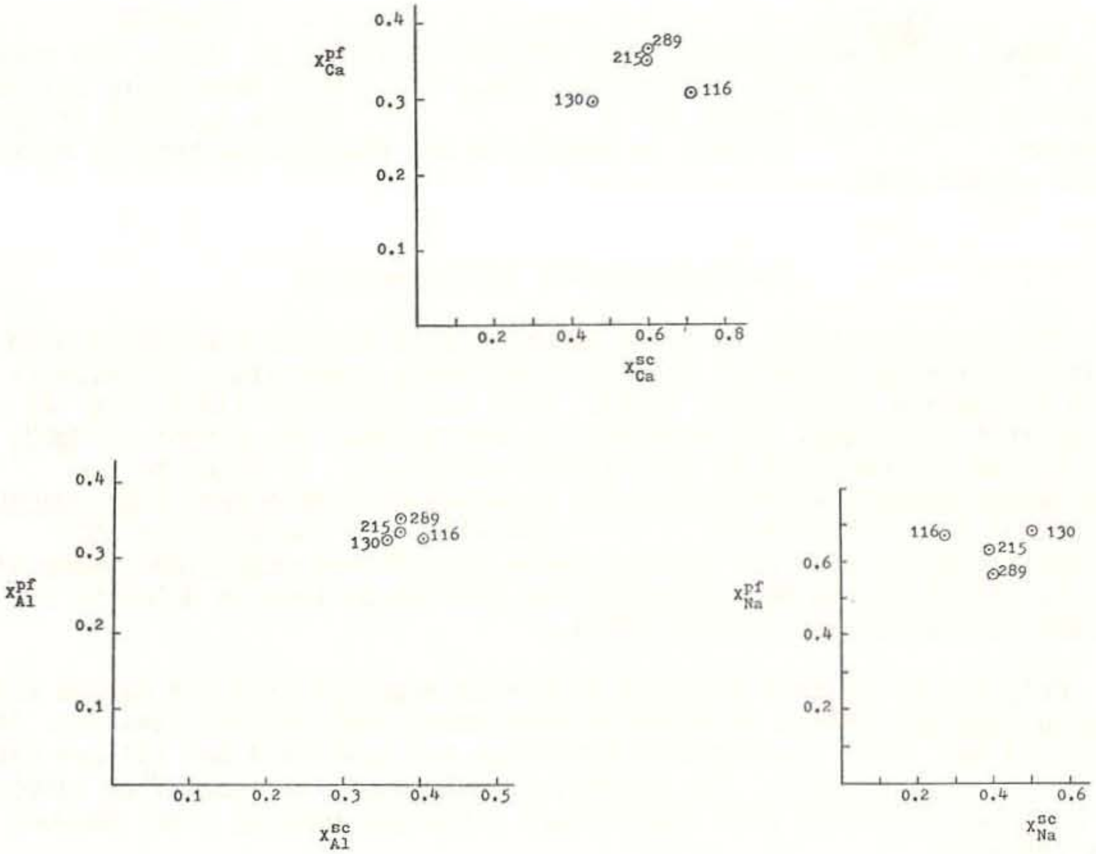

Figure 18. Distribution of calcium, sodium, and aluminum between plagioclase and scapolite.

This meager evidence argues for equilibrium between plagioclase and scapolite in these samples. The data points for sample 116, a marble, lie off the hypothetical distribution curves for data from samples 130, 215, and 289, calc-silicate rocks. The difference between sample 116 and samples 130, 215, and 289 also is expressed in Figure 17. Crossing tie lines are exhibited between two groups of samples: (1) samples 130, 215, and 289 form one group that exhibit nearly parallel tie lines between coexisting scapolite and plagioclase, (2) samples 116 and 176 exhibit tie lines between coexisting scapolite and plagioclase that cross tie lines of group (1). Group (2) samples contain calcite (see Fig. 17) and the scapolites exhibit relatively low contents of chlorine. One possible explanation for these relations between samples 116 and 176 and samples 130, 215, and 289 is that reaction (11) proceeded to the left upon falling temperature following the thermal peak of metamorphism in samples 116 and 176.

No estimate of metamorphic temperature and pressure can be made from coexisting scapolite and plagioclase, with or without calcite, of the mapped area. Newton and Goldsmith (1976) have determined experimentally the stability relations of anorthite, calcite, and meionite. However, their data can be used confidently to estimate metamorphic temperature only where the plagioclase composition is $>An_{70}$ (Goldsmith and Newton, 1977).

Based on the experimental work of Orville (1975, p. 1104), the presence of relatively sodic plagioclase (An_{21}-An_{37}) with relatively calcic scapolite (Me_{45}-Me_{72}) argues for a higher activity of $CaCO_3$ compared to NaCl in scapolite and plagioclase-bearing rocks of the mapped area.

Calcite-Dolomite Geothermometry

The amount of $MgCO_3$ in solid solution with calcite coexisting with a separate dolomite phase can be used to estimate temperature of metamorphism (Goldsmith and Newton, 1969). Graf and Goldsmith (1955, fig. 4) showed that the higher the temperature, the greater the amount of $MgCO_3$ that can be accommodated in the calcite structure. In order to use this geothermometry effectively, CO_2 pressure must have been high enough to prevent decomposition of dolomite. If noncarbonate, Mg-containing phases also are present under equilibrium conditions, they will have no effect on the Mg content of the calcite as long as dolomite is present (Goldsmith and others, 1955).

Only two of 22 thin sections of marble examined from the mapped area contain discrete grains of dolomite coexisting with calcite (see Fig. 16, samples 3 and 161). Temperature estimates for samples 3 and 161 are 650°C and 756°C, respectively. The estimated temperature recorded from sample 161 compares favorably with temperature estimates made by other methods (see Table 1).

CONCLUDING SPECULATIONS

The ultimate origin of the structural and petrologic features of the Adirondacks remains obscure. A possible clue to the mechanisms involved is Katz's (1955) determination of 36 km as the present depth to the M-discontinuity beneath the Adirondacks. Because geothermometry-geobarometry place the peak of the Grenville metamorphism at 8-9 kb (24-36 km), a double continental thickness is suggested. Such thicknesses presently exist in two types of sites, both plate-tectonic related. The first is beneath the Andes and seems related to magmatic underplating of the South American plate (James, 1971). The second is beneath the Himalayas and Tibet and is due to thickening in response to collision (Dewey and Burke, 1973) or continental underthrusting (Powell and Conaghan, 1973).

Because of the wide extent of the Grenville metamorphic belt, we prefer the Dewey-Burke model of crustal thickening in response to a continent-continent collision accompanied by reactivation of basement rocks. Mobilization of the lower crust could lead to the upward displacement of large, recumbent folds in a manner similar to some of Ramberg's (1967) scaled centrifuge experiments. This model is shown diagramatically in Figure 19.

Although it seems that the tectonic style and framework of the Adirondacks are explained satisfactorily by the Tibetan model, there are no good candidates for even a cryptic Indus-type suture in the area or within the Grenville Province itself. Dewey and Burke (1973) suggest that the collisional suture is most likely buried beneath the folded Appalachians. The

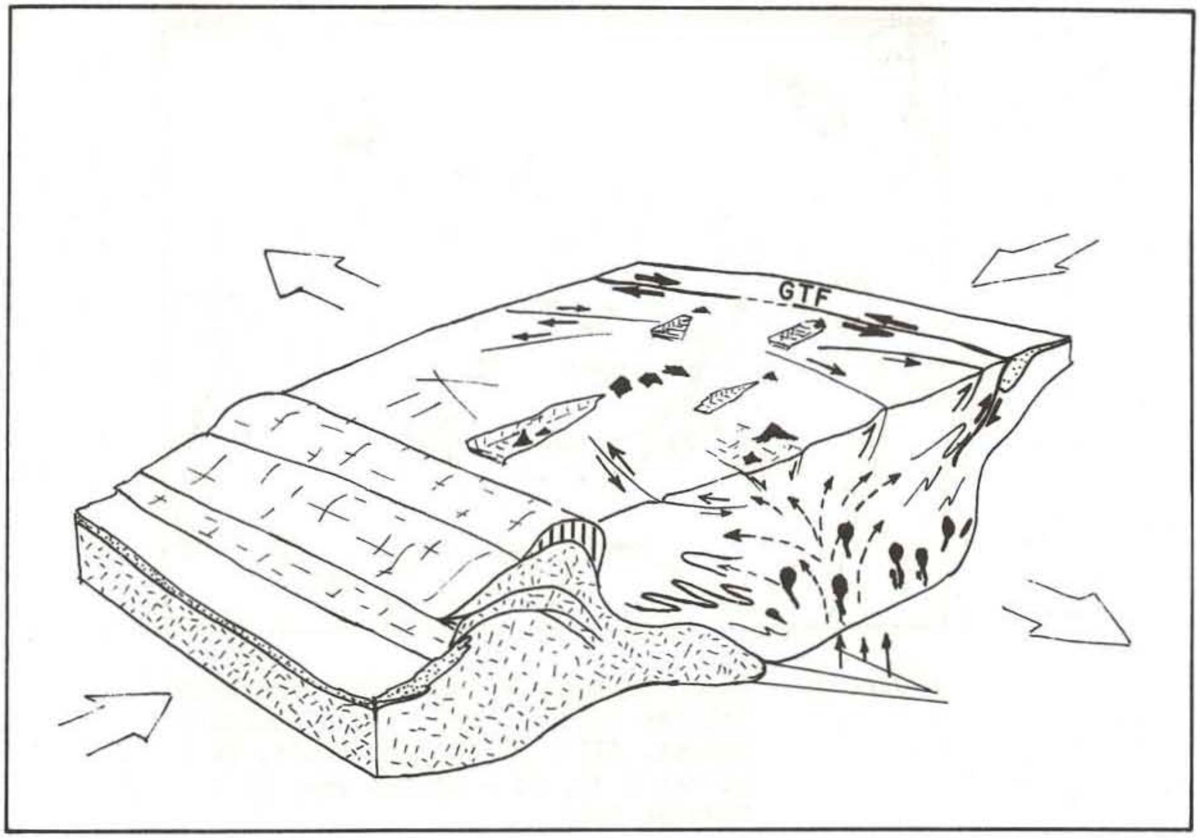

Figure 19. Himalayan type collision and associated tectonic elements. GTF - Grenville Type Front.

Grenville Front itself cannot be a suture, and, as shown by Baer (1977), it has a large component of right lateral motion associated with it. We suggest that the Grenville Front is analogous to features such as the Altyn Tagh Fault in northern Tibet (Molnar and Tapponier, 1975), and, similar to the Altyn Tagh, accommodates the sideways displacement of large crustal blocks by strike-slip motions (Figs. 19, 20). In places the Altyn Tagh Fault lies some 1000 km distant from the Indus Suture. A similar distance measured southeast from the Grenville Front would place the corresponding suture beneath the Appalachians. Perhaps it is this buried suture that gives rise to the New York Alabama aeromagnetic lineament of Zietz and King (1977).

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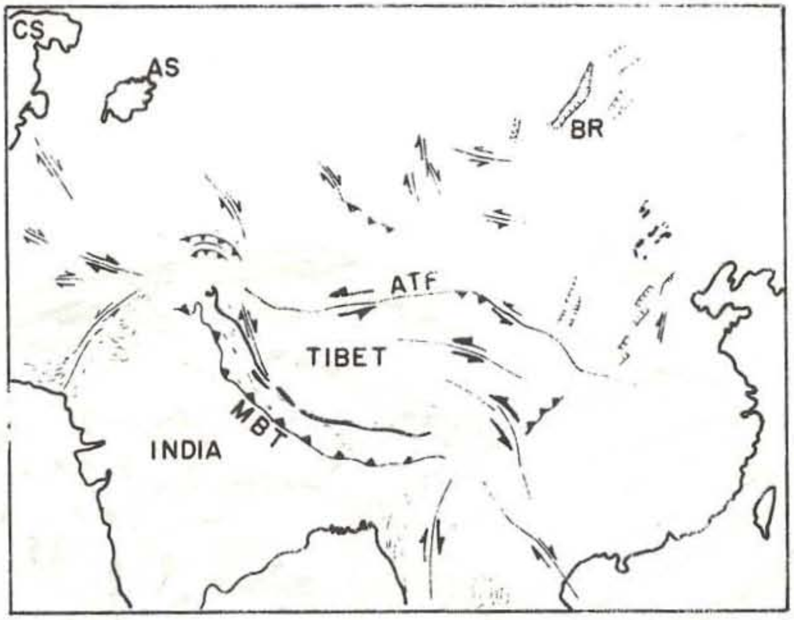

Figure 20. Major tectonic elements of Himalayan - Tibetan region. MBT - Main Boundary Thrust, ATF - Altyn Tagh Fault, BR - Baikal Rift, AS - Astral Sea, CS - Caspian Sea.

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Road Log

Mileage	
0	Intersection of Routes NY28N-30 and NY28-30 in Blue Mt. Lake. Head south on Rt. 28-30.
1.6	- ASSEMBLY POINT IN ROADSIDE PARKING AREA, E, END, NORTH SHORE OF LAKE DURANT. ASSEMBLY TIME 7:30 AM, SATURDAY, 23 SEPTEMBER.

Stop 1: Large roadcut on north shore of Lake Durant. This location is the type section of Lake Durant Formation (D. de Waard, 1970, pers. comm.).

This stop has been described by de Waard (1964b) as follows: "The section of diverse, layered metamorphic rocks includes pink and greenish leucocratic gneisses with thin metabasic layers, marble, and calc-silicate rocks. The section forms part of the supracrustal sequence which overlies the leptites of the Wakely nappe exposed in the hills visible towards the south across the lake, and which underlies the Blue Mountain charnockite sequence towards the north. Lineations on foliation planes indicate a 30° NE plunging fold axis. The intrusive nature of marble into boudinaged layered gneiss is shown on the west end of the north side of the road cut."

Outcrop mapping to the east and south has revealed that the Lake Durant Formation contains large amounts of hornblende granitic gneiss and biotite-hornblende granitic gneiss both above and below the well-layered sequence exposed in the type section at Lake Durant. In addition, a distinctive rock sequence of biotite granitic gneiss (bottom), calc-silicate rock, and platey-quartz gneiss (top) makes up the basal portion of the Lake Durant Formation in areas to the south.

8.0	Trail-side parking area (south) on Route NY28-30. (This is about 1.25 mi north of intersection of Rt. NY28-30 and the Cedar River Road.)

Stop 2: Ledge Mt. Hike 1 mi east through open woods, to well-exposed south-facing cliffs. This is on the southward culmination of the recumbent Ledge Mountain antiform. Quartz-sillimanite lenses increase in size and relative amount from west to east, until they assume the proportions of major layering in the gneiss. Kyanite occurs here in two feldspar-rich portions of the gneiss. We have sought more, without success. If you should discover additional kyanite, PLEASE OBSERVE PETROLOGIC ETIQUETTE OF PHASE PRESERVATION! NOTIFY TRIP LEADER, WHO WILL OFFER SUITABLE REWARD. Note different proportions of magnetite, garnet, and biotite in feldspathic portions of gneiss, as well as in pegmatite. The structural relationships of pegmatite to host gneiss also differ. Note in Figure 21A that biotite compositions within garnet porphyroblasts are Mg-richer and Al-poorer than "Free" matrix biotite. Also, of the four plagioclase - garnet equilibria shown in Figure 21B (representing five pairs), all represent 'probed rims of grain pairs each of which is in mutual contact. The highest-P boundary is that calculated for a relatively large plagioclase grain within a garnet porphyroblast; the others are of small plagioclases within garnet porphyroblasts, and of "free" plagioclases against garnet rims.

It is deduced from these relationships, and from ubiquitous but small-scale late corona structures of albite on magnetite, that the path of P-T

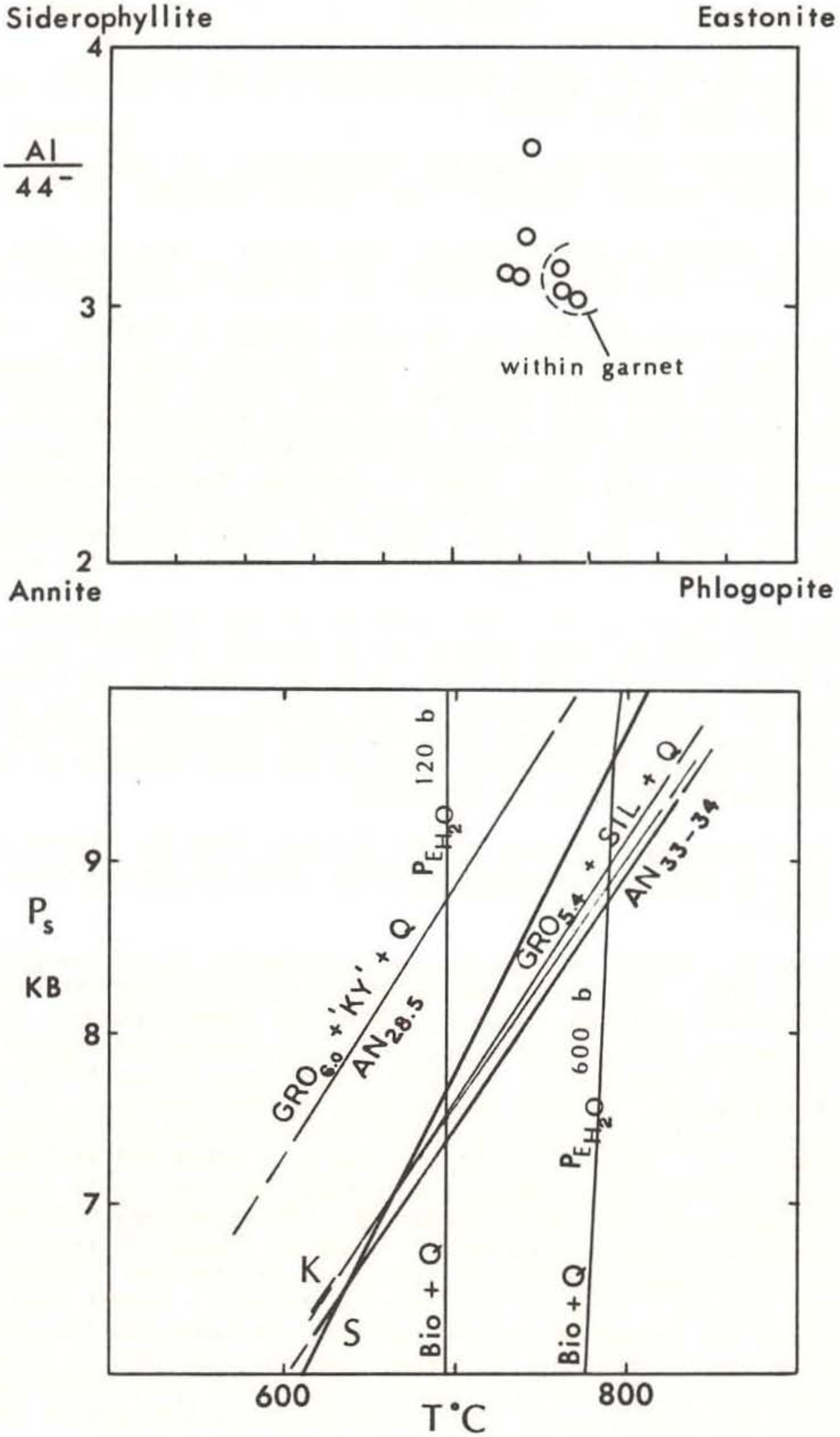

Figure 21. Biotite-garnet-plagioclase relationships. Ordinate in A is number of Al atoms per total of 44 anionic charges. Grossular 6.0% - $An_{28.5}$ (moles) in B refers to large plagioclase inclusion within garnet porphyroblast.

change was prograde along a geothermal gradient which penetrated the kyanite field, followed by partial melting and decrease of lithostatic pressure into the sillimanite field and retrograde cooling within that field, with residual kyanite being trapped within feldspar-rich (solidus?) portions of the gneiss.

11.3 Intersection of Routes NY 28 and 30 in hamlet of Indian Lake. Head south of Rt. NY30.

12.5 Stop 3: Scenic overlook on east side of Route NY30.

Mountainous area to the southeast is part of the Thirteenth Lake complex, cored by anorthosite and charnockite. Overlying gneisses dip to the north (left) and west (towards us) off the complex. To the south metasedimentary rocks dip to the northeast off of Snowy Mountain dome (not visible), which also is cored by anorthosite and charnockite.

Walk south on highway NY30 to roadcut on west side of road. This roadcut is composed of a distinctive "diopside-clot" gneiss and is situated close to the axial core of the Crow Hill synform. The rock is a zircon-apatite±plagioclase±calcite±garnet-sphene-scapolite-clinopyroxene-quartz-microcline granulite. It is part of the distinctive basal portion of the Lake Durant Formation.

Chemical compositions of scapolite and clinopyroxene from this unit at another location were determined by electron-probe microanalysis to be Me_{69}, $(Na_{1.17},Ca_{2.63})_{3.80}(Al_{4.67},Si_{7.33})_{12.00}O_{24}((CO_3)_{0.97},Cl_{0.03})_{1.00}$ and salite, $(Ca_{0.93},Na_{0.06})_{0.99}(Mg_{0.62},Fe_{0.39},Mn_{0.01},Al_{0.02})_{1.04}(Si_{1.96}Al_{0.04})_2O_6$, respectively. Plagioclase composition is oligoclase, An_{21}, based on petrographic determinations using the zone method of Rittman.

17.2 Stop 4: Described by de Waard (1964) as follows: "Large roadcut on the hill 0.4 miles southwest of the intersection of highway 30 with the lake shore road through Sabael. Anorthosite at the lower end of the outcrop is overlain by metanorite (unfoliated andesine-pyroxene-hornblende gneiss) which is in turn overlain by streak andesine-pyroxene-hornblende augen gneiss. Both "Marcy-" and "Whiteface-" type anorthosites are present. The grain size of metanorites ranges from coarse to fine, and the original texture of the rock is preserved to various degrees in different parts of the exposure. Several small amphibolite (metadolerite) lenses may be observed in the streak gneiss. Foliation is nearly horizontal. Walk up the steep hillside above the road to see massive ledges of anorthosite, metanorite, and a rock which is texturally and compositionally intermediate between these two types."

The origin of, and relationships within, the anorthosite-charnockite suite of rocks has been debated for decades. Those favoring a comagmatic association have tended to postulate a dioritic parent magma which yields plagioclase (anorthositic) cumulates and charnockitic residua (de Waard and Romey, 1969). Those who do not accept a comagmatic relationship between these rocks, have generally postulated a parent of gabbroic anorthosite composition (Buddington, 1972). A variant of the gabbroic anorthosite parent is the high-alumina basalt of Morse (1975).

The snowy Mt. Dome is the type area of de Waard and Romey's (1969) comagmatic differentiation process. By detailed mapping beginning at the core of the dome, they showed that there exists an outward gradation from central anorthosite through metanorite, to noritic augen gneiss, to charnockitic gneisses (see Fig. 22). This they interpreted as reflecting a differentiation sequence and variation diagrams were constructed to portray these trends.

A critical aspect of the compositional variation within this suite is that grains (xenocrysts) of andesine occurs within the charnockitic rocks. These xenocrysts increase in abundance as the anorthositic core rocks are approached. Concomitantly the amount of K-feldspar and quartz decrease. Although these changes do result in a gradation of rock types, the transition seems to be mechanical rather than chemical. This is suggested by the constancy of xenocryst composition and the widespread presence of cross-cutting relationship between end-member rock types.

Based upon field and chemical data Buddington (1939, 1972), suggested that the charnockitic rocks are distinctly later than, and unrelated to, the anorthositic rocks. He presented variation diagrams of major oxides demonstrating that the anorthositic and charnockitic rocks follow separate differentiation trends and that discontinuities exist between their paths. Simmons (1976) and Goldberg (1977) have studied trace element and REE patterns in Adirondack anorthosite-charnockite lithologies and concur with Buddington that the two are unrelated. They also show that a gabbroic anorthosite parent is consistent with their trace-element studies. Simmons suggests that such a parent can be produced from dry melting at high load pressure of a gabbroic source rock. Figure 23 shows Emslie's (1971) results for such a system at P_L = 15 Kb and at 1 atm. The minimum melt generated at 45-50 km is essentially a gabbroic anorthosite. As it rises the field boundaries move so as to enlarge the domain of plagioclase crystallization. In this manner anorthosites may result from reasonable petrogenetic processes.

The origin of the charnockitic rocks in the suite remains largely unresolved. Buddington (1972) suggests that they represent an independent magma series in which contamination of granitic magma by garnetiferous amphibolite has been important. Husch, Kleinspehn, and McLelland (1975), as well as Isachsen, McLelland, and Whitney (1975), have suggested that the charnockite-mangerite envelope results from fusion of quartzo-feldspathic country rocks of the intruding anorthositic magma (crystal mush ?). Early in the process the anorthositic rocks attain complete crystallization and are subsequently intruded by the lower melting temperature quartzo-feldspathic lithologies. Wiebe (1975) has suggested a similar mechanism for adamellites near Zoar (Nain), Labrador. All fusion models of this sort depend critically on the initial temperature of the charnockitic rocks and the heat budget within the system. Although the lack of data on heat capacities, heats of fusion, etc., preclude detailed calculations, it does seem possible that at 8-10 Kb anorthositic intrusives with temperatures of 1200-1300°C can melt substantial quantities of quartzo-feldspathic gneisses initially at 800°C. Whether or not this mechanism actually operates is a question deserving of extensive research. It is certainly consistent with field evidence suggesting that stratigraphically continuous units undergo increasing anatexis as anorthositic rocks are approached. Some examples of this anatexis will be seen at Stop 7.

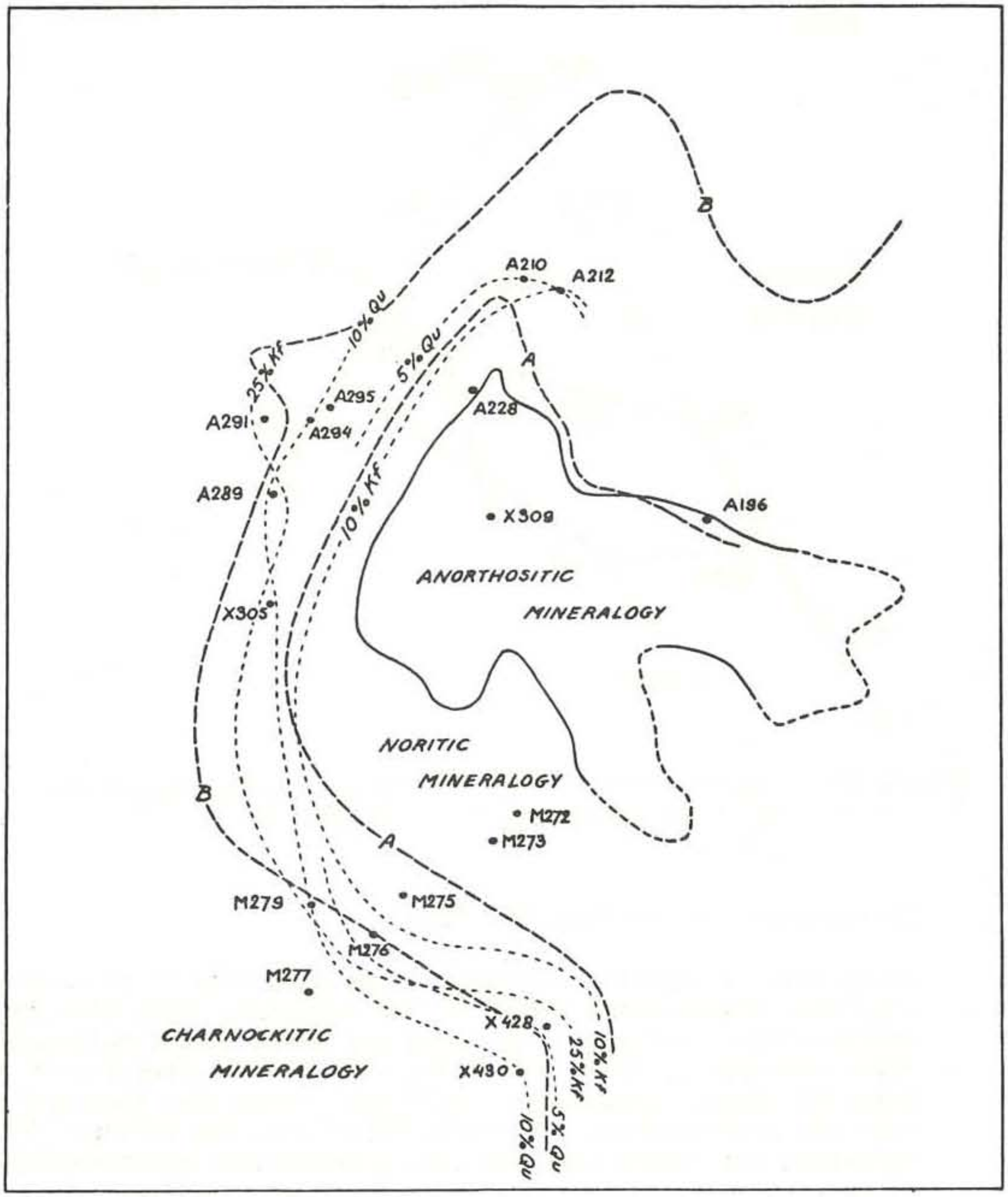

Figure 22. Textural and compositional boundaries and gradations in central part of Snowy Mountain dome. Arbitrary textural lines from center outward: (A) indicates the approximate location of transition from deformed blastonoritic texture to augen-gneiss texture; (B) indicates approximate zone in which number of andesine augen decreases to less than one per square meter. Compositional boundaries and isopleths: solid line indicates boundary zone between anorthosite and metanorite; dashed lines are isopleths of 10 and 25 percent modal K feldspar, and 5 and 10 percent modal quartz. Intersection of structural line A with anorthosite-metanorite boundary zone reflects occurrence of finer grained and foliated Whiteface-type anorthosite developed along this part of the boundary (from de Waard and Romey, 1969 and de Waard, 1964b).

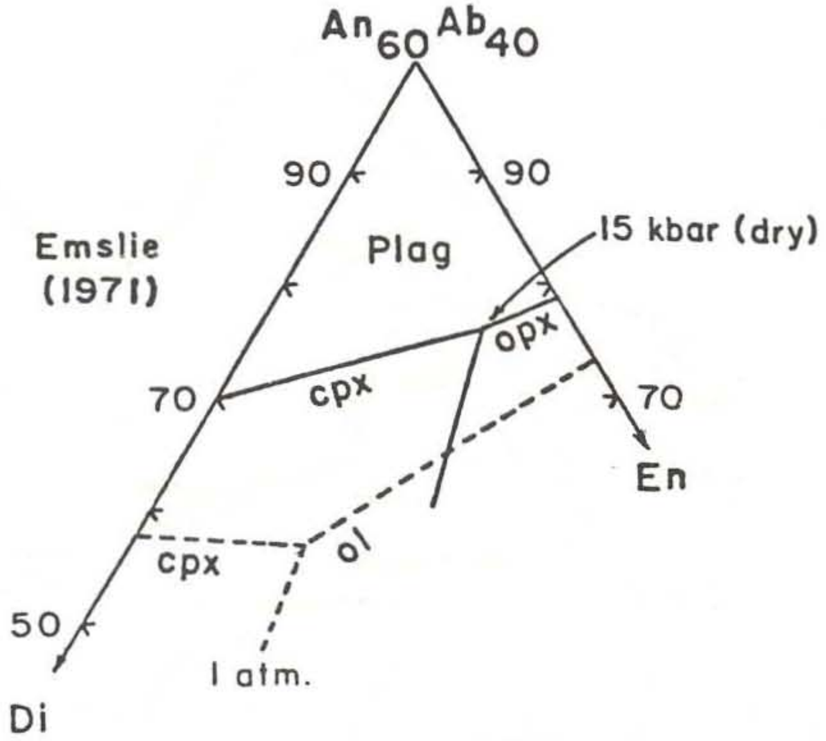

Figure 23. Liquidus phase relations in system $An_{60}Ab_{40}$-Di-En at 15 Kb load pressure, from Emslie (1971).

21.2 Charnockites of the Snowy Mt. Dome.

These type "a" quartzo-feldspathic gneisses tend to be more massive than charnockites higher in the sequence. They also contain xernocrysts of andesine. de Waard and Romey (1969) believed that these charnockites were comagmatic with the anorthosites of the Snowy Mt. Dome. Buddington (1963) has argued that they are later than the anorthosites. Isachsen, McLelland, and Whitney (1975) suggested that these, and similar, charnockites are the products of melting accompanying intrusion of the anorthosites into quartzo-feldspathic country rocks. Rb/Sr whole rock ages obtained by Hills and Isachsen (1975) yield results of ~1.2 by and do not suggest that these charnockites are part of an "older" basement complex.

23.2 State Campsite.

27.4 Mason Lake Parking Area. The lower Lake Durant Fm. and the Lower Marble are exposed in this general vicinity.

27.9 Contact of the Lower Marble with the Lake Durant Fm.

28.7 Contact of the Lake Durant Fm. with the Upper Marble.

29.6- Passing through thick charnockite layer in the Upper Marble.
30.2

30.2 Passing through units of the Upper Marble. Generally low dips have resulted in broad exposure of this unit. Note horizontal foliation in some roadcuts. At 32.9 cross contact with Blue Mt. Fm. which cores a local F_2 syncline.

34.3 Contact of Blue Mt. Fm. with Upper Marble. Passing into the southern limb of the F_2 syncline.

34.7 Long roadcuts of garnetiferous amphibolite in Upper Marble. Some garnets attain diameters of 5-6". A large pegmatite is also present. Note that this outcrop sites astride the hinge line of an F_2 anticline.

34.8 Contact of Upper Marble amphibolites and Blue Mt. Fm.

35.4 Junction of Routes NY30 and 8 in center of Speculator.

-- Side trip, no cumulative mileage --

0 Head southeast on Rt. NY30

1.5- Charnockites of Blue Mt. Fm. At 2.8 cross into Upper Marble.
2.8

3.4 Stop 5: Northern intersection of old Rt. NY30 and new Rt. NY30, 3.3 miles east of Speculator, New York.

The Upper Marble Fm. is exposed in roadcuts on both sides of the highway. These exposures show typical examples of the extreme ductility of the carbonate-rich units. The south wall of the roadcut is particularly striking, for here relatively brittle layers of garnetiferous amphibolite have been intensely boudinaged and broken. The marbles, on the other hand, have yielded plastically and flowed with ease during the deformation. As a result the marble-amphibolite relationships are similar to those that would be expected between magma and country rock. Numerous rotated, angular blocks of amphibolite are scattered throughout the marble in the fashion of xenoliths in igneous intrusions. At the eastern end of the outcrop tight isoclinal folds of amphibolite and metapelitic gneisses have been broken apart and rotated. The isolated fold noses that remain "floating" in the marble have been aptly termed "tectonic fish." The early, isoclinal folds rotate on earlier foliation.

Features such as those seen within this roadcut have led this writer to question the appropriateness of assigning an unconformity to the base of the Lower Marble Fm. Tectonic phenomena in rocks of high viscosity contrast can account for the fact that the marbles are able to come into contact with a variety of lithologies.

A variety of interesting lithologies are present in this roadcut. The marble itself contains diopside (now serpentinized), tremolite, tourmaline, graphite, sphene, phlogopite, and a variety of pyrites. Interesting reaction rims, or selvages, exist between the marbles and quartz-rich boudins. Presumably these selvages reflect the influence of compositional gradients during metamorphism. Quartz and calcite coexist in these rocks, and wollastonite is not known to occur at this location.

Most of the amphibolites in the outcrop are highly garnetiferous and some layers seem to contain 60-70 percent garnet. The garnets are almandine-rich and are similar to those at Gore Mt. However, it is not known whether these amphibolites represent metamorphosed sedimentary or igneous rocks. Note that a number of the garnets are separated from surrounding hornblende by narrow light colored rims. These consist of calcic plagioclase and orthopyroxene and represent products of the reaction:

Garnet + Hornblende = Orthopyroxene + Calcic Plagioclase + Water.

This reaction is characteristic of the granulite facies wherein the association garnet + hornblende is unstable (de Waard, 1965a, 1965b).

Also present in the outcrop are various layers rich in calc-silicates. One of these contains coarse, pale diopside crystals several inches across. Others consist almost entirely of green diopside. Tremolite also occurs in some layers. Rusty weathering, metapelitic units are rich in graphite, calc-silicates, and pyrite. Neither grossular nor scapolite, seems to have developed here.

Near the west end of the outcrop a deformed layer of charnockite is well exposed. In other places the charnockite-marble interlayering occurs on the scale of one to two inches.

Exposed at several places in the roadcut are striking, cross-cutting veins of tourmaline and quartz displaying a symplectic type of intergrowth. Other veins include hornblende and sphene-bearing pegmatites.

Usually included in the Upper Marble, but not exposed here, are quartzites, kinzigites; sillimanite-rich, garnetiferous, quartz-microcline gneisses; and fine-grained garnetiferous leucogneisses identical to those characterizing the Sacandaga Fm. These lithologies may be seen in roadcuts 0.5 mi to the south.

Almost certainly these marbles are largely of inorganic origin. No calcium carbonate secreting organisms seem to have existed during the time in which these carbonates were deposited (> 1 by ago). Presumably the graphite represents remains of stromatolite-like binding algae that operated in shallow-water, intertidal zones. If so, the other roadcut lithologies formed in this environment as well. If so, the other roadcut lithologies formed in this environment as well. This seems reasonable enough for the clearly metasedimentary units such as the quartzites and kinzigites. The shallow-water environment is much more interesting when applied to the charnockitic and amphibolite layers. The fine-scale layering, and ubiquitous conformity of these, strongly suggests that they do not have an intrusive origin. Perhaps they represent the metamorphosed products of volcanic material in a shelf-like environment. Such intercalation is now occurring in many island arc areas where shallow-water sediments cover, and in turn are covered by, ash and lava. Alternatively they may represent metasediments.

Turn around and head back north to Speculator.

35.4 Junction Routes NY8 and 30 in Speculator. Head southwest on Rt. NY8.

46.0 Stop 6: Core rocks of the Piseco Anticline.

Hinge line of Piseco Anticline near domical culmination at Piseco Lake. The rocks here are typical quartzo-feldspathic gneisses "a" such as occur in the Piseco Anticline and in other large anticlinal structures, for example Snowy Mt. Dome, Oregon Dome.

The pink "granitic" gneisses of the Piseco Anticline do not exhibit marked lithologic variation. Locally grain size is variable and in places megacrysts seem to have been largely granulated and only a few small remnants of cores are seen. The open folds at this locality are minor folds of the F_2 event. Their axes trend N70W and plunge 10-15° SE parallel to the Piseco Anticline.

The most striking aspect of the gneisses in the Piseco Anticline is their well-developed lineation. This is expressed by rod, or pencil-like, structures. These may consist of alternating ribbons of quartzite, quartzo-feldspathic gneiss, and biotite-rich layers. In many instances these ribbons represent transposed layering on the highly attenuated limbs of early, isoclinal minor folds. Near the northeast end of the roadcut such minor folds are easily seen due to the presence of quartzite layers in the rock. Slabbed and polished specimens from this and similar outcrops demonstrates that these early folds are exceedingly abundant in the Piseco Anticline. Examination of these folds shows that the dominant foliation in the rock is axial planar to them. Similarly, layer transposition is related to flattening parallel to the axial planes of the early folds. The intersection of this axial plane foliation and compositional surfaces helps to define the strong lineation in the outcrop. Also present is an earlier foliation subparallel to the one associated with the visible folds. Again intersections between these foliations, compositional surfaces, etc., result in a strong intersection lineation. In addition to this a number of rod-like lineations are probably the hinge line regions of isoclinal minor folds which are difficult to recognize because of relative lithologic homogeneity. Lineation in the outcrop is intensified further by the fact the upright and relatively open F_2 folds are coaxial with F_1. Thus the intersection of the F_2 axial planar foliation with earlier foliations results in a lineation parallel to the F_2 trend. Moreover, F_2 minor folds may be of the crenulation variety and their sharp hinge lines define a lineation in the earlier foliation.

As described previously, a number of parallel elements combine to produce an extremely strong lineation in the Piseco Anticline. Past observers have remarked that the lineation appears to be the result of stretching parallel to the long axis of the Piseco Dome. However, the lineation is probably unrelated to "stretching" and is explained more realistically as an intersection lineation of planar fabrics. Moreover, the intensity of the lineation is more the result of the early recumbent folding and flattening than it is of the later, coaxial F_2 Piseco Anticline.

48.5 Junction of Rt. NY8 and Rt. NY10. Turn south towards Canada Lake.

49.0 On both sides of Rt. NY10 are red-stained quartzo-feldspathic gneisses "a" that have been cataclastized by a large N20E fault zone. For the next 5.5 mi we shall pass through a number of road-curves as Rt. NY10 makes its way through the core rocks on the south limb of the Piseco Anticline.

52.5 Cross into the Sacandaga Fm.

55.0 Parking area on east side of highway. The rocks here are quartzo-feldspathic gneisses believed to be part of the Sacandaga Fm.

55.3 Stop 7: Lake Durant and Scandaga Fms. intruded by anorthositic gabbros and gabbroic anorthosites.

These roadcuts are located on Rt. NY10 just south of Shaker Place.

The northernmost roadcut consists of a variety of metasedimentary rocks. These lie directly above the Piseco Anticline and are believed to be stratigraphically equivalent to the Sancandaga Formation. The outcrop displays at least two phases of folding and their related fabric elements. These are believed to be F_1 and F_2. A pre-F_1 foliation is thought to be present. Both axial plane foliations are well developed here. Several examples of folded F_1 closures are present and F_1 foliations (parallel to layering) can be seen being folded about upright F_2 axial planes.

Farther to the south, and overlooking a bend in the west branch of the Sacandaga River, there occurs a long roadcut consisting principally of pink and light green quartzo-feldspathic gneisses belonging to the Lake Durant Fm. About half-way down this roadcut there occurs a large and impressive boudin of amphibolite and diopsidic gneiss. To the north of this boudin the quartzo-feldspathic gneisses are intruded pervasively by anorthositic gabbros, gabbroic anorthosites, and various other related igneous varieties. At the north end of the cut and prior to the metastratified sequences these intrusives can be seen folded by upright fold axes. They are crosscut by quartzo-feldspathic material.

Within this general region the Lake Durant Fm. and other quartzofeldspathic gneisses seem to have undergone substantial anatexis. This is indicated by the "nebular" aspect of the rocks. Good examples of this are seen in the manner in which green and pink portions of the quartzo-feldspathic gneisses mix. Note also the clearly cross-cutting relationships between quartzo-feldspathic gneiss and mafic layers at the south end of the roadcut. Here it seems that mobilized Lake Durant is cross-cutting its own internal stratigraphy. Also note that the quantity of pegmatitic material is greater than usual. This increase in anatectic phenomena correlates closely with the appearance of extensive metagabbroic and metanorthositic rocks in this area. We believe that these provided a substantial portion of the heat that resulted in partial fusion of the quartzo-feldspathic country rock.

56.4	Roadcut on west side of highway shows excellent examples of anorthositic gabbros intrusive into layered pink and light green quartzo-feldspathic gneisses. The presence of pegmatites and cross-cutting granitic veins is attributed to anatexis of the quartzo-feldspathic gneisses by the anorthositic rocks.
56.7	Fine-grained metagabbro on west side Rt. NY10.
57.1	Excellent roadcut in coarse anorthositic gabbro. Ophitic to subophitic texture well preserved. Garnets are sporadically developed and tend to be associated with coarse gabbroic pegmatites showing mineral growth perpendicular to contacts. Compositional layering may be primary.
57.6	Small cut in megacrystic granitic gneiss on east side of highway.
57.8	Begin half-mile of roadcuts exhibiting intrusion of quartzofeldspathic gneisses by members of the anorthositic gabbro suite, several phases of which seem to be present and in cross-cutting relationships. Source metasedimentary areas may be xenoliths. Pods of megacrystic gneiss may be anatectic in origin.
58.4	Kennels Pond - Avery's Fishing Site.
59.5	Lake Catherine to east of highway; metasediments intruded by anorthositic gabbros in roadcut on west.
60.3	Avery's Hotel on west of highway at top of hill.
60.4	Steeply dipping kinzigites with white, anatectic layers.
61.2	Stop 8: On the west side of Rt. NY10 is a rounded roadcut consisting of typical examples of sillimanite-garnet-biotite-quartz-

oligoclase gneisses (kinzigites). These rocks are widespread south of the Piseco Anticline and are thought to represent metapelites associated with a locally deeper sedimentary basin in this region. Throughout the Adirondacks kinzigites are rich in white pods and lenses consisting of perthitic feldspars, garnet, and quartz. These are believed to be anatectic in origin. These anatectic areas seem to pre-date F_1. In places they exhibit the pre-F_1 foliation. Locally they show "fishhook-like" terminations suggesting that they have been involved with substantial transposition.

The kinzigites at this locality have been intruded by anorthositic gabbro which may be seen at the north end of the roadcut. The gabbroic rocks seem to gently transect the earliest foliation but have been involved in all other deformations.

Towards the southern end of the roadcut several generations of minor folds may be seen together with their associated foliations. The earliest recognizable folds have near-horizontal axial planes where they are located on the hinge lines of the upright set of folds that dominates the outcrop. The older set seems to fold a foliation and is assigned to the F_1 generation. This requires that the dominant, upright set with its steep foliation belongs to the F_2 generation of folds. If this is so we note that the F_2-related axial plane foliation can be locally intense.

There seem to be two generations of garnet within most kinzigites. One may be flattened in the plane of foliation and may have formed by an amphibolite facies reaction similar to:

$$\text{biotite} + \text{muscovite} + \text{quartz} \rightarrow \text{garnet} + \text{K-feldspar} + H_2O$$

(Engel and Engel, 1962). The later generation of garnets grow across foliation planes and in several areas form coronitic rims around sillimanite. These garnets are believed to result from a reaction of the following type:

$$\text{sillimanite} + (\text{Fe,Mg,Ti})\text{Biotite} + \text{Quartz} \rightarrow (\text{Fe,Mg})\text{Garnet} + \text{Ti-Biotite} \pm \text{Ilmenite} + H_2O$$

(Kretz, 1966).

61.4 Extremely garnetiferous kinzigites.

62.0 Road sign: Canada Lake - 10 miles.

62.5 Crossing Swamp.

63.2 Crossing swamp that marks contact between the Sacandaga Fm. and megacrystic gneisses of the Rooster Hill Fmm.

63.5 Megacrystic gneisses of Rooster Hill Fm.

63.6 Megacrystic gneisses of Rooster Hill Fm.

64.0 Kinzigite in Rooster Hill Fm.

64.7 North end of Stoner Lake. Type locality of Rooster Hill Fm. The Rooster Hill Formation is characteristic of a wide spread lithology throughout the Adirondacks. Its most characteristic feature is the presence of striking 1-4" megacrysts of K-feldspar. These are almost always flattened within the plane of foliation. Nonetheless, a number of these megacrysts preserve evidence of approximately euhedral crystal outline.

Compositionally the Rooster Hill megacrystic gneisses consist of orthopyroxene, garnet, hornblende, biotite, perthitic microcline, some plagioclase (oligoclase), and quartz. An igneous analogue would be quartz monzonite.

The parentage of the Rooster Hill megacrystic gneisses is obscure. It is not known whether the megacrysts are phenocrysts or porphyroblasts. The fact these lithologies are conformable with the enclosing stratigraphy over broad areas is consistent with a metastratified origin but does not rule out intrusion as sills. The lack of substantial banding across units thousands of feet thick is less consistent with a metasedimentary origin than with an igneous one. However, the problem remains unresolved and requires further research.

Regardless of parentage, the Rooster Hill Fm. seems to correlate with the Blue Mt. Fm.

65.5 Crossing contact of Rooster Hill Fm. and kinzigites of the Peck Lake Fm. Near the contact the Rooster Hill megacrystic gneisses become equigranular. This is probably due to cataclasis.

66.4 Kinzigites in the Peck Lake Fm.

67.3 Junction of Rt. NY10 and Rt. 29A.

End Road Log

Faunal Assemblages in the Lower Hamilton Group in Onondaga County, New York

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INTRODUCTION

This report summarizes a quantitative study of the paleoecology of the Lower Hamilton Group in Onondaga County. This paper describes the faunal elements recognized and the ecological categories into which the taxa were grouped. The study confirms and extends the important works of Cooper (1930, 1933). Information concerning the multivariate statistical techniques, sedimentological data, and detailed analysis of the environments studied will be published elsewhere.

In Onondaga County the Hamilton Group directly overlies the Seneca Limestone of the Onondaga Formation. Samples were taken from the Marcellus Formation, Skaneateles Formation, and the lower portion of Ludlowville Formation (Fig. 1). Although Rickard (1975, p. 6) notes that the Cherry Valley merges with the Seneca Member of the Onondaga Limestone in the western part of the State, we have followed the traditional course in treating the Cherry Valley with the Hamilton Group.

PELAGIC ASSEMBLAGES OF THE MARCELLUS FORMATION

The Union Springs, Chittenango, and Cardiff Members of the Marcellus Formation are characterized by pelagic and epipelagic faunas. The sediments consist of either black shale or black limestone. The weight percent of organic matter in these rocks ranges about 4.4 percent. The delicate laminations and fine-grain sizes in these sediments indicates quiet-water conditions in which the sediments were not disrupted by burrowing animals. The presence of 4 or 5 percent of organic carbon is enough to produce reducing conditions on the seabed. The regional distribution of the black rocks in the Marcellus shows that these sediments were deposited offshore in relatively deep and still water under reducing conditions.

As expected, few species occur in the black sediments of the Marcellus. The main ecological categories are planktonic filter-feeders (Styliolina fissurella), nektonic predators represented by various ammonoids and nautiloids, epiplanktonic filter-feeders similar to Pterochaenia fragilis, Buchiola, Lunulacardium, Leiorhynchus limitare and Longispina mucronata, and terrestrial wood. The wood constitutes vegetation which floated out to sea, became water logged, and sank into the foul muck of the Marcellus Sea. The epiplanktonic oranisms probably were attached to floating seaweeds and in some situations, drifting logs.

Four different pelagic or epipelagic assemblages can be identified in the Marcellus. One is dominated by Styliolina fissurella, a minute cone-shaped organism of unknown affinities (Fisher, 1962). The second is

Group	Formation	Member	Thick-ness	Description
Hamilton	Moscow	Windom	180'	shale & siltstone
		Portland Point	9-10'	limestone & shale
	Ludlowville	Owasco	1-3'	siltstone
		Spafford	25'	shale
		Ivy Point	50-60'	siltstone & shale
		Otisco	160-180'	shale & siltstone
		Centerfield	30'	calcareous siltstone
	Skaneateles	Butternut	100-200'	shale & siltstone
		Pompey	60'	shale & siltstone
		Delphi Station	100'	shale & siltstone
		Mottville	45'	limestone & shale
	Marcellus	Cardiff	125-200'	shale
		Chittenango	100'	black shale
		Cherry Valley	3'	limestone
		Union Springs	13-15'	shale & limestone

Figure 1. Stratigraphic section of Middle Devonian Hamilton Group in Onondaga County, New York.

abundant in Pterochaenia fragilis but also includes some cephalopods. The third is composed mostly of Leiorhynchus limitare, whereas the fourth consists of terrestrial wood, cephalopods, and several bivalves. Low diversity and strong dominance is observed in all of these assemblages. These observations reflect stressed consitions caused by quiet water and the lack of dissolved oxygen and the fact that only a few organisms were able to exploit the pelagic and epipelagic life styles. Some of the bedding planes in the Marcellus are covered with Styliolina fissurella or Leiorhynchus limitare. These are believed to be due to catastrophic mortality of pelagic and epipelagic organisms, perhaps owing to being transported into surface waters with no dissolved oxygen. This killed the animals which then separated from their floating substrates to become buried in the Marcellus black muck. In other instances, the density of fauna is low and normal rates of mortality were involved.

A listing of the faunal and ecological classification of each assemblage follows (Tables 1, 2, 3, and 4). The percentage given is the average occurrence for all smaples of the assemblage. This format will be followed in subsequent tabulations.

CHERRY VALLEY LIMESTONE

The Cherry Valley Limestone contains a transitional bottom-dwelling pelagic fauna. The main pelagic taxa are cephalopods whereas the benthos include brachiopods, crinoid debris, trilobites, Aulopora, Coleolus? sp., and some questionable algal lumps. A depth of less than 100 ft is denoted by the algae and vertical cephalopod shells. The fauna and lithology testify to oxygenated and agitated conditions. Cherry Valley constitutes an interval when bottom-dwelling organisms were able to colonize the seafloor. This environment was short lived, quiet water and anaerobic conditions soon resumed during Chittenango time. The Cherry Valley is relatively thin and poorly exposed in this area, therefore we have not been able to compile data from the Cherry Valley that are comparable with those from the other units examined.

BOTTOM DWELLING ASSEMBLAGES OF THE LOWER HAMILTON

Seven bottom-dwelling communities, two of which are subdivided into two subassemblages each are recognized in the upper Marcellus, Skaneateles, and Ludlowville Formations. The ecological structures of the communities are relatively simple. The two most abundant foodstuffs consist of plankton and organic detritus. As noted by Walker (1972) and numerous others (e.g. Tipper, 1975), the most abundant species are concentrated in different ecological categories where the advantage is of minimizing competition between the most abundant forms of a community. Within a single assemblage, each niche is dominated by one taxon which usually accounts for at least half of all the specimens in that niche. Again, this results in decreased intensity of competion.

The Tropidoleptus carinatus assemblage (Table 5) of the Mottville, Pompey, and Centerfield is dominated by filter-feeding reclining brachiopods. These brachiopods, the deeply attached endobyssate pelecypods and the burrowing protobranch pelecypods are all adapted for life in soft sediments. Both diversity and dominance are relatively high whereas equitability is low, thus demonstrating that significant packing of niches has not taken place. For example, the four most abundant species constitute almost 80 percent of the entire assemblage and Tropidoleptus carinatus accounts for almost half of the individuals.

The Nuculoidea-Bembexia community (Table 6) of the Delphi Station dwelt in a quiet-water habitat at moderate depths. Abundant organic detritus and microorganisms provided a food supply for approximately 29 percent of deposit feeders, mostly infaunal nuculoid pelecypods. Bottom-dwelling filter-feeders account for about 45 percent of the assemblage; these are mostly small chonetid brachiopods which recline on the seafloor, endobyssate pelecypods, and pedicle-attached brachiopods. Abundant epifaunal herbivorous gastropods grazed on algal mats and other submarine

Table 1. Faunal and ecological classification of *Styliolina fissurella* assemblage.

- Planktonic filterfeeder (97%)
  - *Styliolina fissurella*
- Nektonic predator (2%)
  - Orthocone sp.
  - Goniatite sp.
  - *Agoniatites vanuxemi*
  - *Striatoceras*
- Epiplanktonic filterfeeder (1%)
  - *Pterochaenia fragilis*
  - *Longispina mucronata*
  - *Leiorhynchus limitare*
  - *Buchiola* sp.
  - *Lunulacardium* sp.
- Unclassified (<1%)
  - Wood fragments

Table 2. Faunal and ecological classification of *Pterochaenia fragilis* assemblage.

- Epiplanktonic filterfeeder (76%)
  - *Pterochaenia fragilis*
  - *Lunulacardium* sp.
  - *Panenka* sp.
  - *Buchiola* sp.
  - *Leiorhynchus limitare*
- Nektonic predator (21%)
  - Orthocone sp.
  - Goniatites
- Unclassified (3%)
  - Wood fragments
- Planktonic filterfeeder (<1%)
  - *Styliolina fissurella*

Table 3. Faunal and ecological classification of *Leiorhynchus limitare* assemblage.

- Epiplanktonic filterfeeder (84%)
  - *Leiorhynchus limitare*
  - *Pterochaenia fragilis*
- Unclassified (16%)
  - Wood fragments

Table 4. Faunal and ecological classification of "wood assemblage".

- Unclassified (74%)
  - Wood fragments
- Nektonic predator (20%)
  - Orthocone sp.
  - Goniatites sp.
- Epiplanktonic filterfeeder (6%)
  - *Panenka* sp.

Table 5. Faunal and ecological classification of *Tropidoleptus carinatus* assemblage.

- Reclining filter-feeder (64%)
    - *Tropidoleptus carinatus*
    - *Chonetes* sp.
    - *Mucrospirifer mucronatus*
    - *Protoleptostrophia perplana*
    - *Atrypa reticularis*
- Infaunal deposit-feeder (13%)
    - *Nuculoidea* sp.
    - *Nuculites oblongatus*
    - *Palaeoneilo emarginata*
- Epifaunal browsing herbivore (8%)
    - *Bembexia sulcomarginata*
    - *Bellerophon* sp.
    - *Palaeozygopleura hamiltonae*
    - *Holopea* sp.
- Deeply buried endobyssate filter-feeder (5%)
    - *Sphenotus* sp.
    - *Modiomorpha* sp.
    - *Modiella pygmaea*
    - *Glossites* sp.
    - *Paracyclas* sp.
    - *Grammysia* sp.
    - *Macroden* sp.
    - *Goniophora* sp.
- Low-level rooted epifaunal (2%)
    - *Athyris cora*
    - *Mediospirifer audaculus*
    - *Leiorhynchus laura*
    - *Ambocoelia embonata*
    - *Pholidops hamiltonae*
    - *Rhipodomella* sp.
    - *Pterinopecten* sp.
    - *Pseudoaviculopecten* sp.
    - *Camarotoechia*
- Epifaunal crawling or ploughing collector (2%)
    - *Greenops boothi*
    - *Hyolithes* sp.
- Shallow-buried endobyssate filter feeder (1%)
    - *Cornellites flabella*
    - *Actinopteria* sp.
- Nektonic carnivore (<1%)
    - *Orthocone* sp.
    - *Spyroceras* sp.

Table 6. Faunal and ecological composition of Nuculoidea-Bembexia assemblage.

- Infaunal deposit feeder (24%)
    - *Nuculoidea* sp.
    - *Nuculites oblongatus*
- Reclining filter-feeder (16%)
    - *Chonetes* sp.
    - *Tropidoleptus carinatus*
    - *Tentaculites* sp.
    - *Mucrospirifer mucronatus*
    - *Schuchertella* sp.
    - *Pholidostrophia* sp.
- Deeply buried endobyssate filter-feeder (16%)
    - *Glossites* sp.
    - *Modiella pygmaea*
    - *Sphenotus* sp.
    - *Nyassa arguta*
    - *Modiomorpha* sp.
- Epifaunal grazing herbivore (16%)
    - *Bembexia sulcomarginata*
    - *Palaeozygopleyra hamiltonae*
    - *Holopea* sp.
- Low-level rooted filter-feeder (11%)
    - *Ambocoelia umbonata*
    - *Pholidops hamiltonae*
    - *Leiorhynchus laura*
    - *Camarotoechia* sp.
    - *Glyptodesma erectum*
    - *Orbiculoidea* sp.
    - *Athyris cora*
- Epiplanktonic filter-feeder (4%)
    - *Pterochaenia fragilis*
- Epifaunal crawling or ploughing collector (4%)
    - *Hyolithes* sp.
    - *Phacops rana*
    - *Greenops boothi*
- Nektonic carnivore (3%)
    - *Spyroceras* sp.
    - Orthocone sp.
    - *Goniatites* sp.
- Deeply-fully buried filter-feeder (1%)
    - *Lingula* sp.
    - *Paracyclas* sp.
    - *Lingulella* sp.
- High-level attached filter-feeder (<1%)
    - Crinoids
    - Fenestellid bryozoan
- Shallow-buried endobyssate filter-feeder (<1%)
    - *Cornellites flabella*

plants. Small pelecypods were attached to floating or benthonic vegetation. Diversity is high as is dominance. The average number of species is 16.5, whereas the mean equitability is 0.80.

Throughout deposition of the Delphi Station with its Nuculoidea-Bembexia community, the waters shoaled while the average agitation increased. Eventually, the area was covered by siltstones and sandstones with the Actinopteria assemblage (Table 7) of the Pompey. The current-swept habitat was populated by a diversified suite of filter-feeding pelecypods distributed with moderate equitability and brachiopods that were able to tolerate variable conditions of agitation and rapid sedimentation. Filter-feeders make up 83 percent of the fauna; these animals exploited numerous different methods of filter feeding. The low amount of plant and animal organic matter present, perhaps acting in conjunction with high agitation and rapid sedimentation, is responsible for the small numbers of collectors, deposit feeders, and herbivores present (about 11 percent). During intervals of more winnowing and slow rates of deposition, "pioneer assemblages" of hardy solitary zaphrentid corals became established for one or several generations (Table 8). These were soon overwhelmed by rapid sedimentation and the seafloor was repopulated by the Actinopteria community.

The Leiorhynchus laura assemblage (Table 9) is characteristic of the Butternut although it occurs in the Mottville and Delphi Station. The Butternut shales and siltstones were deposited rapidly in poorly oxygenated and turbid water, often by turbidity currents; the seabed was extensively bioturbated. These stringent conditions dictated a low diversity fauna in which only the most tolerant filter-feeders could survive such as Leiorhynchus laura and Chonetes. Epiplanktonic molluscs and infaunal deposit feeders are also abundant.

During Centerfield and Otisco times, more favorable conditions developed due to decreased depth and rate of deposition along with higher amounts of dissolved oxygen. The shelf was invaded by the Mucrospirifer mucronatus assemblage (Table 10), a diversified fauna consisting mostly of filter-feeding brachiopods, such as M. mucronatus, Chonetes, and Tropidoleptus carinatus, and crinoids which make up almost 90 percent of the community. Conditions generally were similar to those that existed during the life and times of the Actinopteria assemblage except that the Mucrospirifer mucronatus occurred farther offshore in slightly deeper water where less sediment was accumulating. Owing to the more equitable environment, brachiopods were able to almost completely exclude pelecypods from the habitat.

The Staghorn Point beds of the Otisco constitutes a second interval where the seafloor was dominated by corals (Table 11). The colonial taxon Edriophyllum forms the base of the coral banks; this is succeeded by sediments with large solitary cystiphyllid and zaphrentid corals. As in the Pompey, the conditions that allowed the existence of the coral beds probably are reduced sedimentation rates and increased agitation.

The assemblages recognized here are definite numerical entities, albeit loosely structured ones. Numerous protean forms, such as Chonetes

Table 7. Faunal and ecological composition of Actinopteria assemblage.

Epifaunal reclining filter-feeder (29%)
- Chonetes sp.
- Productella spinulicosta
- Tropidoleptus carinatus
- Schuchertella sp.
- Mucrospirifer mucronatus
- Protoleptostrophia perplana
- Atrypa reticularis
- Tentaculites sp.

Deeply-buried endobyssate filter-feeder (17%)
- Nyassa arguta
- Modiomorpha sp.
- Glossites sp.
- Sphenotus sp.
- Cimitaria sp.
- Goniophora sp.
- Macrodon sp.
- Grammysia sp.

Shallow-buried endobyssate filter-feeder (17%)
- Actinopteria sp.
- Leiopteria sp.
- Cornellites flabella

Low-level epifaunal rooted filter-feeder (16%)
- Athyris cora
- Mediospirifer audaculus
- Leiorhynchus laura
- Glyptodesma errectum
- Pterinopecten sp.
- Camarotoechia sp.
- Ambocoelia umbonata

Infaunal deposit-feeder (7%)
- Nuculoidea sp.
- Nuculites oblongatus
- Taonurus caudagalli
- Palaeoneilo emarginata

Reclining carnivore (4%)
- Cystiphyllum sp.
- Zaphrentid
- Aulopora sp.

High-level attached filter-feeder (3%)
- Crinoids
- Fenestellid bryozoan
- Taeniopora sp.

Table 7. Continued.

Nektonic carnivore (3%)
    Spyroceras sp.
    Goniatite sp.
    Orthocone sp.

Epifaunal herbivore (3%)
    Bembexia sulcomarginata
    Ptomatis sp.
    Palaeozygopleura hamiltonae

Epifaunal ploughing and crawling collectors (2%)
    Greenops boothi
    Hyolithes sp.
    Phacops rana
    Dipleura dekayi

Epiplanktonic filter-feeder (<1%)
    Pterochaenia fragilis
    Buchiola sp.

Completely buried burrowing filter-feeder (>1%)
    Paracyclas sp.
    Cypricardella sp.
    Lingula sp.

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sp., *Mucrospirifer mucronatus*, *Tropidoleptus carinatus*, and *Nuculoidea* sp., occur in many of the assemblages. Probably chance and random larval settlement played a considerable role in the communities. Within fairly general limits, we suspect that stochastic processes could be used to model or simulate the variations with a community and perhaps to some extent between similar communities.

Some communities are dominated by one ecological niche, for example, the *Tropidoleptus carinatus* and *Mucrospirifer mucronatus* assemblages each have 64 percent reclining filter feeders. This situation is more exagerated in the samples dominated by *Leiorhynchus limitare* some of which may contain over 90 percent of pedicle-attached brachiopods. Ecological categories are more evenly distributed in the *Nuculoidea-Bembexia*, *Actinopteria*, and the equitable *Leiorhynchus laura* assemblages. For example, in the *Nuculoidea-Bembexia* assemblage, the first four ecological categories comprise 24.5, 16.4 and 15.9 percent of the fauna. The same figures for the *Actinopteria* community are 28.9, 17.5, 17.1, and 15.8 percent. Communities that are dominated by a single ecological niche also tend to be invested in one food resource. Filter feeders account for 74 and 94 percent of all the individuals in the *Tropidoleptus carinatus* and *Mucrospirifer mucronatus* assemblages. In the zaphrentid and Otisco coral faunas, 89 and 98 percent are concentrated in the carnivorous and normal filter-feeding roles.

Table 8. Faunal and ecological composition of Zaphrentid assemblage.

- Reclining carnivore (59%)
    - Zaphrentid coral

- Reclining filter-feeder (15%)
    - *Chonetes* sp.
    - *Mucrospirifer mucronatus*
    - *Atrypa reticularis*
    - *Productella spinulicosta*

- Deeply-buried endobyssate filter-feeder (11%)
    - *Nyassa arguta*
    - *Modiomorpha* sp.
    - *Goniophora* sp.

- High-level attached filter-feeder (6%)
    - Bryozoa sp.
    - Crinoids

- Low-level rooted epifaunal filter-feeder (6%)
    - *Mediospirifer audaculus*
    - *Roemerella* sp.
    - *Athyris cora*

- Shallow-buried endobyssate filter-feeders (2%)
    - *Actinopteria* sp.
    - *Cornellites flabella*

- Epifaunal browsing herbivore (1%)
    - *Bembexia sulcomarginata*

- Nektonic carnivore (<1%)
    - *Spyroceras* sp.

- Epifaunal crawling or ploughing collector (<1%)
    - *Greenops boothi*

- Infaunal deposit-feeder (<1%)
    - *Palaeoneilo emarginata*

Table 9. Faunal and ecological distribution of species in *Leiorhynchus laura* assemblage.

Reclining - epifaunal filter-feeder (29%)
Chonetes sp.
Mucrospirifer sp.
Productella spinulicosta

Low-level rooted - epifaunal filterfeeder (28%)
Leiorhynchus laura
Ambocoelia umbonata

Epiplanktonic filter-feeder (27%)
Pterochaenia fragilis

Deeply buried endobyssate filter-feeder (8%)
Modiella pygmaea

Infaunal deposit-feeder (6%)
Nuculoidea sp.

Nektonic carnivore (1%)
Orthocone sp.

High-level rooted filter-feeder (<1%)
Crinoid

The more evenly distributed communities are not so limited in their adaptive strategires. Several different food resources are utilized by the *Nuculoidea*-*Bembexia* community of which the most abundant are filter-feeding 45 percent, deposit 24 percent, plant material 16 percent, small microorganisms and organic detritus on the surface 4.2 percent, and carnivorous 3.4 percent. On the other hand, numerous ecological categories are not correlated necessarily with different food materials. For example, in the *Actinopteria* community which has numerous ecological categories represented, 83 percent of the individuals are filter feeders. Here the diversity stems from different adaptations and strategires of filter feeding.

Table 10. Taxonomic and ecological composition of *Mucrospirifer mucronatus* assemblage.

- Epifaunal reclining filter-feeder (64%)
    - *Chonetes* sp.
    - *Mucrospirifer mucronatus*
    - *Tropidoleptus carinatus*
    - *Protoleptostrophia perplana*
    - *Atrypa reticularis*
    - *Productella spinulicosta*
- Low-level rooted epifaunal filter-feeder (16%)
    - *Camarotoechia* sp.
    - *Athyris spiriferoides*
    - *Mediospirifer audaculus*
    - *Ambocoelia umbonata*
    - *Pterinopecten* sp.
    - *Roemerella* sp.
- High-level attached filter-feeder (12%)
    - Crinoids
    - Fenestellid bryozoan
    - *Taeniopora* sp.
- Infaunal deposit-feeder (4%)
    - *Nuculoidea* sp.
    - *Nuculites oblongatus*
    - *Palaeoneilo emarginata*
    - *Taonurus caudagalli*
- Shallow-buried endobyssate filter-feeder (1%)
    - *Leiopteria* sp.
    - *Actinopteria* sp.
- Deeply-buried endobyssate filter feeders (1%)
    - *Goniophora* sp.
    - *Modiomorpha* sp.
    - *Nyassa arguta*
    - *Sphenotus* sp.
- Epifaunal ploughing and crawling collectors (1%)
    - *Greenops boothi*
    - *Phacops rana*
- Nektonic carnivore (<1%)
    - Orthocone sp.
    - Goniatite sp.
- Completely-buried burrowing filter-feeder (<1%)
    - *Paracyclas* sp.
    - *Cypricardella* sp.
    - Lingula sp.

Table 11. Faunal and ecological composition of solitary coral assemblage of Staghorn Point.

Reclining carnivore (61%)
- *Cystiphyllum* sp.
- Unidentified large zaphrentid
- *Edriophyllum* sp.
- *Favosites* sp.

Reclining filter-feeder (36%)
- *Chonetes* sp.
- *Mucrospirifer mucronatus*
- *Atrypa reticularis*
- *Tropidoleptus carinatus*

Low-level epifaunal rooted filter-feeder (2%)
- *Mediospirifer audaculus*

High-level attached filter-feeder (17%)
- Crinoid

Infaunal deposit-feeder (<1%)
- *Palaeoneilo emarginata*

Deep-level endobyssate filter-feeder (<1%)
- *Goniophora* sp.

Epifaunal crawling or ploughing collector (<1%)
- *Phacops rana*

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ROAD LOG

Paleoecology and Stratigraphy of the Lower Hamilton Group in the Syracuse Area

(The stratigraphic descriptions of stops 1-3, and 5-8 are from Chute and Brower, 1964).

0.0 Syracuse University Field House at corner of Colvin St. & Comstock Ave. Proceed W on Colvin St.

0.8 Turn left (S) on State St.

3.5 Continue S to entrance ramp of I81.

5.2 Exit from I81 at exit 16 (Nedrow)

5.5 Turn left (SE) on Rt NY11

5.7 Turn left (E) on access road to Kennedy Rd.

\- Park just beyond culvert

\- STOP 1: Top of the Onondaga Limestone and basal Union Springs Shale displaced by a small thrust fault.

The upper 8 ft of the Onondaga Limestone and about 10 ft of the Union Springs Shale are exposed on the side of the deep drainage ditch on the east side of the road. Exposures of the top contact of the Onondaga such as this are rare.

The Union Springs is the basal member of the Marcellus Formation. The three pelagic assemblages characterized by *Styliolina fissurella*, *Pterochaenia fragilis*, and *Leiorhyncus limitare* occur in the Union Springs.

At the south end of the drainage ditch a thrust fault with a throw of about 5 ft cuts the top of the Onondaga but is absorbed in the Union Springs Shale above by complex crumpling and jointing.

5.8 Turn right (S) on Kennedy Rd.

6.4 Turn left (E) on Bull Hill Rd.

7.4 Intersection with Sentinal Heights Rd.

8.4 Turn left (N) on LaFayette.

9.1 Turn right (E) on Coye Rd.

9.7 Stay left (N) at intersection with Eager Rd.

10.8 Intersection with Gordon Cooper Dr.

11.0 Intersection with Roberts Rd.

11.3 Turn left (N) on Apulia Rd.

12.1 Turn right (E) on Seneca Turnpike (Rt NY173).

12.2 Intersection with Solvay Rd.

12.5 Onondaga County Penitentiary constructed of the Edgecliff Member of the Onondaga Limestone on right (S).

12.8 Intersection with Taylor Rd.

13.5 Turn right (S) on Gates Rd.

\- STOP 2: Chittenango and Cardiff shales.

The Chittenango and Cardiff Members of the Marcellus Formation are exposed at this stop. Both are sparsely fossiliferous, but representatives of the wood assemblage and the *Leiorhynchus* assemblage as well as scattered fish scales and pyritized cephalopod shells occur.

This shale is quarried by the Alpha Portland Cement Company for use in cement manufacture at its Jamesville plant. Although these shales are similar in appearance, they can be distinguished easily by their streaks. The Chittenango Shale, because of its relatively high content of carbonaceous matter, streaks brown when scraped by a hard object such as a geologic hammer, whereas the Cardiff streaks light gray. Examination of drill core from several test holes has shown that the change in color of the streak takes place within a vertical interval of 3 ft. The contact is placed where, in going downward, the streak becomes distinctly brown. Located in this manner, the contact is near the top of the lower face, 5 to 6 ft above the upper layer of large septarian concretions.

Many of the septarian concretions in the upper part of the Chittenango are several ft across. The Cardiff shale on the other hand has only a few concretions and these are seldom more than 6 inches in diameter. The cracks within the septarian concretions commonly contain calcite, ferroan dolomite, and white, platy barite. Small crystals of barite with some pyrite also coat joint surfaces in the shale in places.

Return (N) on Gates Road.

14.4 Turn right (E) on Seneca Turnpike (Rt NY173).

15.0 View of Allied Chemical Corp., Solvay Process Division Quarry on left (S).

Geomorphology of the Southeastern Tug Hill Plateau

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INTRODUCTION

Few areas of comparable size in New York State are less accessible or less well known than the heart of the Tug Hill Plateau. The heaviest snowfalls in the eastern states make for brief growing seasons. Extensive tracts cleared and farmed in the past century have returned to second growth. The road net involves only jeep trails between a few broadly spaced transverse highways.

Although isolated by peripheral lowlands -- the Black River Lowlands on the north and east, the Ontario Lowlands on the west and the Oneida-Mohawk Lowlands on the south -- the Tug Hill is a crudely triangular outlier of the Southern New York Section of the Appalachian Plateaus Province. Rough accordance of summit elevations (e.g. 1960 ft at Gomer Hill, 1920 ft at Mohawk Hill) led Newell (1940) to relate physiographic history of the Tug Hill to that of the adjacent Appalachian Plateaus to the south, ascribing a major role to Tertiary peneplanation. Regional dip southwesterly away from the Adirondack Massif led Hanefeld (1960) to stress the cuestaform nature of the Tug Hill. The scarped east-facing border of the plateau contrasts with the gradual southerly and westerly dip slopes. Indeed both peneplanation and cuestaform development convey true, but incomplete impressions of the regional character of the Tug Hill subprovince. Each is incomplete in failing to emphasize the role of prolonged and repeated Pleistocene glaciation in isolating the plateau, in reducing summits and in shaping present topography. Perhaps because of the erodibility of underlying rocks, these effects are maximized in the southeastern portion of the plateau.

Rocks of Ordovician and Silurian age underlie the Tug Hill Plateau. At the base of the sedimentary section are carbonate rocks of the Trenton and Black River Groups which lie unconformably upon Precambrian metasediments of the Adirondack terrane. From Forestville north to Carthage, the contact between sedimentary and metamorphic rocks lies roughly along the course of the Black River and presumably exerted structural control upon development of the Black River Lowlands. Trenton, Utica, and Frankfort Formations of Ordovician age comprise the stepped and cuestaform eastern margin of the plateau. They also underlie the narrow, southeastern extension of the subprovince where regional dip approximates regional slope from the Black River to the Oneida-Mohawk Lowlands. As a result, Utica Shale underlies both northern and southern margins of this southeastern portion of the subprovince. The youngest Paleozoic strata of the plateau are the red and green sandstones and shales of the Medina Group which lie unconformably upon Queenston, Oswego and Lorraine rocks in the southwestern portion of the Tug Hill.

Knowledge of the geology of the Tug Hill has long been based chiefly on inference from studies in the peripheral lowlands. Surficial geology, for instance, was inferred from studies such as those of Taylor (1924), Stewart (1958) and MacClintock and Stewart (1963) in the St. Lawrence Lowlands; of Miller (1909a, 1909b), Fairchild (1912), Buddington (1934), Tyler (1938) and Force, Lipin, and Smith (1975) in the Black River Lowlands. Kaiser (1962) showed the responsiveness of glacial drift to immediate bedrock provenance and inferred prevailingly southeasterly glacial flow across the Tug Hill. Street (1966) on lithologic criteria delineated the interlobate area of rapid transition from characteristic eastern (Black River Lobe) to western (Ontario Lobe) till in the area west of Ava. Jordan (1977, 1978) studied glacial deposits in the heart of the Tug Hill with a view to distinguishing relationships of wetland types to glacial geology. More specifically, published geologic information relating to the southeastern portion of the Tug Hill subprovince involves geologic mapping of the Remsen (Miller, 1909a), Oriskany (Dale, 1953) and Utica (Kay, 1953) quadrangles, surficial mapping by Wright (1972) and regional correlation by Fullerton (1971, in press).

DRIFT LITHOLOGY

Drift characteristics reflect primarily the mode of emplacement and the nature of the source terrane from which the materials were derived. Mode of emplacement usually can be inferred on the basis of structural characteristics within the drift. Firm, compact, impermeable lodgment till is distinguishable from relatively loose, coarse, ablation drift. The former indicates deposition by plastering down beneath the base of an actively moving wet-soled glacier. The latter results from the melting out of debris-laden ice, letting down the formerly superglacial drift with variable washing and sorting. Under favorable circumstances, more specific interpretation of the depositional environment and process can be inferred from such characteristics as platy structure (fissility), shear surfaces, silt caps associated with embedded clasts, etc. Except for weathering and soil-profile development, these characteristics are not age dependent and therefore cannot be used directly in inferring age relationships. Factors affecting profile development are sufficiently complex that pedologic criteria likewise are difficult to apply except where great differences in age are to be distinguished. Such is not the situation in the Tug Hill Plateau.

Petrologic and mineralogic characteristics of tills depend primarily upon source terranes. Ordinarily drift lithologies are dominated by local bedrock. The probability of representation of farther traveled constituents depends upon distance from source, relative attrition rates and dilution. Dominance by local rock types is apt to be particularly strong in areas of thin drift and up-hill flow on moderate slopes and in moderate relief. Conversely, far-traveled components tend to be represented for longer distances in through valleys and areas of thick drift. Gradual transition in till characteristics is more usual than sharply defined borders, but patterns of lateral change may be used to reconstruct past glacial flow trajectories and by inference, to correlate or distinguish different till units.

On the basis of till constitution, three rather readily distinguishable tills, derived from contrasting source terranes are recognized in the Tug Hill.

Till of the Ontario Lobe in the western and particularly the southwestern part of the Tug Hill is represented by characteristically red till, moderately stony, with sand to silt matrix. Clasts of red sandstone (Grimsby) and pale green sandstone (Oswego) are dominant in the coarse component with only 1-2 percent of metamorphic rocks. Carbonate content diminishes southeastward.

Till of the Black River Lobe is represented by dark-gray to black, sparsely to moderately stony till with silty clay to clay loam matrix. Clasts of dark siltstone and gray limestone dominate. The source terrane involves the fine clastics and carbonates of the Ordovician Trenton, Utica, and Frankfort Formations. Carbonate content is apt to be moderately high. Together with the relative impermeability of these tills this results in disproportionally shallow leaching and profile development as compared with tills of the same age in the area dominated by the Ontario Lobe.

Till of Adirondack provenance is typically gray to yellow brown, moderately to very stony and with sandy matrix. It is apt to be relatively loose and permeable so that the distinction between lodgment and ablation drift may be obscure. Components derived from metamorphic rocks dominate in all size fractions. Distribution of very large metamorphic boulders on the landscape may be an indicator that obviates the need for clean exposures to distinguish it from either the Ontario Lobe or Black River Lobe tills.

Recognition of the three till types distinguished by provenance usually is clearcut, and made the more so by contouring of lateral variation (Street, 1966) or application of statistical techniques (Jordan, 1978). Nevertheless, transitional and intermediate characteristics are to be expected in interlobate areas, or in exposures of reworked or mixed till components.

DEGLACIATION OF THE SOUTHEASTERN TUG HILL PLATEAU

For present purposes, the southeastern Tug Hill Plateau is that portion of the subprovince drained by the Mohawk River and its tributaries. As such, it lies in Oneida County and largely in the area dominated during glaciation by the Black River Lobe of the continental ice sheet. It is an area of broadly rounded hills separated by open basins and reduced well below the inferred Appalachian summit accordance. Boonville Gorge, the overfit valley inherited by Lansing Kill (Muller, 1964, p. 32) transects this portion of the plateau in a north-south direction from Boonville to Rome. West of Boonville Gorge, the upper course of the Mohawk River separates Quaker Hill from the higher summits of Webster and Clark Hills to the north. East of Boonville Gorge, the Steuben Basin, drained by Wells and Steuben Creeks, similarly separates South Mountain from the more rugged upland area that ranges east-west through Penn Mountain (1813 ft above sealevel).

The parallel alignment of elongate ridges in the central Tug Hill gives evidence of a time of dominantly south-southeastward glacier movement across the entire plateau with flowlines essentially unaffected by

PROGLACIAL IMPONDMENT

Fairchild (1912) outlined the succession of proglacial meltwater lake stages in the Black and Mohawk Valleys, a sequence modified slightly by subsequent work (Wright, 1972).

In the Black River Valley, meltwaters imponded in front of the ice at positions south of and including the Alder Creek Moraine escaped southward past Remsen into the watershed of West Canada Creek. This lake stage corresponds generally to Fairchild's Forestport Lake, although Fairchild considered the lake to have been imponded outside Ontario Lobe moraine.

Northward withdrawal of ice in the Black River Valley to the position marked by kame moraine remnants south of Boonville opened the Boonville Gorge, lowering the imponded waters nearly 100 ft to a threshold on the Trenton Limestone. Although the threshold resisted erosion, downvalley incision into glacial drift and Utica Shale was relatively rapid. This lake stage, referred to as Port Leyden Lake by Fairchild (1912) persisted until northward glacial recession uncovered lower outlets around the north margin of the Tug Hill. The resulting Glenfield Lake occupied only the northern portion of the Black River Valley.

In the Steuben Basin, impondment began as the Black River and Oneida Lobes separated. Although the earliest lake stage may have been above 1000 ft as part of a more widespread lake in the Mohawk Valley, the main or "Steuben Stage" of Wright (1972) persisted later as a local lake draining east past Merrick Corners and Steuben Valley. Paired terraces in the Lansing Kill Valley downstream from the confluence of the Mohawk River record changing base level in this system down to about 830 ft. Below this level, local impondment was restricted to the Lansing Kill Valley (Wright's "Frenchville Stage") during the Stanwix Glaciation. Progressive capture of remaining impondment in the Steuben Basin by westward draining Wells Creek has resulted in subsequent incision of the Wells Creek Gorge east of Frenchtown.

Glacial withdrawal from the Stanwix Moraine exposed the eastern portion of the Oneida plain bringing into existence a series of short lived lake levels collectively referred to as "Hyper-Iroquois" (Fairchild, 1902). The following main Iroquois lake stage, controlled by the threshold near Rome, persisted until initiation of drainage north of the Adirondacks.

POSTGLACIAL MODIFICATION

Landscapes of the southeastern Tug Hill Plateau have a dominantly glacial imprint. They are a legacy of the Pleistocene, but this is not to deny that postglacial modification has taken place.

The draining of Lake Iroquois exposed broad sandy flats to eolian modification. Notable in this regard is that portion of the bed of Lake Iroquois into which streams flowed from the southern slopes of the Tug Hill. Wind erosion and deposition of an extensive area northwest of Rome produced characteristic dune and blowout topography, evidence of dominant west-northwesterly winds during the interval before stabilization by vegetation cover.

underlying topography. This condition is inferred to have persisted as late as Valley Heads time, that is roughly 13,800 years ago.

As a result of subsequent thinning of the ice sheet, irregularity of the glacier margin began to reflect the interference of overridden obstructions. Even while the highest parts of the Tug Hill were ice-covered, lobation of the ice margin began to develop in response to relative ease of glacier flow in the Black River and Oneida-Mohawk Lowlands. Late Wisconsinan retreat from the Valley Heads Moraine was neither continuous nor uniform. In the valley of West Canada Creek between Newport and Poland till overlies laminated lake sediments marking glacial readvance (Kay,1953, p. 97). Numerous lines of independent evidence (for instance, see Andrews, and Jordan, 1978) indicate that more than once in post-Valley Heads time, meltwater drained freely from central New York east to the Mohawk Valley. Three stops in the accompanying guide record oscillations of a fluctuating ice margin and ultimate stagnation. At STOP 1, for instance, the intercalation of lodgment tills and intervening lake beds records oscillation of an ice margin fronting on waters ponded in the Mohawk Valley. Deformation of the intercalated lake beds may have resulted either from static loading of dilatant, water-saturated sediments beneath thickening ice, or from shear beneath actively flowing ice.

A marked change of conditions is recorded during construction of the Oriskany-Whitestown Sand Plain adjacent to STOP 1. This feature described by Dale, (1953, p. 160) is, properly, a dalsandur, a remnant of valley train with surface elevation about 550 ft above sealevel. As exposed in several large pits between Oriskany and Whitestown, the terrace is underlain by 50 to 100 ft of essentially horizontal, ripple-bedded coarse sand and gravel, capped by 25 ft or so of coarse cobble gravel. Clearly, the gravel cap records a distinct change in depositional conditions, as for example might result from approach of the contributing ice margin or the opening of free drainage. Prominent kames mark a portion of the southwestern or proximal margin of the plain. The Whitestown Esker, a 1.25-mi long serpentine ridge develops into a reticulate of minor ridges as it approaches the edge of the plain indicating subglacial drainage through fractures in a stagnant and decaying ice mass.

Closely related to the Oriskany-Whitestown Sand Plain is the plain of Ninemile Creek southwest of Holland Patent. Rather than a simple delta as suggested by Brigham (1898, p. 196), it is a complex surface composed of lake sediments, and outwash. Between Stittville and Floyd, the arcuate pattern of swell and swale is indicative of receding ice margin positions. At Floyd, a well-defined ice-marginal channel incised into Utica Shale opens eastward onto the plain. Southwest of Floyd an east-southeasterly alignment of alternating kame ridges and shallow channels gives way to kettle-pocked outwash plain. The surface of the plain, though remarkably consistent at about 525 ft seemingly is graded to a lower surface than the Oriskany-Whitestown Plain. Northwestward tracing of the ice-marginal alignments represented by these channels and ridges indicates their continuity with and relationship to similar channels and ridges northwest of Rome. Together these features mark the Stanwix Glaciation, a readvance of the Oneida Lobe into the Mohawk Valley at a time when free eastward drainage was well established.

Other areas of former lake bottom, particularly those in which drainage remained impeded either by high-water table or relatively impermeable substrate passed gradually through a cycle of sedimentation, eutrophication and fen development accounting for extensive swampy areas.

Notable as representing the transition from glacial to fluvial landscapes has been the process of gorge incision in upland areas, and flood plain development on valley floors. The Utica Shale, in particular, because of its erodibility and jointing has been particularly susceptible to gorge incision, as is well illustrated in the Wells Creek Gorge, the "Palisade" where Delta Reservoir is imponded, and in parts of the Boonville Gorge.

Nevertheless, landscape adjustment to postglacial environmental conditions had only begun to make a good start when new and traumatic change was set in motion by the arrival of Man and the stresses imposed on natural systems by modern technology.

Topographic maps involved in Field Trip A-4 include: Boonville, Clinton, Forestport, North Western, Oriskany, Remsen, Rome, Westernville, and West Leyden quadrangles of the U.S. Geological Survey 1:24,000 map series.

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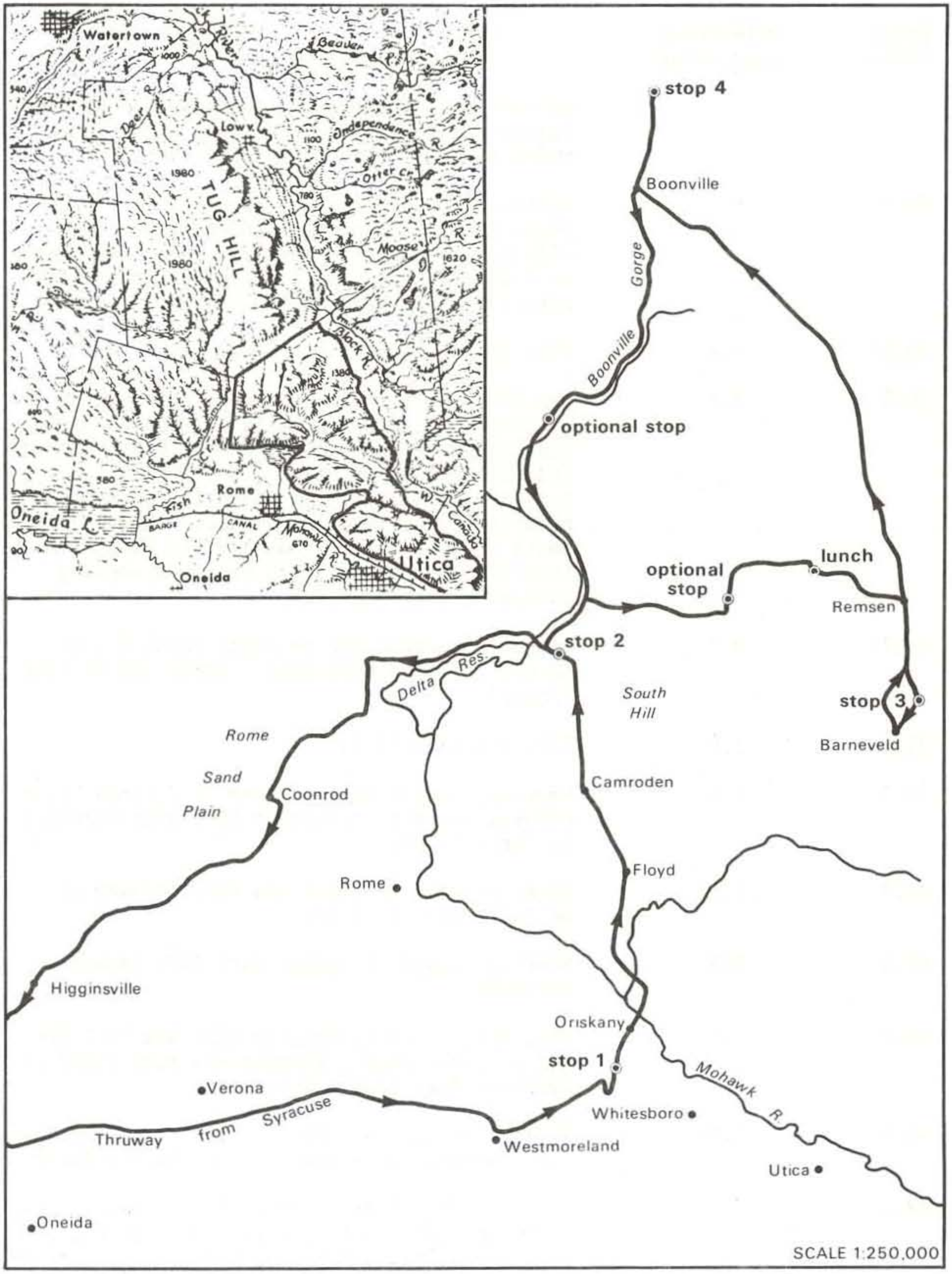
FIELD TRIP GUIDE FOR GEOMORPHOLOGY OF THE SOUTHEAST TUG HILL PLATEAU

Ernest H. Muller

Total Miles	Miles from last point	Route Description
0.0	0.0	Assemble in parking lot at Manley Field House, corner of Colvin St. and Comstock Ave. Proceed west on Colvin across Comstock to railroad overpass.
0.6	0.6	Turn right, north, to enter Interstate Route I81, northbound, immediately beyond railroad overpass and before Route I81 overpass.
		Beyond Adams Street (Exit 18), stay in right lane to be ready for ramp to Route I690.
2.2	1.6	Stay right, east, on ramp to Route I690, eastbound.
		Continue east past Teall, Midler, and Thompson Road (Exits 8, 9 and 10-11) on Route I690. This route follows the lowest of the Syracuse Channels by which proglacial meltwater drained from Onondaga Trough east toward the Mohawk Valley. Exposures of Syracuse Formation in its type area are visible south of Erie Boulevard on right.
4.8	2.6	Pass Thompson Road, Exit 10-11 and move toward left lane to be ready for ramp to Route I481.
6.6	1.8	Stay left on ramp to Route I481, northbound, following signs for New York Thruway. Beyond Kirkwood Road exit all traffic bears right to New York Thruway.
11.2	4.6	New York Thruway Toll Gate 34-A, Follow left lane as it curves right across Thruway to eastbound lane toward Utica.
		Travel east across plainlands, the floor of proglacial Lake Iroquois. This area underlain by nonresistant Vernon Shale accounting for basin. Bedrock topography with local relief of 150 ft in next few miles is concealed by postglacial lake sediments.
16.7	5.5	Sandy, stone-free soil in fields on left. Ephemeral strand line of low lake phase that succeeded Lake Iroquois in the Canastota mucklands is in trees at left. Dune modification



Route for field trip on Geomorphology of Southeastern Tug Hill Plateau

Total Miles	Miles from last point	Route Description
		of the backshore sands is visible briefly and better developed along Chestnut Ridge Road which parallels the Thruway to the north.
22.0	5.3	Vernon Shale exposed in low roadside cut on right (south) side of eastbound lane, opposite Chittenango Service Area. For next several miles the strand of Lake Iroquois trends parallel to Thruway on the South.
26.8	4.8	Pass Canastota Exit 34.
30.5	3.7	One mile south of the Thruway, not readily visible is Wampsville, site of Madison County Courthouse. A well on the property of Hubbard Industries located near a Lake Iroquois spit, taps an artesian system at 90 ft and flows a reported 700 gallons per minute. Gravel pits south of Route NY 5 in Wampsville expose two impermeable lodgment tils with intervening permeable cobble gravel.
33.7	3.2	Iroquois barrier bar on right about 0.2 mi before railroad underpass. Leave bed of Lake Iroquois.
34.7	1.0	Pass Verona Exit 33.
39.3	4.6	Herkimer Sandstone of uppermost Clinton Group exposed south of eastbound lane discontinuously for 0.25 mi.
44.9	5.6	Enter offramp to leave New York Thruway at Westmoreland, Exit 32.
45.4	0.5	Shortly beyond tollgate, turn left toward Oriskany.
45.9	0.5	Stay left at fork, passing over New York Thruway on Cider Road. Immediately turn right on Humphrey Road toward Oriskany.
48.2	2.3	At fork in Colemans Mills, stay left, continuing parallel to Oriskany Creek on its north.
48.8	0.6	At STOP sign, turn right onto Judd Road. Descend and cross Oriskany Creek. Roadcuts expose stratified drift indurated at base, overlying firm, dark-gray, silty clay till.

Total Miles	Miles from last point	Route Description
49.1	0.3	Turn left at high tension power line, toward Whitesboro. Small gravel pit beneath power line was opened in the Whitestown Esker which parallels route on the right.
49.6	0.5	Left at fork. Cross Oriskany Creek and park on right.
49.9	0.3	STOP ONE. Streamcut bluff of Oriskany Creek, exposing intercalated lodgment tills and deformed lake sediments overlain by firmly cemented fluvioglacial gravel. The section records multiple oscillations of the Late Wisconsinan ice margin into proglacially impounded waters.
		Proceed north toward Oriskany. A few exposures of stratified drift across Oriskany Creek on the right. Out of sight to the south, the Whitestown Esker leads to the kame moraine south of Oriskany which fronts on the Oriskany-Whitestown Sand Plain at approximately 550 ft above sealevel. Numerous exposures in bluffs facing the Mohawk River show the Sand Plain to be underlain by 80+ ft of horizontally bedded sand and gravel, capped by 10 to 20 ft of coarse cobble gravel, in part firmly cemented with calcium carbonate.
50.9	1.0	At traffic light, cross River Street in Oriskany. Continue north across Oriskany Boulevard and Mohawk floodplain. Cross Mohawk River and Barge Canal. Continue north following signs to Stittville. Do not turn onto Route NY49.
52.4	1.5	Stay left onto River Road. Shale exposed in roadside ditches and gully at right. Follow River Road northwest.
52.9	0.5	Cross Ninemile Creek
54.9	2.0	Turn right, north onto Stearns Road. Rise onto pitted outwash plain. Irregular closed depressions due to melting of buried stagnant ice masses on both sides of road. Surface of undissected plain is about 525 ft above sea level, graded below the Oriskany-Whitestown Sand Plain. This surface is a *sandur*

Total Miles	Miles from last point	Route Description
		built where meltwater streams flowing along the margin of a progressively receding ice front spread onto the open valley floor.
56.3	1.4	The extensive sand mantle gives way to cobble gravel in a few low knolls. East of the road, weak channel development trends ESE.
56.9	0.6	Turn left on Koenig Road toward Floyd
57.2	0.3	In Floyd, cross Route NY365 and continue north toward Camroden. A well-developed, flat-floored marginal meltwater channel 250-300 ft wide, and cut into Utica Shale opens onto the sandur west of Floyd. North of Floyd, rise on drift mantled slope which in places shows low constructional topography.
59.7	2.5	Continue north through Camroden, crossing west end of South Hill.
63.1	3.4	Turn left, west, on Gifford Hill Road (South Hill Road). Cross Gifford Creek.
63.3	0.2	STOP TWO. GIFFORD HILL ROADCUTS
		Exposure of multiple tills, intercalated with partially indurated intraglacial stratified drift units.
		Continue west on Gifford Hill Road. Note indurated, eastward dipping foreset cobble to boulder gravel in road cut on right.
63.8	0.5	Turn right, north, on Route NY 46 toward Boonville.
65.7	1.9	In Frenchville, cross Wells Creek and immediately turn right, east, onto Wells Creek Road (Route NY 274).
		Eastward from Frenchville, Route NY 274 occupies the floor of a narrow, steep-walled defile incised by Wells Creek. Cut 200-ft deep in postglacial time, the gorge owes its character to rapid incision and the erosivity and vertical jointing of the Utica Shale. The gorge is incised into a fluvioglacial terrace at 800 ft above sea level built eastward into the Steuben Basin.

Total miles	Miles from last point	Route Description
66.9	1.2	Continue eastward on Route NY 274, following Big Brook. Prior to incision of the Wells Creek Gorge, this part of the basin of Big Brook was imponded. As long as the ice margin blocked westward drainage, outflow was east past Merrick Corners and down Steuben Creek. Freeing of the Mohawk Valley north of Rome initiated westward drainage, leading to incision of the gorge.
67.8	0.9	Continue on Route NY 274, climbing from flood plain of Big Brook to floor of proglacial Steuben Lake. Nearshore sands exposed in borrow pit on right. Just beyond borrow area, roadside ditch exposes oxidized calcareous lodgment till with silt-loam matrix.
69.6	1.8	Turn left, north, at Steuben Corners. Ascend sharply.
69.8	0.2	OPTIONAL STOP.
		Gully at right exposes black Utica Shale over Trenton Limestone. Roadside exposures contain dark gray till glutted with Utica Shale material near base, but with bright clast lithologies dominated by blue-gray carbonates with subordinate red sandstone and metamorphic rock types.
		Continue north
71.0	1.2	Turn right, east, toward Steuben Monument, entering Penn Mountain State Forest.
72.2	1.2	Vista southeast over Steuben Valley. Note increasing abundance of metamorphic boulders beyond this point.
72.7	0.5	Follow road as it turns south.
73.0	0.3	LUNCHEON STOP. Turn left into Baron Steuben State Memorial Park.
		Leaving park, turn left, east toward Remsen.
75.3	2.3	Pass Capel Ucha, Cemetery on site of old Welsh Church established 1804.
75.8	0.5	Turn right, south, onto Route NY12 at Remsen boundary.

Total Miles	Miles from last point	Route Description
77.6	1.8	Cross meltwater channel
78.3	0.7	Stay right onto ramp southbound to Route NY365 and Trenton (Barneveld).
78.6	0.3	STOP THREE BARNEVELD KAME COMPLEX Extensive gravel and sand pits expose coarse cobble gravel overlying thick stratified coarse sand section. Proceed south on Route NY365 toward Barneveld.
79.0	0.4	Turn right on old state road at north edge of flood plain before reaching bridge across Steuben Creek.
79.1	0.1	"Drumlin Lodge" on right; not a drumlin sensu strictu.
79.7	0.6	Minor moraine ridge cuts across road, then seen on left, south side of road.
80.4	0.7	Kettles in stagnant ice zone
81.6	1.2	Turn left, north, on Route NY12, roughly parallel to Cincinnati Creek and the course of proglacial meltwaters which drained from proglacial Lake Forestport in the south end of the Black River Valley. This region is broadly underlain by Trenton Limestone.
83.3	1.7	Swampy lowlands now drained by Cincinnati Creek comprised part of the floor of Lake Forestport.
83.6	0.3	End moraine remnants looping across valley presumed to mark minor stillstand of Black River glacial lobe.
88.8	5.2	At Alder Creek, cross dissected Alder Creek Moraine built while the Black River glacial lobe imponded the southward-draining proglacial Lake Forestport in area of present Kayuta Reservoir. Westward, Alder Creek moraine includes extensive stagnant ice deposits and the Echo Lake Esker.
95.7	6.9	Pass Boonville, continue north on Route NY12. Park Hill and Sperry Hill to right (east)

Total Miles	Miles from last point	Route Description
		of Route NY12 in southern outskirts of Boonville are massive sand and gravel mounds, interpreted as dissected remnants of kame moraine.
99.6	3.9	STOP FOUR. ALLIED CHEMICAL COMPANY, BOONVILLE LIMESTONE QUARRY. Formerly DeLia's Quarry, as access to Sugar River. We do not have permission to examine the quarry as such. Warning: beware of mosquitoes, algal slime on rocks in streambed, poison ivy, and cow patties! Objective is to examine classic solution pits in limestone and subterranean piracy in progress.
		Return south on Route NY12 toward Boonville.
		Note masonry of several locks of the old Black River Canal in roadside exposures, first on the left (east), then on the right (west) side of the road. Built in 1855 to link navigable reaches of the Black River north of Lyons Falls with the Erie Canal at Rome, the Black River Canal was only briefly economical. With a total of 109 locks in 35 mi, the canal crossed a divide 700 ft above the Erie Canal.
102.7	3.1	Turn right (W) across tracks on Schuyler Street into Boonville. At west side of triangle, turn left, south, onto Route NY46, Post Road, toward Rome.
104.2	1.5	Morainal topography on right (west). Large sand and gravel knoll on left (east), similar to Sperry and Park Hills. Descend 30 ft to valley floor.
105.2	1.0	Crossing the broad, flat-bottomed rock-floored channel across Trenton Limestone ledgerock at the head of Boonville Gorge. This ledge controlled outflow from proglacial Port Leyden Lake. Cross feeder canal for Black River Canal. Continue south parallel to an incised and constricted channelway, thence crossing diagonally back to west side of valley to parallel the old Black River Canal.
106.8	1.6	Shale bluff in roadcut on right indicates

Total Miles	Miles from Last Point	Route Description
		erosivity of rock into which the Boonville Gorge is cut. To this point the valley has become progressively narrower. The distance that minor ridges of the Alder Creek Moraine project southward down Boonville Gorge indicates prior meltwater drainage toward Rome. At left, across Boonville Gorge, Lansing Kill enters from the east side of the valley. Originating as a meltwater stream marginal to the Alder Creek Moraine on the flank of Potato Hill, Lansing Kill has, from this point downvalley inherited the valley of a short-lived but powerful stream, the outlet of proglacial Port Leyden Lake. Postglacial incision by Lansing Kill accounts for abrupt deepening of the narrow inner gorge at this point. Its proglacial predecessor deepened the valley some 175 ft.
109.2	2.4	OPTIONAL STOP: PIXLEY FALLS, BOONVILLE GORGE STATE PARK Continue south toward Rome on Route NY46.
110.2	1.0	"Five Combines" - a flight of 5 adjacent locks where the old Black River Canal crosses a limestone ledge on the side of Boonville Gorge.
114.5	4.3	Mohawk River enters Boonville Gorge from west with multiple terraces now incised by both Lansing Kill and Mohawk. The highest terrace, above 1000 ft is an ice marginal delta plain. Lower terraces have correlable equivalent remnants on the east wall, indicating they were fluvial and graded to lowering base level controls in the Mohawk Valley to the south.
115.8	1.3	Village of Northwestern. Continue south on Route NY46.
118.6	2.8	Stay right into Village of Westernville.
118.8	0.2	Turn sharply right to cross Mohawk River. Grave of William Floyd, signator of Declaration of Independence is on right. Floyd Homestead was on left.
119.8	1.0	Vista across Delta Reservoir, artificially

Total Miles	Miles from last point	Route Description
		imponded in the basin created by deposition associated with Stanwix glaciation across the mouth of Boonville Gorge. In postglacial erosion the Mohawk River failed completely to recover the bedrock valley. At the site of the Delta Reservoir Dam, it incised a steep-walled, 80-ft deep defile into Utica Shale.
124.0	4.2	Turn left onto Turin Road (Route NY26) at Stokes Corner. The route now crosses a gravel plain (sandur) similar in origin to the plain of Ninemile Creek crossed this morning. Marginal meltwater channels pinned against the plateau margin to the north here spread onto the basin floor.
125.0	1.0	Half a mile west of this point was the Village of Delta. Inundated by construction of the dam in 1911, it survives only in the name of the reservoir that supplanted it.
125.3	0.3	Continue south past first cross road.
125.5	0.2	Turn right on road to Lorena
127.7	2.2	Stay left at fork toward Coonrod, traveling over Rome Sand Plains.
129.4	1.7	At Coonrod, turn left, then in 100 yd turn right again. Continue southwest across Rome Sand Plains. Following demise of Lake Iroquois the sandy sediments delivered by Fish Creek and other streams draining the Tug Hill were vulnerable to wind erosion as indicated by low dune and blowout topography.
131.2	1.8	Cross Oswego Road at STOP sign, then stay right, joining Route NY46 toward New London.
133.9	2.7	Continue on Route NY46; stay left, leaving Route NY49. Cross Barge Canal at New London. Route NY46 follows the abandoned Erie Canal which has been restored as parkway, canoe, and bicycle path.
139.8	5.9	Picnic and parking area alongside Erie Canal.
140.3	0.5	Turn right, west, onto Route NY31, following signs to New York Thruway, West.

Total Miles	Miles from last point	Route Description
143.9	3.6	Turn left, north, onto Route NY13, following signs to Canastota and New York Thruway.
146.6	2.7	Turn left to enter New York Thruway at Canastota Toll Gate. Leaving Toll Gate, stay left across Thruway to enter westbound lane, following signs to Syracuse.
162.2	15.6	Stay right on ramp to Syracuse Exit 34-A and Route I481.
165.4	3.2	Stay right on ramp to Route I690, following signs to Cortland and State Fairgrounds.
168.2	2.8	Pass Teall Avenue Exit 8; work across to left lane to be ready for ramp to Route I81.
169.0	0.8	Stay left on ramp to Interstate Route I81.
170.9	1.9	Stay right onto ramp to Brighton exit, leaving Route I81.
171.2	0.3	Turn right, north, onto State St.
171.5	0.3	At first traffic light, turn right onto Colvin St. Pass under Route I81 and railway overpass.
172.2	0.7	Colvin St. at Comstock Avenue. Enter parking lot at Manley Field House.

Benthic Communities of the Ludlowville and Moscow Formations (Upper Hamilton Group), in The Tully Valley, Onondaga County

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INTRODUCTION

The Devonian System in New York State varies from carbonates below (Ulsterian and lowest Erian Series) to coarse continental clastics at the top (Chautauquan Series), and represents a westward migrating deltaic complex built during Middle and Late Devonian time.

This deltaic complex, the Catskill Delta, is today represented by a wedge of sedimentary rock that thickens and coarsens eastward. The clastic wedge is pierced at several horizons by relatively thin, but geographically widespread, lithologically distinct units that do not change facies as rapidly as the rocks above or below. Serving as time planes, these key beds subdivide the clastic wedge into a number of major time-stratigraphic units.

Three carbonate keybeds in the lower portion of the wedge serve to subdivide the lowest time stratigraphic unit, the Hamilton Group (Middle Devonian), into four formations; which are from oldest to youngest, the Marcellus, Skaneateles, Ludlowville and Moscow Formations.

The Middle Devonian Hamilton Group of New York State is structurally simple and highly fossiliferous, thereby lending itself to detailed stratigraphic, paleontologic, and paleoecologic studies. In Central New York it consists of approximately 1,000 feet of shales, silty shales and silstones lying above the Onondaga Limestone and below the Tully Limestone. The stratigraphic relations of the Hamilton Group of New York as now understood were first clarified by Cooper's classic papers (1930, 1933).

The Hamilton rocks in the Tully Valley dip to the south 25^{0} west at approximately 48 feet per mile, based upon the Centerfield Member as a datum (Grasso, 1966). The value obtained for the dip agrees with Cooper's (1930) estimate of 45 to 50 feet per mile to the southwest.

Superimposed on the regional dip are local low anticlines and faults. A thrust fault with associated folding occurs just south of Marcellus along NY Route 173 (Smith, 1935). Oliver (1951) shows conclusively that several normal faults, downthrown to the north, occur on the southwest side of the

Tully Valley near Lords Hill. A thrust fault in the Onondaga Limestone and overlying Union Springs Member can be seen 1 mile south of Nedrow (Prucha, 1964, p. 49).

HAMILTON SECTION IN THE TULLY VALLEY

In the Tully Valley, the Hamilton is composed mainly of two facies that transgress time westward. The lower is a fissile black and dark shale facies of the anaerobic distal basin containing a low diversity primarily pelagic fauna. Lying above this facies in the Tully Valley, but partly contemporaneous with it farther to the east, is one representing a subtidal shelf - delta platform environment of silty shales and siltstones carrying a high diversity benthonic fauna. The Ludlowville and Moscow Formation typify this facies in the Tully Valley.

STRATIGRAPHY

Ludlowville Formation

The Ludlowville Formation is the most fossiliferous unit in the Tully Valley. It consists of about 260 feet of interbedded silty shales and siltstones and on the basis of these Smith (1935) divided the Ludlowville above the Centerfield into four members, the Otisco, Ivy Point, Spafford, and Owasco (Fig. 1).

Centerfield Member (Stops 5, 7, 8)

In the Tully Valley area, the Centerfield Member is lithologically gradational with the underlying Butternut Member of the Skaneateles Formation. It is a coarse siltstone about 25 feet thick. The lower and upper 10 feet are flaggy but the middle portion is calcareous and fossiliferous. The siltstone beds in the flaggy portions are about one inch thick and at some localities crossbedded. The contact with the overlying Otisco is sharp.

The Tully Valley Centerfield fauna is characterized by a great number of large epifaunal pelecypods.

Otisco Member (Stops 2, 6, 7, 8)

This unit is a soft, thinly bedded, slightly calcareous, silty, medium-gray to medium-dark shale, interbedded toward the top with thin siltstone beds. The contact with the Ivy Point Member, about 165 feet above the Centerfield, is sharp.

Fossils in the Otisco are extremely diverse especially in the lower 20 - 30 feet. Bryozoans, brachiopods, bivalves, gastropods, trilobites and echinoderm stems are all conspicuous in these intervals.

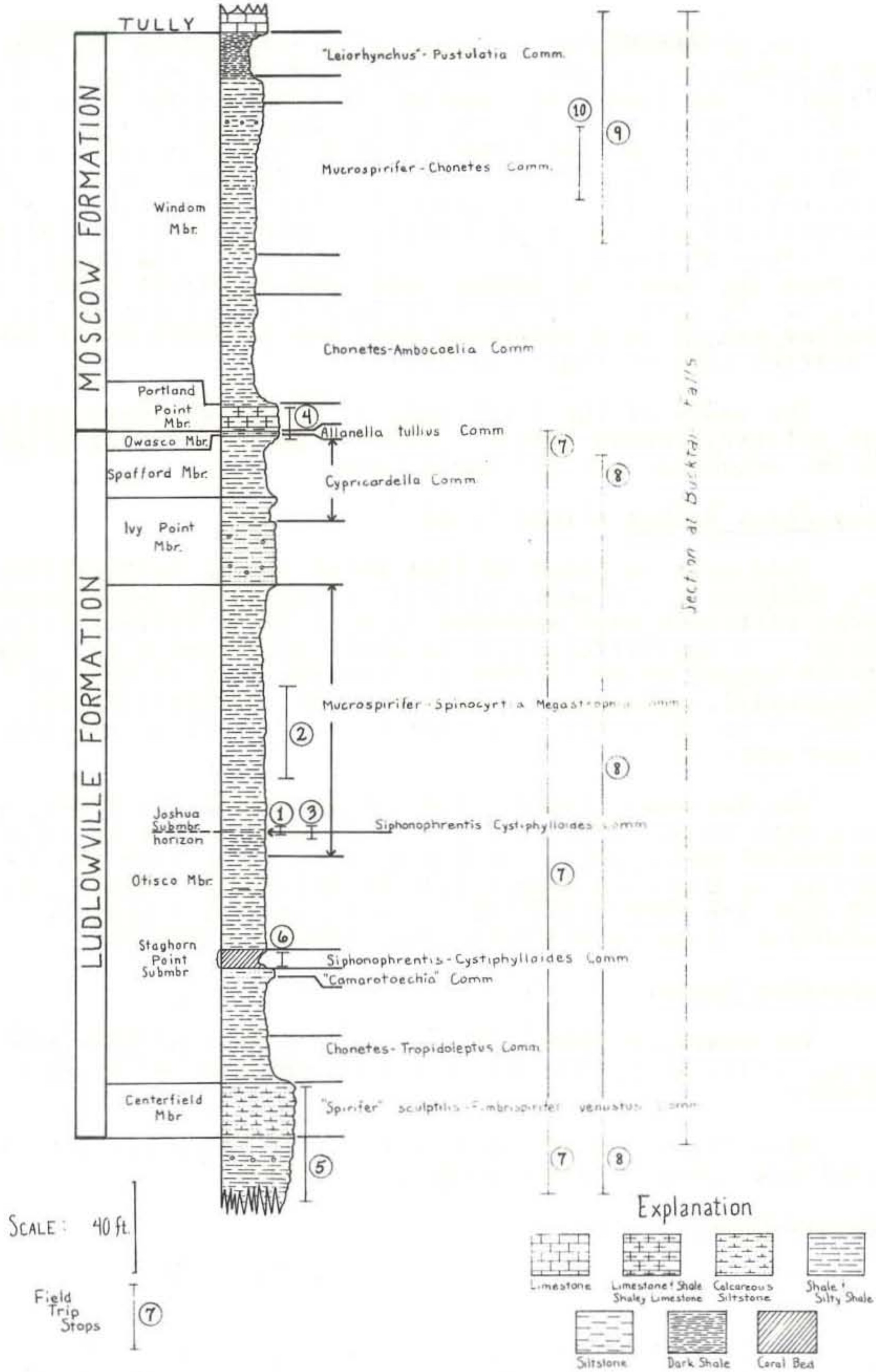


Figure 1. Benthic communities Ludlowville and Moscow Formations, Tully Valley.

The Otisco Member is especially interesting for two coral biostromes which have been given submember status by Oliver (1951). The lower, designated the Staghorn Point by Smith (1935), (Stops 6, 7, 8), is about seven feet thick in the Tully Valley. Oliver (1951) traced this unit over an area of 150 square miles, from Skaneateles Lake eastward to Limestone Creek Valley. It occurs about 50 feet above the top of the Centerfield and rests on a ripple marked, massive, calcareous, siltstone platform about 3 - 6 feet thick. The upper biostrome was named the Joshua Submember by Oliver (1951) (Stops 1,3). It varies from 0 to 55 feet in thickness in the Tully Valley and is less extensive than the Staghorn Point Submember covering some 40 square miles.

The fauna of the coral beds is composed almost exclusively of solitary rugose corals. Aside from a few Favositidae, other organisms are extremely rare.

Ivy Point Member (Stops 7, 8)

This unit is about 40 feet thick in the Tully Valley and is dominantly a flaggy, slightly calcareous, cross bedded, gray siltstone that weathers to a distinct yellowish-brown color. A fossiliferous silty shale unit from 4 to 7 feet thick occurs about 27 feet up from the base of this member. Spheroidal, calcareous, non-septarian, unfossiliferous concretions 3 to 18 inches in diameter are present in the lower and upper portions.

The massive siltstone beds of the lower Ivy Point, are reported to be moderately fossiliferous containing large epifaunal pelecypods, and brachiopods along with the large trilobite Dipleura dekayi (Clarke and Luther 1904). The upper 10 feet are more fossiliferous than the lower beds and contain abundant diverse epifaunal and infaunal elements.

Spafford Member

The Spafford Member consists of 27 feet of thin bedded gray, silty shale sharply overlying the coarse Ivy Point Member.

Faunally the Spafford is similar to the upper Ivy Point, yielding numerous brachiopods and bivalves.

Owasco Member (Stops 4, 7)

This member is a massive, calcareous, well cemented siltstone bed 2 feet thick.

Smith (1935, p. 50) defined the Owasco on the basis of "...the thin but important Spirifer tullius (Allanella tullius) Zone which follows the Spafford and is limited above by the

Portland Point..."

Fossils are difficult to extract and found in discontinuous highly fossiliferous zones, consisting mostly of brachiopods.

Moscow Formation

Exposures of the lower 50 - 70 feet of the 175 foot thick Moscow Formation are limited in the Tully Valley. Therefore, this interval can not be examined throughly. Many of the remarks pertaining to the Portland Point and lower and middle Windom Members were derived from the examination of Bucktail Falls Ravine on the west side of the neighboring Otisco Valley. (Fig. 1).

Portland Point Member (Stops 4, 7)

The upper and lower contacts of the Portland Point Member are sharp in the Tully Valley. A basal crinoidal, shelly limestone about 1 foot thick is succeeded by 11 feet of gray silty shale interbedded with thin crinoidal, shelly limestone bands 2 to 6 inches thick and about 8 inches apart. Cross laminations occur throughout.

Brachiopods, bivalves and crinoids stems dominate the assemblage, many of which are broken and disarticulated.

Windom Member (Stops 9, 10)

The Windom Member in the Tully Valley is a thin bedded gray to medium gray shale grading upward to medium-gray silty shale to a point 20 feet below the Tully, where a sharp lithologic change takes place to a dark gray or grayish black, non-calcareous, pyritiferous shale and this is in turn sharply overlain by the Tully Limestone. This dark shale appears as a reddish-orange zone beneath the Tully due to the weathering of pyrite. Zones of calcareous unfossiliferous, nonseptarian concretions occur throughout the Windom. The upper two zones are particularly noticeable and occur 30 feet and 8 feet below the Tully. The lower concretion zone, about 10 feet thick, consists of flattened elliptical concretions under 8 inches in diameter and 2-3 inches thick. The upper concretion zone is 4 feet thick and composed of round cannon ball type concretions 6 to 10 inches in diameter.

The Windom consists of fossiliferous zones which are separated by intervals of sparsely fossiliferous rocks. The fossiliferous intervals contain numerous epifaunal brachiopods, infaunal pelecypods, small corals, bryozoans, crinoid stems and trilobites. Epifaunal pelecypods are conspicuously low in number.

The dark shales at the top of the Windom contain epiplanktonic brachiopods, small epifaunal brachiopods, and small infaunal bivalves.

BENTHIC COMMUNITIES AND PALEOENVIRONMENTS

In the last several years paleoecological interpretations have been greatly strengthened through the community analysis approach. This concept pivots around the idea that combinations of certain abundant species define a community. This definition closely approaches that of Peterson (1913) and Molander (1930, quoted in Newell and others, 1959, p. 198) and subsequently utilized by Zeigler (1965); Zeigler, Cocks, and Ranbach (1968); Bretsky (1970); Sutton, Bowen, and McAlester (1970); Bowen, Rhoads, and McAlester (1974); Titus and Cameron (1976) and McGhee (1976).

Some of the communities named and delineated herein may include the habitat community of Newell and others (ref. cit.). An inherent problem in all this is the imperfection of the fossil record. Johnson (1964) presents tables illustrating that soft bodied organisms, almost never known as fossils, constitute anywhere from 33% to 99% of the total living community. From fossils we can make some inferences about past communities, but we must keep in mind they are not the same as the total community.

Other approaches to paleoenvironmental studies used in concert with, and as part of, community analyses would be trophic structure and paleoautecology or general adaptive type. The relative proportions of filter and deposit feeding organisms (trophic structure) has been used with some success in several cases (Driscoll, 1969; Grasso, 1973; Scott, 1976). However, Stanton and Dodd (1976) from benthic community studies in San Francisco Bay and the Pliocene of the Kettleman Hills, California, conclude that feeding type proportions in the fossil community are not always indicative of original environmental parameters.

Paleoautecology of the shelly fauna can be important in arriving at general paleoenvironmental conditions. Lophoporate filter feeders such as articulate brachiopods were probably all stenohaline save for some rhynchonellids and lingulids which were more tolerant of fluctuating salinites. In contrast, many bivalves may be euryhaline. Life habits (adaptive types) of various species of bivalves and brachiopods (Bowen, Rhoads, and McAlester, 1974; McGhee, 1976) through taxonomic analogy with modern taxa and functional morphology can yield significant data.

The communities and paleoenvironments outlined below are based on data such as species combinations, abundance, life habits (adaptive type), and trophic structure in addition to the physical criteria of gross lithology and sedimentary structures. These are shown on Figure 1. Most of the fossils mentioned below are illustrated on Figures 2 - 12.

"Spirifer" sculptilis - Fimbrispirifer venustus Community

The "S" sulptilis Community restricted to the Centerfield member is a moderate to high diversity community dominated by filter feeding pedunculate brachiopods and large bivalve molluscs. The ichnofossil Zoophycos (Taonurus) probably a deposit feeder is extremely abundant on many bedding surfaces. Corals (microcarnivorous) occur principally in the central more calcareous part of the Centerfield and include the rugose corals, Heterophrentis and Cystiphylloides as well as the tabulate Favosites.

The epibyssate filter feeding bivalves include Cornellites flabellum, Limoptera macroptera and Leiopteria dekayi. Other epifaunal filter feeders are represented by the brachiopods "Spirifer" sculptilis, Fimbrispirifer venustus, Spinocyrtia granulosa and "Camarotoechia" dotis. The infaunal filter feeding forms include the endobyssate (anchored in the substrate by byssus threds, Stanley 1968, 1972) bivalves Goniophora, Actinodesma (Glyptodesma) as well as the mobile filter feeding bivalves Grammysia, and Cimitaria. Fragments of the large trilobite Dipleura (Trimerus) dekayi are occasionally found.

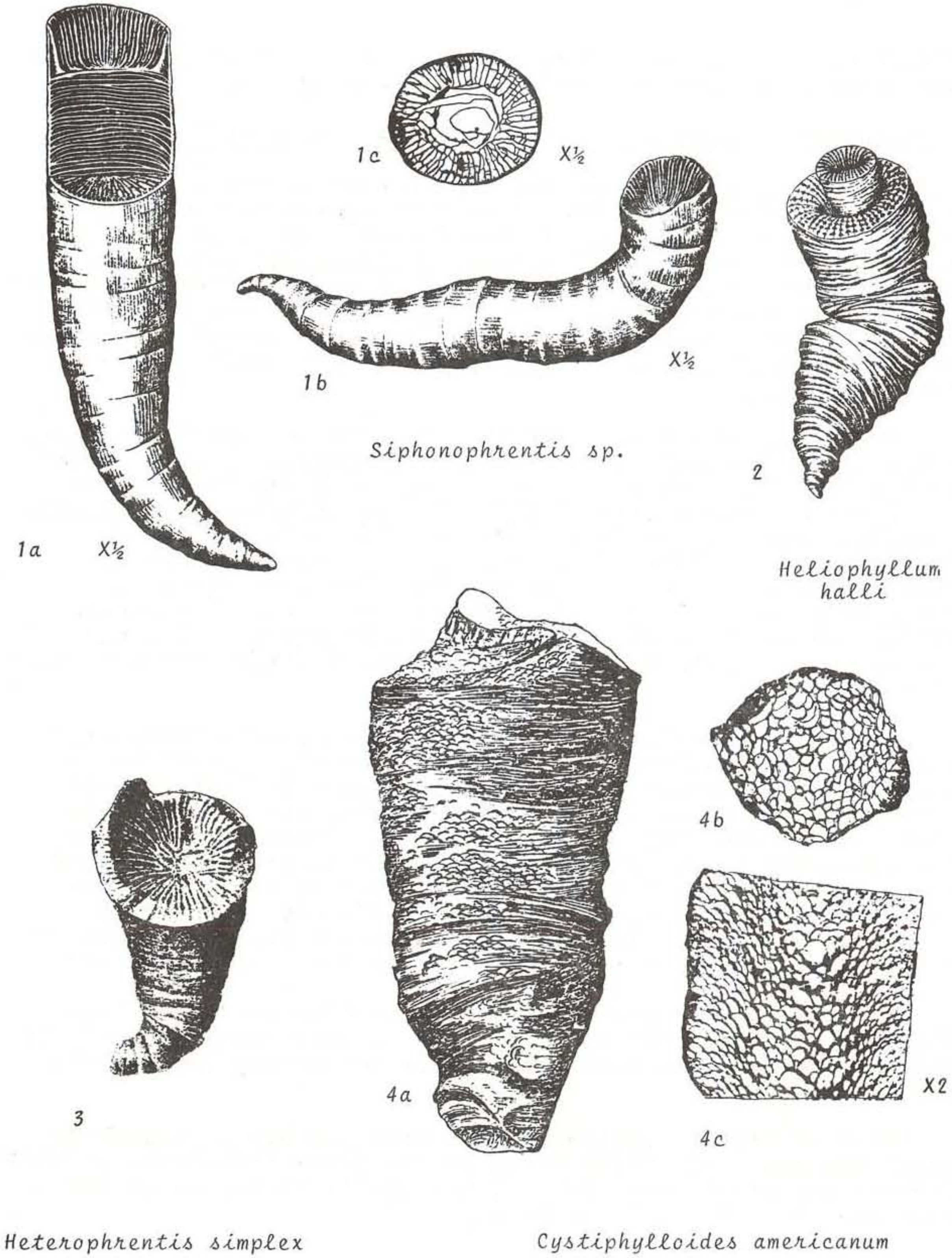
The "S" sculptilis community indicates a relatively high energy, shallow water, environment of the delta platform environment. Current activity was moderate to high, normal marine conditions prevailed, and the substrate was probably firm. Sufficient organic detritus was in suspension and in the substrate to support the varied feeding groups described above. The corals became established during times when the influx of clastic materials were at a minimum as these taxa were probably intolerant of turbid waters because of sediment clogging of their feeding mechanism (Selleck and Hall, 1977).

The crossbedded coarse siltstone or fine sandstone lithology of the Centerfield in the Tully Valley region attests to the high energy conditions that prevailed during Centerfield time.

Kramers (1971) hypothesizes an offshore bar or submarine shoal for the Centerfield based on its gross lithology, primary sedimentary structures, and lateral shifts in facies to the east and west of the Tully Valley.

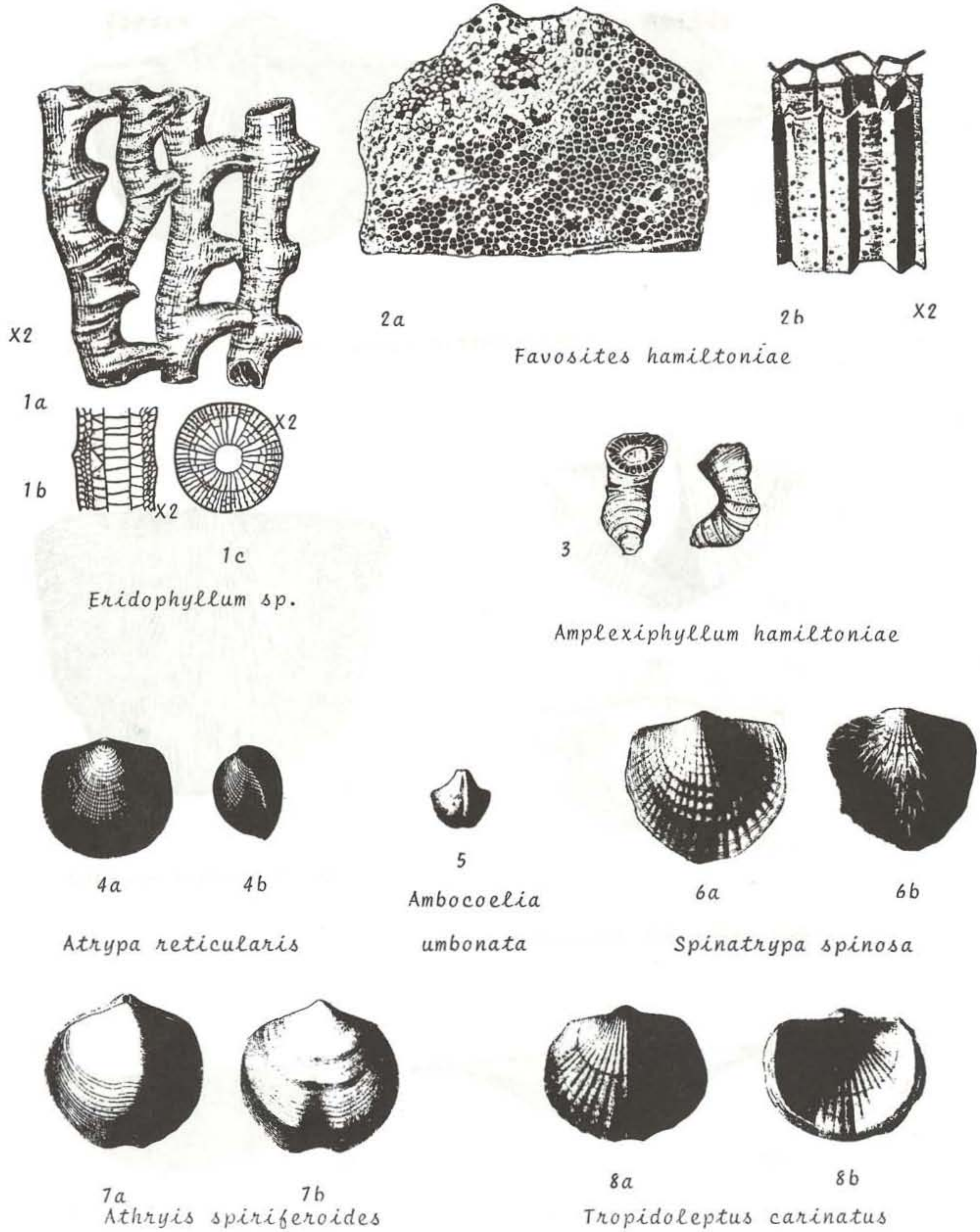
Chonetes - Tropidoleptus Community

The Chonetes - Tropidoleptus Community rests upon the Centerfield member and extends upward into the Otisco for 20 to 30 feet. The faunal diversity of this community is



(ALL FIGURES NATURAL SIZE EXCEPT WHERE NOTED)

Figure 2. Fossils mentioned in text.



Eridophyllum sp.

Favosites hamiltoniae

Amplexiphyllum hamiltoniae

Atrypa reticularis

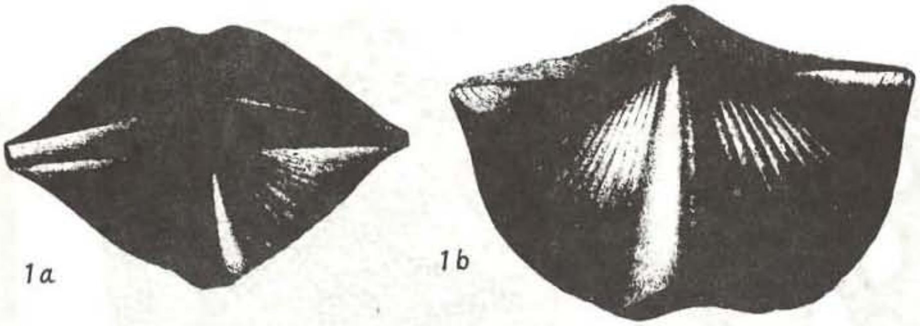
Ambocoelia umbonata

Spinatrypa spinosa

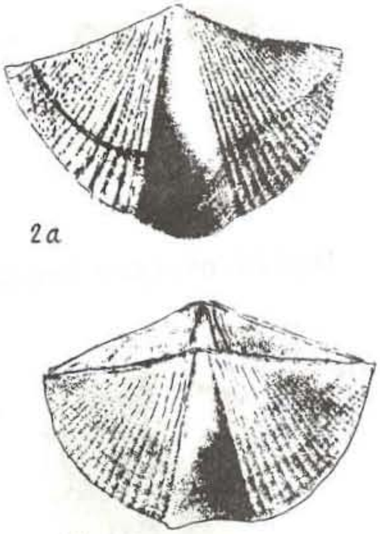
Athryis spiriferoides

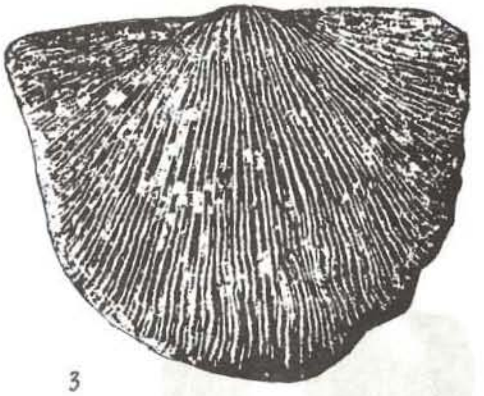
Tropidoleptus carinatus

Figure 3. Fossils mentioned in text.



Spinocyrtia granulosa



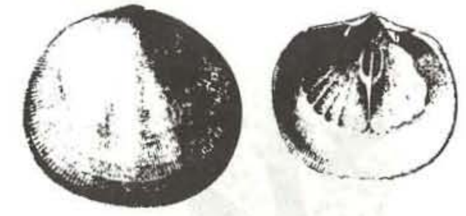


Megastrophia concava

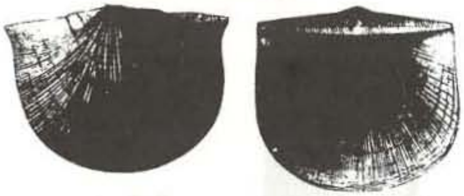
Mediospirifer audaculus

Mucrospirifer mucronatus

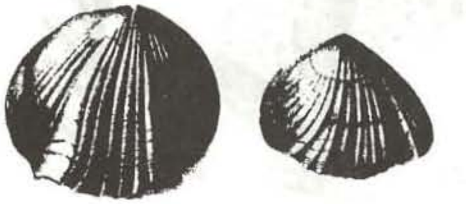
Figure 4. Fossils mentioned in text.



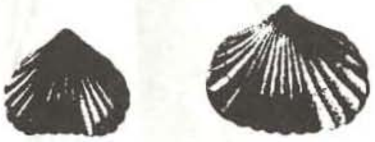
Rhipidomella vanuxemi



Stropheodonta demissa



"*Leiorhynchus*" *multicostata*

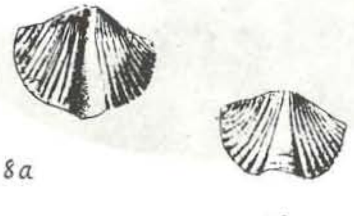


"*Camarotechia*" *sp.*

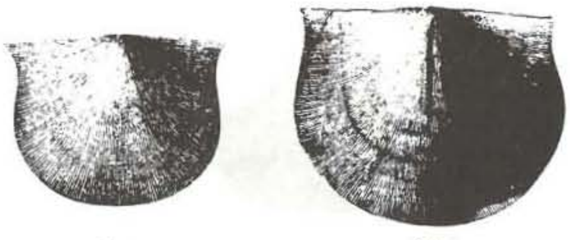
Chonetes coronatus

Spirifer sculptilus

Chonetes scitula

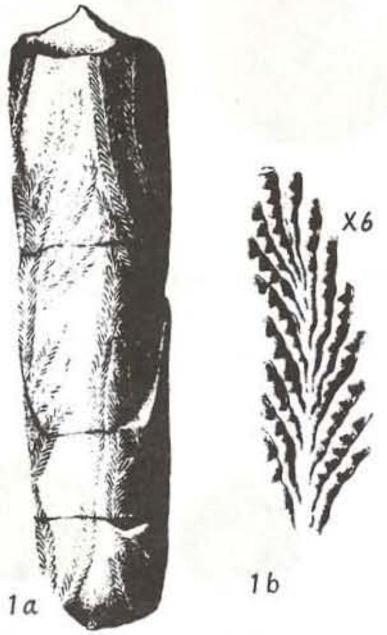


Allanella (Spirifer) tullius

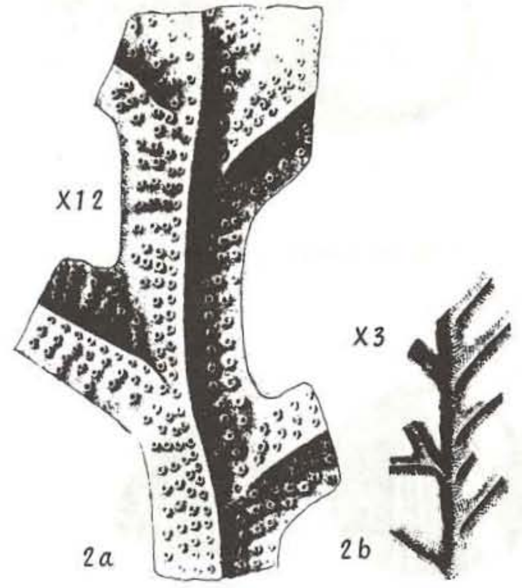


Protoleptostrophia perplana

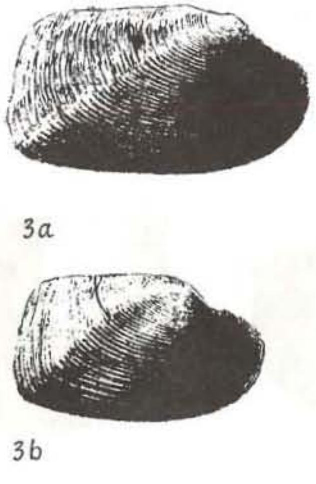
Figure 5. Fossils mentioned in texts.



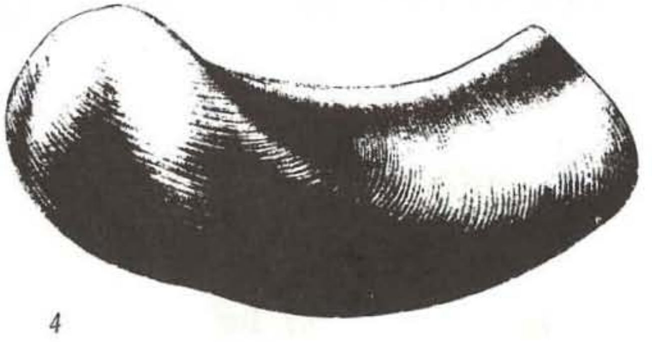
Reptaria stolonifera



Taenipora exigua

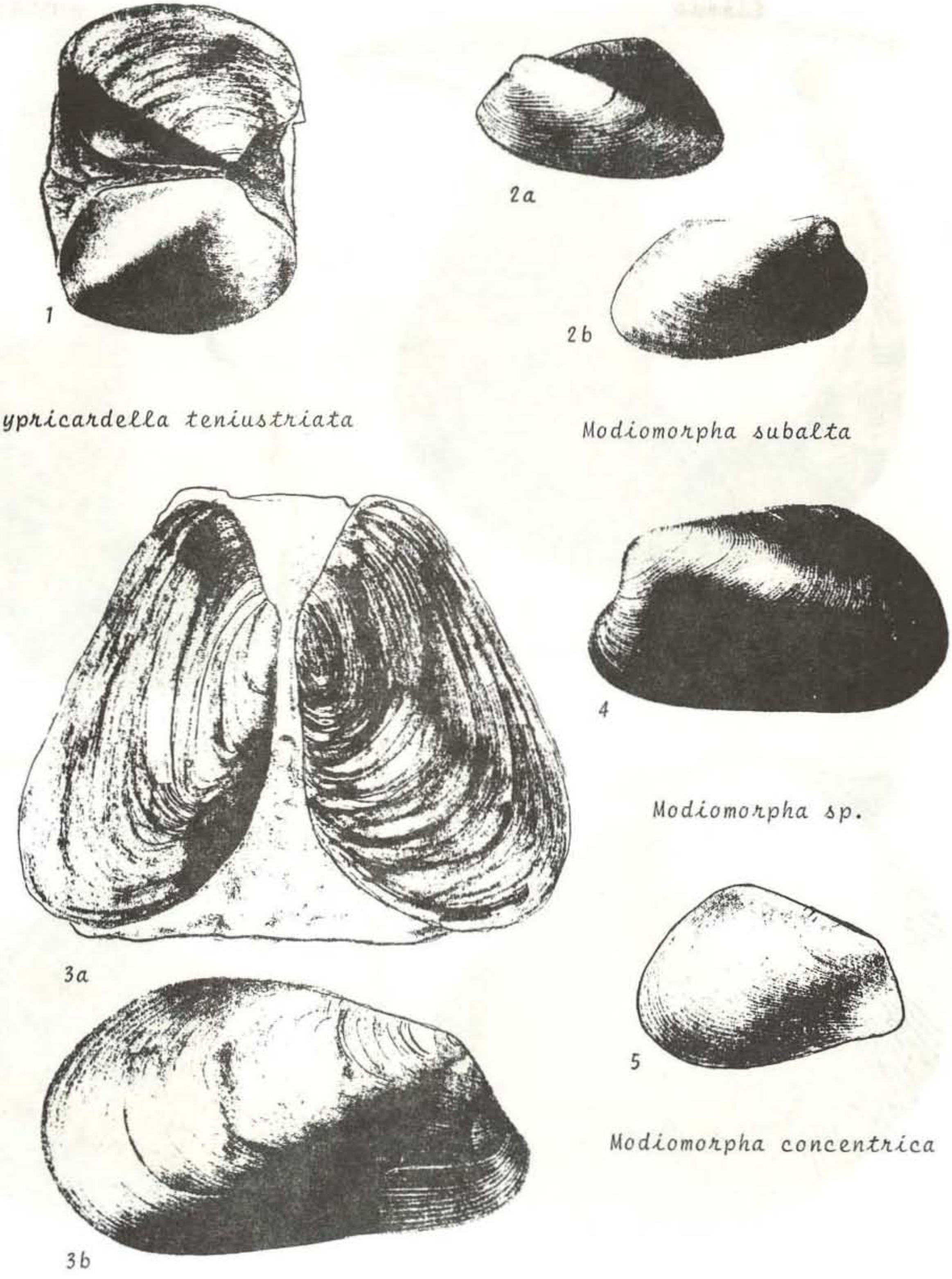


Cypricardella bellistriata



Cimitaria recurva

Figure 6. Fossils mentioned in text.



Cypricardella teniustriata

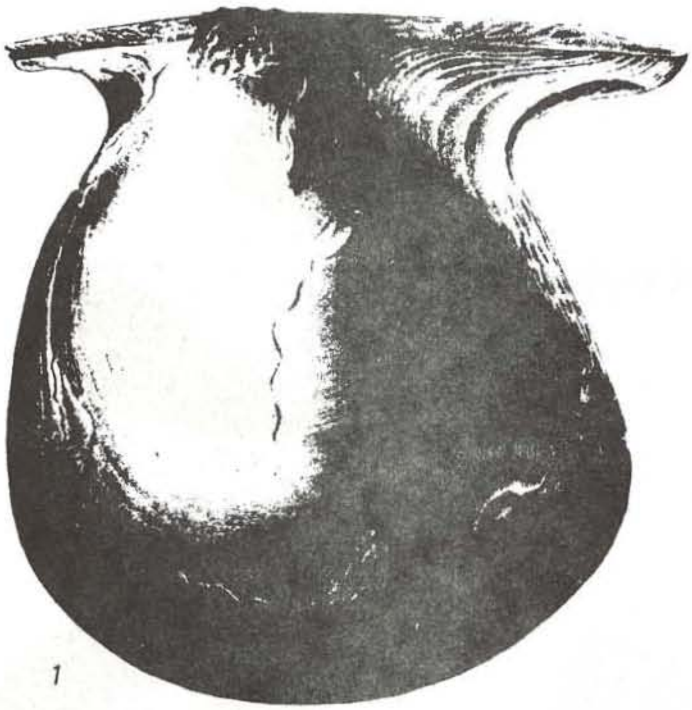
Modiomorpha subalta

Modiomorpha sp.

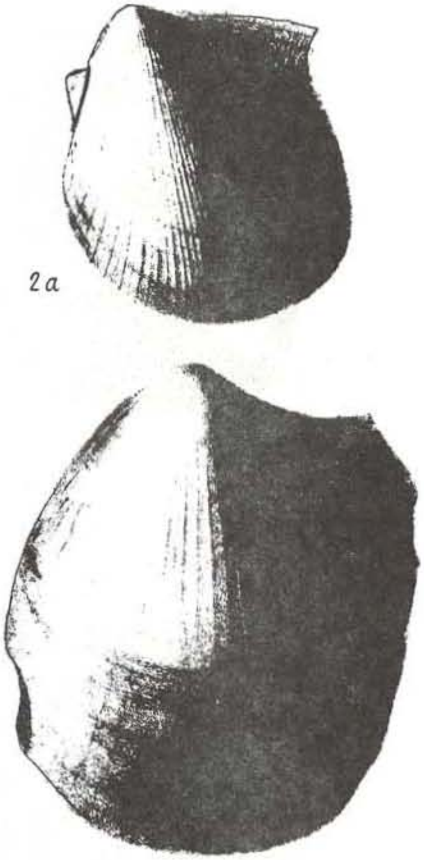
Modiomorpha concentrica

Modiomorpha mytiloides

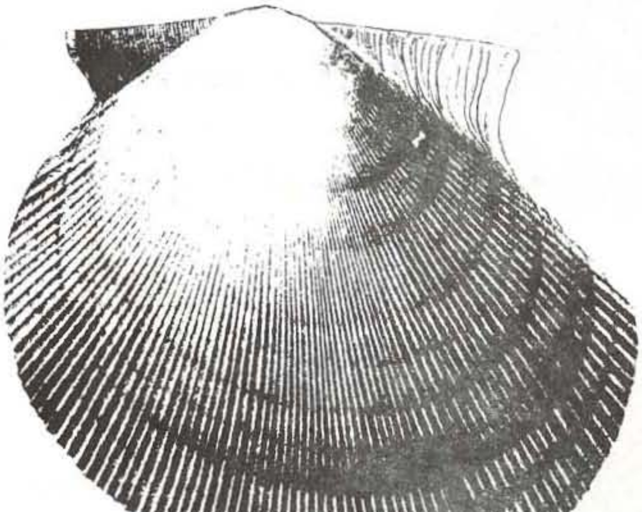
Figure 7. Fossils mentioned in text.



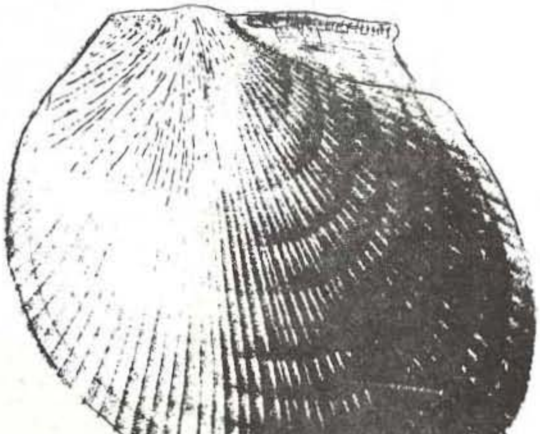
Actinodesma (Glyptodesma) erectum



Limopteria macropteria

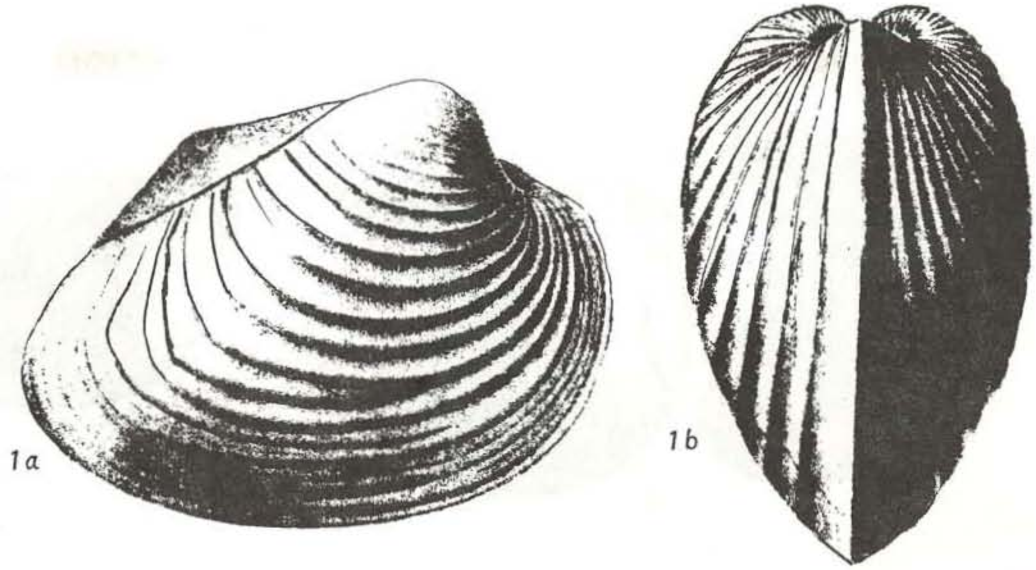


Pseudaviculopecten princeps

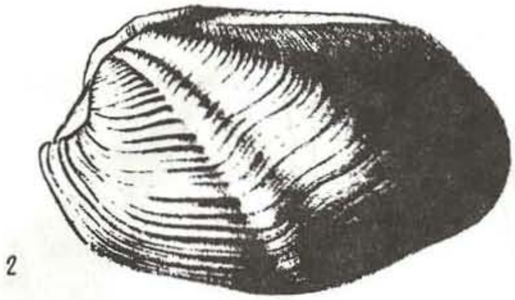


Lyriopecten orbiculatus

Figure 8. Fossils mentioned in text.

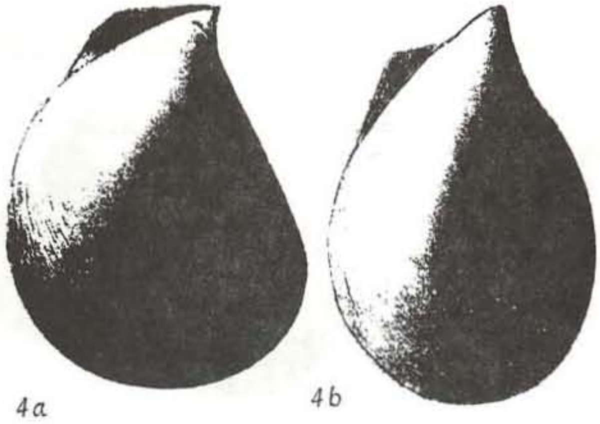


Grammysia alveata



Grammysia bisulcata

Goniophora hamiltonensis



Mytilarca oviformis

Figure 9. Fossils mentioned in text.

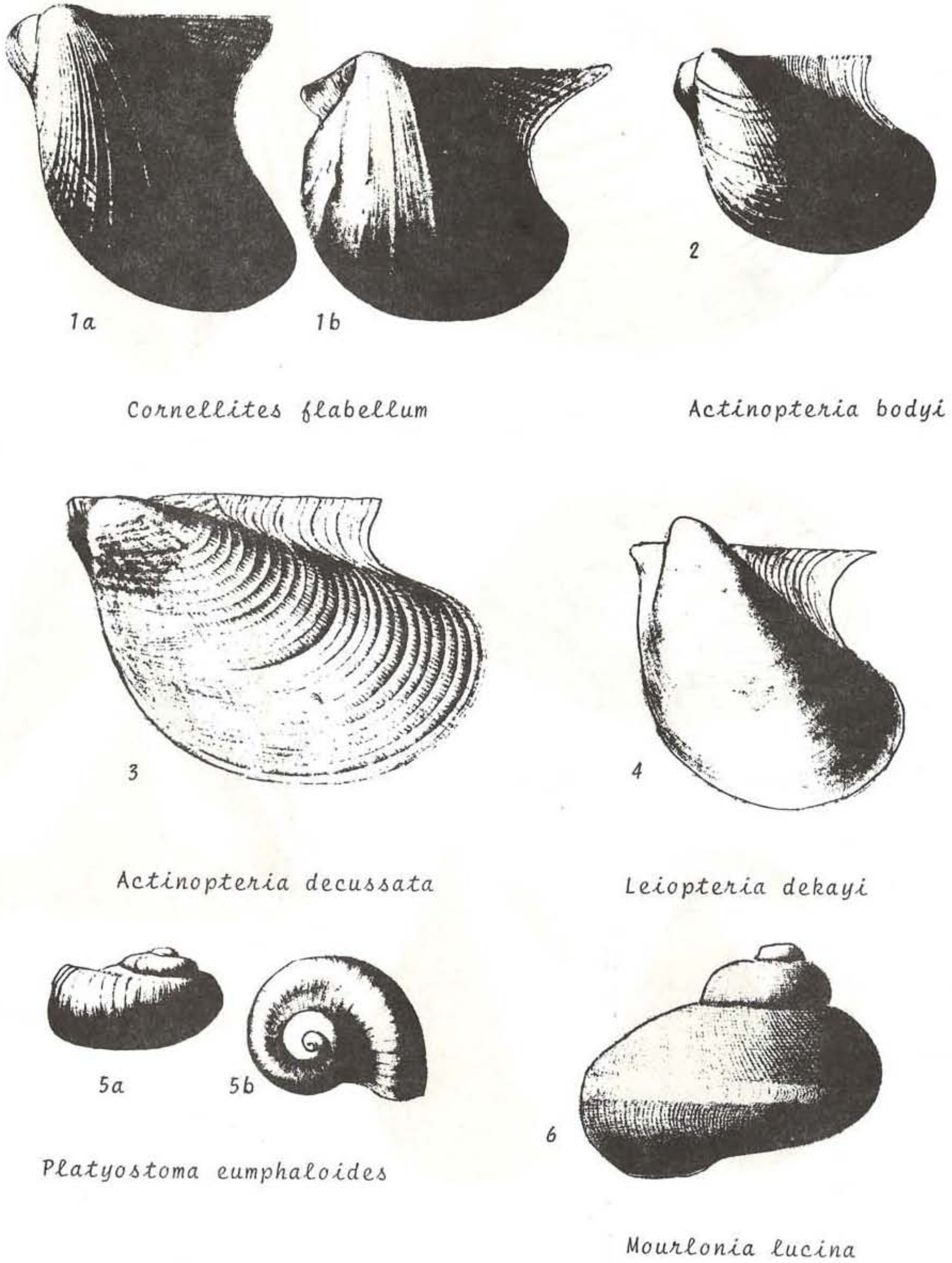
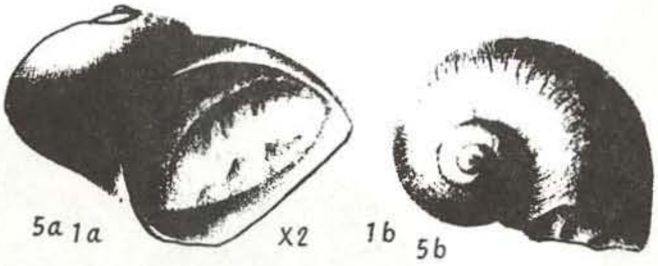


Figure 10. Fossils mentioned in text.

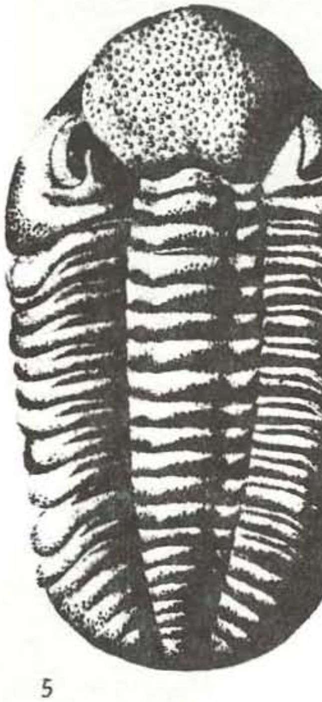


Naticonema (Platystoma) lineata

Loxonema hamiltoniae

Platyceras thetis

Greenops boothi



Phacops rana

Figure 11. Fossils mentioned in text.

1a

2

Zoophycos
(*Taonurus cauda-galli*)

1b

Dipleura dekayi

Figure 12. Fossils mentioned in text.

extremely high yielding over 60 species of typical Hamilton forms. The community is dominated by unattached and attached filter feeding articulate brachiopods such as Chonetes, Tropidoleptus carinatus, Protoleptostrophia perplana Spinocyrtia granulosa, Mediospirifer audaculus, Athyris spiriferoides, Mucrospirifer mucronatus, and Rhipidomella vanuxemi. Numerous worm trails are evidence of infaunal deposit feeders as well as the palp feeding bivalves Nuculites and Paleoneilo. Large epifaunal bivalves constitute a minor fraction of the total community.

The environment occupied by this community, was of low stress, located along the outer muddy-silty edge of the delta platform. Moderate energy for this environment is thereby implied along with low sedimentation rates. Vigorous current action was non operative and the substrate was probably soft to moderately firm. The attached pedunculate brachiopods such as Rhipidomella, Athyris, and Spinocyrtia probably anchored to abandoned shells, where as the strategy of unattached brachiopods was aimed at keeping the commissure free of mud by the snow-shoe effect of a deep incurved pedicle valve and spinose hinge line, e.g. Chonetes and the wide alate hinge of Mucrospirifer.

Camarotoechia Community

This low diversity community is restricted to the 6 to 7 feet of the hard, coarse, massive, siltstone platform that underlies the Staghorn Point Submember.

Camarotoechia dotis and Spinocyrtia granulosa dominate the assemblage with Athyris spiriferoides, Tropidoleptus carinatus and Mucrospirifer mucronatus playing minor roles.

A relatively high stressed, high energy environment is inferred, with abundant organic detritus in suspension.

This community may have inhabited a submarine shoal on the floor of the Ludlowville sea, similar to the one envisioned for the Centerfield in the Tully Valley region (Kamers 1971) reactivated during early Otisco time.

Siphonophrentis - Cystiphylloides Community

The Siphonophrentis - Cystiphylloides Community is conterminous with the Staghorn Point Submember and is characterized by moderate diversity with high density.

Oliver (1951, Table 1, p. 712) lists the dominate rugose species in this community in order of relative abundance as follows: Siphonophrentis halli, Cystiphylloides americanum, Cystiphylloides conifolis, Heliophyllum halli, and Heterophrentis ampla.

This community represents a dramatic change in paleoenvironmental conditions during Otisco time. Being composed nearly 100 percent of turbitidy intolerant microcarnivores, precludes rapid clastic sedimentation. The corals enjoyed optimal conditions for profuse growth such as relatively shallow, well oxygenated, clear, warm marine waters of normal salinities. Currents sufficiently strong to carry organic materials in suspension must have operated over the coral "gardens" which were, probably near wave base. The thriving corals were able to compete with other invertebrate groups so well that they virtually excluded them from becoming established members of the community. Maybe their food source was the larval forms of these invertebrates. With the return of relatively turbid waters and rapid, clastic sedimentation of the Otisco shale the *Siphonophrentis* Community came to an abrupt end.

The siltstone platform provided a firm substrate upon which the initial coral spat falls were able to become firmly established. Succeeding generations used the skeletons of their predecessors as substrates (Oliver 1951).

Mucrospirifer - Spinocyrtia - Megastrophia Community

This community occupies the upper 65-70 feet of Otisco silty shales beginning approximately 43 feet above the Staghorn Point Submember.

Mucrospirifer mucronatus is extremely abundant throughout but completely dominates the lower 20-30 feet of this community where species diversity is low.

Above this point diversity increases rapidly as epifaunal and infaunal filter feeding brachiopods and bivalves, infaunal filter feeding bivalves, infaunal deposit feeding bivalves and worms, and vagrant gastropods and trilobites make their apperance.

In the upper 30 feet the large attached brachiopods *Spinocyrtia granulosa* and the large unattached brachiopod *Megastrophia concava* are very abundant, occuring with numerous other brachiopods both attached and unattached. The large epifaunal bivalves *Pseudaviculopecten*, and *Cornellites* are also common along with the infaunal endobyssate *Modiomorpha mytiloides*. Nuculites and *Paleoneilo* are present as well as the trilobites *Phacops rana* and *Greenops boothi*.

The Otisco Shale is finer grained in the lower, *Mucrospirifer* bearing, 30 feet and gradually coarsens upward coincident with the increase in diversity.

Mucrospirifer probably represents a relatively high stressed pioneer community well adapted to the softer muddy bottoms that existed early. As a response to the moderately increased energy later in time more adaptively varied filter and deposit feeders become established. Lack of disarticulated specimens and the abundance of unattached forms attest to moderate current activity supplying nutrients in suspension for filter feeders yet leaving the substrate rich in organic material for deposit feeders. Any outer delta platform environment is probably represented herein.

Second Siphonophrentis - Cystiphylloides Community

This community is found in the northern part of the Tully Valley region, which marks it farthest extent to the northeast. Southwestward it can be traced to the east side of Skaneateles Lake. It is entirely wanting in the Ludlowville Formation exposed south of Cardiff, New York.

This community is co-extensive with the Joshua Submember and existed simultaneously with portions of the Mucrospirifer-Spinocyrtia-Megastrophia Community in the southern Tully Valley.

The paleoecologic parameters necessary for this community mirror those of the first rugose coral community in the Staghorn Point and need not be reiterated here.

One striking difference, however, is the absence of a siltstone platform in the upper coral bed. Instead the Joshua rests on a thin bed composed entirely of the colonial rugose coral Eridophyllum subcaespitosum. Oliver (1951, p. 717) suggests "...these colonial rugose corals colonized the area during an interval of favorable conditions and formed a crude platform for the solitary corals."

Cypricardella Community

The Cypricardella Community is found in the Spafford silty shales and also includes the upper portion (10') of the Ivy Point Member. Epifaunal filter feeders and infaunal filter feeders dominate the assemblage. Mucrospirifer mucronatus is the dominate brachiopod while the bivalves are represented by Cypricardella, (perhaps a free burrowing filter feeder), Cornellites, Modiomorpha, Actinopteria, Pterinopecten, and Nuculites. An outer delta platform environment was inhabited by this community.

Allanella tullius Community

Restricted to the Owasco Member this low diversity community is characterized by the epifaunal filter feeding brachiopods Allanella, Tropidoleptus and Mucrospirifer. This community probably inhabited a relatively high stressed environment of the middle to inner delta platform.

Chonetes - Ambocoelia Community

This community is characterized by a low diversity assemblage of small epifaunal filter feeders without a functional pedicle in the adult stage. The deep incurved pedicle value of Ambocoelia and Chonetes, and the spinose hinge of Chonetes seem to make these taxa ideally suited for life on soft substrates. The infaunal deposit feeding bivalves Paleoneilo and Nuculites are also fairly conspicuous in this community.

A low energy environment characterized by low oxygen levels of the outer delta platform or prodelta slope is suggested. Abundant organic detritus was available in the substrate, for deposit feeders. It characterizes the lower 40 to 50 feet of the Windom Member in the Tully Valley and will not be observed on the trip.

Mucrospirifer - Chonetes Community

This community is found in the middle and upper Windom Member, from about 80 feet below to approximately 30 feet below the Tully Limestone. Its high diversity suggests opulent ecological conditions on and in the substrate. Numerous filter feeding, deposit feeding, and vagrant invertebrates typify the assemblage. The brachiopods Mucrospirifer, Chonetes, Tropidoleptus, Spinocyrtia, Mediospirifer and Athyris are forms associated with the bivalves Aviculopecten, Nuculites, Paleoneilo, Sphenotus, and Modiomorpha and trilobites and nautiloids. The ichnofossil Zoophycos (Taonurus) is very abundant.

Leiorhynchus - Pustulatia Community

The 20 or so feet of dark shales at the top of the Windom contain epiplanktonic brachiopods and bivalves, small epifaunal brachiopods and small infaunal bivalves. Some of the species found include Leiorhynchus multicosta, Pustulatia pustulosa, Allanella tullius, Pterochaeina fragilis, Nucula varicosa, and Paleoeilo constricta.

This community is a mixture of pelagic and benthonic forms indicative of deeper, poorly oxgenated waters of the lower prodelta slope. The presence of some epifaunal brachiopods and infaunal bivalves indicates some oxygen in the water with the zero Eh surface coincident with or just below the sediment water interface.

ACKNOWLEDGMENTS

The author wishes to thank Richard D. Hamell for compiling the plates of fossils and Karen Weiss for drafting the stratigraphic section.

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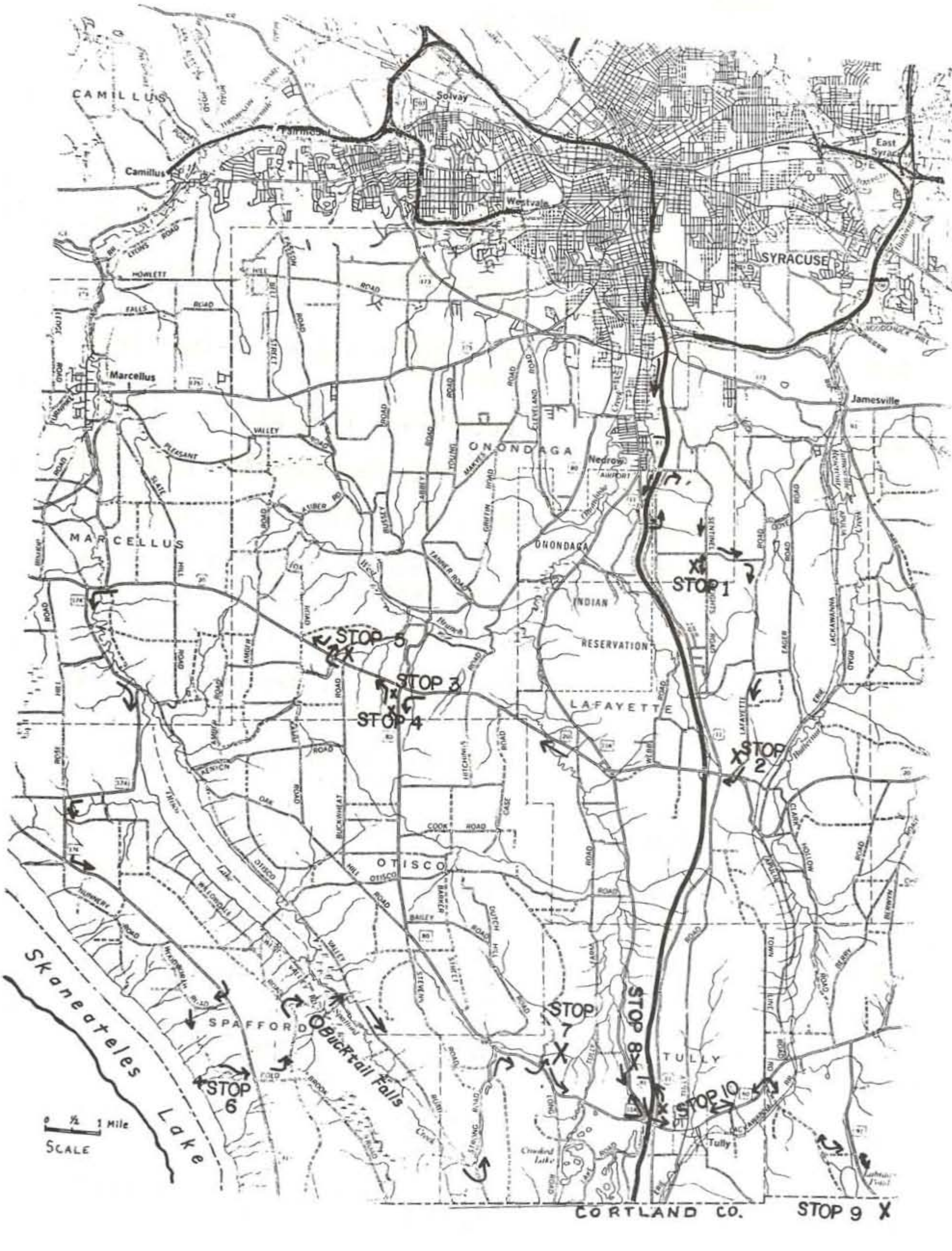
CAMILLUS
Camillus
Fairmount
Solvay
Westvale
SYRACUSE
East Syracuse
Jamesville
Marcellus
MARCELLUS
ONONDAGA
Nedrow
ONONDAGA
INDIAN
RESERVATION
LAFAYETTE
OTISCO
SPAFFORD
TULLY
Tully
Crooked Lake
STOP 1
STOP 2
STOP 3
STOP 4
STOP 5
STOP 6
STOP 7
STOP 8
STOP 9
STOP 10
Bucktail Falls
Skaneateles Lake
CORTLAND CO.
0 ½ 1 Mile
SCALE

ROAD LOG

NOTE: Quadrangles referred to are 7½ minute. See map for stops and route.

Miles from last point	Cumulative Miles	
0.0	0.0	Manley Field House parking lot-turn right (west) on Colvin St.
0.1	0.1	Cross Comstock Avenue-proceed west
0.8	0.9	Jct. South State St.-turn left (south)
0.7	1.6	Enter ramp to I-81
3.6	5.2	Exit 16 (Nedrow)-take exit ramp
0.3	5.5	Jct. US 11-turn left (south)
0.2	5.7	Jct. Kennedy; Camping Rd.-turn left (east)
0.1	5.8	Left (north) on Kennedy Rd.
0.9	6.7	Jct. Sentinel Heights Rd. - turn right (east)
0.7	7.4	Sentinel Heights Rd. curves right (south)
1.6	9.0	Jct. Bull Hill Rd.-proceed south
0.2	9.2	Access road to WSYR-TV tower-turn right
0.2	9.4	<u>STOP 1</u> - Base of tower on Miller Hill (Jamesville Quad.) - Joshua Submember (15')
0.2	9.6	Return to Sentinel Heights Rd. turn left (north)
0.2	9.8	Jct. Bull Hill Rd.-turn right (east)
1.1	10.9	Jct. LaFayette Rd.-turn right (south

2.0	12.9	Reidy Hill Rd. on left proceed south
1.7	14.6	STOP 2 - Roadcut on west side of LaFayette Rd. (Jamesville Quad.) About 30' of the Upper Otisco Member and the *Mucrospirifer*-*Spinocyrtia*-*Megastrophia* Community is exposed here. Proceed south on LaFayette Rd.
0.3	14.9	Jct. US 20-turn right (west)
0.2	15.1	Jct. US 11-proceed west on US 20
0.3	15.4	Jct. I-81 proceed west on US 20
0.9	16.3	Descend east side Tully Valley
1.1	17.4	Jct. NY 11A Cardiff-proceed west on US 20
2.2	19.6	US 20 build on surface of large hanging delta
1.3	20.9	Jct. NY 80-turn left (south)
0.3	21.2	STOP 3 - Roadcut on NY 80 (South Onondaga Quad.) Joshua Submember (Elev. top 1280')-Proceed south on NY 80
0.5	21.7	STOP 4 - Roadcut on NY 80 (South Onondaga Quad.) Owasco (2') Portland Point (10') Members (Elev. 1380') - Return North on NY 80
0.8	22.5	Jct. US 20- turn right (west)
1.3	23.8	Jct. Hogsback Rd.-turn right (south)
0.1	23.9	STOP 5 - Peppermill Gulf just east and parallel to Hogsback Rd. (South Onondaga Quad.) Centerfield Member (20-30') - Return to US 20-turn right (west)
1.6	25.5	Navarino-proceed west on US 20
1.9	27.4	Descend Eastside Tyler Hollow Nine Mile Creek (Otisco Lake outlet)

0.9	28.3	Jct. NY 174-proceed west on US 20 - NY 174
0.4	28.7	Jct. NY 174-turn left (south)
6.4	35.1	Jct. NY 41 at Borodino turn left (south)
1.2	36.3	Old Borodino Quarry-bioherm in Tully Ls. on left and roadcut on NY 41
2.8	39.1	Jct. Woodworth Rd.-turn right (west
0.7	39.8	Jct. Bacon Hill Rd.-turn left (south)
1.2	41.0	Jct. dirt road on right (west) leading down to shore of Skaneateles Lake-leave bus and walk down road .7 miles to shore of lake
		STOP 6 - Staghorn Point (Spafford Quad.). This is the type section of the Staghorn Point Submember (4'). The siltstone platform and overlying Otisco shales are well exposed here. Return to bus-proceed south on Bacon Hill Road.
0.9	41.9	Jct. NY 41 at Spafford-take slight jog to right and proceed east on Cold Brook Road.
0.7	42.6	Jct. Willowdale Rd.-turn left (north)
1.2	43.8	Jct. Moon Hill Rd.-turn right (east)
0.8	44.6	Bucktail Falls Ravine on right-exposing the entire Upper Hamilton Group from the Centerfield Member to the Tully Ls. Jct. Sawmill Rd.-turn left (east)
0.6	45.2	Jct. Otisco Valley Rd.-turn right (south)

4.0	49.2	Jct. Strong Rd. at Bromley-turn acute left (north)
2.5	51.7	Jct. NY 80-turn right (east)
0.8	52.5	Jct. Woodmancy Rd.(Hallinan Rd. on Quad.) turn left (north)
0.2	52.7	STOP 7 - Fellows Falls Ravine down from Woodmancy Rd. (Otisco Valley Quad.). A complete section in the Ludlowville Form. Is exposed at this locality as follows:

Owasco	2'	Elev. 1120' Falls at top of ravine
Spafford	25'	
Ivy Point	40'	
Otisco	165'	Staghorn Point 7'
Centerfield	20'	Elev. 880'

0.2	52.9	Return to NY 80-turn left (east)
0.7	53.6	NY 80 follows crest of Tully Moraine
1.7	55.3	Jct. NY 11A-turn left (north)
0.6	55.9	Descend north side of Tully Moraine
0.7	56.6	STOP 8 - Unamed ravine on east side of Tully Valley up from NY 11A (Otisco Valley Quad.). The section exposed here is similar to Fellows Falls Ravine (STOP 7) with the exception of the lower Otisco covered from the Upper Centerfield to the Staghorn Point siltstone platform. The Owasco is also not exposed here. (NOTE: This stop may be omitted depending on time schedule). Return south on NY 11A.
1.3	57.9	Jct. NY 80-turn left (south)
0.2	58.1	Jct. US 11 and I 81- proceed east on NY 80, US 11
0.4	58.5	Enter Tully

0.2	58.7	US 11 Turns south-proceed east on NY 80
1.7	60.4	Jct. Markham Hollow Rd. at Fabius Town Line-turn right (south)
1.7	62.1	Jct. Labrador Rd.-turn left (east)
0.5	62.6	Jct. NY 91-turn right (south)
0.9	63.5	Cortland Co. line
0.4	63.9	STOP 9 - Tinkers Falls Ravine-up from eastside of NY 91 (Tully Quad.). About 80' of Windom is exposed here with the Tully Ls. forming the cap rock of Tinkers Falls (Elev. 1380'). The *Mucrospirifer*-*Chonetes* Community is well exposed in the first exposure upstream at base of falls. (Elev. 1300'). Return north on NY 91
1.3	65.2	Jct. Labrador Rd.-turn left (west)
0.5	65.7	Jct. Markham Hollow Rd.-turn right (north)
1.8	67.5	Jct. NY 80-turn left (west)
0.2	67.7	Enter Tully
0.4	68.1	Jct. US 11
0.5	68.6	US 11 bends right-to the north-proceed on US 11
0.3	68.9	STOP 10 - Roadcut on eastside of US 11 (Tully Quad.). About 30' of Windom is exposed here carrying the *Mucrospirifer* - *Chonetes* Community. Return to Manley Field House via I-81.

Paleoenvironments of the Potsdam Sandstone and Theresa Formation of the Southwestern St. Lawrence Lowlands

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INTRODUCTION

In northwestern New York State the Upper Cambrian-Lower Ordovician Potsdam Sandstone and Theresa Formation exhibit a variety of primary structures and compositional and textural variations indicative of deposition in nearshore, usually tide-dominated, settings. The purpose of this paper is to provide a descriptive overview of these units, plus an interpretation of the depositional environments of the various lithofacies.

In the study area (Fig. 1) the Potsdam and Theresa are best exposed in the Frontenac Axis region. In this area the Paleozoic rocks lie in profound unconformity upon a paleoerosional surface underlain by metamorphic rocks of Protoerozoic age.

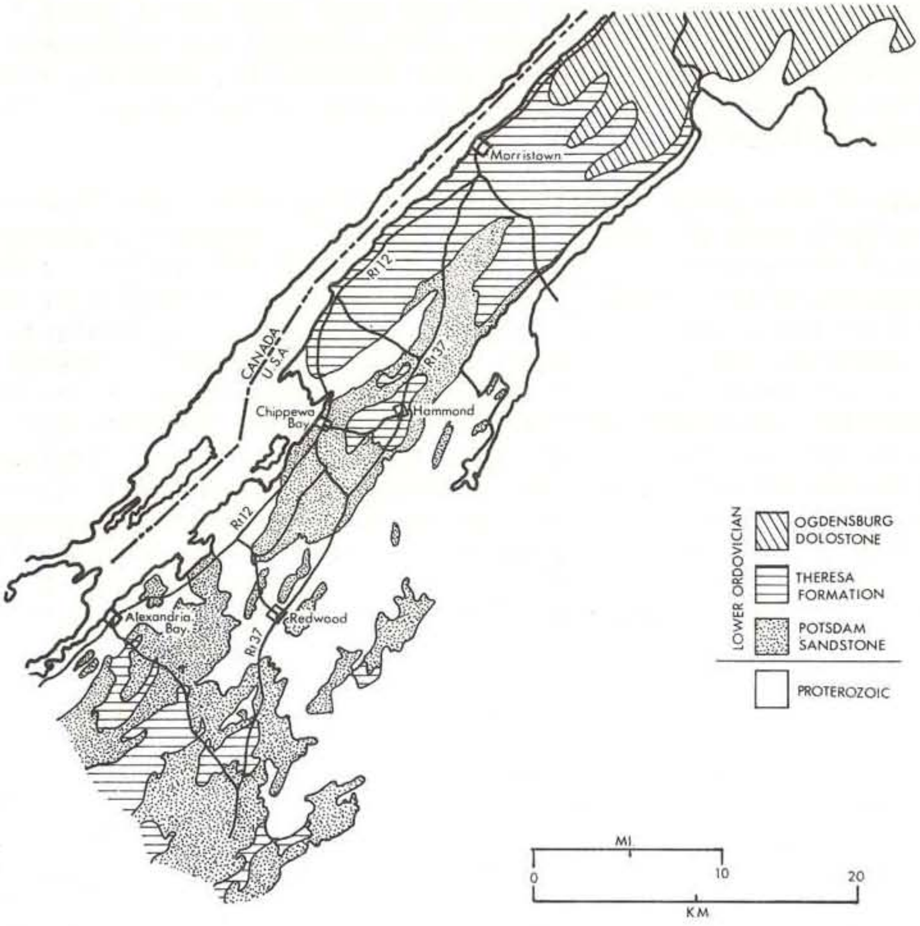


Figure 1. Generalized geologic map of study area.

PREVIOUS STUDIES

Since the Potsdam Sandstone was first described by Emmons (1838), the environment of its deposition has been a topic of discussion. Debate has arisen, no doubt, because the Potsdam, as pointed out by Fisher (1968), is a unit highly variable in both thickness and lithology throughout the area of its exposure. At the type section of the Potsdam, near Hannawa Falls, New York, Chadwick (1920) was convinced that the unit was deposited in an aeolian setting on the basis of the magnitude of crossbeds, the high variability of crossbed-dip directions and the absence of fossils. Lewis (1970) argued for a marine origin for much of the Potsdam, based on the presence of marine fossils and dolomite in the upper portions of the formation and the lack of crossbed-dip angles exceeding 30°. Otvos (1966) recognized terrestrial, intertidal and littoral to nearshore low-energy facies in the Potsdam. Fisher (1968) reported low-energy outer intertidal and inner subtidal environments in portions of Potsdam near Lake Champlain. Fisher stressed, however, that the variability of lithology within the Potsdam makes it difficult to generalize concerning depositional environments of the entire formation.

Kirchgasser and Theokritoff (1971, p. B-7) suggested that crossstratified beds in the upper portion of a section of the Potsdam near Alexandria Bay, New York, indicated "...higher energy conditions in which currents built solitary banks or bars into shallow water just off a beach." Greggs and Bond (1971) interpreted the lower conglomerates and sandstones of the Potsdam-correlative Nepean Sandstone near Brockville, Ontario, as continental deposits grading upward through high-energy stream deposits into offshore marine sandstones.

Because of the great lithologic variability within the Theresa Formation few workers have attempted to make general statements concerning environments of deposition of this unit. Berry and Theokritoff (1966) stated, concerning the probably Theresa-correlative Buck's Bridge Formation east of the Frontenac Axis region, that deposition probably took place "...shallow, nearshore waters, possibly intertidal". Greggs and Bond (1971) concluded that the blue-gray sandy dolostones of the lower March (equivalent to lower Theresa) near Brockville, Ontario, were deposited in a subtidal environment, possibly the Cruziana or Cruziana-Skolithos facies of Seilacher (1967). Greggs and Bond (1971) considered the yellow and white sandstones of the upper March (= upper Theresa) to have been deposited in a shallow-marine intertidal flat environment. Kirchgasser and Theokritoff (1971) proposed a subtidal origin for the lower portion of the Theresa Formation near Morristown, New York.

STRATIGRAPHY

A generalized stratigraphic column is presented in Figure 2. The age relationships of the lower Paleozoic rocks of New York State have been discussed recently by Fisher (1977). Figure 3, drawn mainly from Fisher, depicts the probable age relationships of the Potsdam, Theresa and overlying Ogdensburg Dolostone in the western St. Lawrence Lowlands. The general paucity of useful index fossils in the Potsdam and Theresa has resulted in

OGDENSBURG DOLOSTONE:
Buff to gray sandy dolostone with a few thin quartz arenite beds.

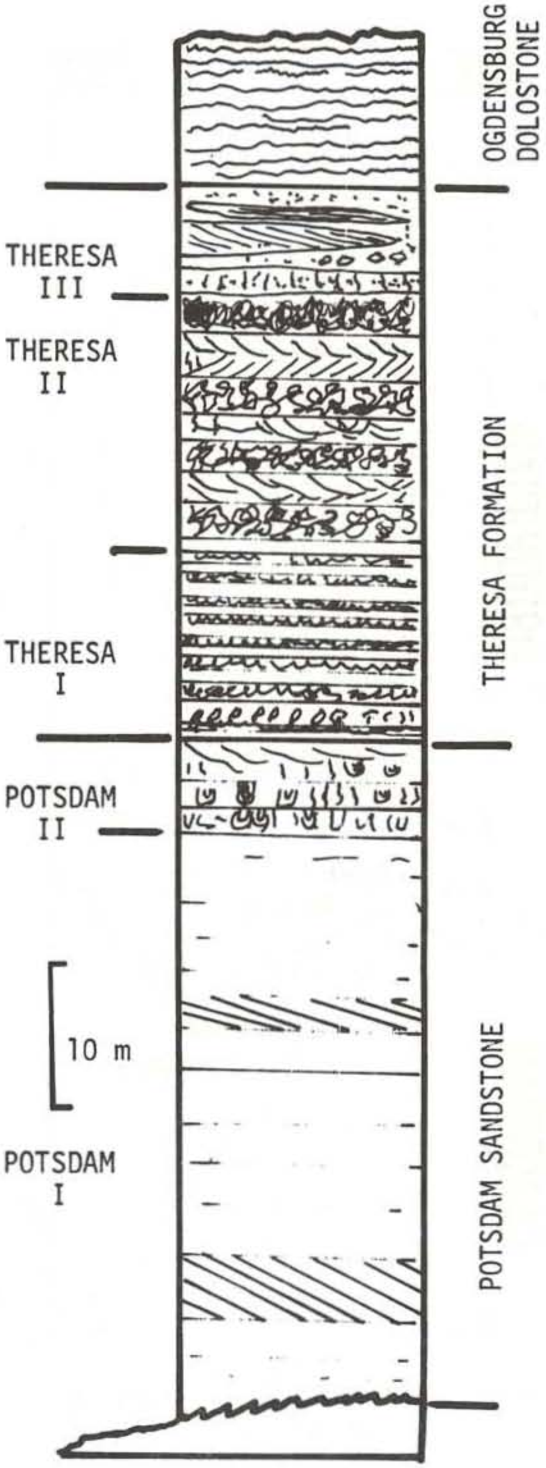
THERESA III:
Complex interbedding of:
brown to yellow calcitic sandstones; white to yellow slightly calcitic and dolomitic quartz arenites; gray to brown sandy dolostones and gray laminated clacitic siltstones.

THERESA II:
White to yellow slightly calcitic quartz arenites interbedded with gray to brown calcitic and dolomitic sandstones.

THERESA I:
Gray to brown thin-bedded calcitic sandstones and siltstones.

POTSDAM II:
Yellow-white to gray slightly calcitic quartz arenites.

POTSDAM I:
Yellow-white, pink, red and salmon quartz arenites.



PROTEROZOIC:
Variety of gneisses, marble, and other metasedimentary rocks.

Figure 2. Generalized stratigraphic column for Potsdam Sandstone and Theresa Formation in study area.

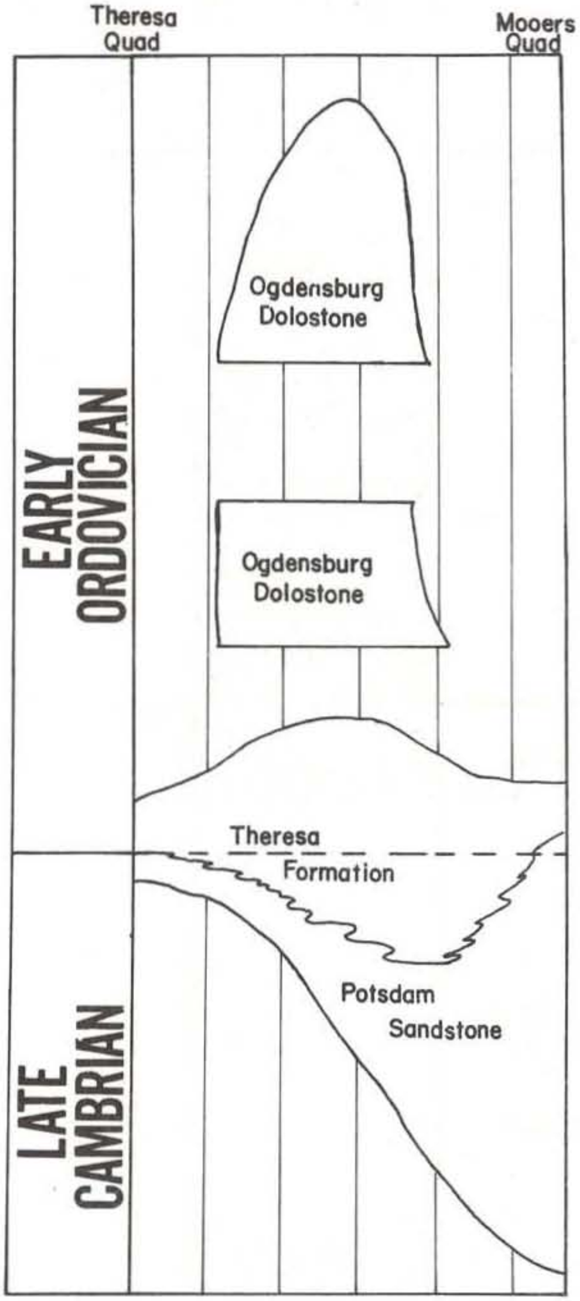


Figure 3. Stratigraphy of Cambrian and Ordovician of St. Lawrence Lowlands (after Fisher, 1977).

considerable debate about age assignment. Studies of conodont biostratigraphy by Greggs and Bond (1971) and Brand and Rust (1977) may allow more rigorous age determination.

The existance of late Proterozoic (Hadrynian?) arkosic sandstones in the region has been pointed out by Fisher (1977) and others. These rocks are distributed sporadically in the western St. Lawrence Lowlands. Such basal arkoses are interpreted as terrestrial graben-fill, temporally and causally related to the initial opening of the Proto-Atlantic in late Proterozoic time.

THE POTSDAM SANDSTONE

The Potsdam Sandstone of the study area may be subdivided conveniently into two lithofacies. Potsdam I, the lowermost facies, consists of yellow-gray, pink, red, and white quartz arenites. Fresh exposures may exhibit numerous crosscutting streaks or bands of red and pink colors.

Crossbedding is abundant in Potsdam I, although the majority of the unit is horizontally bedded. Crossbeds occur as thick (0.5 - 1.0 meters) planar sets and as a variety of trough and festoon styles of smaller scale. Trace fossils generally are absent in the Potsdam I facies.

Texturally, Potsdam I is a medium to fine, well-sorted sand. Grains are well rounded and of high sphericity. Bimodel textures, with a coarse sand mode "floating" in a fine sand mode, are present. Quartz forms 90 - 95 percent of the detrital fraction. Feldspar (5 - 8%) is generally more abundant in fine-grained beds. The accessory suite (1 - 2%) consists of well-rounded grains of magnetite, zircon, and tourmaline. Detrital grains are bound by optically continuous overgrowths of quartz. Cementation generally is complete, but isolated intraformational breccias disrupt "normal" Potsdam I.

The overlying Potsdam II facies consists of gray to yellow-white quartz arenites. Thick to massive bedding is dominant, with extensive bioturbation obliterating any primary current or wave-formed laminations. Vertically oriented burrows, plus the U-shaped structure Diplocraterion yoyo, are present. Low-angle crossbeds are present, plus a variety of symmetrical and assymetrical ripples.

Texturally and compositionally Potsdam II differs little from Potsdam I, with the exception of occasional calcite cement in Potsdam II.

DEPOSITIONAL ENVIRONMENTS

Potsdam I

Potsdam I lithofacies is the result of deposition of rapidly supplied quartz sand by vigorous tidal and wind driven currents in an area of shifting sand belts and estuarine channels. The earliest Potsdam deposition took place on an irregular erosional surface whose topography was similar to the Adirondack Lowlands of today. The currents which deposited the lower portions of Potsdam I were highly variable in direction and magnitude, as indicated by the high variability in crossbed-dip directions (Lewis, 1970) and the variability in texture and bedding type. One pictures an anastamosing series of estuaries and tidal channels with intervening islands controlling and directing current flow. As deposition continued the irregular surface was covered, and current variability decreased. This resulted in the deposition of sand more uniform in texture and less variation in crossbed dip direction in the upper portion of Potsdam I. Locally, a number of facies variants may be observed in Potsdam I. These include apparent stream gravels and associated terrestrial deposits, beach cobble conglomerates and possibly beach-berm-dune systems. Generally such facies are in the lower portion of the unit and serve to emphasize the great irregularity of the depositional surface early in the history of the Potsdam.

Potsdam II

A decrease in the rate of supply of quartz sand and a decrease in wave and current energy ended the Potsdam I phase of deposition in the area. The Potsdam depositional surface at this time is envisioned as a broad, shallow subtidal sand flat, with only local, isolated islands of the most resistant Proterozoic lithologies. Lower rates of physical reworking and decreased rate of sand supply allowed abundant colonization of the sediment by infaunal burrowing organisms. Potsdam II, a product of these conditions, is characterized by the presence of numerous vertical burrows and bioturbation. The calcite cement in Potsdam II indicates the probable existence of shelly organisms. However, the coarse-grained texture of Potsdam II, and diagenetic dissolution of calcite shells have obliterated any fossil traces of the shelly fauna. Among the trace fossils, the U-shaped *Diplocraterion yoyo* is of particular interest. This spreite-type structure was made by a wormlike organism similar to modern chaetopterid annelids. Such organisms live in the sediment and filterfeed from the overlying water, with the mouth at one burrow opening, the anus located at the other opening. As the animals grow in length, the burrow is displaced downward, leaving a weblike trace of former burrows between the vertical portions of the last-formed burrow. Erosion of the sediment surface produces a downward burrow displacement, but destruction of earlier burrow traces may take place. The possible range of normal spatial arrangements and burrow forms is illustrated in Figure 4. As most of the *Diplocraterion* burrows in Potsdam II indicate lengthening in response to growth, it follows that sedimentation rates were relatively low and erosion of the sediment surface rare during the deposition of Potsdam II lithofacies. This conclusion is supported by the presence of intensely bioturbated beds in Potsdam II. However, the general vertical orientation of most burrows indicates that the organisms were required to live within the sediment for protection from physical violence (waves and currents) and perhaps occasional dessication. Modern intertidal sediments are characterized by vertical burrows for these same reasons (Rhoads, 1967).

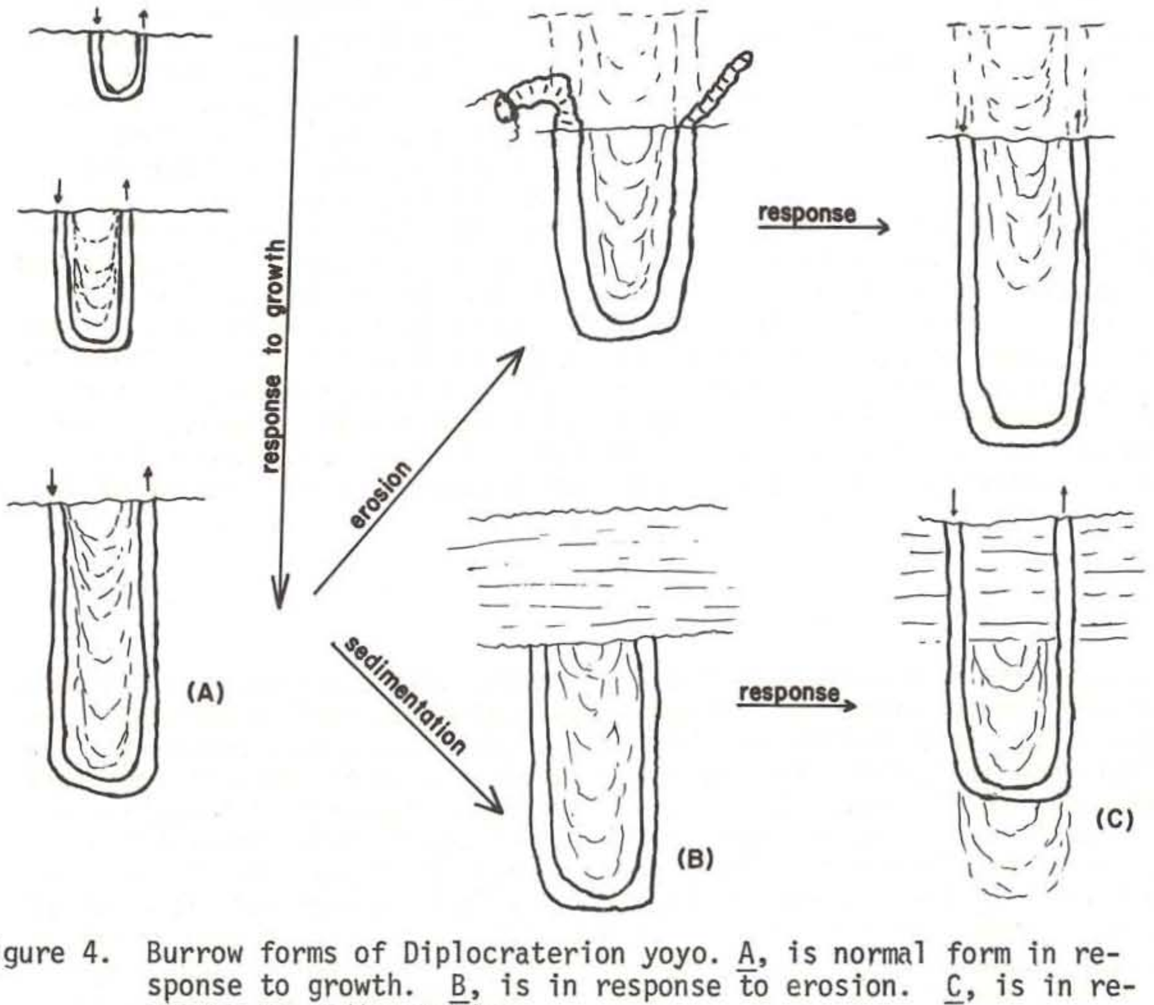


Figure 4. Burrow forms of Diplocraterion yoyo. *A*, is normal form in response to growth. *B*, is in response to erosion. *C*, is in response to sedimentation.

Symmetrical and asymmetrical ripple marks in close proximity on single bedding planes in many portions of Potsdam II are features today associated with breaking waves in shallow water. These features indicate development of shallow shoals and perhaps partial emergence of the depositional interface. Such emergence and development of wide sand flat areas effectively reduced both wave and current activity and thus reduced the rate of supply of quartz sand from source areas.

THERESA FORMATION

The base of the Theresa Formation generally is recognized by an abrupt increase in the carbonate content from the underlying Potsdam. Color change from the light gray and yellow-white of Potsdam II to dark gray-brown of the basal Theresa also marks the formation boundary in the field.

In the Frontenac Axis region and immediately adjacent areas the Theresa Formation can be subdivided into three lithofacies on the basis of consistent variations in texture, composition and primary structures. Theresa I, the lower 3 - 10 m of the formation, a thin-bedded, poorly sorted calcitic, feldspathic quartz sandstone to siltstone. It also is characterized by numerous horizontal trails preserved on the soles of the beds. A given bed generally is laminated near its base, but the upper portions are intensely bioturbated with original laminations destroyed. Low-angle crossbedding may be present in undisturbed portions of beds. Shaly interbeds may separate individual sandstone/siltstone beds. Identifiable body fossils are limited to the inarticulate brachiopod Lingulepis accuminata and a few poorly preserved discoidal gastropods.

Theresa I facies grades into Theresa II via increasing general bioturbation resulting in the loss of the thin-bedded character of Theresa I. The 0.3 - 1.0 m beds of white-yellow quartz arenite mark the first appearance of Theresa II facies. Theresa II (7.5 - 13.0 m thick) typically consists of interbeds of quartz arenite and highly bioturbated calcitic and dolomitic sandstone. The quartz arenite beds (dubbed Theresa IIA) may contain trough crossbed sets up to 10 cm thick. Herringbone (bipolar) crossbeds and rare vertical burrows also are present in Theresa IIA. Theresa IIB, the calcitic and dolomitic sandstone, generally is more poorly sorted and lacks primary structures formed by physical processes, as bioturbation is complete. Sulfide minerals (generally pyrite) and disseminated organic material are important constituents of Theresa IIB.

A cryptalgal laminite (laminated dolostone) and a vuggy, sandy dolostone mark the transition from Theresa II to Theresa III lithofacies. Theresa III (6 - 11 m in thickness) contains four lithofacies: a medium-bedded calcitic quartz sandstone with mudcracks and abundant vertical burrows (Theresa IIIA); a crossbedded, ripplemarked, well-sorted, coarse-grained quartz arenite (Theresa IIIB); a vuggy, sandy dolostone with local cryptalgal laminites and poorly preserved discoidal gastropods (Theresa IIIC); and a thin-bedded organic-rich laminated calcareous siltstone (Theresa IIID). Theresa IIIA and IIIB are present laterally and vertically juxtaposed in outcrop. Theresa IIIC and IIID are vertical associates.

THERESA FORMATION: DEPOSITIONAL ENVIRONMENTS

Theresa I

In Theresa I facies, the paucity of primary structures indicative of physical reworking, the seeming intermittent deposition, the fine-grain size and poor sorting of the sediment, and the relatively shallow depth and character of reworking by biota all indicate deposition in an environment protected from waves and currents and occasionally subject to sediment influx. Seemingly a gradual deepening and restriction of the area occurred following the Potsdam II phase of deposition.

Rhoads (1970, p. 401) in noting the difference in burrowing depth between adjacent intertidal and subtidal environments in Barnstable Harbor and Buzzard's Bay, Massachusetts, states, "Deep vertical burrowing (to a depth of 30 cm) is common in nearshore environments, especially in intertidal sediments. Shallow horizontal burrowing (to a depth of 10 cm) is best developed in offshore level bottoms." This difference in depth and character (vertical vs. horizontal) is, as has been pointed out by other workers (Seilacher, 1964, 1967; Shinn, 1968), the result of the response of infaunal biota to the need for protection from the physical rigors of the environment. In nearshore intertidal environments, wave and current activity, and occasional exposure of the sediment surface require that infaunal deposit feeders burrow to sufficient depth to remain protected both from dessication and physical violence. Also, suspension feeders and microcarnivores in a nearshore environment construct vertical living burrows and leave them, or partially protrude, for feeding purposes. Thus, the shallow burrowing depth and dominance of horizontal over vertical burrows in Theresa I indicate an environment protected from energetic waves and currents and subaerial exposure.

The calcitic sandstones and siltstones of Theresa I were deposited in a subtidal, "low-energy" depositional environment. Sedimentation was episodic and sedimentation events were separated sufficiently in time to permit biogenic reworking of the tops of most beds. The processes responsible for the episodic deposition of Theresa I are problematic, but it is theorized that some occasional events, such as heavy storms associated with higher than normal tides, carried sediment from adjacent nearshore areas offshore to the Theresa I environment. Here, sedimentation was immediate, with no subsequent physical reworking.

Theresa II

Theresa IIA quartz arenites exhibit primary structures indicating deposition in a tide-dominated environment. Bipolar crossbedding is a usual feature of tidal sand bodies (Pettijohn, Potter, and Siever, 1972, p. 477) due to alternating current directions during tidal ebb and flood. The well-sorted textural character of Theresa IIA also attests to deposition in an environment where currents or waves were active. The dominance of vertical burrows in Theresa IIA also suggests a physically active environment.

The intimate and repetitive interbedding of Theresa IIA and Theresa IIB lithofacies requires the close lateral association of the environments in which these two lithologies were deposited. Theresa IIB environments were not subject to continuous wave and current activity as indicated by intense bioturbation, and by the less well-sorted texture. It is probable that the higher carbonate content of Theresa IIB is due to the deposition of carbonate fines, along with quartz sand. The carbonate fines were not deposited in the Theresa IIA environments because of more active winnowing processes.

I propose that Theresa IIA lithofacies were deposited in a lower intertidal bar environment. Modern lower intertidal flats (as described by Evans, 1965; Thompson, 1968) may be characterized by sand bars or large sand waves migrating along shore. The troughs between such bars are more protected environments, usually with marine grasses active as baffles and sediment trapping mechanisms. The trough environment is thus "low energy" with fines accumulating, and abundant substrate colonization and resultant bioturbation. A series of such bars and interposed trough environments, migrating along shore, would produce interbeds of rather different types of sediment. Thompson (1968) noted a similar situation in the lower intertidal flats of the destructive portions of the Colorado River Delta. He states (p. 106), "...shifting of bars in response to overwash and longshore transport results in the generation of a stratigraphic sequence of interbedded sands and muds representing former trough and lower bar facies." In Theresa II environments, the height of a migrating bar above the general lower intertidal flat surface would determine the thickness of a single Theresa IIA bed. As continuous sets of crossbeds rarely exceed 25 cm in thickness in Theresa IIA, the migrating bar surface probably was covered by a series of megaripple or dunelike bedforms. The thickness of Theresa IIB interbeds would then be determined by the rate of sedimentation in, and duration of, the interposed trough environments.

Theresa III

The mudcracked, vertically burrowed dolomitic sandstones of Theresa IIIA were deposited in an upper intertidal flat environment, with occasional subaerial exposure resulting in the dominance of vertical burrows, and possibly the occurrence of dolomite as the major form of carbonate. Although texturally similar to the calcitic and dolomitic sandstones of Theresa IIB, the IIIA lithofacies were deposited in a topographically higher environment.

The medium- to coarse-grained quartz arenites of Theresa IIIB, occurring in beds of lenticular form and possessing abundant crossbedding, represent sediments deposited under "high-energy" conditions in tidal channels meandering across the upper intertidal flat surface. Granule pavements at the base of Theresa IIIB beds are undoubtedly analogous to the shell lags that occur at the base of tidal channels in modern tidal flat settings.

Abundant evidence of subaerial exposure, in the form of mudcracks and associated rip-up features and intraclast breccias, plus the nearly total lack of biogenic structures indicate a supratidal or high intertidal depositional environment for the sandy dolostones of Theresa IIIC. The lack of biogenic structures is attributed to the inability of the larger organisms of this time period to colonize environments subaerially exposed for long periods of time. The association of small "birds-eye" bugs with mudcracks and algal structures also indicates an upper intertidal or supratidal environment for this lithofacies. Shinn (1968) has proposed that small vugs are preserved most readily in supratidal sediments.

The Theresa IIID laminated calcitic siltstones are interpreted as supratidal lagoon deposits, originated, perhaps, in an environment analogous to the "salt pans" of modern supratidal marshes. In such an environment, restriction of water in shallow depressions on the supratidal surface would lead to abnormally high salinities, due to evaporation. High salinities would prevent effectively colonization of the substrate by benthic organisms, thus preventing disruption of sediment laminae. The waters of such lagoons might support a simple planktonic biota. The organic detritus produced then would fall to the bottom to accumulate as organic-rich laminae. Organic-poor laminae would be produced by intermittent influxes of quartz silt and carbonate fines from adjacent environments, perhaps via storm flooding of wind transport from dessicated supratidal flat areas.

An algal mat origin for these laminated siltstones might be considered. However, in view of the extreme parallelism of the laminae and the lateral continuity of single lamina (to tens of meters), this origin is unlikely.

ENVIRONMENTAL RECONSTRUCTION

Given the vertical sequence of lithofacies and depositional environments represented in the Theresa Formation of the study area, the environmental reconstruction illustrated in Figure 5 is proposed. Theresa II and

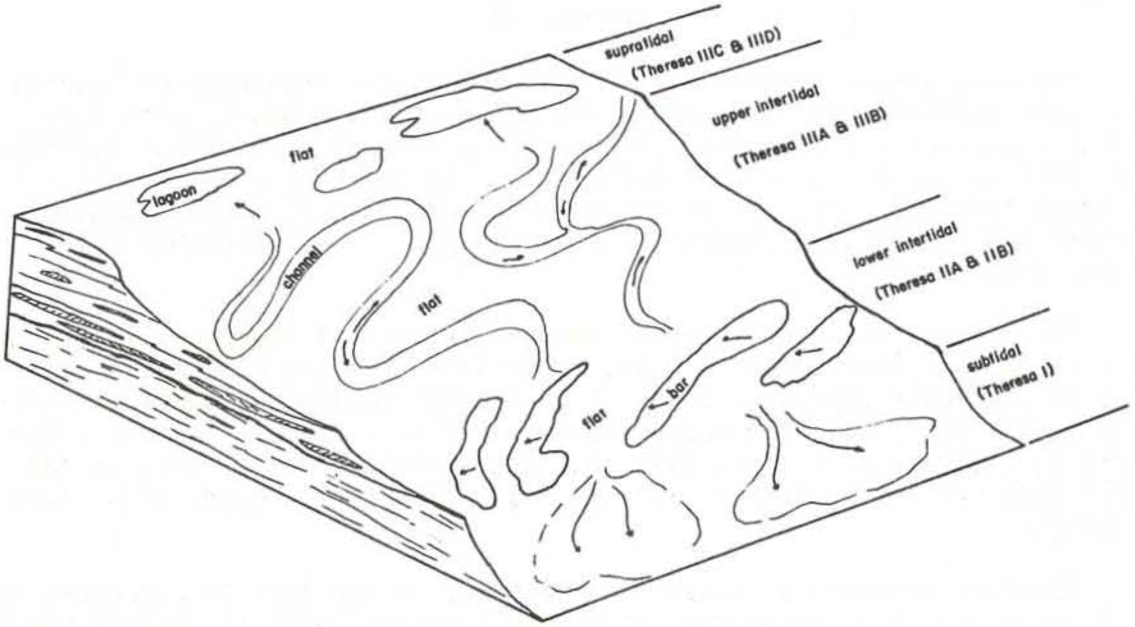


Figure 5. Environmental reconstruction of Theresa Formation.

III were deposited in progressively more landward portions of an advancing tidal wedge environmental mosaic. Theresa I sediments were deposited in perhaps deeper, but certainly more restricted, water at the front of the tidal wedge. Theresa I sediments were derived from the nearshore portions of the tidal flats.

This reconstruction promotes the view that the Theresa Formation is a sequence of shallow marine lithologies with a general trend for those facies that occur higher in the formation to have been deposited in relatively higher topographic settings. The overlying Ogdensburg Dolostone then may be considered as resulting from deposition during the continued regression of marine waters from the area that is now the St. Lawrence Lowlands. Gypsum lenses are known within the Ogdensburg to the northeast, attesting to a restricted basin setting for this unit.

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ROAD LOG*

Cumulative Miles	Miles from last point	Description
0.0	0.0	Start of trip. Thomson Mall parking lot on south side of NYS Rt. 12 in Alexandria Bay, New York. Leave lot, turn right heading NE on Rt. 12.
0.35	0.35	Intersection of Rts. 12 and 26. Continue NE on Rt. 12.
2.45	2.10	STOP 1. Outcrop on both sides of road. This outcrop displays the angular unconformity between the Potsdam Sandstone and Proterozoic rocks metamorphosed during the Grenville Orogeny (approximately 1.1 billion years ago). As the Potsdam here is approximately 500 million years old, the unconformity represents some 600 million years of missing geologic history. The Potsdam here is typical Potsdam I lithofacies. Note the general absence of trace fossils in the Potsdam, the scarcity of metamorphic clasts in the basal Potsdam and the weathering and loading deformation of the Proterozoic rock along the unconformity. Leave continuing NE on Rt. 12.
3.90	1.45	Parking area on left; excellent exposures of Potsdam I on right.
4.95	1.05	STOP 2. Outcrop on both sides of road. This outcrop again exposes the angular unconformity between the Potsdam Sandstone and Proteroizoic metamorphic rocks. Of major interest at this stop are the striking color patterns in the Potsdam. Glacial polish on the top of the outcrop reveals numerous generations of color streaks. The coloring agent of the sandstone is mainly Fe_2O_3 (hematite) but titanium oxides and other trace minerals are locally important. The coloring oxides occupy a variety of petrographic positions in thin section, occurring as grain coatings, oxidation "halos" around detrital opaque minerals and as disseminated blebs and flecks in secondary silica cement. Leave continuing NE on NYS Rt. 12.
6.35	1.40	Entrance to Kring Point State Park on left.

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*Mileage to nearest 0.05 odometer miles.

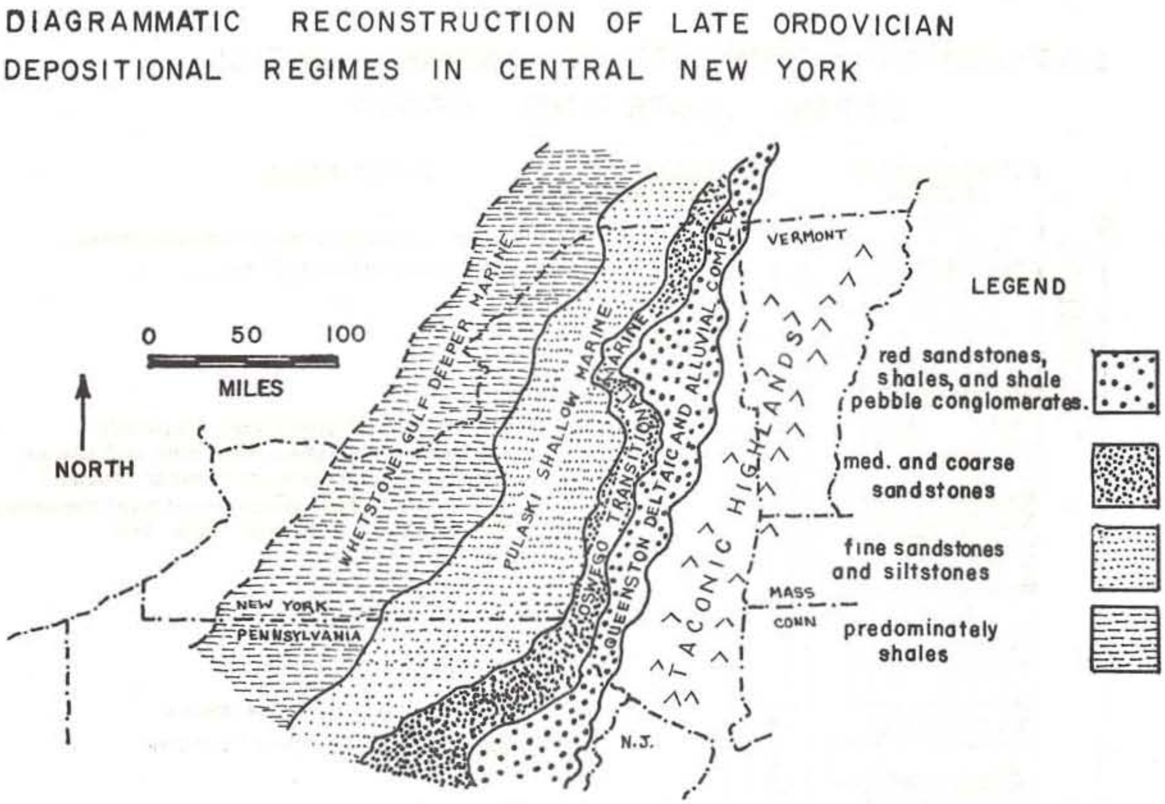


Figure 2. Late Ordovician depositional regimes (from Bretsky, 1970, after Broughton and others, 1962).

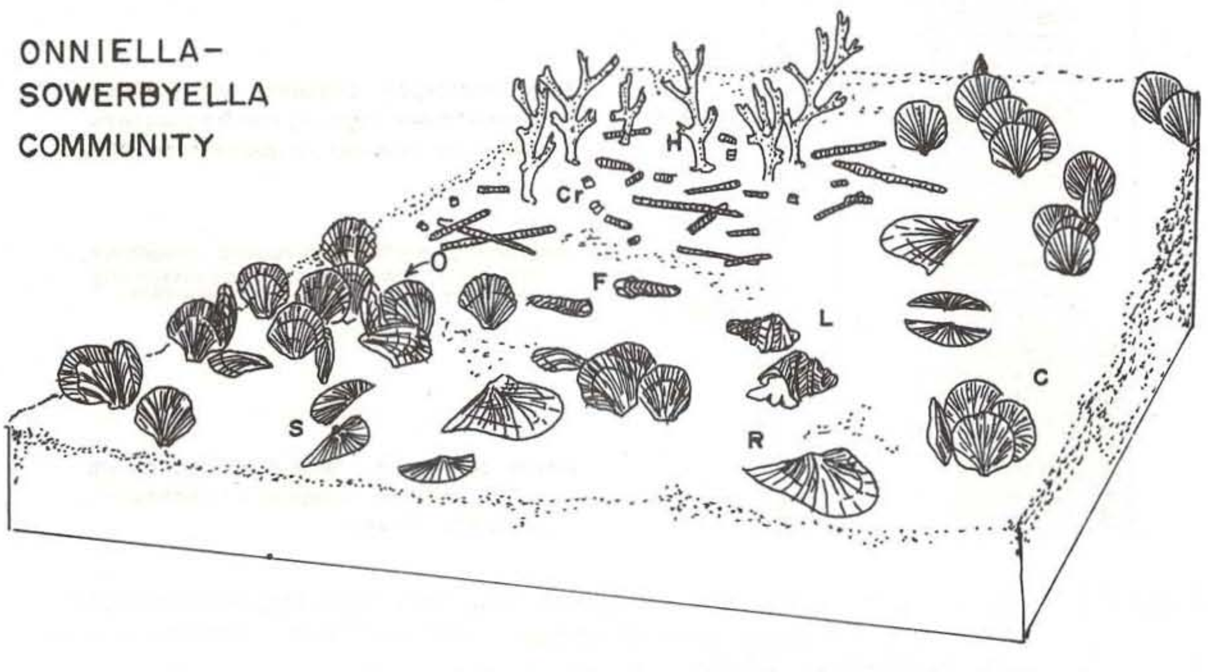


Figure 3. Reconstruction of Onniella-Sowerbyella Community (after Bretsky, 1970).

Nuculites-Colpomya Community

This community is composed of small infaunal detritus and suspension (?) feeding bivalve molluscs (fig. 4). The detritus feeders are Nuculites planulatus, Ctenodonta? cf. pulchella, Praenucula and Palaeoconcha. Infaunal suspension (?) feeders are Lyrodesma poststriatum, Rhytimya, Cuneamya, Cymatonota and Psiloconcha. There are two important epifaunal suspension feeders: Colpomya faba and Glyptorthis crispata.

The fossils are common in the silty shales and siltstones. The faunas extend over a broader stratigraphic range than the Ambonychia-Modiolopsis Community; however, some stratigraphic and zoogeographic differences do exist in the Nuculites-Colpomya Community. Lower in the section there are larger numbers of small (3 to 10 mm) Nuculites, whereas larger (15 to 20 mm) Nuculites are higher up; Lyrodesma and the desmodont bivalves are abundant in the upper part, whereas Glyptorthis is more abundant in the lower Pulaski.

The Nuculites-Colpomya Community occupied the outer and inner infralittoral areas. The substrate was mostly silty mud and the fauna appears to have been normal marine. Some offshore changes in faunal composition occur:

(1) deeper water faunas contain greater numbers of Glyptorthis, Colpomya and Archinacella.
(2) nearer shore faunas (especially those interbedded with the Ambonychia-Modiolopsis Community) have a greater diversity of burrowing, infaunal bivalves (e.g., Rhytimya, Cymatonota, Cuneamya).
(3) Nuculites is small (4mm) in offshore deposits and is larger (17 mm) in nearshore deposits. Is the small size a compensation for decreased substrate firmness because of the increased water content in the muds?

Ambonychia-Modiolopsis Community

This community is dominated by large, epifaunal, suspension-feeding bivalves with fewer numbers of detritus-feeding gastropods and monoplacophorans (fig. 5). Suspension feeders are Modiolopsis modiolaris, Ambonychia praecursa, Cyrtodonta and Ischyrodonta unionoides, while the main detritus feeders are Cyrtolites ornatus and Clathrospira subconica. The fossils are common in thin- to medium-bedded, fine- to medium-grained sandstones. These are interbedded with irregularly crossbedded orthoquartzites and grey-black silty shales that contain a patchy fauna which is the partial remains of the Nuculites-Colpomya Community.

The fossiliferous sandstones and silty shales are cut by shallow channels and commonly filled with crinoid-bryozoan debris. Further, current reworking is evident in the large-scale flattened interference ripples and in the sand-pebble coquinites (disarticulated crinoid stems, worn bryozoan fragments). While the irregularity of bedding and abrupt lithologic change from one rock unit to another is characteristic, the

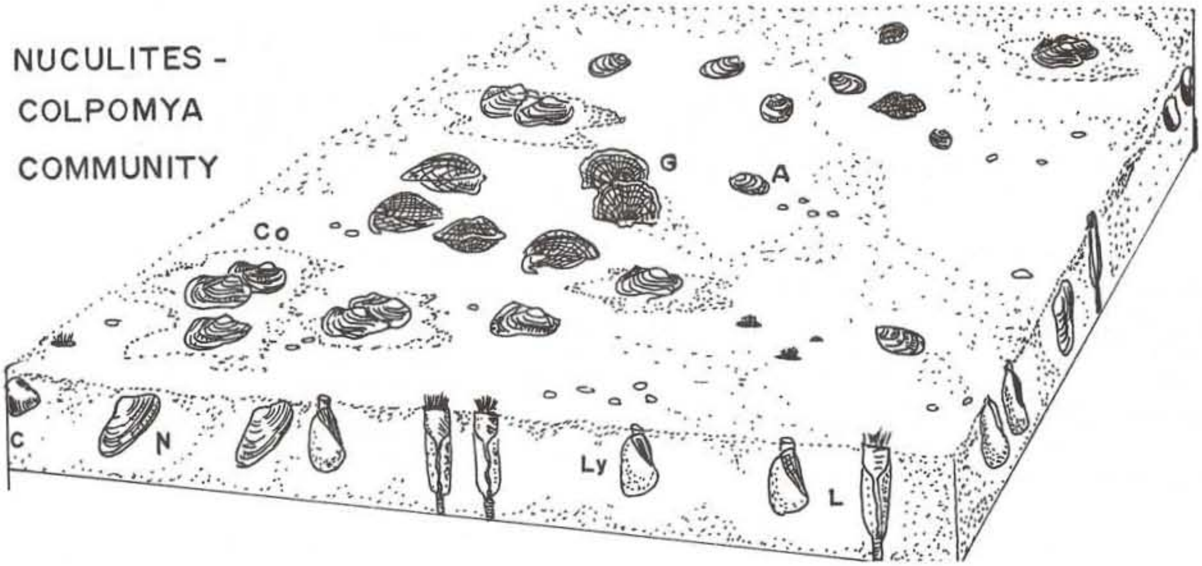


Figure 4. Reconstruction of Nuculites-Colpomya Community (after Bretsky, 1970).

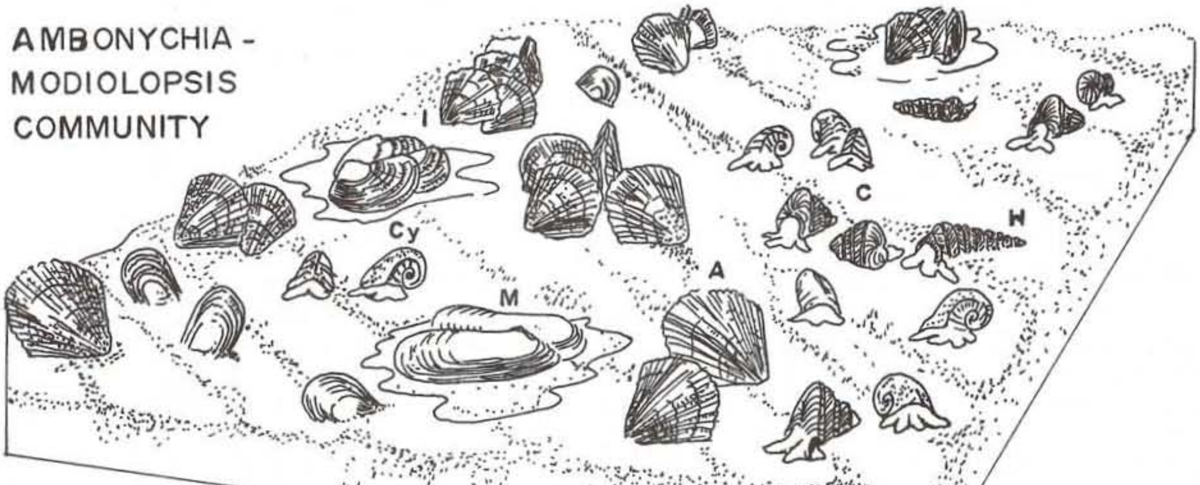


Figure 5. Reconstruction of Ambonychia-Modiolopsis Community (after Bretsky, 1970).

whole sequence grades upward into the unfossiliferous Oswego Sandstone.

The Ambonychia-Modiolopsis Community was the dominant nearshore assemblage. It appears to have been adapted to regions of irregular sedimentation and to areas where mobile bars and barriers existed. The organisms probably existed on a firm but slightly mobile sandy substrate. The high energy nearshore environment is apparent from the cut-and-fill channels, bars, oriented orthocones, crossbedded coquinites and large-scale interference ripples. The fauna was broadly tolerant of salinity fluctuations, of harsh physical regimes (including possibly dessication). Landward this environment graded into transitional nearshore marine and alluvial deposits; seaward into the silts and shales dominated by the members of the Onniella-Sowerbyella Community.

BIOGENIC FEATURES

In the upper part of the Pulaski Shale, numerous burrows, grazing and/or resting tracks are observed. Normally they occur in a particular stratigraphic order and normally within specific lithologies. The first three below are associated with the Ambonychia-Modiolopsis Community; the fourth with the Onniella-Sowerbyella Community.

(1) "Turkey tracks": patterns of 3 or 4 broad, blunt, shallow finger-like projections on bedding planes; common on bedding planes of coarse sandstones that alternate with flattened interference rippled sandstones; probably burrows or grazing tracks.

(2) Longitudinally striated burrows: intersect bedding planes at low angles; 4 to 5 inches long, ½ inch wide; deeper than "turkey tracks"; occasionally filled with crinoid-bryozoan fragments.

(3) "U"-shaped tubes: dumbbell-shaped on bedding plane, usually 2½ to 4 inches apart; found in massive-bedded orthoquartzites (Oswego-like sandstones); tubes filled with dark grey silty shales.

(4) Fine meandering patterns: cover the bedding plane, rarely penetrating from one bed to another; probably a grazing pattern.

SUMMARY

The exposures in the Tug Hill area give a picture of the dynamics of organic change in an offshore-to-onshore depositional regime. Into this general sedimentological framework, three benthic marine communities are placed. They occupied a gently westward sloping shelf that was receiving sediment from the east and that, through time, was experiencing a long, gradual regression. What happened to the faunas in this regression? To explain the exact nature of the faunal transitions in a temporal sense, a detailed bed-by-bed analysis is necessary. For example, the Lorraine Gulf section treated in this manner provides the opportunity to analyze species over a temporal gradient. In these long ranging faunas, species replacements, species additions, species losses and mixing phenomena can be examined throughly. Set in this environmental complex, are the changes in these populations gradual? The exposures in this area are "untapped" with respect to these questions.

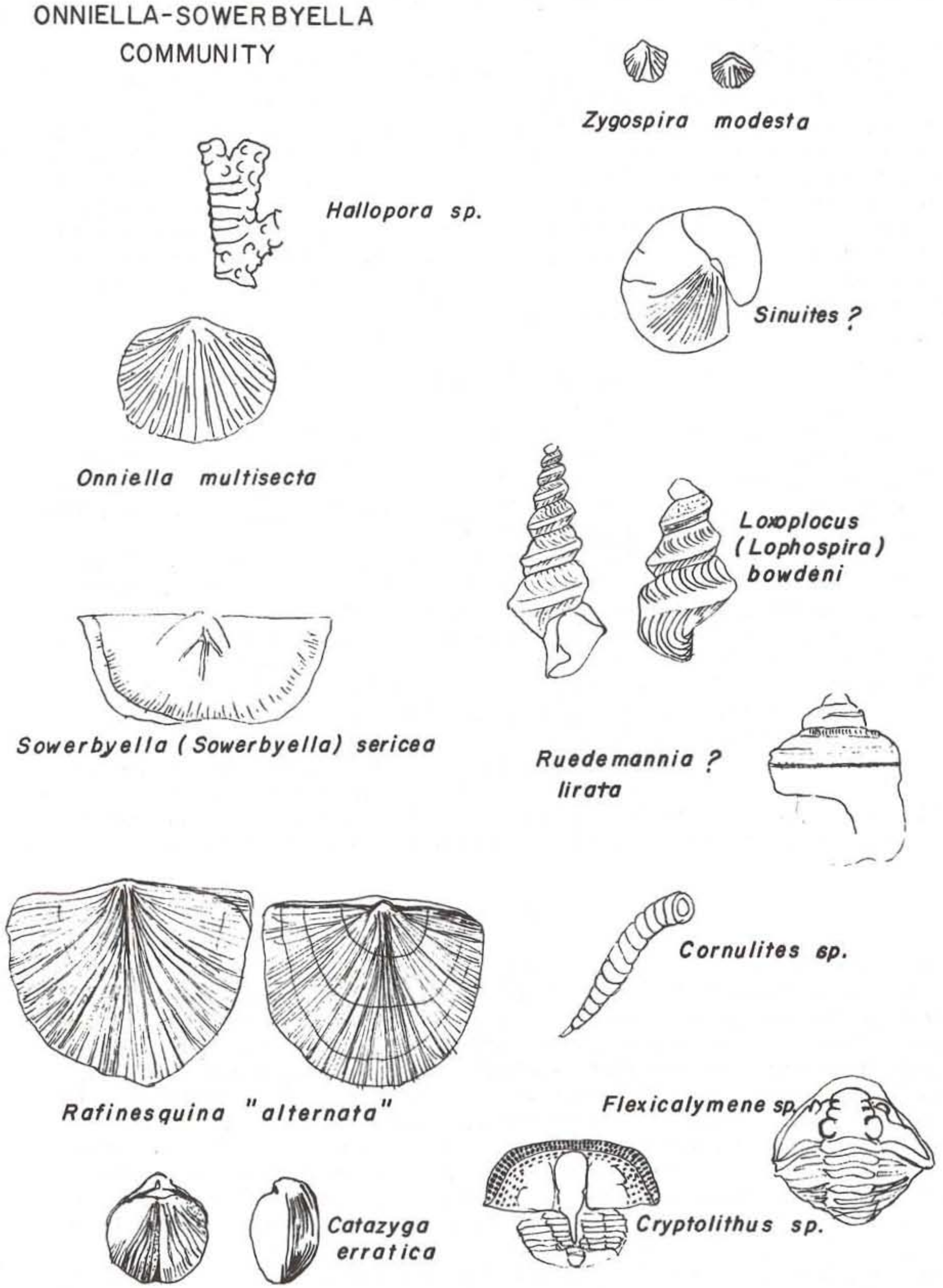
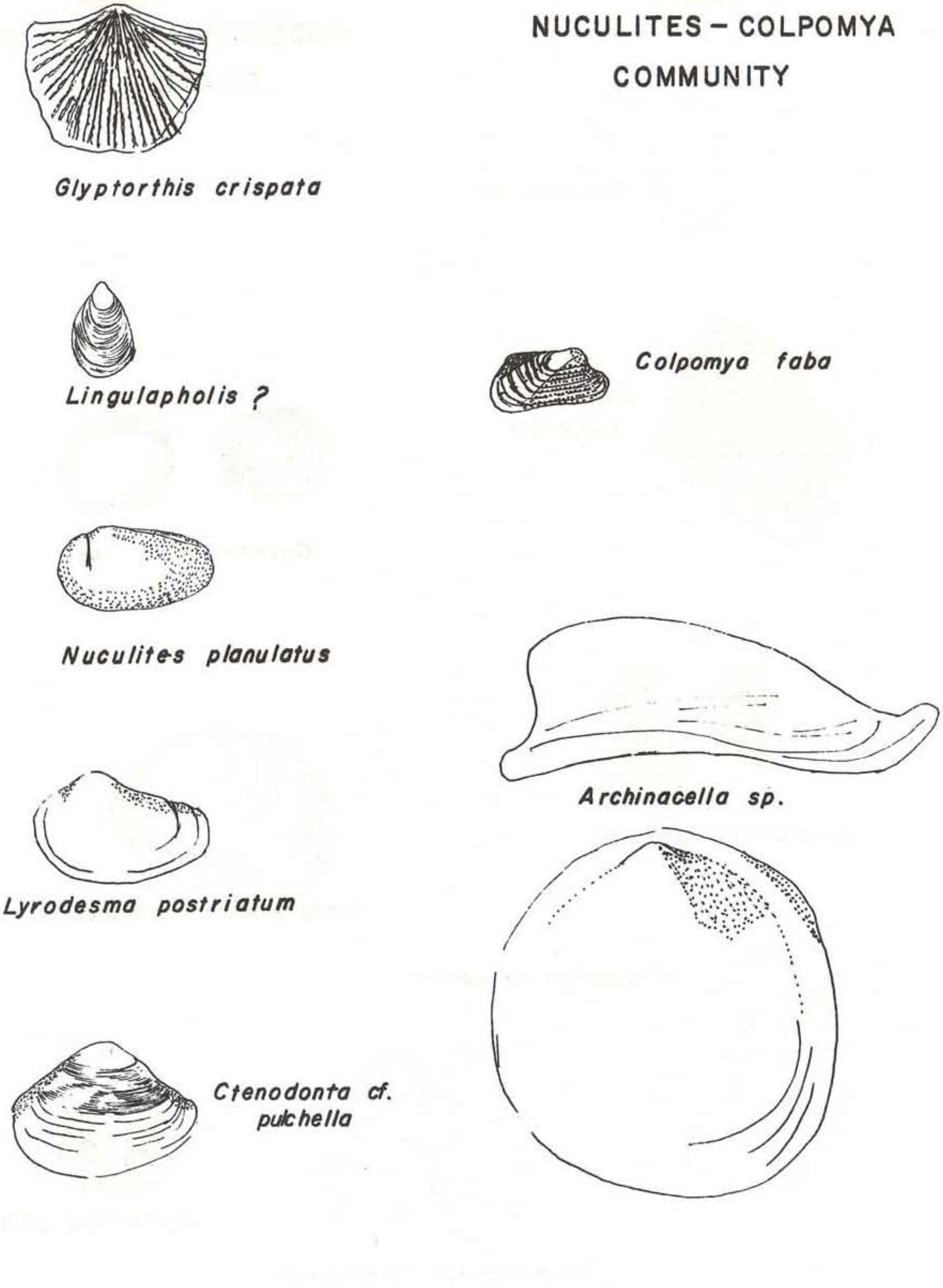


Figure 6. Representative fossils in Onniella-Sowerbyella Community.



Glyptorthis crispata

Lingulapholis ?

Colpomya faba

Nuculites planulatus

Archinacella sp.

Lyrodesma postriatum

Ctenodonta cf. pulchella

Figure 7. Representative fossils in Nuculites-Colpomya Community.

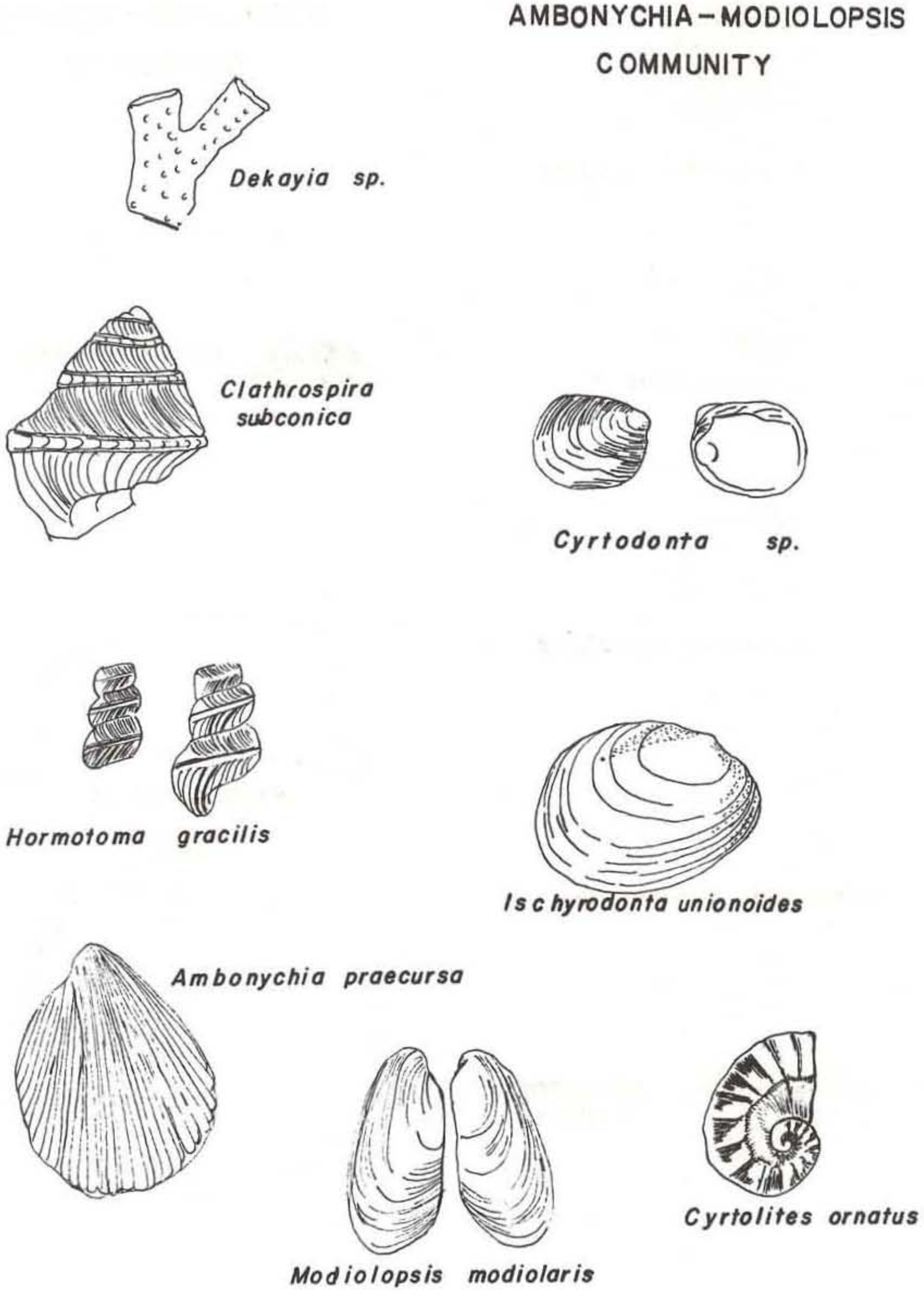


Figure 8. Representative fossils in Ambonychia-Modiolopsis Community.

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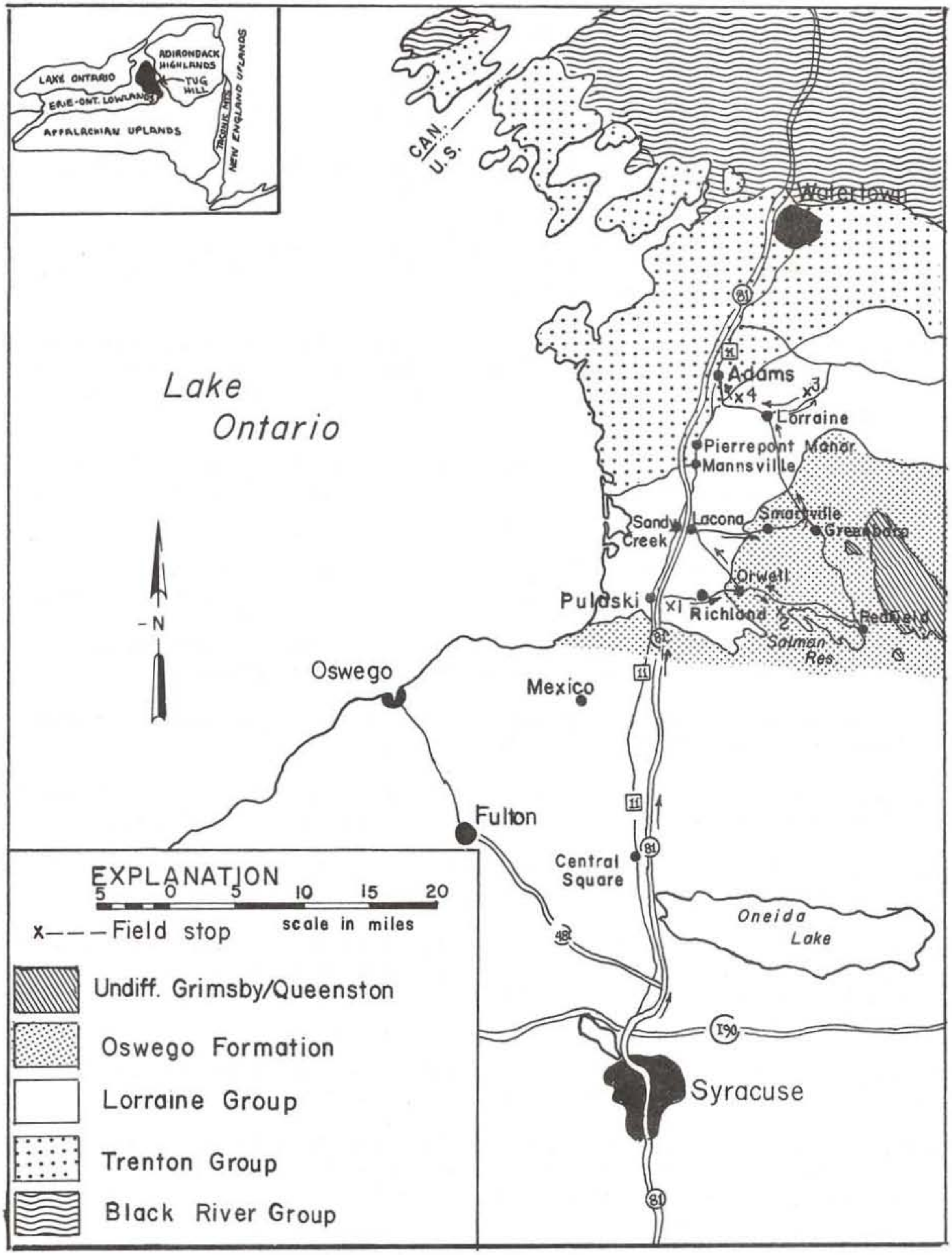

Figure 9. Field trip route with stops.

ROAD LOG

BENTHIC MARINE COMMUNITIES IN THE LATE ORDOVICIAN CLASTICS OF THE TUG HILL REGION, NEW YORK

(All quadrangle references are to the 7.5 minute topographic series)

MILES FROM LAST POINT	CUMULATIVE MILEAGE	ROUTE DESCRIPTION
0.0	0.0	ASSEMBLY POINT: Heroy Hall parking lot, Syracuse University Proceed from university grounds to
0.2	0.2	Crouse Ave.
0.3	0.5	Head north on Crouse Ave., proceed to Harrison St.
0.3	0.8	Turn left (W) on Harrison, proceed to Almond Ave.
0.1	0.9	Turn right (N) on Almond, taking access ramp to I81; follow I81 to Pulaski, New York
4.1	5.0	Cross NYS Thruway
30.7	35.7	Cross Tinker Tavern Road (Exit 35)
3.3	39.0	Take Exit 36 to Pulaski
0.9	39.9	Turn left (W) onto NY13 and follow to intersection with NY11
0.1	40.0	Turn right (N) onto NY11 and proceed thru Pulaski
0.2	40.2	Cross Salmon River
0.2	40.4	Turn right at second stoplight (Maple Ave.)
0.3	40.7	Pass Coho Salmon Collecting Weir on right
0.4	41.1	Cross I81 and take first right, Co. Rt. 2A
1.0	42.1	Proceed to RR tracks which cross highway at Schoeller Paper Company

STOP 1. Salmon River, stream cut exposures near railroad trestle Richland Quadrangle). The organisms here are large, suspension feeding molluscs in the coquinite beds. Note the lack of abrasion and sorting of the shells. The deposition was in the low energy mode on a shallow, gently sloping shelf. Depositional events were episodic but not violent. The mud fauna is made up of infaunal suspension and detritus feeders. Sedimentary structures to be observed here include large dune sets, several sets of ripples and dessication (?) features. "Turkey tracks" and "U"-shaped tubes should also be noted. This outcrop illustrates a proximal facies.

0.3	42.4	Continue SE on Co. Rt. 2A; turn left at fork (Centerville Road)

0.1	42.5	Proceed to Peck Road, turn left and continue
1.7	44.2	Turn right onto Co. Rt. 2 (Richland Rd.)
0.9	45.1	Pass through village of Richland; follow jog in road; proceed to Orwell
2.9	48.0	In Orwell, turn right onto Co. Rt. 22; follow to Falls Road
2.7	50.7	Turn left onto Falls Road
1.4	52.1	Proceed along dirt road to parking area

STOP 2. Salmon River Falls (Orwell Quadrangle). CAUTION !!! This stop involves considerable climbing; footing is poor; do not go near the brink of the falls. This outcrop exhibits the transitional nature of the Oswego -Pulaski boundary. It is the most proximal facies and here we see the last of Upper Ordovician marine sediments. Compare the features of a higher energy regime with those features of STOP 1. Inspect the nature of the fossils and biogenic structures in the Pulaski with the unfossiliferous Oswego Sandstone.

		Turn around; return to Co. Rt. 22; turn right and proceed to Orwell
4.2	56.3	Orwell; continue north on Co. Rt. 22
5.9	62.2	Village of Lacona; turn right (E) onto Co. Rt. 15 (Smartville Road)
8.5	70.7	Proceed to T-intersection; turn left (N) onto Co. Rt.17
8.4	79.1	Village of Lorraine; turn left at intersection with Lorraine-Worth Center Road
0.1	79.2	Pass through village
3.8	83.0	Turn right (E) onto Rt. 178 and proceed to Bullock Corners

STOP 3. Lorraine Gulf (Rodman Quadrangle). Exposures are 0.3 miles north of intersection. Bus will not be able to travel this road. Participants will walk to exposures from here and return to bus at this point. At this outcrop a more distal facies is exhibited. The sediments were deposited early in the regressive phase. Note the taxonomic and preservational changes exhibited here. What is the same when compared to the previous outcrops?

3.8	86.8	Return to Lorraine and continue (W) onto Rt. 178
3.2	90.0	Cross South Sandy Creek
0.2	90.2	Turn right onto Washington Park Road
1.8	92.0	Proceed to parking area in Washington Park

STOP 4. Washington Park (Rodman Quadrangle). Stream cut exposures. This is the most distal sedimentary facies. Stratigraphically, the exposures are lowermost Pulaski, just above the shales of the Whetstone Gulf Formation. Notice the fairly unfossiliferous nature of these beds (what fossils are found?) and the predominance of the shales to siltstones (compare with earlier outcrops).

1.8	93.8	Return to Rt. 178; turn right (N)
1.7	95.5	Proceed to intersection with US11; turn right (N)
0.3	95.8	At first traffic light (Church Street) turn left (W)
0.6	96.4	Pass under I81
0.1	96.5	Take cloverleaf to I81 S
58.3	154.8	Return to Syracuse

Punctuated Aggradational Cycles (PACS) in Middle Ordovician and Lower Devonian Sequences

E.J. Anderson and Peter W. Goodwin, Temple University;
Barry Cameron, Boston University

Hypothesis

Observations of numerous clastic and carbonate sequences as well as recent papers on asymmetric cycles (Ryer, 1977; Beukes, 1977; Talbot, 1974) have led us to the hypothesis that all geosynclinal and cratonic sedimentation occurs as upward-shallowing (aggradational) cycles following rapid non-depositional transgressions (Fig.1). The general hypothesis can be viewed as a series of increasingly interpretive statements:

1) Sedimentary sequences consist of upward-shallowing packages separated by sharply defined surfaces (punctuated aggradational cycles).

2) These sharp surfaces represent intervals of rapid transgression during which no net deposition occurs. All deposition is aggradational during relatively long stable periods following transgressive events.

3) Therefore large-scale transgression is not a continuous process but rather an episodic one. Large-scale transgressive sequences consist of numerous punctuated aggradational cycles (Fig.1): basin-wide transgression is accomplished through a series of deepenings and shoalings, not by a continual deepening.

4) Rapid transgressive episodes are caused by basin subsidence.

5) Rapid basin subsidence occurs in response to abrupt movements of the elastic lithosphere.

The primary purpose of these two field trips is to demonstrate that two chronologically distinct sedimentary sequences, representing a broad range of environments, consist entirely of punctuated aggradational cycles (PACS). These two generally transgressive carbonate sequences (Black River and Helderberg), traditionally described as successions of numerous formations and members, can be viewed in a more genetic and integrative sense as sequences of a single depositional motif: punctuated aggradational cycles. The spectrum of environments is sufficiently broad to suggest that this motif is pervasive and applicable to all paleoenvironmental situations.

A second purpose of the trips is to introduce some of the stratigraphic implications of the PAC Hypothesis. Application of the PAC idea raises questions such as:

1) What is the relationship between aggradational cycles and traditional stratigraphic units (formations and members)?

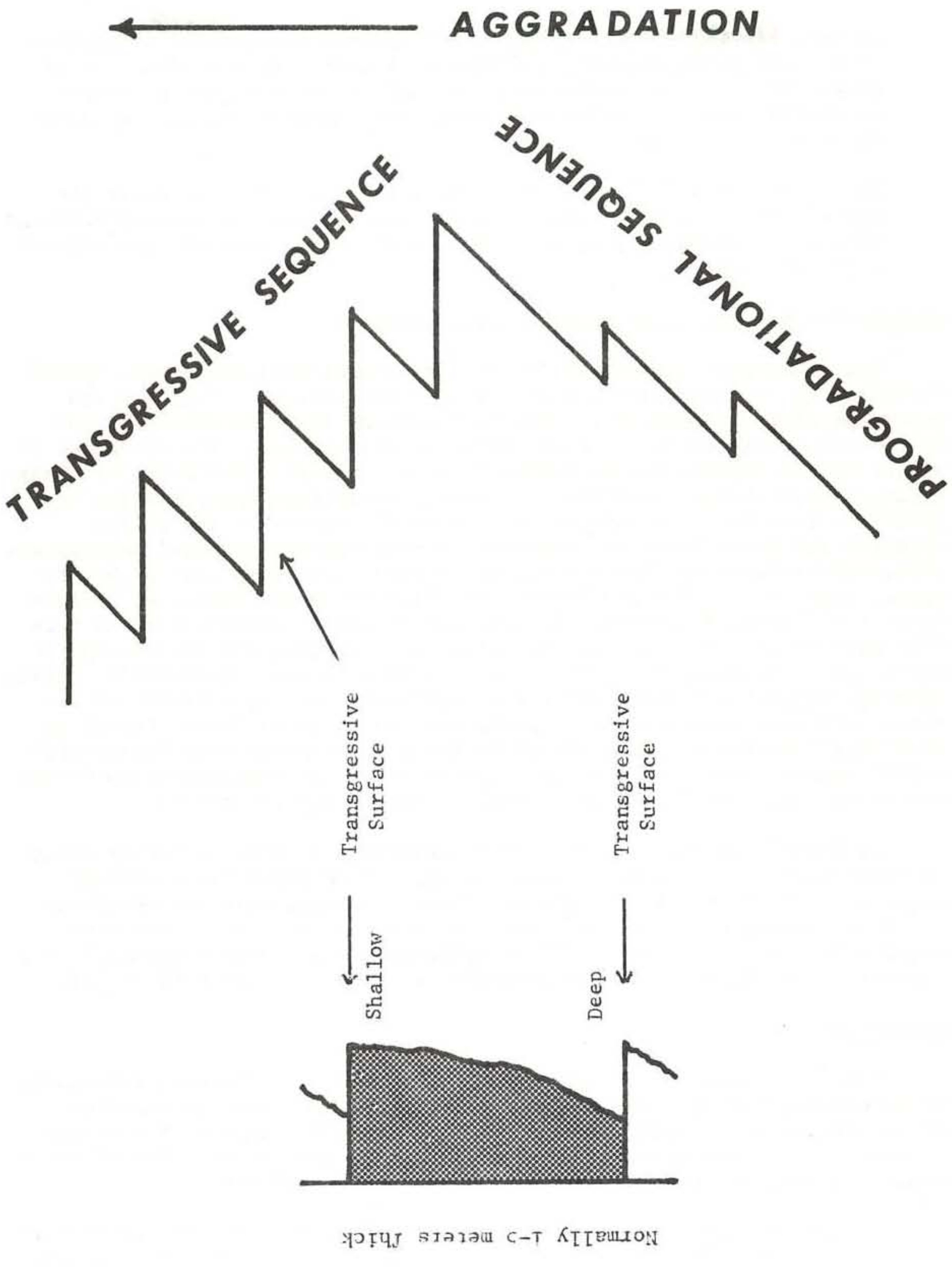

Figure 1. Components of typical PAC and relationship of cycles to transgressive and progradational sequences.

2) What are the paleogeographic implications of episodic transgression? Was paleogeography modified with each transgression? Is it still valid to view large-scale transgression as a gradual shoreward migration of a relatively fixed geographic pattern, i.e. does Walther's Law apply?

3) Can cycles and transgressive surfaces be traced throughout the basin? Are subsidence events basin-wide and essentially synchronous? If so, are transgressive surfaces the ultimate means of intrabasinal correlations?

Recognition of Punctuated Aggradational Cycles

The essential ingredients of PACS are gradational shallowing upward deposits and sharply defined bounding surfaces (Fig.1). Surfaces are generally slightly undulatory, may be erosional (e.g. ravinements) and are always evidenced by an abrupt environmental change. The thickness of cycles varies greatly but is generally 1 to 5 meters. Criteria for recognizing upward shallowing differ for each paleoenvironmental setting but generally fall in three categories: textural parameters reflecting strength and persistence of currents and wave motion; physical sedimentary structures related to flow regime; and biogenic features such as burrow types, algal structures and faunal diversity which are sensitive indicators of ecologic conditions. In conjunction these criteria yield a relative measure of depth, lateral environmental position and circulation in the basin. For example lagoonal cycles generally are calcarenitic, argillaceous, bioturbated and diversely fossiliferous at their bases and micritic non-argillaceous, less bioturbated and sparsely fossiliferous in their upper portions. This set of criteria suggests an open lagoon with normal salinity and good circulation which fills by aggradation to become restricted, thereby decreasing diversity and energy conditions.

On these trips we will attempt to demonstrate criteria for defining aggradational cycles in environments ranging from tidal flats through lagoons and barriers, to the shallow shelf. Ideally each paleoenvironmental situation should be defineable by a basic PAC and its variants. Major shifts of environment will be reflected in a distinct change in the characteristic PAC but all environments will have the basic PAC motif.

Mechanisms

Possible mechanisms to explain the empirically formulated hypothesis of punctuated aggradational cycles include: 1) tectonically produced basin subsidence; 2) eustatic rises of sea level, resulting from changes in sea floor spreading rates or glacial melting and 3) migration of environmental mosaics superimposed on gradual basin subsidence.

Changes in sea floor spreading rates operate at the wrong periodicity to produce cycles (they are too slow). Several environments such as the open shelf and lagoons do not contain a mechanism for causing lateral migration of environmental mosaics and producing sharp cycle bases. Eustatic sea level rises produced by melting of polar ice are difficult to apply to equable climatic geologic periods such as the Cretaceous and cannot produce differential subsidence across a depositional basin. Tectonic mechanisms would appear to work well at continental margins (geocynclinal areas) but are more difficult to apply to cycles in the stable craton. However a tectonic mechanism of some kind seems the best possibility for producing differential subsidence and thus developing a sedimentary basin containing thick stratigraphic sequences.

BLACK RIVER AND TRENTON GROUPS

Introduction

Since the early 19th century geologists have been studying the Medial Ordovician Black River and Trenton groups of the Mohawk Valley (Figs.2,3). Thus, these rocks have become well-known as part of the disputed Medial Ordovician standard reference section of North America - the type Ordovician being in Europe. Although many of the rock units are believed to be time-stratigraphic regionally, some are locally diachronous and locally change facies into each other. Environmentally, the Black River and lower Trenton carbonates change facies eastward into the deeper water Utica black shales. The cyclic aspect of their sedimentation, namely the presence of punctuated aggradational cycles, was not recognized until recently.

Black River Group

The Black River Group in New York is composed of four formations (Cameron and Mangion, 1977): Pamelia, Lowville, Watertown, and Selby, in ascending order. The Pamelia Formation, which disappears south of Boonville, Lewis County, is a supratidal dolostone that overlies Precambrian and Cambrian rocks north of the field trip area. In the field trip area the lower Lowville contains facies similar to those of the Pamelia farther north. The Lowville, once known as the "Birdseye Limestone", comprises most of the relatively thin (26-37 feet) Black River Group in the central Mohawk Valley. It has been divided into two informal members (Cameron and Kamal, 1977): a lower buff-colored, sandy and dolomitic limestone and an upper dove-gray, pure limestone. The overlying Watertown Limestone is the youngest unit of the group in the area and ranges from zero to seven feet thick, increasing in thickness northward. The Selby Limestone is absent this far south.

Trenton Group

In northwestern New York lower Trentonian formations are believed to be essentially time-stratigraphic in nature while they have been shown to be time-transgressive in the field trip area where the paleoshoreline is eastward along the north-south trending Adirondack Arch near Canajoharie. The northern basal Napanee Limestone pinches out southward before reaching the field trip area where the lower Trenton formation is the Kings Falls Limestone. The age of the base of the Kings Falls becomes progressively younger to the southeast because its basal Rocklandian-aged beds disappear indicating that the lower Kings Falls in central New York is Kirkfieldian in age. Conglomeratic beds also sporadically occur at its base, such as

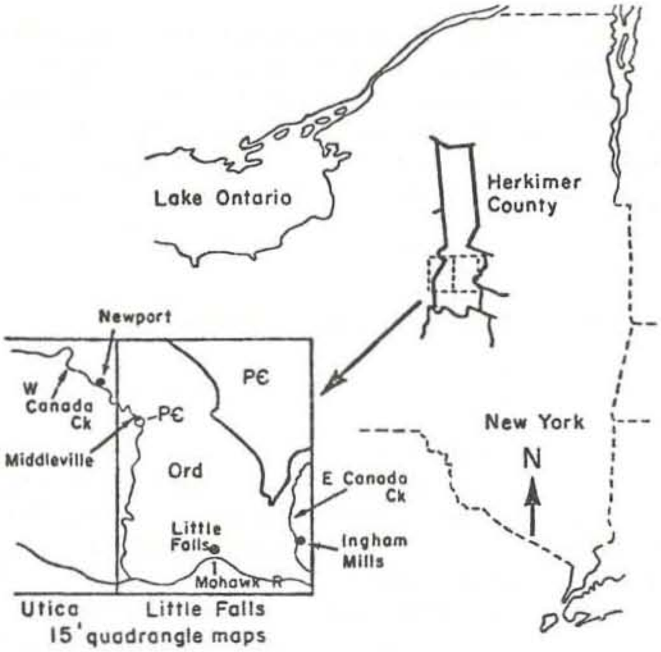

Figure 2. Partial map of New York State with index maps showing location of quadrangles and field trip stops.

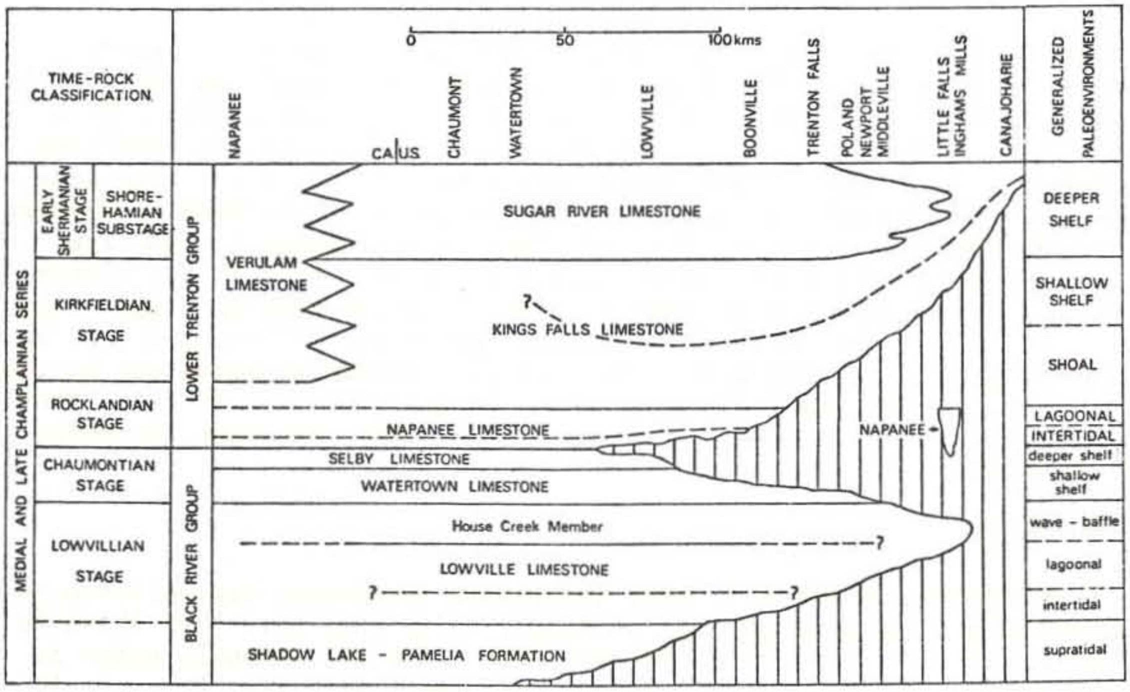

Figure 3. Generalized correlation chart of Black River and lower Trenton groups from central Mohawk River Valley in New York to southeastern Ontario. Width of each unit approximates relative thickness which is estimate of time. Generalized paleoenvironmental framework in shown in right-hand column. Note ambiguous and problematic portrayal of Black River Group in southeast, i.e., central Mohawk River Valley (from Cameron and Mangion, 1977, p. 489).

at Inghams Mills (Stop #2). In addition, the Kings Falls decreases in thickness eastward, becomes Shorehamian in age, and disappears east of Canajoharie.

STOP DESCRIPTIONS

Stop #1, Newport Quarry (Figs.4,5)

Three formations are exposed in the large northwest Newport Quarry: the Late Cambrian Little Falls Dolostone and the Medial Ordovician (Black River Group) Lowville and Watertown Limestones (Cameron & Kamal, 1977). The top of the sandy upper Little Falls presumably forms the quarry floor. The Lowville can be divided into a lower sandy dolomitic member (13½') and an upper purer limestone member (21½'). A metabentonite and a 2-foot thick argillaceous marker horizon, both useful for local correlation (Cameron & Kamal, 1977), are at about 9 and 30 feet, respectively. The Watertown Limestone at the top of the quarry is massively bedded, burrow-reworked, black chert-bearing and fossiliferous calcisiltite and calcarenite. The fauna is more diverse and fossils are more commonthan in the Lowville below, but they are hard to collect. Large tabulate corals, brachiopods, mollusks, and bryozoa are evident.

Ten cycles that average 4 feet in thickness have been identified: three in the lower Lowville Limestone (Cycles 1-3), six in the upper Lowville (Cycles 4-9), and at least one in the Watertown (Cycle 10). Another cycle in the Watertown is postulated by correlation with nearby exposures. The three lower dolomite Lowville cycles are interpreted as representing restricted tidal conditions. At their bases they are argillaceous and contain horizontal burrows. Horizontal algal stromatolitic laminations, fenestral fabrics, and vertical burrows occur mostly in the middle. The quartzose tops of cycles 2 and 3 may be lag deposits from tidal channels. They both contain quartz arenites at the base of the sandy beds and the upper one is quite fossiliferous. The upper Lowville contains six less-restricted tidal cycles. Their bases are typically abrupt, burrow-reworked, and fossiliferous. The lower and middle parts are typically argillaceous. Towards their tops they become more micritic. Vertical burrows, intraclasts, fenestral fabrics, and stromatolitic laminations are common.

The Watertown Limestone is subtidal, possibly shallow shelf or lagoonal in nature, and less restricted than the Lowville, as evidenced by the thorough burrow-reworking and by the diverse invertebrate and calcareous algal fossil assemblages here and elsewhere. Most of the shelly fossils are concentrated at the bases of small subcycles 6 to 12 inches thick that mimic larger cycles.

Stop #2, Inghams Mills (Fig.6)

Three limestone formations of Medial Ordovician age are excellently exposed along with the top of the Late Cambrian Little Falls Dolostone below the dam on East Canada Creek. The Lowville here comprises the whole

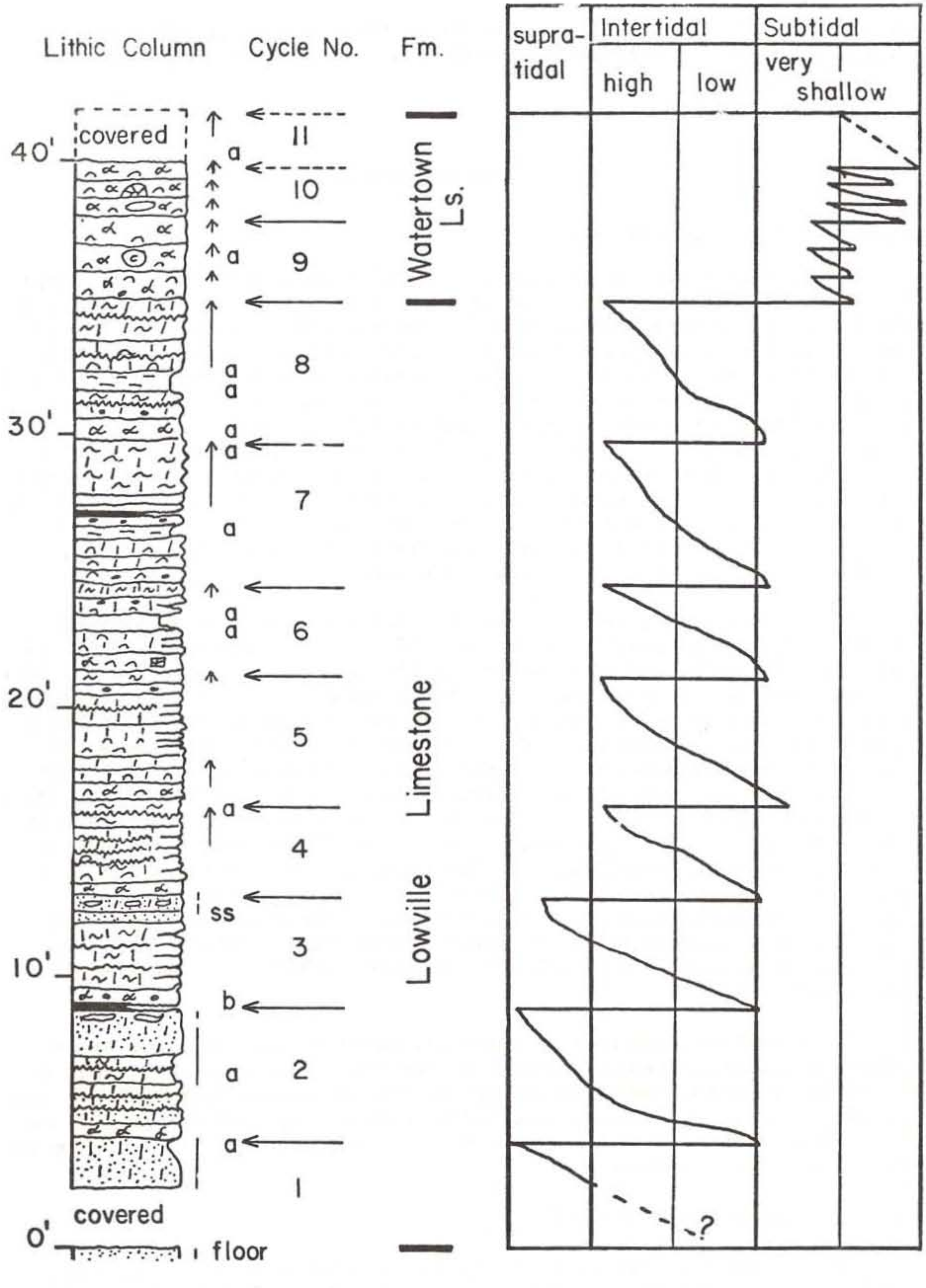

Figure 4. Newport Quarry.

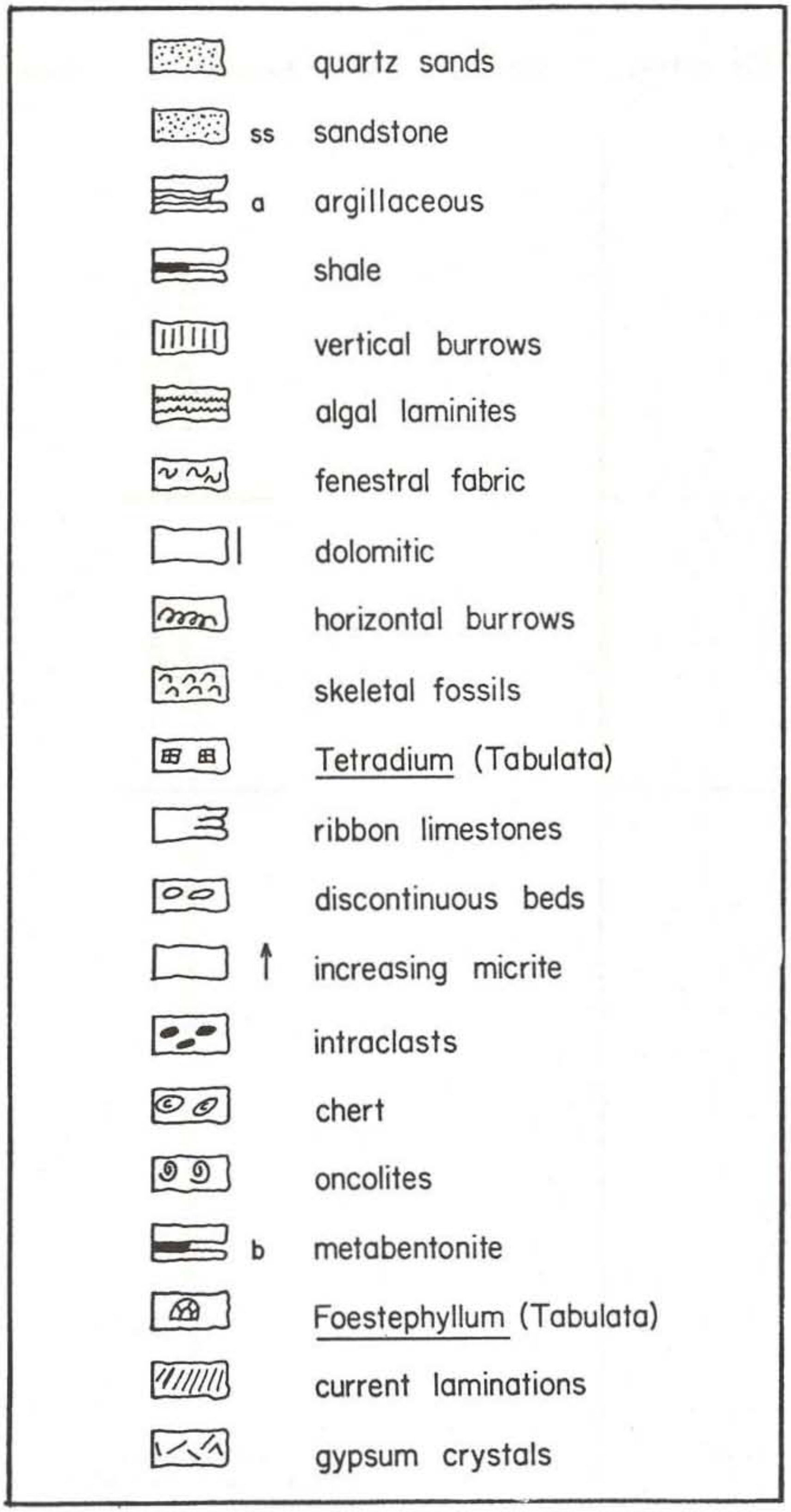

Figure 5. Key to lithologic symbols

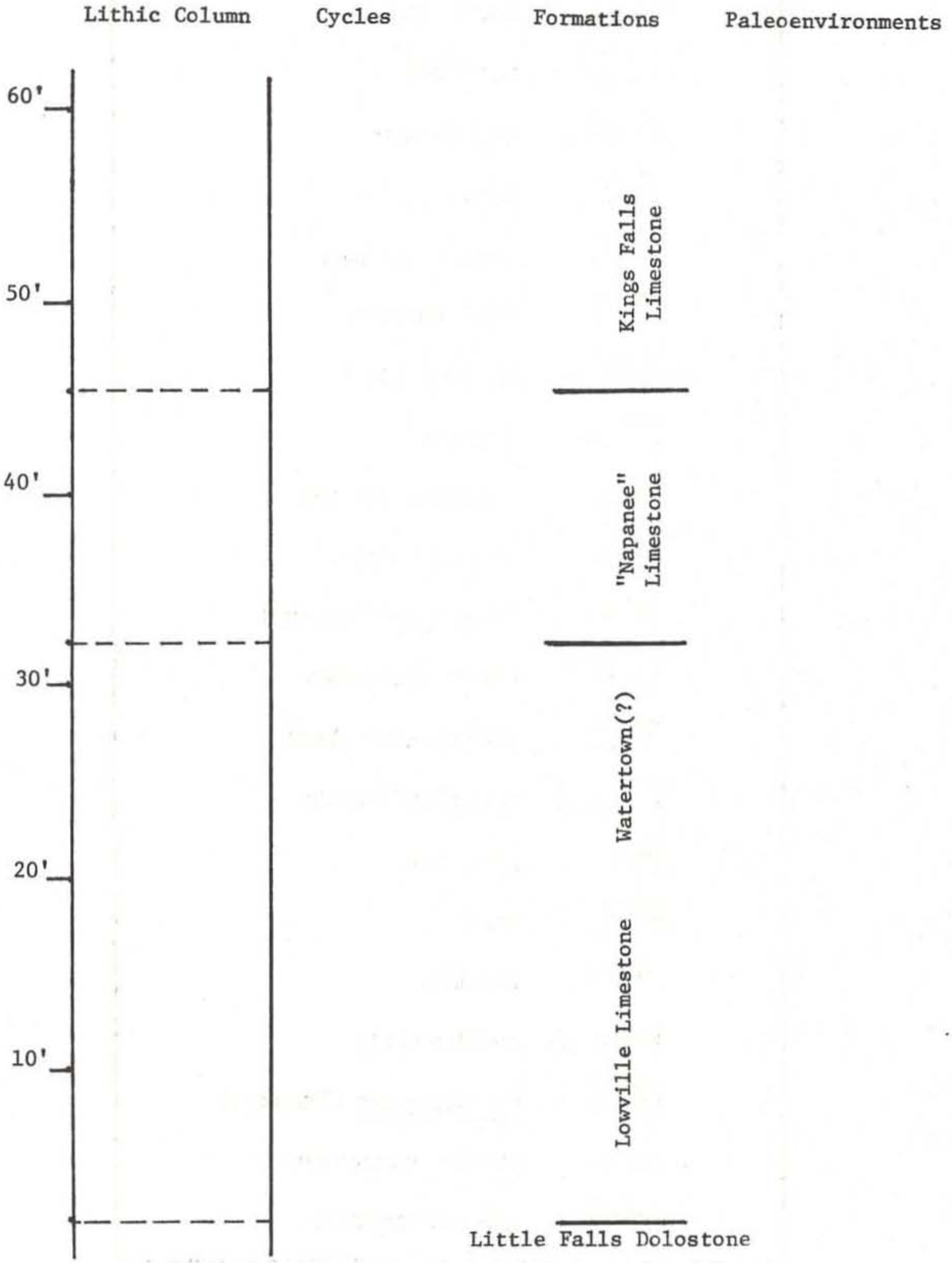

Figure 6. Inghams Mills Section.

of the Black River Group although a Watertown-like 4-foot thick horizon occurs near the top. The Trenton Group above is represented by an unusual facies of the Napanee Limestone and the Kings Falls Limestone, including what was once attributed to the Sugar River Limestone (Kay, 1968; Cameron, 1969). At this well-exposed outcrop, the field trip participants will be encouraged to use the many paleoenvironmental criteria observable here in an attempt to recognize the punctuated aggradational cycles themselves. After an outcrop discussion, we will leave to look at Devonian cycles.

Little Falls Dolostone.- Two feet of the Late Cambrian Little Falls Dolostone are exposed at this locality. The top of this unit has two feet of relief and is relatively thick-bedded, light to medium brown weather ing, quartz arenitic, pyrite-bearing dolostone with thin inter-bedded shale layers.

Lowville Limestone. - Approximately 30 feet of Lowville are exposed, beginning with several feet of fossiliferous gray shaly limestone at the base. Middle Lowville contains horizontally laminated (algal?) calcilutites with abundant vertical burrows, a few ostracodes, and mudcracks confirming an intertidal origin. Tide channels (Cameron, 1969; Cameron and Kamal, 1977) are well-exposed on the southern and western sides of the lower outcrop. The upper half of the formation contains subtidal fossiliferous burrow-reworked calcisiltites overlain by intertidal vertically-burrowed lithologies. The subtidal lithologies resemble the Watertown Limestone to the Northwest.

"Napanee Limestone". - The lowest 13 feet of Trenton(?) limestone consists of a lower 7.5 foot unit of chocolate brown argillaceous calcisiltites and calcareous shales overlain by a 5.5 foot unit of gray less argillaceous calcisiltites interbedded with thinner shales.

Kings Falls Limestone. - Twenty-three feet of brachiopod-rich shelly, lower Kings Falls Limestone overlies the "Napanee". The upper Kings Falls (14 feet) consists of encrinitic bryozoan-rich calcarenites.

Using these general lithologies and thicknesses for stratigraphic location, field trip participants will attempt to recognize punctuated aggradational cycles from criteria demonstrated at Newport Quarry. A blank columnar section (Fig.6) is provided for recording PACS with lithologic documentation. Formational boundaries are indicated along with vertical measurements for purposes of location. After outcrop analysis by small groups of participants there will be a full-group discussion of the outcrop.

LOWER DEVONIAN HELDERBERG GROUP

Helderberg PACS:

The Lower Devonian Helderberg Group (Fig.7) illustrates punctuated aggradational cycles developed in a diversity of environmental settings. Each formation and member of the Helderberg Group is divisible into

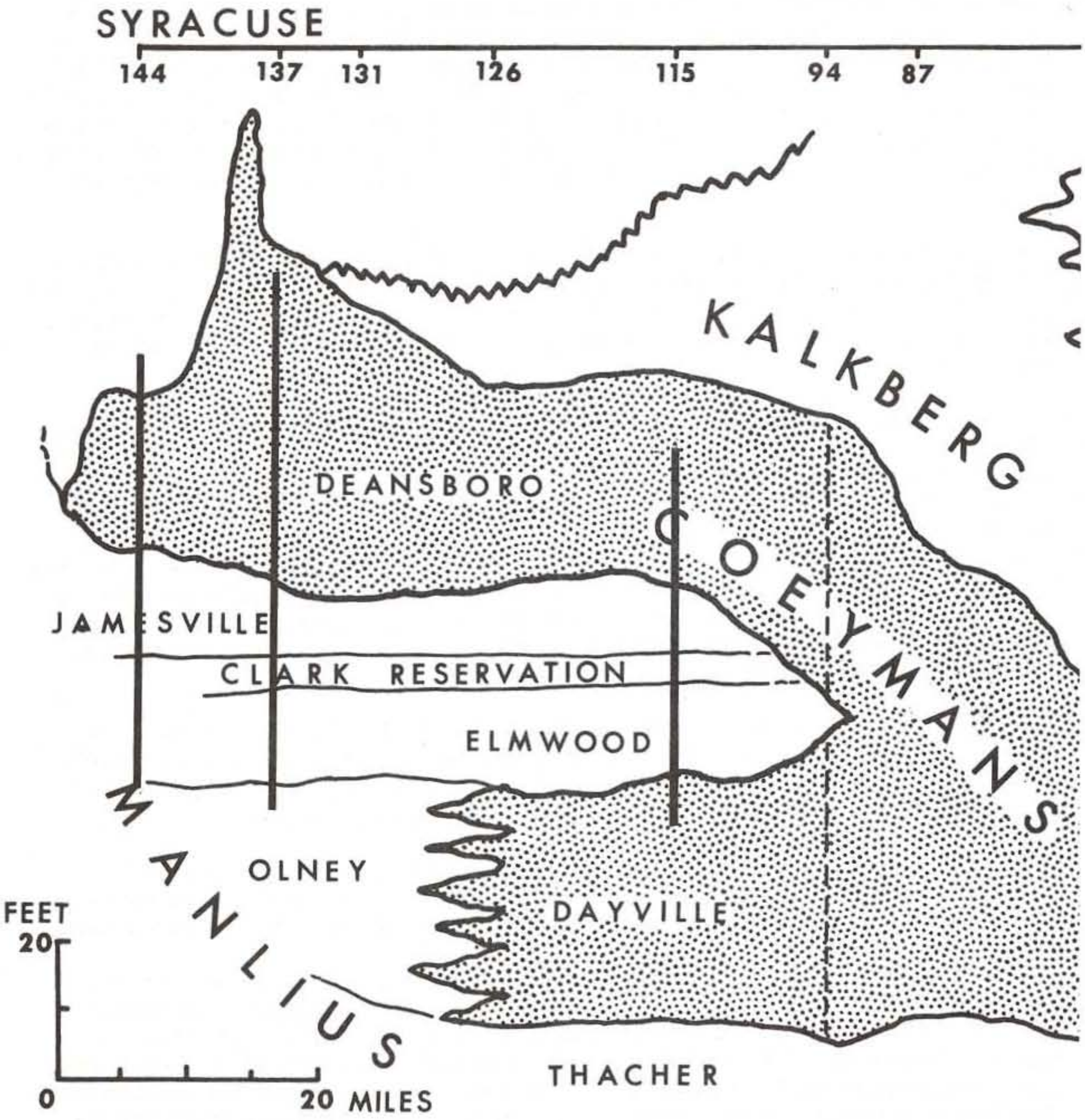

Figure 7. Helderberg stratigraphy in central New York, locality numbers from Rickard, 1962; Jordanville-115, Munnsville-137, and Perryville-144. Interval to be studied is shown by heavy vertical lines.

shallowing-upward cycles, separated by sharp (non-depositional or erosional) surfaces of transgression. Three stratigraphic sections will be studied on this trip: the Jordanville Quarry; the Munnsville Quarry; and the Perryville (Warlock) Quarry. At each of these large active quarries approximately the same stratigraphic interval (Fig.7) is represented and the section is continuously exposed and accessible. Environmental analysis based on PACS requires well exposed, continuous stratigraphic sections.

Jordanville Quarry: Eight cycles are exposed in the quarry, two in the upper Dayville and Elmwood, four in the Jamesville and two in the Deansboro (Fig.8). The Clark Reservation is probably not present (it appears to terminate further west). The two lower cycles (I and II) are thick and grade from coarse more argillaceous and fossiliferous beds up into fine very well sorted dune cross-stratified calcarenite. Note that these beds, which include the Elmwood Member of the Manlius, are not dolomitic algal laminites as they are further west at Munnsville and Perryville. The next three cycles in the Jamesville (III to V) are stromatoporoid-algal laminite cycles; laminites are well-developed only in Cycle III. These laminites, which are well developed in Cycle III in the north wall of the quarry, are not present less than a quarter of a mile away in the south wall. Cycle VI (Fig.8), a three foot cross-stratified calcarenite, has erosional upper and lower surfaces. This can be interpreted as a barrier island deposit bounded on the bottom by a migrating tidal inlet erosion surface and on the top by a ravinement. Cycles VII and VIII (the Deansboro) are shallow open shelf cycles consisting of bioturbated crinoid-brachiopod calcarenite which grades upward into current stratified deposits.

Munnsville Quarry: Nine Helderberg cycles (PACS) are exposed in the Munnsville Quarry (Fig.9), four in the Olney-Elmwood, one equivalent to the Clark Reservation, four in the Jamesville and two (plus a partial cycle) in the Deansboro. The first four PACS contain restricted subtidal micrites grading upward into supratidal laminites. The four cycles in the Jamesville are defined by gradation from argillaceous limestones up into purer bioturbated limestones deposited in restricted subtidal conditions. The two complete Deansboro cycles, like those at Jordanville, grade from bioturbated shelf deposits.

Perryville Quarry: The lower Helderberg Group (Thacher - Jamesville) is well exposed at the north end of the quarry and the upper part (Jamesville - Deansboro) at the south end. Figure 10 is an outline of the stratigraphy of the lower Helderberg (north quarry face) with cycle analysis present up through the Clark Reservation. The section in the south quarry overlaps the top of the north section and within the complete Jamesville and Deansboro at least five cycles are present (Fig.11). Cycles IX and XI, the first and third Jamesville cycles, begin in bioturbated argillaceous calcarenite which grades up into cleaner more current-stratified calcarenites. Cycle X, is a stromatoporoid-laminite cycle like those seen early at Jordanville and Munnsville. Cycle XII, a thin current-stratified deposit bounded by two erosion surfaces, is genetically distinct. This cycle may represent the remains of a barrier, the lower erosion surface having been cut by a migrating tidal inlet, the upper by a ravinement.

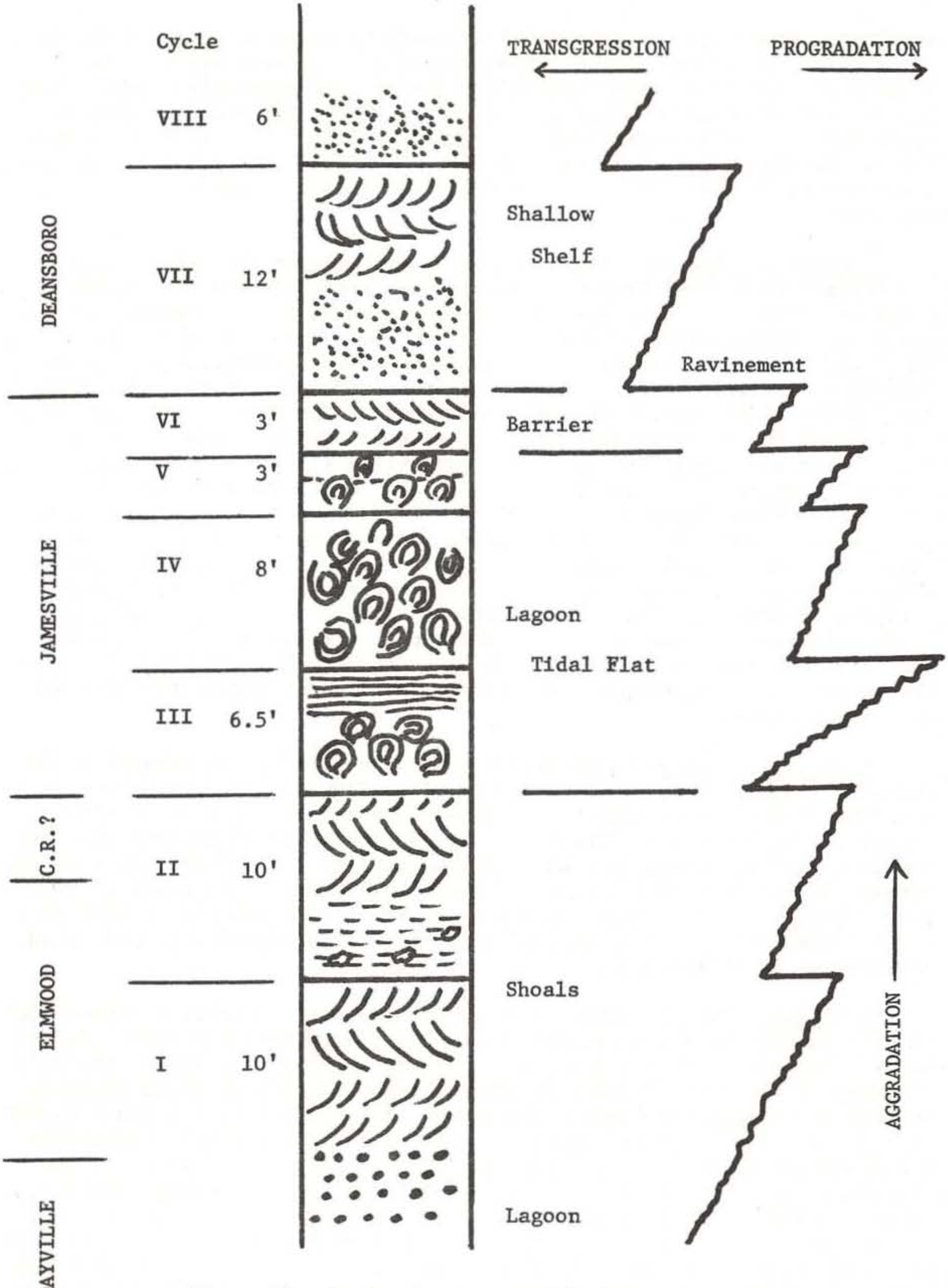

Figure 8. Cycles in Jordanville Quarry.

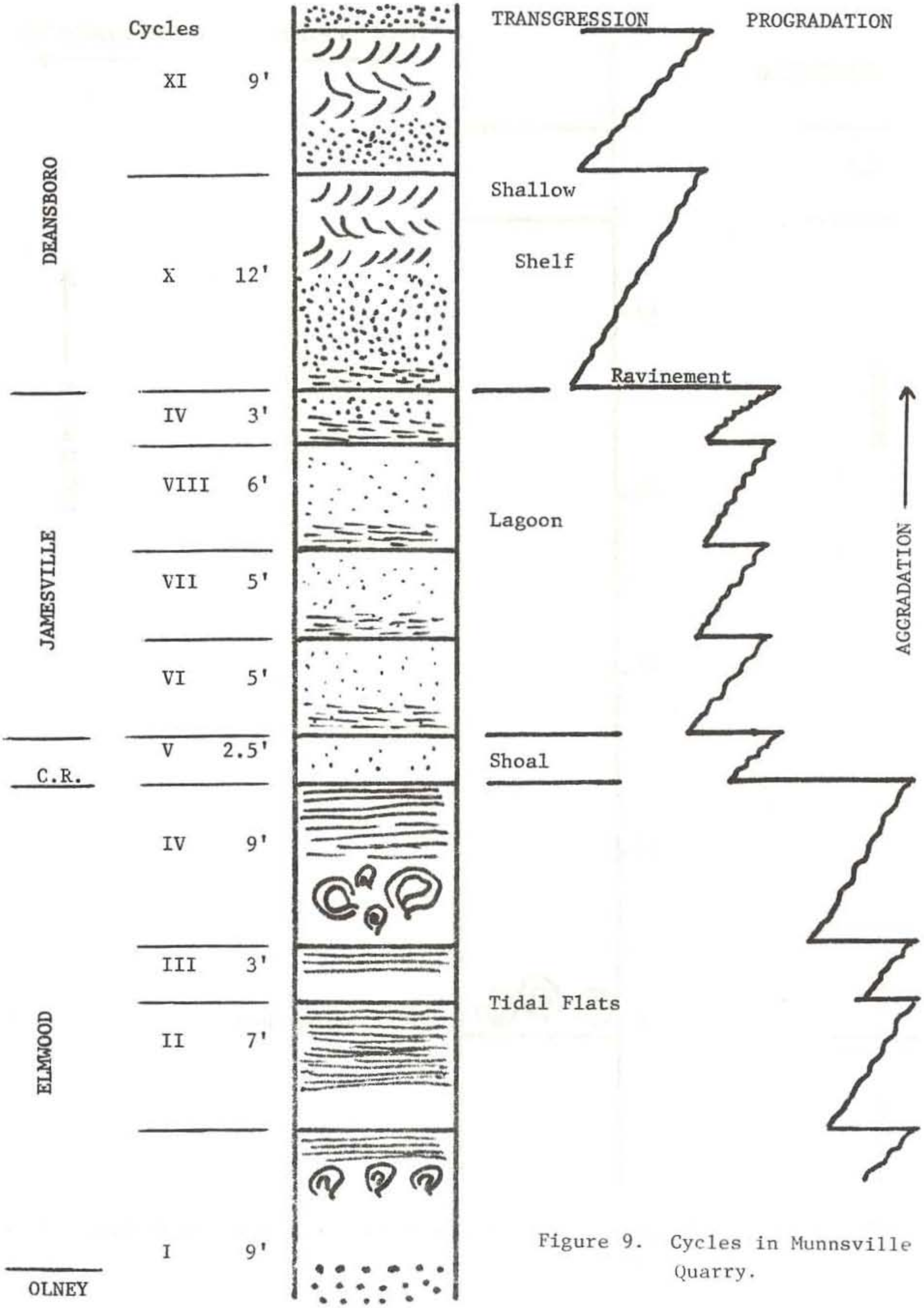

Figure 9. Cycles in Munnsville Quarry.

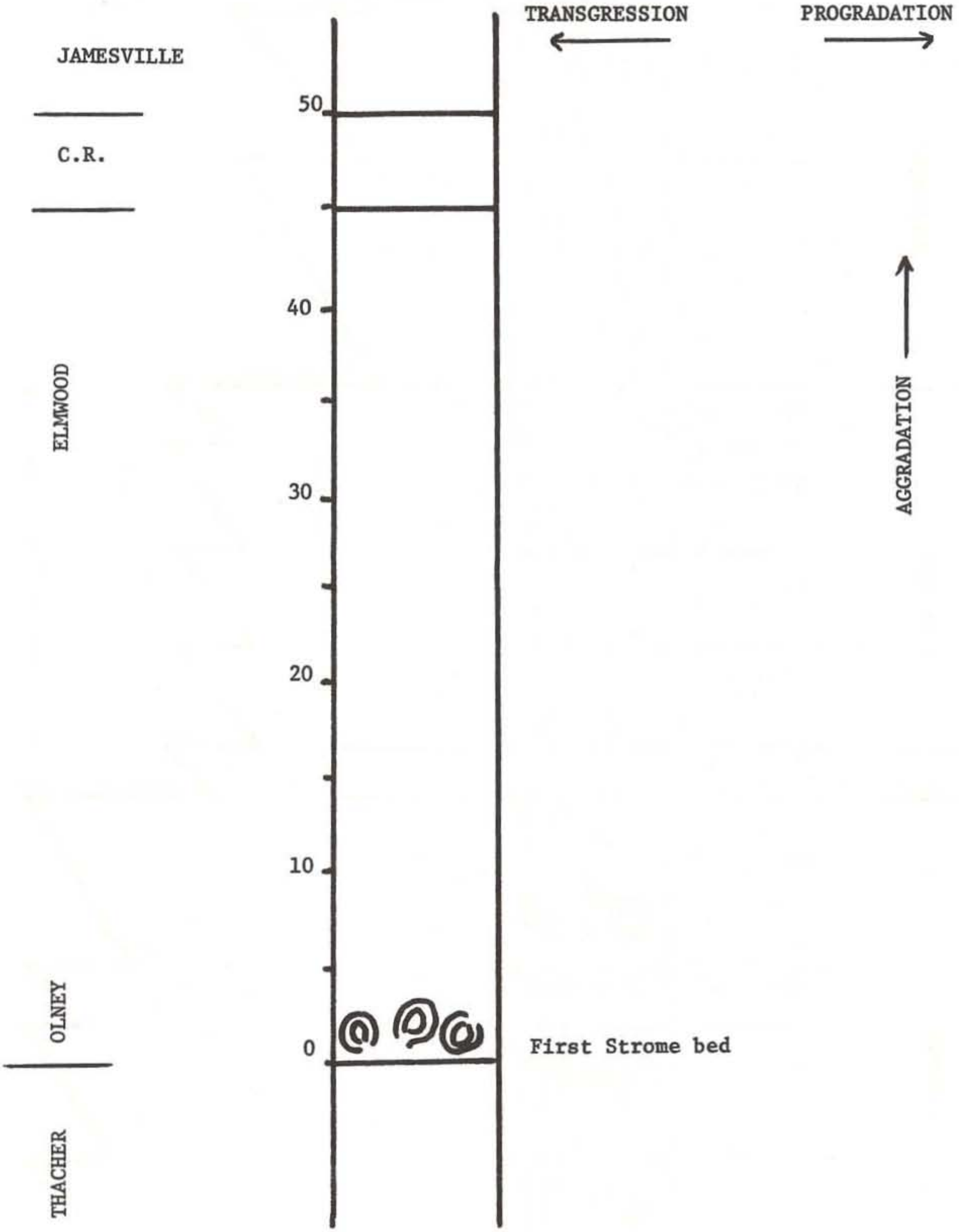

Figure 10. Cycle worksheet for north quarry wall lower Helderberg section at Perryville.

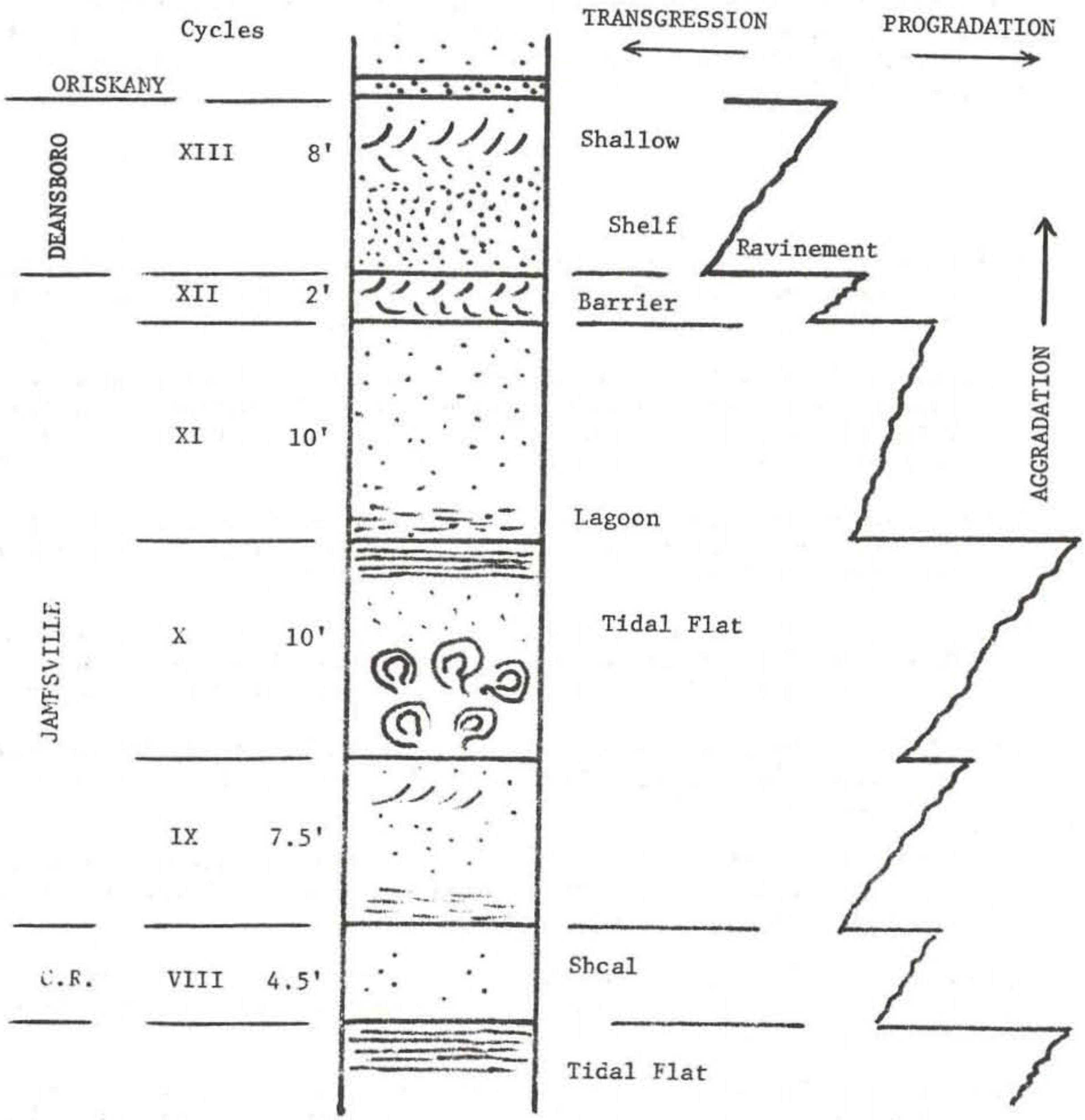

Figure 11. Cycles in upper Helderberg at Perryville south quarry wall.

The same situation is seen at the same stratigraphic position in the Jordanville Quarry. Cycle XIII, like the other Deansboro cycles seen at Jordanville and Munnsville, is represented by a bioturbated fossiliferous open shelf calcarenite grading up into a current-stratified calcarenite. Above the Deansboro, the Oriskany is represented by a quartz-rich trace (< one foot thick) of a migrating barrier island which in turn is overlain by open shelf Onondaga calcarenites.

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MILEAGE LOG (SATURDAY)

InMi	CumMi*	
0.00	0.00	New York Thruway exit 30; start mileage log at intersection with Route 28. Turn right (northeast).
0.25	0.25	Traffic light. Turn left continuing north on Route 28.
0.2	0.45	Traffic light at intersection of Routes 28 and 5. Turn right (east) onto combined Routes 5 and 28.
0.7	1.15	Traffic light. Turn left (north) onto Route 28 and proceed to Middleville.
8.15	9.30	Bear right, continuing on Route 28 towards the bridge.
0.2	9.50	Traffic light after crossing bridge over West Canada Creek. Turn left and continue north on Route 28 towards Newport.
4.4	13.90	Flashing yellow traffic light in Newport. Turn left onto Bridge Street (=Old State Road).
0.15	14.05	Crossing bridge over West Canada Creek.
0.1	14.15	"T"-intersection with West Street (=Newport Road). Turn right (north).
0.75	14.90	Turn right into gravel road leading to a large, old quarry. Park in front of gate, but do not block the entrance for trucks.
		Stop #1: Northwest Newport Quarry (locality NPQ):
		Walk about 300-400 feet along the gravel road and then descend carefully the southeast section of the quarry where the lower and middle Lowville Limestone is well-exposed. Then walk west around the treed promontory to the southwestern part of the quarry where the middle upper Lowville can be examined along with fallen blocks of the Watertown Limestone. Stay away from the southern wall which is about to collapse! Ascend the grassy slope here or walk back around to the center of the treed promontory and walk up the overgrown old "roadway" to examine the Watertown Limestone at the top of the quarry. The contact with the overlying lower Trenton Kings Falls Limestone is exposed in a quarry southwest of Newport (Kay, 1953), but not here.
0.0	14.90	Turn around in quarry driveway and head back to Newport.

*InMi = Incremental Mileage; CumMi = Cumulative Mileage.

0.75	15.65	Turn left (west) onto Bridge Street.
0.2	15.85	Flashing red traffic light at "T"-intersection with Route 28 (Main Street of Newport). Turn right (south) onto Route 28 South.
4.4	20.25	Traffic light in Middleville. Proceed straight ahead onto Route 169 south.
6.3	26.55	Bear left at fork in road, taking secondary road east (Route 169 bears right). You are on Rockwell Road.
0.75	27.30	Intersection with Cole Road. Continue straight. Rockwell Road changes its name to Top Notch Road here.
1.5	28.80	Intersection with dirt road. Bear left, continuing on paved road.
0.7	30.20	Intersection with Burrell Road. Turn left (north).
0.3	30.50	Intersection with Bronner Road. Turn right (east).
1.4	31.90	Intersection. Bear right, continuing on Bronner Road.
0.2	32.10	Bear left where Bronner Road turns left. David Road is to the right.
0.6	32.70	Intersection with Murphy Road. Continue straight on Bronner Road.
0.65	33.35	Turn right (south) onto Route 167.
0.4	33.75	"Y"-intersection with secondary road. Bear left onto East Creek Road.
2.15	35.90	Intersection with Inghams Mills Road. Turn left.
0.75	36.65	After coming down hill, continue straight onto dead end dirt road. Poor exposures of lower Trenton Group (Napanee Limestone) on left. (Do not turn right onto the large bridge over East Canada Creek. However. if the power company (Niagara-Mohawk) does not permit your trespassing, park and walk across the large bridge. Descend the left (upstream) side to the large limestone exposures at the inside of the meander to see all but the base and top of the Lowville Limestone. The 4 foot thick, Watertown-like, burrow-reworked, massively bedded subtidal facies caps the exposure).
0.05	36.70	Turn right and cross small wooden bridge.
0.04	36.74	After crossing bridge, take right fork in dirt road.

0.02	36.76	In front of building, turn left.
0.02	36.78	Turn left, back onto dirt road.
0.05	36.83	Park on grass along right side of dirt road.

Stop #2: Walk to right, through the grass, and proceed to the right of the wire fence, walking beneath the power lines.

At the stone wall along the edge of the field, bear left and walk along the wire fence. CAUTION: Poison ivy often grows in abundance along this path.

Opposits the brick building, turn right and proceed very carefully over to the boulders and across the creek toward the base of the outcrop. The boulders you will have to walk over to get to this exposure are sometimes unstable and tend to move when stepped or climbed upon. Be careful! Traverse at your own risk.

0.0	36.83	Return to cars and drive straight ahead on the dirt road.
0.02	36.85	Turn left onto dirt road leadint from the power plant.
0.05	36.90	Bear right, crossing small wooden bridge. Then bear left.
0.05	36.95	Intersection with Inghams Mills Road. Proceed straight, uphill.
0.8	37.75	Intersection with East Creek Road. Proceed straight ahead.
0.75	38.50	Intersection before small bridge. Bear right onto Dockey Road.
0.4	38.90	Intersection with Bidleman Road. Proceed straight ahead.
0.15	39.05	Proceed straight ahead, joining Route 167 (south) and passing Exxon Station on your left.
2.65	41.70	Blinking traffic light. Stop. Turn right and take Route 167 to Little Falls.

Directions to Jordanville Quarry: (Stop #3):

Follow Route 167 through Little Falls and south to Jordanville, crossing Route 168 at Paines Corner after about 6 miles south of Little Falls, and reaching Jordanville after about 11 miles south of Little Falls. In Jordanville, take the secondary road north about ½ mile north to the quarry.

Return to Syracuse:

Return to Route 167, turn right and continue straight onto Jordanville Road (west) where Route 167 bears sharply left (south). After about 2 miles, turn right (north) onto Route 28 and proceed about another 6 miles through Mohawk to the New York State Thruway in Herkimer. Take the Thruway back to Syracuse.

Mileage Log (Sunday)

InMi	CumMi	
0	0	New York Thruway exit 36, Syracuse; go east on Thruway to exit 34.
21	21	Exit 34, go south on Route 13 through Canastota to route 5.
2	23	Turn east on Route 5, go to Route 46.
6	29	South on Route 46 to Munnsville, the quarry is a mile south of the town on the east side of the valley.
9	38	Munnsville Quarry Return north on Route 46 to Route 5.
9	47	Turn west on Route 5 and go to intersection with Quarry Road.
9	56	Turn south on Quarry Road and drive to entrance of Warlock Quarry.
2.5	58.5	Paved Road into quarry on west side of Quarry Road. Return north on Quarry Road to the intersection with Route 5.
2,5	61	Turn west on Route 5 and return to Syracuse.
16	77	Syracuse University.

Eurypterid Horizons and the Stratigraphy of Upper Silurian and Lower Devonian Rocks of Central-Eastern New York State

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Rochester, New York

INTRODUCTION

There are a number of famous faunas known from classic localities in North America. These include the "Mazon Creek" Fauna (Pennsylvanian) of Illinois, the Kokomo Eurypterid Fauna of Indiana, the Green River Fish Fauna (Eocene) of Wyoming, and the Burgess Shale Fauna (Cambrian) of western Canada. Each is characterized by an unusual abundance and variety of species.

In New York the so-called "Bertie" eurypterids are representative of one such fauna (Fig. 1). Although only one or two species of eurypterids dominate the fauna, a large number of species has been described through the years. Unfortunately, detailed stratigraphic studies of the eurypterid-bearing beds have been noticeably lacking. Until recently, the "Bertie" faunas, one from the Buffalo area (so-called "Buffalo Pool"), and the other from eastern New York (so-called "Herkimer Pool"), were thought to be contemporaneous deposits rather than distinct stratigraphic horizons.

The purpose of this paper and the associated field trip is to relate these and other eurypterid horizons to the stratigraphy of the areas. Several formations are discussed but special emphasis is given to the Chrysler Formation because it is the least known and only recently was well exposed for study.

STRATIGRAPHY AND PALEONTOLOGY

Salina Group

The Salina Group is considered here as consisting of three formations (in ascending order) the Vernon Formation, Syracuse Formation, and Camillus Formation (Treesh, 1972). These units will not be described in detail but will be observed briefly in the field (Fig. 2).

At least three eurypterid horizons are known currently tc occur within the Salina Group. Two were described by Leutze (1956, 1959) from the Syracuse Formation, and one was described from the underlying Vernon (B) Formation (Kjellesvig-Waering and Caster, 1955). The overlying Camillus Formation has not yielded any eurypterid horizons.

The unifying features of the formations of the Salina Group are the "weak" beds (usually described as shaly) exhibited at the outcrop. These may be red and green shales, "shaly" dolostones, etc., containing the principle evaporite deposits (anhydrite, gypsum, halite, etc.) of New York State. Basinal and marginal dolostones of various textures and lithologies also are present. Abundant structures encountered in these rocks include salt hoppers and crystal molds or casts of other evaporite minerals.

Figure 1. Eurypterus remipes remipes De Kay, accumulation of this species preserved in very fine-grained dolostone (waterlime). Specimen No. 090564-1, Phelps Waterlime Member, Fiddlers Green Formation, Passage Gulf, New York (Ciurca Loc. No. 57, Stop 7).

The overlying beds of the Bertie Group, although retaining some features indicative of an evaporite sequence, differ in the nature of their rock strata. Much of the Bertie Group is composed of massive, mottled and straticulate dolostone and "shaly" or thin-bedded dolostones. Waterlimes and some limestone also are present. The Bertie Group also is more fossiliferous than the Salina Group, reflecting more progressive marine influences during the deposition of this unit.

Bertie Group

The Bertie Group, in contrast to the underlying Salina Group, consists of several units of massive dolostones (including waterlimes), beds of limestone, shaly dolostones, and some gypsum and anhydrite. Indications of the former presence of crystalline halite also are present (salt hoppers).

Unlike the major portion of the Salina Group, the Bertie Group seems to be more fossiliferous, and indicates a greater marine influence during the deposition of the Bertie. This is even more true of succeeding units (Cobleskill and Manlius Formations).

The Bertie Group in the Syracuse area consists of three formations. Described in ascending order (Fig. 3) these are the Fiddlers Green Formation, Forge Hollow Formation, and Williamsville (Oxbow) Formation.

Fiddlers Green Formation

The Fiddlers Green Formation (Hopkins, 1914) is the lowest unit of the Bertie Group in central-eastern New York. The author (Ciurca, 1973) described the tripartite nature of the unit and suggested a cyclic origin for the sequence. Three members were named from western New York: a lower waterlime (Morganville Member), a middle unit of crystalline dolostone with some limestone (Victor Member), and an upper waterlime (Phelps Member). It is the Phelps Member which contains the abundant eurypterid remains described from eastern New York (Herkimer County - so called "Herkimer Pool" of early authors), and which yields the abundant eurypterid remains obtained from Passage Gulf (Stop 7).

Morganville Waterlime Member

Although not exposed at Passage Gulf, a waterlime occurs near the base of the Fiddlers Green Formation. This waterlime unit is only well developed in the Syracuse area and to the west as far as Morganville in western New York (type locality). The lower waterlime, the Morganville Waterlime (see Ciurca, 1973) is a persistent massive unit, which breaks with conchoidal fracture and exhibits other features typical of the waterlimes of New York. This unit contains an Eurypterus fauna which is particularly evident in the Cayuga Lake area, and also near Marcellus Falls southwest of Syracuse.

The upper contact of the Morganville Member with the overlying Victor Member may be sharp and irregular, and is noted by a change from very fine-

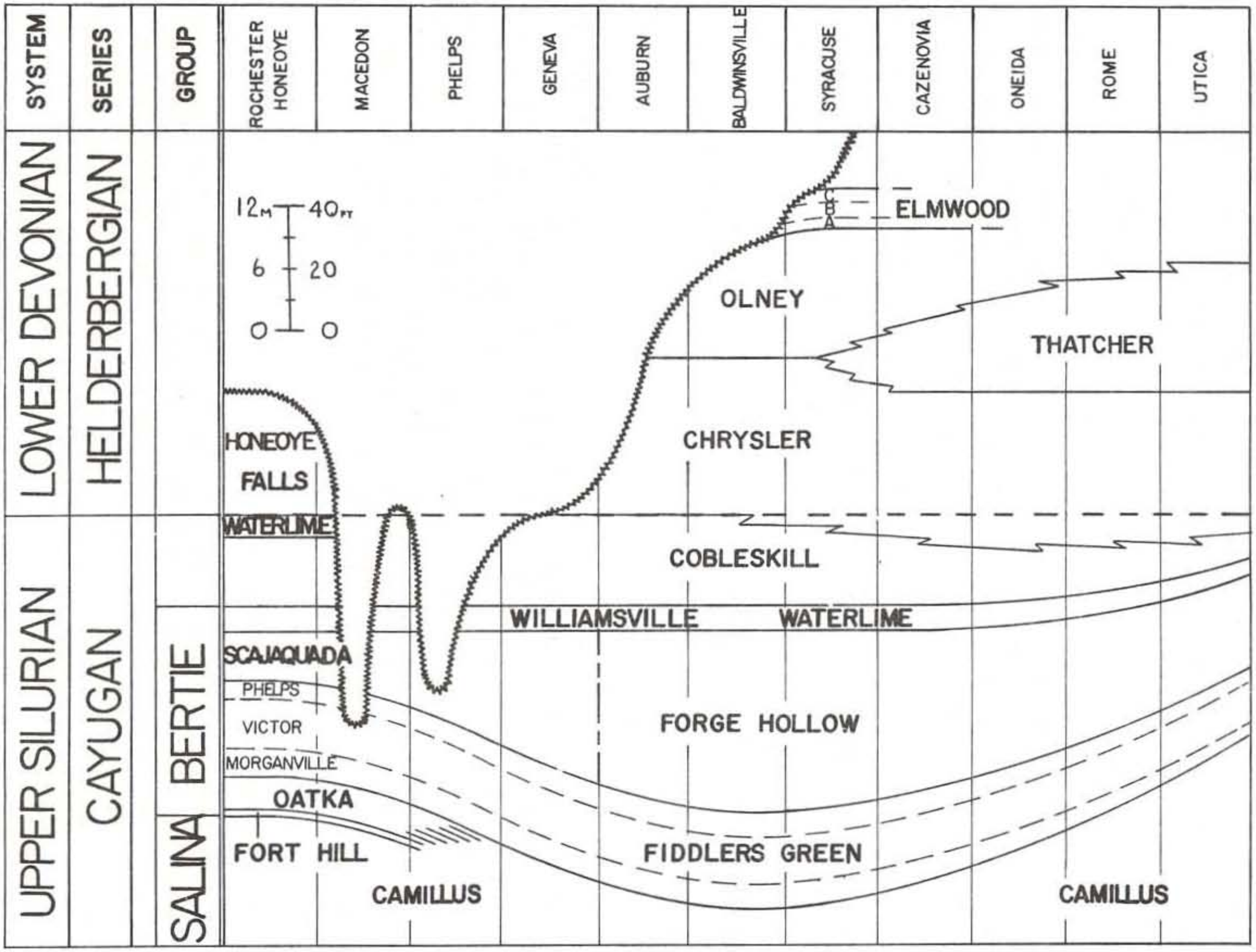


Figure 2. Lithostratigraphy of Eurypterid-bearing sequence. Silurian-Devonian boundary is used as baseline.

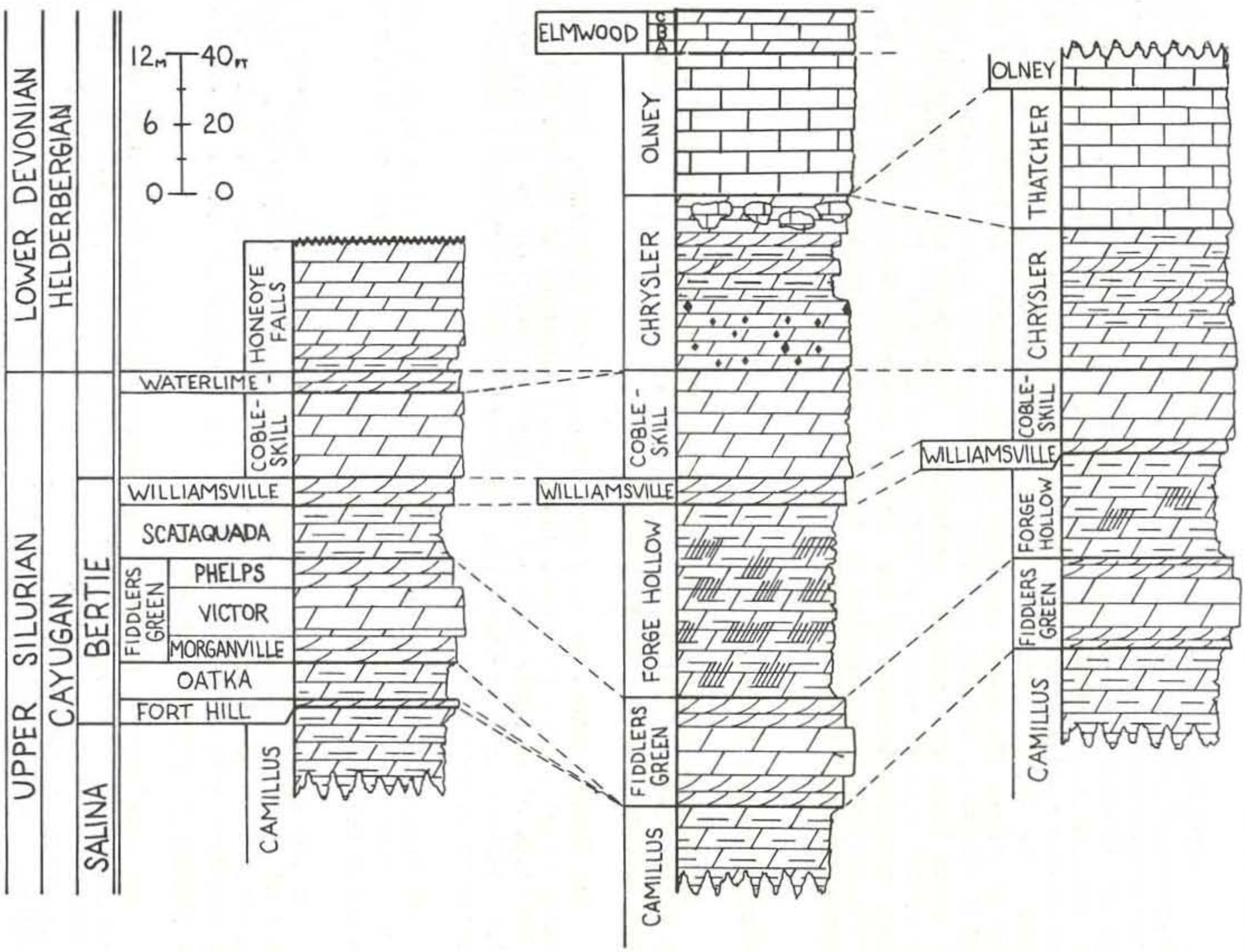


Figure 3. Stratigraphic sections for Syracuse area (center column) and comparable sections to west, south of Rochester (left column), and to east in Stockbridge Valley area (right column).

grained dolostone (Morganville Member) to the coarsely grained and locally mottled dolostone or limestone (Victor A and B, Ciurca, 1973).

Victor Member

The thickest subdivision of the Fiddlers Green Formation, sandwiched between overlying and underlying waterlimes, is the Victor Member. It consists of massive, locally porous and pitted, irregularly bedded, crystalline dolostone and limestone. This unit is analogous lithologically to the stratigraphically higher Cobleskill Formation, and likewise represents more progressive marine conditions during the Late Silurian in this part of the State. The Victor contains abundant brachiopod and ostracod remains, and extends across the State and into Ontario, Canada. At Passage Gulf the Victor contains, besides abundant brachiopod and ostracod remains, Lingula sp. in at least one horizon, gastropods, Eurypterus sp., Pterygotus sp., and probably other species of eurypterids as well. The fauna is little known, probably because of the limited accessibility of this unit, as well as the obvious preoccupation of students and collectors with the overlying eurypterid "bed" (Phelps Member).

Phelps Waterlime Member

At the top of the Fiddlers Green Formation occurs a waterlime unit, the Phelps Member, well known in eastern New York for the countless eurypterid specimens which it has yielded.

The Phelps Waterlime is a very fine-grained dolostone, locally straticulate, usually gray to brown, and is best observed at Passage Gulf. Here it consists of an upper mudcracked waterlime underlain by massive waterlime which weathers into conchoidally fractured layers (eurypterid remains usually occur on the conchoids).

At Passage Gulf only one crystal impression (salt) has been observed by the author in the period 1963-1978. To the west, however, salt hoppers are characteristic of the Phelps Waterlime.

At the type section of the Fiddlers Green Formation (Butternut Creek north of Jamesville) the same features which occur at Passage Gulf are present. The top of the unit is covered with mudcracks. Beneath these are abundant salt hoppers, ostracods, and eurypterids characteristic of the Eurypterus remipes remipes Fauna.

The type section of the Phelps Waterlime Member in western New York (Ciurca, 1973) is a duplicate of the section at Passage Gulf over 100 mi to the east. Mudcracks occur at the top of the unit. Beneath these the eurypterids, Eurypterus remipes remipes De Kay, Pterygotus sp., Dolichopterus sp., and other species occur. Ostracods and cephalopods also are present. Salt hoppers are abundant, and occasionally are large (one specimen measured 5 in on one side).

Scorpions, representing at least four species, also occur in the Phelps Waterlime at Passage Gulf (Ciurca, 1965). Two species have been described previously, Proscorpius osborni and Archaeophonus eurypteroides (Clarke and Ruedemann, 1912, Kjellesvig-Waering, 1966), and two new species, collected by the writer, will be described by E.N. Kjellesvig-Waering.

Other forms obtained from the Phelps Waterlime include cephalopods, rare land plants such as Cooksonia sp., and several unidentified forms. Lingula sp., and other brachiopods are rare or lacking, but do occur in lower beds at Passage Gulf (see Victor Member). A few miles to the west a phyllocarid also was obtained.

Passage Gulf has provided thousands of specimens of eurypterid remains from the Phelps Waterlime during the past 23 years; all from an areally small exposure. An explanation for this unique occurrence is needed. One explanation may be that the eurypterids, for the most part, seem to represent accumulations as windrows. This is not usually apparent when a single specimen is collected at random, but if a larger area is excavated, the orientation of eurypterid debris is more obvious. Telsons, for example, may be aligned parallel to each other (see Fig. 1).

Forge Hollow Formation

In the Syracuse area the Forge Hollow Formation consists of thick dark gypsum beds with a zone at the top consisting of a few feet of shaly dolostone and clayey beds lighter in color.

Exposures of this unit in the valley of Rock Cut Gorge southeast of Syracuse (Stop 3) were well displayed during 1977 because of the construction of Interstate 481. Although the lower contact with the Fiddlers Green Formation was not seen, the stratigraphic relationships of the various units from the Fiddlers Green Formation up to the Manlius Formation were well displayed in an almost continuous sequence.

The upper contact with the Williamsville (or Oxbow, see discussion under Williamsville Formation) Formation is particularly interesting. The mineraliferous shaly beds at the top of the Forge Hollow are succeeded abruptly by hard, fine-grained waterlimes which also are mineraliferous (celestite rather than gypsum?).

The Forge Hollow Formation seems to grade, laterally, possibly due to facies change, into the Scajaquada Formation of western New York (see Ciurca, 1973, p. D-5). The Scajaquada Formation is a thinner unit and consists of resistant beds of dolostone, shaly dolostone, and perhaps some thin intercalated waterlimes. Cherty horizons also are characteristic.

Duskin (1969) studied the gypsum deposits of the Forge Hollow Formation particularly in the Union Springs area. Unfortunately, he misidentified several units. In the Rock Cut Gorge (south side, behind trailer court), for example, his gypsum-bearing Forge Hollow is actually the lower shaly beds of the Chrysler Formation. The gypsum beds are masses of granular celestite in the Chrysler Formation near the upper contact with the cherty Cobleskill Formation. At Seneca Falls Duskin misidentified the Forge Hollow Formation in the banks of the Seneca River. Exposures of the resistant lower Fiddlers Green Formation (Morganville Waterlime) were mistaken for the Williamsville, therefore, it suggests to the writer that Duskin's gypsum beds and Forge Hollow Formation in the banks of this river belong to the Camillus Formation of the Salina Group. Therefore, they are stratigraphically below, rather than above, the Fiddlers Green Formation.

Williamsville Formation

The type section of the Williamsville Formation (Waterlime) is at Williamsville, New York just east of Buffalo. The Williamsville Formation can be traced eastward easily to Mud Creek at East Victor where it contains the eurypterid characteristic of this unit in the Buffalo area, viz. Eurypterus remipes lacustris Harlan and other eurypterids (Pterygotus), as well as associated invertebrates, for example Lingula sp., gastropods, and phyllocarids (Ciurca, 1973).

In central-eastern New York, a similar waterlime occurs beneath the highly variable Cobleskill Formation wherever this interval has been observed. Rickard (1962) termed this waterlime the Oxbow, but later (Rickard, 1975) referred the waterlime to the Williamsville. Presently, either name is appropriate because our knowledge of this interval is limited. There are lithological similarities, as well as differences, between various outcrops of this unit within central New York.

The term Williamsville Formation is preferred here and is defined as an eurypterid-bearing unit of differing characteristics across the outcrop belt. It always occurs (in what few outcrops that are accessible) above a shaly dolomitic interval containing evaporites (Scajaquada - Forge Hollow Formations), and below an extremely variable unit of massive, stromatoporoid and coral bearing, dolostones and limestones (Cobleskill Formation).

No fauna has been described from the Williamsville Formation in the Syracuse area. Indeed, fossils are rare, but over the past several years the following forms were obtained from this unit in the old abandoned gypsum quarries north of Jamesville:

Paracarcinosoma scorpionis

Pterygotus (Acutiramus) macrophthalmus cummingsi

Phyllocarids

Orbiculoidea sp.

Lingula sp.

Cephalopods

Graptolites?

Eurypterus remipes lacustris, so characteristic of the Williamsville Formation of western New York, has not been observed in central-eastern New York (see discussion on correlation).

Other outcrops of the Williamsville Formation in the Syracuse area have provided Lingula sp., other brachiopods, and cephalopods (?), which need further study.

Time correlations of the Williamsville Formation are difficult to establish. It has been considered essentially a time-rock unit. See, for example, the Silurian correlation charts of Fisher (1960) and Rickard (1975). It is suggested here that the Williamsville Formation in the type area of western New York may be younger than the Cobleskill Formation of eastern New York. This interpretation is based on the distribution of eurypterid horizons across the State, the Williamsville-Cobleskill contact, and the occurrence of either an Eurypterus fauna (Late Silurian) or an Erieopterus fauna (Early Devonian) in these horizons. The possible application of this criteria in distinguishing the Silurian-Devonian boundary has been mentioned previously (Ciurca, 1975).

Cobleskill Formation

The Cobleskill Formation needs redefinition as it is one of the most variable units encountered across the State from the type section in eastern New York, westward into Ontario, Canada (Ciurca, 1973). West of Syracuse, near Marcellus Falls, it exhibits a cherty facies, with reef or reef-flank facies containing stromatoporoids and corals. An eurypterid horizon occurs near the top and can be traced to near Jamesville. This horizon has not been recognized to the east.

At Syracuse the Cobleskill Formation consists of massive fine crystalline dolostone about 30-ft thick. Just to the east, north of Jamesville, a reefy facies is evident in the abandoned gypsum quarries. Here massive beds containing abundant stromatoporoids characterize this unit. Favosites and horn corals also are evident. The upper portion contains crystal molds of celestite, and rare eurypterid remains (?Dolichopterus sp.).

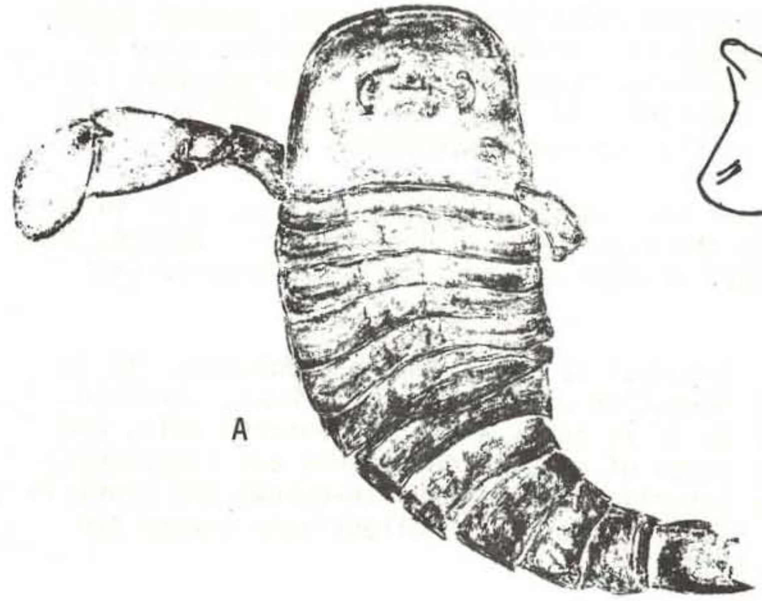
Near Clockville the Cobleskill Formation is a tripartite unit containing a lower massive dolostone, a middle fossiliferous and porous limestone, and an upper massive dolostone. The middle unit contains stromatoporoids, corals, Eccentricosta jerseyensis, and other brachiopods. A large eurypterid may be present in the lower dolostone (ornamented fragment found on a large block in talus). The upper dolostone has been excluded from the Cobleskill by previous writers in order to preserve a more reasonable thickness for this formation from the type locality. Here it is regarded as essentially a duplicate of the lower dolostone, and distinct from the various lithologies represented in the overlying Chrysler Formation, and therefore is placed in the Cobleskill Formation. Large stylolites are characteristic of the Cobleskill Formation at this locality.

In the Stockbridge Valley area additional facies are shown because the lithology and the fossils are different. A very fine-grained limestone is present and contains the brachiopod Howellella corallinensis ssp., associated with Pterygotus sp. (Fig. 4). Whether an Eurypterus is associated with this new occurrence of Pterygotus has yet to be determined.

Just to the east, at Forge Hollow, the Cobleskill Formation displays a tripartite division different from that just described for the Clockville area. In the Forge Hollow area, the lower unit, about 15-ft thick, is a fossiliferous limestone and is succeeded by a dolostone containing possible algal masses. This unit is overlain by at least 3 ft of limestone.

→

Figure 4. Characteristic Eurypterids of Upper Silurian-Lower Devonian of central-eastern New York State. (A) *Eurypterus remipes remipes* De Kay, natural size, Spec. No. 040377-2, Phelps Waterlime Member, Fiddlers Green Formation, Passage Gulf (Ciurca Loc. No. 57). (B) *Pterygotus* sp., free ramus, enlarged. Cobleskill Formation (limestone facies), Stockbridge Valley, Ciurca Loc. No. 49. (C) *Erieopterus microphthalmus* ssp., natural size. Specimen no. 070477-18, Chrysler Formation (believed to have originated in F zone of Chrysler Formation), southeast Syracuse, Ciurca Loc. No. 68. (D) *Erieopterus microphthalmus* ssp., natural size. Spec. No. 041578-2, H zone of Chrysler Formation. Abundant *Howellella vanuxemi* (not shown) occur on specimen. Rock Cut Gorge southeast of Syracuse, Ciurca Loc. No. 70. (E) *Erieopterus microphthalmus microphthalmus* (Hall), large carapace, natural size. Spec. No. 102277-1, Uppermost Olney Limestone, Split Rock Quarry, Syracuse, N.Y., Ciurca Loc. No. 36. (F) *Pterygotus* sp., free and fixed rami, enlarged. Spec. No. 041578-4, from stromatoporoid biostrome, Upper Olney Limestone, quarry on south side of Rock Cut Gorge, Ciurca Loc. No. 70.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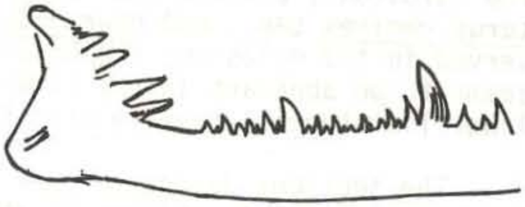
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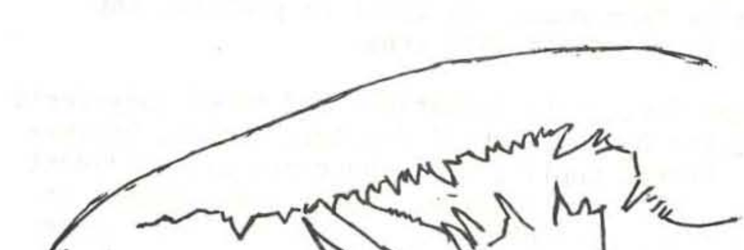
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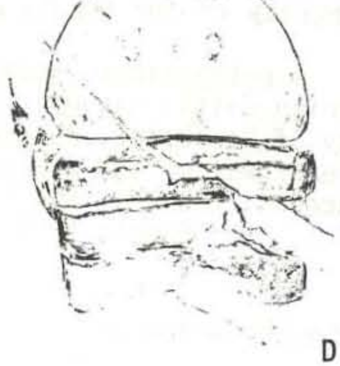
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The dolostone, and the overlying and underlying limestones, contain Eurypterus remipes ssp., and Pterygotus sp. Although no brachiopods were observed in the dolostone the brachiopod Morinorhynchus? interstriatus (Hall) seems to be abundant in the limestone. At least the upper portion of the lower limestone is replete with high-spired gastropods.

The sections described here have been interpreted variously by authors and have little resemblance to the type Cobleskill Formation. Indeed, the sections just described may have no physical or time relationships whatever to the type Cobleskill.

Until this stratigraphic interval is studied more completely, it is best to regard the Cobleskill Formation as a unit of extremely variable character, ranging between 12 to 30 ft thick along the outcrop belt, and usually consisting of various types of massive dolostones and limestones. It seems to be underlain by a waterlime (Williamsville-Oxbow) and overlain by a series of various types of dolomitic rocks collectively termed the Chrysler Formation (30-50 ft thick).

Although a diverse fauna (brachiopods, corals, stromatoporoids, gastropods, crinoids, pelecypods, ostracods, cephalopods, etc.) has been described from the Cobleskill Formation, no eurypterids have been described before from this formation. The various occurrences of eurypterid remains in this formation, as described here, help to refine the stratigraphic ranges of these forms between their occurrences in the Bertie Group below and the Chrysler-Manlius sequence above.

An evolutionary study of eurypterids in the New York Upper Silurian-Lower Devonian sequence could be possible in the future, but many more specimens need to be recovered. Particular attention should be given in future endeavors to recover as much paleontological and stratigraphical data as possible in field studies of eurypterid-bearing strata and associated units. The exact horizon from which fossils are recovered must be recorded as precisely as possible. Orientation data on specimens recovered in situ could prove useful and to date have been largely neglected. Orientation data on associated fossils and structures also would be useful. As an example, excellently preserved ripplemarks were observed in the upper half of the Fiddlers Green Formation west of Cedarville. Unfortunately, before any measurements could be made, the outcrop was buried with wet sod recovered from ditches along area farm roads, no doubt to preserve the integrity of the beauty of the farmlands of this area.

A petrographic study of the Cobleskill Formation, and other eurypterid-bearing units, has been undertaken by R.D. Hamill (masters thesis, University of Rochester, in prep.). Recent publications concerned with at least some aspect of the Cobleskill Formation are Berdan, 1972 (brachiopods, ostracods); Ciurca, 1973 (stratigraphy, paleontology); Rickard, 1975 (correlation); and Stock, 1977 (stromatoporoids).

Chrysler Formation

A prolific eurypterid horizon in the upper Chrysler Formation was discovered in the sixties in the Marcellus Falls area west of Syracuse (Ciurca, 1975). Erieopterus sp. and the brachiopod Howellella vanuxemi were the abundant forms in this horizon. A cephalopod, Geisonoceras? (one specimen) was obtained from a bed immediately overlying this horizon. Several years later, cephalopod remains also were obtained from a bed immediately underlying this horizon. This is the first fauna to be described from this generally unfossiliferous formation.

The Erieopterus bed occurs about 10 ft from the top of the Chrysler Formation which is about 50 ft thick in this area. The horizon could be traced only slightly to the east (not as far as Syracuse), and not to the west.

In 1977, excavations along the Rock Cut Gorge for the new Interstate 481 revealed an unusually complete section of the Chrysler Formation displaying characteristics not previously observed. This section also is important because it lies between the type section at Chryslers Glen, and the appearance of Rickard's (1962) Thatcher Limestone to the east. Because the section was complete, and now is essentially destroyed, it is important to record the features observed during the summer of 1977 and in the spring of 1978.

The sequence (Fig. 5) revealed a lower portion of "weak" mineraliferous beds about 5-m thick, and an upper portion consisting of resistant dolomitic beds including waterlimes and limestone (about 6-8-m thick).

The lower weak unit is composed of two parts: the lower portion (A) consists of fine-grained dolostone, brown, and containing celestite, and an upper part (B) consisting primarily of shaly dolostone with celestite in masses - no crystals were observed. Chrysler A contains the more resistant beds, some of which seem to be transitional in lithology from the underlying Cobleskill Formation.

Chrysler A and B are intriguing because at Chittenango Falls (Ciurca, 1962) east of Syracuse collectors have for many years obtained abundant crystals of celestite and calcite in beds immediately overlying the Cobleskill Formation. Chittenango Falls was the only locality which yielded abundant celestite. Interestingly, near Jamesville, crystals of celestite occur in the upper beds of the Cobleskill Formation (facies change?). Chrysler A is at least 1-m thick. Its lower contact with the Cobleskill Formation is sharp to gradational. It seems gradational along the east end of the Rock Cut Gorge only because one can see a transition from massive, nonbedded, brown Cobleskill Formation into thin-bedded, brown dolostone containing celestite, which in turn are succeeded by the main mass of Chrysler B, that is the "weak" thin-bedded, shaly, dolomitic rocks. The contact appears sharp at the west end of Rock Cut Gorge because layers of granular celestite occur at the contact. The celestite in these beds was mistaken for gypsum by Duskin (1969) who thought these strata belonged to the Forge Hollow Formation.

No fossils were observed in Chrysler A. To clarify further the relationship of this unit with the underlying Cobleskill Formation, more detailed field work is necessary.

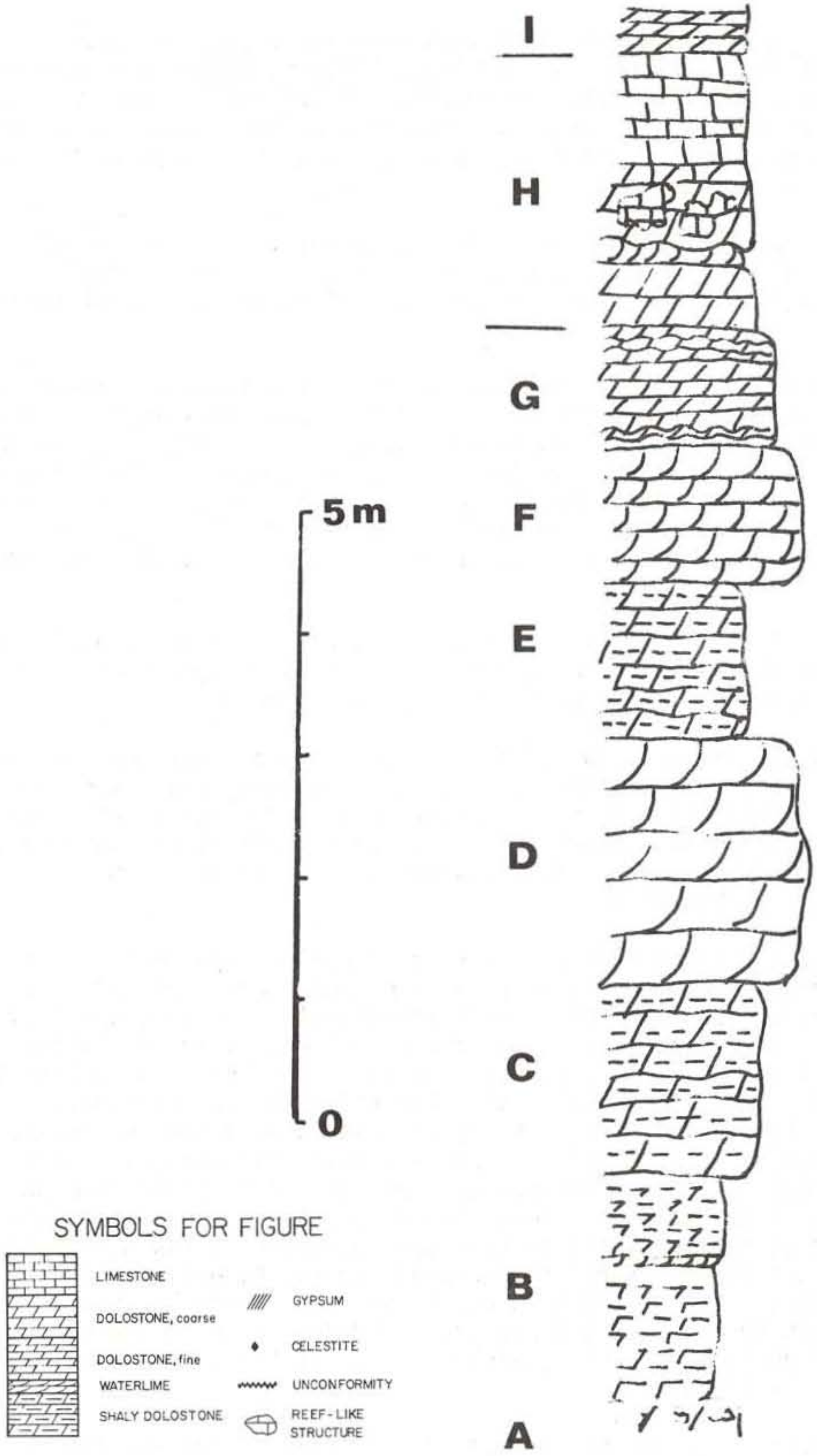

Figure 5. Stratigraphy of Chrysler Formation (based on new, but temporary, exposures near the east side of Interstate 81, south side of Rock Cut Gorge

Above Chrysler B is a unit of greenish, shaly dolostone 1.5-m thick. This unit (C) is a key horizon, repeated above in an obvious cyclic sequence. No fossils were observed (see Chrysler E).

Above Chrysler C occurs a "hard" waterlime 2-m thick. This waterlime (D) is somewhat irregularly bedded, straticulate, and appears crystalline in some beds. This massive waterlime may contain an eurypterid fauna, but no fossils have been observed to date. This unit must be studied further to determine whether it ultimately will reveal either an Eurypterus or an Erieopterus fauna. An Erieopterus fauna is suspected

Overlying Chrysler D is a greenish shaly dolostone (mudcracked?), 1.5-m thick. This unit (E) is the exact analog of Chrysler C, exhibiting the same appearance and approximately the same thickness. No fossils were found. Chrysler E seems to be a shallow-water deposit, and along with Chrysler C may have been formed in a hypersaline environment.

Above Chrysler E is a second thick waterlime (1.1 m) which is straticulate and brittle. This unit (F) is a mostly brown, very fine-grained dolostone with contrasting black laminations. A specimen of Erieopterus microphthalmus ssp. (Fig. 4) probably came from this unit. A portion of the carapace of a Pterygotus also may have originated from this unit. These fossils were obtained from large loose blocks near the outcrops. Although access to this waterlime unit allowed for the examination of countless pieces of the waterlime, no fossils were encountered in the bedrock.

Succeeding Chrysler F Waterlime is a contorted gray, bluish gray, and brown dolostone containing breccia. This unit (G) contains large mudcracks. Chrysler G is 1-m thick. At the base, and at the top, contorted layers and associated breccia delineate this unit. The remainder of the unit is dolostone with a more shaly appearance in the middle unit. This thin shaly layer, greenish in color, seems to be a recurrence of Chrysler C and E lithologies. No fossils were observed in this unit, but a carapace of an Erieopterus recovered from a large loose block of dolostone may have originated from this unit.

The rocks above Chrysler G are the most significant. Nothing to date, either to the east or west, resembles it. These rocks (Chrysler H) consist of various types of dolostone and limestone, mostly brown and crystalline, and are different in appearance from the units previously described (Chrysler A through G). Thin layers approaching waterlime occur at the base. These contain the eurypterid Erieopterus sp.

Chrysler H is characterized by reefrock (nonbedded) and interreef (bedded) strata (Fig. 6). The organic nature of the reefrock is not known at present, but the rock consists of nonbedded masses of fossiliferous limestone surrounded by brownish and bluish dolostone and limestone. Fossils which occur in both the reefrock and in the interreef strata include prolific Howellella vanuxemi, abundant Erieopterus, and poorly preserved cephalopods (four individuals to date).

The reef may have been constructed by a mixture of organisms or may be

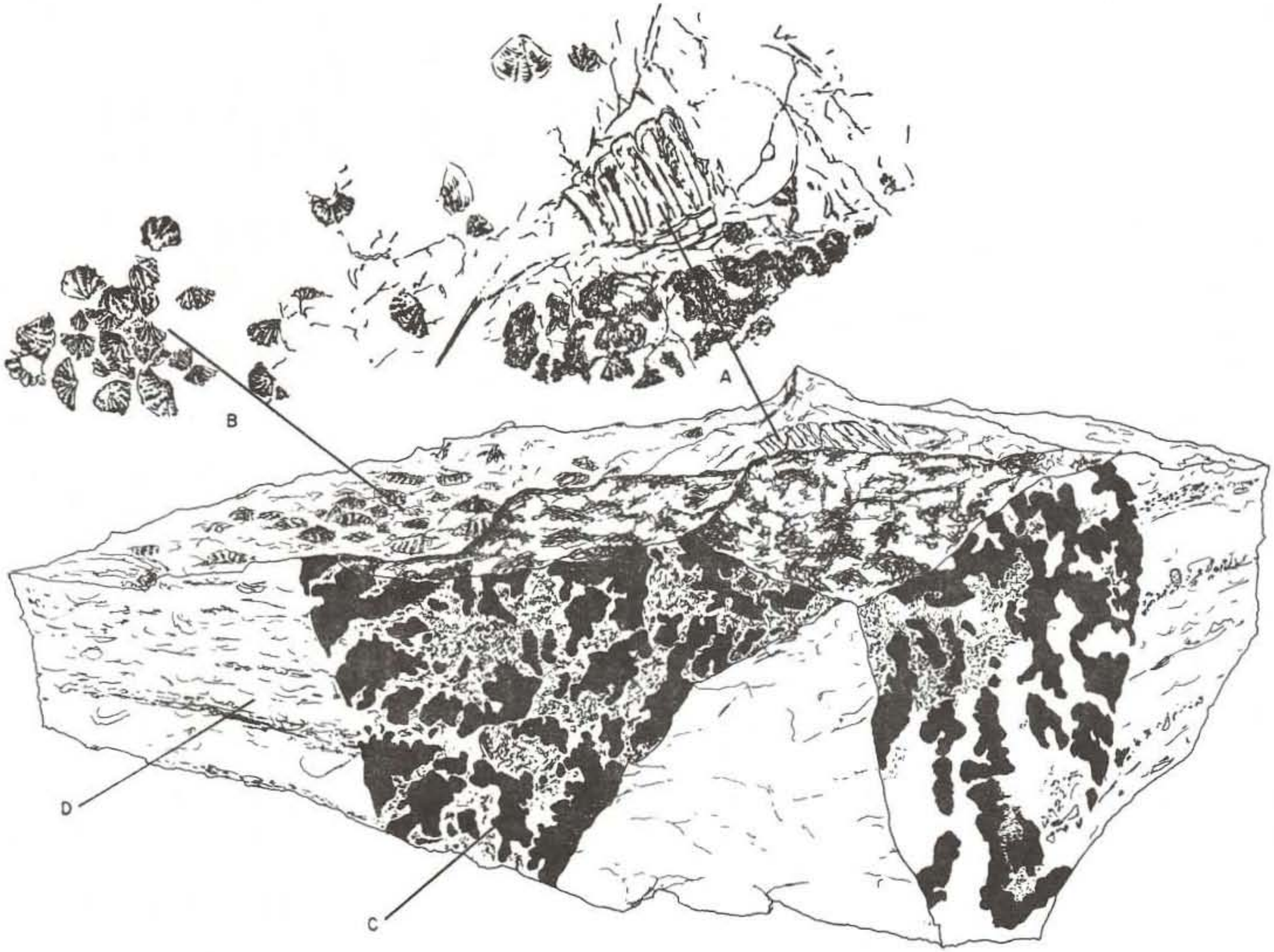

Figure 6. Block (apprx. 3/4 natural size) of Chrysler H showing (A) eurypterid Erieopterus microphthalmus ssp. associated with (B) prolific Howellella vanuxemi in rock consisting of (C) nonbedded reefrock, and (D) bedded interreef strata. Note: block is probably oriented upside down.

the result of a single organism. There is an unusual zone of algal stromatolites in the lower Thatcher (Sanders 1956, p. 18; Rickard 1962, p. 52), just above the Chrysler Formation, at Clockville, so a potential algal contribution to the reefrock must be kept in mind, however, bryozoans also should be considered.

The Erieopterus horizon (about 10 ft. below the upper contact of the Chrysler Formation) discovered several years ago near Marcellus Falls may be an extension of this horizon into the west. If so, this horizon exhibits an interesting facies change. At Marcellus Falls no such reefy masses have been observed. Although Howellella vanuxemi is abundant at Marcellus Falls, the rock is dolomitic with mudcracked zones. West of this locality no brachiopods have been observed. Erieopterus, however, occurs in the fine-grained dolostones farther west near Rochester (Honeoye Falls Formation, Ciurca, 1973, p. D-7), and in Ontario, Canada (Clanbrassil Formation). In these areas no brachiopods have ever been observed associated with Erieopterus.

Thatcher Limestone

The Thatcher Member of the Manlius Formation (Rickard 1962) is a unit of varied lithology. Unfortunately, the type section is distant from those of the other members (or formations) of the Manlius.

At Clockville an eurypterid horizon (Erieopterus) was discovered in 1977 in strata termed Thatcher by Rickard (1962, p. 51, fig. 12). This is the first report of an eurypterid in this unit. The specimen was obtained from a stromatolite horizon (approximately at the level of the person's shoulder shown in Rickard's fig. 12).

The relationship of this new horizon with the stromatolites at this locality, and with exposures of the Thatcher to the east, is under study. A detailed study of what becomes of the Thatcher, westward in the Syracuse area, would be worthwhile, and would contribute to meaningful knowledge of eurypterid biostratigraphy.

Olney Limestone

The Olney Limestone in the area about Syracuse exhibits a number of variations from exposure to exposure, the most notable being the occurrence of, or lack of, the stromatoporoid biostromes. At its type section (Split Rock) only a few stromatoporoids were observed, usually as solitary individuals. Just to the east, however, they are well developed. At Interstate 81, and in exposures in quarries just to the east along the Rock Cut Road, an eurypterid horizon was discovered in 1977 within a stromatoporoid biostrome. Only one eurypterid, Pterygotus sp. (Fig. 4), was observed represented by three specimens (2 pincers, 1 metastoma). Erieopterus was not observed, although it is the typical form in the upper Olney Limestone at the type section at Split Rock to the west. Several years of collecting at Split Rock have yielded abundant specimens of Erieopterus, but none of Pterygotus.

The type Olney is characterized by prolific brachiopods (at least two species) on many bedding planes, bryozoans, rare cephalopods (only one seen to date), crinoids, abundant ostracods, pelecypods, stromatoporoids, and stromatolites.

In the lower type Olney, beds of characteristic Chrysler aspect occur interbedded with the limestone. These transitional beds are currently under study. NOTE: QUARRIES AT SPLIT ROCK ARE NOW BEING USED AS A DUMP, THEIR FUTURE AVAILABILITY FOR STUDY MAY BE LIMITED.

For earlier discussions of the Olney Limestone and the Manlius Formation (see Logie, 1933; Sanders, 1956; Rickard, 1962, 1975).

CYCLIC SEDIMENTATION

All previous notions concerning the stratigraphy of the Upper Silurian Bertie (Group) were based on knowledge of the eurypterid-bearing waterlimes. In the Buffalo area, it was the Williamsville Waterlime which yielded the abundant eurypterid fauna described in so many early publications (Figs. 7 and 8). Specimens usually have the label "Bertie" or "Bertie Limestone".

In eastern New York (so-called "Herkimer Pool") it is the upper waterlime (i.e. Phelps Member) of the Fiddlers Green Formation which provided the abundant eurypterid remains recorded by early writers (see Clarke and Reudemann, 1912). These specimens have been labeled simply as "Bertie".

It is no wonder that these occurrences were regarded usually as being contemporaneous deposits. In fact, at one time or another, many other eurypterid faunas were equated with those within the Bertie (Group). For example, the eurypterid fauna of the Kokomo Formation of Indiana also was regarded as being of the same age as those in the Bertie, simply because the rocks in these areas contained eurypterids.

Actually, the two well known New York eurypterid faunas occur at stratigraphically different horizons. Furthermore, these horizons represent only two of approximately ten such horizons within the State.

These several eurypterid horizons are useful in correlating strata in different areas, especially strata lacking typical marine invertebrate fossils.

During the Late Silurian and Early Devonian, sedimentation occurred over an unusually broad but shallow area. Sediments were exposed frequently to dessication and erosion. For whatever reason, oscillation of environments occurred at frequent intervals during this time. These frequent oscillations resulted in the deposition of a cyclic sequence of carbonates which, when preserved, were lithified into the various strata observed on this trip. Recurrent lithological units usually resulted in recurrent faunas.

Although any one member in a cyclic sequence may be chosen for a reference unit, the waterlime is chosen here because of the persistent association of eurypterids with this lithology, and the writer's interest in these fossils.

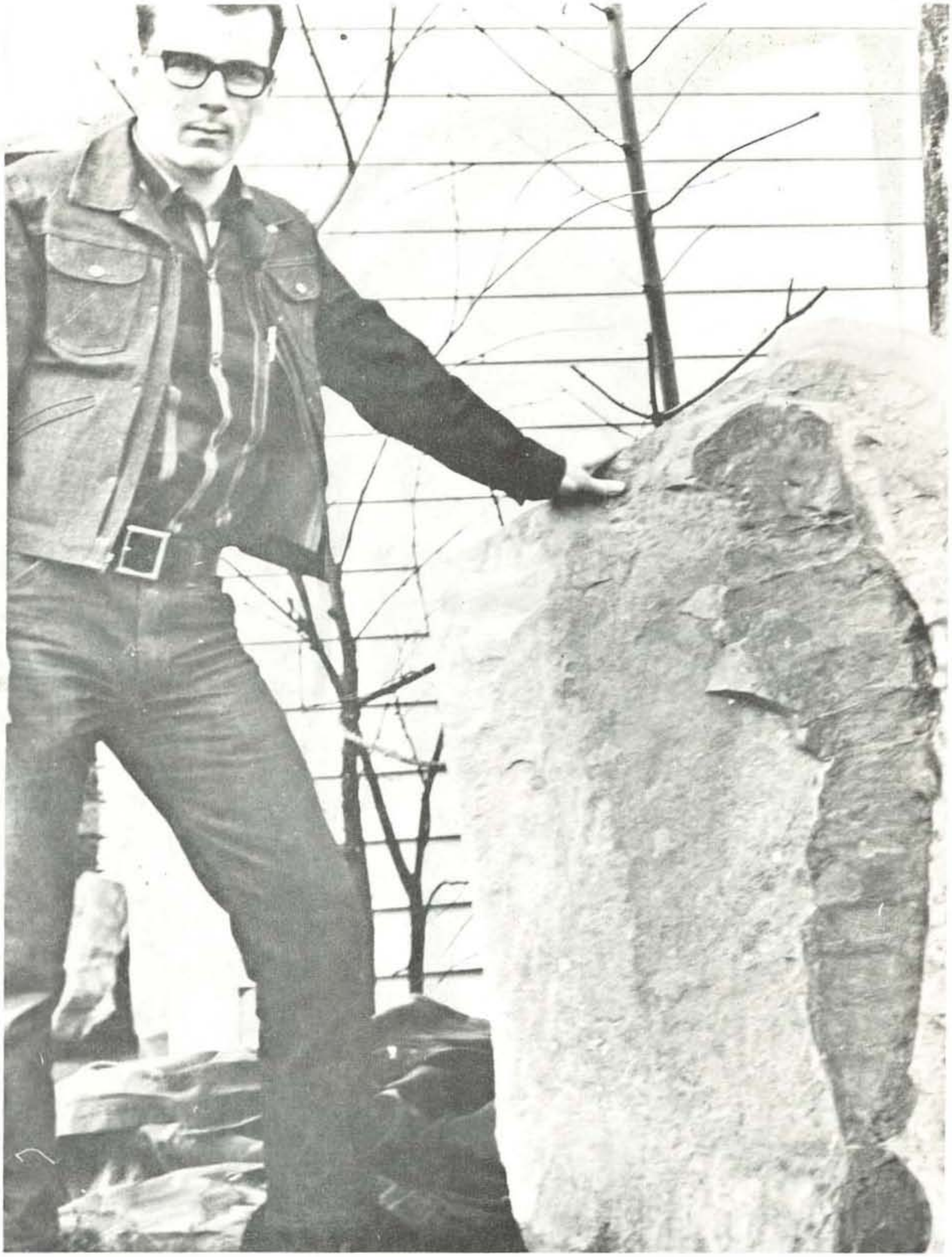

Figure 7. Pterygotus macrophthalmus macrophthalmus, very large specimen (4 ft from front of carapace to telson). Specimen discovered Spring 1965, photograph circa 1965, Phelps Waterlime Member, Fiddlers Green Formation, Passage Gulf, Ciurca Loc. No. 57.

Figure 8. Silurian Scorpion (enlarged), rare form associated with Eurypterus remipes remipes Fauna, Spec. No. 031966-1, Phelps Waterlime Member, Fiddlers Green Formation, Passage Gulf, Ciurca Loc. No. 57.

An example of one cyclic sequence is provided by the Fiddler's Green Formation in western New York (Ciurca, 1973):

LITHOLOGY		FORMATION or MEMBER	FAUNA
shaly dolostone		Scajaquada Formation	barren
waterlime	Fiddlers Green Formation	Phelps Waterlime	eurypterids
crystalline dolostone & limestone		Victor Member	brachiopods, ostracods
waterlime		Morganville Waterlime	eurypterids
shaly dolostone		Oatka Formation	barren

In the Syracuse area, the youngest typical waterlime is Chrysler F (Fig. 5); the oldest is the Morganville Waterlime Member of the Fiddlers Green Formation (Fig. 3). Between these two waterlimes occur a variety of lithologies, including other waterlimes, indicative of the constant shift of hypersaline environments. Throughout this interval, the marine phase was only partially influencial as revealed by the establishment of normal marine faunas, that is stromatoporoid biostromes, corals, numerous brachiopods, etc. in the Cobleskill. It was not until the deposition of the Manlius units, however, that a marine regime displaced the dominant evaporitic regime in central-eastern New York. To the west (western New York and adjacent Ontario, Canada) marine rocks of equivalent age are unknown.

In order to be useful in correlation, the eurypterid faunas occurring in the various horizons will have to be studied in more detail. This is especially true of eurypterid horizons in nearby states, for example, Pennsylvania, Ohio, Maryland, Indiana, West Virginia, and in adjacent Ontario, Canada. Preliminary observations in most of these areas, made by the writer, indicate that all of these areas are rich in potentially new eurypterid horizons reflecting cyclic sedimentational processes.

SUMMARY

Eurypterid remains occur at several horizons (zones) in Upper Silurian and Lower Devonian strata of central-eastern New York State. The genus *Eurypterus* is present in the Fiddlers Green Formation, Cobleskill Formation (which needs redefinition), and probably lower Chrysler Formation. The genus *Erieopterus* occurs in the upper Chrysler Formation, Olney Limestone, and Thatcher Formation. The replacement of an *Eurypterus* fauna by an *Erieopterus* fauna may indicate a disconformable boundary stradling the Silurian-Devonian boundary in this area.

Cyclic sedimentation dominated Upper Silurian-Lower Devonian deposition. This resulted, fortunately, in the formation of recurrent lithologies (eg. waterlime) and the preservation of recurrent faunas (eg. eurypterids).

Pterygotus, previously known only from the Fiddlers Green Formation,

Table 1. Eurypterids of Upper Silurian-Lower Devonian central-eastern New York[1]

- Olney Limestone
  - *Erieopterus microphthalmus microphthalmus* (Hall)
  - *Pterygotus* (*Acutiramus*) sp. NEW
- Thacher Limestone (lower)
  - *Erieopterus microphthalmus* ssp. NEW
- Chrysler Formation (upper)
  - *Erieopterus microphthalmus* ssp. NEW
  - *Pterygotus* sp. NEW
- Cobleskill Formation (upper)
  - *Eurypterus remipes* ssp. NEW
  - *Pterygotus* sp. NEW
  - *Dolichopterus* sp. NEW
- Williamsville-Oxbow Formation
  - *Paracarcinosoma scorpionis* (Grote & Pitt)
  - *Pterygotus* (*Acutiramus*) *macrophthalmus cummingsi* NEW
- Fiddlers Green Formation
  - Phelps Waterlime Member
    - *Eurypterus remipes remipes* DeKay
    - *Pterygotus* (*Acutiramus*) *macrophthalmus macrophthalmus*
    - *Pterygotus* (*Pterygotus*) *juvenis* Clarke & Ruedemann
    - *Dolichopterus herkimerensis* Caster & Kjellesvig-Waering
    - *Dolichopterus jewetti* Caster & Kjellesvig-Waering
    - *Clarkeipterus testudineus* (Clarke & Ruedemann)
    - *Paracarcinosoma* sp. NEW
  - Victor Member (at Passage Gulf)
    - *Eurypterus remipes remipes* DeKay NEW
    - *Pterygotus* (*Acutiramus*) *macrophthalmus macrophthalmus* NEW
  - Morganville Waterlime Member
    - *Eurypterus remipes* ssp. NEW
- Syracuse Formation (upper)
  - *Eurypterus* sp.
- Syracuse Formation (lower)
  - *Waeringopterus cumberlandicus apfeli* Leutze
- Vernon B Formation
  - *Pterygotus* (*Acutiramus*) *floweri* Kjellersvig-Waering & Caster
  - *Pterygotus* (*Pterygotus*) *wayland-smithi* Kjellesvig-Waering & Caster
- Illion Shale
  - *Rhinocarcinosoma vaningeni* (Clarke & Ruedemann)
  - *Parahughmilleria* sp.? NEW

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[1] New occurrences are labeled NEW.

occurs in the Cobleskill Formation, Chrysler Formation, and Olney Limestone.

New exposures of the Chrysler Formation in the Syracuse area reveal an interesting sequence of various lithologies indicative of hypersaline environments in shallow waters. The formation is divided into several units, A through H. The upper portion contains the eurypterid Erieopterus. In Chrysler H this eurypterid is abundant and is associated with prolific Howellella vanuxemi, and cephalopods, in an unusual reefy facies.

Examination of Upper Silurian-Lower Devonian strata in adjacent states indicates that cyclic sedimentation also took place in these areas. It is expected that several new eurypterid horizons and localities will be discovered there in the future.

A summary of the eurypterids which characterize the stratigraphic horizons of central-eastern New York State is listed in Table 1. Several characteristic eurypterids and scorpions are shown in Figures 1, 4, 7, 8.

ACKNOWLEDGMENTS

Joseph Cordovana assisted in several field trips to recover Erieopterus (and associated fauna) from the new eurypterid horizon (Chrysler H) before it became buried for landscaping operations in connection with the construction of Interstate 481.

Richard Hamell and T.X. Grasso read the manuscript and made many helpful suggestions. I would like to thank those who have given me encouragement through the past several years and with whom I have had the benefit of many interesting discussions, especially Erik N. Kjellesvig-Waering, R. Hamell, and T.X. Grasso. The author, however, assumes responsibility for interpretations or opinions expressed.

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FIELD TRIP

STOP 1	Ciurca N.Y. Eurypterid Locality No. 36. Quarry at Split Rock, southwest of Syracuse, N.Y. Syracuse West Quadrangle. Units exposed: uppermost Chrysler Formation, Olney Limestone (type section), Elmwood A, (unconformity), Onondaga Limestone.
STOP 2	Ciurca N.Y. Eurypterid Locality No. 40. Butternut Creek north of Jamesville, N.Y. Jamesville and Syracuse East Quads. Units exposed: Fiddlers Green Formation (type section). The Cobleskill Formation is exposed on the hillside above the creek.
STOP 3	Ciurca N.Y. Eurypterid Locality Nos. 69, 71. Hillside overlooking Interstate 81, beneath the Brighton Apts. (towers). Units exposed: Cobleskill Formation - Chrysler Formation contact.
STOP 4	Ciurca N.Y. Eurypterid Locality No. 46. Large roadcut ascending the hill to the south of Clockville, N.Y., Oneida Quad. Units exposed: Fiddlers Green Formation, Forge Hollow Formation, Williamsville-Oxbow Formation, Cobleskill Formation, Chrysler Formation, Thatcher Formation, Olney Limestone.
STOP 5	Ciurca N.Y. Eurypterid Locality No. 53. Roadcut and hillside at Forge Hollow along the west side of NY 315, Oriskany Falls Quad. Units exposed: Camillus Formation, Fiddlers Green Formation, Forge Hollow Formation (mostly covered), Williamsville-Oxbow Formation, Cobleskill Formation.
STOP 6	Illion Gorge, NY 51 north of Illion, N.Y. Units exposed: Vernon and Syracuse Formations (Salina Group).
STOP 7	Ciurca N.Y. Eurypterid Locality No. 57. Roadcut along Spohn Road in a ravine known as Passage Gulf, near Spinnerville, N.Y. Millers Mills Quad. Units exposed: Camillus Formation, Fiddlers Green Formation, Forge Hollow Formation (mostly covered).

Surface and Near-Surface Sediments in the Northern Part of Seneca Lake, NY

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The purpose of this field trip is to examine data bearing on the origin of the sediments found in the northern part of Seneca Lake. These sediments are apparently typical of those found in the other Finger Lakes of New York so that learning about the processes which formed them gives insight into the general problem of the origin of sediments in these lakes and similar lakes elsewhere.

The valley in which the lake is situated has been cut into the South-dipping Devonian shales and sandstones of the Appalachian Plateau (Figure 1). Apparently, a north-flowing stream occupied the valley during the late Tertiary and then during the Pleistocene glaciers eroded and otherwise sculpted the Tertiary landscape mantling the resulting surface with a wide variety of ice-laid and water-laid sediments. Glacial processes and their effects on local geography have attracted the attention of workers since early in the nineteenth century. A current summary of investigations is given by Muller (1965).

Deglaciation took place locally between 14,000 and 12,500 years BP. During ice retreat several moraines were draped across the land surface as well as across the floor the lakes which preceded Seneca (Figure 1). Many of the moraines formed at the northern boundary of a pro-glacial lake either as shoreline features or at the ice edge beneath a lake surface. Those moraines emplaced the floor of what was later to be Seneca Lake were subsequently buried by lake sediments.

On this trip we will examine directly and by subbottom profile the sediment on the lake floor as well as those in the immediate subbottom available to a light dredge or piston corer.

Seneca Lake's drainage basin boundary, the lake's major tributaries, the local bedrock geology and the location of moraines are given in Figure 1.

THE TRIP

Our route carries us from the dock at the northeast corner of the lake south to the various sampling locations and back again, a total of about 10 km. (See Figure 2). While underway, we will examine the subbottom where possible. At the various locations we will look at bottom sediments collected by Ponar dredge and at the last stop we will examine a sediment core. Since shoreline sediments form such a small fraction of the sediments in the lake basin we will not be concerned with them on this trip.

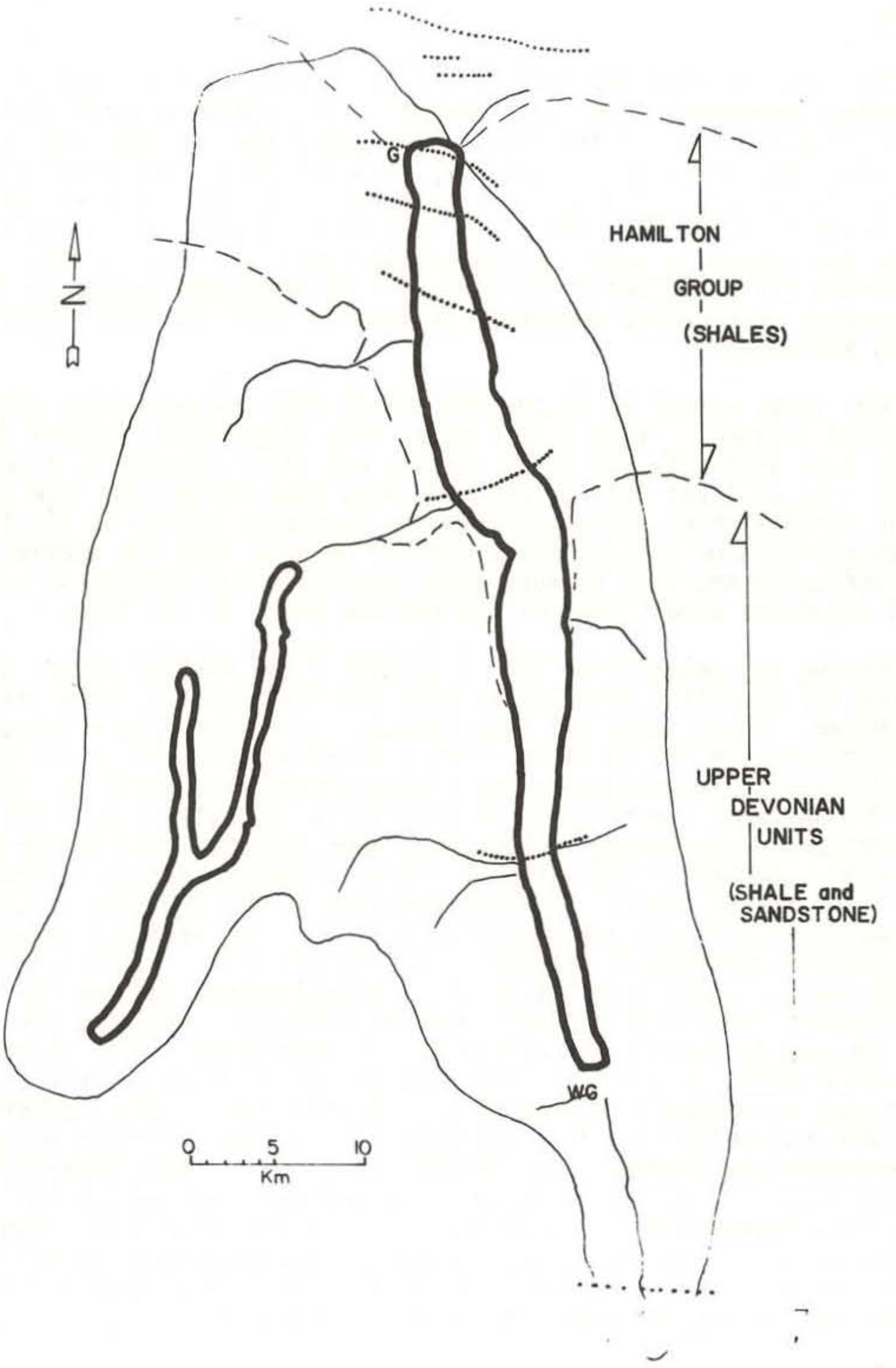

Figure 1. Map showing Seneca Lake drainage basin (with Keuka Lake to the west); bedrock geology and locations of moraines crossing Seneca Lake.

STOP 1

At this location the lake bottom is covered with a sheet of fine sand the exact thickness of which is unknown. The coarsest sands are found at the northeast corner of the lake while toward the southern edge of the sand sheet the silt--and clay-sized fractions become appreciable. Shell debris and whole shells make up a minor part of this sediment mass and at some localities tubules made up of agglutinated sand grains are concentrated in the ripple troughs. Although the exact thickness of this sand sheet is unknown its distribution is broken up by irregular exposures of what are thought to be older sediments suggesting that the sand thickness is highly variable.

The sands appear to be derived mainly from the reworking of previously deposited sediment. Very little other than clay-sized sediment is brought to the lake bottom by the local streams and cliff erosion is a negligible source. So at least part of the sand mass must be derived from winnowing of the moraine which extends across the northeast corner of the lake. An additional part of the sand mass must be derived from the erosion of older lake sediments and till because these materials are exposed in small scattered exposures across much of the shallow parts of the lake.

During the cruise from STOP 1 to STOP 2 the masking effect of the sand on the subbottom profiles is lost and the profiles reveal the sediment below. Three types are illustrated, each defined by a unique acoustic signature, in the profiles. One kind of sediment is characterized by well defined reflectors which are closely spaced and parallel. The reflecting surfaces are taken to be proglacial lake strata and their varying inclinations with respect to the lake floor indicate that either the strata have been deformed or that they have been draped across an irregular surface. The second type of sediment revealed by the profiles is characterized by weak, diffuse, non-planar reflectors. The sediment represented by this acoustic pattern is thought to be glacial till. Support for this interpretation comes from the vertical relationships between the two types of sediment: that with the well defined reflectors rests on the sediment with the poorly defined reflectors at all localities. This is the expected relationship if the interpretation of the profiles is correct. A third type of sediment is recorded by the profiles at the sediment interface and just below it. This sediment mass is characterized either by well defined but discontinuous reflectors or by its near transparency to the sonic pulse from the profiler. The sediment responsible for these acoustic signatures must be complex and dredge samples have shown it to include silts, silty muds and carbonates. Rocks surfaces do not occur, as far as its presently known, within the penetration range of the subbottom profiler anywhere at the north end of the lake.

STOP 2

At this position most of the surficial sediments are made up of finely-ground carbonate debris as well as whole shells. Most of the shells and shell debris are provided by gastropods with a minor contribution from bivales. Micritic sediments of this type are typical of that found at many localities along the west side of the lake in water depths less than

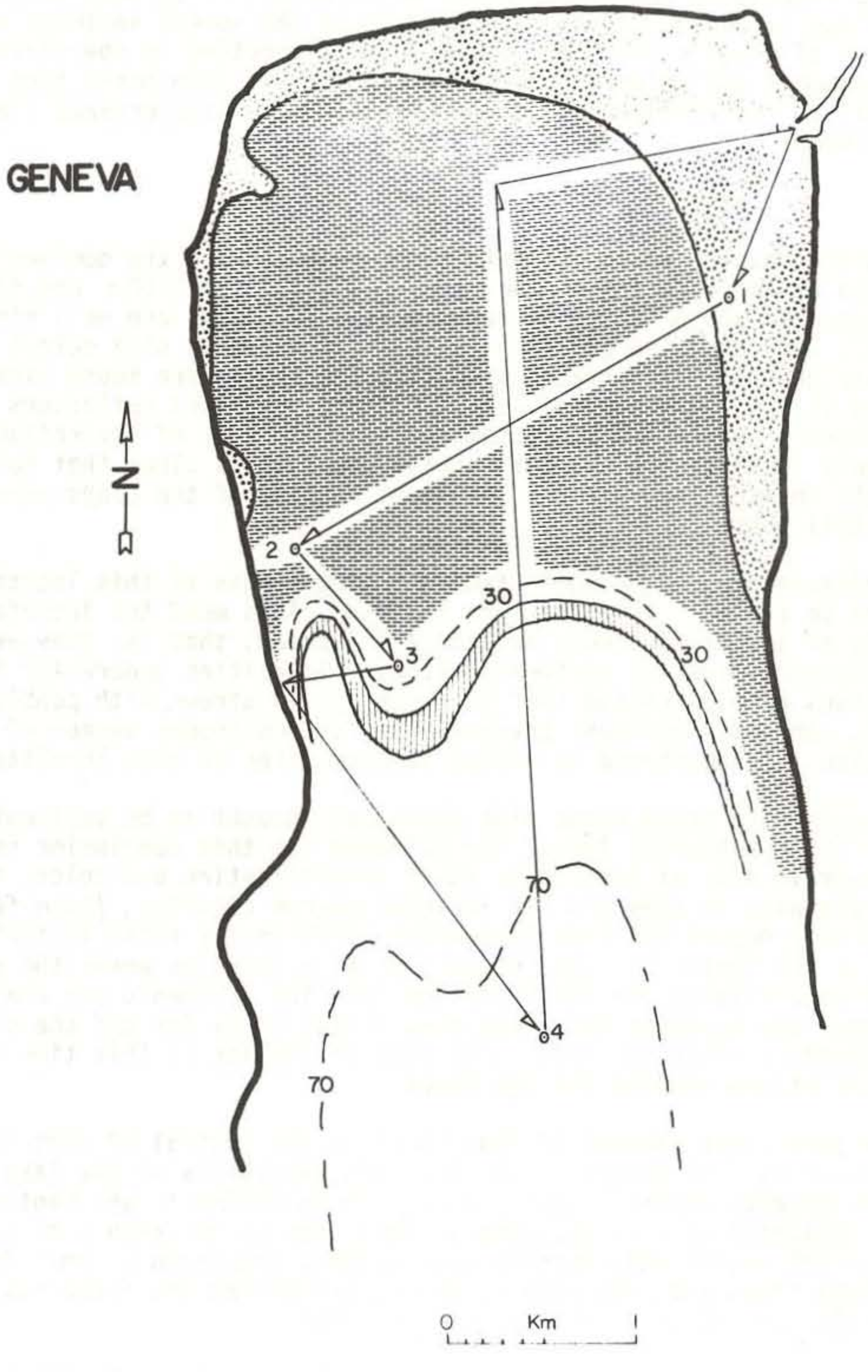

Figure 2. Map showing cruise tracks, sample sites, bathymetry in meters, and sediment facies: stipple - sand, dashes - silts and carbonates, vertical ruling - pink clays and open area to south - black muds.

30 meters especially where only small or intermittent streams enter the lake. These carbonate sediments appear to be the normal sediment where the influx of clastic sediment is low. It is tempting to speculate that if the sediment influx were reduced throughout the lake basin then carbonates would be the dominant sediment instead of the fine-grained clastics normally seen.

STOP 3

Cruising south it appears that the carbonates are the dominant sediment type at least as far as the site of STOP 3. At STOP 3 one finds clay exposed on south-facing bottom slopes. The clays are well stratified (varved?), very cohesive and they exhibit light red to pink colors. Single pebble--or granule-sized grains and ostracode shells are found widely scattered in the clay sequence. Well defined, parallel reflectors characterize these clays in the subbottom profiles and many of the reflectors are steeply inclined. Along this cruise track it is clear that most of the strata inclinations are the result of draping of the clays across a complex till mass.

Sediments exposed on south-facing bottom slopes at this location appear to be eroded. The strata in the pink clays meet the interface at a variety of angles and their exposures are clean, that is, they are free of any younger, covering sediment. At many localities underwater television scans have disclosed that this surface is strewn with pebbles and granules, some with sediment shadows. The discontinuous veneer of co rse clasts also is encountered in dredge samples taken at this locality.

As indicated above these pink clays are thought to be sediments deposited in a proglacial lake. The evidence for this conclusion includes the fine-grain size of the clays, their stratification and color, the lack of organics in them and the included coarse clastics. These features indicate both deposition from suspension sufficiently rapid to inhibit reduction of the ferric iron and deposition at a location where the quantity of organics available for incorporation into the sediments was minimal. The coarser clasts might well have been rafted in by ice and the ostracodes were probably surface dwellers. The edge of the ice at this time most likely was at the moraine through Geneva.

The pink clays exposed at this locality are typical of what is found at depths of 10 - 40 meters in the northern two-thirds of the lake. At lesser or greater depths it appears that these sediments are mantled by younger sediments so that exposure of the clays is the result of a bottom process which selectively removes any sediment deposited at that depth. At the same time, the pink clay is eroded presenting the fresh clay surface seen on the lake floor at the depths specified.

Our work indicates that the internal waves are the only likely sediment transport agent capable of erosion at specific depths in the lake. Internal waves are a dynamic feature of thermoclines in most bodies of water and their existence in Seneca Lake is well documented (Hunkins and Fliegel, 1973; Ahrnsbrak, 1978). They apparently move from south to north in the lake and on striking the south-facing slopes at location 3 they break and erode the bottom sediment. A likely analogy would be that of waves striking a shoreline and carrying away the fine-grained sediment exposed there.

STOP 4

From STOP 3 the ship will pass over a canyon-like feature on the floor and then move south across steep bottom slopes to the flatter floor typical of the deeper parts of the lake. At this location the sediments are very fine-grained, black to very dark gray, stratified and rich in organics. The subbottom profiles indicate that the black muds often overlie older sediments which have the acoustic characterics of the pink clays. These black muds are found over most of the deep floor of the lake. They contain no shell material, few grains coarser than fine silt and much sulfide. South of Geneva the black muds often are as much as eight meters thick. Near large deltas these muds contain turbidite sands and at the base of the steeper slopes subaqueous slide beds as part of the sequence (Woodrow, Blackburn and Monahan, 1969). The deep lake muds are deposited mainly from suspension the fine material having been carried into the lake by streams and by erosion of older, bottom sediments by internal waves.

Our return cruise will carry us back across the bottom facies and varied bottom topography at the north end of the lake.

SUMMARY

The glacially-carved Seneca Lake valley is partly filled with proglacial lake sediments which were laid down on still older Pleistocene sediments. The proglacial lake sediments were subsequently buried by organic-rich sediments. Carbonates are presently accumulating in shallow water parts of the lake where sediment influx is low and sands are accumulating where wave-generated bottom currents sweep the bottom. The deep lake is floored by organic-rich, black muds. At intermediate depths proglacial lake clays are being eroded by internal waves which move the eroded material to the deeper parts of the lake.

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Engineering Geology at Nine Mile Point, New York

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INTRODUCTION

The south shore of Lake Ontario for some time has been considered well suited for many industries, among them nuclear power plants. Several plants are currently in operation along the lake shore, and plans for others are being seriously pursued.

As a result of the critical nature of the engineering structures which comprise a nuclear power plant, details of the geology, seismicity, and geohydrology of the plant site are defined to an extent generally not achieved in most geotechnical investigations. In addition, there is a lengthy and intensive peer review involved in the licensing process. This review focuses attention upon site details that might be classified ordinarily as unimportant, covered in recommendations as "our experience" or "our judgement", or in some instances, perhaps forgotten. Although we may not be pleased to "overexplain" many details of our analyses, it is difficult to agree that the discipline is not good for the soul and, in addition, that information ordinarily not available to the geotechnical profession is documented for future use.

The information presented in this report is an attempt to present the consultant's understanding, although somewhat broadly and generally, of the engineering geology at the Nine Mile Point site, developed through approximately 15 years of study. It is emphasized that much of the detailed and fundamental analyses that are performed ultimately in the process of providing design parameters for the facilities are based upon the parameters presented herein. Obviously, however, the details of all the design analyses are beyond the scope of this discussion. Instead, it is important to emphasize that no matter how sophisticated the analyses, ultimately they are dependent upon precise and detailed geologic data concerning the stratigraphy, structural geology, geohydrology, seismicity, and rock stresses. This presentation focuses upon the importance and relationship of the bedrock stratigraphy to the engineering decisions involved in the design and construction of the nuclear facilities at Nine Mile Point, New York.

LOCATION AND REGIONAL SETTING

Nine Mile Point is a promontory located on the southeastern shore of Lake Ontario in the town of Scriba, Oswego County, New York. It is situated approximately 7 mi northeast of the city of Oswego, and is the present site of two operating nuclear generating facilities owned by the Niagara-Mohawk Power Corporation and the Power Authority of the State of New York (Fig. 1).

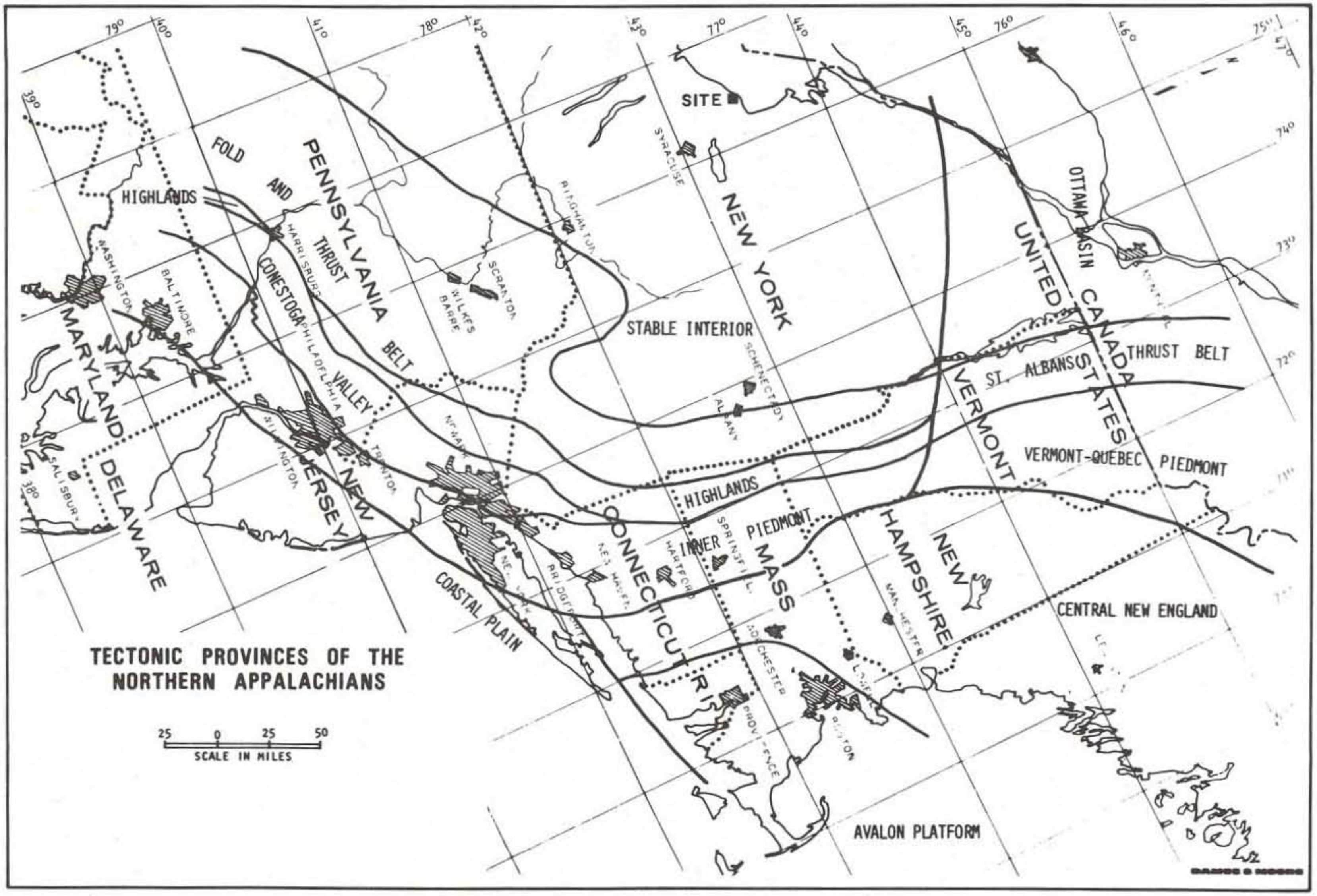

Figure 1. Tectonic provinces of northern Appalachians.

Nine Mile Point is situated within the Erie-Ontario Lowland of the Central Interior Lowland Physiographic Province. The terrain of this province characteristically is flat and gently rolling, controlled by the bedrock surface. The land surface rises gradually to the south and southeast away from Lake Ontario, where, 40 mi distant, the Portage Escarpment is the southern boundary between this province and the Appalachian Uplands. Toward the east, the Erie-Ontario Lowland is bounded by the Tug Hill Upland and the Adirondack Highlands.

Nine Mile Point is located within the Appalachian Plateau Tectonic Province as recognized by the Nuclear Regulatory Commission (Dames & Moore, 1976). This province corresponds to the Stable Interior Tectonic Province defined by Hadley and Devine (1974). The promontory is situated in the northeastern end of the Appalachian Basin, and is bounded on the west, north, and southeast by the Finlay Arch, Canadian Shield and Adirondack Massif, and the Appalachian Fold Belt, respectively.

The region surrounding Nine Mile Point within the Appalachian Basin is composed of sedimentary rocks of Paleozoic age which form a southward-thickening wedge away from the Canadian Shield and the Adirondack Massif (Broughton and others, 1966). The Paleozoic strata have an average regional gradient of 50 ft/mi (9 m/km) to the south-southwest. This gentle gradient corresponds to the southward increase in the depth to basement rocks as shown on the Tectonic Map of the Eastern United States (1962). The approximate depth to basement at Nine Mile Point is 1750 ft (535 m). The tectonic character of the Nine Mile Point region is compatible with the seismic quiescence of this area of New York State.

REGIONAL SEISMICITY OF THE NINE MILE POINT AREA

Nine Mile Point is situated in a region of only minor earthquake activity. The historical record of earthquakes in central New York, through the past 200 years, indicates that only a moderate number of small earthquakes have been recorded in this area, although larger shocks have occurred in the State to the west and northeast. Only minor structural damage has been reported from some of these earthquakes; hence, the absence of any reported earthquakes of Intensity VIII of greater (Modified Mercalli Scale) is indicative of the relative quiescence of the locale.

Locally, no known earthquake activity has originated in the immediate vicinity of Nine Mile Point in historic time. Only minor earthquakes of Intensity III or less (Modified Mercalli) have been reported within 35 to 40 mi (56 to 64 km) of this area (Fig. 2). Beyond this distance, the largest earthquake, reported within 200 mi (322 km), was of Intensity VIII in 1944 near Massena, New York, 130 mi (209 km) to the northeast. Another significant earthquake was recorded in 1929 near Attica, New York, 110 mi (177 km) to the southwest, with a reported Intensity of VII-VIII (probably VII, rather than VIII). There is evidence suggesting that these two earthquakes are each associated with geologic structures. The Cornwall-Massena earthquake seems to have been related to the northwest-trending Gloucester Fault near Massena, New York and Cornwall, Ontario (Dames & Moore, 1974b). The Attica event is associated clearly with the well-known Clarendon-Linden Fault in western New York State (Dames & Moore, 1971; 1974a).

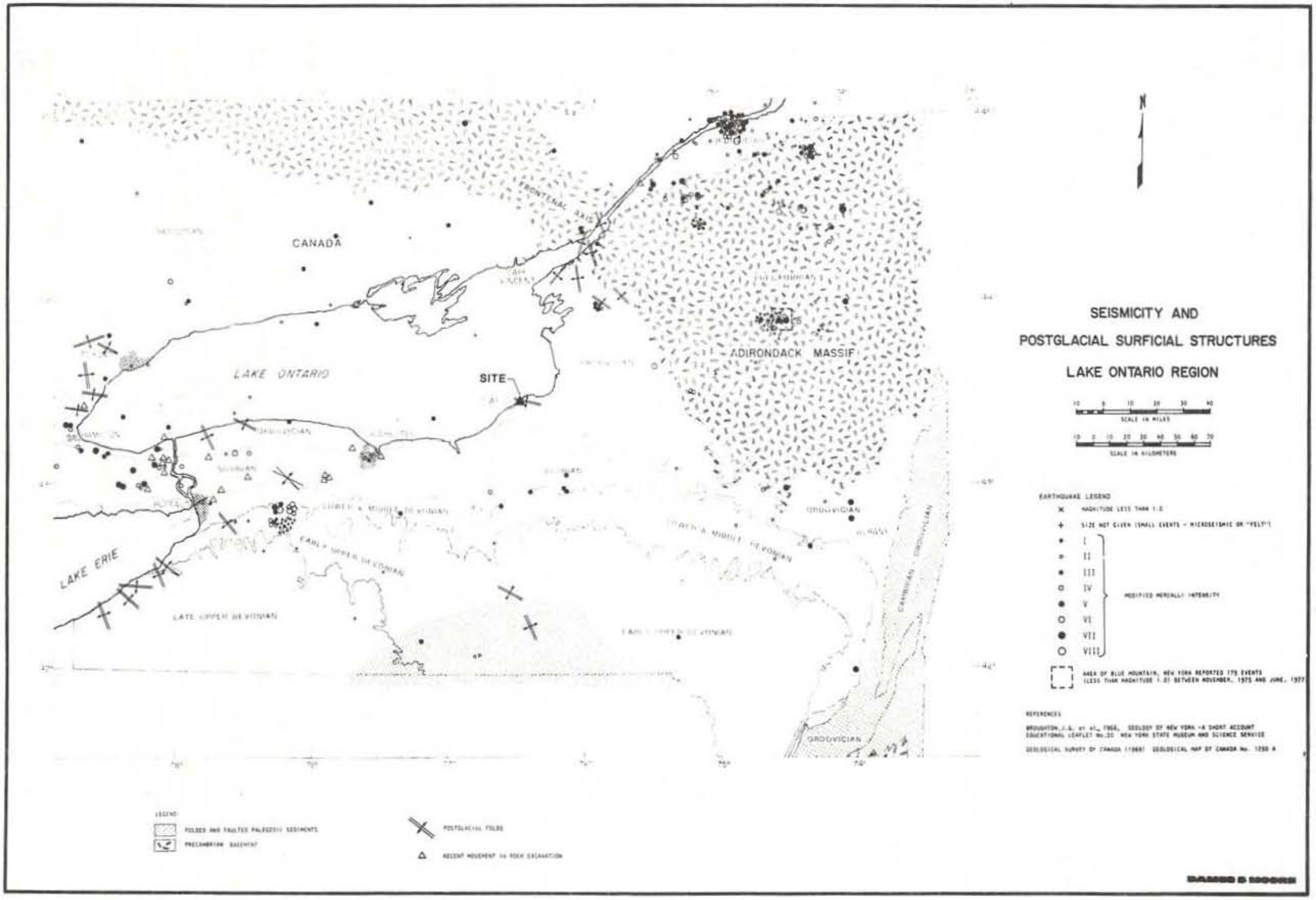

Figure 2. Seismicity and Postglacial surficial structures Lake Ontario region.

Focal plane solutions have been determined recently for earthquakes of small to moderate intensities in western and northern New York State (Fletcher and Sykes, 1977; Yang and Aggarwal, 1977). These solutions indicate high-angle reverse fault movements as associated consistently with the seismic event. The regional stress orientation calculated from these solutions shows a horizontal maximum compressive stress oriented east-northeast. Horizontal stress magnitudes have been measured in the region ranging between 1000 and 2000 lbs/sq in (Rochester Gas & Electric, 1974a, 1974b).

The seismic designs chosen for the two existing nuclear units (and one presently under construction at Nine Mile Point), ranges from 11 to 15 percent gravity (0.11 g to 0.15 g). The early (Unit 1 at Nine Mile Point) recommendation was 0.11 g; the later recommendation of 0.10 g by the consultants for the James A. Fitzpatrick Nuclear Power Plant (PASNY) was raised to 0.15 g by the Nuclear Regulatory Commission (NRC).

STRATIGRAPHY

Bedrock

Drilling at Nine Mile Point provided information concerning the stratigraphy of nearly 375 ft (114 m) of section. Figure 3 represents the stratigraphic section of the study area. Figure 4 is a lithologic log of a drillhole from the site area that is typical of the stratigraphic resolution obtained from the drilling program.

The rocks of the study area consist of sandstone, graywacke, siltstone, and shale which were deposited during Late Ordovician time under transient marine conditions. The entire sequence of rocks is highly variable in short thickness intervals because of complex interbedding of different lithologies; however, there is a general upward gradation toward more sandstone and graywacke and less siltstone and shale.

The rocks which have been expolored at Nine Mile Point belong to three formations. At the surface the rocks are part of the Oswego Sandstone which is characteristically a massive, medium- to coarse-grained feldspathic quartz sandstone, generally well cemented and resistant to erosion. The lowest 10 ft (3.1 m) of this formation represents a transition zone, of thin to medium interbeds of sandstone, graywacke, and siltstone, to the underlying rocks of the upper Lorraine Group.

The rocks encountered in the upper Lorraine Group consist of two formations: the Pulaski Formation and the underlying Whetstone Gulf Formation. The contact between the Oswego and the Pulaski characteristically has been difficult to establish accurately. The first occurrence of fossils traditionally marks the top of Pulaski Formation whereas the Oswego is essentially unfossiliferous. At Nine Mile Point the thickness of the Oswego Sandstone ranges from 60 ft (18 m), decreasing to nearly zero at the southern Lake Ontario shoreline. The Pulaski, below the Oswego, is approximately 100 ft (31 m) thick. The Pulaski has been subdivided into three units by Dames & Moore (Niagara-Mohawk, 1978) which are not

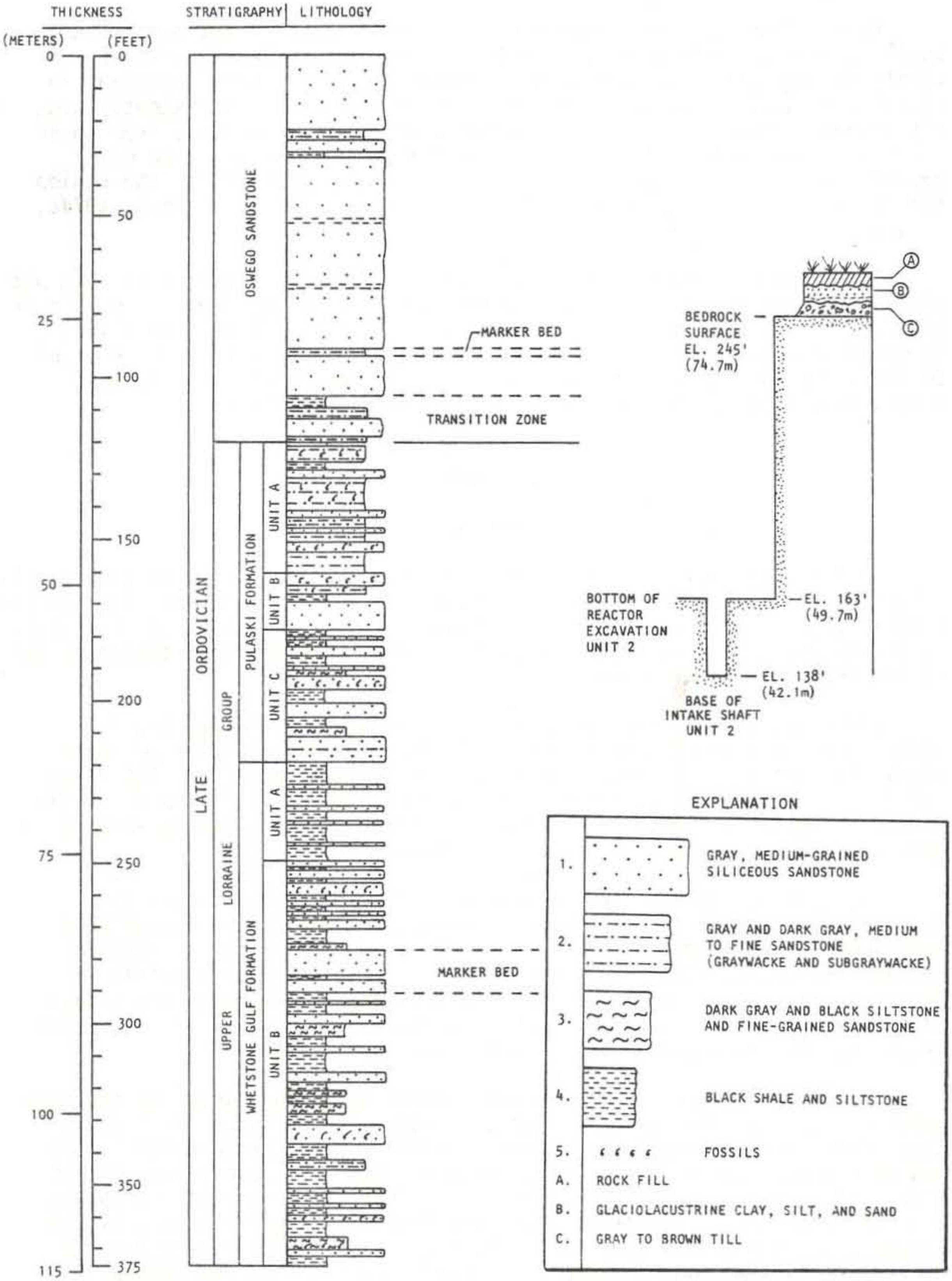

Figure 3. Relationship of stratigraphy at Nine Mile Point to engineering structures.

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STRATIGRAPHY

Bedrock

Drilling at Nine Mile Point provided information concerning the stratigraphy of nearly 375 ft (114 m) of section. Figure 3 represents the stratigraphic section of the study area. Figure 4 is a lithologic log of a drillhole from the site area that is typical of the stratigraphic resolution obtained from the drilling program.

The rocks of the study area consist of sandstone, graywacke, siltstone, and shale which were deposited during Late Ordovician time under transient marine conditions. The entire sequence of rocks is highly variable in short thickness intervals because of complex interbedding of different lithologies; however, there is a general upward gradation toward more sandstone and graywacke and less siltstone and shale.

The rocks which have been expolored at Nine Mile Point belong to three formations. At the surface the rocks are part of the Oswego Sandstone which is characteristically a massive, medium- to coarse-grained feldspathic quartz sandstone, generally well cemented and resistant to erosion. The lowest 10 ft (3.1 m) of this formation represents a transition zone, of thin to medium interbeds of sandstone, graywacke, and siltstone, to the underlying rocks of the upper Lorraine Group.

The rocks encountered in the upper Lorraine Group consist of two formations: the Pulaski Formation and the underlying Whetstone Gulf Formation. The contact between the Oswego and the Pulaski characteristically has been difficult to establish accurately. The first occurrence of fossils traditionally marks the top of Pulaski Formation whereas the Oswego is essentially unfossiliferous. At Nine Mile Point the thickness of the Oswego Sandstone ranges from 60 ft (18 m), decreasing to nearly zero at the southern Lake Ontario shoreline. The Pulaski, below the Oswego, is approximately 100 ft (31 m) thick. The Pulaski has been subdivided into three units by Dames & Moore (Niagara-Mohawk, 1978) which are not

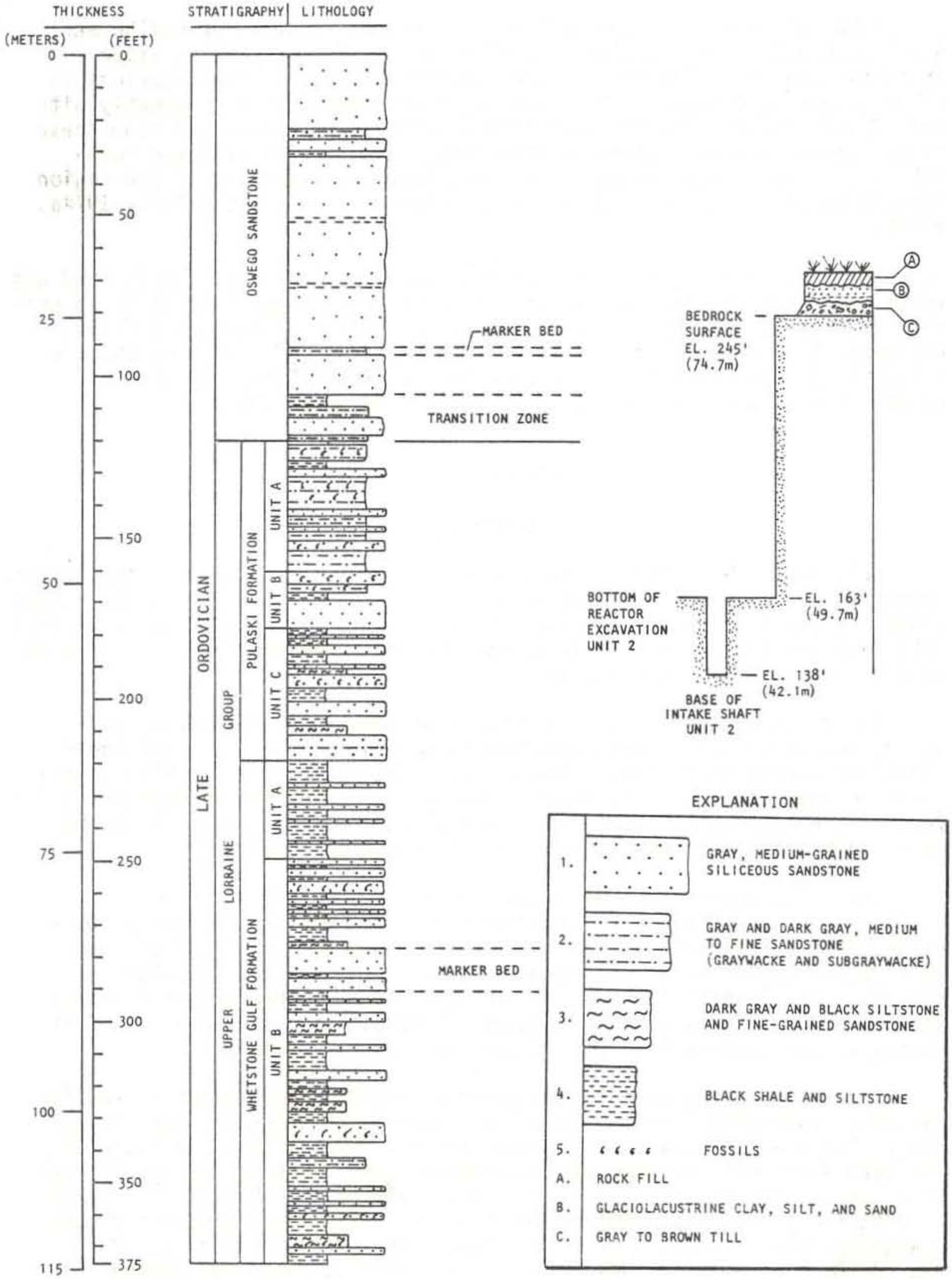
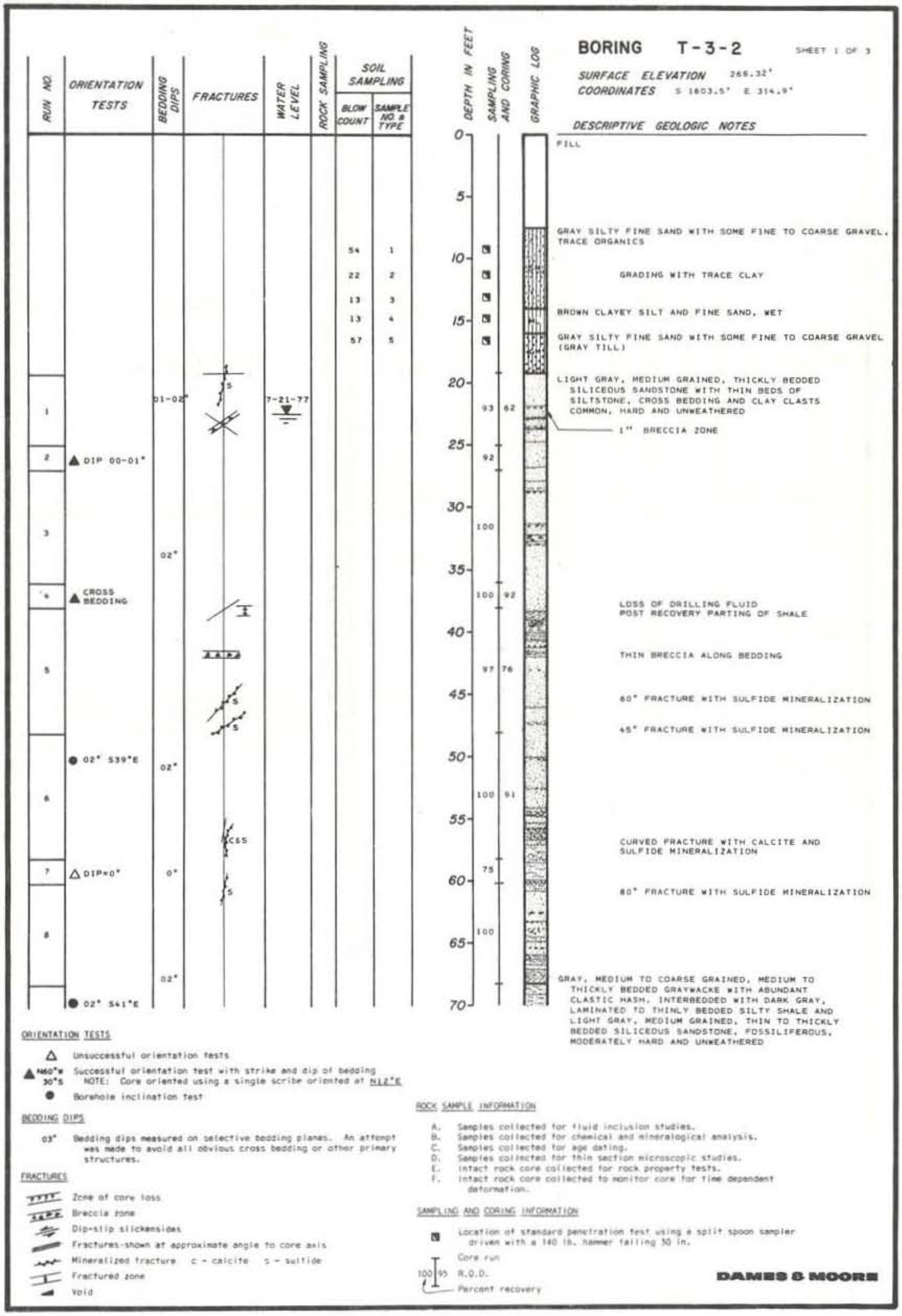


Figure 3. Relationship of stratigraphy at Nine Mile Point to engineering structures.



BORING T-3-2 SHEET 1 OF 3

SURFACE ELEVATION 268.32'
COORDINATES S 1603.5' E 314.9'

DESCRIPTIVE GEOLOGIC NOTES

FILL

GRAY SILTY FINE SAND WITH SOME FINE TO COARSE GRAVEL, TRACE ORGANICS

GRADING WITH TRACE CLAY

BROWN CLAYEY SILT AND FINE SAND, WET

GRAY SILTY FINE SAND WITH SOME FINE TO COARSE GRAVEL (GRAY TILL)

LIGHT GRAY, MEDIUM GRAINED, THICKLY BEDDED SILICEOUS SANDSTONE WITH THIN BEDS OF SILTSTONE, CROSS BEDDING AND CLAY CLASTS COMMON, HARD AND UNWEATHERED

1" BRECCIA ZONE

LOSS OF DRILLING FLUID
POST RECOVERY PARTING OF SHALE

THIN BRECCIA ALONG BEDDING

60° FRACTURE WITH SULFIDE MINERALIZATION

45° FRACTURE WITH SULFIDE MINERALIZATION

CURVED FRACTURE WITH CALCITE AND SULFIDE MINERALIZATION

80° FRACTURE WITH SULFIDE MINERALIZATION

GRAY, MEDIUM TO COARSE GRAINED, MEDIUM TO THICKLY BEDDED GRAYWACKE WITH ABUNDANT CLASTIC HASH, INTERBEDDED WITH DARK GRAY, LAMINATED TO THINLY BEDDED SILTY SHALE AND LIGHT GRAY, MEDIUM GRAINED, THIN TO THICKLY BEDDED SILICEOUS SANDSTONE, FOSSILIFEROUS, MODERATELY HARD AND UNWEATHERED

ORIENTATION TESTS

△ Unsuccessful orientation tests
▲ N60°W 30°S Successful orientation test with strike and dip of bedding
NOTE: Core oriented using a single scribe oriented at N12°E
● Borehole inclination test

BEDDING DIPS

03° Bedding dips measured on selective bedding planes. An attempt was made to avoid all obvious cross bedding or other primary structures.

FRACTURES

Zone of core loss
Breccia zone
Dip-slip slickensides
Fractures-shown at approximate angle to core axis
Mineralized fracture c - calcite s - sulfide
Fractured zone
Void

ROCK SAMPLE INFORMATION

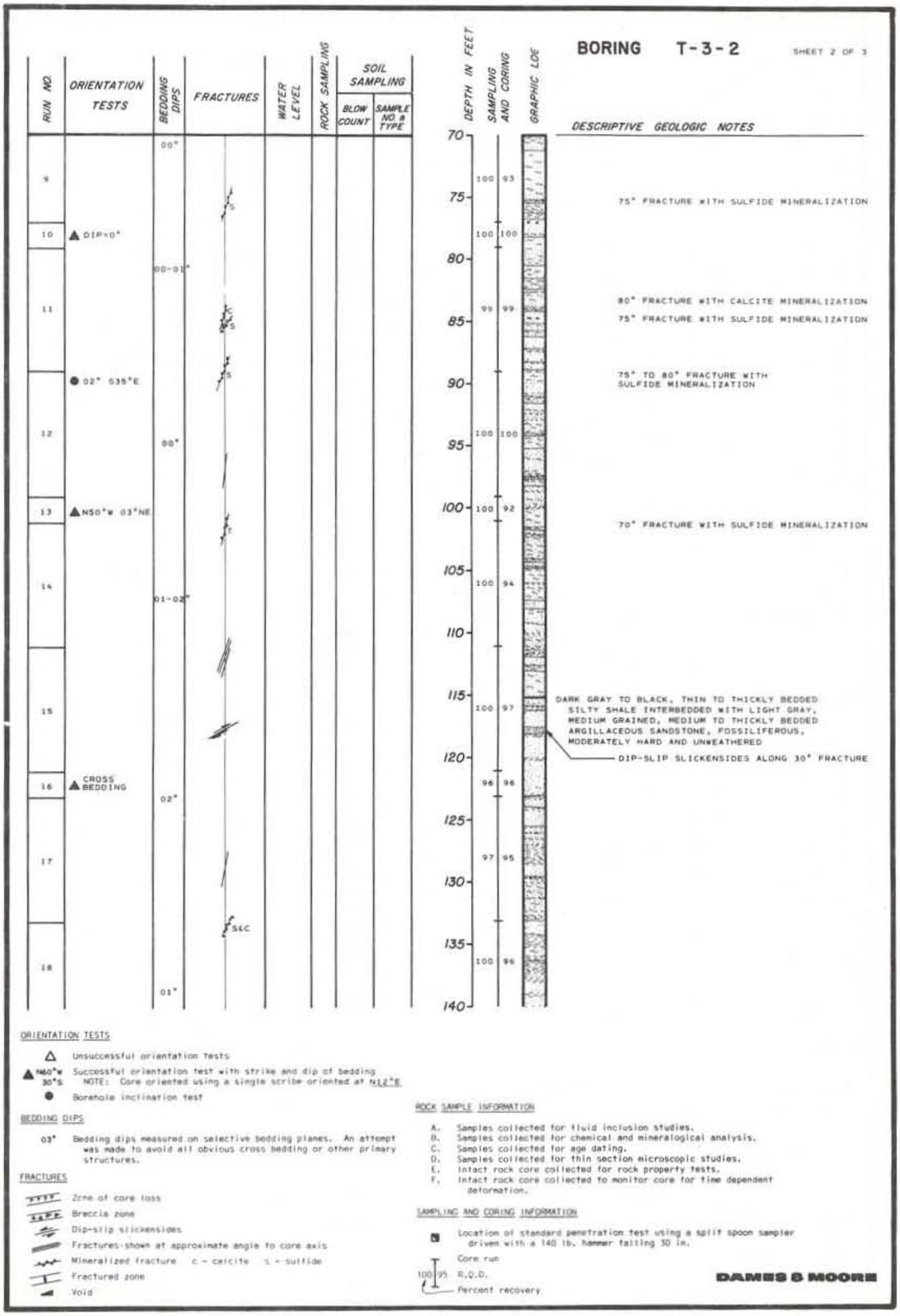
A. Samples collected for fluid inclusion studies.
B. Samples collected for chemical and mineralogical analysis.
C. Samples collected for age dating.
D. Samples collected for thin section microscopic studies.
E. Intact rock core collected for rock property tests.
F. Intact rock core collected to monitor core for time dependent deformation.

SAMPLING AND CORING INFORMATION

Location of standard penetration test using a split spoon sampler driven with a 140 lb. hammer falling 30 in.
100 95
Core run
R.Q.D.
Percent recovery

DAMES & MOORE

Figure 4. Boring T-3-2 at site.



75° FRACTURE WITH SULFIDE MINERALIZATION

80° FRACTURE WITH CALCITE MINERALIZATION

75° FRACTURE WITH SULFIDE MINERALIZATION

75° TO 80° FRACTURE WITH SULFIDE MINERALIZATION

70° FRACTURE WITH SULFIDE MINERALIZATION

DARK GRAY TO BLACK, THIN TO THICKLY BEDDED SILTY SHALE INTERBEDDED WITH LIGHT GRAY, MEDIUM GRAINED, MEDIUM TO THICKLY BEDDED ARGILLACEOUS SANDSTONE, FOSSILIFEROUS, MODERATELY HARD AND UNWEATHERED

DIP-SLIP SLICKENSIDES ALONG 30° FRACTURE

ORIENTATION TESTS

△ Unsuccessful orientation tests

▲ N60°W 30°S Successful orientation test with strike and dip of bedding
NOTE: Core oriented using a single scribe oriented at N12°E

● Borehole inclination test

BEDDING DIPS

03° Bedding dips measured on selective bedding planes. An attempt was made to avoid all obvious cross bedding or other primary structures.

FRACTURES

Zone of core loss
Breccia zone
Dip-slip slickensides
Fractures shown at approximate angle to core axis
Mineralized fracture c - calcite s - sulfide
Fractured zone
Void

ROCK SAMPLE INFORMATION

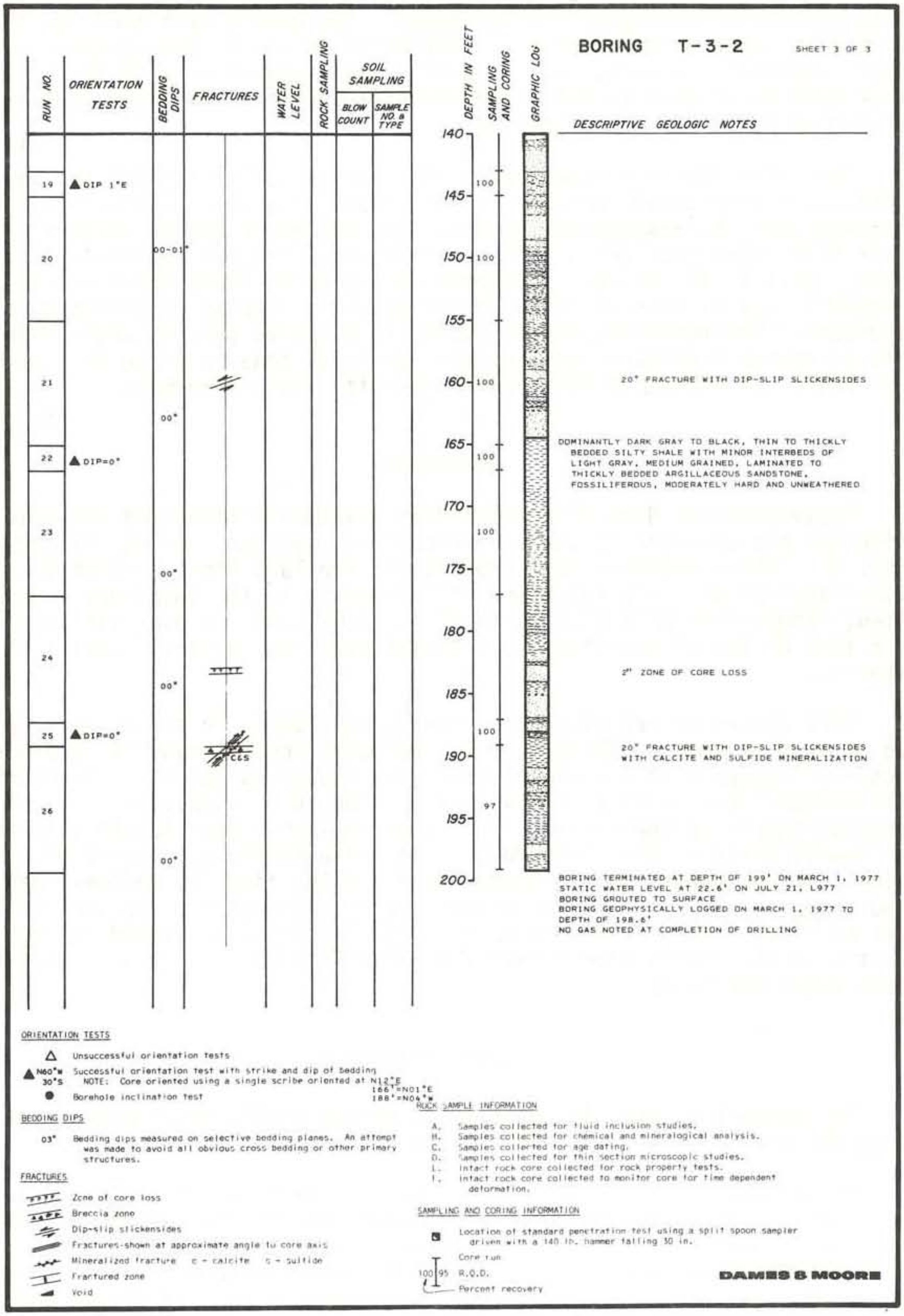
A. Samples collected for fluid inclusion studies.
B. Samples collected for chemical and mineralogical analysis.
C. Samples collected for age dating.
D. Samples collected for thin section microscopic studies.
E. Intact rock core collected for rock property tests.
F. Intact rock core collected to monitor core for time dependent deformation.

SAMPLING AND CORING INFORMATION

■ Location of standard penetration test using a split spoon sampler driven with a 140 lb. hammer falling 30 in.

Core run
100 95 R.Q.D.
Percent recovery

Figure 4. Continued.



20° FRACTURE WITH DIP-SLIP SLICKENSIDES

DOMINANTLY DARK GRAY TO BLACK, THIN TO THICKLY BEDDED SILTY SHALE WITH MINOR INTERBEDS OF LIGHT GRAY, MEDIUM GRAINED, LAMINATED TO THICKLY BEDDED ARGILLACEOUS SANDSTONE, FOSSILIFEROUS, MODERATELY HARD AND UNWEATHERED

2" ZONE OF CORE LOSS

20° FRACTURE WITH DIP-SLIP SLICKENSIDES WITH CALCITE AND SULFIDE MINERALIZATION

BORING TERMINATED AT DEPTH OF 199' ON MARCH 1, 1977
STATIC WATER LEVEL AT 22.6' ON JULY 21, L977
BORING GROUTED TO SURFACE
BORING GEOPHYSICALLY LOGGED ON MARCH 1, 1977 TO DEPTH OF 198.6'
NO GAS NOTED AT COMPLETION OF DRILLING

ORIENTATION TESTS

△ Unsuccessful orientation tests
▲ N60°W 30°S Successful orientation test with strike and dip of bedding
NOTE: Core oriented using a single scribe oriented at N12°E
166'=N01°E
188'=N04°W
● Borehole inclination test

BEDDING DIPS

03° Bedding dips measured on selective bedding planes. An attempt was made to avoid all obvious cross bedding or other primary structures.

FRACTURES

Zone of core loss
Breccia zone
Dip-slip slickensides
Fractures-shown at approximate angle to core axis
Mineralized fracture c - calcite s - sulfide
Fractured zone
Void

ROCK SAMPLE INFORMATION

A. Samples collected for fluid inclusion studies.
H. Samples collected for chemical and mineralogical analysis.
C. Samples collected for age dating.
D. Samples collected for thin section microscopic studies.
L. Intact rock core collected for rock property tests.
T. Intact rock core collected to monitor core for time dependent deformation.

SAMPLING AND CORING INFORMATION

■ Location of standard penetration test using a split spoon sampler driven with a 140 lb. hammer falling 30 in.
Core run
100 95 R.Q.D.
Percent recovery

DAMES & MOORE

Figure 4. Continued.

recognized on a regional basis. The upper unit (Unit A) is a 40-ft (12 m) thick section of graywacke and sandstone. The middle unit (Unit B) is a 20 ft (6 m) thick section of thick sandstone beds with thin graywacke and shale interbeds. Unit C, at the base of the Pulaski is a 40-ft (12 m) thick section of thin to thick sandstone beds with interbedded shale comprising up to 50 percent of the unit.

The Whetstone Gulf Formation is encountered below the Pulaski, and is marked by a pronounced increase in the amount of shale. The base of this formation was not reached during drilling, but the explored section (150 ft or 46 m) also has been subdivided into two units not regionally recognized. Unit A, at the top, is approximately 30 ft (9 m) thick and is predominantly shale, that is 75 to 80 percent, with medium to thin beds of sandstone. The remaining 120 ft (37 m) is 50 to 60 percent shale with thin to medium sandstone beds, except for local zones 5 to 10 ft (1.5 to 3 m) thick, of medium to thick sandstone with shale interbeds.

Overburden

Excavations at Nine Mile Point have revealed a veneer of variable thickness and composition of glaciolacustrine sediments on top of bedrock (Fig. 5). These sediments are products of the last known glaciation, the Wisconsinan stage. The thickness of sediments, in the locations investigated, ranges from 5 ft (1.5 m) to 20 ft (6 m), and is overlain in places by a foot or two of recent peat, alluvial deposits, or artificial fill material.

Till occurs on top of bedrock nearly everywhere in the study area, and is gray to brown. The gray till typically occurs below the brown and contains fragments of the underlying, gray Oswego Sandstone. The brown till contains many exotic clasts derived from the crystalline rocks of the Canadian Shield to the north. Lacustrine sediments overlie the till in the lowest parts of Nine Mile Point. In these sediments, laminated clay and silt grade upward to crossbedded and rippled fine- to medium-grained sand and massive silt. These sediments are capped at the top locally by peat or fluvial sand of Recent origin. Artificial fill placed in conjunction with construction activity at Nine Mile Point occurs in numerous areas about the site.

GENERAL STRUCTURE

The bedrock at the site is dipping gently southward at a gradient of 40 to 50 ft/mi (7.6 to 9.0 m/km) to the south-southwest.

The bedrock is characterized by two systematic vertical fracture sets (or joints) which have been recognized among other sets throughout central and western New York State. One set strikes N45°W (average) and the other strikes N75°E (average). These joints are best developed in the sandstone, and are discontinuous in that many do not crosscut bedding planes which mark a major change of lithology.

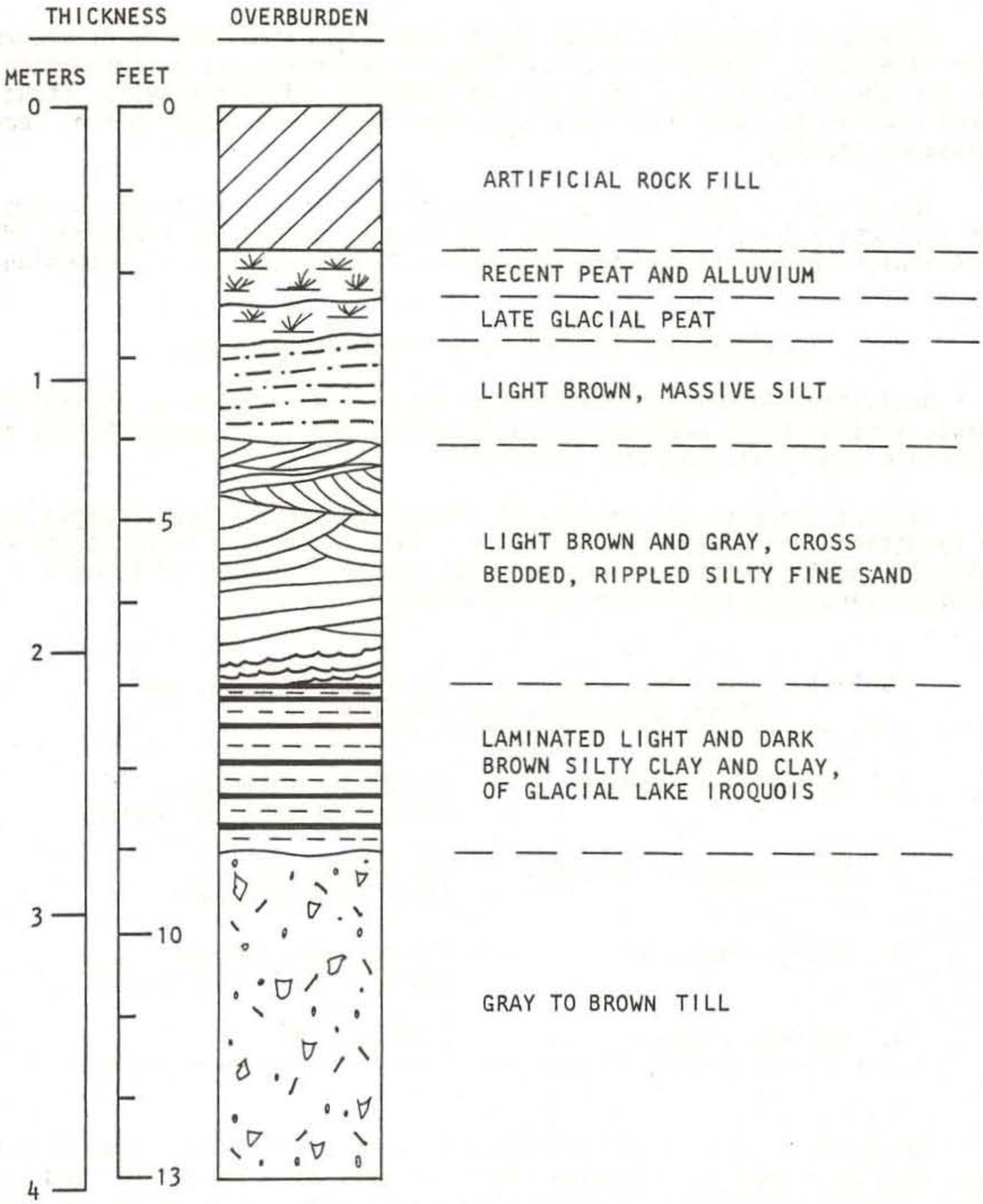


Figure 5. Idealized stratigraphic column of overburden at Nine Mile Point.

Three small high-angle fault structures occur at Nine Mile Point. The faults strike N70°W. Two of them dip 60-70° northward, whereas the third dips southward at 60-65°. The faults are similar in geometry to other structures reported in western New York State, and are not associated with any major tectonic structures in the region. Buckling of the rock in the form of "pop-up" structures has occurred on the two north-dipping faults (Niagara Mohawk, 1978).

A group of low-angle thrust faults and associated drag folds occurs at Nine Mile Point. These structural features generally are oriented N10°E, and the thrust faults dip 15 to 20° to the east and to the west. Structures similar to these also have been observed in the region during reconnaissance mapping.

The origin of the structural development of these features is complex, and reflects a long and varied geologic history of the northeast end of the Appalachian Basin, and therefore is beyond the scope of this discussion.

ENGINEERING PROPERTIES OF GEOLOGIC MATERIALS

During the foundation studies for the nuclear facilities at Nine Mile Point, various tests were run on rock samples and in the bedrock mass to determine some basic physical properties.

Table 1 presents the results of unconfined compressive strength tests on sandstone, graywacke, and siltstone. This table also includes the results of density determinations on these samples. Values of Young's Modulus (vertical) and Poisson's Ratio also are shown.

Table 1. Unconfined compressive strength tests on sandstone, graywacke, and siltstone.

1.	Compressive Strength:	15,200 to 28,700 psi (10.5 + 019.8 x 10^6 Nt/m^2)
2.	Unit Weight or Density:	157 to 167 pcf (2.52 to 2.68 g/cm^3)
3.	Young's Modulus:	4.4 to 9.0 x 10^6 psi (30.4 to 62.1 x 10^9 Nt/m^2)
4.	Poisson's Ratio:	0.08 to 0.24

Geophysical surveys of the site area were carried out. Crosshole surveys were performed to determine the shear wave velocity of soil and bedrock. Uphole surveys and a refraction survey were run to determine the compressional wave velocity of the soil and bedrock. Further testing of drill-core samples was performed with a shockscope to determine the variation of compressional wave velocity with depth.

The shear wave velocity of the overburden averaged 1100 ft/sec (335 m/sec), and of the bedrock averaged 7700 ft/sec (2350 m/sec). The compressional wave velocity of the overburden was approximately 2250 ft/sec (685 m/sec). The results of the uphole and seismic refraction surveys for compressional wave velocities range from 12,500 ft/sec to 14,000 ft/sec for the upper 100 feet of bedrock (3810 m/sec to 4270 m/sec for 31 m of bedrock). Figure 6 illustrates the results of the shockscope tests. This

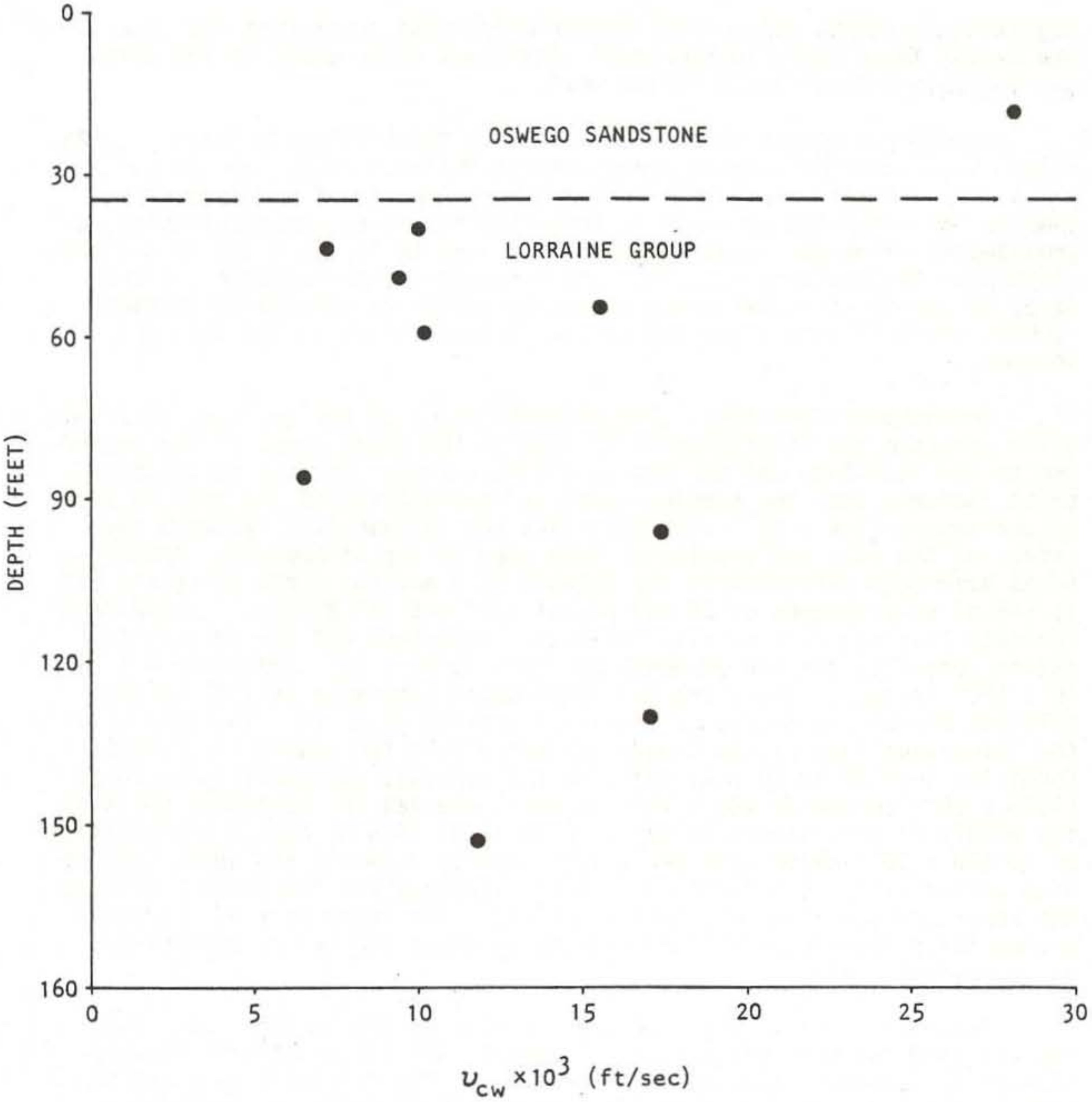


Figure 6. Shockscope tests showing compressional wave velocity measurements versus depth.

figure demonstrates that the Oswego Sandstone has a seemingly higher compressional wave velocity than rocks of the underlying Lorraine Group.

ENGINEERING HYDROLOGY

Surface Water Hydrology: There are no natural perennial streams located at Nine Mile Point. Precipitation which falls in this area is discharged into Lake Ontario via intermittent streams, groundwater flow, and artificially constructed drainage channels. The study area is bordered regionally by three major river basins which also drain into the lake: the Oneida River Basin to the south, the Black River Basin to the east, and the Oswego River Basin to the west.

Hydrologic budget studies of Nine Mile Point (Niagara Mohawk, 1972a, 1972b) show that the average annual precipitation is approximately 36 in (91.5 cm). Stream-flow runoff accounts for one-half of this amount, whereas the remaining one-half is accounted for by evapotranspiration and groundwater recharge. Evapotranspiration uses 16 in (40.6 cm) of the precipitation leaving only 2 in (5.1 cm) for groundwater recharge. Therefore, it can be seen that there is a high annual percentage of surface runoff, which is attributed to the low permeabilities of the soil and bedrock.

Groundwater Hydrology: The permeabilities of the geologic materials, which comprise the stratigraphic section in the study area, differ according to the lithology and the degree of fracturing. Surface percolation tests indicate that the average vertical permeability of the soil is 10^{-5} cm per second (0.4×10^{-7} in/sec). This low permeability reflects the nature of the till and proglacial lake clay on top of bedrock. Packer tests have been performed in the bedrock to a maximum depth of nearly 150 ft (45 m) at pressures of 25 and 50 psi (173 and 345 kN/m^2). These tests indicate that the rock mass in the Oswego Sandstone and the Pulaski Formation generally has low permeability (1.5 to 45×10^{-6} cm/sec or 0.5 to 18×10^{-6} in/sec). There are two zones which typically exhibit permeabilities one or two orders of magnitude greater (Fig. 7). The contact of the Transition Zone of the Oswego Sandstone with the underlying Pulaski Formation (~35 ft or 10.7 m) exhibits the greatest permeability measured (1000×10^{-6} cm/sec or 400×10^{-6} in/sec), whereas the sandstone units in the middle of the Pulaski Formation (~85 ft or 25.9 m) have a permeability up to 600×10^{-6} cm/sec (or 240×10^{-6}in/sec). Clearly the upper zone of high permeability is a function of both lithology and fracturing, because the upper bedrock is more highly fractured. The lower zone of increased permeability is related to the contrasting sandstone layers surrounded by impervious shales.

The static water levels in the vicinity of the nuclear facilities are the same for both the surficial deposits and the underlying bedrock indicating a seeming hydrologic connection. The hydraulic gradient at Nine Mile Point averages about 2 ft per 100 ft (2 m/100 m), and slopes toward Lake Ontario, its natural base discharge. This local gradient is greater than the regional hydraulic gradient of 40 ft/mi (0.75 m/100 m). When surface water percolates down to the watertable in the soil, it will flow toward the lake at a local rate of less than 2×10^{-5} cm/sec (or 8×10^{-6} in/sec). If a liquid were discharged below the bedrock surface, it would flow horizontally toward the lake at an estimated rate of less than 2×10^{-4} cm/sec (or 8×10^{-5} in/sec) in the upper 20 ft or 6 m of bedrock.

Domestic water well discharges in the area are characteristically low. For wells completed in soil, the discharges range from 5 to 8 gal/min (19 to 30 l/min). For wells completed in bedrock, the discharges average 10 gals per minute (38 l/min). Because the upper zone of bedrock is more highly fractured than at depth, few domestic wells extend deeper than 75 ft (23 m).

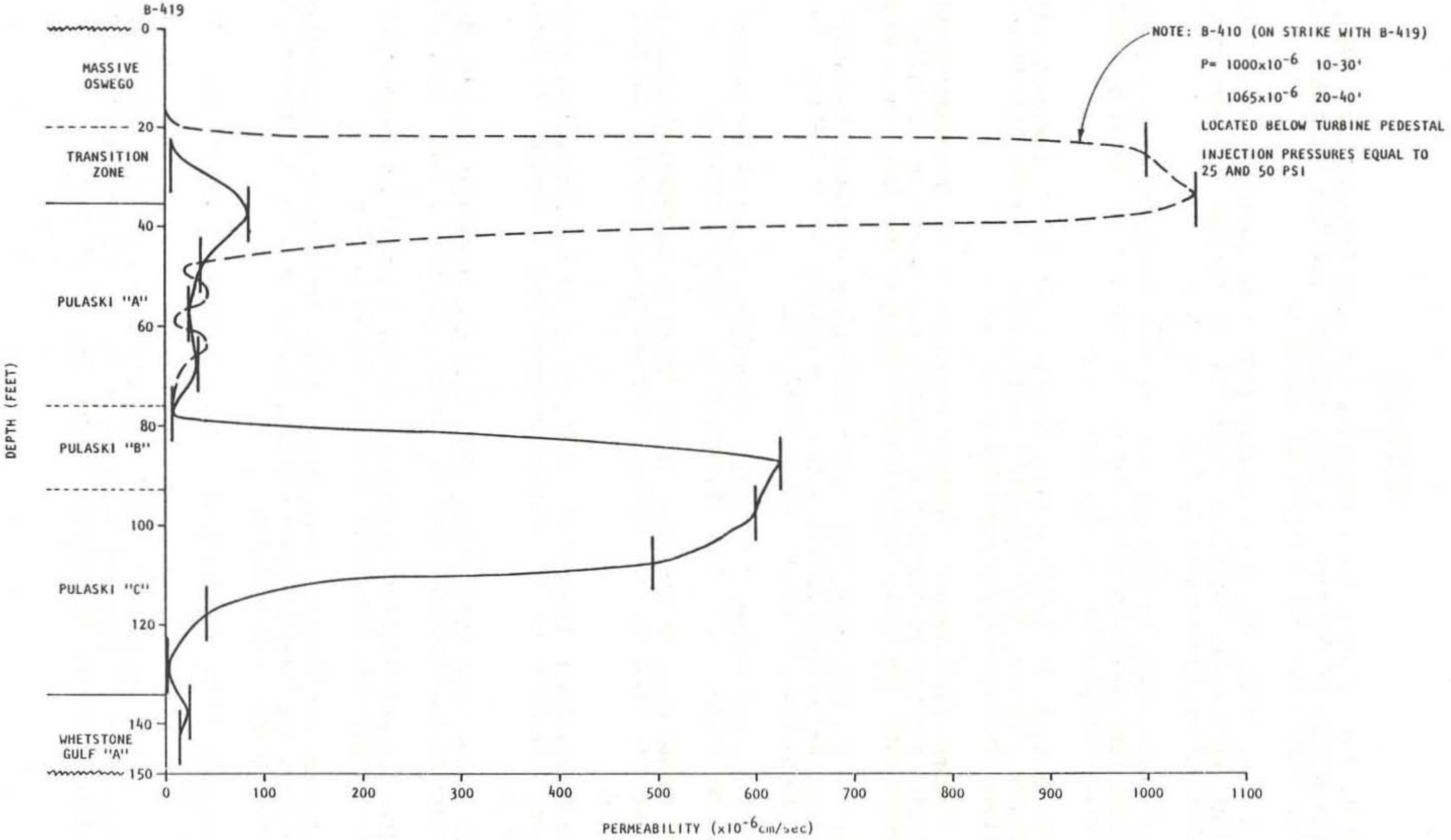


Figure 7. In situ permeability of rock mass at reactor, NMP-2.

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The Tully Limestone of Central New York - Stratigraphy and Facies Variation

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INTRODUCTION

The Tully Limestone of central New York is an anomalous sequence of carbonate rocks lying within thick coarse clastic rocks of Devonian age constituting the Appalachian Basin. The thin carbonates are sandwiched between terrigeneous detrital rocks thickening westwards from the Catskill Delta and represent a significant change of depositional environments through the Devonian epicontinental seas. The events leading to the development of the Tully Limestone have been described in detail by Heckel (1973) and this field trip is designed to provide a description of the Tully Limestone field relationships studied at Syracuse University within the framework of Heckel's study.

STRATIGRAPHY

The position of the Tully Limestone within the clastic wedge of the Catskill Delta has been delineated by Heckel (1973) and Chadwick (1935) (Fig. 1). Previous work recognized that the Tully Limestone was an unusual occurrence within the Catskill deltaic complex (e.g. Grabau, 1917; Cooper and Williams, 1935; Heckel, 1973). However, the majority of the work was oriented towards deciphering the changing patterns of deltaic deposition within the basin and did not consider the problem of unusual events that interrupted the normal succession. Heckel (1973) undertook the detailed examination of the Tully Limestone, the interpretation of the depositional environments and formulated causes for occurrence of a carbonate bed within a major detrital sequence.

The Tully Limestone is recognized for 100 mi in New York State in outcrops from the Chenango Valley on the east to Canandaigua Lake on the west (Fig. 2). It consists of well-bedded, dense, resistant, gray, fine-grained limestone and calcareous clastics that stand out in marked contrast to the adjacent less-resistant formations. Rarely exceeding 30 ft in thickness, the formation lies disconformably on approximately 1000 ft of the Middle Devonian Hamilton Group dark shales and siltstones. In central New York the boundary is marked by a slight diastem (Heckel, 1973) although in western New York the Hamilton-Tully boundary represents a non-depositional period and eastward the contact is erosional. Conformably overlying the Tully Limestone is the Geneseo Shale of the Genesee Formation. Between the Geneseo black shales, sandstones, and redbeds that

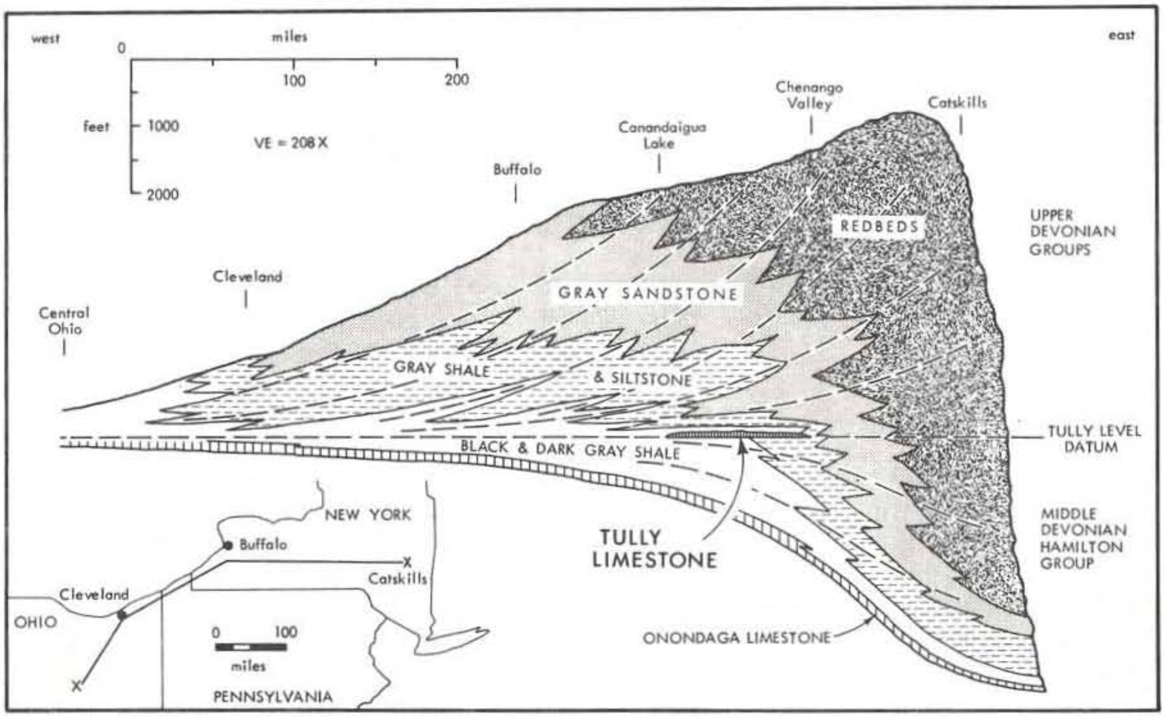

Figure 1. Position of Tully Limestone in cross section of Catskill delta.

exceed several thousand feet in thickness, and the persistent limestone beds of the Tully, occur interbedded limestones and shales from Cayuga Lake to DeRuyter. On the basis of fossil evidence and predominately carbonate lithology, the transitive beds have been assigned a Tully age. The Tully Limestone Formation consists of two members separated by a marked disconformity (Fig. 3). The Lower Member has seven beds of limestone, sandy limestones, and siltstones that are best developed in central New York. Beds of the Lower Member are listed with the dominant lithology in stratigraphic order.

Carpenters Fall Bed	(Limestone)
Vesper Bed	(Silty limestone to thin-bedded siltstone)
Tully Valley Bed	(Limestone to massive calcareous sandstone)
Meeker Hill bed	(Silty limestone to thin-bedded siltstone)
Fabius bed	(Limestone to thick-bedded calcareous siltstone)
Cuyler bed	(Thin-bedded calcareous siltstone)
DeRuyter bed	(Limestone to calcareous sandstone)

Representative sections through these units will be examined in the field trip and are described in Figure 4.

The Upper Member of the Tully Limestone is subdivided into a sequence of six beds. In descending order, these are:

Filmore Glen bed	(Limestone and shale)
Moravia bed	(Limestone)
Bellona coral bed	(Shaly limestone)

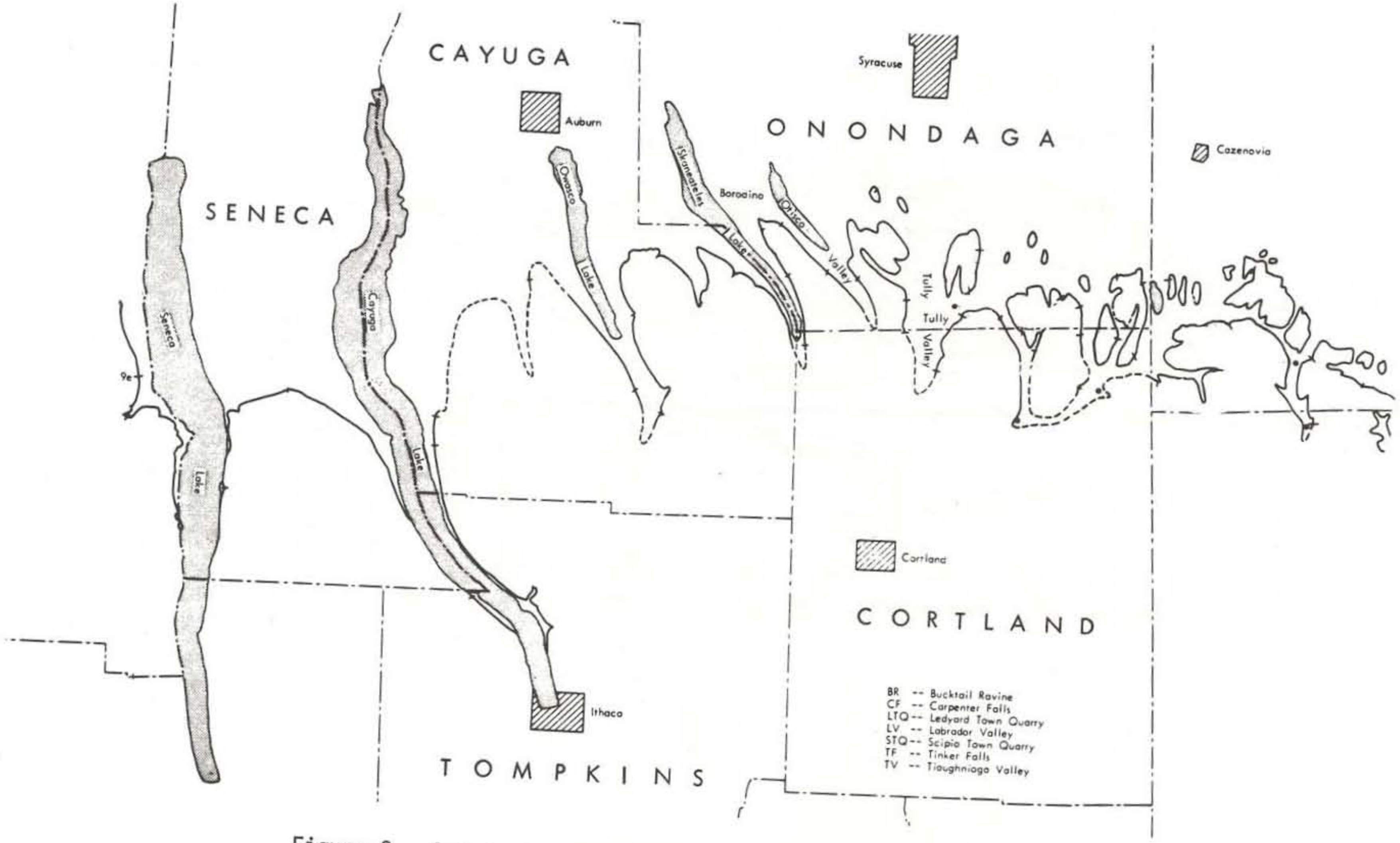

Figure 2. Outcrop map of Tully limestone in central New York.

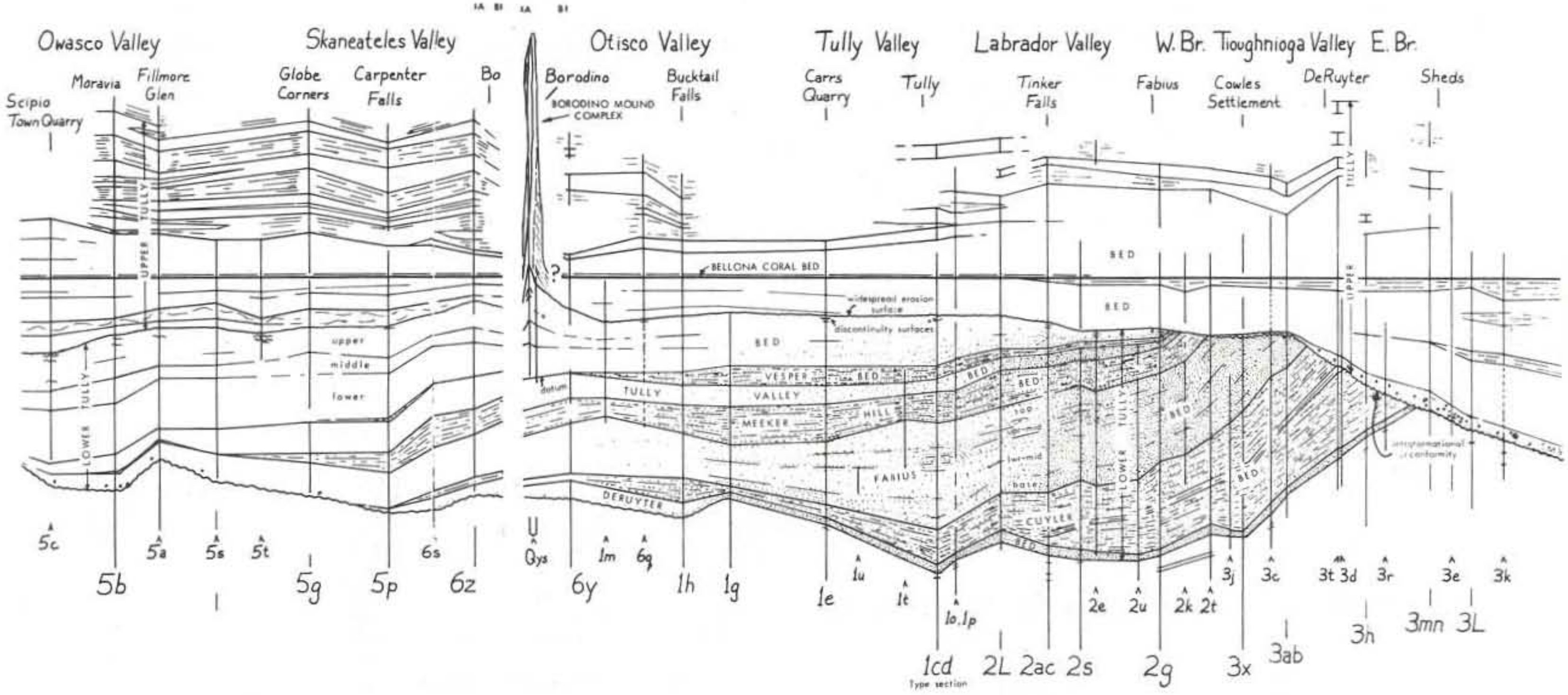

Figure 3. Correlation cross section of Tully Limestone from DeRuyter to Globe Corners.

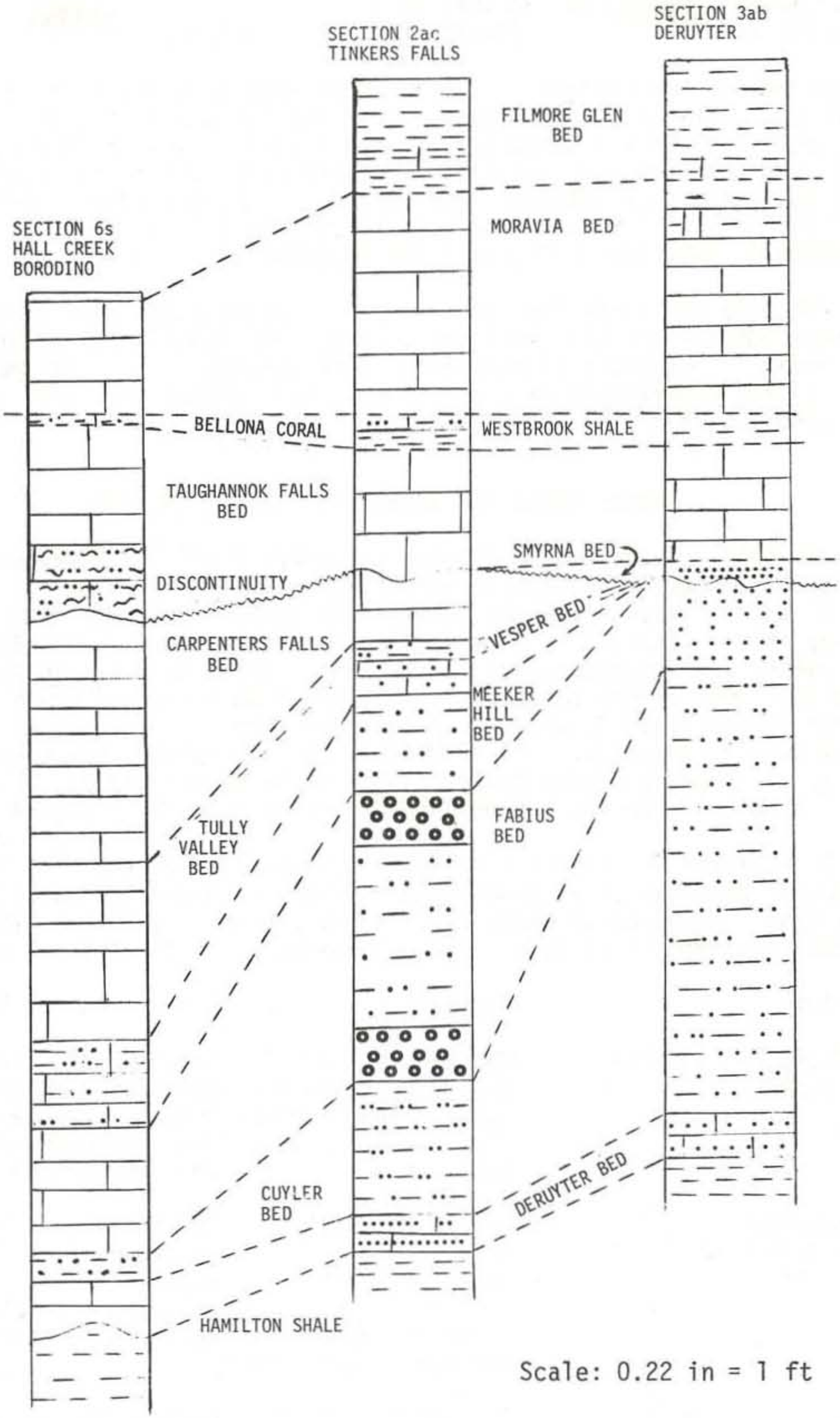

Figure 4. Measured Tully Limestone sections at Borodino, Tinkers Falls and DeRuyter.

Taughannock Falls bed	(Limestone)
Smyrna bed	(Sandy, oolitic limestone)

Separating the two members is a widespread erosion surface, an intraformational unconformity. At the west end of the Tully outcrop, the Taughannock Falls bed rests on the Carpenter Falls bed whereas progressing eastwards the Taughannock rests on successively lower units within the Lower Member until to the east of DeRuyter, the Upper Tully Member lies directly on Hamilton Formation shales. These relationships will be examined at stops 1 through 4, detailed in Figure 4 and Appendix 1.

The only deviation from conformable relationships noted in the Upper or Lower Members, is the development of a thick calcilutite mound complex at Borodino. Southeast of Borodino, the Taughannock Falls and Moravia beds thicken anomalously to 4 or 5 times their normal thickness into massive calcilutite and encrinite units.

FACIES VARIATION WITHIN THE TULLY LIMESTONE

The Tully Limestone, considered by Heckel (1973) to represent a shallow-water carbonate deposit formed during the development of a clastic trap in eastern New York State between the generally coarse deltaic sequences of the Catskill beds, reveals a carbonate facies variation consistent with a terrigenous source to the east. Throughout the Tully Limestone formation, beds in the easternmost sections show a coarser grain size, greater proportions of clastic constituents, and consequent lowering of the carbonate components. To illustrate this variation, three sections will be examined, DeRuyter Quarry [site 3ab in Heckel (1973)], Tinkers Falls (site 2ac), and Hall Creek near Borodino (site 6s) (Fig. 4).

In contrast the fourth site visited in the field trip will represent an unusual exposure of a carbonate mound complex developed outside Borodino (site Qys). Composed of skeletal calcilutites and encrinites, the mound depicts environments of deposition corresponding to the following list.

Facies	Appearance	Environment of Deposition
(1) Mound calcilutite facies	Massive, low content of terrigenous material, stromatactis, tabulate corals dominant	Quiet water, lime-mud deposition similar to Carribean region mud mounds. Local thickening occurred on a topographic high.
(2) Buckmound calcilutite facies	Dark-gray calcilutite with thin shale partings. Contains fine noncarbonate mud and sponge spicules.	Partially restricted marine equivalent to lagoonal conditions with access to normal Tully marine conditions.
(3) Encrinite facies	Consisting primarily of echinoderm fragments, with	Marine environment in which pelmatazoans flourished. Also, abraded

	possible stylolitic contacts and abraded grains in parts.	encinites represents winnowed shoal deposits and unabraded encrinites with mud matrix suggest off-mound conditions.

Heckel (1973) recognized within the Tully Limestone at sites 3ab, 2ac and Qys, both detrital and carbonate facies. Summarizing his published results and incorporating additional field evidence, the following set of facies can be described.

Facies	Appearance	Environment of Deposition
(1) Laminated muddy siltstone	Equal proportions of quartz silt and non-carbonate mud. Thin-bedded and laminated with a restricted brachiopod fauna esp. <u>Chonetes</u> <u>aurora</u>. Lithology is present in the Cuyler bed, Fabius, and east ends of Vesper and Meeker Hill beds.	Represents rapid deposition in a shallow near-shore, perhaps prodelta region, with variable salinity.
(2) Burrowed quartz sandstone	Coarse quartz sand in a carbonate and non-carbonate mud matrix with original lamination obliterated by burrowing. Lithology is present in eastern sections of Fabius, DeRuyter, and Tully Valley beds. Diverse fauna dominated by brachiopods.	A slow accumulation of sediment indicated by thorough burrowing. Normal salinity.
(3) Abraded calcarenite	Abraded, sand-sized, skeletal material forms the Smyrna bed and the eastern Carpenters Falls Bed. A finer grained, glauconitic variety of this facies is the Bellona Coral band.	Slow deposition with winnowing characterizes the facies. Reducing conditions may be prevalent during the Bellona.
(4) Skeletal calcilutite	Lime mud with large grains and with shell lenses. Dense and dark. Three subfacies are noted based on lithology and fauna.	Deposited in a marine environment with an available lime-mud source and low turbulence.

(a)Coral-Stylioline	Shaly laminae impart a wavy, knobbly appearance. Beds in the Moravia, Filmore Glen, and Taughannok Falls all represent this facies. Low faunal diversity. Burrowing.	Shallow-water, marine environment, partially restricted regime.
(b)Brachiopod	Constitutes all Lower Tully calcilutites dominated by brachiopods. Sandy portions prevail in the Fabius, Tully Valley, Lower Carpenter Falls, and DeRuyter whereas nonsandy sections are developed in the Tully Valley, Fabius, and DeRuyter beds particularly in the west. *Emanuella* and *Schuchertella* dominate the nonsandy sections and *Chonetes* in sandy beds.	Quiet water marine environment with diverse brachiopod faunal and well-developed burrowing indicating a low deposition.
(c)Diverse skeletal	Characterized by bryozoans, brachiopods, echinoderms, trilobites, and small corals. Contains shaly laminae, extensive burrows and intraclasts. It comprises parts of the Taughannok Falls and Moravia beds.	Optimum marine conditions for a diverse fauna. Slight wave or current action. Intermittent mud deposition.
(5) Barren shaly calcilutite	High content of noncarbonate mud and low diversity and numbers of fossils. Constitutes the Filmore Glen and Moravia Beds locally. Skeletal material is sparse.	Relatively undisturbed environment with intermittent sources of fine carbonate and detrital muds. Restricted, stagnating waters probably accounted for low fossil content. Deep waters are suggested by absence of agitated sediments.

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Appendix 1. Route Description & Road Log

Start: Heroy Geological Laboratory, Syracuse University, New York

End: Borodino, New York

Total Mileage: 75.8 miles

Total Mileage	Miles from Last Stop	
0.0	0.0	Assemble at Heroy Geology Laboratory. 8:30 AM. Turn R leaving the parking lot and proceed past the security booth down Crouse Drive. At the stoplight proceed directly onto Crouse Avenue. Turn L onto Harrison St. 3 blocks from the stoplight. Turn L at the 3rd stoplight going under the Rt. I81 bridge. Turn right immediately upon executing the L turn and enter the Rt. I81 South entrance ramp (watch the signs)
0.9	0.9	At the stoplight proceed across East Adams St. onto Rt. I81 South. Proceed to Exit 14, Tully.
2.6	1.7	On the R (SSW) observe the view down the Onondaga trough. This is one of a number of U-shaped glacial valleys characteristic of the area south of Syracuse. As glaciers receded a network of troughs and cross channels were established during the Pleistocene Epoch.
4.1	1.5	On the L in this roadcut observe the gently folded, well-fractured limestone strata of the Onondaga Formation. Stratigraphically this formation lies conformably below the Hamilton Formation upon which the Tully Formation disconformably rests.
5.8-6.2	1.7-2.1	Through this roadcut observe the protruding, differentially weathered chert layer in the upper portion of the exposure of this Middle Devonian outcrop.
11.9	5.7	Lafayette Exit. The shale outcrop in view is of the Hamilton Formation.
16.5	4.6	On the R observe the etched Tully moraine terminating this trough. It is part of the Valley Heads moraine system and is associated with kame and kettle topography representing a

Total Mileage	Miles from Last Stop	
		period of stagnation during the retreat of the glaciers in the Wisconsin Glacial Stage of the Pleistocene Epoch. Southward the moraine grades into a pitted outwash plain.
18.2	1.7	Exit 14, Tully; exit from Rt. I81 S. Hamilton shale and siltstones outcrop along the northbound lane. At the end of the exit ramp turn L onto Rt. 11A. At the junction with Rt. NY80 turn L and proceed easterly towards Tully.
18.8	0.6	Off to the R (S) observe the tree lined kettle. Along the rest of the route note the gently to steeply rolling terrain and N-S trending glacially deepened valleys.
---	---	Pass through Apulia Station and Apulia (gas station - opposite land) along Rt. NY80.
26.0	7.2	Fabius
29.8	3.8	Turn R onto W Lake Rd (sign reads only "De Ruyter").
31.5	1.7	De Ruyter Reservoir on L. lower and upper Tully Formation outcrop on R (location 3c, Heckel, 1973).
32.8	1.3	Enter Madison County
34.2	1.4	Enter Cortland County
36.1	1.9	<u>Stop 1</u> Turn R onto Coon Rd. on shoulder and park (W. Lake Rd. has become Highbridge Rd.). The abandoned quarry is located in the postglacial stream valley upstream from Highbridge Rd. (location 3ab Heckel, 1973).
---	---	Continue on Highbridge Rd.
37.3	1.2	Stay R onto Rt. NY 13 and proceed to Truxton
43.6	6.3	Turn R (N) onto Rt. NY 91 in Truxton.
45.8	2.2	Labrador ski slopes
48.6	2.8	<u>Stop 2</u> Pull off onto shoulder or carefully cross the oncoming lane and park in widened shoulder area. Tinker's Falls lies upstream from the road; the stream bed is just N of the

Total Mileage	Miles from Last Stop	
		parking area across Rt. NY91. (Location 2ac Heckel, 1973)
---	---	Continue along Rt. NY91
52.0	3.4	Turn L onto Rt. NY80
56.1	4.1	Junction Rt. NY281
56.2	0.1	Turn L onto Rt. I81 South ramp entrance (Do Not enter Rt. 81, Stay R on Lake Rd.)
57.5	1.3	Stay L
58.9	1.4	Turn L towards Song Mountain
59.0	0.1	Turn R onto Gulf Rd. (sign reads Song Valley - Otisco Rd.)
60.2	1.2	Turn R onto Otisco Valley Rd.
64.7	4.5	Turn L onto Sawmill Rd.
65.3	0.6	Turn R onto W. Valley Rd. The lower and upper Tully members are exposed along the banks of the ravine above the falls seen dead ahead from Sawmill Rd. (Bucktail Falls, location 1h Heckel, 1973).
67.2	1.9	Turn sharply to L and continue up W Valley Rd. Viewing the NE shore of Otisco Lake observe the recut delta deposits where post-glacial streams debauche into the lake.
67.6	.4	Turn R onto Stanton Rd.
68.3	.7	Turn R onto Becker Rd.
70.0	1.7	Stay L
70.1	0.1	Turn L onto an unnamed road
70.4	.3	Turn L onto Rt. 41
70.5	.1	Stop 3 Borodino Mound Complex. (location Qys, Middle Quarry, Heckel, 1973)
73.8	3.3	Turn R onto Woodworth Rd. (no street sign, Pine

Total Mileage	Miles from Last Stop	
		Tree grove on corner
74.3	.5	Stop 4 Intersection with Bacon Rd., park on roadside. This last outcrop is approximately 0.7 miles along Bacon Rd. in the 3rd ravine that is crossed. (location 6s Heckel, 1973)
---	---	Continue along Woodworth Rd.
75.6	1.3	Turn R onto Nunnery Rd.
75.8	0.2	Intersection with Rt. NY41, turn L towards Brordino, Marcellus and Syracuse (approximately 30 minutes to the city boundary).

Syracuse Meltwater Channels

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INTRODUCTION

The channels carved by Pleistocene meltwater through the Syracuse area tell an interesting and complicated story. Their discharge, which rivaled Niagara's, spilled over waterfalls having the plan dimensions of Horseshoe Falls.

Examined in detail, the channels are determined to be products of multiple episodes of cutting, infilling, and reexcavation that collectively span several glacial epochs. The most recent history is complex, because the simple south-to-north activation sequence that has been preferred in the past, turns out to have been impossible. In its place is emerging a new sequence that involves piecemeal flushing of our most spectacular channel, multiple occupation of another, a minor ice readvance in late Pleistocene time, and catastrophic release of water from a large proglacial lake when a 100-ft drift dam failed.

The purpose of this trip will be to view the topographic features which document an ample flow of quantities of meltwater through the Syracuse area in late glacial time. It will focus, however, on the evidence for reinterpretations of the type previously mentioned. Observation will blend into inference, and inference into speculation. However, sufficient opportunities will be available for challenging the more outrageous claims that your leader, in the end, should not get away with too much sleight-of-Hand.

Regional Setting

Syracuse is located along the northern margin of the Appalachian Plateau where this province meets the Ontario Lowland. The Plateau is divided locally into segments by major north-south "through" valleys originally cut by streams flowing southward from somewhere north of the present Plateau margin. When glaciers invaded the region, these "through" valleys provide favorably oriented avenues for thick ice tongues and so became widened, deepened, and modified into U-shaped troughs. During deglaciation the troughs received deposits of till, outwash, lake clays, and delta sediments.

Some 12,000 yrs ago, as the ice withdrew from the Valley Heads Moraine (12 mi south of Syracuse), portions of the "through" valleys were occupied by elongate "finger" lakes. These lakes were filled with meltwater dammed by the Valley Heads Moraine and unable to escape northward because of ice in the Ontario Lowland. Initially, the lakes spilled southward across the moraine and into the Susquehanna drainage system. However, by the time the ice front had retreated to within 5 mi of downtown Syracuse, meltwater collected from much of central New York had begun to escape eastward along the ice margin and into the Mohawk Valley. Onondaga Trough (the "through" valley extending south from Syracuse; see Fig. 1) received substantial meltwater drainage from the west and discharged it, in turn, through any of several cross channels into a second, smaller lake in Jamesville Trough (=Butternut Trough). From there, the flow continued eastward across Moorehouse Flats or through High Bridge (=White Lake) Channel into a third lake in Fayetteville-Manlius Trough (=Limestone Trough).

SEQUENCE OF CHANNEL ACTIVATION

Smoky Hollow

The cross channels through which meltwater drained from Onondaga Trough Lake eastward into Jamesville Trough are shown in Figure 1. Southernmost of these channels is Smoky Hollow, a steep-walled gorge incised 100 ft into Hamilton Shale. A distinctive feature of this particular channel is an ingrown meander loop with neck cutoff isolating an umlaufberg. Inset till deposits show that Smoky Hollow originated prior to the last glaciation, but became filled with till during glacial advance and was subsequently reopened by meltwater drainage during deglaciation. Certain other cross channels (notably Poolsbrook Channel, an outlet for Fayetteville-Manlius Trough) also contain inset till deposits. Indeed most, if not all, of the Syracuse channels are presumed to have had similarly complex histories, although positive proof may be lacking.

When reexcavation of Smoky Hollow began, the surface of Onondaga Trough Lake stood at about 880 ft (Table 1). Flushing of drift from Smoky Hollow entailed a 90-ft drop in the level of Onondaga Trough Lake, bringing it to the present channel floor elevation of 790 ft. Delta gravels at the eastern end of Smoky Hollow resulted from flow into Jamesville Trough Lake, which at that time must have been about a mile wide and a little more than 4 mi long. Elevation of the lake surface was 800 ft, controlled by a spillway across Onondaga Limestone at Moorehouse Flats, 1 mi east of Jamesville.

Clark Reservation Channel

Smoky Hollow was abandoned once the ice margin had retreated to a position just north of Route NY173, and Clark Reservation Channel became active. The approach to Clark Reservation Channel was across a bedrock threshold at 770 ft (scoured clear of drift) and over a double waterfall. The water drop 30 ft over the first step, then plunged 100 ft into a great amphitheater-like basin now occupied by Green Lake, 57-ft deep. The 770-ft sill held the level in Onondaga Trough Lake nearly as high as it had been during the Smoky Hollow stage. However, the lake in Jamesville Trough by now must have dropped 160 ft, bringing it to the 600-ft level. (Otherwise, the main waterfall at the head of Clark Reservation Channel could not have functioned.) This implies that the outlet for Jamesville Trough Lake was no longer across Moorehouse Flats, but through High Bridge Channel (which must have been substantially cleared by then) and into a

Table 1. Proposed summary of major late Pleistocene drainage events, Syracuse area

Elevation of Onondaga Trough Lake (ft)	Drainage phase	Reason for diversion	Elevation of Jamesville Trough Lake (ft)	Outlet from Jamesville Trough Lake	Reason for diversion
1200	Primitive. Drainage southward across Tully loop of Valley Heads Moraine		1250	Southward across Jamesville Trough loop of Valley Heads Moraine	
880 to 790	Smoky Hollow	Ice retreat	760	Moorehouse Flats	Ice retreat
770	Clark Reservation	Ice retreat	600	High Bridge Ch.	Ice retreat
	Rock Cut (I)	Ice retreat	"	"	
760	(a) Trailer park plunge basin				
730	(b) Western plunge basin		"	"	
700	Nottingham Ch. (early)	Ice retreat	"	"	
560	Meadowbrook Ch.	Ice retreat	510(?)	Lyndon Ch. (?)	Ice retreat
700	Nottingham Ch. (late)	Re-advance of ice	600	High Bridge Ch.	Re-advance of ice
Catastrophic drop to 600	Rock Cut (II)	Failure of drift dam in Rock Cut	"	"	
550	Rock Cut (Rams Gulch)	Ice retreat	No lake; Channel drainage at 430	Northward to Lake Iroquois	Ice retreat
420	Erie Canal Ch.		(Dry)		

Unless otherwise noted, water levels reported in this paper are present elevations of spillways. They do not take account of flow depths across spillways, and are not corrected for post-glacial isostatic adjustments.

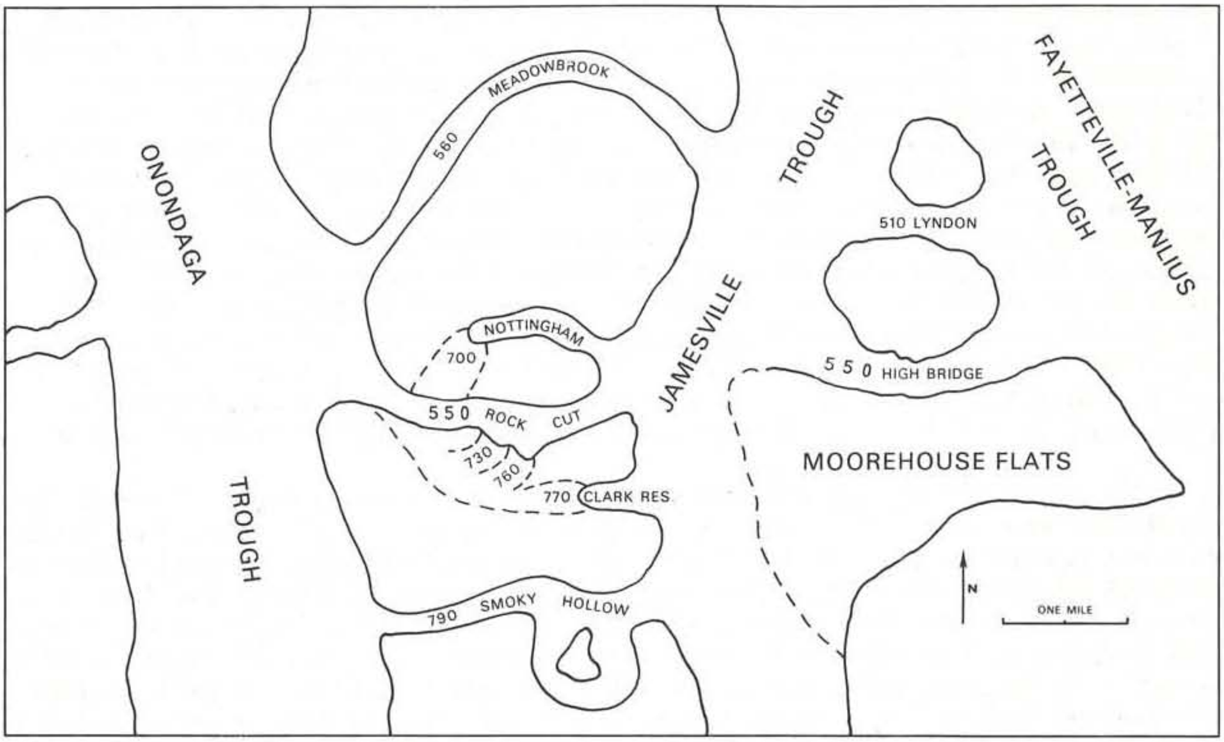

Figure 1. "Through" valleys, cross channels, and threshold elevations between Onondaga Trough and Fayetteville-Manlius Trough. 760 and 730 on south wall of Rock Cut apply to "trailer park" and "western" plunge basins, respectively.

lake in Fayetteville-Manlius Trough. The 600-ft base level seems to have been provided by Poolsbrook Channel (present floor elevation 580 ft) which extends eastward from Fayetteville.

Rock Cut and Nottingham Channels

The next two channels farther north are Rock Cut and Nottingham Channels. It is clear that in their present form they postdate Clark Reservation Channel, but their relationship to one another is more problematic. Free drainage through Rock Cut (threshold at 550 ft) would have precluded later activation of Nottingham Channel which is farther north and accessible only across a sill at 700 ft. On the other hand, assigning Rock Cut a younger age than Nottingham violates the simple, south-to-north activation sequence that has been favored by most previous workers. One tactic has been to ignore Nottingham Channel altogether by assigning it entirely to an earlier interglacial epoch, but this is unacceptable in view of the fresh, well-developed plunge basin which occurs at the head of the channel. Alternatively, Nottingham Channel may have been carved not by through drainage, such as accounted for the other cross channels, but by off-ice or even sub-ice drainage unrelated to the lake in Onondaga Trough. Sissons (1960) has shown that certain of the smaller channelways in the Syracuse area were cut by waters flowing into or off of the ice itself. Such an explanation seems untenable in the present situation, however, because the shape of Nottingham Channel suggests inflow from the south, in size and form it resembers the other channels; the channel below the plunge pool is graded to the same 600-ft level as the Clark Reservation Channel, and the 700-ft access route is underlain by bedrock largely scoured free of till. Locally, the bedrock surface retains remnants of fluvial gravels deposited by the flow as it approached Nottingham Channel from the south.

An alternative interpretation, defended here, was proposed originally by Muller and Hand (1972) and Hand and Muller (1972). It argues that Rock Cut was opened in two stages, that flow through Nottingham Channel occurred between Stages I and II of Rock Cut, and that Stage II (final flushing of Rock Cut) involved catastrophic discharge from Onondaga Trough Lake. How the opening of Meadowbrook Channel fits into this sequence of events (Table 1) will be ignored here, but discussed in a later section. I will presume throughout that all the major channels existed in essentially their present form prior to the last glacial episode, and that what we are concerned with here is principally the history of reexcavation through flushing of drift fill. Of course this is not to deny bedrock scour or waterfall migration during the events that led to the channels' final form, but rather to emphasize that only minor carving of bedrock need have occurred in latest Pleistocene time.

The transition from Clark Reservation Channel to Stage I of Rock Cut was sloppy. Scour features and the absence of till across most of the upland surface between these channels indicate that abandonment of Clark Reservation Channel was gradual, as increasingly the flow was diverted northward, banked against the retreating ice front and shifting northward with it. When the flow "discovered" Rock Cut, it again became channelized, flushing unconsolidated drift fill from the eastern end of Rock Cut, at least to the 600-ft base level which prevailed yet in the Jamesville

Trough. However, it was only the eastern half of Rock Cut that was opened at this time. Rather than following Rock Cut for its entire length, the flow spilled in over the south wall (Fig. 2A). The best evidence for this is a pair of plunge basins incised into the south wall, about midway along Rock Cut. The more easterly of these plunge basins is a beautifully preserved amphitheater now occupied by a trailer park which occasionally is bombarded by blocks of limestone dislodged from the rim. The second plunge basin (immediately to the west) has been disfigured badly by quarrying operations, but its original form can be seen on topographic maps and early air photos. Rock thresholds in the approaches to these two extinct waterfalls are 760 ft and 730 ft, respectively.

Topographic constraints require that when the Rock Cut plunge basins were active, drainage from Onondaga Trough Lake passed for a short distance along the (buried) western end of Rock Cut, but then was deflected south of the gorge before entering by spilling over the south wall (Phase I of Rock Cut). This requires a barrier across Rock Cut about midway along its length. Indeed, for as long as the trailer park plunge basin was active, this barrier must have extended across the site of the second plunge basin (not yet activated). The probable composition of this barrier was drift. One alternative would be ice, but that seems unlikely because a portion of the barrier had to remain in place until after the ice margin had retreated to north of Nottingham Channel. A second alternative would be bedrock. However, this would indicate that the whole western half of Rock Cut (about 1 mi in length) is a first-generation channel. The following considerations argue against such a model:

(1) Inset till deposits along the south wall at the west end of Rock Cut imply that the channel predates the last glacial advance.
(2) The bedrock hypothesis would require nearly a mile of headward channel extension by waterfall migration in less time than it took the ice front to retreat 1000 ft. Such a phenomenal rate of bedrock excavation seems entirely out of line with the behavior of other waterfalls in the area. Taking Niagara Falls as a model, a mile of channel extension would have required about 1700 yrs.
(3) Sudden release of large quantities of water from Onondaga Trough Lake (indicated by other observations) seems more compatible with failure of a drift dam than with through-cutting of bedrock.
(4) Although the delta deposits that resulted from flushing of Rock Cut are composed largely of local bedrock clasts, exotics are also present. (Glacial drift in the Syracuse area is composed principally of clasts derived from local bedrock.)

(Glacial drift in the Syracuse area is composed principally of clasts derived from local bedrock.)

A drumlinoid deposit seems reasonable if only because the locality happens to be on the southern edge of a large field of drumlins.

Many drumlins in the Syracuse area seem to have been localized by bedrock highs. It is interesting in this regard that small bedrock knobs are located on both sides of Rock Cut immediately west of the second plunge basin, and that a chord between them would be nearly aligned with axes of nearby drumlins.

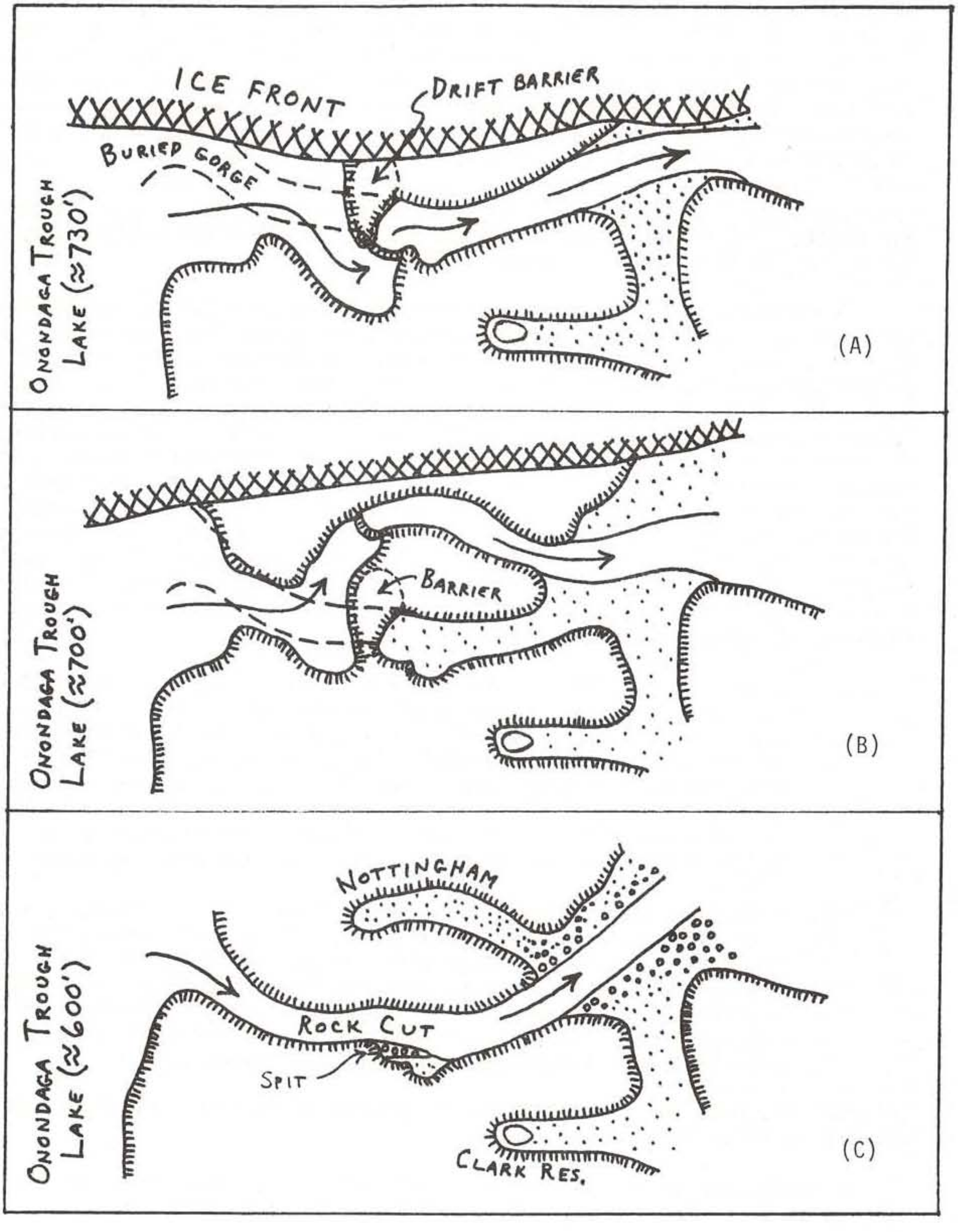

Figure 2. Evolution of drainage routes leading to the (re-)excavation of Rock Cut and Nottingham Channels. (A) Early Rock Cut phase, western plunge basin active. (B) Nottingham phase. (C) Late Rock Cut phase.

Without a barrier in the position described, the point at which the flow entered Rock Cut would have shifted rapidly along the south wall until the channel was clear of drift. This did not happen. Rather, the flow was diverted northward (across the buried western portion of Rock Cut) to Nottingham Channel when that route became free of ice. This diversion gained some 40 ft of vertical advantage and caused abandonment of the plunge basins on the south wall of Rock Cut.

While Nottingham Channel was active (Fig. 2B), the postulated drift barrier must have been extremely vulnerable to headward sapping by gullies fed, in part, by seepage through the barrier. In time, the barrier was breached, releasing catastrophic flow through the entire length of Rock Cut. Initially, this discharge through Rock Cut flowed for 2000 ft over unconsolidated drift with a gradient of 6 or 7 percent. Behind this flow was Onondaga Trough Lake, with an area of 24 sq mi, whose surface fell 100 ft as Rock Cut was flushed. For every foot of downcutting in Rock Cut, another 15,000 acre-ft of reservoir volume was tapped in addition to the normal through drainage. Conditions were right for catastrophic failure, which cleared Rock Cut for its entire length to the 550-ft level (Fig. 2C).

In the terminology of Thorarinsson, a limnic hlaup had occurred.

Depositional evidence for major flow through Rock Cut included a boulder spit (pendant bar) constructed across the two plunge basins on the south wall of Rock Cut. Individual blocks in the spit measure up to 8 ft in length. Where the deposit has been truncated artificially at Cliffside Trailer Park, crossbedding shows that the spit widened by accretion back into the plunge basins while extending itself lengthwise. The top of the spit stands at an elevation of 640 ft, 90 ft above the present bedrock floor of Rock Cut.

At the eastern end of Rock Cut are remnants of a large (1 x 2 mi) delta (expansion bar) consisting of boulder gravels deposited where the catastrophic flow from Rock Cut expanded into the northern end of Jamesville Trough (Fig. 3). A portion of this delta forms a levee-like closure across the eastern end of Nottingham Channel. Thrivikramaji (1977) has shown that as this deposited is traced into Nottingham Channel (which at the time must have been a backwater area) it grades from boulder gravels to sand.

Boulders in the Rock Cut delta usually are 1 to 3 ft in length. Many of the largest clasts (exceeding 6 ft in length) were swept entirely across Jamesville Trough to the most distal (and highest) part of the delta. Some examples will be seen displayed as ornaments in the front yard of homes along Cedar Heights Drive.

The eastern margin of the Rock Cut delta is thought to be the original depositional slip face. Excavations west of Maple Drive (just north of Woodchuck Hill Road) have revealed angle-of-repose, delta-front crossbeds immediately beneath (and parallel to) the present face. At this locality, most of the material composing the deposit is pebble gravel, but a basal layer rich in very large boulders is present. This basal layer, whose clasts resemble the large boulders seen on top of the delta, is interpreted as having formed from over-large fragments which were swept to the lip of the delta and then rolled to the bottom of the slip face.

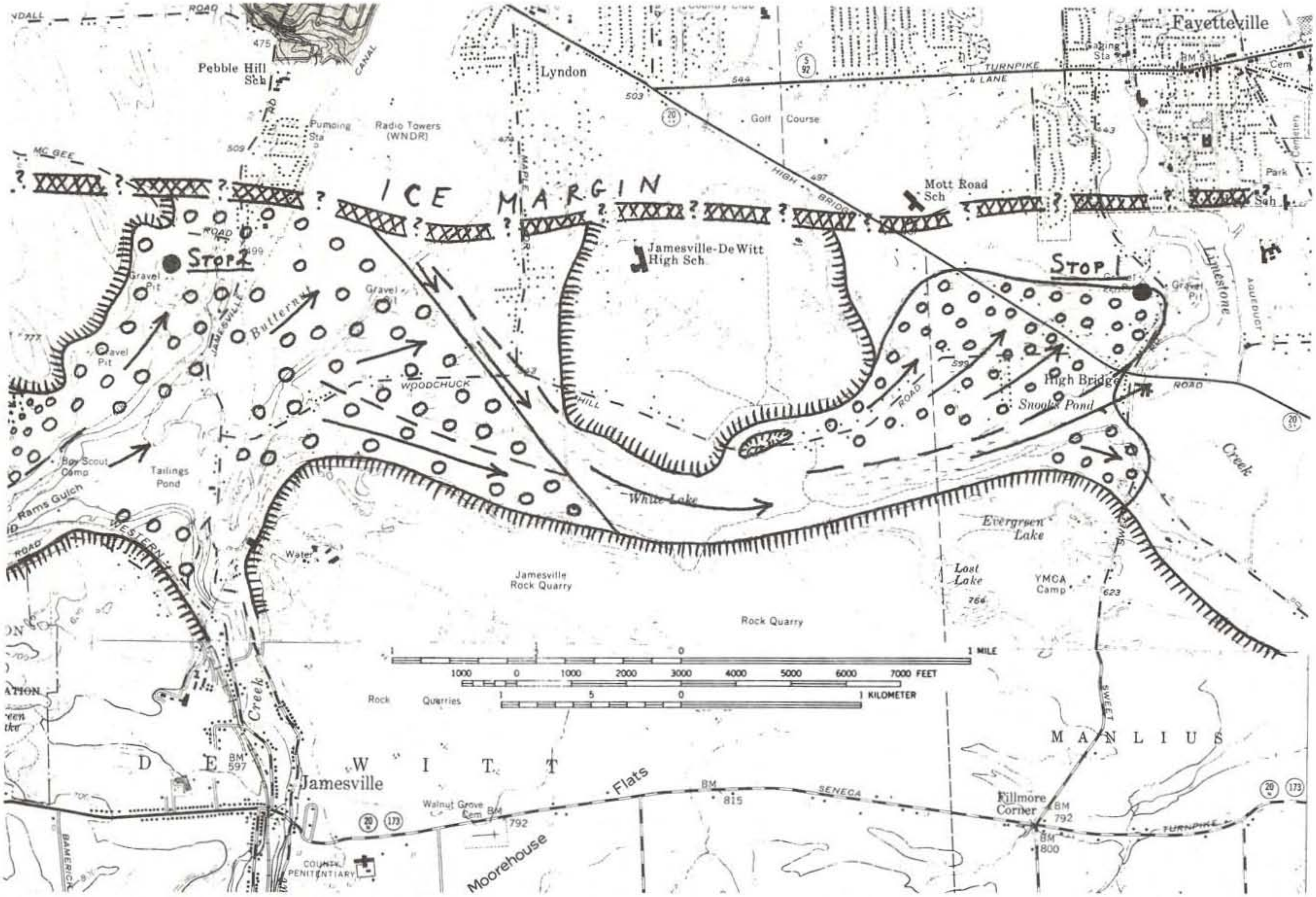

Figure 3. Rock Cut Channel and Delta during period of catastrophic discharge (Stage II of Rock Cut drainage).

Immediately east (in front of) of the delta deposits just described, limestone bedrock has been scoured bare. This is attributed to intense vorticity related to flow separation and reattachment in the lee of the delta. Indeed, it may be that helical flow confined between the advancing delta front and highlands east of Jamesville Trough ultimately limited forward growth of the deposit.

After discharging as a planar jet across the lip of Rock Cut delta, the flow was redirected southeastward parallel to the delta margin, following a southeasterly expanding scourway into High Bridge Channel. By this route, the flow traveled from Jamesville Trough to a lake in Fayetteville-Manlius Trough, where it built High Bridge Delta, another expansion bar similar in most repsects to Rock Cut Delta (Fig. 4). The deposits of High Bridge Delta will be seen in a gravel pit. Except for minor erosion by Limestone Creek, the morphology of High Bridge Delta is interpreted as primary. The deposit is divided into two unequal parts by a channelway 1000 ft wide and 70 ft deep which seemingly carried most of the discharge in the brief period during which the delta was constructed. The delta and scour levels near 600 ft elevation were adjusted to the same flow that deepened the floors of Rock Cut and High Bridge Channels to 550 and 530 ft, respectively, implying water depths of 70 to 80 ft in the more restricted portions. Such flow could have been sustained only by catastrophic release of water from Onondaga Trough Lake, an event whose duration probably was measured in hours.

Meadowbook Channel

The threshold of Meadowbrook Channel stands at 560 ft. Although this is higher by about 10 ft than the floor of Rock Cut, it would not necessarily preclude simultaneous occupation of both channels, provided both channels had achieved their present form. However, the level floor and uniform width of Meadowbrook Channel, and truncation of drumlins by the north wall, suggest that some indeterminate thickness of till has been removed from Meadowbrook by cross channel flow. If so, then flow through Meadowbrook must have been initiated across a higher threshold than exists today. It follows that Rock Cut could not have been fully open when Meadowbrook (farther north) became active. In other words, Meadowbrook must predate clearing of the west end of Rock Cut (Rock Cut Phase II), although it almost certainly followed Phase I of Rock Cut (south wall plunge basins) and probably the Nottingham phase.

However, if we accept the constraint that flushing of Meadowbrook Channel must predate Stage II of Rock Cut drainage, it seems equally clear that the catastrophic flushing of the western end of Rock Cut (initiating Phase II) could not have been forced so long as Meadowbrook was open. This combination of requirements in fact seems impossible to satisfy without invoking a minor readvance of ice. With readvance, however, it becomes possible to view the Meadowbrook drainage phase as a brief interruption in the sequence of events described in the previous section as leading to catastrophic flushing of Rock Cut. In this scenario, ice retreat led to the succession: Rock Cut I, Nottingham, Meadowbrook. Readvance (probably expressed as tongues of ice advancing down Onondaga Trough and other

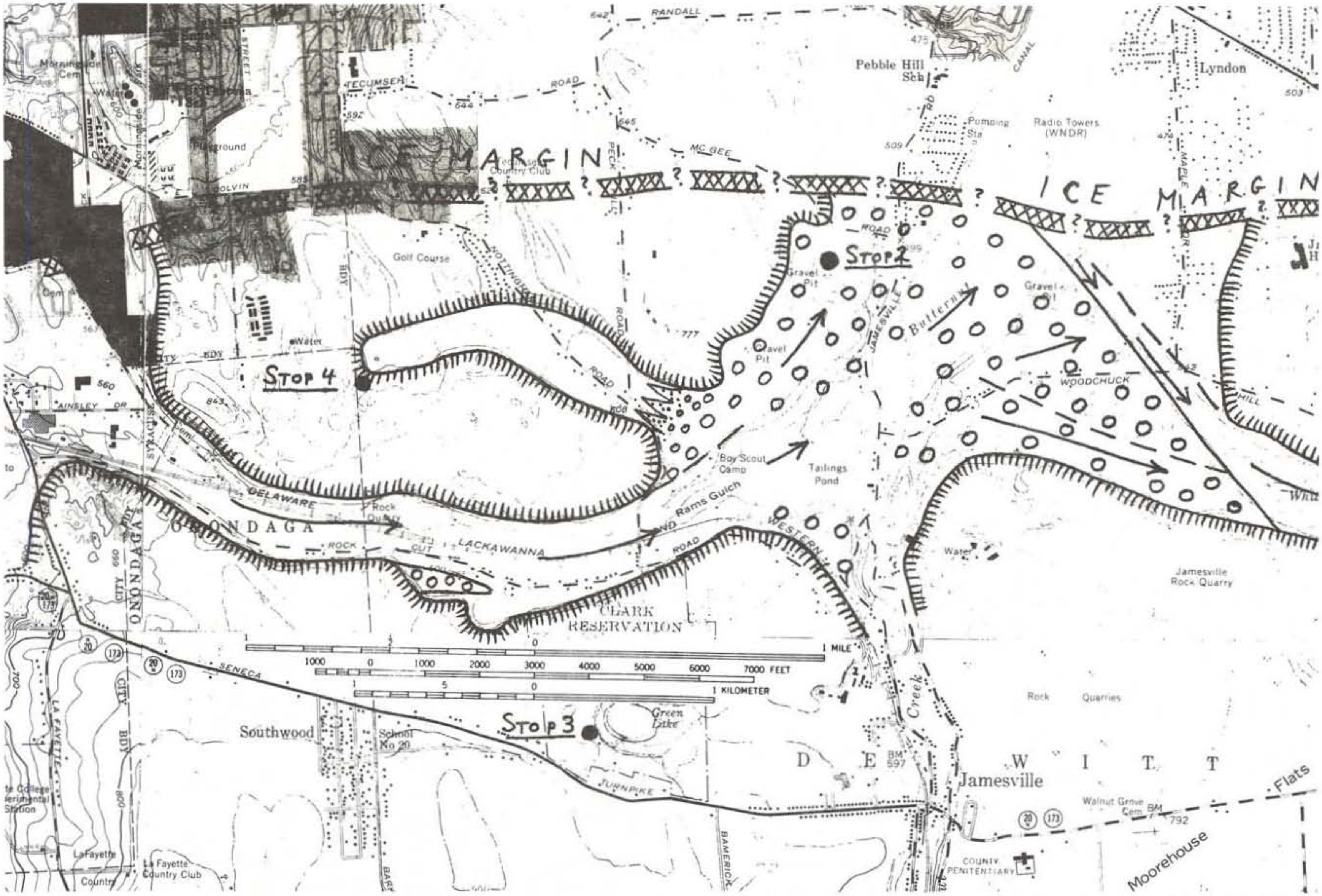

Figure 4. Rock Cut Delta, High Bridge Channel, and High Bridge Delta during period of catastrophic discharge (Stage II of Rock Cut drainage).

"through" valleys) then closed off access to Meadowbrook and forced reoccupation of Nottingham Channel until failure of the drift dam initiated Phase II of Rock Cut drainage.

Evidence of such readvance was uncovered recently in highway excavations at the west end of Rock Cut. There, varved lake clays (representing perhaps 100 yrs) directly overlie bedrock and the clays in turn are overlain by till or flowtill. The locality would have been directly in line with the approach to Meadowbrook Channel, so absence of till beneath the lake clays might well be attributable to scouring by the discharge from Onondaga Trough Lake as it approached Meadowbrook. (Indeed, such scour could have removed a significant amount of the drift plug that still clogged the west end of Rock Cut.) When access to Meadowbrook had become blocked fully by the advancing ice, Onondaga Trough Lake rose again to the 700-ft level and lake clays (containing dropstones) accumulated where scour had previously occurred. Presence of flowtill and till(?) above the clays indicates that the ice tongue ultimately extended at least as far as Rock Cut.

PALEOHYDRAULICS

Normal Discharge

Most, if not all of the Syracuse cross channels have been carved into bedrock by headward-migrating waterfalls. And most, if not all, have achieved their present form through repeated episodes of bedrock cutting alternating with glacial infilling and reexcavation. Their histories span several periods of glaciation and deglaciation, each perhaps with minor advances and retreats superimposed. Even within a single glacial cycle, conditions must have varied considerably. Estimating "the" normal discharge would be hazardous under the best of circumstances, but here we have the further complication that no one value can possibly reflect the actual range of conditions.

Nevertheless, the Syracuse channels are large and surprisingly uniform in character. They occur in a region where the stratigraphy is tailor-made for waterfall migration by continuous undercutting of massive capping units, reminiscent of the situation at Niagara Falls. Compared with Niagara Gorge, the Syracuse channels are only about half as deep (typically 100 ft, vs. 250 ft), but this is more a function of local baselevel controls, regional topography and details of stratigraphy than a reflection of discharge. Impressive is the fact that channel floor widths are comparable with the bottom width of Niagara Gorge (1200 ft for Rock Cut; 600-1000 ft for Niagara). Perhaps even more significant is the fact that the numerous abandoned plunge basins in the Syracuse area are nearly identical, in both shape and size, to Horseshoe Falls, which carries 90 percent of Niagara's discharge.

These observations suggest that the "normal" cross channel discharge through Syracuse rivaled that of the Niagara River at 200,000 cu ft per sec. Impressive as this may be, it can hardly account for the extremely coarse delta deposits at the east end of Rock Cut or the pendant bar composed of giant boulders 90 feet above the floor of Rock Cut. These features seem far better explained by appealing to a brief episode of catastrophic flow.

Catastrophic Discharge

Reference to Figure 2B shows that during the Nottingham phase of flow, all that prevented a 100-ft drop in lake level in Onondaga Trough was a drift barrier in Rock Cut no wider than a few hundred feet. Eventual failure of this drift barrier suddenly released some 60 billion cu ft of water through Rock Cut which swept out the remaining drift fill to bedrock at 550 ft. Dimensions of the cross channels that carried this flow (Rock Cut and High Bridge Channels) and their deltas require flow cross sections 1200-ft wide by 60 to 70-ft deep.

Upper limits can be placed on the Rock Cut flood by assuming instantaneous and complete failure of the drift dam. Although instantaneous failure is obviously impossible, the model may be approximately true viewed against the time scale of flood duration. Regardless, the assumption is useful for two reasons: (1) it greatly simplifies calculation of flood dynamics, and (2) it gives maximum values for velocity, discharge, water depth, etc., which could not have been exceeded without violating physical laws. In the end, these limiting values will be compared with flow conditions independently determined to have been required to transport the materials that were moved.

Simulation of flood dynamics presumed that Rock Cut and High Bridge Channels functioned as Venturi flumes connecting Onondaga Trough Lake, Jamesville Trough Lake, and Fayetteville-Manlius Lake (Fig. 5). Initially, the lakes in Jamesville and Fayetteville-Manlius Troughs stood at 600 ft, 100 ft below the level of Onondaga Trough Lake (700 ft). If the drift dam suddenly fails and the channels immediately assume their final geometries, the problem reduces to the draining of three interconnected bathtubs. In the model, water was assumed to escape freely from the easternmost of the three lakes (Fayetteville-Manlius), thereby maintaining its level at 600 ft. However, the lake in Jamesville Trough was allowed to rise or fall depending on the difference between inflow from Rock Cut and outflow through High Bridge Channel, taking account of the surface area of the lake at any particular stage. Meanwhile, the lake in Onondaga Trough fell at a rate that depended on its surface area, inflow from the west (the normal through drainage), and outflow through Rock Cut as estimated from available potential head and cross section of flow.

Figure 5 shows diagrammatically that either of two flow situations could have existed in a cross channel at a particular moment. When the difference in elevation between the two lakes ($H_1 - H_2$) is greater than $H_1/3$ (Fig. 5A), the second lake might as well be a free overfall. (Note that heads are measured relative to the floor of the interconnecting channel.) The cross channel under these circumstances functions as a broad-crested wier, in which water depth adjusts to 2/3 of H_1 and velocity head becomes 1/3 of H_1. Flow velocity U then can be calculated:

$$U = \sqrt{\frac{2gH_1}{3}}$$

When the two lakes differ in elevation by less than $H_1/3$ (Fig. 5B), the second lake provides a tailwater effect and potential energy available

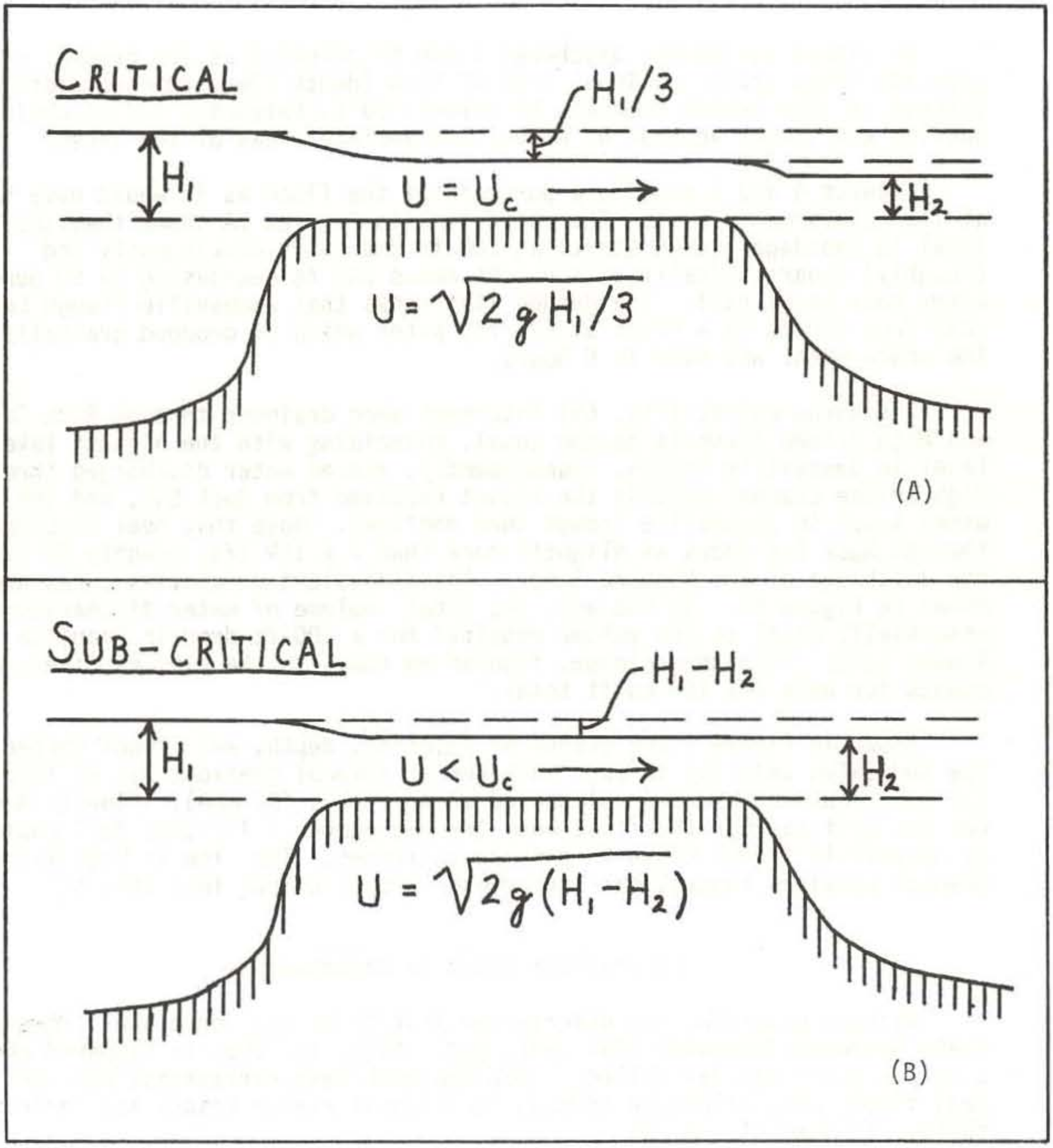

Figure 5. Alternative flow conditions for channel connecting two standing bodies of water. Channel is assumed to function as a venturi flume (broad-crested wier). A. Critical flow prevails when $H_2 \leq H_1/3$, B. Subcritical flow prevails when $H_2 > H_1/3$.

for conversion to velocity is $H_1 - H_2$:

$$U = \sqrt{2g (H_1 - H_2)}$$

In either situation, discharge Q can be computed as the product of velocity times cross-sectional area of flow (depth times channel width). Changes in lake levels then can be calculated by balancing inflow against outflow and taking account of prevailing surface areas of the lakes.

Figures 6 and 7 provide a portrait of the flood as it would have been at its catastrophic best. The solid line in Figures 6A shows that the lake level in Onondaga Trough starts at 700 ft and falls continuously and (roughly) logarithmically, its height above 600 ft decreasing by 50 percent every hour and a half. The dashed line shows that Jamesville Trough Lake rose from 600 ft to a crest at 625 ft, after which it dropped gradually. The whole event was over in 6 hours.

Discharge curves (Fig. 6B) intersect when drainage through Rock Cut and High Bridge Channels become equal, coinciding with the highest lake level in Jamesville Trough. Subsequently, stored water discharged through High Bridge Channel exceeds the amount received from Rock Cut, and the water level in Jamesville Trough then declines. Note that peak discharge through Rock Cut shows as slightly more than 7×10^6 cfs, roughly 35 times the discharge of the Niagara River. The equivalent cumulative cures are shown in Figure 6C. In the end, the total volume of water discharged is essentially equal to the volume required for a 100-ft drop in Onondaga Trough Lake. Through drainage, figured as equal to the Niagara River, accounts for only 4×10^9 cu ft total.

Shown in Figure 7 are graphs of velocity, depth, and Froude number. The indicated velocity through Rock Cut at time of breakout was 57 ft/sec (39 mph). White Lake Channel peaked at 40 ft/sec (27 mph). Flow in Rock Cut was critical for the first hour (Froude number = 1), then fell rapidly as Jamesville Trough began to provide tailwater. The flow in High Bridge Channel remained subcritical throughout (Froude number less than 1).

Calculations Based on Competency

Without question, the description just given is over-blown. However, field evidence indicates that there was a flood and that it happened when a narrow drift barrier failed. But how much less extravagant was the real flood, once allowance is made for natural energy losses and noninstantaneous failure of the dam.

The 6-ft boulders that occur on the highest and most distal parts of the Rock Cut delta were swept into position after climbing an adverse slope leading up from the floor of Rock Cut. Geometries of this deposit and High Bridge Delta require that while the deltas were being built, flow through the cross channels was at least 60 to 70 ft deep.

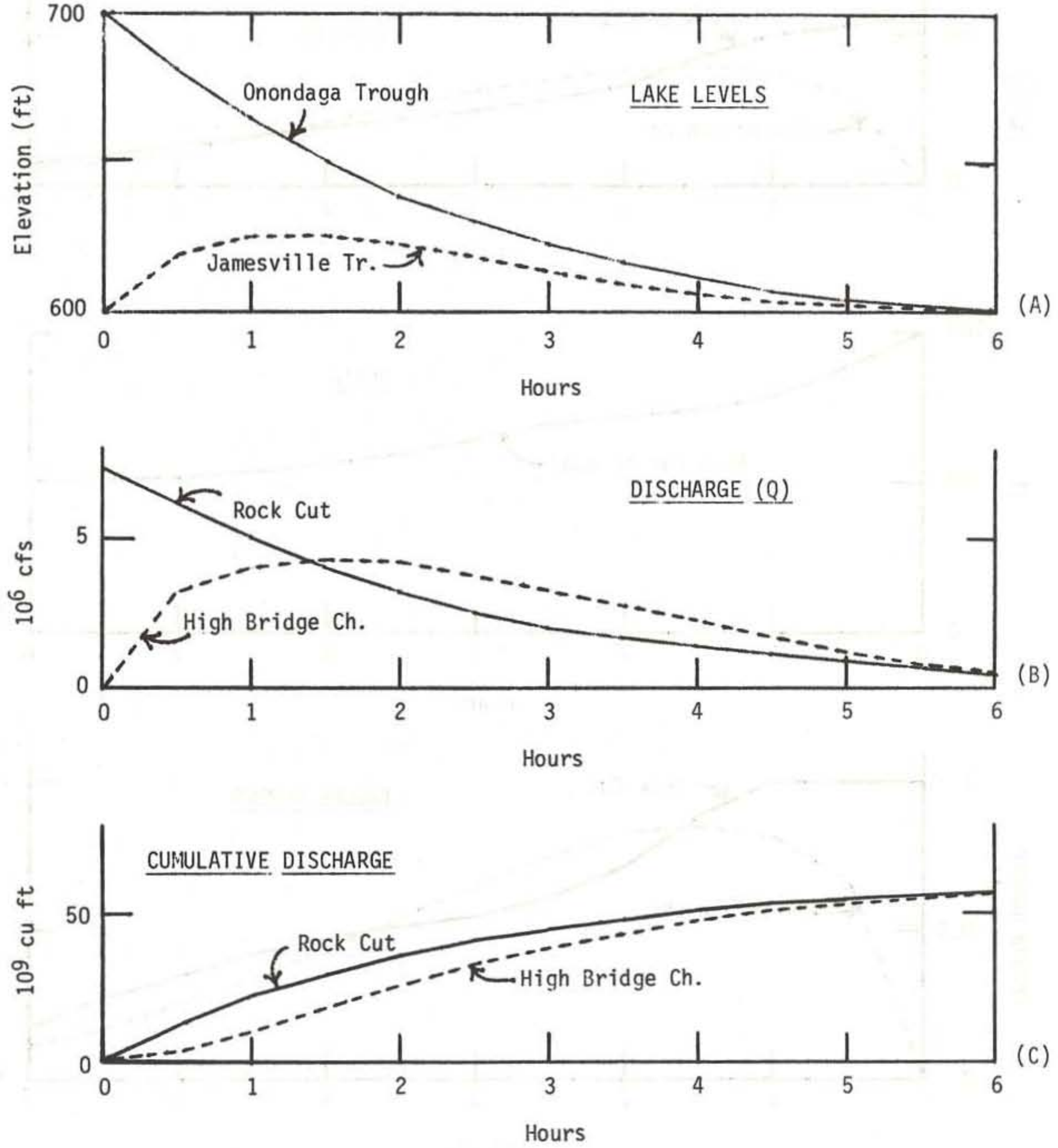

Figure 6. Lake levels, discharge rates, and cumulative discharge computed for Rock Cut flood, assuming instantaneous failure of drift dam, present geometry of cross channels, and zero flow resistance.

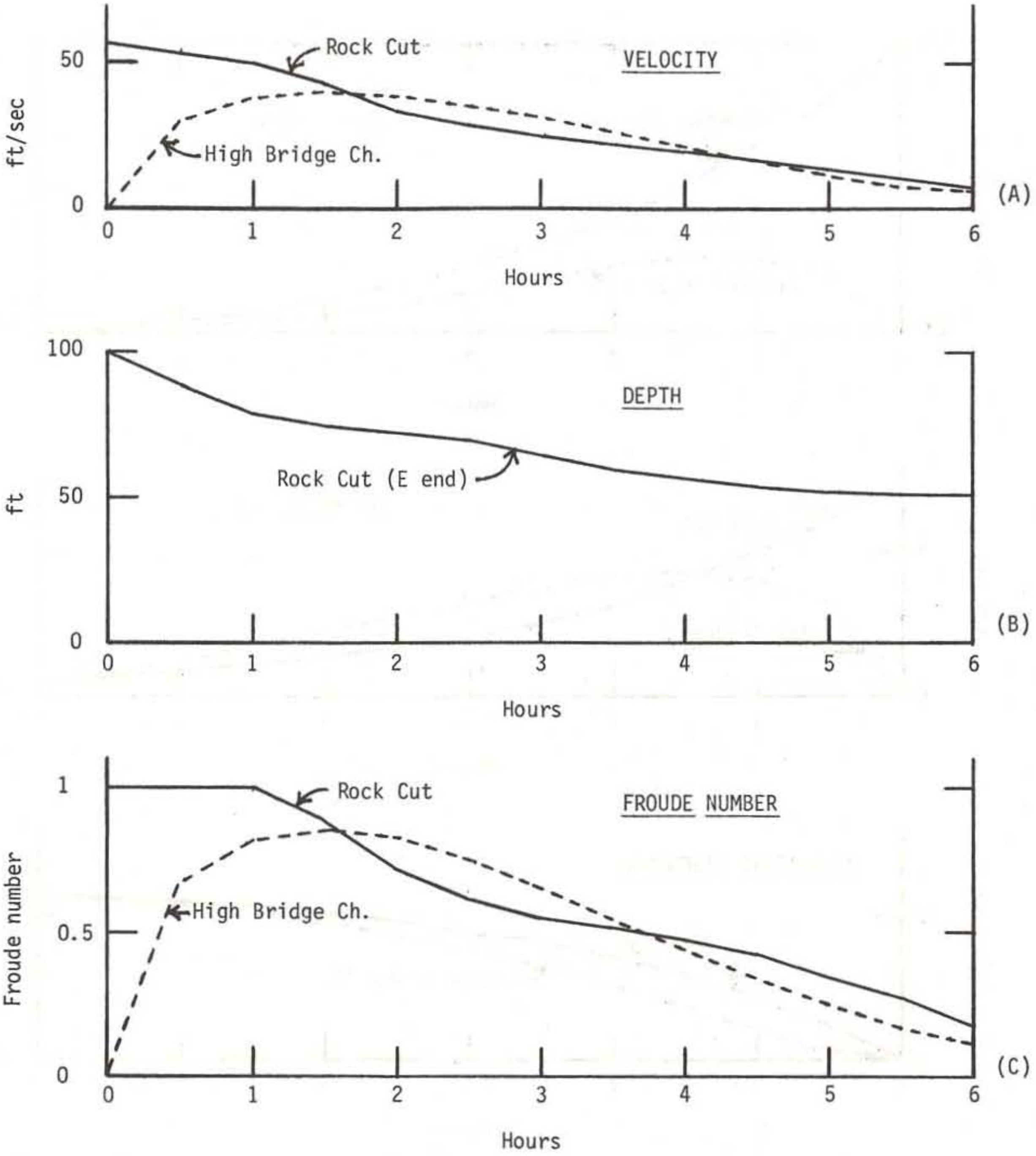

Figure 7. Velocity, depth, and Froude number computed for Rock Cut flood, assuming instantaneous failure of drift dam, present geometry of cross channels, and zero flow resistance.

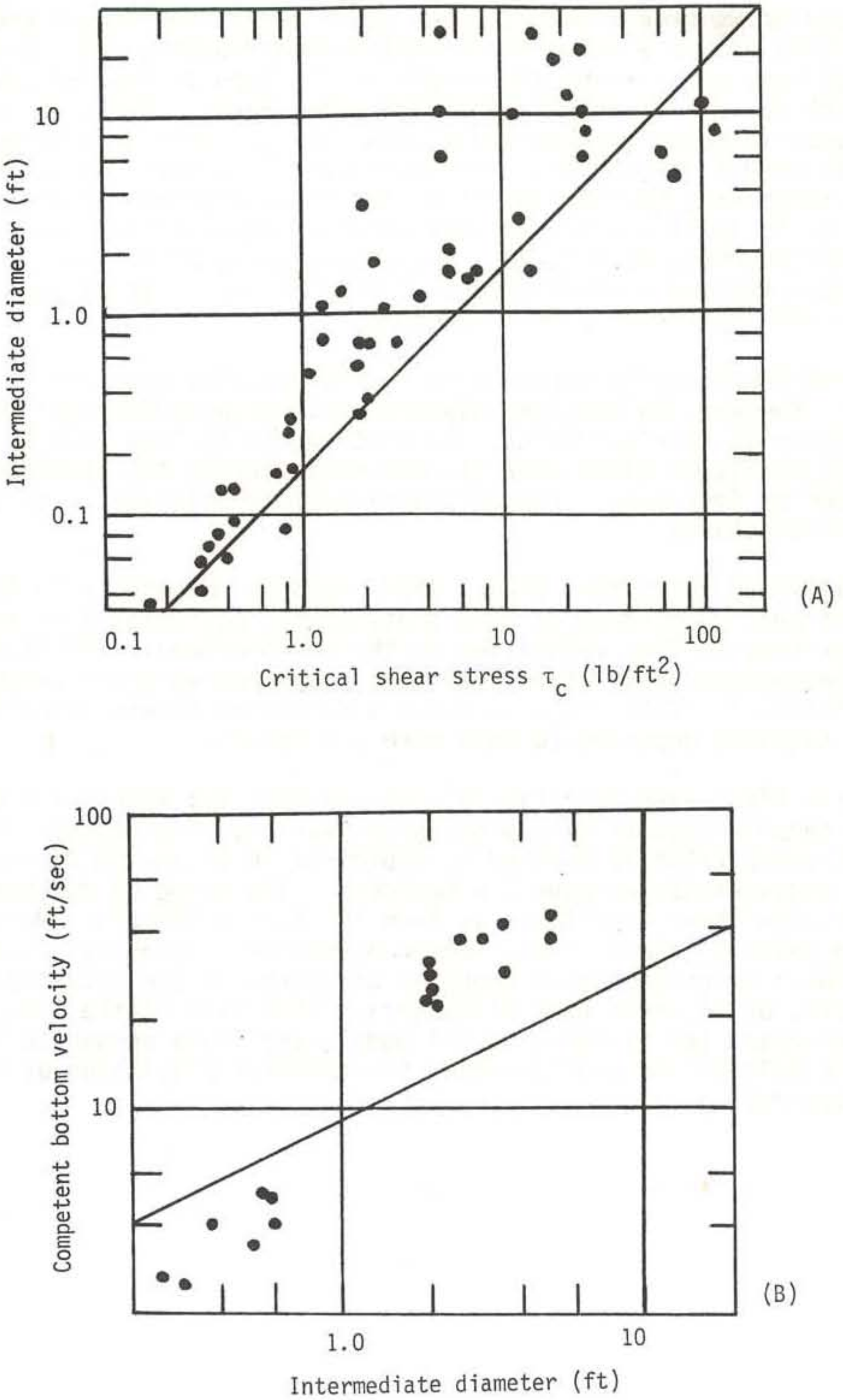

Figure 8. Conditions required to transport quartz-density particles in water. Data from multiple sources. After Baker (1973). A. Particle diameter vs. critical tractive force. Solid line is Shields equation. B. Relation between near-bottom velocity and particle size.

Because we have information on water depth and channel width, it is possible to assume a value for effective bed roughness and to compute bed shear stress, τ_0, for any discharge, Q. It then is feasible to use a diagram such as Figure 8A (modified after Baker, 1973), which relates competency (largest transported clasts) to τ_0. Because intermediate diameter is used in this plot, our requirement is for 3-ft boulders. Figure 8A shows that boulders of this size require shear stresses ranging from 2 to 20 lb/ft^2, with a middle value of about 6 lb/ft^2. Taking effective bed roughness as 1 ft (0.3 m), discharge equal to that of Niagara would have exerted a shear stress of 0.04 lb per sq ft of bed, or enough to move sand particles 2 mm in diameter.

Competency can be improved by decreasing flow depth for a given discharge. However, by the time Niagara could move boulders of the size which occur in Rock Cut Delta, its depth would be less than 10 ft and it would be unable to climb over its own delta (whose top stands 50 ft above the floor of Rock Cut). The only satisfactory solution is to dramatically increase discharge.

Figure 8B (also from Baker, 1973) relates competency to flow velocity near the bed. According to this plot, particles having 3-ft intermediate diameter require flow velocities in the neighborhood of 40 ft/sec. (Recall that the computer simulation predicted a maximum velocity through Rock Cut of 57 ft/sec.). Velocity of Niagara's discharge flowing through Rock Cut at the required depth would have been 2.4 ft/sec.

As a final exercise (Fig. 9), we can plot for Rock Cut a diagram relating shear stress to discharge, given various flow depths. The shaded area at upper right is bounded by depths of 60 ft and 90 ft and by shear stress requirements to move 1-m boulders. The range of discharges compatible with these conditions is from 1.3 to 6 x 10^6 cfs. Moreover, an average value of shear stress (based on center of gravity of published data) would correspond to a probable discharge in our situation of about 3 x 10^6 cfs, or 15 times that of Niagara. This is a little less than half what was predicted by the original model, and close enough to it (in the writer's opinion) to justify using the computer simulation as a guide to what occurred.

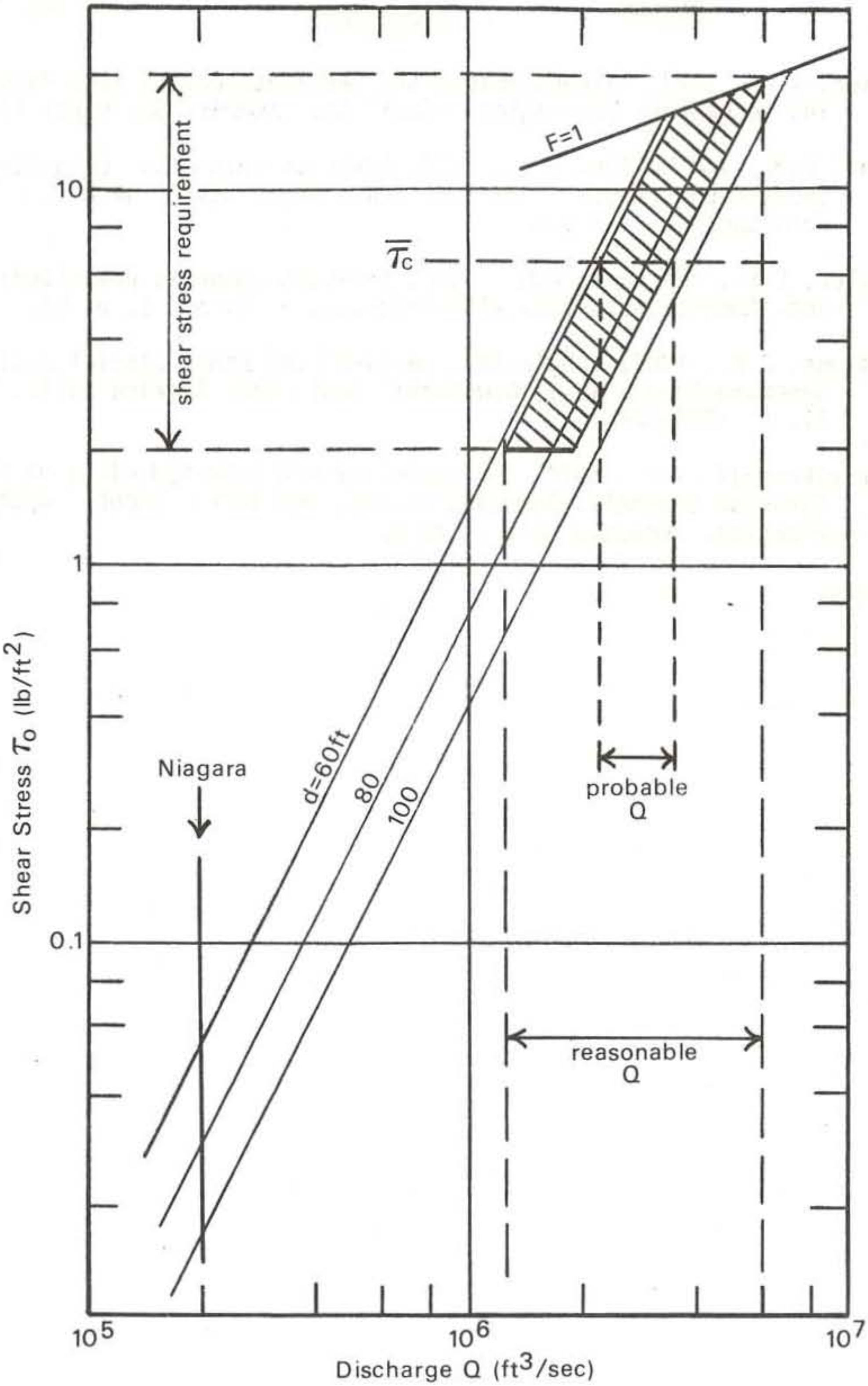

Figure 9. Bed shear stress vs. discharge for water depths d = 60, 80 and 100 ft, through channel having dimensions of Rock Cut and roughness elements of 1 ft. Shaded area is for Rock Cut at time of catastrophic flow.

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Road Log

Note: The field trip passes across the following USGS 7 1/2 minute quadrangles:

Syracuse West
South Onondaga
Jamesville
Syracuse East

Total Mileage	Miles from Last Stop	Route Description
0.0	0.0	Leave Manley Field House (intersection of Comstock Ave. and Colvin St.), heading south on Comstock
0.6	0.6	Turn half-right onto Jamesville Ave.
0.9	0.3	Turn right onto Ainsley Drive. At T-intersection with Brighton Ave., view ahead (west) looks across northern end of Onondaga Trough. Downtown Syracuse is two miles to the right, at the north end of Onondaga Trough.
1.6	0.7	Turn left onto Brighton Ave. Intersection is at west end of Rock Cut cross channel. Elevation of channel floor (road level) is 550 ft Floor of Onondaga Trough is at about 400 ft, so depth of Onondaga Trough Lake was 150 ft when this threshold controlled. Approach to Meadowbrook Channel also was through this area. Highway excavations on left briefly exposed the following sequence: till flowtill varved lake clays (about 100 yrs; upper part contorted by ice thrusting) bedrock (Bertie Formation) Interpretation: Bedrock was cleared of drift by drainage from Onondaga Trough Lake when Meadowbrook Channel was active. (Western end of Rock Cut was still drift-filled.) Readvance of ice blocked Meadowbrook outlet, raising level of Onondaga Trough Lake from 550 ft to 700 ft, reactivating Nottingham Channel. Lake clays were deposited in this interval. Upward increase in dropstones indicates approach of ice front. Ice over-ride then contorted upper part of clay and deposited flowtill and till. This minor re-advance is thought to have been limited to tongues of ice extending southward into "through" valleys.

Total Mileage	Miles from last stop	Route Description
2.1	0.5	Turn half-right onto Lafayette Rd.
3.4	1.3	Smoky Hollow Channel on left.
3.6	0.2	Turn half-right on Graham Rd.
4.0	0.4	Spectacular view of Onondaga Trough. We are approximately on the shoreline for the lake as it would have been during the Smoky Hollow Stage. The lake was 2 mi wide, 350 ft deep, and extended to the Tully Loop of the Valley Heads Moraine, 13 mi south.
4.3	0.3	Turn left on Sentinel Heights Rd.
4.6	0.3	Turn left on Dave Tilden Rd.
5.1	0.5	Turn right on Lafayette Rd.
6.3	1.2	Turn left on Brevity Lane
6.4	0.1	Turn left on Barker Hill Rd, heading north.
6.8	0.4	Cut-off meander loop of Smoky Hollow Channel is on right. Loop surrounds an umlaufberg. 3 mi to the east can be seen the east side of Jamesville Trough, and beyond it (about 8 mi away) the far (east) wall of Fayetteville-Manlius Trough.
7.0	0.2	Begin descent into Smoky Hollow.
7.3	0.3	Turn right onto Smoky Hollow Road. This road follows the main Smoky Hollow Channel.
7.4	0.1	Loop channel on right.
7.7	0.3	Umlaufberg on right.
7.9	0.2	Loop channel returns from right.
8.5	0.6	Continue on Smoky Hollow Road, half-left across intersection.
8.8	0.3	Turn right (south) on Apulia Rd.
9.7	0.9	Jamesville Reservoir (artificial lake) on left.
10.5	0.8	View (southward) of Jamesville Trough.

Total Mileage	Miles from last stop	Route Description
11.4	0.9	Turn left onto Smith Rd (unmarked).
12.2	0.8	Turn left onto Ransom Rd (unmarked).
12.9	0.7	Turn left on NY91. Excellent view of Jamesville Trough.
13.8	0.9	Turn right on Taylor Rd.
14.1	0.3	Stay left at Y.
14.5	0.4	Crossing southernmost scourway of Moorehouse Flats.
15.2	0.7	Moorehouse Flats for next 0.4 mi. Discharge from Jamesville Trough Lake swept eastward (to right) across this threshold on Onondaga Limestone during the Smoky Hollow Stage.
15.6	0.4	Turn right (east) on NY173. Artificial barrier on left partially hides Jamesville quarry of Allied Chemical Corp, which extends for 1.5 miles along the route. Quarry is in Onondaga and Manlius Formations.
17.7	2.1	Turn left on Sweet Rd.
18.6	0.9	Crossing axis of High Bridge Channel (left) where it enters Fayetteville-Manlius Trough (right).
19.1	0.5	Half-left, continuing on Sweet Rd.
19.4	0.3	Underpass.
19.8	0.4	Turn left into gravel pit operated by Jake Hullar.
19.9	0.1	STOP 1. High Bridge Delta, an expansion bar built where White Lake Channel entered Fayetteville-Manlius Lake. At least the final shaping is attributed to catastrophic discharge which occurred when a 100 ft drift dam failed in Rock Cut Channel. Observe large-scale cross-stratification, clast size (mostly sand and pebble gravel, with larger clasts to 6 ft or more), and clast lithology (dominantly carbonate, but some exotics). Till occurs immediately below a cemented gravel zone in the deeper parts of the quarry.

Total Mileage	Miles from last stop	Route Description
20.0	0.1	Leave quarry, turning right (south) on Sweet Rd.
20.3	0.3	Turn right on unmarked road immediately before underpass. Climb delta face. Main channel on left.
20.6	0.3	Cross High Bridge Rd, continuing on Woodchuck Hill Rd. Road is on top of High Bridge delta (expansion bar), elevation 600 ft. Floor of channel (on left, not clearly visible) is at 530 ft. If the topography here is essentially primary, as it appears, flow in the main channel was 60-70 ft deep during delta construction (Rock Cut flood).
22.5	1.9	Descend into scour channel maintained by vortex in lee of Rock Cut Delta. The near (northeast) wall of this scour channel is bedrock while the southwest side is the depositional front of Rock Cut Delta.
22.7	0.2	Turn right onto Maple Dr. Bedrock exposures on left.
22.9	0.2	Left on Bovington Lane.
23.0	0.1	Bedrock behind houses on right was swept bare by vortex scour.
23.1	0.1	Dead ahead is slip face of Rock Cut Delta. Delta forests here consist of pebble gravel, with basal layer of boulders thought to have been emplaced by rolling down the delta face. Some of these boulders are used as yard ornaments. Return to Maple Drive.
23.3	0.2	Turn right on Maple Drive.
23.5	0.2	Turn right on Woodchuck Hill Road. Cross scour channel and climb delta front.
23.7	0.2	Turn right onto Cedar Heights Drive. Here on top of Rock Cut Delta the favored lawn ornaments are boulders 4 to 6 ft long. Most are of local bedrock types, but some are exotics. These boulders occur at an elevation of 600 ft, about 50 ft above the floor of Rock Cut Channel, along which they were transported.

Total Mileage	Miles from last stop	Route Description
24.1	0.4	Turn left on Will-O-Wind Dr (the second time you encounter it).
24.2	0.1	Turn right on unnamed exit road, then right again on Woodchuck Hill Rd, heading west. Immediately after turning onto Woodchuck Hill Rd, note the broad, channel-like depression to the left on the grounds of the Dewitt Fish and Game Club. This scourway is 700 to 1000 ft wide; its axis lies about 35 ft below the adjacent delta surface and slopes gently westward, i.e., up-current. It is interpreted as having developed during catastrophic discharge from Rock Cut Channel, when water level stood near 500 ft elevation. Presumably, most, if not all, of the delta surface was under water at one time, but scourways such as this accommodated a disproportionate part of the flow.
24.6	0.4	Fluvial boulder gravels in road cut on left. The valley into which we are now descending was cut subsequent to formation of Rock Cut Delta and so transects the delta, isolating the remnant we have just crossed from other remnants on the west side of Jamesville Trough.
24.7	0.1	Turn left on temporary road (construction in progress).
24.8	0.1	Right on Jamesville Rd.
25.2	0.4	Till in roadcut on left shows that the flow which sectioned Rock Cut Delta (Rams Gulch phase) cut completely through the delta gravels and into glacial deposits underneath.
25.4	0.2	STOP 2. Turn left into abandoned gravel pit. Large boulders near entrance are common constituents of this segment of the Rock Cut Delta. Whether this pit can be examined in detail depends on interstate highway construction and other factors. However, under favorable conditions one can see imbricate boulder gravels and crossbedding that document radial flow from the mouth of Rock Cut. The till surface on which the delta was built forms the floor of the quarry over large areas. The edge of this delta spills northwestward into the mouth of Nottingham Channel, clearly indicating that the flood gravels (which initiated State II of Rock

Total Mileage	Miles from last stop	Route Description
		Cut drainage and built most of this delta) are younger than the most recent flow through Nottingham.
25.7	0.3	Leave quarry, turning right (south) on Jamesville Rd.
26.7	1.0	Left at intersection to Jamesville.
27.6	0.9	Turn right (east) on NY173.
28.2	0.6	Gravels beyond houses on left are part of the delta built by discharge from Smoky Hollow spilling into Jamesville Trough Lake.
28.8	0.6	Turn right into Clark Reservation State Park. Proceed to parking area.
29.0	0.2	STOP 3 and LUNCH. (Parking lot, Clark Reservation.) From main overlook, observe the steep-walled plunge basin at the west end of Clark Reservation Channel. This dry waterfall, 120 ft high, has plan dimensions nearly identical with those of Horseshoe Falls, which today carries 90 percent of Niagara's discharge. Presumably, the normal flow through Clark Reservation in Late Pleistocene time was comparable to that of the present Niagara River. Green Lake, which now occupies the plunge basin, is about 55 ft deep. A second, smaller plunge basin (Dry Lake) is located immediately upstream from the lip of the main falls. Its height was only about 50 ft. Hike from the parking lot north, then west, following park boundary service roads and foot trail to the south rim of Rock Cut Channel. From the overlook one can see the trailer park plunge basin 170 ft below. This was the earlier of two south-wall plunge basins to be active during Phase I of Rock Cut drainage. By this time, drift had been flushed from the east end of Rock Cut, at least to the 600 ft level. The proposed Rock Cut drift barrier was located immediately west of here. The boulder spit partially barring the plunge basin was constructed by catastrophic discharge when the dam failed. Return to NY173.
29.3	0.3	Turn left on NY173.
30.6	1.3	Left onto Jamesville Rd.

Total Mileage	Miles from last stop	Route Description
31.4	0.8	Stay left (straight ahead, along railroad) onto Rock Cut Rd.
31.9	0.5	Dramatic view of Rock Cut, looking upstream (west).
32.6	0.7	Trailer Park plunge basin on left.
32.7	0.1	Turn left into Cliffside Trailer Park.
32.8	0.1	Turn right and circle park on perimeter road. (This is private property, so permission should be requested.) Immediately after turn, note artificially truncated spit on right. Boulder layers dip southward at angle of repose, indicating accretion into plunge basin accompanied lengthwise growth. Original basin form has been modified through removal of talus and addition of about 30 ft of fill. Boulders have been known to tumble to the base of the talus or slightly beyond, and have caused some concern.
33.0	0.2	Leave trailer park, turning left on Rock Cut Rd.
33.2	0.2	On left was location of the second (western) plunge basin which was operative immediately prior to diversion of the flow to Nottingham Channel. The basin has been enlarged by quarrying operations, and effectively destroyed. The ridge immediately south of the road is what is left of the boulder spit, which once completely barred this plunge basin. Its top stands more than 80 ft above the floor of Rock Cut. Some individual boulders exposed during excavation were 8 ft long.
33.5	0.3	Location of drift barrier which diverted flow to south wall plunge basins, later to Nottingham Channel, and finally failed, releasing the Rock Cut flood.
34.8	1.3	Turn right on Brighton Ave.
34.9	0.1	Turn right on Ainsley Dr.
35.2	0.3	View into Rock Cut, looking downstream.
35.3	0.1	Left on Jamesville Ave.

Total Mileage	Miles from last stop	Route Description
35.7	0.4	Stop sign. Turn half-right on Comstock Ave.
36.3	0.6	Turn right on Colvin St.
36.5	0.2	Turn right on Skytop Rd.
37.4	0.9	Pass Skytop offices of Syracuse University.
37.5	0.1	Continue on dirt road. Stay left.
37.6	0.1	Stay left at Y.
37.7	0.1	STOP 4. You are parked in the approach to Nottingham Channel. Incision is not obvious because the flow was spread wide. However, much of the bedrock has been scoured free of till, and there remain patches of gravel that were deposited by the meltwater. Walk NE into the wooded area, to view the plunge basin at the upstream end of Nottingham Channel. Return to paved road.
37.9	0.2	Paved road begins.
38.8	0.9	Turn left on Colvin St.
39.0	0.2	Manley Field House. END OF TRIP.

Late Pleistocene History of South-Central Onondaga County

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INTRODUCTION

Central New York State offers much for the glacial geomorphologist including examples of both erosional and depositional features associated with the continental ice sheet. Within south-central Onondaga County many of these morphological as well as associated stratigraphic units can be seen. Some pose intriguing problems relating to the chronology of events leading to their birth and subsequent survival. The scope of previous work ranges from broad regional approaches to localized detailed analyses and has been reported in numerous publications and theses (e.g., Blagbrough, 1961; Brainerd, 1922; Durham, 1958; Fairchild, 1899a, 1899b, 1905, 1907, 1909, 1932; Grasso, 1970; Kirkland, 1970; Krall, 1966; Muller, 1964; von Engeln, 1921, 1961). The purpose of this report is to furnish the reader with a short and generalized account of late Pleistocene history of southern Onondaga County. This is supplemented with Figure 1, which depicts approximate terminal zones associated with post-Olean glacial advances.

REGIONAL SETTING

The area is underlain by lower Devonian sediments comprised primarily of shales. These strata, which dip gently to the south, create east-west-trending cuesta-form morphology. Examination of the present topography suggests a pre-glacial drainage system. The dendritic nature of the over-deepened valleys implies ancestral dip slope control with obsequent streams originating at the margin of the escarpment and flowing into the Ontario Basin. It is believed generally that the steeper gradient provided by this latter orientation created excessive headward erosion and subsequent capture of the resequent streams. The barbed juncture between Cedarvale and Onondaga Valleys tends to support this hypothesis. It is however difficult to believe that the secondary drainage patterns represent a preglacial influence. Even though several streams, such as the one at Vesper, join the major valleys acutely, their headwaters and initial courses parallel the ice flow in the area. Much debate has taken place as to the effect of the numerous glacial advances upon the preexisting drainage pattern. Durham (1954) believed that three preglacial erosion surfaces can be ascertained, whereas Clayton (1965) stated that the existing topography is "independent" of the preglacial drainage pattern. Most investigators have chosen to compromise and follow the theory of polycyclic origin as proposed by Coates (1966).

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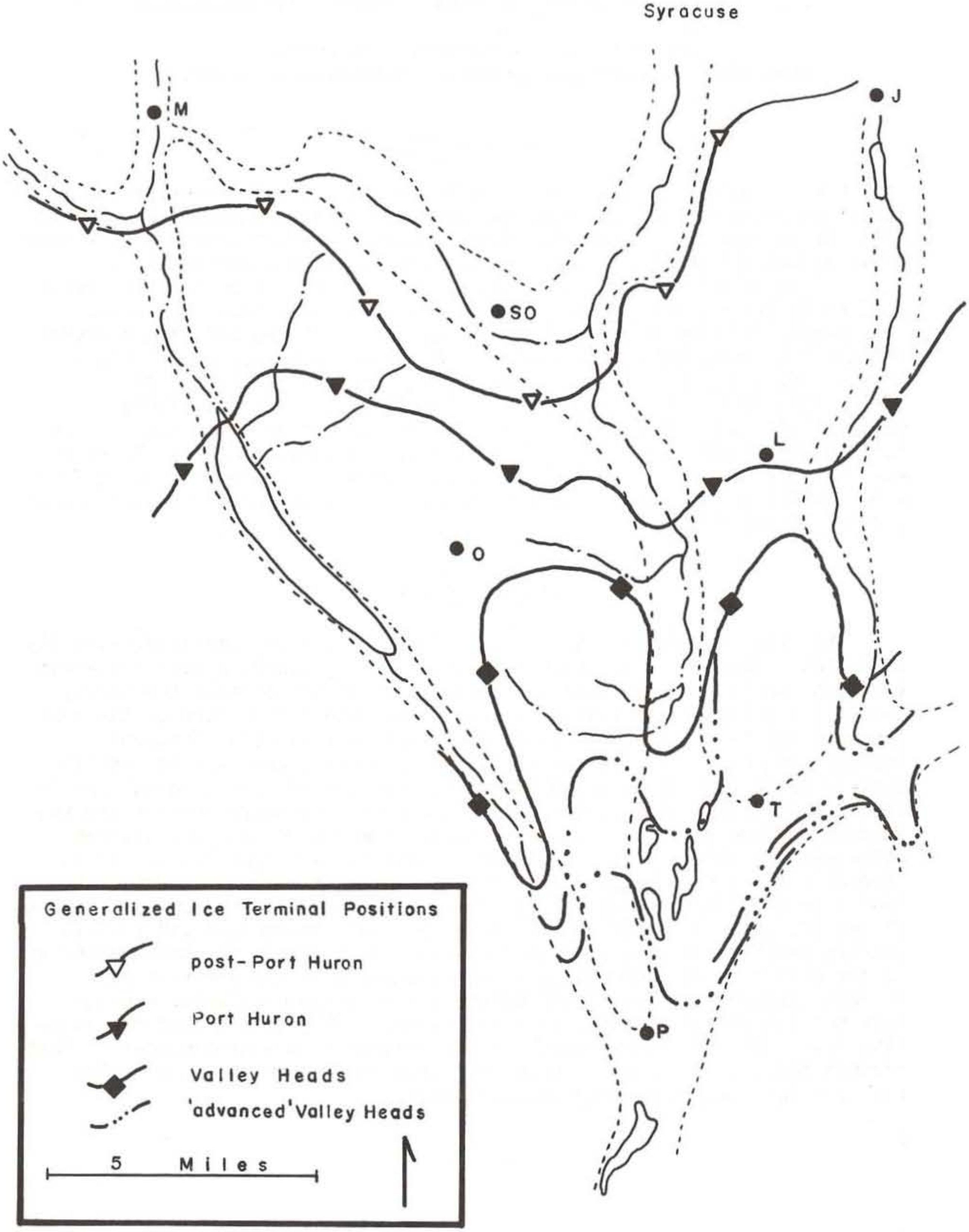

Figure 1. Generalized ice terminal positions.

WISCONSINAN GLACIATION

Much controversy has taken place about the subdivision of Wisconsinan drift in central New York State (e.g., MacClintock and Apfel, 1944; Muller, 1965). However, the classification suggested by Moss and Ritter (1962) is agreed on generally at this time. They proposed an Olean Substage followed by a Valley Heads substage, based upon both morphology and textural studies. No known occurrence of the former drift has been reported in Onondaga County, north of Tully.

Although it is agreed generally that there was a reorientation of ice flow from south-southwest (Olean) to southeast (Valley Heads) (Connally, 1960; Holmes, 1939; Kirkland, 1968), the amount of recession as well as subsequent readvance between these substages is in question. Kirkland (1968) suggested that Valley Heads glaciation represented a relatively limited retreat and rejuvination due to a westerly shift in source area.

For many years the drift barrier located at Tully was considered the terminus for the Valley Heads glaciation. This primarily was based on morphology as well as the fact that it formed the drainage divide between the St. Lawrence and the Susquehanna Rivers (von Engeln, 1921). This type of drift barrier occurs in all through valleys of the region. The upland counterparts of these positions, however, are difficult to trace and in many localities are nonexistent. Kirkland (1970) suggested that Valley Heads ice never covered the uplands surrounding the town of Vesper. Muller (1966) referred to an "advanced" Valley Heads position. This was based upon the location of lateral moraines in addition to well-developed kettle lakes within the outwash plain. These latter features (such as the Tully Lakes) not only suggest a retreat from an "advanced" position but also show close association with the previously mentioned drift barrier. If these features were not contemporaneous with the "Tully Moraine," they would have been filled by outwash and lost their well-defined morphologies. Durham (1954) demonstrated that the "valley stopper" is bedrock controlled with a relatively sharp drop of 800 ft in the bedrock floor near Route NY80. This feature easily could account for a relatively rapid retreat from the "advanced" position and the major standstill at the drift barrier.

With the recession of the ice sheet from the Valley Heads Moraine, the meltwater was unable to escape laterally due to the topographic controls created by the valley walls. Northward escape was blocked by the ice barrier. Thus the elevation of the imponded waters was regulated initially by the height of the moraines.

As the glacial margin retreated, cols of lower elevation were uncovered by the ice, allowing the isolated valley lakes to merge. Many of these marginal meltwater channels, some of which may have been initiated subglacially (Sissons, 1960) were reexcavated. This form of multicyclic usage has been demonstrated by previous workers (Hand and Muller, 1972). The original birth of these cross channels is unknown. For a more detailed description of the channels south of Syracuse, the reader is referred to Hand (1978, pers. comm.).

The ice withdrew to a position north of Cedarvale Valley. During this time the proglacial lakes became the site for deposition of an ubiquitous varved red clay and gray silt. Whether free drainage was initiated at this point is speculative. Krall (1966) suggested this was possible based upon work done in the Camillus Channel. It is known that Smoky Hollow was open because the laminated lake sediments are encountered within the channel.

The ice sheet then readvanced (tentatively correlated to Port Huron) to a position approximately 4 mi south of Cedarvale. This location is based primarily upon exposures of contorted varved red clay and gray silt overlain by lodgment till near Marietta and Cardiff. In addition to this, two subsurface exploration programs undertaken for the dam at Otisco Lake revealed soil profiles suggesting a morainal position. It is believed that both the activity of the ice sheet and its length of time at this position were less than for the western New York counterpart. This is based on the lack of constructional topography and may reflect the effect of distance from the source area or its location in regards to maximum ice flow. Associated with this advance was the formation of the upper levels of the Amber Delta.

Northward retreat of the ice to some unknown position north of the plateau created a second succession of valley occupied lakes. Cross channels were reexcavated and eventual free-eastward drainage along the front of the escarpment took place.

The final glaciation of the area, (here referred to simply as "post-Port Huron") occurred when the ice advanced to a position along the southern edge of Cedarvale Valley. With the exception of a large drift barrier south of Marcellus, the terminal position is marked only by small discontinuous moraines. The valley plug south of Marcellus has been correlated to the Skaneateles-Auburn-Waterloo morainal belt by many previous investigators. This advance initiated Lake Warren II at an approximate elevation of 970 ft. It was in this lake that the lower levels of Amber Delta were formed, being supplied by the rejuvenated Joshua and Navarino Channels.

With the final recession of the ice came the third succession of descending lakes. These have been documented by several writers including Blagbrough (1951), Hand and Muller (1972), and Krall (1966). Previous investigators (Fairchild, 1899; Grasso, 1970; Thrivikramaji, 1976) attempted to correlate the "delta" remnants in Cedarvale and Onondaga Valleys with the descending lake levels and corresponding channel thresholds. Krall (1966) suggested that these deposits reflect ascending lake levels. However, present investigations revealed several anomalous features such as kamic topography, variations in texture and lithology, as well as forset beds dipping in opposing directions. These factors suggest a more complex origin than previously thought. An adequate model of this phase of deglaciation is unknown and should be the focus of future work.

Nearly fifty years ago, H.L. Fairchild, after proposing his model, reflected upon the complexity of this region in the following manner:

> "In the translation of the commingled glacial records in the Syracuse-Oneida district, the Syracuse geologists have an exceedingly difficult, yet exciting task."
>
> H.L. Fairchild, 1932; p. 654.

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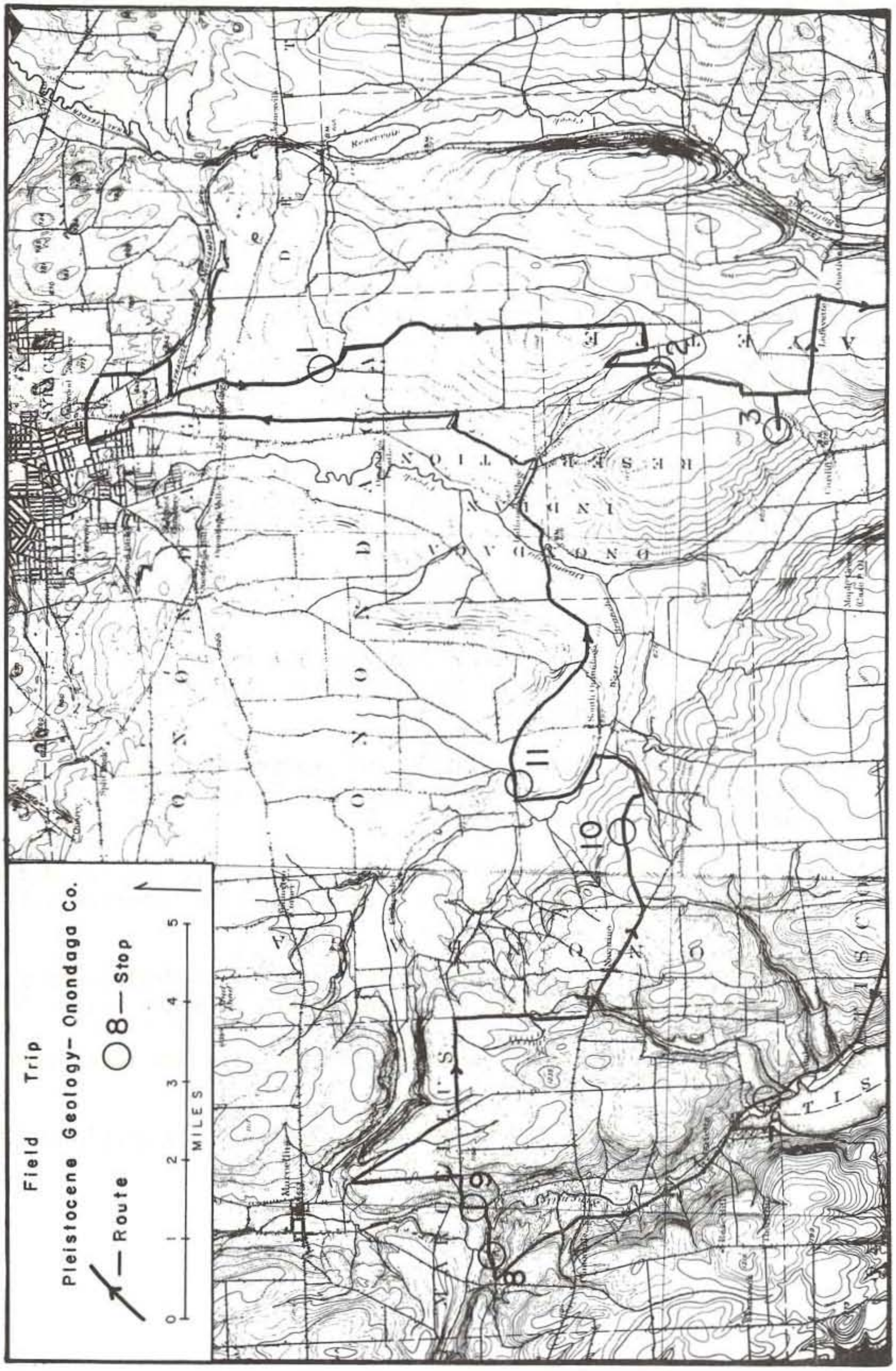
Field Trip
Pleistocene Geology- Onondaga Co.
Route
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MILES
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SYRACUSE
Lafayette
Cardiff
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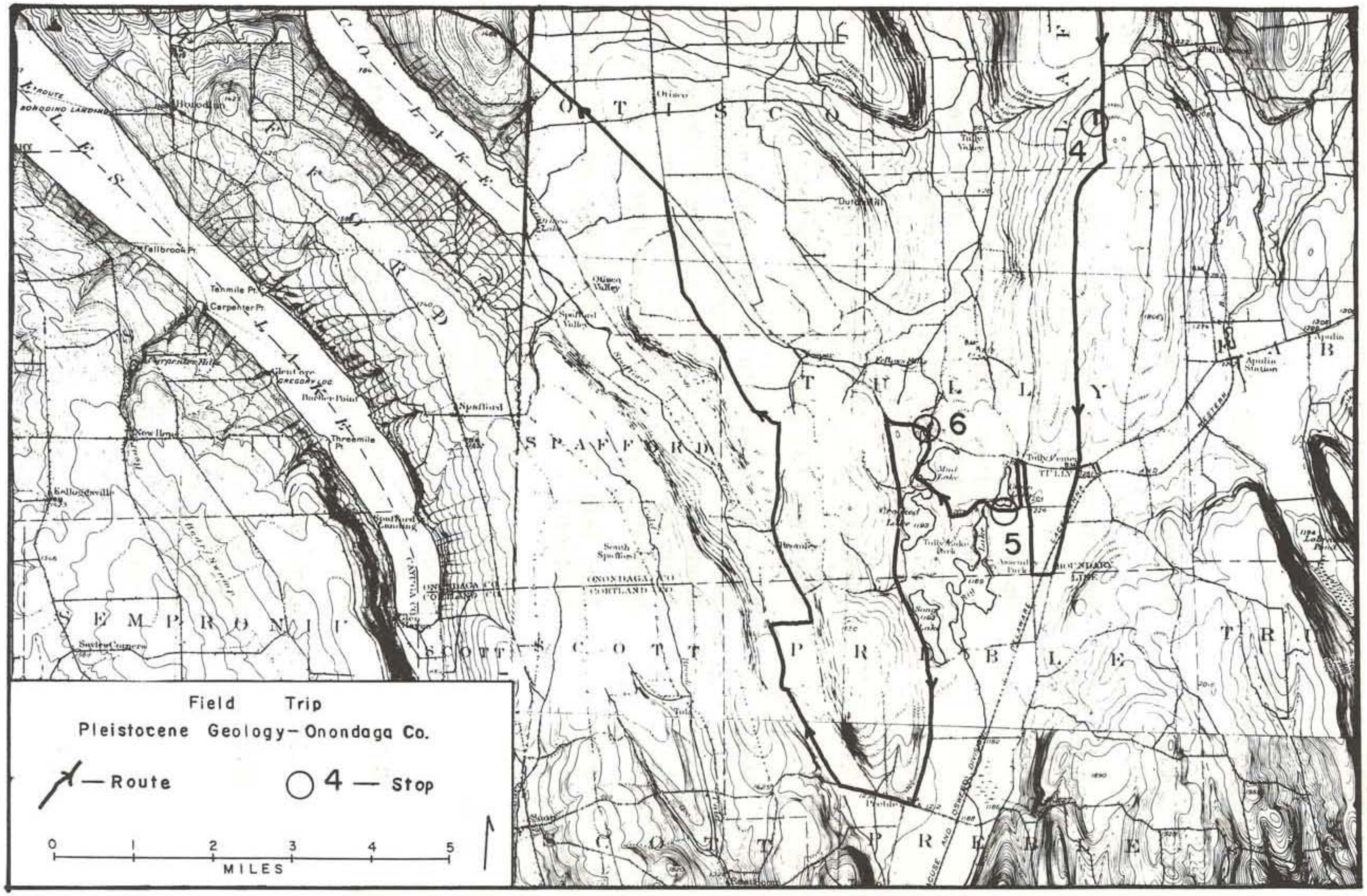

Proposed Route and Referenced Stops for Field Trip

ROAD LOG: PLEISTOCENE GEOLOGY OF SOUTH-CENTRAL ONONDAGA CO.

Total Miles	Miles from last point	Route Description
0.0	0.0	Assembly Point: Parking lot - Manley Field House, Syracuse University
		Departure Time: 8:00 A.M. Sharp! Travel by bus!
		Note: This log is a comprehensive view of the region. Therefore the percentage of material covered will differ depending upon mode of travel, number of people, interest, and weather.
0.0	0.4	Turn left (S) onto Comstock Ave.
0.9	1.3	Stay left (S) onto Jamesville Ave.
1.3	0.4	Turn right (W) onto Ainsley Drive - look southeast and observe a steepwalled, flatbottomed channel. This is Rock Cut, one of several major meltwater channels which controlled the eastward escape of imponded glacial waters.
1.7	0.4	Turn left (S) onto Brighton Ave. at 't' intersection.
1.8	0.1	Corner of Rock Cut Rd. & Brighton Ave. To the left (E) is the channel - elev. 550 ft. To the right (W) is Onondaga Trough, elev. of valley floor is approximately 415 ft.
2.1	0.3	Outcropping of Elmwood Formation; a portion of the scarp developed on Manlius Group.
2.4	0.3	Cross Rt. NY173, continue on LaFayette Rd.
3.3	0.9	On right (W) SUNY - College of Environmental Science & Forestry - Experimental Station. On left (E) LaFayette Golf Course located at base of drumlinoid composed of bedrock with thin veneer of lodgment till. This is typical of upland streamlined features of this region.
3.7	0.4	STOP 1: ENTRANCE - SMOKY HOLLOW MELTWATER CHANNEL

Total Miles	Miles from last point	Route Description
		Discussion of character of channel and relationship to Onondaga Trough History, including preview of broad deltas visible in valley to southwest.
4.3	0.6	Turn right (S) on Dave Tilden Rd. Cross ancillary channel developed during initial stages of Smokey Hollow. Elevation of bedrock at junction of this channel and Smokey Hollow is approximately 780 (a depth of 50 ft)
4.8	0.5	Turn left (SE) on Sentinel Hieghts Rd. Borings at this intersection encountered 24 ft of sand and gravel overlying 17 ft of till. No bedrock was encountered.
5.0	0.2	Note the water tanks positioned on subdued kamic topography; adjacent uplands to south are bedrock controlled.
8.1	3.1	Turn right (W) at base of steep hill on unnamed road. LaFayette Senior High School on left (S).
8.4	0.3	Turn right (N) on Route US11.
8.8	0.4	Turn left (SW) on Webb Rd.
9.4	0.6	Cross under Route I81; note coarseness of till. Road on right leads to LaFayette Landfill approximately 1/2 mi to north. It is located in deltaic sediments deposited in a lowering proglacial lake (elevation 1040±)
9.6	0.2	STOP 2: STREAM CUT - KENNEDY CREEK On right (W), across stream is bouldery till overlying light brown sands. Beneath this is a red-gray silty clay.
9.8	0.2	Close-up of bouldery till in roadcut.
10.6	0.8	Take right (W) at 't' intersection.
10.8	0.2	Enter small meltwater channel.
11.0	0.2	Take right (W) on Amdon Rd.
11.2	0.3	Reenter meltwater channel.
11.5	0.3	STOP 3: OVERVIEW OF TULLY MORAINE

Total Miles	Miles from last point	Route Description
		Discussion of its development as well as other prominent glacial features.
		Turn Around
12.0	0.5	Turn right (S) on Webb Rd.
12.5	0.5	Turn left (E) on Route US20.
13.4	0.9	Cross Route I81.
13.6	0.2	Turn right (S) on Route US11.
14.3	0.7	Note cemetary on right (W) and gravel pit on left (E). These are located on a zone of drift tentatively correlated to the Port Huron advance.
15.3	10.	Stay left onto Tully Rd.
15.7	0.4	Turn right (W) on Maple Grove
15.9	0.2	Turn left at 't' intersection and proceed to end of road.
		STOP 4: OVERVIEW OF RATTLESNAKE GULF
		Discussion of its development and its relationship to the deglaciation of Tully Valley.
		Turn around, return to Tully Rd. and take a right (S).
16.5	0.6	Start of constructional topography of Valley Heads Moraine (proximal end)
18.5	2.0	Leave morainal topography and reenter streamline topography.
20.5	2.0	Stoplight in village of Tully; continue south along Route US11. This gradually sloping surface to the south is the outwash plain formed by Valley Heads Ice.
21.1	0.6	Cross railroad tracks. The rolling hills on left (E) are lateral moraines associated with the "advanced" Valley Heads Ice. The tree line emphasizes the break between the moraine and the bedrock escarpment.

Total Miles	Miles from last point	Route Description
21.9	0.8	Turn right on Marybelle Rd.
22.1	0.2	Turn right (N) on Route NY281. Note the gradual change into a zone of pitted outwash.
23.5	1.4	Turn left (W) at light onto Route NY80.
23.6	0.1	Turn left (S) and proceed parallel to Route I81.
24.4	0.8	STOP 5: GRAVEL PIT SOUTH OF GREEN LAKE
		Examination of features and materials of pitted outwash plain.
25.2	0.8	Turn right (N) on Gatehouse Rd.
25.8	0.6	Stay right (N) on Gatehouse Rd. Note the procession from outwash to pitted outwash to kame and kettle topography as the "moraine" is approached.
26.6	0.8	Cross Route NY80.
26.7	0.1	STOP 6: ALLIED CHEMICAL CORPORATION GRAVEL PITS
		Discussion as to mode of origin of the "moraine".
		Continue west on Route NY80.
27.3	0.6	Turn left (S) on Song Mountain Rd. Note bedrock outcrop on right side of road and deep valley fill on left.
27.7	0.4	On left (E) kame field grades into kame terrace. This is believed to reflect one of the positions for the "advanced" Valley Heads Ice.
28.4	0.7	On right (W), small remnants of lateral moraine.
29.4	1.0	Cross Lake Rd. Lateral moraine is on right and continues down valley. A portion of it has been cut for a parking lot for Song Mountain Ski Resort. Farther south the moraine becomes partially buried by colluvium.
31.3	1.9	Last vestige of lateral moraine as it dips

Total Miles	Miles from last point	Route Description
		under road and into outwash.
31.5	0.2	Cross Currie Rd. Note that slope changes from dipping south to north. This represents the distal edge of a fan built from Otisco Valley and lies above the Tully Valley outwash.
31.9	0.4	Leave Song Lake Rd. and proceed south on Route NY281.
32.3	0.4	Preble - turn right (W) on Preble Rd. On left is von Engeln's (1961) classic example of a truncated spur.
32.8	0.5	Stay left at 'y' intersection. Descent from the terrace cut into outwash gravels. These were deposited by meltwaters from Valley Heads Ice in Otisco Valley.
33.3	0.5	Turn right (N) on W. Bennett Hollow Rd.
34.1	0.8	Note: Scarp of outflow channel on right (E); on left (W) two borrow pits which are remnants of the dissected plain. Above these are vestiges of a lateral moraine deposited during "advanced" stage.
34.7	0.6	Stay left at 'y' intersection.
34.8	0.1	Stay right at 'y' intersection.
35.6	0.8	Turn right (E) on Williams Rd.
36.0	0.4	To south is a partial ridge across the valley. It merges with the "advanced" stage lateral moraine on east wall and can be traced northward past Gulf Rd.
36.1	0.1	Turn left (N) on Otosco Valley Rd.
36.8	0.7	On right is a second "advanced" lateral moraine.
37.1	0.3	Turn right (N) on Strong Rd. This is the proximal edge of the Valley Heads "moraine". On the west wall, remnants of a nearly horizontal lateral moraine can be seen. The valley drops over 500 ft to Otisco Lake. Strong Rd. follows the moraine onto the uplands.

Total Miles	Miles from last point	Route Description
38.3	1.2	Turn left (N) on Loomis Hill Rd.
41.0	2.7	Cross high-level meltwater channel which carried water into Otisco Valley.
41.5	0.5	Turn left (NW) on Oak Hill Rd.
42.7	0.2	Cross Otisco Rd.
45.3	2.6	Cross Patterson Rd.
46.1	0.8	Turn right (N) on Otisco Valley Rd.
47.7	1.6	STOP 7: AMBER DELTA
		Discussion of its character and mode of origin.
48.5	0.8	Stay right on Route NY174. The hummocky terrain is a result of a complex relationship between kames, delta and eroded lake clays. Borings taken at the dam suggest a terminal ice position. This is correlated tentatively with the Port Huron advance.
50.5	2.0	Cross Route US20. The red clays exposed in the slump occur throughout this portion of the valley and create many slope stability problems.
		Continue along road and observe clay mounds and "moraine" to north.
51.8	1.3	Turn right (E) on Masters Rd. Observe the kamic topography and morainal features on left (N).
52.4	0.6	STOP 8: SAND PIT - MASTERS RD.
		Consideration of the nature and history of the deposit.
		Continue east along Masters Rd.
52.6	0.2	Turn left (N) on Route NY174.
52.8	0.2	STOP 9: OVERVIEW OF GUPPY GULF AND BISHOP HILL DELTA
		Further discussion of deglaciation history of the area.
52.9	0.1	Turn right (E) on Seal Rd. The road cuts

Total Miles	Miles from last point	Route Description
		through the moraine near the base of the hill and then transects a delta built into the proglacial lake imponded south of the moraine.
53.3	0.4	Turn left on Rockwell Rd. Proceeding north, three well-developed minor meltwater channels are traversed. Water flowed from east to west and deposited the above mentioned deltaic sediments.
54.6	1.3	Turn right (SE) on Slate Hill Rd.
56.1	1.5	Turn left (E) on Seal Rd. Borings and wells in this upland region generally encountered over 50 ft of till overlying a thick layer of sand and gravel.
57.4	1.3	Turn right on Town Line Rd.
58.2	0.8	Intersection with Collins Rd. Note kamic topography on side hill to southeast. This is associated with small morainal belt which is believed related to a post-Port Huron readvance. The valley in the foreground is the northern extension of the Navarino Meltwater channel which supplied sediments to Amber Delta. Continue south along Town Line Rd. paralleling the channel.
59.1	0.9	Turn left (E) on Route US20.
59.4	0.3	Navarino Channel.
60.7	1.3	Stay left (NE) on Bailer Rd.
61.5	0.8	On left (N) is portion of morainal belt mentioned above (mile 59.2) with small meltwater channel formed between drift and uplands.
61.9	0.4	STOP 10: OVERVIEW OF CEDARVALE DELTAS Discussion of large-scale morphological features and generalized history of deglaciation.
62.5	0.6	Turn left on Hogsback Rd.
62.8	0.3	On left is cobble-boulder delta remnant at elevation 640 ft.

Total Miles	Miles from last point	Route Description
63.0	0.2	Turn left (N) on Red Mill Rd.
63.3	0.3	Turn left (NW) on Cedarvale Rd. The scarp to the right is a result of erosion through the deltaic deposits and into the till.
64.6	1.3	Turn right (E) on Tanner Rd.
64.9	0.3	STOP 11: D.W. WINKLEMAN PIT
		Examination of a nearly complete late Pleistocene stratigraphic section and discussion about mode of origin for the deltas.
66.8	1.9	Contorted varved red silts and clays exposed in stream bank to left (N).
67.0	0.2	Stay left on Route NY80. Road continues along 600 ft terrace.
68.1	1.1	Turn right (E) on Indian Village Rd.
69.0	0.9	Turn left (N) on Route US11.
69.2	0.4	Turn right (E) on Websters Rd.
69.6	0.4	Stay left. Note Onondaga Limestone outcropping. This forms a ledge along the east wall of the valley.
69.8	0.2	Stay left on Quarry Road.
70.4	0.6	On left (W) is large sand and gravel pit excavated into kame terraces. To the right (E) is a thin veneer of sand and gravel over the limestone ledge.
71.1	0.7	Turn right (S) on Route US11.
71.2	0.1	Turn left (N) on Route I81.
73.6	2.4	Note broad bedrock flexures related to the stresses imposed during the Appalachian Orogeny (Chute, 1964).
75.1	1.5	Exit on Brighton Ave., left at stop sign and turn right (N) at second stop light (Route US11).
76.0	0.9	Parking Lot Manley Field House.

Moss Island, Little Falls, New York

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INTRODUCTION

> "I consider this Island and its potholes so unique that I have recommended it most highly for inclusion in the registry of Natural Landmarks of the National Park Service. This island should not be touch in any way or the value of the potholes would be diminished" (Morisawa, 1977, p. G-41).

> "Moss Island merits protection and preservation as a geological landmark." (Muller, Hawley, and Muskatt, 1977, p. G-8).

In May, 1976, Moss Island was declared a National Natural Landmark. It is one of only four hundred such registered natural treasures in the United States.

Plans for construction of a highway across Moss Island by the N.Y.S. Department of Transportation were initiated in 1968. Opposition to the proposed plan arose in 1973 only after some concerned individuals found out about those plans. In the forefront of that battle were the Mohawk Valley Floodplain Association, a local group concerned with the Mohawk River and the Utica chapter of the Izaak Walton League, a national conservation organization. These two organizations requested assistance from the New York State Geological Association in 1974. Through the efforts of these organizations, among many others, as well as individuals, national landmark status was achieved. Nevertheless, even with the granting of such status the N.Y.S. D.O.T. continued to press for construction over the Island. The D.O.T. stand was taken over the objections of such groups as the N.Y.S. Department of Environmental Conservation, National Park Service, Sierra Club, N.Y.S. Office of Parks and Recreation, and the National Audubon Society. Not until the Secretary of the U.S. Department of the Interior strongly recommended against approval of the application to the Coast Guard did the N.Y.S. D.O.T. "gracefully" back down. Disapproval by the Coast Guard was on environmental grounds.

GENERAL GEOLOGY

Moss Island (Fig. 1) is a 14-acre curved, dumbell-shaped feature lying between the Barge Canal to the south and the Mohawk River to the north. Generally the eastern part of the island is referred to as Moss Island. It lies on a horst which raised the Precambrian gneiss to its present position. The throw of the fault is considered to be about 850 ft (Cushing, 1905, p. 40). Isachsen and McKendree (1977) indicate a throw of 250 ft.

Bedrock of the island is a quartzose syenite gneiss of Precambrian age. Potholes and related hydraulic abrasion features, prominently displayed on the island, document the torrent of early postglacial drainage from the Great Lakes through the Mohawk Valley. For some 1000 yrs., from

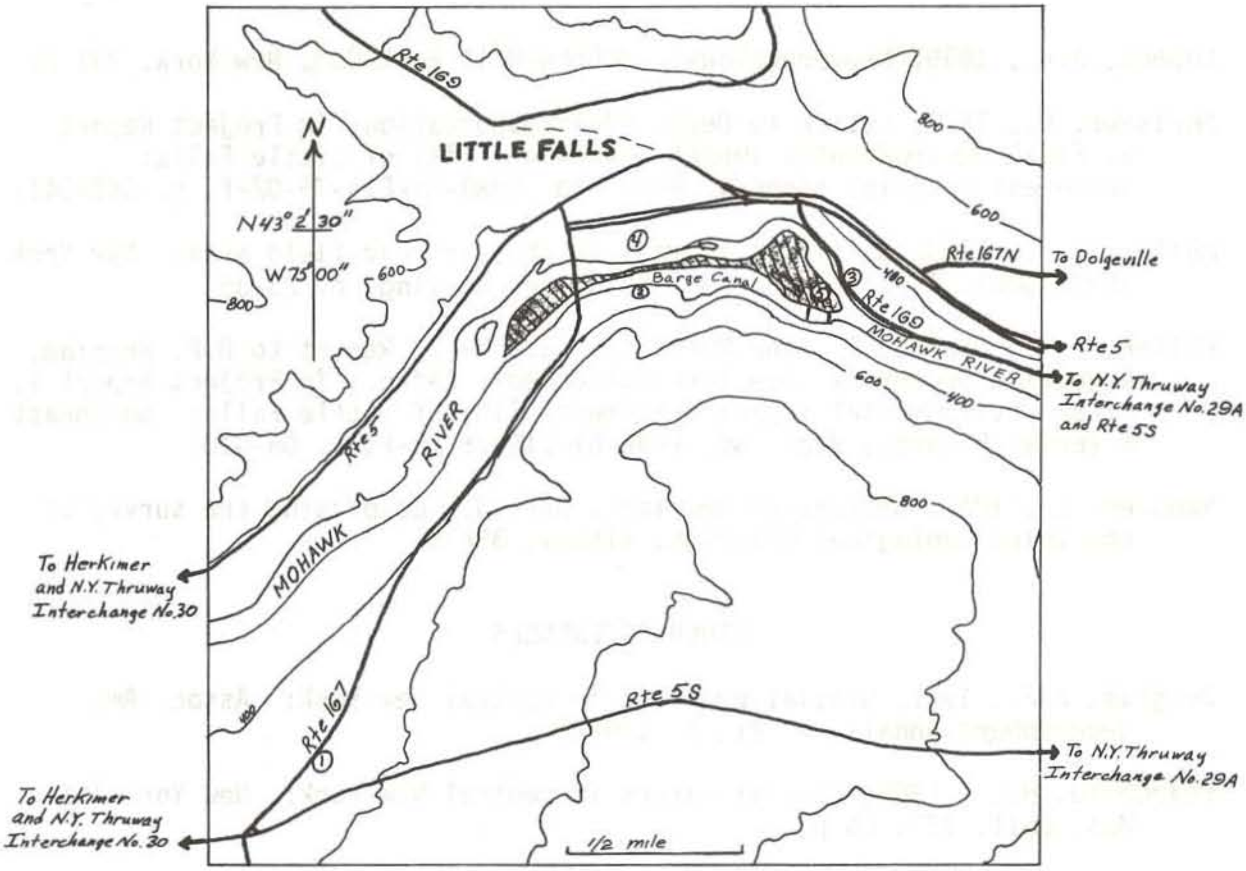

Figure 1. General map showing Moss Island, shaded, and field trip stops.

about 12,000 to 11,000 yrs ago (Lake Iroquois phase), the Mohawk River carried the entire outflow of the Great Lakes while the St. Lawrence valley was blocked by the slowly receding continental ice sheet. The resistant uplifted syenite gneiss here at Little Falls created the preglacial divide between the Hudson and St. Lawrence drainages. As the waters from the Great Lakes poured over this divide the narrow valley at Little Falls was cut. These same rapid swirling waters helped create the spectacular potholes on the island. The potholes were reported first by Vanuxem (1842, p. 209).

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ROAD LOG FOR MOSS ISLAND FIELD TRIP

Start: Colvin St. Parking Lot, Syracuse University, Manley Field House, Syracuse, NY. 8:30 AM. Exit on to Colvin St., turn right (w).

Miles from last point	Cumulative Miles	Route Description
0.0	0.0	Stop light, intersection of Colvin St. and Comstock Ave. Cross intersection, continue along Colvin St. (W).
0.1	0.1	Looking W, straight ahead, view of Onondaga Valley, a N-S glacial trough.
0.5	0.6	Turn right onto Route I81 N, immediately after underpass. Stay in right lane.
1.0	1.6	View of downtown Syracuse on left.
0.6	2.2	Stay right onto Route I690 E. Use center lane if possible. Route I690 follows a glacial meltwater channel, the Erie Canal Channel. The floor of this channel is depositional (Muller, 1964, p. 51).
3.7	5.9	Thruway sign. Stay left.
0.7	6.6	Take Route I481N to N.Y.S. Thruway.
3.6	10.2	N.Y.S. Thruway entrance 34A. Take eastbound direction. Observe 55 mph limit.
		Route cuts through the Lake Iroquois glacial lake plain whose outlet was at Rome, NY. This is part of the Ontario Lowland and is underlain by Middle and Upper Silurian units.
10.3	20.5	View to the right (S), first good view of the northern limit of the Appalachian Plateau. Plateau units here are of Late Silurian age and principally the Vernon Formation and the Syracuse Formation, along the face of the scarp.
1.8	22.3	Low ridges to right (S) and left (N) are ancient glacial lake barrier bars. Additional bars will be seen along route.
2.8	25.1	Another view of Appalachian Plateau front on your right.
13.4	38.5	Outcrop of Middle Silurian Oneida Conglomerate, basal formation of the Clinton Group on your right (S) alongside roadway.

Miles from last point	Cumulative Miles	Route Description
5.7	44.2	Another view of Appalachian front on right.
3.7	47.9	Recent Oneida Lake plain to left (N) with view of the foothills of the Adirondacks in distance. Oneida Lake is a remnant of glacial Lake Iroquois.
1.1	49.0	View of the foothills of the Adirondacks ahead.
2.4	51.4	Riverside Airport on right (S).
2.8	54.2	UTICA on right. My residence and the location of UTICA COLLEGE of Syracuse University.
15.1	69.3	Traveling along a higher floodplain level of ancient Mohawk River.
1.3	70.6	We are located in the Mohawk subprovince. View to the right is again the northern limit of the Appalachian Plateau. The horizontal benches seen in the upper half of the scarp are of Middle Silurian sandstones and conglomerates of the Clinton Group. The Clinton Group disconformably overlies the mudstones and siltstones of the Frankfort Formation of lower Late Ordovician age which occur in the lower portion of the scarp.
1.3	71.9	View of the Adirondack foothills on the left (N).
5.9	77.8	Traveling on an old terrrace of the Mohawk River. Present Mohawk River floodplain seen on right (S).
0.7	78.5	View on left (N), terraces cut into Middle Ordovician Utica Formation to control slumping of slope. Every several years the shaly mudstone slumps, thereby blocking the highway for a day or two. Because of the regional dip, 50-80 ft/mi to the south (right), the Utica Formation is not exposed across the valley to the right (S). The overlying unit, the Frankfort Formation does crop out.
0.6	79.1	View on left (N), another exposure of terraced Utica shale.
		Remington Arms plant on your right (S), in valley.

Miles from last point	Cumulative Miles	Route Description
0.9	80.0	View across valley to right (S) of knobby hills representing the terminal moraine of the Ontarian lobe which moved from the west. This is the easternmost limit of the last glacial advance in this region (Dunn, 1960, p. D9).
0.4	80.4	View on the left (N). A large gravel pit of glaciofluviatile origin. The foreset beds are clearly shown. Being the top elevation of the deltaic deposit is about 520 ft, Fairchild (1912, p. 39) would assign it to post-glacial Lake Amsterdam.
0.9	81.3	EXIT 30, Herkimer Exit, Route 28. GET OFF N.Y.S. Thruway.
0.4	81.7	Toll booth - Pay toll!
0.1	81.8	Route NY28 S, TURN LEFT.
		Cross bridge and Mohawk River.
0.2	82.0	Turn left (E), proceed along Route NY5S. Mohawk River on left (N).
0.5	82.5	Block of tillite on right (S).
1.7	84.2	Old stone Fort Herkimer Church on left (N) completed in 1767. Listed on National Register of Historic Buildings in 1972.
0.3	84.5	Cross N.Y.S. Thruway below overpass.
2.4	86.9	Glacial till on right.
0.2	87.1	Cross N.Y.S. Thruway below overpass. Look quickly down on right. View of Middle Ordovician Dolgeville Formation.
1.6	88.7	Intersection of Route NY167 N and Route NY5 S. Turn left (N) onto Route NY167 N.
0.1	88.8	STOP 1: (30 min) Outcrop of Late Cambrian Little Falls Dolostone. This unit directly underlies the Black River Group in this area. It nonconformably overlies a Precambrian syenite gneiss. The nonconformable contact will be seen at stop 2. The gneiss may be examined on Moss Island in Little Falls, stop 5. The Little Falls Dolostone is a sandy, medium-grained dolostone with some sandstones occurring near the base of the unit. Except for the

Miles from last point	Cumulative Miles	Route Description
		abundant colonial algae *Cryptzoon*, the unit seems to be barren in this area.
1.6	90.4	Cliffs of Little Falls Dolostone on the right (E).
0.2	90.6	On bridge to Little Falls and over the Mohawk River. Moss Island below. (See Figures 1 and 2.
0.1	90.7	STOP SIGN ON BRIDGE. TURN RIGHT.
0.1	90.8	"T" intersection, turn right onto S. Ann St.
		For purposes of expediencey we will leave some cars here and regroup. Cars will be picked up in about one hour when we go to the potholes of Moss Island. We will make three quick photograph stops before picking up cars.
0.1	90.9	Cross bridge over Mohawk River to Moss Island.
0.05	90.95	Stay left at end of bridge toward ONE LANE bridge. CAREFUL. Cross bridge over canal. See Figure 2.
0.1	91.05	Intersection of bridge with E. Jefferson St. Turn left (E).
0.05	91.1	STOP 2: (15 min - picture stop). Parking lot on left. Walk down hill (W) and cross road to empty lot on west side of church. Walk to fence in back center of lot. Across abandoned railroad right-of-way observe nonconformable contact of Little Falls Dolostone overlying Precambrian syenite gneiss. Dolostone is overlain by classic manmade limestone wall. Return to cars and one lane bridge over canal.
0.05	91.15	Intersection of bridge with E. Jefferson St. Turn right (N) over bridge.
0.1	91.25	End of one lane bridge over canal. Stay right.
0.05	91.3	Cross bridge over Mohawk River. Continue on S. Ann St.
0.1	91.4	"T" intersection, turn left (W) toward bridge.
0.1	91.5	Intersection with bridge (Route NY167). Turn right (N).

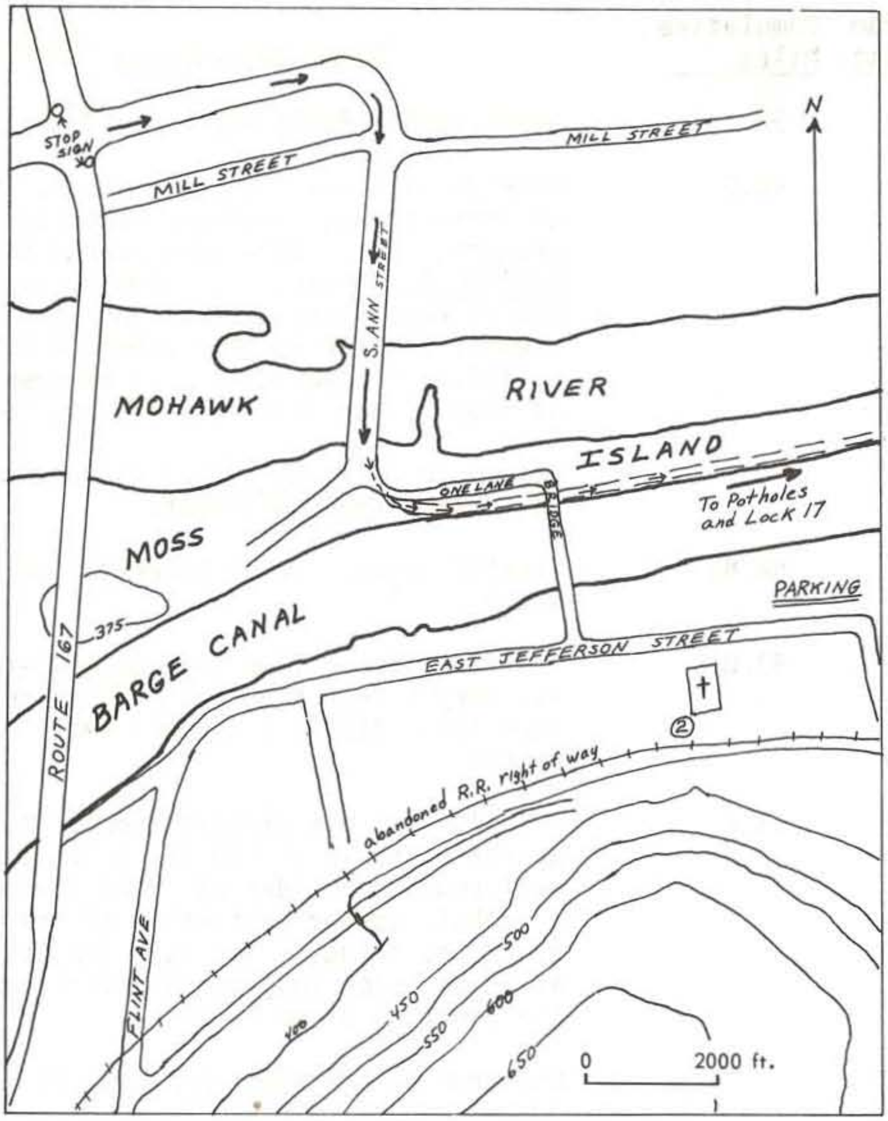

Figure 2. Detail of entrance to Moss Island, Little Falls, N.Y. (arrows) and location of STOP 2 and parking area.

Miles from last point	Cumulative Miles	Route Description
0.05	91.55	Stop sign, turn right, continue on Route NY167 N.
0.05	91.6	Stop sign, turn right, continue on Route NY167 N.
0.1	91.7	Stop light, turn left, continue on Route NY167 N and Route NY5E. Moss Island is on the right (S) across Mohawk River.

Miles from last point	Cumulative Miles	Route Description
0.4	92.1	Stop light. Route NY169 S. Turn right (E).
0.4	92.5	STOP 3: (15 min - picture stop). Park in clearing across the road, north side. CAUTION crossing road. Walk back across the road CAREFULLY. Observe potholes on northeastern end of Moss Island across Mohawk River. This view is similar to that shown in Lobeck (1939, p. 194). The potholes will be seen close up at Stop 5, our last stop on this trip.
		Return to cars CAREFULLY and reverse direction on Route NY169, northwest.
0.35	92.85	Traffic light. Cross intersection with Route NY167.
0.15	93.0	Traffic light. Turn left onto Alexander St. St. Mary's Church on left. Park on right, before turn, displays several small roches moutonees.
0.2	93.2	STOP 4: (15 min picture stop). In front of apartment house at 550 Alexander St. Large well-rounded boulder on front lawn was found in a pothole during excavation of the foundation of the building. This is a typical boulder used as an abrasion tool by the swirling waters for the creation of potholes.
		Continue on Alexander St. and take curve to:
0.1	93.3	Stop sign; cross intersection.
0.1	93.4	Traffic light. Intersection with E. Main St. TURN LEFT, continue on E. Main St.
0.15	93.55	SHARP LEFT to Route NY5.
0.05	93.6	ROUTE 167S. Proceed along Route NY167S partway across bridge.
0.1	93.7	STOP SIGN on bridge. TURN LEFT. See Figure 2.
0.1	93.8	"T" intersection, turn right onto S. Ann St. PICK UP CARS.
0.1	93.9	Cross bridge over Mohawk River.
0.05	93.95	Stay left at end of bridge toward ONE LANE bridge. Just BEFORE bridge entrance take RIGHT

Miles from last point	Cumulative Miles	Route Description
		FORK onto dirt road. Sign reads "This is not a public highway. Dept. Pub. Wks." THIS IS OUR ROUTE. See Figure 2. Road parallels barge canal.
0.05	94.0	Mohawk River on left (N), barge canal on right (S). Precambrian syenite gneiss across canal on right. Late Cambrian Little Falls Dolostone forms cliffs on the right (S). Proceed East along road toward Lock 17.
0.6	94.6	Parking area at Lock 17, Moss Island. STOP 5: End of trip. See Figure 3. Lock 17 is one of the highest lift locks in the world, 40.5 ft. The lower level is 322.5 ft above sea-level and the upper level is 363.0 ft above sea-level. For those who are interested, after we have examined the potholes, you can visit the old Erie Canal lock constructed about 1825. This old lock is located southeast of the existing Lock 17. It may be reached by walking across the catwalk in front of the eastern end of the lock and then down the stairs. The old Erie Canal lock is just a short walk to the east.
		Part of the proposal involving construction of the bridge over Moss Island included covering the old lock. As stated by one local supporter of the bridge, "burying the old Erie Canal lock thus preserves this historic site for posterity".
		Several potholes are located west of the parking area, along the south facing cliff adjacent to the road.
		Walk north from parking area several yards along path to clearing, an old picnic area. Note iron rings in the gneiss. These rings are said by some to have been used as pole support tiedowns for: (1) telephone poles, (2) "A" frames as part of the lock construction, (3) eyelets for hawsers for hauling barges. Perhaps, on the other hand, they may have been used by Rip Van Winkle's friends as croquet wickets when they tired of bowling in the Catskills.
		Walk NNW about 200 yds across the island and then turn N, downhill to potholes. STAY ON PATH and WATCH OUT for WIDE JOINT OPENINGS which require a slight jump. Paint marks represent bridge positioning.

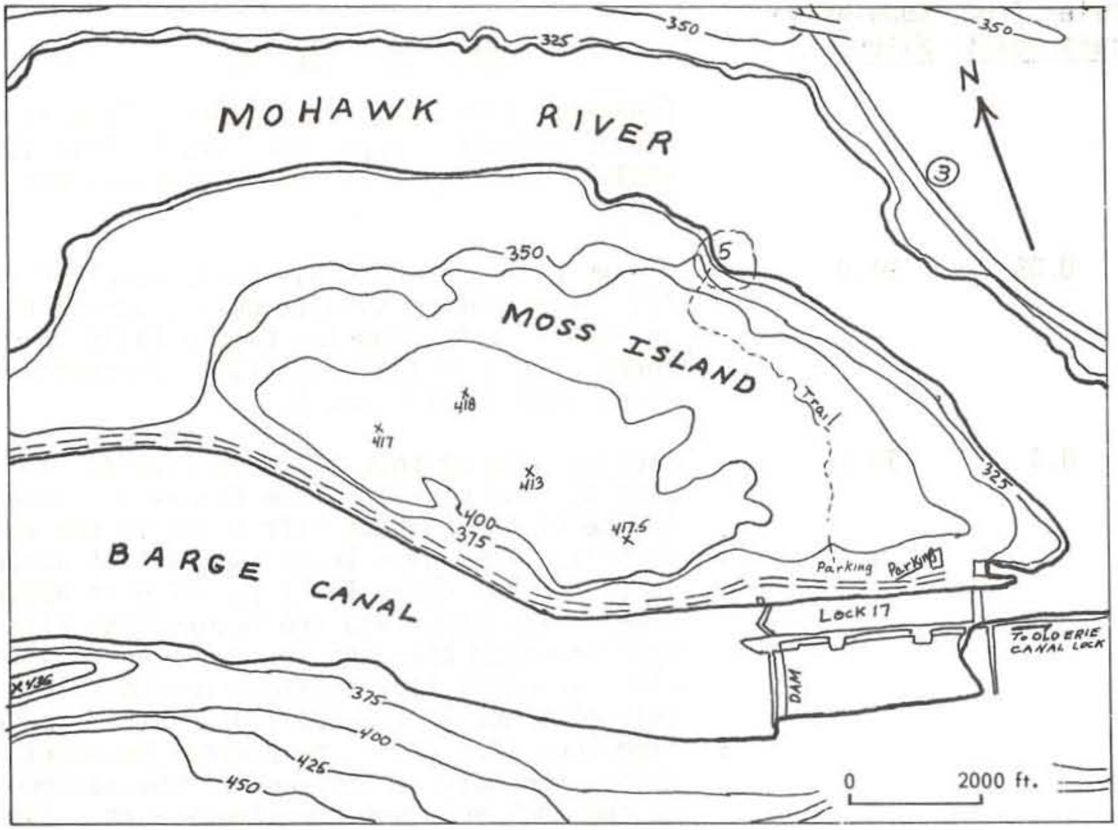

Figure 3. Moss Island, Little Falls, NY and location of STOP 3 and 5 (pothole concentration).

Miles from last point	Cumulative Miles	Route Description
		The ecological balance here is critical, the soil cover is thin. DO NOT pick flowers or destroy foliage. Most of the low-lying bushes are blueberry bushes. You may eat in season. Most of the plant species seen here are characteristic of Adirondack flora.
		Along most of the northeastern margin of Moss Island, facing the Mohawk River, numerous potholes occur. Although several hundred potholes are reputed to be scattered about the island the trip will observe only the area of greatest concentration. The deepest hole measured to the river silt-sand fill is 30 ft. The maximum diameter measured is about 20 ft.
		USE EXTREME CAUTION while moving about. Please do not sit on THE THRONE.
		The bedrock here is a quartzose syenite gneiss of Precambrian age. A number of quartz-rich

Miles from last point	Cumulative Miles	Route Description
		dikelets cut across the relatively horizontal foliation of the gneiss. The dikelets generally strike east-west and dip 45°N. According to Cushing (1905), p. 15), the gneiss consists "mainly of feldspar, always show some quartz, usually from 5% to 15% of the rock in quantity, and usually have only a small content of dark minerals, magnetite, hornblende, pyroxene and black mica." The gneiss on the north side of the island is relatively fine-grained whereas on the south side, near the barge canal, it is more coarse-grained and in places seems to be porphyroblastic, occasionally showing augen structure. Several faults also are present. Return to Route NY167 and HOME. See Figure 1. For the N.Y.S. Thruway take Route 167N to intersection with Route NY5S. To head WEST turn right and intersection with Route NY28, turn right to Thruway entrance. To head EAST turn left onto Route NY5S and proceed to Thruway entrance. The large cut just before the Thruway, after the tollbooth, is in Utica shale, the same unit that has tendency to weather readily and subject to slides as seen previously at mileage 78.5 and 79.1.

Biostratigraphy and Paleoecology of the Upper Devonian Ithaca Formation near Cortland, New York

by

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It is particularly appropriate that we examine the Ithaca Formation in the Cortland area during the Golden Anniversary Meeting of the New York State Geological Association. The rocks of this region are of considerable historical interest, having received attention since the earliest days of geological investigation in New York State. In fact, the presence of fossil shells in the Devonian rocks of New York was first noted in 1751 at a hillside outcrop in Cortland County by John Bartram, a member of the Lewis Evans Onondaga expedition (Wells, 1963).

The New York Devonian is unique in its completeness, fossil content, numerous outcrops, and relatively undisturbed nature. It is the standard reference section for North America and displays a classic example of facies transition. Stratigraphic and paleontologic investigation over the past century has produced a wealth of information, but "Despite this, perhaps another century of rigorous study will be required before a thorough understanding of its paleontology, lithology, stratigraphy and paleoecology can be attained." (Rickard, 1964).

The early stratigraphic work in the Upper Devonian of New York was done mainly by James Hall, J. M. Clarke, and H. S. Williams between 1840 and 1915. These workers subdivided the succession, described the faunas and attempted to correlate along the strike. Due to complex interfingering of the argillaceous western sequence with the thicker arenaceous eastern sequence, correlations proved difficult. Only in the 1930's with the work of Chadwick (1935) did it become apparent that the major facies had migrated across the basin of deposition as the Catskill Delta prograded.

Since 1942 investigation of the Upper Devonian has emphasized physical stratigraphy. The works of Sutton, J. F. Pepper, W. deWitt, Jr. and G. W. Colton have outlined the stratigraphy of the Senecan Series. The cyclic repetition of widespread black shales in western New York has been used to subdivide the succession. Paleontologic studies have, until recently, consisted of clarification and classification of forms originally described by Hall and Clarke between 1847 and 1915. The rarity of new discoveries testifies to the accuracy of their monumental works.

Biostratigraphy

The Ithaca Formation falls within the ammonoid zones of *Ponticeras perlatum* and *Manticoceras simulator*, correlative with the upper part of the Iα and the lowermost portion of the I(β)δ zones in Europe. The distribution of these goniatites has been documented with precision throughout western New York (Kirchgasser, 1975). In the type area, the zone of *Manticoceras* begins approximately 100 feet above the base of the sequence. Although rare in the eastern strata, these goniatites are present in the Cortland County area and provide the most reliable biostratigraphic framework.

Over the past 60 years, a nearshore zonation of the New York Upper Devonian has evolved based on the presence or absence of brachiopod species (Harrington, 1972). Early work by Williams (1913) documented the presence of four recurrent *Tropidoleptus* zones with *Rhipidomella* and "*Spirifer*" *marcyi* (= *Platyrachella?*) which periodically replaced the 'general Ithaca' faunas. Any extensive zonation of benthonic organisms must be critically evaluated. However, these zones seem to be quite reliable within certain limits and may be easily recognized in the field. They are clearly time-transgressive, their limits changing across the basin of deposition.

The zones, in fact, are closely tied to sedimentary types and consist of discrete fossil communities whose areal extent is compatible with the biotic attributes. These communities may be considered in terms of (1) feeding types and vagility, (2) species diversity and population density, (3) animal-sediment relationships and (4) morphologic adaptations of specific forms.

Communities

Many faunas present in the Ithaca Formation appear to represent minimally altered, life or near-life communities (*sensu* Fagerstrom, 1964). Many brachiopods may have self-buried in the fashion shown by Menard and Boucot (1951). Definitely authochthonous are all trace fossils, rarely preserved delicate fossils (asteroids, ophiuroids, and crinoid calices), soft-bodied forms (i.e., the scyphomedusa, *Plectodiscus*) and forms occurring in life position, such as the brachiopods, *Warrenella* and *Leiorhynchus mesacostale*, and the pelecypod, *Grammysia*.

Several community schemes have been proposed for portions of the New York Upper Devonian (McAlester, 1960; Sutton, *et al.*, 1966, 1970; Harrington, 1970; Bowen, *et al.*, 1970; Thayer, 1974; and Bowen, *et al.*, 1974). In the Cortland area, we recognize at least five communities present in the Ithaca strata. These benthic communities, or biotopes, partially intergrade or overlap. The order of these biotopes is essentially one of increasing complexity reflecting increased diversity and specialization. Primary controls on distribution of taxa appear to be sediment type and substrate mobility--factors only indirectly related to bathymetry. In general, the community distribution pattern seems to conform to the tectonically active Model 2 of Anderson (1971) characterized by a high-low pattern of kinetic energy release.

Lateral changes in the faunas reflect onshore-offshore gradients. An offshore increase in epifauna results from decreased environmental stress. Sessile taxa are concentrated offshore, with the nearshore zone dominated by vagile genera. Primarily stenotopic brachiopods are progressively replaced shoreward by eurytopic (and infaunal) pelecypods.

Due to the predominance of epifaunal species, many workers (e.g., Ziegler, *et al.*, 1968) have suggested a relative independence of Paleozoic marine benthos from sediment type. In the New York Upper Devonian, high sedimentation rates and distance from shore as a function of rate of deposition appear to have influenced specific aspects of the development and composition of communities. For these reasons, community patterns do not compare favorably in all aspects with those described in other areas, as in the work of DeKeyser (1977) in Western Canada and Iowa.

Most pedunculate brachiopods were somewhat elevated above low velocity currents near the sediment-water interface and were thus able to colonize a wide range of environments. However, as previously noted (Harrington, 1969, 1970), many Ithaca brachiopods were non-pedunculate, free-living forms or were merely attached to, but not supported above, the substrate in the ephebic stage. Consequently, a number of morphological adaptations occurred in response to problems of support and the separation of inhalent and exhalent currents.

The presence of a well-developed fold and sulcus (i.e., *Platyrachella*), frilly or spinous projections (i.e., *Atrypa*), thickened strut-like antero-lateral costae (i.e., *Hadrorhynchia*), or secondary thickening of the posterior portion of the shell (i.e., *Leiorhynchus globuliforme*), are alternate means of elevating inhalent currents above the interface. In this way, a series of discrete, well defined trophic levels were occupied in Ithaca time.

The following biotopes are recognized in the Ithaca Formation of the Cortland area:

I. *Warrenella* biotope.

This association is characterized by a mixture of benthic and pelagic forms adapted to poorly oxygenated, offshore mud bottoms. Brachiopods typically develop low, expanded outlines (i.e., *Warrenella* and *Leiorhynchus mesacostale*). Deposit feeding pelecypods, such as *Palaeoneilo* and *Pterochaenia* are abundant. Linguloid brachiopods and small crinoids (i.e., *Taxocrinus*) are locally present, as are the microphagous carnivores(?) *Plumularia* and *Conularia*. Species diversity and population density are low.

Perhaps, due to its position in the outer neritic, outer prodelta zone, this community does show affinity to those of other areas. In fact, there appears to be a good basis for recognition of a Warrenella Community, at least in North America, that persistently maintained a soft substrate habitat in a low energy and moderately deep water environment (Ludvigsen and Perry, 1975). In addition to its recognition in New York (Harrington, 1970), Johnson (1971) noted low species diversity and extreme abundance of few taxa (Warrenella kirki and Leiorhynchus meriami) in the upper fauna of the W. kirki zone from Nevada and referred to it as the "Warrenella Community." Furthermore, Noble and Ferguson (1971) recognized a similar "Warrenella-Rhynchonellid Community" from the Headless/Nahanni Formation of the southern Mackenzie Mountains. They placed this community seaward of communities dominated by tabulate corals and stromatoporoids and landward of the pelagic community.

II. Ithaca biotope.

This community was well developed on prodelta mud grade bottoms in areas of moderate currents. It is characterized by a highly diverse epifauna of brachiopods, many of which display morphological adaptations to a soft mud substrate in the presence of reduced sediment influx (.e.g, frilled atrypoids). This biotope is sporadically associated with a rich encrusting epifauna of bryozoans and auloporoid corals. The presence of these forms precludes rapid burial and indicates rather slow and discontinuous sedimentation. The genera present represent an admixture of forms from the Ithaca and Tropidoleptus biotopes. Some faunal similarities exist between this biotope and the Atrypa-Schizophoria community recognized by DeKeyser (1977) in Western North America.

III. Tropidoleptus biotope.

This community represents an adaptation to a delta platform with silt and mud bottoms. It is characterized by an abundant brachiopod epifauna, with especially large numbers of the spiriferid, Platyrachella. Other abundant genera are: Productella, Cupularostrum, Atrypa, Hadrorhynchia, Ambocoelia, and Tropidoleptus. In New York, Tropidoleptus occupies slightly finer grained environments than elsewhere. Isaacson and Perry (1977) consider this to be typical of sandstone-siltstone facies in presumably fairly turbulent, moderate to high energy environments characterized by low diversity and high dominance. Tropidoleptus was free living--the concavo-convex shell would achieve maximum stability with the brachial valve down. The dorsal sulcus would serve to lift the anterior commissive above the water-sediment interface.

IV. Leptodesma biotope.

On silt and shale substrates in delta platform areas of moderate current activity are developed communities of large numbers of filter-feeding epifaunal species, with smaller numbers of deposit feeding genera. In general, species diversity and population density are moderate. Common fossils are: Atrypa, Cryptonella, Pleurotomaria, Leiorhyncus globuliforme, Goniophora and Leptodesma.

V. *Grammysia* biotope.

Communities characterized by large numbers of the semi-infaunal filter-feeder, *Grammysia*, and the byssate epifaunal genus, *Goniophora*, inhabited coarse, unstable sand bottoms in the nearshore delta-front sands. The environment is highly variable in lithology and faunal composition. Strongly developed species dominance and low diversity are characteristic. Brachiopods are typically sharply costate and possess a well-developed fold and sulcus. Locally developed in more sheltered areas are dense colonies of crinoids (*Decadocrinus* and *Acanthocrinus*) or hexactinellid sponges (*Actinodictya placenta*). In these areas, where there is an accumulation of organic debris, gastropods, asteroids, and ophiuroids are abundant.

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ROAD LOG

Leave Manley Fieldhouse parking lot and proceed south on Comstock Avenue, bearing left on Jamesville Road for about .4 mile. Turn right (west) on Ainsley Drive for about .5 mile and turn left (south) on Brighton Avenue. Cross intersection with Route 173 and bear right on Lafayette Road for about 1.7 miles and bear right on Graham Road to Sentinel Heights Road. Turn right and then take first left on Kennedy Road for about 1 mile, turning right on short connecting road to Route 11. Turn right (north) on Route 11 and proceed under the I-81 overpass, turning left into the southbound lane of Route I-81. Travel south on I-81 to Exit 12 at Homer and proceed along entrance road to Route 281. Detailed log from this point below.

	Mileage	Total
Turn right (north) on Route 281.	0.0	0.0
Proceed north along Route 281 to second traffic light, turn left on Route 41.	1.2	1.2
Proceed northwest on Route 41 to junction with Route 41A, turn left.	2.5	3.7
Proceed west on 41A to Homer Gulf, just before rise in road and sharp bend.	1.2	4.9

STOP 1. Outcrop in Homer Gulf on Rte. 41A, 4 miles north of Cortland.

Ponticeras perlatum has been identified from exposures in Homer Gulf. This places the section in the lower portion of the Ithaca formation, probably correlative with the Renwick shale member. The lithology is extremely variable; consisting mainly of gray and reddish shales and siltstones. The fauna contains elements of both the *Warrenella* and Ithaca biotopes. Particularly common are: *Conularia*, *Plumularia*, *Mucrospirifer*, *Hadrorhynchia*, *Cupularostrum eximia*, *Taxocrinus* and linguloid brachiopods.

Turn cars around, proceed back along Route 41A to 41 junction, turn right.	1.2	6.1
Proceed southeast along Route 41 to junction with Route 281, turn right.	2.5	8.6
Proceed south along Route 281 to the fifth traffic light at junction with Route 13.	5.1	13.7
Continue straight through light on Route 13, proceed to large downgrade in road just past the Aquarius Inn and Sweetland Road intersection and the Tompkins County line.	3.6	17.3

STOP 2. Roadcut on Rte. 13, just east of Dryden, Tompkins Co.

This exposure in the lower Triphammer member is one of the most richly fossiliferous outcrops of the Ithaca formation. It contains abundant encrusting epifauna representing an admixture of biotopes, with incursions of the Ithaca biotope from the west and the *Tropidoleptus* from the east. Diversity is at a maximum, with maximum size development of *Leiorhynchus mesacostale*, *Atrypa reticularis* and *Platyrachella mesastralis*. Other common fossils are: *Hadrorhynchia solon*, *Porcellia nias*, *Mucrospirifer posterus* and *Cyrtina hamiltonensis*.

Turn cars around and return to Cortland via Route 13 to Y intersection just past the SCM plant and the Cortlandville shopping mall, bearing right on Route 13.	3.6	20.9
Follow Route 13 to pink house on right (south) side of road just across from Volkswagen dealership on north. Park cars on shoulder and walk to old quarry to rear of empty lot.	0.4	21.3

STOP 3. This locality will be an optional stop, time permitting.

The sequence of shales and siltstones is the source of several of the rarer fossils found in the Ithaca Formation, including the scyphomedusan, *Plectodiscus cortlandensis* and the trace fossil, *Tomaculum problematicum*.

Continue east on Route 13 to third light at Main Street intersection, follow through light onto Port Watson Street.	2.0	23.3
Follow Port Watson Street across Tioughnioga River Bridge and follow Route 11 to Route I-81 interchange 10 and enter I-81 South.	2.7	26.0
Proceed south along I-81 to Marathon Exit 9, leave I-81.	10.6	36.6
Proceed south along Route 11 to center of village of Marathon, taking left turn and follow signs to Rt. I-81 North.	1.3	37.9
Enter Route I-81 northbound and proceed to outcrop on both sides of road past the high bridge over Hoxie's Gorge and just at milepost 47.	9.1	47.0

STOP 4. Road cut on Rte. 81, 3 miles south of Cortland.

This exposure represents the *Grammysia* biotope in nearshore delta-front sands. Lithology is highly *variable* with shales, ripple-marked and cross-laminated siltstones and fine sandstones. Coquinite lenses, especially with *Cupularostrum*, are frequent and usually show distinct size-sorting and *differential* accumulation of valves. Areas of high currents are dominated by the infaunal filter-feeder, *Grammysia*, and the byssally attached bivalve, *Goniophora*. Occasion *vertical burrows* may be seen.

Sheltered areas support an abundant epifauna of crinoids (*Decadocrinus* and *Acanthocrinus*) and occasional brachiopods. This environment is characterized by the accumulation of plant fragments and orthoconic cephalopods, and by the high incidence of carnivores and scavengers--the gastropods, *Pleurotomaria* and *Loxonema*, several asteroids (*Urasterella*, *Lepidasterella*) and ophiuroids.

The orientation of many of the smaller crinoid calices (inverted with free arms outspread) indicates very slight water agitation. However the preservation of fragile specimens such as asteroids and the scyphomedusa, *Plectodiscus cortlandensis*, required periodic rapid sedimentation. *Fecal material* is occasionally found at this outcrop. It has tentatively been identified as *Tomaculum problematicum*, a form not previously reported in North America.

Continue northbound on Route I-81 to high ledges on right side of road about 1/2 mile north of Interchange 11.	6.0	53.0

STOP 5. Roadcut on Rte. 81 at Homer, Cortland County.

The sequence here consists of alternating dark shales and fine siltstones, occasionally ripple-marked. The sparse fauna, representing the *Leptodesma* or *Grammysia* biotope, consists of rare brachiopods and occasional crinoids (*Acanthocrinus*). At several horizons there are colonies of the hexactinellid sponge, *Actinodictya placenta*. These fragile forms were almost certainly preserved *in situ*.

Small hillside quarries immediately north of this exposure have yielded *Ponticeras perlatum*, indicating a correlation with the lower portion of the Ithaca (Renwick or Six-Mile Creek Members) in the Ithaca meridian.

Continue north on Route I-81 to Interchange 12. At this point, trip ends. Cars travelling north can continue on I-81, or exit to travel south or west for homeward trip.	0.5	53.5

Building Stones Used in the Vicinity of Syracuse

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INTRODUCTION

A building provides a visual signpost to the artistic style and the economic framework of the time and culture in which it was built. The materials used in the construction of the building are part of that history and have a story worth telling in their own right. The building stones used in Syracuse are diverse. Many of the classic buildings of central New York are built of Onondaga Limestone or other stone quarried locally, but numerous other buildings were constructed from rocks quarried from distant parts of the United States and Canada. These building stones are representative of nearly every major lithology and geologic age, and therefore are a major geologic resource available to all.

Building stones are selected for appearance, strength, and cost, but other factors may dictate a final selection. For example, architects who build in or around Presidential Plaza in downtown Syracuse must follow the color scheme previously used in the area. Even the road median on Townsend Street was constructed from a commercial granite termed Carnelian Red to conform to this preselected color scheme.

The appearance of a building stone results from a complex of factors. Mineral composition and grain size are prehaps the most obvious and incidentally are the most important characters used by geologists to classify the rock. The red or pink color of many of the granites comes from the presence of numerous pink- or red-colored feldspar crystals. The feldspar is so abundant that it masks the colors of other minerals especially the black micas and hornblende. Feldspar is not always red or pink but may be an off-white to gray to dark purple or blue. In igneous rocks the feldspar generally is by far the dominate mineral in weight percent thus controlling the color of the whole rock, at least when viewed at a distance. Crouse College on the Syracuse University campus is red for another reason. The building blocks are composed of quartz sandstone, a sedimentary rock. Each quartz grain is coated by a thin rind of red iron oxide which binds the sand grains together and imparts a characteristic red color, warmest at sunrise and sunset. Red can be a nuisance however, especially when it results from the chemical breakdown of an unstable mineral producing an unsightly stain. Crystals of pyrite may occur in the Onondaga Limestone. If a facing with pyrite is exposed to the atmosphere, the iron in the pyrite soon oxidizes forming rusty blotches. Other more subtle characteristics add to appearance. Individual grains range in size and shape. Feldspars may occur as long laths whereas quartz occurs as small, glassy, irregular grains seemingly squeezed in between its more regular neighbors. The final arrangement of shapes and sizes presents a characteristic fabric or texture, pleasing to the eye, but not easily described.

Sedimentary rocks usually exhibit characteristic fossils or markings from its origin on the shifting bottoms of turbulent seas. Cross sections of ancient corals appear similar to spoked-wheels in the Onondaga Limestone. The highly polished interior walls of the H.B. Crouse Building on the Syracuse University Campus or in the Foyer of the Herald Journal Building at South Salina and Erie are a naturally cemented accumulation of the shells of millions of marine organisms.

Architects and geologists use different terms. Of course this is acceptable and probably necessary because each profession has different requirements. For those of us interested in tracing the origin of a building stone a promising search may end in a morass of names. For this reason we have only dented the surface of building stones used in the Syracuse region.

The pathway from interesting building to useful data generally followed this course: (1) determine the architect; (2) contact the architect for information which usually leads to: (a) an informative individual with a superb memory; (b) original plans calling for a specific building stone, this bonanza may lead to a blank wall because another building stone with similar characteristics was substituted for economic or other reasons; or (c) complete blank, the architect could not be located, or if located no one alive had any knowledge of the building; (3) determine the geographic source of the stone; (4) consult state surveys, state geologic maps, texts on building stones for leads to the geologic name and pertinent geologic references; and (5) return to the building and check the data. The following publications were most helpful for locally derived building stone, Chute (1970), Hopkins, (1914), Luther (1895), and Vanuxem (1842). Sweet's Architectural Catalogue, (1978) provided a general source for firms and geographic locations of building stone.

BUILDING STONES QUARRIED IN NORTHERN ONONDAGA COUNTY

Syracuse, located on the northern edge of the Appalachian Plateau, is underlain by lower to middle Paleozoic sedimentary rocks which dip gently to the south. North of Syracuse the bedrock is dominated by relatively soft shales which were excavated deeply by the great glaciers of the Pleistocene to form a vast lowland. As the ice melted, its load of sediment mantled the lowland with the unconsolidated gravels, tills, sand, and clays termed glacial drift. Today this area is marked by numerous low hills, swamps, and lakes, and the underlying bedrock is seldom exposed. As a result early builders relied upon wood. Foundations were constructed of field stone, usually a conglomeration of glacially transported boulders which littered the lands to be tilled. An exception was the dolomitic layers of the Lockport Formation.

The Lockport Formation is geologically, the oldest rock unit in the County that has been quarried for building stone (Niagaran stage of the Lower Silurian). Although it holds up a low, rather obscure ridge extending from Lysander in the northwestern corner of Onondaga County through Brewerton just southwest of Oneida Lake, the Lockport is everywhere covered by drift. Where the need for foundation stone could not be satisfied by the availability of fieldstones (cobble- to boulder-sized glacial erratics) or the expense was too great for hauling Onondaga limestone to the building site, the glacial deposits were scraped off and the Lockport was quarried. Many of the older buildings in and around Lysander have cellars and foundations constructed of the Lockport. An interesting combination of local building stones can be seen in a house constructed in 1871 on Plainville Road, Lysander, now owned and being renovated by Mr. Wayne Harney. The foundation is dark-gray Lockport Dolomite, the supporting walls are brick but window and door casings are Onondaga Limestone. Lockport also was used locally for culverts and bridge abutments and in the Oswego Canal.

Although Vanuxem (1842, p. 93) referred to the presence of numerous quarries in the Lockport during the early part of the last century, nearly all of these long since have been filled and overgrown, although Zenger (1965) was able to recover rock samples from four of them.

In recent years the Lockport has been considered as a group (Rickard 1975) or as a formation (Zenger, 1965). Either way this unit is continuous with the massive dolomites which cap Niagara Falls and hold up a major escarpment which can be traced from Rochester, New York, into southern Ontario past Hamilton; to the Bruce Peninsula separating Georgian Bay from Lake Huron; hopskotching Lake Huron via the Manitoulin Islands to the upper peninsula of Michigan; wrapping about the western shore of Lake Michigan to die out south of Green Bay, Wisconsin.

The local facies of the Lockport termed the Sconondoa Member by Zenger (1965), is a dark gray or blue, fine-grained limestone west of Baldwinsville which includes interbeds of shaly limestone and coarser grained dolomites. Zenger observed zones rich in interclasts, ripple marks, and small ostracods. East of Baldwinsville the Sconondoa is a brownish gray to gray black, medium-grained dolomite containing a fair number of fossils including stromatolites, corals, one species each of a brachiopod and a clam, and several ostracod species. Zenger also observed edgewise conglomerates and incomplete mudcracks all of which suggests that the more eastern sediments were deposited in shallow, sometimes intertidal waters that were slightly more saline than normal seawater.

BUILDING STONES QUARRIED IN SOUTHERN ONONDAGA COUNTY

South of the lowlands the more resistant dolomites, limestones, and siltstones of Late Silurian to Middle Devonian age hold up a step-wise series of uplands which mark the northern boundary of the Appalachian Province. Locally the boundary between lowland and upland is marked by an irregular escarpment which is breached by streams with spectacular waterfalls at the most resistant beds, or muddled by the complex erosional and depositional overprints of Pleistocene glaciation. Many of the rocks exposed naturally in the escarpment, or by man in the hillside quarries have provided building materials since the area was settled. Canal building and salt-refining stimulated the need for the inexpensive building materials, so abundantly available in Onondaga County.

Much of the local Silurian bedrock is important economically because it contains major deposits of salt which are exploited today exclusively for the Solvay Process. During the last century Syracuse was the major center for salt in the U.S. Large deposits of gypsum also occur locally but these were used mainly in agriculture as "land plaster". Only a small fraction was mined for use in wall plaster.

As noted by Hopkins (1914, p. 26) nearly all of the limestones and dolomites in the Upper Silurian and Devonian have been used to some extent for building purposes. Most however have only been used for rough building purposes along the outcrop. Only two limestones are durable, workable, and attractive enough for wide-spread use. These are the upper "Blue Layers" of the Manlius and the lower most or Edgecliff Member of the Onondaga Limestone.

Manlius Formation

The limestone beds of the Helderberg Group (Lower Devonian) provided both quicklime from the upper blue lime layers of the Manlius Formation and hydraulic cement from the underlying water limes of the Manlius and Rondout Formations. Hydraulic cement was a major product of Onondaga County produced after the rediscovery of its manufacture and first use in the Erie Canal in 1819 until the early 1900's when Portland cement became available. During this period the thin blue lime layers which were stripped off the underlying water limes were used for building stone, principally as cellar or foundation stone. Some blue stone of the Manlius Formation is used today for fireplaces, decorative walls, and paving. The rock was available from numerous small quarries so that most of the homes built in the preconcrete era and located in Manlius, Fayetteville, Jamesville, Syracuse, etc., have foundations constructed of it.

The Helderberg Group has been the subject of several recent studies, the most notable of these are that by Rickard (1962) and LaPorte (1969). References to other important geological studies can be found in these two publications. The rocks of the Helderberg Group largely are limestones with lesser amounts of dolomite and shale. Although when first seen, these rocks seem alike, careful systematic studies of the lithology, the fossils, and the sedimentary structures such as mudcracks reveal several different rock suites or facies. After the geometric relationships of these different facies were determined, Rickard and later LaPorte concluded that the Helderberg Group was deposited in a vast, shallow-marine sea. Each facies or formation reflected a particular set of environmental factors which, at least in part, could be evaluated and described. LaPorte (1967, p. 78-82) compared the dolomitic, poorly fossiliferous, mudcracked layers of the Manlius Formation to the supratidal, limey, mudflats which can be observed today in the Florida Keys and the Bahamas. The upper part of the Manlius contains large, ovoid fossils of stromotoporoids (probably a sponge) and corals. LaPorte interpreted these as sediments accumulating just offshore from the barren mudflats. The same situation can be observed today in subtropic and tropical seas although the organisms have changed somewhat during the intervening 350 million years or so.

Oriskany Sandstone

The Oriskany Sandstone was quarried on a small scale in the town of Skaneateles during the last century (Luther, 1895, p. 275). Its most n notable contribution was in the construction of the Erie Canal Lock at Jordan, but it also was used for cellar and foundation stone. Locally the Oriskany was selected for the heat resistant linings in lime kilns. Although the Oriskany generally is thin and sometimes absent it is a sturdy well-cemented sandstone and probably would have been used more widely if the Onondaga Limestone were not so readily available. A similar appearing sandstone occurs locally at the base of the Edgecliff Member of the Onondaga Formation. This sandstone was derived seemingly by the exposure and reworking of the slightly older Oriskany deposits (Oliver, 1954). This sandstone can be seen at Jamesville, New York in the Prison quarry and the Allied Chemical quarry.

Onondaga Limestone

The Onondaga Limestone is sturdy and has a pleasing off-white to gray, locally pink color. It is abundant, forming an almost unbroken escarpment from the eastern side of the county to the western side. The principle quarries have been located at Jamesville, the Onondaga Indian Reservation, and at Split Rock. Only the quarry at Jamesville owned by the Allied Chemical Corporation operates today. In this operation the Onondaga is crushed and used in the manufacture of sodium carbonate at the Solvay plant. Vanuxem (1842, p. 136) noted that a single exposure of the Onondaga Limestone extended for more than a mile at Split Rock (just southwest of Syracuse) and this exposure was "farmed out to contractors, furnishing stone for a considerable portion of the western section of the canal."

The unique combinations of color, workability, and a variety of textures make the Onondaga the most visable of building stones used in the county. It also is the most widely distributed of the building stones quarried in Onondaga County. Not only was it used in the construction of the Erie Canal throughout the State but one slab occurs in the Washington Monument.

The Onondaga Limestone was first recognized in the literature by Amos Eaton in 1824 (noted in Vanuxem, 1842) as the Corniferous Limerock. The nomen corniferous, referred to the presence of Hornstone now known as chert. By the 1830's the first New York State Survey had identified a suprajacent limestone which they termed the Seneca. Today four members are recognized (Edgecliff, Nedrow, Morehouse, and Seneca in ascending order). The most important of these for building stone is the Edgecliff, a massive light gray to pink, crystalline limestone.

Hopkins (1914, p. 27) expressed the major reasons for the popularity of the Edgecliff. "Its durability is shown by its strong relief on all the outcrop and in the buildings in which it has been used. The interlocking crystalline grain has destroyed to a large extent the lamination of the rock, so that under the stone cutter's tools it acts like a marble".

The Edgecliff is richly fossiliferous most noted for its assemblage of corals and of large crinoid columnals up to 1 inch in diameter. The matrix between these larger fossils is composed of shell debris, particularly smaller crinoid columnals. Occasionally a sharp eye will discern the presence of small lacey to net-like bryozoans, bivalved brachiopods or snails, and trilobites. Oliver in 1954 judged that the relatively mud-free, fossil-rich, lime sediments of the Edgecliff were deposited in clear-water fairly constant conditions. Oliver pictured the existence of a shallow, marine sea whose floor was dotted with corals which sometimes became abundant enough to be pictured as forests of corals with crinoids living between the corals. This scene is suggestive of the coral-rich seas of the tropics today, but the differences provide room for future thought.

Hamilton Group

The siltstones of the overlying Hamilton Group which outcrop in the southern part of the county have been used on a local basis for retaining walls, foundation stone, or fences. The rocks usually are brown to dark gray and may have numerous fossils particularly clams or brachiopods. Although these rocks are important and interesting geologically, they have not been used widely in Onondaga County and will not be discussed further here.

IMPORTED BUILDING STONES

In this section we have gathered information on building stones quarried elsewhere in the United States and Canada and then transported to the Syracuse area. Locally derived building stones largely are sedimentary limestones and dolomites, which are nearly uniform in mineralogy (calcium and calcium magnesium carbonate) with subsidiary amounts of quartz sand, silt, and clay. Imported building stones are diverse and have been quarried from igneous, metamorphic, and sedimentary sources, and display considerable variation in composition even with a single variety of building stone.

Milbank Granite

Milbank Granite (carnelian red, mahogany granite), Grant County, South Dakota, quarried by the Cold Spring Granite Co. in Cold Spring, Minnesota. (Cost polished: $20.00 per sq ft, 2 in thick slab.) The granite is pink to dark red with a medium granitoid texture. The Milbank generally is equated with the Ortonville Granite which outcrops in the western most portion of the Minnesota River Valley between Ortonville and Odessa, Minnesota. Lund's (1956, p. 1485) analysis of the Ortonville Granite indicates the following composition by volume percent (40-60% microcline, a potassium felspar; 15-22% oligoclase, a plagioclase feldspar; 16-31% quartz; 3-6% biotite and 1% accessory minerals usually sphene or epidote).

The crushing strength of the granite measured by Rothrock (1944, p. 142) was 15,000 lbs/sq in a rather low figure for granite. The rock failed along cleavage planes in the feldspar. In addition to its use in

Syracuse the Milbank Granite has been used in the large columns in the National Catholic Shrine at Washington, D.C.

The Milbank Granite is dated by the lead-alpha method at a venerable 2470 million years (Goldich, Hedge, and Stern, 1970 p. 3689), the oldest rocks used for building stones known in the Syracuse area. Inclusions of quartz-pyroxene granulite in the Milbank Granite probably are remnants of sedimentary rocks which may have formed the crust of a primitive North American continent existing more than 2,500 my ago.

Texas Pink Granite (Sunset Red)

The Texas Pink is equivalent to the Town Mountain Granite of Stenzel (1932, p. 144). The rock is a coarse-grained, porphyritic granodiorite quarried from an exfoliation dome termed Granite Mountain located near Marble Falls, Texas. This places it in the eastern portion of the Llano Uplift of central Texas. Microcline feldspar, plagioclase feldspar, and quartz are the dominate minerals, subsidiary amounts of biotite, hornblende, rutile, apatite, zircon, and allanite occur locally. Many of the large phenycrysts are microcline rimmed by plagioclass. Tilton and others (1957) dated zircons from the granite at about 1 billion years. Other information on the geology of the Town Mountain Granite can be obtained in Barnes and others (1972) and Goldich (1941).

The following information concerning the history of the quarry is condensed from Barnes (1958, p. 20). The Texas Pink Granite Company took over operation of the quarry in 1893, and in 1895 the owners agreed to donate sufficient granite for construction of the State Capitol Building in Austin. By 1940 approximately 34 million tons of stone had been shipped from the quarry for use in buildings and monuments throughout the country, including two wings of the American Museum of Natural History in New York City, the Times Building in Los Angeles, and surprisingly, the Leif Erickson Memorial in Iceland.

During 1950 the Texas Granite Corporation acquired Granite Mountain. This company is a subsidiary of the Cold Spring Granite Company of Minnesota. Stone from Granite Mountain currently is marketed as "Sunset Red", it was formerly known as "Texas Pink."

Westerly Red Granite

The Westerly Red building stone quarried in the town of Westerly, Washington County, Rhode Island is equivalent to the Narragansett Pier Granite. Exposures of the granite occur near the mouth of Narragansett Bay and westward along the south shores of Rhode Island. Quinn (1971) classifies the rock as a quartz monzonite to granodiorite composed of 30 to 35 percent microcline, 30 to 35 percent oligoclase, 35 to 30 percent quartz, and 3 to 5 percent quartz. The list of minor elements includes zircon, apatite, pyrite, sphene, allanite, and the more exotic minerals, uranoan thorianite, bastnaesite, and monazite (Smith and Cisney, 1956).

The granite was intruded into the Pennsylvanian-age sediments of the Narragansett Basin during the Appalachian revolution in late Permian time. This was based on radiometric dating of zircons yielding a date of 234 million years ± 23 million.

Mount Airy Granite

The Mount Airy Granite is quarried 1 mi north of Mount Airy, Surrey County, North Carolina. The rock is a light gray, nearly white, quartz monzonite. It is composed of orthoclase and plagioclase feldspar, quartz, biotite, and minor amounts of apatite, zircon, muscovite, chlorite, and epidote (Stuckey and Conrad, 1958).

Chelmsford Grey (Oak Hill) Granite

This building stone is known geologically as the Ayer Granite (Emerson, 1917, p. 223). Typically the rock is a muscovite-biotite granite occurring in detached areas along a narrow belt from Hempstead, New Hampshire, through Worcester, Massachusetts, into Connecticut. It has been quarried extensively near Worcester, Westford, and near North Chelmsford. It is used mainly for retaining walls, bridge abutments, curbstones, and paving blocks. Detailed lithologic description of samples from individual quarried are given by Dale (1923, 303-313). Zartman and others (1970, p. 3360) has dated a sample of the Ayer Granite at 372 ± 17 my. This would place the origin of the Ayer in the Early Devonian, perhaps older.

Canadian Black Granite (Peerless Black)

The building stone is sold by National Granite Limited, St. Joseph d'Alma, Quebec. The rock is a coarse-grained anorthosite of dark gray almost black color. Approximately 85 percent of the rock is composed of labradorite, a dark-colored plagioclase feldspar. Where coarsely cleaved this mineral may display a spectacular play of blue and green colors reminiscent of a peacock's tail. The remaining minerals include pyroxene, ilmenite, hornblende, pyrrhotite, calcite, and biotite. The anorthosite probably was quarried in the Lac St. Jean area of Quebec, perhaps at the St. Gedeon quarry.

Anorthosite geologically is an unusual rock in that it is almost entirely composed of plagioclase feldspar. It also is uncommon in occurrence. Most of the anorthosite in North America occurs in Quebec, Labrador, and the Adirondack Mountains of New York State.

Polychrome Granite

This building stone, quarried by National Granite Limited probably is obtained from the vicinity of Bagotville, Quebec. The rock is a hornblende granite which contains 60 percent microperthitic orthoclase feldspar, 30 percent quartz, 4 percent plagioclase, 3 percent hornblende, and minor amounts of biotite, apatite, and zircon.

Longmeadow Sandstone

The Longmeadow is a somewhat feldspthic quartz sandstone, cemented mainly by iron oxides, which outcrops in the vicinity of Longmeadow, Massachusetts and along the Connecticut River. The Longmeadow is famous for its dinosaur tracks, ripplemarks, rain-drop impressions, frost crystal impressions, mudcracks, and plant stems. The sedimentary structures led geologists to believe that the longmeadow sands were deposited in shallow basins which often dried out completely. The dinosaurs seemingly traveled in herds leaving only their footprints behind.

BUILDINGS AND BUILDING STONES IN SYRACUSE

Bird Library, Main Campus, Syracuse University
Coarse Aggregate - Croghan Red Granite, Fine Aggregate - (sand) Croghan Red
Granite, Cement - Alpha, Inside Flooring - Tennessee Marble coarse aggregate in Terrazzo material
Completed in 1972

Bray Hall, Environmental Science & Forestry
Indiana Limestone
Built 1917

Cathedral of the Immaculate Conception, Jefferson St. and Montgomery Sts.
Onondaga Limestone (outside material)

City Hall, 233 E. Washington St.
Onondaga Limestone

Civic Center, 411 Montgomery St.
Red pavers outside building - made of coarse aggregate. Croghan Red Granite.

H.B. Crouse, Main Campus, Syracuse University
The bases, cornices, copings, windowsills, frames, outside walls, and trim are constructed of Indiana Limestone.

Crouse Irving Hospital, 736 Irving Ave.
Coarse Aggregate: North Bay Ontario granite. Cement, White Medusa

Dey Brothers Department Store, 401 South Salina St.
Marble outside - Georgia

Everson Museum, Montgomery St. and Harrison St.
Coarse Aggregate: Croghan Red (outside and inside building) - Cement Alpha

Gridley Building, 103 Water St.
Carved Onondaga Limestone

Hall of Languages, Main Campus, Syracuse University
Onondaga Limestone
Built in 1871. This was the first building used for classes on the Syracuse University Campus. Architect was Horatio White.

Herald-Journal Building, Clinton Square
Marble outside: Vermont, Green Slate outside: Vermont

Heroy Geology Laboratory, Main Campus, Syracuse University
Interior lobby floor - Buckingham Slate
Wood over lobby: Douglas fir
Opened 1971. Architects King & King

Holden Obseravatory, Main Campus, Syracuse University
Onondaga Limestone
Built in 1886. Architect was Archimedes Russell

John Crouse College of Fine Arts, Main Campus, Syracuse University
Longmeadow Sandstone
Built in 1889 by Archimedes Russell. The nine bells hanging in the central tower were cast in Belgium and cost $6,000.00. The sandstone ornaments were carved rather than cast.

Lyman Hall of Natural History, Main Campus, Syracuse University
Indiana Limestone, Gouveneur Marble
Built in 1907. A fire on January 11, 1937 destroyed a great part of the museum.

Marine Midland Bank, Corner of Butternut and Salina Sts.
Outside Building (upper portion) Kasota, Minnesota limestone, Polished red granite (outside) - South Dakota

Marine Midland Bank, Presidential Plaza
Outside Marble panels: Vermont, Polished red granite columns: South Dakota, Red Granite bricks: South Dakota, Curbstone: Massachusetts

Merchant's Bank, 220 Warren St.
Vermont Marble (outside of building)

Mony Plaza. 1 Mony Plaza
Outside flooring - Pink "Polychrome" Granite, Quebec Black Granite inside and out - "Canadian Black", Quebec Granite Aggregate outside: North or South Carolina.
More than one acre of "canadian Black" in this building

North Side Parking Garage, Townsend St. across from Presidential Plaza
Red Granite Bricks - South Dakota
Bricks were used to match darker colors of Presidential Plaza

Onondaga Community College, Main Campus, Onondaga Rd.
Granite Curbing: North Carolina, Granite door sills: North Carolina
Pink Granite window sills: Minnesota

Newhouse II, Corner of University Place and University Ave.
Coarse aggregate in Building: Pink granite from Texas

Public Safety Building, 511 State St.
Polished red granite columns and walls; on outside: Carnelian red, South Dakota

St. Joseph's Hospital, Prospect Ave.
Virginia Sand, Coarse Aggregate, New Jersey Marble, Cement: Medusa

St. Paul's Cathedral, 310 Montgomery St.
Onondaga Limestone (outside material).

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H.B. Crouse, Main Campus, Syracuse University
The bases, cornices, copings, windowsills, frames, outside walls, and trim are constructed of Indiana Limestone.

Crouse Irving Hospital, 736 Irving Ave.
Coarse Aggregate: North Bay Ontario granite. Cement, White Medusa

Dey Brothers Department Store, 401 South Salina St.
Marble outside - Georgia

Everson Museum, Montgomery St. and Harrison St.
Coarse Aggregate: Croghan Red (outside and inside building) - Cement Alpha

Gridley Building, 103 Water St.
Carved Onondaga Limestone

Hall of Languages, Main Campus, Syracuse University
Onondaga Limestone
Built in 1871. This was the first building used for classes on the Syracuse University Campus. Architect was Horatio White.

Herald-Journal Building, Clinton Square
Marble outside: Vermont, Green Slate outside: Vermont

Heroy Geology Laboratory, Main Campus, Syracuse University
Interior lobby floor - Buckingham Slate
Wood over lobby: Douglas fir
Opened 1971. Architects King & King

Holden Obseravatory, Main Campus, Syracuse University
Onondaga Limestone
Built in 1886. Architect was Archimedes Russell

John Crouse College of Fine Arts, Main Campus, Syracuse University
Longmeadow Sandstone
Built in 1889 by Archimedes Russell. The nine bells hanging in the central tower were cast in Belgium and cost $6,000.00. The sandstone ornaments were carved rather than cast.

Lyman Hall of Natural History, Main Campus, Syracuse University
Indiana Limestone, Gouveneur Marble
Built in 1907. A fire on January 11, 1937 destroyed a great part of the museum.

Marine Midland Bank, Corner of Butternut and Salina Sts.
Outside Building (upper portion) Kasota, Minnesota limestone, Polished red granite (outside) - South Dakota

Marine Midland Bank, Presidential Plaza
Outside Marble panels: Vermont, Polished red granite columns: South Dakota, Red Granite bricks: South Dakota, Curbstone: Massachusetts

Merchant's Bank, 220 Warren St.
Vermont Marble (outside of building)

Mony Plaza. 1 Mony Plaza
Outside flooring - Pink "Polychrome" Granite, Quebec Black Granite inside and out - "Canadian Black", Quebec Granite Aggregate outside: North or South Carolina.
More than one acre of "canadian Black" in this building

North Side Parking Garage, Townsend St. across from Presidential Plaza
Red Granite Bricks - South Dakota
Bricks were used to match darker colors of Presidential Plaza

Onondaga Community College, Main Campus, Onondaga Rd.
Granite Curbing: North Carolina, Granite door sills: North Carolina
Pink Granite window sills: Minnesota

Newhouse II, Corner of University Place and University Ave.
Coarse aggregate in Building: Pink granite from Texas

Public Safety Building, 511 State St.
Polished red granite columns and walls; on outside: Carnelian red, South Dakota

St. Joseph's Hospital, Prospect Ave.
Virginia Sand, Coarse Aggregate, New Jersey Marble, Cement: Medusa

St. Paul's Cathedral, 310 Montgomery St.
Onondaga Limestone (outside material).

Shea Jr. High School, 1607 S. Geddes St.
Curbstone: North Carolina

State Office Bldg., 133 E. Washington St.
Outside Steps on Washington Ave. - Texas Pink Granite; Curbstone - Texas Pink Granite.

Steele Hall, Main Campus, Syracuse University
Rock faced Onondaga Limestone
Built in 1898

Upstate Medical Building, 750 E. Adams St.
Outside marble - Georgia

ACKNOWLEDGMENTS

We would like to thank Mr. Carl Turner of the Barretto Granite Corp., Charles Doerfler of the Clark, Clark, Millis, and Gilson Architect Firm; Don Sherman of King and King Architects; Lou Fauth of the Clark Concrete Co., Inc.; and Mr. John Cuyle of Syracuse University for their exceptional patience and kind assistance.

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DEPOSITIONAL ENVIRONMENTS OF THE OSWEGO SANDSTONE (UPPER ORDOVICIAN), OSWEGO COUNTY, NEW YORK

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ABSTRACT

The relatively unfossiliferous greenish-gray sandstones, siltstones, mudstones, and shales that comprise the Upper Ordovician Oswego Sandstone near the Salmon River Falls type section in Oswego County were deposited in a sequence of adjacent environments ranging from offshore shelf to intertidal. Vertical changes noted in the Oswego include an upward increase in grain size from predominantly shales and siltstones in the lower part to fine-grained sandstones in the upper part, a color change from gray to green and finally red, and a change in faunal content from fossiliferous lower shales to nonfossiliferous upper sandstones. Along with these changes, a change in characteristic sedimentary structures and bedding characteristic was noted from the bottom to the top of the formation. Combining these data suggests that the lowest Oswego beds were deposited in the deepest waters, probably offshore shelf, and that overlying beds were deposited in progressively shallower water, more nearshore environments that included bar, lagoon, tidal channel and tidal flat. The overlying red sandstones and siltstones of the Queenston (Juniata) Formation were deposited under tidal flat to deltaic conditions. Thus, the Oswego represents the transition from underlying marine Pulaski shales to the overlying red deltaic deposits. This change resulted from a northward regression of the sea concomitant with an uplift in the source area that signaled the beginning of the Taconic Orogeny. Paleocurrent data suggest that this source area was located in southeastern Pennsylvania and that Oswego sediments were dispersed outward in a wedge-shaped mass into New York, western Pennsylvania, and northeastern West Virginia. Therefore, depositional environments in the as-yet unstudied Oswego rocks in West Virginia may be analogous to those in the New York type areas.

INTRODUCTION

A comprehensive stratigraphic and petrographic study of the Upper Ordovician and Lower Silurian rocks in Oswego County, New York, was previously carried out by the author (Patchen, 1966). During the course of that study, several vertical trends were noted in the stratigraphic sequence ranging from the Pulaski to the Grimsby Sandstone (Figure 1). These trends included: (1) an upward increase in grain size from predominantly shales in the lower Pulaski to shales and lenticular siltstones in the upper Pulaski and lower Oswego, to shale and very fine-grained sandstone in the middle Oswego, and finally to fine sandstones in the upper Oswego, Queenston, and Grimsby Formations; (2) a color change from dark gray to medium gray from lower Pulaski to lower Oswego, then greenish-gray to green toward the top

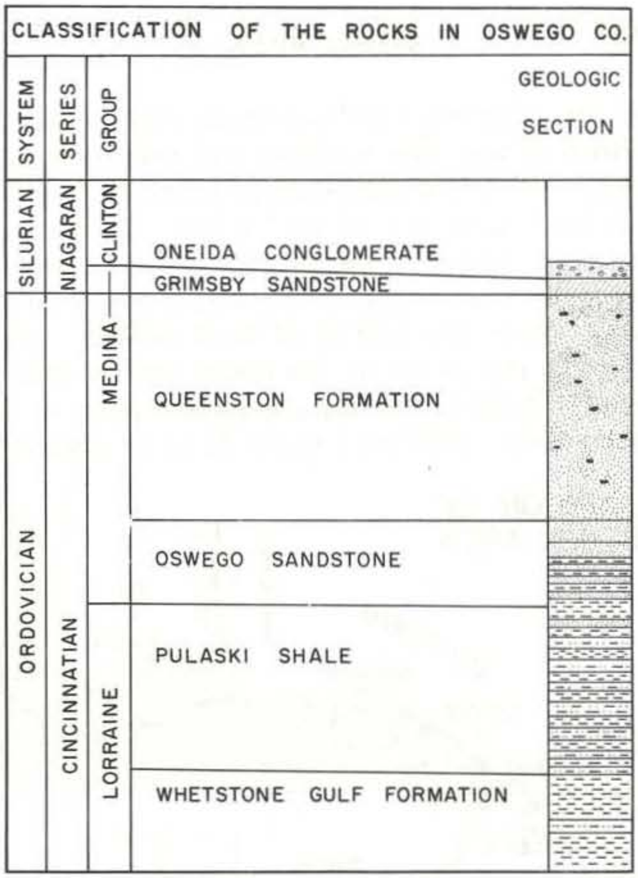


Figure 1. Generalized stratigraphic section and nomenclature for Upper Ordovician and Lower Silurian rocks in Oswego County, New York.

of the Oswego, and (3) a change in the faunal content from the fossiliferous lower Pulaski, to the relatively nonfossiliferous Oswego, to the nonfossiliferous red beds at the top of the sequence. Barren zones increase in thickness in the upper part of the Pulaski (Ulrich, 1913), and fossils are most common in only the lowermost 50 feet of the Oswego. Fossils other than trace fossils (i.e., feeding trails and worm burrows) are relatively rare in most of the Oswego sediments. Thus, the Oswego is the key formation in this transition from dark offshore marine shales to deltaic red beds. Therefore, this paper deals only with the various depositional environments of the Oswego. Most of these have been re-interpreted from data collected in the earlier study and from a recent petrographic study of thin sections made from Oswego core and outcrop samples in the study area. These interpretations are based on: (1) bedding characteristics, (2) associations of sedimentary structures, (3) textural and mineralogic data from thin-section studies, (4) the limited faunal evidence, (5) paleocurrent measurements, and (6) association with adjacent rocks for which an environment has been inferred. This study is preliminary to a similar detailed study of the Oswego rocks in the eastern outcrop areas of West Virginia and the adjacent subsurface areas.

STUDY AREA

The study area included most of Oswego County (Figure 2) although good outcrops were confined to the main streams and river valleys and the southern shore of Lake Ontario. All of the outcrops previously studied are shown, but those emphasized in this paper are all within the area designated by the Oswego outcrop pattern. Those in the vicinity of the Salmon River Falls type section occur in the lower half of the formation, those from Pleasant Point westward to Lakeview are in the middle of the formation, and those from St. Paul's Cemetery to Camp Hollis are in the upper part of the Oswego. Two cores taken by Niagara Mohawk during site preparation for their Ninemile Point nuclear-power facility (APP on Figure 2) were also available for study.

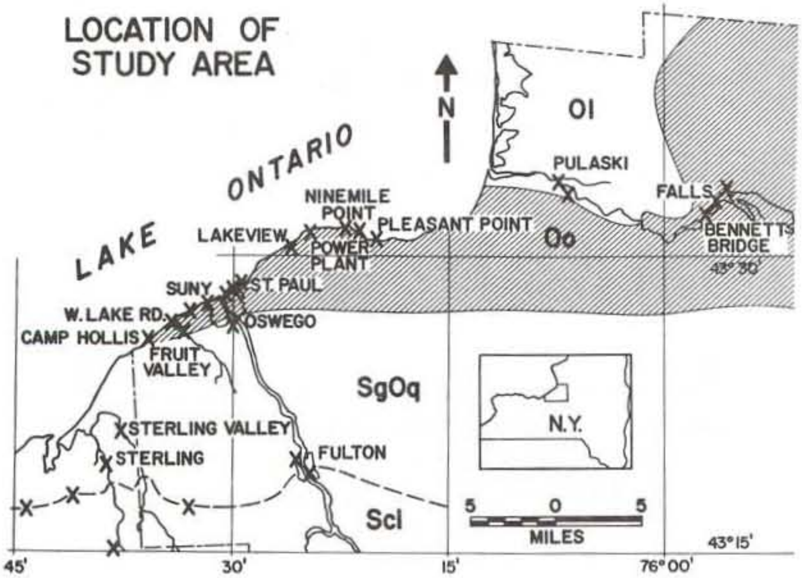


Figure 2. Location of study area in central New York State. Large X's refer to measured sections. Cross-hatched pattern Oo is outcrop area of Oswego Sandstone, Ol outcrop area of Lorraine Group, SgOq combined Grimsby and Queenston outcrop area, and Scl outcrop area of Clinton Group.

STRATIGRAPHY

The regional dip in most of the western part of the study area is approximately 50 feet per mile to the south, whereas farther east the strike is more north-south and the dip is to the west. Using this southward dip of 50 feet per mile, and plotting all outcrops relative to sea level, the stratigraphic relations of most of the outcrops in Figure 2 can be determined. In the central part of the study area, approximately 180 feet of the Oswego are represented by the two cores. The outcrops at Ninemile Point and the atomic-power plant overlap slightly and are the stratigraphic equivalents of the middle part of the cores.

Outcrops at Pleasant Point and Lakeview, although located many miles apart (Figure 2), are the stratigraphic equivalents in this reconstruction.

In the western outcrop area, perhaps 150 feet of Oswego are represented by scattered sections, with 45 to 50 feet of section missing between this western and the central composite sections. This yields a 380-foot thickness for the Oswego from the top down through the uppermost fossil zone, a figure comparable to previous estimates as far back as Prosser (1890). The lowermost beds in these western outcrops are gray and green sandstones, whereas the uppermost beds are red sandstones transitional with the overlying Queenston Formation.

To illustrate the environments of deposition of the Oswego in both a vertical and horizontal reference, several outcrops in Figure 2 will be summarized from the Salmon River Falls type section farther west to outcrops west of the city of Oswego.

Salmon River Falls Section

In the vicinity of the Salmon River Gorge, the lowest outcrops, stratigraphically, are near Bennett Bridge (Figure 3) and consist of fossiliferous (brachiopods and pelecypods) gray shales and mudstones with thin inter-

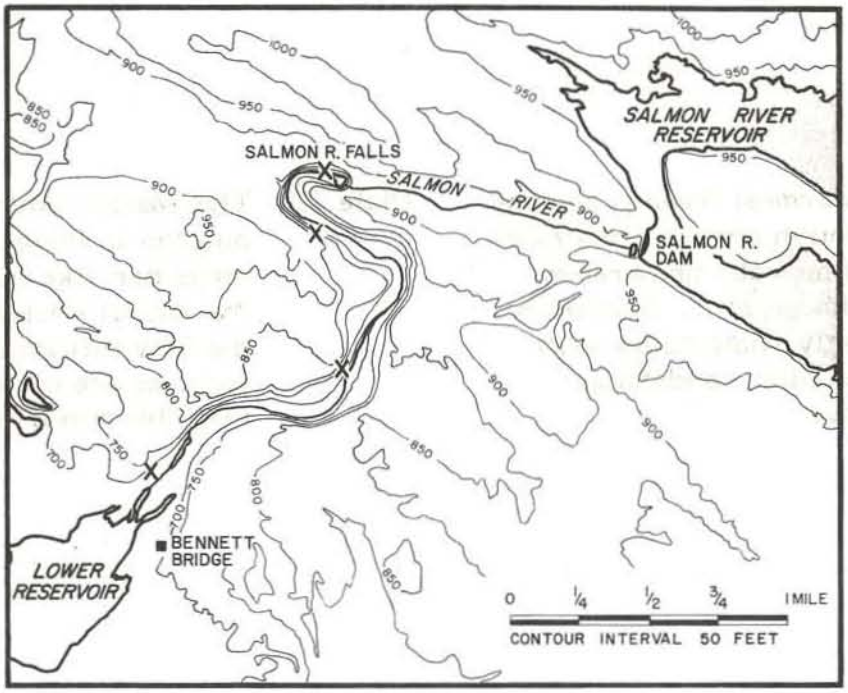


Figure 3. General topography in the vicinity of Salmon River Falls type section. Nearly continuous Oswego outcrops occur in gorge from Bennett Bridge to falls. Plates 1A and 1B are located at second X above Bennett Bridge.

Plate 1A Upper section midway through gorge, overlapping with Plate 1B. Total thickness of the Oswego in these two photos is approximately 100 ft. Thicker sandstones and minor shales dominate upper part.

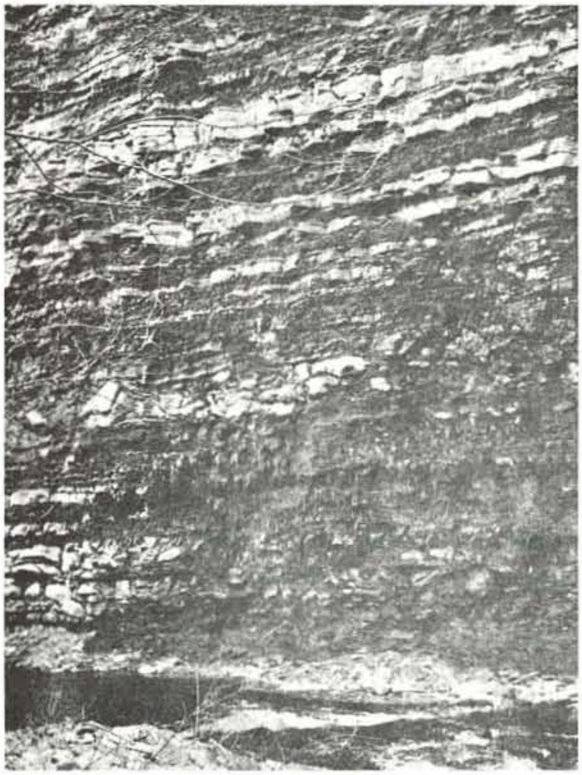
Plate 1B Lowermost Oswego midway through gorge. Two zones of flow rolls are present in lower 20 ft. Section is mostly shale below with lenticular sandstones above.

Plate 1C The Oswego outcrop east of Ninemile Point with thick sandstones at the top, hackly mudstone in the middle, and interbedded sandstones and shale in the lower part. Flow rolls and ripple-marked sandstones occur in the mudstone.

Plate 1D The eastern end of the outcrop in Plate 1C. The large bar-like feature is the lateral equivalent of the flow roll zone. Slump features are associated with this sandstone body.

A

C



B

D

bedded siltstones and very fine-grained sandstones. Sedimentary structures include flow rolls within the thick mudstones, ripple marks on some upper sandstone surfaces, and drag marks on the lower surfaces of other sandstones, trending N_3E to N_3W. The elevation at this point is approximately 650 feet, the level of the lower reservoir, whereas the base of the falls is at 750 feet, the lip is at 850 feet, and the base of the dam at the upper reservoir is at 900 feet. Thus, there are 250 feet of topographic relief in the gorge where the Oswego crops out. Due to the regional dip, however, probably only 200 to 210 feet of Oswego are represented from the lower to the upper reservoir.

The lower part of the Oswego in the gorge near the falls is predominantly gray shale with thin, lenticular gray siltstones and very fine-grained sandstones (Plate 1B). Fossils are found only in the lowermost 8 to 10 feet. Several zones of flow rolls can be observed in the lowermost shales. Other sedimentary structures include ripple marks, flute-, groove-, and load-casts, drag marks, and clay galls. The upper part of this section is more arenaceous and massive (Plate 1A). Sandstones are more prominent relative to shales, and are often cross-bedded. These uppermost beds can be examined in the river bed above the falls and consist of greenish, very fine- and fine-grained sandstone with planar cross-beds, trough cross-beds, sandstone channels, and parting lineation. Paleocurrent directions for these various structures range from $N_{26}E$ to $N_{13}W$.

Thus, there is a change not only in sandstone-shale ratio and faunal content from the lower beds in the gorge to the upper beds, but a change in associated sedimentary structures as well. The lower rocks are interpreted as having been deposited in deeper, more offshore waters than the upper beds, which are nearshore sandstones, probably deposited under the influence of tides in the intertidal zone. These upper rocks resemble those farther west at Lakeview and the atomic-power plant, whereas the lower beds resemble those at the Ninemile Point outcrop, all within the central outcrop area.

Central Area

East of Ninemile Point, thick sandstones are present in the upper 1/3 of the outcrop, with thick mudstone in the middle 1/3, and interbedded thick sandstones and shales in the lower 1/3 as traced along the shoreline of Lake Ontario (Plate 1C). Two flow-roll zones are present in the middle of the mudstone unit (Plate 1C) plus some thin sandstones with ripple-marked upper surfaces and sole marks on the lower bedding surfaces. Farther along the outcrop, the lower flow-roll zone is replaced by a large bar-like feature (Plate 1D). This sandstone body is fine-grained, cross laminated within, and contains large load casts on its lower surfaces. The maximum length is 33 feet and the maximum height is 1.5 feet. The sand body pinches out abruptly not only at each end but backwards into the outcrop. The upper surface descends at a 45-degree angle and the body extends only 2 feet back into the outcrop in the right side of Plate 1D.

The rocks in this outcrop are interpreted as having been deposited in a bar-lagoonal environment. Thin, ripple-marked sandstone lenses were deposited as occasional washover sands into the lagoon that is represented by the hackly mudstone. The thick, interbedded sandstones in the lower part of the outcrop represent the bar sands. Other nearshore sands are represented by the sandstones at the top of the section above the lagoonal muds.

Part of the reason for this interpretation is the close proximity of this outcrop with one less than a mile to the west at Ninemile Point. In that locality, 18 feet of interbedded gray sandstones and shales are present. This is a ripple-mark locality, with 12 of the upper sandstone surfaces exhibiting this sedimentary structure (Plate 2A). The average trend of the ripples is $N_{86}E$. Trace fossils, mainly feeding trails, are present on the lower surfaces of four sandstone beds. Thus, although very close to the section east of Ninemile Point, these rocks are quite different and represent a sandy, muddy, intertidal flat deposit with alternating quiet (mud) and gentle current (rippled sands) deposition. Various organisms fed on the muddy surfaces. This intertidal area would be closely associated with the bar-lagoonal deposits represented in the nearby outcrop.

Above these tidal flat and adjacent bar-lagoonal rocks are sandstone beds resembling those at the top of the type section. These were exposed just west of Ninemile Point during the excavation for Niagara Mohawk's nuclear-power plant (Plate 2B). The 60 feet of vertical section can be divided approximately into three nearly equal parts. The upper 20 feet are very lenticular, cross-bedded, fine-grained gray sandstones. Shales are minor although clay galls are common. The middle 1/3 consists of thinner, darker sandstones and some shales, with sun-crack casts and trace fossils on the lower bedding surfaces. The lower 1/3 consists of thicker, fine-grained gray sandstones with thin shale breaks. These thicker, lower beds formed the pedestal for the nuclear reactor. All of the sandstone beds at this locality probably were deposited as nearshore sands under tidal influence, with muds periodically exposed to form mud-cracks resulting in casts on the overlying sandstone sole (Plate 2C). Raindrop imprints on upper mud surfaces resulted in the formation of raindrop casts on other sandstone soles, again suggesting periodic exposure of the mud layers. Organisms that fed on these muddy surfaces have left their mark as trace fossils on still more sandstone soles.

Adjacent to these rocks just farther to the west at Lakeview, greenish-gray, irregularly bedded, trough cross-bedded sandstones jut out into Lake Ontario at lake level. The long axes of these troughs average N_7W and probably reflect the prevailing direction of the tidal currents that cut and filled them. Thus, the sandstones in the Oswego in the central area represent nearshore sand environments, which include bar, lagoon, tidal channel, and tidal flat.

Plate 2A The upper half of the Oswego outcrop at Ninemile Point. The upper crenulated sandstone surfaces are ripple marked. The entire section contains more shale than shown in this photo.

Plate 2C Sun-crack casts on a sandstone sole from the Oswego at the power plant site. Other sandstone soles in this part of the section contain raindrop imprint casts. Both of these structures suggest periodic exposure of the underlying mud surfaces.

Plate 2B Oswego Sandstone exposed during excavation for the nuclear-power plant at Ninemile Point. Lenticular sandstones are common in the upper, lighter part, with darker shales and sandstones in the middle third. The lowermost sandstones, separated only by thin shales, are more evenly bedded and form the pedestal for the reactor, seen in the lower left.

A

C

B

Western Area

Rocks in all of the western outcrops, which represent the upper half of the Oswego, are predominantly sandstones characterized by planar cross beds, trough cross beds, sandstone channels, sun-crack casts, parting lineation, some ripple marks, and abundant clay galls. Colors range from gray to green, with red beds common in the outcrops representing the uppermost Oswego beds.

Although many outcrops were studied, they can all be generalized into the following approximate vertical sequence: planar cross beds at the top; sandstone channels (Plate 3A) with parting lineation above the channels; trough cross beds; sun-crack casts; more planar cross beds; and a lower series of trough cross beds. Trace fossils are also common in most outcrops. The complete vertical sequence as outlined above can be observed in outcrops along the beach behind the State University of New York College at Oswego campus. That particular section is near the top of the Oswego and contains abundant red beds although many of the trough cross beds are gray sandstones of fine- to nearly medium-grain size which cut into red very fine-grained sandstones, siltstones, and shales (Plate 3B). These are interpreted as tidal-channel and tidal-flat deposits, respectively. All of the outcrops west of the campus to West Lake Road and Camp Hollis exhibit these same features and are interpreted as tidal-channel and tidal-flat deposits. The main variation is in color, with Oswego sediments at West Lake Road, stratigraphically higher than the red beds at the campus, being green, and those at Camp Hollis, near the Oswego-Queenston contact, being red with green mottles. The rocks at Camp Hollis, however, have an association of sedimentary structures typical of the Oswego including trough cross beds (Plate 3C), sandstone channels, planar cross beds, and parting lineation and are correlated as such. Thus, all of the rocks in the upper Oswego west of St. Paul's Cemetery are interpreted as tidal channel and tidal flat. Alluvial sediments may be interbedded with these intertidal deposits, but evidence of possible alluvial deposits could only be observed in one small area, and is not pursued in this short paper. Furthermore, the outcrop at St. Paul's Cemetery is not described in this paper, but it does contain a very interesting channel deposit previously described (Patchen, 1966). That particular channel is similar to those described by Van Straaten (1954) in the Psammites du Condroz (Devonian) in the Belgian Ardennes, which he interprets as of intertidal origin.

Stratigraphic Summary

Figure 4 illustrates the summary of both stratigraphic and environmental interpretations for the scattered Oswego outcrops in the study area. Three composite sections are shown with the correlation from the east to the central area based on the highest occurrence of fossils and a change in sandstone-shale content. The lowest, fossiliferous, lenticular sandstones, siltstones, and shales are interpreted as offshore shelf deposits, whereas the sandstones

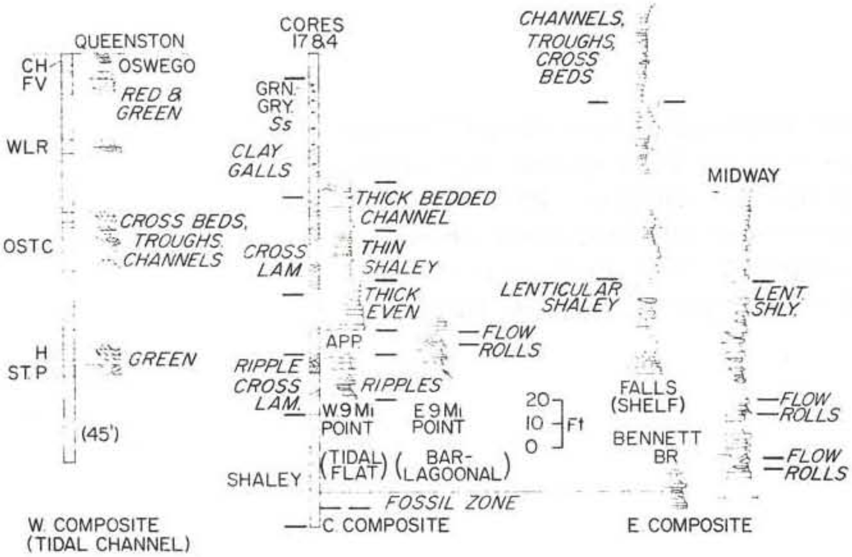


Figure 4. Summary of the sedimentary structures, bedding characteristics, lithologies, and colors for the Oswego Sandstone in the study area. Three composite sections are shown, plus a composite core description adjacent to the central composite. The correlation from that section to the east is on the fossil zone. Interpreted environments are in parentheses. Abbreviations by the western composite correspond to measured sections named in Figure 2.

and mudstones higher in the section east of Ninemile Point are interpreted as bar and lagoon. Ripple-marked intertidal sandstones with interbedded shales at Ninemile Point are interpreted as tidal-flat deposits adjacent to this bar-lagoon complex. These rocks are overlain by a thick sequence dominated by nearshore intertidal sandstones of tidal-channel and tidal-flat origin. In Figure 4 it should be noted that the western composite occurs stratigraphically above the central composite, but is shown in the proper lateral perspective. Red beds are common in the upper Oswego, which is transitional with the overlying Queenston (Juniata facies) red reds.

PETROGRAPHIC SUMMARY

Briefly, some results of the petrographic study can be summarized by referring to Figure 5. Thin-section data from the Oswego samples are shown in the lower part of this figure. Within these samples, collected from a 140-foot vertical interval in Core 17 plus western outcrops in the upper Oswego, grain size gradually increases upward as shown. The sorting and roundness of the quartz grains also increase upward. This relationship of rounded versus angular quartz grains has been emphasized by a pattern in Figure 5 and

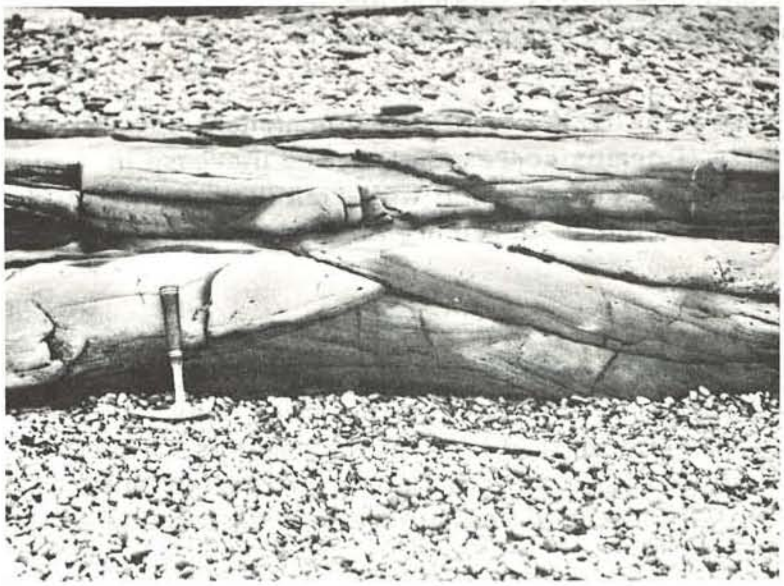
Plate 3A Sandstone channels in red Oswego beds at the State University College at Oswego campus. Parting lineation is common on sandstones above the channels. The average channel is 3-4 ft. wide and 1-1½ ft. high.

Plate 3B Trough cross beds in a gray sandstone at the campus outcrop. This trough cross-bedded zone is generally 3-5 ft. below the channels in Plate 3A. The troughs in this zone average 10-15 ft. in width, 2-3 ft. in thickness, and 25 ft. in length. Bedding conforms to the lower surface and pebble-lag deposits are common.

Plate 3C Overlapping trough cross beds at Camp Hollis in red Oswego beds. Channels, planar cross beds, and sun-crack casts also were observed at this locality. These are the uppermost Oswego beds exposed in the study area.


A


B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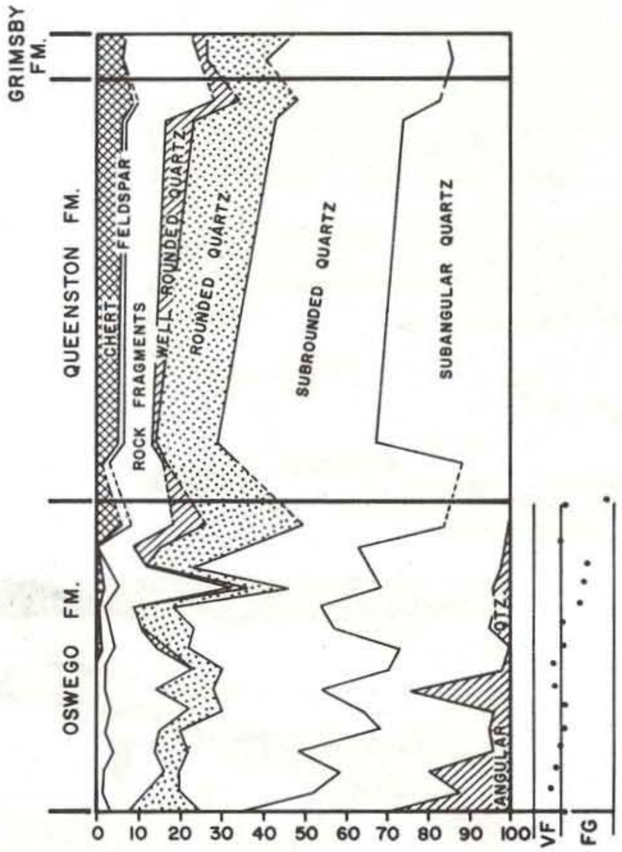

Figure 5. Summary of the thin sections studied from Cores 4 and 17 and uppermost Oswego outcrops. Textural data are emphasized. Grain size increases upwards from very fine (VF) to fine grained (FG). Roundness also increases upward. The overall low roundness, high rock fragment content, and clay matrix suggest low energy levels for Oswego deposition.

may suggest an increase in energy of the depositional environment upward. However, the introduction of chert grains corresponds to the increase in roundness. Therefore, some of these rounded and well-rounded grains could be inherited from a reworked sedimentary source area that also supplied the chert grains.

Although not shown in Figure 5, clay matrix increases with depth to a slight degree, and calcite cement increases with depth relative to quartz overgrowths. Hematite coatings are abundant in the uppermost red beds. Metamorphic rock fragments are common in most of the Oswego samples. These are well rounded and are considered to be indicators of a low-energy environment. Thus, the sum total of the textural and mineralogic data yields an overall picture of low-energy environments in the Oswego, compatible with those previously described.

SOURCE AREA AND PALEOCURRENTS

More than 250 paleocurrent measurements were made at the various outcrops and are plotted in Figure 6. The rose diagram indicates a strong northward trend with minor lobes just to the east and west. The bimodal nearly east-to-west direction is due to the many ripple marks measured. The axes of these ripples should parallel the shorelines and be perpendicular to tidal

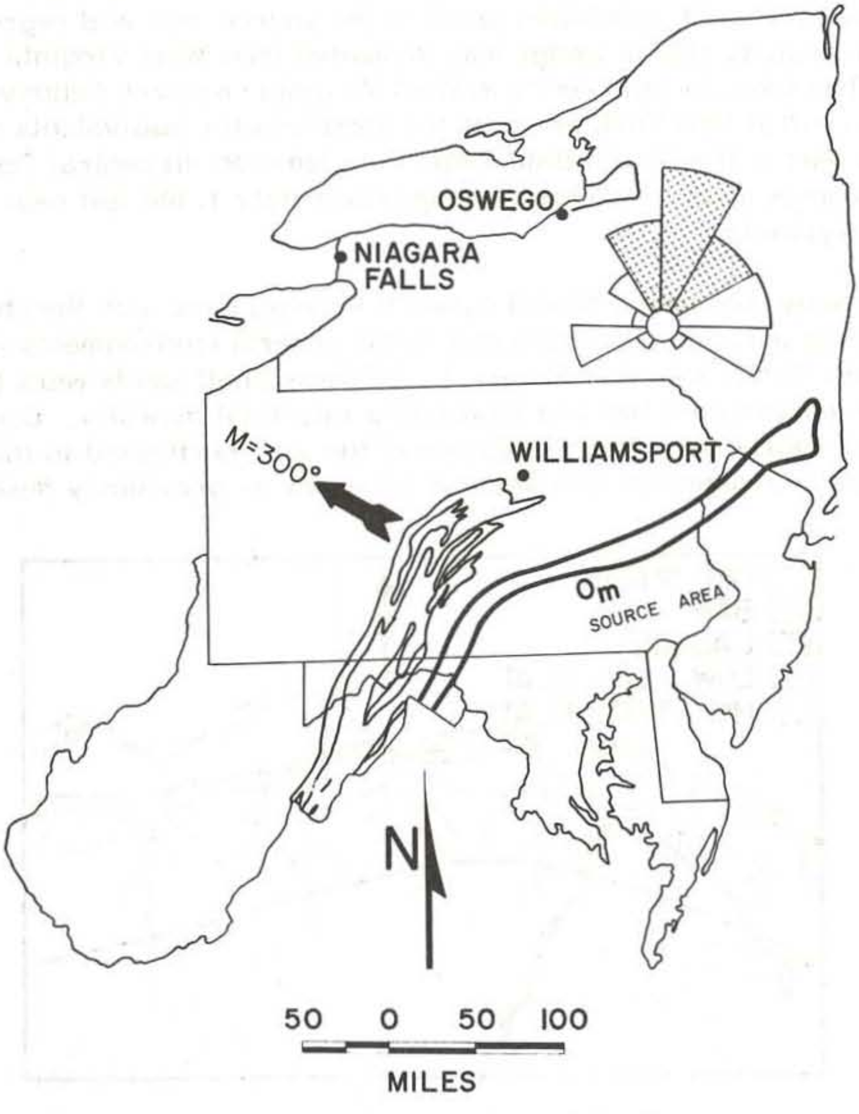

Figure 6. Rose diagram of Oswego paleocurrents in Oswego County outcrops, plus an arrow showing Yeakel's (1962) average trend for the Bald Eagle in central Pennsylvania. Bold line near Om is the Martinsburg Shale outcrop just northwestward from the suggested source area. Oswego outcrops are also shown in West Virginia.

currents that cut and filled sandstone channels and trough cross beds. All of these data are tabulated and illustrated by individual outcrops in the previous study (Patchen, 1966). This general paleocurrent direction can be projected back to the south until it intersects a similar projection made from Yeakel's (1962) Bald Eagle (Oswego) measurements in central Pennsylvania. This pinpoints the source area in southeastern Pennsylvania eastward of the present Martinsburg Shale outcrop area. As the Taconic Orogeny began, sediments from this source area moved southwestward toward West Virginia, westward into central Pennsylvania, and northward toward Oswego County, New York. Initially, clastic material was concentrated in central Pennsylvania (Bald Eagle); however, with continued uplift in the source area and regression of the sea, an arcuate clastic wedge was deposited from West Virginia to Lake Ontario. The Oswego sandstones in West Virginia, western Pennsylvania, and north-central New York are thus the stratigraphic equivalents of the uppermost part of the fluvial Bald Eagle Conglomerate in central Pennsylvania. Those sediments attain a thickness of approximately 1,300 feet near Williamsport, Pennsylvania.

The Oswego sediments moved outward keeping pace with the shoreline of the retreating sea and were deposited in the general environments in Oswego County, New York, shown in Figure 7. Offshore shelf sands were laterally equivalent to nearshore bar and lagoon and intertidal deposits. Continued uplift in the source area and regression of the sea, northward in this area, placed these environments in a vertical sequence as previously described,

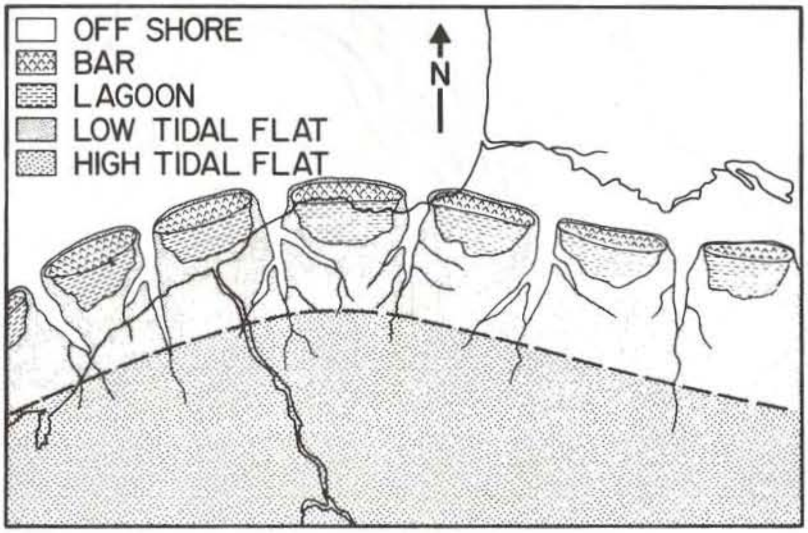

Figure 7. Generalized depositional environments for the Oswego in the study area, ranging from offshore to tidal flat. Large tidal channels cut through these tidal flats. The present shoreline of Lake Ontario and the Salmon and Oswego Rivers are shown for geographic reference.

yielding the coarsening-upward, offshore-to-nearshore sands with faunal and color changes typical of the Oswego vertical sequence. With continued regression, these uppermost Oswego tidal-channel and tidal-flat sediments were overlain, in turn, by red fluvial-deltaic deposits of the Queenston Delta.

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