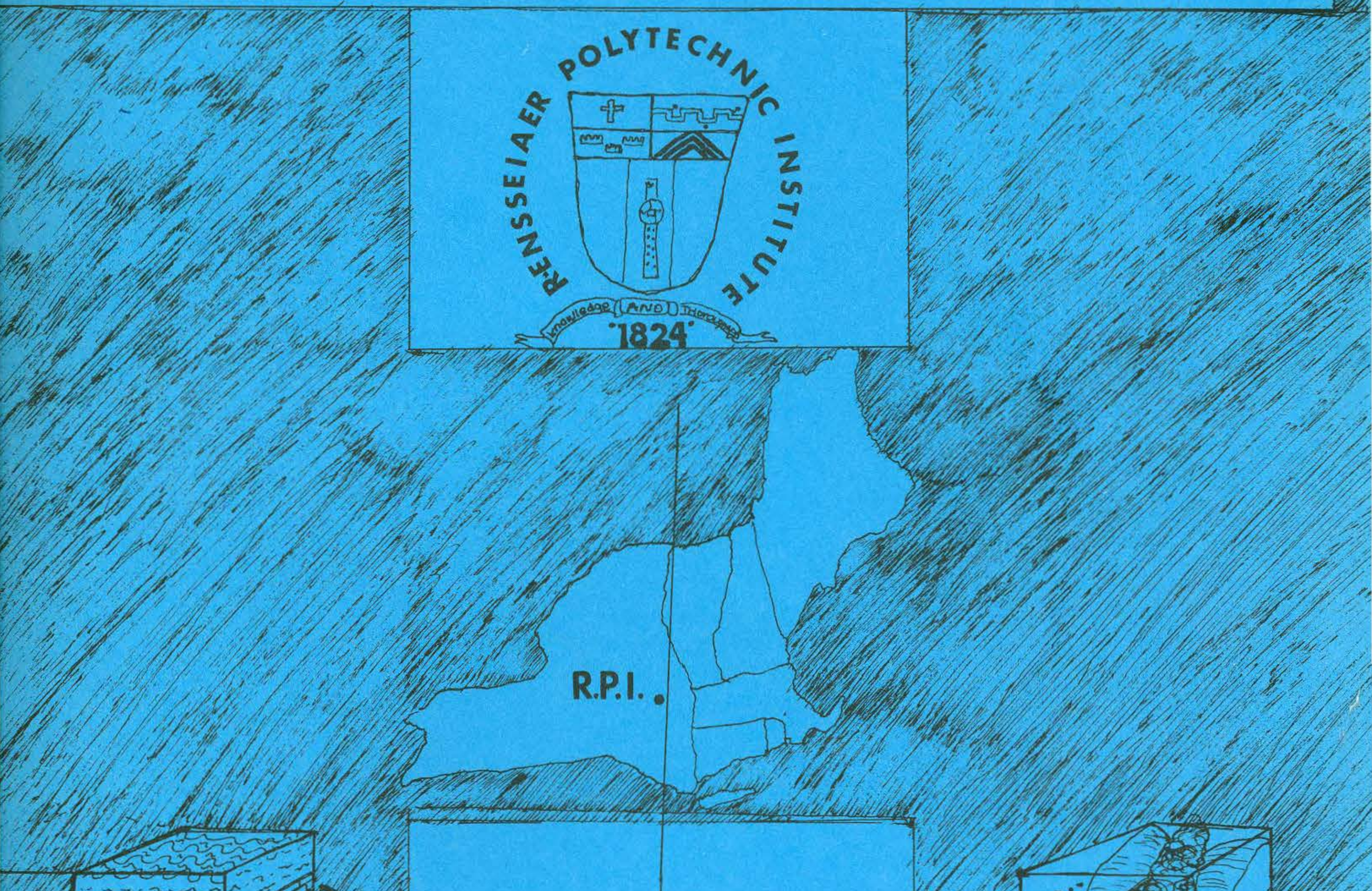
Rensselaer
Polytechnic
Institute

Guidebook

For Fieldtrips

New York State
Geological
Survey



New York State
Geological
Association

51st annual meeting

Joint Annual Meeting

October 5,6,7, 1979

New England
Intercollegiate
Geological Conference

71st annual meeting

E. Brown

JOINT ANNUAL MEETING OF

NEW YORK STATE GEOLOGICAL ASSOCIATION

51st Annual Meeting

and

NEW ENGLAND INTERCOLLEGIATE GEOLOGICAL CONFERENCE

71st Annual Meeting

TROY, NEW YORK

October 5, 6, and 7, 1979

GUIDEBOOK

Gerald M. Friedman, *editor*

Hosts:

Department of Geology
Rensselaer Polytechnic Institute
Troy, New York 12181

and

New York State Geological Survey
Cultural Education Center
Empire State Plaza
Albany, New York 12230

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PREFACE AND ACKNOWLEDGEMENTS

It is a pleasure to welcome all of you to the joint annual meeting of the New York State Geological Association and the New England Intercollegiate Geological Conference. A fine program has been arranged for you. Two overlapping sessions have been planned for October 5, a full-day Symposium on Sedimentary Strata and Tectonic Movements and concurrent workshops for earth-science teachers. Field trips have been scheduled for October 6 and 7 to classical sites of eastern New York State and adjoining New England. Have fun on your field trips.

I wish to extend my thanks to the authors and field-trip leaders for their contributions. Students and staff of the Department of Geology of Rensselaer Polytechnic Institute have given time and effort in preparing for this meeting. Credit for the success of this meeting goes likewise to the New York State Geological Survey, especially to R.H. Fakundiny.

Gerald M. Friedman, President
New York State Geological Association
Department of Geology
Rensselaer Polytechnic Institute
Troy, New York 12181

FIELD TRIPS

October 6 (SATURDAY)

The list below is that of the original schedule announced in April-May 1979. By the time this field guidebook comes off the press some of the originally planned field trips may have been cancelled. Please make sure that you join the field trip to which you have been assigned space.

A-1	Early and Medial Devonian Stratigraphy and Paleoenvironments in east-central New York: leader, Donald W. Fisher, N.Y. State Geological Survey, N.Y. State Museum
A-2	Sedimentary Environments and Their Products: Shelf, Slope and Rise of Proto-Atlantic (Iapetus) Ocean, Cambrian and Ordovician Periods, Eastern New York State: leader, Gerald M. Friedman, Rensselaer Polytechnic Institute
A-3	Sedimentary Environments in Glacial Lake Albany and Its Successors on the Albany, Delmar, Niskayuna, and Voorheesville 7 1/2 minute quadrangles: leaders, Robert J. Dineen and William B. Rogers, New York State Geological Survey, New York State Museum & Science Service
A-4	Structural Framework of the Southern Adirondacks: leader, James McLelland, Colgate University
A-5	Microstructure of a Vermont Slate, an Adirondack Gneiss, and Some Laboratory Specimens: leaders, W.D. Means, SUNY, Albany, and M.B. Bayly, Rensselaer Polytechnic Institute
A-6	Studies of Cleavage and Strain in the Shaly Rocks of the Cossayuna - Salem Area, Washington County, New York: leader, Lucian B. Platt, Bryn Mawr College
A-7	Thrust Sheets of the Central Taconic Region: leader, Donald B. Potter, Hamilton College
A-8	Detailed Stratigraphic and Structural Features of the Giddings Brook Slice of the Taconic Allochthon in the Granville Area: leaders, D.B. Rowley and W.S.F. Kidd, State University of New York at Albany
A-9	Sedimentology of a Transgressive Clastic Wedge Within the Marcellus Formation (Middle Devonian) in Southeastern N.Y.: leaders, Fred Wolff, Hofstra University, and Peter Buttner, New York State Department of Parks and Recreation
A-10	Faults, Stratigraphy, and the Mineral Waters of Saratoga: Implications for Neogene Rifting: leaders, J.R. Young, State University of New York at Albany, and Dunn Geoscience Corp., and G.W. Putman, State University of New York at Albany

October 7 (SUNDAY)

The list below is that of the original schedule announced in April-May 1979. By the time this field guidebook comes off the press some of the originally planned field trips may have been cancelled. Please make sure that you join the field trip to which you have been assigned space.

B-1	Economic Geology of the Hudson River Valley: leaders, G.M. Banino and W.E. Cutcliffe, Dunn Geoscience Corporation
B-2	Stratigraphic and Paleoenvironmental Problems of the Middle Ordovician Black River - Trenton Limestones in the Eastern Mohawk Valley, New York: leaders, Barry Cameron and Ewa Newman, Boston University, and D.W. Fisher, Geological Survey, New York State Museum (CANCELLED)
B-3	Eurypterid Horizons and Stratigraphy, Lower Devonian, Eastern New York State: leader, S.J. Ciurca, Jr., Rochester (CANCELLED)
B-4	Sedimentary Environments in Glacial Lake Albany and its Successors on the Albany, Delmar, Niskayuna, and Voorheesville 7 1/2 Minute Quadrangles: leaders, R.J. Dineen and W.B. Rogers, New York State Geological Survey, New York State Museum & Science Service (CANCELLED)
B-5a	Geology in State Service: leaders, William Lilley, New York State Department of Public Service, Robert Fakundiny, New York State Geological Survey, Peter Buttner, New York State Dept. of Parks and Recreation, Kernan Davis, New York State Dept. of Environmental Conservation, George Toung, and Frank Irving, New York State Dept. of Transportation
B-5b	The Building Stones of the Nelson A. Rockefeller Empire State Plaza: leaders, R.H. Fickies and R.J. Dineen, Geological Survey/State Museum
B-6	Stratigraphy of Glacial Lakes Albany, Quaker Springs, and Coveville, and Relationships to Late Woodfordian Mohawk and Hoosick River Discharge History: leader, R.G. LaFleur, Rensselaer Polytechnic Institute
B-7	Stratigraphy and Depositional History of the Onondaga Limestone in Eastern New York: leader, R.H. Lindemann, Skidmore College and Rensselaer Polytechnic Institute
B-8	Structural Framework of the Southern Adirondacks: leader, James McLelland, Colgate University (Repeat of A-4)
B-9	Microstructure of a Vermont Slate, an Adirondack Gneiss, and some Laboratory Specimens: leaders, W.D. Means, SUNY, Albany, and M.B. Bayly, Rensselaer Polytechnic Institute (Repeat of A-5)

B-10 Thrust Sheets of the Central Taconic Region: leader, Donald B. Potter, Hamilton College (Repeat of A-7)

B-11 Recent Structural Investigations in N.W. Massachusetts for the New Bedrock Geologic Map of Massachusetts: leader, Nick Ratcliffe, U.S. Geological Survey, Reston

B-12 Precambrian Structure and Stratigraphy of the Southeastern Adirondack Uplands: leader, Brian B. Turner, George Mason University

B-13 Late Wisconsinan - Recent Geology of the Lower Rondout Creek Valley, Ulster County, Southeastern New York: leader, R.H. Waines, SUNY, College at New Paltz

B-14 Faults, Stratigraphy, and the Mineral Waters of Saratoga: Implications for Neogene Rifting: leaders, J.R. Young, State University of New York at Albany, and Dunn Geoscience Corp., and G.W. Putman, State University of New York at Albany (Repeat of A-10)

GEOLOGY AT RENSSELAER: A HISTORICAL PERSPECTIVE

Address of the Retiring President of the New York State Geological Association

Gerald M. Friedman
Department of Geology, Rensselaer Polytechnic Institute
Troy, New York 12181

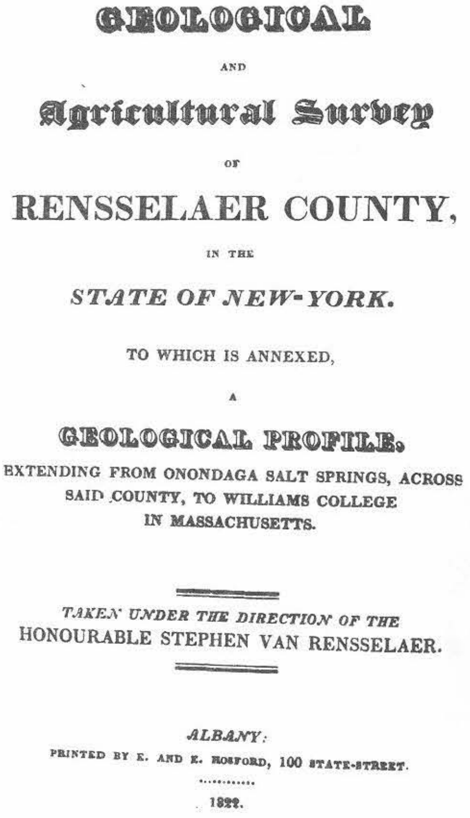
Geology is a tradition at Rensselaer. As R.P. Baker (1930) assessed the first one hundred years of the history of R.P.I., he emphasized "in Geology and Mineralogy, of course, Rensselaer was long supreme. From those connected with the Institute came the first standard texts -- the first, you may be interested to know, in which figures and plates were used to supplement the text -- and from them also came the first epoch - making reports. Indeed, approximately half of the notable developments in these two subjects before 1850 were due to graduates of the Institute. They were responsible for the official surveys of Alabama, Delaware, Iowa, New Jersey, New York, North Carolina, South Carolina, Michigan and Wisconsin. In other states their advice and assistance were hardly less useful. Moreover, in a number of colleges and endowed universities as well as in the State universities of Alabama, Iowa, Michigan and Wisconsin, they established a tradition of research, which has been honorably maintained by their successors."

The founder and first senior professor of Rensselaer Amos Eaton has been acclaimed as the Father of American Geology (Fig. 1). Hence geology was allotted prominence early at Rensselaer, as shown on a circular of 1827, which reads "it is now required that each student take two short mineralogical tours to collect minerals for his own use, for the purpose of improving himself in the science of mineralogy and geology." Founded in 1824, incidentally in the same year in which Eaton introduced the term birdseye texture for

Fig.1. Amos Eaton, founder of American geology as well as founder and first senior Professor of the Rensselaer School, later to become known as Rensselaer Polytechnic Institute.

some kinds of limestones (an important descriptive feature still known by this same term today), the advancement of American geology was stimulated in large measure by the strong science curriculum at R.P.I., then known as the Rensselaer School. The school was extremely strong in the geological sciences. By 1860, as an example, seven state geological surveys were headed by graduates of Rensselaer, a number exceeding that of any other university in the United States.

Before the Rensselaer School was founded Eaton completed geological surveys of Albany and Rensselaer Counties (Fig. 2), commissioned by the New York State Agricultural Society, but paid for by the philantropic patroon Stephen Van Rensselaer, eighth and last patroon of a landed estate. Van Rensselaer also supported Eaton's geological survey of the territory adjoining the Erie Canal route during 1823-1824. In 1818 Eaton published a textbook, <u>An Index to the Geology of the Northern States</u> (Fig.3).



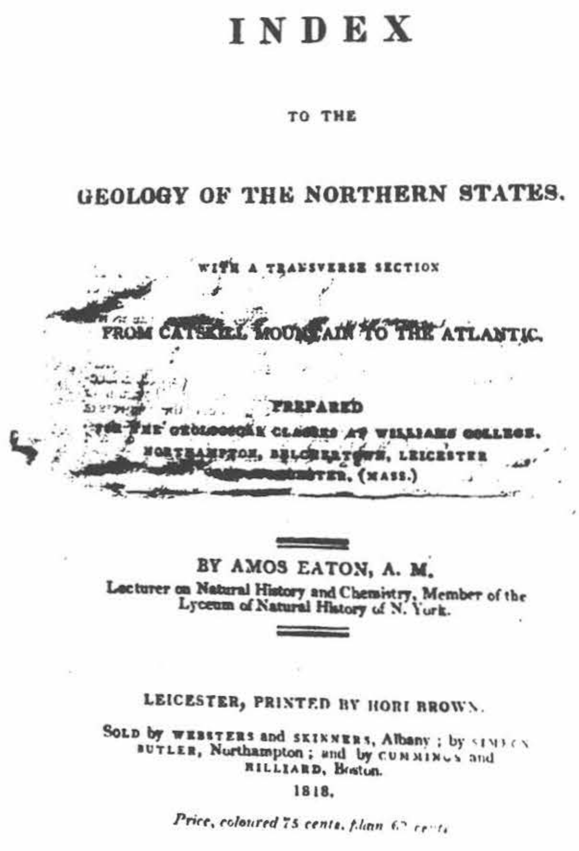
GEOLOGICAL
AND
Agricultural Survey
OF
RENSSELAER COUNTY,
IN THE
STATE OF NEW-YORK.
TO WHICH IS ANNEXED,
A
GEOLOGICAL PROFILE,
EXTENDING FROM ONONDAGA SALT SPRINGS, ACROSS
SAID COUNTY, TO WILLIAMS COLLEGE
IN MASSACHUSETTS.

TAKEN UNDER THE DIRECTION OF THE
HONOURABLE STEPHEN VAN RENSSELAER.

ALBANY:
PRINTED BY E. AND E. HOSFORD, 100 STATE-STREET.
1822.

Fig. 2. Title page of Amos Eaton's geological survey of Rensselaer County(1822); this study was supported by Stephen Van Rensselaer. Amos Eaton's name does not appear on the title page. In the preface he addressed Van Rensselaer (p. vii) "with the ardent hope that my efforts may not have fallen short of your expectations, and that the following report may be useful to those for whom it was intended, I subscribe myself, Your grateful humble Servant, Amos Eaton."

In this book Eaton not only incorporated a time and rock classification scheme, but also introduced a local guidebook, and published a cross section extending from the Atlantic Ocean to the Catskill Mountains (Fig. 4). In 1824 Eaton appealed to Van Rensselaer for $300 as part of the effort to establish the Rensselaer School in Troy. Van Rensselaer provided these funds immedieatly and continued his financial support until 1829 when he ceased direct support of the school. Despite a heavy load of teaching and administration



INDEX

TO THE

GEOLOGY OF THE NORTHERN STATES.

WITH A TRANSVERSE SECTION

FROM CATSKILL MOUNTAIN TO THE ATLANTIC.

PREPARED

FOR THE GEOLOGICAL CLASSES AT WILLIAMS COLLEGE.

NORTHAMPTON, BELCHERTOWN, LEICESTER

[illegible] WORCESTER, (MASS.)

BY AMOS EATON, A. M.

Lecturer on Natural History and Chemistry, Member of the Lyceum of Natural History of N. York.

LEICESTER, PRINTED BY HORI BROWN.

SOLD by WEBSTERS and SKINNERS, Albany; by SIMEON BUTLER, Northampton; and by CUMMINGS and HILLIARD, Boston.

1818.

Price, coloured 75 cents, plain 62 cents

Fig. 3. Title page of Amos Eaton's Index to the Geology of the Northern States (1818).

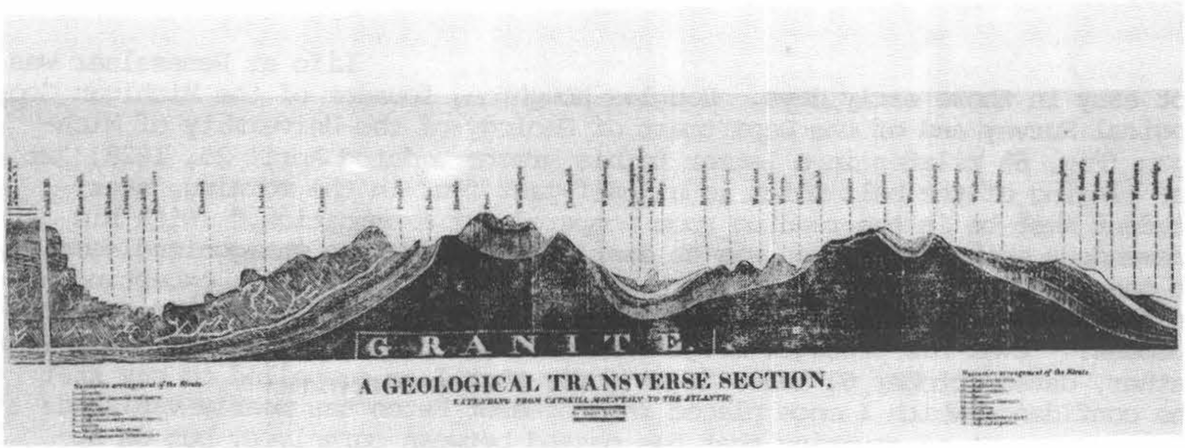
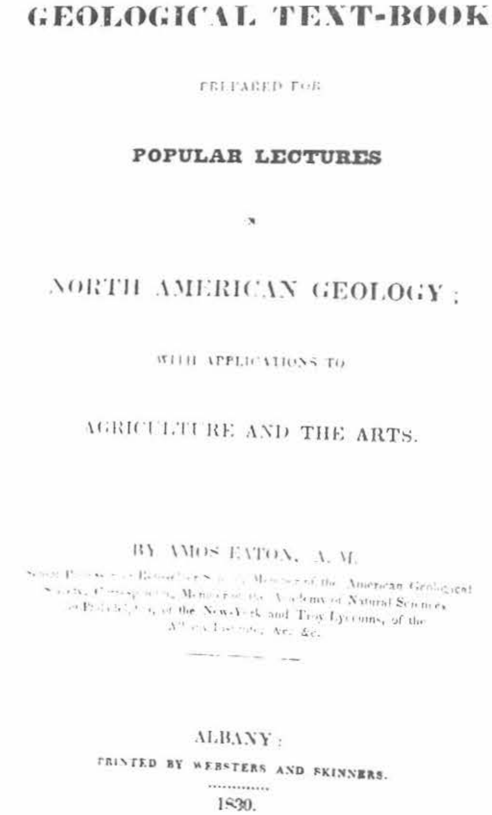


Fig. 4. Amos Eaton's section across the Appalachians extending from the Atlantic Ocean to the Catskill Mountains (1818).

Eaton published in 1830 a Geological Text-Book, Prepared for Popular Lectures on North American Geology (Fig. 5); its second edition appeared in 1832. In the second edition Eaton emphasized the importance of field work, a tradition still cherished at Rensselaer: students: "must be shown the nearest rocks, from day to day."



GEOLOGICAL TEXT-BOOK,

PREPARED FOR

POPULAR LECTURES

ON

NORTH AMERICAN GEOLOGY;

WITH APPLICATIONS TO

AGRICULTURE AND THE ARTS.

BY AMOS EATON, A. M.

ALBANY:
PRINTED BY WEBSTERS AND SKINNERS.
....
1830.

Fig. 5. Title page of Amos Eaton's Geological Text-Book, first edition (1830).

Eaton took his students on long field excursions into the mountains of New England and along the Erie Canal in the "Rensselaer School Flotilla." At the time of his death in 1842 Eaton had become the most influential American geologist. In 1841 Sir Charles Lyell, father of British geology, made his pilgrimage to visit Eaton at Rensselaer. Eaton likewise received the respects of the Rev. William Buckland, the first professor of mineralogy and geology in the University of Oxford, England. In American geology the period between 1818 and 1836 is known as the "Eatonian Era."

Life at Rensselaer was not easy in those early days. Douglas Houghton, founder of the Michigan Geological Survey and of the Department of Geology of the University of Michigan (Fig. 6) relates in a letter to his brother, dated April 25, 1829, "at the ringing of the bell which is at half-past four in the morning, every student must be in the reading room prepared for examination." With his tremendous enthusiasm Eaton was an inspiring man, yet he antagonized some. In one letter he wrote, "I do not aspire at anything original, excepting in the geology of this country. On this point I am vain of my industry and success." Even his protege, Douglas Houghton, stated in a letter to his father, dated October 6, 1830, "I am sorry that I am compelled to say that the confidence which I once placed in Professor Eaton has nearly vanished; not on account of anything that has passed between ourselves, but on account of his conduct to the students of the last class. The students supported the insults heaped upon them, as long as possible, but it terminated in complete rebellion."

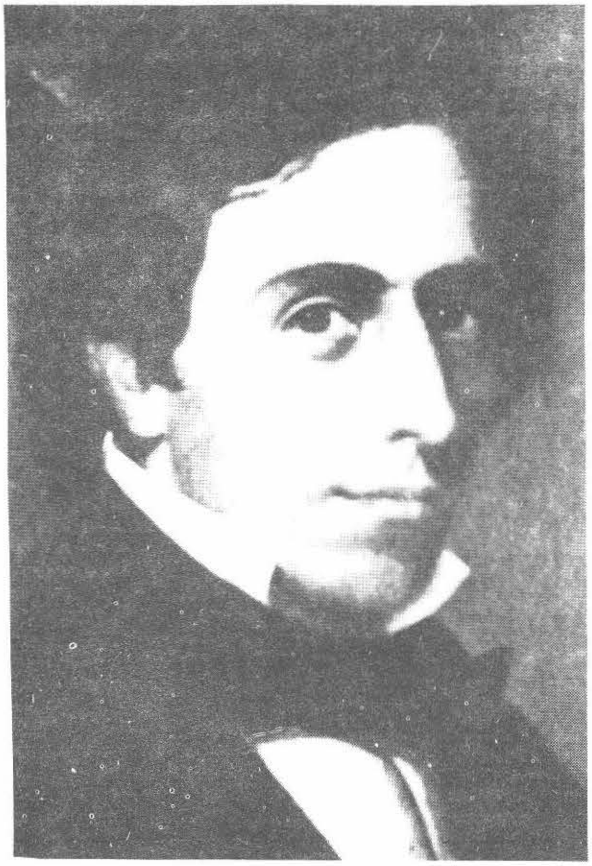


Fig. 6. Douglas Houghton, alumnus and professor of geology at Rensselaer, and later founder of the Michigan Geological Survey and of the geology program at the University of Michigan.

From Rensselaer students carried the geological banner far and wide. In 1830 some patrons of science in Michigan, including General Cass, then governor of Michigan, and Lucius Lyon, Member of Congress, asked Professor Eaton to recommend a lecturer. Lyon, in fact, specifically for this purpose came to Rensselaer. After listening to Lyon, Eaton opened a door adjoining his office and presented his young protege, Houghton. "Mr. Lyon, a man of reserve and much dignity, was surprised at such a presentation. He could hardly believe Professor Eaton in earnest - proposing to send a boy, still in his teens, to discourse on subjects of science, and to address mature men of culture" (Wallin, 1970, p. 3). Retaining his professorship at Rensselaer, Houghton moved to Michigan where his accomplishments not only included founding member and Treasurer of what was to become the American Association for the Advancement of Science as well as founder of the Michigan Geological Survey and the Department of Geology at the University of Michigan, but also Mayor of the city of Detroit. At the age of 36 he drowned on a geological survey in Lake Superior. The Michigan city of Houghton has been named in his honor.

Eaton's successor as senior professor, an office which today incorporates the presidency of the Institute, was George H. Cook, who later became founder of the New Jersey Geological Survey and founder of the Department of Geology of Rutgers University (Fig. 7). Following him in 1850 was Benjamin Franklin Greene, who changed the name to Rensselaer Polytechnic Institute, and divided its academic program into three departments: geology, chemistry and engineering.

Among the most influential alumni of Rensselaer was James Hall, the Father of the Geosyncline (Fig. 8). In 1857 (published in 1859) Hall

Fig. 7. George H. Cook, Eaton's successor as senior professor at Rensselaer and later founder of the New Jersey Geological Survey and of the Department of Geology of Rutgers University.

Fig. 8. James Hall, alumnus and professor of geology at Rensselaer (see Fig. 9), state geologist and state paleontologist of New York, father of the geosyncline, father of American stratigraphy, and father of American paleontology.

"observed that, where the Paleozoic marine strata are thin (thicknesses of only a few hundreds or few thousands of meters), they are flat lying. In contrast within the Appalachians, where strata of the same ages are present, thicknesses of equivalent strata amount to tens of thousands of meters and the strata are not horizontal. Hall hypothesized that the subsidence of the strata within a trough, where they would be extra thick, provided the mechanism for folding them" (Friedman and Sanders, 1978, p. 435). In 1873, James Dwight Dana modified this concept and introduced the term geosyncline. Hall has likewise become known as Father of American Stratigraphy and Father of American Paleontology. Hall earned his Bachelor of Natural Science (1832) and the Master of Arts (1833) degrees at Rensselaer. Probably no other single person exerted a more influential role in the development of paleontology in North America.

Hall is alleged to have literally walked 220 miles from his home in Hingham, Massachusetts, to Rensselaer so that he might enroll and study under the great Eaton. Hall's first job at Rensselaer included whitewashing one of its buildings and tidying up the school; later he became librarian, and by 1835 he was listed as a full professor. Persuaded by Eaton the New York State Legislature established a Geological and Natural History Survey in 1836 to which James Hall was appointed. Hall remained loyal to Rensselaer and gave preference in employment to Rensselaer graduates. Rensselaer alumni George Boyd, Ezra Carr, and Eben Horsford distinguished themselves by mapping 17 1/2 counties or approximately one quarter of the state of New York on foot and horseback over a four-year span. Hall remained on the R.P.I. faculty on a part-time basis for almost 70 years; he was listed as Professor of Theoretical, Practical, and Mining Geology. A plaque on Hall Residence Hall, one of the freshmen dormitories currently in use, attest to his devotion to Rensselaer (Fig. 9). Hall put together an outstanding geologic collection for which the alumni donated the funds to provide the building, known as the Cabinet Building. By 1898, the year of his death, Hall had published 42 books and 260 papers. His 13 volumes of Paleontology of North America remain as a monument to his dedication.

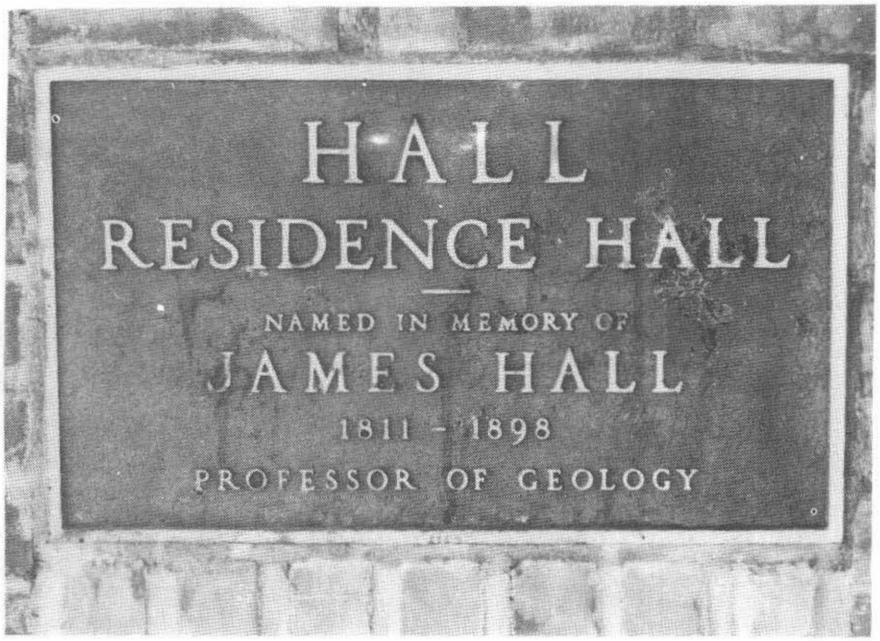


Fig. 9. A grateful R.P.I. named a residence hall, known on Campus as Hall Hall, in James Hall's honor and provided a plaque near entrance to "Hall Hall."

Another early alumnus who became a giant in the nineteenth century was Ebenezer Emmons (Fig. 10). A graduate of Rensselaer in the first class of 1826, Emmons had been inspired by Eaton. Emmons became Junior Professor at Rensselaer, a position he held for ten years, and a member of the New York State Geological Survey in 1836. Later he was state geologist of North Carolina, spreading Rensselaer's influence in American geology through his texts and advocacy of the Taconic system (Fig. 11).

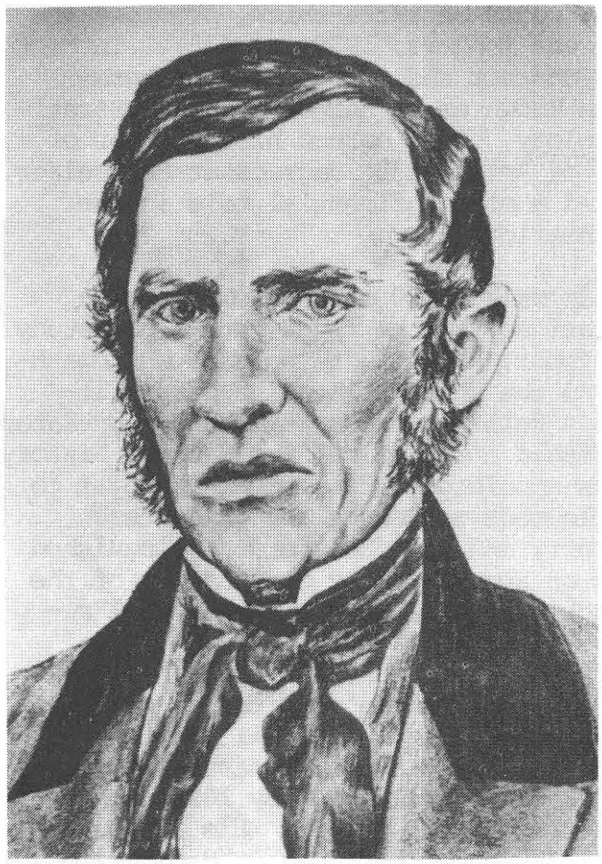


Fig. 10. Ebenezer Emmons, alumnus and Junior Professor at Rensselaer, member of the New York State Geological Survey, founder of the North Carolina Geological Survey, and State Geologist of North Carolina; father of the Taconic System.

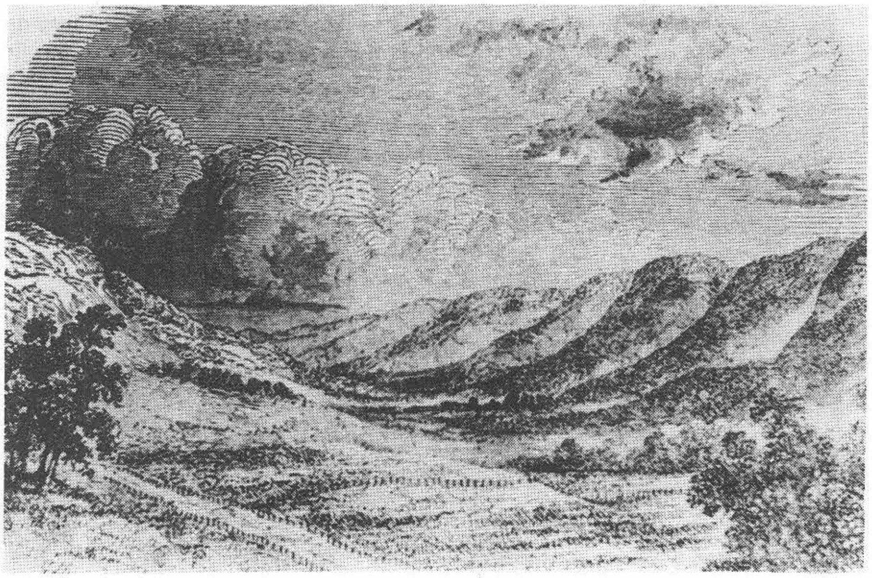
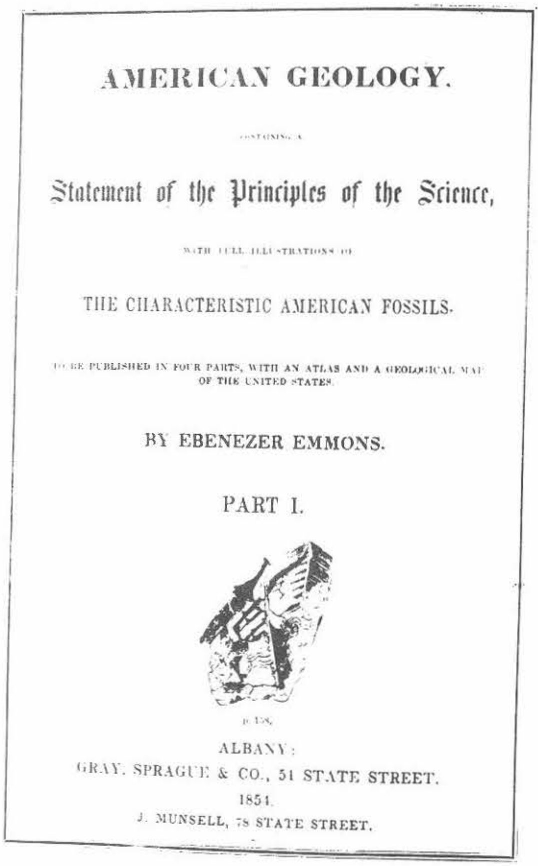


Fig. 11. Drawing of part of the Taconic Range published in one of Emmons' classical studies (Emmons, 1848, p. 75).

Emmons had noted the presence of a group of rocks between the Potsdam Sandstone, the lowest of the sedimentary formations in New York and what was at the time called the Primitive Rocks of Central Vermont. This interval he proposed to call the Taconic System. Emmons acquainted the public with the Adirondack region and gave the names to principal mountains. Classics which Emmons published include Manual of Mineralogy and Geology (1826), Report on the Second Geological District of New York (1842), Natural History of New York (1848), American Geology Containing a Statement of Principles of the Science With Full Illustrations of the Characteristic American Fossils (1854) (Fig. 12), Treatise Upon American Geology (1854), The Swamplands of North Carolina (1860), and Textbook of Geology (1860).



AMERICAN GEOLOGY.

CONTAINING A

Statement of the Principles of the Science,

WITH FULL ILLUSTRATIONS OF

THE CHARACTERISTIC AMERICAN FOSSILS.

TO BE PUBLISHED IN FOUR PARTS, WITH AN ATLAS AND A GEOLOGICAL MAP
OF THE UNITED STATES.

BY EBENEZER EMMONS.

PART I.

p. 158.

ALBANY:
GRAY, SPRAGUE & CO., 51 STATE STREET.
1854.
J. MUNSELL, 78 STATE STREET.

Fig. 12. Title page of Emmons' American Geology (1854).

Louis C. Beck was appointed Junior Professor at Rensselaer in 1824 when the school opened, but resigned in 1828 and became state mineralogist of New York in 1836.

As matters stood by 1860 in state geological surveys of the United States, the following Rensselaer alumni held positions of responsibility: New Jersey, G.H. Cook; Virginia C. Briggs, Jr.; New York, E. Emmons, J. Hall, E.S. Carr, E. Horsford, G. Boyd; Pennsylvania, J.C. Booth; Ohio, C. Briggs, Jr.; Delaware, J.C. Booth; Michigan, D. Houghton; South Carolina, M. Tuomey; Alabama, M. Tuomey; North Carolina, E. Emmons; Wisconsin, E.S. Carr, J. Hall; Iowa, J. Hall.

Overlapping with James Hall were Edward A.H. Allen, who served as professor of Geology from 1851 to 1855, and Robert P. Whitfield, who held the same position between 1875 and 1878. A few months before the U.S. Geological Survey was born on March 3rd 1879 C.D. Walcott's term as assistant to James Hall in the New York State Geological Survey expired. Clarence King, first Director of the newly formed U.S. Geological Survey, telegraphed Professor Whitfield, asking him about Walcott. Whitfield recommended Walcott, who then moved on to become the third Director of the U.S. Geological Survey, fourth Secretary of the Smithsonian Institute, and founder of the Geophysical Laboratory in Washington. Although Walcott was not an R.P.I. student it was R.P.I. Professor Whitfield's recommendation which led to Walcott's distinguished service to the nation. Whitfield left Rensselaer to become curator of geology at the American Museum of Natural History in New York City. His numerous publications relate mostly to paleontology.

The period between 1859 and 1894 was the tenure of Henry B. Nason (Fig. 13).

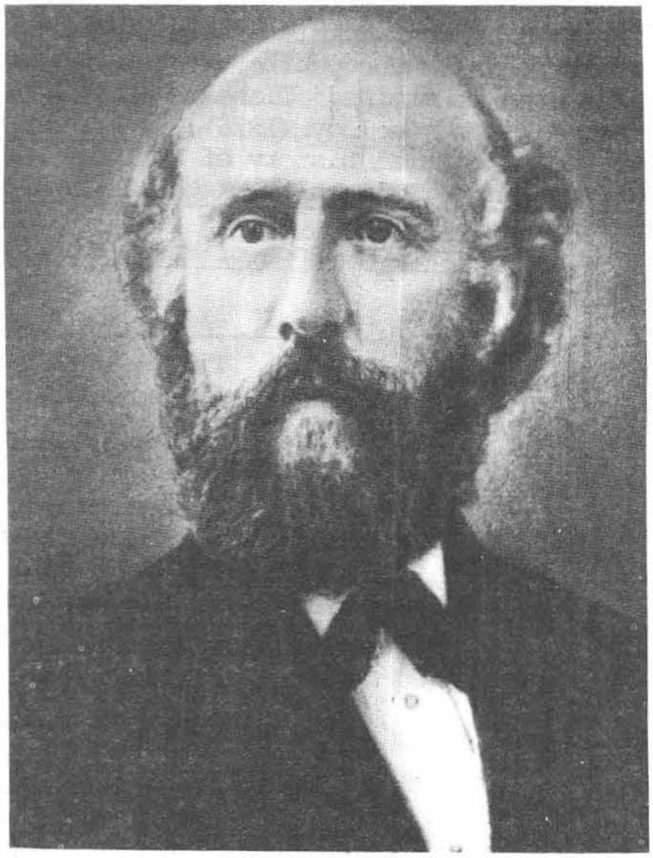
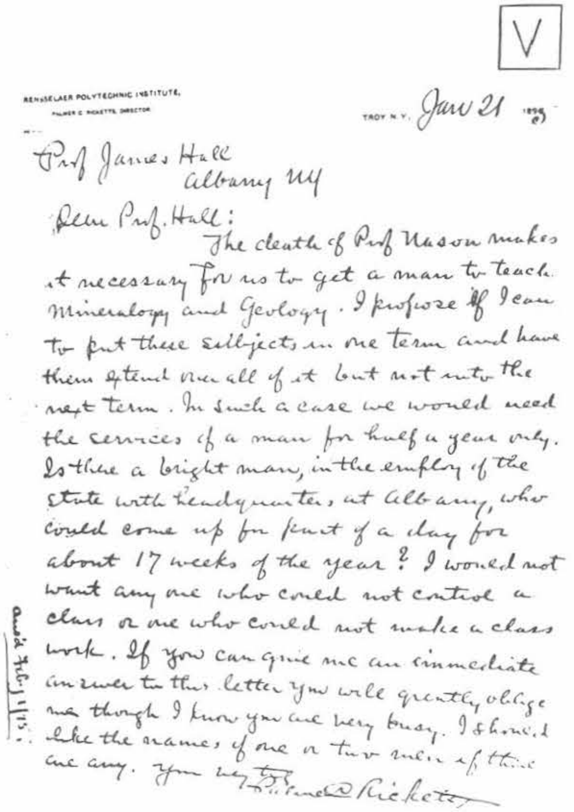


Fig. 13. Henry B. Nason, professor at Rensselaer, renowned mineralogist of his time, who inspired Washington A. Roebling of Brooklyn-Bridge fame to devote much of his life to the science of mineralogy.

Nason was the de facto curator of the vast mineral collections of Rensselaer. Nason acted as agent for Rensselaer in acquiring specimens and with Hall arranged and labelled them. He maintained the tradition of field work. Contemporary records indicate that the extended geological field trips Nason lead each term were extremely popular; in fact, so was Nason. Archivist Samuel Rezneck records that the largest party ever thrown by the Institute was in commemoration of Nason's 25th year year on the faculty. Nason's interest in mineralogy had a profound influence on the scientific advance of mineralogy. Washington A. Roebling of Brooklyn-bridge fame took Nason's course at Rensselaer. Inspired by Nason he embarked on a study of systematic mineralogy which led to a collection of minerals that included not only all known species and sub-species of minerals, but also representives of all the useless names with which some mineralogists have confused and confounded the science. The Roebling collection was donated to the National Museum of the Smithsonian Institute. The liberal terms of the gift and the generous endowment by Roebling's son John allowed for further acquisition of specimens and the preservation of the collection. Roebling's collection was a source of much of the work of E.S. Larsen and H. Berman in their classical The Microscopic Determination of the Non-Opaque Minerals (U.S. Geological Survey Bulletin 848, 1934); the varieties of 75 clay minerals form the basis of much of the modern work of this group. Likewise many rare uranium minerals have been found invaluable in the scientific study in this metal in the 1940's and 1950's. Specimens of this collection have "gone round the world, around and around like a merry-go-round." Continuing to digress on Roebling serves to bring into focus some of the lasting scientific legacies of Nason. Roebling who became Vice President of the Mineralogical Society of America gave $45,000 to the endowment fund of the Mineralogical Society in 1926 which permitted the society to expand materially The American Mineralogist. He also left a large sum of money for a medal, the Washington A. Roebling Medal for Meritorious Achievement in the Mineral Sciences, which is awarded annually as the highest medal of the Mineralogical Society of America. Some of the recipients of this medal credit Rensselaer for the inspiration which Roebling received (see, as an example, William F. Foshag, acceptance of the Roebling Medal of the Mineralogical Society of America, American Mineralogist, v. 39, p. 296-299, 1954). As a further tribute to Roebling a mineral has been named roeblingite. But now back to Nason. Nason travelled extensively, particularly to mining regions and volcanic areas. Places he visited included Germany, Northern Europe, Finland, Russia, France, Italy, Sicily, California, and Nevada. In 1877 President P. Hayes appointed him juror for the United States government at the Paris Exposition in the Department of Mineralogy. His publications include various editions of Elderhorst's "Manual of Blowpipe Analysis" (1873, 1875, 1876), Manual of Blowpipe Analysis and Determinative Mineralogy (1880) as well as internal Rensselaer publications, such as Semi-Centennial Catalog of Rensselaer Polytechnic Institute (1874) and Biographical Record of the Officers and Graduates of the Rensselaer Polytechnic Institute (1886). Nason's impact was such that he received honorary degrees from Amherst College, Union College, and Beloit College. In the 19th Century mineralogy was considered to be as much part of chemistry as of geology. Nason's influence led to his election to the presidency of the American Chemical Society. Nason's dedication to Rensselaer is memorialized by his private collection of 5,000 rocks and minerals which he donated to the Institute in 1883, the largest single acquisition made by Rensselaer. The present museum of the Department of Geology bears the mark of Nason more than that of any other and remains of interest to students of this important figure in the history of Rensselaer.

Following the death of Nason in 1894, Palmer C. Ricketts, then Director of Rensselaer, wrote to James Hall in a letter dated January 21, 1895: "Dear Professor Hall: The death of Professor Nason makes it necessary for us to get a man to teach mineralogy and geology" (Fig. 14). Hall recommended John M. Clark who became instructor of Geology (Fig. 15). After Hall's death Clark became State Paleontologist and State Geologist of New York, but continued as Adjunct Professor. Clark authored 300 scientific papers, and named 135 genera and 870 new species of fossils.

The vacancy created after Hall's death and the ensuing unavailability of Clark because of his full-time committments with the New York State Geological Survey opened the opportunity for another giant to enter the halls of Rensselaer: Amadeus W. Grabau (Fig. 16). Like his predecessors Grabau had close working relationships with the New York State Geological Survey. With the support and cooperation of the Buffalo Society of Natural Sciences and the New York State Geological Survey, Grabau prepared a Guide to the Geology and Paleontology of Niagara Falls and Vicinity (New York State Museum Bulletin 45, 1901), probably one of the best prepared and most professional of the New York State Museum Bulletins. His title and address in this publication are listed as "Professor of Geology at Rensselaer Polytechnic



V

RENSSELAER POLYTECHNIC INSTITUTE,
PALMER C. RICKETTS, DIRECTOR

TROY N.Y. Jan 21 1895

Prof James Hall
Albany NY

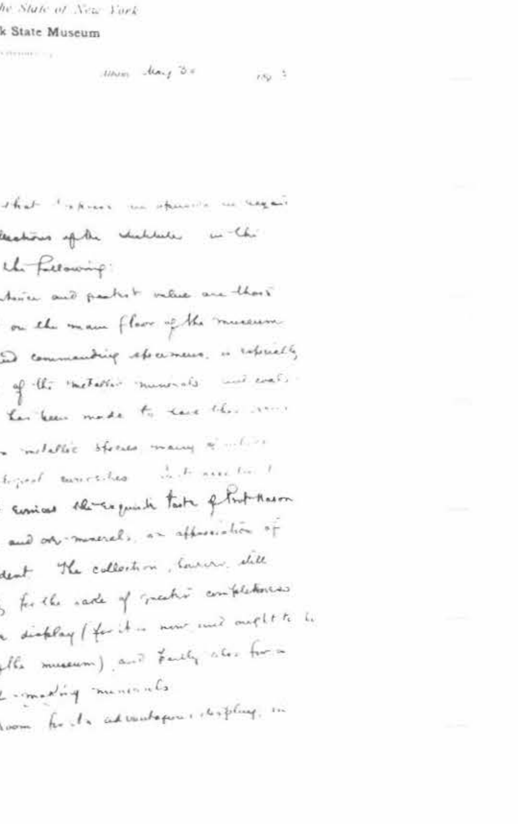
Dear Prof. Hall:

The death of Prof Nason makes it necessary for us to get a man to teach Mineralogy and Geology. I propose if I can to put these subjects in one term and have them extend over all of it but not into the next term. In such a case we would need the services of a man for half a year only. Is there a bright man, in the employ of the State with headquarters at Albany, who could come up for part of a day for about 17 weeks of the year? I would not want any one who could not control a class or one who could not make a class work. If you can give me an immediate answer to this letter you will greatly oblige me though I know you are very busy. I should like the names of one or two men if there are any. Yours very truly

Palmer C. Ricketts

Ans'd Feb. 1 '95.

Fig. 14. Letter written by R.P.I. Director Palmer C. Ricketts to James Hall, following the death of H.B. Nason, requesting a recommendation for a prospective staff member to teach Mineralogy and Geology. John M. Clark became Nason's successor.



University of the State of New York
New York State Museum

Fig. 15. Letter addressed by John M. Clark to R.P.I. Director Palmer C. Ricketts evaluating the mineralogical collections of the Institute, This is the first page of a three-page letter; the other pages deal with fossils and rocks.

Fig. 16. A.W. Grabau (left) father of American sedimentology, in animated conversation with E.O. Ulrich (right).

Institute," although in the archives of R.P.I. he is listed as Professor of Geology and Mineralogy. In the preface to New York State Museum Bulletin 45 John M. Clark introduced Grabau. Grabau may truly be considered the Father of Modern Sedimentology. To backtrack and digress one of the most-effective pioneers in making the doctrine of actualism useful as a stratigraphic tool for a better understanding of the rock record was the German geologist Johannes Walther (1860-1937) (see Friedman and Sanders, 1978, p. 9-10). His writings present some of the first real data for use in the interpretation of sedimentary strata in the bedrock. Some of Walther's observations form the cornerstone of modern stratigraphy. He explained that lithologies whose antecedent sediments formed beside one another in space, such as point-bar sands beside overbank muds and next to marshes, lie on top of one another in vertical sequence. Geologists neglected Walther's prolific writings; but Grabau picked them up. Grabau's textbook Principles of Stratigraphy (1913), a classic far ahead of its time followed in the footsteps set by Walther. In fact Grabau dedicated his book to Walther. As his writings attest, the pioneer sedimentologist W.H. Twenhofel, continued the tradition of Walther and Grabau. By their philosophy, Twenhofel's influential books, Treatise on Sedimentation (1925, 1932) and Principles of Sedimentation (1939, 1950), assured the continued influence of Grabau. Unfortunately for Rensselaer, Grabau, and American geology Grabau later transferred to Columbia University, where he became a victim of political infighting in the Department of Geology, which led to his emigration (some even say expulsion) from the United States. In retrospect Grabau probably treasured his association with Rensselaer. As an example, in his Textbook of Geology (1921) he makes sure that from the title page readers realize that he was formerly "Professor of Mineralogy and Geology in the Rensselaer Polytechnic Institute" (note here that in the Rensselaer archives his title is reversed as Professor of Geology and Mineralogy). Among Grabau's other books should be mentioned Geology of the Non-Metallic Mineral Deposits (1920), The Rhythm of the Ages; Earth History in the Light of the Pulsation and Polar Control Theory (1940), and The World We Live In (1948).

In 1924 Joseph L. Rosenholtz was appointed Professor of Mineralogy and Geology (Fig. 17). With the expansion of activity and staff he became Head of the department in 1945. Even before that date Dudley T. Smith joined Rosenholtz in teaching all geology courses (Fig. 18); the two men likewise worked closely in their research. To understand the significance of their research it is necessary to provide some background which takes us back to the 1920's and 1930's. In those days the field of sedimentology was mostly concerned with provenance studies. Heavy minerals can be employed

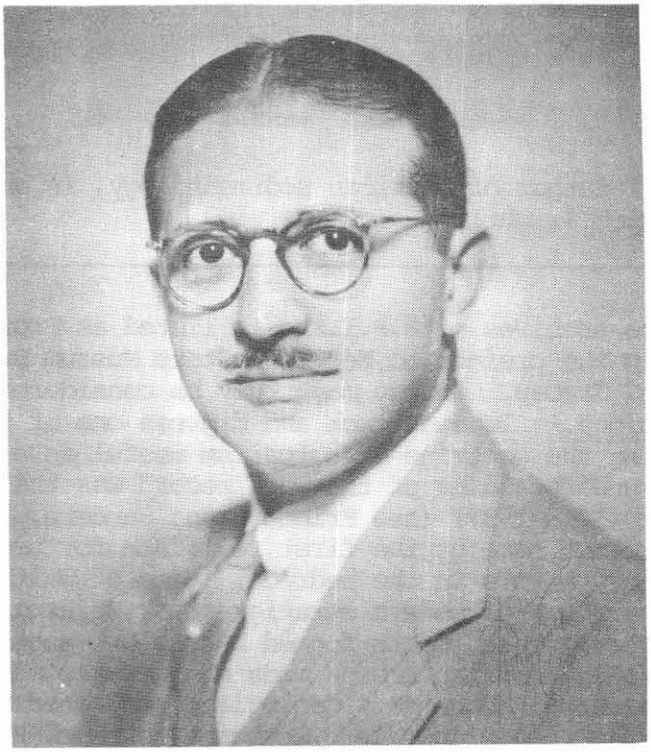


Fig. 17. Joseph L. Rosenholtz, Professor of Mineralogy and Geology, Head of the Department of Geology.

Fig. 18. Dudley T. Smith, Professor of Geology and close associate of Rosenholtz's.

in such studies in a general way to recognize broad catagories of possible parent rocks, or more specifically, to pinpoint the provenance of the particles. A few species of heavy minerals are diagnostic of a particular kind of parent rock; mere identification suffices to determine provenance. When heavy minerals have been determined from a sample network of regional extent, the distribution of certain species may form a distinct areal pattern. In the subsurface heavy minerals have proved to be a valuable means for distinguishing one sandstone from another in single boreholes and in matching sandstones from one hole to another. Such uses are possible even where the provenance of the particle is not known. Heavy-mineral studies of this type were the dominant line in sedimentology of the 1920's and 30's. This work closely depended on careful separations of suites of the heavy minerals. At the time heavy minerals were most commonly separated by means of heavy liquids (liquids having a specific gravity > 2.9). Yet better methods of separation were needed. Many advances in geology have taken place because some new kind of tool or technique has been invented or improved. With it new analytical results could be obtained. Rosenholtz and Smith realized this. With their publications Tables and Charts of Specific Gravity and Hardness for Use in the Determination of Minerals (1931) and especially The Dielectric Constant of Mineral Powders (1936) they helped advance early sedimentology (Fig. 19). Dielectric separation of mineral particles, as developed by Rosenholtz and Smith, became an important technique in provenance studies. W.H. Twenhofel in his influential book Methods of Study of Sediments (1941), co-authored with S.A. Tyler, gives much credit to Rosenholtz and Smith (p. 87-88), and explains their technique in detail and presents their table (p. 87) captioned "Average Value of Dielectric Constant of the Common Minerals as Given by Rosenholtz and Smith." Rosenholtz also developed new techniques for testing the strength of a material from its thermal expansion characteristics and directed a study of the physical properties of rocks and minerals of interest in lunar research. He served as President of the Eastern Section of the National Association of Geology Teachers and of the New York State Geological Association. In 1961 under Rosenholtz's presidency the New York State Geological Association held its 33rd Annual Meeting on the Campus of R.P.I.

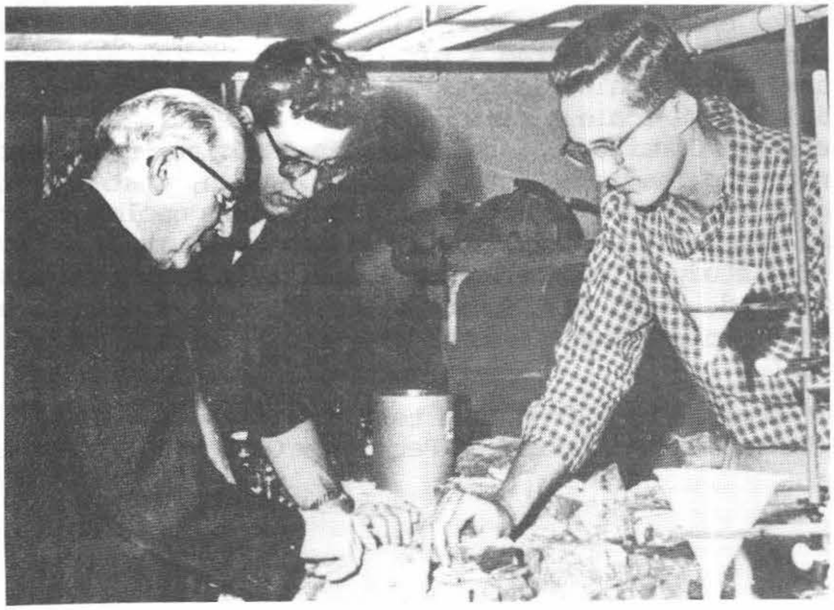


Fig. 19. Joseph L. Rosenholtz instructing students in heavy-mineral techniques. Student at left is George P. Allen, now well-known sedimentologist in France (University of Bordeaux and Centre National pour l'Exploitation des Océans; student at right is Alex Yatsevitch, geologist working in New York State Government.

By 1950 Rensselaer realized the prospect of the fuel problem and started a program known as Fuel Resources, headed by Shepard W. Lowman, a former Chief Research Geologist of the Shell Oil Company (Fig. 20).

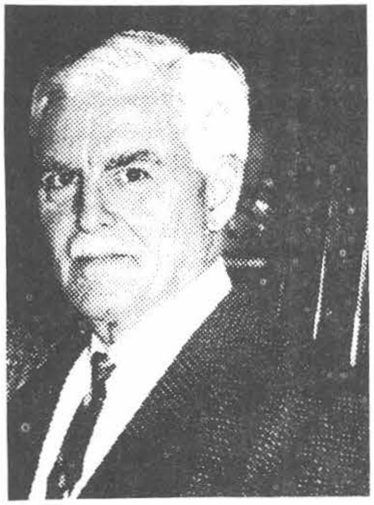


Fig. 20. Shepard W. Lowman, Professor of Geology, former Chief Research Geologist of the Shell Oil Company, Head of R.P.I. Fuel Resources program and pioneer sedimentology leader of Project 51, largest-of-all projects of the American Petroleum Institute. Lowman received the highest award of the Society of Economic Paleontologists and Mineralogists. Lowman was recognized as one of the nation's leading authorities in petroleum geology.

In 1952 this program listed six staff members. The options for specialization were in (1) petroleum geology, (2) petroleum geophysics, and (3) geological engineering, subjects which are the most sought after specialties among the sciences even today, almost 30 years later. The choice of Lowman as head of this program was remarkable indeed. To explain this I must briefly digress. Despite an august history of 150 years, sedimentology as a science advanced most rapidly within the last thirty years. This rapid advance resulted from a change of sedimentology as a pure to an applied science. Whereas previously used techniques in oil and gas exploration consisted solely of a search for closed subsurface anticlines, known as structural traps, emphasis shifted to exploration for subsurface stratigraphic traps in which porous and permeable sedimentary rocks are in lateral stratigraphic contact with impermeable sedimentary rocks. Such lateral contacts of different and distinct sedimentary rocks reflect differences in depositional conditions and hence two or more contiguous paleoenvironments. Such recognition of the enormous value of sedimentology as a key to the discovery of stratigraphic traps represented a turning point in the history of the science. Beginning with this recognition in the late 1940's and early 1950's, the first large-scale research projects materialized. The 1947 Report of the Research Committee of the American Association of Petroleum Geologists, under the leadership of Shepard W. Lowman, stated that research in sedimentology is the most-urgent need in petroleum geology. Project 51 of the American Petroleum Institute, established by Lowman, led to a methodical and detailed study of modern depositional environments on a scale not previously attempted. Much of the background of this largest-of-all projects of the American Petroleum Institute was prepared by Lowman, who first conceived the idea.

A classic book emerged from this team effort published as a special volume by the American Association of Petroleum Geologists. Lowman's background hence was eminently fitted to join the Rensselaer program in the petroleum field. His peers recognized Lowman's contribution and he was bestowed the highest award of the Society of Economic Paleontologists and Mineralogists, namely Honorary Membership, at the meeting of the Society in St. Louis in 1966. His citation read "In recognition of His Many Contributions to Paleontology and Stratigraphy, his Leadership in Research on Recent Sediments of the Gulf of Mexico and his Classic Paper on Sedimentary Facies in the Gulf Coast'". On his death in 1967 the Journal of Sedimentary Petrology published an obituary: a most unusual step as this journal has published no other obituaries before or since. It served to recognize Lowman as a pioneer and leader in the newly important science of sedimentology. In this obituary Lowman was referred to as one of the nation's leading authorities in petroleum geology.

By 1954 the program of Fuel Resources had provided added strength to the geology department. James Robert Dunn (Fig. 21) joined as an economic geologist to develop a program in Mineral Resources, comparable to that of Fuel Resources. Dunn made a reputation not only as an Economic Geologist, but also as an administrator in professional societies. He served as Vice President and is currently serving as President of the American Institute of Professional Geologists. He founded a successful consulting firm known as Dunn Geoscience, of which he is Chairman of the Board. He left Rensselaer after nearly 20 years of service to devote full time to this important and critical field of economic geology.

In 1968 the Department of Geology served as co-host of the Annual Meeting of the Geological Society of America, Northeastern Section. One member of the Department's faculty was the Program Chairman. In 1972 the Department was the host to the Annual Field Meeting of the Society of Economic Paleontologists and Mineralogists, Eastern Section. A special Guidebook was published for this occasion. Between 1964 and 1970 the Department served as home and editorial office of the prestigious national and international Journal of Sedimentary Petrology. A new regional journal Northeastern Geology has begun publication in the Department.

Those currently on the faculty or faculty members who spent only brief periods in recent years at Rensselaer will not be mentioned by name in this historical review. Diversified research and close contact with the students are the hallmark of the Rensselaer Department of Geology. Two textbooks authored in the department, one in petrology and one in sedimentology are widely used all over the world; a textbook in mineralogy is ready for the press. Recognition in research has led to the election of some faculty to the presidencies of national and international geological societies. There is much activity. As Resnick (1965, p. 134) pointed out "Rensselaer Institute from the first acquired a tradition of geological and scientific

Fig. 21. James Robert Dunn, Professor of Economic Geology, Chairman of the Board of Dunn Geoscience, President of the American Institute of Professional Geologists.

instruction which has persisted and grown to the present day."

This history has been written for publication on the occasion of the 51st Annual Meeting of the New York State Geological Association and the 71st Annual Meeting of the New England Intercollegiate Geological Conference. For the first time in their histories both associations have met together on one campus: another first for the Rensselaer geology program.

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ACKNOWLEDGMENTS

I want to express my thanks to archivist and historian Samuel Rezneck who inspired me in tracing the history of R.P.I.'s geology program from its inception to the present day. Robert R. Shrock of Massachusetts Institute of Technology gave me the reference to the photograph of A.W. Grabau (Geol. Soc. America, Proc. 1944, Plate 23). Robert K. Olsson of Rutgers University provided the photograph of George H. Cook for which I am most indebted. Mrs. Joseph C. Rosenholtz loaned me a photograph of her late husband. All other illustrations are from R.P.I. archives.

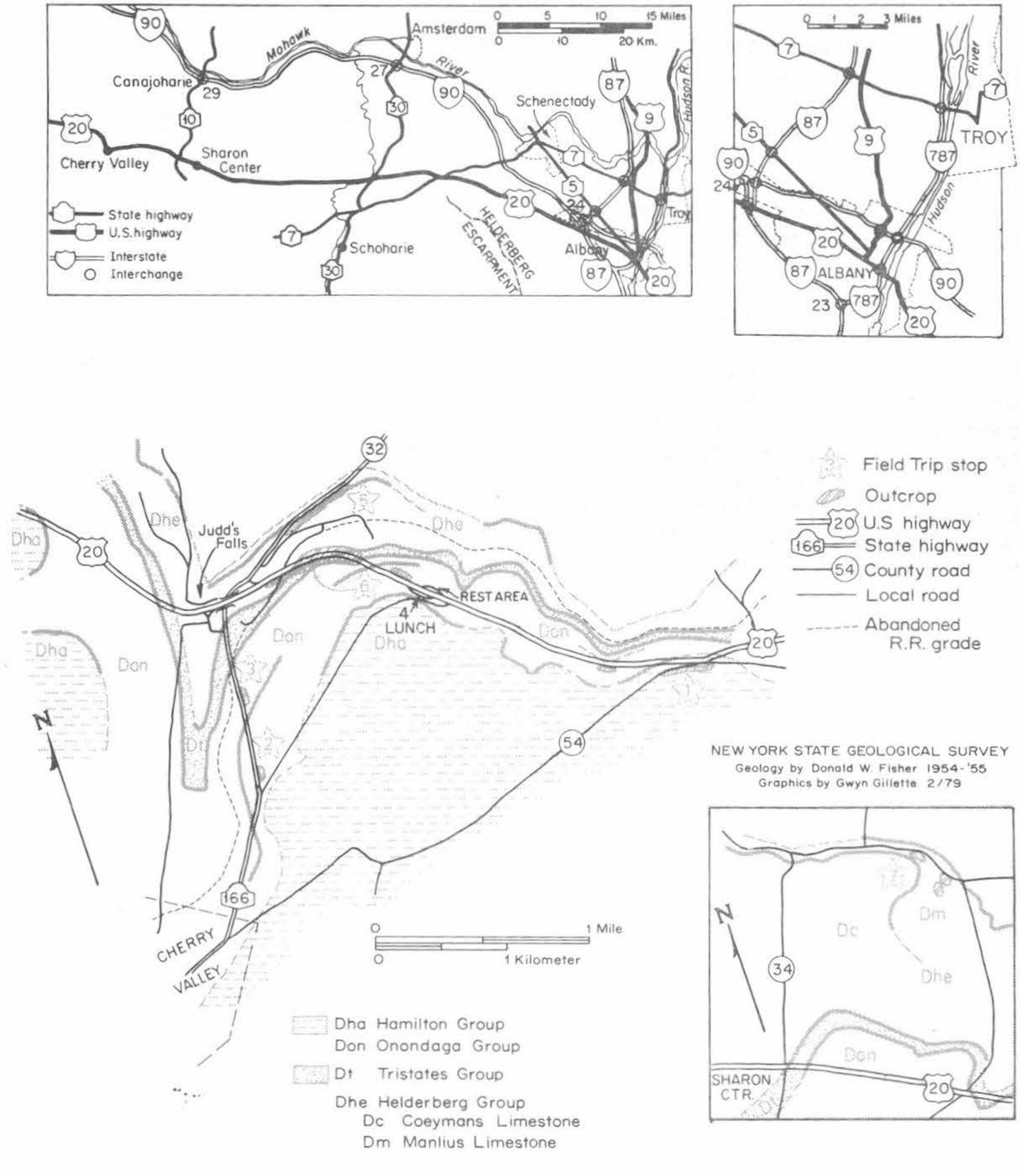

Figure 1. Index map: location of Cherry Valley area with respect to Albany-Schenectady-Troy region; detail of field trip stops shown in lower enlargements.

TRIP A-1

DEVONIAN STRATIGRAPHY AND PALEOECOLOGY IN THE CHERRY VALLEY, NEW YORK REGION

by

Donald W. Fisher
State Paleontologist

N.Y. Geological Survey-N.Y. State Museum, State Education Department,
Albany, N. Y. 12234*

PROLOG

In the northern parts of Otsego and Schoharie Counties, New York and bordering the southern margin of the Mohawk Lowlands and the northern margin of the Allegheny Uplands, is an exceptionally well exposed Early and Medial Devonian (400-365 million years old) sequence. These flat-lying sedimentary rocks record a broad spectrum of paleoenvironments. It is my intention to introduce you to the physical and organic makeup of these Devonian strata and to show how their combined characteristics enable a reconstruction of past environments and their associated role in the events of geologic history.

ACKNOWLEDGEMENTS

Gwyneth Gillette and John B. Skiba, cartographers with the N.Y. Geological Survey, prepared Figures 1 and 2-3, respectively. For their contribution to the better understanding of Devonian geology in the Cherry Valley region, I am deeply grateful.

HISTORY OF PREVIOUS WORK

As early as the 1820's and 1830's, exquisite fossils were collected by the Gebhards, John Sr. and Jr., from the Devonian rocks of their native Schoharie Valley - a reference area bordering the Cherry Valley region to the southeast. The establishment of the Geological and Natural History Survey of New York on April 15, 1836 was a tremendous impetus toward learning more about the State's rocks. William W. Mather's First (eastern) District Report (1843) and Lardner Vanuxem's Third (central) District Report (1842), both classics in early American geology, covered Schoharie and Otsego Counties, respectively. The descriptions of the rocks with their entombed fossils are amazingly complete and a testimony to the meticulosity and perspicuity of these indefatigable pioneer field geologists.

The field geologists of the Seward Survey of 1836-41 were responsible for establishing the first formal stratigraphy of the Devonian rocks examined on this trip. Vanuxem, especially, was the perceptive observer who categorized the sub-divisions of the "Helderberg Division":

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Vanuxem's units	Modern name
Corniferous limestone (Selenurus limestone of Gebhard)	Moorehouse Member of Onondaga Limestone
Onondaga limestone (gray sparry limestone of Eaton)	Edgecliff Member of the Onondaga Limestone
Schoharie grit	Schoharie Formation
Cauda-galli grit (Cocktail grit of Dr. James Eights)	Carlisle Center Formation and Esopus Formation
Oriskany sandstone	Oriskany Sandstone
Upper Pentamerus limestone (Scutella ls.)	Becraft Limestone
Delthyris shaly limestone (Catskill shaly)	New Scotland Limestone
Lower Pentamerus limestone	Coeymans Limestone
Water Limestone (Tentaculite limestone and hydraulic limestone of Eaton)	Manlius Limestone and Rondout Formation
Pyritous shales	Brayman Shale

Note: Today, only the Manlius thru Port Ewen limestones (Becraft of this area) comprise the Helderberg Group.

Among the oldest reported fossils in New York is the crinoid *Melocrinus (Astrocrinites) pachydactylus* (Conrad) from Lasall Park, Schoharie. This was first illustrated in a Schenectady newspaper in 1835. Another early recognized unique fossil, is the interesting cystid *Lepocrinites gebhardii*, first distinguished by Timothy A. Conrad (1840, p. 207), paleontologist with the Seward Survey. Both of these pelmatozoans were found in strata referable to the Coeymans Limestone.

Following the dissolution of the Seward Survey of 1836-1841, James Hall, America's most colorful and prestigious invertebrate paleontologist, assumed the monumental task of describing New York's fossils and issuing monographs of them (Hall, 1861-1894). Using much of the Gebhard's collection and relying on younger John's field work for Mather's report, Hall described and illustrated hundreds of fossils from the Devonian strata of eastern New York State.

During the early 20th century, the splendid, well illustrated, monograph "Geology and Paleontology of the Schoharie Valley", by Amadeus W. Grabau (1906) excelled as the preeminent reference to the Devonian rocks of the area. The most exhaustive paleontologic and stratigraphic study of the Hamilton Group of New York was conducted by G. Arthur Cooper (1930, 1933); these accounts are but condensations of his voluminous Yale doctoral thesis. The Onondaga Limestone received intensive paleontologic and stratigraphic study by Oliver (1954), who applied subdivision names. Goldring and Flower (1942, 1944) rightly recognized that the Carlisle Center Formation should be separated from the Esopus as a distinct formation. During the summer of 1953, Lawrence V. Rickard commenced his stratigraphic studies of the Helderberg Group. His field studies resulted in a comprehensive work on the Helderberg Group (1962) and, with Donald H. Zenger, in the mapping of the Stratigraphy and Paleontology of the Richfield Springs and Cooperstown Quadrangles, adjacent to Cherry Valley on the west (1964). Subsequent paleoecological studies of the Manlius and Coeymans Limestones were made by Laporte (1963, 1967) and Anderson (1967), respectively.

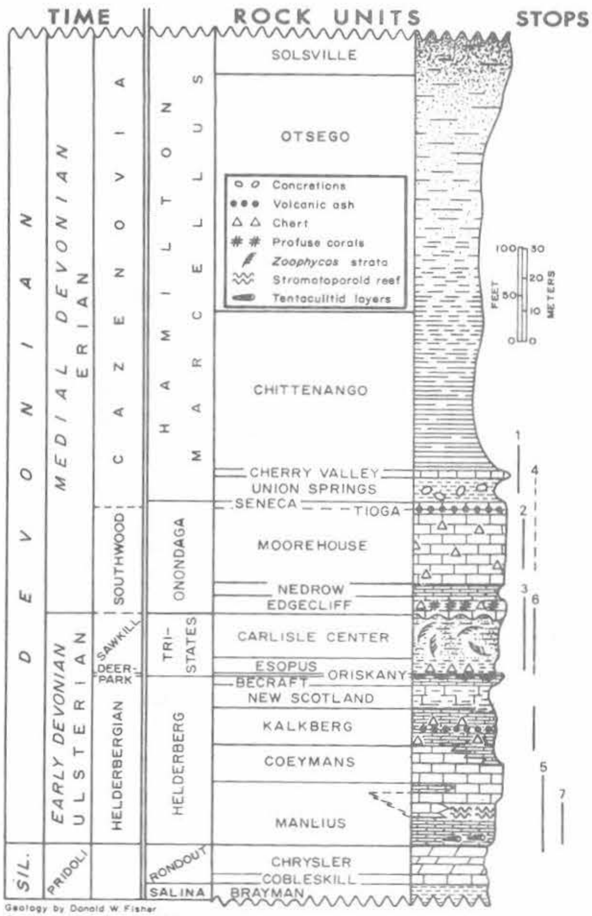
My involvement with Devonian rocks of eastern New York began in the summers of 1946 and 1947 while mapping the bedrock geology of the Fonda 15' Quadrangle for a master's thesis; subsequently, the Devonian strata of the westerly adjacent Canajoharie 15' quadrangle were mapped during the summers of 1952 and 1954 and updated in 1959, 1977, and 1978. The results are incorporated in a project covering fifteen 7½' quadrangles on the bedrock geology of the central Mohawk Valley,----to appear in the N.Y. State Museum, Map and Chart Series.

PHYSIOGRAPHY AND GEOLOGIC SETTING

The area to be examined occurs along the southern margin of the Mohawk Valley Lowlands and the northern margin of the Allegheny Uplands and forms a belt along U.S. 20 (Figure 1). The Mohawk Lowlands farmland is floored with Upper Cambrian, Lower Ordovician, and Middle Ordovician sandstones, dolostones, limestones, black shales, and gray shales and siltstones. Resting disconformably atop the siltstones and shales (Frankfort) is a thin representative of Upper Silurian pyritiferous and gypsiferous shales (Brayman), dolomitic limestones (Cobleskill), and argillaceous dolostones (Chrysler). A north-facing escarpment, the western extension of the more pronounced Helderberg Escarpment to the east, consists of Lower Devonian limestones (Helderberg Group), Lower Devonian sandstone and siliceous shales (Tristates Group), capped by another carbonate terrace of Onondaga Limestone. The prominent rounded hills south of the Cherry Valley-Sharon Springs region consist of shales and siltstones of the Middle Devonian Marcellus Formation of the Hamilton Group. These "Cherry Valley Hills" may be considered as foothills of the Catskill Mountains, a dissected plateau of flat-lying sedimentary rocks and the northeastern portion of the Allegheny Uplands.

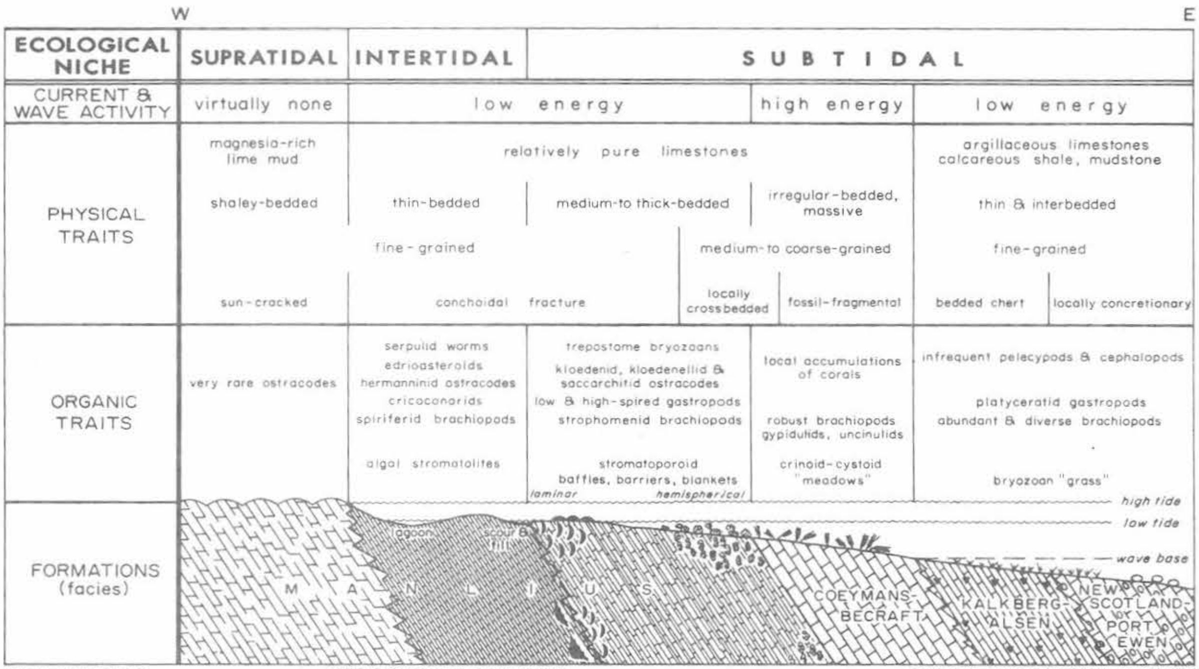
North of the Mohawk Valley are the very maturely eroded Adirondack Mountains, consisting of Middle Proterozoic (Helikian) metamorphosed rocks, which unconformably underlie the flat-lying Upper Cambrian sandstones and dolostones. Block faulting has dissected the Mohawk Valley to create a horst and graben topography; these faults increase in throw to the north and hinge-out or disappear under the Silurian strata. No evidence is known that these faults cut the Silurian or Devonian strata. The Devonian escarpment is notched by many north-flowing streams. The positioning of some of these seems to be influenced by low anticlines with an amplitude to wave length ratio of greater than 1:50. The headwaters of Canajoharie Creek, occupying the valley upon which the village of Cherry Valley lies and over which Judd's Falls occurs, is carved into one of these low anticlines. Six miles to the east, Sharon Springs, too, seems to lie on one of these low, breached anticlines.

Karst topography, the chemical perforation of the limestones of the landscape by sink holes and widened joint crevasses, is prevalent in this region. Most of the sinks are developed in the Coeymans and Manlius Limestones.



Geology by Donald W. Fisher
Graphics by John B. Skiba 2/79

Figure 2
Stratigraphic column: Devonian and Silurian strata in Cherry Valley-Sharon region (Sprout Brook and Sharon Springs 7½' quadrangles).



	W				E
ECOLOGICAL NICHE	SUPRATIDAL	INTERTIDAL	SUBTIDAL		
CURRENT & WAVE ACTIVITY	virtually none	low energy		high energy	low energy
PHYSICAL TRAITS	magnesia-rich lime mud	relatively pure limestones			argillaceous limestones calcareous shale, mudstone
	shaley-bedded	thin-bedded	medium-to thick-bedded	irregular-bedded, massive	thin & interbedded
		fine-grained		medium-to coarse-grained	fine-grained
	sun-cracked	conchoidal fracture		locally crossbedded fossil-fragmental	bedded chert locally concretionary
ORGANIC TRAITS	very rare ostracodes	serpulid worms edrioasteroids hermanninid ostracodes cricoconarids spiriferid brachiopods algal stromatolites	trepostome bryozoans kloedenid, kloedenellid & saccarchitid ostracodes low & high-spired gastropods strophomenid brachiopods stromatoporoid baffles, barriers, blankets laminar hemispherical	local accumulations of corals robust brachiopods gypidulids, uncinulids crinoid-cystoid "meadows"	infrequent pelecypods & cephalopods platyceratid gastropods abundant & diverse brachiopods bryozoan "grass"
FORMATIONS (facies)					

Geology by Donald W. Fisher
Graphics by John B. Skiba 2/79

NOTE: Strata are horizontal in the field

modified from Rickard (1962) & Laporte (1967)

Figure 3. Paleoecology profile: Lower Devonian Helderberg facies in eastern New York State.

STRATIGRAPHY AND PALEOECOLOGY
(Figures 2 & 3)

PRE-DEVONIAN ROCKS

Directly beneath the Early Devonian Manlius strata of this region are the Late Silurian Rondout and Brayman Formations, respectively. The Rondout is divisible into an upper Chrysler Dolostone Member and a lower Cobleskill Limestone Member; the two are vertically gradational. The Cobleskill contains diagnostic Late Silurian fossils, foremost of which is the "chain" coral *Halysites*. The Chrysler has not yielded diagnostic fossils for age determination hence it is uncertain whether this thin unit should be classed as latest Silurian or earliest Devonian; I prefer to regard it as Silurian. The Brayman Shale has yielded Late Silurian fossils (Fisher and Rickard, 1953, p. 8) establishing a Pridolian age. Except for the subtidal coral-bearing rocks, these Upper Silurian units were formed in shallow hypersaline waters largely within the supratidal and intertidal zones.

In proceeding north from the Cherry Valley region, Upper Silurian strata rest unconformably on peneplained Upper Ordovician Frankfort gray shales and argillaceous siltstones which, in turn, rest on Utica black shale. Successively beneath the Utica are thin Middle Ordovician Trenton and Black River limestones. These limestones (not everywhere the same) rest, disconformably on Lower Ordovician Tribes Hill dolostones and dolomitic limestones and Upper Cambrian Little Falls Dolostone. Unconformably beneath these Early Paleozoic strata are Proterozoic rocks metamorphosed during the Grenville Orogeny of 1,100-975 million years ago. The Cambrian and Ordovician carbonates represent shallow water supratidal, intertidal, and subtidal deposits on an ancient continental shelf; the Ordovician pelites are basinal deposits formed some 450 million years ago, on this downwarped shelf during the Taconic Orogeny. About 450 m (≈1500 ft) of Ordovician and Cambrian strata lie between the Silurian and Proterozoic rocks.

DEVONIAN ROCKS

Helderberg Group (for details, see Rickard 1962)

Manlius Limestone (Vanuxem, 1840, p. 376) STOPS 5 & 7

The Manlius Formation consists of several members throughout its extent from Port Jervis to the Manlius region, Onondaga County. In the Cherry Valley area, the Thacher Member (Rickard, 1962, p. 43-54) enters from the east as a basal unit. At the west edge of the Sprout Brook Quadrangle the Thacher changes physically and organically to a thicker-bedded less fossiliferous unit termed Olney westward. Furthermore, between a lower Coeymans and upper Coeymans, there appears an intervening Manlius lithology (Elmwood Member).

The Thacher Limestone is a very light gray to white weathering, dark gray to black, thin to thick bedded, fine to medium grained limestone with rare calcareous shale interbeds and rare crossbedding in some few coarser beds. The thinner bedded (ribbon limestones) and blocky medium bedded layers break with a conchoidal fracture and "ringing" sound. Fossils are abundant but only a few species are represented. Cabbage-like stromatoporoid reefs and baffles are locally present at the top of the Thacher. The tentaculitid *Tentaculites gyracanthus* and the ostracode *Hermannina alta* are ubiquitous in the ribbon strata, together with rare edrioasteroids *Postibula* n.sp., scarce bryozoans, and common spiriferid brachiopods *(Howellella vanuxemi)*; low-and high-spired gastropods are more common in the reefs and baffles.

The Thacher represents at least three different environments (Figure 3); each characterized by specific physical and organic traits; supratidal, intertidal, and proximal subtidal. Clearing of marine waters from the hypersaline Rondout sea permitted a more diverse and abundant life to pervade the Manlius sea.

Coeymans Limestone (Clarke and Schuchert, 1899, p. 874-875) STOP 5

The Coeymans is a medium to dark gray weathering, light to medium gray, medium to thick irregular bedded, medium to coarse grained, fossil-fragmental limestone. The formation is moderately fossiliferous, characterized by the pentamerid brachiopod *Gypidula coeymanensis*, meristellid and uncinulid brachiopods, and crinoidal and cystoidal debris. The westwardly thickening Coeymans (Ravena Member-Rickard, 1962, p. 65-68) splits along the Judd's Falls Valley into a lower Dayville (Rickard, 1962, p. 68-72) Limestone and an upper Deansboro (Rickard, 1962, p. 72-77) Limestone, separated by a tongue of Manlius lithology.

The Coeymans seems to have been deposited on the seaward side of fringing stromatoporoid barriers and baffles in agitated, clear, shallow water with crinoid and cystoid meadows fluorishing on the sea floor (Figure 3).

Kalkberg Limestone (Chadwick, 1908, p. 346-348) STOP 6

The Kalkberg is a light to medium gray weathering, medium to dark gray, thin to medium regularly bedded, fine to medium grained siliceous limestone with calcareous shale interbeds. Dark gray to black chert pods and beds are characteristic. A 2-3 cm bentonite (volcanic ash) occurs along the south side of U.S. 20 at the overpass for the abandoned Cherry Valley Railroad. This ash has been radiometrically dated (Miller and Senechal, 1965) as 395 million years old, using Rb-Sr isotopes.

The Kalkberg contains abundant and varied fossils, dominated by brachiopods, bryozoans, and crinoid columnals; The unit is believed to have formed in the proximal low energy subtidal zone below wave base (Figure 3).

New Scotland Limestone (Clarke and Schuchert, 1899, p. 874-878)

The New Scotland is a thin-bedded, dark gray to brown, argillaceous limestone interbedded with calcareous shales. Brown iron-oxide staining is common. The New Scotland is the most fossiliferous unit in the Helderberg Group; brachiopods and bryozoans were represented abundantly by many species. In this region, the New Scotland is poorly exposed beneath the overlying Becraft terrace. The most westerly exposure of the New Scotland is at the top of the

U.S. 20 roadcut at the west edge of Sharon Springs; the unit is absent at Cherry Valley. The New Scotland is believed to have formed on the distal continental shelf (Figure 3).

Becraft Limestone (Hall, 1893, p. 8-13)

The youngest division of the Helderberg Group in the southern portion of the Canajoharie 15' quadrangle is the Becraft Limestone. It is a medium gray weathering, light gray to tan, medium to thick bedded, coarse grained, fossil-fragmental limestone. It is replete with crinoid columnals and characterized by the crinoid base *Aspidocrinus scutteliformis*; these "scutellas" are convex upward and consist of well-cleaved tan to yellow calcite. Uncinulid brachiopods are also common. The Becraft is absent at Cherry Valley but makes its appearance at Sharon Center and forms a conspicuous ledge and terrace southeast of Sharon, continuing to the type Helderbergs at Thacher Park and thence southward to Kingston. Its lithologic and organic makeup is very similar to that of the older Coeymans and it is presumed to record the same kind of depositional environment (Figure 3).

Alsen (Grabau, 1919, p. 468-479) and Port Ewen ((Clarke, 1902, p. 666) Limestones

These younger divisions of the Helderberg Group are not present in the Cherry Valley or Sharon areas. The cherty Alsen makes its appearance in the Schoharie Valley and continues east and south along the Hudson Valley. The argillaceous Port Ewen appears near Coxsackie and is thickest in the Kingston area of the Hudson Valley. Their facies are similar, but not identical, to those of the Kalkberg and New Scotland, respectively (Figure 3).

Helderbergian time is recorded in New York as a period of quiescence reflected by stable shelf environments in which lime accumulated without benefit of very much detritus from adjacent peneplained source areas.

TRISTATES GROUP

Oriskany Sandstone (Vanuxem, 1839, p. 273)

In the Cherry Valley region, the Oriskany is actually a medium gray weathering, light bluish-gray limestone with relatively large spherical frosted quartz grains "floating" in a lime matrix. West of Cherry Valley, the Oriskany becomes a relatively pure quartz sandstone, although its distribution is patchy. East of Cherry Valley, the Oriskany becomes very quartzitic in the Schoharie Valley and in the Helderberg Mountains at Thacher State Park; south along the Hudson Valley in the Kingston Area, the stratigraphic position of the Oriskany is occupied by siliceous cherty limestone (Glenerie) or a pebble conglomerate (Connelly). The Oriskany contains very large, robust brachiopods such as *Acrospirifer, Costispirifer, Hipparionyx,* and *Rensselaeria;* large platyceratid gastropods are also common.

The source and environment of deposition of the Oriskany are puzzling. It is almost certain that the unit formed as a sand beach in a well agitated shallow sea but the source area for the quartz has not been determined; it may have been derived from a pre-existing quartz sandstone such as the older Cambrian Potsdam Sandstone. The virtual absence of clay minerals in the

Oriskany would seem to preclude derivation from a Proterozoic metamorphic terrane of feldspar-rich rocks. Radiometric dates in New England confirm that the initiation of the Acadian Orogeny occurred during Early Devonian (Deerpark) time.

Esopus Formation (Mather, 1840, p. 246-250) STOP 6

The Esopus is a dark brown weathering, dark gray to black, medium to thin bedded, compact, chertified argillite with dark gray shale intercalations and intervals. The blocky argillite displays conchoidal fracture and contains poorly preserved silicified brachiopods and gastropods.

A relatively large percentage of clay minerals in this unit signifies an abrupt increase in erosion of the source area, which lay to the east and southeast, and an intensity buildup during the Acadian Orogeny.

Carlisle Center Formation (Goldring and Flower, 1944, p. 340) STOPS 3 & 6

This is a buff weathering, light gray to tan, uniformly thin bedded, calcareous, argillaceous siltstone and silty shale; green glauconite is commonly present at the upper contact. Bedding planes are covered with "roostertail" markings presumed to be feeding trails of the worm *Zoophycos (Taonurus) caudagalli*. Strangely, no other fossils have been reported from this formation, other than trace fossils. There are abrupt lithologic contacts with both the Esopus below and Onondaga above.

The environment of deposition is a mystery! Certain it is that the sediment was thoroughly worked over by organisms; normal marine shelled forms were seemingly absent. Some have suggested very deep water whereas others have suggested an intertidal situation. There does not now seem to be adequate evidence with which to postulate the type of paleoenvironment which existed in the Carlisle Center sea.

Onondaga Limestone (Hall, 1839, p. 293-309) (for details, see Oliver, 1954 1956a, 1956b)

The Onondaga Limestone is divisible into the following subunits (in ascending order) with varying degrees of difficulty or ease of identification:

Edgecliff Limestone (Oliver, 1954, p. 626-627) STOP 3

> This is a medium to dark gray weathering, light to medium gray, medium to coarse grained limestone characterized by nodules and nodular beds of light gray, tan, to cream-colored chert and profuse, often silicified, colonial and solitary rugose and tabulate corals. The lower 1 to 6 feet is finer grained, non-cherty, and less fossiliferous. Elsewhere in New York State, there may be a sandstone at the base which has been confused as Oriskany in the subsurface. Sink holes and terraces are often associated with the Edgecliff Limestone.
>
> This unit formed in warm, agitated, shallow, clear subtidal water. In some areas the coral buildup was such that mounds were constructed and exceedingly coarse fossil-fragmental limestone accumulated as flank deposits.

Nedrow Limestone (Oliver, 1954, p. 627-628) STOP 2

This is a medium to dark gray weathering, dark to medium gray argillaceous limestone tending to be thinner bedded than the other Onondaga limestones. Fossils are scarcer, with platyceratid gastropods and phacopid trilobites diagnostic.

Moorehouse Limestone (Oliver, 1954, p. 628-629) STOPS 2 & 4

This is a light to medium gray weathering, medium to dark gray, medium bedded, fine to medium grained, slightly argillaceous limestone characterized by nodules and nodular beds of dark gray to black chert. Fossils uncommon, but brachiopods, gastropods, corals, trilobite fragments, and crinoid columnals may be locally abundant. The Moorehouse appears to be a more offshore subtidal shelf deposit in quieter water. Often, it forms a terrace.

Tioga Bentonite (Ebright, Fettke, and Ingham, 1949, p. 10)

This is a light gray to cream colored, sticky clay. Where exposed (rarely), a deep re-entrant marks its horizon. This volcanic ash forms the contact between the Moorehouse below the Seneca Limestone above. The Tioga is widespread in the eastern U.S. having been recognized as far away as West Virginia.

Seneca Limestone (Vanuxem, 1839, p. 377)

This is a very light gray weathering, dark gray to black, massive, fine grained argillaceous limestone. Fossils are scarce; brachiopods are most abundant, chiefly *Atrypa* and, west of here, *Chonetes*. The Seneca seems to be a distal shelf deposit in fairly quiet water below wave base.

The Onondaga Limestone environments (Southwood time) denote a period of quiescence between Phase 1 (Deerpark-Sawkill) and Phase 2 (Cazenovia and later Devonian time) of the Acadian Orogeny.

HAMILTON GROUP

Marcellus Formation (Hall, 1839, p. 295)

The Marcellus, is primarily black and gray shales and siltstones with scarce thin black limestones; normally the formation is sparsely fossiliferous with a limited mixture of benthonic and pelagic forms. The Marcellus is part of the Catskill Delta, a complex clastic wedge of erosional detritus, which extended into western New York and beyond. Members are (in ascending order):

Union Springs Shale (Cooper, 1930, p. 132, 218, 219) STOP 1

This is a slightly calcareous, black fissile shale with a few thin beds of hackly, bituminous limestone that are fossiliferous. The Union Springs holds a pelagic fauna of tentaculitids and styliolinids in the shales and a benthonic fauna of corals, trilobites, and pelecypods in the limestones. There is an abrupt contact with the Seneca Limestone below. A deep water depositional site is postulated. Disrupted concretions (some with barite or siderite mineralization) and shale deformation ("pseudo-cleavage") may be contemporaneous with sedimentation. This may denote a response to Acadian thrusting via decollement', as evidenced in the Hudson Valley.

Cherry Valley Limestone (Clarke, 1903, chart) STOP 1

This is a cream to tan weathering, black, fine grained, massive, compact bituminous limestone which may create a terrace. The unit is characterized by the large coiled goniatite cephalopod *Agoniatites vanuxemi* and the straight nautiloid cephalopod *Striacoceras*, both of which are rare and exceedingly difficult to extract. The Cherry Valley is considered to be a deep water limestone; it is the youngest limestone in eastern New York. For details, see Rickard (1952).

Chittenango Shale (Cooper, 1930, p. 131, 219) STOP 1

This is a non-calcareous, black, grading upward through dark gray to medium gray, shale; locally, it may be slightly silty and micaceous. There is an abrupt contact with the Cherry Valley Limestone below, however, the contact with the Otsego Shale above is transitional. Except for occasional seams of pelagic tentaculitids and styliolinids, fossils are very rare in Chittenango Shale. The unit is obviously a basin deposit.

Otsego Shale (Cooper, 1933, p. 544, 548)

This is a light brown weathering, medium to light gray, slightly calcareous, silty mudstone and shale with a few argillaceous siltstones and fine grained sandstones near the top of the unit. The shales are virtually barren of fossils but a few brachiopods and pelecypods occur in the silty beds. This unit probably represents very rapidly deposited mud, whose source was the Taconic area, rejuvenated during the second and main pulse of the Acadian Orogeny. The Otsego makes up the slopes of the "Cherry Valley Hills".

Solsville Sandstone (Cooper, 1930, p. 133, 219)

This is a brown weathering, gray, fine to medium grained sandstone with interbedded argillaceous siltstone and silty argillite, all interbedded silty shale. The sandier and siltier layers predominate in the upper one-half of the unit. Brownish-orange iron oxide staining is locally common. Fossils are scarce; plant remains and pelecypods have been observed in the Cherry Valley region. This unit caps many of the "Cherry Valley Hills".

POST-DEVONIAN SEDIMENTS

Resting unconformably on the Devonian rocks of the Cherry Valley region are transported glacial gravels, sands, silts, and clays of Pleistocene age. Outwash and till are most common although there are notable west-east drumlins along the northern margin of the Devonian outcrop belt. These are products of a westward thrust of ice up the Mohawk Valley during the latter stages of glaciation.

NOTES

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TRIP A-1 (DEVONIAN STRATIGRAPHY & PALEOECOLOGY, ETC.)

ROAD LOG

I - Interstate Highway
US - Federal Highway
NY - New York State Highway
OC - Otsego County Highway
NOTE: Turn only where directions are underlined

TOTAL MILES	MILES FROM LAST POINT	DIRECTIONS & DESCRIPTIONS
0	0	Leave Rensselaer Polytechnic (R.P.I.) Houston Field House parking lot.
0.1	0.1	W(downhill) on Peoples Ave.
0.2	0.1	S(left) on Burdett St., at first signal.
0.2	0.1	SW(half-right) on Sherry Rd., Chapel and Cultural Center on right corner.
0.3	0.1	Join Sage Ave. and continue W(downhill) to intersection with 15th St. (student center on left) and continue straight ahead on Federal Ave. R.P.I. Buildings on left.
0.7	0.4	Deformed Taconic Sequence rocks at bend of hill on right.
1.1	0.4	Crossing "Emmon's or Logan's Line", the western limit of major Taconic gravity slides.
1.7	0.6	S(left) on River St., "Uncle Sam Mall" on left.
		Bear right on River St., join Congress St. (NY 7)
		Crossing Hudson River on NY 7.
2.0	0.3	Watervliet, intersection with NY 32, continue W (straight ahead) on NY 7.
5.3	3.3	Latham traffic circle; intersection with US 9.
5.9	0.6	S(left) on Adirondack Northway (I-87).
9.9	4.0	Intersection with NY 5.
11.1	1.2	Intersection with NY State Thruway (I-90).
12.1	1.0	W(right) on Western Turnpike (US 20).
14.5	2.4	Intersection with NY 155.

15.6	1.1	Guilderland; former site of glass manufacturing, using sand from dunes atop Lake Albany clays.
17.1	1.5	McCormick's Corners; intersection with NY 146 to Schenectady.
17.5-21.5	0.4	Helderberg Escarpment in view to S(left); note terraces caused by differing horizontal limestone formations.
19.6	2.1	Watervliet Reservoir; intersection with NY 158.
24.5	4.9	Climbing hill of eroded fault scarp; southern extension of easternmost of Mohawk Valley normal faults.
27.1	2.6	Crossing site of new I-88.
27.8	0.7	Duanesburg; intersection with NY 7 to Binghamton.
28.9	1.1	Middle Ordovician Schenectady sandstone and shale exposures scattered and small from here to Sloansville.
34.1	5.2	Crossing Schoharie Creek, Esperance; Schenectady-Schoharie County line.
34.7-35.3	0.6-1.2	Schoharie Creek parallels US 20 on S(left).
37.8	2.5	Sloansville; intersection with NY 30A and NY 162.
38.3-39.5	0.5-1.7	Several exposures of Schenectady sandstone and shale on hill at west end of Sloansville.
42.2	2.7	Passing from region underlain by Middle Ordovician strata to region underlain by Silurian and Devonian strata.
43.7	1.5	Carlisle.
44.8	1.1	Karst topography; sink holes on N & S of US 20 in Lower Devonian Manlius and Coeymans Limestones.
48.0	3.2	Sharon; intersection with NY 145 from S(Cobleskill) and Schoharie County 5A from N.
49.9	1.9	Long exposure of Onondaga Limestone on S(left), showing Moorehouse Member with 2 m of Nedrow Member at W end.
52.9	3.0	Sharon Springs; intersection with NY 10 to Canajoharie.

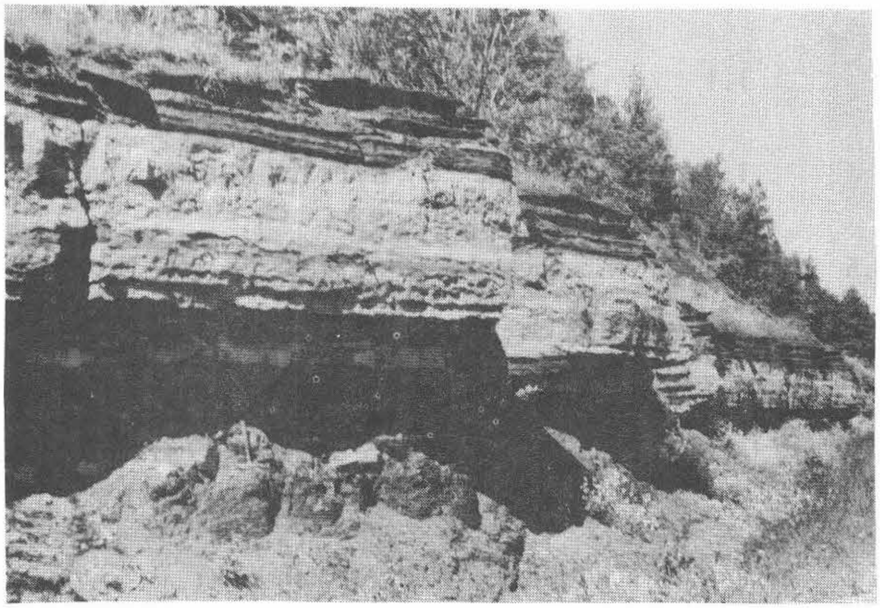

Figure 4. STOP 1. North-facing roadcut along OC 54, showing Chittenango Shale (top), Cherry Valley Limestone, and Union Springs Shale.

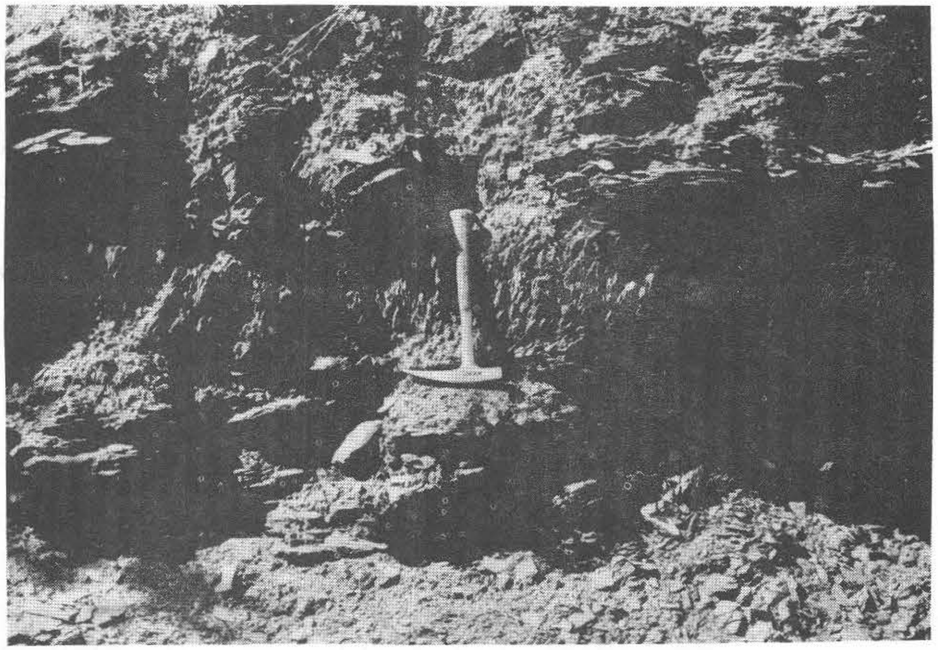

Figure 5. STOP 1. Closeup of "pseudocleavage" (shown at hammer level) in horizontally bedded Union Springs Shale.

53.3	0.4	Roadcuts on both sides of US 20 in Kalkberg Limestone; about 2m of New Scotland argillaceous limestone at top of exposure.
54.2	0.9	Leesville.
54.6	0.4	Roadcuts on both sides of US 20 in Kalkberg Limestone; forms conspicuous terrace.
55.0	0.4	Roadcut on S(left) of Esopus Shale, deformed by glacial shoving(?).
55.1	0.1	Otsego-Schoharie County Line; Cherry Valley hills to S(left).
55.3-57.1	0.2-2.0	Exceptional landscape view to N(right) across Mohawk Valley farmland floored with Ordovician and Upper Cambrian strata; Proterozoic gneisses of Adirondack Mountains in distance.
56.8	1.5	S(left) then immediate W(right) onto OC 54.

STOP 1 (35 minutes) - Parking area on right shoulder beyond W end of exposure. Roadcut on S (left) of road.

FIGURES 4 & 5

Three Middle Devonian units of Marcellus Formation of the Hamilton Group are well displayed here: Chittenango Shale (topmost), Cherry Valley Limestone, Union Springs Shale.

The dark gray-black Chittenango Shale contains the small, needle-like fossil *Styliolina fissurella* believed to have been pelagic in habit. No proven benthonic fossils have been found in the Chittenango. The hard, massive Cherry Valley limestone has yielded several species (Rickard, 1952) but they are scarce and exceedingly difficult to extract. Nautiloid and goniatite cephalopods are diagnostic, chief of which are *Striacoceras* and *Agoniatites vanuxemi*. The Union Springs Shale has a few thin limestone beds in its upper few feet which contain horn corals, trilobites, ostracodes, pelecypods, lingulid brachiopods, and the small goniatite *Werneroceras plebeiforme*, extremely useful for correlation purposes.

Of especial interest here are some unexplainable structural oddities in the Union Springs. One is the "pseudocleavage" and the other is the disrupted limestone concretions. These features may be manifestations of a large westward decollement', created during the Acadian Orogeny in Early Erian (Early Cazenovian) time as continental plate overriding (or underriding) produced a temporary basin on the site of the Devonian carbonate shelf in which black muds accumulated. Whatever their causes, these are anomalous structures in otherwise virtually structureless strata.

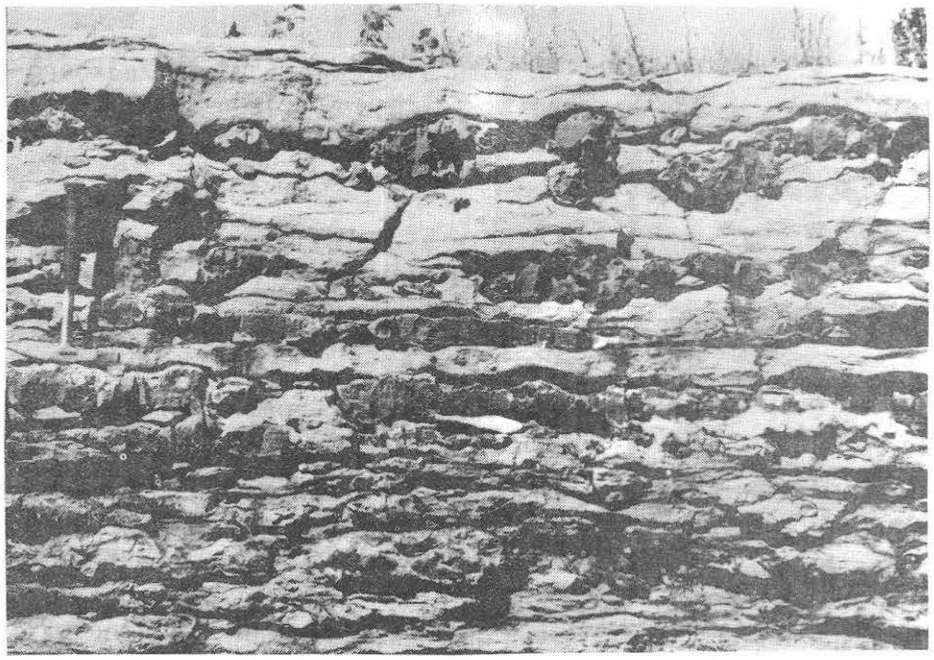

Figure 6. STOP 2. Nodular and bedded dark gray to black chert in Moorehouse Member of Onondaga Limestone.

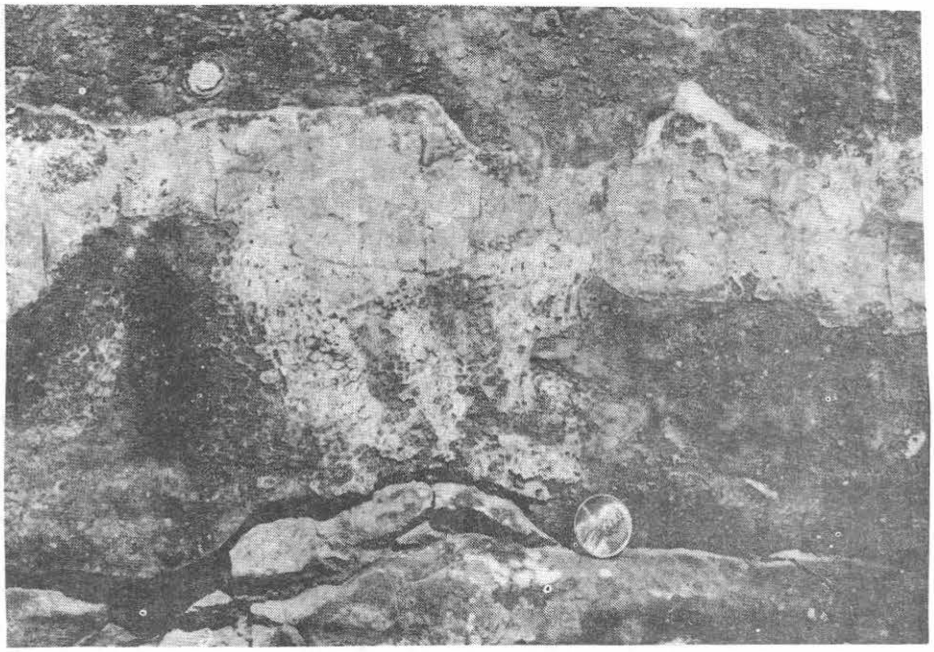

Figure 7. STOP 3. Nodular bedded tan to light gray chert in silicified coral-rich Edgecliff Member of Onondaga Limestone.

		LEAVE Stop 1 and continue SW on OC 54.
58.2	1.4	Roadcut in Otsego Shale on N(right) side of road. Cherry Valley hills capped by younger Solsville sandstone and shale whereas Otsego forms slopes and Chittenango floors the intervening valleys.
58.4	0.2	Onondaga (Moorehouse) Limestone on S(left) of road.
58.5	0.1	N(right) on NY 166 at east edge of village of Cherry Valley.
59.8-60.0	0.3-0.5	Road ditch on W(left) shows Nedrow shaley limestone.
60.1-60.5	0.1-0.5	STOP 2 (25 minutes) - Park off highway on right shoulder. FIGURE 6
		The roadcut on the E(right) shows the Moorehouse Member of the Onondaga Limestone; the Nedrow Member may be examined by walking back to the ditch exposure on the west side of NY 166.
		A little over 60' of medium to thick bedded, dark to medium gray, fine to medium grained limestone with bedded and nodular dark gray to black chert is well shown. The unit is not overly fossiliferous although brachiopods, bryozoans, and pelmatozoan debris may be collected.
		By contrast, the Nedrow is a thin to medium bedded, shaley, argillaceous limestone which weathers lighter. Platyceratid gastropods are diagnostic.
		LEAVE Stop 2 and continue N on NY 166.
60.6	0.1	Roadcuts on both sides exhibiting Moorehouse Member.
60.7-60.8	0.1-0.2	STOP 3 (30 minutes) - Park off highway on right shoulder. FIGURES 7 & 8
		The roadcut on the E(right) shows the Edgecliff Member of the Onondaga Limestone resting with sharp lithologic contact on the Carlisle Center calcareous, silty mudstone.
		About 15' of massive, irregular bedded, light to medium gray, medium to coarse grained Edgecliff Limestone with tan to light gray nodular to bedded chert and with prolific corals (often silicified) and crinoidal debris is splendidly exhibited here. The lower 4' is non-cherty and finer grained and

		the basal few inches contains angular shale fragments. The contact with the subjacant Carlisle Center is abrupt and a marked lithologic change.
		LEAVE Stop 3 and continue N on NY 166.
60.8	60.9	Carlisle Center in sharp contact with Esopus Shale on E(right).
60.9	0.1	Kalkberg Limestone on E(right).
61.0	0.1	W(left) on access road to US 20 east.
61.2	0.2	Kalkberg limestone, chert, and shale on S(right).
61.3-62.1	0.1	Long, high roadcut on S(right) - Will be visited later as Stop 6.
62.1		S(right) on parking area road. STOP 4, LUNCH (40 minutes)
		Slope underlain by Union Springs Shale capped by terrace of Cherry Valley Limestone (now completely grassed over); excellent view to N across Mohawk Valley to Adirondack Mountains in distance.
62.3		LEAVE lunch stop, turn W(left) on westbound lane of US 20 by taking crossover at E end of parking area. USE EXTREME CAUTION!
62.5-62.7	0.2	Roadcut on N(right) in Onondaga (Moorehouse) Limestone.
62.8	0.1	Good view to N(right).
63.1	0.3	Overpass of abandoned railroad.
63.3	0.2	Turn right off US 20 and turn N(right) on OC 32. Note: NY 166 only goes S from here.
63.4	0.1	Roadcut on E(right) shows about 28' of Upper Coeymans (Deansboro) Limestone with great profusion of gypidulid brachiopods, often silicified, and crinoid debris. Few chert nodules signify stratigraphic nearness of overlying Kalkberg Limestone.
63.6	0.2	Roadcut on E(right), now largely concealed, of about 16' of upper Manlius Limestone.

		STOP 5 (40 minutes) - Park on E(right) shoulder.
63.7-64.0	0.1	Long, high roadcut on E(right) in Lower Coeymans (Dayville), Manlius (Thacher), and Rondout (Chrysler). Thicknesses of each are 50', 44' and 12', respectively. Orange paint mark shows Coeymans-Manlius contact. Note that there is no reef rock in the uppermost Manlius nor *Tentaculites*- bearing ribbon limestones in lowermost Manlius in this section (compare with more easterly Manlius at Stop 7).
		Coeymans and Manlius are distinguished in that the former is lighter gray, thicker or irregularly bedded, coarser grained, and breaks with an irregular fracture; here, it is more fossiliferous than the underlying Manlius and has crinoidal debris and larger brachiopods. There is a 4' dolomitic shaley zone 25' from the base of the Manlius which is somewhat gradational into the subjacent Rondout Dolostone.
		The Manlius here is less fossiliferous than to the east and its environment may have been somewhat more saline so as to be less conducive to normal marine invertebrates.
64.5	0.5	LEAVE Stop 5 by proceeding N on OC 32 to first house on right and turn around in loop.
65.7	1.2	Retrace route to join NY 166 and pass under US 20 overpass.
65.8	0.1	Roadcuts on both sides of NY 166 in Kalkberg Limestone.
		W(right) on access road to US 20 and proceed east.
66.0	0.2	Roadcut on S(right) in Kalkberg Limestone.
66.1-66.7	0.1	Long, high roadcut on S(right) in Kalkberg, Oriskany, Esopus, Carlisle Center, and Onondaga Formations.
		STOP 6 (40 minutes) - Park off highway on right shoulder. FIGURES 8 & 9
		Beginning at the overpass for the abandoned Cherry Valley Railroad, and midway within the Kalkberg Limestone, is a 1-3 cm sticky clay bentonite (volcanic ash) which has been radiometrically dated (Miller and Senechal, 1965), using Rb-Sr isotopes, as 395 million years old. Note the regularity of the thin to medium bedded siliceous limestones, the shale intercalations, and the dark gray to black chert beds and nodules, as well as the great profusion and diversity of brachiopods and bryozoans.

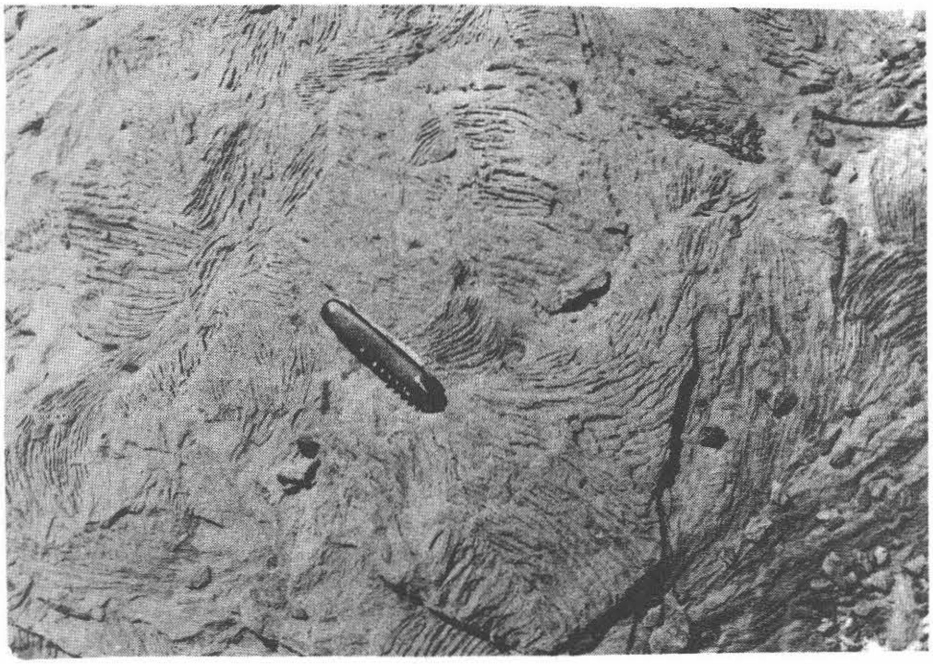

Figure 8. STOPS 3 & 6. Bedding plane exposure of "rooster-tail" markings, *Zoophycos (Taonurus) caudagalli*, in Carlisle Center Formation.

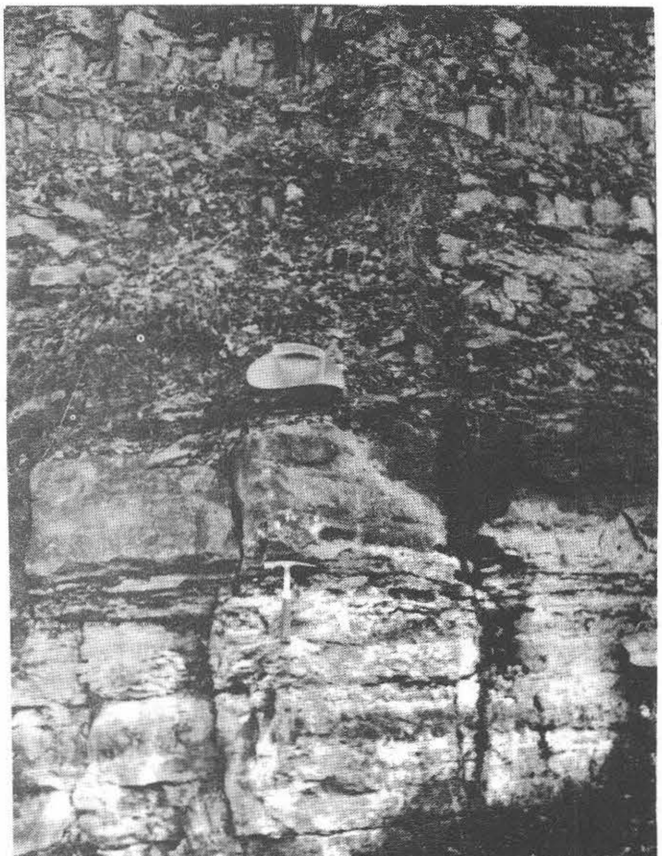

Figure 9.
STOP 6. Portion of stratigraphic sequence showing Esopus cherty shale (top), Oriskany "Sandstone" (hat at top, hammerhead at bottom), and Kalkberg Limestone.

The next overlying unit is a famous one in New York stratigraphy---the Oriskany Sandstone. Its fame as a gas producer has long been known in central and western New York. Here, however, it is a quartzose limestone with large, rounded, sand grains of quartz in a calcite matrix. The contact with the Kalkberg is a "welded" one.

Seventeen feet of chertified argillite, chert, and dark gray shale make up the overlying Esopus Formation, here. Eastward, in the Hudson Valley, the Esopus reaches a thickness of over 300'. In sharp contact is the next overlying Carlisle Center Formation. This is a curious unit lithologically and paleontologically. Physically, it consists of about 45-55% clay minerals, 25-30% quartz of silt size, and 25-30% calcium carbonate. Organically, it is replete with only one trace fossil, the worm feeding trail, *Zoophycos (Taonurus) caudagalli*. Its environment of deposition is a puzzle!

The Edgecliff Member of the Onondaga Limestone rests with a marked lithologic and paleontologic change on the Carlisle Center mudstone. This and other units of the Onondaga have been previously described and observed at Stops 2 and 3. Note the green mineral staining, attributed as glauconite, along the contact.

LEAVE Stop 6 and proceed E on US 20.

67.0	0.3	Roadcut in Seneca Limestone Member of Onondaga on N(left).
67.1	0.1	Roadcut in Seneca Limestone on S(right). During highway construction, this showed an abrupt lithologic contact with the overlying Union Springs black shale. Note the Cherry Valley Limestone terrace above.
67.3	0.2	Roadcut on S(right) in massive, dark gray Seneca Limestone with re-entrant at base showing 8-13 cm of sticky, light gray clay,--the Tioga Bentonite.
67.7-67.9	0.4	Long roadcut in Chittenango-Cherry Valley-Union Springs Members of the Marcellus Formation (STOP 1)
68.0	0.1	Intersection with OC 54 (to STOP 1). Continue E on US 20.
71.8	3.8	Sharon Springs; intersection with NY 10.

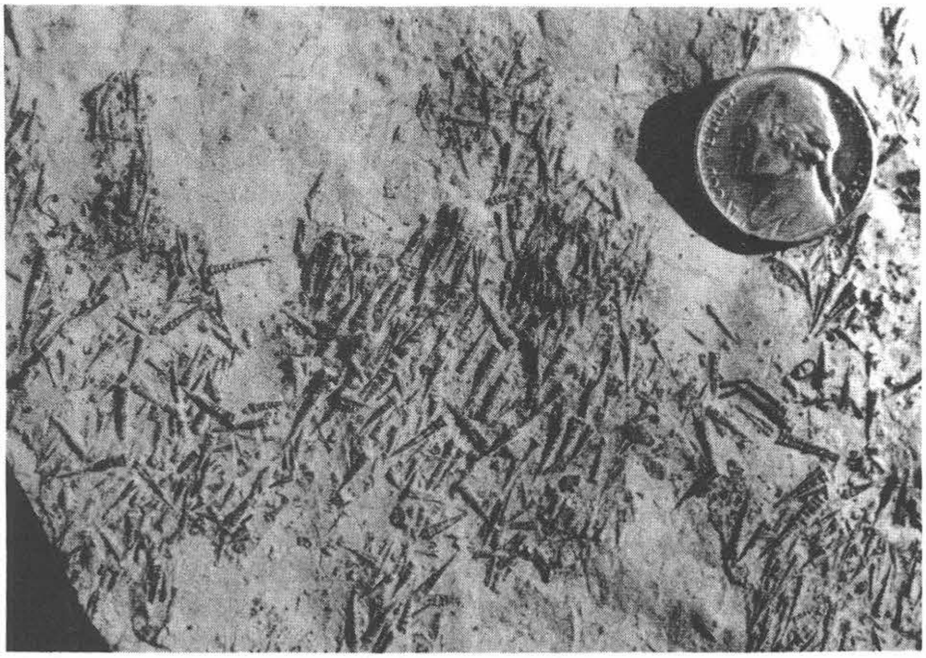

Figure 10. STOP 7. Bedding plane exposure of the extinct cricoconarid, *Tentaculites gyracanthus*, presumed to have been a mollusk. Thacher Member of the Manlius Limestone.

Figure 11.
STOP 7. Unbedded stromatoporoid biostromal reef resting on regular-bedded Thacher Limestone.

73.7	1.9	N(<u>left</u>) across westbound lane of US 20 onto town road. This intersection is termed Sharon Center on the topographic map.
74.1-74.4	0.4	Karst topography region; sink holes on W(left) about 400' from road.
74.7	0.3	E(<u>right</u>) on town road. Continuous ledge of lower Coeymans and upper Manlius limestones parallels road on S(right).
75.3	0.6	STOP 7 (45 minutes) - Buses will unload passengers on left shoulder opposite roadcut and load at right bend, 0.1 mile to the SE. <u>FIGURES 10 & 11</u> Roadcut in Manlius (Thacher Member) Limestone on S(right) side. Thin-bedded (ribbon) limestone, fine grained, dark gray to black, weathers very light gray. Rock breaks with a "ringing" sound and conchoidal fracture. Numerous shale intercalations. Bedding planes covered with the extinct mollusk, the narrow conical *Tentaculites gyracanthus*, the ostracode *Hermannina alta*, and the small spiriferid brachiopod *Howellella vanuxemi*. Bryozoans and gastropods are occasionally found. In 1954 I was fortunate in discovering an horizon covered with the rare edrioasteroid *Postibula* n. sp. Walk SE past abandoned farmhouse to next limestone ledge. Here, crossbedded coarse grained limestone occurs in the upper 18" of the ledge; this is a rare sedimentary feature in the Helderberg Group. Proceed W across field to next limestone ledge. This is a stromatoporoid reef, marking the summit of the Manlius Formation. The "cabbage-looking" unbedded limestone rests on regular bedded Thacher Limestone. These stromatoporoids acted as barriers blankets, and baffles and caused waves to break offshore creating differing environments of quite protected areas and agitated open areas. LEAVE Stop 7 and proceed SE along town road.
78.2	2.9	Sharon; rejoin US 20, turn E(<u>left</u>) and retrace route to R.P.I. Field House.
101.7	23.5	Spectacular view ahead to the east, looking across Hudson River Valley to Taconic and Berkshire Mountains in distance. Albany's Empire State Plaza is visible in the Valley.
103.4	1.7	Another excellent view to the east, in case you missed the earlier one!

113.6	10.2	Passing over N.Y. State Thruway (I-90); BE PREPARED TO MAKE LEFT TURN!
113.7	0.1	N(left) on Adirondack Northway (unnumbered!).
119.9	6.2	E(right) on NY 7; continue on NY 7 thru Troy on Congress St.
123.8	3.9	N(left) on 15th St. (NY 7) thru R.P.I. Campus.
124.7	0.9	E(right) on Peoples Ave., past Samaritan Hospital to Field House.
125.2	0.5	END OF TRIP

TRIP A-2

SEDIMENTARY ENVIRONMENTS AND THEIR PRODUCTS: SHELF, SLOPE, AND RISE OF PROTO-ATLANTIC (IAPETUS) OCEAN, CAMBRIAN AND ORDOVICIAN PERIODS, EASTERN NEW YORK STATE

by

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My thanks are extended to my student, friend, and colleague Brian D. Keith with whom I enjoyed collaboration in the study of the rocks of the Taconic Sequence. Parts of this guide are an abbreviated version of our papers Keith and Friedman (1977, 1978).

INTRODUCTION

On this field trip, instead of tracing formations, we shall study sedimentary facies. We plan to hop from the products of one environment to those of another. At each exposure we shall study the rocks in terms of lithology, geometry, sedimentary structures, and fossils, and concentrate on the pattern of deposition which created the facies that we shall examine. Remember that the various exposures of Cambrian and Ordovician rocks to be visited are not time correlative. Each field stop will stand on its own; facies analysis will proceed within the boundary conditions of a single exposure. On this field trip the name of the formation becomes secondary; hence this field trip has been designed irreverently; it pays no heed to formation boundaries.

The fascination of the area around R.P.I. is its diversity of sedimentary geology: in one day of field trips we can examine sedimentary facies of Cambrian-Ordovician age which originated in shallow as well as in deep marine waters. Few other areas can match this diversity of sedimentary facies. The geologic coincidence for this diversity of sedimentary environments in the area of the R.P.I. Campus is its unique location: from Early Cambrian through Early Ordovician R.P.I. would have been on a carbonate shelf. Between Early Cambrian and Early Ordovician times the shelf to basin transition was east of Rutland, Vermont. Tectonic movements shoved Cambrian and Ordovician rocks of slope, rise, and basin facies across the shelf facies so that today the exposures on and near the Campus of R.P.I. are basin or basin margin (rise) facies with shelf facies of Cambrian and Ordovician age occurring to the west (Friedman, 1972) (Fig. 1).

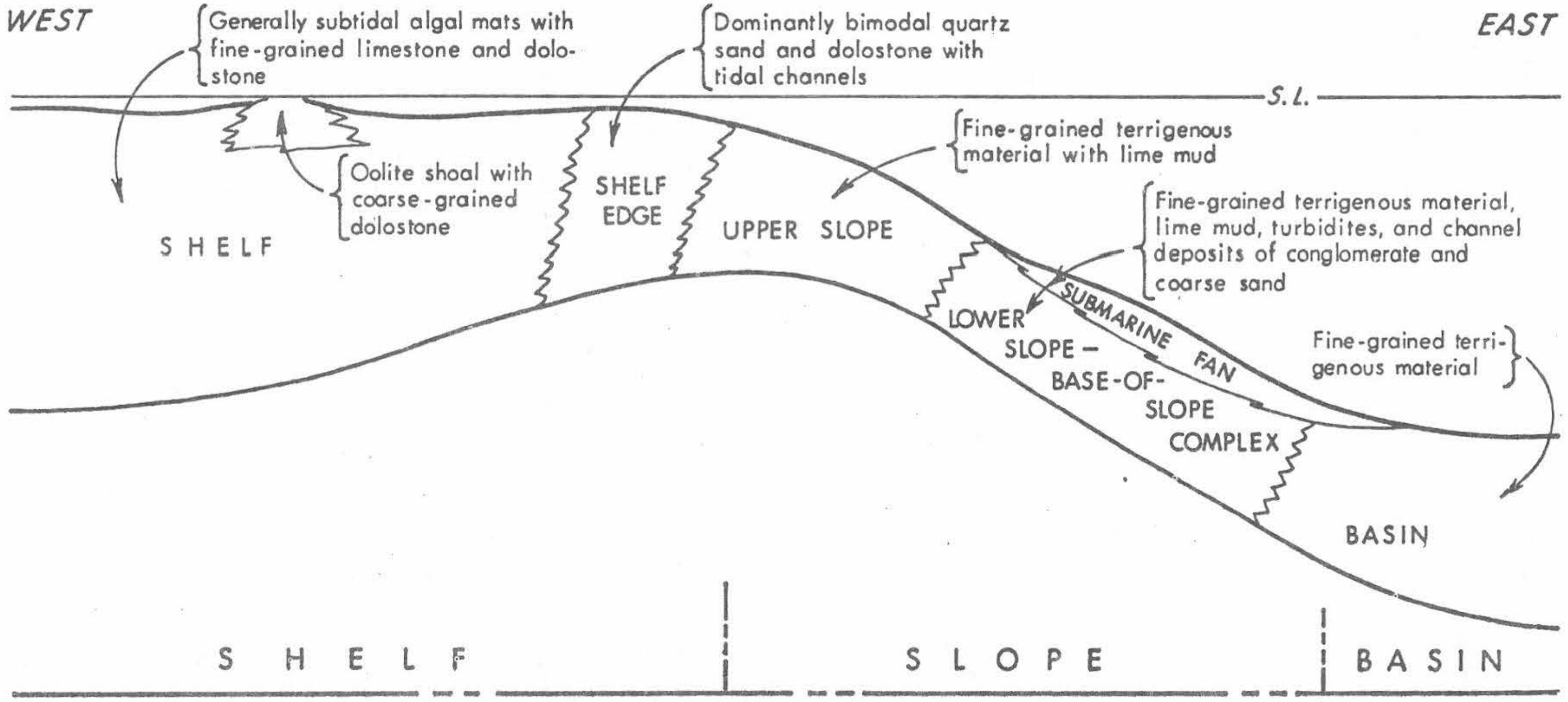

Figure 1. Diagrammatic sketch map showing depositional environments and characteristic sediments of Proto-Atlantic (Iapetus) Ocean for eastern New York and western Vermont during the Early Paleozoic (Keith and Friedman, 1977, Fig. 2, p. 1222).

During Cambrian-Ordovician time, most of the North American continent was a shallow epeiric shelf sea, like the present-day Bahama Bank. At the eastern edge of this shallow sea, i.e. at the eastern edge of this continent, a relatively steep slope existed down which carbonate sediment moved by slides, slumps, turbidity currents, mud flows, and sandfalls to oceanic depths to come to rest at the deep-water basin margin (rise), where a shale facies was deposited (Sanders and Friedman, 1967, p. 240-248; Friedman, 1972, p. 3; Keith and Friedman, 1977, 1978; Friedman and Sanders, 1978, p. 389,392). Shale also formed much of the basinal facies in the deep water beyond. Because allochthonous transport has been inferred for large blocks of rocks presently exposed on and near the R.P.I. Campus, the evidence on the ground shows that the Campus is the site of Cambrian and Early Ordovician rocks of basin margin (rise) and deep basin facies (shales deposited in the Middle Ordovician (Schenectady) west of Campus are autochthonous basin facies). Thus deep-water basin margin (rise) and basinal facies can be visited on and near the R.P.I. Campus, whereas to the west carbonate shelf facies are exposed that are analogous to those of the west shore of Andros Island on the Great Bahama Bank (Fig. 1). The paleoslope was probably an active hinge line between the continent to the west and the deep ocean to the east, similar to the Jurassic hinge line of the eastern Mediterranean between carbonate shelf facies and deep-water shales (Friedman, Barzel, and Derin, 1971). Such hinge lines in the early geosynclinal history of mountain belts are fixed by contemporaneous down-to-basin normal faulting (Rodgers, 1968, quoting Truempy, 1960), as probably occurred with the rocks of the area near R.P.I. Later thrusting to lift the deep-water facies across the shelf facies along hinge-line faults resulted in the contiguity of the two facies. This later displacement was so great that the Cambrian and Early Ordovician deep-water sediments were shifted far west of their basin margin.

This field trip has been divided into two parts, each part corresponding to half a day. In the morning and early afternoon we shall study facies of deep-water origin and in the late afternoon those of shallow epeiric origin. Each of the two depositional settings will now be explained.

DEEP-WATER SETTING: A SLOPE-FAN-BASIN-PLAIN MODEL

The strata of deep-water setting are part of the Taconic Sequence (Fig. 3). These rocks have received the attention of geologists for more than 150 years, and because of their exceedingly complex structural and stratigraphic relations have been the object of considerable debate. In fact approximately 150 years ago Ebenezer Emmons' advocacy of the Taconic System (1842, 1844, 1848, 1855) and the division of thought on this problem resulted in the famous duel between James Hall and Emmons which ultimately forced Emmons to leave New York State. A court decision involving several of the most well-known geologists of the last century assured Hall's victory by forcing Emmons out of New York; he settled in North Carolina away from his Taconic rocks.

Strata of the Taconic Sequence extend from north to south approximately 150 miles (Fig. 2), and for the most part within New York State,

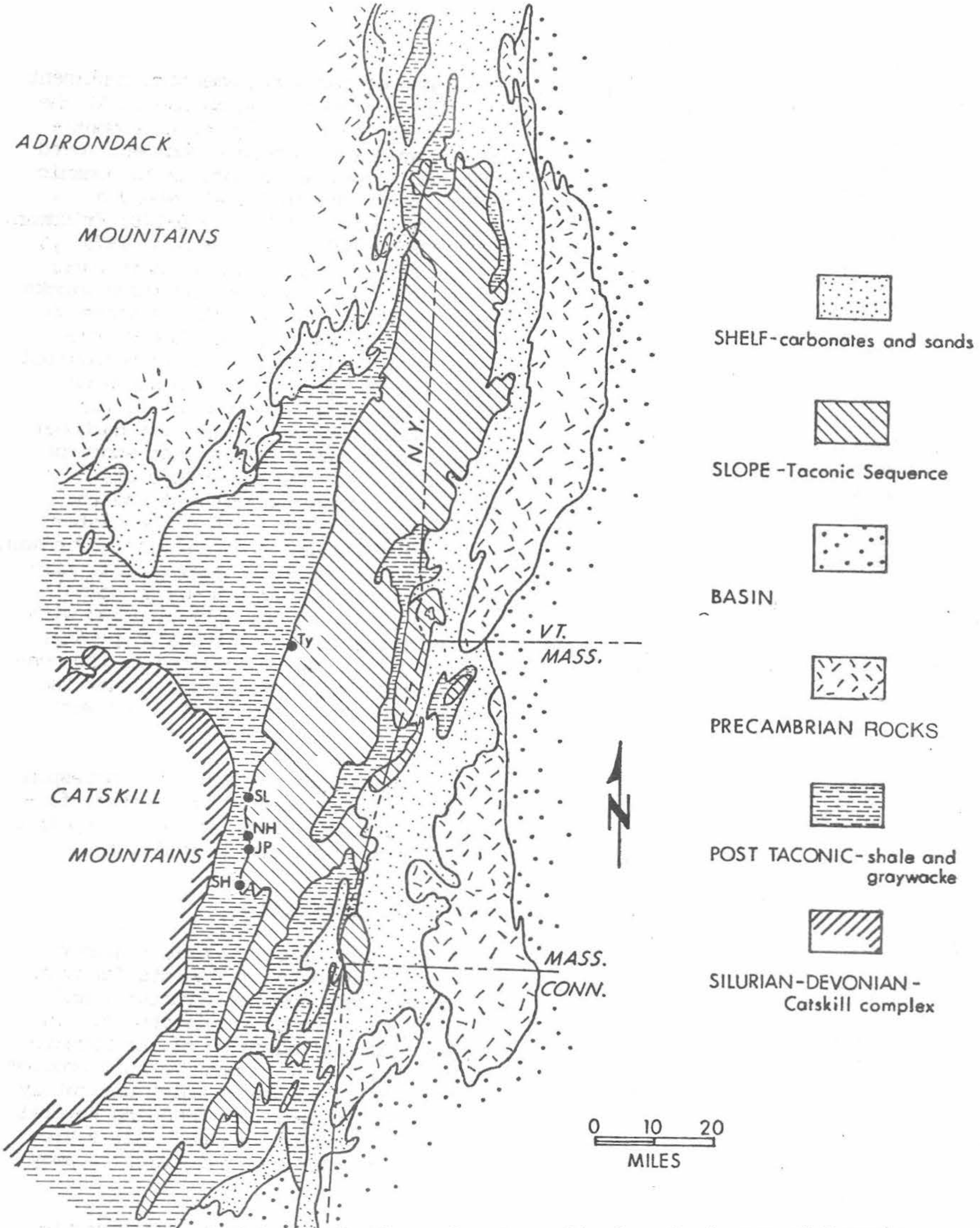

Figure 2. Generalized geologic map of Taconic area showing general rock types and localities visited on field trip. Localities are SH = South of Hudson (Stop 1); JP = Judson Point (Stop 2); NH = Nutten Hook (Stop 3); SL = Schodack Landing (Stop 4); TY = Troy area (R.P.I. Campus) (Stops 5-7) (after Keith and Friedman, 1977, Fig. 1, p. 1221).

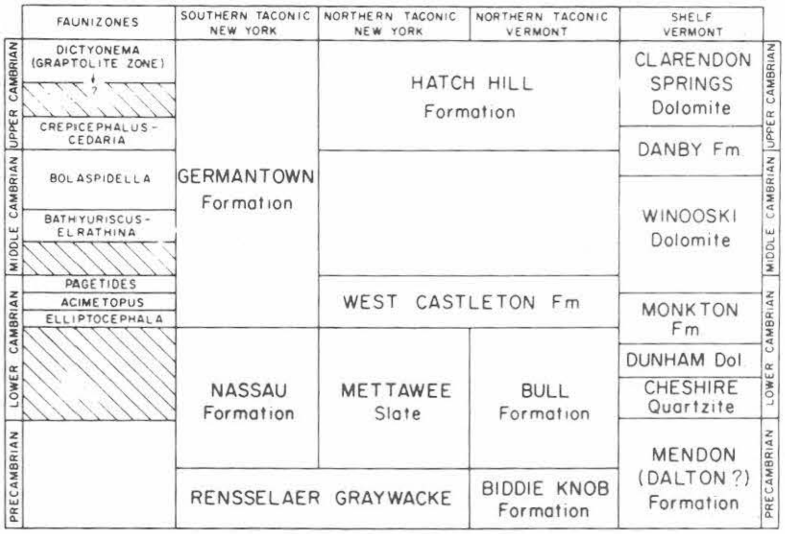

Figure 3. Stratigraphic correlation chart. Deep-water deposits seen on field trip are of West Castleton Formation (Lower Cambrian). Hachured areas represent faunizones not represented in rocks shown on chart (Keith and Friedman, 1977, Fig. 3, p. 1222).

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are composed of shales and sandstones. Carbonate rocks are minor by comparison, but are important as they reflect depositional conditions. Although the stratigraphy and tectonics of the area have been the subject of considerable controversy, a debate that has become known as the "Taconic Problem," stratigraphic succession and structure have more recently been clarified (Bird and Rasetti, 1968; Zen, 1967).

Environmental reconstruction for the Cambrian part of the Taconic Sequence in eastern New York State indicates a depositional environment analogous with a modern continental rise or more specifically with a slope-fan-basin-plain model (Fig. 10) (Keith and Friedman, 1977, 1978). Carbonate sediment and generally coarse quartz sand were removed from the Cambrian shelf and deposited with muds of the slope, now slates and siltstones, by a variety of processes at work on the slope and within submarine canyons. The shelf-derived sediment can be divided into six main lithofacies, each bearing the imprint of the principal process or processes involved in its deposition. These include: (1) carbonate-clast conglomerates (inferred products of debris flow), (2) massive, coarse sandstones (apparent deposits of fluidized sediment flow and grain flow), (3) graded sandstones and limestones (presumed turbidites), (4) parallel-laminated sandstones and limestones (probable turbidites), (5) thin, structureless micrites (inferred deposits of vertical settling-out of suspension), and (6) current-ripple-laminated limestones and sandstones (thought to be the products of reworking by contour-following bottom currents or submarine overbank levee deposits). All of these processes were working together or in opposition. Analysis indicates that only the lower slope and base-of-slope portion of the early Paleozoic continental margin has been preserved in the Taconic Sequence (Keith and Friedman, 1977, 1978).

We shall discuss briefly these lithofacies.

Carbonate-Clast Conglomerate (Figs. 4 and 5)

Monomictic carbonate to polymictic carbonate conglomerates occur throughout the Taconic Sequence; a significant percentage of sandstone clasts may be present in some beds. The clasts have a general preferred orientation parallel to the bed boundaries, where they are exposed, but some clasts in a bed will be oriented up to 90° to the general trend.

Conglomerates resembling those described here have been mentioned in the literature extensively (Walker, 1970; Mountjoy et al., 1972; Walker and Mutti, 1973; Walker, 1975; Friedman and Sanders, 1978). Walker (1975, 1976) has proposed descriptive models for conglomerates of turbidite association (resedimented conglomerates) based on the presence or absence of grading (inverse or normal), stratification and imbrication. The conglomerates seen on this field trip with their lack of grading and stratification and local imbrication fall closest to Walker's disorganized-bed model. The recognition of a debris-flow model for many of these conglomerates having a lack of organized internal structure has become well established (Dott, 1963; Johnson, 1970; Cook et al., 1972; Hampton, 1972; Middleton and Hampton, 1973; Walker, 1975, 1976; Friedman and Sanders, 1978). A debris flow is defined as a flowing muddy mixture of water and fine particles that supports and transports abundant coarser particles (Friedman and Sanders, 1978, p. 95, 558). The mechanics of motion in any sediment gravity flow are complex, and a simple debris flow model cannot fully explain the features in the conglomerates of the Taconic Sequence (Keith and Friedman, 1977, 1978).

Such a model does fit well with the large clasts in a clay matrix, the lack of size grading, and the poor to nonexistent sorting. The range of composition of the clasts can be easily accounted for, as being derived from the shelf buildup and the basin-margin beds. Some conglomerates appear to be quite local in origin, and interbedded with beds similar to the source beds for the clasts, which also seems compatible with a debris-flow model. The upward decrease in clasts in some beds, with the pervasive preferred orientation and local imbrication all are puzzling as they indicate movement and settling of the individual clasts within the flow. The smaller grain size and presence of some degree of rounding, especially for clasts derived from the shelf, suggest some degree of transport. With increased transport, progressive dilution of the debris flow would take place (as suggested by Hampton, 1972), producing more fluid-like behavior and transition towards turbidity

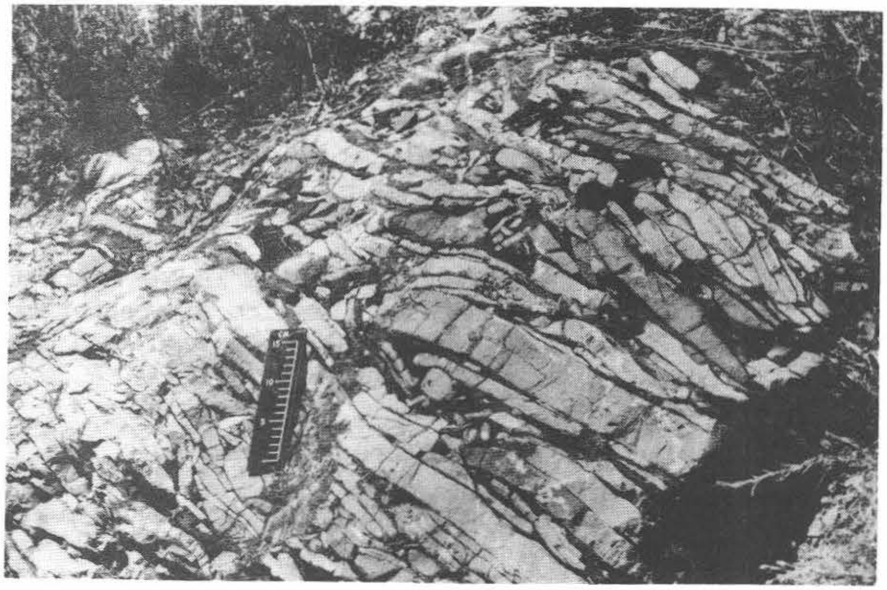


Figure 4. Carbonate-clast conglomerate of shallow-water origin displaced by debris flow from shelf edge into deep water. From exposure south of Hudson (Stop 1; SH on Fig. 2).

Figure 5. Rubble of incoherent slump or debris flow composed of boulders of limestone, sandstone, and chert. This rubble, known as brecciola, originated in shallow water behind shelf edge and was displaced into deep-water, dark-colored shales. Note calcite-healed fractures in view. Boulder in center is approx. 30 cm across. Campus of Rensselaer Polytechnic Institute (Stop 5).

current flow. However, none of the conglomerates discussed here show features indicative of turbidity-current activity such as grading and stratification. At this point all that one can say is that the depositional mechanism appears to be closer to debris flow than to any other (Keith and Friedman, 1977, 1978).

It is not clear whether the conglomerates of the Taconic Sequence were deposited as sheets or were confined to channels. Some of the conglomerates are associated with turbidites, which are generally considered to be confined to submarine canyons or to channels on a submarine fan. Thus, these conglomerates might have been similarly confined.

In summary, the carbonate-clast conglomerates appear to be the products of deposition by debris flow. The question of whether they are channel deposits or sheet flows is not fully resolved, and both types may well be present (Keith and Friedman, 1977, 1978).

Massive, Coarse Sandstone

These beds of massive sandstone show no bedding, lamination, or grading. The beds seem to fall into two groups, which are: (1) coarse-grained sandstone, and (2) thicker, coarse- to very coarse-grained sandstone. The beds are generally very coarse grained, with no internal features other than a few micrite pebbles. In places the beds contain either micrite pebbles, or wisps that stand out on the weathered surface which appear to be concentrated zones of sand that are more resistant to weathering than the bulk of the bed (Keith and Friedman, 1977, 1978).

The massive beds correspond to beds described extensively from turbidite sequences in the literature (Friedman and Sanders, 1978; Walker, 1967, 1970). Beds generally fitting this description have been called "fluxoturbidites" after the original description by Dzulynski et al. (1959). This term has become of limited usefulness due to the vagueness of the description and resulting misuse. Walker (1970) found, after extensive literature study, that there does exist a facies with certain features including: (1) unusually thick beds; (2) coarse grain size; (3) grading that was repetitive, poor or absent; (4) erosional bases with the finer interbeds being thin, irregular or absent; (5) pebbles commonly present; and (6) tops that may be sharp, rather than gradational. Walker (1970) compared these beds to classical proximal turbidites compiled from the literature and found no significant differences (Keith and Friedman, 1977, 1978).

A depositional mechanism that appears to fit these thick coarse-grained, generally structureless sandstone beds is fluidized sediment flow. This mechanism works when a loosely packed sand is subjected to an initial shock, destroying its fabric, so that water is incorporated and the sand liquifies, i.e., the grains are supported by excess pore pressure. Since the sand is not sealed, pore fluid loss is rapid, and the flow short-lived. As the pore fluid escapes the viscous properties of the mass disappear and the sediment comes to rest. Because the concentration of sediment relative to fluid is high, features associated with traction deposits, such as different types of lamination, cannot form (Keith and Friedman, 1977, 1978).

Generally, the beds of this lithofacies appear to fit a nebulous category of thick, coarse-grained massive sandstones "proximal" in nature (or possibly channel deposits). They were deposited by one or more processes, involving fluidization of the sediment (Keith and Friedman, 1977, 1978).

Graded Sandstones and Limestones

The graded beds are found associated with beds of other lithofacies. These beds are prominent except south of Hudson, where they are only a minor constituent of the exposed section. Shales are interbedded with this lithofacies at all exposures, except for Judson Point, where sandstone beds are commonly in depositional contact with each other, or with only a very thin shale parting between them (Keith and Friedman, 1977, 1978).

The graded beds range in composition from pure sandstone to limestones, with little or no sand. There are some beds that are half sand and half carbonate. Generally, within one exposure the lithology will be fairly constant. At Judson Point, the beds of this lithofacies are essentially pure sandstone. South of Hudson the beds all contain nearly equal amounts of carbonate and sand. Carbonate is present as rounded intraclasts, individual grains, and as a matrix in the sandy beds. The rounded intraclasts are commonly found near the base of the bed. The intraclasts are composed of pelmicrite, pelsparite or micrite. One intraclast of oomicrite was seen. Sparite and pelmicrite occur as matrix for sandy carbonates (Keith and Friedman, 1977, 1978).

Beds of this lithofacies display many kinds of sedimentary structures. Graded beds, parallel lamination, and cross-lamination (commonly ripple lamination) are all common. Grading takes on several forms in the beds studied. Many beds at Judson Point show delayed grading (Dzulynski and Walton, 1965), where most of the bed is coarse- or medium-grained sand, uniformly distributed, up to the very top, where the bed quickly becomes argillaceous with essentially no intermediate grain sizes. The grading then takes place in a narrow zone at the top, rather than throughout the bed. Beds at the locality south of Hudson commonly show coarse bimodal sand at the base in a carbonate matrix, with the sand decreasing in amount upward, leaving only the carbonate at the top. This would be a type of discontinuous grading with no medium-grained portion (Keith and Friedman, 1977, 1978).

Parallel lamination is quite common. It appears to be especially well developed in the medium-grained sandstone and the carbonate beds. The laminae are generally less than 1 mm in scale, and in the limestone the lamination is commonly due to fine-grained quartz being concentrated along the laminae. The coarse-grained sandstones, as seen at Judson Point, show only faint lamination, if any at all. Ripple lamination is quite well developed in some beds, but is not common. Not seen elsewhere was larger scale cross-lamination that could be considered cross-bedding in a bed south of Schodack Landing. Many examples of the various internal structures, alone or in combination with others, can be seen (Keith and Friedman, 1977, 1978).

Beds of sand-sized material, displaying grading and lamination in a systematic order (Bouma Sequence) and which are interbedded with basinal shales are turbidites (Fig. 6).

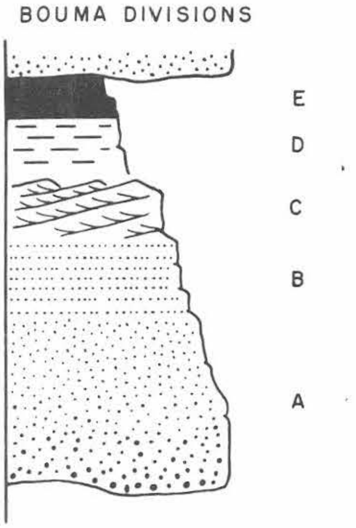


Figure 6. Vertical sequence in sediments deposited by gravity-powered bottom flows. This sequence consists ideally of five divisions, labeled A, B, C, D, E, and named the Bouma sequence after A. H. Bouma (1962):

A. Either a graded sandstone in which the particle size decreases systematically upward or a massive sandstone; the original sand of this "high-speed" depositional layer has a sharp base that divides it from the underlying "low-speed" shaley layer of the preceding sequence. A typically is a product of liquefied cohesionless-particle flow.
B. Parallel-laminated sandstone that represents conditions of upper-flow regime, hence is likewise a "high-speed" structure.
C. Ripple cross-laminated fine or very fine sandstone that represents the lower-flow regime, hence is a "low-speed" structure.
D. Faint parallel laminae of mudstone.
E. Shaley layer at top of sequence. At the contact between E and the overlying sandstone A of the next sequence, abundant sole marks may be present. The fine-grained fallout from the tail of a turbidity current may be difficult or impossible to distinguish from pelagic sediments.

Sequences of turbidites commonly consist of monotonously interbedded alternating and laterally persistent layers of sandstones and shales.

Not all divisions of the Bouma sequence need always be present;

sequences may consist of any combination of the five divisions, such as B-C-E, A-E, A-B-C-D-E, E-C, or others. The characteristics of gravity-powered bottom flows include (1) sharp base with sole marks, (2) divisions of Bouma sequence, (3) graded layer or massive sandstone, and (4) monotonously interbedded alternating and laterally persistent sandstones and shales (After Bouma, 1962; Walker, 1976, Fig. 1, p. 26; Friedman and Sanders, 1978, Fig. 12-52, p. 393).

There is a considerable body of literature on the problem of proximal versus distal environments in turbidites. A proximal turbidite has : (1) sharp and flat based beds, (2) thicknesses of 10 cm to 1 m, (3) a sand/shale ratio of about 5:1, (4) amalgamation of sandstone beds present, but uncommon, (5) uncommon parallel and cross-lamination, and (6) the typical bed is an AE sequence where the intervening BCD divisions are missing (Walker and Mutti, 1973). The graded beds at Judson Point fit these characteristics fairly well, although the sand/shale ratio is not as high. A distal turbidite has (1) sharp and flat based beds, (2) thicknesses of 1 cm to 10 cm, (3) a sand/shale ratio of 1:1 or less, (4) prominent grading, (5) grain sizes from fine sand to silt, and (6) base-cut-out sequences, usually BCDE, BDE, and CDE (Walker and Mutti, 1973). The graded beds seen at localities other than Judson Point generally fit the first four criteria fairly well, but are coarser grained and generally do not have base-cut-out sequences with the possible exception of certain laminated beds to be discussed in the next section. In general, these graded beds bear more resemblance to distal, rather than proximal, turbidites, but may be transitional (Keith and Friedman, 1977, 1978).

Parallel-Laminated Sandstones and Limestones

Beds identified as belonging to this lithofacies comprise a significant amount of the lithofacies at all of the major sections to be seen on this field trip and are the major lithofacies at Nutten Hook. They are also the only lithofacies besides the conglomerates found in the city of Troy area, especially on and near the R.P.I. Campus.

The beds of this lithofacies range from medium-grained, parallel laminated sandstones (60%), to medium-grained sandstones with parallel lamination and some cross-lamination (22%), to limestones (9%), and coarse-grained sandstones (9%). Most of the coarse sandstones occur at Judson Point. The limestone beds are pelmicrites with the lamination due to the concentration of fine quartz sand and silt along the laminae. In places a bed will contain fossil fragments. Most of the sandstone beds are composed of medium-grained quartz sand with a variable amount of carbonate matrix forming the laminae. Some of the sandstone beds will contain fossil fragments, and, in fact, nearly all the identifiable trilobite fauna recovered by Bird and Rasetti (1968) from Judson Point, and Nutten Hook, and used by them for dating, came from beds identified in the Keith and Friedman (1977) study as belonging to this lithofacies. All but one of the sandstone beds and all of the limestone beds of this lithofacies show lamination of some sort. Commonly, only parallel lamination is present in the sandstones, but some sandstone beds and most of the limestone beds show some cross-lamination.

The beds here probably represent channel-edge equivalents of the coarser, probable channel deposits represented by the conglomerates, massive sandstones and turbidites. For the most part, the beds of this lithofacies would appear to be single beds of division B of the Bouma Sequence.

In summary, beds of this lithofacies are intimately associated with turbidites and may even be types of turbidites themselves (Keith and Friedman, 1977, 1978).

Thin Structureless Micrites

This lithofacies is composed of beds of dense, texturally simple micrite that does not show any features in thin section other than neomorphism where the original lime mud has become recrystallized (Fig. 7). Beds of this lithofacies are found at several of the sections seen on this field trip and comprise a significant amount (approximately 20%) of all the lithofacies south of Schodack Landing and Nutten Hook. Single and multiple beds are found interbedded with beds of other lithofacies. At other localities isolated stringers can be found in places. South of Hudson and Nutten Hook even beds of micrite are interbedded with shale (Fig. 8) and beds of cross-laminated and parallel-laminated pelmicrite. These beds show some pull-apart or boudinage structure and, locally, slump folds. South of Schodack Landing the micrite beds are not associated with any coarser beds and make up 70-75% of that part of the section. Pull-apart is common in these beds. The beds south of Schodack Landing change upward to lenses and stringers of micrite in shale gradually becoming thin and discontinuous. A local conglomerate is present in part of the exposure at Schodack Landing (Keith and Friedman, 1977, 1978).

Thin interbeds of fine-grained limestone (usually micrite) intercalated with dark shale, as described for this lithofacies, have been noted from a number of areas (Sanders and Friedman, 1967; Wilson, 1969). These beds are generally referred to as hemipelagic, because they are a combination of terrigenous sediment and pure pelagic sediment.

The beds discussed here do not contain pelagic microfauna, thus, the only source of abundant lime mud is very shallow water (< 30 m) environments. Shallow-water production of lime mud can be quite high, coming from a variety of sources. Once produced, currents can move the lime mud quite easily from the shelf into deeper water. This process would seem to be the only plausible explanation for the micrite beds of this lithofacies. The lime mud was probably carried in dilute suspensions, either by contour currents, nepheloid layers, or dilute turbidity currents (Walker and Mutti, 1973). Isolated beds of micrite could conceivably be attributed to single or an episode of several dilute clouds of lime mud being carried into deeper water. A problem

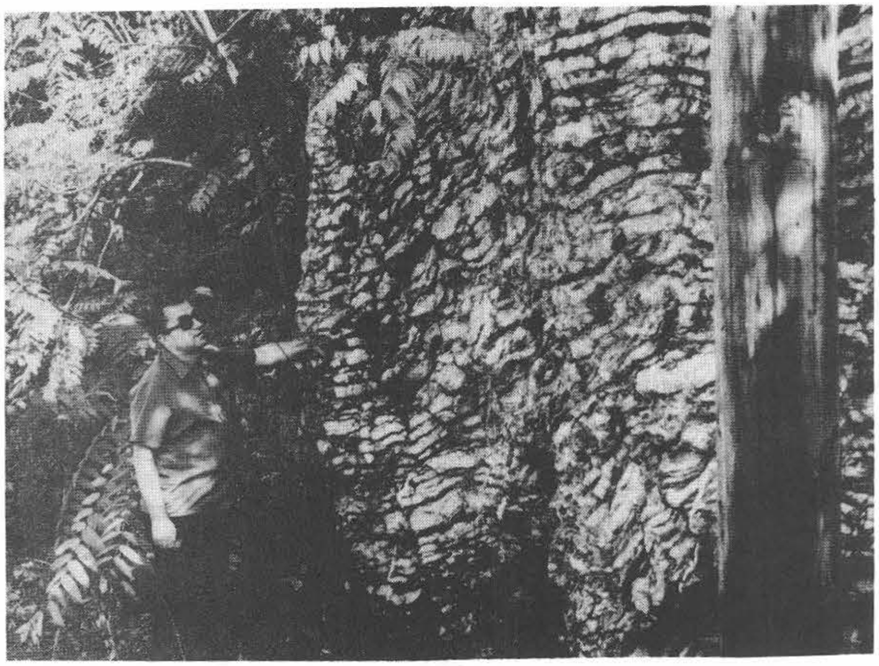


Figure 7. Interbeds of micrite with shale partings. The abundant lime mud was derived from very shallow-water (< 30 m) environments. Currents moved the lime mud into deep water. On left is the well-known Polish geologist S. Dzulynski whose work on deep-water deposits is now classical. Schodack Landing (Stop 4; SL on Fig. 2).

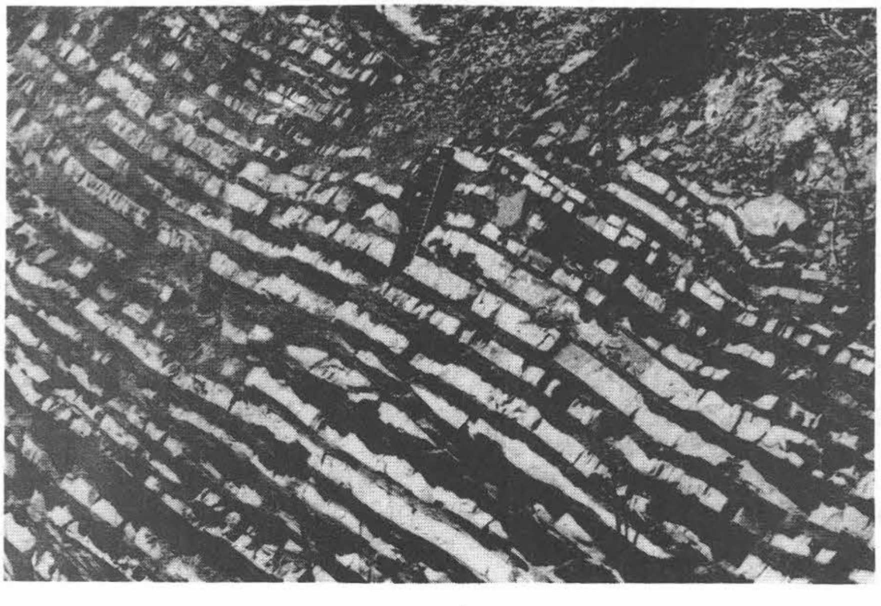


Figure 8. Interbeds of micrite and shale. This micrite is mostly a pelmicrite. The original lime mud was derived from very shallow-water environments. South of Hudson (Stop 1; SH on Fig. 2).

arises, however, with rhythmic succession of micrite and shale beds of very constant and even thickness. Sanders and Friedman (1967) stated that the environmental interpretation of such sequences may be extremely difficult, for similar sequences are seen in near-shore environments.

To summarize, these beds are composed of structureless micrite that is commonly associated with beds or laminae of pelmicrite. This fine-grained material was picked up in suspension on the shelf and carried into deeper water, possibly by contour currents, nepheloid layers, or dilute turbidity currents. The resulting deposits are thin beds of carbonate interbedded with fine-grained terrigenous material (Keith and Friedman, 1977, 1978).

Current-Ripple-Laminated Limestones and Sandstones

This facies consists of thin beds generally ranging from 1.3 cm to 10 cm, with the average thickness of 4.1 cm. This average is considerably less than that for the graded beds (about 19 cm) and less than that for the parallel-laminated beds (about 7 cm), both of which are similar in terms of sedimentary structures. As with the graded sandstones and limestones and thin, structureless micrites, the best exposures of these beds are in the cuts, south of Hudson, Judson Point, and Nutten Hook. No beds of this lithofacies were found south of Schodack Landing. South of Hudson and at Nutten Hook, beds of this lithofacies occur with the thin structureless micrites (Keith and Friedman,'77, '78).

Lithologically, these current-ripple-laminated beds seem to fall into two types -- pelletal limestone with fine-grained quartz sand, or fine-grained quartz sandstones to siltstones. These beds are always laminated with either parallel laminae or striking cross-laminae.

These current-ripple-laminated beds do not show the variety or orderly sequence of features associated with average turbidites. They are also finer grained and thinner bedded than the graded beds described earlier. The laminated beds of this lithofacies probably were deposited by one of three separate processes: submarine overbank levee deposits associated with turbidity currents, distal turbidites, or possibly contour-following bottom currents (Fig. 9). For a more detailed discussion see Keith and Friedman (1977, 1978).

Environmental Reconstruction for Deep-Water Deposits

The rocks of the Taconic Sequence studied here are clearly the products of deposition in a slope environment (Figs. 1 and 10). The depositional mechanisms that were active (debris flow, sediment flow, turbidity currents, hemipelagic sedimentation, and contour currents) appear to be characteristic of the lower part of the slope and the base of the slope. All of these processes, except the contour currents, form a continuum such that one sediment gravity flow could act as a debris flow, sediment flow, turbidity current, or suspended cloud depending upon its time and spatial position on the slope.

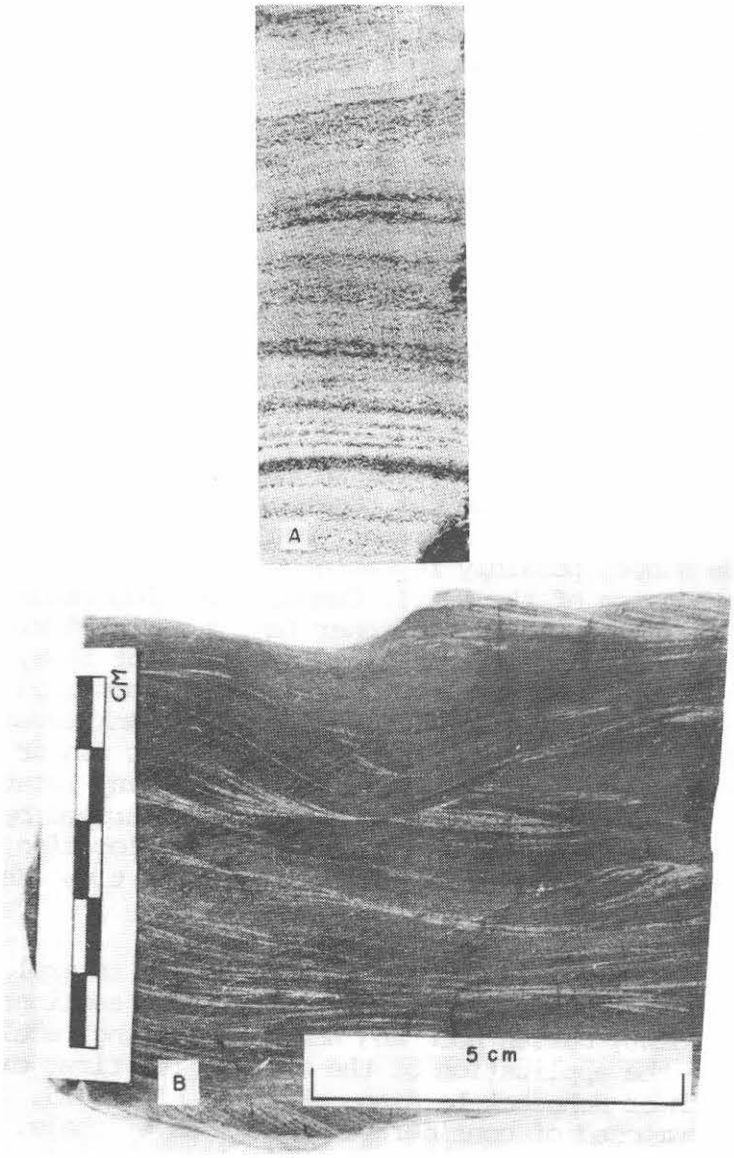


Figure 9. Photographs of modern- and ancient contourites.
A. Core of modern contourite raised from Caicos Outer Ridge, Bahamas, western Atlantic Ocean. This sediment is a well-sorted, medium-grained skeletal sand; note horizontal laminae. (E.D. Schneider.)
B. Polished slab of inferred contourite of Cambrian age (West Castleton Formation) sampled near campus of Rensselaer Polytechnic Institute, Troy, New York. This inferred contourite is a current-ripple cross-laminated pelletal limestone; quartz silt accentuates the laminae. (B.D. Keith.)
(Friedman and Sanders, Fig. 12-51, p. 392).

There are many problems associated with the reconstruction of the slope environment of the Taconic Sequence. Foremost is the tectonic complexity that has been superimposed since deposition of the sediments. Details of physiography cannot be compared with modern slopes, but the general type and rate of sediment input and the transport mechanisms that were active can be compared with modern analogs. The modern example that fits very nearly with the lithofacies described in the Taconic Sequence is the slope-fan-basin-plain system that is fed by submarine canyons. The conyon is incised into the slope and acts as a conduit for the movement of shelf sediments into deep water. The fan built out from the mouth of the canyon is then primarily composed of shelf-derived sediment. The fan can be divided into several morphologic features. The inner (or upper) fan has one major channel with prominent levees to either side. This leads to the mid-fan area (or supra-fan) composed of many distributary channels and interchannel areas. The outer (or lower) fan is characterized by no defined channel system and merges into the basin plain (Keith and Friedman, 1977, 1978).

The relationship between the model in Figure 10 and the lithofacies described in this guidebook can be put together. The coarsest and least structured sediments (conglomerates) would form thick deposits at the base of the slope, possibly represented by some of the thicker conglomerates in the area of the R.P.I. Campus. Conglomerates would also be found in the lower canyon and inner fan, associated with coarse sands, as products of debris flow and fluidized sediment flow, respectively. Farther out into the fan, turbidity-current deposition becomes dominant, as channel and interchannel deposits. Overbank levee deposits could be found associated with any channel in the inner fan or mid-fan area. The hemipelagic micrite beds could be found at any location on the slope and fan where they were not subsequently destroyed by current activity. Contourite beds could also be found at any location, depending upon the position of the current at any particular time (Keith and Friedman, 1977, 1978).

The test of this model is whether it can be used to explain some of the exposures seen on this field trip. The exposed sections (South of Hudson, Judson Point, Nutten Hook and Schodack Landing) would best serve to illustrate the application of the model. The first example is the section south of Schodack Landing, shown in Figure 15. The base of the section is composed of considerable thickness of shale, and at least one conglomerate bed; overlying the shale is a sequence of thin micrite and shale beds, possibly the product of transport from the shelf. The conglomerate overlying these beds is probably the result of local slumping, since the clasts all appear to be derived from the underlying limestone beds. The next higher conglomerate indicates that feeding from the shelf has started, producing coarse sand and biosparite clasts, but only as an isolated event. However, the subsequent presence of channel and interchannel turbidites and a conglomerate, followed by massive sandstones and more turbidites shows active feeding from the shelf and fan development. The beds show definite mid-fan development and possibly an inner fan channel as well. Abruptly, the system appears to have been abandoned, as shown by the resumption of shale deposition, with only a local thin limestone (Keith and Friedman, 1977, 1978).

The section at Judson Point (Fig. 13) is dominated by turbidite beds and several massive coarse sandstone beds. The presence of

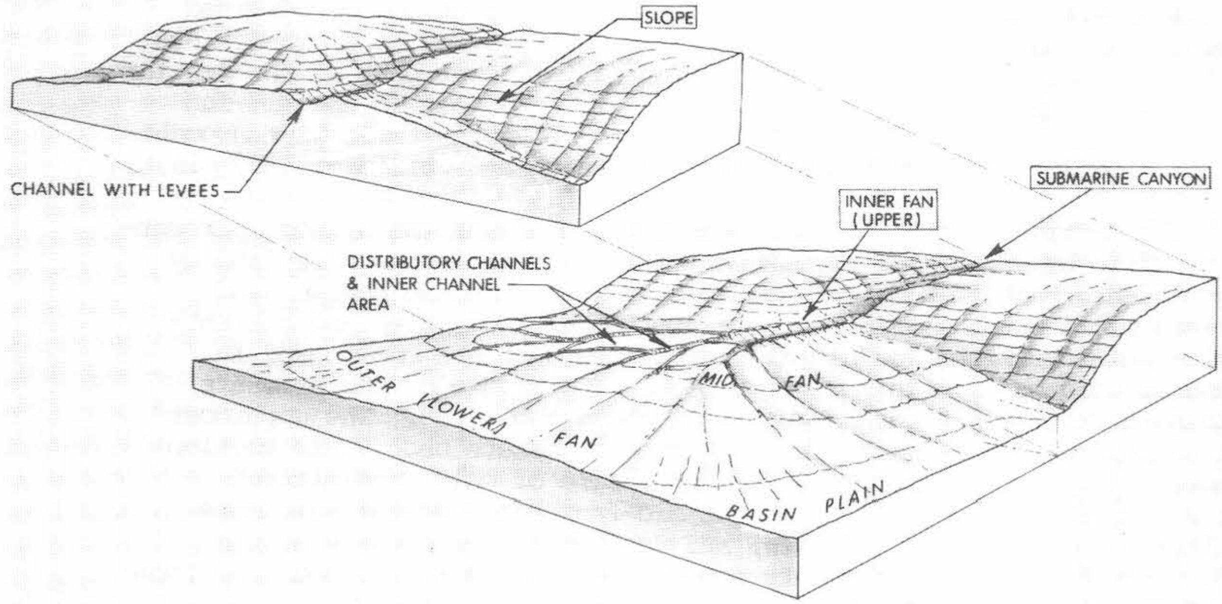


Figure 10. Diagrammatic block diagram of submarine canyon and fan complex, showing major morphologic features. Vertical relief exaggerated (Keith and Friedman, 1977, Fig. 19, p. 233).

several AE beds of the Bouma Sequence is characteristic of "proximal" turbidites. The massive beds are common in the lower part, but uncommon in the upper part of the section. The presence of thick massive sands and local conglomerates and thin-bedded laminated sands suggests channel and levee deposits of the inner fan area with the main channel periodically changing its course. Two of the conglomerates are somewhat lenticular in nature and truncate some underlying bed, suggesting channel deposition. For reasons that are not entirely clear, the only carbonate present is a 2 m-thick section at the top of the lower half of the exposure. The beds appear to be fine- to medium-grained hemipelagic and contourite beds, with a conglomerate near the top that contains clasts of the beds below. Possibly the section at Judson Point was influenced by locally dominant sand source. A more likely possibility is that the inner fan area is generally characterized by sands and that carbonates are generally carried farther out by more mature turbidity currents (Keith and Friedman, 1977, 1978).

The section at Nutten Hook is more difficult to interpret, because it is faulted in several places (Fig. 14). The interval below the covered zone is quite sandy and probably represents an environment similar to that just discussed for Judson Point. The section above this zone is dominated by thin interbeds of limestone of hemipelagic type. The lower fault interrupts the section, but the rocks above and below are quite similar. In places thicker laminated beds are distributed that are probably a "distal" turbidite. This was a local area of quiet sedimentation, with virtually no interruption by sediment gravity flows. The section above the upper fault contains several carbonate conglomerate beds in which the thin limestones, and the top of the section contains conglomerates, thick, coarse, laminated sandstones, and graded sandstones. It would appear that the environment shifted at some point in a "proximal" direction, with the influx of a considerable amount of coarser-grained debris. This shift might be due solely to reactivation of a channel system that was not in use during deposition of the lower part of the section, or due to the buildup of a new channel system, probably in the mid-fan area. The alternative is that the sediments above the fault were brought in tectonically from a more proximal area (Keith and Friedman, 1977, 1978).

The section south of Hudson, New York, contains the highest percentage of shale of any of the exposures (Fig. 12). It is characterized by intermittent, thin turbidite beds, most of which contain coarse sand and even micrite pebbles in the basal portions. Laminated and current-ripple-laminated probable "distal" turbidites also are common and in places associated with thin micrite beds. The middle of the exposure contains a regularly bedded sequence of these two types. The uppermost part of the section is marked by a thin conglomerate bed. This section is more difficult to interpret. It was a site of only intermittent coarse sedimentation, possibly in the mid-fan area. Hemipelagic beds of alternating limestone (micrite) and dark shale are present at the section south of Hudson; currents moved lime mud and terrigenous mud from the shelf into deep water (Keith and Friedman, 1977, 1978).

SHALLOW-WATER SETTING

Repeating from the Introduction, during the Cambrian and Ordovician periods, a shallow epeiric sea covered most of the North American continent. At the then-eastern edge of this submerged continent, shallow-water limestones and dolostones accumulated. Those which we shall study on this field trip are part of the Tribes Hill Formation of lowermost Ordovician age (Fisher, 1954). The steep paleoslope, which marked the transition from the submerged continent to the deep sea, lay about 35 miles east of the present Tribes-Hill exposures which we shall visit.

The carbonate rocks of the Tribes Hill Formation show many features that suggest that they were subjected to repeated shoaling and intermittently were exposed subaerially. These features include mud cracks, birdseye textures, undulating stromatolitic structures, mottles, lumpy structures, scour-and-fill structures, flat pebbles, cross-beds, and, as a lithology, syngenetic dolostone (Friedman and Sanders, 1967; Friedman and Braun, 1975). Features identical to these are known from most Paleozoic shallow-water carbonates that underlie much of North America. The site of accumulation of the Tribes Hill carbonates, however, differed markedly from that of most other Paleozoic carbonates that stretch across North America. The Tribes Hill carbonates were deposited close to the edge of the continent. Hence diurnal or semi-diurnal fluctuations of the waters of the deep ocean should have left their mark on the Tribes Hill deposits. If so, such deposits can be classed as tidal.

In modern tidal sediments perhaps the most obvious of the morphologic features are tidal channels. In the rocks of the Tribes Hill Formation, what may be ancient tidal channels can be observed. Such channels have not been reported from the Cambro-Ordovician carbonate-rock sequences in other parts of North America.

The sizes of the channels in the Tribes Hill Formation are comparable to the sizes of modern tidal channels. Sharp basal truncations are typical. The material filling the channels consists mostly of carbonate skeletal and intraclastic sand (biosparite and intrasparite) a high energy facies. These channels cut into a mottled dolomitic micrite and biomicrite, a low energy facies. Large blocks of micrite, up to 1 meter in diameter, which are lodged in the fills within the channels, are thought to have been derived by undercutting of the banks (Fig. 19). Hence, to accomplish such undercutting, the currents in these channels must have flowed fast. The contrast between the high-energy facies filling the channels and the low-energy facies in the flats adjacent to the channels likewise suggests that currents in the channels flowed swiftly.

Although in Paleozoic limestones the products of shoal waters are ubiquitous, tidal deposits may have been restricted to the margins of the continents where the epeiric shelf faced the deep ocean. The carbonate rocks of the Tribes Hill Formation may be an example of such a tidal sequence.

Authigenic feldspar is an essential constituent of the carbonate rocks of the Tribes Hill Formation. The high concentration of feldspars caused stromatolitic laminae to weather in positive relief. Such feldspars commonly are the end products of the alteration of zeolites. However, zeolites are unknown from sedimentary rocks as old as Early Ordovician. In rocks older than mid-Paleozoic, any original zeolites probably have changed to feldspars. In volcaniclastic rocks of Cenozoic age, authigenic feldspar is known to be the end product of volcanic glass whose initial alteration product was a zeolite (Sheppard and Gude, 1969; Goodwin, 1973).

The feldspars in the Tribes Hill Formation are interpreted as wind-transported tephra that accumulated at the margin of the Proto-Atlantic (Iapetus) Ocean. The active volcanoes responsible for such tephra may have been parts of ancient island arcs.

ITINERARY

Figure 11 is the road log and shows the location of all the seven stops.

Depart from parking lot of R.P.I. Houston Field House, take People's Avenue west past Samaritan Hospital (on right) downhill to Eighth Street.

Miles	Distance between points	
0.7	0.7	Proceed for one block to Federal Street, turn right and cross bridge across Hudson River and continue to Interstate 787 south
1.2	0.5	Enter Interstate 787 south
5.8	4.6	Take Interstate 90 east; cross Hudson River
19.0	13.2	Take Exit 12 (sign U.S.9 south) and follow route to Hudson
20.4	1.4	Enter Columbia County
23.7	3.3	Junction with Route 9H; continue on U.S.9
24.3	0.6	Enter Valatie
25.6	1.3	Enter Kinderhook
27.7	2.1	Town of Stuyvesant
29.3	1.6	Enter Stuyvesant Falls
30.0	0.7	Enter Columbiaville; Junction with Route 9J
34.6	4.6	Enter Stottville
35.4	0.8	Town of Greenport
36.0	0.6	Enter Hudson; continue south on U.S.9 through Hudson

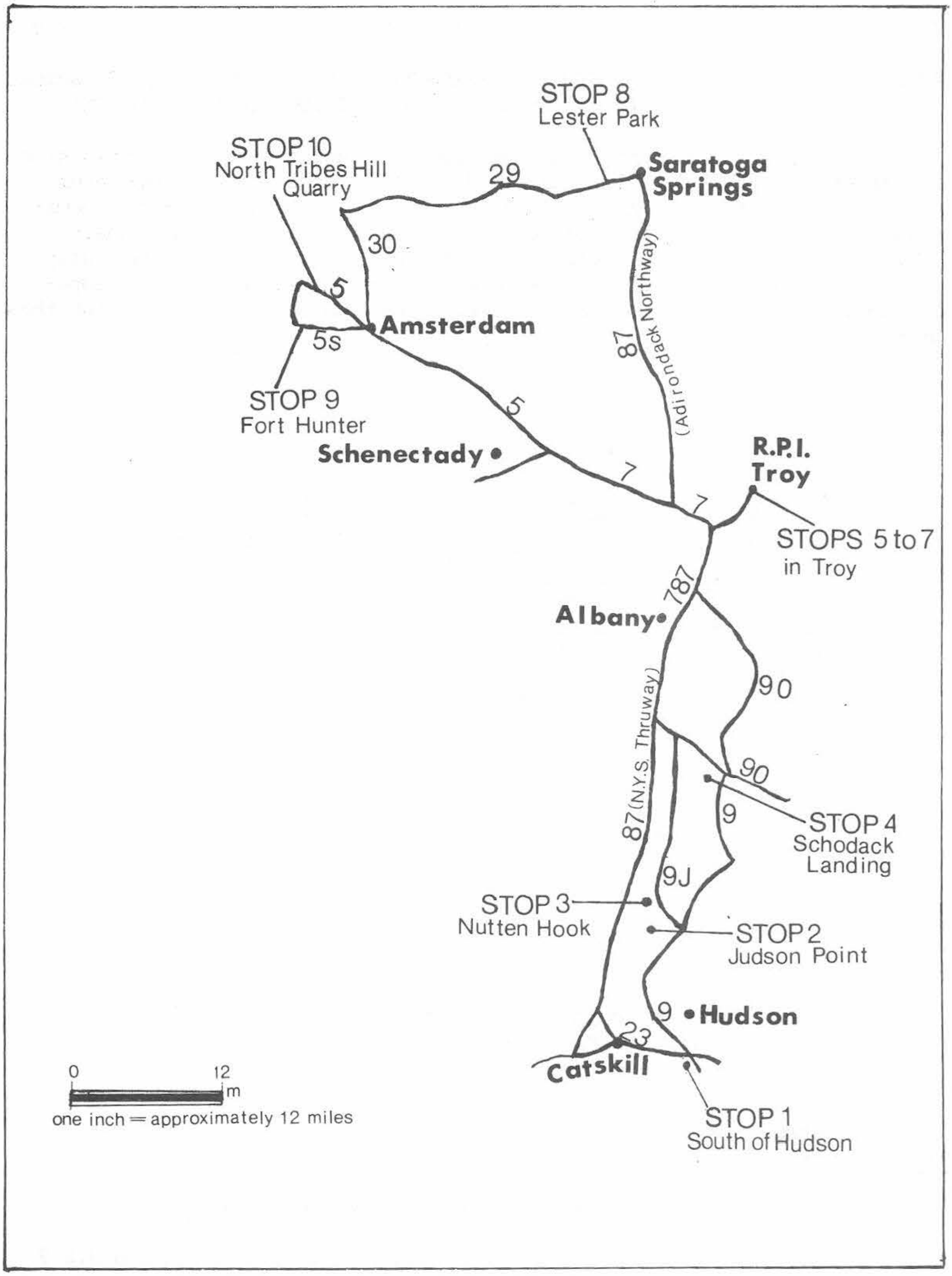


Figure 11. Road log with stops

Miles	Distance between points	
41.4	5.4	Junction with U.S.23; continue south on U.S.9
42.2	0.8	STOP 1 EXPOSURE ON EAST SIDE OF U.S.9 (across from a white house) (SECTION SOUTH OF HUDSON)

Figure 12 shows and describes the lithofacies exposed at this stop, and interpretes its depositional setting. The rocks are of deep-water mid-fan origin (Figs. 1 and 10). Note especially the interesting "hemi-pelagic" interbeds of fine-grained limestone (micrite) and dark shale (Fig. 8) and the carbonate-clast conglomerate (Fig. 4). Read carefully the material covered under the heading of "Deep-Water Setting: a Slope-Fan-Basin-Plain Model" so that you understand the objective of making this stop.

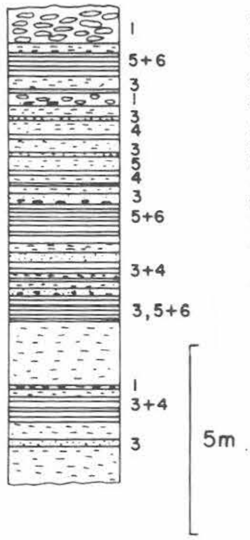
Section	Lithofacies and Description	Interpretation
	Carbonate-clast conglomerate (1). Generally to bottom of section: thin beds of graded limestones and sandstones (3), micrite beds (5), and laminated limestones (4 and 6) with shale. Regularly bedded sequence of micrite (5) and laminated limestone (6) and shale.	More "distal" environment of probable mid-fan area. Generally low rate of sedimentation.

Figure 12. Section south of Hudson Stop 1 (SH on Fig. 2) (Keith and Friedman, 1977, Fig. 23, p. 1237).

Miles	Distance between points	
		Make a U-Turn and head north on U.S.9
43.0	0.8	Junction with U.S.23; continue north on U.S.9

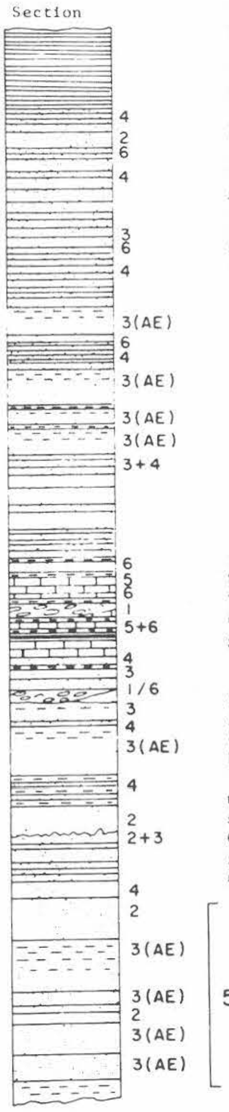
Miles	Distance between points	
46.4	3.4	Enter Hudson; continue through Hudson north on U.S.9
50.1	3.7	Enter Stottville
52.3	2.2	Enter Columbiaville
53.5	1.2	Junction of U.S.9, Route 9J, and an unmarked asphalt road identified by sign "Dead End." Turn sharp left onto asphalt road and head west towards Hudson River
54.5	1.0	At fork take lower road marked "Dead End"
54.6	0.1	STOP 2. JUDSON POINT

Figure 13 illustrates the section seen at this stop and describes the lithofacies; it also provides an interpretation of the depositional setting. The rocks are of inner- to mid-fan origin (Figs. 1 and 10). The section is dominated by turbidite beds, and several massive coarse sandstone beds. The presence of several AE beds of the Bouma Sequence is characteristic of proximal turbidites. The occurrence of thick massive sands and local conglomerates and thin-bedded laminated sands suggests channel and levee deposits of the inner fan area. Two of the conglomerates are somewhat lenticular and truncate an underlying bed, suggesting channel deposition. Again review the section entitled "Deep-Water Setting: a Slope-Fan-Basin-Plain Model" for a better understanding of the features observed at this stop.

Miles	Distance between points	
		Return to Rte. 9J
55.8	1.2	Head north on Rte. 9J
57.4	1.6	Town of Stuyvesant
58.2	0.8	Cross railroad tracks at Ferry Road (on left); note historic marker. Head west on Ferry Road.
58.5	0.3	STOP 3. NUTTEN HOOK

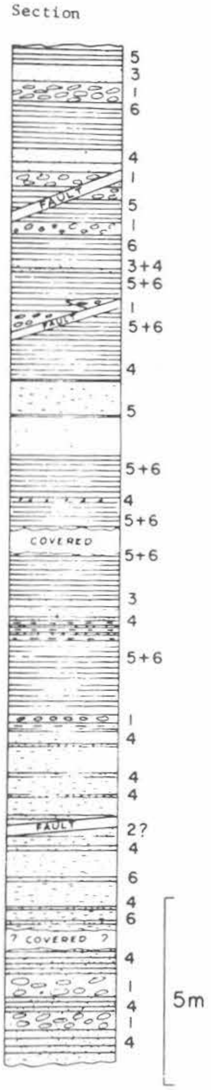
Figure 14 gives details on this section, including an interpretation of depositional environment.

		Return to Rte. 9J
58.9	0.3	Head north on Rte. 9J
60.8	1.9	Enter Stuyvesant



Lithofacies and Description	Interpretation
Laminated shale and siltstone.	
Dominantly thin, medium-grained, laminated sandstone beds (4) with some AE graded beds (3) and laminated fine-grained sandstones (6). Thin shale interbeds present throughout (not shown).	Area of inner fan channels and levee deposits, with sporadic reworking by contour currents. (No very coarse debris brought in.)
Fine-grained, laminated beds (6). Thin micrite beds (5). Carbonate-clast conglomerate (1).	Influx of carbonate sediment, dominantly lime mud.
Sandstone-clast conglomerate pinching out (1/6). Dominantly graded beds (3), often AE with massive, coarse sandstone beds (2). Occasional medium-grained, laminated sandstone bed (4).	Dominantly channels of inner to mid-fan.

Figure 13. Section at Judson Point (Stop 2; JP on Fig. 2) (Keith and Friedman, 1977, Fig. 21, p. 1235).



Lithofacies and Description	Interpretation
Dominantly thinly interbedded micrite (5) and laminated limestone (6) with occasional beds of carbonate-clast conglomerate (1) and sandstone (4). Section is interrupted by two faults.	Possibly mid-fan channel and interchannel sedimentation with periods of hemipelagic sedimentation and reworking. Relationship between sections above and below second fault uncertain.
Dominantly thinly interbedded micrite (5) and laminated limestone (6) with shale.	Dominantly an area of hemipelagic sedimentation.
Thin sandstone beds (4), one graded (3). See above, often showing small scale slump folds.	
Thin conglomerate (1). Dominantly shale with occasional thin sandstone bed (4), rare laminated sandstone (6), and one massive sandstone truncated by a fault at the top (2?).	Area of only sporadic coarser sedimentation.
Thin, medium-grained, laminated sandstone (4) and sandstone-clast conglomerates (1). Occasional shale partings (not shown).	Inner fan (?).

Figure 14. Section at Nutten Hook (Stop 3; NH on Fig. 2) (Keith and Friedman, 1977, Fig. 22, p. 1236).

Miles	Distance between points	
62.5	1.7	Overpass, New York Central Railroad
63.5	1.0	Railroad overpass
65.4	1.9	STOP 4. EXPOSURES SOUTH OF SCHODACK LANDING

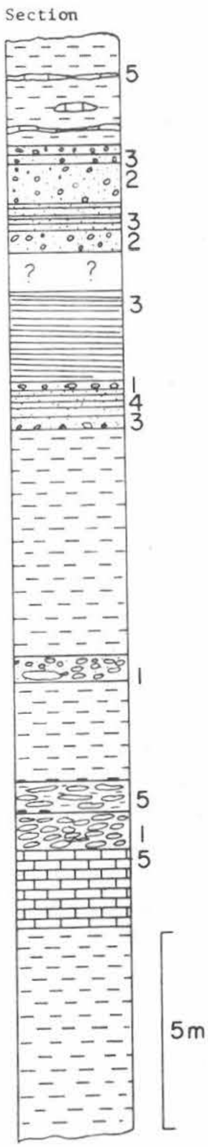
Bus parks on dirt road east of highway. We shall first examine the road cut on the east side of the highway and then walk on dirt road across the railroad tracks to view more fine exposures.

Figure 15 describes and illustrates the section seen and provides interpretation of the depositional setting. Note exposures of bedded micrite with shale partings. This micrite represents lime mud which was derived from the shelf and probably settled from suspension. The conglomerate overlying the bedded micrite is probably the result of slumping, since the clasts appear to be derived from the underlying limestone beds. The strata at this stop show mid-fan development and possibly an inner fan channel as well. Again review the earlier section entitled "Deep-Water Setting: a Slope-Fan-Basin-Plain Model" for additional interpretation of depositional setting.

Continue north on Rte. 9J

66.3	0.9	Enter Rensselaer County
66.8	0.5	Enter Schodack Landing
69.1	2.3	2 overpasses; New York Thruway and railroad
70.6	1.5	Enter Village of Castleton on Hudson
77.9	7.3	Overpass of U.S.9; junction with U.S.9; follow U.S.9 west (labelled north)
78.1	0.2	Enter Rensselaer
78.5	0.4	Enter bridge to cross Hudson River
79.2	0.7	From bridge take Interstate 787 north
86.0	6.8	Take Troy-U.S. 7 Exit (23rd Street, Watervliet, Green Island)
86.5	0.5	Cross Hudson River bridge to Federal Street, Troy
87.1	0.6	Proceed east uphill on Federal Street to '87 Gymnasium of R.P.I. Campus

STOP 5. RENSSELAER POLYTECHNIC INSTITUTE, '87 Gym. Exposure behind fence adjacent to gym.



Lithofacies and Description	Interpretation
Shale with thin beds of micrite (5).	Abandonment of the system.
Graded beds (3) and massive, coarse sandstone beds with pebbles (2).	Mid-fan or possibly inner fan channel.
Covered. Fine-grained, thin, laminated graded beds (3).	Mid-fan interchannel deposition.
Thin conglomerate (1). Laminated, medium-grained sandstone (4). Graded bed (3).	Mid-fan channel.
Carbonate-clast conglomerate (1).	Possible start of channel development as an isolated event.
Shale with lenses and nodules of micrite (5).	
Micrite-clast conglomerate (1).	Local slumping.
Micrite (5) with shale partings.	Influx of lime mud in suspension from shelf.

Figure 15. Section at Schodack Landing (Stop 4; SL on Fig. 2) (Keith and Friedman, 1977, Fig. 20, p. 1234).

Ruedemann (1930, p. 114; also fig. 64) described and photographed this exposure as a good example of a "cliff of mylonite," one of the "excellent exposures of a fault breccia" on the campus of Rensselaer Polytechnic Institute. According to Ruedemann and reconfirmed by Elam (1960) a thrust fault follows part of this street (Sage Avenue) and Ruedemann mistook this conglomerate for a fault breccia. Perhaps the presence of criss-crossing veins in this exposure led to his interpretation of a "cliff of mylonite." Jack G. Elam (1960; unpublished Ph.D. thesis at Rensselaer Polytechnic Institute) assigned the rocks at this exposure to the Schodack lithofacies of Early Cambrian age. Cushing and Ruedemann (1914, p. 69) had introduced the "Schodack Formation" which according to Fisher (1961, p. D8) has now fallen victim to a nomenclatorial "snafu." Zen (1964) has renamed this formation the West Castleton Formation.

Lowman (1961) recognized that the boulders are a conglomerate and not a breccia, and following Kuenen and Migliorini (1950), he introduced the term brecciolas. The term brecciolas refers to graded limestone breccia beds that alternate with dark-colored shales (Lowman, 1961, p. B6; Sanders and Friedman, 1967, p. 242; Friedman, 1972, p. 25; Friedman and Sanders, 1978, p. 390, 395).

The limestone- sandstone- and chert boulders which are embedded in shales at this exposure range from angular to rounded and show considerable variation in size (Fig. 5). Some boulders are coarse-grained fossiliferous limestone fragments with a micritic dolomite matrix. The rocks above the brecciolas are greenish-gray shales.

The boulders are those of rocks that formed under shallow shelf conditions. Their emplacement as boulders into shales, which are considered to be offshore deep-water sediment, indicates that the boulders moved downslope. The environment of deposition inferred for the brecciolas at this stop is that of the lower slope or base of slope (Fig. 1). Although the boulders came from the west down the slope, shelf carbonates (their source) extend many miles east of Troy (and presumably underlie Troy at depth).

Brecciolas which formed along the original east edge of the carbonate shelf parallel to the depositional strike for hundreds of miles define the site of the basin margin (rise) in Cambrian-Ordovician time. This Cambrian-Ordovician basin margin was located east of Troy near the present site of the Green Mountain axis. A relatively steep slope must have existed between the shelf edge and the basin margin with resultant instability that helped initiate slides, slumps, turbidity currents, mud flows, and sand falls.

Miles	Distance between points	
		Continue uphill (east) on Sage Avenue, pass Student Union (on right) to Burdett Avenue, cross Burdett Avenue, and drive on to Parking Lot of Troy High School. Keep to extreme left (north end) of Parking Lot. Walk north to wall of old quarry.

Miles	Distance between points	
87.5	0.4	STOP 6. TROY HIGH SCHOOL QUARRY

The spectacular brecciolas at this exposure consist of three members with eleven sub-members (Lowman, 1961). For details of the rocks, refer to Lowman's descriptions (1961, p. B11-B12). The brecciolas are Schodack lithofacies of the West Castleton Formation of Early Cambrian age, as at Stop 5.*

A thin-section study shows the limestones to consist of biomicrites, biointramicrites, and micrites with varying terrigenous quartz and clay minerals. The intraclasts are of pelmicrite. Shell fragments have been selectively dolomitized.

The observation that the limestone boulders are mostly micrites indicates that before removal downslope from their site of deposition the limestones were deposited under low-energy conditions on the shallow shelf to their original west, but at a place now still far to the east of Troy. The abundant fauna shows that the shallow waters were well aerated. The carbonate sediments must have lithified before their displacement downslope.

Miles	Distance between points	
		Return to Burdett Avenue, turn right (north) on Burdett Avenue to Hoosick Street (NY 7)
88.1	0.6	Turn right on Hoosick Street for one block and turn left on 21st Street to Troy Jewish Community Center.
88.4	0.3	STOP 7. TROY JEWISH COMMUNITY CENTER

One large block of orthoquartzite, approximately 30 feet by 15 feet, probably settled in deep-water shale. Although limonitic, this orthoquartzite is devoid of rock fragments, hence is a second-cycle or multicycle rock. Note that the exposed shales surrounding this erratic block show that this block occurs singly. This exposure occurs along strike of the brecciolas and many more exposures of the brecciolas occur north of here in Frear Park. In a pit about 100 feet or so north of this block we exhumed from the shale a block of dark gray, fractured and veined micritic dolomitic limestone.

The size and shape of the block of orthoquartzite suggests more than a steep slope. To detach a block of this dimension required considerable instability near the shelf edge, such as severe shakes as occur during earthquakes. This block of rock differs in lithology from the brecciolas which we have seen at the previous two stops. In contrast to the flat limestone boulders of the previous stop this huge

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*Note that the carbonate shelf west of Troy contains no rocks older than Late Cambrian; somewhere between west of Troy and the present Green Mountains the Middle Cambrian (?) and Lower Cambrian strata wedge in.

block with its irregular outline suggests that solid bedrock of sandstone was forcibly detached from the shelf edge or basin slope. By analogy with modern events, turbidity currents, slumps, mud flows, and slides are usually funneled through submarine canyons. Could it be that this block was part of the wall of a submarine canyon which became detached during one of the slides and was moved by gravity into the basin or basin margin?

The alternative interpretation would be to consider this block to have been caught up in fault movement. Indeed slicken-sides are present on this block. However, the lower exposed contact with the shale is depositional and not faulted. Because the orthoquartzite block occurs along strike with the other brecciolas, and a limestone block has been found about 100 feet away, the evidence suggests that emplacement was by gravity rather than by faulting.

Convince yourself that this block is not a glacial erratic.

The shales at this stop have been assigned to the Schodack lithofacies of the West Castleton Formation of Early Cambrian age; the displaced orthoquartzite block may be as old as Precambrian.

Miles	Distance between points	
		Return to 21st Street and Hoosick Street (NY7)
88.3	1.2	Turn right on Hoosick Street (NY7) and proceed west following NY7; cross Hudson River; continue on NY7
91.6	3.3	Latham Circle (continue on NY7)
96.0	0.5	Turn right (north); enter north entrance of Northway, Interstate 87.
97.9 to 98.0	1.9-2.0	Note two exposures of westernmost deep-water sedimentary facies, consisting of Middle Ordovician Normanskill graywacke and shale, in roadcut on right (northbound lane). West of here and underneath the Normanskill at a depth of several thousand feet are Cambrian-Ordovician rocks of shelf facies.
98.4	0.4 to 0.5	Cross Mohawk River on Northway. This beautifully designed bridge won an award in 1958.
110.9	12.5	Note exposure of Middle Ordovician Canajoharie Shale, a dark gray silty shale of outer shelf to slope facies.
113.1	2.2	Take Exit 13 N from Northway (sign: U.S.9 North Saratoga) and follow Route 9 north.

Miles	Distance between points	
114.9	1.8	Note on left traffic light to Performing Arts Center (Main Gate to Saratoga Spa State Park), but continue straight for another 1.0 mile to traffic light for Performing Arts Center (sign: Saratoga Spa State Park, Summer Theater, Roosevelt Bath, Golf Course).
115.9	1.0	Turn left at traffic light and drive along pine- and spruce-lined lane through Saratoga Spa Golf. Course
116.5	0.6	Turn north (right) on NY50. Bear left following sign to NY29.
117.7	1.2	Drive to traffic light and turn left (west) on NY29.
119.8	2.1	Turn right (north) on Petrified Garden Street where sign on tree says "Petrified Gardens." Drive past "Petrified Gardens" to Lester Park.
121.0	1.2	Alight at Lester Park

STOP 8. LESTER PARK

This locality is the site of one of the finest domed algal mats to be seen anywhere preserved in ancient rocks. On the east side of the road in Lester Park a glaciated surface exposes horizontal sections of the cabbage-shaped heads composed of vertically stacked, hemispherical stromatolites. These structures, known as *Cryptozoons*, have been classically described by James Hall (1847, 1883), Cushing and Ruedemann (1914), and Goldring (1938); an even earlier study drew attention to the presence of ooids as the first reported ooid occurrence in North America (Steele, 1825). Interest in these rocks has been revived as they are useful environmental indicators (Logan, 1961; Fisher, 1965; Halley, 1971). The algal heads are composed of discrete club-shaped or columnar structures built of hemispheroidal stromatolites expanding upward from a base, although continued expansion may result in the fusion of neighboring colonies into a *Collendia-type* structure (Logan, Rezak and Ginsburg, 1964). The stromatolites are part of the Hoyt Limestone of Late Cambrian (Trempealeauan) age. An intertidal origin has been inferred for these stromatolites.

The evidence for deposition under tidal conditions for the Hoyt Limestone at Lester Park includes: (1) mud cracks, (2) flat-pebble conglomerate, (3) small channels, (4) cross-beds, (5) birdseye structures, (6) syngenetic dolomite, and (7) stromatolites (for characteristics on recognition of tidal limestones, see Friedman, 1969).

At Lester Park the heads which are circular in horizontal section range in diameter from one inch to three feet; many are compound heads. The size of the larger heads suggests that they formed in highly turbulent waters.

The line of depositional strike along which the domed stromatolites occur was probably where the waves were breaking as they came across the deeper ocean from the east and impinged on the shallow shelf.

Several petrographic observations in these rocks permit an analogy with modern algal mats in hypersaline pools of the Red Sea Coast (Friedman and others, 1973). Mat-forming algae precipitate radial ooids, oncolites, and grapestones which occur in these rocks; interlaminated calcite and dolomite which in part compose the stromatolites of the Hoyt Limestone correspond to alternating aragonite and high-magnesian calcite laminites which modern blue-green algae precipitate. In modern algal mats the high-magnesian calcite laminites contain abundant organic matter in which magnesium has been concentrated to form a magnesium-organic complex. Between the magnesium concentration of the high-magnesian calcite and that of the organic matter sufficient magnesium exists in modern algal laminites to form dolomite. Hence the observation in ancient algal mats, such as observed in the Hoyt Limestone, that calcite and dolomite are interlaminated, with calcite probably forming at the expense of aragonite and dolomite forming from high-magnesian calcite.

Miles	Distance between points	
		Turn around and drive back (south) to NY29.
122.2	1.2	Turn right (west) on NY29.
		Pass basal Paleozoic quartz-cobble conglomerate (a possible talus deposit) on weathered Precambrian gneiss 1/2 mi. east of Kimball's Corners (NY147).
141.3	19.1	Turn left (south) on NY30.
147.6	6.3	City limits of Amsterdam
149.0	1.4	Cross bridge over Mohawk River.
149.3	0.1	Take Exit for Amsterdam Armory; Turn right on Florida Avenue and go west.
149.8	0.5	Turn right on Broadway.
150.6	0.8	Turn right (west) on NY5S.
153.0	2.4	Fort Hunter, turn right (north) on Main Street.
153.2	0.2	Turn right (east) to Queen Ann Street.
154.1	0.9	STOP 9. FORT HUNTER QUARRY. Alight at slight bend in road and walk to Fort Hunter Quarry which is across railroad track close to Mohawk River. (Fort Hunter Quarry cannot be seen from road; another small quarry visible from road is approximately 0.1 mile farther east, but will not be visited on this trip).

Stromatolites in the Fort Hunter quarry consist almost entirely of dolomite in the form of irregularly bedded, finely-laminated, undulating structures. The rocks in this quarry are part of the Tribes Hill Formation of earliest Ordovician age (Fisher, 1954). The lithofacies of the Tribes Hill Formation have been studied in detail by Braun and Friedman (1969) within the stratigraphic framework established by Fisher (1954). Figure 16 is a columnar section showing the relationship of ten lithofacies to four members of the Tribes Hill formation. At Fort Hunter we will study the lowermost two lithofacies of the Fort Johnson Member (see column at right (east) end of section, in Fig. 16).

Two lithofacies are observed; (1) lithofacies 1, mottled feldspathic dolomite, and (2) lithofacies 2, laminated feldspathic dolomite. Lithofacies 1 is at the bottom of the quarry, and lithofacies 2 is approximately half way up.

Lithofacies 1. This facies occurs as thin dolostone beds, 2 cm to 25 cm but locally more than 50 cm thick, with a few thin interbeds of black argillaceous dolostone which are up to 5 cm thick. In the field, the dolomite shows gray-black mottling and in places birdseye structures. In one sample, the infilling of the birdseyes shows a black bituminous rim which may be anthraxolite. In the field, trace fossils are abundant, but fossils were not noted. Authigenic alkali feldspar (microcline) is ubiquitous throughout this lithofacies; its identity as alkali feldspar was determined by x-ray analysis and staining of thin sections with sodium cobaltinitrite. The insoluble residue makes up 22 to 54% by weight of the sediment in samples studied with most of the residue composed of authigenic feldspar.

Lithofacies 2. This lithofacies is mineralogically identical to the previous facies but differs from it texturally and structurally in being irregularly bedded and in containing abundant undulating stromatolitic structures ("pseudo-ripples") (Fig. 17), as well as disturbed and discontinuous laminae. In places there are a few thin interbeds of black argillaceous dolostone. The thickness of the laminites of this facies ranges from 1/2 mm to 2 or 3 mm; on freshly broken surfaces the color of the thinner laminae is black and that of the thicker ones is gray. The insoluble residue, for the most part composed of authigenic feldspar, constitutes between 35% and 67% by weight in samples studied.

These two lithofacies which form the basal unit of the Ordovician, were formed on a broad shallow shelf. Stromatolites, birdseye structures, scarcity of fossils, bituminous material, syngenetic dolomite, authigenic feldspar, and mottling suggest that these rocks were deposited in a tidal environment (Friedman, 1969). Based on analogy with the carbonate sediments in the modern Bahamas, Braun and Friedman (1969) concluded that these two lithofacies formed under supratidal conditions. However in the Persian Gulf flat algal mats prefer the uppermost intertidal environment, and along the Red Sea coast they flourish where entirely immersed in seawater, provided hypersaline conditions keep away burrowers and grazers (Friedman and others, 1973). Hence on this field trip we may conclude that the stromatolites indicate tidal conditions without distinguishing between intertidal and supratidal. For more details on these lithofacies refer to Braun and Friedman (1969).

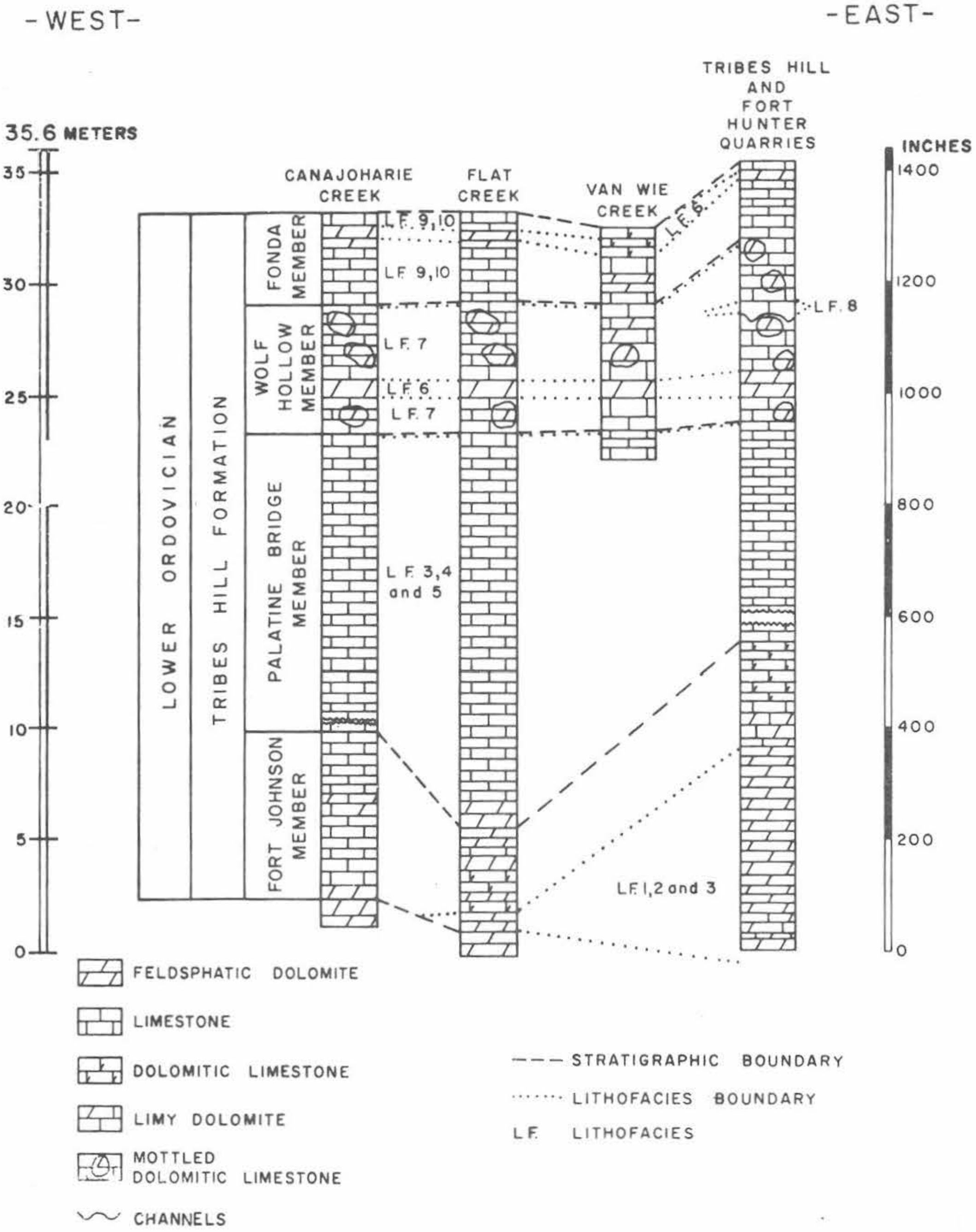

Figure 16. Columnar section showing the relationship of ten lithofacies to four members in Tribes Hill Formation (Lower Ordovician) (after Braun and Friedman, 1969).

Miles	Distance between points	
		Turn around and drive back to Main Street, Fort Hunter.
155.0	0.9	Turn right (north) into Main Street, Fort Hunter.
155.1	0.1	Cross original Erie Canal, built in 1822. Amos Eaton surveyed this route at the request of Stephen Van Rensselaer; after this survey Amos Eaton and Van Rensselaer decided to found a school for surveying, geological and agricultural training which became Rensselaer Polytechnic Institute.
		Follow Main Street through Fort Hunter.
155.7	0.6	Cross Mohawk River
156.2	0.5	Turn right (east) on Mohawk Drive (town of Tribes Hill).
156.6	0.4	Turn left (north) on Stoner Trail.
156.8	0.2	Cross Route 5 and continue on Stoner Trail.
159.5	2.7	Turn right on NY67 (east).
161.0	1.5	Fulton-Montgomery Community College; continue on NY67.
162.6	1.6	STOP 10. NORTH TRIBES HILL QUARRY (on left)

Route of Walk. Take the trail towards old abandoned crusher, but instead of heading towards the quarry move uphill to the first rock exposures. The rocks to be examined are near the edge of steep cliff.

Description and discussion. In the rocks at this exposure the field relationships show typical channels truncated at their bases (Fig. 18). Lodged within the channels are limestone blocks of variable shape ranging in diameter from about one to three feet (Fig. 19). These blocks resemble similar blocks in tidal channels of the Bahamas which are derived by undercutting of the banks of the tidal channels. The blocks at this exposure are rounded, suggesting that they have undergone some transport.

The rocks composing the channel (i.e. the channel fill) and the blocks of rock within the channels have been described as lithofacies 8 (channel fill) and lithofacies 7 (blocks) of the Wolf Hollow Member of the Tribes Hill Formation (lowermost Ordovician) (see columnar section of Fig. 16); column at the right end of the section) (Braun and Friedman, 1969). The channel fill (lithofacies 8) consists of intrasparite and biointrasparite with sporadic ooids, a high-energy facies, whereas the blocks (lithofacies 7) consist of mottled dolomitic micrite and biomicrite, a low-energy facies of the undercut bank. The micrite blocks which foundered

Figure 17. Stromatolitic structures of lithofacies 2 (laminated feldspathic dolomite), Tribes Hill Formation (Lower Ordovician). Fort Hunter quarry.

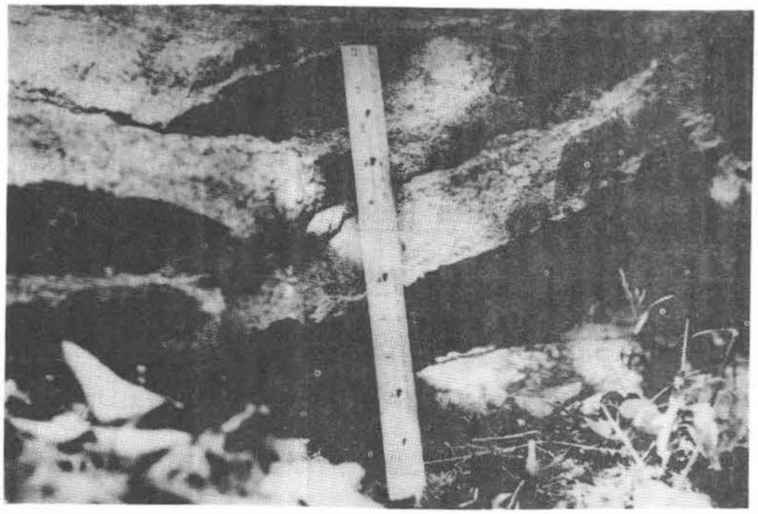

Figure 18. Truncation at base of tidal channel. Rocks in channel consist of lithofacies 8 (intrasparite and biointrasparite), Tribes Hill Formation (Lower Ordovician). North Tribes Hill quarry.

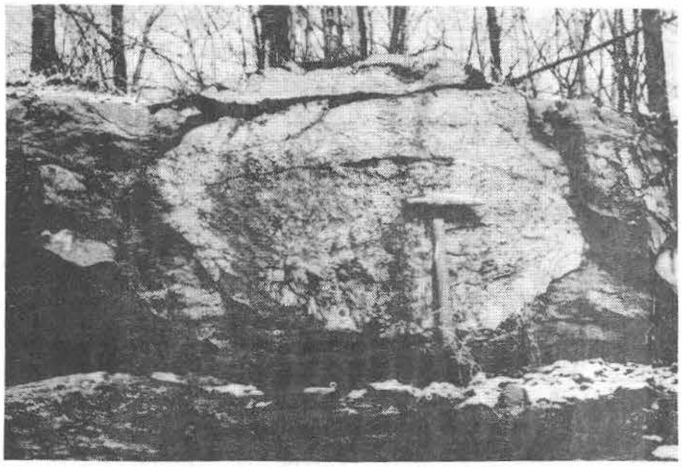

Figure 19. Block of lithofacies 7 (mottled dolomitic micrite and biomicrite), foundered in tidal channel (lithofacies 8), Tribes Hill Formation (Lower Ordovician). North Tribes Hill quarry.

in the channels must have been indurated penecontemporaneously.

Hence during earliest Ordovician time high-energy tidal channels crisscrossed tidal flats at this site. In them water coming from the deep ocean to the east rose and fell with the changing tides.

Return to R.P.I. Campus via New York Throughway and Interstate 787.

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TRIP A-3

SEDIMENTARY ENVIRONMENTS IN GLACIAL LAKE ALBANY IN THE ALBANY SECTION OF THE HUDSON - CHAMPLAIN LOWLANDS

by

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Introduction

The history of Lake Albany has intrigued glacial geologists since the turn of the century. The simple, single-stage lake of Peet (1904) soon was modified by Woodworth (1905) to a two-stage model where varved Lake Albany clay is overlain by sand of Lake Quaker Springs. Later workers, up to the present time, have defined more lake stages using the elevations of beaches, deltas, and terraces and by the character of the deposits of each lake stage. Stratigraphic sections revealed in new exposures and test borings have permitted the definition of sedimentary packages associated with each stage of Lake Albany. This field guide is a preliminary description of this new stratigraphy and provides the student with selected field stops that allow examination of the sediments.

The study area is in the mid-Hudson section of the Hudson-Champlain Lowlands (Fenneman, 1938). It lies between the Adirondack Mountains on the northwest, the Taconic Mountains on the east, and the Helderberg Plateau on the southwest (Fig. 1). The lowlands were deeply dissected by a southward drainage system prior to the Wisconsinan glaciation (Davis and Dineen, 1969). This drainage system consisted of the Colonie Channel and its tributaries - the Mohawk, Ballston, and Hudson-Battenkill Channels (Fig. 1). Only the Hudson-Battenkill channel is occupied by major drainage at present.

The Hudson Lobe of the Laurentide ice sheet occupied the lowlands during the Wisconsinan Glacial Stage. As the Hudson Lobe retreated, proglacial Lake Albany developed on the south. Lake Albany occupied the area from 15,000 to 12,600 y.b.p. (Connally and Sirkin, 1973). Drainage from the Great Lakes Basins entered this lake _via_ the Mohawk River Valley (Stoller, 1911). The lake expanded from south to north as the Hudson Lobe retreated, with the ice margin as the north shore of the lake (LaFleur, 1965b). The initial lake deposits were ice-contact sand and gravel that grade up into varved silt and clay (LaFleur, 1969, Dineen, 1979). Kame deltas developed when the ice margin hesitated during its retreat. Lake Albany extended 225 km from Newburgh to Glens Falls (Peet, 1904). Several large ice blocks were left behind by the retreating glacial lobe. The locations of the five ice blocks in the Albany area were the Hudson-Battenkill Channel near Selkirk (Dineen, in prep.), the Colonie Channel between Schenectady and Troy, at Round Lake, at Saratoga Lake (Hanson, 1977), and the Mohawk Channel at Schenectady (LaFleur, this volume). These ice blocks impeded sediment transport and controlled glacial and post-glacial drainage.

Glacial Lake Albany

Lake Albany developed in the preglacial channels between the ice margin and some obstruction to the south. Major tributaries entered the lake north

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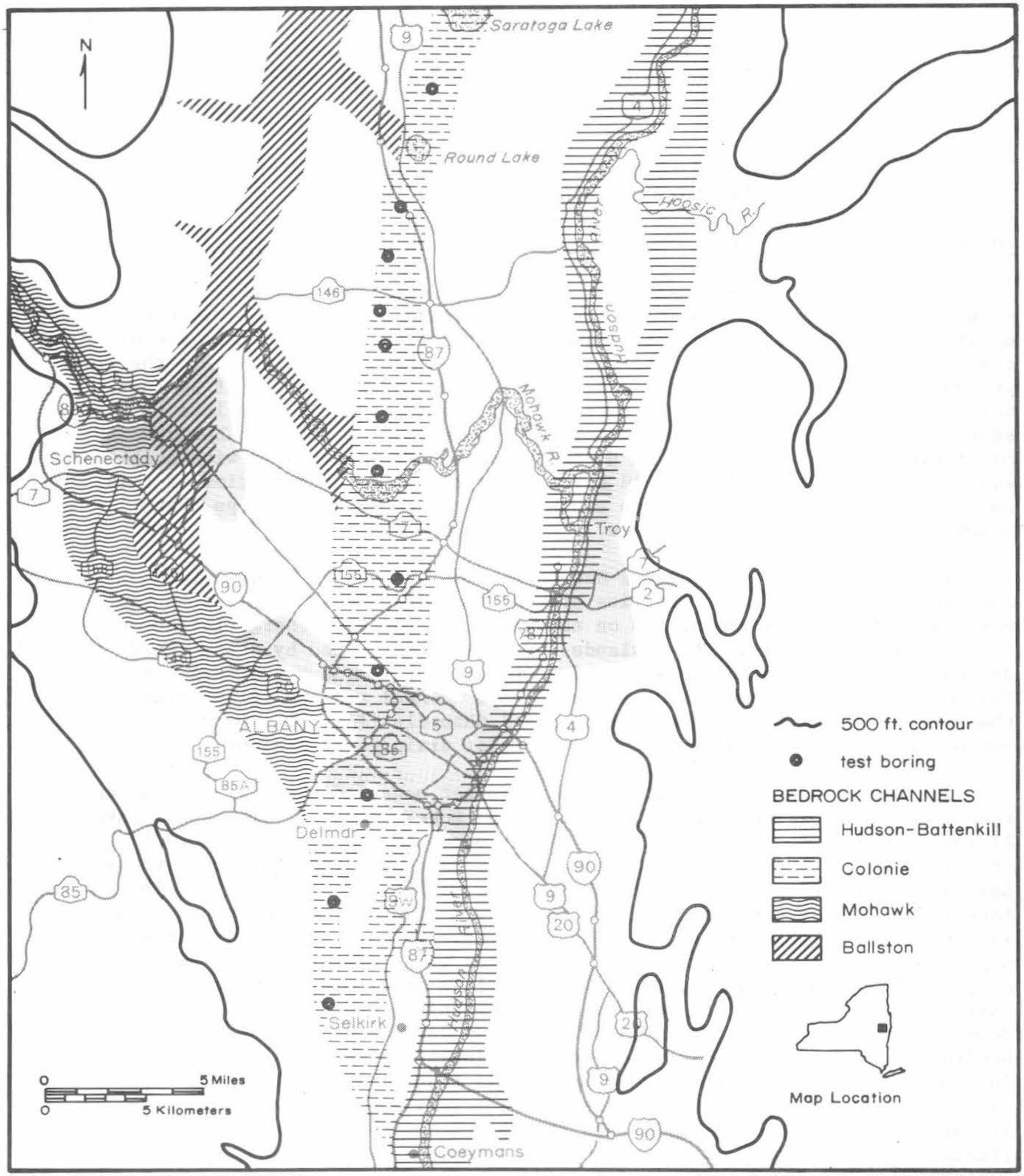

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Geology by R. Dineen, Graphics by J. Skiba 3/79

Figure 1. PREGLACIAL DRAINAGE CHANNELS

of the latitude of Troy (Figs. 1 and 2). The lake tended to widen and to become shallower from south to north (Fig. 2 and Table 1). The preglacial river channels divided the main lake basin into several north-south subbasins (compare Figs. 1 and 2). Lake sediments in these basins provide the evidence for the detailed history of the lake by their origin, altitude, and geographic position. The primary contributors of sediment to Lake Albany were:

1. Meltwater from the retreating ice margin;
2. Major tributaries that built large deltas into the lake (Fig. 2);
3. Minor tributaries that drained the adjacent highlands.

The Mohawk delta at Schenectady (stop 2) was dumped into the Mohawk subbasin, the Hoosic delta was deposited into the Hudson-Battenkill subbasin, and the Kayderosseras delta was deposited in the Ballston and Colonie subbasins near Saratoga Lake (Fig. 1). The ice margin provided sediment to all the subbasins during the early Lake Albany stage and was the major sediment contributor to the Colonie subbasin. Lake deposits draped over the bedrock topography with the thickest section of sediment developed along the axis of the channels (Fig. 3Ba). Time-equivalent deposits were higher in elevation along the margins of the channels than in the center, because of the initial dip caused by lake bottom topography and the compaction of the sediment column (Fig. 3Ba and Dineen, Waller, Hanson, in prep.). The cluster of large tributaries debouching into the lake north of Troy (Fig. 2) caused the sedimentary deposits of Lake Albany to become thicker and more coarse northward, (Dineen, Waller, Hanson, in prep.). Individual units wedge out and overlap northward, i.e., the basal layers are older to the south because of the progressive northward retreat of the ice margin (Fig. 3Bb). Thus, the base of Lake Albany's sediment column is time-transgressive northward.

The column of sediment that was deposited in Lake Albany is characteristically coarse at the base, fine in the middle, and coarse at the top (Fig. 3Aa), although this general trend was interrupted by specific depositional episodes. The sequences on Fig. 3A and the maps on Figures 1 and 2 are based on test borings, water wells, field exposures, and map patterns (Dineen, Waller, Hanson, in prep., DeSimone, 1977, Hanson, 1977, Dineen, 1977, LaFleur, 1969, 1965a, 1961a, Schock, 1963). The basal part of the sequence includes gravel, flowtill, and sand that pass upward to varved silt and clay (Fig. 3Aa). The coarse-grained basal sediments were deposited in deep lake water at the ice margin by meltwater streams and sheet flow from under the glacier. They were predominantly bedload and lag deposits. The deepwater varved clay and silt sequence contains turbidites that fine upward from sand and/or gravel to rippled silt to planar laminated silt and clay. The turbidites were probably deposited during catastrophic floods of meltwater from the ice front and the major tributaries. LaFleur (1975) and Hanson (1977) cite geomorphic evidence for catastrophic floods from the Mohawk Valley. The varved silty clay grades upward into laminated sandy silt, which coarsen upward into sand and gravel. The upper, coarser-grained sediments were deposited in shallow water, and prograded across the lake bottom as the central part of the basin filled in with mud. This progradation of coarse sediment over fine sediment is well shown on the cross section for Stop 4 (Fig. 6). The Delmar Readvance occurred as the Hudson Lobe readvanced into Lake Albany. This event is reconstructed from several lines

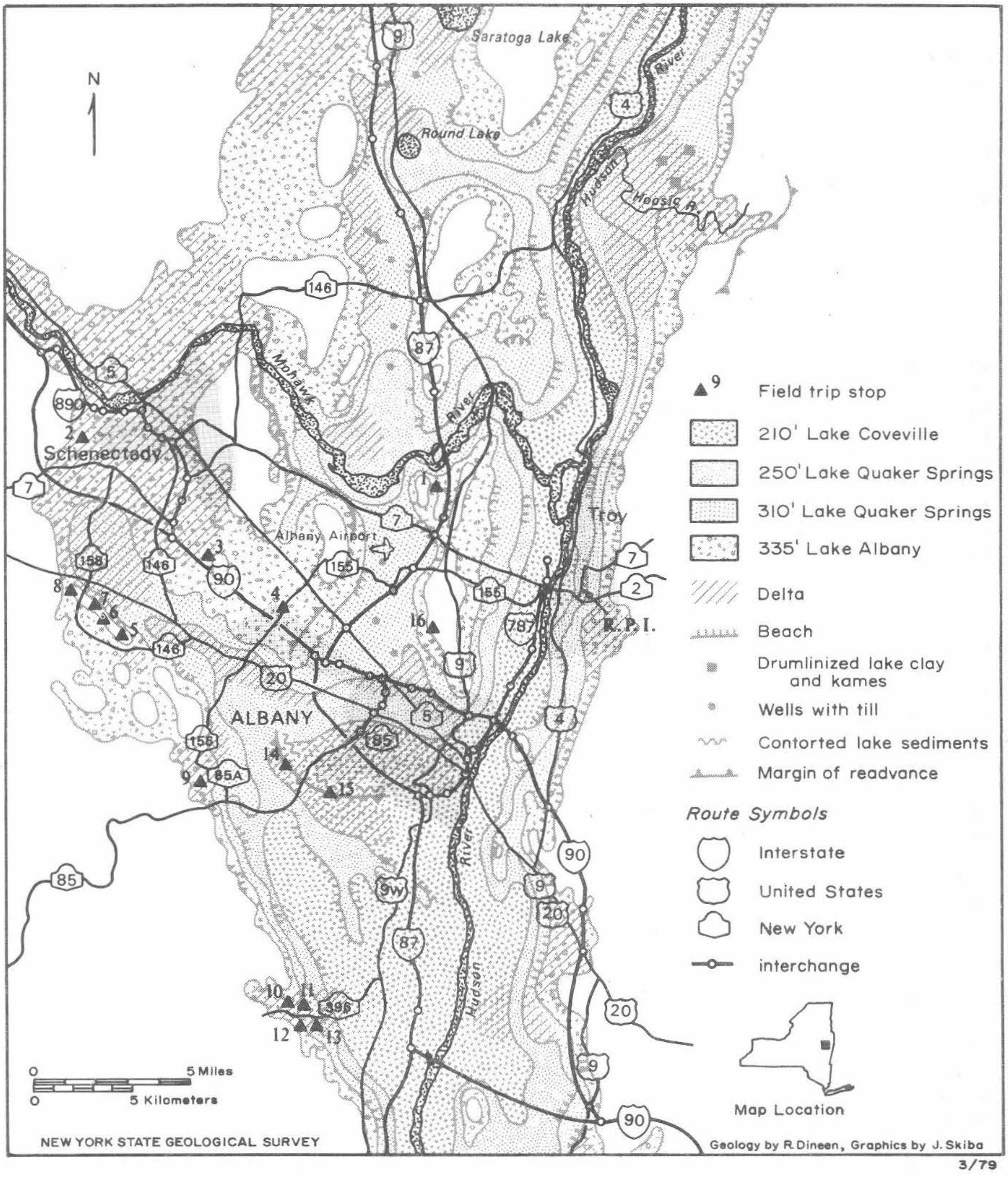

Figure 2. FIELD STOPS & GENERALIZED GLACIAL GEOLOGY

of evidence that include:

1. Folded beds of fine-grained lake deposits with associated outwash sand and gravel which occur near Delmar, south of Albany (Fig. 2 and Dineen, in prep., and Fig. 9, Stops 14 and 15). These folds are push-ridges.
2. Patchy till and outwash deposits enclosed in the upper lake sediments which occur in wells and test borings between Round Lake and Albany (Dineen, Waller, and Hanson, in prep., Fig. 2).
3. Contorted clay and silt beds in the area south of Round Lake (Fig. 2 and Hanson, 1977).
4. Till overlying kame deltas (Stop 1, Fig. 5a, and Hanson, 1977).
5. Drumlinized clay and kames in the Hoosic River area (Fig. 2).
6. Anomalously high seismic velocities that are probably over-compacted lake deposits near the mouth of the Hoosic River.

Broad sandy flats, exposed at the lake shore as the lake level dropped from +330 ft. to +310 ft., supplied large quantities of fine sand and silt to the upper part of the sequence of Lake Albany sediments. Wind, eroding these newly exposed areas, delivered these size grades to the nearshore lake environment where wedges of blown sediment spread into the lake. At the same time, aeolian dunes developed on these exposed flats. Stops 3 and 4 (Fig. 6) are in these dunes. The lake and dune sand is 75 to 100 ft. thick in the area of Stops 3 and 4 (Fig. 6). The axis of maximum sand thickness trends northwest to southeast, and lies between NY5 and I-90 (Fig. 2 and Dineen, 1975). The lake sand becomes siltier and eventually grades into lake clay towards the east and with depth (cross section, Fig. 6).

Wind action was intense, being unimpeded by vegetation. The resulting dune complex was particularly well developed in the sand-abundant newly exposed and abandoned Schenectady Delta (Dineen, Rogers, and Buyce, 1978).

The presence of well-developed beaches on the east shores of Lakes Albany and Quaker Springs, and on the west shores of islands in the lakes (Fig. 2 and Dineen, in prep., DeSimone, 1977, LaFleur, 1961a and 1965a), and of poorly-developed beaches on the west shores of the lakes (Dineen, in prep.), and of the southeast dune and cross bed orientation (Dineen, Rogers, Buyce, 1978) indicate that the dominant wind was from the northwest. The progradation from northwest to southeast of the wedges of windblown-lake deposited sand (Dineen, 1979) corroborates this conclusion. The Mohawk River was deflected northward into the Ballston Channel by the emergent Schenectady delta. Overflow of catastrophic floods from the Mohawk Valley built deltas at the mouths of the channels cut into the rock ridge separating the Ballston and Colonie Channels in the area of Round Lake (Figs. 1 and 2).

Lake Quaker Springs

A relatively abrupt drop in Lake level from +310 ft. to +270 ft. marked the transition from Lake Albany to Lake Quaker Springs. This lake was shallower than Lake Albany, and like the latter, became shallower and narrower north of the latitude of Albany than it was south of there to the latitude of South Bethlehem (Fig. 2 and Table 1).

The deposits of Lake Quaker Springs coarsen upward rapidly (Fig. 3Ab). Sand and gravel deposited in shallow water and the wedges of windblown lake deposited sand and silt rapidly prograded across the lake bottom. Much of this sediment was recycled from the older lake deposits. Few coarse-grained turbidites were deposited in Lake Quaker Springs in the Albany area, perhaps because the mouth of the Mohawk River had migrated north to Saratoga and Round Lakes (Stoller, 1922, LaFleur, 1965b) and the ice margin was no longer nearby.

The sediment column of Lake Quaker Springs is significantly thinner than the column of Lake Albany (compare Figs. 3Aa and 3Ab) because:

1. The sediment influx from the ice margin dwindled as the ice margin moved north out of the Hudson Valley;
2. The sediment influx from the Mohawk River was displaced to the north; and
3. Lake Quaker Springs lasted a much shorter period of time than Lake Albany (Fig. 4).

Glacial Lake Coveville

Lake Coveville began when the water level in the Hudson-Champlain Lowlands dropped from +270 ft. to +230 ft. Once again, large areas of sandy lake plain were exposed in places around the newly stabilized lake. Again, winds began to erode the lake plains, building subaerial dunes and lacustrine silty sand wedges. Beaches, dune orientation, and a complex of nearshore sand bars in the Delmar area suggest that the dominant wind was still from the northwest (Dineen, Rogers, and Buyce, 1978; Dineen, in prep.). The beaches are well-developed on the east shore of the lake. The beaches, terraces, and deltas show a lower lake level at +200 ft. Thus, Lake Coveville, like Lake Albany, consisted of at least two closely-spaced and closely-timed lake levels.

The depth the Lake Coveville was greatest in the South Bethlehem area, where it was less than 21 m. (Table 1). The depth and width of Lake Coveville decreased from South Bethlehem north to Troy, and actually, the lake resembled a wide river (Fig. 2).

The sedimentary column of Lake Coveville, which is no more than 5 m. thick near Albany, coarsens upward very rapidly, reflecting the rapid filling of the basin by wind-blown sand and silt and by the fluvial reworking of lake plain sand, silt, and gravel.

Lake Fort Ann

Lake Fort Ann is well recorded in the Champlain Valley (Chapman, 1937, LaFleur, 1965b). The Hudson River Valley was the spillway for the lake. Fort Ann was basically a wide river in the Albany area. It is recorded by cut terraces with thin (3 to 5 m. thick) veneers of sand.

Relationship of Later Lake Sediments to Lake Albany

As discussed above, much of the sediment that was deposited in Lake

Quaker Springs and Coveville was recycled from the newly-exposed lake plains of Lake Albany. Stream and wind action tended to transport the sandy sediments towards the south and east. A preliminary analysis of beach and bar orientation and morphology suggests that the long-shore lake current trend was also towards the south (Dineen, in prep.). Thus, sedimentary facies migrated towards the south-southeast.

Sediments of succeeding lakes have an off-lapping relationship (Fig. 3Bb). The off-lapping facies sequence is similar to that of a regressive sea (Matthews, R.K. 1974 p. 41), with conformable sedimentary sequences in the center of the basin and disconformable sequences around the edges within the areas affected by shallow water environments (Fig. 3Ba and 3Bb). The younger lake shores are topographically lower than the older lake shore because the water levels dropped through time. The dropping water level, plus filling-in of the basin, resulted in thinner sedimentary columns for younger lakes (Fig. 3), a rapid progradation of shallow-water, coarse-grained clastics across the lake basin (Figs. 3Aa, 3Ab, 3Ac), and narrower, shallower lakes through time (Fig. 2). The dropping water level also caused the off-lapping relationships of the lake sediments (Fig. 3Ba, 3Bb).

Environments of the Lakes

The environments of the Glacial Lake Albany sequence (Fig. 4) can be described using the sediments observed in the field and test boring data:

1. Ice-Contact Environment: is recorded by imbricated lag and bedload gravel and trough and planar cross-bedded sand, gravel, and silt, with minor flow tills. This facies was deposited in the lake in close proximity to the ice margin by sheet flow from under the glacier and melt water channels in the glacier. The facies geometry is generally that of a blanket draped over pre-existing basin topography, although eskers, kames and kame deltas are also present. This facies forms the basal units of the Lake Albany sequence (Fig. 3Aa), which are exposed at Stops 1, 5, 6, 7, 8, 14, 15, and 16.
2. Deep Water Environment: is recorded by varved clay and laminated silts with some turbidite gravel. This facies was deposited in deepwater below wave base, and consist of distal delta and basinal sediment. This facies is exposed at Stops 1, 2, and 5.
3. Nearshore Environment: produced ripple-trough laminated, ripple-laminated, to planar-laminated sand and slightly gravelly, silty sand. Planar to trough cross-bedded gravel occurs in the toe of deltas. This facies includes proximal delta sediments and sediments that were deposited above wave base. It is recorded at Stops 1, 2, 8, 9, 10, 11, 12, and 13.
4. Windblown - Lake Deposited Environments: produced ripple-laminated to planar cross-laminated, silty sand to sandy silt. This is a subdivision of the nearshore facies. Wedges of sediment formed off-shore from dune fields, because the sediments were blown into the lake from exposed lake plains. Such sediments are poorly exposed at Stop 3.
5. Shore Environment: is recorded by trough cross-bedded to planar cross-bedded sand and gravelly sand deposited in beaches, in delta

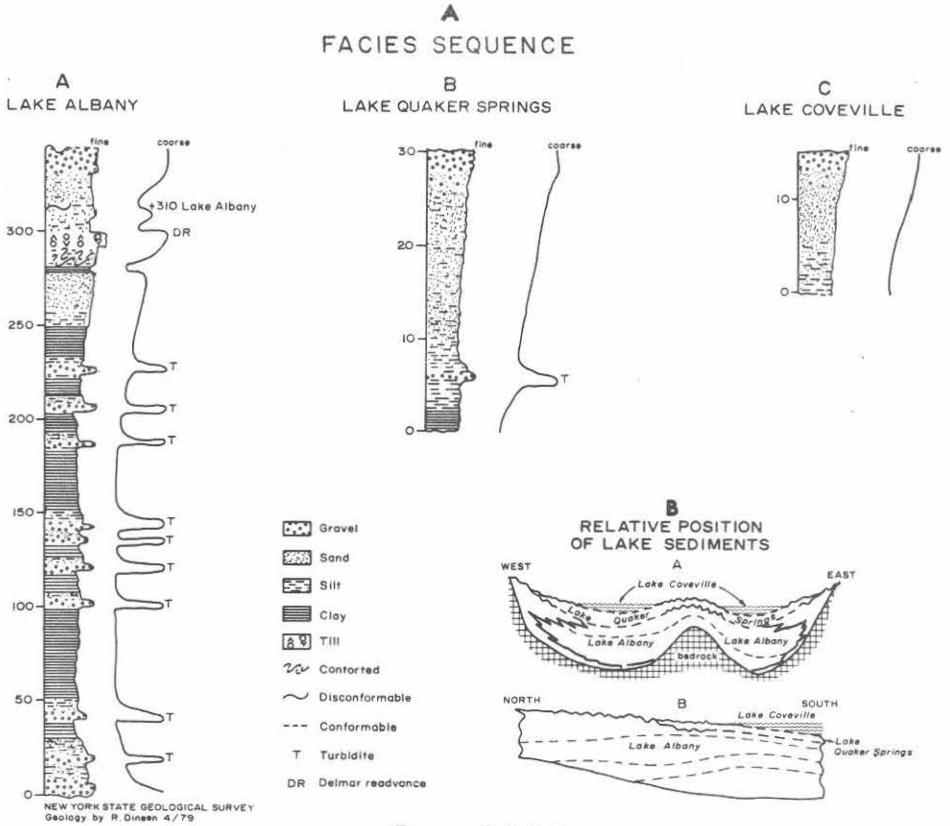

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Figure 3 A & B

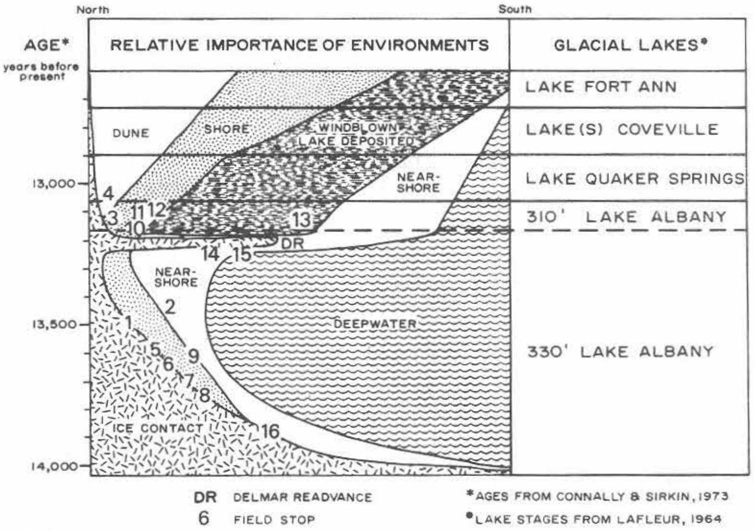

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Figure 4. STRATIGRAPHY & ENVIRONMENTS OF THE GLACIAL LAKES

topset beds, and tributary streams. Such deposits are exposed at Stops 1, 2, 3, 10, 11, and 12.

6. Aeolian Environment: produced planar cross laminated, fine sand that was deposited in dunes, and ripple-laminated, silty sand and peat that were deposited in interdune bogs. These facies prograded across the exposed lake plains from west to east. They are exposed at Stops 3 and 4.

The relative importance of these environments was different in each of the lake stages. Figure 4 illustrates these changes. The earliest stage of Lake Albany was dominated by the ice-contact environment, which decreased in importance as the ice margin retreated from the area. The Delmar Readvance resulted in a brief increase in the importance of the ice-contact environment in the time of late Lake Albany.

The deepwater environment was important during most of Lake Albany time (Fig. 4), but its importance decreased dramatically in the later lakes as the basin filled with sediment and the lake level dropped.

The nearshore environment increased in importance in the lakes of lower water level. The windblown - lake deposited facies of this environment became dominant as the water level continued to drop.

The shore environment increased in importance as streams and deltas prograded across shallow Lakes Coveville and Fort Ann. The aeolian environment became important after the inception of the +310 ft. Lake Albany (Fig. 4), and continued through the later lake stages until approximately 5,000 y.b.p. (this date is based on a radiocarbon date from the base of an interdune bog in the Pine Bush, R. Pardi, Queens College Radiocarbon Laboratory, pers. comm. 1979).

Lake Stage	Elevation in Feet				Depth in Feet			
	1	2	3	4*	1	2	3	4
LAKE FORT ANN	140	140	140	140	20	30	20	30
LAKE COVEVILLE	210	200	190	190	20	20	20	20
LAKE COVEVILLE	240	230	220	210	20	30	70	30
LAKE QUAKER SPRINGS	280	270	260	250	20	20	100	80
LAKE ALBANY	320	310	300	290	30	60	150	130
LAKE ALBANY	340	330	325	325	270	530	300	300

1 = Saratoga Lake (from Round Lake, Mechanicville, and Schaghticoke 7½ minute quadrangles).
2 = Albany (from Voorheesville, Albany, and Troy South 7½ minute quadrangles).
3 = South Bethlehem (from Clarksville, Delmar, and East Greenbush 7½ minute quadrangles).
4 = Coeymans (from Ravena, Kinderhook, and Alcove 7½ minute quadrangles).

* General locations from north to south.

TABLE 1 -- GLACIAL LAKE STAGES IN THE ALBANY-SCHENECTADY AREA

Lake Stage	Width in Miles				Notes
	1	2	3	4	
LAKE FORT ANN	1.6	1.6	1.6	1.6	Predominantly fluvial deposits in the Albany area. Recorded by erosional terraces with thin veneers of coarse sediment along the valley wall of the Hudson.
LAKE COVEVILLE	2.4	2.4	5.9	2.4	Thickest sediments in the South Bethlehem area, sediments are related to the S.B. deltas. Erosional terraces common north of Albany.
LAKE COVEVILLE	2.1	2.4	6.3	2.8	Off-shore bars common SE of Delmar. Recorded by Hoosic and South Bethlehem deltas, and by erosional terraces north of Albany. Good beach development.
LAKE QUAKER SPRINGS	3.5	12.6	6.7	5.5	Recorded by North Albany, Normanskill, Hoosic, and South Bethlehem deltas.
LAKE ALBANY	11.0	16.5	7.9	5.9	Recorded by Wynantskill and Normanskill deltas, and at South Bethlehem. Dunes are graded to this lake. Deltas at Shenendehowa related to this stage. Good beach development.
LAKE ALBANY	15.8	17.8	9.9	4.0	Good beach development. Poor delta preservation at South Bethlehem. Prominent Hoosic, Schenectady, Wynantskill, and Kinderhook deltas.

TABLE 1 -- GLACIAL LAKE STAGES IN THE ALBANY-SCHENECTADY AREA (cont'd)

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Road Log

Total Mileage	Mileage From Last Stop	
		This trip will be on the Troy South, Niskayuna, Schenectady, Voorheesville, Albany and Delmar 7½ minute quadrangles. This field log describes 16 stops, more than one can visit in a single day. It is intended as a guide to glacial exposures that show relationships of local stratigraphic interest or that illustrate general principles of sedimentation in the glacial-lacustrine environment. We will visit those exposures that are accessable and in good shape on the day of the field trip.
0.0	0.0	We start at the Houston Field House - Rensselaer Polytechnic Institute. The bluff to the east of the field house is a beach of +330 ft. Lake Albany (LaFleur, 1965a).
		Proceed west on Burdett Avenue to the intersection of 40th Street (NY 7).
0.3	0.3	Turn left (south) on 40th. Proceed along 40th St./NY 7 to Congress St.
1.0	0.7	Turn right (west) on Congress St. and follow NY 7.
1.8	1.1	Cross the Hudson River on the NY 7 bridge.
		We have driven down the east wall of the preglacial Hudson-Battenkill Channel. Test borings for the bridge and its approaches indicate that a -20 ft. terrace underlies the floodplain in this area. A +40 ft. bedrock terrace underlies Watervliet to the west. The test borings indicated that only a thin layer of till underlies the floodplain silty sands (J. Rumsey, N.Y.S. Dept. of Transportation, personal communication). The -20 ft. bedrock terrace can be traced 12 miles south as far as Castleton and 3 miles north as far as Waterford.
3.0	1.2	Proceed up the west wall of the Hudson-Battenkill channel.
4.0	1.5	Proceed along NY 7 (west) to the Latham circle. Follow ramp to US 9 (north).
5.7	1.7	Proceed north along US 9 to Dunsbach Ferry Road.

6.1 0.4 Turn left (northwest) on Dunsbach Ferry Road. Proceed to intersection of Pollock Road. Turn left (west) on Pollock Road. We have been driving along the interfluve between the Colonie Channel (west) and the Hudson-Battenkill Channel (east). Proceed down the hill into the Dephuskill Valley. The access road to the Wunderlich pit is on the right.

6.5 0.4 Stop 1 Wunderlich Pit (Fig. 5a)

This pit is in the Pollock Road kame delta. The ice margin was to the north. Meltwater built a kame delta into Glacial Lake Albany at the end of an esker complex, which lies north of the kame delta. Some clay lies draped over the eskers to the north, implying that the ice had melted away by the time of Lake Quaker Springs. The Section exposed in the pit is:

Top to 4m	Grayish brown sandy, silty, boulder till.
4 to 24m	Gravity and thrust-faulted, yellow-brown, planar cross-bedded, gravelly sand, with ripple laminae at the base and contorted laminae at the top.
24 to 30m	Trough cross-bedded, gravity faulted, sandy gravel

The basal gravel was deposited by southward-flowing water in an esker channel, the gravelly sand, in a kame delta. These beds grade southward into trough cross-bedded, silty sand. They are partially overlain by varved clay to the south. The till at the top was deposited during the Delmar Readvance.

Leave the Wunderlich pit, turn left (west) and proceed along Pollock Road.

7.2 0.7 Follow the left-hand fork to the intersection with Sparrowbush Road.

7.6 0.4 Turn right (west) on Sparrowbush Road.

7.7 0.1 Turn left (northwest) on Forts Ferry Road.

7.8 0.1 Turn left (southwest) on Mill Road.

8.7 0.9 Proceed to intersection of NY 7. Turn right (west) on NY 7. We have crossed the east wall of the Colonie Channel. A test boring in the channel along strike with the Loudonville

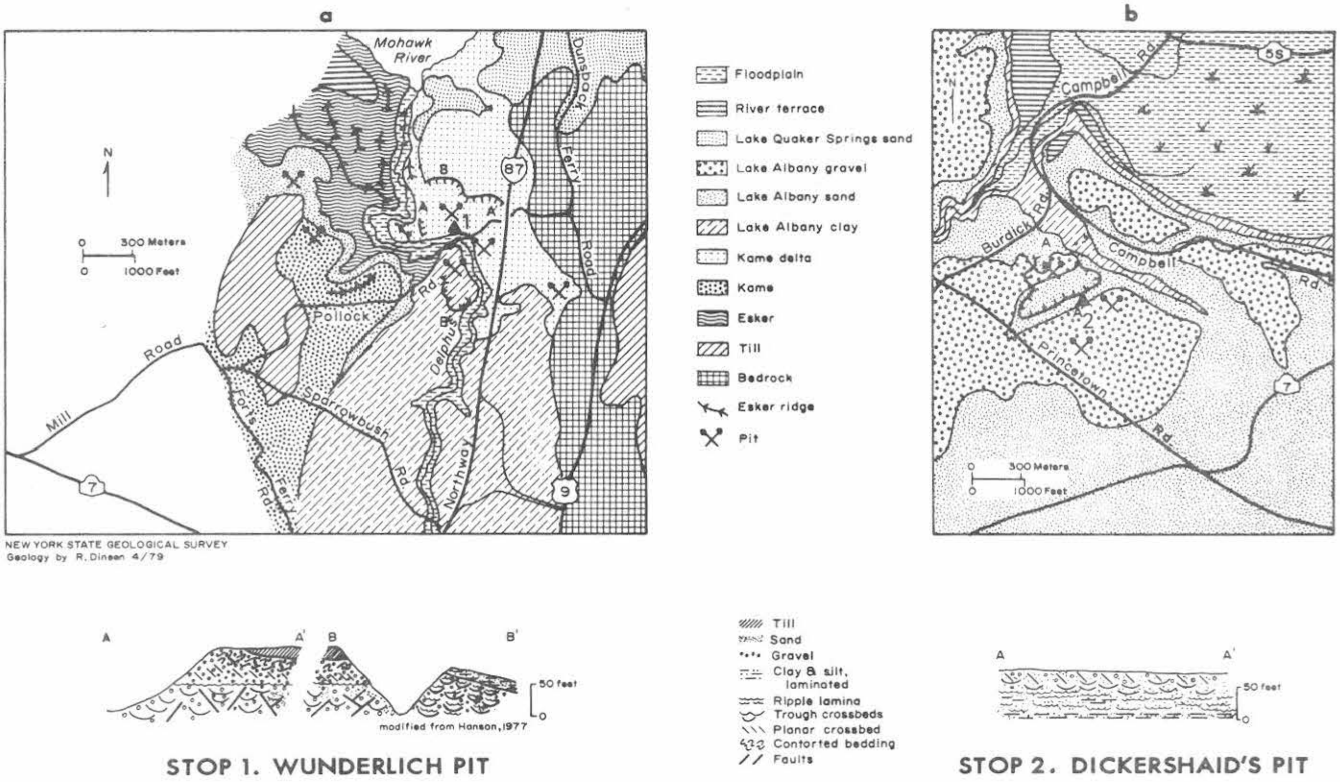


Figure 5.

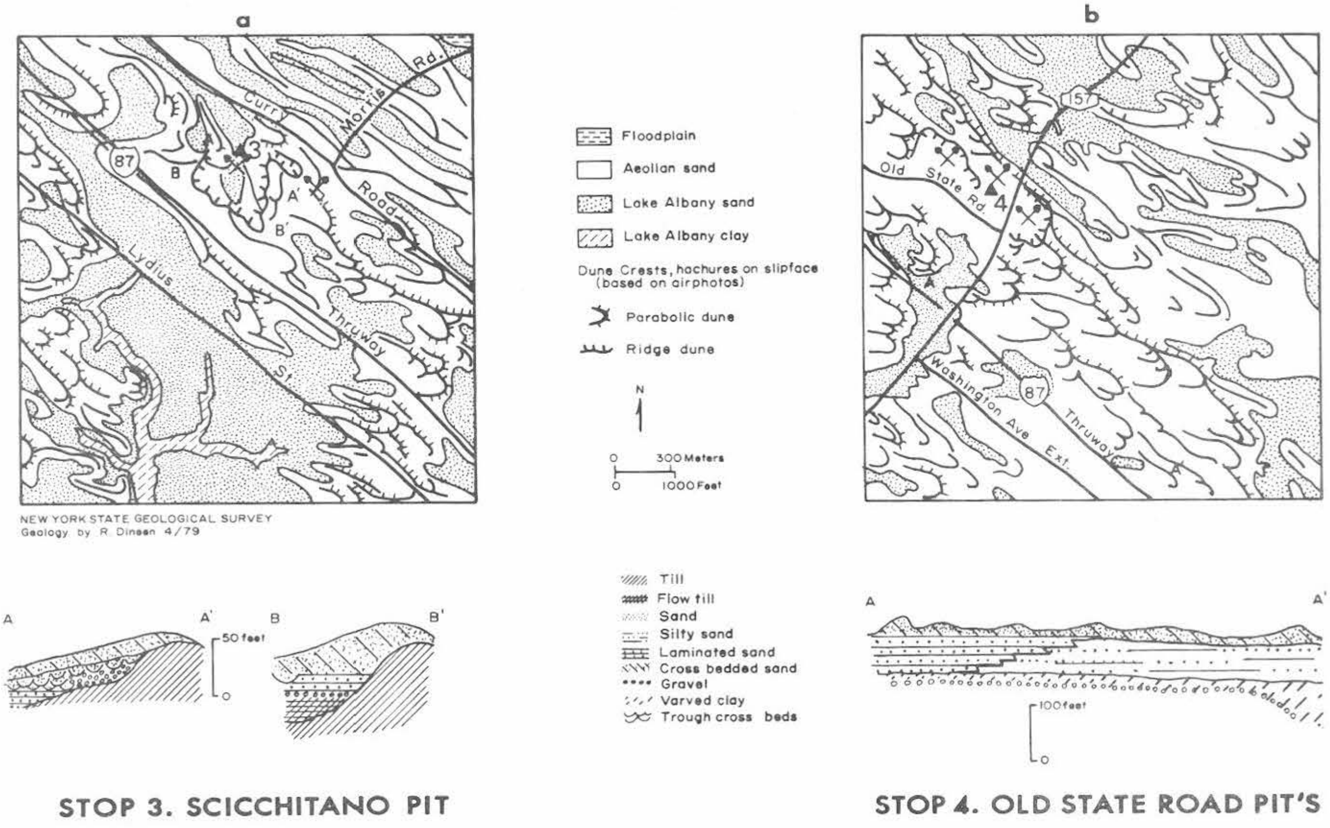


Figure 6.

		esker contains large quantities of ground water under artesian pressure. Roger Waller measured a 12m artesian head in that well (Dineen, Waller, and Hanson, in prep.).
10.4	1.7	We are now crossing dune sand that mantles Lake Albany clay (Hanson, 1977). We are also crossing the west wall of the Colonie Channel.
13.9	3.5	Intersection of Union St. and NY 7. Bear left, stay on NY 7.
16.1	2.2	Entrance to Interstate 890 west, proceed on I-890 west. Crossing Ballston Channel, we are on (and in) the Schenectady delta that the Mohawk River built into Lake Albany (Stoller, 1911). A test boring for I-890 penetrated 174 ft. of silty sand and 20 ft. of till without hitting bedrock. Dunes are well developed in this area. Gastropods occur locally in sand just below the dune sand - lake sand contact.
18.3	2.2	We are now on the Mohawk River floodplain. Test borings for the General Electric Plant and US 5 Schenectady - Scotia bridge penetrated 40 ft. of fining-upward sand, gravel to organic silt. These floodplain deposits overlie 50 ft. of alternating beds of sand and silty clay that overlie till (Winslow and others, 1965 and J. Rumsey, N.Y.S. Dept. of Transportation, personal communication). The floodplain deposits tend to coarsen to the west (Winslow and others, 1965). They are the main source of water for the City of Schenectady (Stoller, 1929) and yield over 16 million gallons of water per day (Winslow and others, 1965).
20.4	2.0	Exit at Campbell Road -- The Schenectady well field is to the west.
21.4	1.0	Intersection of Princetown and Campbell Roads, bear left following Campbell Rd.
21.8	0.4	Intersection of Campbell and Burdeck Road, bear right on Burdeck Rd.
22.0	0.2	Intersection of Burdeck and Thompson Roads, bear left on Thompson Road. The next stop on the left is less than 0.1 mile from this point.

Stop 2 Dickershaids Pit (Fig. 5b)

This pit is cut into the Schenectady delta. Its section consists of:

Top to 7.6m	light brown, trough cross-bedded, medium to fine sand with some gravel
7.6 to 20m	light brown, ripple-laminated, fine sand. Concretions are common in this zone
20 to 23m	yellow brown, varved silt and clay

Test borings to the east indicate that the clay extends to a depth of 230 ft. (Winslow and others, 1965).

The gravelly sands at the top of the pit are topset/fluvial beds that prograded eastward across the delta front sand, which in turn had prograded eastward across bottomset clay and silt. The sand is the source beds for the dunes that lie to the east (Dineen, Rogers, and Buyce, 1978).

Leave Stop 2, turn left (south) onto Thompson Road.

22.3	0.3	Intersection of Thompson and Princetown Roads
23.2	0.9	Turn left onto Princetown Road. Intersection of Princetown, Curry, Fort Hunter, and Duanesburg Roads. Proceed on to Curry Road (NY 7). We are travelling across the topset beds of the Schenectady delta.
24.6	1.4	Intersection of Altamont Ave. and Curry Road. Bear right on Curry (proceeding east). Dunes are just starting to appear in this area.
26.5	1.9	Crossing over I-890. Notice the small dunes to the left (northeast). We are proceeding along a series of dune ridges.
28.1	1.6	Access road to Stop 3 on right. Turn right, proceed south to end of road.
28.4	0.3	Stop 3 Scicchitano Pit (Fig. 6a) This pit shows dune, beach, and lake sediments (Dineen, 1977). The hill to the east is a dune-sand mantled drumlin. A compound dune cluster built up around the drumlin. Bedrock lies approximately 60 ft. below the surface, the Ballston Channel lies to the west.

The drumlin stood as an island in Lake Albany, as the Schenectady delta built out into this area. A +330 ft. beach is exposed on the east side of the pit. It consists of a wave-cut platform, cut into till, overlain by a lag concentration of boulders and trough cross-bedded, gravelly sand. Horizontal to ripple-laminated sand and silt were deposited offshore. Planar cross-laminated dune sand overlies the lacustrine deposits.

Parallel ridges with a NW-SE trend are the dominant form of dune crests in the Pine Bush sand plain, the name of the pine and oak brush-covered sandy area between Albany and Schenectady. A secondary mode of dune form comprises crescentric ridges that are convex to the southeast. Ridges of this concentric type commonly join adjacent parallel ridges or form hooks curving to the southwest from the southeast end of a ridge. In the past, these crescentric dunes have been interpreted either as barchans (which suggests a southeast wind direction) or as parabolic dunes (which suggests a northwest wind). These interpretations were based on shape, directions of steeper slopes and linear trends. Recently, we have been able to settle this controversy with cross-bedding data, gathered from deep cuts made in the dunes during a recent flurry of construction projects throughout the Pine Bush area (Dineen, Rogers, and Buyce, 1978). Weathering and bioturbation have destroyed the primary sedimentary structures in the top three meters of the dune sand, so that a substantial excavation is required to expose undisturbed deposits that contain directional features. Measurements of over 200 cross-beds at 35 localities in the Pine Bush dunes give down-dip modes to the northeast, southeast, and south. These data combined with the NW-SE trend of the linear ridges and the southeast convexity of the arcuate ridges indicate that the dominant dune-forming winds were northwesterly, hence the crescentic dunes are parabolic.

That southwest winds were also important is indicated by a prominent northeast mode in the dip directions. Fig. 6 of the dune crests shows the characteristic dune ridge pattern. Careful analysis of dune morphology, especially on aerial photos, shows the northeast side of linear ridges to have steeper slopes than the southwest side, and the southwest limbs of parabolic dunes to be atrophied. These observations corroborate the evidence for wind directions given by cross beds.

Only one measurement was recorded of a crossbed dipping toward the northwest quadrant, which indicates a nearly complete absence of dune-forming winds from the southeast during the post-glacial period.

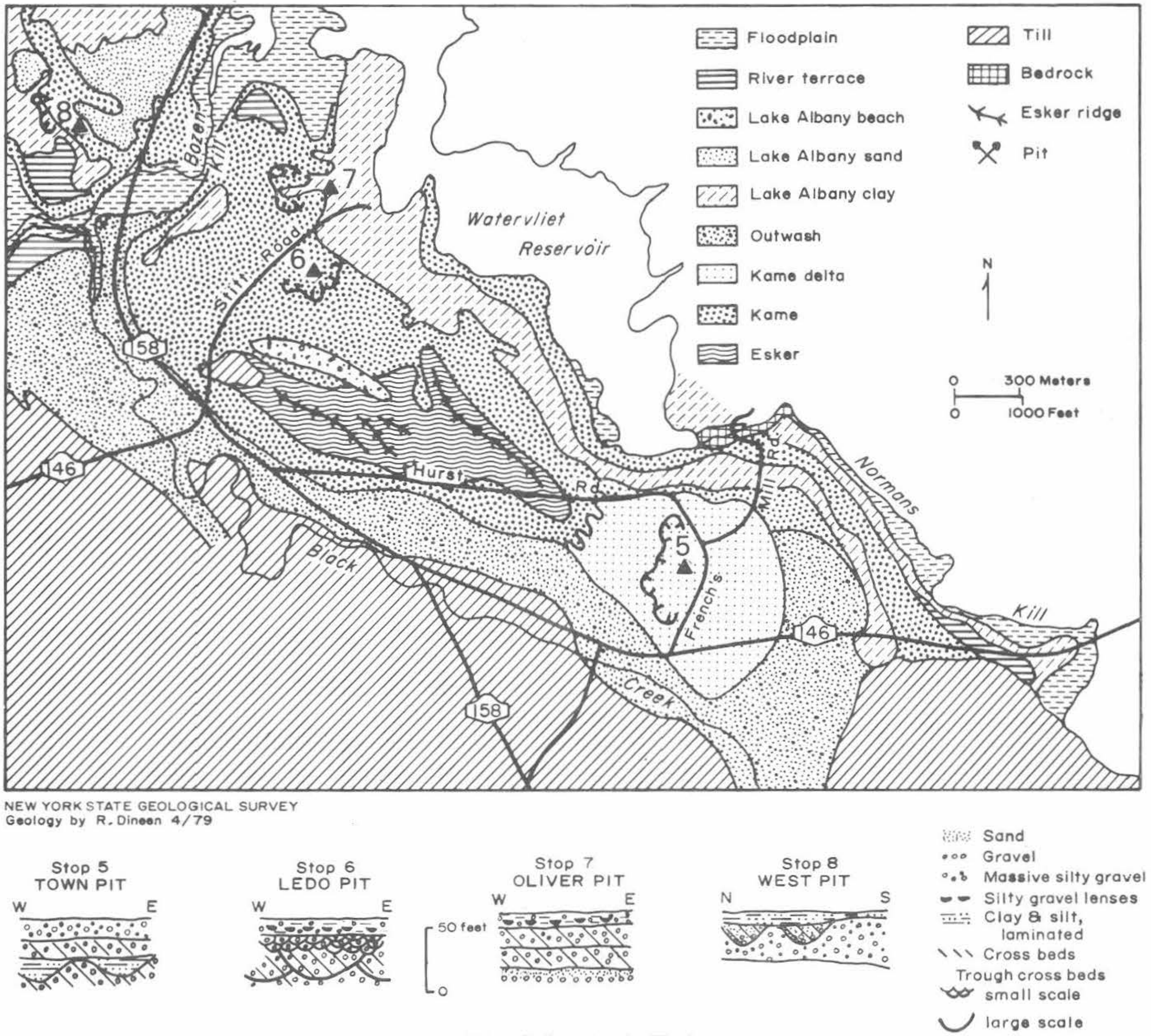
The parabolic dunes have a relatively gentle convex upwind slope of $<10^{\circ}$ and a steeper concave downwind slope of $>15^{\circ}$. They are transverse forms as opposed to the longitudinal ridge-forms.

The dune ridges in the Pine Bush are sinuous, generally parallel, and as much as two kilometers long. They are generally lower than the parabolic dunes.

28.7	0.3	Leave Stop 3, proceed up (north) the access road to Curry Road. Turn right (east) on Curry Road.
29.0	0.3	Intersection of Curry and Morris Roads. Proceed right on Curry Road.
30.2	1.2	Intersection of Curry and Kings Road, turn right (east) on Kings Road.
31.1	0.9	Intersection of Kings and Old State Roads. Turn left (east) on Old State Road.
31.7	0.6	Intersection of Old State Road and NY 155. Turn right (south) onto NY 155 and park on access road that parallels NY 155.

Stop 4 Old State and NY 155 pits (Fig. 6b)
Cross NY 155 and follow the dirt road eastward for approximately 0.3 mile: We have walked along the northeast limb of a parabolic dune. The blow-out hollow lies to the right. Sand blown from this hollow was deposited at the dune crest. Migration of these two features leave the limbs trailing, and produces the parabolic dune form. The southwest limb of this dune is subdued. The slipface of another dune lies to the right (south). Several small hollows can be seen along the inside of the limb that we are on. These are blowouts that formed recently due to tree throw or denudation

		of vegetation by fire. The taller trees are pitch pine, the low scrubs are dwarf or scrub oaks. The pits to the northwest and west show aeolian cross-bedding in dune sand that disconformably overlies the lake sand. This dune is part of a large compound dune cluster. The dunes of the cluster are connected on their northeast limbs, which can be seen to the east of this dune crest. The connected northeast limbs form a continuous ridge that can be traced for over 3km. Leave the dune crest and walk back to bus. Proceed south on NY 155.
32.4	0.7	Notice the till overlain by dune sand in the road cuts.
33.6	1.2	Intersection of NY 155 and US 20. A sand pit just northeast of here showed trough cross-bedded, gravelly, coarse sand. This gravelly sand underlies dune-shaped hills, implying that some "dunes" are erosional forms that have been wind-sculpted. The gravelly sand was probably deposited in a kame delta of the Delmar Readvance. Turn right (west) on US 20.
35.5	1.9	Intersection of US 20 and NY 146. Turn left (west) on NY 146. We are crossing the buried preglacial Mohawk Channel. A drumlin field buried by lake sediment cuts across the channel (Dineen, 1975). The drumlin field is flanked on the west by a thick gravel blanket. The drumlins act as underground dams by impeding the west-to-east movement of ground water in the gravel blanket.
36.4	0.9	Crossing the Normanskill. Climbing the south wall of the Mohawk Channel.
37.7	1.3	Intersection of French's Mill Road and NY 146. Turn right (north) on French's Mill Road.
37.9	0.2	Entrance to Town Pit on left.
		Stop 5 Town Pit (Fig. 7) This pit is cut into the distal, kame delta portion of the Guilderland kame terrace. This stop, and stops 6, 7, 8 will illustrate the distal-to-proximal increase in labile (shale) lithic clasts, in angularity of clasts, and in clast size, that accompanies the decrease in



NEW YORK STATE GEOLOGICAL SURVEY
Geology by R. Dineen 4/79

STOPS 5, 6, 7, 8

Figure 7.

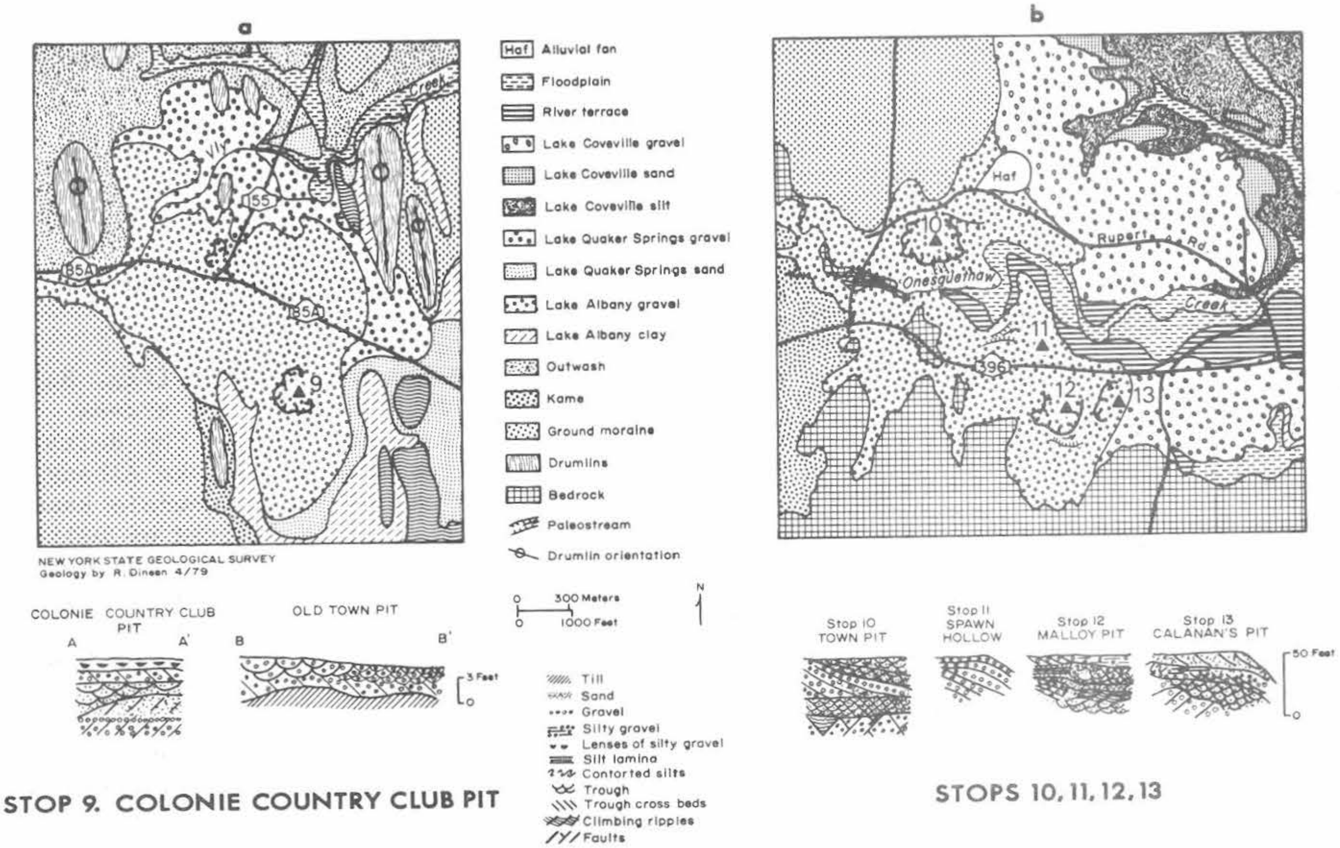
sorting typical in a kame terrace. The Guilderland kame terrace was first mentioned by Woodworth (1905) when he observed the existence of a large gravel terrace northwest of Guilderland Center. He considered the terrace to be an ice marginal kame. LaFleur (1965b) called attention to glacial lake beaches that are cut along the northern margin of the kame. LaFleur also reported southwest dipping gravel and irregular beds of rhythmic clay in the kame. Woodworth (1905) and LaFleur (1965b) interpreted the kame as having been deposited by meltwater streams in an elongate hole in the ice. LaFleur (1965b) suggested that the streams were the outflow of Lake Amsterdam in the Mohawk Valley. Dineen (1975) found that the kame is continuous with a buried gravel blanket which extends north to Schenectady.

The kame consists of well-sorted, sub-rounded, ice-contact sand and gravel to the east, and poorly-sorted, subangular, silty, bouldery sand and gravel to the west. The number of shale clasts and the overall grain size decrease from west to east. The surface of the kame slopes to the southeast, from +360 ft. at Stop 8 to +330 ft. at Stop 5. Stop 5 is in a kame delta that was built into Lake Albany, and shows planar cross-bedded, rhythmic silt and sand overlying trough cross-bedded, ice-contact sand and gravel. The rhythmites are overlain unconformably by planar-bedded, silty, cobbly sand that grades into clay to the southeast. These upper beds are delta foresets, and dip S20°E.

Leave Stop 5, proceed north on French's Mill Road to Hurst Road.

38.0	0.1	Turn left (northwest) onto Hurst Road.
39.3	1.3	Intersection of Hurst Road and NY 146. Turn right (west) on NY 146.
39.5	0.2	Intersection of NY 146 and Stitt Road. Turn right (north) on Stitt Road.
40.0	0.5	Stop 6 Ledo Pit (Figure 7) Stop at entrance to pit and walk in. This pit contains large-scale, trough cross-bedded, cobbly, gravelly sand, dipping N20°E and overlying ripple trough cross-bedded, coarse sand. The cobbly sand grades upward into channels filled with rhythmic silt and clay. The channels trend N20°W. They are overlain by cobbly, silty gravel that is overlain by varved clay to the north. Leave Stop 6, proceed north on Stitt Road to the access road (to the west).

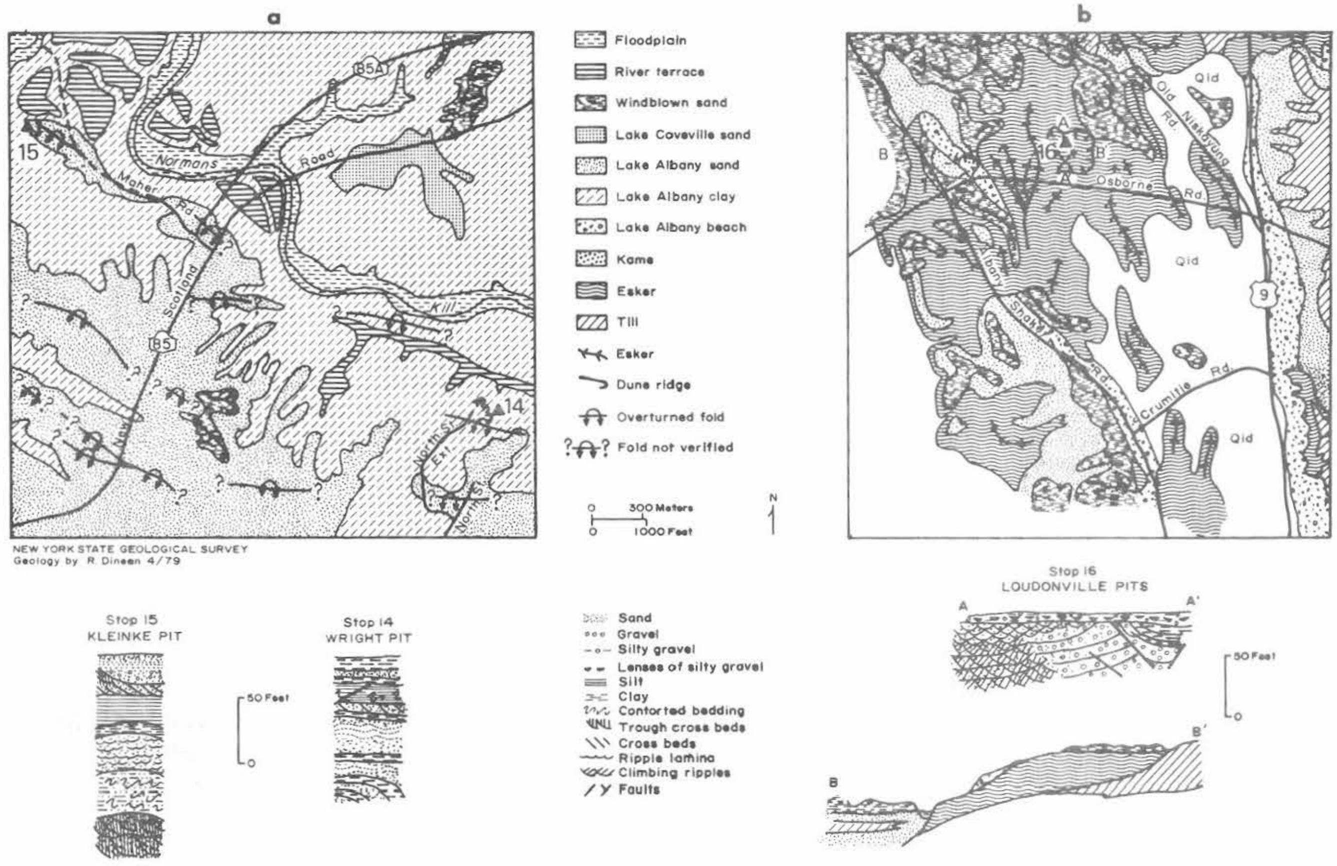
40.4	0.4	Stop 7 Oliver Pit (Fig. 7) This pit contains planar cross-bedded, cobbly, sandy gravel that dips N80°E, and which overlies ripple-laminated coarse sand. These beds are overlain by pebbly, silty cobble gravel with channels filled with rhythmic silt and clay. Varved clay overlies the sequence to the north. The lower gravel layers extend north of the kame, where they partially fill the Mohawk Channel; and they are overlain by lake deposits northward. They can be traced to Schenectady. This gravel probably was deposited on the ice block that occupied the Schenectady area during the early Lake Albany time (see LaFleur, this volume). The channels that cut into the top of the gravel slope northeastward, perpendicular to the axis of the kame terrace.
41.5	1.1	Turn around in the Oliver Pit, and proceed south on Stitt Road to NY 158. Turn right on NY 158.
42.4	0.9	Proceed north on NY 158 to Becker Road. Turn left (west) on Becker Road.
42.6	0.2	Proceed to access road to Stop 8 (on north side of road). Pull off road.
		Stop 8 West Pit (Fig. 7) This pit contains poorly bedded, poorly sorted, shale-rich, silty, bouldery gravel, overlain by varved clay that fill erosional channels cut into the top of the gravel. Turn around in access road, proceed back to NY 158.
42.8	0.2	Turn right (south) on NY 158.
43.7	0.9	Intersection of NY 158 and NY 146. Turn left (east) on NY 146.
44.5	0.8	Intersection of NY 146 and School Road. Bear right (southeast) on School Road.
46.5	2.0	Intersection of School and Altamont Ave. Bear right (south) on Altamont Ave.
48.2	1.7	Intersection of Altamont Ave. and NY 156. Bear left on NY 156.
48.4	0.2	Intersection of NY 156 and NY 85A.



STOP 9. COLONIE COUNTRY CLUB PIT

STOPS 10, 11, 12, 13

Figure 8.



STOPS 14, 15

STOP 16. LOUDONVILLE PITS

Figure 9.

		Bear left (east) on NY 85A.
50.0	1.6	Access road to Colonie Country Club. Turn right (south) on to access road.
50.3	0.3	Go to club house parking lot. Walk along the road to the west for 0.1 mile.
		Stop 9 Colonie Country Club Pit (Fig. 8a) This is the Voorheesville delta. The access road runs along the foreset slope of the delta. The delta was deposited into early Lake Albany, and is at the distal end of the Meadowdale kame and outwash complex that was deposited by meltwater from a stagnant ice block in the Guilderland Center-Voorheesville area (Dineen, 1977). The section in the pit consists of planar bedded, ice-contact gravel and sand at the base, overlain by planar cross-bedded, foreset sand and gravel, which are overlain by topsets of trough cross-bedded, silty, gravelly sand. The Town of Voorheesville derives its water supply from the delta. Leave the Colonie Country Club.
50.6	0.3	Turn left (west) on NY 85A.
51.2	0.6	Intersection of NY 85A and NY 155. Turn right (north) on NY 155.
55.2	4.0	Intersection of NY 155 and US 20. Turn right (east) on US 20.
57.6	2.4	Intersection of US 20 and Interstate 87. Turn left (north) on I-87.
58.3	0.7	Entrance to I-90. Turn on I-90 (east).
64.3	6.0	Intersection of I-90 and I-787. Turn on I-787 (south).
68.2	3.9	Intersection of I-787 and US 9W. Turn right on US 9W (south).
73.9	5.7	Intersection of US 9W and NY 396. Turn right (west) on NY 396.
76.5	2.6	Overpass-abandoned Penn Central railroad right-of-way, in the Village of South Bethlehem. We are travelling up the foreset slope of the South Bethlehem delta.

77.5	1.0	Intersection of NY 396 and Snyders Bridge Road. Turn right (north) onto Snyders Bridge Road. We are cutting across the apex of the delta.
77.9	0.4	Intersection of Snyders Bridge Road and Rupert Road. Turn right (east) on Rupert Road.
78.1	0.2	Intersection of Rupert Road and access road to Town Pit (to south).

Stop 10 Town Pit (Fig. 8b)
Park at the entrance to the access road and walk down into the gravel pit. The South Bethlehem deltas lie at +340, +300, +220, +190, and +170 ft. The +340 ft. delta is wholly contained within the Onesquethaw Creek Valley, and lies approximately 1 mile (1.6 km) west of Stop 10. The +300 ft. delta is the largest and best developed delta. The lower deltas prograde eastward across varved silt and clay. The +300 ft. delta was described as an ice-marginal kame delta by Woodworth (1905) and Cook (1930). Woodworth (1905) noted that the +300 ft. delta had a boulder and till covered, raised outer margin, with a southwest gradient. These features imply that the delta was deposited in the ice-contact environment. Airphoto and field observations suggest that the +300 ft. delta's outer margin is not raised more than 2m (5 ft.). Exposures in gravel pits and along the Onesquethaw Creek reveal a predominance of fining-upward beds of coarse sand and gravel, and some lenses of boulders. These beds dip to the northeast at Stop 10, and to the southeast at Stops 11, 12, and 13. No till has been observed in the pits, but gravity faults are common west of a rock ridge in Stop 10, and in ice-contact gravel that is exposed in Stops 10, 12, and 13. Boulders mantle the northeast slope of the delta along Rupert Road. Several channels cut southeastward across the delta's surface in the areas of Stops 10 and 12. Rhythmic silts and clays overlie the southeast and east margins of the delta (Stops 11 and 12). No kettle-holes were observed. A test boring 3500 ft. (1.3km) east of the delta showed a 70m (200 ft.) section of deltaic gravels interbedded with varved clay (Dineen, Waller, and Hanson, in prep.). The delta had been deposited in open ice-free water when the Onesquethaw Creek was carrying large quantities of very

		coarse sediment. The sediment was probably derived from a rapidly melting ice block that lay in the upper Onesquethaw Valley. The lower deltas were deposited in lower lakes by the Onesquethaw recycling the upper deltas. This stop (Stop 10) is at the apex of the +300 ft. Lake Albany delta. This pit shows normal-faulted, ice-contact, gravelly, coarse sand at the base. The sand is overlain by trough cross-bedded, bouldery sandy gravel foreset beds. The foreset beds are overlain by trough cross-bedded to structureless, silty gravel topset beds. The bouldery cross-beds indicate that this is the proximal section of delta. Leave pit, turning around in access road. Turn left (west) on Rupert Road.
78.3	0.2	Intersection of Rupert and Snyders Bridge Roads. Turn left (south) on Snyders Bridge Road.
78.7	0.4	Intersection of Snyders Bridge Road and NY 396. Turn left (east) on NY 396. Intersection of NY 396 and Spawn Road.
79.4	0.7	Turn left (north) on Spawn Road.
79.6	0.2	Access road to Spawn Hollow pit. Park and walk in.
		Stop 11 Spawn Hollow Pit (Fig. 8) This pit is within planar cross-bedded, foreset beds of the central part of the delta. A thin section of topset beds is at the top of the pit. The exposed face shows the break in slope between the topset and foreset beds. Leave Stop 11, turn vehicle around in the access road. Proceed south on Spawn Road.
79.8	0.2	Intersection of Spawn Road and NY 396. Proceed straight across road onto the access road to the Malloy pit.
80.0	0.2	Stop 12 Malloy Pit (Fig. 8b) Notice that the delta foreset beds here are finer grained, and tend to be trough cross-bedded rather than planar cross-bedded as they are at Stop 11. The topset beds are siltier and thicker than to the west.
80.2	0.2	Turn around in the pit, proceed out to NY 396. Turn right (east) on NY 396.
80.6	0.4	Intersection with access road to Callanan pit.

		Turn right (south) into pit.
		Stop 13 Callanan Pit (Fig. 8b) This pit is on the prodelta slope of the +300 ft. delta. Ice-contact sandy gravel lies at the base of the pit. This is covered by bottomset beds of trough cross-bedded, coarse sand. The bottomset beds are overlain by foresets of planar cross-bedded, coarse sand and gravel. Very silty, trough cross-bedded, topset gravels and varved clays cap the sequence. Turn around in the pit, turn right (east) on NY 396.
83.2	2.6	Intersection of NY 396 and US 9W. Turn left (north) on US 9W.
88.2	5.0	Intersection of NY 32 and US 9W. Turn onto NY 32 (west).
88.8	0.6	Intersection of NY 32 and Kenwood Ave. Turn right (northwest) on Kenwood Ave.
91.2	2.4	Intersection of Kenwood Ave. and North St. Turn right (north) on North St.
91.7	0.5	Intersection of North St. and North St. Extension. Turn left (west) on North St. Extension.
92.2	0.5	Stop 14 Wright Pit (Fig. 9a) This stop shows lake silt and sand layers that were folded and faulted by ice shove during the Delmar Readvance. The section at this site consists of:

Top to 2.0m	yellow brown, varved clay and silt with laminae of fining upward, very fine sand. Layering is 6cm thick. The sand is ripple to planar-laminated, the planar-laminae are at the base of the beds over fine lag gravel and a truncation surface.
2.0 to 3.3m	yellow brown, compact, ripple to planar-laminated, very fine sand with 0.5cm laminae of clay. The sand fines upward. Bedding is faulted and folded, the fold axes trend N15°E and N80°E. The faulting is thrust up to the S40°W, soft sediment deformation is common.

3.3 to 3.7m	yellow brown, very fine sand with silt laminae. The varves fine-upward, and are 0.5cm thick. The varve sequence coarsens-upward to ripple-laminated sand, which fines-upward to varved silt.
3.7 to 4.7m	yellow brown, structureless, very fine sand, with contorted fragments of clay. Concretions are common at the base.
4.7 to 6.3m	gray brown, folded, very fine silt, clay, and fine sand in 5 to 20 cm thick coarsening-upward folded layers. The fold axes trend N60°E to N70°E. The tops of the folds are truncated and are covered by fining-upward, ripple cross-laminated, very fine sand.
6.3 to 13.3m	light gray, laminated silt.

Base of pit. Test boring log:

13.3 to 32.5m	pinkish gray to light gray, varved silty clay.
32.5 to 35.4m	light gray, varved, slightly silty clay
35.4 to 39.0m	light gray, varved, sandy, silty clay
39.0 to 63.0m	gray, varved clay
63.0 to 79.2m	light gray, varved clay
79.2 to 82.0m	gray, soft, varved clay with a trace (<5%) fine sand grading down to sandy clay with subrounded shale and quartzite clasts.
82.0 to 87.2m	Black shale.

The upper silty beds are folded parallel to the interfluve ridges that are present throughout the Delmar area. The upper part of the section was probably folded by the Delmar Readvance.

92.7	0.5	Leave Stop 14, proceed south on North St. Extension to North St. Turn right (south) on North st.
93.2	0.5	Intersection of North St. and Kenwood Ave. Turn right (west) on Kenwood Ave.
94.2	1.0	Intersection of Kenwood Ave. and NY 140.

		Turn right (north) on NY 140.
95.1	0.9	Intersection of NY 140 and NY 85. Turn right (north) on NY 85.
95.7	0.6	Intersection of NY 85 and New Scotland Ave. Turn left following NY 85.
95.8	0.1	Intersection of NY 85 and Maher Rd. Go straight on Maher Road.
96.4	0.6	Stop 15 Kleinke Pit (Fig. 9a) This pit is also developed in folded lacustrine silts and sands. The fold axes trend N40°E. The section is:

Top to 0.8m	very light yellow brown, planar-laminated, very fine sand. A truncation surface is at 0.8m.
0.8 to 3.8m	yellow brown silt to medium sand that coarsens-upward. This unit is mostly ripple cross-laminated with climbing ripples at its base and top. Ripples climb to the S80°S and N80°W.
3.8 to 5.0m	yellow brown, structureless silt.
5.0 to 11.0m	yellow brown, folded and convoluted silt to very fine sand. Dewatering structures are common. The fold trends N40°E.
11.0 to 11.5m	yellow brown, contorted, varved sand, silt and clay.
11.5 to 13.5m	yellow brown, ripple-laminated, fining-upward, fine sand to silt. Truncated and cemented at 11.5m.

This area was probably folded by the Delmar Readvance.

96.9	0.5	Leave Stop 15, proceed east on Maher Road to NY 85. Turn left (north) on NY 85.
101.2	4.3	Proceed to I-90 (west). Get on I-90 (west).
102.9	1.7	Proceed to I-87 (north). Get on I-87.
106.0	3.1	Proceed to Shaker Road (Exit 4). Exit on Wolf Road. Turn left (northeast) on Wolf Road.
106.2	0.2	Intersection of Shaker Road and Wolf Road.

		Turn right (southeast) on Shaker Road.
107.9	1.7	Intersection of Shaker and Osborne Roads. Turn left (northeast) on Osborne Road.
108.1	0.2	Access road to Stop 16 on left. Turn left.
108.3	0.2	Stop 16 (Malloy) Loudonville Pits (Fig. 10b) These pits are on the axis of the Loudonville esker complex. The Loudonville esker complex was described by Peet (1904) as a moraine-kame-delta complex that extended from North Albany to Newtonville. It is bounded on the north by a "boulder strewn" moraine ridge with elongate kettles (Woodworth, 1905). The esker system slopes to the south, with coarser gravels and cobbles to the north and finer gravel and sand to the south (Woodworth, 1905). Kettle holes are common, with faulted bedding near the kettles, and unfaulted bedding dominating to the south. The lenticular gravel at the north grades southward into horizontally bedded, fine-grained sediments (Woodworth, 1905). The eskers are overlain by cross bedded, gray and yellow sand (Cook, 1905). The esker complex grades southward into the Schodack kame terrace (Woodworth, 1905, Cook, 1930, LaFleur, 1965a, 1965b). Woodworth (1905) interpreted the Loudonville complex as being built by south-flowing, in-glacial streams. Cook initially interpreted the complex as a crevasse filling (Cook 1930), but later re-interpreted it as being deposited in a blind, lake water-filled, ice-walled tunnel (Cook, 1946). He misinterpreted the rounded bluffs surrounding the complex as being molded by over-hanging ice walls (Cook, 1946), rather than as beach-cliffs cut by Lake Albany waves (Fairchild, 1918, LaFleur, 1961b, 1965b). Stop 16 shows a 16m. fining-upward sequence of poorly-to well-sorted, ice-contact sand and gravel. The lower gravel contains boulders, silt, and cobbles in planar cross-beds which interfinger with cobble lenses. These lower beds are overlain by ripple-laminated sand that is overlain by lenticular, fining-upward, trough cross-bedded gravel and ripple-laminated sand. This sequence is overlain to the south by planar cross-bedded, ripple-laminated, deltaic fine silt and sand. The entire sequence is cut by gravity-faults that bound basins which filled with varved clay. The varved clay reaches an elevation of +400 ft. The +400 ft. varved

clay and delta complex at Stop 16 was deposited in a lake that existed up-stream (north) from Lake Albany. The western edge of the esker complex was exposed in a building excavation at the corner of Osborne and Shaker Roads in 1976. This excavation contained a fining-upward sequence of trough cross-bedded gravel and sand. The gravelly sand beds were planed off, and were overlain by horizontally laminated, yellow brown sand. The entire sequence contained numerous gravity faults. The lower trough cross-bedded, gravelly sand was deposited in the esker. The upper, laminated sand was deposited in a Lake Albany beach. Stagnant ice lay in the area until after the lake dropped below the +330 ft. level, as indicated by the gravity faults. The area of this pit is probably the recharge of the Loudonville eskers' artesian groundwater system.

110.3	0.2	Leave Stop 16, turn left (east) on Osborne Rd.
111.3	1.0	Intersection of Osborne Road and US 9. Turn left (north) on US 9.
114.3	3.0	US 9 and NY 7 (Latham Circle).
119.1	4.8	Turn east on NY 7. Proceed to Houston Field House.

The Structural Framework 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 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 similar to 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. 2-5) 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 (Fig. 2). 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.

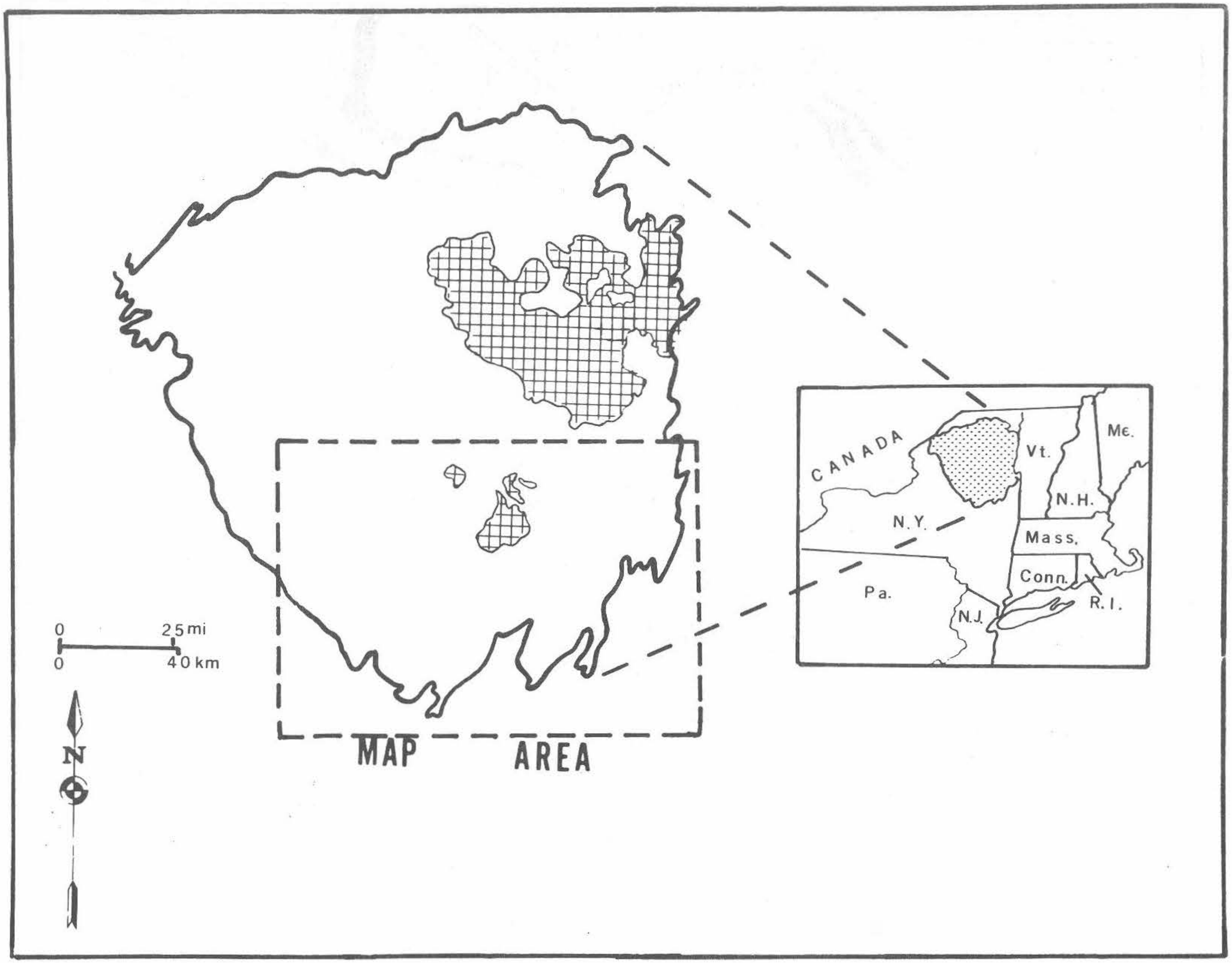


Fig. 1 - Location of central and southern Adirondacks. Anorthosite massifs patterned.

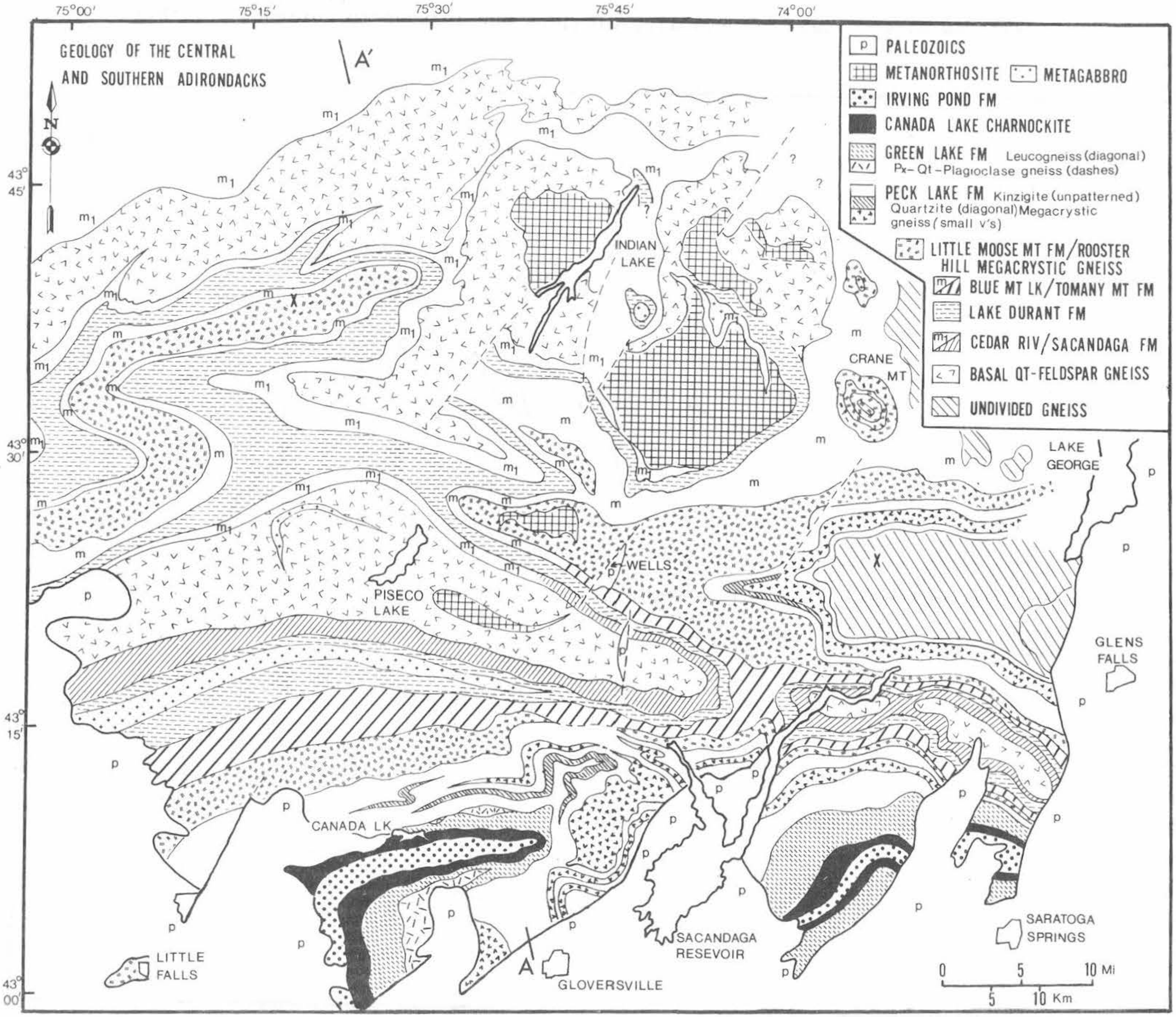


Fig. 2 - Geologic map of the central and southern Adirondacks showing distribution of formational units. The two X's locate bodies of metagabbro referred to in text.

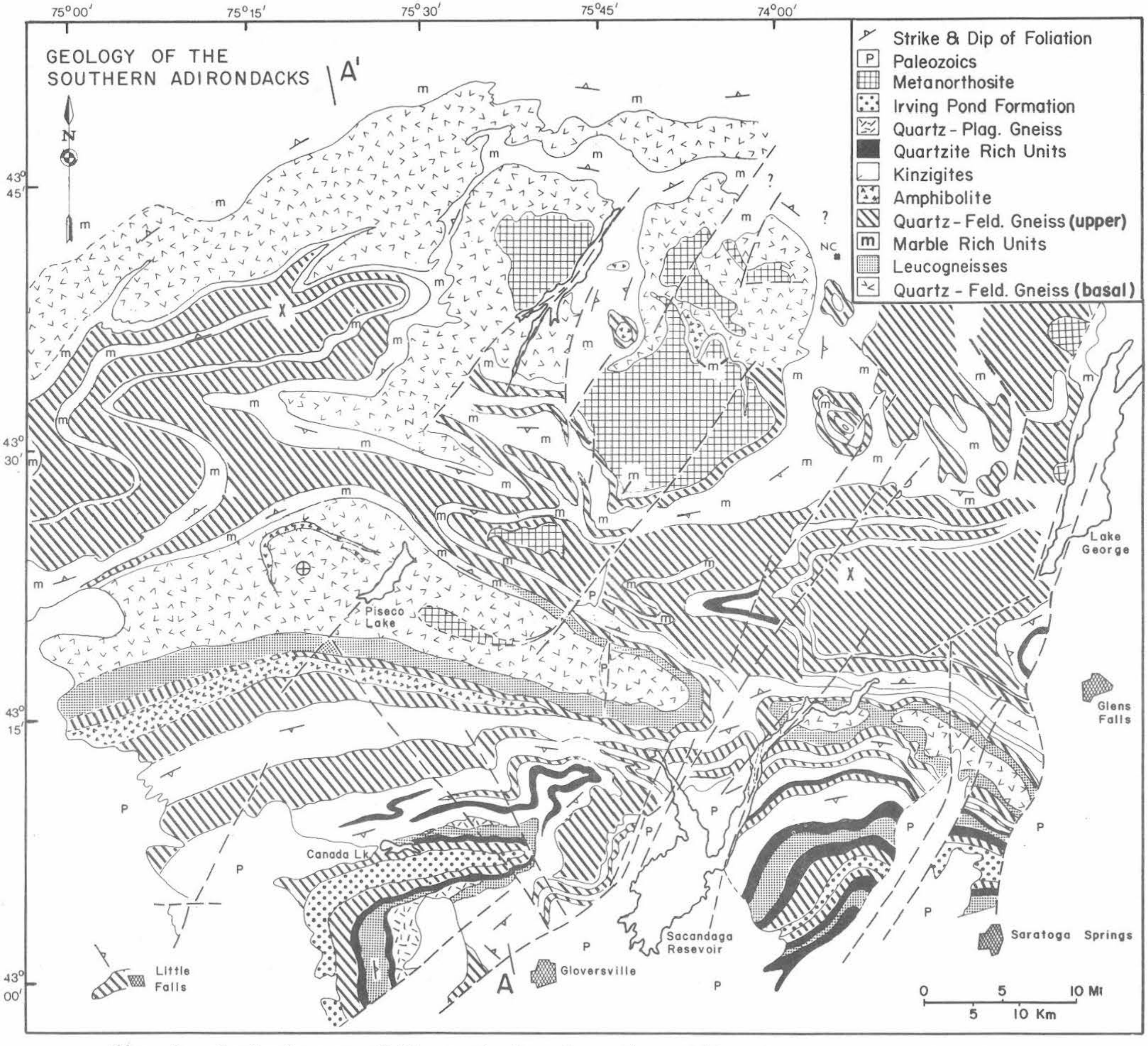


Fig. 3 - Geologic map of the central and southern Adirondacks showing distribution of lithologies throughout area. Major faults shown by dashed lines.

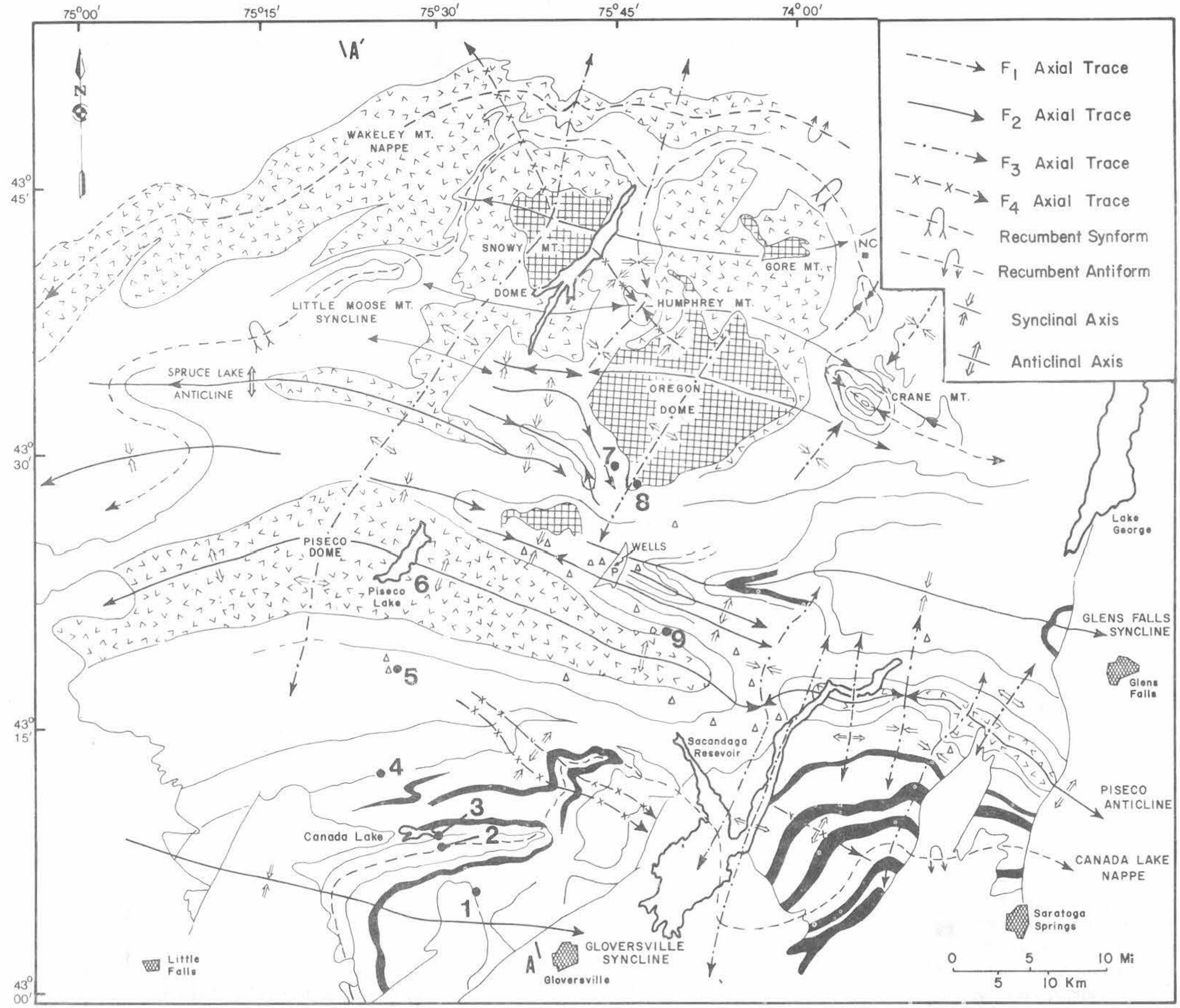


Fig. 4 - Structural framework of the central and southern Adirondacks showing the interference pattern produced by the four regional fold sets. The open triangles locate small anorthositic intrusives referred to in the text. Indicated numbers are those of stops.

The earliest and largest of these folds are recumbent, isoclinal structures (F_1) -- for example the Little Moose Mt. syncline (de Waard, 1962) and Canada Lake nappe (McLelland, 1969)(Figs. 2 and 5). These isoclines have axes that trend approximately E-W and plunge within 20° of the horizontal. As seen in Figure 5 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 Little Moose Mt. Fm. may be identical to supposedly older quartzo-feldspathic gneisses (basal) which lie at the base of the lithologic sequence. Given this situation, then the Cedar River and Blue Mt. Lk. Fms. 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 pre-F_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. 2 and 5). 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.

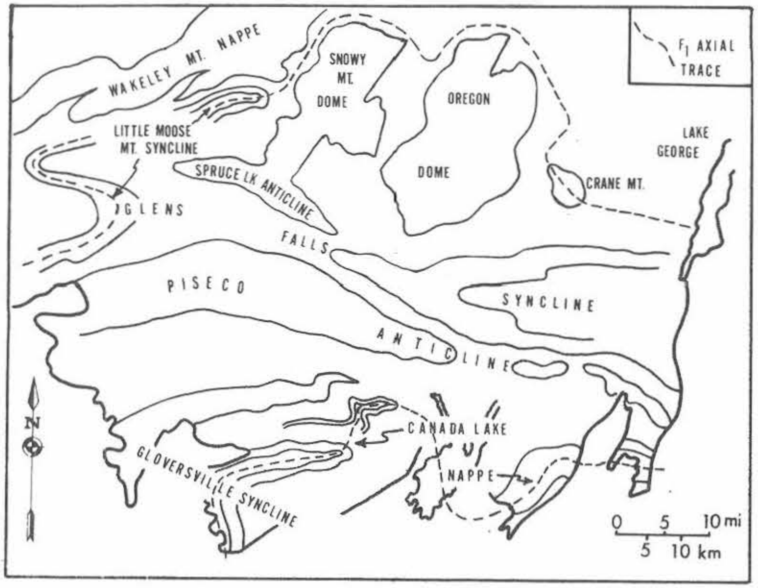


Fig. 5 - Blocked out major folds of the central and southern Adirondacks. The major F_1-folds are the Wakeley Mt. nappe and the Canada Lake-Little Moose Mt. nappe whose axial trace is shown as a dashed trajectory.

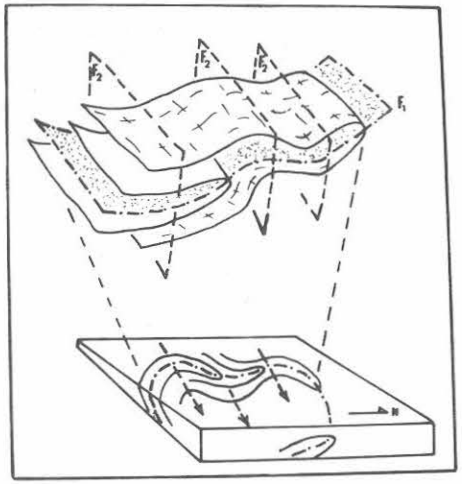


Fig. 6 - Three dimensional cartoon depicting the manner in which axial plane folding of the Canada Lake nappe effects the trajectory of the axial trace.

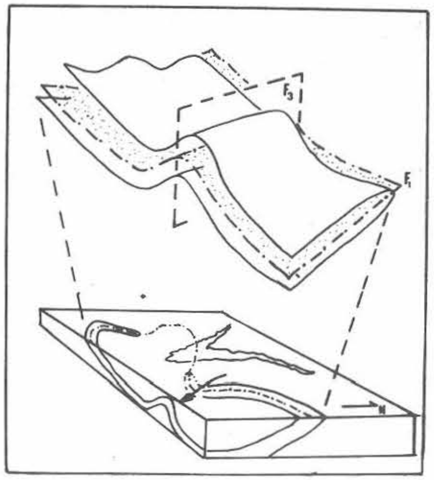


Fig. 7 - Three dimensional cartoon depicting the manner in which fold interference effects the axial trace of the Canada Lake nappe east of Sacandaga Reservoir.

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. 6). 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. 7). 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 (Figs. 3 and 8).

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 basal quartzo-feldspathic gneiss in Figure 3. The basal Cedar River Fm. 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 9. Although our own research agrees with the generalized lithologic sequences of de Waard and Walton, two major provisos are necessary and are given here.

(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 basal quartzo-feldspathic gneisses of Figure 2 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 of the Cedar River Fm. exposed north of the Piseco anticline (Figs. 3,4). 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, calcsilicates, 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.

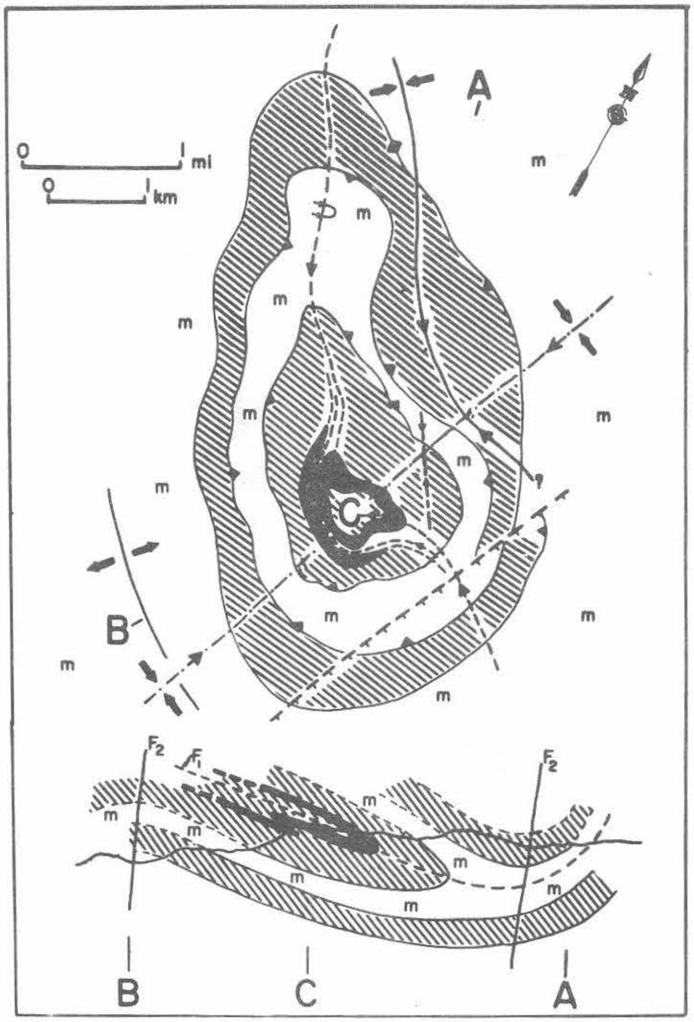


Fig. 8 - Generalized geologic map and cross section of Crane Mt. showing the structural basin produced by interference of F_1, F_2 amd F_3 folds. Charnockite gneiss is shown by the line patterns; marble-rich units by m; and a mixed metasedimentary unit by solid black. A younger normal fault is shown near the eastern edge of the structure. Numbers refer to the dip of the foliation.

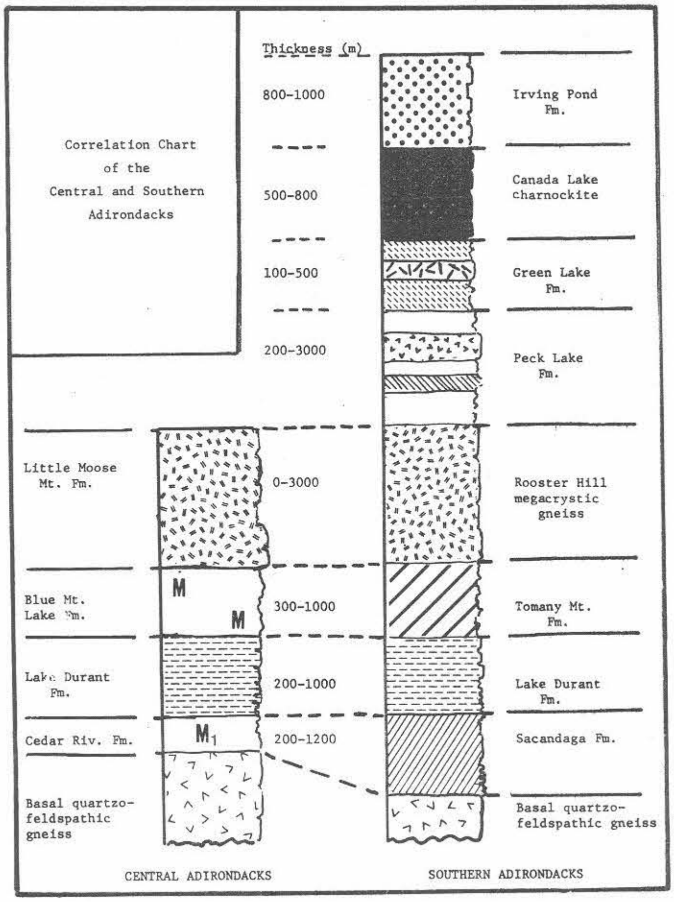


Fig. 9 - Stratigraphic columns for the central and southern Adirondacks. The central Adirondack section is taken from de Waard (1963) and Geraghty (1979).

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. 10). 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. 11). 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 11 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 12 and suggests that most Adirondack structure is explicable in terms of the four large fold sets described here.

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).

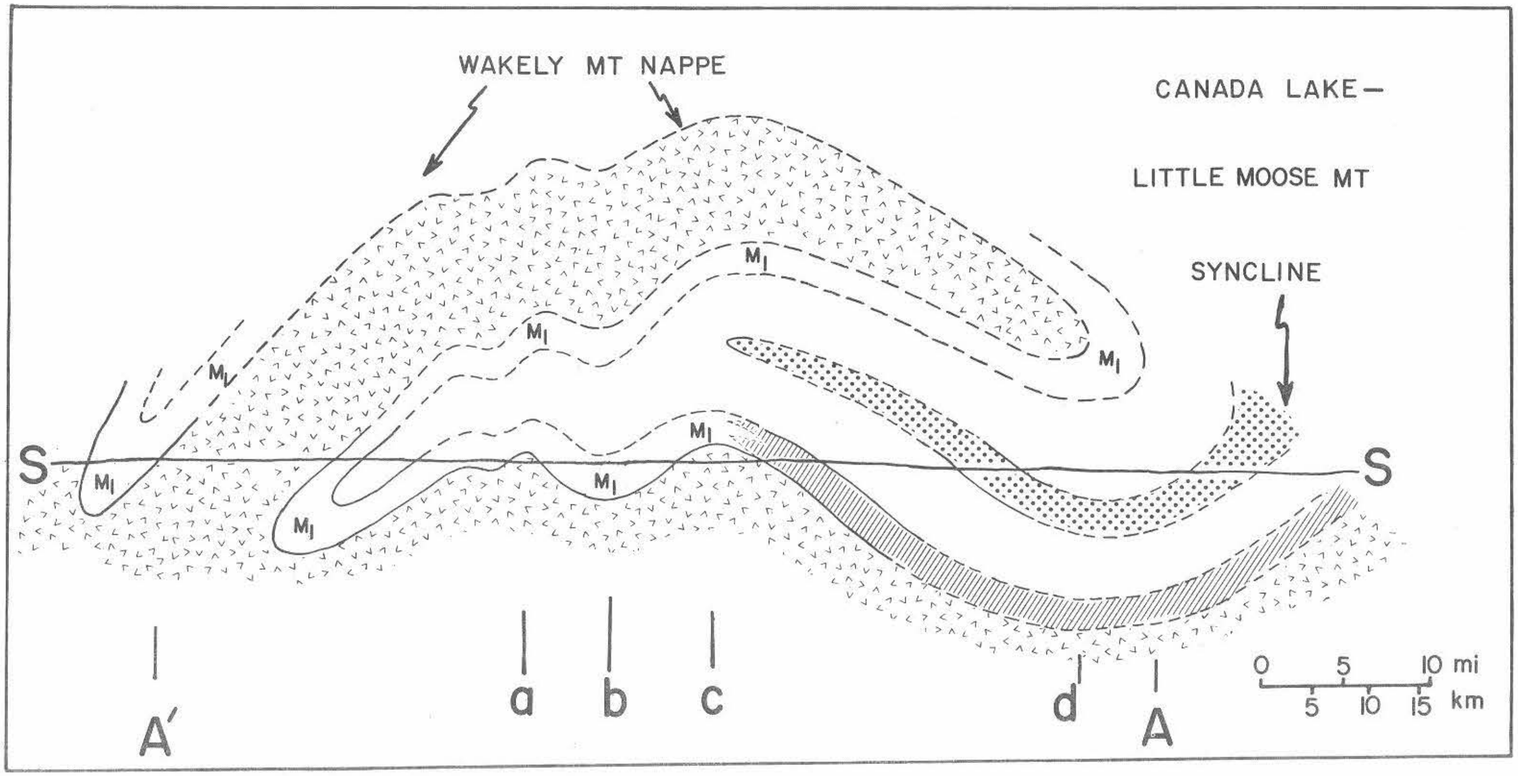


Fig. 10 - Generalized cross section along AA' of Figs. 2, 3 and 4 showing isoclinal folds and subsiding F_2 folds as follows: (a) Spruce Lake anticline; (b) Glens Falls syncline; (c) Piseco anticline; (d) Gloversville syncline. Several map units have been omitted for clarity. Patterned rock unit symbols as in Fig. 2.

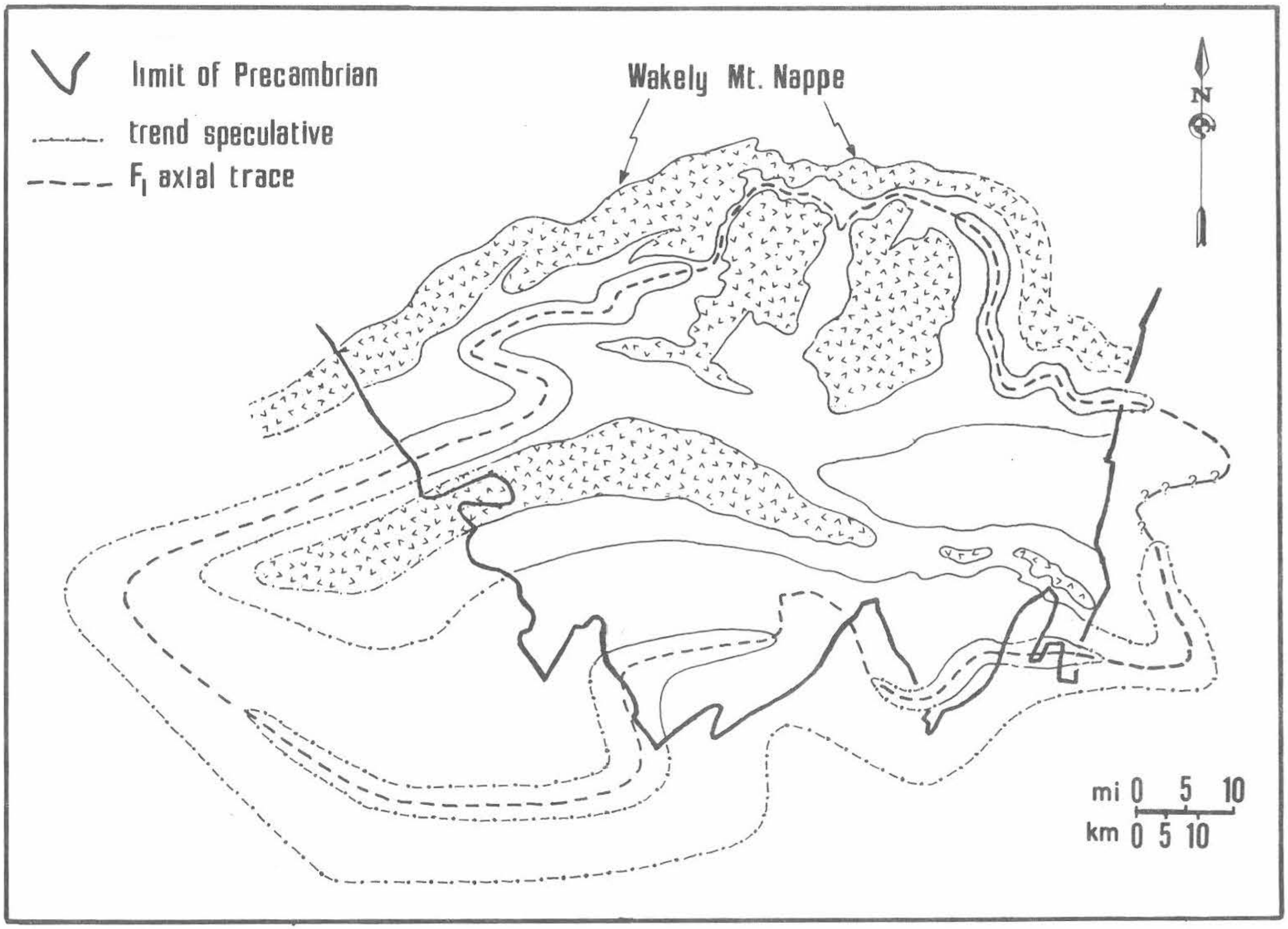
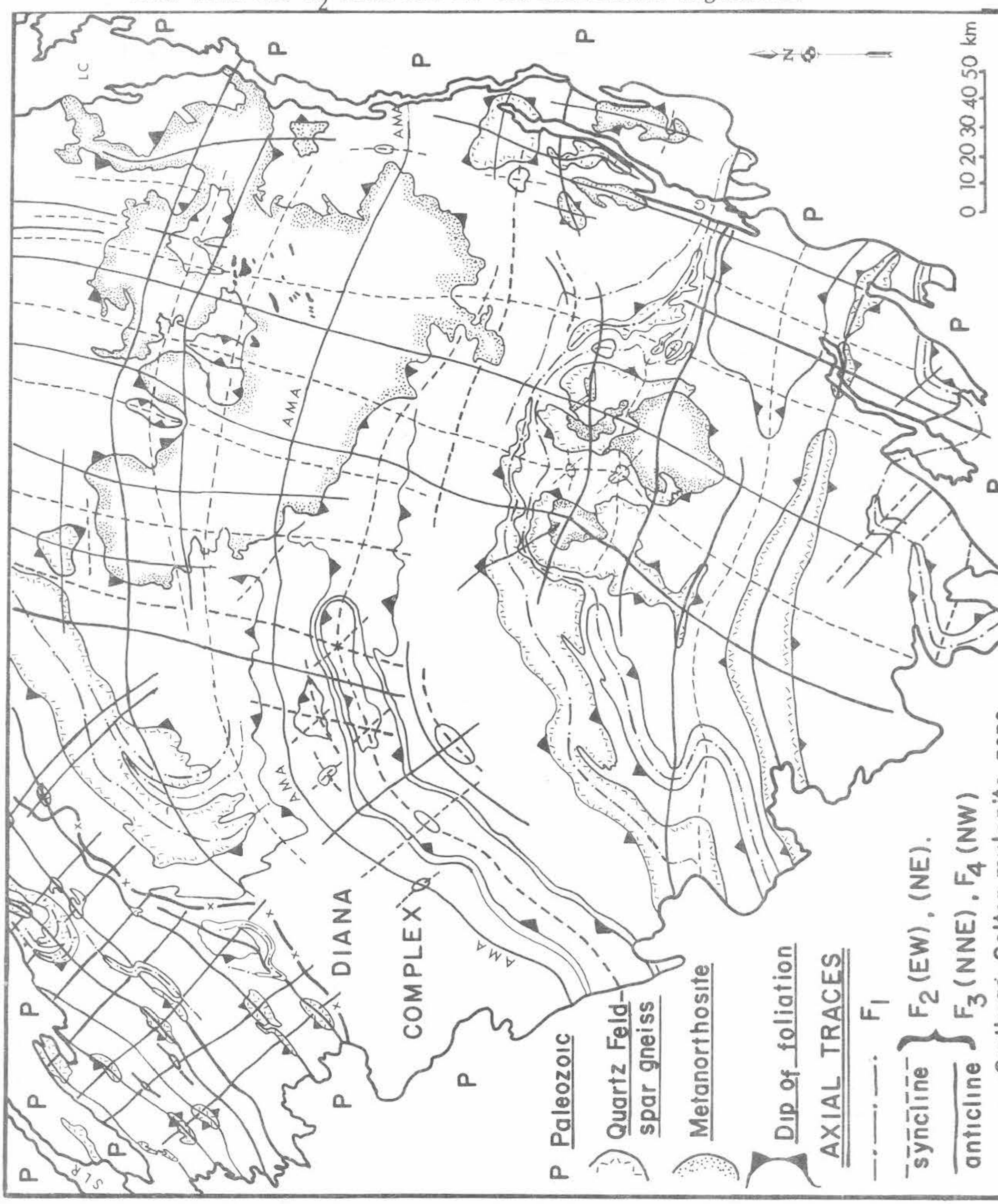


Fig. 11 - Generalized map showing the known axial trace of the Canada Lake-Little Moose Mt. syncline and its projection beneath Paleozoic cover.

Fig. 12 - Suggested framework of ductile deformation in the Adirondacks. White areas within the Adirondack perimeter represent various lithologies, including quartzofeldspathic gneisses not here divided. Black patches within the main anorthosite body are xenoliths and mixed rocks (roof pendants) suggestive of downfolds. SLR-St. Lawrence River; LC-Lake Champlain; LG-Lake George; AMA-Arab Mt. anticline. The northeast trending lines in the northwest Adirondacks (lowlands) represent fold axes thought to be correlative with the F_2 fold set in the Adirondack highlands.



Because of the wide extent of the Grenville metamorphic belt, we prefer the Tibet-India 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.

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 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. 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).

ACKNOWLEDGMENTS

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ROAD LOG

Mileage

0 Junction of Willie Road, Peck Hill Road, and NY Rt. 29A

1.3 Mud Lake to northeast of NY Rt. 29A

2.8 Peck Lake to northeast of NY Rt. 29A

3.6 Stop 1. Peck Lake Fm.

This exposure along Rt. 29A just north of Peck Lake is the type locality of the sillimanite-garnet-biotite-quartz-feldspar gneisses (kinzigites) of the Peck Lake Fm. In addition, there are exposed excellent minor folds of several generations. Note that the F_1 folds rotate an earlier foliation.

The white quartzo-feldspathic layers in the kinzigites consist of quartz, two feldspars, and garnet and are believed to be anatectic. Note that fish-hook terminations on some of these suggest that they have been transposed. It is also clear that these anatectites have been folded by F_1 indicating a pre-F_1 metamorphic event(s). In a similar fashion some garnets in the rock appear to be flattened while others do not.

6.1 Junction NY Rt. 29A and NY Rt. 10

8.0 Nick Stoner's Inn on west side of NY Rt. 29A-10

8.6 Stop 2. Irving Pond Fm., .5 mile north of Nick Stoner's Inn, Canada Lake.

The outer portion of the Irving Pond Fm. is exposed in low cuts along the east side of Rt. 29A just prior to the crest in the road heading north.

At the southern end of the cut typical, massive quartzites of the Irving Pond are seen. Proceding north the quartzites become "dirtier" until they are essentially sillimanite-garnet-biotite-feldspar gneisses (kinzigites).

At the northern end of the cut, and approximately on the Irving Pond/Canada Lake Fm. contact there occurs an excellent set of F_1 minor folds. Polished slabs and thin sections demonstrate that these fold an earlier folation defined by biotite flakes and flattened quartz grains.

The Irving Pond Fm. is the uppermost unit in the stratigraphy of the southern Adirondacks. Its present thickness is close to 1000 meters, and it is exposed across strike for approximately 4000 meters. Throughout this section massive quartzites dominate.

8.8 <u>Stop 3</u>. Canada Lake Charnockite

These large roadcuts expose the type section of the Canada Lake charnockite. Lithogically the charnockite consists of 20-30% quartz, 40-50% mesoperthite, 20-30% oligoclase, and 5-10% mafics. The occurrence of orthopyroxene is sporadic. These exposures exhibit the olive-drab coloration that is typical of charnockites. Note the strong foliation in the rock.

Although no protolith is known with certainty for these rocks a metavolcanic history is suggested by their homogeneity and lateral continuity.

10.0 Canada Lake Store. Good exposures of Royal Mt. member of Green Lake Fm.

11.8 Pine Lake, Junction NY Rt 29A and NY Rt. 10. Proceed north on NY Rt. 10.

17.5 <u>Stop 4</u>. Rooster Hill megacrystic gneiss at the north end of Stoner Lake.

This distinctive unit is believed to be, in part, correlative with the Little Moose Mt. Fm. Here the unit consists of a monotonous series of unlayered to poorly layered gneisses characterized by large (1-4") megacrysts of perthite and microcline perthite. For the most part these megacrysts have been flattened in the plane of foliation. However, a few megacrysts are situated at high angles to the foliation. The groundmass consists of quartz, oligoclase, biotite, hornblende, garnet, and occasional orthopyroxene. An igneous rock analogue would be quartz-monzonite.

The origin of the Rooster Hill is obscure. Its homogeneity over a thickness approaching 2.5 km suggests an igneous parentage. This conclusion gains support from the presence of localities where megacrysts appear to retain a random orientation, and from the occasional presence of what may be drawn out xenoliths of biotitic or amphibolitic gneisses. However, these features may be explained by other models. The contacts of the Rooster Hill are always conformable with enclosing units, and this suggests a metastratified (metavolcanic?) origin. However, the anorthosites of the region also show conformable contacts, and this may, in part, be due to tectonic flattening.

Recently Eckelmann (pers. comm.) has studied zircon population morphologies in the Rooster Hill and similar lithologies. His results strongly suggest an igneous plutonic origin. This would be consistent with the igneous origin assigned the Hermon granite of the northwest Adirondacks - a rock that is markedly similar to the Rooster Hill.

20.0 Low roadcut in kinzigites of Tomany Mt. Fm.

21.4 Avery's Hotel on west side of NY Rt. 10

22.5 Long roadcuts of quartzofeldspathic gneisses and metasediments of Lake Durant Fm. intruded by metagabbro and anorthositic metagabbro.

23.6 Roadcut of anorthositic metagabbro and metanorite.

23.9 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.

24.0 <u>Stop 5</u>. Lake Durant and Sacandaga Fms. intruded by anorthositic gabbros and gabbroic anorthosites.

These roadcuts are located on Rt. NY 10 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 Sacandaga 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 the 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 quartzo-feldspathic gneisses seem to have undergone substantial anatexis. This is suggested 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.

31.0 Red-stained basal quartzofeldspathic gneissses that have been faulted along NNE fractures.

31.5 Junction NY Rt. 10 and NY Rt. 8. End Rt. 10. Turn east on NY Rt. 8.

33.0 Stop 6: Core rocks of the Piseco anticline.

Hinge line of Piseco anticline near domical culmination at Piseco Lake. The rocks here are typical basal quartzo-feldspathic gneisses 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 transportation 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.

In summary, 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 readily 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.

43.5 Junction NY Rt. 8 and NY Rt. 30 in Speculator. Head southeast on NY Rt. 8-30.

47 Stop 7. Northern intersection of old Rt. NY 30 and new Rt. NY 30, 3.3 miles east of Speculator, New York.

The Blue Mt. Lake 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.

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.

Commonly included in the Blue Mt. Lake Fm., 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 .5 mile to the south.

Almost certainly these marbles are of inorganic origin. No calcium carbonate secreting organisms appear to have existed during the time in which these carbonates were deposited (> 1 b.y. 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. 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.

47.5 Extensive roadcuts in lower part of Blue Mt. Lake Fm. Quartzites, kinzigites, and leucogneisses dominate. Minor marble and calcsilicate rock is present.

47.9 Large roadcuts in lower Lake Durant Fm. Pink, well-layered quartzo-feldspathic gneisses with subordinate amphibolite and calcsilicate rock.

49.0 Stop 8. One half mile south of southern intersection of old Rt. 30 and with new Rt. 30.

On the west side of the road small roadcut exposes an excellent example of Adirondack anorthositic gneiss intermediate in character between the so-called Marcy type (uncrushed) and the Whiteface type (crushed). About 50% of the rock consists of partially crushed crystals of andesine plagioclase. Some of these crystals appear to have measured from 6-8" prior to cataclasis. Excellent moonstone sheen can be seen in most crystals. In places ophitic to subophitic texture has been preserved with the mafic phase being represented by orthopyroxene.

In addition to the coarse grained anorthosite there exists a fine grained phase and a clearly crosscutting set of late orthopyroxene rich dikes. The latter may represent a late mafic differentiate related to cotetic liquids responsible for the ophitic intracrystalline rest magma. This would be consistent with the iron enrichment trend characteristic of Adirondack igneous differentiation. The fine-grained phase may have intruded early in the sequence, but this is uncertain.

Near road level there can be found several inclusions of calcsilicate within the anorthositic rocks. These are believed to have been derived from the Cedar River Fm. and are consistent with a non-basement status for the anorthosite.

The upper, weathered surface of the outcrop affords the best vantage point for studying the textures and mineralogy of the anorthositic rocks. In several places there can be seen excellent examples of garnet coronas of the type that are common throughout Adirondack anorthosites. These coronas are characterized by garnet rims developed around iron-titanium oxides and pyroxenes. Recently McLelland and Whitney (1977) have succeeded in describing the development of these coronas according to the following generalized reaction:

Orthopyroxene + Plagioclase + Fe-bearing oxide + quartz = garnet + clinopyroxene.

This reaction is similar to one proposed by de Waard (1965) but includes Fe-oxide and quartz as necessary reactant phases. The products are typomorphic of the garnet-clinopyroxene subfacies of the granulite facies (de Waard 1965). The application of various geothermometers to the phases present suggests that the P,T conditions of metamorphism were approximately 8 Kb and 700 ± 50^{o}C respectively.

51.0 Cedar River Fm. Minor marble, amphibolite, and calcsilicate rock. Predominantly very light colored sillimanite-garnet-quartz-k-feldspar leucogneisses.

52.0 Junction NY Rt. 8 and NY Rt. 30. Continue south on NY Rt. 30. To the west of the intersection are roadcuts in leucogneisses of the Blue Mt. Lake Fm. A large NNE normal fault passes through here and fault breccias may be found in the roadcut and the woods beyond.

52.5 Entering Little Moose Mt. Fm. on northern limb of the Glens Falls syncline. Note that dips of foliation are to the south.

54.8 Entering town of Wells which is situated on a downdropped block of lower Paleozoic sediments. The minimum displacement along the NNE border faults has been determined to be at least 1000 meters.

58.3 Silver Bells ski area to the east. The slopes of the ski hill are underlain by coarse anorthositic gabbro intrusive into the Blue Mt. Lake Fm.

60.3 Entrance to Sacandaga public campsite. On the north side of NY Rt. 30 are quartzo-feldspathic gneisses and calcsilicate rocks of the Lake Durant Fm. An F_1 recumbent fold trends subparallel to the outcrop and along its hinge line dips become vertical.

60.8 Gabbro and anorthositic gabbro.

62.0 Stop 9. Pumpkin Hollow. Large roadcuts on the east side of Rt. 30 expose excellent examples of the Sacandaga Fm. At the northern end of the outcrop typical two pyroxene-plagioclase granulites can be seen. The central part of the outcrop contains good light colored sillimanite-garnet-microcline-quartz gneisses (leucogneisses). Although the weathered surface of these rocks are often dark due to staining, fresh samples display the typical light color of the Sacandaga Fm. The characteristic excellent layering of the Sacandaga Fm. is clearly developed. Note the strong flattening parallel to layering.

Towards the southern end of the outcrop calc-silicates and marbles make their entrance into the section. At one fresh surface a thin layer of diopsidic marble is exposed. NO HAMMERING, PLEASE. Many "punky" weathering layers in the outcrop contain calc-silicates and carbonates.

At the far southern end of the roadcut there exists an exposure of the contact between the quartzo-feldspathic gneisses of the Piseco anticline and the overlying Sacandaga Fm. The hills to the south are composed of homogeneous quartzo-feldspathic gneisses coring the Piseco anticline (note how ruggedly this massive unit weathers). The Sacandaga Fm. here has a northerly dip off the northern flank of the Piseco anticline and begins its descent into the southern limb of the Glens Falls syncline.

No angular discordance or other indications of unconformity can be discerned at the base of the Sacandaga Fm. However, this does not preclude the prior existence of an angular discordance which may have been swept into pseudoconformity by tectonism.

Along most of the roadcut there can be found excellent examples of faults and associated pegmatite veins. Note that the drag on several of the faults gives conflicting senses of displacement. The cause of this is not known to the author. Also note the drag folds which indicate tectonic transport towards the hinge line of the Piseco anticline.

62.5-67.0	All exposures are within the basal quartzo-feldspathic gneisses at the core of the Piseco anticline.
67.0	Re-enter the Sacandaga Fm. Dips are now southerly.
68.0	In long roadcuts of southerly dipping quartzo-feldspathic gneisses of Lake Durant Fm.
70.4	Cross bridge over Sacandaga River.
74.4	Bridge crossing east corner of Sacandaga Reservoir into Northville, N.Y.

END LOG

MICROSTRUCTURE OF A VERMONT SLATE, AN ADIRONDACK GNEISS, AND SOME LABORATORY SPECIMENS

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The aim of this trip is to examine the microstructure of some naturally and experimentally deformed materials and to discuss the relationships between the observed structures and the deformations they represent. The microstructures at each stop will be described using hand-out photomicrographs. The trip is therefore not very suitable for future use by independent field parties. These notes will accordingly be brief.

Road Log*

Miles	
0.0	Depart R.P.I. Field House. Proceed west on People's Avenue to second traffic light.
0.4	At second light, turn left on 15th Street (N.Y. Route 7) and follow south 3/4 mile to T-junction.
1.1	Turn right on N.Y. 7 and follow through Troy.
2.1	Still following N.Y. 7, turn left at light onto bridge over Hudson River.
2.5	West end of bridge. Turn right following sign for I 787.
2.7	Turn right at light following sign to I 787.
2.8	Turn right just past light onto I 787 south.
7.4	Leave I 787 following signs for I 90 west, to Buffalo.
11.5	Exit 4. Leave I 90 following signs for NY 85, to Slingerlands. Shortly after completing the exit loop...›

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*People who omit the laboratory visit to S.U.N.Y.A. can pick up the road-log by proceeding directly to Fort Ann (mileage 83.6 on this log). For people following this plan, mileages from Fort Ann are provided in parentheses.

12.1 Take Exit 1. Leave N.Y. 85 following signs for Washington Avenue.

12.3 Merge and move toward left lane.

12.6 Bear left, following sign for Washington Avenue West.

13.0 First light on Washington Avenue. Thruway House Motel on right. Turn left at light on S.U.N.Y.A. campus.

13.1 Turn left on ring-road around campus. Continue on ring road 4/10 mile to pair of driveways on right. First driveway enters parking lot; second driveway leads west to main academic buildings. Turn right onto second driveway and

13.5 park at nearest building on left, Earth Science. (Avoid nearby buildings on right surrounding a tall square tower. These are dormitories.) Go to Earth Science Bldg., Room 241.

Stop 1. S.U.N.Y.A. Deformation Laboratory.

Experiments are conducted here in a deformation cell that operates at temperatures close to room temperature and pressures less than 300 bars. These restrictions allow the cell to be fitted with glass windows through which the deformation and associated microstructural adjustments in a thin sample can be observed continuously with a microscope. The experiments to be demonstrated are simple-shearing experiments on an organic material (paradichlorobenzene). The shearing is carried out at 47°C, which on the absolute temperature scale is within 2% of the melting point of the material. Dynamic recrystallization and recovery effects are observed. The relationships of foliations and other microstructural elements to the shearing direction and various strain directions will be demonstrated, as progress of the experiments permits.

13.5	Leave Earth Science Building and return to Thruway House intersection.
14.0	Turn left at Thruway House intersection, proceeding west on Washington Avenue.
14.8	Turn right at second light, following signs here and at several more points, for I 87 (the Adirondack Northway).
15.6	Enter I 87 and head North.
72.6	Exit 20. Leave I 87 and follow signs for N.Y. 149 and Fort Ann.
*83.6 (0)	Fort Ann, intersection of route 149 and route 4. Head north (left) on Route 4 toward Whitehall.
85.5 (1.9)	Just short of bridge over railway tracks, turn left off 4 onto short access road connecting present Route 4 to new version under construction. Park at side of access road.

Stop 2. Quartzo-feldspathic gneiss

Exposure is mainly west side of new Route 4. Two small-scale features of interest occur here. The first is a quartz ribbon lineation trending east in the plane of the main southeast-dipping foliation. This is a common type of lineation in Adirondack gneisses, of obscure kinematic significance. The nature of this lineation will be discussed — is it transposed quartz layering? stretched quartz aggregates or grains? synkinematic secretion? or ....?

The second microstructure of interest consists of partial feldspar rims, in preferred orientation, around feldspar grains. The hypothesis that these are in-fillings of potential voids between rigid grains in relative motion will be discussed.

85.5 (1.9)	Continue north on Route 4 toward Whitehall.
94.8 (11.2)	Whitehall. Bear right at light, still following Route 4.
103.0 (19.4)	Exit 2. Leave Route 4 and follow Vt. route 22a to Fair Haven.
104.1 (20.5)	Approaching center of Fair Haven. Bear left around north end of town green. Turn left on Vt. route 4a East, and follow this to Hydeville.
106.1 (22.5)	Hydeville. Turn left just beyond Exxon station, following road on west side of Lake Bomoseen toward West Castleton.
110.0 (26.4)	Vermont State Campground on right; go straight ahead past campground entrance onto dirt road, soon turning east toward Lake Bomoseen.
111.4 (27.8)	End of dirt road. Park at base of path up to quarry. Please do not block access to nearby house.

Stop 3. Cedar Mountain Slate Quarry.

The quarry displays many structural features of interest, including variously shaped green spots and a large recumbent synform. The synform closes to the east (hinge-line subhorizontal, trending north); a folded surface is exposed on the west wall of the quarry and fold profiles are exposed in the north wall. The main cleavage that provides the slate is subhorizontal, axial-planar to this fold. On this trip, attention will be focussed on the crenulation cleavages which overprint the main slaty cleavage.

antithetic

synthetic

Crenulation cleavages

The crenulation cleavage is mostly an antithetic kink-like variety; it may be seen in places in two conjugate orientations consistent with shortening parallel to the (shallow) dip direction of the slaty cleavage. Puzzling features which will be illustrated and discussed are the less frequent occurrence of synthetic crenulation cleavage (perhaps suggesting extension in the dip direction of the slaty cleavage), and some dark layers enriched in "insoluble" material. In a few places these layers coincide with crenulation cleavage planes, but in many places the crenulations and the dark layers seem to be independent of each other —— not parallel and not genetically related although close together in the rock.

111.4 Retrace steps to Fairhaven, but now proceed south along east side of town green, through town.

118.9 Bear left up hill following Vt. route 22a south.

131.3 Join N.Y. route 22 and turn left on it.

176.4 Turn right from N.Y. route 22 onto N.Y. route 7, toward Troy.

196. Going down final hill into Troy —

For Field House: turn left at light onto Burdett Avenue (blue HOSPITAL sign on right). Follow Burdett Avenue past hospital on right to intersection (Peoples Avenue). Turn left to Field House.

For Communications Center and main campus: go down hill past blue HOSPITAL sign on right, 3 blocks to next light (15th Street). Turn left on 15th Street and continue south to Armory building (red brick with conical turrets). At blinking light, turn right onto main campus and right again into parking lots. The nearest building is the Communications Center.

CLEAVAGE IN THE COSSAYUNA AREA, as seen at the outcrop

by Lucian B. Platt, Bryn Mawr College

ABSTRACT

This trip crosses the Taconic allochthonous sheets in Washington County, N.Y., eastward on Saturday and westward on Sunday. The purpose is to look at various structures visible at outcrop and with a hand lens and to consider how much of the deformation can be attributed to dissolution. I believe that much rock has moved through solution, but many features seen at outcrop are not easily interpreted. At the west edge of the klippe rocks, the underlying carbonates are remarkably undeformed, and the Taconic Sequence, though folded and cleaved, does not show obviously massive rock loss. Eastward the situation becomes more complicated, and at the easternmost stop, extension fibers have formed in fanning "cleavage." I hope those taking the trip will share their observations and thoughts at the outcrop so that we all learn.

INTRODUCTION

The Cossayuna quadrangle lies in Washington County, N.Y., along the western edge of coherent thrust sheets of Cambrian to Middle Ordovician shales known collectively as the Taconic Sequence. The Shushan quadrangle is southeast of the Cossayuna quadrangle, and about a mile farther east carbonates re-emerge from beneath the Taconic slices. The age, succession, and allochthony of these rocks have been discussed elsewhere (Platt, 1962; Zen, 1964; Cady, 1968; Rodgers, 1971; among many) as have discussions of their environment of deposition (Rodgers, 1968; Platt, 1969). NEIGC has run numerous field trips through various parts of these complexly deformed rocks, including the 1976 meeting, so no discussion of regional relations is presented for this trip. Figure 1 shows the location of the area visited on this trip, and indicates the general structure from my Ph.D. thesis and some later work. All the mapping in the Taconics seems to me to owe much to T.N. Dale's comprehensive work (1899).

Dale was especially involved with the slate in eastern New York and Vermont and elsewhere (Dale and others, 1914), for all through the Nineteenth Century the rock was of substantial economic importance. Even though the rock no longer provides the main roofing material, and annual production has declined for decades, study of its origin has increased recently. Just since the reviews of Siddans (1972) and Wood (1974), there has been a flood of data indicating that selective dissolution has produced cleavage of many types in many kinds of rock. A summary of some of the data is presented in the Atlas of Rock Cleavage (Bayly and others, 1977).

Solution along stylolites is not new, nor is the interpretation that they form in anisotropic stress fields. Durney (1978) gives a review of theories about pressure solution, and Stockdale (1922) gives a review of the occurrence of stylolites in limestone. Apparently Sorby and Heim recognized the dissolution origin of pitted pebbles a century ago. Excellent photos of quartz grains penetrating chert grains are in the article by Sloss and Feray (1948), thus showing selective solubility; the succession of solubilities of several minerals is indicated by Trurnit (1969). That stylolites and cleavage are at least in part caused by the same process was suggested by Plessman (1964) and Nickelsen (1972) among others, and has been supported by Alvarez and others, (1976; 1978).

That pressure solution results in cleavage is a fairly new idea. Quite a few other proposed causes have been recorded in the literature on slate. Some of the best evidence against these alternatives has been published since my cleavage conference, so a few remarks on the newer papers follow. Early in this century Leith (1905) suggested that slaty cleavage could form by flattening while fracture cleavage could form by shear strain. White (1949) showed this to be erroneous, for "slip cleavage" grades into schistosity in eastern Vermont. That cleavage surfaces should be 45° from maximum compression as fostered by Becker (1896) was refuted by Goguel (1945) and recently by Groshong (1975a). That major rotation of platy minerals is most important in slate fabric has been weighed by Beutner (1978) and found wanting. Intracrystalline deformation has been considered important by many, including Deelman (1976) who rejects pressure solution as a substantial factor even in diagenesis. Yet crushing is notable for its absence in many natural specimens from terranes with widely different amounts of strain (Marlow and Etheridge, 1977; Engelder and Engelder, 1977; Gray, 1978). Clearly some mechanical reorientation occurs as individual grains are dissolved away (Means and Williams, 1974) or as they grow into pores (Etheridge and others, 1974). Maxwell's (1962) suggestion that slaty cleavage could form in wet mud was widely accepted for a time but now seems less satisfactory (Geiser, 1975; Maltman, 1977).

While emphasizing the importance of pressure solution in deformation of rocks generally, recent literature has attempted to evaluate what are conditions under which it accounts for less than other kinds of distortion. For example, Kerrich and Allison (1978) indicated that cataclasis is dominant at low confining pressure and temperature, pressure solution at intermediate temperature, and dislocation creep at high temperature. Of course, such a qualitative scale will be shifted up and down for different minerals and for various other conditions; Kerrich and others (1977a) say the transition from grain-surface diffusion to intracrystalline creep occurs near 450°C for small grains of quartz and near 300°C for small crystals of calcite. Mitra (1977) suggests that pressure solution is linear Newtonian while dislocation creep obeys a power law and that the latter becomes dominant as the strain rate increases. McClay's review (1977) shows that at low stress pressure solution is orders of magnitude faster than intracrystalline creep and surface diffusion in quartz and still at least ten times faster in calcite. In fact, most discussion of dissolution and diffusion have dealt with calcite and quartz; more data on rates of deformation by dissolution, diffusion, and dislocation movement for other minerals would be useful. It is clear that selective dissolution of certain minerals can change the bulk rock chemistry (Kerrich and others, 1977b; Mitra, 1979).

In summary, dissolution of selected mineral grains and along selected surfaces of those grains is increasingly recognized as a major factor in rock deformation in the upper crust generally (Groshong, 1975b), and in the formation of rock cleavage especially. The properties of minerals in various deformation modes have been studied extensively. That different minerals behave very differently is well known, but only recently has it been recognized that this diversity of behavior could be mostly due to orders-of-magnitude differences in solubility and rates of dissolution rather than to solid deformation. Distinguishing these from each other can be difficult; Williams (1972) notes the difficulty of distinguishing detrital from authigenic mica. At higher grades early pressure solution effects may be lost in later recrystallization (Stephens and others, 1979).

While this review has been cursory, I hope it will stimulate discussion at the outcrops.

Thanks to Robert Metz, who offered suggestions based on his mapping in the Cambridge quadrangle, and to Mark Steuer, who assisted in planning the trip and produced the photomicrographs.

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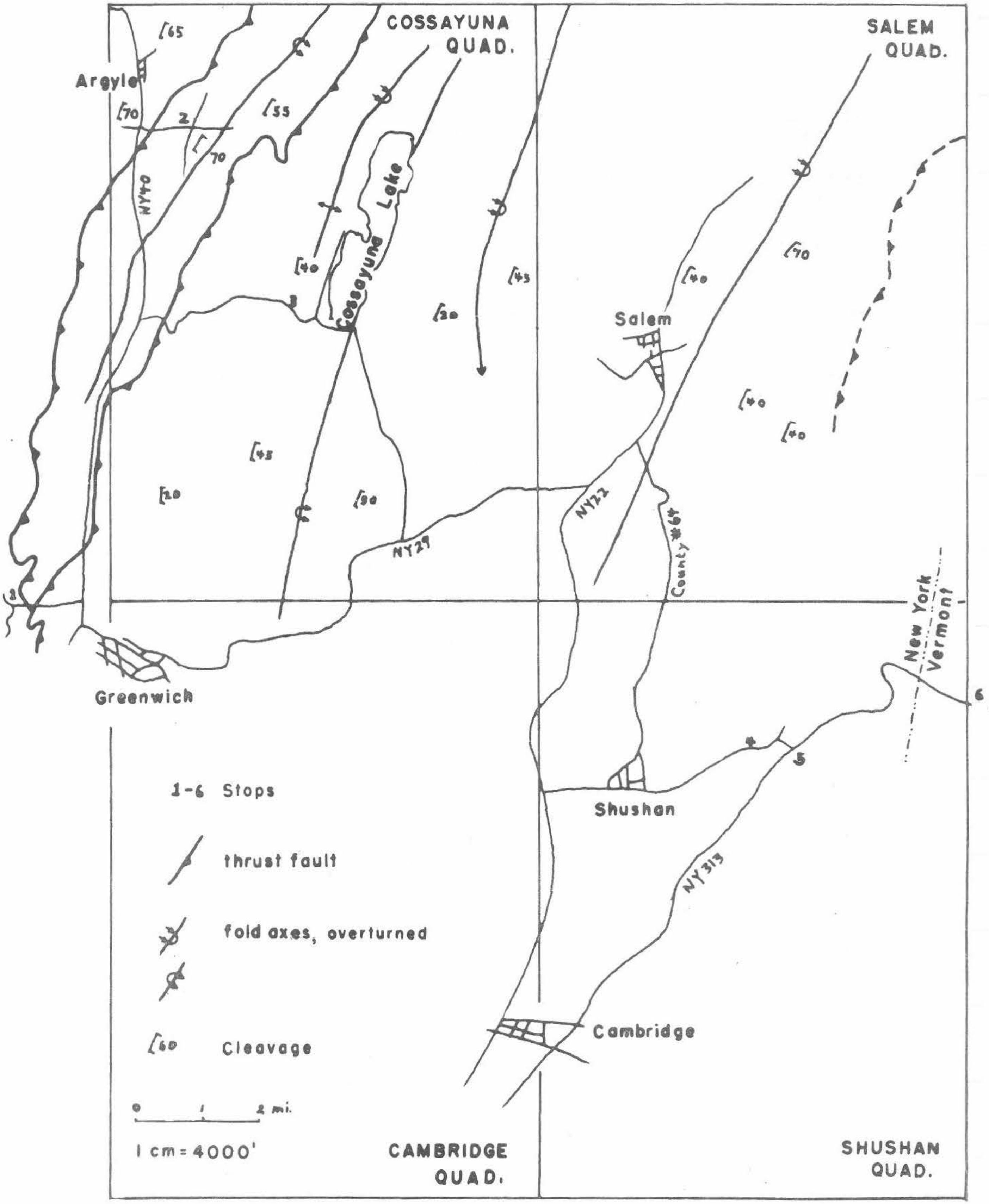


Fig. 1. Location of stops 1 through 6 and generalized structural map of the Cossayuna area and vicinity.

DESCRIPTION OF STOPS

STOP #1. Bald Mountain, near Middle Falls, N.Y.

Re-enter the bus 1 hour after getting out.

Enter the quarry on the west side and walk around the southwest side of the hill along the old road. The quarry existed to produce lime, and some evidence of kilns remain. The geologic relations at Bald Mountain have been examined by scores of geologists for over a century. Published mapping by Ruedemann (Cushing and Ruedemann, 1914) shows Lower Ordovician limestone overlain by a thrust plate of Lower Cambrian shale. In fact, a screen of Middle Ordovician shale intervenes between, and the best explanation of the geology in this vicinity is that the carbonate floats as a tectonic fish in the Ordovician shale which is overlain by the thrust plate of Taconic rocks. Our interest in the locality is that we can see shale with pebbles of carbonate, and we can see some dissolution features adjacent to some of the carbonate. One point to note is how LITTLE deformation there is in the Ordovician carbonate, even in small pieces, in contrast to the cleaved shale.

STOP #2. One mile southeast of Argyle, northwest quadrant of road intersection. Re-enter the bus after no more than an hour.

Some small folds in these Lower Cambrian carbonate, silt, and shale beds can be seen in the southwest part of the corner field. The chevron folds do not show much cleavage, but other parts of the pasture do. Dale (1899) found trilobites in both the pebbles and the matrix, but the conglomeratic look to the carbonate beds is probably due to insoluble residue concentrated along dissolution surfaces. The main point of this stop is to examine the styles of deformation in this more or less carbonate-rich part of the Taconic Sequence.

STOP #3. 1000' west of the south end of Cossayuna Lake.
Re-enter the bus in one hour.

At the road cut it is easy to see conglomerate of carbonate pebbles in shale and some beds of limestone in shale. Walk up to the outcrops of this rock on the slope north of the road cut. In several places the glacially scraped rock shows solution features in the carbonate. Seeing this requires getting down on hands and knees and using a hand lens in many cases; hence if it is raining, we will abandon this stop. One aspect of the solution of these rocks is that many solution features do not continue very far in the rock; they are approximately parallel to tight fold axes in the area. How much change in thickness of beds around tight folds, particularly in area of "similar folds, is due to removal of rock? In nearly isoclinal folds, it is possible to show that dissolution could cause virtually all of it.

LUNCH. Re-enter the bus in 59 minutes.

STOP #4. BM564, 1 mile northwest along County 61 from NYRoute 313, 3/4 mile due north of Eagleville, Shushan quad. Bus pull off on south. Re-enter bus after 30 minutes.

Folds in Lower Cambrian Mettawee and West Castleton Formations. This small outcrop is rich in deformation features. Chevron folds and kinks. Microboudins. "Slip" both ways on vertical cleavage. It is not clear to me how slip both ways could occur on parallel cleavage surfaces; hence I conclude that during folding a substantial part of the rock went into solution, and the plane along which material was removed only appears to be a line of slip. Years ago, Donath (1961) showed that slip occurs along surfaces of mechanical anisotropy; here we can infer that the cleavage we see was not a place of particular anisotropy before or during the early stages of its formation. Flattening by selective dissolution seems a better way to me. But where does the material go? What is the reservoir rock for this source rock?

STOP #5. Intersection of NYRoute 313 and County 61, 2 1/4 mi. due east of Shushan, northern Shushan quad.
Re-enter bus after about an hour and a half.
Quite a variety of wonderful things are visible at this roadcut. I suggest that you walk east along the outcrop before you get down to the details. The paucity of veins at previous outcrops is in sharp contrast to this spot. I doubt it is merely a matter of metamorphic grade, though this rock is obviously more metamorphosed than the first stops. These rocks are folded and veined (calcite before quartz?) but the cleavage is not particularly impressive. Nevertheless, small crenulations show concentrations of micaceous minerals along limbs quite like the drawings of Gray (1979, Fig.3), and I infer, as he does, that solution of quartz is a major factor in the wrinkling. A thin section of sandstone from this outcrop shows extensively twinned calcite vein material, some sutured sand grain boundaries, and very little but nevertheless some dark submicroscopic material in strings along some grain boundaries and in sutured grain contacts. In one vein it appears that the calcite twin lamellae are bent. In the thin section, only two sand grains other than quartz were found, so this particular section was not

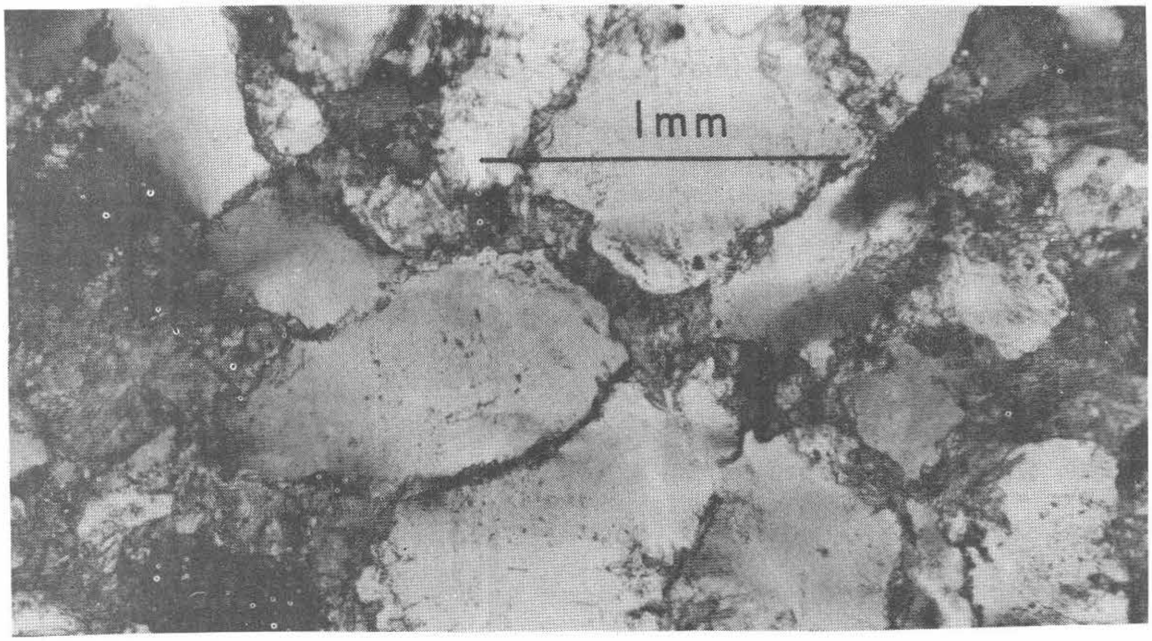


Fig. 2. Photomicrograph of clean quartz sandstone from stop #5. Note grain contacts. In the western part of the Taconic Sequence, similar rocks have frosted and very well rounded grains. As one may infer the same diagenesis for the similar rocks, the difference in grain contacts now is related to deformation and metamorphism.

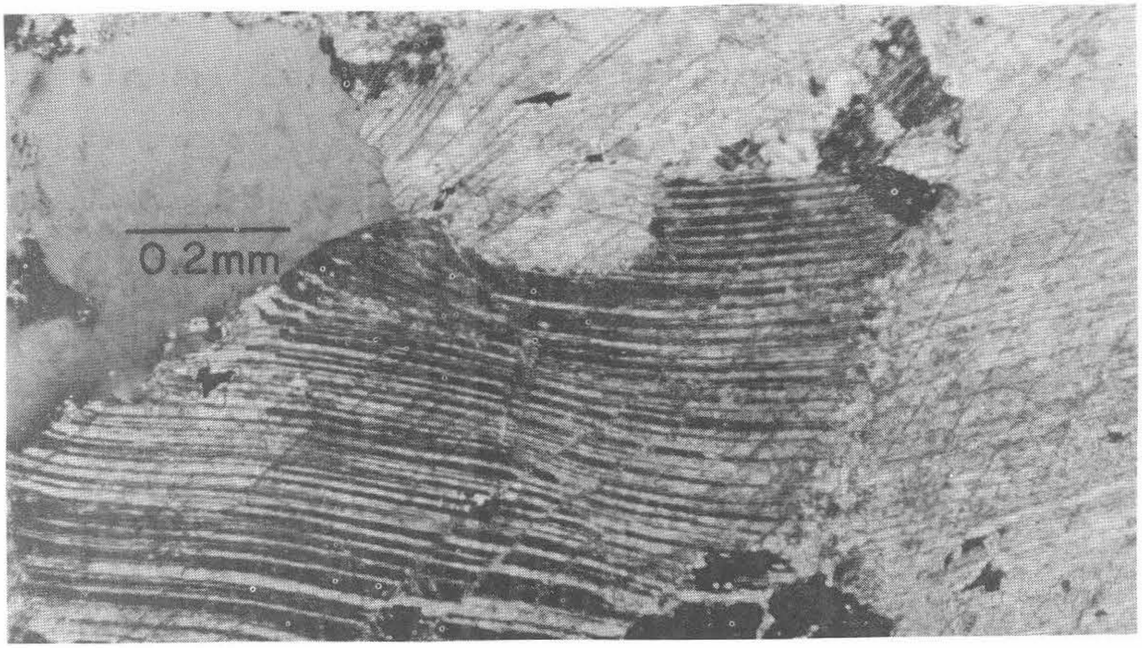


Fig. 3. Photomicrograph of clean quartz sandstone from stop #5. Curved and offset twin lamellae in calcite vein. Clearly the deformation has not been simple, for some quartz veins seem to cut calcite veins.

ideal rock to see mica beards, etc., as shown by Means (1975, Fig. 1).

STOP #6. Across from 1852 covered bridge over Battenkill in Vermont 2.4 miles east of N.Y.-Vt. border and 4.4 miles east of stop 5. Re-enter bus after 1 hour.

These carbonates are so-to-speak out from under the east side of the Taconic rocks we have been looking at between here and Bald Mountain (stop 1). As we have moved east and southeast across the Taconic Sequence, the metamorphism has increased, as was clear at the last stop. How does this affect the carbonates? Things to look at here include the following:

a. Crinoid stems in coarse beds. Although the crinoid is dead, the ossicle is in good condition.

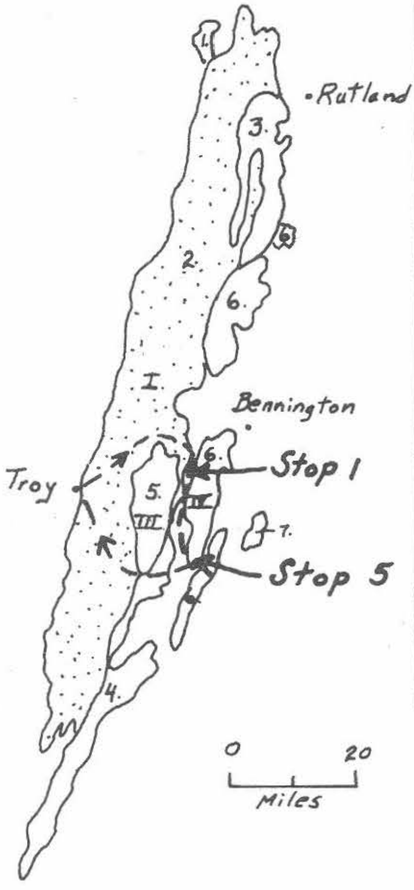
b. Some calcite layers look schistose. Are these beds?

c. The difference in ductility between different layers is apparent.

d. Where are the stylolites in these strongly deformed rocks? Or are there just no insoluble residues?

e. Near the west end of the outcrop folded layers have fanning "cleavage" but the feature that is fanning has calcite fibers.

f. Some curved veins have fibers. Did the fibers survive folding, or did the fibers form after the folding of the veins, or did the veins from with their present curvature? This would seem to imply that the fibers are related to something different from compressional dissolution cleavage fanning the fold.



Thrust sheets of the central Taconic region - This report (in order of relative age of emplacement, oldest at bottom)	Zen's (1967) thrust slices
	7. Greylock slice
IV Berlin Mountain sheet	6. Dorset Mountain slice
III Rensselaer Plateau sheet	5. Rensselaer Plateau slice
II Butternut Hill slices (too small to plot)	4. Chatham slice
	3. Bird Mountain slice
I. Giddings Brook sheet	2. Giddings Brook slice
	1. Sunset Lake slice

Figure 1. Field trip route, and thrust sheets of the Taconic allochthon.

Thrust Sheets of the Central Taconic Region

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INTRODUCTION

This field trip is based on mapping in the Berlin, Hancock, and Williamstown Quadrangles during the summers of 1976, 77, and 78. This work was done for the U. S. G. S. and in conjunction with Nicholas M. Ratcliffe in preparation for the new geologic map of Massachusetts. The field trip concentrates on key exposures in the valleys of the Hoosic and Little Hoosic Rivers. In addition to the recent field mapping, the author has made some important reinterpretations of faults mapped earlier (Potter, 1972) in the Hoosick Falls area.

Three major thrust sheets and a group of minor thrust slices are recognized in the central Taconic region. Their relative age of emplacement (oldest at bottom), correlation with previously named thrust sheets, and probable times of deformation are as follows:

Former designations (Potter, 1972)	Present designation	Stages of deformation
Not recognized as separate sheet	IV. Berlin Mountain thrust sheet	F_3
Rensselaer Plateau thrust sheet	III. Rensselaer Plateau thrust sheet	F_2
Not named	II. Butternut Hill thrust slices	
North Petersburg thrust sheet	I. Giddings Brook thrust sheet	F_1

Figure 1 shows the field trip route and the thrust slices of the Taconic allochthon. Alas, Zen's (1967) interpretation bears close resemblance to the author's present interpretation in the central Taconic region (Figures 1. and 2.).

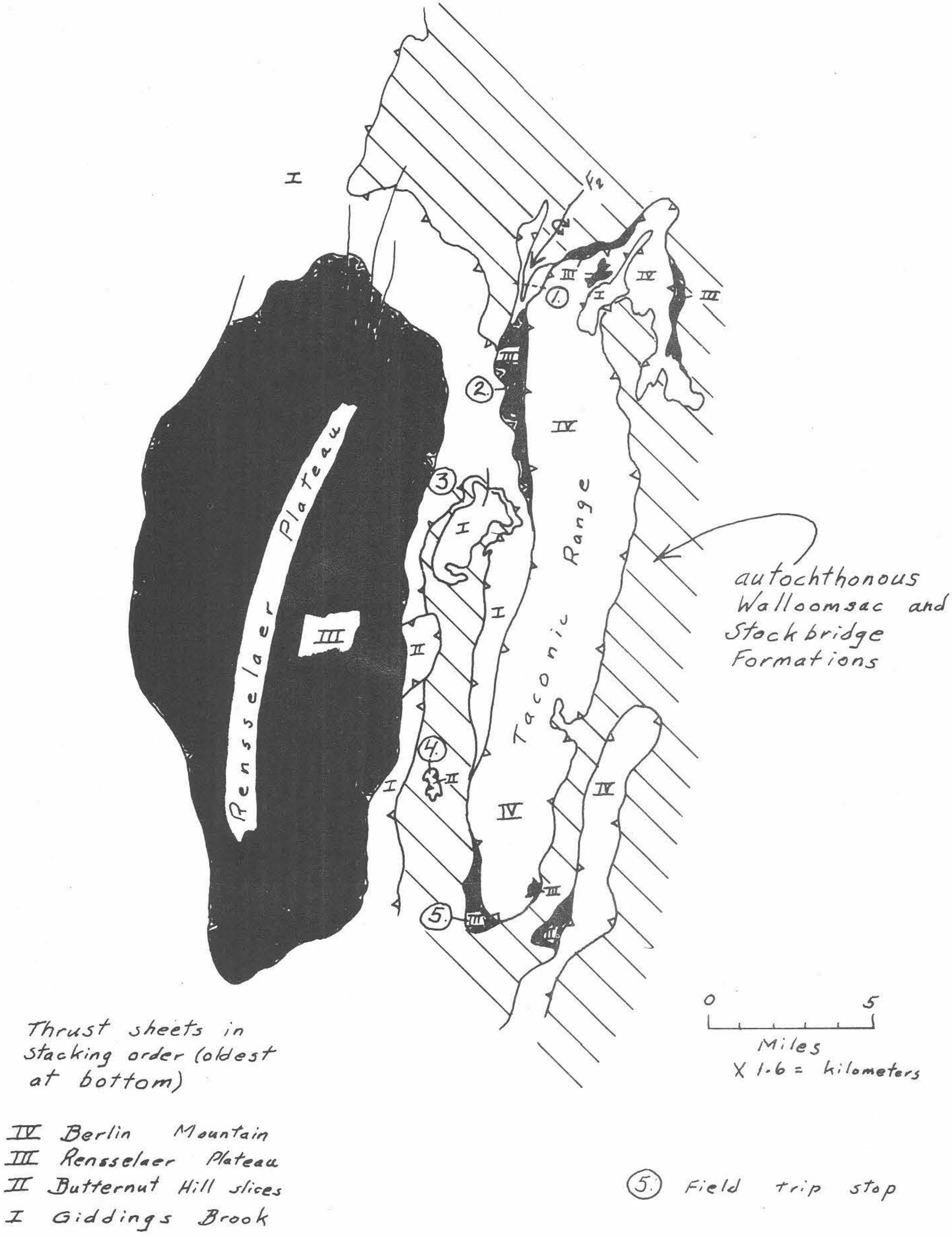


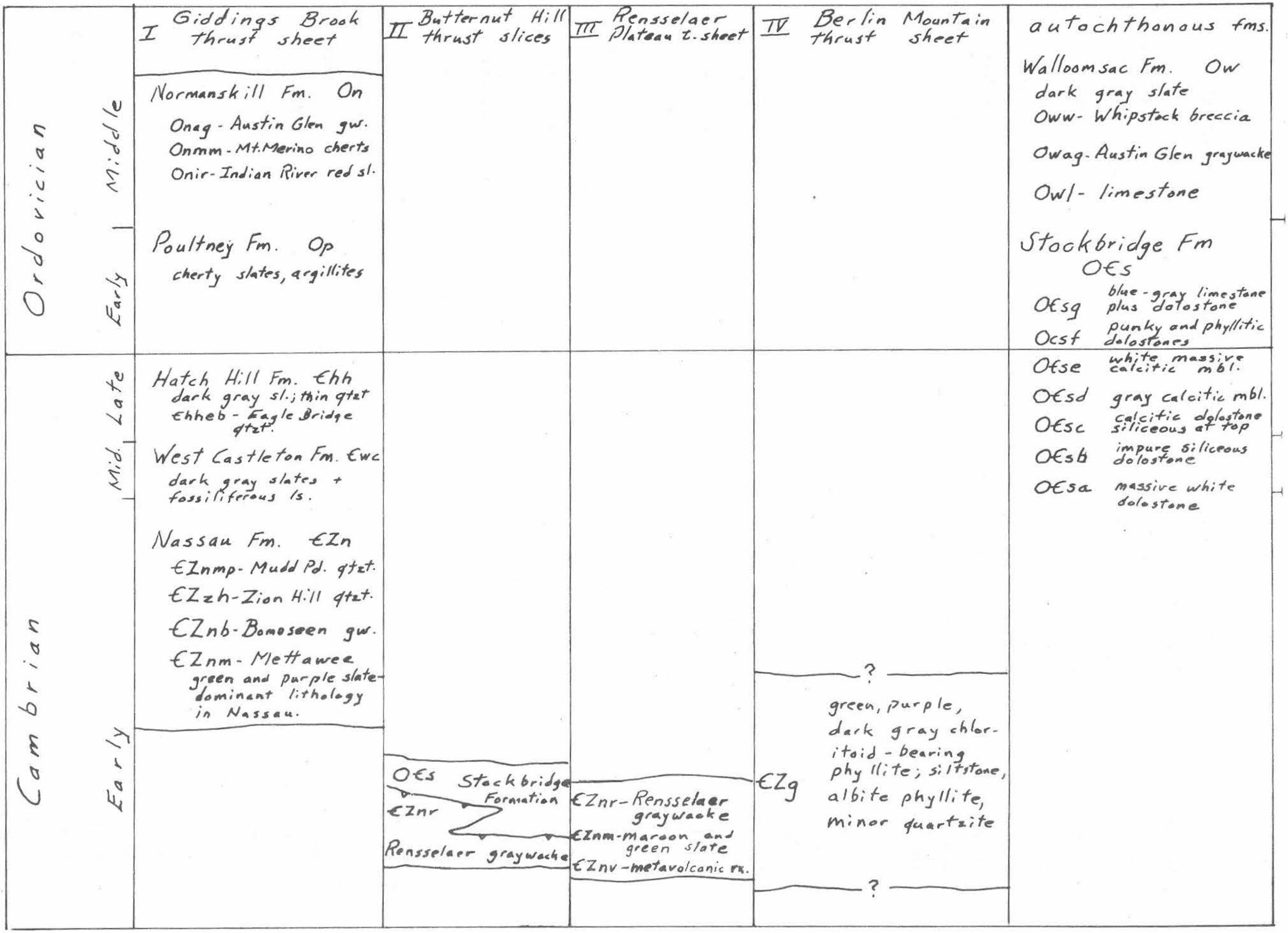
Figure 2. Tectonic sketch map, central Taconic region

I. The Giddings Brook thrust sheet, a name from the northern Taconics and worthy of perpetuating in the central Taconic region, consists of very distinctive stratigraphic units (Figure 3.) several of which are fossiliferous. The dominant thrust sheet in the Taconic allochthon, it was emplaced in Mid-Ordovician time as a gravity slide. Beneath it in the central Taconic region is Mid-Ordovician Walloomsac slate with its Whipstock Breccia member, a wildflysch type of block and shale unit. The Giddings Brook thrust fault is recumbently folded, and the internal structure of the sheet itself is commonly that of a major recumbent anticline opening east with youngest formations at the base of the sheet.

II. The Butternut Hill thrust slices are small lenticular masses consisting of limestones and dolostones of the Stockbridge Formation with infaulted lenses of Rennselaer Graywacke. Near Berlin Village one of these slices truncates the trace of the Giddings Brook thrust fault and is, itself, truncated by the trace of the Rensselaer Plateau thrust fault. The Butternut Hill slices are envisioned as hard dry slices of rock dragged along the base of the advancing Rensselaer Plateau thrust sheet.

III. The Rensselaer Plateau thrust sheet consists dominantly of Rensselaer Graywacke with interbeds of maroon and green-gray slate. Near its base the Rensselaer sheet contains metavolcanic rocks. The position of the Rensselaer Plateau sheet structurally above the Giddings Brook is clearly indicated by numerous excellent exposures many of which have limestone or dolostone slices (Stockbridge Formation) at the thrust contact. This relationship is seen at Stop 2.

IV. Berlin Mountain thrust sheet. This name is given for the greenish and purple chloritoid-bearing slates and phyllites with few distinctive marker beds that make up the bulk of the Taconic Range. Berlin Mountain is a major crest in this range. That this is a separate thrust sheet is suggested by the following evidence: north of the Hoosic River (Stop 1) the chloritoid phyllites in question are separated from distinctive formations of the Giddings Brook thrust sheet by slices and slivers of Stockbridge carbonate rocks. The Giddings Brook sheet is isoclinally folded (F_2) with the Rensselaer Plateau sheet and both lie beneath the Berlin Mountain thrust fault. Also, the position of the Rensselaer Graywacke in the Taconic Range (Figure 2.) casts doubt on an earlier working hypothesis in this region which states that the



		I Giddings Brook thrust sheet	II Butternut Hill thrust slices	III Rensselaer Plateau t. sheet	IV Berlin Mountain thrust sheet	autochthonous fms.
Ordovician	Middle	Normanskill Fm. On Onag - Austin Glen gw. Onmm - Mt.Merino cherts Onir - Indian River red sl.				Walloomsac Fm. Ow dark gray slate Oww - Whipstock breccia Owag - Austin Glen graywacke Owl - limestone
	Early	Poultney Fm. Op cherty slates, argillites				Stockbridge Fm OЄs OЄsg blue-gray limestone plus dolostone Ocsf punky and phyllitic dolostones
Cambrian	Late	Hatch Hill Fm. Єhh dark gray sl.; thin qtzt Єhheb - Eagle Bridge qtzt.				OЄse white massive calcitic mbl. OЄsd gray calcitic mbl. OЄsc calcitic dolostone siliceous at top
	Mid.	West Castleton Fm. Єwc dark gray slates + fossiliferous ls.				OЄsb impure siliceous dolostone
	Early	Nassau Fm. ЄZn ЄZnmp - Mudd Pd. qtzt. ЄZzh - Zion Hill qtzt. ЄZnb - Bomoseen gw. ЄZnm - Mettawee green and purple slate - dominant lithology in Nassau.	OЄs Stockbridge Formation ЄZnr Rensselaer graywacke	ЄZnr - Rensselaer graywacke ЄZnm - maroon and green slate ЄZnv - metavolcanic rk.	? ЄZg green, purple, dark gray chloritoid-bearing phyllite; siltstone, albite phyllite, minor quartzite ?	OЄsa massive white dolostone

Figure 3. Stratigraphy of thrust sheets and autochthonous formations

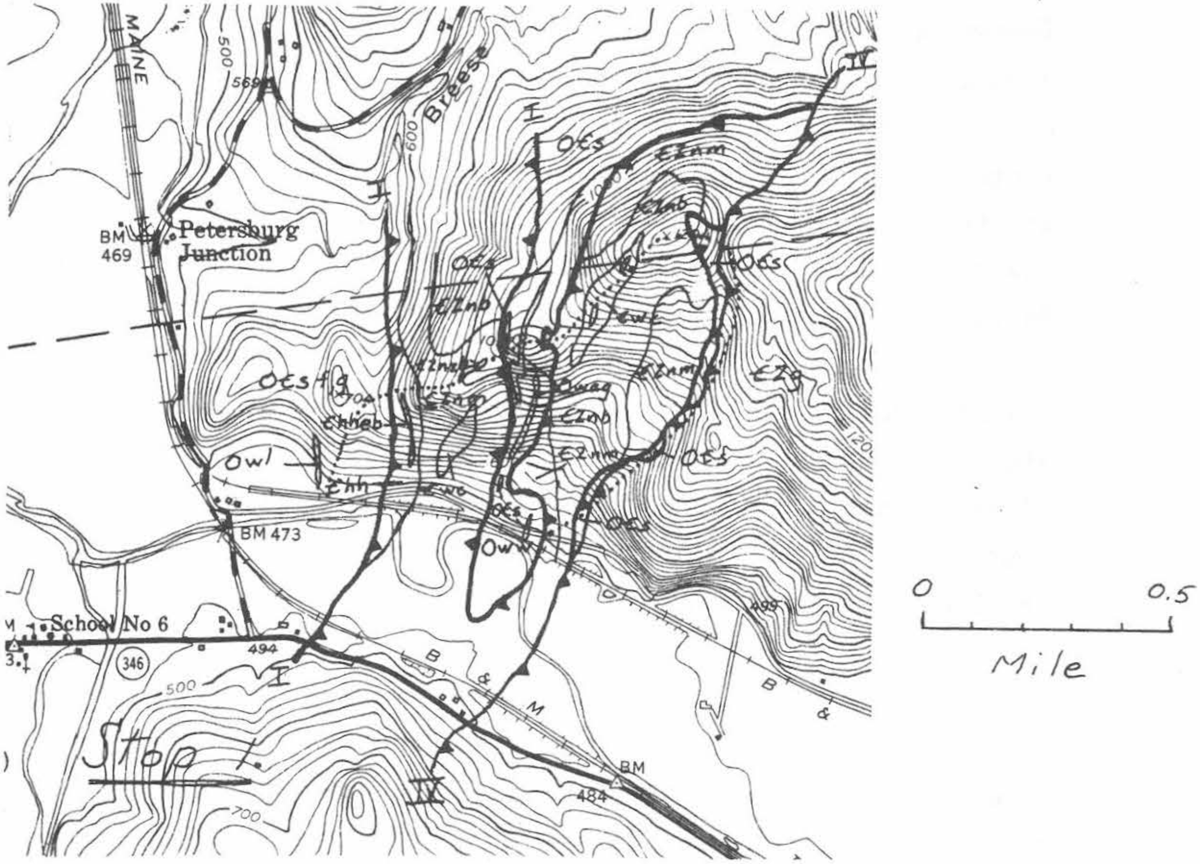
Rensselaer Graywacke was a basal stratigraphic unit in the thrust sheet that formed the range. The graywacke is seen to be limited to the north and south ends of the range and does not occur along the east or west edges nor in the center. Had that Rensselaer Graywacke been present as a stratigraphic unit at the base of the chloritoid phyllites it seems highly likely that it would now be found infolded with them. An alternate hypothesis is proposed: the Rensselaer Graywacke in the Taconic Range belongs to the Rensselaer Plateau thrust sheet; over the top of this was emplaced sheet IV, Berlin Mountain thrust sheet. Both sheets were subsequently cupped into a broad F_3 synform whose axis trends northwest - southeast. Subsequent erosion has exposed the older, Rensselaer Plateau thrust sheet, albeit patchily, at the north and south noses of the synform. Elsewhere the Rensselaer sheet is covered by the Berlin Mountain (IV) thrust sheet.

At least three stages of deformation are recorded. Initial large and small scale recumbent folding (F_1) occurred during the emplacement of the Giddings Brook sheet; the axial plane cleavage (S_1) that formed at this time has been subsequently rotated to a moderately steep southeast dip and has generally been overwhelmed by the development of a pronounced slip cleavage (S_2). This slip cleavage is co-planar with the axial planes of F_2 folds, isoclinal to asymmetrical with axial planes dipping east or southeast. F_2 folds are seen in the outcrop pattern at Stop 3; and a large south-plunging isoclinal anticline involving the Giddings Brook and Rensselaer Plateau thrust sheets is interpreted to be an F_2 fold at Stop 1. F_3 folds have northwest-trending axes. At Stop 3 they bring to the present surface the south-plunging Giddings Brook thrust fault and account for the northwest-southeast outcrop pattern superposed on a large F_1 recumbent fold there; also, F_3 folding accounts for a major fishhook pattern on the east side of the Taconic Range. The doubly plunging synform of the Berlin Mountain and Rensselaer Plateau thrust sheets in the Taconic Range probably is an F_3 fold, and the Hoosick Falls embayment (west of Bennington, Figure 1.) is probably produced by erosion of an F_3 anticlinal warp.

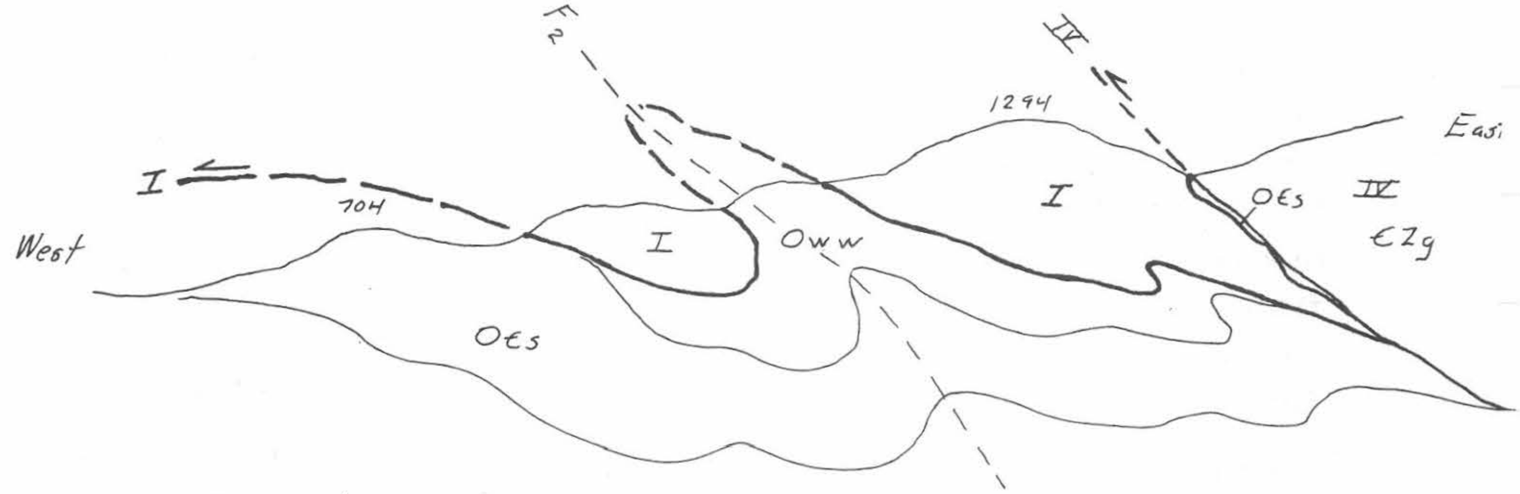
ROAD INFORMATION (Troy to North Petersburg Rts. 7 and 22)

From the RPI campus we will take Route 7 northeast across the Giddings Brook thrust sheet and gain some appreciation of the glacial drift in this

Stop 1.



North Powнal 7½' Quad.



Schematic structure section along ridge crest (route of Stop 1 traverse) from elevation point 704 to 1294. See Figure 3 for stratigraphy. Thrust faults and thrust sheets numbered according to Figure 2.

I - Giddings Brook thrust sheet
IV - Berlin Mountain thrust sheet
.... traverse route

part of the Taconics. About 8 1/2 miles out we see the bold escarpment of the Rensselaer Plateau to the east. The base of this escarpment marks the trace of the Rensselaer Plateau thrust fault and the rocks of the plateau comprise the thrust sheet of that name. Our route continues on the Giddings Brook thrust sheet and skirts around the north end of the Rensselaer Plateau. After passing over Potter Hill and signs that direct one south to Babcock Lake, we start to descend into Shingle Hollow. We are now traversing across younger formations on the inverted limb of the recumbent nappe that makes up the Giddings Brook thrust sheet. The major formation in the hollow is the Bomoseen Graywacke. We cross the Giddings Brook thrust fault at a bend in the road where there is a picnic area, so that when we reach the intersection of Route 22 we are about 0.4 mile into the autochthonous formations. We turn right (south) on Route 22 and traverse across Walloomsac and Stockbridge Formations to North Petersburg, with the trace of the Giddings Brook thrust at the base of the steep hills on our right. The Giddings Brook thrust sheet on the steep slopes displays spectacular large recumbent folds, first recognized by Prindle and Knopf (1932).

ROAD LOG

00.0 North Petersburg, intersection of Routes 22 and 346; go east on 346;
00.5 turn left (north) on Green Road, cross B&M railway and Hoosic River;
00.8 turn sharp right 200 feet north of river and follow river road east for 0.3 mile; cross rail spur and PARK HERE to start a round trip traverse two miles in length with a climb of 800 feet.

STOP-1. The aim of this traverse is to demonstrate the anticlinally folded Giddings Brook (I) thrust sheet with Stockbridge Formation beneath the thrust fault to the west, and chloritoid schists of the Berlin Mountain (IV) thrust sheet above the Giddings Brook to the east. The latter contact is marked by long slivers of limestones and dolostones (Stockbridge Formation). A large F_2 anticline is indicated by the exposure, half-way through this traverse, of autochthonous formations - Whipstock Breccia and Austin Glen Graywacke members of the Walloomsac - beneath the folded Giddings Brook thrust fault.

In the fields above the parking location are limestones and dolostones of the Stockbridge Formation (probably units F and G). One layer in this sequence yields early Ordovician brachiopods. Other layers in these fields carry Post-Canadian brachiopods, ostracods, trilobites, bryozoa and are mapped as Walloomsac limestone (Owl).

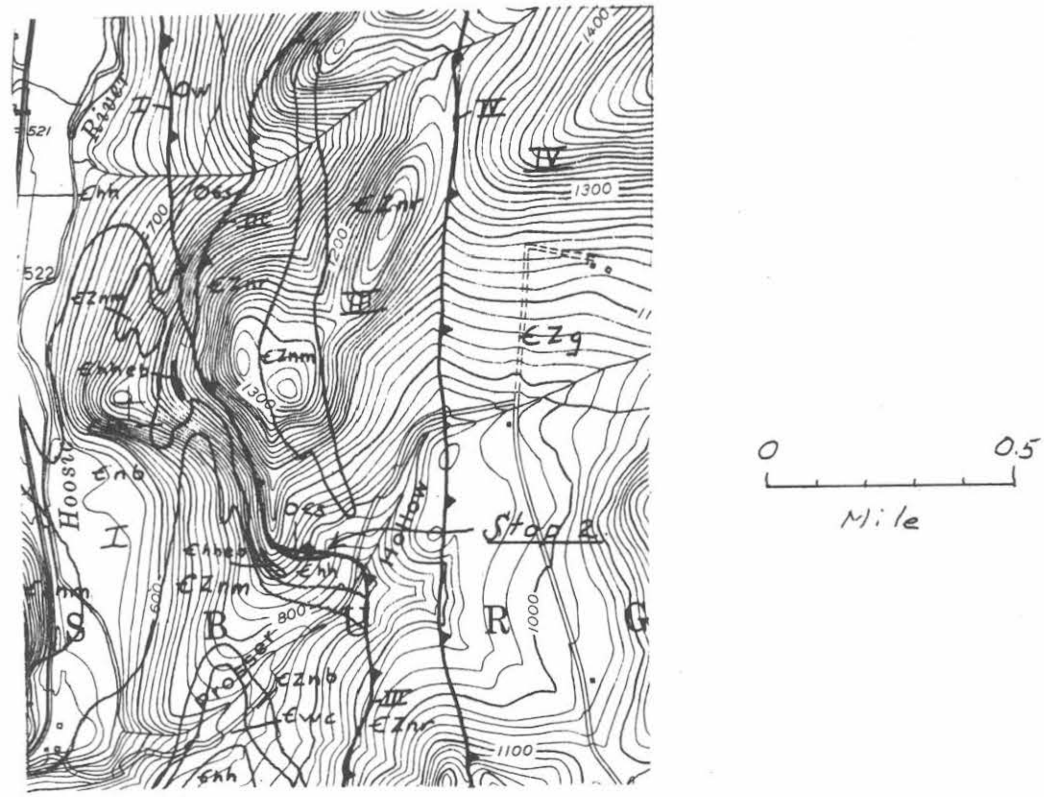
Crossing the Giddings Brook Thrust Fault at the saddle, we encounter various formations of the G. B. thrust sheet: medium-light gray, some dolomitic slates (Poultney); dark gray and black slates (Hatch Hill) enclosing the Eagle Bridge Quartzite; green-gray slate (Mettawee) and Zion Hill Quartzite. At the 1027 crest we cross the Giddings Brook thrust and see autochthonous rocks of the Walloomsac Formation. The dominant lithology here is the Whipstock Breccia, a dark gray slaty rock crowded with rusty and white-weathering chips of siltstone and sandstone. The Whipstock encloses lenses of sheared limestone and dolostone (Stockbridge Fm.) and lenses and beds of Austin Glen Graywacke. The Whipstock is interpreted to be a submarine slide breccia facies of the Walloomsac, deposited in front of the advancing Giddings Brook thrust sheet and containing blocks and lenses of the Taconic Sequence as well as of the Stockbridge Formation and the co-deposited Austin Glen Graywacke.

From crest 1027 to crest 1294 we cross the Giddings Brook thrust again and then traverse across variably foliated olive-weathering siltstone (Bomoseen), and dark gray slates containing limestone lenses (West Castleton); east of crest 1294 we encounter a large sliver (2000 feet long and up to 200 hundred feet wide) of sheared limestones and dolostones (Stockbridge Formation) which marks the sole of the highest thrust sheet (Berlin Mountain (IV) Thrust Sheet). The dominant lithology of the Berlin Mountain sheet is green and purple chloritoid schist, with coarsest chloritoid commonly near the thrust fault.

Return to parking area by traversing along the trace of the Berlin Mountain thrust sheet marked by slivers of carbonate rocks. Retrace route to North Petersburg.

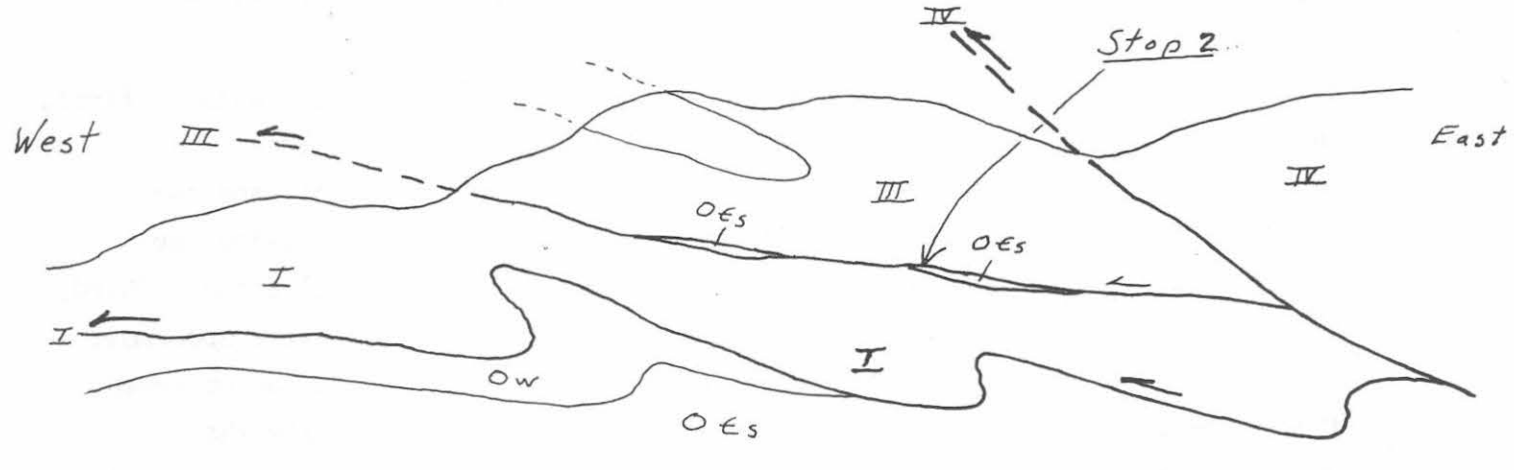
00.0	Intersection of Routes 346 and 22 at North Petersburg. Turn left (south) on Route 22.
00.6 - 00.8	Large exposures of recumbently folded Stockbridge (unit G) and Walloomsac limestone on right (west) side of highway.

Stop 2.



North Pownal 7½' Quadrangle

See Figure 3 for stratigraphy. Thrust faults and thrust sheets as in Figure 2. I - Giddings Brook, III - Rensselaer Plateau, IV - Berlin Mountain.



Schematic structure section at Stop 2.

01.5	Cross trace of (Giddings Brook) thrust fault, and proceed south on Taconic Sequence formations near base of G. B. thrust sheet.
01.6	Barn on east side highway, house on west. Bold cliffs on Taconic Mountains to east are Rensselaer Graywacke near base of Rensselaer Plateau thrust sheet.
02.3	Bomoseen Graywacke on right side of highway.
02.4 - 02.9	Massive exposures of Mettawee slate on west side of highway. These slates are at the core of the Giddings Brook nappe.
02.9	Junction of Prosser Hollow Road and Route 22; turn left (east) on Prosser Hollow Road.
03.1	Cross Little Hoosic River.
03.8	Woods Road to left. Unload for STOP-2. Walk up to spur for exposure of Rensselaer Plateau thrust fault.

STOP-2. Exposure of the Rensselaer Plateau thrust fault north of Prosser Hollow. Below the thrust fault is an apparently normal sequence of Bomoseen, Mettawee, and Hatch Hill (with Eagle Bridge Quartzite) - all part of the Giddings Brook thrust sheet. The Rensselaer Plateau (III) thrust fault is marked by slivers of limestone and dolostone (Stockbridge Formation) that have been tectonically dragged to their present positions. Immediately above the Rensselaer Plateau thrust is the Rensselaer Graywacke, perhaps several hundreds of feet thick and intensely sheared. The Graywacke is faulted against chloritoid schist 0.3 miles east of this stop, at the trace of the Berlin Mountain thrust fault.

The following details of the Rensselaer Plateau fault zone are noted. First, the Rensselaer Graywacke above the thrust is mylonitic through a zone approximately 150 feet thick (measured perpendicular to foliation), and the mylonitic foliation is concordant with normal foliation above and below the thrust zone. Second, the thrust plane truncates the mylonitic foliation. Third, a well-developed foliation parallel to the thrust plane occurs in the uppermost 2-3 feet of the limestone. Numerous other structural features may be observed. Widely spaced fractures, parallel to the thrust plane, also truncate the foliation and show a similar sense of movement to that on the thrust. Several warps in the thrust plane apparently represent areas where (later) movement on the thrust has locally followed the foliation instead of cutting across it.

Near the upper (western) end of the outcrop, a sliver of mylonitic graywacke about 5' x 5' is completely enclosed within the limestone. West of this, the thrust plane steepens and follows the trend of the foliation in the graywacke for an indefinite distance.

The earliest structural event well-represented at this stop is the formation of the pervasive axial plane foliation, S_2, and the accompanying regional metamorphism. Emplacement of the graywacke along the Rensselaer Plateau Thrust may have occurred prior to the formation of S_2. Evidence for this is the occurrence in several places along the thrust of tectonic slivers of autochthonous carbonates around which S_2 has been refracted.

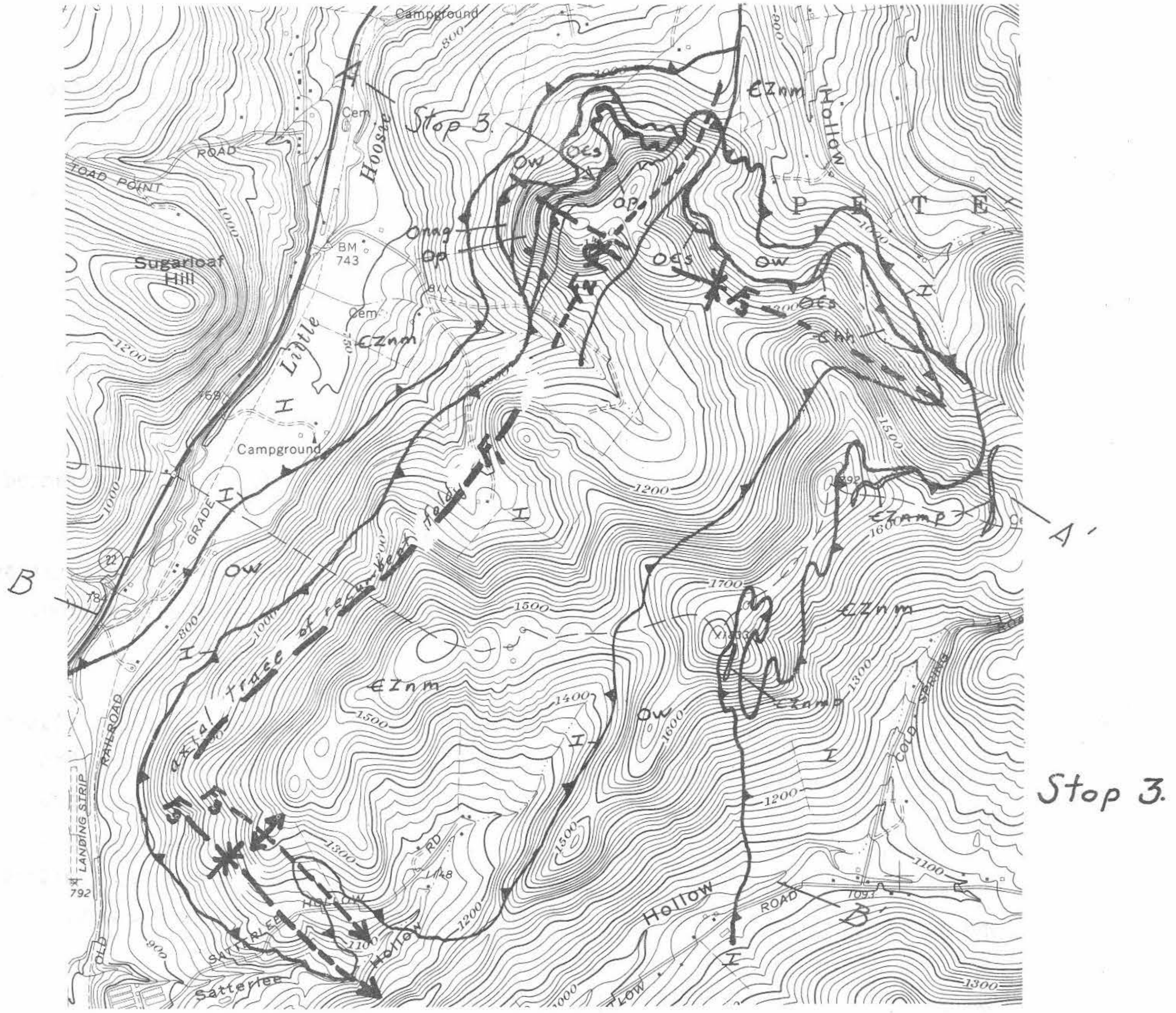
The mylonites either were pre S_2 and rotated into their present orientation during the formation of S_2, or else formed at the same time as the foliation. The latter explanation is preferred.

Following S_2, minor movement occurred between the Graywacke and the slates beneath. This movement caused the presently observed thrust plane, the thin zone of well-developed foliation in the upper few feet of the limestone, and the low angle fractures in the rocks immediately above and below the thrust. Perhaps we are seeing the results of a stick/slide phenomena of thrust faulting and not desrete periods of foliation formation followed by minor movement.

Return via Prosser Hollow Road to Route 22.

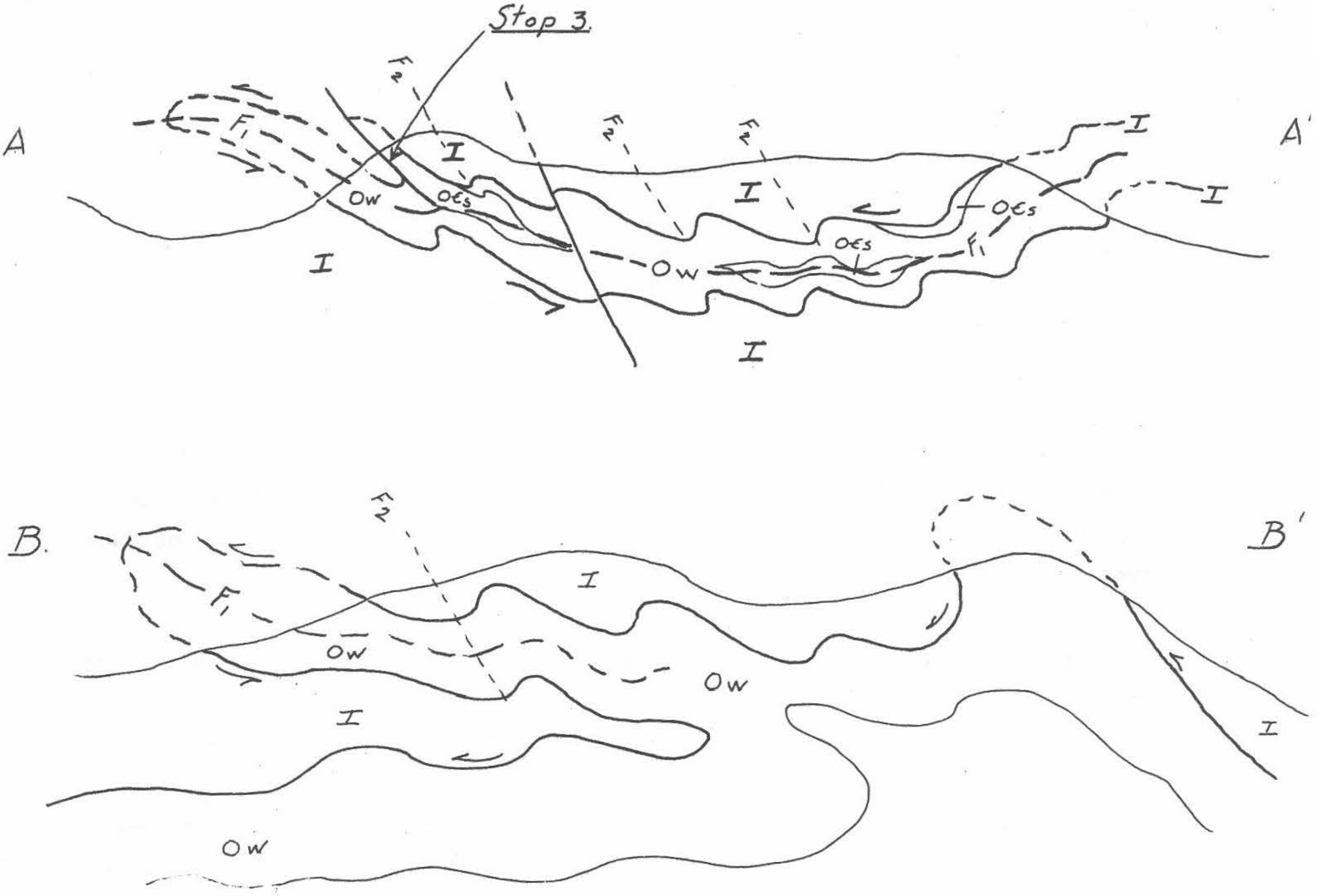
04.7 Intersection of Prosser Hollow Road and Route 22. Bomoseen and Mattawee members on west side of Route 22. Turn left (south) on 22.

From here to Petersburg we are in the lower part of the Giddings Brook thrust sheet which has a recumbent anticline structure. Formations exposed in the channel of the Little Hoosic, or near road level, are typically younger formations of the Taconic Sequence on the inverted limb of the recumbent anticline; higher on the east and west slopes of the Little Hoosick Valley are older formations of the nappe, and above these is the Rensselaer Plateau thrust sheet.



Berlin 7½' Quadrangle

Stop 3. See Figure 3 for stratigraphy.
I - Giddings Brook thrust fault and thrust sheet.



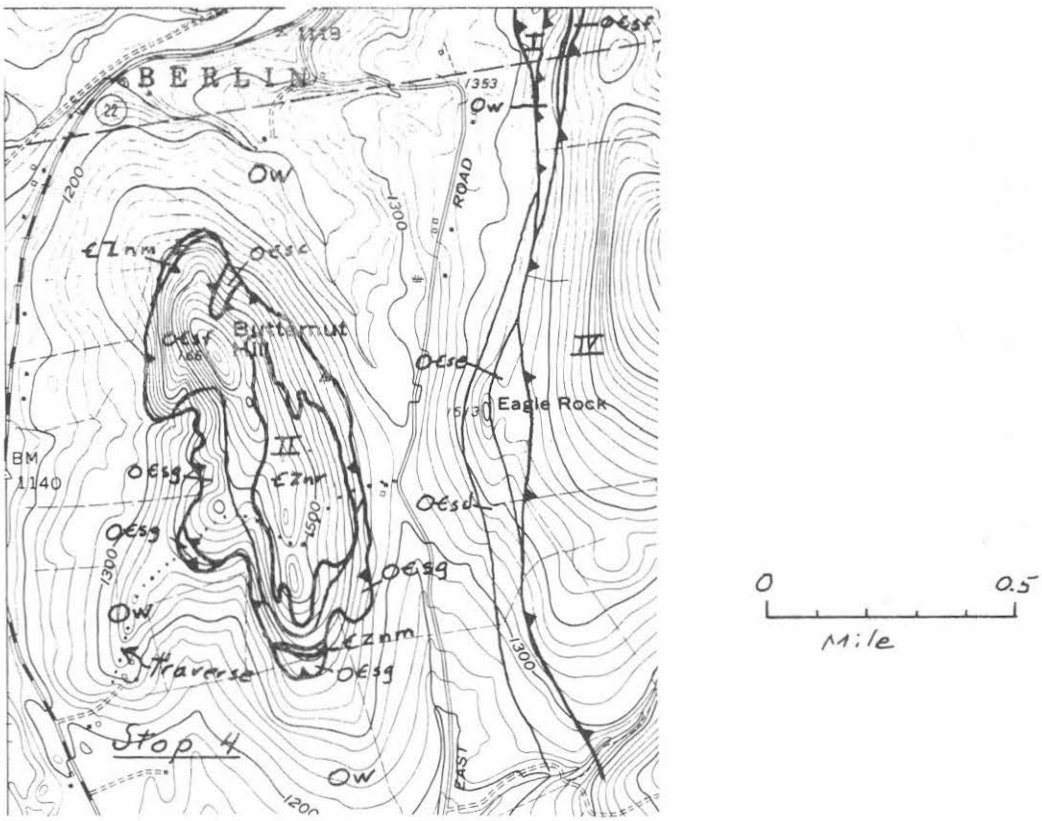
Schematic structure sections across Jones Hollow - Satterlee Hollow refolded recumbent (Stop 3)

06.3 - 06.5	Mettawee on right.
06.6 - 06.8	Mettawee on right.
07.1	Intersection of Routes 2 and 22; turn left (east) just before overpass and proceed through downtown Petersburg.
07.5	After crossing bridge over Little Hoosic River, turn right on Town Road leading to Jones Hollow.
07.7	Jones Hollow Road goes left; keep straight.
08.0	Bear left at intersection and proceed uphill on residential dirt road 0.7 miles park near log house.

STOP-3. Jones Hollow-Satterlee Hollow refolded recumbent. The southward plunge of the Giddings Brook thrust is interupted here by F_3 cross-folds bringing the sole of the Giddings Brook thrust and underlying Walloomsac to the surface. Walloomsac floors the valley of the Little Hoosic River southward from this point.

The JH-SH recumbent covers an area about two miles long and one mile wide. Its outcrop pattern and small scale structures indicate three stages of deformation. The core of the large recumbent fold is marked by Walloomsac slate, and by Stockbridge units F and G.; its upper limb consists of slates of the Mettawee and Poultney formations; its lower limb consists of Mettawee slates, Mudd Pond Quartzite, Hatch Hill Formation. The stages of deformation can best be understood by referring to the map pattern and section. On the map the upper limb has the pattern of a 2 mile-long ram charging northeast. The ram's back gives the northeast trace of the axis of the recumbent fold (F_1); the axial plane cleavage (S_1) associated with this recumbent fold has been rotated from its presumed low angle of dip and it is not as easily seen as is S_2. The second stage of deformation resulted in a northeast - striking slip cleavage (S_2) which dips 35-50 degrees southeast and is co-planar with axial planes of F_2 folds. The ram's head and chest are produced by F_2 folds and the northeast - trending fault that truncates the ram's nose is parallel to S_2. Northwest - trending F_3 folds form the pointed foreleg and the ram's tail.

Stop 4.



Hancock 7½' Quadrangle

Stop 4. Butternut Hill thrust slice. See Figure 3 for stratigraphy. See Figure 2 for thrust slices. I - Giddings Brook, II,- Butternut Hill, IV - Berlin Mountain

We will visit outcrops of Walloomsac and Stockbridge units F and G in the core of the recumbent fold, and the Poultney and Mettawee formations on the upper limb. Of particular interest are the long splinters of Poultney slate formed by S_1-S_2 intersection.

Return to Route 22 via Petersburg

09.6	Overpass of Route 2 over Route 22. Turn left (south). Jones Hollow-Satterlee Hollow recumbent forms prominent hills at 10-11:00 o'clock.
10.0 - 10.4	Outcrops on both sides of road of green Mettawee slate
11.5	Mettawee slate on right in woods. Outcrops above this on east slope on Sugarloaf Hill show pronounced development of S_1 and S_2 cleavages.
12.0 - 12.1	Mettawee slate on right.
12.3	Mettawee slate on right.
14.3	Berlin - Taconic Valley Bank on left, sign to sheriff's office on right.
15.2 - 15.5	On the right (west) side of road, large outcrops of Stockbridge limestones and dolostones (units D and E) which are part of the Butternut Hill thrust slice.
16.7	Little Hoosic River at center Berlin.
17.5	Berlin Lumber Co., Inc.
18.6	Cherry Plain Rd. on left.
19.1	Derby Lane on left.
19.4	Walloomsac slate on right.
19.8 20.1	Walloomsac slate on left.
21.1	Walloomsac slate on both sides of road; turn left (east) off Route 22 on residential Road.

STOP-4. Butternut Hill. We will traverse 3/4 mile east over the top of Butternut Hill to East Road where we will be picked up by busses.

The purpose of this stop is to see one of the smaller thrust slices in this part of the Taconic allochthon: the Butternut Hill (II) thrust slice. The age of its emplacement relative to other thrust sheets cannot be demonstrated here for it is simply floating in Walloomsac. However, one-half mile south of the village of Berlin, an identical thrust slice cuts the trace of the Giddings Brook thrust fault and is, itself, truncated by the Rensselaer thrust fault, thus establishing the Butternut Hill slice as number II in a series of IV sheets or slices.

The Butternut Hill slices (they are not connected) consist of various members of the Stockbridge Formation with in-faulted Rensselaer Graywacke. This distinctive combination of autochthonous carbonate formations and massive allochthonous turbidite can be found as scores of slices ranging from 2 miles^2 in area (Berlin Village locality) down to slices a few a few feet in length. The slices are generally tucked up under the Rensselaer Plateau thrust fault and may simply represent slabs of Stockbridge carbonate formations into which the Rensselaer Graywacke was neaded as the Rensselaer thrust sheet advanced. Some features of the Butternut Hill slices still remain a puzzle: Why wasn't Walloomsac drawn up with the Stockbridge in these slices? Why do we see only one lithology of the Taconic Sequence (Rensselaer Graywacke) in these slices?

Our traverse will take us across Walloomsac which displays S_1 and S_2 cleavages; a thin mylonite zone; units G and F of the Stockbridge; Rensselaer Graywacke and associated green phyllite.

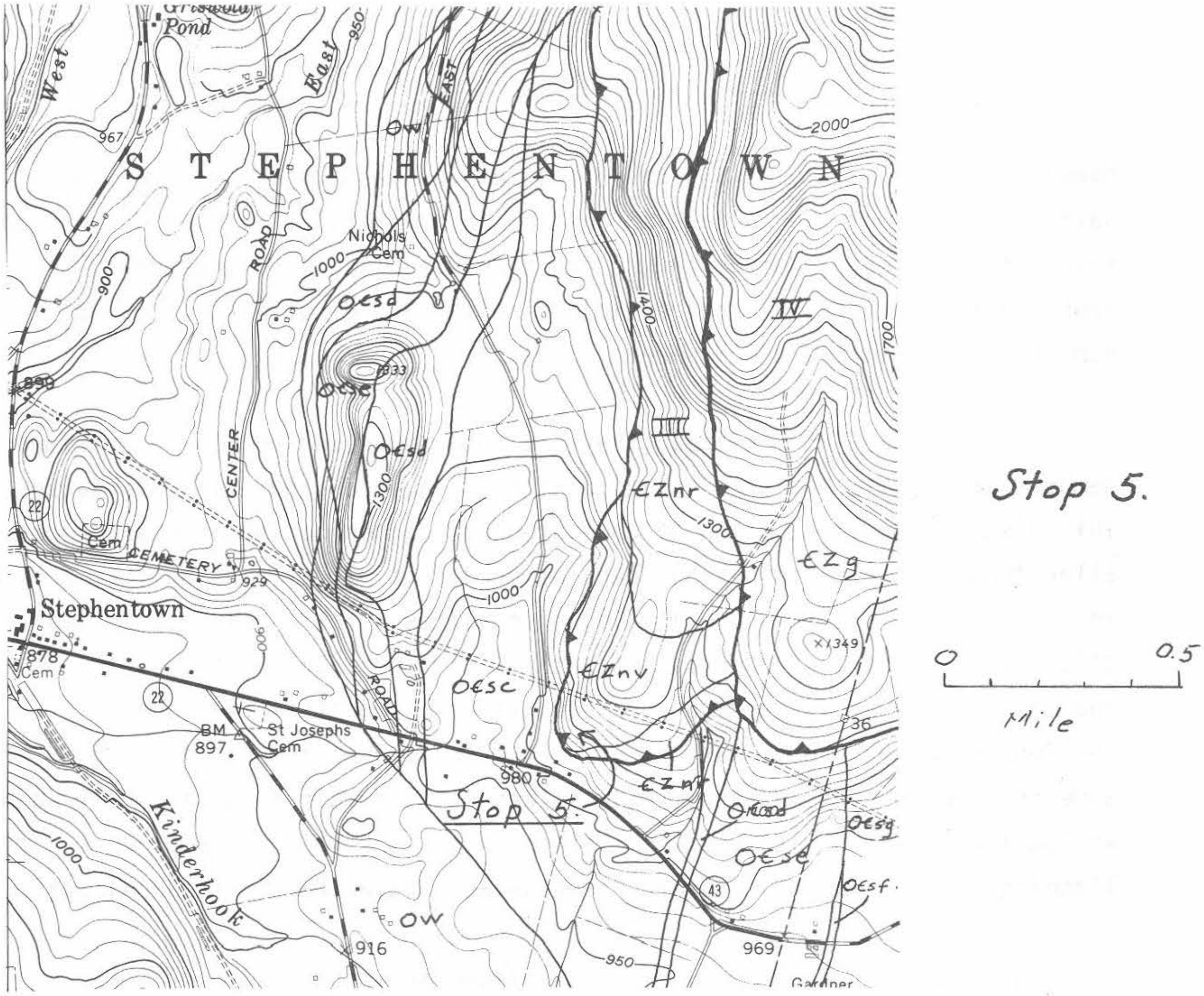
23.5 East Road, 0.2 mile southwest of Eagle Rock. Drive south on East Road to intersection with Giles Road.

24.4 Intersection of Giles Road and East Road. Drive south on East Road. Gentle slopes on your left (east) underlain by Walloomsac and Stockbridge formations; above these on the steep slopes is a thin wedge of the Rensselaer Plateau (III) thrust sheet and above that the Berlin Mountain (IV) thrust sheet.

26.2 Intersection with Jones Road, keep straight.

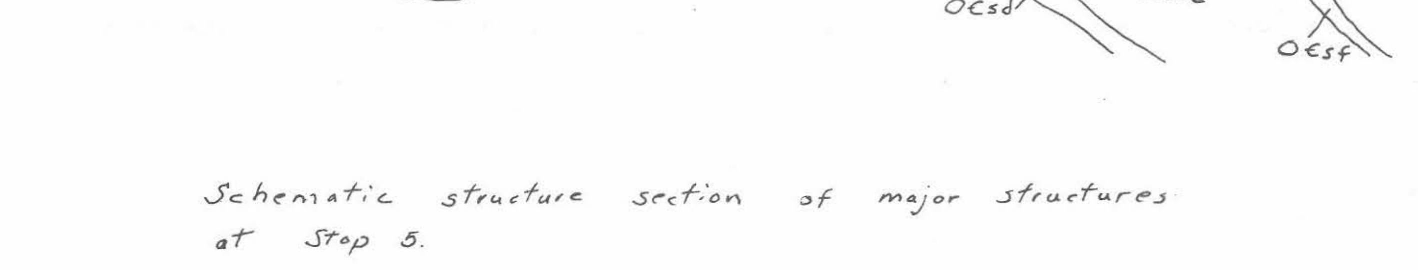
26.9 Stockbridge (unit D) thin platy gray limestone on left.

28.2 Turn left (east) about four hundred feet north of the intersection with Route 43.



Hancock 7½' Quadrangle

Stop 5. Metavolcanic rock and Rensselaer graywacke in Rensselaer Plateau thrust sheet (III). See Figure 3 for Stratigraphy. Figure 2 gives thrust sheets. IV is Berlin Mountain thrust sheet.



Schematic structure section of major structures at Stop 5.

STOP-5. Volcanic rocks and Rensselaer Graywacke at the base of the Rensselaer Plateau Thrust sheet.

Here, as at many localities along the east edge of the Rensselaer Plateau and to the southeast, the base of the Rensselaer Plateau thrust sheet is marked by a dark green hard metavolcanic unit rich in epidote and chlorite. At one locality within the graywacke terrain on the plateau a similar volcanic unit displays pillow structure. Elsewhere, as at the present locality, the metavolcanic rock appears banded to massive and is characteristically highly deformed. The parent rock was probably a mafic tuff or flow.

We will examine the outcrops of deformed metavolcanic rock and then traverse about 1/4 mile north to see the overlying Rensselaer Graywacke.

END OF TRIP

Return to Troy by going west on Route 43 to Route 66, then northwest on Route 66 to Troy.

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Prindle, L. M., and Knopf, E. B., 1932, Geology of the Taconic Quadrangle; Am. Jour. Sci., 5th Ser., v. 20, pp. 257-302.

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DETAILED STRATIGRAPHIC AND STRUCTURAL FEATURES OF THE GIDDINGS BROOK SLICE OF THE TACONIC ALLOCHTHON IN THE GRANVILLE AREA

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SUMMARY

The trip will visit localities in the "Giddings Brook Slice" of the lower Taconic allochthon in the vicinity of Middle Granville, New York. Eight localities will be visited, at each the stratigraphy and structure of the lower Taconic allochthon will be described and investigated in detail. Stratigraphically, the stops will emphasize our recognition of a more detailed stratigraphy than previously defined, specifically, the presence of two Cambrian black-green lithologic boundaries, abundant sedimentologic evidence for deep water North American continental rise depositional environment and the need for a Taconic reference section with well defined stratigraphy and known stratigraphic contacts. Structurally, the trips will focus on the nature of the continental rise sediments at the time of emplacement on the continental shelf and the nature of the deformation associated with emplacement. Particular emphasis will be placed on evidence suggesting that the low Taconics were emplaced as coherent tectonic slices and not as soupy soft sediment slides as all previous tectonic interpretations have suggested.

INTRODUCTION

The allochthonous, predominantly deep water argillaceous and subsidiary arenaceous and calcareous rocks of Cambrian(?), Cambrian to Middle Ordovician (Late Caradocian) age of the Taconic Allochthon crop out in an elongate belt approximately 200 km long, from the vicinity of Sudbury, Vermont to Poughkeepsie, New York. The Allochthon extends laterally 20-30 km and approximately parallels contiguous sections of the New York, Vermont, Massachusetts and Connecticut state borders. Taconic rocks, now primarily slates, commonly show evidence of at least two phases of deformation and have undergone low grade regional metamorphism (chlorite to biotite). Structurally, the Allochthon consists of a series of imbricate and partially nested thrust slices with complex internal deformation. Six major thrust slices are recognized in the Taconics by Zen (1967); they are, from structurally lowest (west) to highest (east), the Sunset Lake Slice, Giddings Brook Slice, Bird Mountain-Chatham Slice, Rensselaer Plateau Slice, Dorset Mountain-Everett Slice and Greylock Slice. See Figure 1a. In general, deformation and metamorphism increases from west to east within the Allochthon. The Taconic Allochthon tectonically overlies and is surrounded by an autochthonous to parautochthonous, coeval sequence of dominantly shallow marine carbonates and clastics of the

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Champlain Valley and Vermont Valley Sequences (Shumaker, 1967). Facies, thickness, sedimentary structures and paleontologic considerations suggest that the coeval carbonate-clastic and argillite-clastic sequences represent a carbonate shelf "starved" continental rise pair of the east-facing Atlantic-type North American continental margin during the Early Paleozoic (Bird and Dewey, 1970; Rodgers, 1968, 1970). The Taconic Allochthon was emplaced onto the carbonate shelf during the Middle Ordovician (Late Trenton-Caradocian) "Taconic" orogeny. A discussion of the "Taconic" orogeny will be deferred until later.

The field trip will be conducted through a part of the Giddings Brook Slice in the northern Taconics, near Granville, New York (Figure 1a). Recent detailed mapping in contiguous portions of the Granville, Thorn Hill, Wells and Poultney 7 1/2 minutes quadrangles (Figure 1b-d) by Jacobi (1977), D.B. Rowley (1979) and regional work by W.S.F. Kidd (1974-1979) while running the SUNY/Albany field course provide us with a more detailed stratigraphic (Figure 2) and structural picture of the northern Giddings Brook Slice than previously available. Our mapping, during more than ten months of field work, encompasses approximately 100 square kilometers, from the allochthon-autochthon boundary on the west to the approximate base of the Bird Mountain Thrust on the east. The map shown in Figure 1b is a compilation of outcrop maps done at a scale of 1:12,000 by Jacobi (1977) and Rowley (1979).

Previous mapping in this and adjacent areas by Dale (1889), Zen (Castleton 15 minutes Quadrangle, 1961, 1964a), Theokritoff (Granville and Thorn Hill 7 1/2 Quadrangles, 1964) and Shumaker (Western Portion of the Pawlet 15 minutes Quadrangle, 1960, 1967) and the work of Potter (Hoosick Falls 15 minutes Quadrangle, 1972) provided an initial stratigraphic and structural framework. The more paleontologically oriented work of Theokritoff (1964), Berry (1962) and others provided a time-stratigraphic framework with which to compare our lithostratigraphy. Our work has yielded a number of interesting stratigraphic and structural observations that have significant implications for Taconic litho- and time-stratigraphy and the emplacement history of the Taconic Allochthon. These implications will be detailed below.

The purpose of this field trip is three-fold:

(1) We will describe and examine a detailed conformable litho-stratigraphic section from basal Bomoseen wackes to upper Pawlet flysch. (We will also describe variations in litho-stratigraphy across the Giddings Brook Slice.) Attention will be focused on a) the presence of two Cambrian black-green lithologic boundaries; b) problems of litho- and time-stratigraphic correlations and c) possible depositional environment as indicated by composition and sedimentary structures.

(2) We will describe and examine both mesoscopic and macroscopic structural evidence that provide insight into the nature of the Giddings Brook Slice at the time of emplacement and structural complexities produced during allochthon emplacement.

(3) We will outline an actualistic plate tectonic corollary model for the evolution of the North American continental margin during the Early Paleozoic and the emplacement of the Taconic Allochthon. The implications of this model for the regional geology of western New England will be discussed during the field trip and in a separate paper (Rowley and Kidd, in prep.).

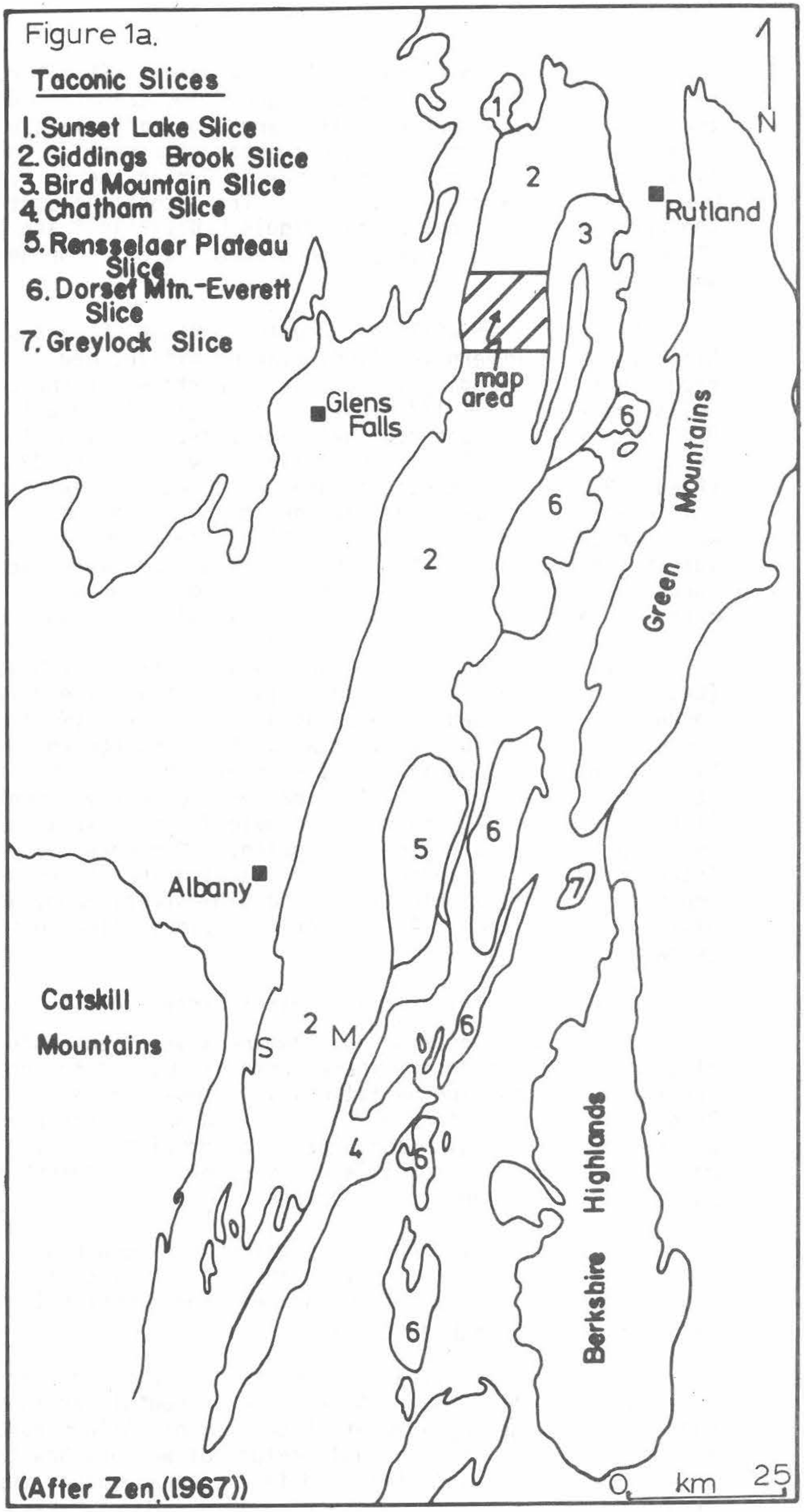


Figure 1a. Structural slices of the Taconic Allochthon after Zen (1967). Numbers refer to slices. S - Schodack Landing, M - Malden Bridge.

Figure 1b.

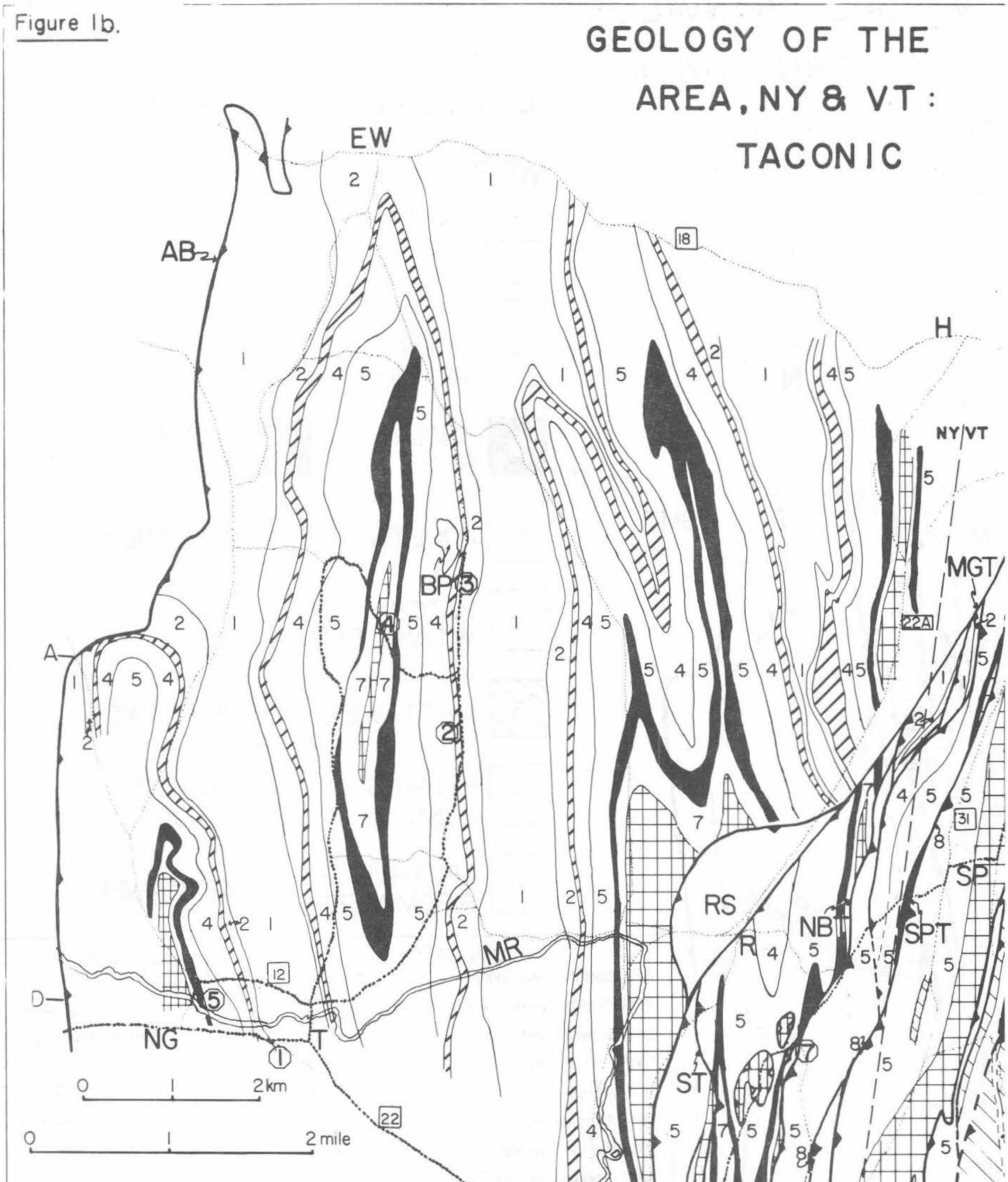
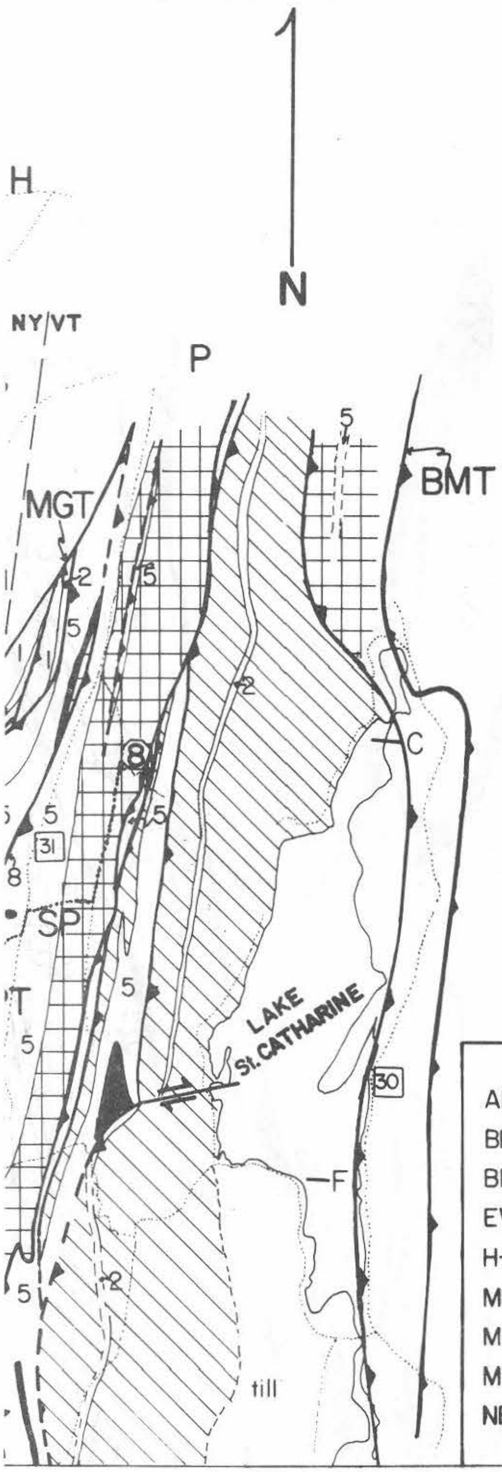


Figure 1b. Geologic map of field trip area. Compiled from outcrop maps (scale 1:12,000) of Jacobi (1977) and Rowley (1979). Stops and route are shown.

MIDDLE GRANVILLE : NORTHERN LOWER ALLOCHTHON



LITHOSTRATIGRAPHY

WESTERN REGION	EASTERN REGION
8 PAWLET	8 PAWLET
7 MOUNT MERINO	
6 INDIAN RIVER	6 INDIAN RIVER
5 POULTNEY	5 POULTNEY
4 HATCH HILL & W. CASTLETON	
3 METTAWEE	"3" "METTAWEE"
2 BROWNS POND	2 BROWNS POND(?)
1 TRUTHVILLE & BOMOSEEN	"3" "METTAWEE"

ABBREVIATIONS

AB-Allochthon Boundary
BMT-Bird Mountain Thrust
BP-Browns Pond
EW-East Whitehall
H-Hampton
MR-Mettawee River
MG-Middle Granville
MGT-Middle Granville Thrust
NBT-New Boston Thrust
NG-North Granville
P-Poultney
R-Raceville
RS-Raceville Slice
SP-South Poultney
SPT-South Poultney Thrust
ST-Stoddard Road Thrust
T-Truthville

SYMBOLS

Contact
Thrust Fault
Early Thrust Fault
Road
Route Number 22
Fieldtrip Route
Stop Location ③

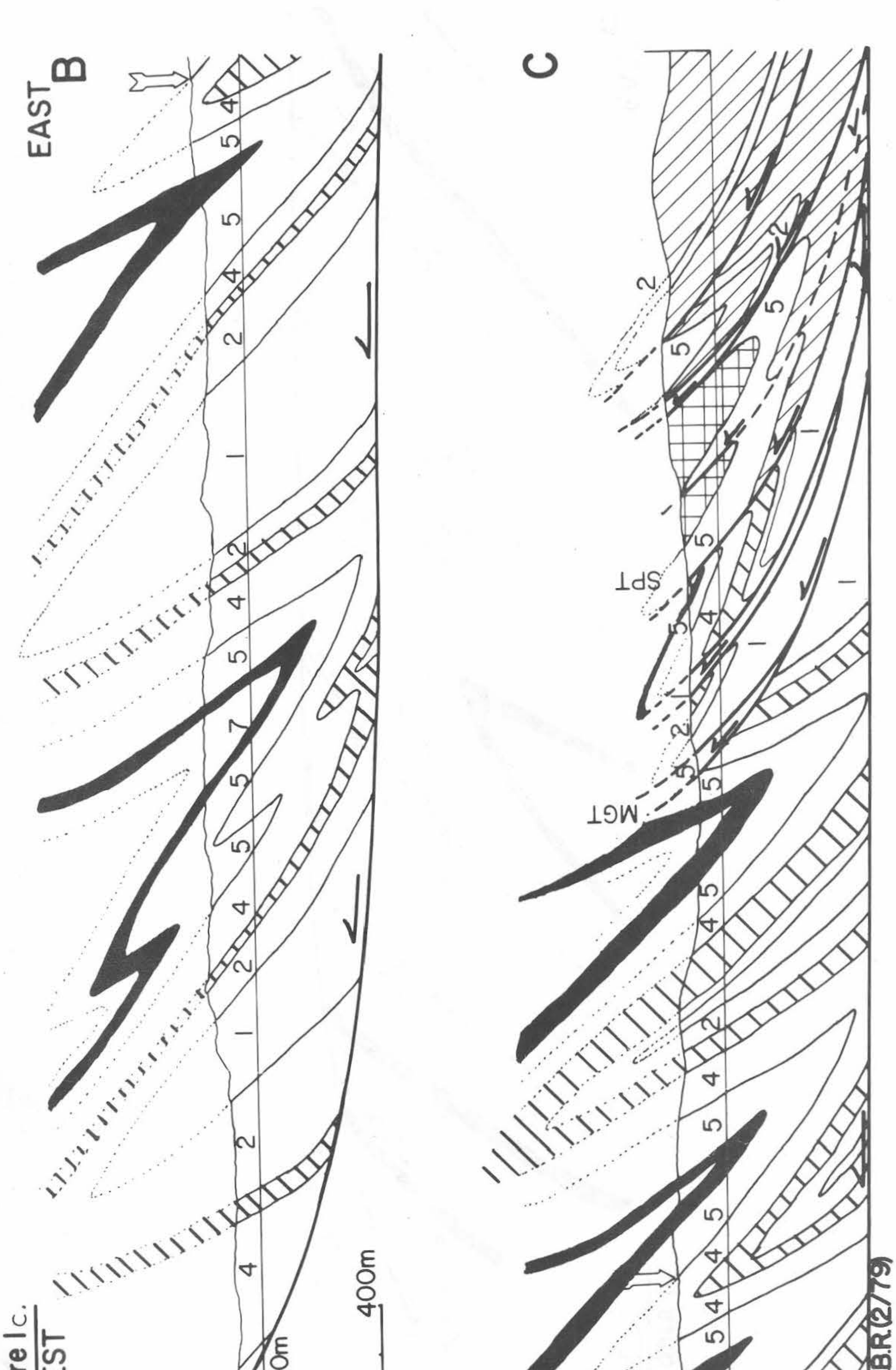
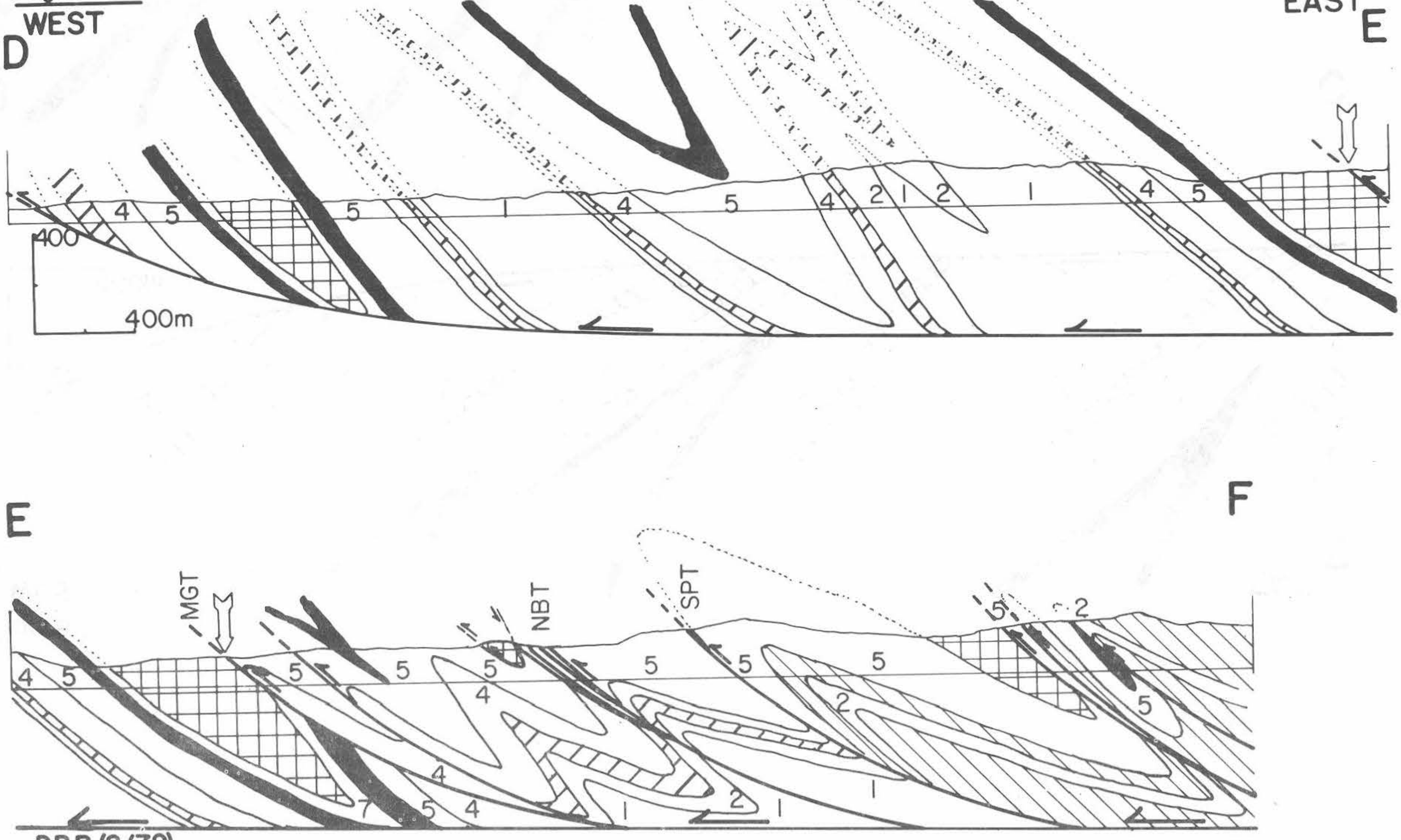


Figure 1c and 1d. Cross sections A-C and D-F from map (Figure 1b). Depth of basal decollement inferred from gravity data of Rickard (1973) and regional relations at the north end of the Allochthon.

Figure Id.



D.B.R. (2/79)

Figure 2

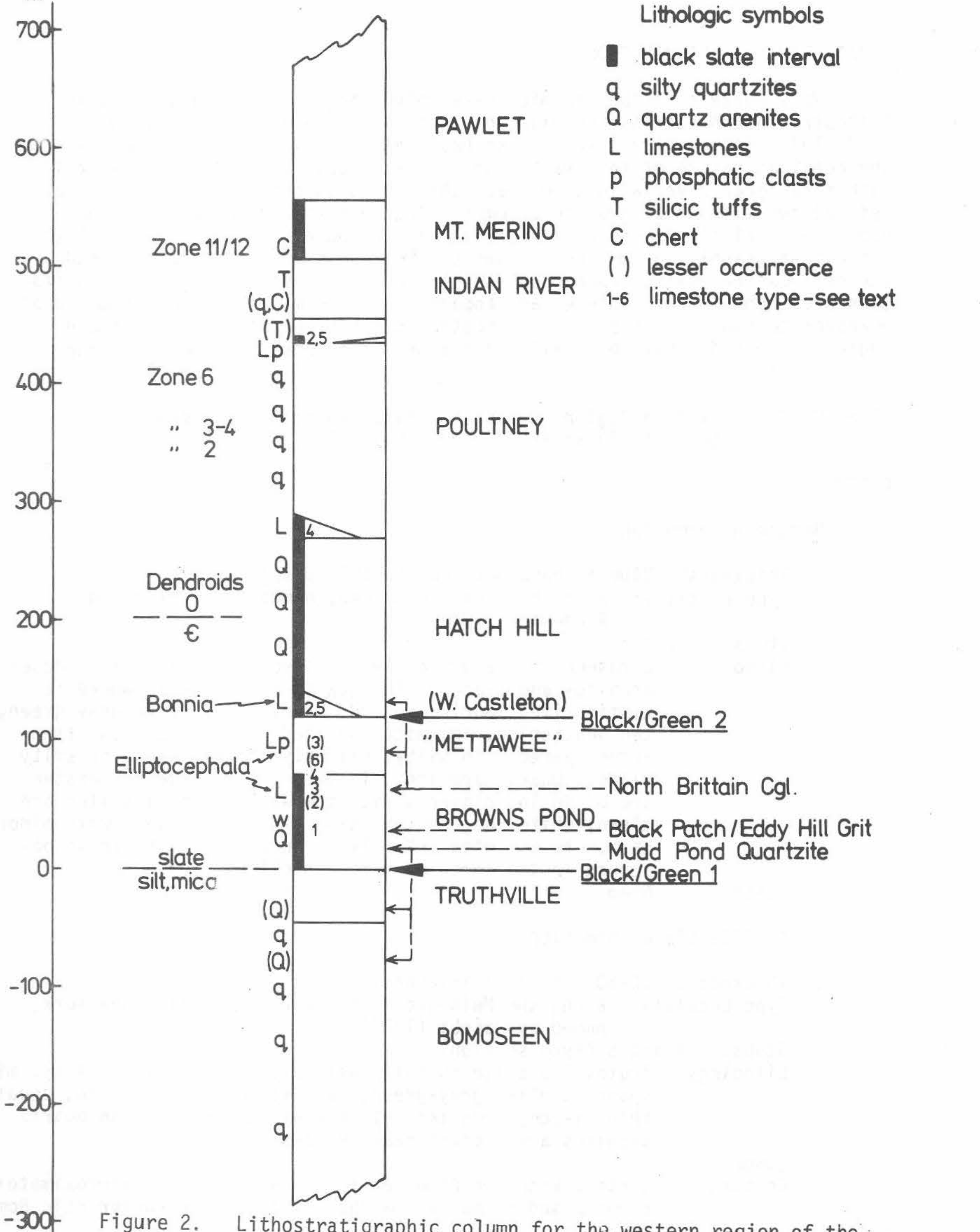


Figure 2. Lithostratigraphic column for the western region of the Granville area.
Typical post-deformation thicknesses are given. Unstrained thicknesses are probably three times post-deformation thicknesses. Graptolite zones after Berry (1962). See Fisher (1977) for correlation with Riva (1974).

STRATIGRAPHY: INTRODUCTION

Many workers in the Taconics have noted large lateral variations in lithostratigraphy across the Giddings Brook Slice (e.g. Zen, 1961, 1964a, 1967, 1972; Potter, 1972) yet no one has specifically addressed themselves to the detailed nature of this variation. We also observe a striking lateral lithostratigrahic variation, and feel that it is so significant that we have defined two lithostratigraphic columns. The western and eastern sections apply respectively to the west and east of the South Poultney Thrust. The lithostratigraphic column for the western region is very well constrained and defines the maximum number of easily and consistently recognizable units. This area contains a complete, and apparently conformable sequence from basal Bomoseen to Pawlet flysch. The lithostratigraphic column for the eastern region is considerably less well constrained as a result of complex structure.

STRATIGRAPHY: Western Region, Allochthon-Autochthon boundary east to South Poultney Thrust (Figure 2).

CAMBRIAN(?)

Bomoseen Formation

Thickness: 240m + (base not seen in this area)
Type Locality: west shore Lake Bomoseen, named by Cushing and Ruedemann (1914)
Stops: 1 and 5
Lithology: Bomoseen is predominantly composed of wackes, with lesser arenites and slates. The quartz-rich type of wacke is distinctive, poorly cleaved, hard, dull, olive gray-green, tan weathering, and mica spangled. This wacke is often interlayered with silty, slightly softer, wacke or silty slate. Quartz arenites, 1-100cm thick, usually massive, are often interlayered with the wacke. The arenites are clean, white to greenish, silty to coarse sand, with minor carbonate and mica. Rarely, a purple silty slate is observed in the cores of some anticlines.
Fossils: None

Truthville Slate Formation

Thickness: 20-60m, typical thickness 45m
Type Locality: along the Mettawee River near Truthville, New York, named by Jacobi (1977)
Stops: 1 and 5 (type section)
Lithology: Truthville slate is soft, well cleaved, fissile, silty, mica spangled olive gray-green, tan weathering with rare, usually thin (1-2cm) arenites. In places, thicker, clean quartz arenites are present near the base.
Lower Contact: Contact with the Bomoseen is gradational over approximately a meter and is marked by the absence of characteristic Bomoseen wacke.
Fossils: None

Cambrian

Browns Pond Formation

Thickness: variable, 25-130m, typical thickness 80m

Type Locality: near Browns Pond along Holcombville Road, at the Granville-Thorn Hill 7-1/2" quadrangle boundary. Named by Jacobi (1977).

Stops: 2 and 3 (type locality), 5

Lithology: The Browns Pond Formation is a heterogeneous assemblage of lithologic types all lying within a predominantly black slate matrix. The slate is predominantly black with lesser dark gray, intermittently calcareous, finely cleaved, rather fissile, and forms the matrix of the formation. Other lithologic types include limestones, limestone conglomerates and breccias, black calcareous quartz wacke, thin dolomitic calc-arenites, and one or two thick clean quartz arenites.

Limestones: are compact, light gray weathering, dark gray micrites, calcisiltites, or calcarenites, sometimes finely laminated, and usually occur as thin (2-3cm) beds or intraformationally slumped horizons.

Limestone Conglomerate: jumbled blocks of carbonates, with lesser amounts of slate, arenites, and calcareous quartz wacke in a black or dark gray slate matrix. The matrix often displays tight, irregular intrafolial folds, and flow structures around larger blocks.

Limestone Breccia: closely packed breccia of dove gray weathering limestone in a slaty to sandy dolomitic matrix. The matrix often constitutes less than about 10% of this lithology. The limestone clasts show little size and type variation. Locally, intraclasts of slate are present.

Calcareous Quartz Wacke: This is a very distinctive lithology. The wacke contains medium to coarse, rounded to subrounded quartz grains set in a black to very dark gray slaty wacke matrix. Lithic clasts within this wacke are predominantly black slate, however, locally clean and rusty-weathering medium grained arenites, blocks of bedded dark gray to black argillite and thin arenites, and black phosphatic pebbles are observed.

Thin Dolomitic calc-arenites: These are locally present and are often finely parallel and cross-laminated.

Thick Quartz Arenites:	One or two hard, white to light gray weathering, clean vitreous, medium to coarse grained, locally faintly rust speckled, massive or locally finely laminated quartz arenites are present. Bed thicknesses vary from 1-10 m and are often associated with a calcareous quartz wacke.

All of these lithologies form demonstrably lensing, intermittently present horizons within this formation. Generally the calcareous quartz wacke and thick, clean quartz arenites occur in the lower to middle part, while the closely packed limestone breccia is only known to occur at the top.

Lower Contact:	Contact is sharp and marked by distinct color change from gray-green to black.
Fossils:	The late Early Cambrian <u>Elliptocephala asaphoides</u> fauna has been collected from some of the limestones and the closely packed limestone breccia at the top. (See Theokritoff (1964) for details.)

Mettawee Slate Formation (sensu stricto)

Thickness: 15 to 95 m, typical thickness 50 m
Type Locality: Quarries along the west side of the Mettawee River, north of Middle Granville, New York. Named by Cushing and Ruedemann (1914).

Stops 2, 3, 5:

Lithology:	Mettawee slate is one of two extensively quarried slates in this region. The slate is well cleaved, non-fissile, commonly buff weathering, purple, green and near the top gray with black bioturbated laminae. Thin (1 cm), green micritic limestone may occur, and in places, lenses of micritic and arenaceous limestone are present near the base of this formation. Black phosphate pebble-bearing calcarenite and dolomitic matrix micrite breccia are rarely found in middle part.
Lower Contact:	The contact with the Browns Pond is usually gradual, over 1-2 m, and marked by color and hardness change, or sharp where limestone is present.
Fossils:	The limestone conglomerates within the lower and middle part of the Mettawee also contain the late Early Cambrian <u>Elliptocephala asaphoides</u> fauna.

West Castleton Formation

Thickness: 0 to 20 m (best included with Hatch Hill Fm in this area).

Type Locality: near West Castleton, Vermont in the Castleton Quadrangle named by Zen (1961).

Stops 3 and 5:

Lithology: West Castleton Fm is demonstrably lensing, often poorly exposed, and only a marginally mappable unit in this area. It is characterized by interbedded black, fissile, well cleaved, often pyritiferous slate and medium to dark gray limestones (calcarenites and calcisiltites). Dolomitic quartz arenites are also present, making the distinction from Hatch Hill marginal.

Lower Contact: Contact is sharp and marked by color change from gray or green to black. This is the second Cambrian black-green boundary.

Fossils: Trilobites of the Paedeumias-Bonnia, Pagetia connexia, and Pagetides elegans faunules have been reported. These are slightly younger than the Elliptocephala asaphoides fauna found in the Browns Pond and Mettawee Formations (Theokritoff and Thompson, 1969).

Hatch Hill Formation

Thickness: 35 to 205 m - typical thickness 150 m

Type Locality: on Hatch Hill in the Thorn Hill Quadrangle. Named by Theokritoff (1964).

Stops 2, 4 and 5:

Lithology: Hatch Hill is also characterized by rusty, black, fissile, well cleaved, slightly silty slate. Interbedded with the black slate are thin (2-10 cm) to thick (30-400 cm), medium to coarse grained, dolomitic sub-quartz arenites. The arenites are massive, sometimes finely parallel-laminated, and only rarely are cross-laminated or affected by soft sediment deformation. Extensively developed quartz and calcite veins characterized the thicker arenite beds. A closely packed arenite breccia is locally observed near the top of the unit in the thickest beds.

Comment: Distinguishing Hatch Hill from West Castleton is often not possible, particularly where the West Castleton is thin and contains dolomitic quartz arenites. We suggest that the West Castleton may be better regarded as a facies of the Hatch Hill, possibly an overbank deposit of Hatch Hill distributory fan channels.

Lower Contact: The West Castleton-Hatch Hill contact is placed at the first substantial dolomitic quartz arenite bed. Where Hatch Hill is in contact with Mettawee the contact is sharp. No conclusive evidence for the presence of an unconformity below the Hatch Hill is observed, however, a local disconformity may be present.

Fossils: Dendroid graptolites from near the top of the Hatch Hill have been found by Theokritoff (1964) and identified by Berry as of probable Tremadocian age (latest Cambrian in North America; earliest Ordovician in Europe).

ORDOVICIAN

Poultney Formation

Thickness: 70-210 m, typical thickness 185 m

Type Locality: along the Poultney River, west of Poultney, Vermont. Named by Keith (1932), but included the Hatch Hill Fm.

Stops: 4,6,7

Lithology: Poultney Formation is divisible into two members, informally called the Dunbar Road Member (lower) and Crossroad Member (upper). These members are similar to Potter's (1972) White Creek and Owl Kill members, respectively, in the Hoosick Falls area.

Dunbar Road Member is known to be lenticular, and is composed of fissile, thinly cleaved, dark gray to black slate with interbedded thin (3 cm), micritic, and sometimes silty limestones. Crossroad Member crops out extensively, and is characterized by hard, often chalky weathering, nonfissile, moderately to well cleaved slate. Color of the slates varies considerably, but is predominantly medium gray, with lesser, light gray to green, and black, and rare maroon, purple and red slates present. Finely color laminated slates are common and often show prominent bioturbation features. Commonly interlayered with the slates are: Thin (1 mm - 1 cm), clean, white, (some with fine black laminae) often 'ribboned' silty quartzites and quartz arenites. Also seen are: much less common, thicker (~30 cm) medium-grained quartz arenites; chalky weathering gray chert, only very close to the top; disrupted, non-transported, recemented limestone or quartz arenite conglomerate horizons; rounded limestone and/or black phosphate pebble conglomerate and associated laminated calcarenites/siltites.

Lower Contact: Where the Dunbar Road Member is present the contact is placed at the first limestone bed above the dolomitic arenites. The Crossroad-Hatch Hill contact is sharp and marked by both color and hardness changes.

Fossils: Graptolites from Berry's (1962) zones 2,3,4,6 in this area and 7 and 9 in other areas. According to the graptolite classification of Riva (1974). Poultney extends at least as high as *Glyptograptus dentatus* (Upper Canadian or upper Arenigan and possibly into *Climacograptus angustatus* or lowest *Nemagraptus gracilis* (Whiterockian, lowest Champlainian-Llanvirnian to lowest Llandeilian (Fisher, 1977), though no graptolites of this period have been reported, possibly because of unsuitable host rocks.

Indian River Formation

Thickness: 25-55 m, typical thickness 50 m

Type Locality: Quarries close to Indian River, south of Granville, New York. Named by Keith (1932).

Stops: 4,6,7

Lithology: Indian River slates are the second of the extensively quarried slates in this region of the slate belt. The slate is strong, well cleaved, non-fissile, red, green to blue-green, and locally gray at the top. Locally present in the slates are red and green chert layers and rare narrow, white, fine grained, silty quartzites. Distinctive, white to yellowish weathering, pale grey flinty horizons, interpreted to be silicic tuff beds, are present in the middle to upper Indian River. Small rounded to ellipsoidal, poly-crystalline quartz grains, presumably radiolaria, are often seen on slaty cleavage surfaces.

Lower Contact: The nature of the contact depends on the color of the lowest Indian River; if red, the contact is sharp, if green the contact is gradational over 1-2 m from gray to green.

Fossils: No datable fossils have been reported from within the Indian River.

Mount Merino Formation

Thickness: 25-70 m, typical thickness 50 m.

Type Locality: Mount Merino, west of the town of Hudson in the Southern Taconics. Named by Cushing and Ruedemann (1914).

Stops: 4,6,7

Lithology: Mount Merino is divisible into two distinctive members. A lower banded chert member and an upper black slate member, informally called the Stoddard Road Member.

Lower Chert Member: Composed of chalky white weathering predominantly black with lesser dark green, 3-5 cm thick, banded cherts with minor interlayered black slates. Both cherts and slates are often pyritiferous.

Stoddard Road Member: A very distinctive, coal black, rusty weathering, well cleaved, slightly silty graptoliferous slate.

Lower Contact: This is probably the best exposed contact in this area, due to the extensive quarrying of the Indian River. The contact is very sharp, marked by both color and hardness changes.

Fossils: Graptolites of Berry's zones 11 and 12 (*N. gracilis* to *Climacograptus biconis*, or Rivas *N. Gracilis* zone. (Llandeilian to lowest Caradocian)

Pawlet Formation

Thickness: greater than 150 m, the top is never observed.

Type Locality: Pawlet, Vermont, in the Pawlet Quadrangle. Named by Zen (1967) after usage by Shumaker (1960, 1967).

Stops: 5,6,7

Lithology: Pawlet is characterized by easterly-derived deep-water turbidite flysch sequence of interbedded brownish to gray weathering, medium to dark gray, variably calcareous, fine to coarse grained, quartz-rich lithic greywackes and fine to finely silty, well cleaved, often fissile grey slates. The greywackes vary from fine grained, sometimes silty, often finely parallel or cross-laminated, moderately clean 3-10 cm beds, to medium to coarse grained, commonly grading to silty, 10-300 cm thick, lithic wackes. Lithic fragments are almost exclusively slate rip-up clasts, although some possible chert fragments have been observed.

Lower Contact: The Pawlet is conformable in this area on the Mount Merino and its base is marked by the incoming of greywackes.

Fossils: Graptolites of Berry's zones 12 and 13 are reported (*C. bicornis* and *Orthograptus truncatus*, var. *intermedius*). Riva's zones are upper N. gracilis, *Diplograptus multidens*, and *Corynoides americanus* and possibly *Orthograptus ruedemanni*. (Middle to upper Caradocian). The latter may only occur in parautochthonous or neoautochthonous Pawlet - Austin Glen.

STRATIGRAPHY: Eastern Region, South Poultney Thrust to Bird Mountain Thrust

CAMBRIAN(?)-CAMBRIAN

"Mettawee Slate" (*sensu lato*)

Thickness: unknown, greater than 30 m

Stop: 8

Lithology: Primarily purple, green and gray, with minor black, red, and maroon, non-fissile, well cleaved, extensively quarried slate. Often interlayered with the quarried slates are thin (1-2 cm) green micritic limestones, called 'rubber beds' by quarry workers in this area. Also present are purple, green, and less commonly gray, fine silty to silty moderately to coarsely cleaved slates and argillites. Interlayered with the silty argillites are thin (1-2cm) fine to silty clean, often finely laminated greenish to white quartz arenites. Rarely, 30-100 cm thick, vitreous, medium to coarse grained quartz arenite beds are observed.

Fossils: None

Browns Pond Formation (?)

Thickness: less than 10-30 m, average 15.

Lithology: Lying within the Mettawee Slates (*sensu lato*) are pale to medium gray, and locally dark gray, fine, fissile well cleaved, slates with interlayered medium to coarse clastic horizons, including:

(1) Calcareous quartz wacke with medium to coarse, rounded to sub-rounded quartz grains within a dark gray to black slaty matrix.

(2) Associated with(1) is an argillaceous quartz arenite, 5-15 cm thick, of medium to coarse arenite with minor interstitial clay.

(3) Medium grained, well rounded thoroughly rotten-weathering quartz arenite.
(4) Thick, 20-60 cm, vitreous, medium to coarse grained, clean, hard white to light gray weathering, rarely, faintly rust speckled quartz arenite.
(5) White weathering, black phosphate(?) pebbles to discontinuous 0.5-1.0 cm thick layers in a dark gray slate.

Note: all lithologies described above are lensing, and may grade into one another either along strike or vertically.

Fossils: None

West Castleton-Hatch Hill-lower Poultney

These lithostratigraphic units are unrecognized in this area. The reasons for this missing section are unclear. Four hypotheses may be suggested, but none is entirely satisfactory.

(1) An unconformity below the Poultney, possibly due to scouring by bottom currents.
However, this seems improbable because the medium to coarse sand character of the Hatch Hill is not easily transported, and one would expect that winnowing would have left this sand fraction behind. Evidence for strong bottom currents is not observed to the west, and the presence of Hatch Hill and West Castleton to the east and west also argues against such a hypothesis.

(2) Large-scale down slope slumping, resulting in local removal of these units in this locality, similar to that discovered by DSDP drilling off the coast of Africa (Leg 47, Geotimes, 1976). This model requires that somewhere to the east extremely large thicknesses of black slates, limestones, and dolomitic quartz arenites should have been present originally, presumably in a chaotic, olistostrome-like deposit. Data from areas to the east do not allow us to test this, as most of the black slates and phyllites have been mapped as Undifferentiated Cambrian-Ordovician black slates by Shumaker (1967).

(3) These units have been systematically removed tectonically during emplacement of the allochthon in the Middle Ordovician. This requires either tectonic excisions along all Mettawee-Poultney boundaries after early F_1 folding or pre-folding thrust removal of these units in this area. The first mechanism appears to be highly improbable. There is no field evidence to support large-scale pre-folding thrusts, but this possibility cannot be entirely ruled out.

(4) There was a facies change from black slates with interbedded limestones and dolomitic arenites to the west to purple, green and gray slates with thin interbedded micritic limestones to the east. This hypothesis does not explain the lack of arenites to the east, even though they were probably confined to channels, or the presence of Hatch Hill and West Castleton farther to the east in the Edgarton Half-Window, as mapped by Shumaker (1967).

ORDOVICIAN

Poultney Formation

Stop: 8

Lithology: Predominantly medium gray, often interlayered with gray, dark gray, black, and locally green, in some places silty, moderately to well-cleaved slates and argillites. Argillites tend to be hard, sometimes siliceous, white weathering with only a spaced cleavage developed in them. Thin (2 cm) white weathering, silty to fine grained, clean, often finely laminated quartz arenites characterize the Poultney of this area. Thicker (2-10 cm) white weathering, silty to medium grained, clean, parallel and irregularly cross-laminated quartz arenites are also observed. Rare, thin (1 cm) white weathering black cherty layers in a dark gray silty argillite are sometimes observed near the lower contact of this unit.

Indian River Formation (Rare)

Lithology: Red, green to blue-green, with minor maroon well cleaved, non-fissile slate. Thin (1 cm) silty to fine grained, parallel and irregularly cross-laminated quartz arenites are often present near to lower contact with the Poultney. This contact appears to be gradational over about a meter, from predominantly medium gray to red. Rare, flinty green, silicic tuff bands are present.

Mount Merino Formation (Very Rare)

Lithology: Only very poorly exposed in this area and only as demonstrably tectonically-bounded thrust slivers. Both members, black cherts and sooty black, locally graptoliferous slates have been observed.

Pawlet Formation

Stop: 8

Lithology: Medium to dark gray, fine to slightly silty, well cleaved fissile, slates interbedded with very distinctive silty to coarse grained lithic greywackes. The greywackes are often graded, with locally observed current lineations, and other sole markings. Internal structures within the greywackes are very rarely observed and usually consist of fine cross-liminations at the tops of some beds. Bed thicknesses range from 3-300 cm ; locally evidence of composite beds are observed. Average bed thickness is 30-40 cm. Very locally, Poultney-like medium gray silty argillites and thin silty quartz arenites are interbedded with greywackes. These lenses do not appear to be intraclasts, however, this origin cannot be entirely ruled out.

Lower Contact: Zen (1961, 1964a, 1967) Shumaker (1967), Potter (1972) and others suggest that the Pawlet unconformably overlies lithostratigraphic units as old as the Mettawee (Cambrian-(?)-Cambrian). Shumaker (1967) suggests that the unconformity is at least locally angular. In this area Pawlet does appear to rest with depositional contact on Poultney, but nowhere is it unequivocably in depositional contact with rocks any older, in fact depositional contacts cannot be unequivocably demonstrated anywhere in this area. The nature of the basal contact is extremely difficult to pin down. Locally a thin 5-20 cm thick dark gray argillite is present between undisputable Poultney and Pawlet, however, nowhere is a basal breccia, conglomerate or rafts of older units observed that would support an unconformable or at least angular unconformable relation.

DISCUSSION

The great stratigraphic advantage of the western area, besides better outcrop, over most other areas of the Giddings Brook Slice, is that the lithostratigraphy of the early Cambrian and possibly older rocks is divisible into clearly distinguishable formations. Instead of finding large thicknesses of purple and green slates below one (or no) black-green boundary as in the eastern area mapped by Rowley, here there is a well defined unit with black to dark slate (Browns Pond Formation) below a thin purple and green slate (Metawee Slate Formation (ss)) and, in addition, there is the easily defined green wacke and quartzite of the Bomoseen Formation separated from the Browns Pond by a silty micaceous green slate (Truthville Formation). The boundaries between these readily mappable formations provide a framework to define, more precisely than has been previously possible, the positions of occurrence of distinctive lithologic members in this part of the succession. This precision is not possible where only undistinguishable green and purple slates and silts occur below one black-green boundary, as is the case in much of the Giddings Brook slice. These members have been very extensively used in mapping in many areas of the Taconics mostly because they are more resistant than the surrounding slates and hence outcrop preferentially. Knowledge of their constancy (or lack of it) in lithostratigraphic position will therefore allow improvement of existing maps of other areas that show these members. Three lithologies are of concern 1) a clean medium to coarse grained thick-bedded quartzite (Mudd Pond Quartzite) 2) a highly distinctive grey to black cleaved silty wacke containing dispersed coarse well-rounded quartz grains and dark slate rip-up clasts (Black Patch Grit or Eddy Hill Grit) and 3) limestones, especially varieties of limestone conglomerate and breccia (North Brittain conglomerate, Ashley Hill conglomerate, Beebe limestone).

In the western map area, the Mudd Pond Quartzite lithology is most commonly found, when present, in the lower half of the Browns Pond Formation as one, or two, thick (to 10 m) multiply bedded, lenticular units that most probably occupy channels. They are clearly associated with the Black Patch/Eddy Hill Grit lithology in this position (Stop 3), although one may often be present in any section without the other (Stop 5). Unlike the Black Patch Grit lithology, which <u>only</u> occurs in this position low in, but not at, the base of the Browns Pond Fm., less prominent (in this area) occurrences of the Mudd Pond Quartzite lithology are found in the lower and upper part of the Truthville Slate (seen at Stop 5), and in the upper part of the Bomoseen Formation. As lithostratigraphic markers, therefore, we regard the Black Patch Grit lithology as a much more reliable indicator of stratigraphic position than the Mudd Pond Quartzite lithology, which may appear at several places within a range of about 130 m of section (15% of the exposed thickness of the pre-Pawlet Greywacke section).

In this area, limestones in the two units above and below the Metawee Slate (s.s.), and within it, are usually distinguishable from one another when taken as assemblages of lithologies. Individual lithologies, for example, laminated calc-arenites are, however, common to more than one of these units, so distinction of units cannot be made on the basis of single limestone lithologies. Limestone lithologies occurring in this area and their position in the stratigraphy are as follows (numbers keyed to Fig. 2) This listing may be of assistance in identifying lithostratigraphic position in the absence of two black-green slate boundaries, etc.

1) Blocks and pebbles of calcarenite to micrite, which may or may not be dolomitic, widely dispersed in a dark calcareous wacke (Black Patch Grit lithology) or dark calcareous slate showing evidence of debris flow and slumping. This occurrence is restricted to the lower and middle parts of the Browns Pond Formation (Stops 3, 5).

2) Thin-bedded (1-10 cm), parallel-laminated (lesser cross-laminated), calcarenites and calcisiltites; lesser micrites. Occurs locally near the top of the Browns Pond Formation (Stop 3); otherwise seen at the base of the Hatch Hill Formation (West Castleton "Fm") (Stop 3) and in an uncommon carbonate horizon high in the Poultney Formation. Although calcarenites do occur in the carbonate horizon of the basal Poultney Formation (Dunbar member), this tends to be dominated by micrites (see below). Rare thick (20-100 cm) individual beds of laminated calcarenite occur at the Browns Pond-Metawee Formation contact, and within the latter. F m. (Stop 2)

3) Limestone breccia with mainly grey micrite in compact but irregularly shaped pebbles and cobbles; less common calcarenite clasts; orangy-weathering arenaceous dolomite matrix. Clasts are closely-packed. Lithology is restricted to the topmost Browns Pond Fm. (Stop 3), except for rare occurrences of a single bed less than 50 cm thick in the middle of the Metawee Slate Formation.

4) Nodular grey micrites mostly 1-5 cm thick. These may occur as very disconnected nodules if diagenetic dissolution was intense. They occur up to a few metres on either side of the Browns Pond Formation-Metawee Slate formation (s.s.) contact (Stop 2). The layers in the green Metawee Slate are characteristically more nodular and the nodules more widely separated. Micrites are also dominant where carbonates occur in the lower Poultney Formation (Dunbar Member).

5) Limestone conglomerate/breccia with up to 1 cm pebbles of micrite and lesser calcarenite. Uncommon lithology which occurs in base of Hatch Hill Fm. (West Castleton) (Stop 3), and in the carbonate horizon found high in Poultney Fm.

6) Limestone breccias other than those of 1), 3) and 5), typically with relatively closely packed clasts dominantly of micrite in a shaly matrix. These are uncommon in the map area, occurring mostly in the lower part of the Metawee Slate Fm. (s.s.).

The use of these data on Taconic carbonates in lithostratigraphic correlation may be illustrated by using two well known central-southern Taconic sections, that have been studied by the authors, at Schodack Landing and Malden Bridge. The latter section consists dominantly of calc-arenites in black slate, above purple slate. We suggest that the purple slate correlates with the Mettawee Slate Formation (s.s.) and that the calcarenites are equivalent to basal Hatch Hill Formation (West Castleton).

The Schodack Landing section described by Bird and Rasetti (1968), Bird and Dewey (1975), Keith and Friedman (1977) and Friedman (this guidebook)and our observations consists of nodular, bedded micrites overlain by a lenticular micrite/shale matrix breccia and highly nodular micrites in green shale, lie below black shales with dolomitic arenites and quartzites identical to the Hatch Hill Formation. We correlate these micrites with those straddling the Browns Pond-Mettawee Slate Fm (s.s.) contact. The single black-green boundary seen at both localities is lithostratigraphically correlated with the upper one in the Granville area; faunal collections from them and other Taconic sections (Bird and Rasetti, 1968) and in the Granville area (Theokritoff, 1964) support the proposal that this upper black-green boundary is essentially isochronous. We suggest that it is likely to be so, when properly identified throughout the Taconic region.

Phosphatic clasts have been proposed (J.M. Bird, pers. comm.) to be characteristic only of the Cambrian part of Taconic stratigraphy. While they are prominent in some calcarenites and breccias in the Mettawee Slate Fm. (s.s.) and the carbonates of the basal Hatch Hill (West Castleton) Fm., they also occur in the upper Poultney Fm. carbonates.

SEDIMENTARY FEATURES AND ENVIRONMENT OF DEPOSITION

The present stratigraphic thickness in this area of the section from the top of the Bomoseen Fm. to the base of the Pawlet Fm. ranges from 380 to 840 meters. Most estimates are in the range from 450 to 650 meters with a typical value of 610 meters. This variability probably results from both sedimentary and tectonic causes. Channelized deposition, non-deposition and/or scouring by bottom currents may account for some of the thickness variation. Small faults, probably thrusts, minor folds and inhomogeneous strain, particularly during D_1, may also produce some part of the observed variability. At present it is not possible to estimate the relative contribution of these effects.

Paleontological evidence indicates that this stratigraphic section of about 600 meters represents the time from late early Cambrian to late medial Ordovician (Caradocian), a period of perhaps 110 m.y. (560-450 m.y.). An approximate average rate of deposition can be obtained, once the present thickness has been corrected for tectonic thinning during D_1 folding and cleavage development. Wood (1973, 1974) estimated 75% shortening perpendicular to slaty cleavage, using deformed reduction spots in purple slates from near this area. Taking into account the effects of strain variation in different lithologies we estimate an original thickness of approximately 2000 meters. An average deposition rate of about 20 m/m.y. (or 20 mm/1000 yr.) results. This very slow overall rate supports the suggestion of Elam (1960) and Bird and Rasetti (1968) that the environment was "starved." Bird and Dewey (1970) pointed to the continental rise off a carbonate shelf as the specific "starved" depositional environment of Taconic rocks.

Sedimentary structures and facies seen within Taconic stratigraphy are wholly compatible with deposition in deep water on a continental rise prism (Jacobi, 1977; Keith and Friedman, 1977). In the framework of mudrocks, the silty arenaceous and coarser beds are either channelized debris flows and traction grain flows*, turbidites, or contourites*. Evidence of soft-sediment disruption (incipient slumping), mud injection structures and sedimentary (clastic) dikes**, some of large size, are seen in good outcrops. Burrowing is prominent in non-black mud units. No autochthonous carbonate can be proven and much is demonstrably transported. The only fossil types seen in mudrocks are graptolites and poorly preserved radiolaria, both pelagic forms.

The arenaceous and coarser detritus in units from the Browns Pond to the Indian River Formations must be originally derived from the carbonate platform and environments landward of it where quartz silt and sand were being supplied. Possible sedimentary environments for parts of the Cambrian section have been described by Keith and Friedman (1977). Prior to deposition of the Browns Pond Formation, the 'framework' sediment is silty, with a prominent detrital mica component, suggesting active erosion of exposed crystalline basement. The rocks of the Truthville and Bomoseen Formations, however, still show some evidence of deep-water deposition and no evidence of shallow water structures. The schematic evolution of this source as a newly rifted continental margin evolving into a subsiding carbonate platform is well known (Bird and Dewey, 1970).

The uppermost unit, the easterly derived Pawlet Formation (a flysch) is interpreted as heralding the convergent tectonics of the Taconic orogeny (Bird and Dewey, 1970). The mineralogic and lithic composition of Pawlet greywackes, suggests that they were, at least in part, derived from erosion of Taconic or Taconic-like rocks. This suggests that these greywackes might best be thought of as the products of erosion of material already incorporated in an accretionary prism, and transported as turbidites down into and along the morphologic trench at the front of the moving prism.

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*Best displayed in two large contiguous outcrops of the Hatch Hill and Poultney Formations on the west bank of the Poultney River, northwest of Fair Haven. If you visit these outcrops, please do not vandalize them by attempting to collect specimens. Please take nothing but photographs.

**Small clastic dikes are well exposed in the Poultney River outcrops described above. Large clastic dikes are exposed in an outcrop of Poultney Formation, with unusually thick, fine-grained quartzite beds in it, on the west side of Rt. 22A, 1.3 miles north of Middle Granville, directly opposite a dirt parking area on the other side of the road.

Reference Section for Taconic Lithostratigraphy

A plethora of stratigraphic names, both lithostratigraphically and biostratigraphically defined have been used in the Taconics. Zen (1964b) provided a great service for Taconic geology by compiling and systematizing Taconic stratigraphic names, descriptions and synonomies. Without Zen's compendium Taconic stratigraphy would be in chaos. Even so, many lithostratigraphic units remain poorly and inadequately described, particularly with respect to lithologic assemblages and stratigraphic relationships. This results in part from poorly chosen and described type-localities, as well as generally mediocre outcrop in many parts of the Taconics. We suspect that much confusion and misidentification of lithostratigraphic units results from this situation. In order to help rectify this situation we propose the western part of the Granville area to the west of the Middle Granville Thrust, as a lithostratigraphic reference area for the low Taconic Giddings Brook Slice. The following attributes of this western area support this proposal: 1) good outcrop, with excellent, easily accessible exposures; 2) well described stratigraphy and stratigraphic relationships for a complete, regionally conformable lithostratigraphic section from Bomoseen to Pawlet Flysch. 3) Presence of four to ten lithostratigraphic unit type localities within this area. 4) Simple, coherent, well defined structure. We feel that a well mapped, well exposed reference area should help in the correlation of Taconic lithostratigraphy, at least in the Giddings Brook Slice, and provide a standard lithostratigraphic column upon which to refine biostratigraphic work.

STRUCTURE

The deformation history of this region involves syn-depositional, soft-sediment slumping and slump folding (D_0), and two north-trending, essentially coaxial tectonic deformations. Structures associated with the first tectonic deformation (D_1) are responsible for the map geometry of the lithostratigraphy. D_1 deformation primarily involves large-scale overturned folds that are progressively dismembered to the east by mid- to late syn-D_1 east over west thrusting. This tectonic dismemberment, associated with D_1, results in a macroscopic, west to east pattern of increasing deformation and structural complexity. Second generation structures (D_2) result in only minor redistribution of earlier structures and are of distinctly secondary importance. Mesoscopically, the D_2 related crenulation cleavage (S_2) becomes more pronounced to the east. Zen (1961, 1964, 1967), Wright (1970), Potter (1972) and others have noted a similar mesoscopic pattern for S_2.

D_0 Pre-regional Deformation

Syndepositional slumping (Stop 1, 3, Stop 5) is observed in many units, and is particularly well developed in the Bomoseen, Browns Pond, Mettawee Slate (s.s.) and Poultney Formations. D_0 deformation usually involves dismemberment, or folding of one or several beds. Slump folds are often demonstrably intrafolial and tend to be tight to isoclinal, locally involving transposition. Individual soft-sediment related structures never affect more than a few beds, and never influence the macroscopic outcrop distribution of lithostratigraphy. It is more important to realize that all D_0 structures have been significantly modified by later, tectonic deformation. Unless folding is demonstrably intrafolial, or S_1 cuts both limbs of the fold (Wright, 1970), the distinction between mesoscopic F_0 and F_1 is very difficult.

In order to better appreciate structural variation, the map area has been divided into three contiguous regions, each with similar structural style, and separated by tectonic boundaries.

Tectonic Structures - Western Area

The westernmost region extends from the allochthon-autochthon boundary on the west to the Middle Granville Thrust on the east. The structural style of this region is characterized by large, coherent, west-facing, overturned, tight to isoclinal, gently plunging folds (F_1) and an associated moderately dipping, penetrative, axial surface slaty and locally spaced cleavage (S_1). The map pattern of this region reflects this structural style. Local thrusting along some limbs of these folds may explain some of the large variations in lithostratigraphic thickness, but nowhere do these thrusts grossly disrupt the map pattern. Second generation structures, generally involving open to angular upright to asymmetric folds (F_2) and associated upright to steeply east dipping crenulation cleavage (S_2) are only locally observed. Small, steep late schuppen are locally present, but the offset associated with these is never more than a few meters.

Central Area

The central region extends from the Middle Granville Thrust to the New Boston Road Thrust. This small region is intermediate in structural style between regions to the west and east. This region is characterized by large, tight to isoclinal, gently plunging overturned F_1 folds with well developed axial surface slaty and locally spaced cleavage (S_1). Slides (Bailey, 1910, p. 593, Dennis, 1963) occur along the short limbs or in the hinges of some of the F_1 folds, best seen in the Stoddard Road Thrust (Stop 6). Thrusting is believed to be associated with D_1; micro- and mesoscopic evidence suggests that a late D_1 timing is probable (see description of mesoscopic structures associated with thrust faults below). D_2 structures include open to angular folds (F_2) and associated steeply east-dipping axial surface crenulation cleavage (S_2). Late, syn-D_2 to post D_2 schuppen and granulated vein quartz with angular clasts of slate are locally observed, but neither demonstrably offsets stratigraphy. The time of emplacement of the small klippe of Pawlet greywackes in to the hinge region of the large F_1 fold to the west of Stoddard Road is not clear. Outcrop density is not sufficient to determine if the klippe thrust is or is not folded with the underlying Poultney. The wackes of the klippe are tightly folded and may indicate that they were in their present position at the time of F_1 folding, but this need not be so. At the present time we are biased towards a pre-F_1, early to pre-D_1 age, but this cannot be conclusively demonstrated.

Eastern Area

Farther to the east, from the New Boston Road Thrust to the Bird Mountain Thrust, large scale sliding and slicing pervades the structural pattern giving rise to linear outcrop belts. Macroscopic F_1 hinges are poorly defined, for example, the Indian River-Poultney contact in the central eastern part of this area. Mesoscopic F_1 folds are tight to isoclinal of similar-type, with well developed slaty cleavage axial surface to them. Locally, polyclinal folds are well developed, particularly in Poultney, thin quartz arenites. Bedding and cleavage tend to be parallel supporting the inference that folding is regionally tight to isoclinal. Mesoscopic pre- to syn-S_1 thrust faults are recognized and tend to dip slightly less steeply east than S_1, and locally they are demonstrably openly folded by F_1. Macroscopic, large scale tectonic slides have clipped off primarily hinges and short limbs of the major F_1 folds. Thrusting occurred syn-to late D_1 (see below). Mesoscopic D_2 structures are common, but always distinctly secondary to D_1. F_2 folds are open to angular, gently plunging, low amplitude (less than 1 m), short wavelength (less than 2-3 m) with an associated steeply east-dipping, spaced crenulation cleavage. Conjugate crenulation cleavages are observed, but only rarely. Brecciated and granulated zones are present, but do not seem to be significant structures. Late, small northwest trending steep kink zones are the last deformation observed in this area.

EVIDENCE FOR THRUSTING

As a result of the poor outcrop characteristics of thrust fault related rocks in this and most regions of the Taconics, the presence of thrust faults is inferred and supported by the following observations. The most conclusive are presented first.

1) Pawlet greywackes younging directly into older lithostratigraphic units without an intervening oppositely facing limb.

2) Thin, discontinuously exposed unbedded Pawlet greywackes often only a few meters wide, surrounded by older lithostratigraphic units.

3) Complexly interdigitated, distinctive lithologies from two or more lithostratigraphic units, in a zone from two to approximately ten meters thick.

4) Along strike loss of a limb of a large structure.

5) Along strike loss of lithostratigraphic units.

6) Extreme thickness variations and loss of units across repeating sequences.

MESOSCOPIC CHARACTER OF THRUST FAULTS

Thrust zones vary in thickness from 10 to greater than 400 cm and are characterized by an argillite matrix within which slivers, often with a 'shredded' appearance, of greywackes or quartz arenite can be found (Stop 6). The matrix argillites possess a moderately to well developed slaty cleavage, often with a more phyllitic appearance than surrounding slates. The slaty cleavage within the fault zones tends to be parallel or slightly less steeply east-dipping than the regional slaty cleavage. The slivers of greywacke and quartz arenite occur as disrupted and probably transposed lensoid layers with a distinct planar preferred orientation parallel to the slaty cleavage of the matrix. In some instances a preferred linear orientation can be demonstrated that plunges down the dip of the cleavage. No reclined folds have been observed that are unequivocably associated with thrusting. It is important to note that the mesoscopic evidence for thrusting does not involve brittle-looking fault breccias or mineralized zones, the lack of which are commonly cited as evidence against large-scale thrusting within the lower Taconics. All mesoscopic and macroscopic evidence points to a 'hard rock' not soft rock origin of these thrust faults.

MESOSCOPIC AND MICROSCOPIC FABRIC ELEMENTS

The primary meso- and microscopic tectonic fabric element in these rocks is the S_1 slaty and spaced cleavage. The nature of this S_1 foliation varies continuously from a very fine, well developed slaty cleavage in fine argillites, such as the Mettawee, Indian River and slates of the Pawlet, to a spaced cleavage in silty argillites Poultney Bomoseen and finer grained wackes of the Bomoseen and Pawlet Formations. S_1 is not demonstrable in most of the medium to coarse grained quartz arenites, although strained quartz is often observed. Cleavage refraction is well developed where suitable grain size and compositional variations occur. The S_1 foliation is defined by the planar preferred orientation of clay minerals, chlorites, white micas and elongate quartz and carbonate grains. The development of the chlorites within the S_1 foliation suggests that low grade metamorphism occurred synchronously with D_1 as has been suggested by others (Zen, 1961, 1960; Potter, 1972).

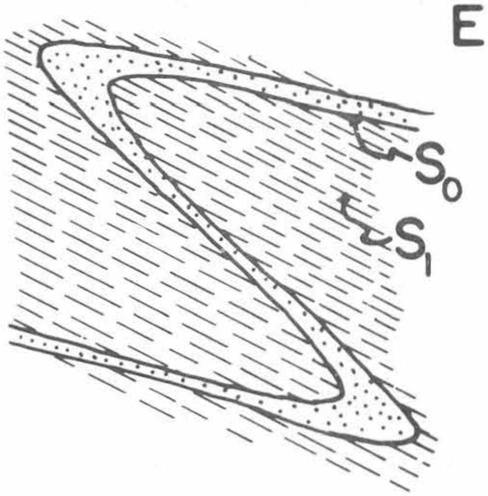
Wood (1973, 1974) has done finite strain analysis in fine grained, quarried purple slates of the Taconics using ellipsoidal reduction spots as finite strain markers. His analysis indicates that the slates have enjoyed approximately 75% shortening perpendicular to slaty cleavage (Z or λ_3 direction), and simultaneously, approximately 150% and 50% extension approximately perpendicular and parallel to F_1 hinge lines (X or λ_1 and Y or λ_2) within the plane of S_1. Slaty cleavage was found to lie precisely within the plane of maximum finite shortening. The down-dip lineation, commonly referred to as the "grain" was found to be parallel to the direction of maximum finite extension (Wood, 1973, 1974; Wright, 1970).

The crenulation cleavage (S_2) axial surface to F_2 folds is a spaced, locally developed fabric. The spacing of the crenulation cleavage appears to be correlated with two factors, one, the tightness of F_2 folds and secondly, with the grain size of the affected rocks. Spacing varies from 1 to 10 mm. No new minerals appear to be associated with the crenulation cleavage, though our observations are not detailed enough to state this unequivocably. It is important to recognize that the presence of a second, crenulation cleavage is not necessarily associated with or indicative of a second, wholly separate and later, in this case, Acadian deformation. This is well demonstrated in other regions where a second tectonic event is unrecognized, yet a second cleavage, often coaxially associated with the first is observed. These 'second' generation structures appear to be relatively late readjustments of the rocks, with slaty cleavage to continuing progressive deformation and strain (W.D. Means, 1979, pers. comm.).

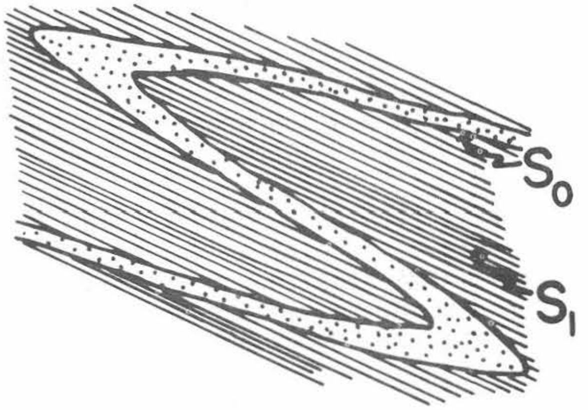
Figure 3 diagramatically illustrates the envisioned structural evolution.

Figure 3.

SCHEMATIC STRUCTURAL EVOLUTION

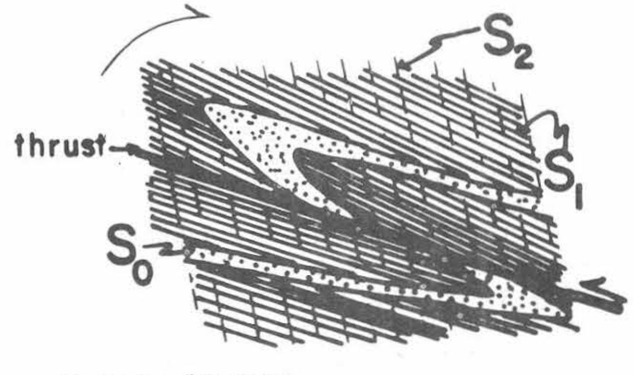


INITIAL ASYMMETRIC FOLDING (F_1) OF BEDDING (S_0). INCIPIENT AXIAL SURFACE CLEAVAGE (S_1) DEVELOPMENT.



TIGHTENING OF F_1 FOLDS.

S_1 SLATY CLEAVAGE WELL DEVELOPED.



ROTATION OF F_1 AND S_1, THRUSTING OCCURS ON SHORT LIMBS AND IN HINGE REGIONS OF F_1 FOLDS. DEVELOPMENT OF SMALL F_2 FOLDS WITH SPACED AXIAL SURFACE CRENULATION CLEAVAGE (S_2).

D.B.R.(2/79)

TECTONICS

Plate tectonic corollary models for the emplacement of the allochthonous continental rise (Taconics) sediments onto the autochthonous and parautochthonous continental shelf ("synclinorium") sequence are of two varieties. The earliest model, proposed by Bird and Dewey (1970, 1975) and reiterated by others suggests that the initiation of a west-dipping subduction zone led to the following related events.

(1) Development of an Andean-type volcanic arc in the outer continental rise region (Ammonoosuc volcanics), (2) uplift of the continental rise terrain to the west of the volcanic arc, (3) collapse of the continental shelf and development of the 'Normanskill Exogeosyncline,' (4) soft-sediment gravity sliding of the low Taconics in the Middle Ordovician and (5) progressive emplacement of the high Taconics by 'hard-rock' thrusting during late Middle and Late Ordovician. According to this model the Taconics were assembled in their present location and subsequently folded with the underlying shelf sequence in the Middlebury Synclinorium, as first suggested by Zen (1961).

Chapple (1973, 1979) and Rowley and Delano (1979) proposed a second type of plate tectonic corollary model. They suggest that the emplacement of the Taconic Allochthon resulted from partial subduction of the Atlantic-type North American continental margin in an east-dipping subduction zone. Chapple (1973) argued that the post-Chazy history of the continental shelf, involving uplift, erosion and development of a karst surface, followed by block faulting and rapid subsidence, accords well with the trajectory of crust entering subduction zones. Chapple (1973) followed previous models by suggesting that the low Taconics were emplaced as soft-sediment gravity slides prior to emplacement of the high Taconics slices by subduction accretion 'hard-rock' thrusts. Rowley and Delano (1979), however, argued that structural evidence from within the low Taconics does not support a soft-sediment gravity slide origin, but instead indicates emplacement by 'hard-rock' thrusts. Rowley and Delano (1979) and Chapple (1979) propose that most of the deformation associated with D_1 occurred during subduction accretion tectonics as the accretionary prism of the island arc overrode the continental rise. The allochthonous continental rise sediments were therefore already assembled as a series of thrust packages prior to overriding of the outer continental shelf edge. Independently, Rowley and Kidd (in prep.) and Chapple (1979) proposed that continuing convergence between the two lithospheric plates resulted in: (1) overriding of the shelf edge by the Allochthon, as a composite thrust sheet, not as a detached slide block (a suggestion first made by J. Sakes (1971)), incorporation of carbonates slices occurred along the base of the Allochthon (e.g., Dorset Mountain); (2) thin-skinned shortening, by folding and thrusting within the carbonates (i.e., Sudbury Nappe and early folding of the Middlebury 'Synclinorium' (Voight, 1965, 1972)), (3) late imbrication and open folding (D_2) of the Taconic Allochthon to form the presently defined major slice boundaries, as demonstrated by the presence of thin carbonate slivers and locally Grenville basement (e.g., Ghent Block, Ratcliffe and Bahrami, 1976) along all major slice boundaries, and (4) westward-directed thrusting involving crystalline basement, of the Berkshire Massif (Ratcliffe, 1965, 1969, 1977) and the Green Mountains (maps of Hewitt, 1961; and MacFayden, 1956); these thrusts progressed outward to the Champlain Thrust and other thrusts of the shelf carbonate sequence in front of and along-strike with the edge of the Allochthon (Coney, et al., 1972; Fisher in Rodgers and Fisher, 1969).

A major difference between the models of Bird and Dewey (1970, 1975) and Chapple (1973, 1979) and Rowley and Kidd (this publ. and in prep.) is the presence or absence of a suture between the volcanic arc (Ammonoosuc) and the eastern edge of the Atlantic-type North American continental margin. Bird and Dewey accepted the 'dogma' that a continuous Cambrian(?) to Medial Ordovician, time-stratigraphic, "eugeosynclinal" sequence is present in the Eastern Vermont sequence, equivalent to the Taconic sequence and thus did not place a suture between the arc and continental margin. The second model requires a suture within the Eastern Vermont sequence. We prefer to place the suture along the Vermont Ultramafic belt, probably to the east of the Chester Dome in the Connecticut River "Synclinorium." This requires that at least in parts of the Eastern Vermont sequence where ultramafics are present, a continuous time-stratigraphic sequence does not (Gregg, 1975; Nisbet, 1976) and cannot exist (as pointed out in Burke, Dewey and Kidd, 1976).

The model proposed here requires that the initial stacking sequence of Taconic rocks progress from east (oldest-structurally highest) to west (youngest-structurally lowest). This is opposite to that commonly described for the Taconics (Zen, 1967, 1972). Palinspastic reconstructions of lithotectonic assemblages in mountain belts (Dewey, 1976, in press); foreland fold-thrust belts (Elliot, 1976, Chapple, 1978) and accretionary prisms (Seeley, et al., 1974) indicate that the stacking sequence suggested here is most common. Examples where the opposite stacking sequence, i.e., the one commonly attributed to the Taconics are rare or do not exist (Dewey, 1979, pers. comm.).

Figure 4 illustrates a schematic evolutionary for the emplacement of the Allochthon as described above.

FIGURE CAPTION FOR FIGURE 4 . Schematic Evolution of the Taconic Orogeny

Lithologies:

(1) Oceanic crust and mantle. Ophiolite.
(2) Continental crust. Everything shown is Grenville age.
(3) Accretionary prism proper. Pelitic rocks associated with polyphase deformed, tectonized pelitic rocks with associated wackes, and exotic lenses of amphibolite, pillow basalts, gabbros, and serpentinized ultramafics.
(4) Taconic rocks. Continental rise-slope sediments.
(5) Shelf sequence. Basal clastics, both arkosic sediments and sheet sands and overlying thick predominantly carbonate sequence.
(6) Black argillites, shales and slates deposited on the shelf. Correlative and equivalent black slates are present within the Taconic sequence, but are not differentiated on the figure. Black argillites are younger than medial N. gracilis zone.

Sections:

(A) Atlantic-type continental margin of eastern North America during early N. gracilis time, the first evidence of a volcanic arc to the east is seen in thin tuff bands in the Indian River Fm. and then volcanogenic cherts (Mount Merino Fm.).

(B) Trajectory of oceanic lithosphere entering a subduction zone. Possibly also applicable to continental lithosphere. On the bulge and to the east crust is in an extensional regime. If this trajectory is applicable it could explain the sub-Balmville unconformity and the so-called Tinmouth orogeny (Chapple, 1973)

(C) Taconic rocks already incorporated in accretionary wedge due to eastward subduction of the Atlantic-type continental margin. Deposition of black argillites on the rapidly subsiding eastern and central parts of the continental shelf. Continued carbonate deposition to the west. Approximately medial to late N. gracilis time.

(D) Continued subduction, now involving underthrusting of continental basement and shelf. Peeling of cover sequence from basement along deeper parts of the overthrusting wedge (Sudbury Nappe, base of Dorset Mountain). Folding of early thrust surfaces as active thrust surface migrates westward and considerably less rapidly downward. Approximately late N. gracilus zone time.

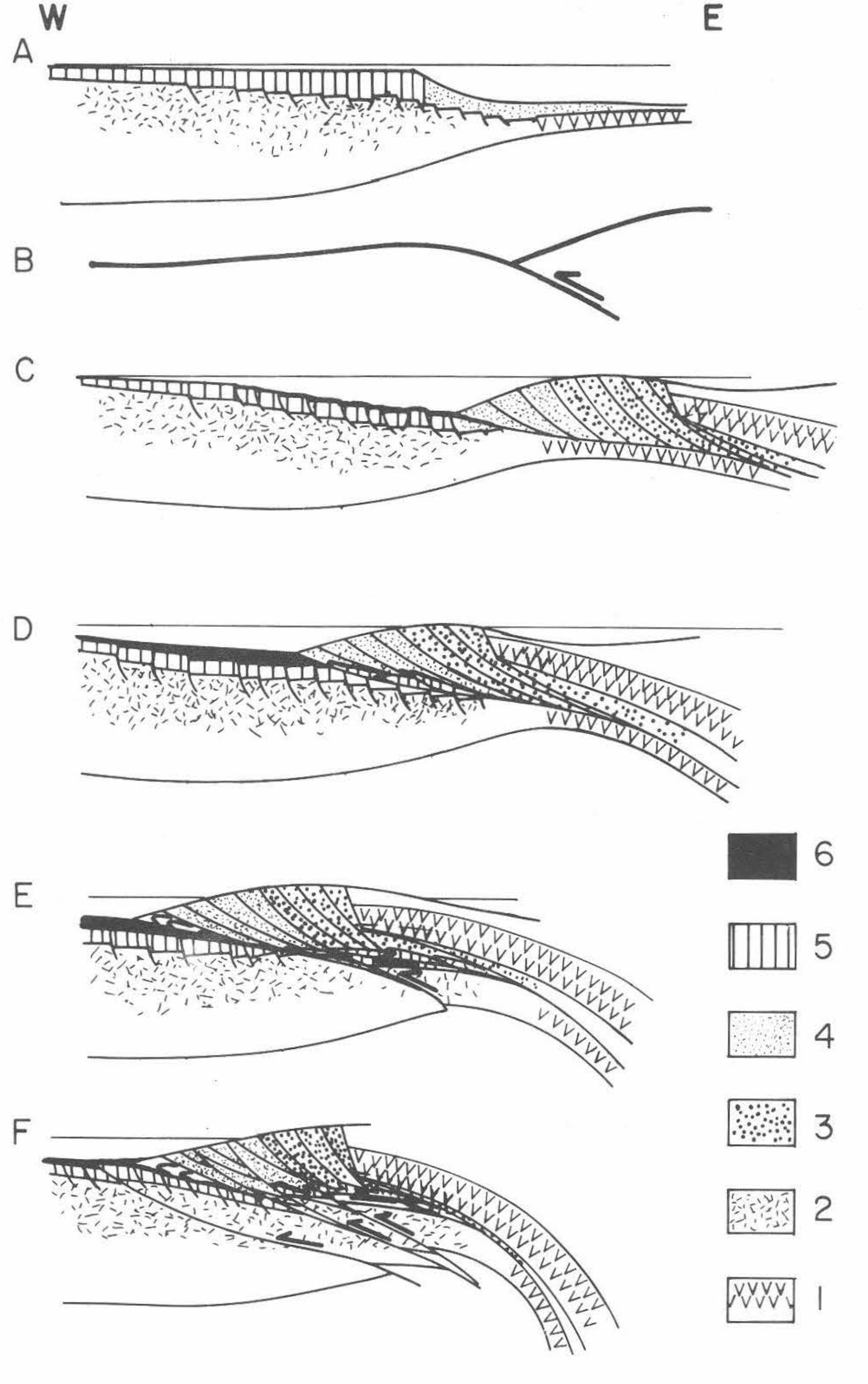
(E) Continued convergence of lithospheric plates, shortening within the continental crust (due to bouyancy effect of attempting to subduct light. bouyant continental crust) gives rise to initial imbrication of the continental crust. Subduction rates lessens as more continental crust is underthrust. Melanging of parautochthonous Austin Glen in front of advancing composite thrust wedge. Approximately C. americanus zone time.

(F) Progressive westward imbrication of the basement along listric thrust surfaces. Imbrication of the basement results in late imbrication of the overlying shelf and allochthonous Taconic sequences. Final emplacement of the Allochthon. Approximately *O. ruedemanni* zone time. Basement thrusts correspond to the Hoosic Thrust (Norton, 1967, 1976), Beartown Mountain Thrust Ratcliffe (1969), Champlain and/or Orwell Thrust (Coney, et al., 1972; Zen, 1972) in front of and to the north of the Allocthon.

Presently defined Taconic slice boundaries result from thrusting illustrated in sections D through F of Figure 4.

Figure 4.

Schematic Tectonic Evolution of the Taconic Orogeny



D.B.R. (5/79)

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Instructions to Participants

Participants must bring their own pack lunch. There will be no opportunity to obtain it during the trip. This trip involves 1 1/4 hours travel before the first stop but compensates for that by having little distance between stops in the field area. Good outcrops in the Taconics are rare -- PLEASE DO NOT HAMMER OR DEFACE OR OTHERWISE DESTROY OUTCROPS -- Please take samples only if you will be doing bona fide research with them.

ROAD LOG

Mileage

cumulative	interval	
0.0		RPI Houston Field House. Go north on Burdett Avenue.
	(0.4)	
0.4		Turn left at light. Proceed W on Route 7 and follow signs for Rte. 40N through 2 lights.
	(0.5)	
0.9		At third light turn right on 40N and stay on it to its end 54 miles away where it meets Route 22.
	(3.4)	
4.3		Sharp right at light followed by sharp left at next light. Stay on 40 N. Route 40 follows closely the western edge of the Taconic Allochthon Lowlands to the west are mostly underlain by autochthonous and parautochthonous shales and lesser greywackes (Normanskill/Snake Hill).
24-25		Road cuts on right of deformed (shelf) carbonates that are at the sole of the Taconic allochthon.
27.4		Turn right following 40N and 29E combined through Middle Falls.
	(1.0)	
28.4		Turn left following 40 N. Road runs within the Taconic allochthon for the next 9 miles
	(9.6)	
38.0		Take sharp right in Argyle. Remain on 40 N.
	(10.3)	
48.3		Passing the village of Hartford and junction with Rte. 149.
	(7.0)	
55.3		End of Rte. 40. Junction with Rte. 22.

**Optional stops: (a) 1.5 to 2.5 miles west of the junction of 22 and 40--Road cuts show gently east-dipping autochthonous carbonates whose unfolded, undeformed structural condition contrasts markedly with that of rocks in the Taconic Allochthon only 2 miles to the east.

(b) 1.2 miles north of the junction - go straight across 22 from Rte. 40 and follow dirt road to dirt parking area on right above Metawee River.

Go over stile and follow path down slope to river. Gently east-dipping (10-15°) carbonates (autochthonous or parautochthonous) extend ot north along west bank of river and also illustrate little deformed nature of platform rocks, in this case less than 1/2 mile from the western edge of the Allochthon. Dark shales on east bank have lenticular cleavage and may be part of mélange terrane bordering Taconic Allochthon.

Mileage

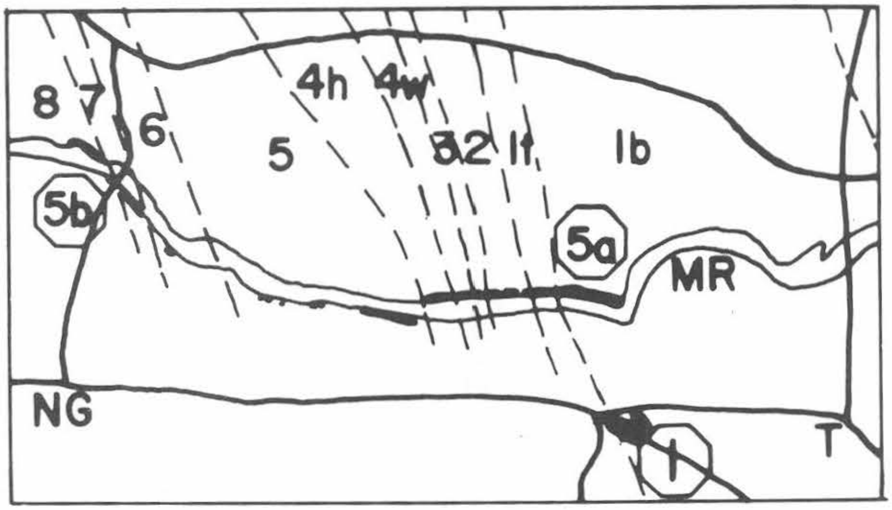
cumulative	interval	
55.3		Junction of 40 and 22. Turn right onto Rte. 22E. Pass through the village of North Granville. Immediately after next large bend, to right.
	(1.8)	
57.1		Take left fork off Rte. 22 onto County route 12 and stop. Park at roadside. Walk east along Rte. 22 (N side) past road cut and angle left down to stream at east end of cut. PLEASE DO NOT WANDER IN THE ROAD OR OBSTRUCT TRAFFIC - IT TRAVELS AT LETHAL SPEEDS HERE.
		<u>Stop 1</u> - Bomoseen Formation and part of Truthville slate. The lowest lithounits exposed in the area. The glacially-polished outcrop by the stream and the roadcut expose typical lithology in atypically good outcrop.
57.1		Continue on county route 12.
	(0.3)	
57.4		Turn left in hamlet of Truthville
	(0.2)	
57.6		Cross Mettawee River and go straight across at crossroads onto Truthville Road.
	(1.1)	
58.7		Turn right onto DeKalb Road.
	(0.8)	
59.5		Turn left onto Holcombville Road (dirt)
	(0.7)	
60.2		Entrance to quarry on left - pull in and stop.
		<u>Stop 2</u> - Mettawee Slate Formation
	(0.6)	
60.8		Tanner Hill Road on left - continue straight.
	(0.6-0.8)	
61.4-61.6		Browns Pond area (pond is visible from road at site). Turn around and park at side of road.

Mileage cumulative	interval	
		Stop 3 - Browns Pond Formation and Metawee Slate Formation.
61.6		Drive south on Holcombville Road, back the way you have just come.
	(0.8)	
62.4		Turn right onto Tanner Hill Road.
	(0.3)	
62.7		Stop 4 - Roadcut on right on hill is the beginning of Stop 4. This stop involves walking along the road for 1.1 miles on the bus-transported trip. For trips with cars, it is better to park first at the top of the hill and walk back; the remainder of the outcrops can be seen in stages moving the vehicles part of the way each time.
	(0.2)	
62.9		Contact of green Poultney Formation with red Indian River Formation. Road runs N-S.
	(0.2)	
63.1		Road curves to left - outcrop of Mt. Merino cherts on right.
	(0.2)	
63.3		Road curves to right - outcrop of Mt. Merino cherts on right at top of hill
	(0.1)	
63.4		Road runs N-S. Indian River red slates exposed on left.
	(0.2)	
63.6		Road turns to W - Poultney Formation outcrop on left reported fossiliferous.
	(0.2)	
63.8		Junction with Truthville Road (dirt). Turn left and drive south on it.
	(1.0)	
64.8		Pass dirt track to left which leads to **old Indian River slate quarries (permission required). Follow track, taking left fork when choice encountered. After fork, park when track turns sharply S after tall ridge outcrop (of Mt. Merino cherts) in trees on right (south). Head NE from track; south end of quarry should be encountered after 30 metres. Tight F_1 folds well-displayed in south wall of quarry are prominent because of pale-weathering siliceous tuff beds (meta-bentonites) up to 10 cm thick. DO NOT HAMMER, PLEASE.
65.9		Junction with DeKalb Road - continue south - road becomes paved.
	(1.1)	
67.0		Junction at stop sign with Middleton Road. Turn right.
	(0.8)	
67.8		Junction with road to North Granville. Turn left.

Mileage		
cumulative	interval	
	(0.1)	
67.9		Turn left on dirt track just before old bridge. On bus-transported trip, we will get out here and walk the 0.35 mile to the parking lot. Cars can drive in unless it is very muddy.
	(0.35)	
68.25		Parking lot by Mettawee River. Walk on foot path directly to falls at eastern end of this section. LUNCH STOP. Examine section after lunch.
		Stop 5 - Mettawee River section - Bomoseen through Hatch Hill Formations.
	(0.35)	Return to road by old bridge.
68.6		Turn left, cross bridge (on foot with bus trip; small parking lot for cars on left on south side of bridge). Find foot path down to river on right (west) side of road. Stop 5b - Mettawee River section - Indian River through Pawlet Formations. Either (in cars) - go south 0.2 mile from bridge, turn left on 22 in North Granville; follow 22 east for ~3 miles to flashing yellow light at intersection with 22A and rejoin road log there.
	(0.1)	
68.7		Or (in bus) - go north to junction with county road 12. Turn right.
	(0.9)	
69.6		Turn right at crossroads. Cross Mettawee River bridge to Truthville.
	(0.2)	
69.8		T-junction, turn left.
	(0.3)	
70.1		Stop sign at junction with 22. Turn left.
	(2.2)	
72.3		Turn left at junction onto Rte. 22A at flashing yellow light.
	(0.4)	
72.7		Turn right across green bridge.
	(0.05)	
72.75		Turn left onto Fox Road.
	(0.25)	
73.0		Cross D&H railroad.
	(0.5)	
73.5		Turn left onto Stoddard Road. Park on left just before pond. ASK PERMISSION at farmhouse on corner.
		Stop 6 - Thrust contact between Poultney and Pawlet Formations.
	-(1.3)	Continue north on Stoddard Road.
74.8		Stop just beyond white house on right at top of hill. Ask permission at white house. See sketch map of outcrops in stop description.

Mileage

cumulative	interval	
		Stop 7 - Complex geology due to thrusting involving Poultney through Pawlet Formations - this stop may be omitted if time is short.
	(0.2)	
75.0		Intersection with New Boston Road. Turn left
	(1.5)	
76.5		Intersection with Vermont State Route 31. Turn left
	(0.1)	
76.6		Turn right on minor paved road.
	(0.3)	
76.9		Turn left at T junction.
	(0.7)	
77.6		Stop just before white house on left. Park at roadside. Dirt track making 150° angle with road on right. Stop 8 - Walk up this dirt track for ~0.3 mile past outcrops of Pawlet Fm. to contact with Poultney Fm. Follow contact north into woods for ~0.1 mile. Return to vehicle(s).
	(0.5)	
78.1		Junction with Vt. Route 31. If going to Vermont, New Hampshire, etc., turn right and go north on Vt. Rte. 31 to Poultney, follow signs for Rte. 22A, follow this to Fair Haven and junction with Route 4. If returning to Capital District or points W, S and SE - Turn left. Go south on Vt. Rte. 31.
	(3.9)	
82.0		Turn right onto Fox Road at Vermont-NY border (this intersection is easily missed - if you do, go on into Granville and follow signs or ask for Rte. 22. Go N + W on 22 to rejoin the road log).
	(1.7)	
83.7		Cross D&H railroad.
	(0.2)	
83.9		Stop sign - turn right - cross bridge over Metawee River.
	(0.1)	
84.0		Turn left at stop sign onto 22A
	(0.4)	
84.4		Turn right onto Route 22
	(4.5)	
88.9		Turn left at junction with Route 40 and follow it back to Troy. (For those wishing to return to anywhere but Troy, continue west on 22 to its junction with Rte. 4. Turn left and go south about 4 miles on Rte. 4 into Fort Ann. Turn right in Fort Ann onto Rte. 149 and follow it to Rte. 9 in Lake George. Turn left on Rte. 9 and follow signs for Interstate 87 (North for Quebec, south for everywhere else.)



[Stop maps 1,2,3,5, 6, approximate scale 1:12,000, Stop 4; approximately 1:14,000. North at top, except for Stop 8. Black spots are known outcrop locations (not all of which will be visited.]

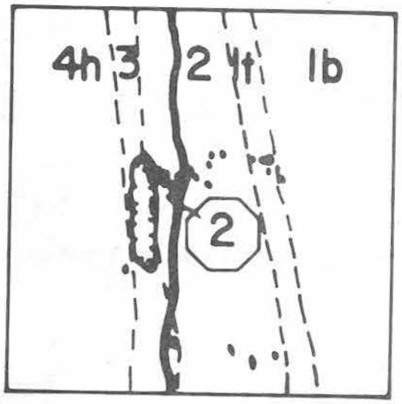
Stop 1: Roadcut and stream outcrop on NY Rte. 22 near Truthville - parts of Bomoseen and Truthville Formations. BEWARE OF TRAFFIC!

This outcrop shows typical Bomoseen lithologies in atypically clean outcrop. The dominant rock type is a poorly and lenticularly-cleaved green silty wacke. Where a polished surface is seen, as in the stream outcrop, this lithology is in part internally finely laminated and bedded, although it is not possible to detect this in the road cut or weathered outcrops. A subordinate lithology, which is almost always present in outcrops of Bomoseen, consists of rather diffusely bounded thin (cm) beds of fine sandy green quartzite. These always contain narrow extension gashes perpendicular to bedding.

The etched polished surface of the stream outcrop shows the fine bedding and some cross-lamination in the wacke, disturbed in places by sediment loading/ injection structures. Folds in this outcrop are probably due originally to soft sediment deformation and slumping, as is the disruption of the quartzites seen here and locally in the northern roadcut.

At the western end of both roadcuts, about 2 meters of thicker and well-defined planar-bedded green medium-grained quartzites from a contrasting member, which would be identified as "Zion Hill quartzite." It is not common in this area. The Bomoseen is structurally underlain and stratigraphically overlain at the western end of the outcrop by green silty micaceous slates of the Truthville Formation.

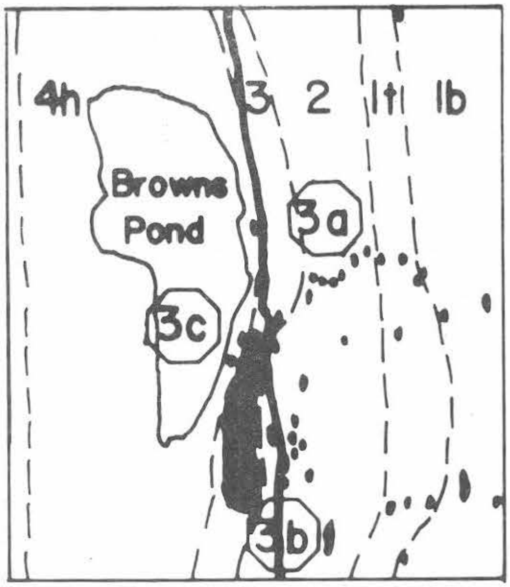
The gently to moderately east-dipping bedding and near-parallel slaty cleavage are characteristic of almost all outcrops in the Giddings Brook Slice, and imply the presence of very tight folds. A mesoscopic, tight antiformal fold with a gently south-plunging hinge is seen in the center of the northern cut. Although this example may owe its existence to disorientation of layering during soft-sediment deformation, its geometry and orientation are representative of the larger-scale folds. Bedding/cleavage orientations at the Truthville Slate-Bomoseen contact in the southern cut imply (correctly) that the succession is inverted in this outcrop. Many post-cleavage, slickensided faults with small offsets are seen.



STOP 2: Quarry adjacent to Holcombville Road - Mettawee Slate Formation and contacts.

The basal contact of the Mettawee Slate Formation is exposed on the east side of this quarry (the strata are inverted) next to the track leading to the waters' edge (bear slightly left past the ruined shed). The stratigraphically lowest beds exposed consist of 1 to 5 cm nodular micritic limestones in dark grey slate, assigned to the top of the Browns Pond Formation, as is the single 30 cm bed of laminated calcarenite, which can be seen in the northwall of the quarry in a thicker development. The rest of the rocks exposed in the quarry, stratigraphically above this calcarenite are assigned to the Mettawee Slate Formation (*sensu stricto* - see stratigraphic discussion). Some diagenetically dissolved nodular micritic limestones occur in the basal few meters of green slate, together with a limestone breccia less than a meter thick which is only exposed along the base of the east wall of the quarry (water level usually prevents easy access to this bed). Several meters of purple slate with diffuse boundaries occur within green slate on the north wall of the quarry (we will *not* examine this; purple slate may be seen in loose pieces near the quarry). The rock then turns from green to shades of grey slate, exposed on the west wall.

Fissile, sooty, black, pyritiferous slate of the basal Hatch Hill Formation lie not more than 5 meters, stratigraphically above (structurally below) this porcellanous gray slate. At least two beds of coarse dolomitic arenite occur not more than 10 m above the slate in the west wall of the quarry. These exposures which will *not* be visited on the formal field trip,** may be found by walking south on Holcombville Road from the quarry entrance to the dirt-track that runs around the south end of the quarry. Follow this track until it comes to an open space in front of a large slate heap. Outcrops are in the track and to the west in the bushes.



STOP 3: Browns Pond Formation and Mettawee Slate Formation at Browns Pond

Stop at or before the place where Browns Pond comes closest to the road. At this point a dirt track can be found leading east from Holcombville Road. Turn vehicles around, park at side of road, and follow the trace for:

STOP 3A: - Lower part of Browns Pond Formation in the type area.

10 m from road along track there is a small outcrop of buff-weathering green Mettawee Slate in the bed of the track. Track turns left and up slope. In bushes on right, thin bedded calcarenites and black slates outcrop that are much better exposed in Stop 3b (below). Track turns right; passing by cabin small outcrops also of dark calcareous slate and thin-bedded limestone are seen. Track passes small pond/swamp on left and turns right (to S). At bend in track is outcrop and loose pieces of distinctive grey-black wacke (Black Patch Grit lithology) containing large rounded quartz grains, and dark slate rip-up clasts. Track turns left (to E) and after 20 m. a low ridge occurs. To left (N) of track, exposure of about 7 m thick homogenous pale-weathering coarse quartzite (Mudd Pond Quartzite lithology). Grey-black quartz wacke found at base of outcrop. Rejoin track, finding more wacke in outcrop west of the track just north of where it turns from NE to N-trending opposite a cabin down the slope. North of the cabin, below the track, another thick quartzite is exposed. Black slate can be found in poor exposures stratigraphically below this second quartzite which we will not visit. Beyond the slope is a swamp-filled narrow valley on both sides of which Truthville slate is exposed and beyond which Bomoseen Formation is encountered. Return to Holcombville Road.

Mudd Pond Quartzite lithology may occur in 2 large beds (here-rare), one (e.g., Stop 5), or, more commonly, is not present. These highly lenticular discontinuous quartzites probably occupy channels.

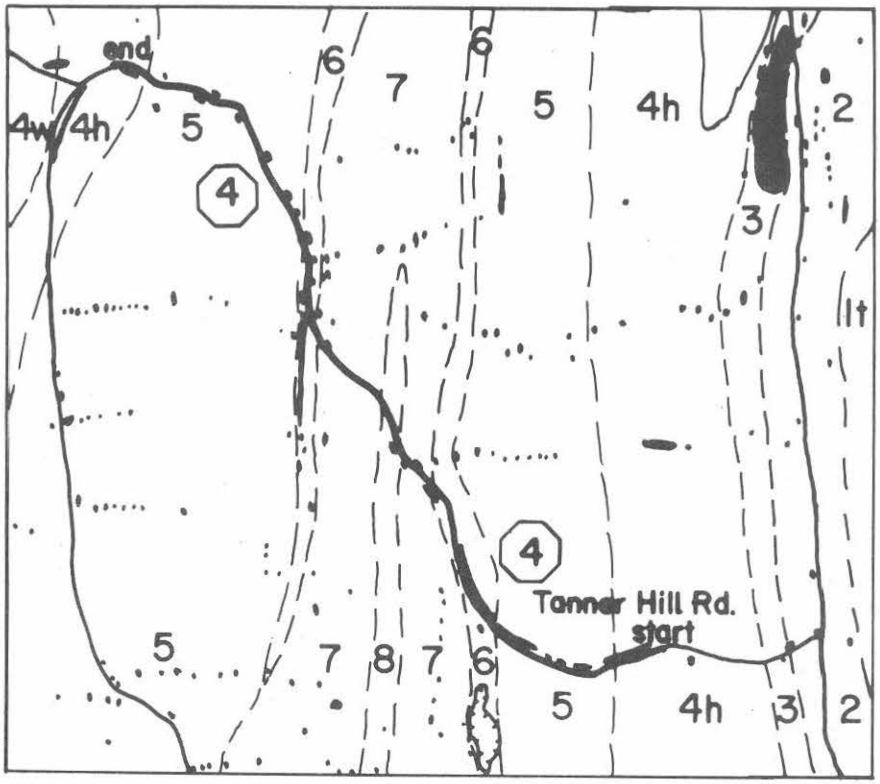
Black Patch Grit lithology is more often present than Mudd Pond, and is a better lithostratigraphic marker (see Stratigraphic discussion). Its extreme mixture of grain sizes, rip-up clasts and, locally, included pebbles and boulders, suggest a slump to debris flow origin.

STOP 3B: - Upper part of Browns Pond Formation in the type area.

From dirt track, walk south along Holcombville Road to first roadcut on left (east) side of road on small rise. Thin-bedded, dolomitic, laminated and cross-laminated, dolomitic calcarenite and calcisiltite are interbedded with black calcareous slate. Cross-lamination demonstrates inversion of these beds. This lithologic assemblage, although prominent in this local area, is not common in the Browns Pond Formation.

Walk north on the road to the roadcut on the western side. This mostly consists of a distinctive limestone breccia with close-pakced homogenous grey limestone clasts of irregular but compact shape, set in an orange weathering dolomite-rich matrix, containing some quartz grains, that occupies a small proportion of the whole rock. Probable crack-injection relationships between matrix and clasts can be seen in places. Contacts of this breccia with areas of dark fine-grained thin bedded limestone and calcareous slate are seen, with the bedding truncated and no convincing signs of faulting. At the north end of the outcrop a possible block of breccia 2 m. across rests within bedded material. In other places the bedded material seems to be in large clasts within or perhaps forming a matrix to large blocks of the breccia. Thus there seems to be evidence of mutual breakup of breccia and bedded limestones; however, there is no evidence that the breccia itself was formed in situ. Instead we suggest that it was deposited as consolidated blocks. Theokritoff (1964) reports fossils from this outcrop. This distinctive breccia is only seen, when it occurs, very close to the top of the Browns Pond Formation. A rather similar breccia, seen rarely in the overlying Mettawee Slate Fm. is in a much thinner bed and has a significantly larger proportion of matrix. Debris flow deposits with carbonate blocks and slaty matrix are more common than this type in the Browns Pond Formation and will be seen at Stop 5.

STOP 3C: - Go through gate in fence on the western side of the road, north of the roadcut just examined. Walk west to shore of pond across outcrops of distinctively buff-weathering green slate of the Mettawee Slate Formation. These are stratigraphically above the carbonates of the Browns Pond Formation, just seen. At the pond shore, a ledge-like outcrop exposes sooty black pyritiferous slate and some beds of laminated calcarenite and calcisiltite. Inverted cross-lamination can be seen. At the north end of the ledge, a 10 cm bed of pebbly limestone breccia is seen containing a minor amount of dark phosphatic pebbles. This green-black slate change is the upper of the two black-green boundaries in the area and correlates with the one seen in other areas of the Taconics. The locally developed limestone and black slate assemblage can be mapped as West Castleton; however, it is perhaps more easily mapped as a basal member of the Hatch Hill Formation. The limestones in this outcrop, and in 3b are probably turbidites, mostly representing the D and E horizons.



STOP 4: - Hatch Hill, Poultney, Indian River, Mt. Merino and Pawlet Formations repeated across syncline-Tanner Hill Road.

This stop entails walking for 1.1 miles west along Tanner Hill Road. Start at roadcut on north side on slope of hill. Thin to thick (1cm-3 m) bedded dolomitic sandstone and quartzite beds; distinctive orange deep weathering rottenstones, interbedded with fissile black pyritiferous slate. Thickest beds are internally massive, very close sandstones and contain rip-ups of finer dolomitic sandstone. Thinner beds are finer grained, parallel laminated, uncommonly cross-laminated and only some show grading. In this outcrop, one side of a channel (proving inversion of this section) can be seen at the base of the thickest bed. The dolomite in these sands (10-50%) was originally clastic although now recrystallized.

The thick beds are either grain flow deposits or traction deposits at the base of large turbidity flows; in either case they fill channels. The thinner laminated beds are more problematic; those showing grading are probably turbidites, but the laminated beds with sharp tops and bottoms are harder to interpret. They are probably too coarse to represent deposits on levées of submarine turbidite channels.

The top of the Hatch Hill Formation at this locality, proceeding up the hill, consists mostly of black slate with a few very rotten weathering sandstones. If limestones occurred in this black slate, as they do in places, they are traditionally (Theokritoff, 1964; Potter, 1972) placed as a basal member of the Poultney -- another instance where the lithostratigraphy might usefully be changed. However, the resulting confusion might be worse than the existing kind.

Just west of the small borrow pit on the north side of the road, the low outcrop shows a rapid gradation from black to green slate with thin subordinate dark slate laminae. This is the base of the Poultney Formation. Opposite the quarry entrance, thin (mm) silty quartzite laminar beds are seen; these are characteristic of the Poultney and may be seen in the low, more or less continuous outcrop on the north side of the road, in varying abundance, throughout this formation. Their universally silty grain size, fine parallel and lesser cross laminations, the absence of associated coarser quartz-rich sands and the abundant indications of burrowing in the associated slightly silty slates, (particularly well shown near the top of this section), are suggestive evidence that these silty quartzites were deposited by deep contour currents and that they are contourites.

By a track leading off the road to the north a 1 m. section of maroon slate is exposed and two more sections containing maroon slate, one 5 m thick, are exposed to the west, up the hill. This maroon horizon can be traced locally to the north but is not found elsewhere in the area and is regarded as rare. The color of the slate is somewhat different and moderately distinguishable from the purplish Mettawee slate below and the red Indian River slate above.

In the whole of the section thus far up to the Indian River Formation contact, bedding is sensibly parallel with cleavage, reflecting the tightness of the large-scale folds.

The Indian River Slate Formation follows across a 5 m thick zone of interlayered red and green slate. The sea (blue) green porcellanous slate of the interlayered zone contrasts with the olive-green and silty nature of the Poultney slate and sea-green slate of this type is always placed with the Indian River, since red slates within the Indian River can be seen elsewhere to alter to this type. A good illustration of this may be seen at the western contact (top) of the Indian River exposed on the west side of the road about 0.2 mile north of the contact with the Poultney Fm., where relic patches of red slate may be seen diffusing into the sea-green slate. Elsewhere the Indian River may in places be altered to this green slate across its entire thickness.

Rare silty quartzite laminae identical to those in the Poultney occur within the lower part of the Indian River. Pale buff-weathering laminae or layers, pale greyish-white on a fresh surface, are siliceous but well-cleaved and interpreted to have been silicic ash beds, now tuffs. These are slightly better developed in the second occurrence of Indian River, 0.5 mile along the road, but the thickest beds (10-15 cm) can only be seen in exposures not readily shown to large groups. The spotty appearance of many cleavage surfaces in the Indian River, as if coarse sand grains are scattered through it, is due to ellipsoidal, microcrystalline quartz aggregates, probably recrystallized radiolaria.

Beddrug-cleavage obliquities reflecting mesoscopic folds are seen locally within this belt of Indian River Fm.

The source of this notably red clay is proposed (Bird & Dewey, 1970) to be terra rossa soils developed on the karst surface that cuts the sub-Black River and Trenton platform carbonates. The soils provided the clays transported out to the continental rise; the rocks do not seem to provide clues to their last agent of transport, which may have been contour currents.

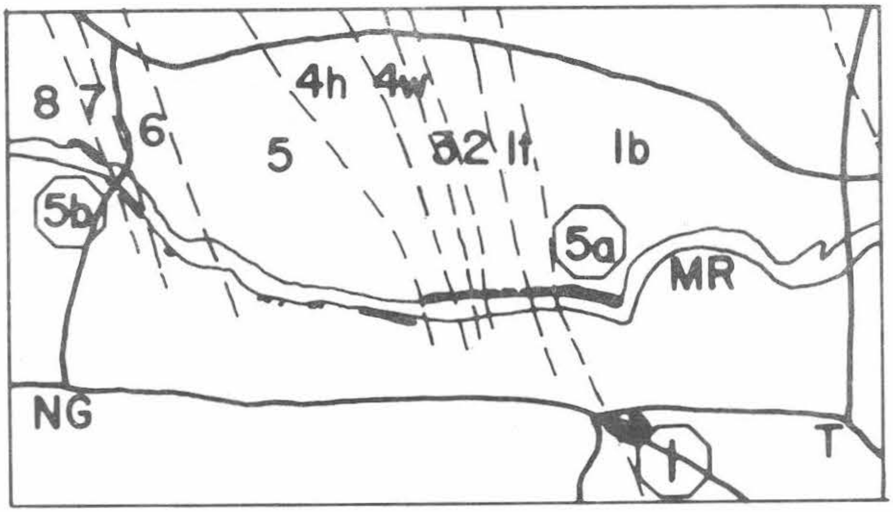
From the north-south road segment along which Indian River is exposed, the road turns west. On the southwest side there is a small outcrop of greyish cherty slates transitional to the Mt. Merino Formation, whose lower member is seen in a cut on the northeast side of the road. Chalky-weathering dark cherts 1-5 cm thick are interbedded with dark grey and black slates and cherty slates. The upper member of the Mt. Merino Fm. is not seen here or elsewhere on this trip; it consists of a sooty black slate that is commonly graptolite-bearing (Zones 11 and 12 of Berry). The two members can be shown to be a facies of one another, with the variable being the abundance or lack of chert.

To the west of this outcrop, where the road turns back to the north, a small excavated outcrop to the west and southwest of the road exposes fine silty greywackes of the basal Pawlet Formation. A fine development of a spaced cleavage oblique to bedding and bedding-parallel parting produces a well developed pencil-slate.

North and west along the road, the major synclinal axis is crossed and then the stratigraphy is repeated in reverse order. At the top of a gentle hill, an outcrop of the cherts of the Mt. Merino Fm. is seen on the right, followed by red slates of the Indian River down the slope on the left. At the north end of this outcrop the contact with the Poultney Fm. is exposed. Intermittent outcrop of Poultney Fm. occurs as the road turns from N-S to about E-W. Just around this bend, a larger outcrop of Poultney on the left has been reported by Theokritoff (1964) to contain graptolites of Berry's Zone 6. The next outcrop on the left contains black slate and lesser dolomitic arenites of the upper Hatch Hill Formation; Theokritoff (1964) reports dendroid graptolites of Tremadocian age from this cut. More Hatch Hill Fm. outcrop occurs at and south of the intersection with Truthville Road.

All along this road, except locally near the core of the syncline, bedding and cleavage are sensibly parallel and dip 20-40° east. We emphasize that this requires the large-scale folds to be near isoclinal in geometry with axial surfaces dipping at the same attitude as the slaty cleavage.

End of Stop 4.



STOP 5: - Mettawee River section by North Granville - Bomoseen To Pawlet

STOP 5A: - Starting at waterfall where Mettawee River bends sharply north and smaller stream joins it from SE. Get to top of falls by going up the bank and around behind the small cliff, in the woods. Typical Bomoseen lithology of green silty wacke and cm. thick diffusely bounded, green fine-grained quartzites seen beside falls and in cliff. An M-style fold of D_1 generation may be seen at the base of the cliff. Where the cliff curves away from the river into the earth bank, the contact with the Truthville Slate Formation is exposed.

This consists of typical silty mica-spangled olive-green slate: very close to its contact with the Bomoseen, there is a 20 cm thick bed of clean medium-grained quartzite, of Mudd Pond type. Thicker occurrences of Mudd Pond Quartzite in this stratigraphic position exist in several places. A thin lenticular occurrence of green, planar bedded quartzite of "Zion Hill" type is seen in the top of the Bomoseen at the base of the cliff. A few thin (mm) laminae of silty quartzite are present here in the Truthville Slate Fm.

At the first rapids with a large erratic boulder in midstream, the first black-green boundary is exposed, the contact between the Truthville Slate Fm. and the Browns Pond Fm. The slate grades rapidly from green to dark grey and loses its silty nature and mica-flakes. Upward (stratigraphically) there is a debris flow with limestone, laminated micrite and dark slate clasts in a slaty matrix. Above this, at the small promontory, several 30 cm to 4 m thick beds of Mudd Pond-type quartzite occur within dark slate and minor black calcareous wacke. (Black Patch grit lithology). Large load casts can be seen on the base of the quartzite beds and evidence is seen for injection of black slate and wacke into the quartzite. A small fault cuts across the quartzites parallel to the stream.

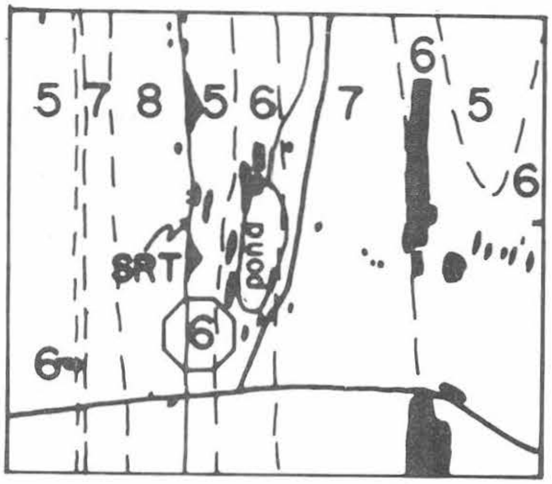
Small quantities of black quartz wacke are found in black slate for a short distance above the quartzites, as at Stop 3a. Here it is not clear if they are pieces in a debris flow or in lenticular beds. In either case their shapes have been much changed by flattening in the slaty cleavage. Very thin bedded calcareous black slate and slaty limestone occur to the west. Opposite a large erratic block on the south bank, there is 2 m. thickness of limestone breccia containing calcarenite to micrite and black slate clasts, in a slaty matrix. Bedded micrites of varying nodularity, 1-10 cm thick, are found in calcareous dark grey to black slate above this breccia. Some thicker micrite lenses in this interval are associated with soft-sediment disruption. At the east end of the stone foundation of an old mill, there is a rapid gradation from dark grey and black to green slates over a meter or two. Micrite, mostly in disconnected nodules, occurs on both sides of this contact in a similar manner to the same one seen at Stop 2, between Browns Pond Fm. and Metawee Slate Formation.

If the water is high, it will be necessary to go up the bank and around the outcrop of green slate under the mill foundation. Some thin calcisiltite and a few calcarenite beds occur in the green slate; no purple slate exists here, as is the case in many places, particularly on the western side of the area. The slate becomes greyish in its upper part and just to the west of a small cave in the outcrop, there is a contact with black slate of the overlying unit.

This might be mapped as West Castleton, since laminated calcarenites, calcisiltites and micrites are exposed within the base of this black slate. However, they form a very thin interval and are succeeded, close to another stone wall foundation, by orange-weathering dolomitic sandstone and quartzite beds typical of the Hatch Hill Formation. These can be found in fairly continuous outcrop, with decreasing dips to about 10°E by the parking lot. The thicker arenite beds here are at about the same stratigraphic level as those seen at the beginning of Stop 4 on Tanner Hill Road.

To the west along the river, there is reasonably good exposure along the south bank, exposing Poultney Formation from a short distance west of the parking lot. We will not visit this part of the section. Instead, walk (if on bus trip) or drive back to the road, turn left and cross the bridge. Park cars on the left just across the bridge, and find the footpath down to the river on the west side of the road.

STOP 5B: - Dark slabby cherts of the Mt. Merino Formation are exposed under the bridge. To the east of the bridge, pale green slates are assigned to the Indian River. The cherts are somewhat disturbed by minor faulting. To the west, across an unexposed interval, outcrops of well-bedded silty and sandy greywacke with interbedded grey slates belong to the Pawlet Formation. These are better exposed on the north bank, where inverted sedimentary structures can be found, but it is not feasible to take a large group there.

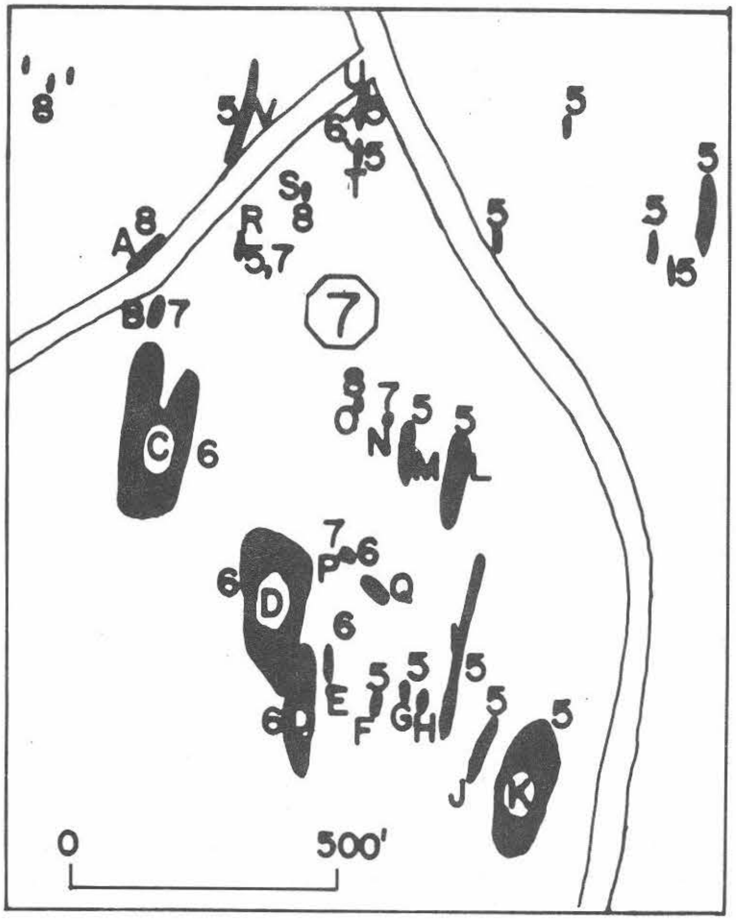


STOP 6: Stoddard Road Thrust

At this stop we will visit outcrops of Indian River, Poultney, and Pawlet Formations. Indian River and Poultney Fms. lie on the western (lower) limb of a large F_1 syncline which is cored by Mount Merino Fm. (not visited). The lower limb of this syncline is thrust westward over Pawlet greywackes which lie in the core of an F_1 syncline to the west. This stop is important because here a thurst relationship can be unequivocably demonstrated due to the well constrained stratigraphy and regional structural framework. Equally important is the presence of fault or at least fault-related rocks in outcrop. Mesoscopic and microscopic examination of these fault-related rocks constrain the timing and style of faulting in this area. The stop also demonstrates that caution is necessary in statements concerning the density of faults in regions where stratigraphy is less well constrained.

Indian River; hard, green, well cleaved, porcellanous slates, crop out alongside Stoddard Road and south and immediately adjacent to the pond. The small abandoned quarries to the north of the pond are in the Indian River. To the west of the Indian River are a series of low outcrops of gray-green, less fine grained argillites and slates with interlayered, thin silty quartzites, characteristic of the Poultney Formation. A short distance to the west-northwest is a steep, 1-1.5 m high ledge of medium to dary gray, fine silty, moderately to well cleaved, moderately fissile argillite with thin (0.1-3 cm), silty, often laminated, discontinuous and lensoid quartzites. At the base of the ledge are a series of small outcrops of poorly exposed, though very distinctive, gray weathering, medium to dark gray, medium grained, lithic greywackes of the Pawlet Formation. On the hill to the northwest the greywackes are well bedded and interlayered with dark gray slate.

The 1-1.5 m high ledge outcrop, containing Poultney lithologies, is interpreted to be fault-related. The mesoscopic character of these fault related rocks is more completely described in the structure section above. Important features to note here are: 1) the mesoscopic foliation in the argillite matrix, 2) sharp, tectonic truncations of laminations in the quartzites, 3) shape preferred orientation of the discontinuous quartzites, 4) presence of isolated fold hinges (none have been noted so far), and 5) lack of mineralization, brecciation or other evidence so commonly cited as evidence against the presence of thrust faults in other parts of the Taconics.



STOP 7: (Optional) Complex Stratigraphic and Structural Relations

This stop illustrates the problems that result in regions of complex stratigraphic and structural relationships. Specifically the problems here include: (1) difficulty of assigning lithologies to lithostratigraphic units in areas where stratigraphic succession is disrupted, even in areas with reasonably good exposure, (2) all contacts are unexposed or at best poorly exposed and thus the nature (sedimentary or tectonic) of the contacts is uncertain, (3) local relationships that are not in accord with regional relations, and (4) problems of distinguishing between pre-D_1, syn- to late D_1 or D_2 structures.

Very brief lithologic descriptions of each of the outcrops (lettered) is provided below. Possible lithostratigraphic unit assignments are given. Participants visiting the outcrops may thus experience for themselves the local complexities and problems. Structures observable in these outcrops include F_1, F_2, S_1, S_2 and local late veining.

(A) Dark gray partly silty argillites with thin silty greywackes. Pawlet.

(B) Black argillite, moderately cleaved. Mount Merino.

(C) Pale green to blue-green (sea green) moderately hard, well cleaved slate. Indian River.

(D) Pale green to pale gray, hard, moderately to well cleaved argillite with thin silty quartzites(?) (possibly tuff bands). To the south, red well cleaved slate. Indian River.

(E) Pale gray to pale green to gray argillite. Indian River.

(F) Medium gray argillite with moderate cleavage. Poultney-top of the Indian River.

(G) Gray weathering, medium to dark gray, fine silty argillite. Poultney.

(H) Same as G.

(I) Gray weathering, medium to dark gray, some almost black, slightly fine silty, moderately-cleaved argillite. Also 25 cm layer of brown weathering gray, fine grained, laminated, dolomitic arenite. Poultney (?).

(J) Gray weathering, dark gray, fine to partly silty moderately cleaved argillite. Poultney.

(K) Gray to dark gray, fine to silty argillite, moderately to poorly cleaved, locally highly veined. Poultney.

(L) Medium to dark gray, fine to partly silty argilite, moderately cleaved, with thin (1-15 mm) silty quartzites. Local bioturbated color laminated slate. A few 2-10 cm thick, brown weathering, fine-grained, dolomitic quartz arenites in medium gray argillite. Poultney.

(M) Pale gray-green, argillite with thin (less than 15 mm) silty quartzites. Poultney.

(N) Gray weathering, pyritiferous(?), dark gray to black siliceous argillite.

(O) Brown weathering, calcareous, medium to fine grained greywacke. Pawlet.

(P) Pale green-gray, moderately soft, well cleaved argillite. Indian River. Just to the north (approximately 3 m), sooty black graptoliferous (poorly preserved) argillite. Mount Merino.

(Q) Medium to dark gray moderately to well-cleaved argillite with some dark gray siliceous mudstones. Poultney(?), Mount Merino(?).

(R) Medium gray, moderately hard argillite. Poultney(?), Mount Merino(?).

(S) Brownish weathering greywacke with minor dark gray slate. Pawlet.

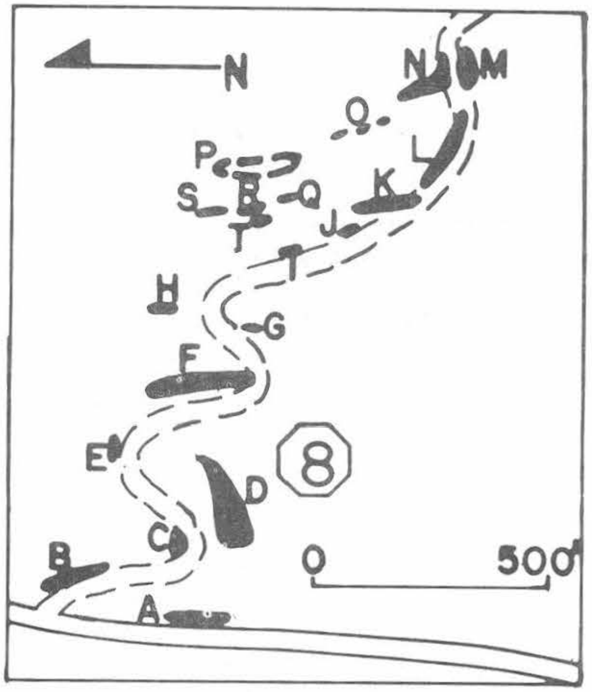
(T) Medium to dark gray partly silty argillite with thin, fine siltstone layers. Poultney.

(U) Medium to dark gray partly silty argillite with thin fine siltstone layers and a few silty quartzites. Poultney. On west side of outcrop small amount of pale green to blue green well cleaved argillite. Indian River (?).

(V) Medium gray partly silty argillite with moderately to well developed cleavage. Poultney(?) Mount Merino(?).

Regional Picture:

To the south along strike, a well defined east-facing sequence from Poultney to Pawlet lies on the upper (eastern) limb of a large F_1 anticline. This limb is truncated to the east by the New Boston Thrust, which juxtaposes Poultney over east-facing Pawlet greywackes. To the north and immediately to the west is a small klippe of Pawlet Formation. Thrusting of the klippe probably occurred as a pre- to early D_1 event. The overall distribution of lithologies outlined above suggest the presence of a north or west-facing sequence. This is not compatible with the relationships defined both to the north or the south. For this reason we suggest that the area is disected by a series of essentially phacoidal thrust faults which give rise to the apparent reversal in facing.



STOP 8:

The purpose of this stop is to examine a typical section of Pawlet Formation and the complex character of it's contact with stratigraphically underlying lithostratigraphic units. Most workers, including Zen (1961, 1964) Shumaker (1967) and Potter (1972) have argued that the Pawlet Formation unconformably overlies lower Taconic lithostratigraphic units. Shumaker (1967) interpreted the Pawlet contact at this locality to be sedimentary and unconformable, possibly angular. We interpret this contact to be tectonic. Support for this contention include the following observations: (1) complex interleaving of lithostratigraphic units. (2) East-facing Pawlet greywackes just below (topographically) the overturned contact. (3) Regionally, there is a marked apparent thinning from the lower (west) limb to the overturned upper (east) limb of the F_1 syncline defined by the Pawlet Formation, suggesting that part of the upper limb has been tectonically excised. The outcrops visited at this stop illustrate the extreme difficulty of demonstrating the precise nature of this contact on the outcrop scale.

The majority of the outcrops are of Pawlet greywackes and slates. Other lithologies include: (1) dark gray variably siliceous argillites and slates. (2) Medium gray fine silty argillites with thin, mostly silty quartzites. Poultney. (3) Medium to dark gray finely cleaved slates with a silky sheen on cleavage surfaces. Poultney (?). (4) Green, gray and gray - green fine well cleaved slates. Minor thin calcareous siltstone (silty limestones) and quartzites. Mettawee (sensu lato). Figure   shows the distribution of lithologies. Numbers refer to the lithostratigraphic units, following the scheme of Figure   1b . Letters refer to the brief descriptions that follow.

Descriptions:

Start at small roadcut on the main road 10 m south of H. & H. Slate Co. quarry access road.

A - Greywackes and slates. Folded by F_1, moderately NE plunging fold with an axial surface slaty cleavage. Note cleavage refraction through greywackes. Moderately developed steep spaced crenulation cleavage. Veining and late disruption of the south end of cut.

B - Low outcrops on the east side of access road. Greywackes and slates. East-facing.

C - Bulldozed greywackes at the first turn.

D - Across small stream, south of C. West part of outcrop, east-facing bedded greywackes and slates. Central part of outcrop, deformed, tectonically sliced greywackes and slates. East side of outcrop, bedded, east-facing greywackes and slates in gently south plunging antiform.

E - Bedded greywackes, bounding steep zone of veined and disrupted greywackes.

F - Bedded greywackes and slates. Slates more abundant. Bed thickness varies from a few to 10's of cms. Fresh greywacke exposed at corner. Note medium grain size and lithic component.

G - Very small, mostly covered outcrop of greywackes and slates.

H - More greywackes to the north of access road.

I - Small outcrop of thinner (4-8 cm) greywackes and slates. Possibly west-facing.

J - Another outcrop on the east side of the access road, same as I.

K - Contact. Three lithologies present, from west to east these are: discontinuous, west facing(?), greywackes and slates. Dark gray, variably siliceous argillites and slates, some chert. Interlayered medium gray fine silty argillites and thin, fine grained to silty quartzites, typical Poultney. The thin siliceous lithology is often observed at this contact. Contact appears sedimentary at this outcrop.

L - Predominantly medium gray argillites and slates with thin quartzites. Poultney.

M and N - Bulldozed cut in medium to dark gray slates, thin calcareous siltstone layers, thin quartzites and minor Pawlet-like greywacke. Relationships of lithologies not clear, but probably tectonic. Second generation structures prominent.

O - Small outcrops along jeep track, taking off to the north of the access road. Lithologies include gray to dark gray slates, greywackes, gray, green and gray-green slates, some slates with thin quartzites, some dark gray siliceous slates.

P - Scattered outcrops of finely cleaved medium gray slate (Poultney?). Locally highly veined.

Q - Chalky weathering, medium to dark gray, variably siliceous argillites. Brecciated chert. Greywackes downslope.

R - Graywackes

S - Same as Q. Note greywackes and small amounts of gray slate with thin quartzites 1 m below ledge. Also, in bottom part of ledge of siliceous argillite a 'layer' of greywacke lithology truncates the siliceous lithologies across at least the cleavage. This greywacke 'layer' does not possess bedding characteristics and is not believed to be of primary sedimentary origin. Other possibilities include injection or tectonic slicing.

T - Downslope to the southwest of R, small outcrop of medium gray slates with thin quartzites, typical of the Poultney. Greywackes occur both above and below this exposure.

As you can see simple contacts cannot be drawn in this area.

MARINE AND FLUVIAL DELTA PLATFORM ENVIRONMENTS OF THE TRANSGRESSIVE CLASTIC CORRELATIVES OF THE MIDDLE DEVONIAN (ERIAN) MOTTVILLE LIMESTONE MEMBER OF THE SKANEATELES FORMATION IN EASTERN NEW YORK STATE

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INTRODUCTION:

In west-central New York, the base of the Skaneateles Formation is in arenaceous limestone and coquinite designated by Smith (1916) as the Mottville Limestone. When traced eastward toward Kingston, N.Y., this unit and the associated calcareous siltstones thicken and grade into lenses of calcareous, planar crossbedded sandstones and dark gray laminated and bioturbated shales and coquinites, without the diagnostic faunal correlatives (Grasso and Wolff, 1977).

The sequence is interpreted as a zone of carbonate deposition (organic and inorganic) formed on the marine delta platform during a temporary clearing of the Proto-Atlantic seaway. Eastward this clearing produces a short transgression enabling a reworking of the sandy sediments on the marine delta platform to produce a series of offshore and nearshore sand bars and associated embayments. A major embayment located between two nearly-merging lobes of the alluvial delta platform forms an area of practically restricted circulation producing a variety of shallow water environments (nearshore and river mouth bars, sand flats, channels, beaches) and restricted environments (irregular shelf ponds, lagoons, mudflats, interdistributary bays and swamps). These "transgressive" sediments are abruptly truncated by a sequence of gray "channel" sandstones and "overbank" olive-green to maroon silty shales - the return of distributary progradation as the rivers of the classic Catskill Delta Complex once again spill their sediments across the subsiding basin.

This field trip will examine the transgressive and restrictive nature of the marine sediments that are wedged between the initial redbeds of the Catskill delta. Some of these stops and environments described here have also been described elsewhere. (Buttner, 1968; Wolff, 1969; Pedersen, Sichko, Wolff, 1976)

PREVIOUS WORK

The earliest studies of the Middle Devonian strata in this region, described as the "Hamilton Group", date back to the work of L. Vanuxem in his report of the "Third Geological District" for the newly conceived N.Y. State Geological Survey (1842). The sequence was reexamined by Darton (1894) who included the Skaneateles and Marcellus Formations in the Hamilton Group, and by Prosser (1895, 1899) and Grabau (1906) who subdivided these Formations but provided erroneous correlations. Cooper (1930,1933) clarified the subdivisions across the state, and aided Goldring (1935, 1943) in tracing these subdivisions eastward from the Schoharie Valley. Wolff (1969) presented a simplified nomenclature for these subdivisions, but the lack of definitive biostratigraphic criteria for correlation has prevented their acceptance. This nomenclature has since undergone further modification after more extensive field investigation. (Pedersen, Sichko, and Wolff, 1976; Grasso and Wolff, 1977)

Once the time-stratigraphic regional correlations of the Catskill Delta were firmly established for the Middle Devonian Hamilton Group (Cooper, 1930, 1933) and the Upper Devonian sections (Chadwick, 1933) more detailed correlations and sub-environmental discriptions were possible. It became recognized that the thick wedge of coarse clastic sediments spread across N.Y. and Pennsylvania is constructed within a thin but widespread series of stratigraphic markers that are lithologically distinct and that do not change facies as rapidly as adjacent strata. During the Upper Devonian, it is the black shales that cut through the various deltaic phases as marker beds (Richard, 1964; Sutton, Bowen and McAlister, 1970). These were interpreted as short-lived pulses that produced regional stagnation and restricted circulation, and that separated the Catskill Delta into 5 overlapping progradational sequences (Wolff, 1965).

During the Middle Devonian period the stratigraphic marker horizons are limestones and calcareous sandstones (McCave, 1968, 1973; Johnson and Friedman, 1969) that can be traced eastward into their transgressive clastic correlatives. The purpose of this trip is to examine the initial sequence that provided the characteristic patterns of shallow water, high energy, and restricted circulation - patterns that would later be used to subdivide and identify the environments of the Catskill Delta Complex (Friedman and Johnson, 1967).

REGIONAL STRATIGRAPHY:

As designated by Smith (1916, 1935) the Mottville Member at the base of the Skaneateles Formation consists of 0.3 meters of limestone (biomicrite) at the type section in the Skaneateles U.S.G.S. 7½' quadrangle. The unit is found associated with underlying fossiliferous and calcareous siltstones and shales. This lithology and association persists eastward toward the Chinango Valley where a 0.2 meter coralline and crinoidal limestone appears, and where the entire unit represents and interval of 16 meters. Eastward the limestone and associated shales can be traced to the Unadilla Valley (west of the field area) where it grades into a section of megarippled and planar crossbedded sandstones and calcareous shales. As a limestone, the Mottville Member makes its last appearance; as a calcareous crossbedded sandstone with a diagnostic marine fauna, it makes its last eastward appearance in the Susquehanna Valley (west of this field area) - Grasso and Wolff, 1977). However, the lithologic associations and marine fauna persist eastward into Richmondville and (finally) into the Schoharie Valley where it will be viewed on this trip. The diagnostic fauna (now limited to coquinite horizons) with the large brachiopods Mediospirifer and Paraspirifer have not been found - thus the use of the term "clastic correlatives". Based on the sediment facies and stratigraphic nomenclature established by Fisher and Richard (1975) the various members of the Marcellus and Skaneateles Formations have been placed into the deltaic environments of Figure One.

The Marcellus and Portage facies, which represent the seaward basin and distal delta slope environments are found west of this area at this interval, and will not be observed. In eastern N.Y. the Hamilton facies is represented by the Otsego and lower Mt. Marion Members. These units consist of dark gray shale, burrowed mudstone, and interbedded light gray siltstone and sandstone, 2-4 cm. to 0.9 meters thick. These sandstones become thicker and coarser higher in the section, and frequently contain "ball and pillow" structures. In addition, they contain a moderately diverse benthic and epipelagic fauna of brachiopods and pelecypods.

The Chemung facies (represented by the Solsville, Panther Mt. and upper Mt. Marion Members) consists here of medium-grained sets of planar cross-bedded sandstones with flat or megarippled basal contacts interbedded with horizontal sandstones (flagstones) siltstones and dark shales. Characteristic structures include: low angle planar cross-bedding, scour and fill pockets, current lineation, oscillation or current ripples, lateral and vertical burrows, horizontal laminations and wavy or flaser bedding. Coquinites, pebble beds plant fragments, and shale clasts also occur in certain units.

The Catskill facies, represented by the Ashokan and Plattekill Members, consists of olive-gray, olive-green, and maroon-red siltstones and mudstones, truncated by thick sets of medium-coarse grained gray planar and trough crossbedded sandstones. The location of the field trip stops within each of these members is indicated in Figure Two.

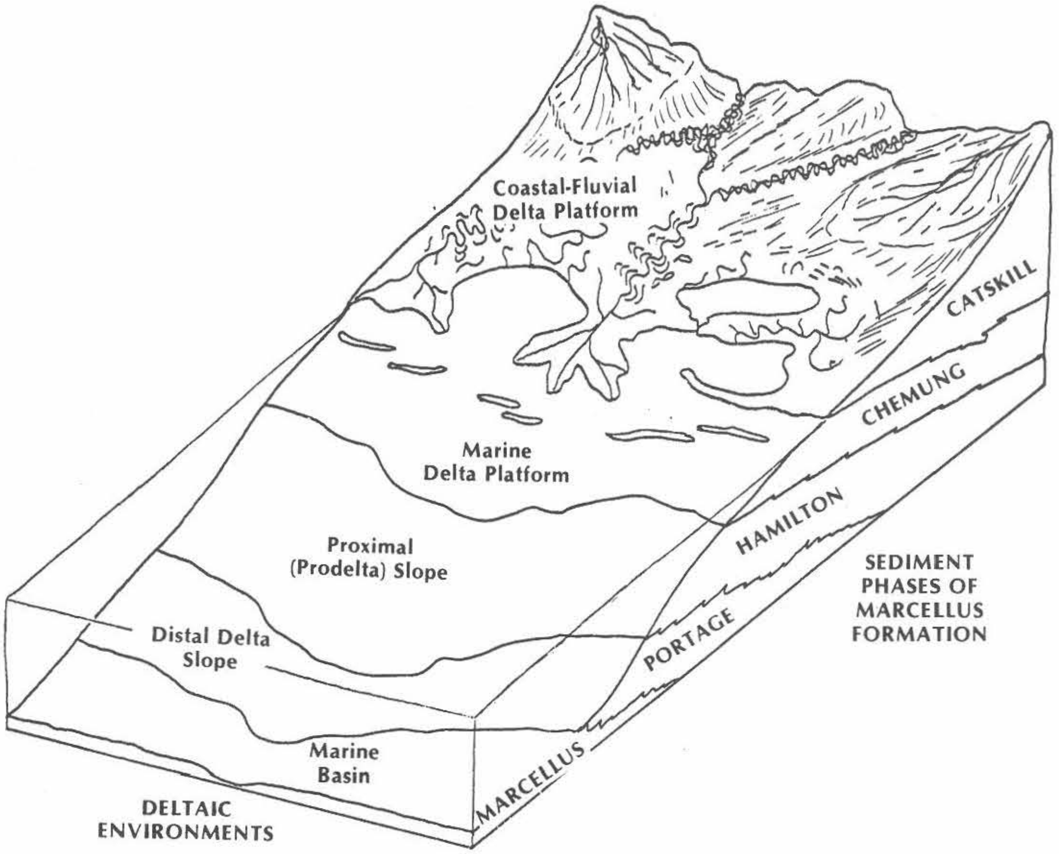


Figure 1. Depositional phases of the Devonian "Catskill Delta Complex" and this associated deltaic environments within the Marcellus and Skaneateles Formations.

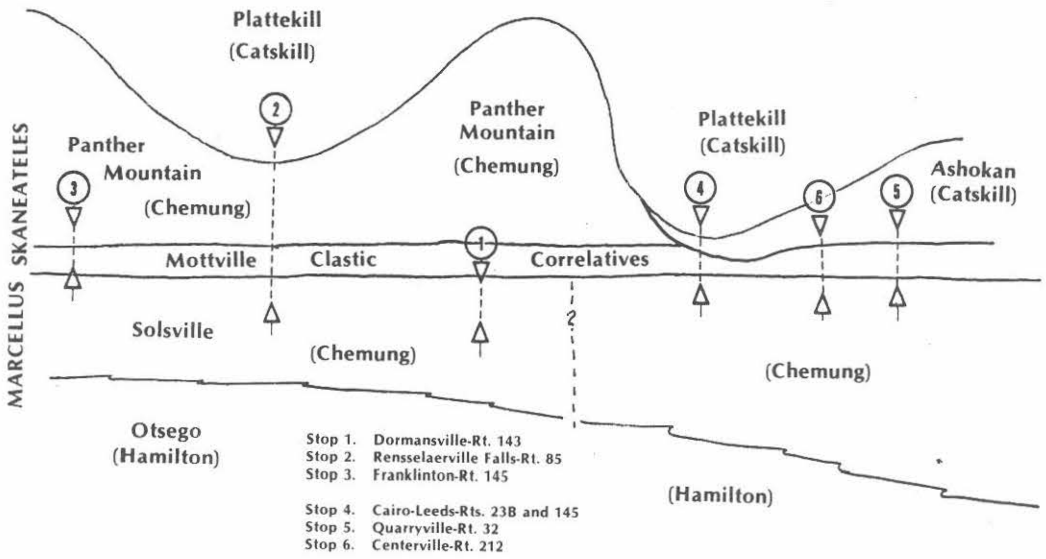


Figure 2. Correlation of the Mottville Clastic Correlatives between the various Members of the Marcellus and Skaneatles Formations and their associated depositional phases.

The Mottville clastic correlatives can be recognized in all of these facies. The calcareous, planar crossbedded sandstones pinch out into blue-gray siltstones and shales with wavy or horizontal lamination and are also underlain or overlain by interbedded rippled and bioturbated sandstones and dark gray shales. The megarippled sandstones initially appear as wide lenses, with bimodal (onshore-offshore) dipping planar crossbeds west of this area. The appearance of laterally equivalent sandstones and shales suggests an environment of shoals with sandbars producing a more restricted but still shallow water environment for the interbedded sandstones and shales of the marine delta platform (see Figure 3).

LOCAL STRATIGRAPHY AND PETROLOGY:

West of the area covered by this field trip, near Otsego Lake and on the east side of the Unadilla Valley, the Mottville Member consists of 3-3.5 meters of bioturbated, cross-bedded sandstone with a few brachiopod coquinites containing Mediospirifer and Paraspirifer. These were

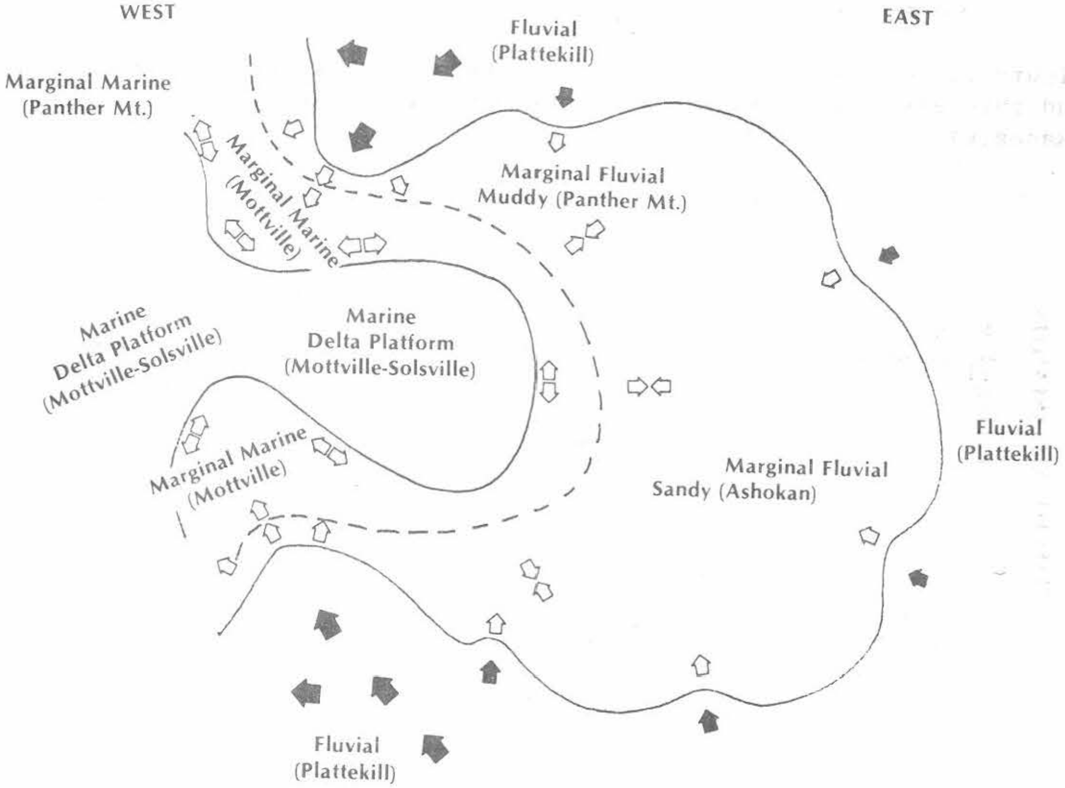


Figure 3. Schematic representation of the sediment environments and paleogeography associated with the members of the Mottville Clastic Correlatives. (Arrows indicate direction of sediment transfer).

interpreted as delta front sand deposits, reworked on the distal delta platform (Grasso and Wolff, 1977). While the open seas promoted some winnowing of the delta front sands to produce local shoals, the suspended silts and muds were deposited as rippled and cross-laminated deposits with coquinites in partially restricted irregular troughs or ponds between the shoals (see Figure 4). The platform sands provided barriers that restricted coastal circulation and their later lateral migration, across the silts and muds provided for local small scale ravinement - similar to the recent erosion or ravinement of lagoonal deposits in front of migrating barrier islands (Wolff, 1975). Similar associations occur near Richmondville, just west of the area viewed on this trip; here the megarippled, bioturbate sandstones form the Solsville and Panther Mt. Members - the Mottville clastic correlatives between them are difficult to distinguish, but can be determined by their content of quartz cement and slightly improved sorting.

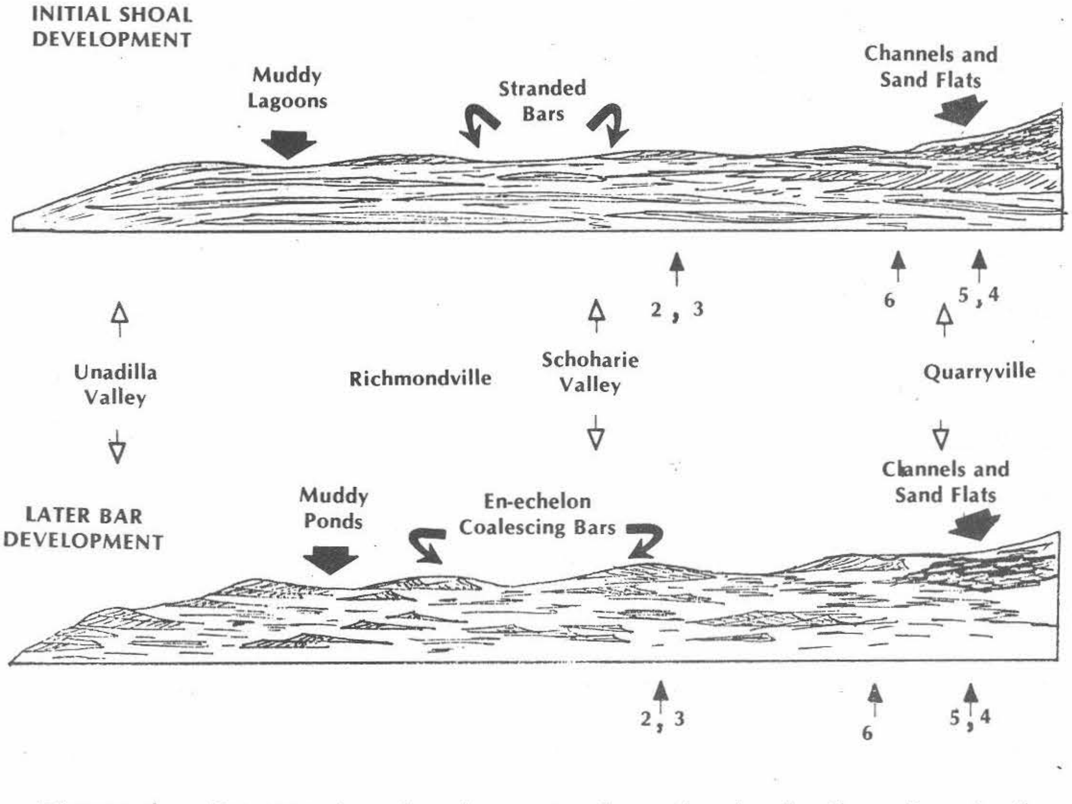


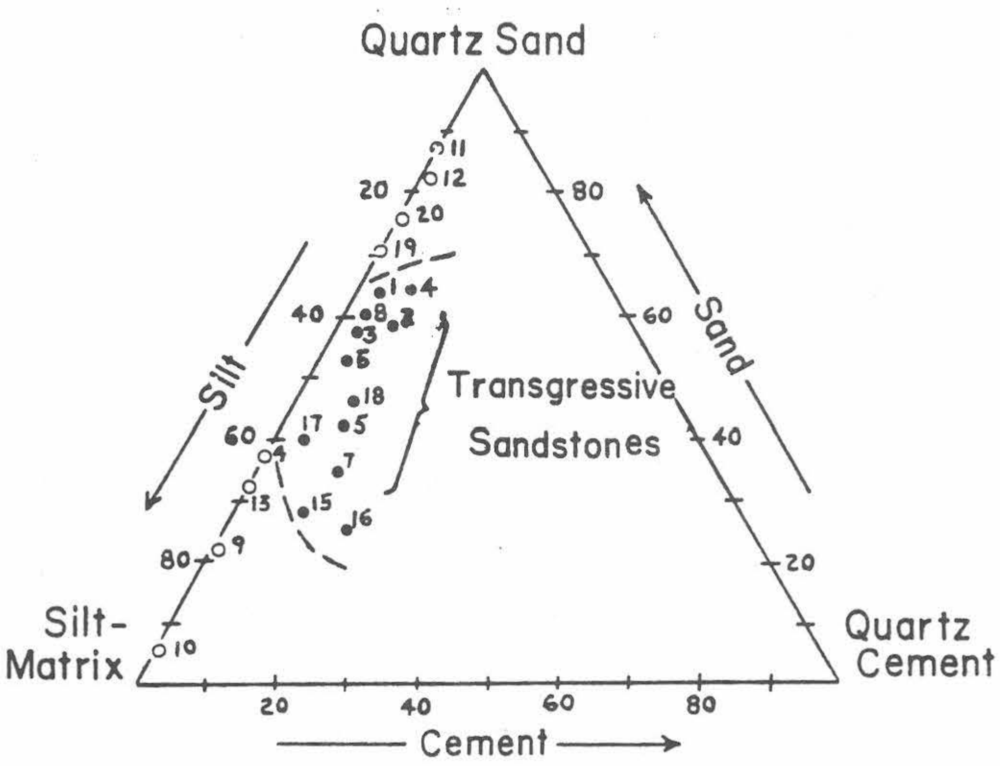
Figure 4. Progressive development of sandy shoals into lenticular migrating sand bars and the formation of the associated irregular muddy ponds by small scale migration and ravinement on the marine delta platform.

Besides the lithologic association across the marine delta platform the faunal indicators change from one of moderate diversity (Camarotoechia community) on the distal end to one of high diversity (Rhipidomella and/or Limoptera community) on the proximal side (Grasso and Wolff, 1977). This high diversity association occurs just above the Mottville throughout the region and is characterized by abundant sessile epifaunal and infaunal filter feeders, non-sessile epifaunal filter feeders, and vagrant benthos forms. Along with the coquinites and bioturbation the assemblege suggest sediment redistribution and high current activity. The abundance of filter feeders indicates that a substantial amount of suspended organic detritus had to be available for them - an environment of lenticular sandy shoals separated by deeper partially restricted irregular shaped ponds and lagoons across a wide embayment also seems appropriate (see Figure 4). This also explains the lack of the characteristic open marine fauna representative of the Mottville Member on the prodelta slope - these species avoid the partially restricted environments of the delta platform.

East of the Schoharie Valley the crossbedded megarippled sandstones associated with the Mottville Member become more asymmetric and "bar-like" with a gently inclined seaward slope (2-5^o), a steep landward slope (6-17^o), and unidirectional crossbeds trending westward or southeastward. The overlying shales contain a diverse marine fauna, but they become sparse and diminutive eastward, and are replaced by fine grained sandstones that contain brackish-water ostracods (Beyrichia) and phyllopods (Esthyria membranacea). At Rensselaerville these units grade into 11 meters of mottled red-green siltstone and shale. This section thus demonstrates the change from nearshore restricted marine conditions (Mottville Member) into a brackish embayment (Panther Mt. Member), and the gradual infilling of this interdistributary bay by overbank and floodplain strata (Plattekill Member). This embayment persists throughout this region as a more open but slowly subsiding basin (Albany Bay of Goldring - 1935). The underlying Marcellus Formation thickens from 270 meters in Richmondville to nearly 400 meters in this region; instead of bar-like shoals the subsiding embayment is represented by thick lenticular sand bodies and coquinites.

Southeast of the Catskill Mts. the Mottville Member is again represented by the calcareous sandstones that appear in the Schoharie Valley; rimming the south side of the embayment. The rippled and laminated crossbedded sandstones are interbedded by bioturbated sandstones and shales. The overlying strata of planar and trough crossbedded sandstones with abundant mud clasts, scour and fill structures, and plant fragments - all suggesting intertidal conditions and the appearance of marginal channels and river mouth bars (see Figure 4).

In the absence of diagnostic faunal criteria these clastic correlatives can be distinguished from adjacent strata by their petrologic characteristics. Westward from the Schoharie Valley the lenticular megarippled sandstones are calcareous, light gray in color, with observable quartz cement. They can therefore be distinguished from somewhat similar sandstones within adjacent strata (Solsville and Panther Mt. Members) which have less quartz cement (see Figure 5). As a check, a similar pattern was determined for other transgressive, reworked calcareous delta platform sandstones in the Portland Pt.-Cooksburg and Tully-Laurens Members of the Hamilton Group. Southward, between Dormansville (Stop 1) and Kingston, these petrographic criteria are still consistent. In addition, the appearance of asymmetric en-echelon sandbars at one persistent interval (used for this analysis) between the interbedded marine shales and sandstones and the crossbedded gray sandstones associated with olive-green and maroon shales are taken to represent the continuation of the Mottville Member (Wolff, 1969).



Petrology of transgressive marine and alluvial delta platform sandstones of the Hamilton Group in the Oneonta-Kingston area. (250 counts/slide measured perpendicular to bedding)

Figure 5

Stratigraphic Member (Sandstone)	Location
1. Gilboa (Tully)	1. Rt. 30 N. of town of Grand Gorge
2. Gilboa (Tully)	2. Reed Hill Quarry, NE of Schoharie Reservoir
3. Cooksburg (Portland Pt.)	3. Rt. 30, S. of town of Blenheim
4. Cooksburg (Portland Pt.)	4. Rt. 30, S. of town of Blenheim
5. Mottville correlative	5. Rt. 145 at town of Franklinton
6. Mottville correlative	6. Glasco Tpke. below Kingston Reserv.
7. Mottville correlative	7. Rt. 28, E. of town of West Hurley
8. Mottville correlative	8. Rt. 28-A, near town of Stony Hollow
9. Ashokan	9. Rt. 28, near Stony Hollow
10. Ashokan	10. Schoharie Co.Rd.#54 at "Zucks Corners"
11. Ashokan	11. Rt. 32, town of Quarryville
12. Plattekill	12. Rensellaerville Falls, town of Rensellaerville
13. Plattekill	13. Rt. 32, town of Quarryville
14. Plattekill	14. Rt. 23, town of Palenville
15. Mottville correlative	15. Button Falls, Rt.8, Unadilla Valley
16. Mottville correlative	16. Otsego Co.Rd.#51-Plainfield Ctr.Quarry
17. Mottville correlative?	17. Off Rt. 20, Twelve Thousand Quarry, Otsego County
18. Mottville correlative?	18. Leatherstocking Falls off Rt. 28
19. Solsville	19. Rt. 10, Richmondville
20. Solsville	20. Rt. 10, Richmondville

The bimodal northwest-southwest crossbeds and current lineation are also associated with a northeast-southwest series of smaller planar crossbeds and cross lamination. The latter suggest the influence of a longshore component operating along the marginal edge of the embayment as well as an onshore-offshore sand transfer system (see Figure 6A). In comparison, the marginal and fluvial channels, with their scour and fill structures, small scale planar and trough crossbedding, and fining upward textural sequences all display a predominant northwest current component with a secondary northeast trend, suggesting a fluvial or peritidal sand transfer system (see Figure 6B). When taken together the physical stratigraphy, paleoecology, sedimentology and petrology all suggest a paleogeography that was dominated by a shallow, locally subsiding, but well agitated and partially restricted marine delta platform, with linear shoals and embayments.

FIGURE 6B

Current Indicators
Ashokan-Plattekill Members

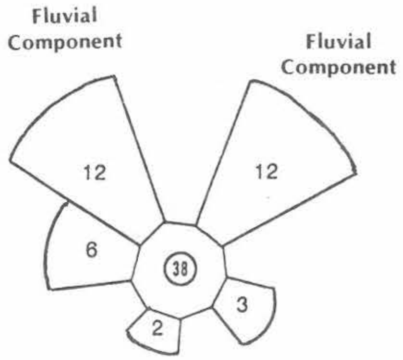


FIGURE 6A

Current Indicators
Mottville Member

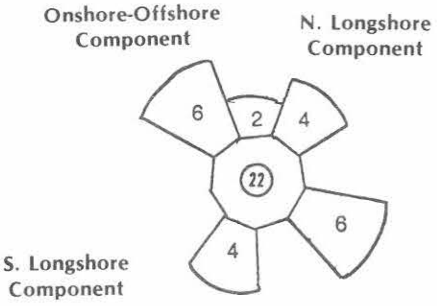


Figure 6. Current vectors for crossbedding and current lineation structures between the Mottville Clastic Correlatives and adjacent members on the eastern side of the Appalachian Basin.

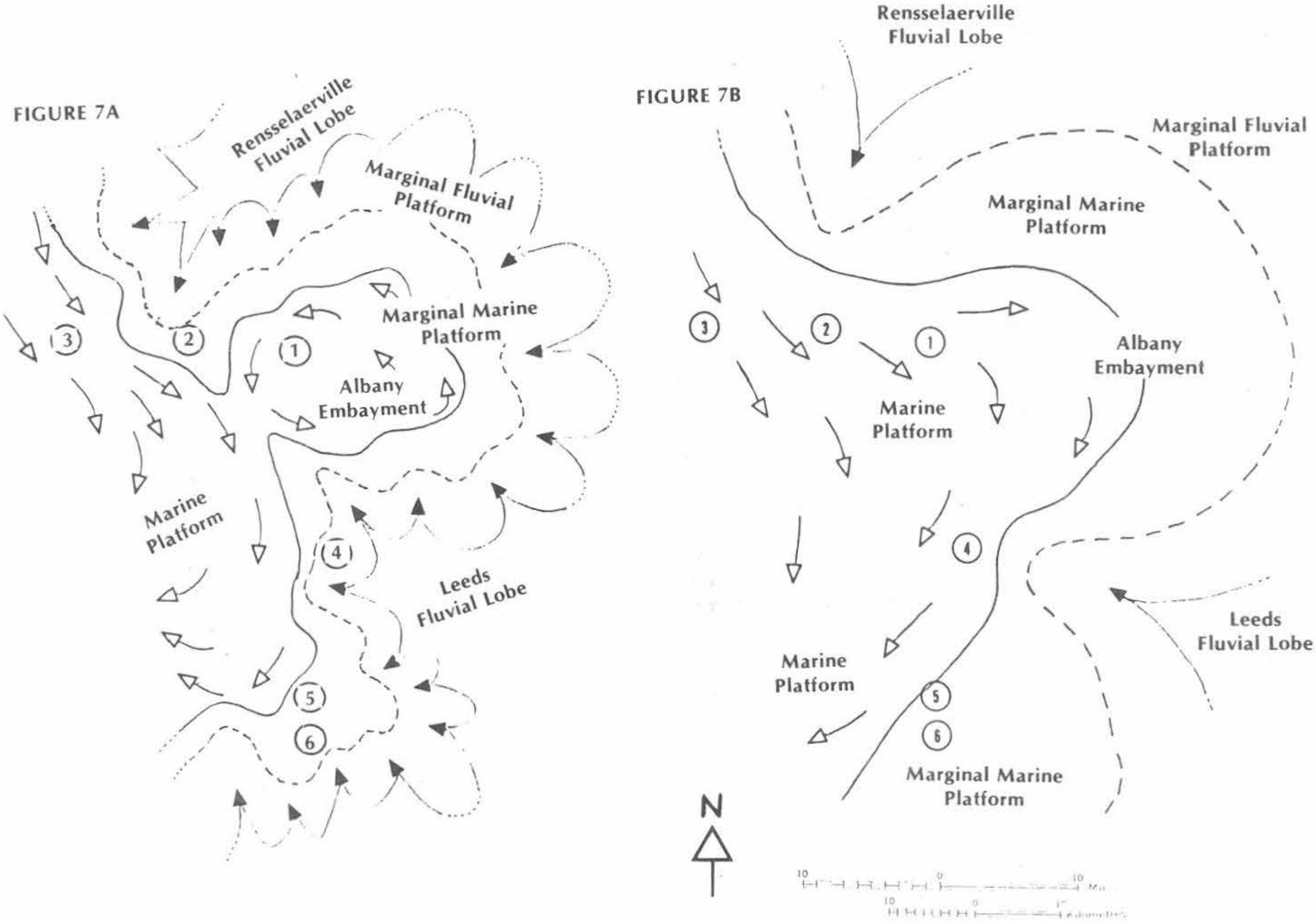


Figure 7. Paleogeography and depositional environments associated with the constructional (7A) and destructional (7B) phases of delta development.

A persistent subsiding basin existed in the present Westerlo - Albany area while fluvial and marginal deltaic distributaries with extensive sand flats continued to develop prograding deltaic lobes on each side of Albany Bay (Figure 7A). During the short transgression represented by the Mottville carbonates and clastics, the seas cleared, corals grew on the substrate of the delta slope, and shoals and bars developed on the shallow delta platform. The intervening muds had a rich fauna of bivalves and brachiopods. Vertical accretion was minimal as sediment was often redistributed into nearshore or offshore lateral transport systems. The strandline contained extensive tidal flats and broad channels along the embayments with reworked river mouth bars and sand shoals developing along the deltaic lobes. The interdistributary bays, originally filled with silt and mud now became the brackish coastal swamp that provided the habitat for the growth and development of extensive <u>Eospermatoperis</u> seed ferns (Figure 7B).

Within a relatively short time the pattern of reworking and lateral accretion again gave way to deltaic progradation. This change in pattern was almost unnoticed on the marine delta platform, but in the nearshore area the transgressive sands which had truncated the earlier marginal fluvial deposits were themselves nearly truncated and eroded by the following fluvial succession. This field trip road log, which follows, will examine the transgressive and restrictive nature of the Mottville clastic correlatives as they were developed on the marine and fluvial delta platform.

Acknowledgments - during the periodic field work of the past five years the senior suthor would like to thank Hofstra University for its support through faculty research awards, and for field and/or lab assistance from the following students: Christine Anderson, William O'Brien, Leo Matthews, Richard Smath, Rosemary Hickey, and Connie de Prado.

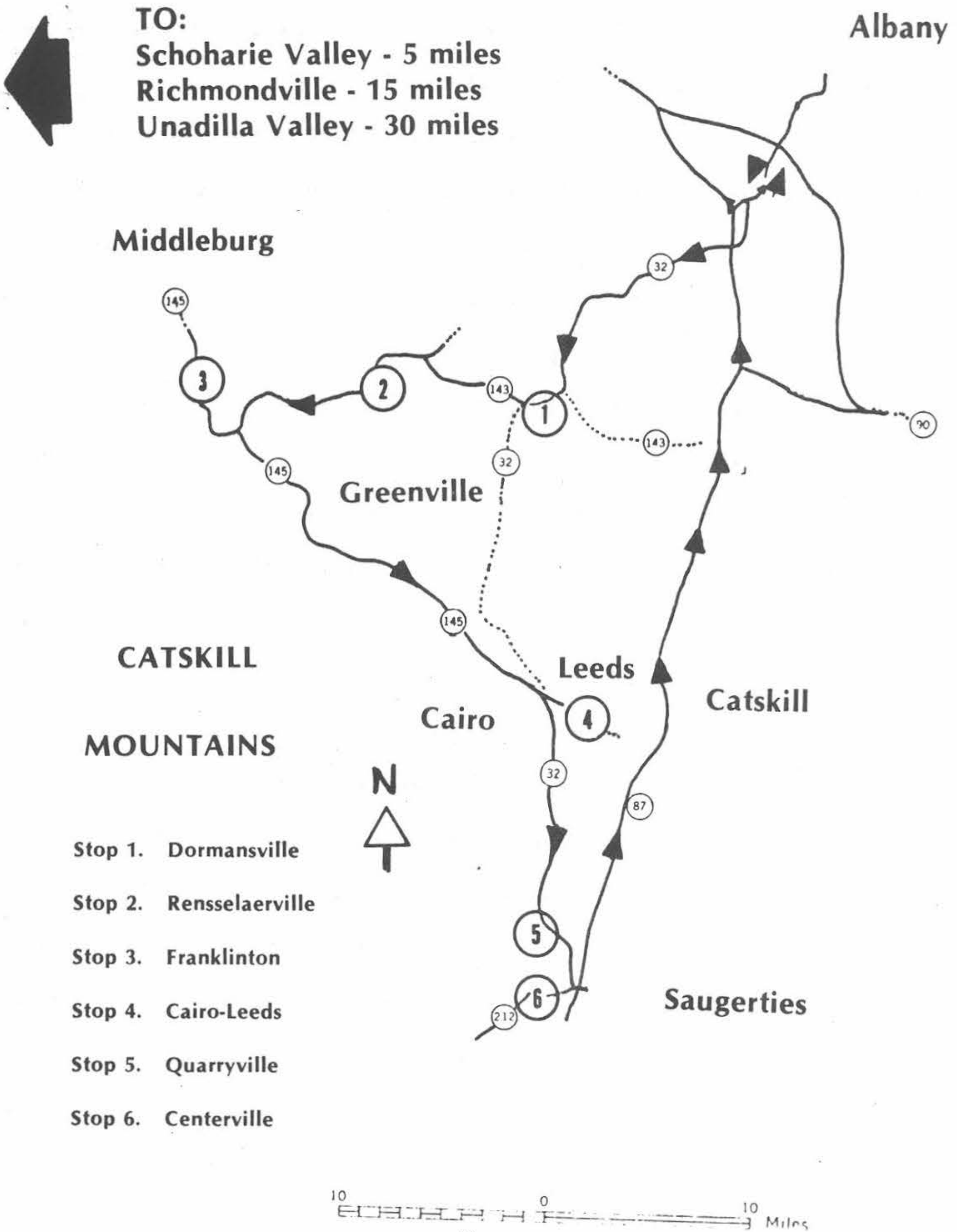

TO:
Schoharie Valley - 5 miles
Richmondville - 15 miles
Unadilla Valley - 30 miles
Albany
Middleburg
145
3
2
143
1
32
143
90
145
Greenville
32
145
CATSKILL
MOUNTAINS
Leeds
Catskill
Cairo
4
32
87
N
5
6
212
Saugerties
Stop 1. Dormansville
Stop 2. Rensselaerville
Stop 3. Franklinton
Stop 4. Cairo-Leeds
Stop 5. Quarryville
Stop 6. Centerville
10
0
10
Miles
10
0
10
Kilometres

FIGURE 8

Road Log Troy - Field Trip Area - and Return

	Mileage	Cumulative Mileage
Leave Houson Field House on R.P.I. Campus	0.0	0.0
Follow signs to Rt. 7 west	1.2	1.2
Cross bridge and follow signs to I 787 South	1.0	2.2
Continue S. on Rt. 787 to junction with Rt. 32 Exit here	9.1	19.3
Junction of Rts. 32 with 9W and 144 - turn right on Rt. 32	1.3	12.6
Junction of Rt. 32 S. and 9W (turn left at light onto Rt. 32)	0.6	13.2
On Rt. 32 - Pass through Haucks Corners and Feura Bush	5.0	18.2
Just after outcrop of Otsego Shale - junction of Rts. 32 and 143 east bear right onto Rt.32S	5.2	23.4
Junction of Rts. 32 and 143 West - continue straight on Rt. 143	2.7	26.1
Climb hill on Rt. 143 and enter Dormansville - park in wide driveway near crest of hill at home of M. Rossner	0.5	26.6
Stop 1A - Dormansville		
Drive across Rt. 143 to dirt road opposite driveway (Lobdell Mills Rd.) and park at first quarry on left	0.2	26.8
Stop 1B Lobdell Mills Rd. Quarry		
Return to Rt. 143 and turn left (west) toward Westerlo	0.3	27.1
Junction of Rt. 143 and Albany Co. Rd. #1 in Westerlo - continue straight on County Rd.#1	3.6	30.7
Junction with Rt. 85 at stop sign (opposite Dutchman's Rest) - turn left onto Rt. 85	2.7	33.4
T-junction at Rensselaerville; turn right onto Rt. 85 and once across bridge, continue on	4.4	37.8
Albany Co. Rd. #353. Climb hill and park in Rensselaerville Primary School parking lot	0.3	38.1
Stop 2 Edmund Hyuck Preserve - Rensselaerville Falls		
Upon return - continue up hill and take right	0.2	38.3
fork toward Livingstonville. Enter Schoharie Co. on Albany Co. Rd. #353	4.4	42.7
Follow winding road to junction with Rt. 145 at Livingstonville - turn right onto Rt. 145	3.3	46.0
Continue W. on Rt. 145 to outcrop on right	3.8	49.8
Stop 3 Roadcut on Rt. 145 at Franklinton		
Turn around and return on Rt. 145 toward Livingstonville	5.4	55.2
Continue E. on Rt. 145 to Rt. 81 - stay on Rt.145	6.2	61.4
Continue E. on Rt. 145 to junction with Rt. 23 and turn left onto Rt. 23	12.6	74.0
Continue E. on Rt. 23 to junction with Rt. 32 - stay straight on Rt. 23. Alternate Stop 4	2.5	76.5
Continue E. on Rt. 23 to Cairo Junction Rd., turn right (S.) and park. Stop 4 - Catskill Creek near Leeds	3.7	80.2
Continue S. on Cairo Junction Rd. to junction with Rt. 32 and then S. on Rt. 32	2.4	82.6

	Mileage	Cumulative Mileage
Continue S. on Rt. 32 across intersections with Rt. 23A and 32A	5.1	87.7
Slow down at roadcut between Quarryville gas stations and stop on roadside	2.7	90.4
Continue 50 meters and turn left onto Ulster Co. Rd. #36	0.1	90.5
Stop 5A Quarry at town garage - Quarryville		
Return on Rd. #36 to Rt. 32 and turn right -stop at road cut below gas station	0.3	90.8
Stop 5B Roadcut on Rt. 32 near Quarryville		
Continue S. on Rt. 32 past Thruway - south entrance	2.7	93.5
Junction of Rt. 32 with Rt. 212; turn right onto Rt. 212	0.3	93.8
Pass through Veteran, turn right onto old Rt. 212 before sign to Custerville, and follow this "loop" back out to junction with Rt. 212	2.1	95.9
Stop 6 Roadcut - Rt. 212 at Centerville		
Turn left and follow Rt. 212 north to Thruway N. entrance at Saugerties	2.5	98.4
Follow Thruway N. to Albany Exit 23 and then Rt. 787 back to R.P.I. campus	52.2	150.6

DESCRIPTION OF FIELD TRIP STOPS

Stop 1 - Rt. 143 west of Dormansville

Units - Solsville Member; facies - Chemung; depositional environment - nearshore marine delta platform in marginal embayment (Albany Bay)

Stop 1A - Quarry on N. side of road near home of Mr. M. Rossner

Description: While a few 0.2-0.5 meter planar crossbedded sandstones appear somewhat lower in the section, this is the first major lenticular sandstone in the area. The 2-meter sandstone has crossbeds, thin laminations, and local truncation surfaces. It contains a few bivalves (Cypricardella) lateral bioturbation structures, mud clasts, and plant fragments. The planar crossbedding trends N. 70° W - S 60° E, suggesting an onshore-offshore current influence. The sandstones are interpreted as prograding river mouth bars. The section is unique because strata at this interval are redbeds in the adjacent quadrangles - the marine Marcellus being nearly 60 meters thicker than sections to the west and south. The area has been termed "Albany Bay" by Goldring (1943) - see Figure 7.

Stop 1B. Quarry on Lobdell Mills Road across Rt. 143. Quarry consists of 2 meters of medium-dark gray siltstone and shale with several *Mucrospirifer* coquinite horizons. Associated fossils include a diverse assemblege consisting of: *Camarotoechia*, *Athyris*, *Chonetes*, and the bivalves *Modiomorpha*, *Paracyclas*, and *Grammysia*. Flatbedded, fine-grained sandstones with coquinites are common in the Dormansville-Westerlo area at an elevation of 1200-1300 feet, suggesting brief periods of strong agitation in relatively shallow water. The abundance of sessile epifaunal filter feeders suggests an abundance of suspended organic matter in deep quiet water. These contrary interpretations may be resolved by considering the embayed marine platform to also contain localized sandy shoals and broad muddy lagoons. A 0.8 meter crossbedded calcareous sandstone occurs on the N. side of Rt. 143 0.3 miles west of here (8 meters higher in the section) and this is believed to represent the clastic correlative to the Mottville in this region (Wolff, 1969).

Stop 2. Rensselaerville Falls. Edmund N. Huycks Preserve (Walking tour - cameras only; no hammers please)

Units - Solsville, Mottville correlatives, Panther Mt., Plattekill; facies - Chemung and Catskill; depositional environment - marine delta platform, brackish lagoonal (interdistributary), and floodplain - alluvial channel.

Description: The 22 meter section below the roadway bridge consists of flat, thick-bedded to massive sandstones or low-angle planar crossbedded sandstones interbedded with dark gray silty mudstones and shale - lithologically and stratigraphically similar to the Solsville Sandstone section at Stop 1, but without the coquinites. In the park, the section below the falls consists of 1-2 meters of medium-grained sandstones with some sinuous ripples (crests trend N 50° W). These may represent the top of the Solsville, though the presence of <u>Pterinopectin</u> <u>macrodonta</u> suggested the lowest Skaneateles (Mottville?) to Goldring (1943 p. 266 and 268).

The lower falls contain megarippled sandstones capped by a light-gray, bar-like, 1-1.2 meter crossbedded sandstone with cross sets trending S 70° W (3°) and N 70°E (15°). These are unique - the only such sandstones with such an internal and external geometry within either stratigraphic formation - see Figure 8A. They are interpreted as reworked river mouth or nearshore sand deposits formed during the clearing of the seas that produced the Mottville Limestone.

In ascending the falls, note that the bars are overlain by 16 meters of fine-grained, flat-bedded thin sandstone and siltstone with thin seams of black shale. These are non-marine

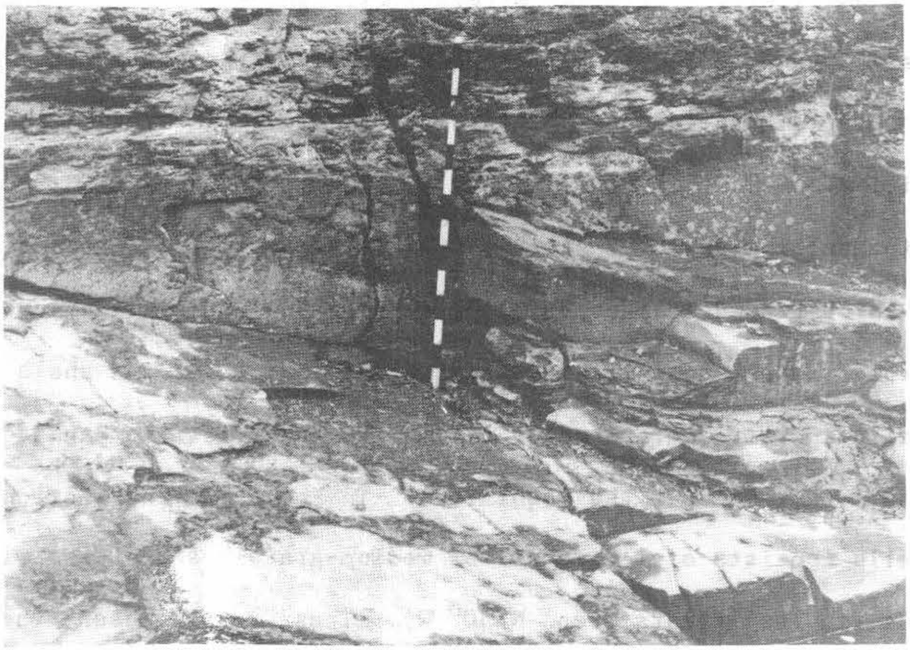


Figure 8A Inclined rippled surface of bar-like Mottville Clastic Correlatives at base of Rensselaerville Falls. (Stop 2) (Rod equals 14 decimeters or 1.4 meters) strata, formed by vertical accretion, with the black shales containing small ostracods (Beyrichia) and phyllopods (Estheria) that indicate a brackish water environment (Goldring, 1935, p.164). There is also a gradual color change from medium-gray to olive-gray to mottled olive green-maroon red to red as one ascends the section. The falls are capped by 2.3 meters of gray, medium-coarse grained sandstones that truncate the red mudstone. These trend S 75° W and contain basal clasts of white micrite and red-green mud.

The section is interpreted as one demonstrating the progressive change from open marine to marginal shoal-lagoon brackish water conditions. The persistence of fine-grained sandstone and shale suggest the continual infilling of a marginal embayment - perhaps the continuation of "Albany Bay". The erosional contact at the base of the channel sandstones, with the encroachment of a deltaic distributary from the northeast indicates the start of alluvial sedimentation on the delta platform.

Climb to the top of the falls, cross over the footbridge, climb a short hill, and then return on the trail that descends on the opposite side of the ravine.

Stop 3. Rt. 143 at Franklinton

Units: Mottville clastic correlatives; facies - Chemung; depositional environment - shoal on nearshore marine delta platform.

Description: This 6-meter section exhibits the interfingering of two en-echelon "bar-like" sandstones that are overlain by 1 meter of fossiliferous dark gray shales. The medium-grained sandstones are light-gray in color (weathers a dark brown) and calcareous with individual planar crossbeds 2-4 cm. thick and trending N 50-70° E at slopes of 4-7° (similar to the section at Stop 2 - see Figure 9 on page 22).

The unit coarsens upward and grades into the overlying marine shales which contain Glyptodesma, Mucrospirifer and Camarotoechia. The entire section is 0.2 miles long and is interpreted as a reworking of marine delta platform deposits into these transgressive sand bars on the outer fringes of the prograding deltaic lobe visited at Stop 2 (see also Figs. 2, 4 and 7).

Alternate Stop 4. Rt. 145 S. of Cairo after the junction with Rt.32.
Unit: Plattekill of the Catskill Facies on the alluvial delta platform.
Description: This 12-meter section represents two upward-fining fluvial cycles well within the Plattekill Formation and illustrates the major difference between the progradational marine sandstone lenses of the platform (Stops 1 and 2), reworked transgressive coastal marine sandstone bars (Stop 3) and the fluvial sandstone channels.

The sands are dark gray, medium-coarse thick bedded (10-30 cm.) and planar-crossbedded depositional units with infrequent scour and fill pockets across a sharply truncated megarippled surface. Plant fragments and olive-red mud clasts are common.

The gradational nature of the massive, irregularly bedded sandstones into gray-red silty mudstone indicate, through channel abandonment, the gradual change from channel to levee to floodplain environment. This rhythmic pattern is prevalent through the next 400 meters of section in the nearby Catskill Mts. The dominance of gray channel sandstone over red floodplain siltstone-mudstone at this interval suggest rapid seaward delta progradation of many distributaries, with relatively little vertical accretion in floodplain and interdistributary bay environments. Gradients were probably low, but the large scale megaripples and scour suggest high current velocities and perhaps gently curved rather than true meandering rivers. In places, channel deposits directly overlay earlier deposits of similar origin, indicating complete lateral and vertical erosion of the overbank red mudstones and a nested sequence of irregular, sub-parallel distributary channels prograding into the basin.

Stop 4 - On Catskill Creek off Rt. 145 and Rt. 23B near Leeds
Units: Mottville and Plattekill Members; facies - Chemung and Catskill; depositional environment - marginal fluvial and fluvial.

This section is stratigraphically similar to the one at Stop 2 (Rensselaerville Falls) but begins within a 4-meter upward-fining sequence of planar crossbedded channel sandstones overlain by olive gray and dull maroon mudstones and shales as overbank and floodplain deposits. This first fluvial cycle also has the first "redbeds" of the Plattekill Formation. North and south of this area the first fluvial deposits are not red, and the thickness of this non-red alluvial sequence increases to locally form the Ashokan Member. Nearly all of the important flagstone quarries in this region came from the Ashokan. The unit consists of flat-bedded and low angle planar and trough crossbedded sandstones with sharp basal contacts and an abundance of mud clasts and plant fragments. The associated olive and gray shales rarely contain marine fossils.

The Ashokan Member is distinguished from the Plattekill by the lack of redbeds, the dominance of medium-sized (2-4 cm.) flat-bedded sandstones (as flagstone) and the dominance of thinly laminated flat-bedded sandstone. These criteria along with current lineation, bioturbation, mottling, load casts, and lateral sediment associations suggest the development of extensive sand flats and marginal channels between the major deltaic lobes (Figures 3 and 7).

Above the initial fluvial sequence are red-green mottled sandstones and some thin seams of black shale with ostracods (Beyrichia). The overlying 3 meter section consists of gray-green flagstone, massive, calcareous sandstone with mud clasts, and interbedded slumped and bioturbated sandstone with an erosional top. This represents a short "upward coarsening" sequence, with some period for reworking and burrowing by organisms before erosion, and is taken to represent a tidal or supertidal sandflat and also the clastic correlatives to the Mottville interval in this area. Above this truncation the next 6 meters consist primarily of light-gray-olive green siltstone mudstone and shale, with abundant plant fragments and believed to represent overbank disposition as marsh deposits above the sandflats. These mudstones are truncated by a 1.6 meter section of planar crossbedded gray sandstones with megaripples, scour and fill pockets, load casts, and some bioturbation - the return to fluvial conditions. It is overlain by the typical sequence of gray to olive-green to maroon-red mudstones and shales - the second fluvial cycle.

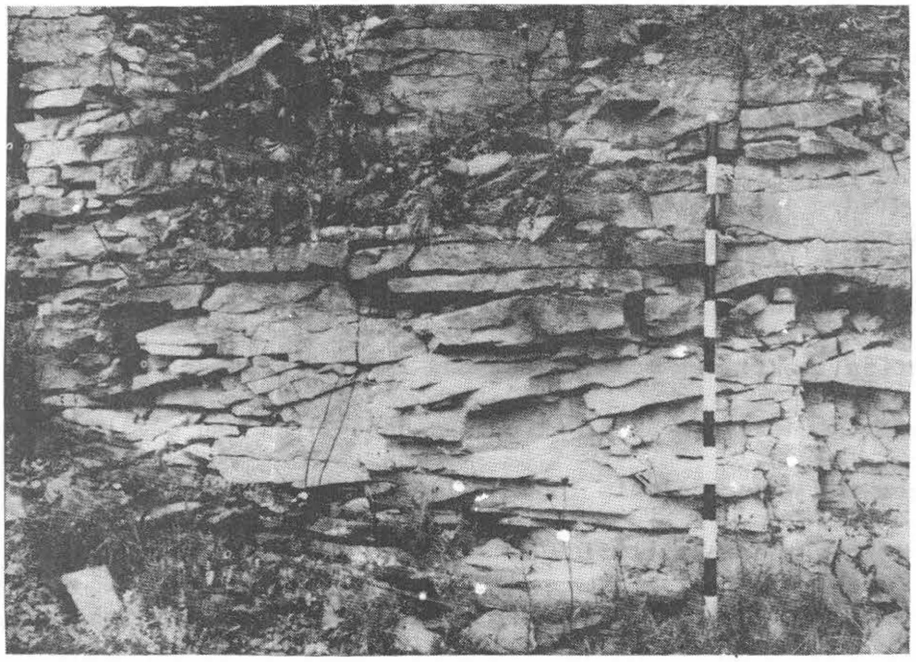


Figure 9. Planar crossbedded light gray calcareous sandstones of en-echelon "bar-like" Mottville Clastic Correlatives on Rt. 145 at Franklinton (Stop 3).

The correlation of the light gray calcareous crossbedded sandstones as "Mottville correlatives" is based partly on the unique lithology within the fluvial section but moreso on the position of this unit between the first two fluvial cycles, as will be re-examined at Stops 5 and 6 when we again view this interval within an embayment.

Stop 5 - off Rt. 32 near Quarryville

Units - Upper Mt. Marion (Solsville), Mottville correlatives, and Ashokan; facies - Chemung; depositional environment - nearshore marine, marginal channel and sandflats.

Stop 5A - Along Rt. 32 before junction with County Rd. #36, and at quarry near town garage on Rd. #36.

Description: The top of the section (on Rt. 32) contains extensive flat-bedded and low angle planar crossbedded and laminated gray sandstones (Unit C) - the type used for the flagstone industry that has dominated this region for the past 75 years. These truncate a 1.2 meter section of massive calcareous sandstones and olive mudstone (the Mottville clastic correlatives - Unit B) that are underlain by a 1.8 meter interval of megarippled and planar crossbedded and laminated sandstones with mud clasts and scour and fill pockets, and massive flat-bedded sandstones - Unit A. Here too the clastic correlatives form marginal sandflat or marsh environments between two marginal or fluvial channels (as at Stop 4).

The quarry on County Rd. #36 consists of 2 meters of thin-bedded planar crossbedded gray sandstone (Unit A) overlain by an 0.5-0.8 meter undulatory surface with scour and fill structures, in turn overlain by a 1.3 meter light gray calcareous, crossbedded sandstone (Unit B).

The laminated flat-bedded and cross-bedded sandstones are interpreted as tidal sand flats and beaches fronting the deltaic marshes. The megarippled surface and scour and fill with pockets of olive mudstone add support to this, the upward fining sequence suggesting the filling in of a shallow embayment behind the tidal sand flats. The overlying laminated and slightly sorted "bar-like" sandstone represents the reworking of the sandflats into a shoal or beach (Unit B). The truncation of this sequence by the next series of gray crossbedded sandstones with basal mud clasts and plant debris suggests the presence of a marginal channel or river mouth bar. The large tree molds (Wolff, 1969) indicate a close proximity to the seed fern forests that inhabited the local coastal swamp.

Stop 5B - On Rt. 32 below junction with County Rd. #36.

This 24-meter outcrop consists of massive marine sandstones and dark gray shales with several horizons of ball and pillow structures (Figure 10). It is known locally as the Mt. Marion Formation and is correlative with the Solsville Member of the

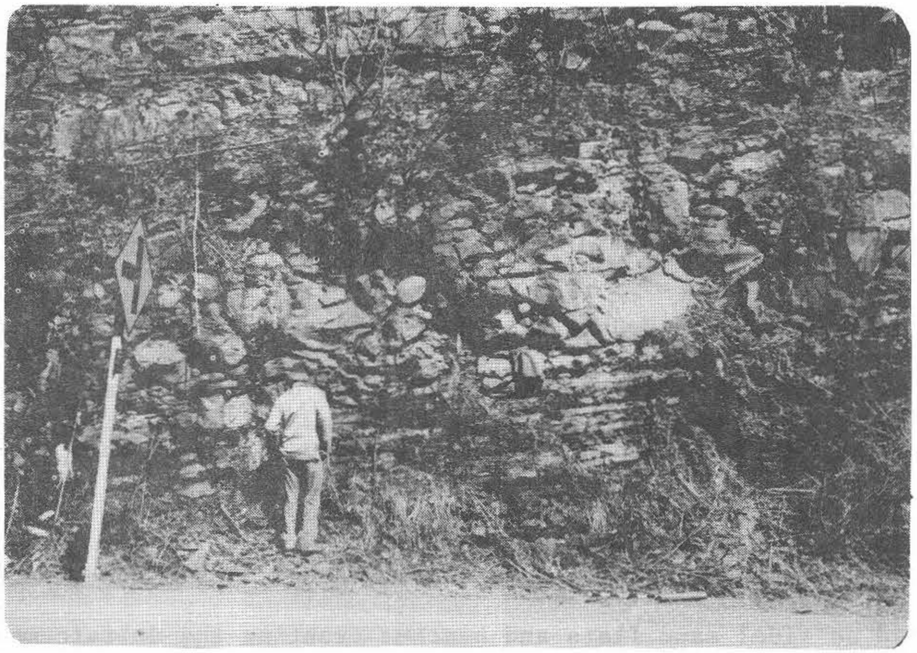


Figure 10. Massive sandstones and interbedded shales of the marine delta platform with "ball and pillow" structures. (Stop 5B)

Marcellus Formation. Other characteristic features include long, low angle planar forests, coquinite horizons and the thin but persistent 7 cm. Alcove Conglomerate that can be traced to Stop 1 at Dormansville.

The section (as at Stop 1) represents the marine delta platform with the ball and pillow structures interpreted as load casts developed from sediment foundering during earthquake activity. The seismic tremors could also create tsunami which extend into the embayments and channels and transport the marginal and fluvial deposits (and the pebble bed) onto the marine platform (Wolff, 1977). A possible Middle Devonian astrobleme may be buried within the Catskill Mountains only 9 kilometers from this outcrop (Isachsen, Y.W. et.al. 1977) suggesting an even more extreme origin for these deposits.

Stop 6. Rt. 212 near Centerville

Units - Mottville Correlatives and Ashokan Member; facies - Chemung; depositional environment - marginal marine and fluvial.

Description - Here the suggested Mottville correlatives are sandwiched between the first two marginal channels or river mouth bars (See Figure 11). The lower 2.2 meter section consists of medium-grained planar crossbedded gray sandstones with basal mud clasts directly overlying marine strata. The unit is overlain by 0.3 meters of dark shale and 1 meter of massive light gray sandstone.

The next 4.5 meters comprise the Mottville correlatives and consist of 2 meters of alternating massive gray calcareous sandstones and dark shales with bioturbation markings and load casts. These are truncated by 2 meters of thinly laminated and crossbedded sandstone, 1.3 meters of massive light gray calcareous sandstone, and 1.2 meters of interbedded fine-grained sandstone and dark shale with flaser bedding. The sequence ends with 1 meter of rippled sandstone and shale with extensive lateral worm burrows. (Figure 12)

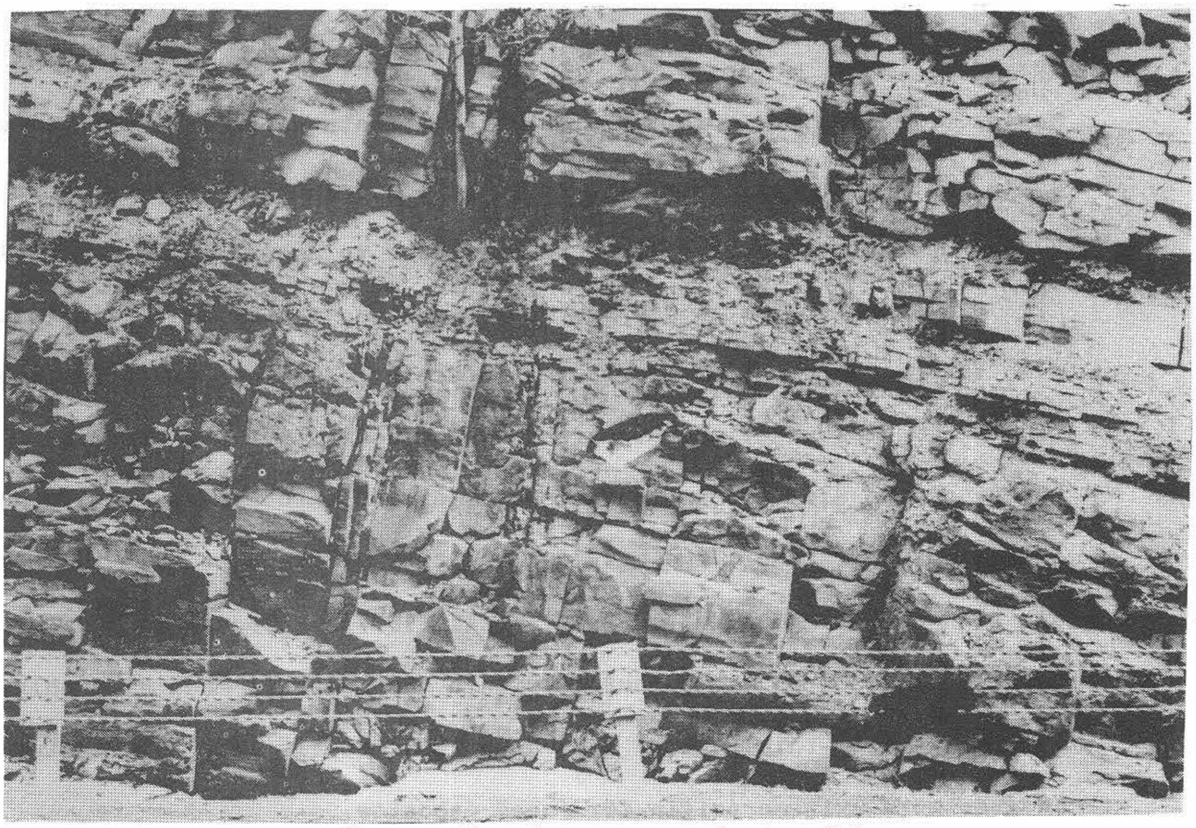


Figure 11. Wedge of "Mottville Clastic Correlatives" between the first two major fluvial sequences of the Ashokan Member. (Stop 6.)

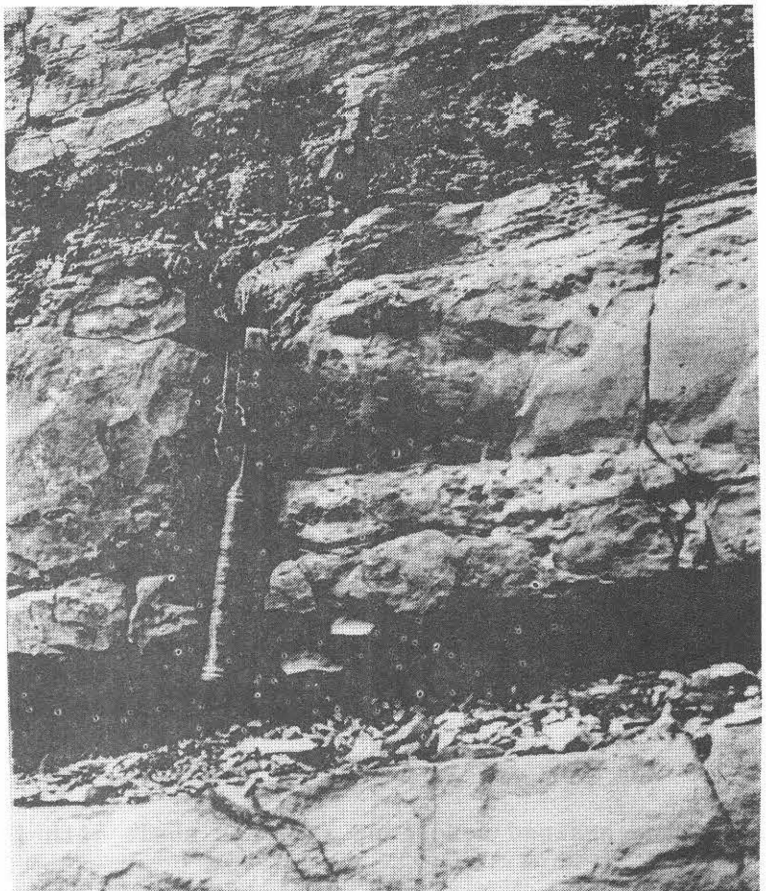


Figure 12. Massive calcareous sandstones and interbedded rippled and bioturbated shales - the reworked intertidal deposits of the Mottville Clastic Correlatives.

The outcrop is capped by an 8 meter sequence of thick beds of gray planar crossbedded sandstone with megarippled surfaces and abundant mud clasts.

The lower sequence shows small scale polymodal trough cross bedding and lamination suggesting the periodic reworking of a marginal channel or river mouth bar. The middle section with the massive, crossbedded and cross laminated calcareous sandstones, ripples, flaser bedding and bioturbation suggests the preservation of intertidal sand flats, and shallow lagoons. The massive crossbedded and burrowed light gray calcareous sands may indicate the pressure of a beach or reworked sand flat environment. This short interval of marine resedimentation is sharply truncated by the overlying fluvial progradation that nearly erodes this transgressive sequence. However, the persistence of these unique reworked deposits both to the north and to the south of this region (Wolff, 1969) and to the west (Grasso and Wolff, 1977) indicates that the extension of the Mottville clastic correlative is possible through these unique lateral sedimentary associations.

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STRATIGRAPHY, STRUCTURE, AND THE MINERAL WATERS OF SARATOGA SPRINGS - IMPLICATIONS FOR NEOGENE RIFTING

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INTRODUCTION

The carbonated mineral springs of Saratoga have been the object of considerable interest ever since their discovery by colonists in the late eighteenth century. The three major previous studies (Kemp, 1912; Cushing and Ruedemann, 1913; and Colony, 1930) express the crux of the problem as we see it today. Foremost, among these, is the abundant CO_2 gas and the difficulty of explaining its presence in such large amounts by known shallow, oxidizing mechanisms of generation, or by hydrolysis reactions involving carbonates, the reasons for which will be partially addressed below and further during the field trip. The only known applicable methods remaining are thermal: 1) either direct degassing of an igneous melt or decarbonization of carbonate rocks adjacent to an intrusion, or 2) decarbonization in water-rock equilibria during metamorphism. Recourse to the former mechanism in terms of cooling Paleozoic plutonism has been taken by all three of these earlier workers because of chemical inconsistencies that are also incompatible with low-temperature methods of CO_2 formation; i.e., negligible sulfates, nitrates, and phosphates. This interpretation presents an apparent paradox for all known igneous activity in the Northeastern United States ceased with dike swarms in the middle Mesozoic--about 100 million years ago. Since it is now known that anomalous convective and conductive heat flow from this time should have long since ceased allusions to dying metamorphic or igneous fires from the past are not a really very satisfying explanation; indeed, they have only served to deepen the mystery.

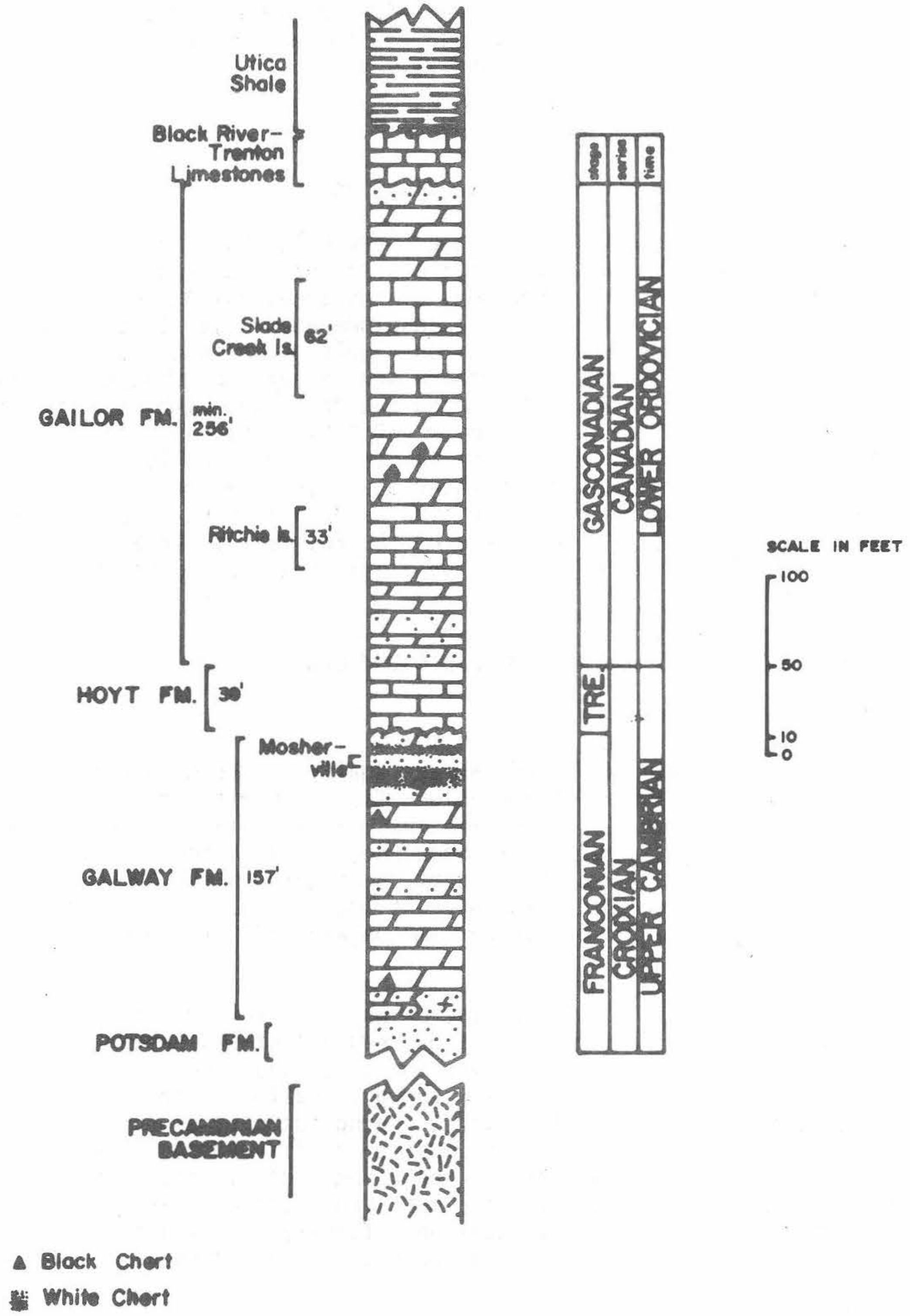
We must ask then, are the waters and gas at Saratoga really thermally generated; and, if so, how can we understand the source of the thermal processes in more definite terms?

STRATIGRAPHY

A large geologic literature exists on the Paleozoic stratigraphy of eastern New York, especially the Cambrian and Ordovician carbonate rocks of the Mohawk Valley and adjacent areas and only a brief description is included here. We will note or briefly stop at all the major lithologies present at Saratoga, however, appreciable time will only be spent with the carbonate section; the principal portion of the aquifer containing the carbonated waters.

A generalized stratigraphic column for the area is depicted in Figure 1. It is based partly on new data from several drill core logs obtained in two quarries near the City of Saratoga Springs (one of which will be visited during this trip) and partially on the published literature. A brief, weighted description of the units is offered below.

GENERALIZED STRATIGRAPHY OF THE SARATOGA AREA



(Modified after Mazzullo etal. 1978)

FIGURE 1

PRECAMBRIAN BASEMENT ROCKS

Precambrian basement rocks underlie the sedimentary basin. These rocks are from 1 - 2 billion years old and consist of mixed metasediments including calcitic and dolomitic marbles, quartzites, and various metaclastics (paragneisses), and mixed igneous rocks with iron- and titanium-rich anorthosites and gabbros forming an Adirondack core. Granitic and syenitic gneisses (charnockites and mangerites) are very common, with the former frequently enriched in radioactive minerals with or without magnetite.

PALEOZOIC AQUIFER SEQUENCE

Potsdam Sandstone - Upper Cambrian

Unconformably overlying the Precambrian basement, the Potsdam sandstone displays moderate lateral variations in thickness and may even have onlapped onto islands which were portions of the ancestral Adirondacks. It is nearly always characterized by a basal conglomeratic layer that grades upward into a well-sorted beach sand with common ripple marks that usually weathers white or buff in outcrop along the southern and eastern Adirondack periphery. It is primarily composed of well-rounded quartz grains with siliceous interstitial cement often making the rock over 95% SiO_2. The basal beds reflect poorer sorting with detrital feldspar, in particular, locally comprising up to 15% or more of a given outcrop. Individual strata form thin layers separated by well-defined bedding planes that may aid in forming effective fracture permeability. While the thickness of the Potsdam is variable, it is believed to total about 100 feet in the Saratoga area and to increase fairly rapidly eastward.

CARBONATE SERIES LOWER TO MIDDLE ORDOVICIAN

Galway Formation

The Potsdam sandstones are gradually replaced upwards by quartzose dolostones and dolostones of the Galway formation without a distinct separating stratigraphic horizon. The name Theresa was commonly used in the past for this alternating transitional sequence, however, the type Theresa occurs north of Watertown and is not continuous through the subsurface. The type Theresa is Ordovician in age whereas that in the eastern Mohawk Valley is Cambrian, hence, the preferred name Galway (Fisher and Hanson, 1951; and Rickard, 1973).

In its upper portions, the Galway is a rather monotonous series of thinly bedded, (two to four feet) fine grained dolostones broken primarily by thin (usually two feet or less) layers of sands and sandy dolostones. Apparently deposited as lime muds in a low energy, shallow marine environment, the formation has been extensively dolomitized, wiping out many of the primary structures. The top 16 feet of this formation consist of interbedded light gray, medium grained, dolomitic sandstone and chert, including a distinctive marker bed of novaculite with characteristic banding and mottling. Its greater resistance to weathering has made it the site of a local unconformity upon which the Hoyt limestone was deposited in the Saratoga Area (George Banino, personal communication).

The remainder of the formation is composed of beds of medium to light gray, massive crystalline, fine to medium grained dolomite. Dolomite and calcite inclusions (usually white and occasionally rose colored) are found throughout the formation but are more abundant in several zones containing vugs with quartz crystals. Quartz grain content in general increases toward the bottom of the formation, reflecting the gradational contact with the Potsdam sandstone.

Hoyt Limestone

A medium gray, cryptocrystalline to coarse crystalline limestone with variable sand content, the Hoyt has received a great deal of attention due to the presence of abundant authigenic K-feldspar and its large, well preserved specimens of cryptozoa. Approximately 40 feet thick in the Saratoga area, the Hoyt reef has been interpreted to represent a high-energy area of carbonate buildup immediately landward of the point of wave-base impingement on the upper Cambrian shelf (Owen, 1973).

Gailor Formation

A series of massive bedded, medium crystalline dolomites varying from light to dark gray, the beds of the Gailor have been extensively dolomitized and are noticeably free of primary structures. Interbedded within the dolomites are occasional thin beds of finely crystalline to cryptocrystalline light gray limestone as well as two major (though local) limestone members. The Ritchie limestone (Fisher and Hanson, 1951; Fisher and Mazzullo, 1976; Mazzullo, et al, 1978) is described as approximately 43 of dark gray, fine to medium crystalline, slightly dolomitized calcilutite. The Slade Creek limestone (Mazzullo, et al., 1978) consists of about 62 feet of dark gray, fine to coarsely crystalline calcilutite.

Trenton and Black River Carbonates

Following deposition of these lower Ordovician carbonates, most of the eastern North American continental shelf was uplifted and eroded forming the regional Knox Unconformity. Deposited on top of this surface are the Middle Ordovician Amsterdam and Trenton Black River limestones; coarsely crystalline, dark gray, fossiliferous limestones separated by a marked disconformity (Fisher and Hanson, 1951). Their thickness is quite variable in the Saratoga area, but the range seems to be from zero to a possible maximum of 250 feet (Colony, 1930).

CAP ROCK - LATE ORDOVICIAN

Shales

Efficiently confining the carbonated mineral waters to the aquifer are an eastward-thickening wedge of poorly understood shales that are truncated at Saratoga by the McGregor and Saratoga faults. Respectively termed the Canajoharie and Schenectady formations (equivalent to the Utica shale) in parts of the Saratoga area; these rocks unconformably overlie the thin Trenton Black River carbonates. Further east and south, the assumed lateral equivalent, the Snake Hill shale, is overlain by the allochthonous rocks of the Taconic thrust sequence.

STRUCTURE

One of the few points which all previous workers have agreed upon is that faults play a major role in controlling the pathways and points of issuance of the waters. This is indeed the case at Saratoga where the large McGregor Fault "breaks up" into several smaller faults, one of which, the Saratoga Fault, has helped contain a vast reservoir of the carbonated waters. Striking about N15E, this system is subparallel to the dominant fault set spanning the Adirondack uplift (Isachsen, 1975). The vast majority of these faults are of the high angle, normal type although a few high angle reverse faults also exist. As the Adirondacks are approached from the Mohawk River, the relief of these scarps tends to increase suggesting that they may have been recently reactivated.

A secondary set of faults with generally less apparent vertical displacement but more sharply defined scarps also exists in this area. These are clearly displayed in the brittle carbonates which are quite literally diced by these breaks. Perpendiculars drawn to the dominant members of this set point toward the center of the Adirondacks, suggesting that they are tensional features formed in response to the uplift. In a few places, small grabens have even been formed, one excellent example of which will be visited during the field trip.

Although mapping has not disclosed evidence for Quaternary movement of these structures, their youthful aspect appears clear. The steep scarps that occasionally exhibit faults directly at their feet decry a prolonged exposure to weathering or glacial unroofing. Should their sharp, blocky character persist under the masking shale cap, the heterogeneity of mixing in the mineral waters can be better understood.

THE WATERS

While the name of Saratoga Springs tend to conjure up visions of bubbling natural orifices, most of carbonated mineral waters actually issue from driven wells that have punctured a thin shale cap to tap the water-bearing Gailor Formation. Only at Gurn Spring, Reid's Mineral Spring, the original Old Iron Spring in Ballston Spa, and the original High Rock Spring in Saratoga Springs has the water had sufficient "force" to drive its way to the surface. Shearing and crushing along the fault from which these springs rise has apparently created sufficiently permeable zones for the waters to flow for a time.

CO_2-charged waters are found not only in the immediate vicinity of Saratoga Springs, but over much of the Cambro-Ordovician basin from Albany north to Whitehall and west along the Mohawk Valley at least as far as Rotterdam Junction (Figure 2). The northern and western boundaries coincide roughly with the first carbonate outcrops while the eastern limit is not known. The areal extent of these waters approaches 1,000 square miles with all observed occurrences confined to the western limb of the central Hudson Valley "geosyncline".

A final physical observation concerns the temperature of the waters. In earlier measurements (Kemp, 1912) as well as recent ones, the waters of Saratoga Springs and Ballston Spa have been found to span a narrow range of $48^{o}F$ to $56^{o}F$. Seasonal variations are noted, yet the range of temperature fluctuation is more

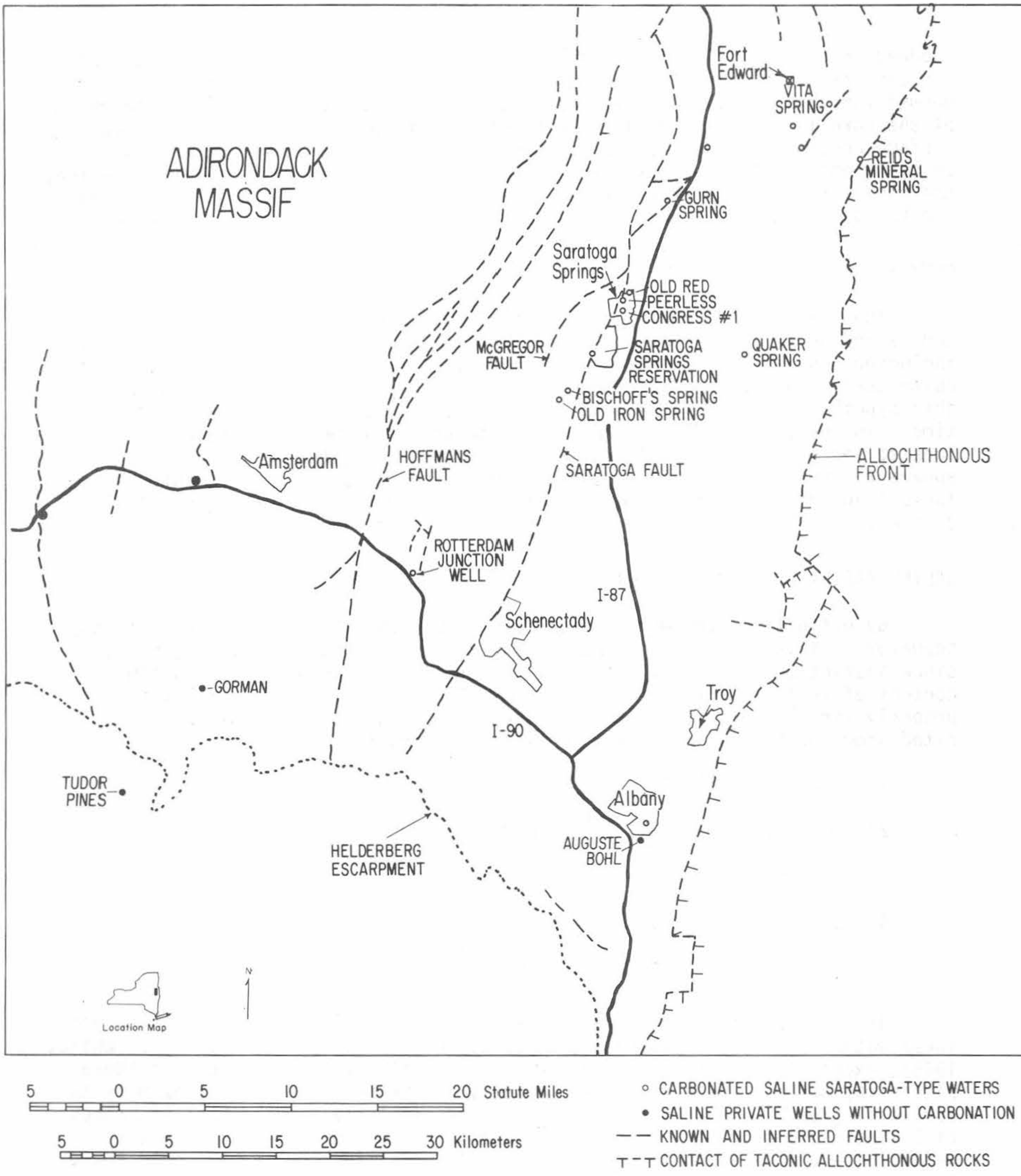


FIGURE 2 LOCATIONS OF WELLS WITH SARATOGA TYPE WATERS OR SALINE WATERS IN THE SARATOGA BASIN

Geology from Geologic Map of New York, 1970, New York State Museum and Science Service Map and Chart No. 15

subdued than in gravel aquifer wells of the same area. Since the mean annual air temperature of Saratoga Springs is 48^{o}F, the wells average about 4^{o}F above normal for this area. This range can be explained quite adequately in terms of the normal geothermal gradient and the average depth of the wells, since surface control wells of similar depths exhibit the same temperature span. In conjunction with the known lack of igneous activity in eastern North America, the cool surface temperature of the water has been one of the major stumbling blocks to any interpretation of thermal processes in an origin of the waters.

CHEMISTRY

The third major complicating factor that appears to have inhibited our understanding of the carbonated waters is complex mixing of water components, including a significant connate water component. Although this was suggested quite early (Cushing and Ruedemann, 1913), no attempt was ever made to test this hypothesis, possibly because uncarbonated wells were not known at the time. In the course of new work several pristine "brine" wells have been located south of the City of Albany and westward along the Mohawk Valley, apparently outside the zone of carbonation. These results are presented in Table 1 and discussed first below because their chemical nature is critical to the task of gauging the proportions of mixing at Saratoga.

SALINE BASINAL OR FORMATION WATERS

By definition, the word brine means to possess at least as much salt as seawater. It is accordingly used loosely herein for the sake of convenience since inspection of Table 1 will show that the total dissolved solids (TDS) content of these waters varies only from 1900 ppm to 6000 ppm and they are properly termed as saline waters. In other respects, the 3 sample waters cited show the following distinct chemical patterns:

1) High Cl^-, Na^+, Br^-, I^-, Sr^{++}

2) Low HCO_3^-, K^+, SiO_2, Ca^{++} and Mg^{++}

3) A ph of 7-8

4) Distinctive groupings of the following molar ratios:

$$Na/Cl \text{ and } \frac{Br \times 1{,}000}{Cl}$$

In their proportions of major ($Cl^- > Na^+ >> HCO_3^-$) and minor constituents these waters are very similar to connate basinal brines of the NaCl type (White, 1965), except for their much lower salinity. While it is possible that these waters may not have been of higher salinity in the geologic past, proximity to surficial ground water, isotopic data and the similarly diluted basinal brines of Illinois all suggest a continuing and considerable dilution with meteoric water. The ultimate age of at least some of the saline components could therefore be as old as the Paleozoic.

TABLE 1

	SOUTHERN BRINE WATERS			METEORIC SURFACE WATERS		SARATOGA SPRINGS CARBONATED WATERS								
	TUDOR PINES	YEZZI	GORMAN	BLOODGOOD	SARATOGA VETERINARY HOSPITAL	HATHORN no. 3	ORENDA	GEYSER	LINCOLN no. 12	ROSEMARY	HATHORN no. 1	BIG RED	PEERLESS	RED
Date & Time of Sampling	5/25/10	5/02/11	10/20/10	10/06/23	10/06/11	4/19/14	4/09/11	4/09/11	5/04/12	4/18/14	4/18/13	4/09/13	4/18/13	4/18/11
Water Temperature °C	11.1	15.5	10.6	15.5	11.5	10.0	10.0	5.0	12.0	12.0	11.9	11.0	11.0	12.0
Ph(field)	8.2	7.2 SU	7.2	9.2	8.5	6.0	6.2	6.0	6.4	6.0	6.2	6.0	6.0	6.3
Chloride	800	1700	3,000	3 LT	3	6300	4500	1200	1400	280	1800	2300	1000	550
Sulfate (SO_4)	20	2 LT	2	2	3	4.0	23.0	11.0	12.0	20.0	11.0	28.0	11.0	6.0
Alkalinity (Methyl Orange)	283.0	276.0	194	116	216	4010	3020	2140	2020	1650	1990	2460	1825	1150
Sodium	590	1100	1800	36	70	2600	1900	800	720	280	930	1400	730	310
Potassium	7	11	20	.8	2.8	320	240	98	100	72	94	91	93	36
Calcium	7.2	18	75	2.1	10	680	510	330	410	240	410	340	420	260
Magnesium	2.0	4.5	19	.44	4.7	420	270	200	90	160	100	260	100	76
Iron	3.4	.30	.50	.05	.12	3.8	2.7	9.3	8.7	7.0	2.1	11.0	1.9	6.7
Nitrate and Nitrite	0.2 LT	0.2 LT	.2 LT	.2 LT	.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT
Nitrogen, Nitrite	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT
Ammonia	4.5	3.8	13	.30	1.7	18.0	12.0	6.0	NA	3.6	7.0	11.0	4.6	4.0
Phosphate	0.008	0.008	.007	.059	.009	0.015	0.018	0.041	0.047	0.039	0.015	0.050	0.036	0.030
Bromide	13.0	35.0	130	.56	1.5	90.0	61.0	22.0	24.0	11.0	2.7	3.5	2.0	11.0
Iodide	1.0	5.3	3.5	.006	.098	3.6	2.5	0.56	0.79	0.12	0.80	1.0	0.38	0.28
Boron	0.93	0.9	1.0	.2 LT	.50	2.3	3.0	1.4	1.3	1.1	1.6	2.0	1.1	0.79
Lithium	2.0	4.4	8.7	.02	.19	10.0	7.8	2.6	2.7	0.63	3.8	4.9	2.4	0.83
Silica	5.4	11.0	10	11	11	7.1	7.3	27.0	33.0	38.0	7.9	46.0	9.6	37.0
Strontium	1.4	6.7	34	.1	1.3	21.0	16.0	6.9	6.7	4.2	6.7	18.0	4.2	5.2
Barium	0.5 LT	0.9	12	.5	.5	8.6	8.6	1.8	3.4	1.1	3.2	5.0	1.1	1.1
Zirconium	0.01 LT	0.01 LT	.003 LT	.003	.010	0.32	0.23	0.04	0.04	0.01	0.10	0.04	0.08	0.01 LT
Total Dissolved Solids	1870	3310	6550	140	230	15190	10580	4280	4210	3220	5250	7710	3820	2170

LT = less than

GROUND WATERS OF METEORIC ORIGIN

Two analyses of representative natural surface waters from ground waters in wells near Saratoga Springs without a saline or connate component are also offered in Table 1. These waters are low in total dissolved solids with bicarbonate contents typical of waters in equilibrium with air or soil gas (Deines, et al., 1974) and a pH commonly near 8 or greater.

SARATOGA WATERS

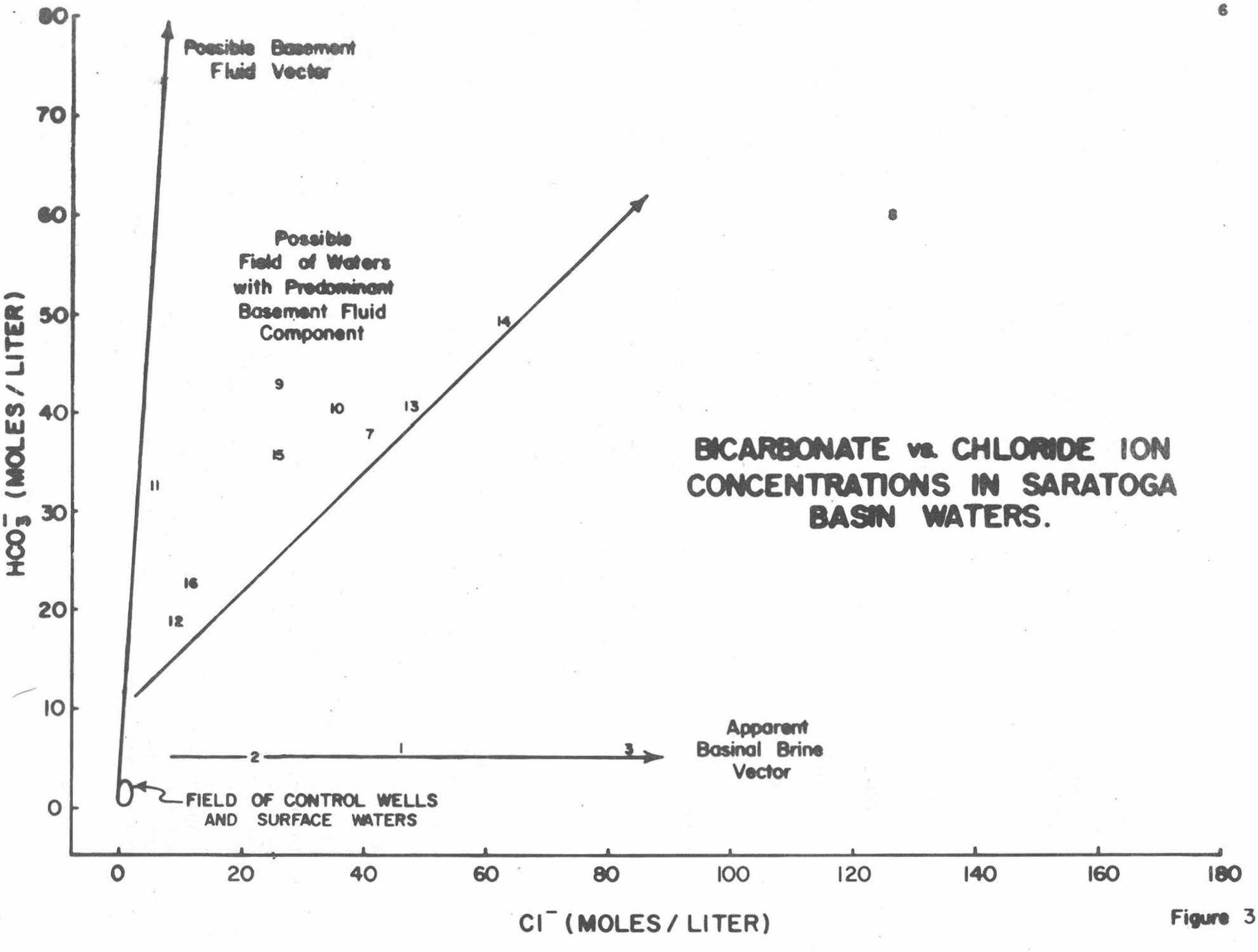
The wells tapping the waters of this group constitute what is usually thought of as the famous carbonated "springs" of Saratoga, new analyses of which are listed from south to north in Table 1. The primary and striking feature of these waters is, of course, the presence of large amounts of HCO_3^- and, particularly, free CO_2 in amounts up to 6 gms/ℓ or more. Equilibrium between dissolved CO_2 (CO_2 aqueous) and water produces carbonic acid, which in turn tends to be neutralized by reaction with the aquifer or host rocks. A simplified version of this reaction would be:

$$\begin{array}{ccccc} 2H^{+} + 2HCO_3^{-} & + & CaMg(CO_3)_2 & = & Ca^{++}+Mg^{++}+4HCO_3^{-} \\ \text{From Carbonic Acid} & & \text{From Carbonate} & & \text{Ions in Solution} \\ & & \text{Wall Rocks} & & \end{array}$$

It is considered very significant that all of the carbonated waters have large bicarbonate contents (commonly from 2,000 to 4,000 PPM) but are commonly not neutralized to a pH of 7. Indeed, measurements made at the wellhead show pH values as low as 5.5, although readings between 5.8 and 6.5 are more usual. With such pH values, approximately a tenfold or greater increase in the existing bicarbonate content would be needed to reach neutrality under conditions of constant CO_2 content. Used alone, however, the bicarbonate content is not a direct measure of the content of dissolved CO_2. Used in conjunction with the pH, an apparent P_{CO_2} at equilibrium can be calculated that commonly yields values between 2-4 atmospheres. With lower pH values probable in the resevoir, an entry of the gas into the carbonate aquifer at a point(s) not too far distant from the wells is implied.

An illustration of the variations among bicarbonate and chloride in these waters is shown in Figure 3. On this plot, saline basinal waters (low HCO_3^-/Cl form a vector along the abscissa which is quite distinct from the field of carbonated waters. Also of note are the presence of several wells where HCO_3^- exceeds Cl^- towards a possible steep (ordinate) composition vector. All carbonated waters contain greater amounts of Ca^{++} and Mg^{++} (derived by reaction with the wall rocks) than saline basinal waters of comparable salinity, but more significant is the trend in general stoichiometry: $HCO_3^- > Na^+ > Cl^-$. This shift in relative Na/Cl indicates that for the most part, the carbonated waters are not derived by simply adding carbon dioxide to the saline basinal waters, although a component of the latter is required by the contents of Cl^-, Br^- and other minor ions common to both waters.

If due allowance is made for Ca^{++} and Mg^{++} gained by carbonate wall rock dissolution, then a distinct sodium (with minor potassium) bicarbonate water component emerges for many of the carbonated waters. The presence of this component is reflected in a number of older analyses of Saratoga mineral waters



BICARBONATE vs. CHLORIDE ION CONCENTRATIONS IN SARATOGA BASIN WATERS.

Figure 3

where sodium (+ potassium) bicarbonate is reported as one of the presumed "salts" in solution where stoichiometric Na exceeds Cl. This water component is represented on Figure 3 as a "basement" fluid vector in that the source or site of initial carbonation is considered to be along faults and fracture zones in the underlying Late Proterozoic rocks.

STABLE ISOTOPES AND THEIR BEARING ON CO_2 DERIVATION

The results of standard isotope ratio analyses of hydrogen, oxygen and carbon in several samples are listed below:

SAMPLE	δD	$\delta^{18}O$	$\delta^{13}C$ IN CARBONATE ppt*	$\delta^{13}C$ IN CO_2 gas
Hathorn #3	-64.2	-9.22	+.57	-5.03
Orenda	-63.6	-10.39	+.60	-5.15
Big Red	-65.9	-10.36	-3.92	-6.84

Where δ = isotope fractionation in sample; expressed in parts per thousand

(per mil) difference relative to the standard, SMOW for D and ^{18}O, PDB for ^{13}C

D = deuterium isotope of hydrogen

^{18}O = oxygen isotope mass 18

^{13}C = carbon isotope mass 13

*precipitate

These analyses were made in the isotope geochemistry laboratory of the U.S. Geological Survey, Menlo Park, California, under the supervision of J.R. O'Neil and I. Barnes.

While the characteristics of the Saratoga waters strongly imply mixing with a connate or formational water source, meteoric "flushing" of this component appears to be required to understand the isotope data. Most formational waters of high salinity (>100,000 TDS) are characterized by relatively high δD and higher $\delta^{18}O$ values from isotopic exchange with the host rocks, therefore plotting to the right of the meteoric water line (Craig, 1961). Low salinity wells comparable to Saratoga have been measured in the shallow parts of the Illinois basin, however, and clearly exhibit flushing. These plot closer to the meteoric line than the deep wells into the same basin as shown in Figure 4 (Clayton and others, 1966). Small volumes of a very highly saline brine (~30-40% in magmatic high temperature or metamorphic water) added to meteoric water might account for the observed isotope data, but is problematical in terms of the chemistry of the uncarbonated saline wells until systemwide analyses are performed.

ISOTOPIC TRENDS OF SARATOGA WATERS

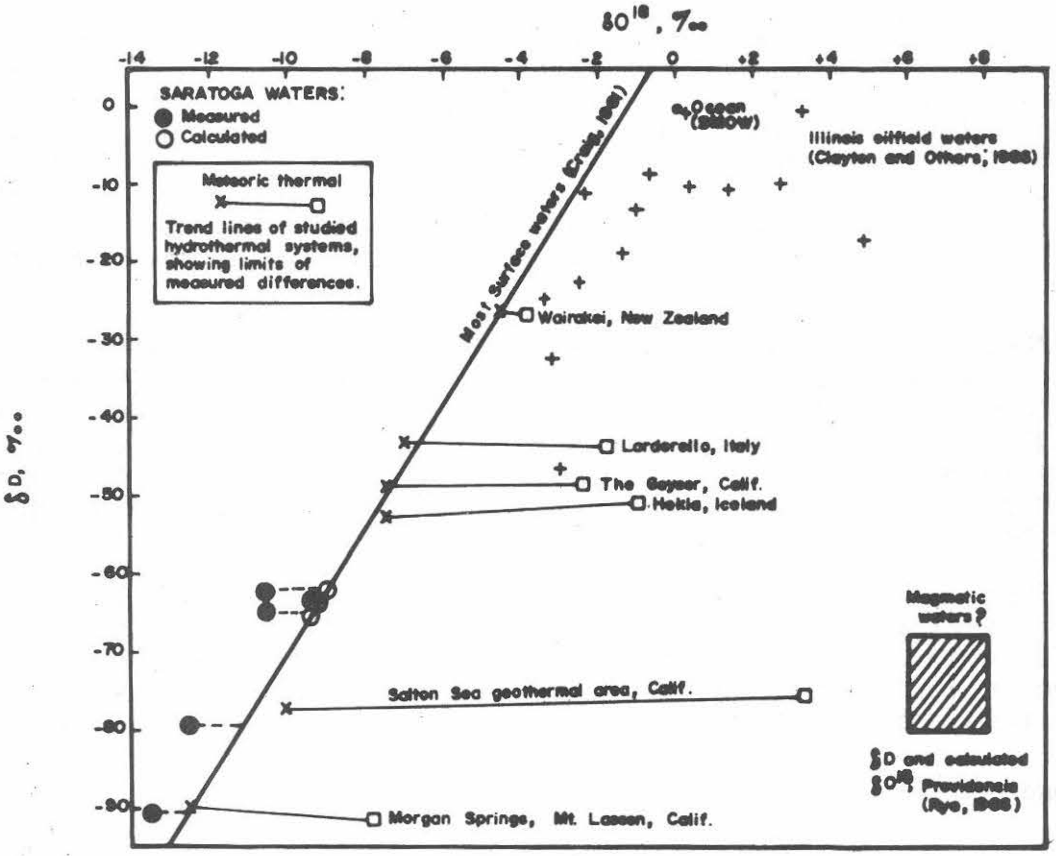


Figure 4. Isotopic composition of some thermal and mineral waters (modified after White, Barnes and O'Neil, 1973).

An oxygen isotope "shift" (-.8 up to -1 per mil) was found in two of the three samples above; i.e., $\delta^{18}O$ values relative to δD which are depleted from meteoric water and opposite to the effects of mixing with non-meteoric waters described above. The significance of the shift lies in the implication of prior higher temperatures for the CO_2 (or CO_2 + water); upon cooling, ^{18}O is strongly fractionated into the aqueous CO_2 phase thus depleting the water in this isotope. This type of oxygen isotope shift has been predicted for carbon dioxide-water systems, but has not actually been observed until now.

Carbon isotope data are not conclusive as to the source of carbon dioxide but do limit the possibilities. Interpretations are complicated by the fact that some dissolved carbon (as bicarbonate) is derived by solution of shallow crustal carbonate wall rocks; dissolved CO_2 gas exist as aqueous CO_2, carbonic acid, and bicarbonate ions by ionization; and small amounts of methane may also be present. Isotope exchange occurs among all these carbon species, so that the actual analyses reflect the fractionation effects at ambient temperature (as between aqueous CO_2 and $HCO_3{}^-$ ion) as well as a blend of carbon from different sources.

These complications notwithstanding, total ^{13}C values of a few per mil negative are indicated for these Saratoga waters. A composite analysis made from drill core through the carbonate sections indicates ^{13}C values from 0 to -1 per mil negative for these aquifer rocks. CO_2 of igneous or deep crustal origin generally has values in the -4 to -8 per mil range, whereas that derived by decarboxylation or oxidation of organic matter is commonly much more depleted (large negative values -15 to -25).

The carbon isotope data are therefore consistent with a mixture of "deep" CO_2 and carbon from the known surficial rocks. Small amounts of methane present in a few of the wells may be derived from organic matter in the shales, but the reduced nature of the waters, in conjunction with the carbon isotope ratios, argue persuasively against oxidation of organic carbon as a source of CO_2 at Saratoga.

CO_2 SOURCES

Accepting the evidence for thermally generated CO_2, the implied heat requirement does not appear to be satisfactorily met by remnant heat from a cooling Mesozoic pluton. Heat flow measurements made in plutons throughout New England exhibit slightly higher values than the worldwide average (1.5×10^6 ucal/cm^2), or 1.5 HFO only in the most granitic members (Roy and Birch, 1968).

Worldwide CO_2 occurrences compiled in a recent map (I. Barnes, 1978) show a strong correlation with active plate boundaries where associated igneous activity, metamorphism and deep faulting are going on today. One of the very few exceptions is, not surprisingly, Saratoga which is all the more notable for its relative strength, i.e. free CO_2 not completely neutralized to HCO_3^-. Situated as it is in an ancient mountain belt, Saratoga derives its uniqueness not so much from its unusual waters, but from being in an area apparently lacking recent vulcanism. The cool surface temperature of the waters has served mostly to compound this problem with a peculiar irony.

In seeking an adequate mechanism, then, we turn to the growing body of knowledge on Northeast neotectonics and the axiom that, "once the impossible has been eliminated, whatever remains, no matter how improbable, must be the solution" (S. Holmes, c. 1910). With no other tangible expression of recent igneous activity, it seems necessary to conclude that the system is embryonic; that is, created by subsurface igneous and/or metamorphic activity that has had insufficient time to be more directly expressed at the surface.

Evidence for this view stems from the releveling study done by Isachsen (1975) which has shown the Adirondacks to be rising at the rate of 6 cm/100 years in an oblate domal configuration. This in turn has prompted speculation that the uplift may be caused by thermal upwelling from a juvenile hot spot (K. Burke, personal communications) and the hypothesis, based on the tectonic record and recent structural evidence (the Neogene grabens of Lake Champlain and Lake George), that the Hudson Valley linear system may be a reactivated rift zone (K. Burke, 1977). The large Bouguer gravity low between Albany and Bennington, Vermont seems consistent with this interpretation and may signal a thinning of the crust as do the negative anomalies associated with the African rift systems.

The data do not permit a clear definition of the particular thermal process operating at Saratoga; i.e., leakage of "mantle" CO_2, degassing of an upper or mid-crustal igneous intrusion, and/or decarbonation of basement marbles. They do clearly suggest, however, that one or more of these mechanisms is responsible for the principal characteristics of the waters. Considered in conjunction with the evidence for recent faulting, the Adirondack uplift and the notable gravity low east of Albany, the thermal data for Saratoga are added evidence for the hypothesis that the greater Hudson Valley linear represents the surface expression of an embryonic, reactivated rift zone.

ACKNOWLEDGEMENTS

Portions of the data discussed herein were obtained as part of an investigation of the geothermal potential of the greater Saratoga Basin. This research is currently being supported by the New York State Energy Research and Development Agency through contract to Dunn Geoscience Corporation, Latham, New York.

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ADDED:

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ROAD LOG

CO-LEADERS: JAMES R. YOUNG
GEORGE W. PUTMAN

TOTAL MILES	MILES FROM LAST STOP	
0.0	0.0	Assembly Point - RPI Field House at 8:15 a.m. Departure Time 8:30 a.m. Leave Parking Lot and Proceed to Route 7
7.2	7.2	Turn right (north) on Adirondack Northway at Exit 6, Latham
21.7	14.5	Pass over pre-glacial Mohawk River Channel Between Exits 11 & 12
24.0	2.3	Pass excellent road cut exposure of Utica Shale cap rock. Stopping not permitted
32.4	7.4	Leave Adirondack Northway at Exit 15. Turn left on Route 50 toward City of Saratoga Springs
33.6	1.2	Turn right (north)on Route 9 McGregor Fault scarp on left
37.5	3.9	Turn left on Parkhurst Rd. Small exposure of Paleozoic carbonates in creek bed (Snook Kill) at Junction. Proceed up McGregor Fault Scarp
38.0	0.5	Turn left on Greenfield Road
38.4	0.4	Precambrian metasedimentary quartzite unit exposed in streambed
38.8	0.4	Stop 1 (15 minutes) Precambrian paragneiss exposed in roadcut. Note almandine garnet and sillimanite needles parallel to the foliation planes.
42.0	3.2	Turn left on Locust Grove Rd.
44.0	2.9	Cross Route 9N and proceed south on Brock Rd.
45.9	1.0	Turn right on Route 29

TOTAL MILES	MILES FROM LAST STOP	
46.5	0.7	Turn right on Petrified Gardens Rd.
46.7	0.2	Stop 2 (one hour) Pompa crushed stone quarry excellent exposures of the Gailor and Galway Formations, a variety of sedimentary features, and several fault zones. Note upper-most Gailor novaculite zone, Hoyt unconformity, vuggy zone with quartz crystal fillings, karst breccia fillings, and fault gouge. Proceed east across road to the rim of a possible small Neogene graben
47.3	0.6	Proceed north on Petrified Gardens Rd. Passing over several small, sharp fault scarps and another possible Neogene graben
47.7	0.4	Stop 3 (15 minutes) Lester Park - well preserved specimens of cryptozoa of the Hoyt formation. Note its position at the lip of another fault scarp. Reverse direction and return to Route 29.
48.9	1.2	Turn left on Route 29 in the direction of Saratoga Springs
51.2	2.3	Turn right on West Avenue
52.6	1.4	Turn right on Route 50. Saratoga Springs State Park to the east and Saratoga Vichy bottling plant on the west
53.5	0.9	Turn left into Saratoga Springs State Park. Hathorn #3 mineral well on the left. Proceed on to Geysers Brook
54.0	0.5	Stop 4 (45 minutes) Disembark and walk up Geysers Brook passing the Polaris, Karista, Hayes, Island Spouter mineral wells. The Ferndell spring on the right is normal surface groundwater. Continue up the brook to the Orenda well and picnic area. Lunch stop. 12:00 p.m.

ROAD LOG (Cont'd)

TOTAL MILES	MILES FROM LAST STOP	
		Discussion of the chemistry of the waters. pH and temperature measurements of the Orenda well and several others. Note the large tufa mound from the Orenda discharge. Time: 1:30 p.m.
54.0	0.0	Leave Lunch area from parking area of Saratoga Performing Arts Center and turn right on Route 50
54.3	0.3	Turn right into park again
54.5	0.2	Pass old State Bottling Plant on right. Site of Geyser and State Seal wells. Proceed through park.
55.4	0.9	Turn left on Route 9. Lincoln and Washington baths on the left.
56.2	0.8	Stop 5 (10 minutes) Grand Union Motel on the right is the site of the anomalous Rosemary well. pH and temperature measurements of the water and a brief discussion of the significance of its different chemistry
56.2	0.0	Proceed north on Route 9 through City of Saratoga Springs. Pass Congress Park
57.4	1.2	Turn right at Library then left onto High Rock Avenue
57.4	0.0	Proceed up High Rock Avenue, passing Hathorn #1 mineral well
58.5	1.1	Stop 6 (15 minutes) High Rock and Peerless springs are across the road from one another. The natural High Rock is at the base of the Saratoga Fault scarp, a continuation of the McGregor Fault
58.5	0.0	Proceed north on High Rock Avenue to Route 50. Pass Red Spring
59.2	0.7	Turn right on Route 50
60.9	1.7	Turn right onto Adirondack Northway at Exit 15
93.3	32.4	Return to assembly point retracing outward trip

Economic Geology of the Hudson River Valley

George M. Banino; Dunn Geoscience Corporation; Latham, New York
William E. Cutcliffe; Dunn Geoscience Corporation; Latham, New York

INTRODUCTION

The purpose of this field trip is to examine some of the economic uses of the rock and mineral deposits of the Hudson River Valley, and to discuss the importance of economic geology in helping to bring these commodities to the market. The area we will study has a wide variety of economic deposits and mining operations, all of which are related to the construction industry. This is in part due to the location near major metropolitan markets and the presence of a major transportation route, the Hudson River, but is basically controlled by the nature and location of the geologic deposits.

During this trip four sites will be examined, each producing a different product, and each with a different geologic setting that must be considered in the mining process. The sites to be visited are Norlite Corporation, Cohoes, New York, producing lightweight aggregate; Atlantic Cement Co., Ravena, New York, producing portland cement; Callanan Industries, Port Even, New York, producing construction aggregate; and another portion of the Callanan property producing sand for bituminous concrete.

There is a long history of geologic work in the Hudson River Valley, going as far back as Amos Eaton in the first quarter of the 1800's, which has led to a large volume of geologic studies and innumerable field trips. This guidebook draws principally from three previous trips, the 33rd New York Geological Association trip in 1961 (Dunn & Rickard, 1961), the 61st New England Intercollegiate Geologic Conference in 1969 (Brown & Cutcliffe, 1969), and the 14th Annual Forum on the Geology of Industrial Minerals in 1978 (Banino & Brown, 1978).

GEOLOGIC SETTING

The geologic units to be studied on this trip include the Ordovician Snake Hill shale, the Silurian and Lower Devonian units which form the Helderberg Group, and Pleistocene glacial deposits. The Snake Hill and associated basinal shales such as the Normanskill shale form the bedrock floor of the Hudson River Valley and are exposed over wide areas where they are not covered by glacial deposits or recent alluvium. Along the west side of the valley are a prominent series of hills known as the Helderbergs which form a major escarpment from Schenectady south to about Catskill, New York. From this point south, the Helderberg formations form a less prominent scarp which is overwhelmed by the Devonian sandstone and shale of the Catskill Mountains which rise majestically behind them. Overlying the rock units are a wide variety of glacial deposits including till, varved clay, sand and gravel, and aeolian sands.

The rock units to be observed during the trip range from the Ordovician Snake Hill shale through the Devonian Esopus shale. These units, with some minor changes, persist from Albany to Kingston at which point they become separated from the Hudson River by the abrupt rise of the Silurian Shawangunk quartzite which forms the sharp ridge known as the Shawangunk Mountains. The structures are dominated by thrust features indicating compression from the east. The deformation becomes more intense southward, so that at Atlantic Cement the structural features consist of low-angle thrust faults and broad, open folds, while at the Callanan quarry the structures consist of both low and high-angle thrusts and tight complex folds. The regional strike is north-south to northeast-southwest with an overall dip to the west, under the Catskills.

BEDROCK STRATIGRAPHY

The stratigraphy covered in this trip has been studied by many workers, but is based largely on work by Cutcliffe, Dunn, Bird and others during the early 1960's in a number of quarries in the Hudson River Valley. Other sections were studied and measured to gain a more complete understanding of the stratigraphy. A synopsis of the stratigraphy is presented in Figure 1. Additional more detailed work by LaPorte, Rickard and others has been carried out since that time to interpret the depositional environments and stratigraphic relationships.

SNAKE HILL SHALE

The Snake Hill shale is a dark gray to black, somewhat silty shale with occasional beds of laminated siltstone. It is a thick sequence, estimated to be 3000 to 4000 feet thick, of basinal sediments that is well exposed during low water in the Cohoes gorge of the Mohawk River. The Snake Hill, of late Middle Ordovician age, is slightly older than the Normanskill formation which underlies the Helderberg sequence near Ravena and Kingston, New York.

Because of its more uniform nature, the Snake Hill is suitable for production of lightweight aggregate, whereas the Normanskill with chert and graywacke beds would not provide a consistent product for the manufacturing process.

RONDOUT FORMATION

The Upper Silurian Rondout formation has varying units of dolomite, magnesian limestone and limestone that formerly were extensively mined to produce natural cement. The formation is characterized by buff-weathering greenish-gray, magnesian limestones which in the field trip area lie with sharp unconformity over the Ordovician Normanskill shales. Thickness decreases to the north. In the vicinity of Rosendale, the thickness of the unit is almost 50 feet and at the quarry about 40 feet. To the north at the Atlantic Cement quarry, the unit averages three to five feet.

FIGURE 1

STRATIGRAPHY AND USE OF FORMATIONS IN THE CENTRAL HUDSON VALLEY

Age	Formation	Lithology	Uses
Lower Devonian	Esopus	Shale to sandstone	Lightweight aggregate, portland cement*
	Glenerie	Quartzose limestone to sandstone	Coarse aggregate
	Connelly	Sandstone	Coarse aggregate
	Port Ewen	Calcareous siltstone to shale	Coarse aggregate
	Alsen	Limestone	Coarse aggregate, portland cement**
	Becraft	Limestone	Coarse aggregate, portland cement
	New Scotland	Calcareous shale to limestone	Coarse aggregate, portland cement**
	Kalkberg	Limestone	Coarse aggregate, portland cement**
	Coeymans	Limestone	Coarse aggregate, portland cement
	Manlius	Limestone	Coarse aggregate, portland cement
Late Silurian	Rondout	Dolomite to magnesium limestone	Coarse aggregate
Ordovician	Snake Hill Normanskill	Graywacke and shale	Lightweight aggregate

* Used as an additive for alumina

** When blended with the more pure Manlius, Coeymans and Becraft limestones

In the Kingston-Rosendale area, the Rondout is divided into four members. From bottom to top they are the dark gray Wilbur limestone (3-15 feet), the greenish-gray Rosendale magnesian limestone (17-27 feet), the dark gray Glasco limestone (10-15 feet), and the greenish-gray Whiteport magnesian limestone (9-14 feet). The Rosendale and Whiteport members are the classical "water-limes" that were extensively mined underground in the Rosendale area.

MANLIUS FORMATION

The Manlius formation is divided into the Thacher, Olney, Elmwood, and Clark Reservation members in the Mohawk River Valley. However, only the lowest member, the Thacher, is present in the Hudson River Valley, and the following discussion refers only to the section to be observed on this trip.

The Manlius consists of interbedded dolomitic "ribbon" limestones, and dark gray, pure, massive to biostromal limestones. Primarily for mining control in the cement quarries, this formation has been subdivided into units designated from bottom to top as M-1 through M-6. At the Atlantic Cement quarry, where the entire formation is mined for cement limestone, the Manlius is 52 to 55 feet thick. At another cement quarry in East Kingston, the Manlius is 52 feet thick but only the M-3 through M-6 units are used for cement limestone.

The M-2 and M-5 units reflect Rondout-type lithologies, being light-gray, "ribbon" bedded, magnesian limestones. The two to four-foot thick M-5 unit is a distinctive marker horizon in most outcrops and quarries where it is present.

COEYMANS FORMATION

The Coeymans is a pure, bluish-gray, medium to coarsely crystalline limestone that forms prominent ledges along the Helderberg escarpment. It lies between the dark gray, finer grained M-6 unit of the Manlius and the chert beds of the overlying Kalkberg formation. The unit is generally massive-bedded, with individual beds recognized only with difficulty. White calcitic crinoid stems, locally silicified, are common.

The upper contact with the Kalkberg is gradational, but determination of the contact is important for cement chemistry control. The contact is placed at the base of the first horizon at which black chert beds are spaced about a foot aprt. This closely approximates a sharp change in silica content, from about 10 percent below to about 25 percent above. At Atlantic Cement, the Coeymans is 28 feet thick, and occasional black chert nodules and discontinuous chert beds are included at the top of the formation. At Callanan, the Coeymans is 20 feet thick and little if any chert is located below the lowest, nearly continuous chert bed.

KALKBERG FORMATION

The Kalkberg ranges from a bluish-gray, chert-rich limestone to gray, fine grained, argillacesous limestone. Primarily on the basis of lithology, the formation has been divided into four members in the field trip area; the Lower and Upper Hannacroix, and the Lower and Upper Broncks Lake.

The Lower Hannacroix is the dominant bluff-maker of the Helderberg Escarpment and is readily recognized by the prominent black chert layers spaced about one foot aprt. The rock is massive-bedded and is finer grained and darker than the underlying Coeymans. It ranges in thickness from 11 feet at Atlantic Cement to 18 feet at the Callanan quarry.

The Upper Hannacroix is a fine-grained, fairly massive, gray limestone with anastomosing argillaceous partings which give a "tennis net" appearance on weathered surfaces. This unit does not contain layers of chert, but has numerous small nodules of black and dark gray chert nodules. With the absence of chert, this unit is similar in appearance to the Coeymans, though it is generally finer-grained. The top of this unit is marked by the first appearance of a dark gray, euxinic shale bed, about two feet thick, containing pyrite nodules and small brachiopods. Thicknesses range from 10 feet at Atlantic Cement to 18 feet at Callanan.

The Lower Broncks Lake has fine-grained, bluish-gray limestone beds one to three inches thick interbedded with one to two-inch beds of calcareous shale. Fossils are abundant in this unit and encrusting bryozoans are common. Thicknesses range from 15 feet at Atlantic Cement to 14 feet at Callanan.

The Upper Broncks Lake is a fine grained, bluish-gray limestone with beds from three to over twelve inches thick and fewer shale layers than the underlying unit. One to three thin, black to dark gray chert layers occur near the base. Thicknesses range from 30 feet at Atlantic Cement to 27 feet at Callanan.

Although the lithology of the Kalkberg varies, the chemistry of the formation is fairly consistent. A silica content of from 25 to 30 percent is found regardless of whether it is in the form of bedded limestone and chert, shale and limestone layers or argillaceous limestone. The top of the Kalkberg marks a distinct change in chemistry, with silica jumping from less than 30 percent in the Kalkberg to nearly 50 percent in the New Scotland.

NEW SCOTLAND FORMATION

The New Scotland can generally be described as an alternating, medium gray, very fine grained, impure limestone and dark gray calcareious mudstone with varying amounts of chert and pyrite. There is a significant facies change in this formation along the Hudson River Valley. To the north, near Atlantic Cement, it is generally a calcareous mudstone while to the south, near Callanan, it is generally a more or less argillaceous limestone. In both cases, the lowest beds are chemically a calcareous mudstone or siltstone having less than 45 percent total carbonate. The uppermost beds become more calcareous and coarser grained as they grade into the Becraft formation. The contact with the Becraft is placed at the first appearance of a green shale layer. Thicknesses vary from about 98 feet to the north and about 100 feet to the south. In the Kingston area, the formation is divided into ten subunits, each about ten feet thick.

BECRAFT FORMATION

The Becraft is an easily recognizable formation consisting of very coarse grained, light gray to nearly white, pure limestone with more or less pink calcite. It is very massive, forming prominent ledges, and bedding is often difficult to distinguish. Locally, gray chert occurs near the base and top of the formation. While it frequently forms ledges, it also often underlies extensive wetlands, lying between high hills formed by overlying sandstone and shale formations.

Thicknesses range from 45 feet at Atlantic Cement to about 37 feet at Callanan. It is the formation with the highest carbonate content in the central Hudson River Valley, with over 90 percent total carbonate. Magnesium oxide comprises from less than one or two percent of the rock. This high purity led to the excavation of many pits by early miners who used the Becraft for agricultural limestone and cement.

ALSEN FORMATION

The Alsen forms the top of the Helderberg sequence and is present from near the Town of Catskill on the south. It is a medium to dark gray, cherty limestone with interbedded, thin, shaly partings. It is somewhat similar in appearnce to the Lower Hannacroix of the Kalkberg. At Atlantic Cement, the Alsen is absent, and the Becraft is directly overlain by the brownish-dark gray Glerie sandstone. At Callanan, the Alsen is 20 feet thick. In the cement quarry in East Kingston, it is mined along with the Becraft for cement limestone.

PORT EWEN FORMATION

The Port Ewen forms the base of a group known as the Tristates Group which lies below the Onondaga Formation. It is a medium to dark gray cherty argillaceous limestone to limy siltstone. Locally, it becomes very siliceous, and black chert occurs as bands and nodules. It is similar to the New Scotland formation but is almost barren of fossils. From a thickness of about 150 feet at its type section near Kingston, it thins rapidly northward. At Callanan, the unit is about 100 feet, and only a few feet remain at Atlantic Cement.

CONNELLY FORMATION

The Connelly is a coarse grained, white to light gray quartz sandstone. It is locally conglomeratic and has an argillaceous matrix. Iron, as pyrite, is common and occasionally serves to cement the grains. The formation, over 15 feet thick at Kingston, thins rapidly to the north. At Atlantic Cement, it is represented by a few feet of sandy limestone.

GLENERIE FORMATION

The Glenerie is a thin, cherty, siliceous limestone containing Oriskany fossils in the lower central Hudson Valley. It ranges from 5 to 110 feet thick, thinning rapidly to the north. The unit is only a few feet at Atlantic Cement.

While the formations from the Rondout through the Becraft change only slightly from East Kingston to Ravena, the overlying formations, the Alsen, Port Ewen, Connelly and Glenerie change dramatically. From a full, well developed sequence at the Callanan quarry, they thin rapidly to the north so that the approximately 250 foot Hudson section is represented by only about 5 feet of rock at Atlantic Cement. Here, there are about 2½ feet of cherty, quartzose limestone immediately above the Becraft which have elements of the Alsen and Port Ewen. The next 2½ feet are sandy, fossiliferous, calcareous siltstone having elements of the Connelly and Glenerie. The Glenerie-Connelly formation equivalent in the Ravena area is mined as a decorative building stone. It is locally known as "fossil rock" and is used as a facing stone on many local structures.

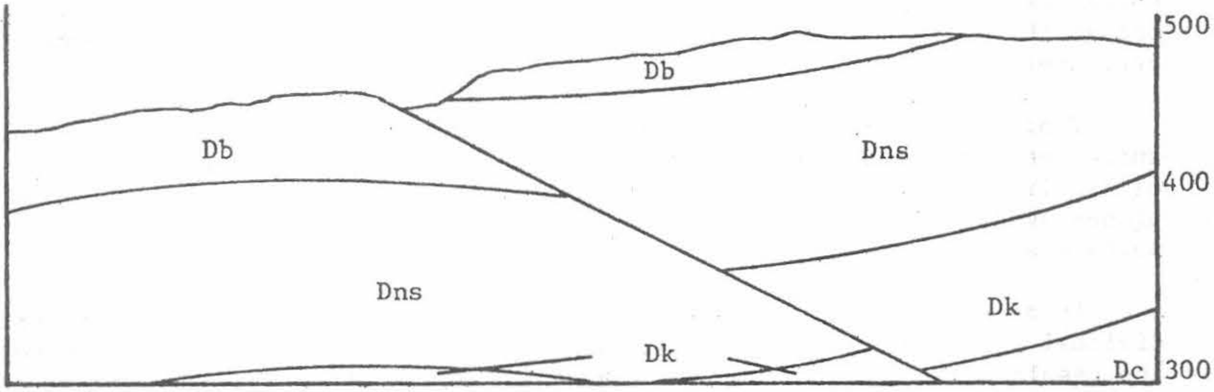
ESOPUS FORMATION

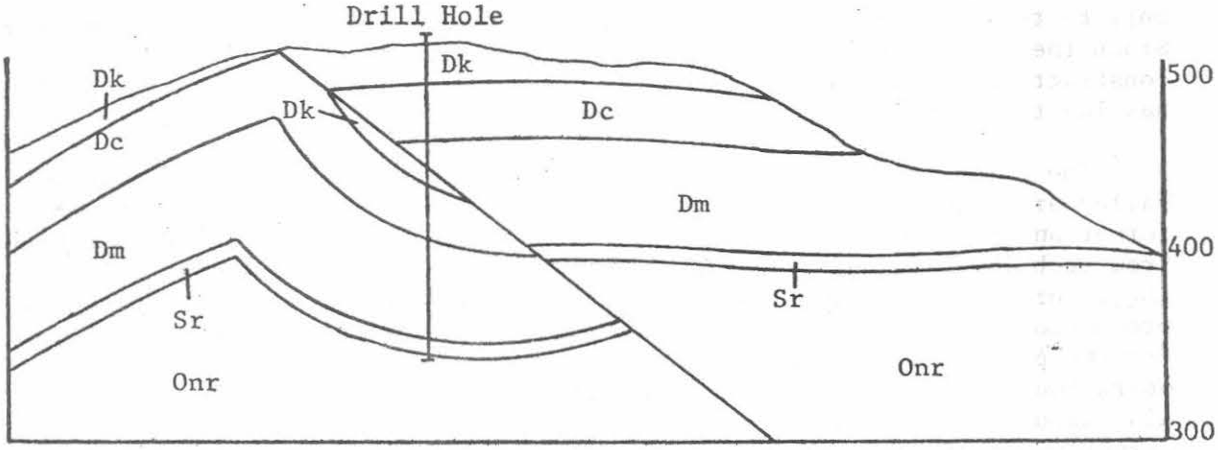
The Esopus is a dark gray, silty shale to shaly siltstone that forms gentle to steep slopes above the Glenerie limestone. The lower portion of the unit contains occasional beds of silty limestone and in general is somewhat more calcareous than the remainder of the unit. Commonly, it is a monotonous sequence of shale that ranges in thickness from 120 feet near Callanan to 150 feet at Atlantic Cement.

STRUCTURES OF THE CENTRAL HUDSON RIVER VALLEY

Underlying the Helderbergian formations is the thick sequence of shale and sandstone known as the Normanskill Shale that is highly folded and faulted. Separating the carbonates from the Normanskill is a sharp unconformity that can be considered a decollement. Deformation increases in intensity at the contact, and the lowest Rondout is locally fractured and thickened by thrust faulting. The Helderbergian units were under compression from the east, giving a general north-south strike to the structures. Intensity decreases to the north.

FIGURE 2





Scale 1" = 100'

TYPICAL HUDSON VALLEY-TYPE
FOLD-THRUST FAULT STRUCTURES

These sections show typical fault-fold relationship in the field trip area. Note in the lower section that the size and even the presence of the syncline under the thrust fault is not indicated in surface outcrops. The stratigraphic relationships at the surface actually suggest normal faulting.

Normal faulting is seldom encountered, although the outcrop pattern and topography created by high-angle reverse faults locally may resemble normal fault geometry. Similar structures persist from south to north, though the intensity of folding and displacement along the faults generally decrease.

Typical fold-fault structures in the Helderbergian rocks consist of an anticline thrust over its adjacent syncline so that in plan view two anticlines lie next to each other, separated by the fault. In some cases, the hidden syncline may be very large, but the size may not be determined from surface evidence alone.

In areas of particularly intense deformation, local thickening of individual beds can occasionally be found. This increase in thickness is not the result of "plastic" flow, but rather of slight offsets along closely spaced axial cleavage planes. An example of this is exposed at Atlantic Cement and such structures have also been observed at Callanan.

ECONOMIC GEOLOGY

The use of rock materials in the central Hudson River Valley is related to the construction industry: limestone for cement, limestone and some sandstone for coarse aggregate, and shale for lightweight aggregate. The location of many operations along the Hudson River enables low-cost transportation not only to the New York metropolitan area but to the southeastern U.S. and beyond. Since the early 1960's, when many facilities such as Atlantic Cement were constructed, the decreasing demand for construction materials in the Northeast has led to the closing or sale of several cement plants.

The principal economic uses of the formations in the central Hudson Valley are shown in Figure 1. The high-lime Manlius, Coeymans and Becraft formations are used for the manufacture of cement with some additional blending from such low-lime units as the Kalkberg, New Scotland and Alsen. All of these formations, as well as the Port Ewen and Glenerie, are used for the production of aggregate. The Esopus shale has been used by three producers for the production of lightweight aggregate, however, only one remains in operation today. The more uniformly shaly portion of the Snake Hill also used by one producer for the manufacture of lightweight aggregate. Formerly extensive operations in the Rondout formation utilized the dolomitic limestone members for natural cement, chiefly from underground mines that extended from East Kingston to Rosendale. The last operation closed in the 1960's. These beds occur in strongly overthrusted structures and sometimes very steep folds. Interestingly, the New York Thruway passes over the Rondout across one of the few stretches in many miles where there had been no mining.

FIELD TRIP

STOP 1 -- Norlite Corporation

The Norlite Corporation, a subsidiary of P. J. Keating Co., Lunenburg, Massachusetts, produces expanded shale aggregate, or lightweight aggregate, by a rotary kiln process. The property consists of the deep quarry and manufacturing facility. The Snake Hill shale which is quarried is overlain by glacially derived overburden consisting of clay, silt, and cobbles, which are stripped off prior to drilling and blasting.

Geology

The Snake Hill is a thick sequence of shale with occasional mudstone and sandstone beds. As revealed in the quarry and drill core, the rock is a monotonous sequence of medium dark gray to dark gray, very fine grained shale with occasional thin beds of convoluted mudstone or very fine sandstone. Overall, bedding dips about 50 degrees to the southeast and cleavage dips about 60 degrees to the southeast.

Close inspection of the quarry reveals more detailed structural features. Where bedding is sufficiently apparent, the noses of isoclinal folds can be observed, particularly where the rock is more of a siltstone than a shale. Along the west wall of the quarry, one of several faults can be observed. This fault cuts the rock at a lower angle than either the bedding or the cleavage. The age of the faulting is not known.

Manufacturing

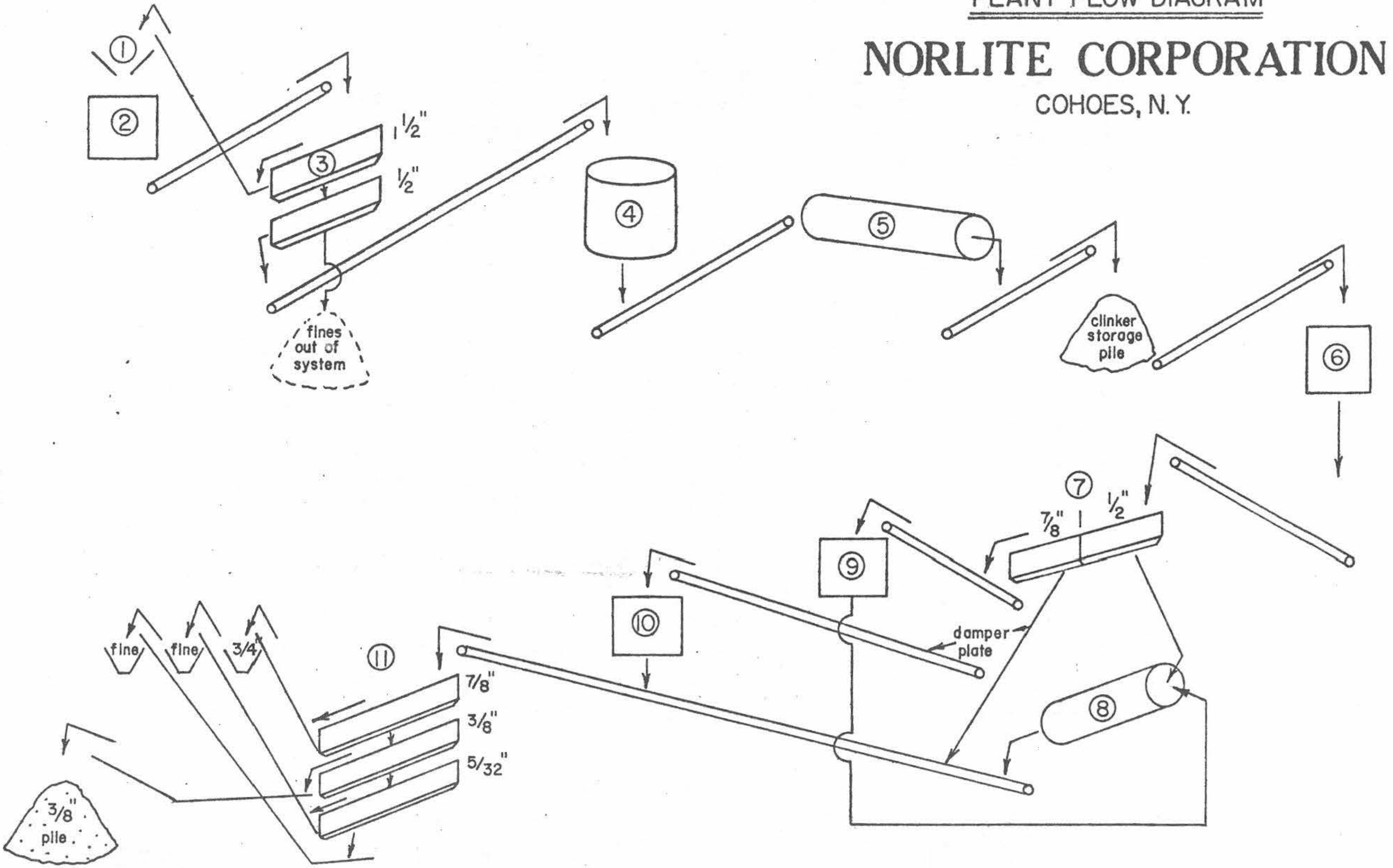
Norlite lightweight aggregate is a manufactured product in which crushed shale is expanded to produce an aggregate used, normally, for Portland cement concrete. The advantage of this product is its reduction in weight as compared to normal weight aggregate. This allows the production of lightweight concrete, either for small structures to be moved by hand, such as concrete blocks or curbing, or for structural concrete, particularly in tall buildings where there is a considerable savings in reducing the total weight of the building. Typically a cubic foot of Norlite coarse aggregate weighs 45 pounds compared to about 100 pounds for regular weight concrete.

Expanded shale aggregate also has several other properties that make it attractive for specific uses. Because lightweight aggregate contains very small separated air cells, it has enhanced insulatory value. The air cells greatly enhance the thermal resistance (R value) of concrete, so that lightweight aggregate concrete has the capability of providing over twice the thermal insulation of normal weight concrete. Also, because all combustible material has been burned out in the manufacturing process, the fire resistance of lightweight aggregate concrete is greater than that for natural aggregate concrete.

PLANT FLOW DIAGRAM

NORLITE CORPORATION

COHOES, N. Y.



① Kennedy Van Saun Pan Feeder
② Kennedy Van Saun 150 hp., 36" x 48" Impact Crusher, 2" Setting
③ Kennedy Van Saun Two-deck Screen
④ 35' High, 35' Wide Silo
⑤ # 2 Kiln, 11' x 175'
⑥ Kennedy Van Saun 20 hp., 20" Single Roll Crusher, 3/4" Setting
⑦ Single Deck, Multisize Screen
⑧ 150 hp., 5 x 12 Ball Mill, 3/8" Setting
⑨ Kennedy Van Saun 40 hp., Impact Crusher, 3/4" Setting
⑩ Frontier Crusher 18" Double Roll Crusher, 3/8" Setting
⑪ 2-3 Screen Decks With Same Screens
  a) Simplex 6 x 12 Deck
  b) Kennedy Van Saun 5 x 14 Deck

The basic process in expanding shale is the introduction of crushed shale into an oil fired rotary kiln where temperatures in the burning zone are maintained between 2000 and 2100 degrees Fahrenheit. At this temperature the shale reaches what is known as the point of incipient fusion where the shale is in a semiplastic state and gasses are generated by the breakdown of carbonates and oxides. The gasses are generated but contained within the semiplastic mass, expanding the shale and creating individual non-connecting air cells. As the material is passed out of the kiln, it is air quenched to form a vitreous clinker that is then recrushed and sized to make the final product. Figure 3 is a plant flow diagram of the Norlite process.

STOP 2 -- Atlantic Cement Company

Atlantic Cement went into production in 1960 following detailed geological analysis which preceded the investment of $44,000,000. There are three major quarries on the property: the Becraft quarry, the North Coeymans-Manlius quarry, and the South Coeymans-Manlius quarry. Adjacent to these are several other mining faces, including the high face of the Esopus shale and lower benches in the Kalkberg. The Becraft and Coeymans-Manlius quarries provide the high-calcium limestone for cement while the Esopus face provides an alumina additive and the Kalkberg is stripped to gain access to the Coeymans-Manlius.

The Kalkberg is a New York State Department of Transportation-approved coarse aggregate source. However, an aggregate processing plant has never been established here. Because the Kalkberg that is being removed is a future resource, it is placed separately in stockpiles for possible future use. The top of one of these stockpiles is undergoing reclamation, though it is realized that it may be disturbed later.

The Coeymans-Manlius face is excavated from a few feet above the Rondout-Manlius contact, to avoid incorporating the dolomitic Rondout in the shot, to about ten feet above the Coeymans-Kalkberg contact. Silica from the Kalkberg requires some adjustment of the design mix, but this increases reserves and decreases the amount of Kalkberg that must be removed.

Stop 1a

The walls of the access ramp of the North Coeymans-Manlius quarry expose a complete section from the Rondout to the Lower Hannacroix member of the Kalkberg formation. The contact of the Rondout with the underlying Normanskill shale is at the water level of the sump at the bottom of the ramp. The Rondout can be seen to be about four feet thick, increased over its normal two foot thickness by faulting. The Manlius units and Coeymans are well exposed along the ramp. Note the gradational contact of the Coeymans and Lower Hannacroix near the top of the ramp where chert can be seen on both sides of the contact.

Stop 1b

The full section of Becraft is exposed in the Becraft quarry. The lower contact is gradational but can be placed about two feet below a discontinuous blue-gray chert horizon that can be found on the face. The high shale face above the Becraft is in the Esopus formation which is used as an alumina and silica source. Below the Esopus, the upper two feet of the Becraft face in places reveal the remnants of the Alsen, Port Ewen, Connelly and Glenerie formations that are fully developed at the Callanan quarry.

A high-angle thrust fault, with relatively minor displacement, is located at the north end of the quarry. The area around this quarry has well developed synclinal ridges, with the youngest unit, the Esopus, forming the ridges and the high-carbonate Becraft forming the valleys which occasionally contain wetlands.

Stop 1c

The access into the South Coeymans-Manlius quarry displays a complex local structure. This exposure is at the northern end of a major thrust fault, at the point where the displacement is small enough that the rock has failed by folding rather than by faulting. The black chert bands of the Lower Hannacroix mark the asymmetrical anticlinal fold. However, the bedding is largely obscured by very well developed fracture cleavage. There is marked thickening of the beds along the fold crest as a result of slippage along the cleavage surfaces.

POINTS OF INTEREST -- New York State Thruway

Thruway Markers	
123.7	The slope of the road climbs the Helderberg Escarpment passing from the Normanskill to the Helderberg group.
122.0	East Side. Lower Hannacroix member of Kalkberg formation; note black chert bands. West Side. Long cut contains all units from Manlius through New Scotland in a very complex structure.
120.6	Kalkberg formation.
120.3	New Scotland formation.
120.1	Becraft formation.
119.2	Esopus formation. Note the difference in weathering response between the clean Becraft limestone road cuts and the highly fragmented Esopus shale cuts. The latter indicates a high sensitivity to wet-dry or freeze-thaw alternations. A breakdown of the fine material at the base of a cut is an almost certain indication that the rock is unsuitable for use as crushed stone.

118.9 Becraft formation, steeply dipping.

118.4 New Scotland through Becraft.

117.7 Esopus formation.

117.0 Onondaga formation. Note chert layers.

116.4 Highly fractured Becraft. These calcite-healed fractures suggest nearness to a thrust fault.

116.0 Note long, north-south lake on right. Structure and stratigraphy suggest the lake marks the position of a thrust fault, a common occurrence in this area.

113.8 East Side. Note New Scotland faulted onto New Scotland.

113.7 Becraft above New Scotland. The bridge crosses Austin Glen, the type locality of the Austin Glen member of the Normanskill formation.

112.9 Esopus below Schoharie.

111.9 Schoharie. The cut in the median strip is synclinal.

111.5 Esopus-Schoharie-Onondaga.

110.1 Schoharie-Onondaga.

109.8 Cut east of Thruway. Esopus with lowest portion high in bedded chert.

109.1 Esopus below, Schoharie above with broad transition zone.

108.0 To east of Thruway lie three cement plants clustered in the beds of the Helderberg group. South to north they are: The Alpha Portland Cement Company; The Lehigh Portland Cement Company; and the Marquette Cement Manufacturing Company.

103.8 Port Ewen formation above Becraft. Note the large blocks that break loose from the face of the road cut. These are known to engineering geologists as wedge failures. These bedding plane and joint intersection problems have largely been eliminated by pre-split blasting of the final face.

STOP 3 -- Callanan Industries, Inc. - Port Ewen Crushed Stone Quarry

The Port Ewen quarry is owned and operated by Callanan Industries, a subsidiary of Penn Dixie Corporation. The principal product is New York State Department of Transportation approved coarse aggregate (crushed rock). Within the past five years a small fine aggregate (sand) operation was initiated to produce asphatic sand for the company's asphalt plant located on the property.

Two crushed stone products are produced; high friction bituminous concrete aggregate, and portland cement concrete aggregate. The reserves are within the Lower Devonian Helderbergian rock units.

High friction aggregate is specified by the New York State Department of Transportation for use in top coarse asphaltic concrete pavements to obtain an aggregate that does not polish when exposed to heavy traffic. High friction aggregate specification requirements are divided into noncarbonate and carbonate rock types. Most noncarbonate high quality rocks such as granites, diabases, and quartz feldspar gneiss, can be used as high friction aggregate and also as a 20% blend to upgrade high quality aggregate that does not otherwise meet the high friction aggregate specifications.

The second classification, carbonate rocks, which the entire Port Ewen quarry sequence falls within, to meet high friction aggregate requirements either must contain 10 percent material pluss 100 mesh insoluble residue in concentrated hydrochloric acid (presumably quartz) or contain 20 percent noncarbonate material (chert).

Ten formations are mined at the Port Ewen operation. They are the upper two units of the Rondent, Manlius, Coeymans, Kalkberg, New Scotland, Becraft, Alsen, Port Ewen, Connally, and Glen Erie formations. With the exception of the Connally formation which is a calcareous sandstone, all of the other formations are either dolomitic limestones (Rondent and Manlius), high calcium pure limestones (Coeymans and Becraft), cherty limestones (Kalkberg, Alsen and Glen Erie) or argillaceous limestones (New Scotland and Port Ewen formations).

Listed below are the formations and their uses:

Formations	Approximate Thickness	Use	
Glen Erie	100	Regular aggregate - high friction	Upper High Friction Sequence
Connally	15	Regular aggregate - high friction	
Port Ewen	100	Regular aggregate - high friction	
Alsen	20	Regular aggregate	
Becraft	40	Regular aggregate	
New Scotland	115	Regular aggregate - high friction	Lower High Friction Sequence
Kalkberg	65	Regular aggregate - high friction	
Coeymans	20	Regular aggregate -	
Manlius	50	Regular aggregate -	
Rondout (2 units)	40	Regular aggregate -	

The two products must be mined, processed, stockpiled and delivered separately. Plant production demands necessitate maintenance of separate operating faces and loading units for each product. For example, high friction aggregate will be mined from two separate faces for two or more 8-hour shifts followed by regular aggregate production from two additional faces for several shifts or days.

Structure

The Helderbergian limestone formations are intensely folded and faulted. The initial stop at this site will be in the northeastern portion of the quarry where the lower Rondout, Manlius, Coeymans, Kalkberg, and New Scotland vertical beds are forming the east limb of north-south trending syncline which plunges to the north. The Becraft, Alsen and Port Ewen formations are complexly faulted in the northeastern portion of the quarry and challange certain geological interpretations without additional subsurface drill hole information.

The northern face exhibits several moderate angle thrust faults in the Glen Erie, Connally, and Port Ewen formations. The distinctive Connally calcareous sandstone unit makes an excellent marker bed to discern the structural relationships.

In the western portion of the quarry a major thrust fault has been mapped and mined during the past twenty years. The eastward dipping thrust sheet has caused numerous mining stability problems.

Quality of Products

New York State Department of Transportation requirements for high friction aggregate demand that only the approved formations be included in that product. This demands good quality control beginning with well defined geology, ongoing mine planning and regular production control.

Dunn Geoscience Corporation personnel are retained to complete biannual geologic source reports which represent in both map and cross section form the areas of proposed operation for the next two years of both products by formation boundaries. In addition, the boundaries of each product are marked with spray paint on the faces and targets are set on the upper levels to indicate the orientation of the third dimension extension of the contact.

A mine plan has been completed by Dunn Geoscience Corporation to allow annual and monthly planning to be fitted into a long term mining and reclamation plan. Triennial reclamation plans are required and submitted to the New York State Department of Conservation

Market

The large majority of the finished products are barged to New York City via the Rondout Creek and Hudson River. The crushed rock and fine aggregate that is supplied to the Callanan asphalt plant is used within the local region.

Sand

The sand deposit appears to be an upland erosional remnant of a formerly larger deposit. Similar material can be found on the east side of the railroad tracks and to the north along the north valley wall of Rondout Creek at Wilbur, New York.

The source is glacio-lacustrine in origin, displaying a single mode of deposition. The several local deposits exhibit similar structure suggesting that the depositional environment was fairly extensive in the Rondout-Hudson Valley region. Damming by glacial ice in the Hudson River valley is believed to have created a lake both in the Rondout and Wallkill River valleys that extended to the south to within 2½ miles of New Paltz, New York.

Material composition and bedding configurations suggest that the Port Ewen deposit was laid down in a pro-delta glacio-lacustrine environment. The slight coarsening upward and distinct bedding indicated either a slight shallowing of water or an advance of the sediment source into the lacustrine environment. The aeolian sand probably represents final deposition in the pro-glacial zone as lake waters receded.

The soil layer and the aeolian fine sand is stripped from the proposed area of operation. The sand deposit is removed by front-end-loader, into trucks, and hauled to the asphalt plant site where it is stockpiled and blended as needed. The gradation and quality of the deposit is such that no additional processing of aggregate is required.

Material from the source primarily is used to make bituminous concrete aggregate as required.

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Geology in State Service

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I. Introduction

The various agencies of New York State require diverse geologic investigations, reviews and research to carry out their legislated duties. Each agency must prepare environmental impact statements for all actions that significantly effect the environment under the new State Environmental Quality Review Act. State agencies are involved in review of various impact statements, safety analyses, reports and legislation of other State and federal agencies. Geologic investigations are needed before, during and after various State construction projects. Geologic research and data collection is a prime responsibility of the Geological Survey in cooperation and participation with other State and federal agencies.

II. Legislation

The State legislature passes many laws requiring consideration of geology. These laws generally contain vague outlines of the information required to satisfy their intent. The designated agency must draft rules and regulations that comply with the law. The rules and regulations frequently detail the type and arrangement of information required in an application to the agency. The rules and regulations go through various internal reviews and public hearings. The final environmental regulations must be approved by the New York State Environmental Board which is composed of several State commissioners.

Several State agencies are required by law to contract construction projects that require geologic analysis.

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[3] 50 Wolf Road, Albany, New York.

[4] Building 7A, State Campus, Albany, New York.

[5] Agency Building #1, Nelson A. Rockefeller Empire State Plaza, Albany, NY

III. Implementation of Rules, Regulation and Projects

The final rules and regulation indicate the analysis and informational requirements of applications for various permits, licenses and projects. The geologic parts of the various applications sometime appears to be brief and deceiving. The real geology issues may be under groundwater, erosion and sedimentation controls or solid waste. Other areas such as terrestrial ecology and noise, and the environmental impact of a project can to some extent be dependent on geologic conditions. An integrated environmental analysis by all disciplines is the only successful approach for a complete analysis. The isolation of geology from other areas leads to missing important interdisciplinary issues. Therefore, the agency geologist has an important position - not only geologic analysis, but to see that geologic aspects of related areas are carefully considered.

Agency project responsibilities include highway, parks, water supplies, and housing construction. Each project and site has particular geologic impacts and assessments required. Safety of structures, cuts and fills are an important aspect of any geologic review.

Frequently any agency geologist is required to make an independent assessment of a project or problem relying on experience to make a rapid evaluation of the situation. In addition to the field inspections and reports, agency geologists are called on to provide expert testimony in public hearings. The geologist makes a professional assessment and frequently undergoes cross-examination by adversary parties. Projects involving millions of dollars may hang in the balance of these proceedings.

The State Geologic Survey provides the agency geologist with resource of information and a multi-talented staff who assist in analysis.

IV. New York State Department of Public Service (DPS)

The staff of the Department of Public Service is also the staff of the Public Service Commission and the New York State Board on Electric Generation Siting and the Environment. The prime responsibility of the DPS geologist is the review and evaluation of proposed nuclear and coal-fired power plant sites under the 1972 Article VIII of the Public Service Law. The analysis of these applications for new power plants involves facilities' impact on the environment and the environment's impact on the facilities. The environmental impacts of the facility to assess are erosion, sedimentation, groundwater change and solid waste caused by the facilities. The environments impact on the facilities to assess are earthquake hazard, erosion, sedimentation, slope stability and foundation stability. The analysis of these impacts is presented in testimony before the New York State Board on Electric Generation Siting and the Environment which must decide the site location and mode of generation. In seven power plant siting cases the DPA geologists have evaluated 15 different sites and 19 different facilities. Currently, the DPS staff is preparing the environmental impact statement for the Nuclear Regulatory Commission.

Other areas of responsibilities of the DPS are as follows:

a. investigate problems and costs of underground transmission lines;

b. review geologic research program of utilities, State and federal agencies and proposing changes and research needs;

c. evaluate utilities investment proposals for uranium mine ventures;

d. work with other agencies such as the State Geologist, DEC, OGS, Corp of Engineers, USGS and NRC to see that there is thorough review of all proposals;

e. propose, review and comment on new legislation, policies, rules and regulations relating to geology, groundwater on solid waste; and

f. advise and review proposals related to nuclear waste disposal.

The DPA geologist works closely with State Geologist's staff and Department of Environmental Conservation staff geologists in many of these evaluations.

V. New York State Geological Survey

The New York State Geological Survey is in its 142nd year of continuous service and has as its basic program a balance between (1) service to other State and federal agencies, industry, and the public and (2) geologic mapping and other basic research. Our advisory services and research efforts continue in three major areas: economic resources; environmental geology; regional mapping and data-collecting studies. Our attention during the next few months will be concentrated on moving to our new quarters in the Cultural Education Center of the Nelson A. Rockefeller, New York State Plaza in Albany. The following discussion highlights some of the new projects and significant results of the larger continuing projects.

Economic Resources - New York stands 28th among the states with $439.5 million in mineral production. An estimated 7100 people produced 5 metals and 16 nonmetals. New York remained first in the production of garnet, ilmenite, and talc, and was the only producer of wallastonite. Crude oil production in 1977 was 813,000 barrels; natural gas production was 10.4 million cubic feet. With mineral production decreasing through time, the Geological Survey plans to help stimulate the State's production by intensifying its program of mineral resource studies.

As part of our desire to increase support for the development of the State's economic resources, the Geological Survey co-hosted the 14th Annual Forum on the Geology of Industrial Minerals. Other co-hosts were: Empire State Concrete and Aggregate Producers Associates, Inc., Dunn Geoscience Corp., Rensselaer Polytechnic Institute, State University of New York at Albany, New York State Department of Transportation and the New York State Department of Environmental Conservation. Publication of the proceedings is under way and should be available later this year.

Environmental Geology - Our Energy/Environmental Geology Section has been bolstered by the addition of two new staff members, Robert H. Fickies and Henry H. Bailey. The section will continue to review nuclear and fossil fueled power plants proposed or under construction in New York. At the time of this writing, we are still awaiting the minority decision from the U.S. Nuclear Regulatory Commission Appeals Board on New York State's request for a review of the Indian Point Nuclear Power Plants Seismic Hazard Evaluation. This hearing, for which we petitioned and participated in, probably influenced to some measure the NRC's decision to review and revise Appendix A to 10 CFR Part 100 of the federal regulations on nuclear power plant siting. Disposal of nuclear waste continues to be a major concern to us. Our research at the West Valley Nuclear Fuels Service Center in western New York is continuing with the discovery that gaseous emissions of ^{14}C and tritium from the low-level nuclear waste burial trenches may be the most prominent radionuclide migration pathway. In cooperation with the U.S. Geological Survey, Water Resource Division and the State Health Department we have collected in-site cores of host material from beneath the burial trenches and are measuring radionuclide migration rates in them. A third part of the program is the continuation of an erosion-rate study. Our next efforts, if funding becomes available, will be the study of geologic and hydrologic conditions prevailing at the high-level waste storage tanks also situated at the Service Center. Another continuing project is our review of leasing for petroleum exploration on the Outer Continental Shelf by the U.S. Bureau of Land Management. We have just completed a massive study for the National Science Foundation of the impact of natural resource data on land-use decision making. The results indicate that data producers will have to design their information packages in closer cooperation with translators of the data and the ultimate data user, if the data are to have the impact desired toward forming more enlightened decisions.

Mapping and Regional Studies - Several of our long-term, regional research projects are continuing and will be published eventually in our Bulletin, Map and Chart, or Circular Series. Bedrock mapping of the Taconic klippen is essentially complete and in preparation for publication. Research on the stratigraphy of Devonian black shales in the subsurface of central and western New York continues to reveal exciting new facts about the paleo-environments of the Catskill Delta. Glacial mapping and compilation continues in the Finger Lake region toward the eventual publication of the second sheet of the 1:250,000 scale map of the Quaternary Geology of New York. Investigation of the buried valleys of the Hudson River has now progressed from the Lake George area in the north to the Coxsackie and Catskill area in the south. Maps showing the brittle deformation and neotectonics of New York are being compiled and will be added to the State Tectonic Atlas. These will be accompanied by a statewide aeromagnetic map, now under compilation in cooperation with the U.S. Geological Survey, which should be available to the public by the end of the year.

Future Research - By combining outside funding sources for intermediate term research, we hope to be able to expand our study efforts in the areas of economic resource evaluation, hydrology and regional aquifer mapping, and geology of deposits under the navigable waters of New York. This last project would attempt to compile data already in existence and acquire new information on the Outer Continental Shelf, New York Bight, Long Island Sound, the Hudson River estuary, and the lakes within and bordering New York.

VI. The New York State Department of Environmental Conservation

The New York State Department of Environmental Conservation (DEC) presently employs five engineering geologists: four at the senior level and one at the associate level. In Civil Service parlance, the Associate is senior to the Senior. Another curious feature is that in the DEC organization, no geologist has a geologist as his supervisor nor is he supervisor to any other geologist.

Further, no bureau has more than one "geologist" assigned as a member, although people who have degrees in geology do work as "mined land reclamation specialist" or as "hydraulic engineer" or as "civil engineer" or even as "hearing officer", and to some greater or lesser extent, apply their science to the practice of government administration.

The bureaus to which the geologists are assigned are: Hazardous Wastes, Land Disposal (in the Division of Solid Waste Management), Reservoir Releases and Basin Management (in the Division of Water Resources), Mineral Resources (in the Division of Land Resources), and Energy (in the Division of Permit Coordination).

The Department is now (spring, 1979) undergoing a major reorganization so by the time you read this, the structure may be different.

Each geologist position has been created as a result of an urgent need for the application of geotechnical expertise to a management or regulatory responsibility assigned to the Commissioner by the Legislature.

The first geologist employed was hired in 1965 by the Division of Water Resources as a result of the drive to plan for coping with future droughts.

The second was hired a few years later, to help administer the Oil and Gas Laws.

The third was hired in 1973 to work on the environmental analysis of major construction projects, for which a myriad of DEC permits are required.

The fourth and fifth were hired within this past year, in response to the recognized need to cope with solid waste disposal problems.

No research is done. No nice publications are prepared. Difficult and specific problems regarding limited areas (often of deep concern) are handled, using the knowledge and techniques of the geosciences. The resultant products are advisory memoranda and conferences aimed at helping the appointed officials make rational decisions to protect the environment of the State.

VII. New York State Department of Transportation

The "soils" program of the Department of Transportation implements the Department's goals and objectives in the areas of earthwork and foundations for transportation and techniques of earth engineering. Earth engineering includes the broad subject areas of earthwork engineering and foundation engineering and utilizes various disciplines including soil and rock mechanics, engineering geology, geophysics and earth science.

The major work effort is involved with capital projects in the highway program. The soils program involves participation in all phases of project development from planning through construction and includes the maintenance phase. Complete soils services are also provided for most projects assigned to consulting engineers. The soils program also participates in airport projects under the Development Division.

The services of the soils program are also furnished to other State agencies after written approval of the Chief Engineer. Project investigation and reports are prepared for the Office of General Services (buildings, water supplies, etc.), Environmental Conservation (water supplies, dams, etc.) and Commerce (foundation and water supply at proposed industrial sites). Work is also done for authorities such as Atomic and Space, New York State Thruway, Niagara Frontier Development and others.

The soils program consists of a combined effort of the ten Regional Soils Sections and the Bureau of Soil Mechanics. The program includes explorations, testing, analysis and design, construction inspection and preparation of earth engineering specifications and standards. Geologists are engaged in all phases of the program to varying degrees.

Geologists employed by the Bureau conduct the geophysical portion of the exploration program. They use seismic and electrical techniques. They also use a bore hole T.V. camera to determine orientation of rock structures and reasons for core loss in drill holes. Under the exploration program they also prepare rock outcrop maps and work on the engineering soils maps of various projects.

The Bureau maintains both a soil mechanics laboratory and a general soils laboratory for the testing phase of its program. Geologists have access to the services of these laboratories whenever they have a need to know such things as strength and durability of rock specimens or grain size distribution of well samples.

Geologists work on the design of rock cut slopes and structure foundations in rock for the analysis and design phase of the program. They are responsible for meeting the design requirements of hazard free, low maintenance rock cut slopes and for determining allowable pressures for structures founded on or in rock. This work includes the analysis and/ or design of mechanical systems for stabilization of rock cuts and rock anchorage systems for tie-back walls and buried structures subject to uplift.

Geologists provide inspection services to the project engineers on problems that come under the Bureau's responsibility. They evaluate the contractors blasting program and make sure that the State's presplitting requirements are being complied with. They evaluate the stability of the finished cut slope and determine the location of any mechanical support or additional scaling that may be necessary. They inspect exposed rock at foundation sites for its ability to support design loads. They inspect and approve stockpiles for stone filling items. Under this phase of the program Geologists also provide technical assistance on rock or ice removal projects undertaken by maintenance personnel or by local governments under the Department's Local Assistance Program. They monitor construction generated vibrations on projects adjacent to sensitive structures.

Geologists also work on the preparation of specifications and standards for such items as stone filling, rock anchorage systems, allowable vibration limits, and controlled blasting.

The Geology Section of the Materials Bureau is responsible for the evaluation and acceptance of all aggregates used by the New York State Department of Transportation for RR ballast, bridges, portland cement concrete pavements, and bituminous concrete pavements. The operation of this program is comprised of the following parts:

(a) Preparation of aggregate specifications

(b) Evaluation of physical tests performed by our laboratory on aggregates:

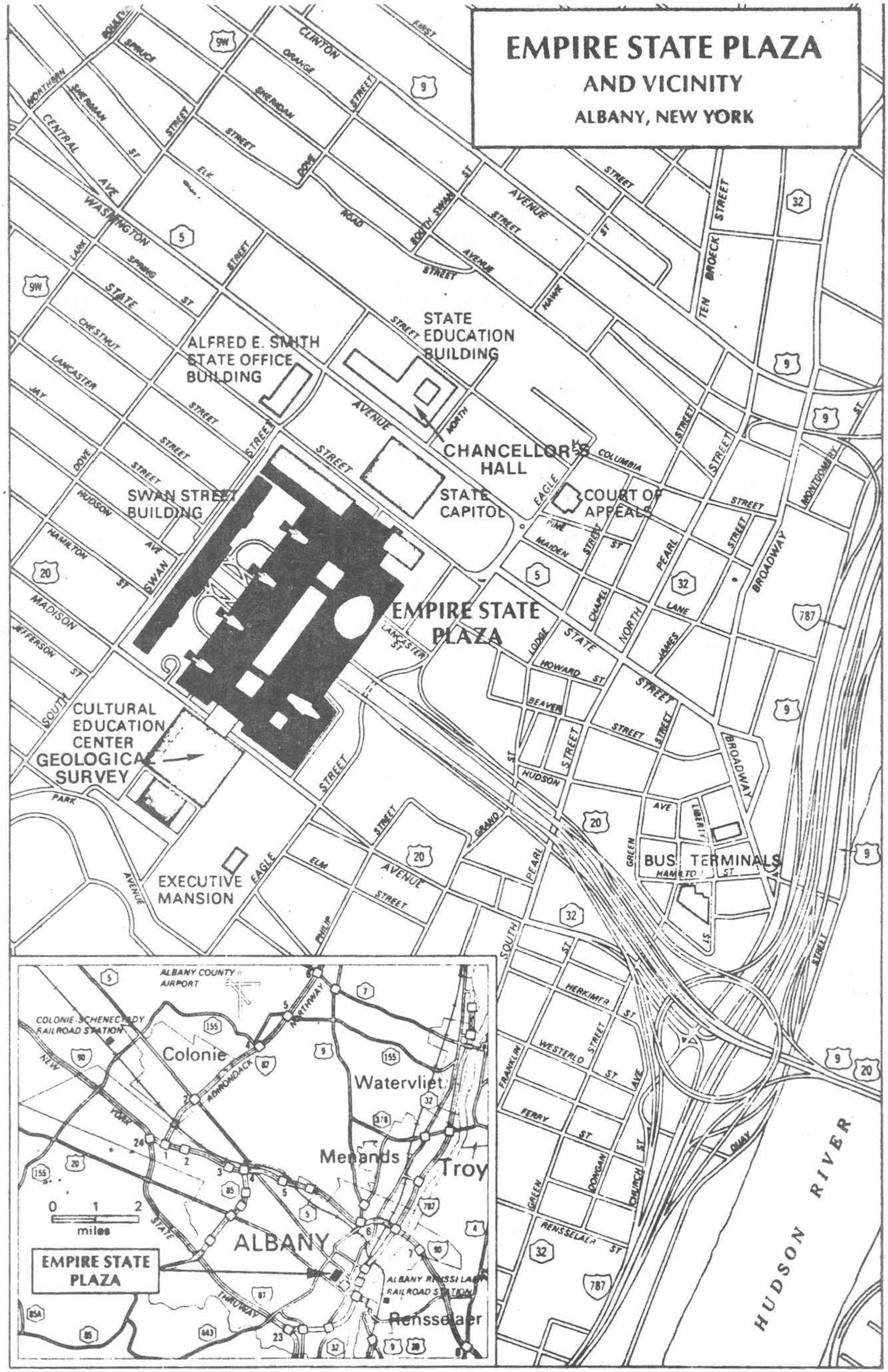
1. Magnesium Sulphate Soundness
2. Freeze-Thaw
3. Los Angeles Abrasion

(c) Review and analysis of the Geological Source Reports which are prepared by independent consulting geologists hired by each aggregate producer

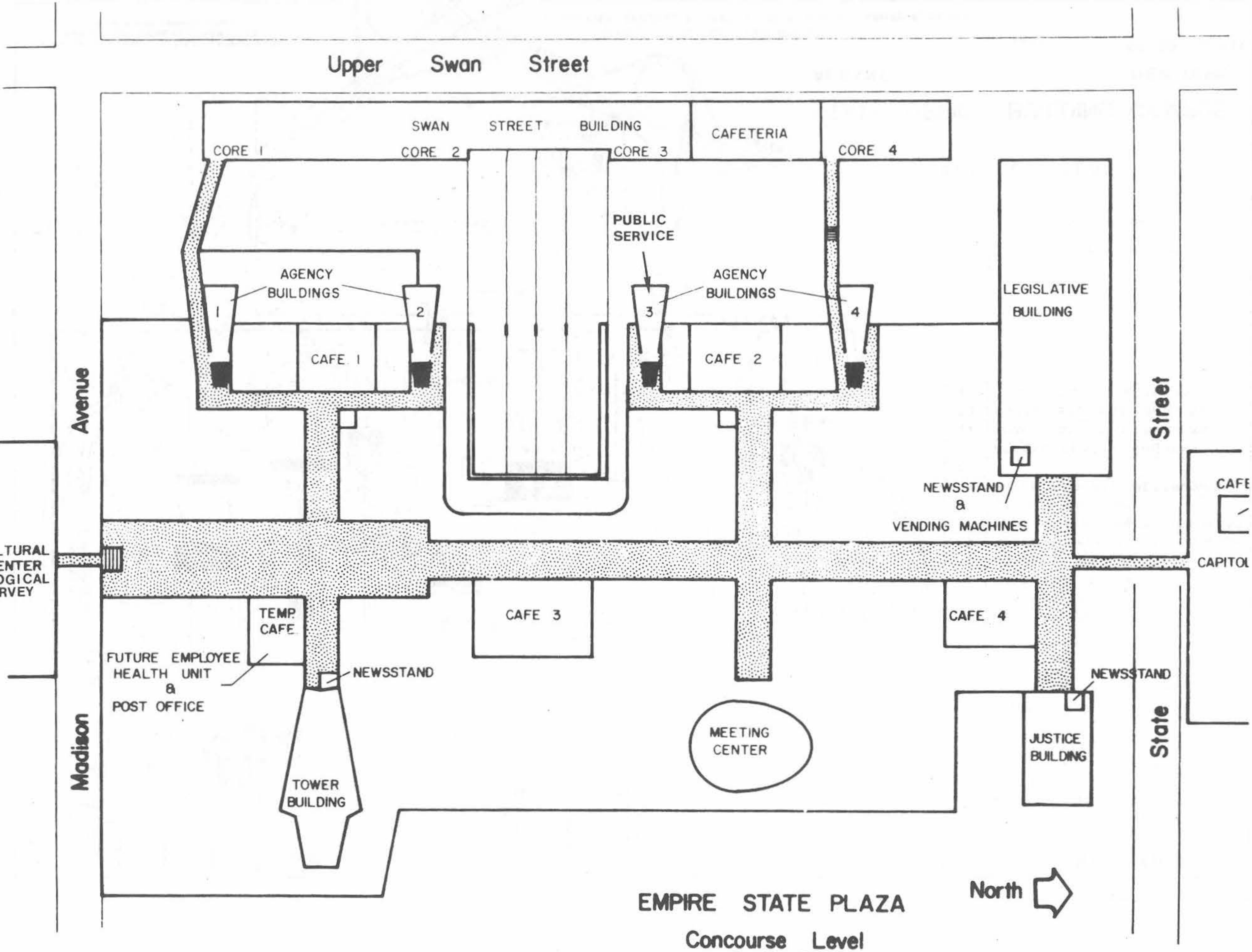
(d) Petrographic inspection of quality assurance samples received during the construction season

(e) Field inspections of aggregate sources and changing the area of operations when required

The Geology Sections for the New York State Department of Transportation are a portion of the Division of Design and Construction as has been indicated under the titles for each of our summaries. The Technical Services Subdivision is comprised of three Bureaus; the Bureau of Soil Mechanics, the Bureau of Materials, and the Engineering Research and Development Bureau. Only the Bureau of Soil Mechanics is primarily concerned with all materials beneath the surface of a finished pavement section.

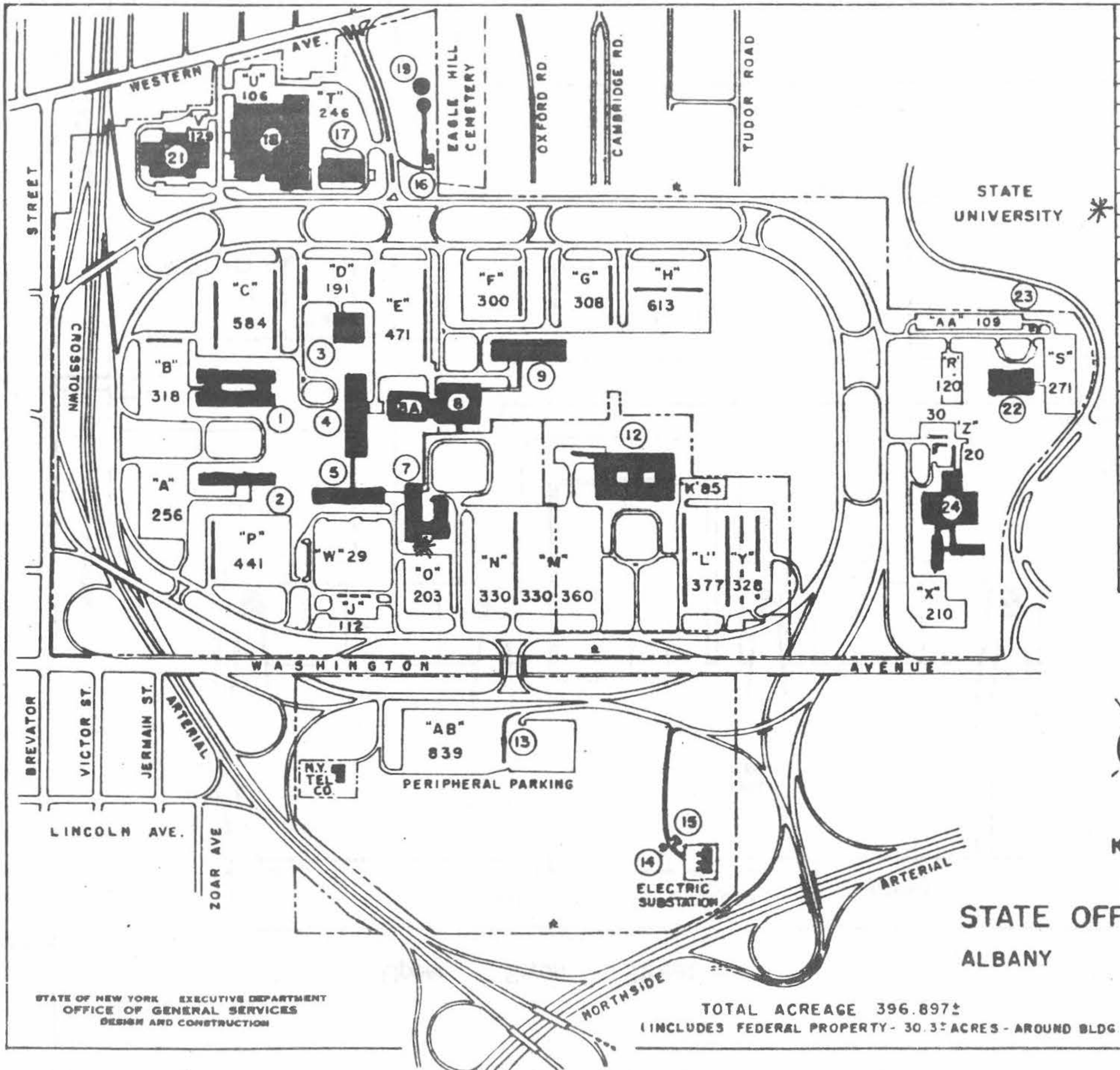


EMPIRE STATE PLAZA
AND VICINITY
ALBANY, NEW YORK



EMPIRE STATE PLAZA

Concourse Level
2-19-76



BUILDING INDEX

NO.	NAME
1	CIVIL SERVICE BUILDING
2	MULTI-AGENCY BUILDING
3	CAFETERIA
4	O.G.S. - DESIGN & CONSTRUCTION
5	TRANSPORTATION, ADM. & ENG.
6	
7	LABORATORIES - TRANSP. - AG & MAR.
8-8A	INCOME TAX BUREAU BUILDING
9	TAXATION & FINANCE BUILDING
10	
11	
12	DEPT. OF LABOR
13	BUS SHELTER
14	SALT STORAGE BUILDING
15	STORAGE BUILDING
16	WATER SUPPLY PUMPING STATION
17	HEATING & REFRIGERATION PLANT
18	SERVICE BUILDING
19	WATER STORAGE RESERVOIRS
20	
21	RECORD CENTER BUILDING
22	PUBLIC SECURITY BUILDING
23	WASTE STORAGE BUILDING
24	STATE POLICE ACADEMY

KEY PLOT PLAN

STATE OFFICE BUILDING CAMPUS

ALBANY NEW YORK

MAY 1973

PT 50 (5-73)

TOTAL ACREAGE 396.897±
(INCLUDES FEDERAL PROPERTY - 30.3± ACRES - AROUND BLDG 12)

STATE OF NEW YORK EXECUTIVE DEPARTMENT
OFFICE OF GENERAL SERVICES
DESIGN AND CONSTRUCTION

V.I.

X-207

The Building Stones of the Nelson A. Rockefeller Empire State Plaza

Leaders: R. H. Fickies and R. J. Dineen, N.Y. State Geological Survey

The construction of the Nelson A. Rockefeller Empire State Plaza, on 98 acres of land adjacent to the New York State Capitol Building represents the largest single-project use of a variety of industrial mineral products in the Northeastern U.S. in recent years. The project drew heavily on the Capital District's sand and gravel resources and provided a ready market for Portland Cement produced in the Hudson Valley. At lease one Vermont marble quarry was depleted of reserves and closed down after supplying large quantities of stone to the project.

Facades of the Plaza present both rough and polished surfaces of several types of dimension stone selected from various parts of the United States, Europe, and South America for both exterior and interior facing on the walls of 10 of the 11 buildings in the complex. This walking tour will begin in the lobby of the Cultural Education Center (State Museum), whose walls are faced with polished creamy, white Alabama marble. From there the tour will proceed in a general clockwise direction around the Plaza (see Plaza map Fig. 1).

A listing of the various industrial minerals, their locations and uses in the Plaza is provided to aid the reader in taking a "self guided" tour of the Plaza.

TABLE 1

Building Stones and Other Industrial Minerals

Used in Construction of the Empire State Plaza

DIMENSION STONES

Metamorphic Rock	Location
Cherokee White Marble; Tate, Georgia - early Paleozoic	Exterior facing of Cultural Education Center
White Pearl Marble; West Rutland Vermont-Ordovician Sherburne Fm.	Exterior facing of Tower Building and the four Agency Buildings
Creamy White Marble; Sylacauga, Alabama - early Paleozoic	Interior facing of Cultural Education Center
Cherokee Melange Marble; Tate, Georgia - early Paleozoic	Exterior facing of Justice, Swan Street, and Legislative Buildings
Vert Tinos; Serpentinite, Isle of Tinos, Greece	Interior facing of portions of the Legislative Office Building lobby
Pavanazzo Marble; West Rutland Vermont, - Ordovician Shelburne Fm. (3" to 9" thick layer)	Interior Facing of portions of the Legislative Office Building lobby, all elevator lobbies in that building
Danby-Montclair Marble; Danby Vermont,-Ordovician Shelburne Fm.	Legislative Office Building, main entrance floor
Bluetone Marble; West Rutland, Vermont-Ordovician Shelburne Fm.	Walkways around reflecting pools on the outdoor plaza.

Sedimentary rock	Location
Travertine; Tivoli area, Italy	Interior facing of Grand Concourse, Elevator Lobbies in Tower and Agency Buildings
Indiana limestone	Paving stones on the Health Department Courtyard
Lenrock Stone; Greywacke Sandstone and Siltstone - Devonian Sonyea Group, Ithaca, New York	Exterior facing of the Main platform (The "great wall")

Igneous rock	Location
Lake Placid Blue "Granite"; Light Adirondack Anorthosite, Upper Jay, New York	Outside amphitheater adjacent to the Cultural Education Center, Legislative Building entrance steps, curbing and various fixtures on the plaza
Cold Springs Green "Granite"; Dark Adirondack Anorthosite, Upper Jay, New York	Ornamental stone fountain in the Legislative lobby. Water spouts on the Great Wall and elsewhere on the Plaza
Mount Airy "Granite"; North Carolina	Curbing - Swan Street & Madison Avenue
Uba Tuba "Granite"; Brown Monzonitic Stone from Brazil	The cornerstone - north end of outdoor plaza

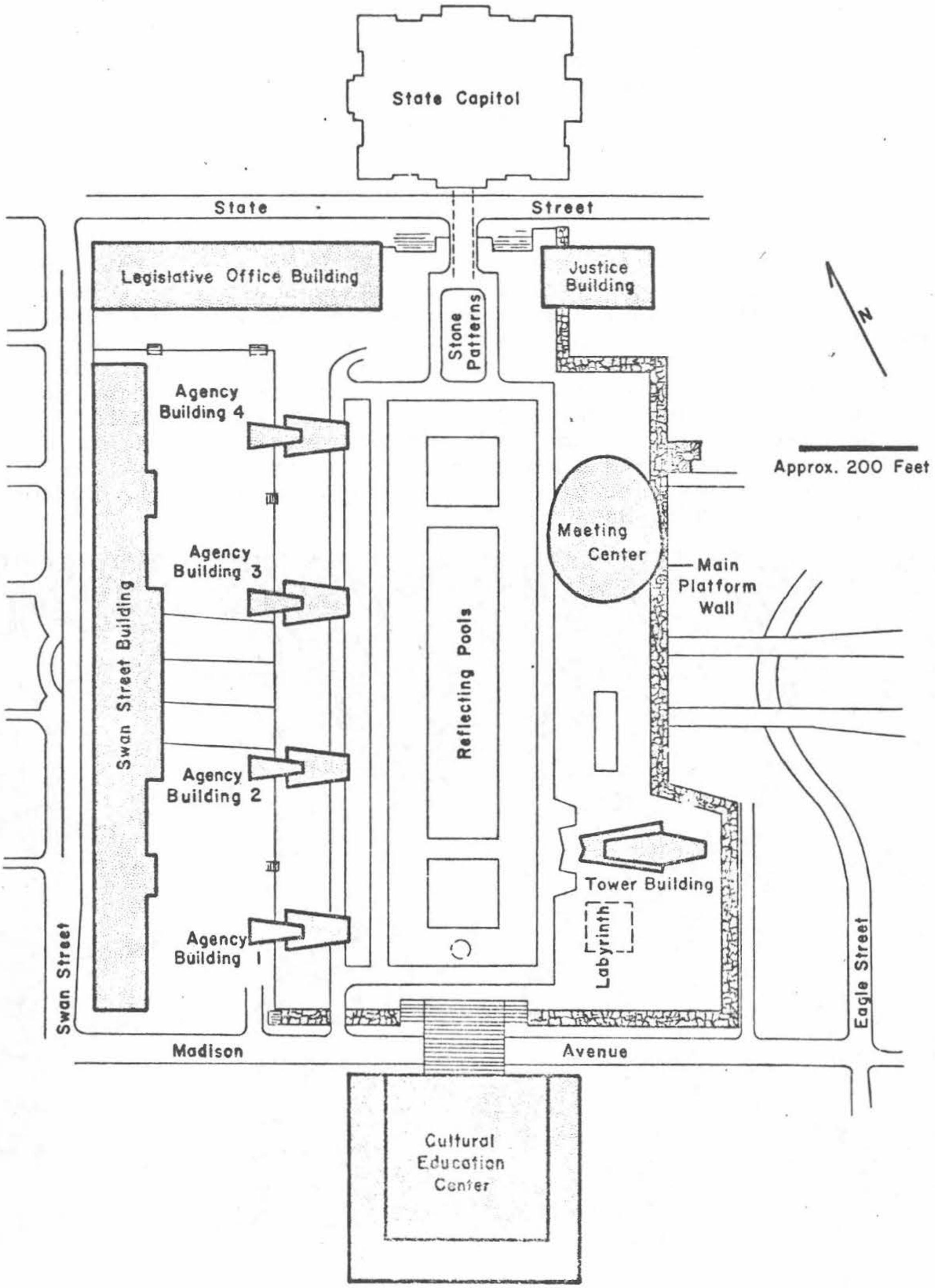
CONCRETE

Portland Cement Several producers in the Hudson and Mohawk Valleys (Helderberg Limestone)	Over 900,000 yd^3 of concrete used in the Plaza. The Meeting Center is the only building with a concrete exterior facing.
Concrete Sands Cow Bay, Long Island, New York, and numerous local sources	
Concrete Gravels (crushed stone) Hudson Valley dolomites	
Mortar Sand Corinth, New York	

OTHER INDUSTRIAL MINERALS

Red Natural Gravel Vermont river gravels composed of Cambrian Monkton Quartzite	Walkways on the Plaza
Buff Natural Gravel Cape May, New Jersey	Labyrinth area
Red Paving Bricks Ohio	Walkways on the Plaza
Buff Brick Ohio	Various Parapet Walls

FIGURE I
NELSON A. ROCKEFELLER - EMPIRE STATE PLAZA
OUTDOOR PLAZA LEVEL



DEGLACIAL EVENTS IN THE EASTERN MOHAWK - NORTHERN HUDSON LOWLAND

by

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Troy, New York 12181

Introduction

The Mohawk Lowland extends some 90 miles east from Rome to the modern Mohawk's junction with the Hudson River at Cohoes (Figure 1). Woodfordian ice advancing south and westward through the Hudson-Mohawk Lowland emplaced the Mohawk till and formed an extensive drumlin field on older drift. A variety of deglacial events included lake development, glacial readvances, large-scale Great Lakes through-drainage, and subdued river flow. This history becomes complex to the east because pulses of the Oneida lobe alternating with lake outbursts in the western Mohawk basin influenced discharges into Lakes Albany and Vermont in the Hudson Lowland (LaFleur, 1975; Hanson, 1977).

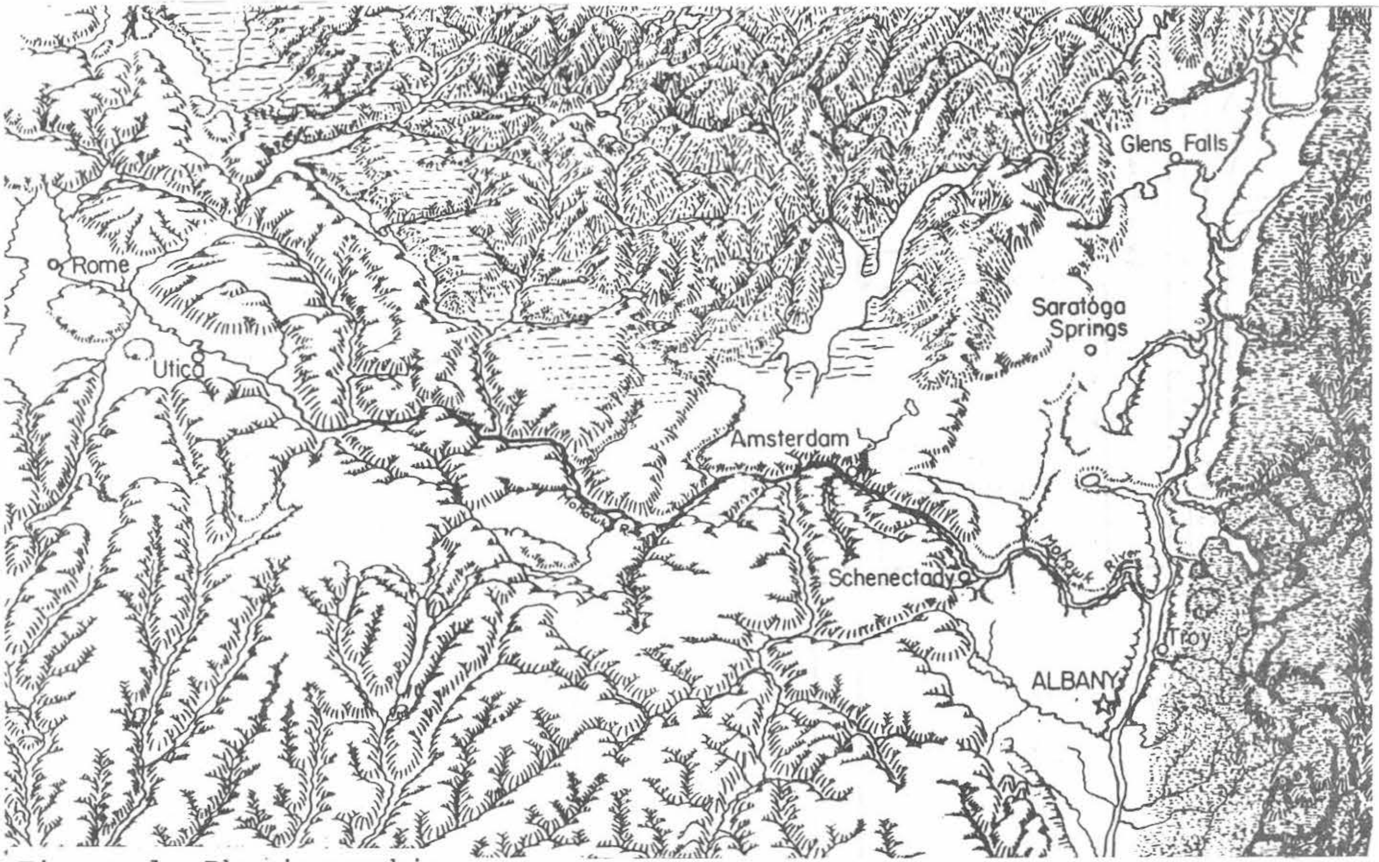


Figure 1. Physiographic diagram of east-central New York (by W.Webster in Geol. Map of NY,1961)

FIELD TRIP 6B


Fonda
Tribes Hill
Fort Hunter
South Amsterdam
Nelliston
Stone Arabia
Fonda Reservoir
Fultonville
Palatine Bridge
Canajoharie
Marshville
Minaville
Rural Grove
Charleston
Ames
Browns Hollow
Charleston Four Corners
Oak Ridge
Burtonsville
Bremen Corners
Duanesburg Reservoir
Esperance
Sharon Springs
Sharon
Bear Swamp
Carlisle
Central Bridge
SCHENECTADY COUNTY
SCHOHARIE COUNTY
Seward
Hyndsville
Cobleskill
West Richmondville
Summit Lake
Breakabeen
Gilboa
Conesville
Grand Gorge
Broome Center
Middleburgh
West Berne
Triangle Lake
Crystal Lake
Schoharie
Cripplebush
King Creek

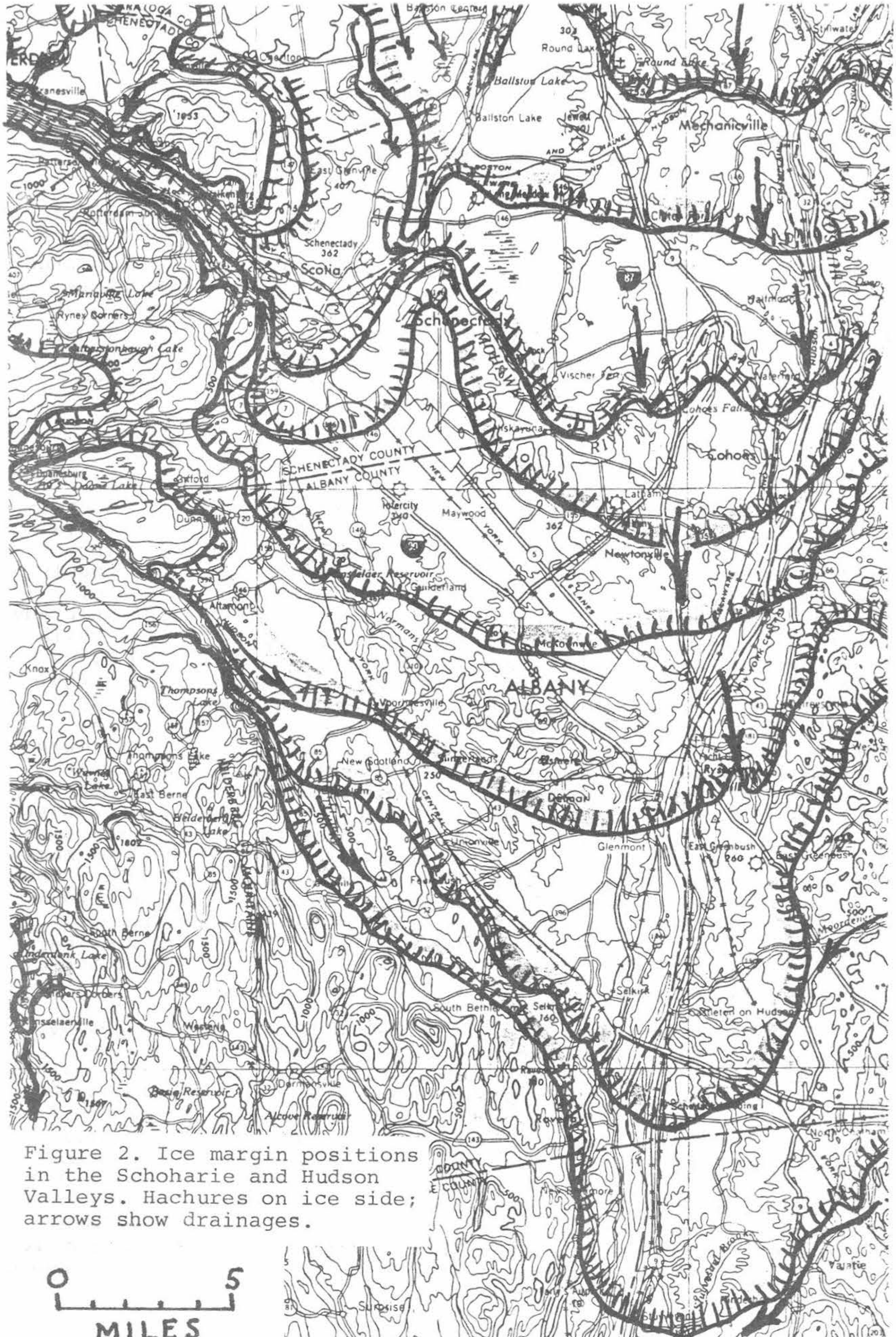


Figure 2. Ice margin positions in the Schoharie and Hudson Valleys. Hachures on ice side; arrows show drainages.

A series of active ice-margin positions, recognized in the Schoharie Valley, are associated with the development of glacial Lake Schoharie (LaFleur, 1969). See Figure 2. In the Hudson Lowland, well-defined, progressively younger ice margins defended northward-expanding Lake Albany which maintained an elevation of about 330 feet at the latitude of Troy. However, tracing of ice-border positions westward through the Mohawk Lowland has proven difficult. Because the broad interfluve of the Helderberg upland did not receive ice-contact deposits in abundance, it is even difficult to secure correlations over short distances between Hudson and Schoharie valley ice margins. Rather than try to achieve a regional synthesis by using ice-front positions, our purpose here is to suggest relationships between high and low Mohawk discharges and lake stages, based on channel and terrace development and lacustrine stratigraphy.

Lake Amsterdam

At many localities west of Amsterdam, Mohawk till is overlain by up to 50 feet of limy silt and clay rhythmites. There is no evidence that the Mohawk till was eroded by eastward-flowing water or subaerially exposed prior to clay deposition. Presumably Lake Amsterdam accompanied deglaciation of the axial portion of the Mohawk Lowland while ice dammed its eastern end near Schenectady (Figure 3). Lake Amsterdam may have extended west to Little Falls and probably consisted of disjointed water bodies separated by isolated ice blocks and topographic highs. Although an ice surge of about one mile at South Amsterdam deformed and smoothed clay onto the stoss end of a Mohawk till drumlin, it does not appear that the lake was created by a readvance. The exit for overflowing Lake Amsterdam water is suggested at 500 feet at West Hill, west of Schenectady where a broad-floored, terraced and beheaded channel, cut in till and bedrock, carried water marginal to ice from the north and west onto bare ground and then over Hudson lobe ice to the south. This drainage contributed to the Voorheesville and Guilderland kame terraces marginal to Lake Albany. Active ice also occupied the West Hill outlet, and the same minor readvance cited at South Amsterdam may be responsible for a single thin till ridge 15 feet high and 1000 feet long on the West Hill channel floor. These features may be easily seen from the Thruway at milepost 161 just east of the Rotterdam Junction exit.

The extinction of Lake Amsterdam may have been caused by earliest Great Lakes drainage from the west [unless the Mohawk glaciation proves to be as young as Lavery or Hiram (LaFleur, 1979)].

According to Mörner and Dreimanis (1973), this discharge could have occurred during the Erie Interstade when Lake Leverett drained eastward. Whether this discharge occupied the West Hill outlet is not certain, but the outlet is large enough to accommodate major flow. Alternatively, a small ice plug in the eastern Mohawk could have suffered final deterioration under Great Lakes discharge, quickly lowering Lake Amsterdam by 90 feet to the next stable elevation provided by a till and bedrock sill at Cranesville. Two small deltas near Hoffmans at 410 feet record the final presence of ice in the eastern Mohawk.

Fonda Wash Plain

The Fonda wash plain at about 420 feet, recognized by Brigham (1929), consists of 5 to 10 feet of sand and pebble gravel overlying Lake Amsterdam clay (Figure 4). Sand terrace remnants can be traced westward from Cranesville to the mouth of East Canada Creek near St. Johnsville. The eastern Mohawk Valley was deglaciated by this time, but there was not accompanying high discharge from the west. The fine grain size of the sand plain and the abundance of locally derived lithologies suggest derivation from eroding uplands nearby, particularly from Schoharie Creek draining Lake Schoharie and from the Cayadutta draining the lower Sacandaga Basin. Kame delta deposits along the Lake Albany ice margin at Waterford and Niskayuna appear equivalent in age.

Schenectady Delta

Northward recession of the Hudson lobe past Schenectady permitted the Mohawk to discharge directly into Lake Albany for the first time (Figure 5). Dissection of the Fonda wash plain and Lake Amsterdam clay provided fine grained sediment for delta construction. Still this was not a time of abnormally high discharge through the Mohawk but rather a continuation of modest flow typical of the Fonda wash plain. North of Schenectady small deltas were built into Lake Albany at East Glenville by the Alplaus Kill, at this time an ice-margin stream. The Hoosick River constructed gravel terraces at 360 feet east of Schaghticoke, while at Halfmoon along the ice margin a kame delta complex formed in Lake Albany. The first of several detached ice blocks, all having importance in lake drainage history, was abandoned at Niskayuna.

Hoosick Delta and Willow Glen Kame Delta

Further recession of the Hudson lobe margin north of Mechanicville provided the location for the Willow Glen kame delta complex (Figure 6). As the Mohawk delta continued to build at Schenectady, the ice margin receded northward far enough to permit the Hoosick River to build a small sand delta in Lake Albany. Considering the size of the Hoosick drainage basin, it is surprising that the Hoosick River did not build a larger delta into Lake Albany. Other tributaries draining the Taconic Mountains behaved similarly in Lake Albany time. The western New England uplands may have remained ice-covered, denying a sediment supply.

Continued northward recession of the Hudson lobe margin toward Glens Falls was accompanied by lowering of Lake Albany (Hanson, per comm.). The reason for the drop in lake level is not apparent. Discharge from the Mohawk continued to be modest through the duration of Lake Albany, and the Hudson lobe at this time shows little evidence of activity.

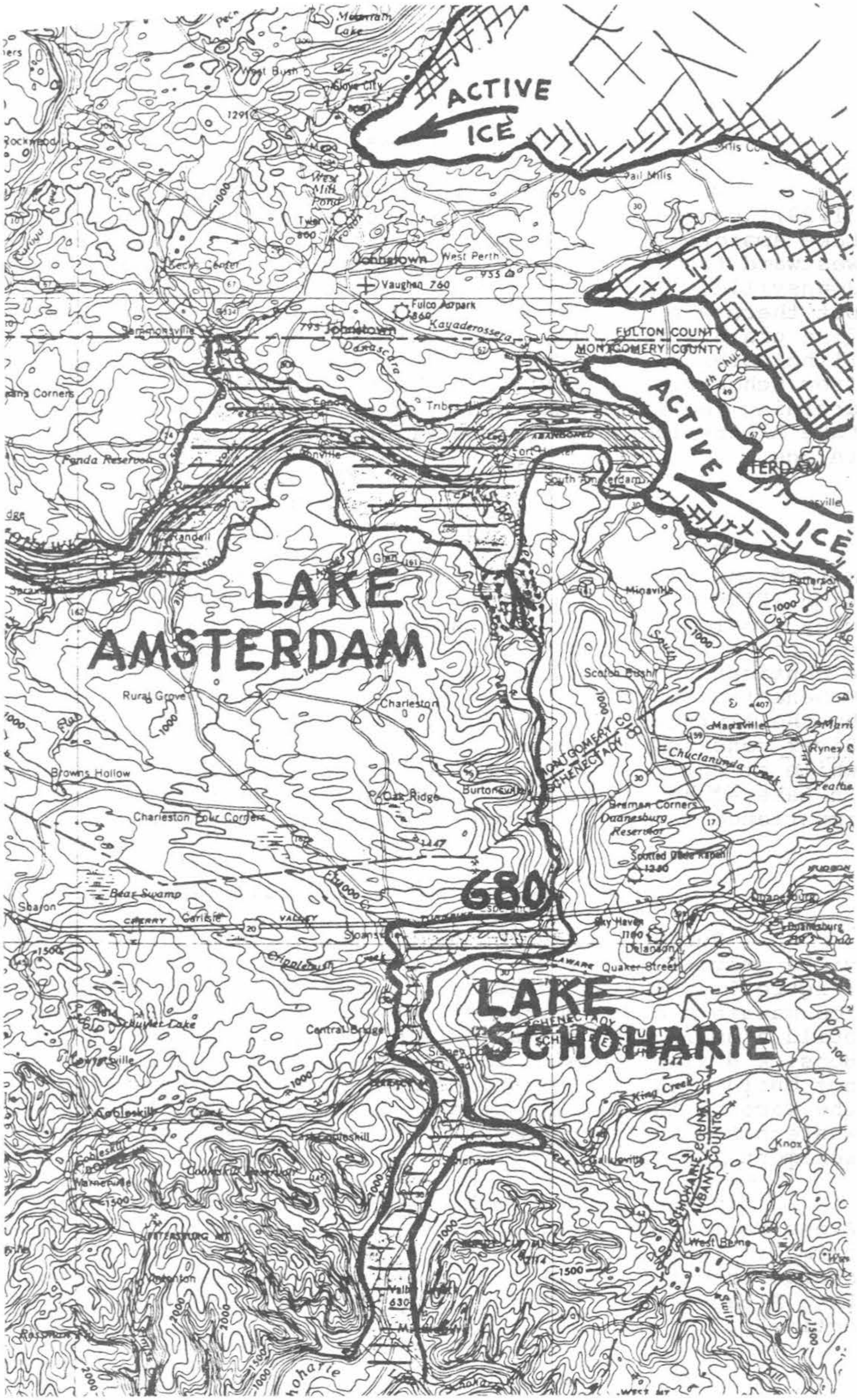
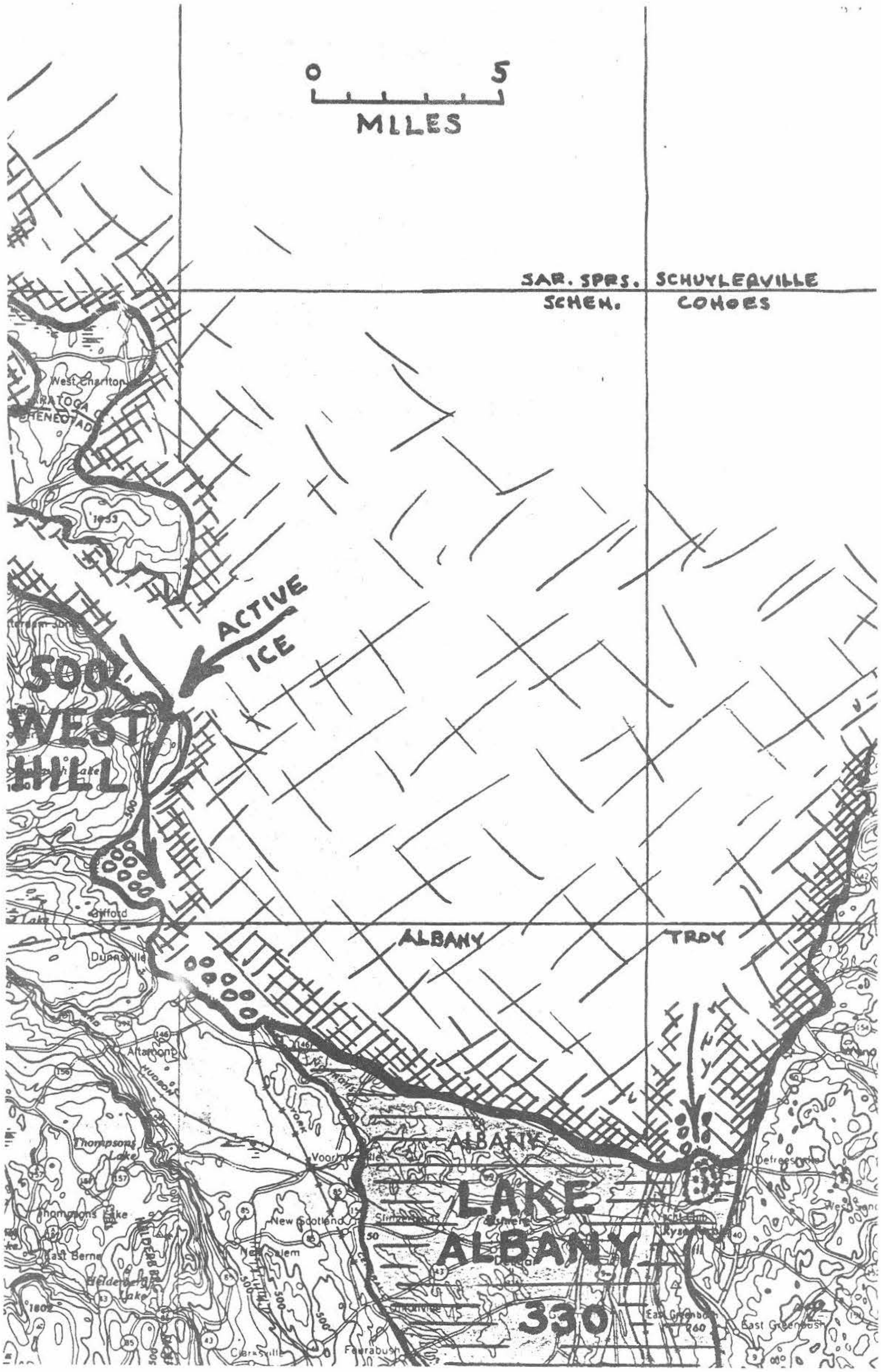


Figure 3. Active ice margin in Lake Amsterdam. Numbers are feet above sea.


0
5
MILES
SAR. SPRS.
SCHUYLERVILLE
SCHEN.
COHOES
West Charlton
ACTIVE ICE
500
WEST
HILL
Gifford
Dunnsville
Altamont
ALBANY
TROY
Thompsons Lake
Voorheesville
New Scotland
New Salem
East Berne
Helderberg Lake
Slingerlands
Delmar
Clarksville
Feurabush
Defreestville
East Greenbush
LAKE
ALBANY
330

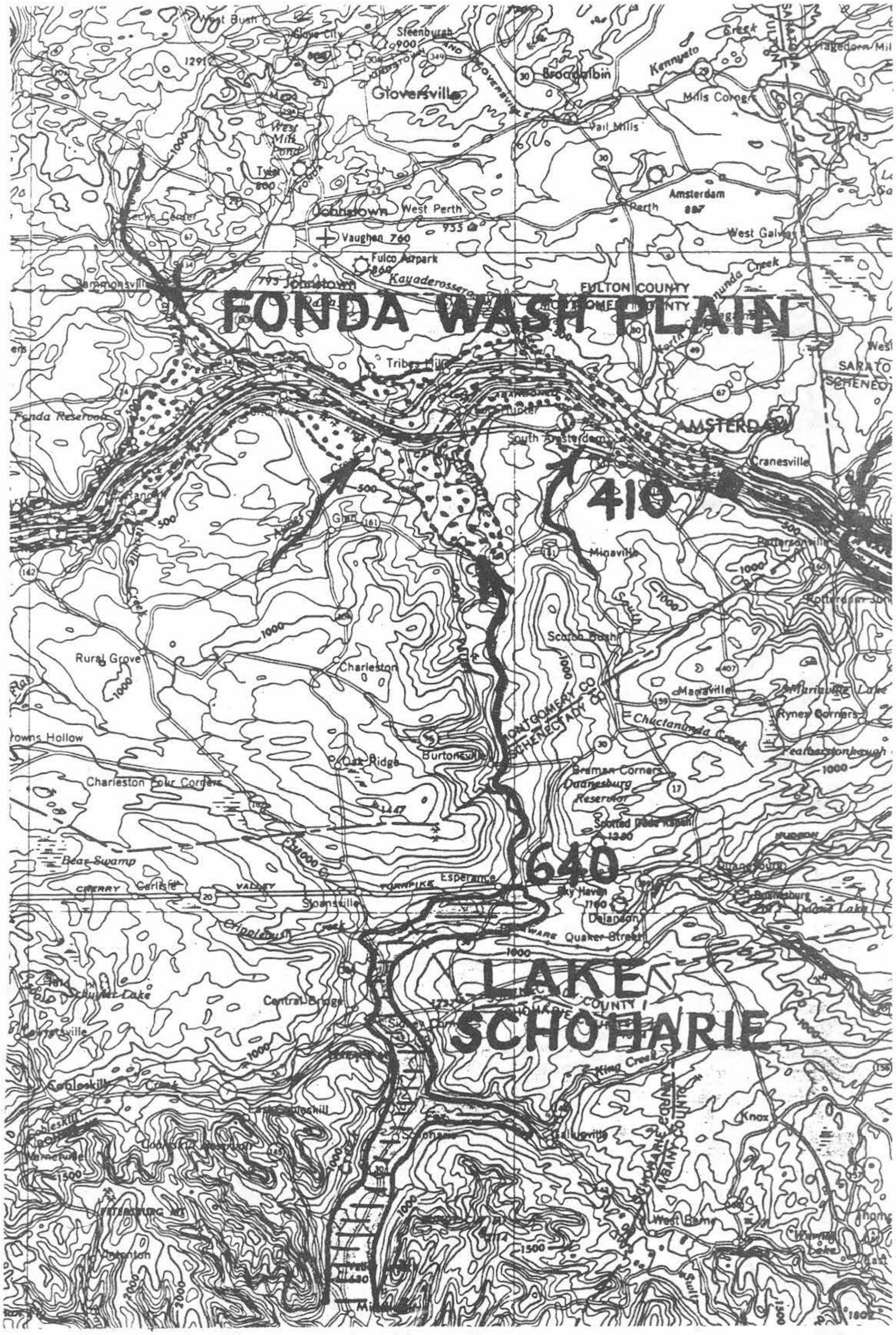
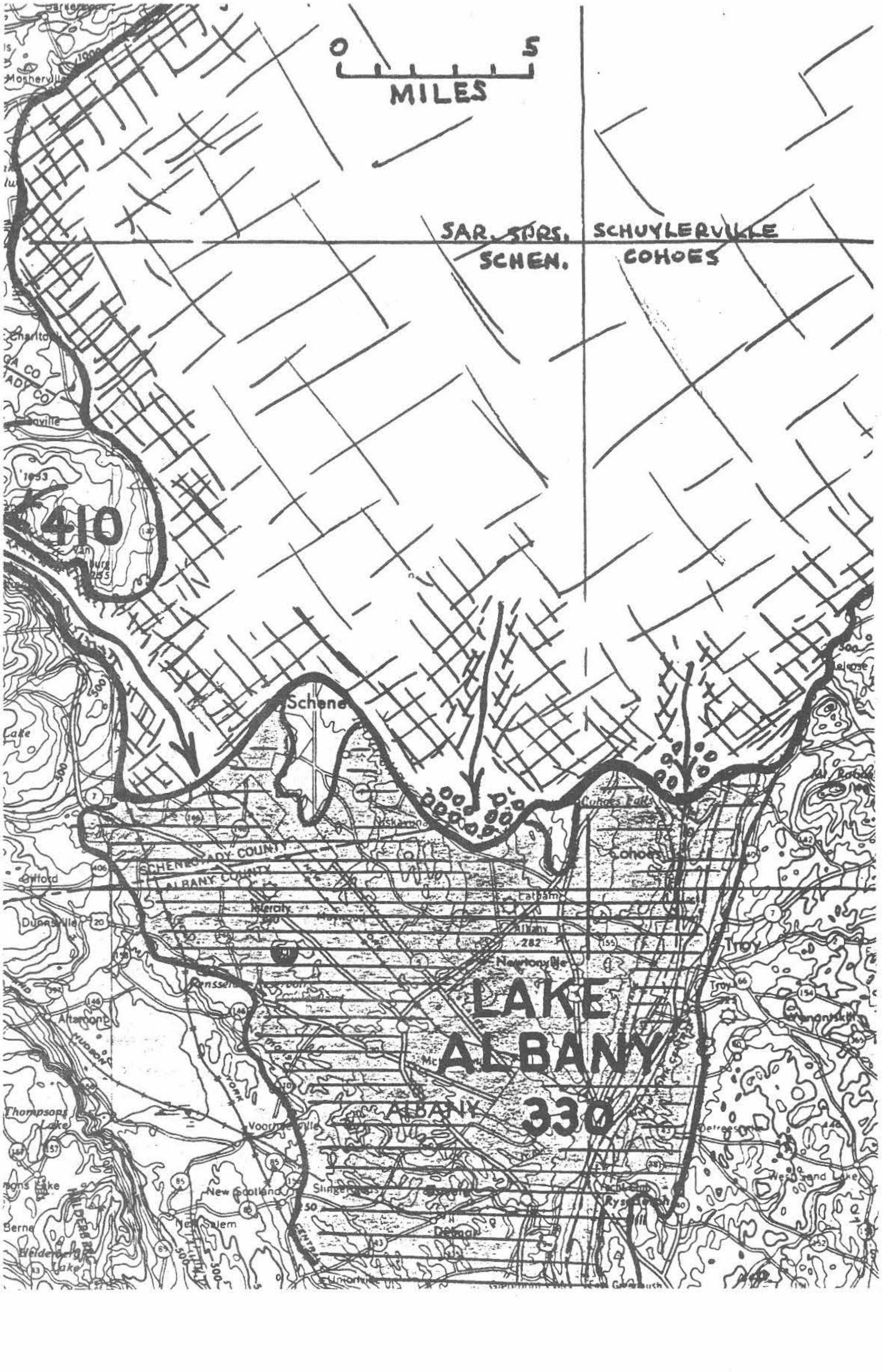


Figure 4. Fonda wash plain and final ice plug in eastern Mohawk Valley.


0
5
MILES
SAR. SPRS.
SCHUYLERVILLE
SCHEN.
COHOES
410
LAKE
ALBANY
330
Schene
Cohoes Falls
Cohoes
SCHENECTADY COUNTY
ALBANY COUNTY
Latham
Newtonville
Troy
ALBANY
Altamont
Voorheesville
New Scotland
Slingerlands
New Salem
Berne
Thompsons Lake
Guilford
Duanesville
Charlton
Mosherville

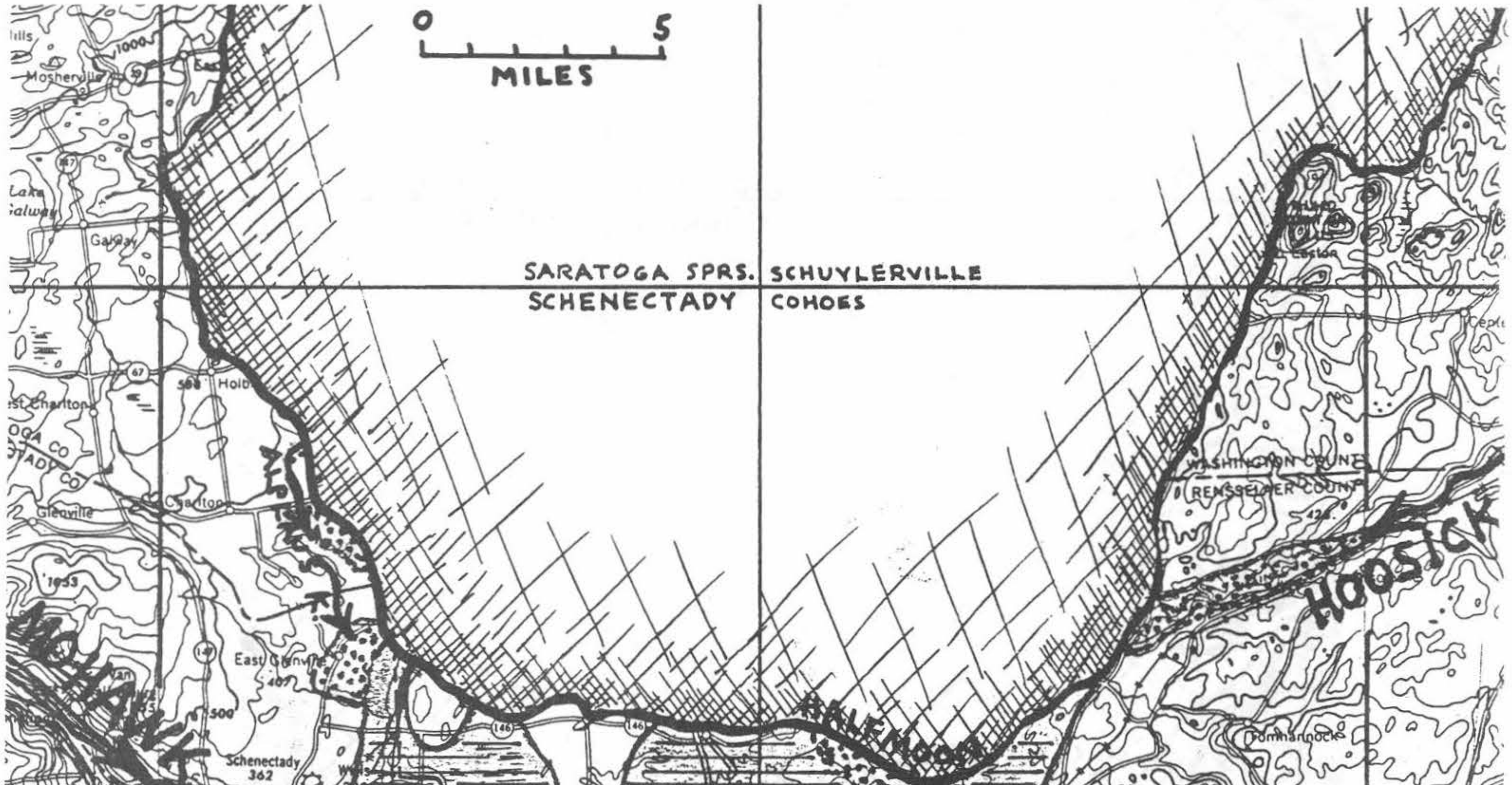


Figure 5. Ice front position during early deposition of Schenectady delta.

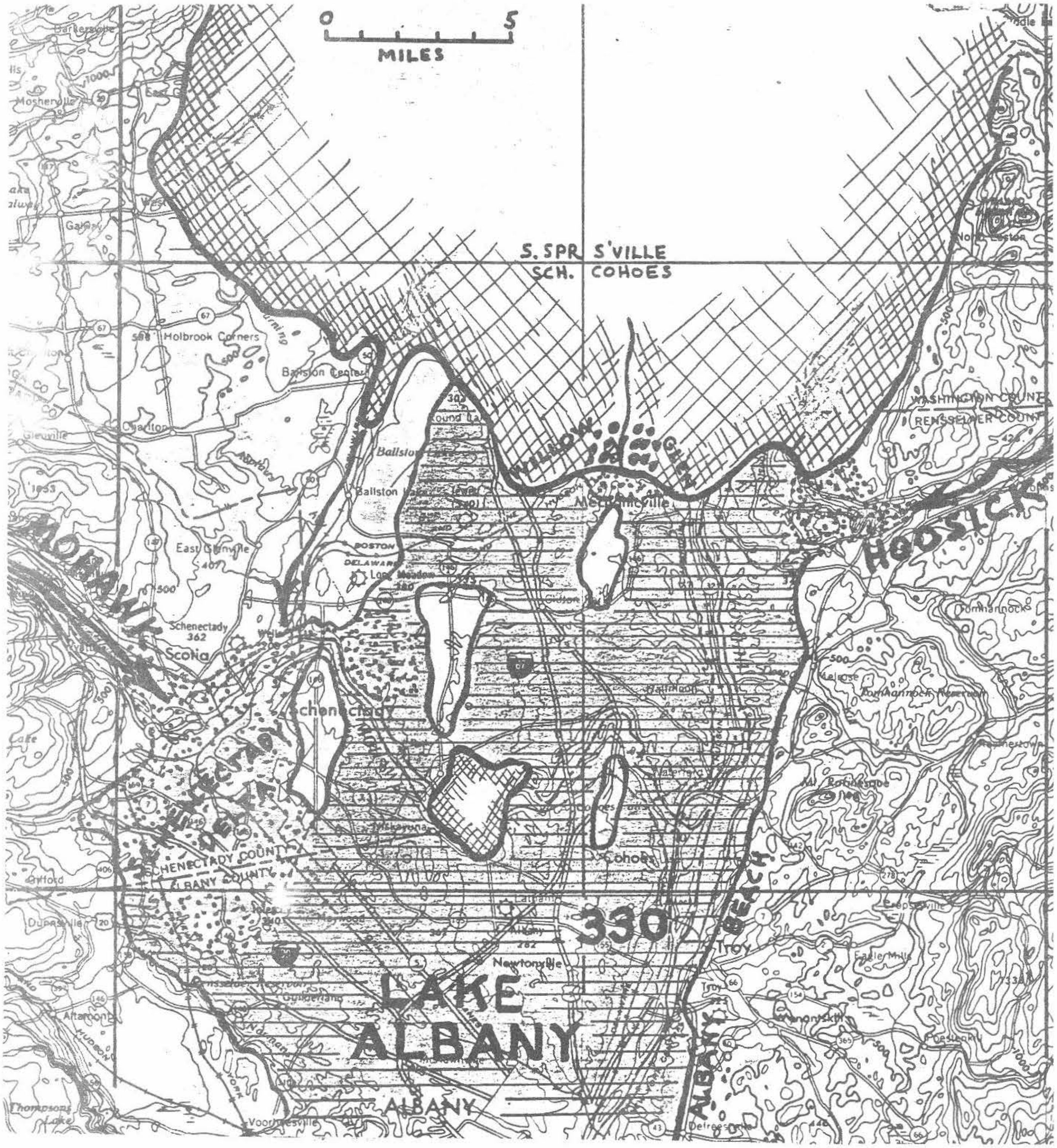


Figure 6. Ice front position at time of Willow Glen kame delta and Hoosick delta.


Upper Benson
SACANDAGA RESERVOIR
Sacandaga Park
Cranberry Creek
Northampton
Benedict
North Broadalbin
Caroga Lake
Peck Lake
Mountain Lake
Jackson Summit
Dennies Hollow
Riceville
Mayfield
Scout Island
West Bush
Steenburgh
Gloversville
Broadalbin
Kennyetto Creek
Mills Corners
Mosherville
Hagedorn Mills
Vail Mills
West Mill
Amsterdam
Perth
West Perth
Lake Desolation
West Galway
Galway
Vaughn
Fulco Airpark
Johnstown
Kayaderosseras Creek
Sammonsville
Berkshire
FULTON COUNTY
MONTGOMERY COUNTY
North Chuctanunda Creek
Hagaman
West Charlton
SARATOGA CO
SCHENECTADY CO
Tribes Hill
Fonda
Fultonville
Fort Hunter
South Amsterdam
AMSTERDAM
Cranesville
Randall
Glen
Minaville
Scotch Bush
Rural Grove
Charleston
Mariaville
Chuctanunda Creek
Ryners Corners
Oak Ridge
Burtonsville
MONTGOMERY CO
SCHENECTADY CO
Braman Corners
Duanesburg Reservoir
Charleston Four Corners
Bear Swamp
Carlisle
Esperance
Sloansville
CHERRY VALLEY TURNPIKE
Duanesburg
ns Hollow
1000
1500
500

Figure 7. Base map (right half) of Figures 8, 9, 10, and of Mohawk Valley west to Randall.

Lake Quaker Springs

Partial extent of the successor to Lake Albany, Lake Quaker Springs, some 50 feet lower, is indicated on Figure 8 (see Figure 7 for base map details of Figures 8, 9, 10). This lake stage was defended on the north by ice receding through the upper Hudson and Champlain Lowlands. In addition to the ice block detached in Lake Albany near Niskayuna, others at Ballston Lake, Round Lake and in the Saratoga Lake Basin prevented immediate northward diversion of the Mohawk River from Schenectady, and required its flow to pass over a rock sill at Rexford where a channel was cut in Lake Albany sand at 320 feet. Discharge past the lingering Niskayuna ice block joined Lake Quaker Springs at the site of the present Albany Airport. Erosion of the exposed Schenectady delta by the Mohawk continued as did dissection to 300 feet by the Alplaus Kill of the East Glenville deltas. Discharge of the Mohawk during this time appears to be no greater and perhaps even less than the flow that deposited the Schenectady delta in Lake Albany. Extensive deltas of the Hoosick and Battenkill, built to a Quaker Springs Lake level of 300 feet, suggest more active deglaciation of the Taconics than previously.

Mohawk Valley Gravels

West of Schenectady, massive, well-rounded cobblestone gravels up to 40 feet thick are found in separated masses at Randall, Fort Hunter, Rotterdam Junction, and Scotia. Rich in western Mohawk basin "bright" lithologies, these gravel units have a grain size and thickness much greater than one might expect to find near the end of a river of low gradient and nominal discharge. The source of these gravels appears to be a 50-foot-thick gravel unit which lies beneath tills, and is now exposed along Route NY 5, one to three miles east of the Little Falls plunge basin. The transport history of these gravel masses requires at least three events involving high discharge from unconfined glacial lakes west of Rome. The first discharge eroded the gravel valley fill at Little Falls and reworked it to a new location at Randall. The second discharge reworked part of the Randall gravel, and deposited it as a valley fill between Rotterdam Junction and Scotia. A third discharge dissected the Scotia gravel and lowered the western half of the deposit to an elevation of 250 feet at Rotterdam Junction.

Summit elevation of the gravel mass at Randall lies at 350 feet, too low for correlation with Lake Albany. Lake Quaker Springs did not receive a Mohawk River delta of any consequence, so it would seem the first of these outbursts occurred late in Quaker Springs time, and may actually have caused the lake to lower.

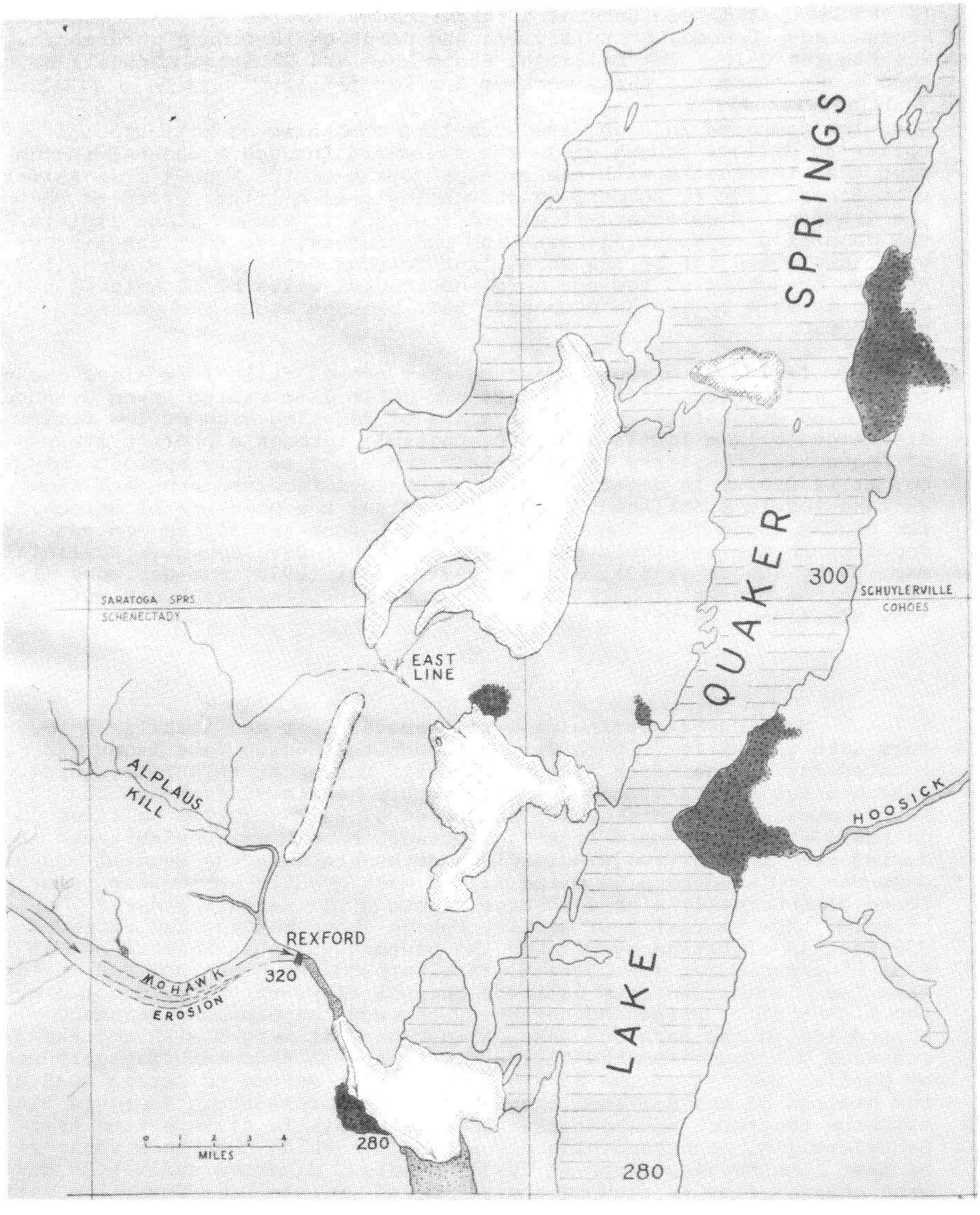


Figure 8. Drainage configuration during Lake Quaker Springs.

Channel Systems

Important to the development of Lakes Coveville and Fort Ann is the occupation sequence of a three-channel system shown on the Schenectady, Cohoes, Schuylerville and Saratoga 15-minute quadrangles. See Figures 7-10. The Ballston, Round Lake and Saratoga channels have been known since the early work of Stoller (1911), Fairchild (1912) and Chadwick (1928).
Chadwick proposed an elaborate wave-like mechanism of post-glacial uplift to deflect Mohawk discharge southward through a channel succession that terminated with the present course of the Mohawk from Rexford near Schenectady to Cohoes. Although regional tilting served to reduce the gradient of northward-flowing discharge, it cannot alone explain the channel diversions at East Line and Rexford. Neither can piracy by headward erosion be the cause, for reasons detailed by Hanson (1977). Rather, breaching of low spots in the channel walls by high-level discharge appears to be the mechanism that brought about the channel sequence.

If it is correct to assume that gravel fills form along channel routes, and coarse deltaic deposits are built into waning lakes by abnormally high discharges, then some means of relating high or low river discharge to lake levels should be possible through a profile study of sequential temporary base levels. Imperfect as this approach may be, it is useful in determining which channel received abundant flow as lake levels stabilized, then fell. Also, the presence of detached ice blocks along the channel routes adds a sequence of ice-contact deposits to the available evidence for channel development. Surficial mapping by Schock (1963), Hanson (1977), Dahl (1978) and DeSimone (1978), between the present Mohawk River and Schuylerville, has contributed many additional details.

Lake Coveville

Lake Quaker Springs lowered some 50 feet and stabilized to form Lake Coveville (Figure 9). Although the Hudson lobe front was located far to the north in the Champlain Valley at this time, three detached ice blocks lingered in the future basins of Saratoga and Round Lakes, and at Niskayuna, southeast of Rexford. The Ballston Channel, extending north from Schenectady, became well established during the first of two glacial lake outbursts when the Randall gravel mass was emplaced some 30 miles to the west. While subsequent recurrence of abnormally high discharge reworked the Randall gravels bringing them to rest near Scotia, Mohawk flood waters that exceeded 300 feet in elevation overflowed the bedrock sills at Rexford and at East Line emplacing ice-contact gravel around the Niskayuna and Round Lake ice blocks. Interim Ballston channel flow, which could not overtop either sill, proceeded northward through the Drummond channel, around ice in the Saratoga Lake basin, where it merged with the Kayaderosseras drainage from the Adirondack front. A sediment trap, produced by partial melting of the Saratoga ice block, served to retain most of the bedload of the Ballston channel and Kayaderosseras. There is little evidence that much sediment reached Lake Coveville at this time near Schuylerville. A second high discharge, breaching the black shale sill at East Line to elevations of 290' and below, diverted sufficient Ballston channel flow to produce a sizable influx into Lake Coveville south of Mechanicville. Dissection of the Lake Quaker Springs Hoosick River delta supplied additional sand there from the east. Some southward current flow in Lake Coveville is suggested by the sand distribution. At Rexford, however, the Schenectady sandstone cap was persistent. Little evidence for discharge into Lake Coveville at Cohoes is found.

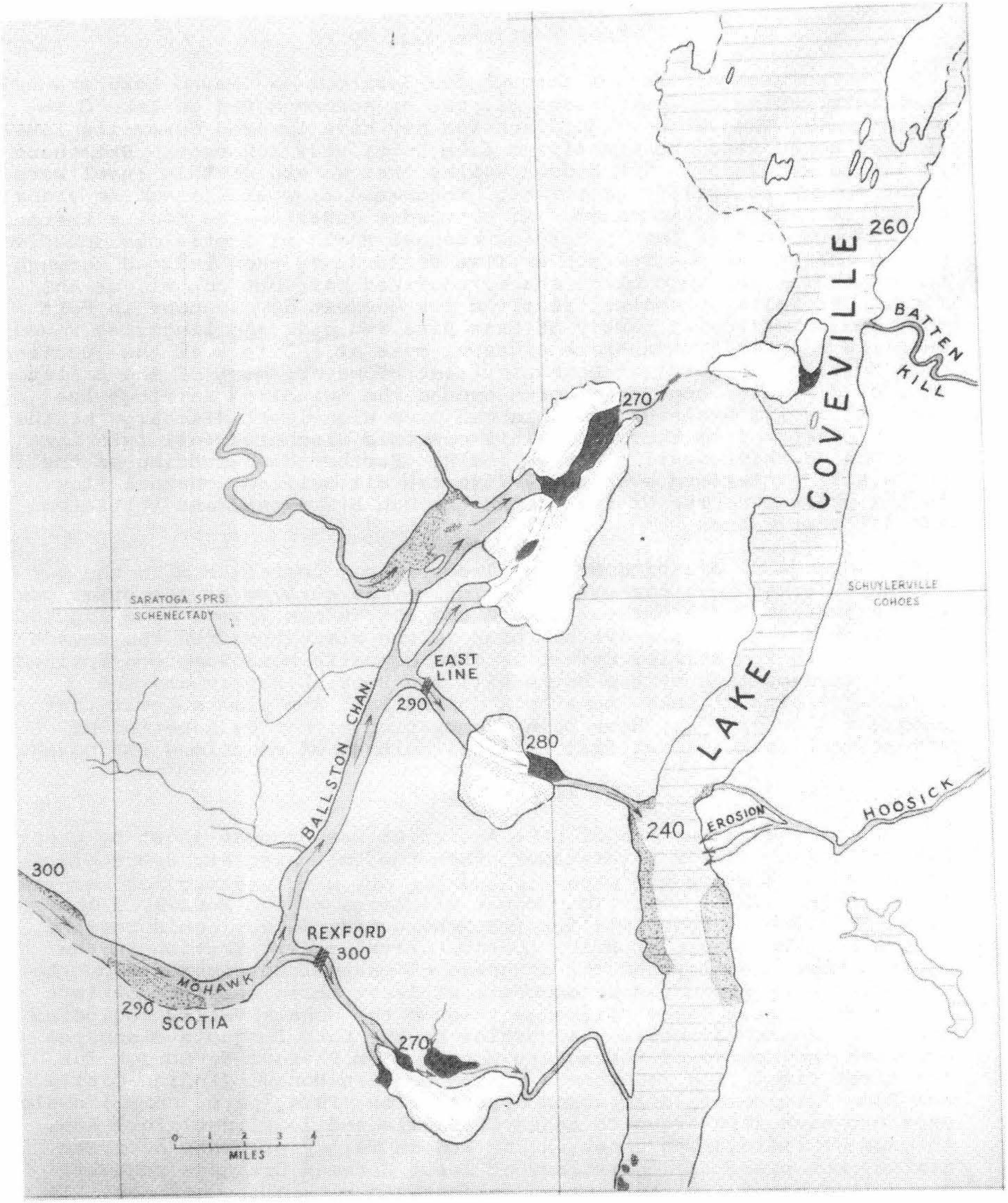


Figure 9. Drainage configuration during Lake Coveville.

Lake Fort Ann

Two high discharges through the Saratoga and Round Lake channels, with intervening nominal discharge, can be accommodated in Lake Coveville time. The second high discharge may have lowered Coveville level as much as 80 feet and stabilized lake level near 160 feet. But there is little evidence in the Hudson Valley that waters at this level were quiet enough to qualify as a lake. Southward flow sufficient to erode Coveville sands is indicated. At Rotterdam Junction the Scotia terrace was reduced some 40 feet. Harding channel north of Scotia was occupied by the Mohawk and the bedrock sill at Rexford, by then reduced through the sandstone cap into black shale, confined most but not all of the flow. The Ballston channel received its deepest development in Fort Ann time, overflowing partly at East Line and over the lingering Round Lake ice block to concentrate a gravel mass at 160 feet at the junction with Fort Ann "River," at Mechanicville. However, most of the Ballston channel discharge continued north around the dwindling Saratoga ice block where its drainage was enhanced by a high-level discharge of the Kayaderosseras from the west. This combined discharge fell into Lake Fort Ann at the Coveville plunge basin. Further down-cutting of the shale sill at Rexford eventually diverted all Ballston channel flow to the present course of the Mohawk through Niskayuna, and initiated the falls at Cohoes.

Eastward draining of Lake Iroquois may correlate with the latest, southernmost channel formation -- the cutting of the upper part of the bedrock gorge between Cohoes and the Hudson River. See Figure 11. Note again (Figure 10) the high-volume discharge from the Kayaderosseras eroding earlier Coveville sand deposits near Saratoga Springs. Severe down-cutting by the Battenkill and Hoosick Rivers and the sudden draining of Lake Tomhannock during Fort Ann time suggest that Iroquois discharge may have been accompanied either by a period of exceptional regional rainfall or final meltout of an upland ice cover.

Timing

If the extinction of Lake Amsterdam was brought about by Great Lakes discharge (Erie Interstade), then the following Pt. Bruce glacial stade is correlative not with ice advance but with wasting ice margins in northern Lake Albany. The modest discharge of the Mohawk following Lake Amsterdam, responsible for the Schenectady delta, could reflect Oneida lobe readvance at Rome. Coarse gravel redistribution in the eastern Mohawk Valley and the sequence of channel developments on the exposed Albany plain can accommodate at least three episodes of late Woodfordian Great Lakes discharge through the Mohawk Valley including draining of Lake Iroquois. A portion of the Lake Iroquois discharge occupied the course of the modern Mohawk from Rexford to Cohoes for the first time. Ice readvances in the western Mohawk (Indian Castle and Rome (Iroquois), diagrammed by Fullerton (1974, pers. comm.) could separate high discharges to Lakes Coveville and (earliest) Fort Ann. Absence of radiocarbon dates in the Hudson Valley prevents accurate timing, but there is consistency at least between drainage requirements, and channel formation and lake stages.

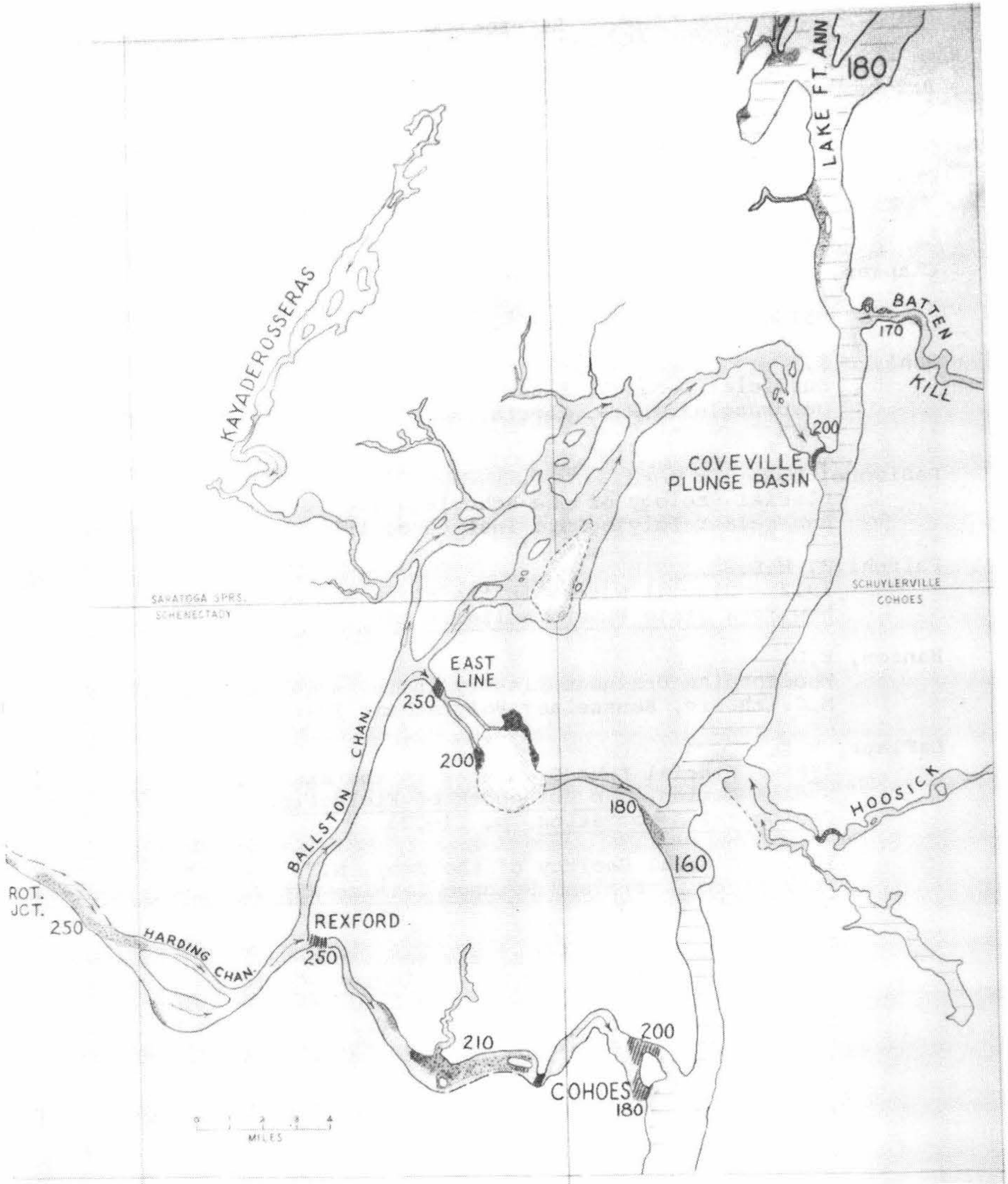


Figure 10. Drainage configuration during Lake Fort Ann.

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Selected Localities

Stop 1. Lake Albany 330-foot beach. West of Bloominggrove Rd., one mile north of Defreestville, Troy South quad. Reworked kame terrace gravels, berm, beach pond rhythmites.

(The remaining stops are all on the west half of the Cohoes 15 min. quad, and are located on Figure 12.)

Stop 2. Cohoes Falls. Gorge of the Mohawk River is cut in folded Ordovician shale. Nickpoint marks post-Iroquois falls recession, about 2000 feet, from former point of upper gorge intersection with Fort Ann waters in the Hudson Valley. (Figure 11.)

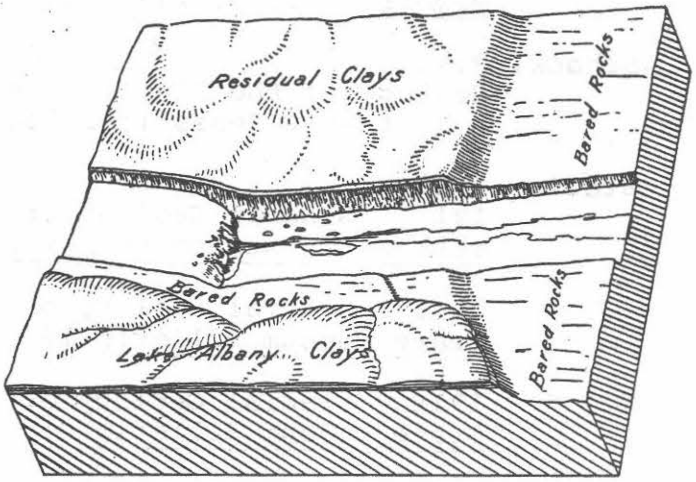

Figure 11. Block diagram by Stoller (1918) showing upper and lower gorge of Mohawk at Cohoes.

Stop 3. Pit south of Lower New Town Rd. in Lake Albany Halfmoon kame delta. About 60 feet of section shows interbedded clinoform gravel and blue-gray flow till, fining upward to sand and silt-clay varves. Typical of south-facing ice-edge lacustrine deposits from which the ice recedes northward. See Figure 5.

Stop 4. Coveville 240-foot sand terrace, inset in Albany clay, and fed by discharge through Round Lake channel into Lake Coveville at Mechanicville. See Figure 9.

Stop 5. Willow Glen kame delta; D.A.Collins pit. About 100 feet of section shows black shale overlain by cemented gravel and sand and blue-gray boulder till, in turn covered by clinoform, locally-deformed pebble gravel, sand, and Albany clay. Is the cemented gravel pre-Mohawk, or does the entire section show only a readvance into Lake Albany, followed by ice recession?

Stop 6. Coons Crossing. Round Lake terraced channel with modern underfit Anthony Kill.

Stop 7. Bemis Heights clay pit. About 55 feet of section exposes ice-contact Albany gravel and clay overlain by Quaker Springs clay and Coveville sand.

Stop 8. Reynolds pit. Late Coveville 200-foot terrace is underlain by 5-15 feet of fluvial gravel with abundant Taconic lithologies derived from Hoosick basin. Flow sense is to the south. Beneath the Coveville gravel, 15 feet of Albany clay overlies 15 feet or more of ice-contact gravel and sand containing mainly Hudson valley lithologies.

Stop 9. Gullies eroded in distal end of Quaker Springs Hoosick delta, later beheaded by Hoosic River dissection of delta.

Stop 10. Several Holocene terraces near modern stream inside eroded Hoosic delta; road climbs eastward over older terraces related to drainage of Lakes Quaker Springs, Coveville and Fort Ann.

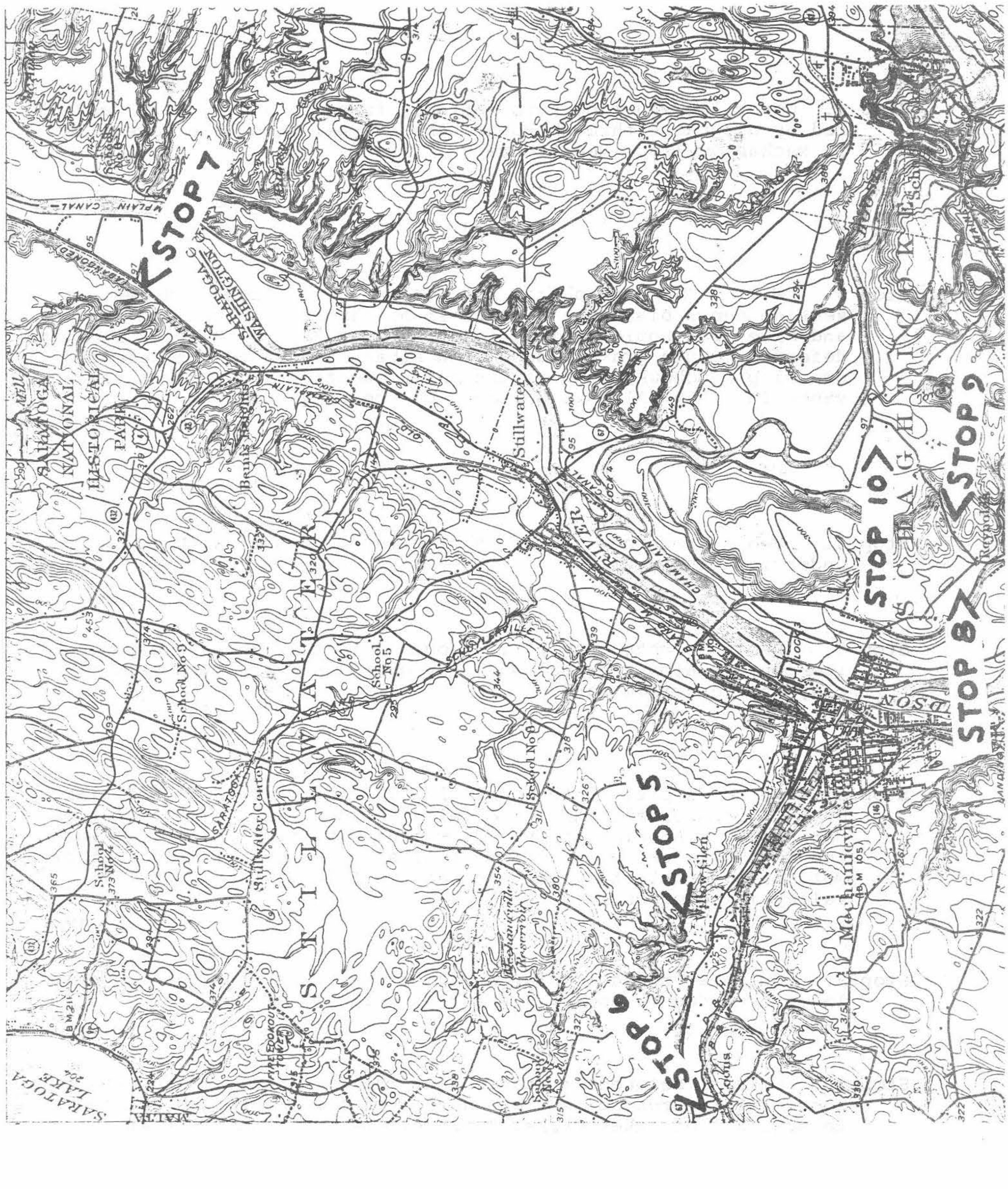
STOP 5
STOP 6
STOP 7
STOP 8
STOP 9
STOP 10
SARATOGA NATIONAL HISTORICAL PARK
Stillwater
Bemis Heights
Mechanicville
Willow Glen
SARATOGA LAKE
CHAMPLAIN CANAL
RIVER
HUDSON
STILLWATER
SCHAGHTICOKE
SARATOGA
WASHINGTON
School No 5
School No 3
School No 4
School No 8

Figure 12. West half of Cohoes 15-minute quadrangle showing trip stops.

Stratigraphy and Depositional History of the Onondaga Limestone in Eastern New York

by

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INTRODUCTION

The Onondaga Limestone is prominently exposed in hundreds of outcrops over a 550+ km. belt extending from Buffalo to the Helderbergs and south to Port Jervis. The formation is a coarse- to fine-grained limestone, which ranges in thickness from 21.5 m. in the central New York type sections, to 49+ m. in the eastern and western parts of the state. The Onondaga Formation was deposited during Eifielian time (Middle Devonian) (Rickard, 1975), prior to and during the initial clastic influxes from the Acadian Orogeny. The unit represents the last extensive carbonate and reef-building phase in the region.

In modern times the stratigraphy, petrology, and bioherms of the formation have been extensively studied. Most investigations have neglected the formation's non-biohermal paleoecology, as well as its eastern sections. Whole formation studies have concentrated in western and central New York, and have extended typical characteristics to eastern areas. The purpose of this trip is to examine the lithologic and faunal characteristics of the Onondaga Formation in an area extending form the Helderbergs to Catskill, and to consider the paleoenvironmental conditions under which the unit developed.

STRATIGRAPHY

The Onondaga Limestone consists of five members. Member thicknesses at several localities across the state are given in Table 1. Characteristics of each member in type section and in eastern New York are presented below.

Edgecliff Member

The type locality is Edgecliff Park, southwest of Syracuse (Oliver, 1954). The Edgecliff is a light-gray, coarse-grained, crinoidal limestone, with beds up to 1 m. thick. Crinoidal columnals 2 cm. or more in diameter are characteristic of the unit. The Edgecliff bears a rich and abundant fauna of rugose corals

MEMBERS	Buffalo	Leroy	Syracuse	Richfield Springs	Cherry Valley	Cobleskill	Helderbergs	Catskill-Leeds	Saugerties
Seneca	12.3	9.2	7.8	2.1	2.1	-	-	-	-
Moorehouse	17	17	7	22.9	22.9	21.3	21.3	11.3	30.5
Nedrow	Uncertain	Uncertain	4.3	3.7	3.7	4	4.6	13.1	10.4
Clarence	13.8	13.8	-	-	-	-	-	-	-
Edgecliff	0-5-3.1	3.1	6.1	6.1	7	9.1	9.1	10.7	11
Total	45.7+	42.7	25	34.7	35.7	34.4	35	35	51.8

Table 1. Average thickness of the Onondaga Limestone throughout N.Y.S. The units are meters.

and tabulates. Brachiopods, bryozoans, gastropods, and trilobites are present, though not usually abundant. In places the Edgecliff swells into coral bioherms. Typical Edgecliff fauna and lithology can be traced to the Helderbergs. South of the Helderbergs, in the areas of Leeds, Saugerties, and Kingston, the unit gradually becomes fine-grained, darker, and less fossiliferous. Further south, at Wawarsing, the Edgecliff can be recognized only by the presence of crinoid columnals.

The Edgecilff has been divided into three faunal zones; descriptions of these can be found in Oliver (1954, 1956a). Zone A is the basal unit at many localities west of Richfield Springs. This is a brachiopod dominated unit with quartz sand and silt scattered about in the limestone. The abundance of quartz decreases upwards with the lowermost bed occasionally containing sufficient quartz to be referred to as a sandstone. Zone A ranges in thickness from less than 2 cm. to 1.2 m. Zone B is a discontinuous, coral dominated, limestone which exists only in western New York and Ontario. This zone has been found to consist of erosional remnants of the Early Devonian Bois Blanc Formation and has been removed from the Onondaga Formation (Oliver, 1966, 1967). Zone C is the predominant and typical Edgecliff faunal zone. This zone is dominated by rugose corals and tabulates and is the "coral biostrome" of Oliver (1954, p. 635), as well as the "great coral-bearing limestone" of Hall (1879, p. 140). The coral fauna and coarse-grained texture of this unit can be traced from Buffalo to Leeds, a distance of about 490 km. East of West Winfield two subzones, designated C_1 and C_2, can be recognized. C_1, the lower of the two, is a medium-gray, fine-grained limestone with a non-prolific coral (dominant) and brachiopod fauna. C_2 is the typical and predominant coarse-grained, light-gray, coraliferous Edgecliff Member.

Clarence Member

The Clarence Member of the Onondaga Formation (Ozol, 1963) is that portion of the formation in western New York which overlies the Edgecliff Member and consists of 40-75% chert. The Clarence roughly corresponds to the Cornitiferous Limestone of Hall (1841) and the Nedrow black chert facies of Oliver (1954). The member is a medium- to dark-gray, non-argillaceous, fine-grained, limestone with such an abundance of chert that the limestone is often found only as small "islands" floating in the chert. Fossils are typically absent or very scarce, though occasionally the lower beds bear a fauna similar to that of the underlying Edgecliff Member. The Clarence is approximately 13.8 m. thick over most of its extent. It can be traced from

Ontario, though its type locality in Clarence, New York, to Avon, New York. East of Avon it pinches out.

Nedrow Member

The Nedrow is typically a thin-bedded, very fine-grained, argillaceous limestone. Clay content can range up to about 25%. At its type locality, Indian Reservation Quarry south of Nedrow, New York, the unit measures 4.6 m. with an abrupt base and a gradational upper contact (Oliver, 1954). The member maintains its typical thickness over most of its range, except in the vicinities of Leeds and Saugerties where it is 13 m. and 10.5 m., respectively.

Despite lithologic variations, the Nedrow frequently bears a distinct fauna. The base of the member often consists of a 0.6-1.5 m. zone of thinly bedded, argillaceous limestone containing Heliophyllum halli and Amplexophyllum hamiltonae, as well as a diversity of platycerid gastropods and brachiopods. This unit, designated Zone D of the formation (Oliver, 1954), contains very few corals other than those mentioned above, and is widespread thoughout the state. Zone E, which succeeds the latter, has thicker beds, is less argillaceous, and bears a low diversity, high density, brachiopod fauna to the exclusion of most other taxa.

Moorehouse Member

The type locality of the Moorehouse Member is the Onondaga County Prison Quarry at Jamesville, New York (Oliver, 1954). Here the unit is a limestone, 6.3-7.7 m. thick, medium-gray, and very fine-grained with numerous shaley partings. Bedding ranges from 0.6-1.5 m. Chert is found throughout, but is most abundant in the upper half of the member. The Moorehouse increases in thickness both east and west of its type area.

In central New York, two Onondaga faunal zones can be recognized in the Moorehouse (Oliver,1954). Zone F is a sparsely fossiliferous unit with a low diversity, brachiopod dominated fauna. Zone G, which is gradational with the subjacent Zone F, has the most diverse fauna of any unit in the formation. Numerous brachiopods, gastropods, cephalopods, and trilobites are present , and often abundant. Several mollusc species are characteristic of this zone. The two zones are not continuous throughout the state. They lose their typical faunas and lithologies both east and west of central New York.

Seneca Member

The Seneca Member was first described by Vanuxum (1839) from several exposures in Seneca County. Oliver (1954) established the type section at Union Springs, in Cayuga County, where the member is fully exposed. Here it measures 7.8 m. It is a fine-grained limestone which becomes darker and less fossiliferous upward as it grades from a Moorehouse-like lithology to a shale above. The Seneca and Moorehouse members are separated by the Tioga Bentonite. Thinning eastward from its type area, the Seneca passes out of existence beyond Cherry Valley. Its position in eastern New York is physically and temporally occupied by the Marcellus Shale.

Eastern Stratigraphy

Onondaga facies changes across the state have resulted in several lithologic variations form the formation's type localities. East of Cherry Valley the Seneca Member pinches out. Cherry Valley also marks the easternmost extent of the typically shaley Nedrow Member. In eastern New York, the Nedrow and Moorehouse members are lithologically similar to the Edgecliff Member. These facies changes cause some difficulties in the application of central New York nomenclature ot eastern lithologies.

Oliver (personal communication, 1973) first subdivided the Onondaga Formation in the Helderberg area. He described the Edgecliff Member as 7 m. of coarse-grained, coraliferous, limestone bearing the characteristic crinoid columnals. Initially the top of the Edgecliff was placed at the top of a 4 m. section of limestone containing light chert. The 22 m. of Onondaga which supersede the Edgecliff were originally left unpartitioned because of a lack of lithologic discriminators. These rocks, referred to only as the "Upper Onondaga" (Oliver, 1954), were described as a succession of 4-5.6 m. chert-free limestone, 6.1-7.6 m. dark-chert-bearing limestone, and 9.1 m. chert-free limestone,

In 1956, Oliver reconsidered Onondaga stratigraphy in the Helderberg area. He assigned the formation's lower 8.2-9.1 m. to the Edgecliff Member, based on faunal characteristics. The Edgecliff's top was now placed several feet below the uppermost light-colored chert nodules. Succeeding the Edgecliff, 4.6 m. of section were assigned to the Nedrow Member. The criteria used in this case were the presence of thin beds and platycerid gastropods. The strata extending from here to the formation's top, about 21.3 m., were assigned to the Moorehouse Member. The base of the Moorehouse was placed about 2 m. above the uppermost light-colored chert. This unit includes about 3.9 m. of chert-free limestone, 7.6 m. of limestone containing dark-colored chert, and 9.1 m. of chert-free limestone. The Nedrow-Moorehouse contact was placed in a chert-free section, at the upper limit of beds containing platycerid gastropods. Oliver (1963) retained this partitioning of the formation. With some reservations it is retained here.

The author's reservations regarding Onondaga subdivisions in eastern New York arise from the fact that members, lithostratigraphic units, are discriminated on faunal criteria. Intermember boundaries correspond to faunal variations and not to lithologic breaks, or even to arbitrary horizons within gradational lithologic sequences. Consider the typically shaley Nedrow, which can contain up to 25% clay. In the Helderbergs, the Nedrow has a mean argillaceous content of 2%. This compares with 5-6% in the typically cleaner Edgecliff and Moorehouse members. In fact, maximum clay content and maximum gastropod abundance do not occur in the Nedrow but rather in the dark-chert section of the Moorehouse. Again, the typically spar-free Nedrow has a mean spar abundance of 8% in the Helderbergs where the other members have a comparable 10%. Nontypical lithologic characteristics also extend to fossil and calcisiltite abundances. These nontypical characteristics extend at least from the Helderbergs to Leeds. The eastern subdivisions arose from a "layer cake" approach to stratigraphy. Though they are not actual lithostratigraphic units, the eastern New York member designations are firmly entrenched in the literature (Rickard, 1975) and can be used if an awareness of their faunal origins is maintained.

ONONDAGA BIOHERMS

Historic Review

The presence of organically constructed mounds within the Onondaga Formation was first recorded by Hall (1859). It appears that he was impressed by the abundance of coral in the Edgecliff Member and referred to the entire unit as "reef". Grabau (1903, 1906) was the first to examine a discrete organic mound. He described an 11 m. domal mound with flanking beds dipping outward at about 10°. Oliver (1954, 1956b, pers. comm., 1975) located over thirty mounds outcropping in eastern and western New York. Lindemann and Simmonds (1977) noted the presence of an additional bioherm near Syracuse, thus bridging the gap between eastern and western occurrences. Subsurface bioherms (Cumings, 1932) were discovered in 1967 in south western New York (Waters, 1972) and in adjacent Pennsylvania (Piotrowski, 1976).

Subsurface Bioherms

The faunal and lithologic characteristics of five subsurface bioherms were recently summarized by Kissling and Coughlin (1979). The following is primarily derived from the above source and from D. L. Kissling (pers. comm.,1979).

Several large Onondaga bioherms have been located in the subsurface of western New York and northern Pennsylvania, at depths exceeding 4600 feet (Piotrowski, 1976). With heights up to 63 m. and diameters up to 3200 m., these structures are morphologically more akin to an inverted pie than to a multi-tiered wedding cake. Therefore, these mounds are classed as bank structures rather than pinnacle reefs. Despite their large diameters, the subsurface bioherms stood as prominent elevations on the sea floor. They project above the remainder of the formation by in excess of 50 m., and extend above the interreef portions of the Edgecliff Member by as much as 60 m.

These bioherms show an orderly succession of faunas and associated lithologies. They began with a pioneer community dominated by thickets of *Acinophyllum* and *Cladopora*. The thickets grew on slightly elevated areas of the sea floor, during a transgression of the sea. The corals trapped lime mud and grew rapidly upward. A second stage of biohermal growth is shown by a more diverse assemblage of *Cladopora*, *Cylindrophyllum*, *Acinophyllum*, and various solitary rugosans. *Cylindrophyllum* dominates the central areas of the mound, while *Cladopora* dominates the periphery. These corals grew in dense thickets which accumulated a matrix of crinoid sand, which occasionally inundated them. Crinoids, which provided the matrix sediment, lived amongst the thickets. The quantity of lime mud deposited during this growth stage is conspicuously small. A terminal growth stage is marked by a *Cladopora* and *Cystiphylloides* dominated assemblage. *Acinophyllum* and *Syringopora* are present, though not numerous. The fauna of this stage is enclosed by a matrix of lime mud and fenestrate bryozoans.

Bioherms of the subsurface are believed to have grown on a hinge between a rapidly subsiding basin to the south and a slowly subsiding, relatively shallow, shelf lagoon to the north (Warters, 1972). Kissling and Coughlin (1979) cite evidence for this conclusion. First, both outcrop and subsurface bioherms were initiated and grew under similar environmental conditions. This is shown by similarities in their faunal and lithologic successions. Despite similarities, the subsurface bioherms attained thicknesses of about 50 m. in excess of their outcrop counterparts. Second, the subsurface bioherms have the steepest slopes on their southern, basinward, sides. Regardless of their proximity to a deep basin, it is apparent that biohermal growth in southern New York was influenced by a rate and extent of subsidence which far outstripped that of areas to the north.

An Ontario Bioherm

A mound of similar morphology to the subsurface bioherms, crops out west of Port Colborne, Ontario (Cassa, 1979). The mound is 15 m. vertically and about 1 km. horizontally. Unlike other Onondaga bioherms, this one is bedded rather than massive and contains chert. This mound qualifies as a bioherm because it swells above the combined thicknesses of the Edgecliff and Clarence members by about 9 m. and must have stood erect on the sea floor.

Successional development of the Port Colborne bioherm is comparable to that of other Onondaga bioherms (Cassa, 1979). The pioneer community is dominated by Acinophyllum which trapped a shale and calcisiltite matrix. Acinophyllum grades upward into argillaceous, crinoidal wackestones and packstones. The second stage fauna is more diverse than the first, including solitary rugosans, laminar stromatoporoids, massive tabulates, and branching tabulates. The mound is capped by a third stage fauna of solitary and colonial rugosans, Fistulipora, and large crinoids. The lithology of this stage includes non-argillaceous, crinoidal packstones and grainstones. Crinoid holdfasts found in this unit indicate that the crinoidal debris was deposited near its life site. The mound is gradationally terminated and superceded by a cherty, argillaceous wackestone.

The Port Colborne bioherm is believed to have developed as a bank in a shallow lagoon (Cassa, 1979). Though evidence of turbidity fluctuations is present, the prime environmental controls on the bank's development were the differential rates of subsidence and coral growth. The subsidence rate, possibly coupled with a rise in sea level, exceeded coral growth and growth of the bank was terminated.

Bioherms in Outcrop

The majority of Edgecliff bioherms seen in outcrop differ greatly in size and shape from the Port Colborne and subsurface mounds. The former are round or ovoid in plan view, with diameters or lengths rarely exceeding 400 m. In cross section these bioherms are domal or lensoid, with heights of 1-22 m. (Oliver, 1954,1956b).

Five, of the approximately thirty, outcrop bioherms have been studied to characterize successional lithologies and faunas and to interpret paleoenvironmental conditions (Mecarini, 1964; Bamford, 1966; Poore, 1969; Collins, 1978; Williams, 1979).

These studies have shown the bioherms to be generally similar in their respective successional patterns. Four facies common to most bioherms of the Onondaga Formation are described below.

1) Basal Facies

This unit is found wherever the base of a bioherm is exposed. 30-70% of the facies' volume is occupied by *Acinophyllum* corallites. This branching coral acted as a baffle, trapping a matrix of terrigenous mud, calcisiltite, and quartz silt. Exclusive of intracorallite spaces, pore filling spar is absent.

This facies represents a pioneer community, strongly dominated by a single opportunistic genus. The unit corresponds to the "quiet water stage" of Lowenstam (1957) and to the "basal stabilization zone" of Walker and Alberstadt (1975). Finks and Lamster (1979) have reported *Acinophyllum* growth rates of 5-15mm./year. Therefore, through rapid lateral and upward growth, *Acinophyllum* was able to colonize a portion of the sea floor and raise a stabilized platform for further coral growth.

2) Core Facies

This unit, comprising the main body of the mound, overlies and is gradational with the basal facies. The fauna is diverse and spatially distributed in more or less complex patterns. The more abundant genera include *Cylindrophyllum*, *Cladopora*, *Favosites*, *Emmonsia*, *Cystiphylloides*, and *Acinophyllum*. The core of each bioherm is unique in relative abundances of the above taxa and in their spatial segregations and integrations. Faunal complexity precludes a biologic generalization of whole-core of sub-core characteristics.

Despite complex faunal characters, the core facies contain lithologic traits which can be generalized. Sediment grain-size and spar abundance increase upward and terrigenous mud and calcisiltite diminish upward. Core lithologies grade from calcisiltite to sparry calcarenite and/or calcirudite. Lindemann and Simmonds (1977) related subdivisions of the core facies to the "overlying colonization zone" and the "diversification zone" of Walker and Alberstadt (1975).

3) Cap Facies

Where exposure permits, a third facies can be seen overlying the core. This cap is usually dominated by *Heliophyllum*. In what appears to be the cap of an eastern New York bioherm, Finks and Lamster (1979) report a single *Heliophyllum* corallum which exceeds 12 m. in diameter. *Cystiphylloides* may also be abundant, present, or absent. Lithologically, this facies is a sparry calcarenite or calcirudite. Instances have been reported where calcisiltite is totally absent except within the coralla of dendritic and phaceloid corals (Bamford, 1966).

4) Flank Facies

Many bioherms have beds of bioclastic sediment which dip from the unbedded coral mounds at angles of 10-15°. These beds are primarily composed of bioherm derived detritus. Flank lithologies are highly variable. Spar dominates the proximal and upper beds, while calcisiltite dominates the distal and lower areas. The flank beds grade distally from biohermal to normal Edgecliff lithologies and faunas (Bamford, 1966).

Paleoenvironmental Interpretations

Among those who have studied them, there is general agreement that Onondaga bioherms developed on a shallowly submerged lagoonal shelf (Bamford, 1966; Collins, 1978; Kissling and Coughlin, 1979; Ossa, 1979). Biohermal growth began in relatively quiet water, as Acinophyllum thickets stabilized the substrate and raised a slight mound above the surrounding sea floor. This pioneer community was succeeded by the diverse fauna of the core facies, which continued to accumulate sediment and build the mound upward. During upward growth, the mound was exposed to ever increasing water agitation. This is shown by the upward abundance trend of pore filling spar cement. With the onset of agitation, some bioclastic sediments were swept from the mound and deposited as flanking beds. Eventually, the mound reached a position at which water turbulence and shifting sediments exceeded faunal tolerances and coral growth was extinguished (Mecarini, 1964; Bamford, 1966; Poore, 1969). Contrary to the statements of Turner (1977) and Lindemann and Simmonds (1977) there is no evidence that an influx of clastic mud eradicated the corals.

It has been suggested that biohermal growth was terminated because of the inability of coral growth to keep pace with the rate of subsidence (Kissling and Coughlin, 1979; Ossa, 1979). This may hold true for the subsurface bioherms, but it contradicts the faunal succession and spar abundance trends of most outcrop bioherms. Furthermore, if the 5-15 mm./cycle growth rate of Acinophyllum reported by Finks and Lamster (1979) is in fact an annual rate, it is difficult to imagine a subsidence rate exceeding this on a persistent regional basis. To date, the environmental condition or conditions which terminated the bioherms are uncertain.

Banks of Reefs?

During the past two decades, there have been so many semantic manipulations of the term "reef" that it has become a term of dubious meaning. The problem has partly arisen from divergent perceptions and purposes of the various geolinguists. It has also partly arisen form the use of "reef" as a genetic rather than a descriptive term, requiring interpretation rather than strict observation. In this paper the author uses Heckel's (1974, p. 96) definition of reef. In accord with this definition, a reef must be an organically constructed buildup that displays:

(1) Evidence of (a) potential wave resistance, or
(b) growth in turbulent water, which implies wave resistance;
(2) evidence of control on the surrounding environment.

According to Heckel, wave resistence can be evidenced by:

(1) Inorganic spar cementation
(2) Organic construction of rigid skeletal frameworks
(3) Sediment binding by encrusting organisms
(4) Sediment binding by rooted organisms
(5) Coherence of lime mud
(6) Inertia of large skeletons

To evaluate the degree to which Onondaga bioherms conform to the above characteristics, we will examine the characteristics of these bioherms as compared to those of a Florida patch reef. The patch reef described here is Clearwater Reef, which lies in the back reef lagoonal area of the Florida Reef Tract. Clearwater Reef is within the bounds of Biscayne National Monument, a short distance from Margot Fish Shoal. The fauna and sediments of this reef were mapped and studied in detail by Black and others (1975).

Clearwater Reef is a coral bioherm which rises from a depth of 5 m. to within 0.2 m. of sea level at low tide. This reef is approximately 50 m. long, ovoid in plan view, and oriented parallel to prevailing currents. Sediments on the reef surface are reef derived bioclasts with approximate grain--size frequencies of 15% mud, 65% sand, and 20% gravel. The gravel fraction consists primarily of fragmented reef corals. The sediment is mobile and sometimes inundates corals growing on the reef surface.

A sediment apron surrounds and flanks Clearwater Reef. It extends from the reef surface to a water depth in excess of 5 m. Apron sediments are reef derived bioclasts, with an average mud content of 20%. No discernable grain-size frequency trends were found in radial transects around the reef. Due to bioturbation, the sediment apron shows no laminations.

Onondaga bioherms are coraliferous mounds of ovoid shape. They are believed to have been oriented parallel to prevailing currents (Poore, 1969; Kissling and Coughlin, 1979; Williams, 1979; R. M. Finks, pers. comm. 1979). Mud content in the core and cap facies ranges from 40% (Mecarini, 1964) to nearly 0% (Bamford, 1966). Higher calcisiltite contents are found within the coralla of branching corals. Sediments of flanking beds are mound derived bioclasts containing as little as 8% calcisiltite and as much as 35% pore filling spar cement (Bamford, 1966).

From the foregoing, it can be seen that Onondaga bioherms satisfy Heckel's (1974) reef definition as well as, or more fully than, a Holocene patch reef. Onondaga reefs have less surface mud than Clearwater Reef. Where calcisiltite is abundant in Onondaga reef cores it is confined to coralla interiors, imparting stability and wave resistance. The lime mud in these bioherms may have resulted from original skeletal framework material that underwent biodegradation and subsequent cementation by cryptocrystalline cement (G. M. Friedman, pers. comm., 1979). This process is common just below the living surfaces of post-Paleozoic reefs and masks the original rigid structure of the reef (Friedman, 1978). The flanks of Onondaga reefs contain less mud than the cores and show more biohermal control of nearby sediments than do the flanks of Clearwater Reef. Onondaga reefs contain an abundance of spar cement. The flanks also were life sites of organisms, such as crinoids, which served to stabilize the sediments. Submarine cementation which occurs in Holocene reef just beneath the living surface could also have helped in sediment stabilization (Friedman, Amiel, Schneidermann, 1974). Unless we are willing to claim that Holocene Patch reefs, of proven wave resistant abilities, are not reefs then we must consider Onondaga bioherms to be reefs also. The main area of remaining doubt lies with the degree of "agitation" or "turbulence" they could or did withstand.

Albrights Reef

Albrights Reef is a crinoidal coraliferous mound measuring 305 m. x 250 m. x 6 m. A regional dip of 20°W and irregular exposure obscure the original dimensions. Bamford (1966) divided the reef core into two subfacies and recognized a total of five reef facies. The spatial relationships of the facies, as seen in an east-west transect through the reef center, are shown in Figure 1. The facies descriptions of Bamford (1966) are given below.

1) Acinophyllum Facies

This facies is bedded to massive limestone consisting of 50+% Acinophyllum corallites with a matrix of calcisiltite and fossil fragments. Matrix bioclasts include crinoids, ostracods, brachiopods, and bryozoans. Spar cement is present only within the corallites. Bedding is best developed at the unit's base, and is gradually obscured upward. These deposits represent the basal facies and the poineer community of the reef.

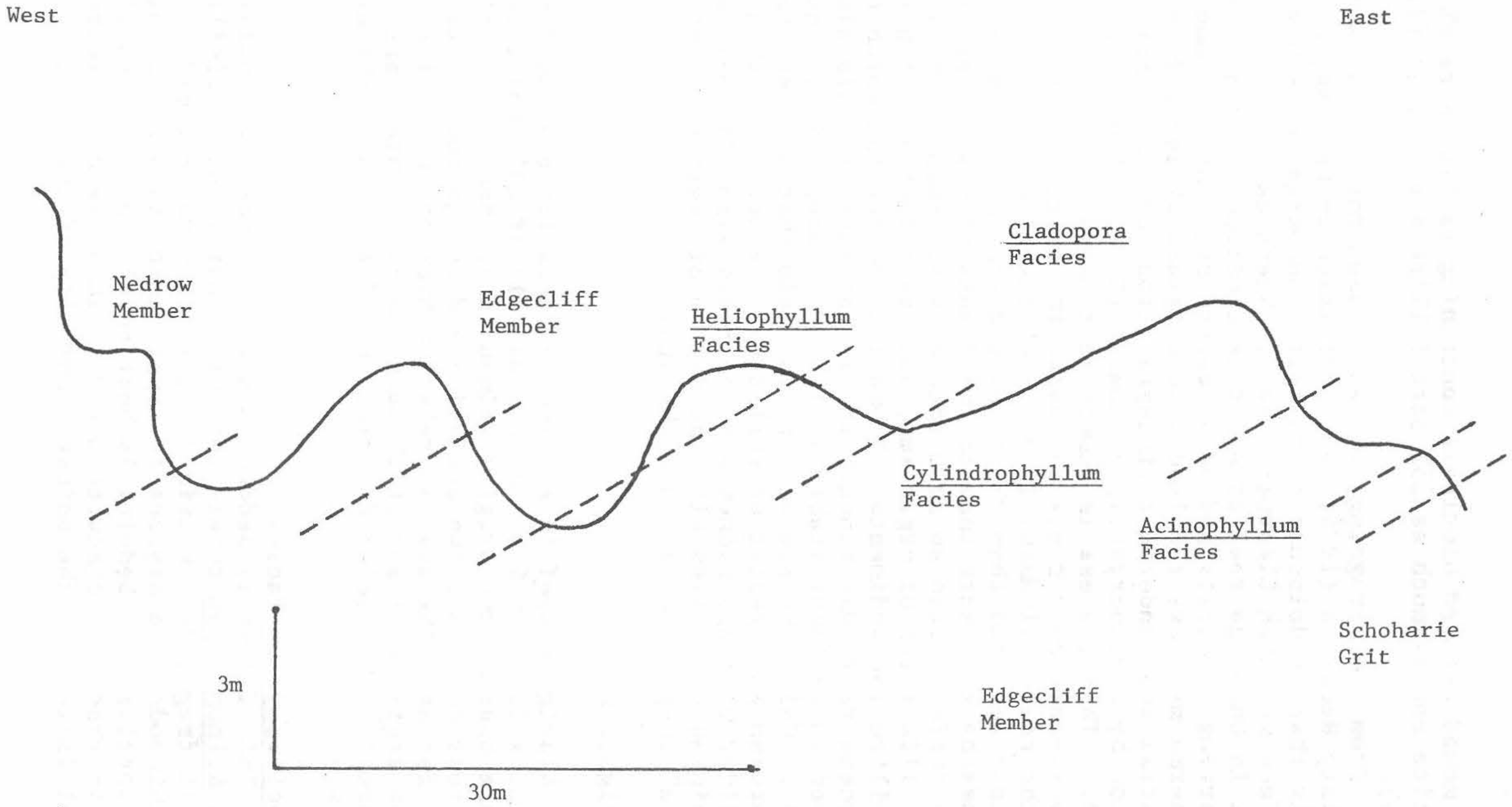

Figure 1. Schematic cross section of Albrights Reef. (From Bamford, 1966)

2) *Cylindrophyllum* Facies

This unit is characterized by an abundance of *Cylindrophyllum*, with an accessory fauna of *Acinophyllum*, *Cladopora*, and *Favosites*. The facies is lithologically variable. Calcisiltite ranges to 50%, and spar ineceasrs upward from nearly 0% to a maximum of 35%. Massive *Favosites* coralla are most abundeant in the sparry sediments. The branching corals are best developed in muddy areas. The sediments are primarily crinoidal. Crinoid holdfasts helped stabilize the sediment substrate. During this facies' development, water agitation increased to the extent that calcisiltite was swept from the mound.

3) *Cladopora* Facies

Here the reef attains maximum diversity. The coral fauna includes *Cladopora*, *Syringopora*, *Siphonophrentis*, *Heliophyllum*, *Favosites*, and *Emmonsia*. The latter two are large, massive, and hemispheric. Crinoids attain maximum abundance in the sediments where they are found with ostracods, brachiopods, bryozoans, platycerid gastropods, and coral fragments. This unit is a packstone or grainstone. Calcisiltite is virtually absent. Development occurred as the reef grew into an environment of ever increasing water agitation.

4) *Heliophyllum* Facies

This unit is a grainstone or biosparite. Bioclasts are larger and better sorted than elsewhere on the reef. This facies caps the reef and grades laterally into reef flank beds. The unit was deposited in agitated water which precludes the growth of most corals other than large colonies of *Heliophyllum* . Bamford (1966) concluded that high levels of agitation prevented further reef growth.

5) Flank Facies

A series of graded beds, which flank the reef, were deposited lateral to and gradational with the reef cap. These deposits become finer distally and grade into normal Edgecliff fauna and lithologies.

Roberts Hill Reef

In outcrop, this reef is a mound 370 m. long with a 9 m. east facing cliff exposure. The hill formed by the reef is elongate in a north-south direction. The reef's true orientation and dimensions have been obscured by erosion and by a regional dip of 24° W. Collins (1978) studied the reef facies to determine their spatial relationships and depositional environments. Five facies were recognized, four belonging to

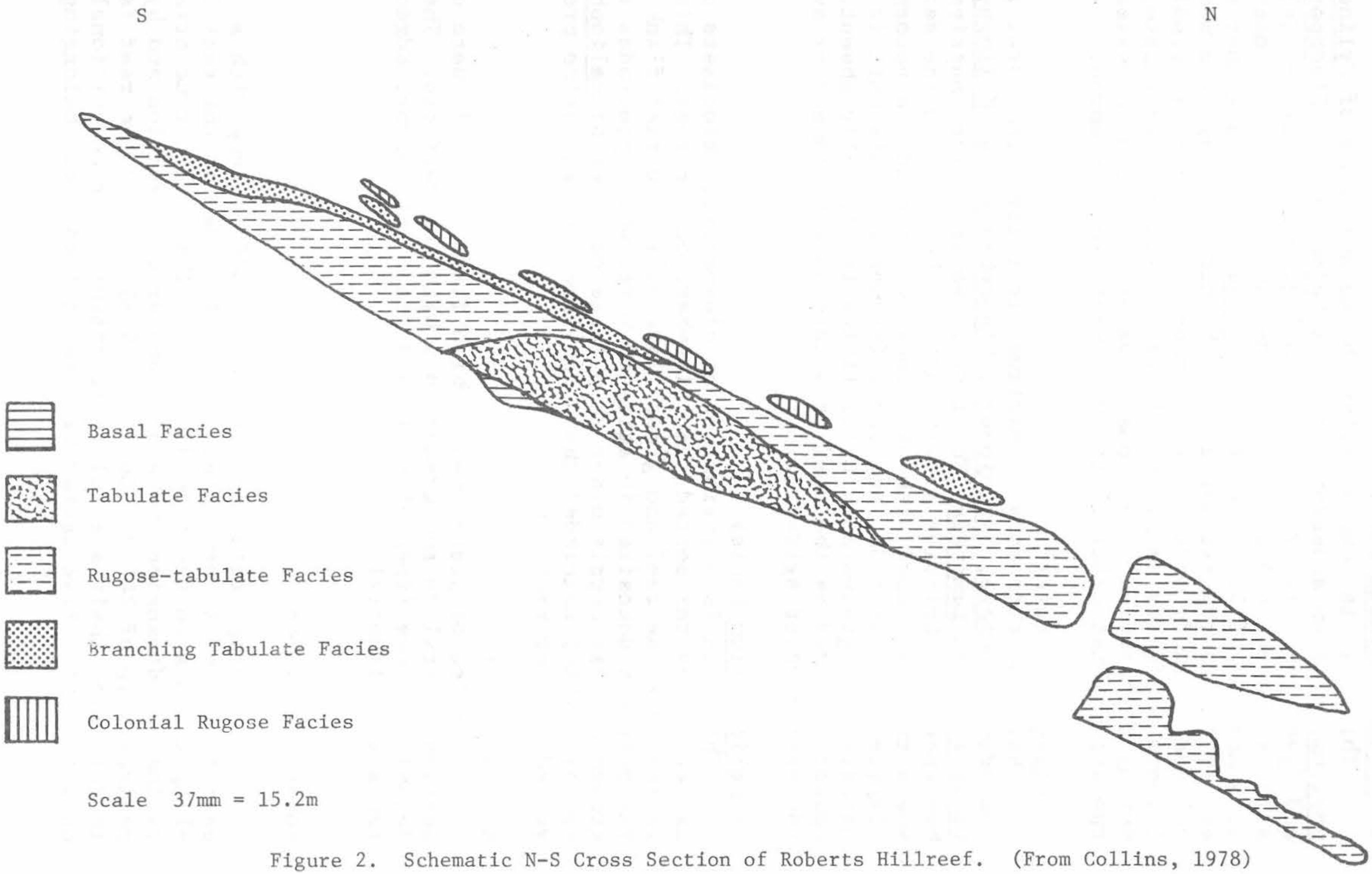

Figure 2. Schematic N-S Cross Section of Roberts Hillreef. (From Collins, 1978)

the reef core. The remaining facies is either part of the core or is an unusual cap facies. Figure 2 is a schematic of the facies exposed in the east facing cliff. Characteristics of the facies (Collins, 1978) are given below.

1) Basal Facies

The lowermost section of Roberts Hill Reef is overwhelmingly dominated by Acinophyllum. The corallites are enclosed in a matrix of calcisiltite. Additional bioclastic particles include fragments of crinoids, ostracods, gastropods, and bryozoans.

2) Tabulate Facies

The fauna of this unit is dominated by large, hemispheric or laminar, coralla of Favosites and Emmonsia. Acinophyllum is also present. The corals are enclosed by a sediment of large, well-washed, crinoid columnals, some of which attain lengths of 15+ cm. Crinoidal sediments appear to have occasionally smothered the corals. Calcisiltite is rare or absent in most samples. These sediment characteristics indicate deposition in agitated waters which may have been influenced by storm waves.

3) Rugose-Tabulate Facies

The fauna of this unit is dominated by Cylindrophyllum, Cystiphylloides, Favosites, and Emmonsia. The latter two genera are neither as large nor as numerous as in the previous facies, and are restricted to areas where well-washed bioclastic sands and gravels predominate. The regose coralla, some of which attain heights of 3 m., contain a calcisiltite matrix. In outcrop, this facies extends up and around the tabulate facies. It has been postulated that Cylindrophyllum formed a wave baffle, partly protecting the interior tabulate facies. This pattern is exactly opposite to that seen at Thompsons Lake Reef (Williams, 1979) where tabulates are peripheral to Cylindrophyllum. A definitive determination of the relationships between these two facies was not accomplished at Roberts Hill due to insufficient exposure.

4) Branching Tabulate Facies

This unit contains the reef's greatest faunal diversity. Thirteen coral genera occur here, dominated by Thamnopora, Coenites, Favosites, and Acinophyllum. The branching coralla are loosely arranged in a calcarenite matrix. Calcisiltite content is generally low except in proximity to the superceding unit.

5) Colonial Rugose Facies

Corallites of *Cylindrophyllum* and *Acinophyllum* occupy over 40% of the volume of this unit. These corals, along with *Coenites* and *Heliophyllum*, trapped a calcisiltite matrix. The sediments also include ostracods and *Styliolina*. As far as can be determined from the exposures on hand, this facies caps the bioherm. Judging from the successive faunas and lithologies of other Onondaga bioherms, it may be concluded that the actual cap facies is not exposed. If this is not the case, this facies represents an atypical cap developed under abnormal reef termination conditions.

ONONDAGA LITHOLOGIES

Discrimination of carbonate petrologic types within the Onondaga Formation is based on relatively few lithologic variables. The only particle types or textures of sufficient abundance to be quantitatively significant are lime mud, biogenic grains, spar cement, and terrigenous mud. Quartz sand is abundant in very few samples and absent in almost all others. Small quantities of silt-size subhedra and euhedra of quartz and dolomite are nearly ubiquitous and are the result of syntaxial overgrowths on 1-5 micron eolian grains of corresponding composition (Lindholm, 1969b). Volumetric increase due to grain-growth and the pervasive low-abundance distribution of these grains preclude their use as discriminators in the reconstruction of primary petrologic characteristics. Pyrite is also present in small quantities (1-3%) in almost all samples. Ooids and glauconite are present in less than 2% of the samples studied. Oncolites and pellets are absent. Sedimentary structures, such as ripples or crossbeds, are extremely scarce. The result is that Onondaga lithologies are relatively simple compared to many other carbonate formations in New York.

The formation is volumetrically dominated by silt-size carbonate particles with diameters in excess of 5 microns (Lindholm, 1967, 1969a). The remaining volume is occupied by recognizable fossil material, in various states of degradation, and by pore-filling spar cement. Spar cement is often common or abundant where fossil abundance is high. Where carbonate silt is abundant, spar is rare or absent. Noting that the carbonate mud particles are poorly-sorted, of variable shape, and frequently associated with terrigenous mud, Lindholm (1969a) concluded that they are of detrital origin and not the result of micrite neomorphism (Folk, 1962). Lindholm further concluded that the carbonate mud was produced by the mechanical and organic breakdown of invertebrate shell material. This conclusion is supported by the presende of recognizable organic microstructures in some of the silt-size grains and by the fact that they often form a continuum between unrecognizable minute grains and larger identifiable fossil grains. For these resons Folk's (1962) lithologies which contain the term "micrite" are not applicable to this formation. Calcisiltite is the term most appropriate for the carbonate mud of the Onondaga Limestone.

Lindholm (1967) recognized four limestone types in the Onondaga Formation. They are discriminatdd by abundances of biogenic allochems (fossil grains), calcisiltite, and spar cement. The lithologies are described below.

1) Fossiliferous Calcisiltite - Composed of 1-10% fossil material in a calcisiltite matrix. Terrigenous mud can comprise up to 20% of the rock volume and quartz silt less than 7%.
2) Sparse Biocalcisiltite - Composed of 10-50% fossil material in a calcisiltite matrix. Quartz silt, dolomite, biotite, and terrigenous mud are common, though not abundant.
3) Packed Biocalcisiltite - Composed of fossil material in excess of 50% with a calcisiltite matrix. Terrigenous materials are scarce or absent.
4) Biosparite - Composed of fossil material with sparry calcite cement. Calcisiltite and terrigenous mud are usualły absent.

The above lithologies are primarily divided at arbitrarily selected fossil abundance thresholds. This type of classification strategy is excellent for pigeonholing samples. However, it attempts to subdivide the continua of several rock components based on abundance subdivisions of one component. This obscures the rock's true characteristics, because the component grains or textures do not vary in a totally inclusive/exclusive manner. To avoid the nebulization of potentially significant rock component intergradations, Q-mode cluster analysis has been used in accord with the classification strategy of Park (1974).

Q-mode cluster analysis relates samples according to the joint consideration of the abundances of all their variables. In this case the lithologic variables used in the classification included calcisiltite, fossils, spar cement, argillaceous material, pyrite, quartz silt, quartz sand, and glauconite grains. The latter three failed to contribute to the clustering process and were deleted. Pyrite, being extremely common but always scarce, did not significantly effect the classification. It is, however, retained because its abundance is inversely related to spar abundance, and , therefore, environmentally significant. Thus, Onondaga lithologies were discriminated on the relative abundances of only the first four lithologic variables listed above.

The Q-mode cluster dendrogram of 87 lithologic samples collected in eastern New York segregates six lithologic types. Though the dendrogram is not included here, the variable percent

I	II	III	IV	V	VI	Lithologic Types
42-81	72-84	29-44	6-30	13-26	3-14	Calcisiltite Extremes
53	78	36	22	19	9	Calcisiltite Means
10-43	4-18	39-68	55-73	45-53	59-68	Fossil Extremes
35	14	54	61	50	62	Fossil Means
0-5	0-1	0-14	9-16	21-31	20-30	Spar Extremes
2	1	5	11	25	25	Spar Means
1-13	3-10	2-12	1-10	1-11	1-9	Mud Extremes
8	6	5	4	5	4	Mud Means
1-4	0-3	0-2	0-2	0-1	0-1	Pyrite Extremes
1	1	1	1	1	1	Pyrite Means

Table 2 - Compositions of the six lithologic types.
Numbers are expressed as persents.

abundance extremes and means for each of the lithologic types is provided in Table 2. Examination of this table reveals that the lithologic types are not segregated by abundances of a single variable, but by the relative abundances of calcisiltite, fossils, and spar. All of the lithologic types, except I and II, are discretely segregated by their component abundances. Though I and II haveoverlaps in the four prime variables, the mean abundances of these variables differ greatly and they do plot as discrete clusters in the Q-mode dendrogram. Thus is developed a quantitatively based classification of limestone types within the formation. The paleoenvironmental significances of the six lithologic types will be considered in ane other section.

FOSSIL ASSEMBLAGES

Fossil assemblages were discriminated by Q-mode cluster analysis performed on faunal census samples. Faunal variables used in assemblage identification are in the form of percent abundance data and include more than thirty taxa, most extending to the generic level. The fossil assemblages identified here are recurrent groups of samples having similar faunal structures. They correspond to the "quantitatively defined communities" of Kauffman and Scott (1974, p. 11) and, therefore, are not considered to be paleocommunities as defined by Kauffman (1974, p. 12.3). The term assemblage which "consists of organisms derived from more than one community" (Kauffman and Scott, 1974, p.18) is more appropriate in that the faunal units identified here have similar but not "identical" structure. No attempt is made here to discern faunal interactions.

Table 3 provides information on the percent abundances of organisms in each of the fossil assemblages. The abundances of organisms in a group of samples, designated assemblage X, which

Faunal Assemblages	Solitary Rugose	*Acinophyllum*	Massive Tabulates	Branching Tabulates	Auloporids	Trilobites	Gastropods	Brachiopods	Fenestrate Bryozoans	Ramose Bryozoans	Massive Bryozoans
A	18	2	15	4	1	16	1	34	1	8	1
B	2	1	1	1	2	6	2	12	7	64	2
C_1	8	1	1	1	18	9	1	29	11	20	1
C_2	5	-	-	-	22	14	1	48	1	8	1
C_3	2	1	1	1	7	15	1	37	11	23	1
D	32	1	1	-	1	6	5	50	1	2	1
E	31	11	26	2	1	1	1	25	1	1	-
X	3	-	-	1	-	9	-	84	1	1	1

Faunal Elements

Table 3 - Percent abundances of faunal elements in fossil assemblages

clustered at very low levels are also recorded. Data have been reduced to high level taxa or to growth forms within taxa. The faunal integrity of the fossil sssemblages is retained even at these levels. The numbers in Table 3 were calculated by dividing the total number of occurrences of a taxon by the total number of fossil specimens in that assemblage. Taxa which comprise less than one percent of the total fauna within the assemblage are scaled to one percent to facilitate presentation. Thus data from all samples within an assemblage are combined to present a typical or average characterization of the assemblage. In this way faunal abundances are based on large samples which are more representative of the whole assemblage than any small sample could be (de Caprariis, Lindemann, and Collins, 1976). This approach partially circumvents the problems of sampling patchy fossil distributions (de Caprariis and Lindemann, 1978).

PALEOENVIRONMENTS AND DEPOSITIONAL HISTORY

Context From Previous Investigations

Oliver (1954, 1956a) and Lindholm (1967, 1969a), in their respective studies of Onondaga stratigraphy and petrology, came to similar conclusions regarding paleoenvironmental conditions of deposition. Their interpretations are summarized below.

The Onondaga Limestone was deposited in an initially shallow, subsiding, epicontinental sea, within 30° of the equator. A westward transgression is indicated by the formation's base. In eastern New York the base is gradational with the subjacent Schoharie Formation. Between Sharon Springs and Richfield Springs the gradational contact is marked by phosphate nodules and glauconite, indicating a slight unconformity. Westward from Richfield Springs the Onondaga rests unconformibly on successively older formations. At many localities the contact is erosional and the lowermost Onondaga beds contain quartz sand reworked from the underlying formations. This transgression follows the pattern of the lower Devonian transgressions during which the Helderberg Group was deposited. Unfortunately in the case of the Onondaga ravinements (Anderson, 1971) have removed all of the supratidal and intertidal deposits created by the transgression.

During and immediately following the initial Middle Devonian transgression, the Edgecliff Member was deposited in shallow, wave-affected waters (Laporte, 1971). This is shown by the lithologic characteristics of the member and its coral reefs. Fluctuations in water turbidity and agitation were the major environmental factors controlling deposition throughout the eastern half of the Edgecliff Member (Lindemann, 1974). Continued subsidence carried the sea bottom beneath the effects of waves and set the stage for deposition of the succeeding members (Laporte, 1971).

Deposition of the Nedrow Member took place during an influx of clastic mud which was synchronous with a pulse of subsidence. The Nedrow was most typically deposited in a topographic depression which developed in central New York (Oliver, 1954; Lindholm, 1969a). This trough extended from beyond the northern erosional limit of the formation, southward into southern New York. The Nedrow contains several cycles of turbid water/clean water sedimentation. The turbid cycles have sharp bases and gradational tops. These cycles may be the result of pulses of subsidence followed by rapid deposition (E. J. Anderson, pers. comm., 1977).

The Moorehouse Member marks a return to relatively nonturbid conditions. Deposition took place in quiet water. The Seneca Member was deposited in quiet water during the westward progradation of the Marcellus Shale. The gradational and interbedded relationship between the Seneca Limestone and the Marcellus Shale indicates that turbidity levels waxed and waned for a time prior to the inundation of the sea by clastic mud. This argillaceous influx took place in eastern New York prior to deposition of the Seneca in central and western New York. Therefore, in the eastern area the uppermost member of the Onondaga Formation is the Moorehouse Member.

Lithologic Paleoenvirommental Interpretations

The Onondaga Limestone of eastern New York differs significantly form its type characteristics of central New York. Therefore, because regional depositional environments were originally interpreted from central New York sections, a reexamination is in order. This was partly accomplished by use of a Q-mode ordination analysis performed on the lithologic samples previously used in the identification of lithologic types. For references and a description of the ordination technique see Park (1968, 1974). Briefly, ordination arrays samples along orthogonal axes based upon their mutual similarities or dissimilarities. The axes represent environmental gradients which influenced sample characteristics. This type of analysis has been successfully applied to the interpretation of sedimentary environments (Ali, Lindemann, and Feldhausen, 1976) and in paleoecologic studies of fossil assemblages (Park, 1968; Lindemann, 1974). The ordination array itself is only an arrangement of samples in a space, it does not provide its own interpretation.

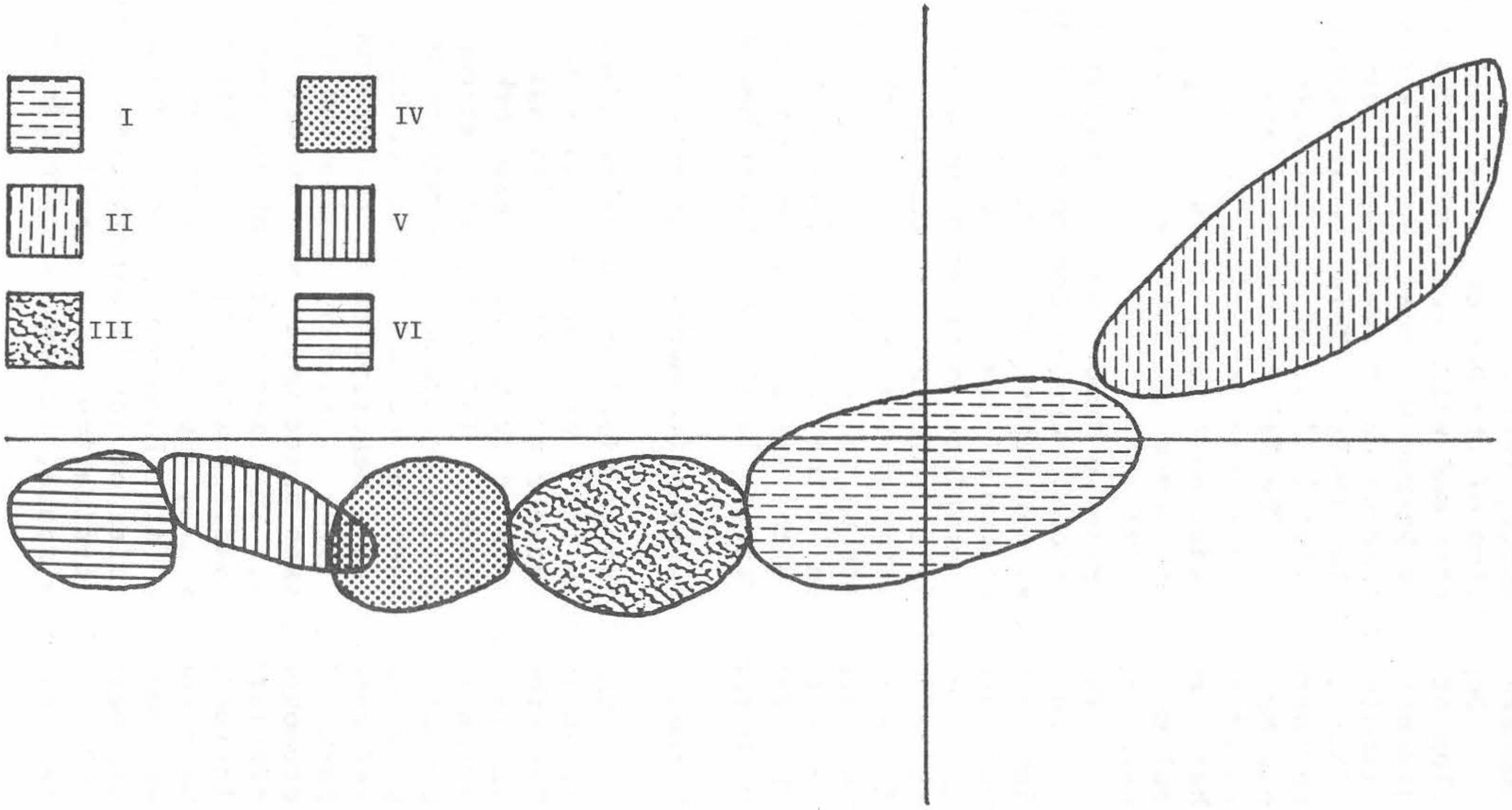

Figure 3. Q-mode ordination of lithologic data showing distribution of lithologic types.

A plot of Onondaga lithologic types on a Q-mode ordination model of lithologic samples (Fig. 3) shows their mutual arrangement with respect to the axes. The trends of mean variable values of the lithologic types on the ordination diagram (Fig. 3) reveal that the two axes correspond to gradient complexes. What is shown is the opposition of sparry fossiliferous sediments and spar-free calcisiltite rich deposits. Because spar requires an abundance of pore creating fossils, its abundance is dependent on fossil abundance. Therefore, the separate natures of the two axes are indistinguishable. It appears that these axes, which account for 74% of the dissimilarity between samples, represent an overall gradient of water agitation. Agitated water is indicated to the left while quiet-water sedimentation is indicated in the central and upper right of the diagram. This is evidenced by the opposed positions of abundant spar and abundant calcisiltite.

A third ordination axis was anticipated to reveal fluctuations in turbidity levels. It failed to show any trend whatsoever. Therefore, it is concluded that mud influxes in the area had little effect on deposition, and must have been eigther minimal or constant.

Examination of formational lithologic successions at Leeds and in the Helderbergs (Figs. 4,5) reveal paleoenvironmental dissimilitaries. In both areas, deposition began in slightly turbid, quiet water. At Leeds, turbidity and agitation generally remained low. Fluctuations in environmental conditions were small and lacked a real trend in any direction. The only prolonged divergence from the quiet water condition is shown by lithologic type V. This indicates a long period of water agitation and, presumable, shallower water. Unfortunately, the top of the formation is not exposed at Leeds and the Marcellus Shale contact is unavailable for study.

In the Helderbergs, the water remained rather clean and agitated throughout much of Onondaga deposition. The dark chert section of the Moorehouse Member reveals increased turbidity levels, and may be correlative with the shaley Nedrow Member of central New York. Following a period of relatively turbid, quiet-water conditions, a time of cleaner more agitated water prevailed. Agitation fluctuations eventually gave way to persistent quiet-water conditions until the termination of limestone deposition in the area. Despite the examination of beds at and very near the formations top, evidence of gradually increasing turbidity was not seen.

The quiet-water, relatively anoxic conditions of lithologic type II were not evident in the eastern sections. Lithologic type II is present further west in the Cobleskill and Cherry Valley areas.

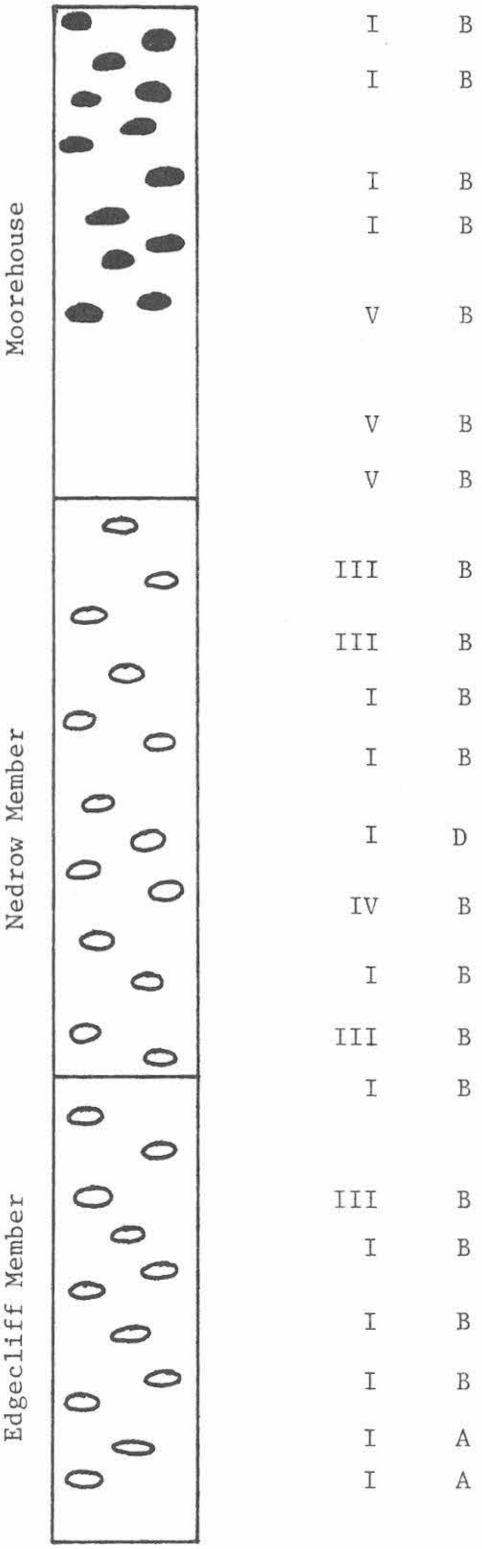

Figure 4. The Onondaga section at Leeds showing distribution of faunal assemblages and lithologic types. Scale 6mm = 1m. The ovals represent chert.

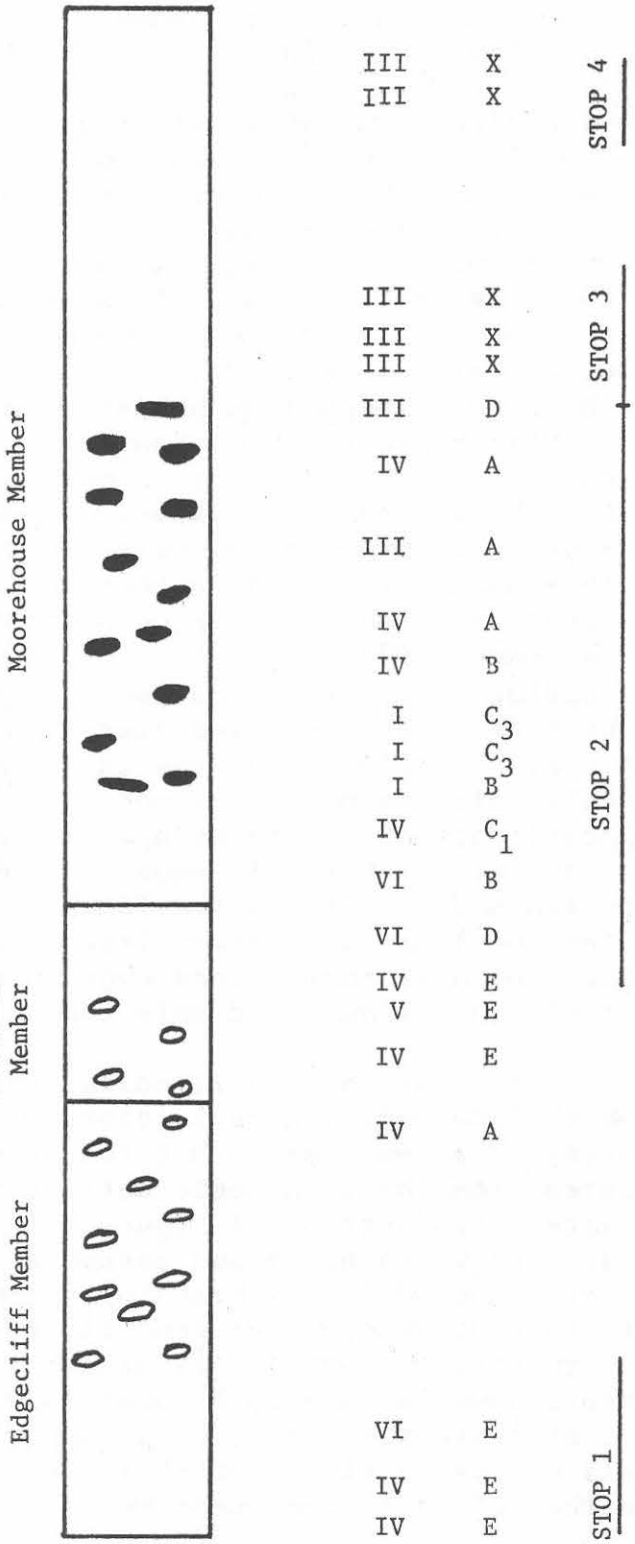

Figure 5. Idealized Onondaga section in the Helderberg area showing trip stops, distribution of fossil assemblages and lithologic types. Scale 6mm = 1m. The ovals represent chert.

Biologic Paleoenvironmental Interpretations

A Q-mode ordination performed on faunal census data failed to account for sufficiently reliable dissimilarity between samples. This is often the case with biologic data, where many environmentally significant variables are complexed resulting in a large amount of variability between samples. The biologic ordination model did show a general trend of coral-rich opposed to brachiopod dominated faunas.

Several of the faunal assemblages can be interpreted by classic paleoecologic generalizations. An abundance of massive tabulates such as found in assemblages A and E indicate life in clean, shallow, agitated waters (Wells, 1967; Philcox, 1970; Crowley, 1973). Because <u>Acinophyllum</u> prefered somewhat calm waters (Mecarini, 1964; Bamford, 1966; Poore, 1969) assemblage E probably developed in slightly deeper or more protected areas than assemblage A. The abundance of ramose bryozoans in assemblage B indicates an environment of relatively calm water near wave-base (Anderson, 1971). The auloporids of assemblages C_1 and C_2 are indicative of quiet water conditions (Lowenstam, 1957; Vopni and Lerbekmo, 1972).

From the preceding, it appears that water agitation and corresponding substrate characteristics exerted a great deal of control on the fauna. Unfortunately, the environmental tolerances of most Paleozoic organisms are not sufficiently understood to be diagnostic of most environmental parameters. However, by plotting the occurrences of faunal assemblages on the lithologic ordination model (Fig, 6) the fauna can be more fully interpreted and the model tested. Assemblages X and D are not included in Figure 6 because their areas overlap several other assemblages and their inclusion would only result in visual confusion.

Bear in mind that Figure 6 is a lithologically based ordination model on which independent data is plotted. It is evident, from the array of assemblages, that the water agitation gradient interpreted from the lithologic data is also reflected in the biologic data. Examination of Figure 6 in conjunction with Table 3 clearly shows coraliferous assemblages of clean, well-agitated waters opposed to the brachiopod dominated assemblages of more turbid, quiet-water conditions. Thus the paleoecologic interpretations previously arrived at and the lithologic paleoenvironmentas are both substantiated. Through the formal use of both types of data, biolithologic paleoenvironmental models can be developed which are more sensitive to change than either of their component models.

PALEOENVIRONMENTAL RECONSTRUCTION

Figures 4 and 5 show successional faunal and lithologic changes in the Onondaga Formation at Leeds and in the Helderbergs. They show less than perfect correspondence between the faunal assemblages and the lithologic types. This lack of correspondence has several possible sources. 1) A thin-section may not fully represent the bed from which it is taken, even if that bed is fairly homogeneous. 2) A bed may contain several different lithologies resulting from synchronous deposition in microenvironments. 3) Organisms respond to different environmental stimuli than do sediments. A small change in water agitation could significantly alter the character of a sediment and be totally unrepresented in the fauna if that fauna was not extremely sensetive to water agitation. The opposite also holds true. A slight change in water chemistry or temperature could affect the fauna and leave no trace in the sediment. This may explain the demise of the Edgecliff reefs in rocks which haven't revealed a reason for their termination. Despite their imperfedt correspondences, the lithologic and faunal successions within the formation do not present any paleoenvironmental contradictions.

The Leeds section shows little environmental change throughout the formation's development. Deposition began with a coral dominated, brachiopod rich fauna, which lived in relatively calm, slightly turbid water. Following this, the ramose bryozoan domianted assemblage B colonized the area, and remained throughout the formation's duration. The lithology does not record an environmental change accompanying the change to assemblage B. The ordination models and the persistence of assemblage B indicate that the ramose bryozoans were tolerant of fluctuations in turbidity and water agitation. The fauna flourished and caused the deposition of more limestone in less time than in the western part of the formation. Therefore, despite its calm character, water circualtion must have been sufficient of supply the nutritional requirements for such prolific growth.

The only major environmental change in the Leeds section is shown by three successive occurrences of lithologic type V. This indicates deposition in clean, agitated water and may represent shallower than normal conditions. Even this change is not reflected by a faunal change. The upper Leeds samples mark a return to calm water conditions. Despite lack of exposure of the uppermost Onondaga in this area, it is interesting that those upper beds which are present show no evidence of increasing turbidity in preparation for deposition of the Marcellus Shale.

Unlike Leeds, the Helderberg section shows significant environmental changes during Onondaga deposition, The lowermost beds contain a coraliferous assemblage which lived in clean, shallow, agitated waters. These conditions are indicated by spar-rich, calcisiltite-poor lithologies and by the prolific fauna of massive tabulates and rugose corals. This environment endured through the deposition of those beds assigned to the Nedrow Member and represents a significant deviation from type area conditions. Moorehouse deposition began in agitated water, but under conditions which favored a brachiopod-ramose bryozoan assemblage rather than a coraliferous one. The black chert section of the Moorehouse is coincident with a mud maximum in this area and fossil assemblages rich in brachiopods, bryozoans, and detritus feeding trilobites. This fauna indicates deposition in quiet, slightly turbid waters. If there is any "shaley Nedrow" of Oliver (1954) in the Helderberg area, the black-chert section is most likely it. Near the top of the black-chert section, and above, turbidity decreased and water agitation increased somewhat...Brachiopods remained common and corals returned to the area. The bryozoans, which appear to have been selectively favored by turbidity, decreased in abundance. Following a period of mildly agitated conditions, the waters near the sea bottom once again calmed. The water did not become turbid. Relatively calm, nonturbid conditions favoring an overwhelmingly brachiopod dominated fauna continued until termination of the limestone deposition.

Paleoenvironmental Significance of the Missing Mud

The eastern New York sections of the Onondaga Formation do not reflect the prominent argillaceous influxes which caused Nedrow deposition in central New York. Within the Nedrow Member the abundance of terrigenous mud decreases east and west of the type area. If the mud originated as an early pulse from the Acadian Orogeny, it would have had to be transported westward across the eastern areas where it should have left its mark. Environmental conditions were correct for mud deposition, but very little was deposited. It is unreasonable to expect the mud to bypass eastern New York where calcisiltite was deposited in quantity. Therefore, the mud must have originated to the north and was transported southward into central New York through the trough postulated by Oliver (1954) and Lindholm (1967). Paleocurrent direction measurments taken in central New York support this conclusion.

Another significant aspect of mud deposition in the eastern Onondaga is seen in the contact of the limestone with the overlying shale formation. In central New York the contact is gradational over a sequence of beds measuring a meter or more.

Eastward the gradational sequence thins until it is so abrupt in eastern New York that it was once believed to be an erosional surface (Chadwick, 1944). The uppermost Onondaga beds in the Helderberg and Cobleskill areas show no significant argillaceous increase except in the very top limestone bed. Also absent from the east are the shale/limestone cycles of the type area. It is concluded that the mud influx which terminated Onondaga deposition inundated the eastern area very rapidly and then slowly prograded across the remainder of the state. This rapid influx could have been initiated by a subsidence pulse of the P.A.C. variety (Anderson, Goodwin, and Cameron, 1978), by infilling and overrunning an eastern basin (Oliver, 1954), or by a rapid uplift of the Acadian Orogeny. In the final analysis the latter mechanism caused the termination of Onondaga deposition as the limestone's fauna was choked and buried beneath the thickening muds of the Marcellus Shale.

ACKNOWLEDGMENTS

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ROAD LOG

Miles Total	Miles from last point	Route Description
0	0	Leave RPI Field House by way of Peoples Ave.
0.7	0.7	Left on 8th Street.
1.2	0.5	Right on Rt. 7, cross bridge over Hudson River.
2.1	0.9	Right on Rt. 32.
2.3	0.2	Through intersection and right onto 787.
7.3	4.8	Exit right onto Rt. 90.
11.3	4.0	Take Exit 4 onto NY 85, south.
23.6	12.3	Right onto Rt. 157, toward Thacher Park.
23.8	0.2	Take the first left onto Indian Ledge Rd.
24.5	0.7	STOP 1. Park on right side of road just above lowermost limestone outcrop. Figure 5.
25.3	0.8	Return to 157 and hang a right.
25.5	0.2	Right on 85 W.
27.6	2.1	Left on Rt. 443 through Clarksville.
30.6	3.0	Right onto Flat Rock Road.
31.7	1.1	Right onto Rt. 32.
32.5	0.8	STOP 2. Park in pulloff on left above limestone outcrops. Fig. 5.
37.4	4.9	Return to intersection of 443 and 85, take a left on the latter.
37.6	0.2	STOP 3. Park in abandoned quarry on right side of road. Fig. 5.
38.5	0.9	Return to 157 and turn left, continue through Thacher Park.
44.2	5.7	Left on Beaver Dam Road.
45.7	1.5	STOP 4. Park on right side of road and walk down old lane in Thacher Park until you come to an abandoned quarry. Figure 5.
47.0	1.3	Continue west on Beaver Dam Road and turn right onto 157.
53.8	6.8	Follow previous directions to 32, turn right.
59.1	5.3	Turn left onto Rt. 143 toward Revena.
68.1	9.0	In Revena turn right onto Rt. 9W.
70.2	2.1	Turn right onto Green County Road 51.
71.3	1.1	Turn left onto Roberts Hill Road
71.4	0.1	STOP 5. Figure 1.
71.9	0.5	Right onto Green County Road 54.
72.6	0.7	Left on Highmont Road.

Miles Total	Miles from last point	Route Description
72.9	0.3	Left on Reservoir Road.
73.1	0.2	Right on Limekiln Road.
73.6	0.5	STOP 6. Park in wide area on left side of road. Figure 2.
75.3	1.7	Continue south on Limekiln Road and turn left on Titus Mill Road.
76.9	1.6	Turn left on Rt. 81.
80.0	3.1	Turn right on Rt. 9W.
89.5	9.5	Take a right onto entrance ramp to and a left onto Rt. 32, just north of Catskill.
90.9	1.4	Take the first exit off of 23 onto Green County Road 23B towards Leeds.
92.8	1.6	In Leeds turn left on Gilfeather Park Road just past Gilfeather's Silgo Hotel.
92.9	0.1	STOP 7. Park at the end of Gilfeather Park Road. Walk down into creek to lowermost limestone outcrop. Figure 4.

Return to RPI.

TRIP B-11

Field guide to the Chatham and Greylock slices of the Taconic allochthon in western Massachusetts and their relationship to the Hoosac-Rowe sequence

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Introduction

Since 1977, the U.S. Geological Survey has been engaged in a program to compile data for a new bedrock geologic map of Massachusetts. Don Potter and I have been mapping in northwestern Massachusetts in an attempt to fill in unmapped or poorly understood areas. Detailed mapping of the Pittsfield West, Hancock, Berlin, Williamstown, and parts of the North Adams and Cheshire quadrangles have been completed.

This trip will deal principally with new data regarding the age, distribution, and structural characteristics of major boundaries at the soles of the Taconic allochthons (Fig. 1) exposed along the New York State line, and on Mount Greylock. An attempt will be made to relate these features to rocks exposed in the eugeoclinal Hoosac-Rowe belt east of the Berkshire massif. Time constraints for movement of these materials across the autochthon and the modes of emplacement will be discussed.

Stratigraphy

The stratigraphic columns can be divided into three sequences: 1) allochthonous group of rocks exposed in thrust slices resting on 2) the lower autochthonous miogeoclinal sequence, and 3) a tectonically separate eugeoclinal sequence east of the Berkshire massif.

A correlation chart is given in Figure 2.

The base of the autochthonous section, the dark albitic Hoosac Formation, interfingers with basal beds of the Dalton Formation on Hoosac Mountain (Herz, 1961). This relationship has been confirmed in remapping of the Hoosac belt. The Dalton consists of feldspathic quartzite schist and conglomerate. It rests unconformably on basement gneiss of the Berkshire massif or of the Green Mountains. Quartzites assigned to the Dalton contain Ollenelus fragments near North Adams (Walcott, 1888). Chesire Quartzite, vitreous quartzite, and the Stockbridge Formation form a continuous sequence of shallow water quartzite and carbonate rocks deposited as a miogeoclinal wedge that is the time equivalent of deeper water slope and rise sediments in the Taconic allochthons.

A major sedimentary break occurs in the Middle Ordovician, where an unconformity is recognized beneath the Walloomsac Formation. Taconic allochthons commonly rest on a cushion of Walloomsac.

The Taconic allochthonous rocks have been assigned to four slices, after Zen (1967), for discussion here: the Giddings Brook, Chatham, Rensselaer Plateau, Everett, and Greylock slices. These slices overlap eastward. In addition, several slices of distinctly Taconic-like rock are exposed east of the main Taconic allochthons. The diagrammatic

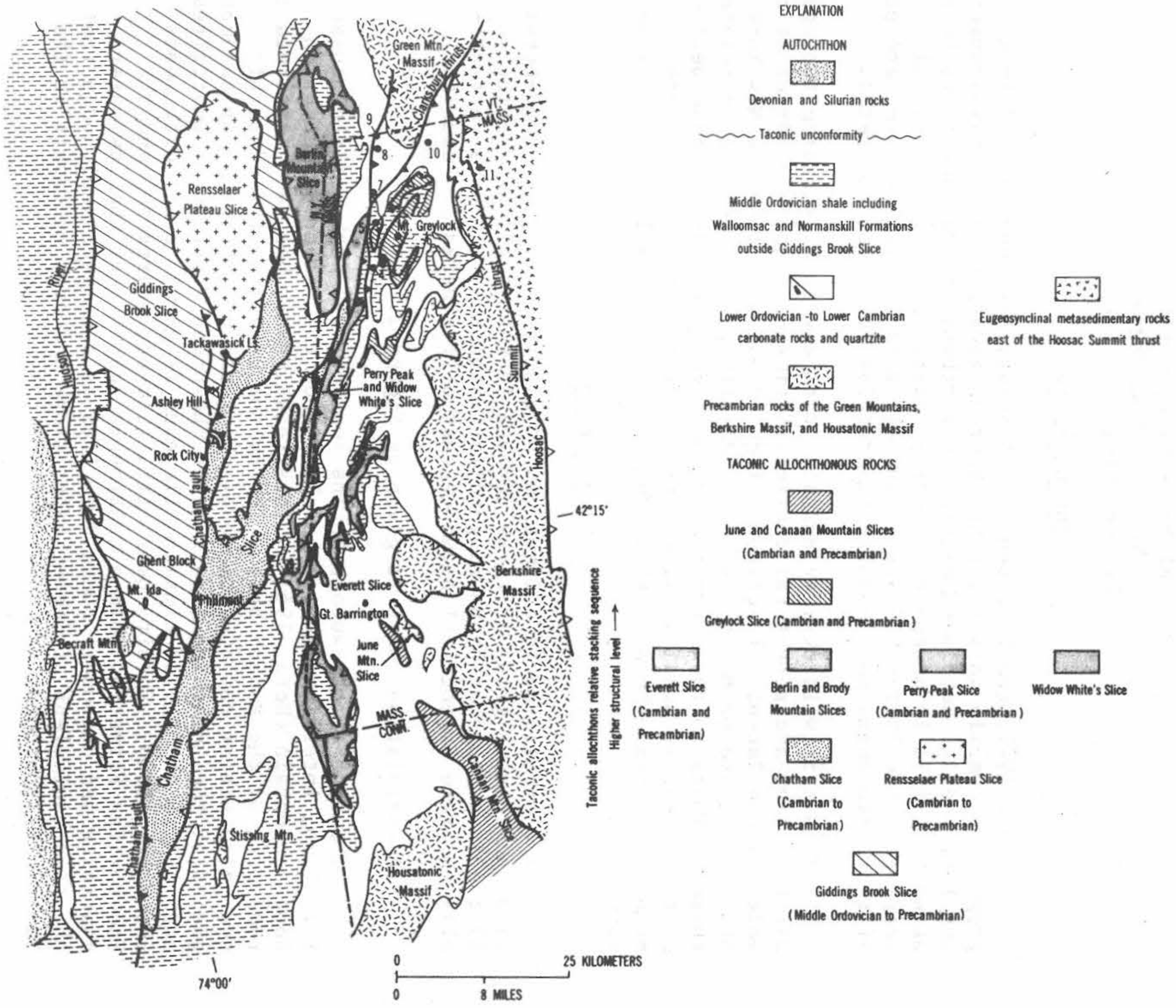


Figure 1. Regional geologic map showing generalized slices of the Taconic allochthon modified from Zen (1967), based on data in Ratcliffe (1947a), Ratcliffe and Bahrami (1975), and Potter (1972). The Chatham fault and other Acadian faults are shown with solid triangles. For relationships among Rensselaer Plateau and other slices in New York and adjacent Vermont, see Potter, this guide book

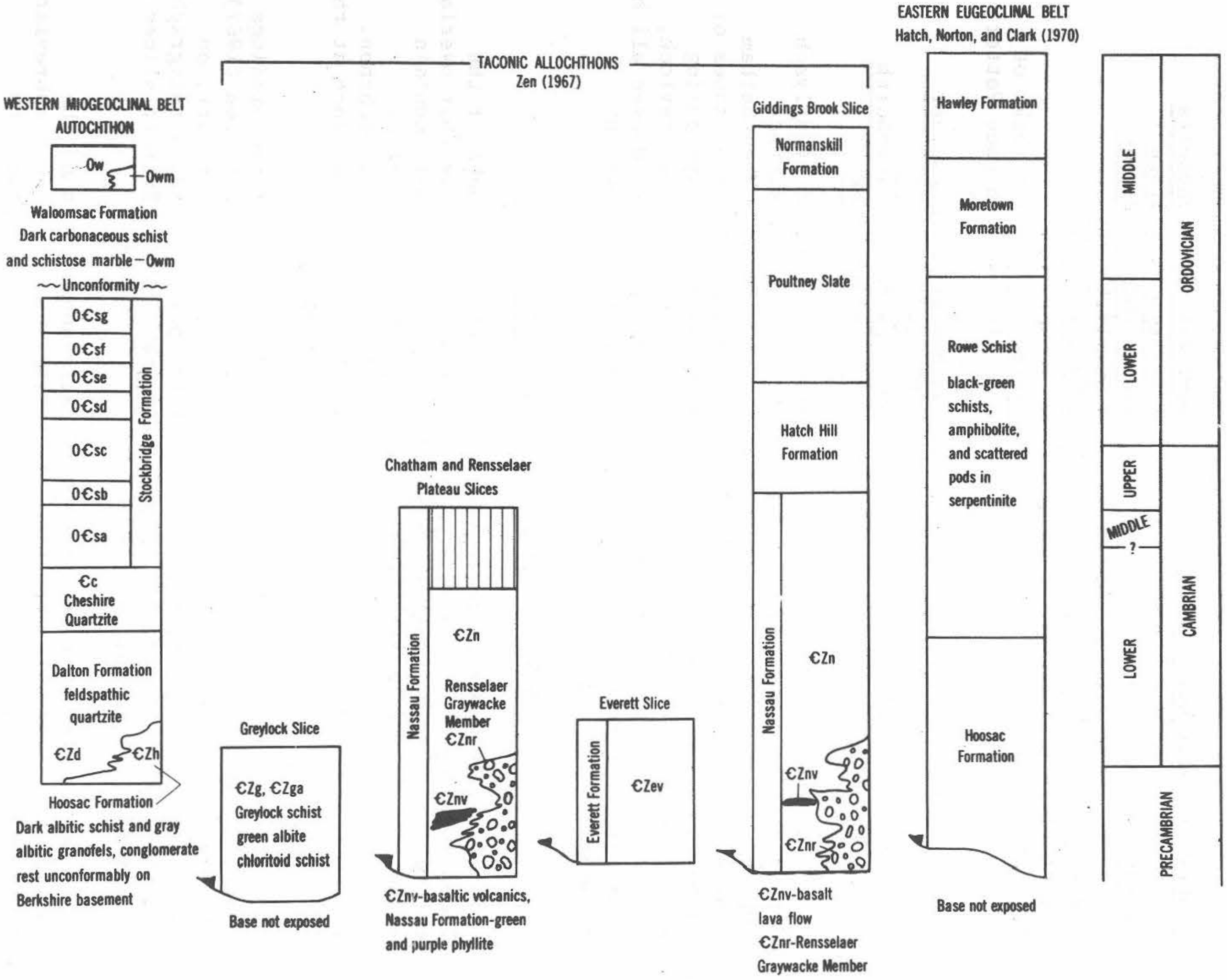


Figure 2. Correlation of major rock units in the autochthon, Taconic allochthons, and eastern eugeoclinal belt

listing below shows the general stacking sequence, and possible correlation between slices exposed in the southwest and northwest of Figure 1.

Southwest Massachusetts	Northwest Massachusetts Eastern N.Y. State
Canaan Mountain Slices (Harwood, 1975)	Hoosac east of Hoosac Summit thrust
Rocks on June Mountain (Ratcliffe and others, 1975)	Greylock slice
Everett slice	Everett slice(?) = rocks on Berlin Mountain (see Potter, this guidebook)
Chatham slice	Chatham slice=Rensselaer Plateau slice(?)
Giddings Brook slice	Giddings Brook slice=North Petersburg slice

The lowest slice contains dated Middle Ordovician wildflysch deposits along the sole, suggesting soft rock or near surface emplacement of the Giddings Brook slice (Zen, 1967). The Chatham Rensselaer Plateau and Everett slices are marked locally by zones of carbonate blocks ripped from the autochthonous Stockbridge during emplacement as hard rock slices. The highest slices, the Greylock, Canaan Mountain and June Mountain, and the allochthonous Hoosac all have synmetamorphic fold-thrust emplacement fabrics that cross cut metamorphic foliation in the slices.

A brief survey of Taconic allochthons

Zen (1967) has proposed that the allochthonous rocks of the Taconic belong to six or seven discrete structural slices that overlap eastward so that the highest structural level, the Dorset Mountain slice, in western Massachusetts is known as the Everett slice (Ratcliffe, 1969) and crops out at the east edge of the allochthon. Rocks of the Everett slice constitute the high Taconic sequence at this latitude and are presumed to have been emplaced last.

The low Taconics here are represented by rocks of the Giddings Brook, Chatham, and Rensselaer Plateau slices according to Zen (1967). The distinction between high and low Taconic is based, in part, on topographic expression, relative structural position, and stratigraphic considerations. For this discussion the Greylock and Everett slices are considered high Taconic slices.

Zen further proposed that the stratigraphic range of the individual slices is greatest in the lowest slices and most abbreviated in higher slices, which contain rocks largely of inferred late Precambrian (Proterozoic Z) age (Zen, 1967). The lowmost and westernmost slices, the Giddings Brook and Sunset Lake (in Vermont), were emplaced by gravity gliding in the Middle Ordovician, contemporaneously with wildflysch-like (Forbes Hill Conglomerate of Zen, 1961) material that contains fossiliferous and nonfossiliferous fragments of the allochthon itself. Graptolites of Zone 13 (Berry, 1962, p. 715) in the matrix of the wildflysch-like conglomerate that underlies the Giddings Brook (North Petersburg slice of Potter, 1972) and Sunset Lake slices date the time of submarine emplacement (Zen, 1967; Bird, 1969). Graptolites of Zone 12 (Berry, 1962) have been collected from the Walloomsac Formation which underlies wildflysch-like conglomerate at the eastern (trailing) edge of the Giddings Brook slice (North Petersburg slice) at Whipstock Hill (Potter, 1972). This suggests that the Giddings Brook slice was emplaced during the timespan represented by Zones 12 and 13, although the lack of fossils in the matrix at Whipstock Hill precludes proof of this point.

The Chatham slice overrides the Giddings Brook slice along the Chatham fault of Craddock (1957) (Fig. 1). The fault zone contains slivers of carbonate and other rocks and appears to be an Acadian fault (Ratcliffe and Bahrami, 1976). To the east, the Chatham slice is overlain by the Everett slice at the sole of which are distinctive tectonic breccias that consist of complex mixtures of fragments of all the shelf sequence carbonate rocks, and Walloomsac and Everett, lithologies concentrated along the soles of imbricate slices (Zen and Ratcliffe, 1966; Ratcliffe, 1969, 1974a).

Chatham slice and the Chatham fault

The rocks of the Chatham slice were studied previously by Craddock (1957) and Weaver (1957), who did not map detailed stratigraphy within the slice. Thus, Zen in his 1967 compilation had only limited data available bearing on Chatham slice stratigraphy. Rocks assigned to the Chatham slice extend northward along the New York-Massachusetts State line (Fig. 1).

Rocks of the Chatham slice resemble closely gray-green and purple slate (Mettawee), Rensselaer Graywacke, and other rocks of the Nassau Formation (Bird, 1962a) in the Giddings Brook and Rensselaer Plateau slices. The Chatham slice sedimentary rocks (Nassau) probably also are pre-Olenellus in age. Distinctive but sporatically developed diabasic basalts, pillow lavas, and pyroclastic volcanic rocks are spatially associated with the base of the Rensselaer facies in all three slices (Balk, 1953; Potter, 1972; Ratcliffe, 1974a).

Massive quartzites, similar to those of the Zion Hill Member of the Bull Formation of Zen (1961) and the Curtis Mountain Quartzite of Fisher (1962), which crop out in the Chatham slice are not clearly one horizon but underlie coarse Rensselaer-type Graywacke in many areas. One of these quartzites that has a polymict basal conglomerate (Ratcliffe and others, 1975, stop 5) contains angular fragments of basaltic or andesitic scoria. This suggests that the relatively thin subgraywackes and quartzites exposed in the western part of the Chatham slice may be tongues of Rensselaer-like material that extended westward into the sedimentary basin.

Importantly, the Rensselaer-like graywacke of the Chatham slice in the Austerlitz outlier and in the State Line quadrangle overlies a considerable thickness (300-1,000 m) of purple and green slate, siltstone, and laminated green slate typical of the Nassau elsewhere. However, Rensselaer Graywacke of the Giddings Brook and Rensselaer Plateau slices appears at or near the base of the preserved stratigraphic succession. The stratigraphic position of the Rensselaer within the original (as opposed to the allochthonous) sequence is really moot, because the original sequence is nowhere preserved intact, and we do not know at present if the Chatham slice relationships are the rule rather than the exception.

Internal structure of the Chatham slice is complex and folds of pre-emplacement age have been recognized in many areas, however, the regional Taconic slaty cleavage crosscuts the thrust contacts. Locally, a wildflysch-like zone is preserved at the sole (Ratcliffe and others, 1975, p. 82) and Stop 3 of this trip. In addition, evidence for interleaved fault slivers of autochthnous carbonate and allochthonous rocks as well as localized recumbent folding in the autochthon are recognized (see Stop 1).

Everett slice

Rocks of the Everett Formation that form the high Taconic Everett slice are greenish-gray, green, and locally purplish slate containing relatively minor amounts of interbedded Rensselaer-like graywacke. In general, the Everett Formation resembles rock of the lower part of the Nassau Formation when the effect of increased metamorphic grade is considered. Zen and Hartshorn (1966), Zen and Ratcliffe (1966), and Ratcliffe (1969, 1974a, 1974b) consider the Everett rocks to be as old or older than rocks of the western slices. No fossils have ever been found within rocks of the Everett slice, and are not likely to be, so that the age problem may never be completely resolved. The Everett slice is about 12 km wide and probably originated from a depositional site at least this wide. Internal structure within the Everett slice, however, is poorly known, owing to the lack of coherent stratigraphy, the possibility of stacked slices of material that all rooted from the same zone could reduce this 12 km estimate for the original sedimentary width.

The contact relationships of the Everett and Chatham slices are complicated because the leading edge of the Everett slice is a zone of intense imbrication involving both allochthonous and locally detached autochthonous rocks. A belt of parautochthonous Walloomsac commonly separates the two slices (Fig. 1). Locally slivers several kilometers long of purple and green slates typical of Chatham slice rocks are found incorporated in the parautochthonous belt of Walloomsac. In addition, at least two imbricate slices of Everett rocks are found above the Walloomsac sliver and above the slivers of Chatham slice rocks (Ratcliffe, 1974a).

The contact of parautochthonous Walloomsac on the Chatham slice and between the Everett and all other rocks is marked locally by an intensely developed tectonic breccia composed of inclusions of Stockbridge Formation. These breccias mark tectonic movement zones that differ from conventional fault zones in one important aspect. The carbonate clasts in the highly imbricated slate matrix are exotic blocks, not derived from the present hanging wall or foot wall, but from the autochthonous Stockbridge belt, and thus are considered tectonic inclusions transported within the movement zone from some site to the east. The tectonic breccia is evidence for a thrust beneath the Everett slice, which is independent of the regional stratigraphic arguments (Zen and Ratcliffe, 1966). These breccias have been mapped throughout southwestern Massachusetts (Zen and Ratcliffe, 1966; Ratcliffe, 1974a, 1974b) and are found in east and west dipping contacts as well as along the noses of plunging folds of the thrust contacts. The emplacement of the breccias predated the first regional metamorphism and the penetrative foliation that crosscut the contact of the thrust slices with the autochthon. Emplacement of the Everett slice resulted in brittle deformation (plucking) of the carbonate rocks, indicating that the carbonate rocks were lithified at the time of thrusting. Similar brittle deformation of the pelitic rocks is not recognized, although an abnormally strong phyllitic foliation has been noted by Zen (1969) immediately adjacent to the carbonate slivers. Clearly, emplacement of the Everett slice involved hard rather than unconsolidated sediments. The age of emplacement of the Everett slice is unknown, but on the basis of geometric relationships, its final movements postdated emplacement of the Chatham slice in the Middle Ordovician and predated formation of the regional slaty cleavage that probably is Late Ordovician in age.

Structural Geology of the Greylock slice

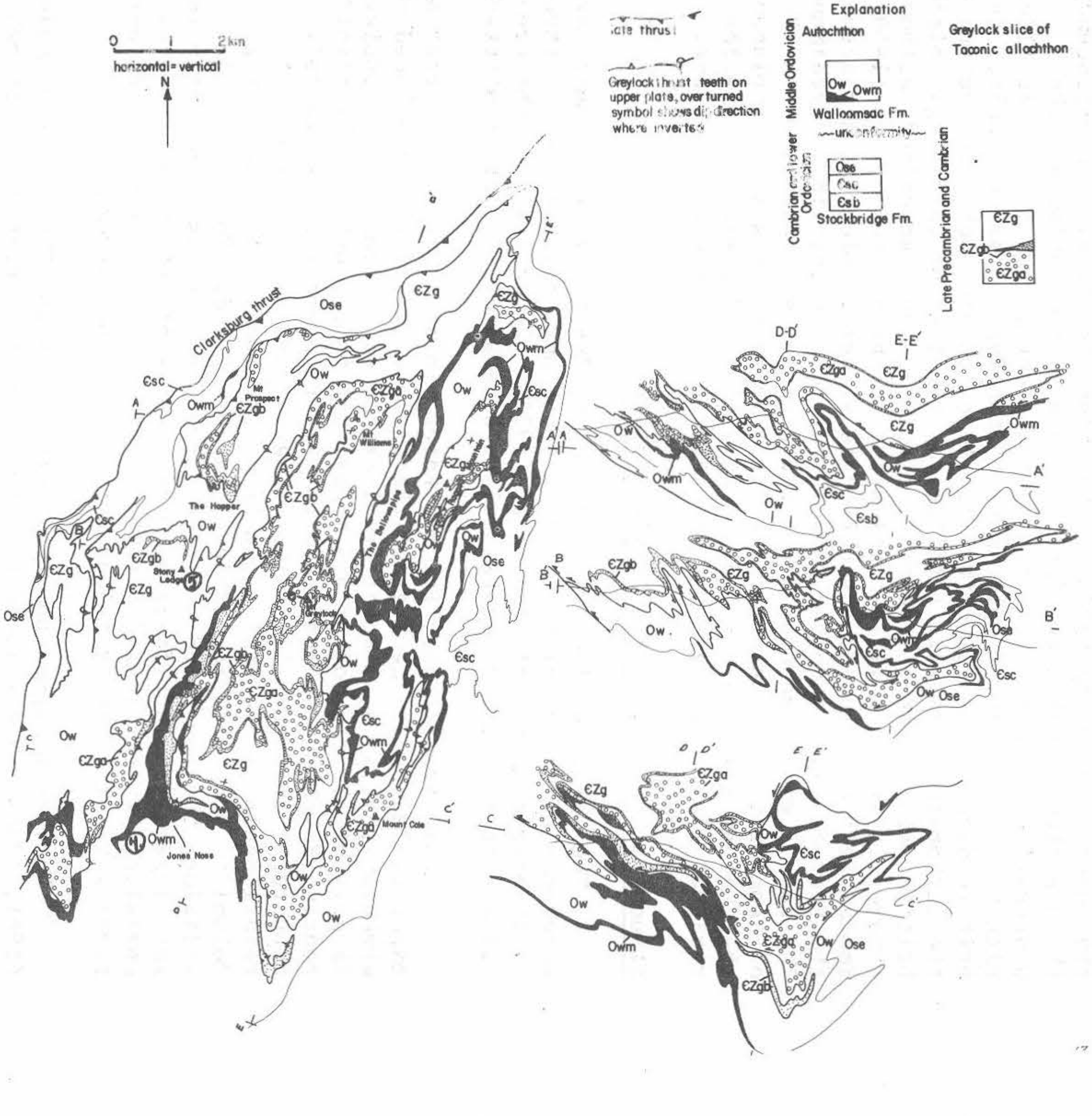
The Greylock slice was proposed by Zen (1967) to account for the occurence of Taconic-like rocks on the Mount Greylock above a thrust fault mapped by Prindle and Knopf (1932). Zen correlated the Greylock slice with the Dorset Mountain slice because of similar stratigraphy.

Louis Prindle and Eleanora Knopf, in an extremely penetrating paper (1932) on the geology of the Taconic quadrangle, concluded that greenish phyllites on Mount Greylock formed a thrust sheet consisting largely of albitic Hoosac and minor amounts of lustrous chloritoid-bearing Rowe Schist (rocks of the eastern eugeoclinal sequence). Structural arguments for a thrust were based on the discordant relationship of the schists on Mount Greylock to the underlying dolomitic and calcitic marble of the Stockbridge Formation. In addition, they proposed that the thrust contact was recumbently folded into large recumbent folds with amplitudes of approximately 6 km. They envisioned a complicated movement history in which the already emplaced rocks were recumbently folded during continued movement.

Norm Herz mapped both the North Adams and Chesire quadrangles (1961, 1958) and concluded that the Greylock Schist was conformable with the underlying Walloomsac Formation of Middle Ordovician age.

Results of remapping Mount Greylock in the Williamstown, North Adams, and Cheshire quadrangles are shown in Figure 3 and Figure 4. The contact of the Greylock Schist with the autochthon is shown as a highly

GEOLOGIC MAP AND CROSS SECTIONS OF THE MOUNT GREYLOCK ALLOCHTHON



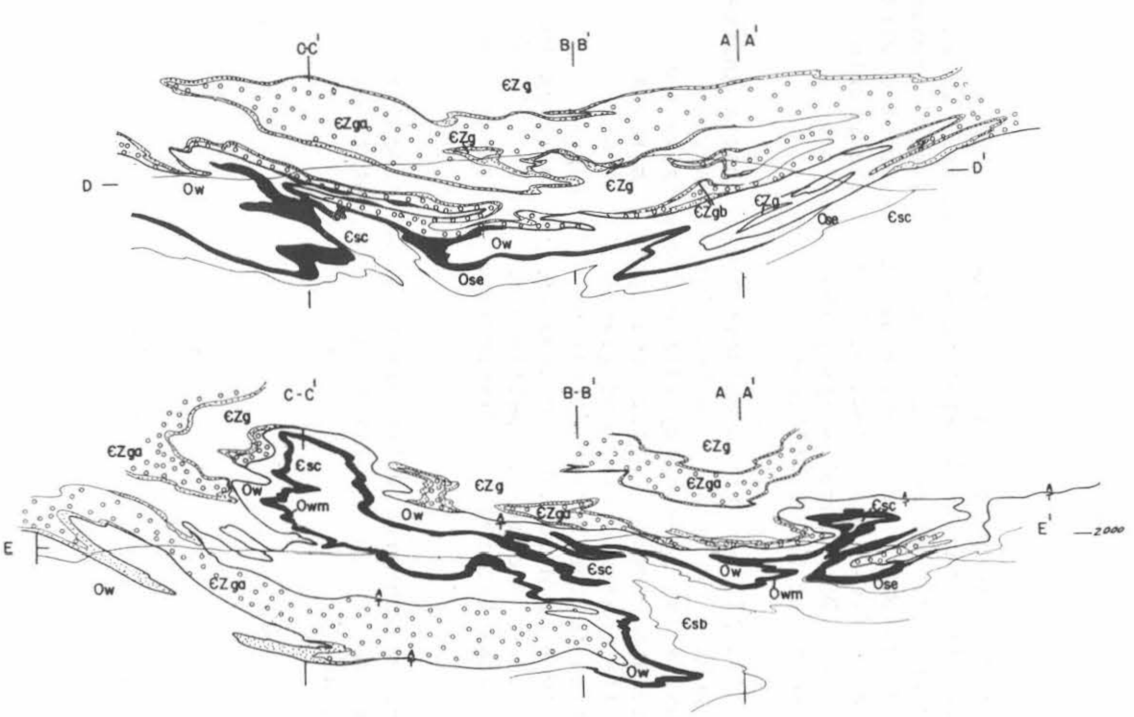
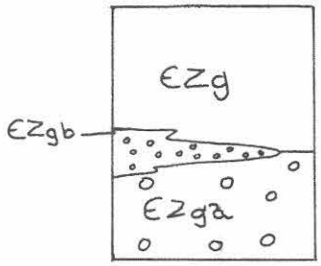


Figure 3. Geologic map and cross sections of the Greylock allochthon. Designs are intended to correlate with designs used on Fig. 5.

Figure 4. Stratigraphy of the Greylock slice. Compare with descriptions of Hoosac Formation on Fig. 5.

Greylock Schist



ЄZg Predominantly light-green to pale yellowish-green, lustrous chloritoid quartz phyllite with minor beds spotted with white albite. Local well-laminated gray and gray-green phyllite contain discontinuous beds 1 to 2 cm of quartzose dolomite or of white quartzite spotted with brown weathering pits of ankerite. Minor beds of blue quartz pebble conglomerate up to 1 m thick. Dark purplish-gray phyllites are interlayered in roadcuts south of Mount Williams.

ЄZgb Black, dark-gray chloritoid or stilpnomelane-albite quartz knotted schist and quartz pebble schist or metagraywacke. Lenses of gray pinstriped feldspathic quartzite, green-gray vitreous quartzite and quartz pebble conglomerate are common. Minor beds up to 5 m thick of white-spotted biotite albite quartz schist and granulite resemble closely the more albite beds in the Hoosac Formation. On Ragged Mountain, salmon pink weathering dolostone in beds up to 1 m thick is interbedded with albitic schist and quartz pebble conglomerate. Unit grades into more albitic rocks lacking the distinctive quartz-knotted appearance.

ЄZga Dark-gray to light-greenish-gray white-albite studded schist chlorite granulite, either massive or poorly bedded. Magnetite or ilmenite locally is abundant.

folded thrust fault. Internal structures within the allochthon are discordant to the fault. Various units of the autochthon terminate against the contact as Prindle and Knopf described.

The general structure of Mount Greylock is a doubly plunging synformal mass produced by crossfolding of older structures by two episodes of late northeast trending folds with northwest overturned to upright axial surfaces. The late folds are given expression by a strong crenulation cleavage or spaced slip cleavage in the axial planes.

Older foliated structures are complexly folded and appear to consist of at least two recumbent to strongly westward to southwesterly overturned structures. One of these nearly recumbent fold phases folds the thrust contact in two large scale recumbent and reclined folds as shown in the cross sections A-A′ through E-E′. Fold styles are isooclinal with fold axes commonly inclined at high rake angles to the northeast, east, southwest, and west, depending upon the dip direction of the axial surfaces. These folds postdate metamorphic foliate structures both in the autochthon and the allochthon. Near thrust contacts, minor recumbent folding of foliation is especially intense. This indicates that thrusting postdated some metamorphism in both autochthon and allochthon alike.

Folds older than the allochthon's emplacement are found within the allochthon. Detailed tracing of the three part stratigrahy within the Greylock allochthon reveals a major recumbent fold repetition, with the plane of symmetry passing through the outcrop belt of the chloritoid-rich phyllite unit on Mount Greylock. This recumbent structure is judged to be a west-facing syncline. This assumption is based on correlation of the albitic member with the observed lower units of the Hoosac Formation on Hoosac Mountain. The fold closure shown in section D-D′ is not observed on the ground and is conjectural. However, early hinge lines in the northern part of Mount Greylock plunge southwest to west and could intersect section line D-D′ in the air north of Mount Williams. The large lefthand digitation on the lower limb in the area of A-A′ crossing of section D-D′ suggest that the closure may be expected where drawn.

The interpretation of the Greylock structure presented here differs from that of Prindle and Knopf. Previous workers (Pumpelly, Wolf, and Dale, 1894) showed carbonate rocks (Bellowspipe Limestone) encircling Greylock Schist on Mount Greylock. This belt formed the axial portion of the large recumbent anticline shown by Prindle and Knopf. Remapping shows that this limestone belt is not continuous around the north end of the mountain but is traceable into the main belt of autochthonous Stockbridge in the Adams area, as Prindle and Knopf show. Rather than encircling Mount Greylock, this belt of Stockbridge is interpreted as a recumbent anticline cored by unit C of the Stockbridge, that is downfolded in the main synform on Mount Greylock. The lower limb of this structure is exposed in the hooklike bend west of Mount Cole where carbonate rocks and the Walloomsac Formation overlie Greylock Schist in northeast-plunging folds.

The model for emplacement of the Greylock slice differs little from that outlined by Prindle and Knopf. Emplacement took place under metamorphic conditions and involved folding of older metamorphic structures. Metamorphism outlasted thrusting as chloritoid and albite clearly are imprinted on the foliated fault fabric. Folding accompanied thrusting presumably as a result of large scale westward transport of higher slices of the tectonic cover, that consists of the Berkshire massif and the eastern eugeoclinal sequence.

Cross folds and slip cleavages of two different orientations are superposed on all of the Taconic fabrics.

Relationship of Greylock slice to the Hoosac Formation, the Hoosac summit thrust and root zone of the allochthons

Stratigraphic comparisons of Greylock stratigraphy with that of the Hoosac Formation show striking similarities. Prindle and Knopf correlated the two sequences but suggested that the more aluminous green phyllite on the Greylock represented Rowe rather than Hoosac. Remapping of the Hoosac belt has shown that a major fault exists within the type Hoosac along the Hoosac summit thrust (Fig. 5). East of this fault, the Hoosac contains interbedded green aluminous phyllite identical to the chloritoid phyllite unit on Mount Greylock. Albitic units also are present as shown in Figure 5.

The green chloritoid unit on Mount Greylock is interbedded with albitic rock and is more coarsely crystalline than the type Rowe exposed east of the Hoosac belt. This unit compares more favorably with the green unit mapped within the Hoosac Formation (Fig. 5).

Coarse green or grey albitic rocks similar to those at the base of the eastern Hoosac sequence are found in the Greylock schist but are lacking in the Rowe. The Hoosac, however, contains distinctive beds of Dalton-like units and appears to have been deposited on the Berkshire 1 b.y.- old basement.

These relations suggest that the Greylock slice was derived from the Hoosac belt east of the Hoosac summit thrust but west of the Rowe depositional position. Examination of the rock fabric near the Hoosac summit thrust shows phyllonitic rock with green spears of chlorite and ultrafine grained paragonite-sericite matrix. Isoclinal recumbent folds with reclined axes are formed by folding of an older schistosity within the Hoosac of both plates. In addition, the allochthonous Hoosac contains recumbent fold repetitions that predate the Hoosac summit thrust. Post-thrust metamorphism, however, has produced static albite and garnet overgrowths of probable Acadian age on this fault fabric.

The structural characteristics of the Hoosac summit thrust and the sole of the Greylock slice are, therefore, quite similar.

A comparison of the stratigraphy, internal structure, and emplacement fabrics of the Greylock allochthons with the Hoosac allochthon suggests a common tectonic history. The final emplacement of

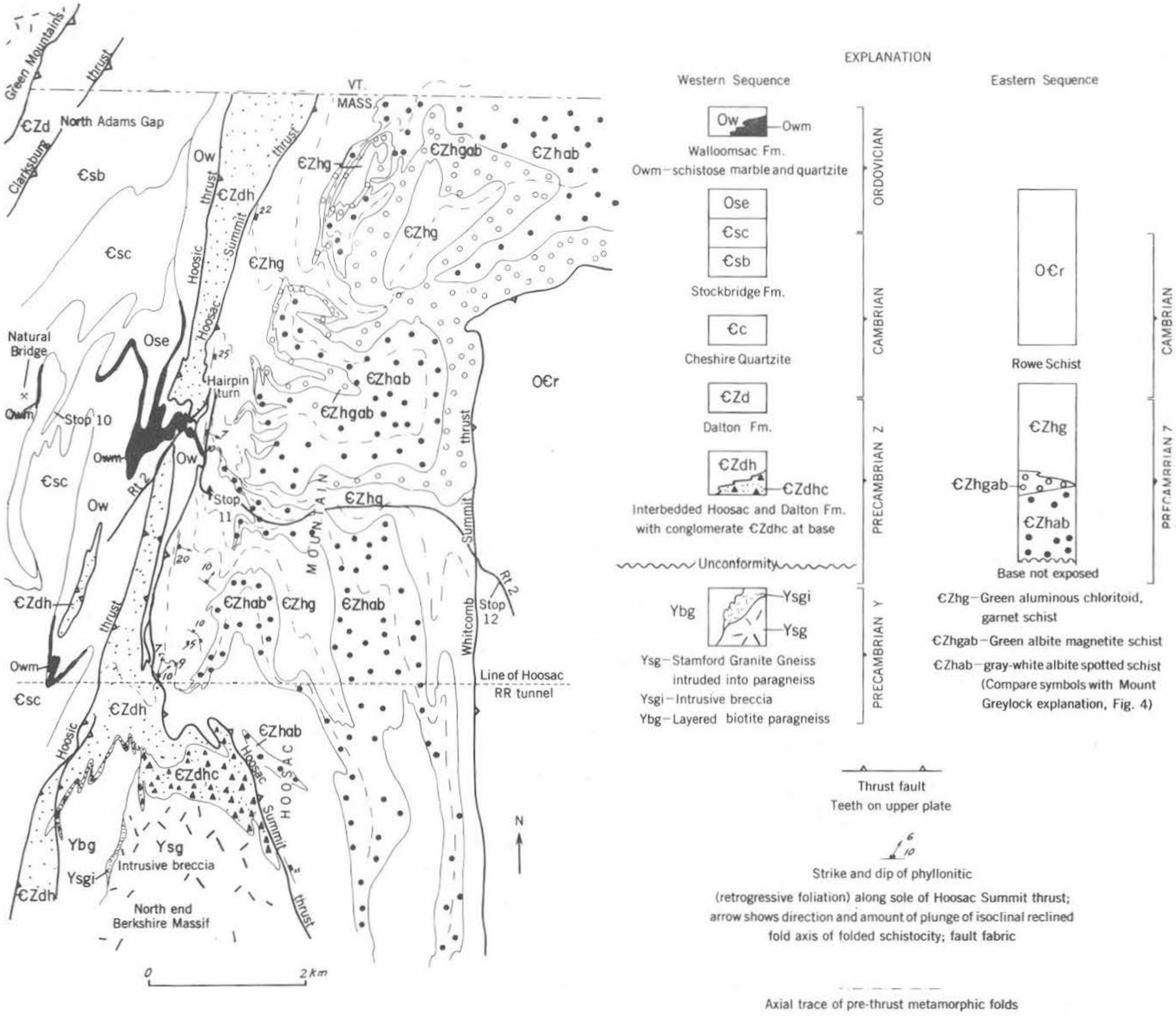


Figure 5. Geologic map of Hoosac Mountain based on mapping by N. Ratcliffe and R. Stanley, 1976-77, (unpub. data).

the Greylock allochthon across the miogeoclinal sedimentary rocks was a hard rock thrust that may have been rooted within the Hoosac belt east of the Berkshire massif. Possibly the root zone for the Greylock and other slices is buried beneath the Whitcomb summit thrust (Stanley, 1977) at the base of the Rowe sequence (Ratcliffe and others, 1975, p. 64).

Comparison of the Greylock Slice with other Taconic allochtonons

No other allochton in the main Taconic range from Vermont south to Connecticut has the structural characteristics of the Greylock allochthon. The combination of recumbent folding of the thrust surface and relatively late emplacement is remarkable and is unlike the relationships at the sole of the Giddings Brook, Chatham, or Everett slices. Allochthonous rocks similar to the Hoosac Formation on June Mountain (Ratcliffe and others, 1975) and in the Canaan Mountain allochthons (Harwood, 1979, 1975) do have these structural attributes and may have been transported westward with the Berkshire massif following initial upthrusting onto the massif rocks.

Evidently the Taconic allochthons of Giddings Brook, Rensselaer Plateau, Chatham and Everett slices were ejected from a root or slide zone east of the Hoosac summit slice prior to dynamothermal metamorphism. The Greylock and Canaan Mountain fault slices, however, did not escape metamorphism prior to emplacement. The fold style and character of emplacement fabrics for these rocks resembles closely that found in the remobilized and thrust-faulted basement rocks of the Berkshire massif itself. Large scale westward overthrusting and compressional tectonics were responsible for final emplacement of the Greylock slice probably during the event in which the Berkshire massif was thrust over the miogeocline.

The relative stacking order requires that the Everett, Greylock, and June Mountain slices were emplaced last under conditions of increasingly greater metamorphic intensity and under greater tectonic cover than the western slices. Williams (1975), on the other hand, suggested that the Newfoundland Taconic allochthons had been preassembled, with movement first occurring on eastern and highest metamorphic slices and associated ophiolite. The prestacked assemblage moved last on the melange at the floor of the lowest and nonmetamorphic slice.

Although the stacking sequence within the Chatham and higher slices is similar to that proposed by Williams, the higher slices here are all marked by evidence of tectonic slivering of local autochthonous carbonate rocks between the slices. Such a relationship requires that the present stacking order of Taconic slices with interleaving of fault slivers of the autochthon cannot be the same as a preassembled one that formed in a tectonic staging area prior to ejection of the allochthons.

The very close stratigraphic and structural similarity between the Hoosac and Greylock allochthons suggest that the higher slices in Massachusetts traveled the shortest relative distance and that the structurally lowermost and now westernmost Giddings Brook, Chatham and other slices traveled the farthest from more oceanward realms. It is important to appreciate that these arguments involve relative positions of allochthons in their restored pre-thrust positions east of the restored position of the Berkshire massif and its Hoosac cover.

These observations suggest that the Taconic allochthons in Massachusetts were emplaced sequentially. This process may have involved 1) unroofing or unpeeling from a single source (diverticulation) or, 2) hardrock thrusting and westward driving of successive fault slivers, which are samples of different paleogeographic areas in the Taconic sedimentary realm. Zen (1967) preferred the first hypothesis in order to explain the existence of older rocks and abbreviated sections found in the higher slices. He suggested that the Giddings Brook slice was detached from the upper part of the sediment column for which the high Taconic sequences formed the base.

Because of the rather extensive overlap in the stratigraphy of the oldest (Nassau) and of Nassau-like rocks of each allochthon, and the unique association of basaltic volcanics with only certain of these slices, it appears that the basal stratigraphic units (in the separate allochthons) actually are samples of quite different geographic realms. Therefore, the various allochthons probably did not all occupy the same paleogeographic position but represent lateral correlatives.

I prefer hypothesis (2) with hardrock thrust faulting produced by the accumulation of westward driven slices. Movement was initiated in the easternmost parts of the Taconic basin first (west of the palinspastic site of the Rowe). The most proximal (closest to the western craton) thrust slices (Greylock Schist) were driven out last and moved westward under a growing tectonic overburden. Tectonic imbrication within the autochthon then became important and the basement massif rocks were mobilized and thrust westward. The present stacking sequence is a result of large scale imbrication of slablike wedges of basement gneiss and cover rocks that have been thrust westward over the earlier emplaced Taconic slices.

Original depositional basin of Taconic allochthonous rocks

The original depositional basin of the Taconic allochthon rocks at this latitude, on the basis of the admittedly insecure arguments above, should have been more than 70 km wide. Palinspastic reconstruction of the Berkshire massif (see Ratcliffe and others, 1975) suggests that the Precambrian (Proterozoic) crystalline rocks of the Berkshire massif, in the Middle Ordovician, were very likely about 60 km wide and located at least 21 km farther east than their present position with respect to the miogeocline. The entire Taconic sequence could not likely have been deposited on the "basement" that was to become the Berkshire massif, as has generally been suggested (for example, Zen 1967) because rocks of the Dalton-Cheshire-Stockbridge shelf sequence were deposited on at least the western 30 km of the gneiss. Bird and Dewey (1970) suggested that much of the sequence was deposited to the east of the Grenville basement. The Taconic depositional basin probably was located largely to the east of the rocks making up the present Berkshire massif, and east of the Hoosac facies. This argument suggests that the root zone of the allochthon lies somewhere within the vicinity of the Hoosac-Rowe boundary east of the Berkshire massif. The Taconic rocks were probably deposited (initially) in an ensialic basin, with graben and horst structure and basaltic volcanism (Bird and Dewey, 1970; Bird, 1975). This basin may have evolved into a true oceanic basin with some sediment deposited on oceanic crust; however, clear evidence of this is lacking. Grenville gneissic detritus in these Taconic rocks may have been derived largely from intrabasinal sources, as the spatial relationships of the Giddings Brook-Chatham and Rensselaer Plateau slices cited earlier require. If such a model is true, and the comparison with Triassic and Jurassic(?) rift basins is valid, the Rensselaer (border conglomerate) may have been deposited throughout a considerable period of time and may not be the oldest rocks of the allochthon as commonly assumed.

Metamorphic and tectonic events in the central Taconic area of New York and Massachusetts

Figure 6 (reproduced from Ratcliffe and Harwood, 1975) presents the major tectonic features recognized in a 50 km east-west belt extending fom Mt. Ida and the Giddings Brook slice eastward into the core of the Berkshire massif.

Structures associated with emplacement of the allochthon

D_1 - Phase A of Taconic orogeny

Large recumbent folds, such as Zen (1961) reported from the northern region of the allochthon, have not been generally found in the central Taconic region. Potter (1972) presents data indicating that rocks of the Giddings Brook slice are locally overturned as if on the brow of a nappe. However, broad areas of lower limb (inverted rocks) are not present in the areas mapped by Potter. Zen and Ratcliffe (1971), and Ratcliffe (1969, 1974a, 1974b), report the existence of prefoliation minor folds both in the autochthon and allochthon. Through recent mapping in the Chatham slice, Ratcliffe and Bahrami (1976) have noted that a wide range of bedding-cleavage intersections are found within individual outcrops. Steeply plunging, almost reclined, axes of major and minor folds are characteristic of both autochthonous and allochthonous rocks. The Giddings Brook slice reveals similar steeply plunging F_2 fold structures. No evidence for truly recumbent folds has been found. Wildflysch-like conglomerates are found at the sole of the Giddings Brook (Zen, 1967) and Chatham slices (Ratcliffe and others, 1975). However, the Chatham slice also contains intercalated fault slivers of autochthon near the sole but locally shows intensely developed recumbent folding of Stockbridge units beneath the thrust. These relationships suggest near surface emplacement of coherent rock rather than of unconsolidated sediments. (Stop 1).

Phase B of Taconic orogeny

Emplacement of the Everett slice (high Taconics) was marked by tectonic breccia zones that are distributed along the Everett-Walloomsac

Deformational event	Number of fold system	Types of folds and areal extent	Important tectonic features	Metamorphic event	Important crystalloblastic and other structures	Igneous intrusion	Probable age of rocks in figure 1	Orogeny
D_6	F_6	North-south open folds of foliation locally recognized in Stockbridge valley	Northwest- and north-trending normal faults		Hematite-cemented breccias		Uncertain (Middle Devonian to Late Triassic)	
D_5	F_5	N. 25°–40° E.-trending upright to northwest overturned folds of foliation, with axial planar slip or crenulation cleavage. Folds recognized throughout area of figure 1 west to Mount Ida in SW corner of Kinderhook 15-minute quadrangle, N. Y., where Taconic unconformity is folded by N. 40° E. upright folds	Refolds thrust sheets and blastomylonitic foliation	M_2 Thermal maximum Acadian metamorphism	Crenulation of sillimanite alined in axial surface of F_4 folds; granulation of garnet and staurolite that includes F_4 foliation		Middle to Late Devonian (Ratcliffe 1969a, b, 1972)	Acadian orogeny
D_4	F_4	Northwest-trending upright to southwest-overturned folds with axial planar slip, crenulation, and flow cleavage. Folds recognized throughout area of figure 1, west to Chatham, N. Y., in center of Kinderhook 15-minute quadrangle	Folds thrust sheets and blastomylonitic foliation resulting in local overturning of thrusts; northwest-trending high-angle reverse faults		Muscovite, biotite realined and recrystallized in axial surface foliation; coarse sillimanite crystallized in foliation. Garnet, staurolite include folded F_2 fabric, and blastomylonitic foliation		Middle to Late Devonian (Ratcliffe 1969a, b, 1972)	
			Granite crosscuts thrust fault and blastomylonitic foliation	Thermal maximum Taconic metamorphism	Granite lacks blastomylonitic foliation in country rocks	Granite stock, South Sandisfield quadrangle	Late Ordovician(?) (Harwood, 1972)	Phases of Taconic orogeny Degree of basement participation and intensity of deformation increasing with time
D_3	F_3	Northwest-trending recumbent to strongly southwest-overturned folds of basement gneiss and large-scale southwestward thrusting of Precambrian rocks of Berkshire massif across autochthon. Fold and thrust style recognized from Windsor quadrangle, Massachusetts (Norton, 1969), south to Norfolk quadrangle, Connecticut (Harwood, unpub. data), along west front of Berkshire massif	Faulted recumbent folds and nappes, mylonite gneiss, blastomylonite associated with major thrusts Thrust sheets at June and Canaan Mountains transported with Berkshire massif		Alaskite has weakly developed blastomylonitic foliation but intrudes more highly cataclastic rock in fault zones; mylonite gneiss, blastomylonite has muscovite, biotite, hornblende with lepidoblastic texture, cataclasis of F_2 foliation, thrusting synmetamorphic	Alaskite sills in faults and magnetite mineralization	Synchronous with latest movements or thrusts (Late Ordovician?) Thrusting probably late Ordovician based on age of crosscutting granite	D
D_2	F_2	Isoclinal northeast-trending northwest-overturned to nearly recumbent folds with strong axial planar foliation which is dominant foliation in most autochthonous and allochthonous (Taconic) rocks, but not clearly present in Paleozoic rocks attached to Berkshire massif. Folds extend west to Mount Ida where unconformable beneath lowermost Devonian	Folding of Taconic thrust contacts, regional foliation and refolding of slump or soft-rock folds in Taconic allochthonous rocks	M_1	Lepidoblastic muscovite, chlorite, biotite, and ilmenite in foliation; chloritoid, albite include foliation but are linked by F_4 structures		Middle to Late Ordovician(?)	C Taconic orogeny
D_2(?)	F_2(?)	Folding and metamorphism of Lower Cambrian metasedimentary rocks attached to Berkshire massif and in independent thrust slices at June and Canaan Mountains	Coarse foliation or schistosity formed	M_1(?)	Muscovite, biotite lepidoblastic in schistosity		Time of metamorphism very uncertain depending upon original position of these rocks, and timing of tectonic events at that site (Middle Ordovician to Cambrian?)	(C)?
D_1	F_1	Intrafolial minor folds associated with Taconic thrust contacts. Soft rock or slump folds in Taconic allochthonous rocks; scale of pre-F_2 folds not determined but widespread, area shown in figure 1, west to Mount Ida	Emplacement of upper Taconic slices (here, Chatham and Everett slices) Emplacement of lower Taconic slices to west of area shown in figure 1	No metamorphism recognized	Tectonic breccias with inclusions of Stockbridge Formation along thrusts (Zen and Ratcliffe, 1971) Wild-flysch-like sedimentary rocks along base of thrusts		Uncertain (Middle Ordovician?) Middle Ordovician (Zen, 1972b, table 1)	B A
		Middle Ordovician unconformity						
D_0		Warping of Lower Cambrian to Lower Ordovician carbonate shelf sequence; locally dips near vertical (Ratcliffe, 1969a); possible block faulting					Late Early to Middle Ordovician (Zen, 1972b, table 1)	Pre-Taconic disturburance
		Pre-Dalton unconformity						
$D_{pЄ}$	$F_{pЄ}$	Isoclinal east-west-trending folds with generally steeply dipping axial surfaces and strong axial planar foliation; deformation of all Precambrian rocks including granitic intrusions such as Tyringham Gneiss	Gneissosity in Precambrian rocks of Berkshire massif	$M_{pЄ}$	Diopside, sillimanite, hornblende, microcline, perthite formed in dynamothermal event	Granodiorite-quartz monzonite intrusions such as Tyringham Gneiss, syntectonic	Dynamothermal event and granite intrusion approximately 1.04 b.y. (Ratcliffe and Zartman, 1971)	Grenville orogeny
		Pre-Tyringham foliation						

Figure 6. Chronology of tectonic events recognized in southwestern Massachusetts, northwestern Connecticut, and adjacent eastern New York (reproduced from Ratcliffe and Harwood, 1975).

contact and locally between the Everett and Chatham slices (Stop 3). The emplacement of all of the Taconic slices at this latitude was premetamorphic, and no firm evidence is known in support of Bird and Dewey's (1970) suggestion that the Rensselaer Plateau and higher slices might have been metamorphosed prior to emplacement in the Ordovician. The offset chloritoid isograd shown by Potter, 1972, at the west edge of his Berlin Mountain slice might be used to support this argument; however, similar relationships could be produced by offset on Acadian thrust faults.

Phase C of Taconic orogeny (D 2 and M 1 Taconic metamorphism)

Following emplacement of all slices, regional dynamothermal metamorphism took place, and a slaty cleavage or true axial planar foliation (S_2) formed in the rocks from the vicinity of Mt. Ida eastward into the area of the Berkshire massif and presumably beyond. In the low-grade rocks, fine-grained sericite, chlorite, and lenticular quartz define the slaty cleavage. Small, round blebs of chlorite that has a 001 cleavage subparallel to bedding are ubiquitous in the low-grade rock and may be retrograded detrital biotite or diagenetic chlorite. However, lepidoblastic grains are not developed parallel to beds. Sandstone and siltstone dikes have not been found parallel to S_2, and no evidence, thus far, indicates that tectonic dewatering was an important mechanism in the formation of the Taconic slaty cleavage. Large finite strain is indicated by flattened pebbles within the slaty cleavage. Locally, intense transposition structures are developed, and false bedding is common, particularly in laminated slates and some quartzites. Taconic thrust contacts of the Giddings Brook slice (Zen, 1961; Potter, 1972), Chatham (Ratcliffe, 1974a; Ratcliffe and Bahrami, 1976), and Everett slices (Zen and Ratcliffe, 1966; Ratcliffe, 1969, 1974a, 1974b) were cross foliated and folded during the D_2-M_1 metamorphic event to produce F_2 Taconic folds on a regional scale.

Phase D of the Taconic orogeny

Emplacement of the slices of the Berkshire massif and large-scale, westward overthrusting was concommitant with metamorphism. Recumbent folds formed both in the autochthon and in gneissic rocks (see Trips B-2 and B-6 of the 1975 N.E.I.G.C. guide book for further information).

Acadian orogeny

Post-Taconic foliation structures are common throughout this belt and increase both in intensity and degree of concommitant mineral growth eastward. By using inclusion textures, we may delimit the approximate extent and character of the post-Taconic metamorphic imprint. East of the biotite isograd, approximately at the New York State line, post-S_2 mineral textures are abundant, indicating that the Acadian thermal overprint produced new mineral growth of muscovite (second generation with decussate texture), albite, chloritoid, biotite, garnet, and staurolite. The prominent mineral zonation is almost certainly composite (polymetamorphic) and is dominantly controlled by the Acadian overprint in areas east of the biotite isograd.

F_4 and F_5 folds are inconsistently developed and show contradiction of relative ages from place to place. In eastern areas, the northeast-trending refolds are the F_5 folds, whereas in the low Taconics east to the Stockbridge valley, the northwest-trending refolds are the later folds.

The Chatham fault formed during the northeast-trending refolding episode, for it is refolded by northwest crenulation folds north of Chatham (Ratcliffe and Bahrami, 1976). Locally, thrust faults with mylonitization of pre-existing foliation and chlorite-quartz-albite mineralization formed in sections of the Chatham slice containing massive quartzite and graywacke. The contact between the Chatham slice and the overlying Everett(?) slice in the area of this trip also is such a late, presumably Acadian fault.

K-Ar age data from Taconic phyllites

Two new K-Ar age dates on muscovite concentrates from phyllite in the vicinity of this field trip have been obtained. A sample of lepidoblastic fine-grained muscovite aligned in the regional foliation (M_1) event of Figure 6 yielded a K-Ar age of 434 ± 16 m.y. (442 ± 16 m.y. using newer decay constants).* The dated sample of purple Nassau phyllite collected 2 km southwest of Stop 1 contains well-developed F_2 folds (Fig. 6). This age confirms the Taconic age of the regional schistosity and is the first such Taconic age from the central part of the Taconic area.

A second sample of phyllonitic (retrograded) muscovite-rich phyllite was collected from the imbricate thrust zone at the contact between the Chatham and Everett(?) slices, 1 km north of Stop 2. K-Ar age of this phyllonitic muscovite is 367 ± 13 m.y. (374 ± 13 m.y.).* Thin-section examination and field observations show that the muscovite dated is aligned in the phyllonitic fabric that is subparallel to the imbricate faults. These faults cross cut and produce folds of older F_2 foliation. This age determination suggests that the imbrication and cataclasis marking the contact between the Chatham slice and the higher Everett(?) slice in the area of Stop 3 is an Acadian fault.

Regional metamorphism during the Acadian, M_2 event of Figure 6, has overprinted wide areas of western Massachusetts and the general lack of K-Ar or Rb/Sr mineral ages east of the biotite isograd probably reflects this overprinting.

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* values in parentheses are ages using new decay constants

Field trip stops will be in the following quadrangles: Canaan, N.Y.-Mass., Pittsfield West, Cheshire, Williamstown, and North Adams, Mass. Stops 1, 2, and 3 are located in the published geologic map (Ratcliffe, 1978).

Road log for N.E.I.G.C. '79 field trip

Log starts at large parking lot on Rt. 22, 0.3 mi. north of Interstate 90 (Berkshire spur of N.Y. State Thruway).

Cumulative mileage

0 Proceed north on Rt. 22 over RR tracks.

1.2 Turn left on Tunnel Hill Road.

2.1 Park at bend in road before RR tunnel.

Stop 1. Contact between rocks of Chatham Slice of Taconic allochthon and autochton. Canaan 7-1/2 quadrangle.

Walk down the slopes to the east to the railroad tracks. Caution! This railroad is operating and trains may come from either direction. There is enough room in the center island or along the rock walls, should a train arrive.

The geologic relationships at this stop are shown in Figures 7 and 8. The exposures in the tunnel are on the east flank of a doubly plunging anticline that produces a semi-window exposing unit g of the Stockbridge Formation. The allochthonous rocks of the Chatham slice consist of purple and green slate, green silty slate, massive beds of Rensselaer Graywacke, and basaltic volcanic rocks believed to be flows and tuffs.

The outcrops in the railroad cut expose the contact between the Chatham slice and the autochthon. A folded thrust contact (T_1, Fig. 9) between overlying green phyllite of the Nassau Formation can be seen. Note the truncation of beds in the limestone by the contact. In addition, a fault sliver of green phyllite underlies an inverted sequence of Stockbridge and Walloomsac in a small anticline nearer the portal (thrust T_2, Fig. 9).

Fault T_1 traces out of the cut and forms the western limit of the allochthon. Fault T_2 is not exposed again in recognizable form.

The relationship here suggests that the autochthon and allochthon were tectonically mixed during emplacement. In this model, rocks of the autochthon were overturned during thrusting and overridden by younger thrusts as illustrated below in Model 1 of Figure 9.

An alternative model involves recumbent folding of the thrust contact as shown in Model 2.

Return to Rt. 22 via Tunnel Hill Rd.

3.0 Turn left on Rt. 22 north.

4.0 Outcrops of unit c of the Stockbridge.

4.5 Intersection of Rt. 295. Proceed North.

4.7 Outcrops of unit c of the Stockbridge.

6.1 Turn into Berkshire Farm for Boys. Stop and ask permission to drive through property. Road log resumes on leaving Farm area.

Drive through the property and bear left on the drive leading

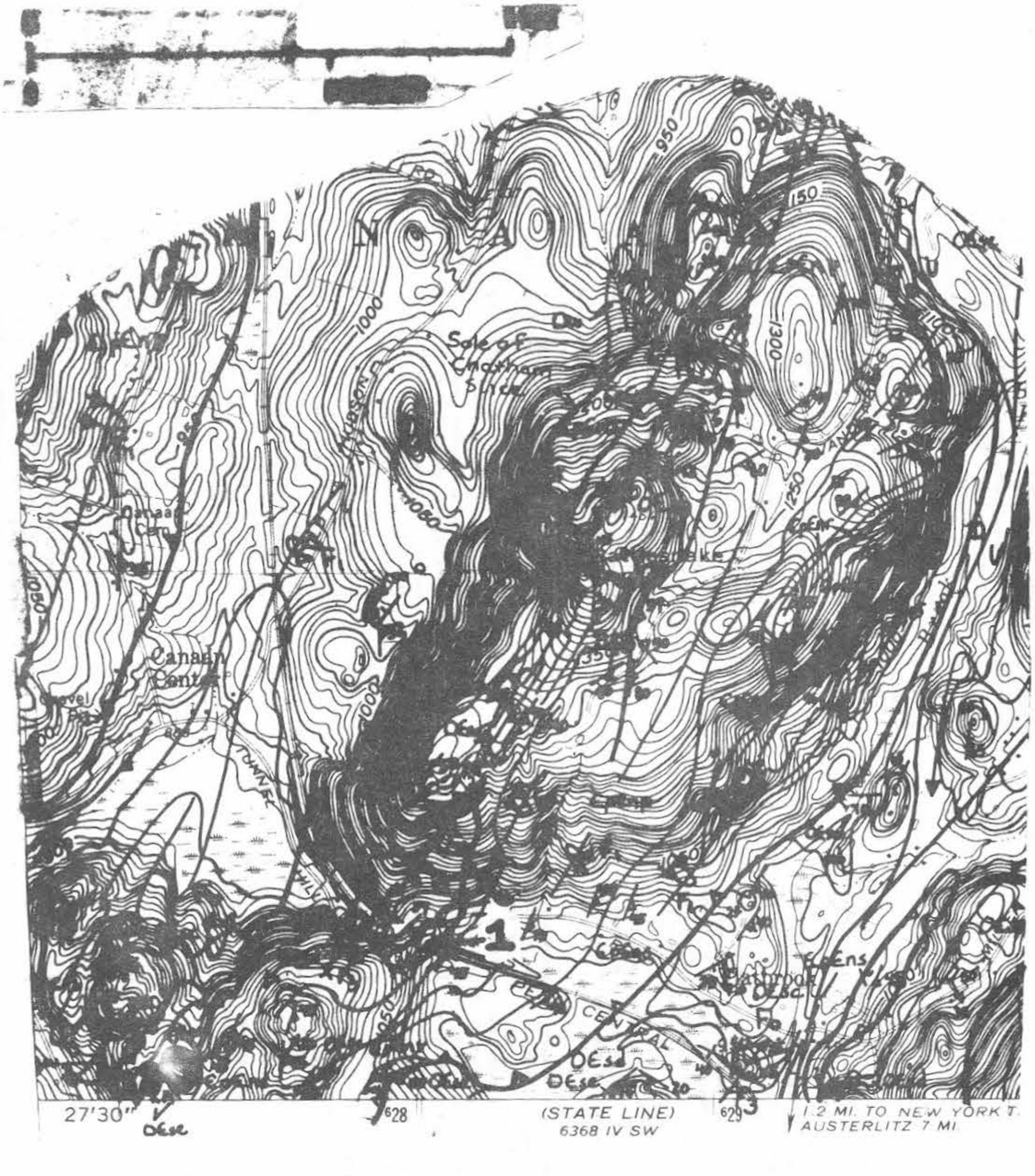


Figure 7. Geologic map of area around Stop 1. (Reproduced from Ratcliffe, 1978). See following pages for explanation

Figure 7. cont'd.

DESCRIPTION OF MAP UNITS
(Major minerals are listed in order of increasing abundance)

BEDROCK OF THE AUTOCHTHON

WALLOOMSAC FORMATION (UPPER? AND MIDDLE ORDOVICIAN)

Ow Dark-gray to black, carbonaceous, sooty-gray-weathering, fissile phyllite or schist containing minor punky-weathering limy phyllite, schistose marble, and calcite marble. Biotite, plagioclase, and garnet developed in more highly metamorphosed rocks exposed to the east. Recognized as higher metamorphic grades by dark color, coarse black biotite metacrysts, and punky-weathering limy layers. Distinguished from Everett Formation by being less garnetiferous, much richer in biotite, and lacking chloritoid, ilmenite/magnetite, and green iron-rich chlorite

Owl Dark-blue-gray crystalline, discontinuous basal limestone and limestone conglomerate containing pelmatazoan, bryozoan, algae, gastropod, and rugose coral remains; weathers to buff gray. Rugose corals from fossil locality xF1, 0.75 km southwest of Shaker Village, are no older than Black Riverian and may be Trentonian (Zen and Hartshorn, 1966). At this locality the unit (Owl) rests on the uppermost unit (O€sg) of Stockbridge Formation; thus the fossil date establishes the minimum age of the Stockbridge Formation. Pelmatazoan, bryozoan, and possible brachiopod fragments are found in the unit (Owl) west of Queechy Lake, fossil locality xF2 and at the west end of the Penn Central Railroad tunnel, fossil locality xF3

Owm Impure feldspathic, schistose calcite marble studded with metacrysts of black biotite and black albite forms the basal limestone in the eastern part of the map area. The feldspar component probably was derived from erosion of the Precambrian gneisses and Dalton Formation during Middle Ordovician time. This unit thickens eastward, being 50-70 m thick in the Stockbridge quadrangles (Ratcliffe, 1974b), and passes gradationally through interbedding of schist in dark-gray to black calcitic biotite schist

STOCKBRIDGE FORMATION (LOWER ORDOVICIAN TO LOWER CAMBRIAN)

O€sg Medium- to dark-gray calcite marble; massive, white, coarsely crystalline calcite marble; light-gray, fine-grained, phyllitic marble; and bluish-gray and white-mottled calcite marble that weathers to a smooth glistening surface. Subordinate beds of cream- to beige-weathering dolostone commonly are boudinaged

O€sf Predominantly tan- to gray-weathering, massive, sandy-textured dolostone to calcitic dolostone; more calcite-rich layers are punky-weathered and reddish; weathered surfaces commonly "wood grained" resulting from weathering of fine, quartz-rich sandy laminae less than 1 mm thick; local cross-bedding abundant; beds of light-tan vitreous quartzite as thick as 0.75 m are locally found

O€se Coarsely crystalline, white to light-gray, blue-gray and white-mottled, bluish-gray and white-layered, or massive white calcite marble in Massachusetts. Excellent exposures at the abandoned quarries north and south of Richmond Pond are exceptionally pure and coarsely crystalline. Gray to bluish-gray, pale-blue-gray-weathering, finely layered calcite marble interlayered with dark calcite dolostone, and light-gray and white crystalline calcite marble characterize the unit in New York State at lower metamorphic grade

O€sd In Massachusetts, beige-weathering sandy dolostone, reddish-weathering calcitic sandstone, and gray sandy-textured calcitic marble. Minor white vitreous quartzite 1 to 3 cm thick and thin interbedded black phyllite are characteristic. In New York State, at lower metamorphic rank massive gray- to light-tan-weathered calcitic dolostone with sandy crossbedded laminae of positive relief and intense orangish-tan-weathered, massively bedded, dark-blue-gray dolostone with punky-weathering, crossbedded calcitic metaquartzite beds several centimeters thick

O€sc Massive, light-gray-weathering, steel-gray, very fine grained calcitic dolostone and gray and light-gray, layered calcitic dolostone with scattered silvery-gray phyllitic partings. Massive white calcitic dolostone and dull-gray-weathering, fissile calcitic dolostone with milky-white quartz knots and vuggy cavities 1 to 2 cm thick (possible metachert nodules) common near top of the unit. West of the Massachusetts State Line nodules of black chert as much as 2 cm in diameter are common

O€sb Beige- to light-cream-weathering, gray to dark-gray, non-calcitic dolostone with punky-weathering quartzites, white vitreous quartzites 1 to 2 cm thick, rare blue quartz-pebble conglomerates, black pyritiferous calcareous schist, and green and reddish phyllite beds. Silvery-gray partings of phlogopite, black phyllitic partings or discontinuous quartz chaining several millimeters thick are common except in the middle of the unit which contains about 50 meters of dark-blue-gray-weathering, dark-gray, fine-grained dolostone, and light-powder-blue-gray-weathering, gray nonsiliceous dolostone

BEDROCK OF THE ALLOCHTHON

Allochthonous rocks are tentatively assigned to four structural slices on the basis of stratigraphic uniqueness of some rocks and on the basis of stuctural position. Owing to the high degree of imbrication along relatively late thrust faults the original boundaries of the slices have been modified.

Rocks assigned to Chatham slice

NASSAU FORMATION (LOWER CAMBRIAN? AND (OR) UPPER PRECAMBRIAN?) [Lithic subdivisions may appear at different stratigraphic levels in different areas owing to widespread interfingering]

€p€ns Massive greenish-gray to gray metasiltstone or chlorite-sericite-rich phyllite locally containing 1- to 3-cm beds of greenish metaquartzite and olive-drab, fine-grained metasiltstone; pale-greenish, fine-grained chlorite-sericite phyllite with minor quartz metaconglomerate lenses and, more rarely, granitic gneiss-boulder metaconglomerate beds or dark-green graywacke beds as much as 10 cm thick

€p€nr Rensselaer(?) Graywacke Member--Massive, bedded, dark- to pale-green metagraywacke or metasubgraywacke containing minor blue-quartz pebble-, coarse gneiss boulder-, and gneiss pebble-conglomerate layers. Unit interfingers with and grades into massive green-gray to gray metasiltstone unit (€p€ns) having many lenses of graywacke (€p€nr) too small to be shown on map

€p€nvt Metavolcanic rock, dark-brownish-green-weathering, ilmenite-leucoxene-amphibole-stilpnomelane-epidote-plagioclase metatuff(?) having fragmental relict plagioclase phenocrysts as much as 2 mm long; unit is fine grained and passes gradationally upwards into metasiltstone unit (€p€ns) or into metavolcanic rock (€p€nv)

€p€nv Metavolcanic rock, dark-green to yellowish-green, ilmenite-leucoxene-chlorite-actinolite-hornblende-epidote-plagioclase greenstone forming conformable, massively layered units as much as 10 m thick. Individual layers commonly show relict intersertal igneous texture grading toward a finer grained, strongly foliated rock with scattered akeritic amygdaloidal(?) fillings at lower contacts with the metasiltstone unit (€p€ns) and the Rensselaer(?) Graywacke Member (€p€nr). Well exposed in the Knob, on a slope southwest of Queechy Lake, and on the slopes east of the Berkshire Farm for Boys. A contact zone at the base is marked by alternating layers of metasedimentary rock and thin layers of volcanic rock. Locally the volcanic rocks interlayer with plagioclase-rich Rensselaer(?) Graywacke Member (€p€nr), while at other localities they appear to discordantly overlie the graywacke

€p€np Dark-maroon phyllite, green and purple laminated or mottled sericite-hematite-quartz phyllite including red or pale-green shale-chip metaconglomerate layers, and many light-green or purple-tinted metaquartzites 10 cm thick that commonly are crossbedded. Beds of soft yellowish-green to gray paper-thin phyllite are interlayered with the predominantly purple and green mottled rocks

€p€nq Massive-bedded, light-green to gray-weathering metaquartzite or metasubgraywacke as much as 20 m thick forms lenticular bodies near the top of the phyllite unit (€p€np) in the western part of the Chatham slice

Rocks assigned to the Perry Peak slice

ROCKS NEAR PERRY PEAK (LOWER CAMBRIAN? AND (OR) UPPER PRECAMBRIAN?)

€p€s Light-greenish-gray to gray metasiltstone, chlorite-rich siliceous phyllite or dark-green gritty metagraywacke with 1- to 3-cm beds of vitreous metaquartzite. Overall this unit is quartz rich and well bedded, and it closely resembles the metasiltstone unit of the Nassau Formation (€p€ns) of the Chatham slice, although volcanic rocks, abundant in rocks of the Chatham slice, are absent

€p€p Light-yellowish-green and deep-purple variegated phyllite, dark-purplish-gray phyllite, and soft yellow-green lustrous quartz-chlorite-paragonite-muscovite phyllite. Minor interbeds of purplish-gray to dark-green metagraywacke 1 to 2 cm thick are widely distributed. This unit resembles closely the phyllite unit of the Nassau Formation (€p€np) of the Chatham slice, although the purplish coloration is less intense in areas of higher metamorphic grade to the east where dark-gray phyllite with a subtle but distinctive purple cast is found

Rocks assigned to the Widow Whites slice

(The Widow Whites slice is named for occurrences on Widow Whites Peak in the southern part of the Hancock quadrangle.)

€p€g

ROCKS NEAR WIDOW WHITES PEAK (LOWER CAMBRIAN? AND (OR) UPPER PRECAMBRIAN?)

Dark-gray to black lustrous chloritoid-quartz-muscovite phyllite interlayered with gray-green quartzose albitic phyllite. Distinctive dark-gray beds rich in ilmenite and chloritoid have a sparkling luster

Rocks assigned to the Everett slice

€p€ev

EVERETT FORMATION (LOWER CAMBRIAN? AND (OR) UPPER PRECAMBRIAN?)

Green to greenish-gray and lustrous, silvery-gray sericite-(muscovite)-quartz-chlorite phyllite or schist in which chloritoid, paragonite, ilmenite, and garnet may be present; gray-green and dark-gray laminated phyllite; gritty-textured, white sodic plagioclase-spotted, greenish phyllite that weathers to a distinctive pitted surface and occurs in single beds as much as 7 m thick; and greenish-gray phyllite with quartzite layers 0.5 to 1 cm thick grading into a quartzose, gray-green phyllite with abundant pea-sized magnetite metacrysts. The bulk of the rocks assigned to the Everett Formation on Lenox Mountain are dark-gray to gray-green with abundant dark flecks of chloritoid, deep-red garnet, and black biotite. With allowances for higher metamorphic grade and the consequent elimination of the abundant chlorite present in the lower grade rocks, the Everett may be compositionally equivalent to the metasiltstone unit of the Nassau Formation (€p€ns) or to the metasiltstone unit near Perry Peak (€p€s). It resembles most closely the dark albitic phyllite of Widow Whites slice (€p€g).

BEDROCK OF THE MOVEMENT ZONE

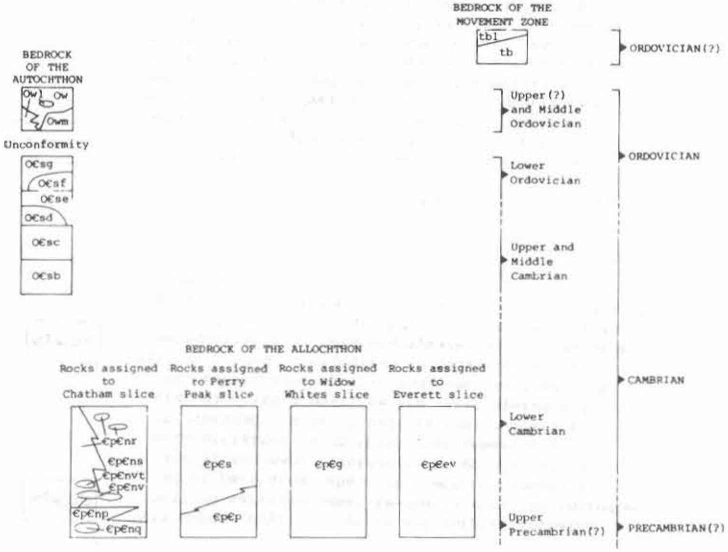
tbl

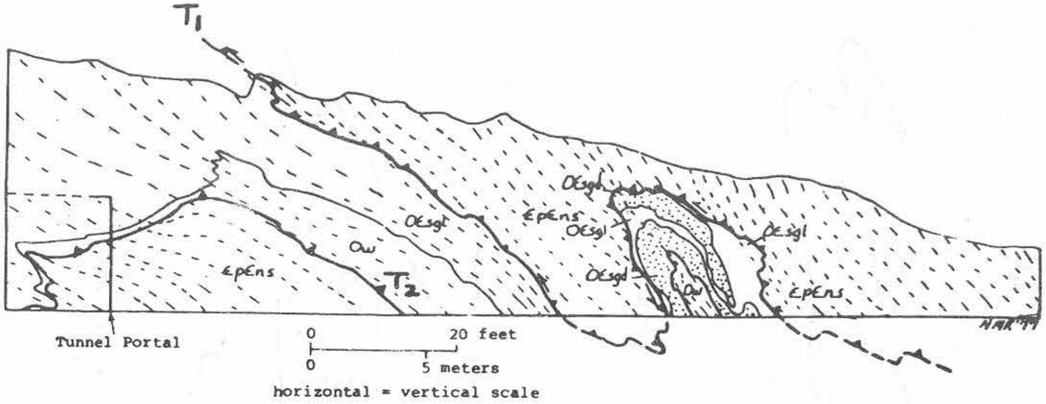
TECTONIC BRECCIA (ORDOVICIAN?)--A zone rich in inclusions of carbonate rock of the Stockbridge Formation in a polymict tectonic breccia interleaved tectonically during Ordovician(?) time with slices of black Walloomsac and greenish-gray metasiltstone unit near Perry Peak (€p€s) at or near the sole of overriding plates of allochthonous rock. Because of the fine scale of imbrication of rocks in the movement zone, separate rock types in the breccia are not distinguished. Where individual fault slices are of sufficient size and are composed of coherent strata, they are mapped as standard fault slices and the units identified. These breccias mark tectonic movement zones that differ from conventional fault zones in one important aspect. The carbonate clasts in the imbricated phyllite matrix are exotic blocks not derived from the hanging wall or the footwall but from the autochthonous carbonate rock of the Stockbridge Formation; carbonate clasts are considered tectonic inclusions transported within the movement zone from some site to the east

tb

Completely intermixed zone of black Walloomsac and greenish phyllite with irregular inclusions of either rock type in a matrix of the other. Zones exhibit variation of rock types on a scale of centimeters to tens of meters. The distribution and shape of inclusions indicates that incorporation predated formation of the regional slaty cleavage (S_1). Breccias of this type found in zones below the sole of the Perry Peak slice may represent highly disarticulated and "kneaded out" remnants of earlier fault slices dismembered during overthrusting of the Perry Peak slice. The presence of these breccias within the body of the Walloomsac Formation suggests that fault displacements of considerable magnitude may exist within the "autochthonous" belt of Walloomsac underlying the Perry Peak and Widow Whites slices.

CORRELATION OF MAP UNITS





EXPLANATION

Ow	Phyllite and schist of the Walloomsac Formation	Ordovician
OЄsgl	Limestone beds in the medium- to dark-gray calcite marble (OЄsg) of the Stockbridge Formation	Ordovician and Cambrian
OЄsgd	Dolostone beds in the medium- to dark-gray calcite marble (OЄsg) of the Stockbridge Formation	
ЄpЄns	Green phyllite of the Naussau Formation. Part of the Chatham slice	Cambrian and (or) Precambrian

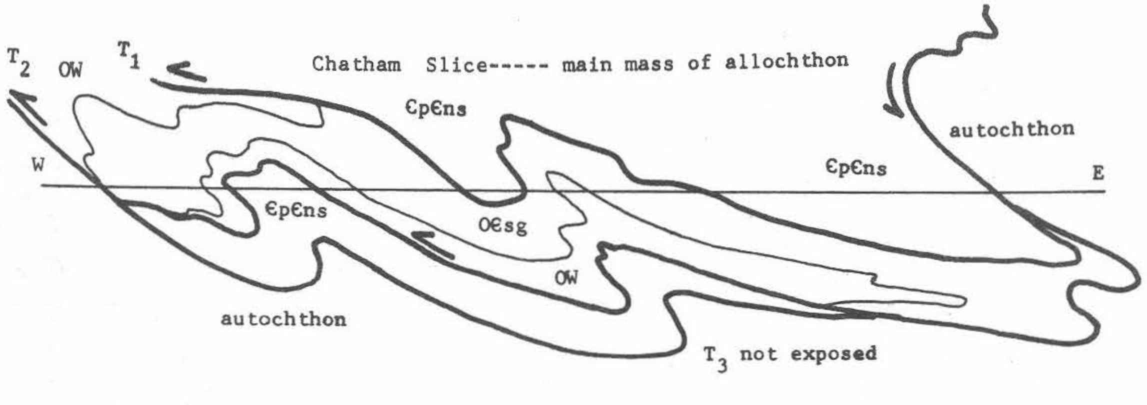
——— Contact

——▲—— Thrust contact of green phyllite of the Nassau Formation (ЄpЄns) on autochthon. Teeth on overthrust plate; dashed where inferred; contact is discordant to beds in autochthon

- - - - - S_1 foliation crosscuts thrust faults as axial plane of F_1 folds

Figure 8. Contact relationships of the Chatham slice with Stockbridge and Walloomsac Formations exposed in north face of Penn Central railroad cut, east portal of tunnel at the southern edge of the Canaan quadrangle, showing interleaved units in complex tectonic **breccia (tb).**

MODEL 1: TWO FAULT SLIVERS OF TACONIC ALLOCHTHON WITH INTERNAL RECUMBENTLY FOLDED SLIVER OF STOCKBRIDGE AND WALLOOMSAC. THRUSTS LATER FOLDED BY UPRIGHT ACADIAN FOLDS.



MODEL 2: RECUMBENT FOLDING OF A SINGLE FAULT FOLLOWING OR DURING EMPLACEMENT, FOLLOWED BY ACADIAN FOLDING.

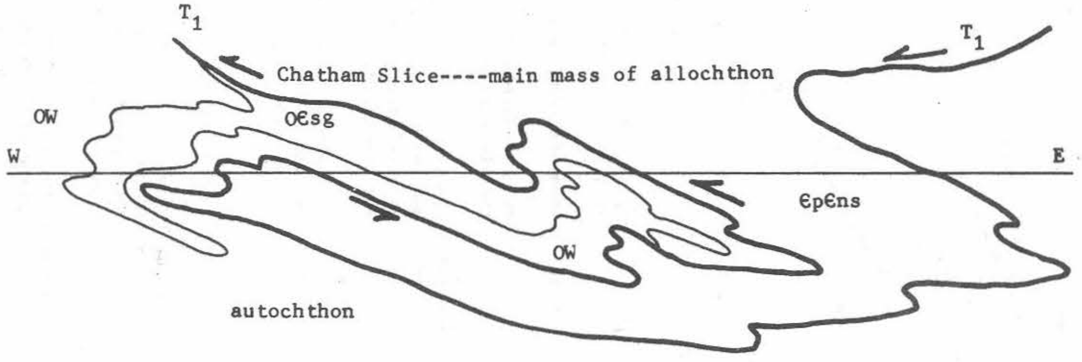


Figure 9. Sketch of alternate models for explanation of fault relationships seen at Stop 1. On map, Fig. 7, area is shown as tectonic breccia (tb), and model 1 is the preferred interpretation. T_1, T_2, and T_3 refer to faults identified in Fig. 8.

to the home of the director. Park at edge of large field before house. Walk east-northeast across field to slopes.

Figure 10 shows the location of Stop 2. Basaltic volcanic rocks of the Chatham slice are well exposed on the slopes above the Boys Farm. This zone associated with graywacke has been traced continuously from the State Line quadrangle north to the Jiminy Peak area for a distance of 19 km. Similar occurrences are on the Knob across the valley to the west. This eastern belt of volcanic rocks is better laminated than those on the knob and at Fog Hill in the State Line quadrangle. The associated graywackes contain fragments of coarse-grained granite containing oligoclase and perthitic K feldspar.

The association of coarse, continentally derived clastic rocks with basaltic volcanics and probable fluviatile red beds suggests rift facies rocks similar to Triassic and Jurassic rocks of the Atlantic passive continental margin. These rocks are restricted Chatham and Rensselaer Plateau slices.

Return to Rt. 22 and turn right.

9.5 Turn right on Rt. 20 at New Lebanon

10.2 Rt. 20 branches right. Follow it toward Pittsfield.

12.9 Stop 3, just past curve in road. Large roadcut of purple and green phyllite.

Excellent roadcuts expose purple and green laminated phyllites of the next higher Taconic slice, the Perry Peak slice that is correlated with the Everett slice on Figure 1. Strong secondary slip cleavage and microfaults, accentuated by pods of bull quartz are common. The contact between the Chatham slice and the higher Perry Peak slice is a late thrust probably of Acadian age. From this contact zone eastward to the carbonate belt, a complex system of late thrust faults have been mapped in which slivers of carbonate, Walloomsac, and Taconic rocks are found. To the north, this thrust zone roots in the Precambrian (Proterozoic) rocks of Clarksburg Mountain.

Volcanic rocks and thick graywacke are not recognized in the higher Taconic slices. Is the absence of these rocks of stratigraphic significance, or are the volcanic rocks absent because of faulting? This is a serious problem that has not been resolved. Certainly the Greylock and Hoosac Mountain rocks are different stratigraphically than either the Chatham or Perry Peak rocks, as will be discussed at Stop 4.

From the roadcut, walk southwestward down to the old road and then follow the new wood road up the hill westward past green phyllite of the Perry Peak slice.

At 1550 ft elevation on bench a sliver of dolostone may be seen. The fault sliver occupies a position between the Perry Peak slice and Walloomsac of the autochthon below in a late fault.

This anticlinal belt of Walloomsac, however, underlies the Chatham slice rocks seen to the south at Stop 2.

From the carbonate rocks, walk northeastward down the slopes toward the brook, where inclusions of greenish-gray Taconic rocks may be found imbedded in the Walloomsac matrix.

This chaotic zone of wildflysch-like material evidently underlies the Chatham slice. Similar rocks are exposed to the south

Figure 10. Geologic map of the Chatham and Perry Peak Slices of the Taconic allochthon on the east side of the Canaan Valley showing the location of Stops 3 and 4. For explanation, see Fig. 7

beneath the Chatham slice (Ratcliffe, Bird, and Bahrami, 1975, p. 82).

When the observations at Stop 1 and 3 are compared, the relations suggest that the Chatham slice was emplaced by a mechanism that involved recumbent folding, slivering of the autochthon, plucking of carbonate blocks signifying deformation of consolidated rocks. On the other hand, more ductile behavior with turbulent mixing of materials from autochthon and allochthon is necessary to account for the wildflysch-like breccias seen. A gravity induced spreading model to allow for creep in the autochthon may be the best explanation of these relationships. However, there is little evidence in favor of soft rock gravity sliding. Continue east on Rt. 20 toward Pittsfield.

14.5 Side road leads to fossil locality in the basal part of the Walloomsac.

15.0 Hancock Shaker Village and intersection with Rt. 41. Continue on Rt. 20.

16.5 Y branch in road. Follow Rt. 20 left.

20.0 Intersect Rt. 7, Pittsfield. Turn left. Follow around the circle in Pittsfield 90° and follow Rt. 7 and 9 north. Left turn at light, and follow Rt. 7 north out of Pittsfield.

25.7 Town of Lanesboro.

27.1 Turn right onto entrance road to Mount Greylock (N. Main St.).

28.0 Turn right. Follow signs to Greylock Reservation.

28.4 Take left Y, Rockwell Rd.

28.9 Entrance to Reservation.

31.9 Rounds Rock. Excellent cliffs west of road of green albitic Greylock Schist (optional stop).

32.9 Jones Nose. Stop 4.

Walk up the Meadow along the Appalachian Trail across limey albitic schist and schistose marble of the Walloomsac Formation here exposed by breaching of a refolded antiform that has a north-dipping axial surface. This carbonate-rich unit is found at or near the base of the Walloomsac Formation regionally and on Mount Greylock, thus suggesting that older rocks are coming to the surface here. To the north, farther up the slope, a complementary, nearly recumbent syncline and anticline pair are exposed, also with north-dipping refolded axial surfaces. Section C C′ of Mount Greylock, Figure 3.

33.9 Ashfort Rd.

34.7 Entrance to campground. Turn left to Stony Ledge.

The bench the road follows is located on the contact between Greylock Schist and Walloomsac of the autochthon.

Follow dirt road to Stony Ledge.

36.4 Stony Ledge. Stop 5.

Magnificant view to north and east into the Hopper. The ridge to the north is underlain by Greylock Schist, the valley by Walloomsac. To the east, the peak of Greylock and the steep west slope can be seen. Recent mapping suggests that there is double section of Greylock Schist exposed on Greylock with the axial surface of a large recumbent fold separating the mountain into lower-limb and upper limb structures.

The Bellowspipe Limestone shown by Prindle and Knopf (1932) does not exist as a throughgoing unit but is sporadically developed.

Excellent late crenulation cleavage can be seen in the ledges of green phyllite. These folds are postmetamorphic and correlate with the Green Mountain uplift folds or folds of F_5 regional structures.

39.8 Return to Rockwell Rd. Turn left and climb road past dark albitic and green albitic schist of the lower limb into fine lustrous phyllites forming the core of the recumbent synform.

41.3 Large cuts of albitic Greylock and associated quartzite repeat sequence into upper overturned limb of recumbent synform. Turn right to top.

42.0 Park in lot at top. Stop 6.
Excellent view all around, weather permitting. Discussion of the regional geologic relationships.

At crest of Greylock, we are standing on chloritoid-rich phyllite in the axial part of a large westward topping syncline. Darker albitic phyllite, quartzite and graywacke form a rather continuous marker horizon that separates the more chloritoid-rich rocks from green and gray-white albite spotted granulites. Locally, this transition zone contains lenses of salmon pink dolostone in boudins, magnetite-rich schist, and gneissic pebble conglomerate. Albitic schists crowded with albite in massive exposures can be seen on the crest of Ragged Mountain to the north, on Cole Mountain to the south, Rounds Rock, Jones Nose, and on Mount Prospect to the west.

The structural interpretation of Mount Greylock shown in Figure 3 calls for a thrust sheet that has been recumbently folded. Plunges are to the north and south into the sections. In addition to recumbent folds that involve the thrust contact, internal structures are shown which are also recumbent but which are truncated by the thrust contacts. This suggests that rocks of the Greylock slice were folded prior to emplacement on the Stockbridge-Walloomsac sequence.

Relationship of the Greylock to the Hoosac Schist

The ridge seen to the east is the Hoosac Mountain underlain by Precambrian (Proterozoic) gneiss to the south and Hoosac Schist to the north. The carbonate valley narrows to the north in the North Adams gap where the Hoosac Mountain approaches the Green Mountains. A longitudinal sketch section is shown in Figure 11. It identifies two major thrusts on Hoosac Mountain: a lower thrust places Precambrian (Proterozoic) gneiss with its unconformable cover (Hoosac Schist and interfingering Dalton Formation) over carbonate rocks of the autochthon. This fault is essentially the fault mapped as "Hoosic thrust" by Herz (1961). A higher thrust places Hoosac with a more easterly facies above the western Hoosac belt. This fault is termed the Hoosac summit thrust. The eastern Hoosac sequence contains green albitic schist, dark albitic and garnet-bearing schist and light green chloritoid schist. This sequence resembles closely Greylock Schist units, although a greater development of albite-rich rocks is found on

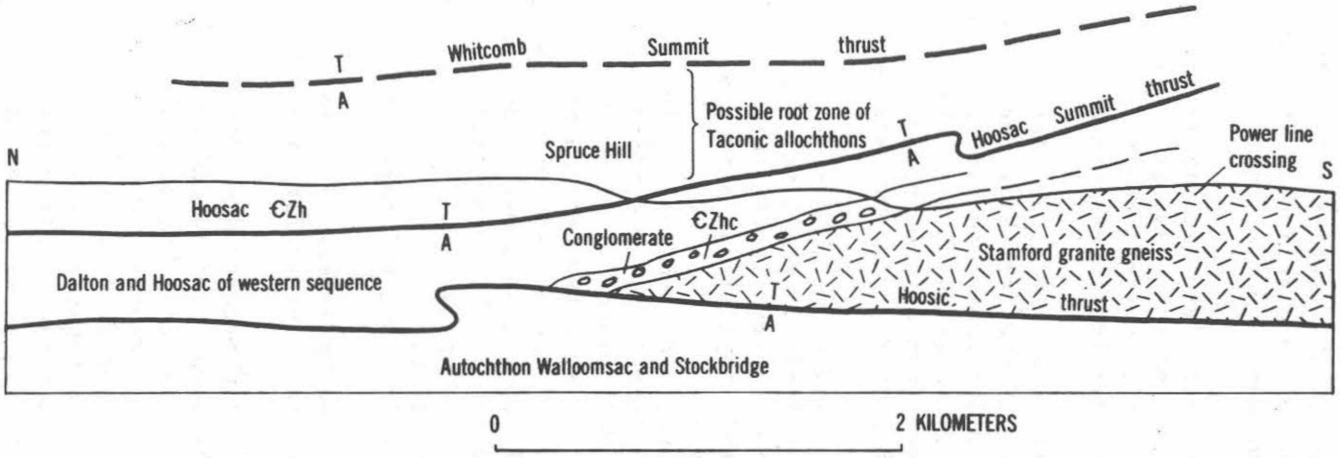


Figure 11. Sketch of Hoosac Mountain looking east from Mount Greylock, showing position of Hoosic thrust with wedge of Berkshire Massif with unconformable Hoosac cover and higher thrusts. T=Toward A=Away, show movement on fault

Hoosac Mountain than on Mount Greylock. Stratigraphic units defining recumbent metamorphic fold structures within the eastern Hoosac are truncated by the Hoosac summit thrust.

East of the Hoosac belt is the Rowe Schist, a pale-green, fine-grained chloritoid phyllite with interbedded dark carbonaceous phyllite and amphibolite all of presumed Cambrian through Ordovician age. Stanley has recently suggested (1978) that a major thrust fault (Whitcomb summit thrust) separates the Rowe from the Hoosac on the basis of recognized truncation of units in the footwall and hanging wall (see Fig. 5). The Rowe also contains abundant pods of ultramafic rock. This unit may mark the locus of crustal convergence in the Cambrian and Ordovician (Stanley, 1978).

On the basis on the stratigraphic similarities between the eastern Hoosac sequence and the Greylock section, and the lack of similarity of Greylock with western Hoosac, the root zone of the Greylock slice lies either in the eastern Hoosac belt or between belt and the Rowe.

The root zone of the Greylock slice lies east of exposed Precambrian (Proterozoic) of the Berkshire massif at this latitude. Because the Greylock slice shows the closest affinity to cover rocks of the massif, it seems clear that the lower slices of the allochthon were derived from more easterly sites.

Return via Rockwell Rd. to Rt. 7 along same route taken up mountain.

52.4 Turn right, north on Rt. 7 from N. Main St.

53.4 Small crops of green chloritoid phyllite, with strong late fault fabric. Crops continue intermittently for 0.7 mile. Dark Walloomsac biotite grade phyllite is seen near north end of crops.

54.4 Large crop of Walloomsac.

54.8 Crop of Walloomsac (Owl) and isoclinal F_1 folds.

55.3 Road to Jiminy Peak. Turn left for optional stop. Stop at large crops of black Walloomsac 1.1 miles west. Cataclastically deformed phyllite can be seen faulted against green phyllite of the Nassau Formation. Characteristic plication of foliation, slickensides, and bull quartz pods mark a series of late faults in the Buxton Hill fault zone. This zone projects east of the late fault zone seen at Stop 3.

Return to Rt. 7. Turn left.

56.1 Crops of Stockbridge (O€sg) and Walloomsac (Ow), Brodie Mountain ski area.

56.4 Large outcrops of sheared Walloomsac in a late thrust zone. Slickensides, sulfide quartz mineralization mark faults in Buxton Hill zone.

56.9 Stop 7. Large roadcuts in Stockbridge (O€sg). Excellent recumbent folds can be seen, crossfolded by folds in N. 20° W. 22° NE dipping axial planes. The origin of the cross folds is not known but may be an expression of compression of a faulted sliver within the Buxton Hill fault zone.

57.1 Large crop of Stockbridge (O€sg) on east. Thin zone 1 m thick of Walloomsac in a slickensided fault sliver is traceable for 75 m in this outcrop. This is an excellent example of character of the fault slivering within this late fault zone.

58.0 Large crops of fault slivered and cataclastic Walloomsac opposite the Mill on the Floss.

The valley to the north at South Williamstown to the east are highly fault intercalated zones of green albitic and nonalbitic phyllite of the Greylock slice. To the west and north are green phyllites of Brody Mountain and Deer Hill. Exact placement of the boundary of the Greylock slice has not been possible. Allochthonous rocks on the northern end of Brody Mountain, however, are separated from the autochthon by a complexly intermixed zone of Walloomsac and green phyllite similar to the zone of mixed rocks seen below the Chatham slice at Stop 3, according to work by Don Potter. Because the Greylock slice does not have similar emplacement breccias and because the Greylock stratigraphy contains a greater abundance of albitic rocks than the Brody Mountain slice, the two slices are believed to be discretely different allochthons.

62.1 Intersection Rt. 43. Continue north on Rt. 7.
At crest of hill, excellent view of Mount Greylock and the Hopper, and the Green Mountains to the north. The broad carbonate valley extending from Williamstown east to North Adams consists of complexly folded rocks that appear to be detached from the Green Mountains by a major thrust fault that roots in the Hoosac Gap area. This fault slice, the Stone Hill slice, is named for exposure of the faulted rocks on Stone Hill south of Williamstown.

63.4 Turn right on Scott Hill Rd. and shortly turn left on Stone Hill Rd.

63.7 At dirt road, continue to north if permission to drive in is available. If not, we will walk in.
The Stone Hill section can be traced north to Buxton Hill where slivers of Stamford Granite Gneiss, Dalton and Cheshire thrust across units b and c of the Stockbridge in a complex thrust zone (see Stop 9).

The Stone Hill slice is believed to be a thin flap of autochthon originally rooted in the Adams or North Adams area that was thrust westward out of the North Adams gap area during an early deformation stage.

East-west trending hinge lines for early folds dominate the structure within the slice eastward to Mount Greylock where a late fault, the Clarksburg thrust, truncates structures in the slice.

64.5 Stop 8. Stone Hill slice.

One of the most complete stratigraphic sections of the Dalton Formation through unit C of the Stockbridge Formation is exposed in the area of Stone Hill. Thin Cheshire Quartzite 10-0 m thick is interlayered with underlying black quartzose phyllite of the Dalton Formation. Dolostone of unit a of the Stockbridge overlies the Cheshire. Lithostratigraphic units of the Stockbridge here match closely rock section of the Vermont Valley sequence to the north.

The most anomalous features of the Stone Hill section are the very thin Cheshire and the dissimilarity of this section to the Dalton-Cheshire section exposed on the Green Mountains to the north. Dark quartzose schists with a very thin quartzite is also a characteristic of the more easterly belt of Dalton and Cheshire mapped along the base of Hoosac Mountain and in the North Adams gap area.

Excellent recumbent folds can be seen in the cliffs above the road. The contact between the Cheshire and dolostone of unit a of the Stockbridge can be seen at the base of the quartzite cliffs to the north.

65.0 Return to Rt. 7. Turn right.

66.9 Just after Bee Hill Rd. turn left on Thornliebank Rd. Crops to right are Chesire Quartzite.

67.0 Turn right on Hawthorn St. Park at east edge of field.

Stop 9. Buxton Hill - Outlier of Stamford Granite Gneiss and blastomylonite and the sole of the Stone Hill slice.

The ridges to the south consist of blastomylonitic gneiss and Dalton with excellent recumbent fold thrust style. Syntectonic biotite from the blastomylonite yielded a K-Ar age of 387 ± 14 m.y. (394 ± 14 m.y.).* The biotite age is interpreted as a cooling age and a minimum for emplacement.

Crops around the north and east end of the hill are dolostone of the autochthon. Continue straight down Hawthorn St. to intersection. Turn left on Buxton Hill Rd. Follow Buxton Hill to next intersection.

67.6 Turn right at end of Buxton Hill Rd.

67.9 Intersect Rt. 7 and 2. Bear right around island and follow Rt. 2 to east. Williams College.

69.7 Luce Rd. east of Williamstown. Follow Rt. 2 east to North Adams and beyond on Rt. 2 and 8.

79.0 Just past mills, east of North Adams, turn left on Rt. 8 north.

79.6 Just after Red Mill and entrance to natural bridge, stop.

Stop 10. Hoosic thrust.

Herz (1961) drew the Hoosic thrust at the base of the exposures which he assigned to the Hoosac Formation. Reexamination indicates that these dark albitic, graphitic schists quartzites and limy schist should be assigned to the Walloomsac. Faulting is indicated by the shallow dipping spaced crenulation cleavage.

These exposures are on the north-plunging lower limb of a large recumbent syncline cored by Walloomsac that is refolded by north-trending late folds.

If time allows, we will drive into the quarry at natural bridge where an excellent recumbent anticline in unit e of the Stockbridge can be seen. This structure is on the lower limb of the major synclinal structure.

Those wishing to examine the excellent solution features in Mr. Elder's natural bridge, may do so for a slight fee.

Those wishing to disband at this point, feel free to do so. Hard core elements may continue on to Hoosac Mountain!

Turn right at Rt. 8, where road log resumes.

79.9 Turn left on Rt. 2.

At the base of Hoosac Mountain are small crops of Dalton Formation interfingering with dark albitic schists of the western

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* age calculated using new decay constant.

autochthonous Hoosac.

82.8 At the hairpin turn, green muscovitic chloritoid and garnet-bearing schist of the eastern Hoosac may be seen. Excellent recumbent folds outlined by thin vitreous quartzite. This section is separated from the autochthonous Hoosac by the Hoosac summit thrust.

83.3 Top of Hoosac Mountain by observation tower. Stop 11.

Excellent view back at Greylock, Taconic Range beyond, Green Mountains, and the North Adams Gap. Summary discussion of the relationships of the Hoosac-Greylock-Taconic belts and paleogeographic reconstructions.

- End of trip -

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TRIP B-12

PRECAMBRIAN STRUCTURE AND STRATIGRAPHY OF THE SOUTHEASTERN ADIRONDACK UPLANDS

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ABSTRACT: The area of interest for this paper is the northern portion of the Bolton Landing quadrangle and adjacent parts of the North Creek and Paradox Lake quadrangles. Although there appear to have been at least five episodes of folding in the region, the southeastern Adirondacks appear to have undergone only four of the events (F-1, F-3, F-4 and F-5). F-1 folds are large nappes. F-3 folds range from isoclinal to tightly appressed similar folds in the study area. F-4 folds are moderately appressed similar folds, and F-5 folds are relatively open similar folds. A large body of charnockite associated with F-3 folding has the geometry of a nappe but was emplaced as a magma in advanced stages of crystallization. A structural dome of leucocratic granite was produced anatectically and solidified after F-5 folding. Similar dome-like bodies of granite which do not show evidence of anatexis have fabric elements suggesting they were subjected to all four episodes of folding. The stratigraphic column of metasedimentary "formations" interspersed with "formations" of layered granite and quartzofeldspathic gneiss proposed by Walton (Walton and deWaard, 1963) is reinterpreted as recumbent synformal bodies of metasedimentary

rocks separated by antiformal granitic nappes whose amplitudes are measured in tens of kilometers.

STRUCTURE

The southeastern-south central Adirondacks appear to have been subjected to at least five episodes of folding (Turner, 1979). F-1 folds are the most enigmatic because they fold foliation, but no earlier fold set has yet been recognized in the three-dimensional domain of basement plus supracrustal rocks in the study area. They are also the most difficult to map due to the subsequent multiple deformations of the terrane. F-1 folds are large nappe structures, the axial planes of which strike east-west and dip gently to the north (vertically in the one root zone recognized). F-1 fold axes plunge gently east or west, depending on later cross folds.

F-2 folds are isoclinal to tightly appressed similar folds. They are associated with intrusion of highly viscous charnockitic magma from the vicinity of the Marcy anorthosite massif on the north. Axial planes strike east-west and dip moderately to the north, with dip becoming steeper and approaching vertical at the southern margin of the charnockite. Plunge of axes is shallow.

F-3 folds are isoclinal to tightly appressed similar folds in this area. They are associated with intrusion of highly viscous charnockitic magma from somewhere to the south or southeast. Axial planes strike progressively from N 30 E to S 80 E from west to east across the Bolton Landing quadrangle and dip moderately to the southeast and south. Plunge of axes is gentle to the northeast and southwest, depending on the domain of cross-folding and doming.

F-4 folds are moderately appressed similar folds. Axial planes strike S 60-70 E and dip steeply south to vertically. Axial plunge is 0-20 degrees east or west, depending on cross fold domain.

F-5 folds are open similar folds whose axial planes strike gradationally from N 20 E in the southeastern Adirondacks to N 20 W in the south central Adirondacks. Dip of axial planes is very steep to vertical. Axial plunge is horizontal

F-1 nappes have been studied to the west of the study area (Turner, 1979; McClelland and Isachsen, 1979; and others) but evidence for such in the Bolton Landing quadrangle is still circumstantial. F-2 nappe-like bodies of charnockite have been reported a few kilometers to the north of the study area (Turner, 1979), but no F-2 structures are yet recognized in this area. An F-3 nappe-like body of charnockite and associated structures comprise a significant portion of the study area (Turner, 1971 and 1979). F-4 folds are common and well-defined in the study area. F-5 folds are present in the study area and commonly produce a basin and dome map configuration because of their high angle of intersection with F-3 and F-4 folds.

F-1 and F-2 folds are locally difficult to distinguish from each other because of the similarity of axial plane orientation in some portions of the Adirondacks. Romey and Jacoby (1978) believe that in the northwest Adirondacks F-1 folds are enormous nappes, but they have not yet been able to demonstrate the existance of such. McClelland and Isachsen (1979) suggest that the Wakely Mountain nappe (F-1) of DeWaard and Walton (1967) may have an amplitude on the order of 70 kilometers. The length of the trace of the axial plane in the root zone of the Wakely Mountain nappe is on the same order of magnitude as its amplitude, although there is a suggestion from preliminary studies that the axial trace may continue a few tens of kilometers to the southeast into the North Creek quadrangle.

F-2 folds associated with the intrusion of charnockitic magma from the north are of limited regional significance. Although the charnockitic lobe, which has some features of a nappe structure, has an axial trace length on the order of 50-70 kilometers, the degree of appression of folds south of its "leading edge" decreases away from the contact.

F-3 folds are hypothesized to be associated with the intrusion of a charnockitic magma from the southeast because elements of the geometry of the charnockitic sheet or lobe (Turner, 1971) are parallel to elements of these folds. In the study area, F-3 folds are isoclinal to tightly appressed and have been suggested to be portions of nappes (Turner, 1979). To the west northwest of the study area, F-3 folds become progressively less appressed and, in the Newcomb quadrangle, can be described as open folds. To this extent, F-3 folds may be of as limited a regional significance as are F-2 folds.

In the study area F-3 folding produced an incipient axial planar foliation in the more quartzose units, but pre-existing foliation in gneissic units is folded by F-3 folds. In one outcrop of "basement" paragneisses, polycrystalline aggregates of sillimanite are rotated into parallelism with the axis of a large F-3 fold. In other outcrops, sillimanite needles parallel the axes of F-3 folds. Mineral lineations, measured axes of minor folds and beta intersection stereographic projections are in close agreement with respect to F-3 folds in the area.

The tabular body of charnockite associated with F-3 folding underlies about 340 square kilometers of terrane and is 300-400 meters thick in the study area. Berry (1961) studied the eastern portion of the body in the Whitehall quadrangle. He found evidence of shearing near the base of the sheet and hypothesized that it had been emplaced by thrust faulting. Careful examination of the base of the body in the study area has produced no evidence which would support Berry's hypothesis.

The charnockitic body is sill-like, although its "leading edge" is rounded or lobate. Some igneous layering has been mapped in this study area. A central layer of anorthosite is bordered by jotunite below and mixed jotunite, anorthosite lenses and mangerite above. The outer envelope of the body is mangerite on the bottom and in much of the leading edge, but mangerite grades into charnockite on top. The form and igneous layering of this body are strikingly similar to what Crosby (1968) called the Jay-Whiteface nappe in the northeastern Adirondacks and what Martignole and Schrijver (1970a and 1970b) described in the east lobe of the Morin anorthosite massif. Although this author hesitates to use the term "nappe" to describe the charnockitic body because of the connotation of ductile, solid-state flow, and here there is evidence of magmatic emplacement, the shape of the body and the structural association of F-3 folds tend to comport in a general sense with the tectonic concepts associated with nappes. To that end, this author cautiously calls the body "the Lake George nappe" in the same vein as he has termed a similar body at the southern border of the Marcy anorthosite "the Minerva nappe".

F-4 folds are believed to be of regional importance insomuch as folds of similar geometry occur across much of the Adirondacks (Turner, 1979; McClelland and Isachsen, 1979; Geraghty, 1979; Wiener, 1979). All F-4 folds mapped by the author across several quadrangles fold pre-existing foliation but produce a pervasive quartz rodding or lineation parallel to fold axes. F-4 folding produced some of the most easily mapped structures because of these fabric elements, as well as the relatively slight impact of F-5 folding on F-4 features in map pattern. In the quadrangles to the west,however, the low angle of intersection between F-4 axial traces and both F-1 and F-2 axial traces can create some confusion unless attitudes of axial planes are known.

F-5 folds are open similar folds which occur across a significant portion of the Adirondacks. However, the gradual and progressive change in strike of axial planes from the southeast to the south central areas suggests that these folds may be a sub-regional feature. F-5 folds fold foliation and rotate lineations. No mineral fabric ostensibly produced by F-5 folding has been recognized, nor is any expected except perhaps at the petrofabric scale in marble.

Several dome-like structures occur in the study area. Bickford and Turner (1971) described a large granitic dome just to the southeast of Brant Lake, and the reader is referred to that publication for a more complete statement. It should be noted that Turner's concepts of the area's stratigraphy and structure have evolved considerably since that publication. However, in brief, the core of the dome is a highly foliated alaskitic granite (leptite) and is surrounded by a heterogeneous assemblage of granitic paragneisses which lie stratigraphically below the basal metasedimentary unit. Modal analyses of most of the alaskitic rocks plot near the ternary minimum composition on the 2000 kg/cm^2 isobaric diagram of the system $Or-Ab-SiO_2-H_2O$ (Tuttle and Bowen, 1958). The temperatures around the ternary minimum correspond to temperatures of metamorphism recently suggested by Bohlen and Essene (1979) for this area.

STRATIGRAPHY

Metasedimentary strata which are interpreted to be the base of a relatively coherent sequence of metasedimentary rocks are in contact with various granites, granitic gneisses, paragneisses and charnockitic rocks in the study area. The stratigraphic column, from the base, is: garnet-sillimanite gneiss (khondalite), a local highly graphitic schist, marble, thinly interbedded graphitic-pyritic-sillimanitic schists and quartzites, a thick quartzite, and possibly another section of thinly interbedded schists and quartzites. Total thickness is difficult to estimate because of structural complexity. To the north and west, the basal khondalite and graphitic schist disappear, leaving the marble as the basal unit. In the Paradox Lake quadrangle, immediately to the north, Walton (Walton and deWaard, 1963) suggested that the basal marble rested on an unconformity because of the diversity of rock types in contact with one of the surfaces of the stratum of marble. Although this author has proposed that the charnockites which are in contact with the marble were emplaced as highly viscous magmas in a catazonal tectonic environment, there is agreement with Walton's hypothesis of an unconformity with respect to the geometric relationship between the marble and the other granitic gneisses.

Walton (Walton and deWaard, 1963) proposed a stratigraphy for the southeastern Adirondacks which consisted of metasedimentary "formations" interlayered on a large scale with "formations" of granitic gneisses. He distinguished the "layered" granitic gneisses from the "basement" granitic gneisses with the general observation that the former tended to be K-feldspar rich and the latter plagioclase feldspar rich. Turner (1970) accepted Walton's stratigraphy and added a unit to it without essentially any modification of concept. This author does not now concur with Walton's general observation and has found that the spectrum of layered granitic gneisses generally corresponds petrographically with the spectrum of basement granitic gneisses. This author (1979) proposed that the layered granitic gneisses are actually basement granitic gneisses emplaced in a pseudostratigraphic column as the cores of a pile of large nappes.

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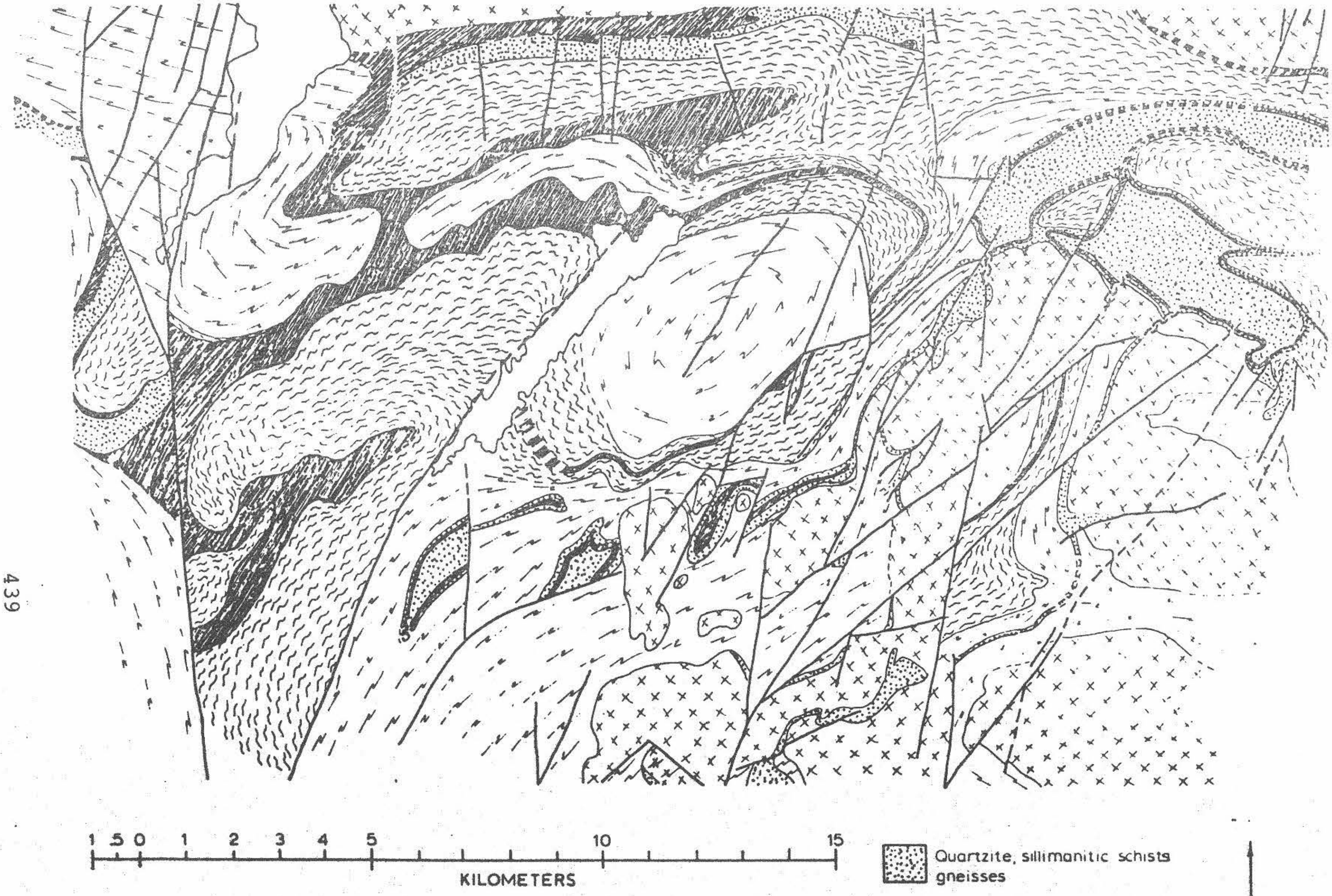
LOCATIONAL MAP - SAME AREA AS BEDROCK MAP WITH OUTLINE OF GEOLOGIC CONTACTS AND REPRESENTATIVE ATTITUDES. FROM UPPER LEFT, SE CORNER SCHROON LAKE QUADRANGLE, SOUTHERN BORDER PARADOX LAKE QUADRANGLE, NE CORNER NORTH CREEK QUADRANGLE AND N HALF BOLTON LANDING QUADRANGLE.

PLATE 1

(ACKNOWLEDGEMENT - NORTH CREEK PORTION BY GERAGHTY (1973) AND PARADOX LAKE PORTION BY WALTON (1960))



BEDROCK GEOLOGY OF PARTS OF THE SCHROON LAKE, NORTH CREEK, PARADOX LAKE AND BOLTON LANDING QUADRANGLES, ADIRONDACK MOUNTAINS, NEW YORK.

BRIAN BUDDINGTON TURNER 1979

PLATE 2

OUTCROP - STOP #4 - SOUTH SIDE OF N.Y. ROUTE 8, NEAR NORTH POND, BOLTON LANDING 15' QUADRANGLE - THREE FOLD SETS.

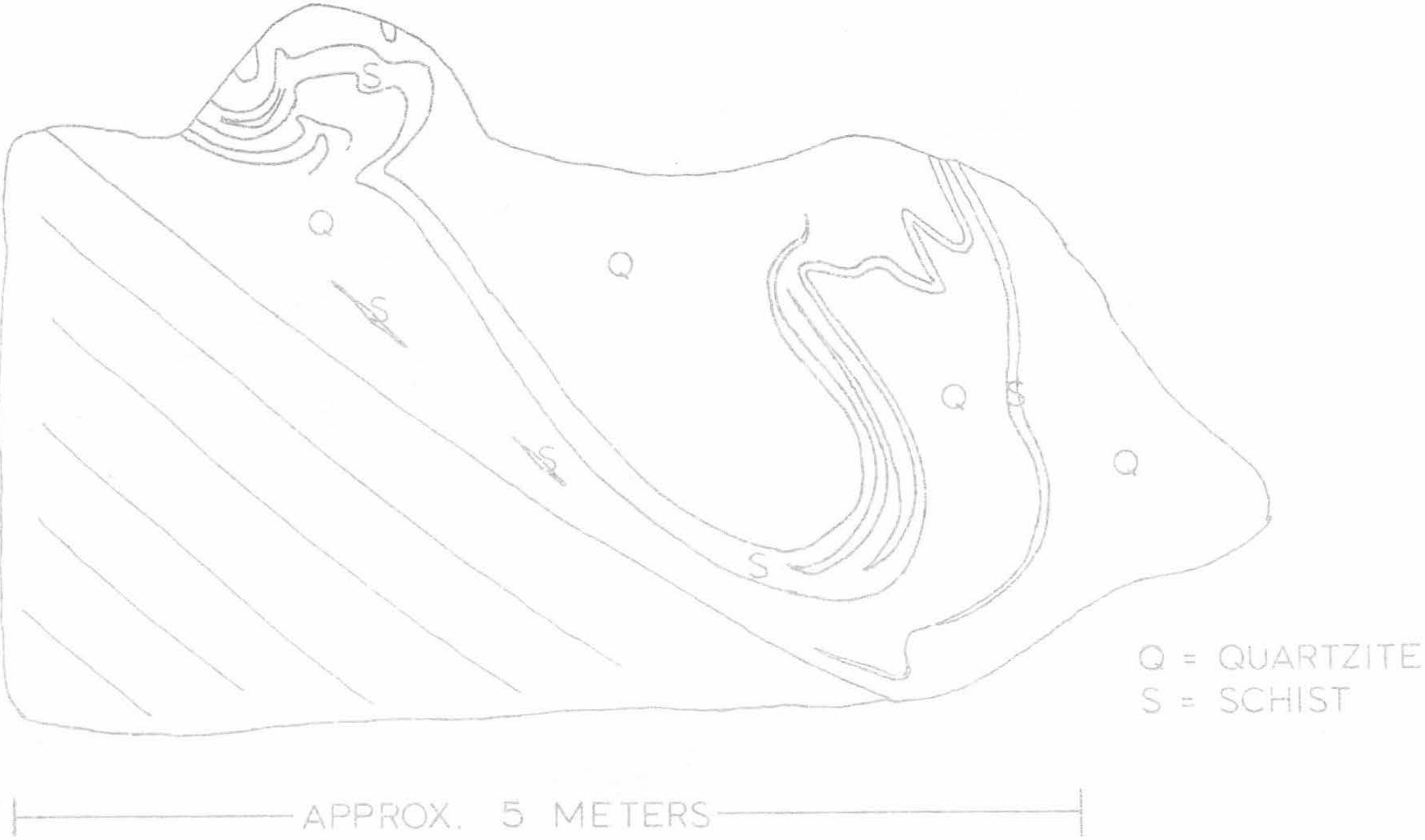
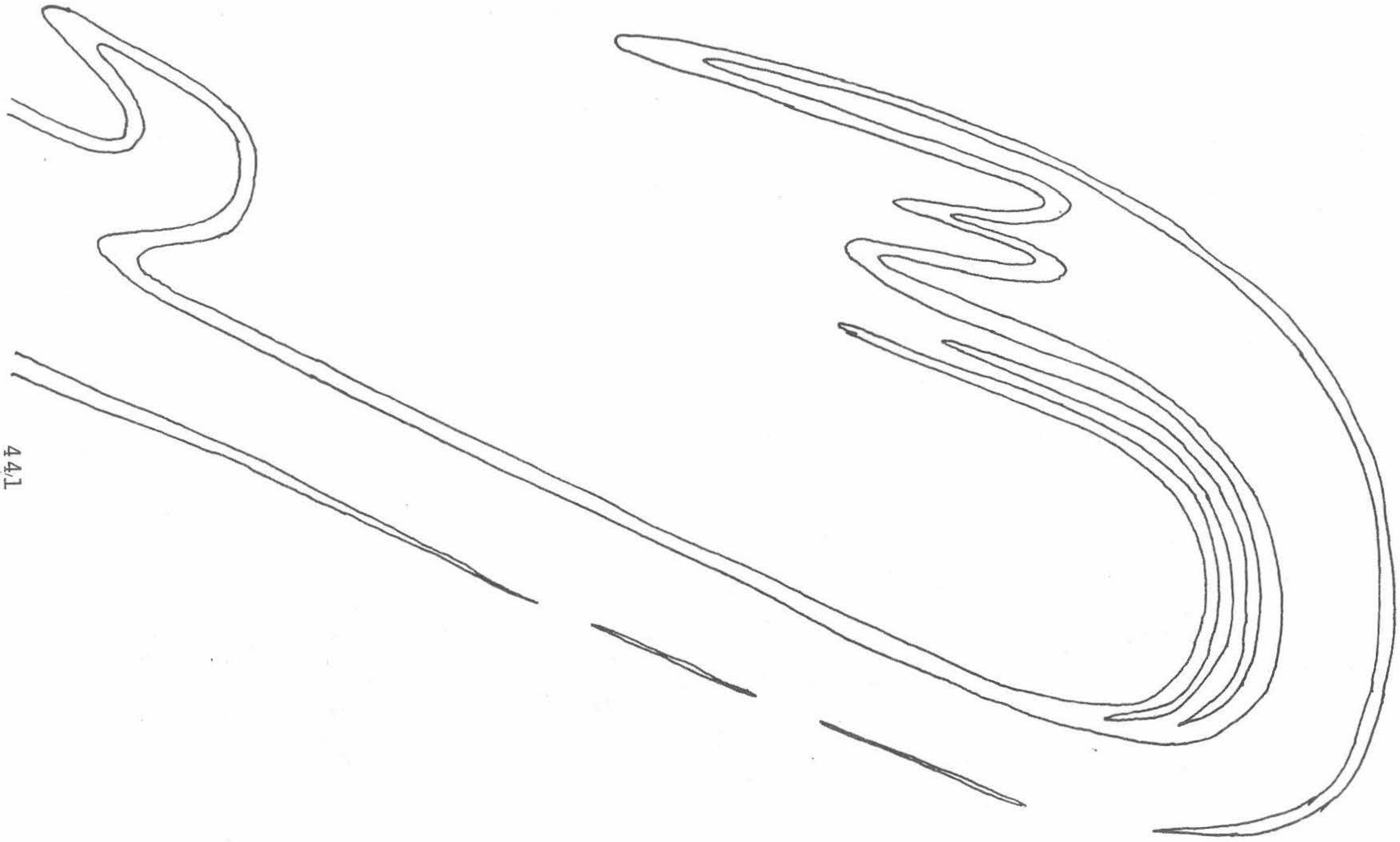
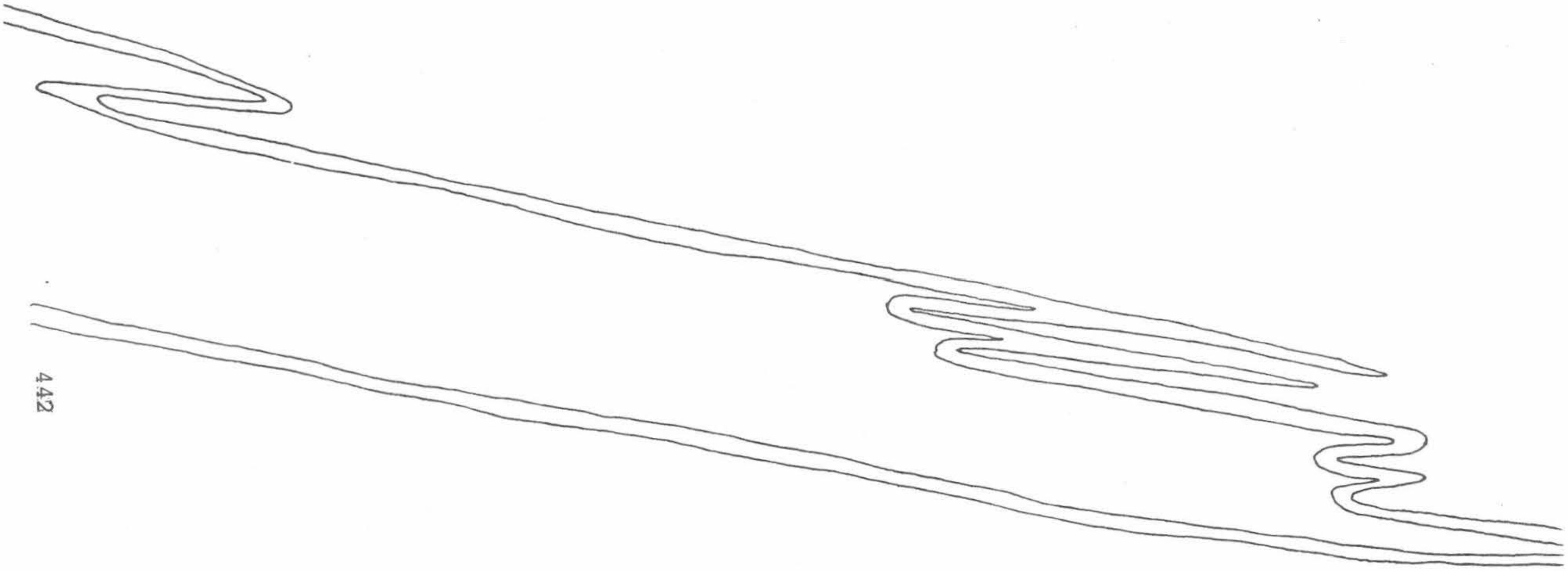


FIGURE 1



PROJECTED CONFIGURATION OF FIG. 1 IF LAST FOLDS (F-4) WERE REMOVED. F-2 (?) SYNFORM IMPOSED ON F-1 ISOCLINE.

FIGURE 2



PROJECTED CONFIGURATION OF FIGURE 1 IF BOTH REFOLD SETS (F-4 and F-2 (?)) WERE REMOVED.

F-1 ISOCLINE REMAINS.

FIGURE 3

FIELD TRIP

Although the field trip departs from the RPI Houston Field House, the road log mileages for the two legs of the trip start at the ends of the ramps for northbound Exits 24 and 25 of Interstate 87 (the Adirondack Northway) for future reference. The distance from RPI to Exit 24 is approximately 65-70 miles.

MILE - FIRST LEG

0.0 Field trip starts at end of ramp of northbound Exit 24, Interstate 87. Turn right toward Bolton Landing. Within 50 meters turn right again and head south on the River Road.

0.5 STOP #1 - Outcrops on right (west) side of road are largely alaskitic granites with some strongly contorted layers of paragneiss. Although the outcrop is just outside the leader's field area, it was mapped at his suggestion by McConnell in 1964 and is deemed to be "basement". A two-meter exposure of an isoclinally refolded isoclinal fold is one of the main features of this stop. The first-formed fold has axial plane foliation and is believed to be an F-1 fold. The second-formed fold deforms foliation and is believed to be an F-3 fold. The other important feature of this exposure is the strong suggestion that the granite is an anatectic product of the paragneisses.

Turn cars around, head back to I87 and continue north to Exit 25. RESET mileage for the second leg of the field trip which begins at the end of the ramp for northbound Exit 25.

MILE - SECOND LEG

0.00 End of ramp, Exit 25. Turn right onto N.Y. Route 8 and proceed eastward through the hamlet of Brant Lake and thence along the lake of the same name (Bolton Landing 15' quadrangle).

7.3 Turn left onto Palisades Road. It is difficult to see this turn until you are practically on top of it. Go 1.3 miles to the first stop of this leg.

8.7 STOP #1 - At the T-intersection with the Beaver Pond Road, an outcrop of Older Paragneiss (informal stratigraphic name) is located on the south side of the road. The outcrop contains a heterogeneous group of gneisses, quartzites and amphibolites. Of particular interest are the rotated (penetrative) clots of sillimanite and minor folds whose axes plunge about 20° in an azimuthal direction of 60°-65°, which is the local axis of F-3 folding. This unit is believed to lie unconformably below the base of the supracrustal metasedimentary rocks, and in the opposite stratigraphic direction grades into granitic gneisses. A whole-rock, Rb-Sr age of 1210± 45 m.y. has been obtained from this outcrop.

Turn around and head back to N.Y. Route 8; turn left on Rt. 8.

10.3 STOP #2 - Brant Lake Gneiss (informal name) is exposed on the south side of the road. This rock is found throughout a structural dome to the south of this exposure. This granitic gneiss has a very uniform modal composition of approximately 35% quartz, 25% microcline, 30% sodic plagioclase, 3% mesoperthite, 5-7% biotite and 1% opaques. The granitic rocks of this dome yield a whole-rock, Rb-Sr age of 1119±39 m.y. It has been proposed that this granitic gneiss is an anatectic product of the Older Paragneiss (Bickford and Turner, 1971). This is a very brief stop.

10.7 OPTIONAL STOP - (1979 NEIGC-NYSGA will not stop here) - Older paragneiss in the road cut on the north side of Rt. 8 consists of quartzofeldspathic gneisses with accessory biotite and garnet. Most, if not all, minor isoclinal folds in this exposure show axial planar foliation. This paragneiss mantles the structural dome whose granitic core rock was observed at Stop #2, and may be traced almost continuously around the dome (see Plate 2 of accompanying description).

14.7 STOP #3 - In the road cut on the east side of the road is perhaps the simplest set of folds in the Swede Mountain structural complex. A large isoclinal synform is outlined by the contrast between quartzite and sillimanitic schists. Sillimanite needles just above the quartzite closure plunge about 5° in an azimuthal direction of 80°. Closer to the road, a minor fold crenulation plunges 20° in an azimuthal direction of 80°. The synform is thought to be an F-3 fold. The isoclinal synform is clearly refolded. A stereographic beta diagram of attitudes of compositional layers shows an intersection which plunges 22° in an azimuthal direction of 116°, which comports with the axis of F-4 folding. About 15 meters uphill along the road cut, a pair of refolded isoclinal folds about 3 meters long may be observed. Measurements of hinges and crenulations in these produce the same pair of data as for the large refolded synform.

15.4 STOP #4 - Pull into turn-out area on the right and park. Walk back across Rt. 8 and continue east for about 50 meters. On the south side of the highway is a low road cut about 70 meters long. An isoclinal fold, whose limbs may be traced 55 meters to its closure, is exposed. Crenulations in the hinge plunge about 10° in the azimuthal direction of 103°. At least one minor isoclinal fold within the larger isocline displays axial plane foliation. This is probably an F-1 fold. In the eastern part of the road cut, the limbs of the isocline have been refolded by an F-4 fold. A beta diagram of the refold shows an axis plunging 30° in the azimuthal direction of 117°.

Returning to the western end of the road cut, and at about right angles to the cut, the outcrop portion of the exposure contains evidence of three episodes of folding (see Figures 1,2 and 3 of accompanying description). A complex F-1 isocline has been isoclinally refolded into an F-? synform, and several smaller F-4 folds have been superimposed on the refolded mass. Axial plane foliation in the F-1 fold has been rotated by F-?, and a weak F-4 foliation with strong quartz rodding penetrates the outcrop. A beta diagram of compositional layers in the nose of the synform shows an intersection plunging about 5° in an azimuthal direction of 110°. This does not correspond with an F-3 axis, and may represent an F-2 refold. A beta diagram of the limbs of the refold shows an intersection plunging 15-20° in an azimuthal direction of about 120°, which corresponds with F-4 fold axes. Although the beta maxima are only 10° apart in azimuth, the difference is believed to be real because measured hinge axes correspond with the 110° beta direction and measured quartz rods with the 120° beta direction.

Return to vehicles, continue around turn-out loop back to Rt. 8, turn left and proceed back in a westerly direction.

16.0 Pull into turn-out area on left. At this point the group may wish to split into two parties. Assuming that time permits, the leader will take a group of physically able participants on a 4-kilometer hike (total distance) to examine evidence of large nappe structure in Swede Mountain. Those persons not wishing to take the hike are invited to examine the 1.0 kilometer of nearly continuous exposure of Swede Mountain beside Rt. 8, which includes the structures seen at Stop #3.

After returning from the hike, if time still permits, an attempt will be made to round up all participants for a final but optional stop. Proceed westerly on Rt. 8 toward I87.

28.3 Within seeing distance of I87, turn right onto the Starbuckville Road, continue until a long one-lane bridge is crossed and look for an intersection.

29.0 Turn left onto the River Road and go 0.25 miles.

29.25 STOP #6 (optional) - You are in the northeast quadrant of the North Creek 15' quadrangle, mapped by Geraghty (1973). The outcrops on the east side of the road are predominantly quartzofeldspathic schists and gneisses with abundant biotite, sillimanite and garnet (kinzigite) and quartzite. The author believes the kinzigite is an iron-rich facies of the basal khondalite seen in Swede Mountain. Some minor folds display axial plane foliation and may be F-1 folds. Numerous axial traces of minor folds strike 60°-70° in azimuth, a biotite-sillimanite crenulation shows plunge of about 42° in an azimuthal direction of 59°, a beta diagram of one fold shows an intersection at plunge 26° in an azimuthal direction of 53°, and one minor fold hinge plunges 15° in an azimuthal direction of 70°. The foregoing reflect F-3 folding. Several F-4 cross folds are present and measured lineations and hinges have a range of plunges of 45° to 55° in azimuthal directions of 115° to 120°. At least one F-5 fold is apparent in the cutcrop, and its axial trace is about 10° in azimuthal direction.

GOOD LUCK ON YOUR TRIP HOME!

Late Wisconsinan - Recent Geology of the Lower Rondout Valley, Ulster County, Southeastern New York

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Lower Rondout Creek extends eleven miles northeast from High Falls through Rosendale to the Hudson River at Kingston, New York. In this distance it drops from an elevation of about 120 feet at High Falls to sea level at Kingston. From High Falls to Rosendale the stream represents an easterly departure of the northeasterly-flowing Rondout Creek from its ancestral (preglacial) valley northwest of the Shawangunk Mountains. Maximum bedrock depths in the central Rondout Valley are considerably lower than the level of High Falls (Frimpter, 1970). A northeasterly retreating ice lobe in the central Rondout Valley with attendant proglacial impoundments and sedimentation at ever decreasing elevations controlled a final base level at about 400 feet.

At this point the ice lobe in the Wallkill Valley had begun to melt in such a way that the 400 foot level could not be maintained in the central Rondout Valley and base level was lowered to 250 feet or less. In the lower Wallkill (now lower Rondout) most sand deposits occur below 260 feet. The deflected Rondout now flowed into the northern (lower) portion of the ancestral Wallkill Valley bringing with it considerable sands and silts and some gravels as it cut headward in the central Rondout Valley cannibalizing proglacial sediments previously formed at higher elevations. The ultimate effect may have been the deposition of "wall-to-wall" sand in the lower Rondout Valley.

There is some question as to whether the interlaminated (varved) clays and silts of the lower Rondout Valley are contemporaneous in part with the sands which generally overlie them. The clay beds appear to have formed in front of ice, beside ice or under floating ice. The variation in elevation of the clay-sand contact, the absence of clay from some parts of the lower Rondout Valley and the general absence of interbedded clays, silts, and sands suggest the clays were formed before the sands and were even partly eroded before the sands were deposited. This would require considerable fluctuation of base level, largely controlled by the disposition of the ice lobe in the Hudson Valley, especially opposite Kingston.

In any event the sands seem to have been deposited under fluvial conditions with an ascending base level. The maximum elevation of 250 feet seems to have been controlled by spillage into the Hudson Valley through The Hell opposite Ulster Park (fig. 1). Soils maps suggest a dissected delta at the foot (east side) of The Hell.

After some evidence of a local glacier readvance over the sandplain at Maple Hill (Connally, 1968) and the development of possible small dunes at Tillson and Maple Hill the ice on the uplands on the north side of lower Rondout Creek appears to have stagnated. The ice lobe in the Hudson Valley seems to have withdrawn little by little, lowering base level in successive stages. In response to this, Rondout Creek seems to have begun headward erosion into sands and clays and eventually the production of paired and unpaired terraces at at least six different levels (Irving, 1972).

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MAP REFERENCES

Topographic: U. S. Geol. Survey, 7½ Minute Series: Scale 1:24,000

Name	Edition	Contour Interval
Hyde Park, N. Y.	1963	10'
Kingston East, N. Y.	1963	10'
Kingston West, N. Y.	1964	20'
Mohonk, N. Y.	1964	20'
Rosendale, N. Y.	1964	20'

Soils: Soils maps of Ulster County portions of the above quadrangles are available through the Ulster County Planning Board. They have been prepared by the Board on New York State Department of Transport base maps and are based on a soil survey of Ulster County by the Soil Conservation Service of the U. S. Department of Agriculture.

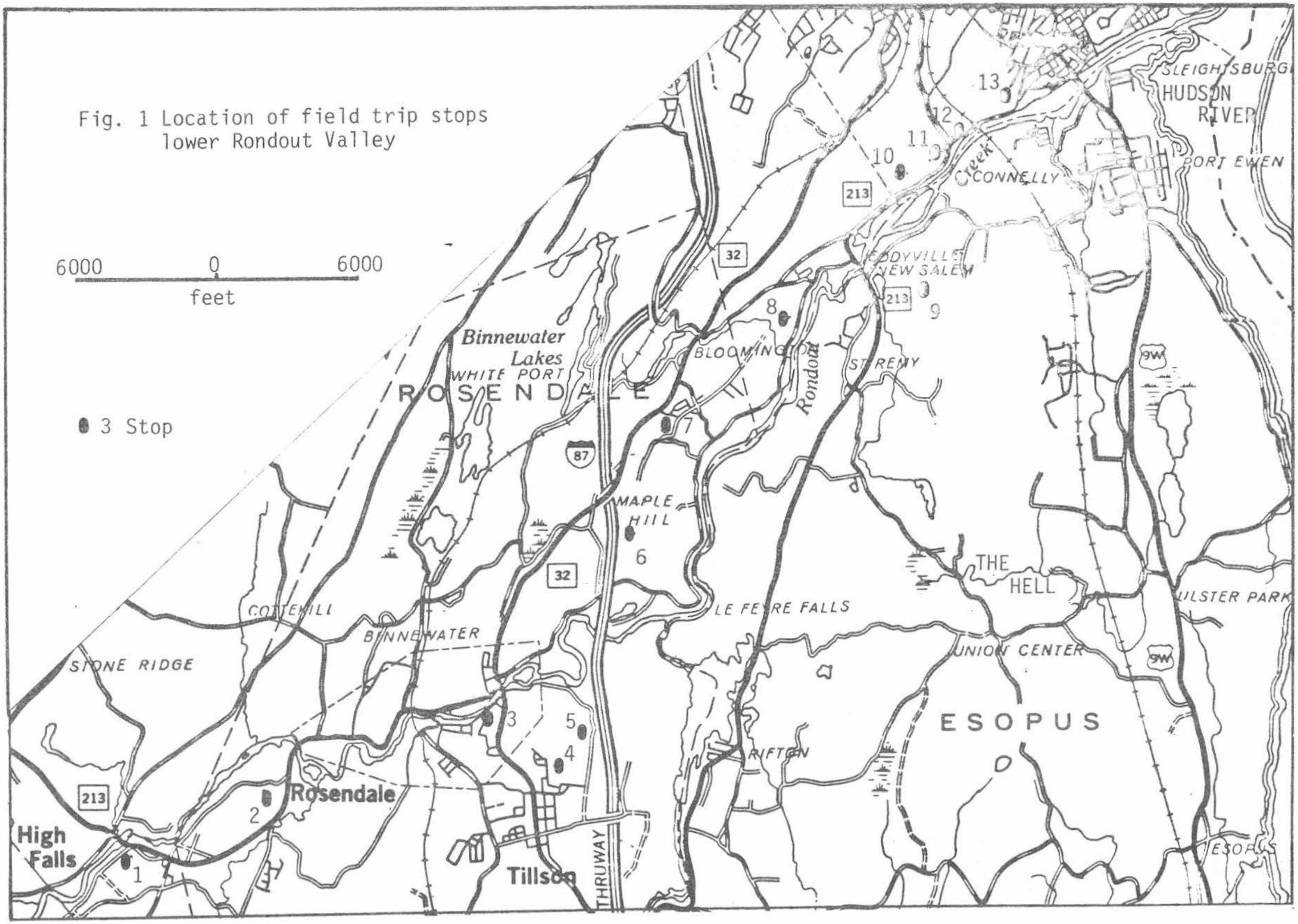

Fig. 1 Location of field trip stops lower Rondout Valley

ROAD LOG - FIELD TRIP B-13

Mileage	Cumulative Mileage	
----	-----	Leave R.P.I. grounds and proceed by N.Y. 2 and 7 across bridge over Hudson River to Expressway 787. Proceed south to N.Y. State Thruway then south to Kingston, N.Y. Mileage begins at toll booth of Thruway exit.
0.0	0.0	Toll booth, Exit 19, New York State Thruway, Kingston, New York. Bear right into traffic circle and bear right onto N.Y. 28 heading west.
0.3	0.3	Bridge over New York State Thruway
0.1	0.4	Traffic lights.
0.2	0.6	Bridge over US 209. Bear right immediately after bridge onto offramp circling to US 209 and Ellenville.
0.25	0.85	Bear right onto US 209 and pass under NY 28 bridge heading south on US 209 across Esopus Creek floodplain.
1.25	2.1	Bridge over Esopus Creek.
3.6	5.7	Esopus Creek and floodplain on right.
3.7	9.4	Veer left onto Leggette Road in Stone Ridge. The Bank on near left.
0.25	9.65	Divide between present day Esopus and Rondout drainage systems ca. 400 feet.
0.3	9.95	400 foot sandplain, somewhat dissected and possibly terraced for next 0.4 miles.
0.4	10.35	Road descends through cut in sandplain for 0.15 miles.
0.8	11.15	Yield. Turn right onto Lucas Ave.
0.1	11.25	250 foot sandplain.
0.2	11.45	Stop. Turn left onto NY 213.
0.1	11.55	Bridge over Rondout Creek.
0.05	11.6	Berme Rd. on right. Park where possible. Continue on NY 213 after Stop.

STOP NO. 1 - High Falls. When blocked to the north while at a 400 foot base level Rondout Creek apparently found an outlet eastward into, under or around ice in the lower Wallkill drainage system. The river later established a base level at 250 ft. and subsequently has cut down to approximately 170 feet, the present level of bedrock (late Silurian Rondout Formation) at the top of the falls. The 250 foot sandplain can be seen to the north.

Mileage	Cumulative Mileage	
0.25	11.85	Village of High Falls, Delaware and Hudson Canal, Locks and Museum.
0.25	12.1	Enter Town(ship) of Rosendale.
0.2	12.3	Hairpin turn left off NY 213 onto Old NY 213 just as approaching 210 foot sandplain terrace.
0.2	12.5	Road veers left but continue straight on Old NY 213.
0.1	12.6	Stop. Turn right on Bruceville Rd. Rondout Creek on left.
0.95	13.55	Park on right side of road. Continue on Bruceville Rd. after Stop.

STOP NO. 2 - Hurley Sand and Gravel Co., Inc. Sand and gravel pit. This extensive pit has been developed in the 210 foot sandplain terrace. Remnants of the original 250 foot sandplain occur locally. Although stratigraphic exposures are poor, several large piles of coarse water-worn gravels remaining from sieving operations attest to the considerable gravel content of the sands. About 50 feet of gravels and sands fine downward to silts which in turn are underlain by clays. No where else in the lower Rondout Valley are gravels so abundant in the upper sands.

0.15	13.7	Till on hillside to left.
0.05	13.75	Stop. 90 foot floodplain ahead. Turn left onto NY 213.
0.2	13.95	Bridge over Rondout Creek.
1.3	15.25	Turn right and cross bridge over Rondout Creek. Village of Rosendale.
0.1	15.35	Keep left on James St. and continue on sloping sandplain terrace ca. 100 foot level.
0.35	15.7	Descend to 50 foot floodplain and/or terrace.
0.1	15.8	Pull over to right. Do not block driveway. Continue on James St. after Stop.

STOP NO. 3 - Rondout Creek, Rosendale. This floodplain and/or terrace was flooded in the summer and fall of 1955. Buildings on the north side of the river were flooded to the middle of their second stories. Part of the Army Corps of Engineers' stream channelization efforts in response to the 1955 floods can be observed.

0.15	15.95	Stop. Right onto NY 32-213.
0.25	16.20	Town of Rosendale Recreation Center on 70 foot terrace on right. Ascend through sands to sandplain level.
0.65	16.85	250 foot sandplain for next 0.35 miles. Village of Tillson.
0.35	17.2	Turn left onto Grist Mill Rd. at U.S. Post Office.
0.05	17.25	Turn left onto Hardenburg Ave. Drive north up the gentle slope of the 250 foot sandplain.
0.3	17.55	Four-way stop. Jog left and continue north on Hardenburg Ave.
0.1	17.65	Entering region of low sand hills on 250 foot sandplain. Swing right (east).
0.05	17.7	Stop. Turn left onto Mt. View.
0.1	17.8	Pull over to right. Continue north after Stop.

STOP NO. 4 - Tillson sand hills. Low sand hills rise 10 to 15 feet above the 250 foot sandplain along the southern margin of the Rondout Valley in the vicinity of Tillson. Inspection of a trench in the flank of one sand hill revealed a structureless non-stratified fine sand to silt. The hills are here thought to represent small sand dunes formed on the 250 foot sandplain just in advance of an ice front in the uplands on the north side of the Rondout Valley.

0.05	17.85	Turn left.
0.05	17.9	Turn right over sand hill onto Carroll St.
0.05	17.95	Turn left onto Spring St.
0.25	18.2	Stop. Turn right (south) onto Mt. View.
0.1	18.3	Swing left (east).
0.1	18.4	Stop. Turn left.
0.05	18.45	Swing right leaving sand hill area.
0.05	18.5	Stop. Continue straight (east) on Grove St.
0.15	18.65	Stop. Turn left (north) on Bloomingdale Road.
0.15	18.8	Sand hills to left (west) behind houses.

0.2	19.0	Park on left where possible. Continue north on Bloomingdale Rd. after Stop.

STOP NO. 5 - Sand pit in 250 foot sandplain. Almost the entire uppermost 110 feet of section is exposed with varying degrees of perfection. This is a shovel-stop. Sands fine downward into silts which overlie interlaminated (varved) clays and silts at about the 150 foot elevation. Extensive slump structures have been observed in the silts about 20 to 30 feet above the silt-clay interface. Gravels in the sands are fine and very infrequent. Current bedding, current and climbing ripples have been noted in the sands where bedding is generally thin to laminar.

0.1	19.1	Descend cut in sands.
0.2	19.3	Bear left.
0.2	19.5	Bear left.
0.2	19.7	50 foot terrace and sometime floodplain. Modern floodplain at 40 feet along south side of Rondout Creek.
0.2	19.9	Flood control dike on right.
0.15	20.05	Stop. Turn right (north) on NY 32-213.
0.05	20.1	Bridge over Rondout Creek.
1.85	21.95	Bridge over N. Y. State Thruway.
0.05	22.0	Turn right onto Alberts Ave. immediately after bridge.
0.35	22.35	Park on right. Return on Alberts Ave. after Stop.

STOP NO. 6 - Maple Hill sand pit in 250 foot sandplain. Here in an 80 foot sequence sands grade downward into silts which overlie interlaminated (varved) clays and silts at an elevation of about 160 feet. Little can be seen presently of the structure in the sands and silts. This pit was investigated as a potential sanitary landfill site but a high water table and water-saturated silts above the clays preclude its use for that purpose. A few low sand hills occur in the wooded area northeast of the pit. Of some interest is the till-like material overlying the sandplain near the pit entrance and elsewhere. Sieve analysis has yielded a polymodal distribution of particle sizes. This material is one line of evidence for the Rosendale Readvance of Connally (1968). Several samples of split-spoon core obtained in test-borings in the pit will be displayed.

0.35	22.7	Stop. Turn right(north) on NY 32.
0.7	23.4	Turn right onto Taylor St.
0.05	23.45	Bloomington Fire Company. Park but keep clear of fire house. Continue of Taylor St. after Stop.

STOP NO. 7 - Bloomington sandplain 190 foot terrace. Local borings, some over 100 feet to bedrock, have encountered an almost total sand-silt sequence with little or no clay. Exposures of the upper sands may be seen in cuts southeast of the fire house.

0.1	23.55	190 foot sandplain terrace.

0.05	23.6	Stop. Bear left(north).
0.15	23.75	Stop. Turn right on Main St., pass graveyard and proceed down hill.
0.3	24.05	Stop. Turn right onto Creeklocks Rd.
0.45	24.5	Lock of Delaware and Hudson Canal on left.
0.25	24.75	Large glacial clasts form "boulder train" crossing Rondout Creek on left. "Fines" have been removed from glacial till by the downcutting creek leaving clasts too large to move.
0.1	24.85	Delaware and Hudson Canal on left.
0.8	25.65	Turn around at entrance to Webster Lock Rd. on left and retrace route on Creeklocks Rd.
1.6	27.25	Pass Main St. on left.
1.0	28.25	Small bridge over Greenkill Creek. Rondout Creek and modern floodplain to right. Slightly higher floodplain terrace on far side of Rondout Creek.
0.2	28.45	50 foot terrace to right across Rondout Creek.
0.1	29.55	Pull over carefully to right. Do not block traffic. Continue on Creeklocks Rd. after Stop.

STOP NO. 8 - Sand pit. Do-it-yourself stop. This pit is developed in the side of a typical sand-silt sequence rising to a 170 foot sandplain terrace. Ultimately about 130 feet of sands and silts are exposed and none of the typical interlaminated clays and silts have been encountered, even as low as the 40 foot elevation.

0.35	29.9	Stop. Proceed straight ahead (north) out onto Canal St.
0.15	30.05	On the left, the ancestral Wallkill River probably passed. On the right the Delaware and Hudson Canal descended through locks to tidewater.
0.2	30.25	Stop. Turn right onto NY 213.
0.05	30.3	Bridge over Rondout Creek.
0.15	30.45	Turn left onto New Salem Rd. (Salem St.).
0.1	30.55	Turn right on Lake View Ter.
0.2	30.75	Turn in dead end and park. Walk uphill on path to sand pit. Retrace route along Lake View Ter. after Stop.

STOP NO. 9 - New Salem sand pits. The sequence on the hillside from the top down is as follows: The top sands occur 170 feet above the road or at about 260 feet elevation. The sands fine downward to silts for some 90 feet and red clays start about 80 feet above the road or about 170 feet above sea level. The sequence is somewhat similar to those of Stops 5 and 6 and unlike those of Stops 7 and 8.

0.2	30.95	Stop. Turn left onto New Salem Rd.
0.1	31.05	Stop. Turn right onto NY 213.
0.15	31.2	Bridge over Rondout Creek.
0.35	31.55	Ancestral Wallkill River may pass under Show Boat on right.
0.5	32.05	Park on left in entrance to chained road. Continue on NY 213 (Abeel St.) after Stop.

STOP NO. 10 - City of Kingston sand and gravel pit. Foreset beds of deltaic sands and gravels rest against steep bedrock surfaces. Sands and silts in attitudes of slump appear to have been deposited over ice. High up on the hillside to the northwest glacial striations are well-developed. Some of the foreset gravels are cemented to the hillside by means of calcium carbonate.

0.1	32.15	Gravel pit on left.
0.25	32.4	Sand pit on left.
0.05	32.45	Pull off on left and park. Continue on NY 213 (Abeel St.) after Stop.

STOP NO. 11 - Sand pit. View stop. This pit is developed in the lower portion of a sand-silt sequence rising to a 210 foot sandplain terrace to the northwest. The exposed sediments represent the bottom 160 feet or so of a 190 foot plus sequence. To the northwest sediments have been deposited against steep bedrock surfaces. Slumped sediments in the southwest corner of the pit may have been deposited over ice.

0.15	32.6	Flashing light. Stay right.
0.1	32.7	Pull off and park on right. Walk back to Davis Ave. and look northwest up the Twaalfskill Valley and Wilbur Ave. Continue on Abeel St. after Stop.

STOP NO. 12 - Twaalfskill Valley. This narrow valley incised into Upper Silurian and Lower Devonian strata may represent an ancient drainage system from the north, possibly the ancestral Esopus. The bedrock profile in the center of the Twaalfskill Valley is not entirely known. This valley appears to have allowed passage of glacial waters and sharing of base level between the Esopus and lower Rondout Valleys. Sands at the 250 foot level extend through part of Kingston up the east side of the Esopus Valley.

0.15	32.85	Pass under R.R. bridge.
0.25	33.1	Bear left up Hudson St.
0.4	33.5	Turn left onto Montrepose Ave.
0.05	33.55	Turn left onto West Chestnut.
0.2	33.75	Turn at end of road and park. Follow path about 50 paces southwest. Retrace route on West Chestnut after Stop.

STOP NO. 13 - View stop, 250 foot sandplain remnant. From the road the confluence of the Hudson River and Rondout Creek can be viewed. Glacier ice in the Hudson Valley at this point influenced drainage and effective base level in the lower Rondout Valley. A second location about 50 paces southwest of the end of the road affords a view southwest up the lower Rondout Valley as far as Maple Hill. With skill various terrace levels and remnants of the 250 foot sandplain can be distinguished.

0.2	33.95	Stop. Turn left onto Montrepose Ave.
0.1	34.05	Turn right on West Chester.
0.45	34.5	Traffic light. Turn left on Broadway and proceed northwest.
1.05	35.55	Traffic light. Get into right lane and proceed straight ahead toward N.Y. State Thruway onto Col. George F. Chandler Drive.
0.65	36.2	Bridge over Esopus Creek.
0.5	36.7	Enter Kingston traffic circle. Bear right.
0.1	36.8	Bear right to N.Y. State Thruway toll booth entrance 19. Proceed north toward Albany or south toward New York City.