GUIDEBOOK
TO
FIELD EXCURSIONS

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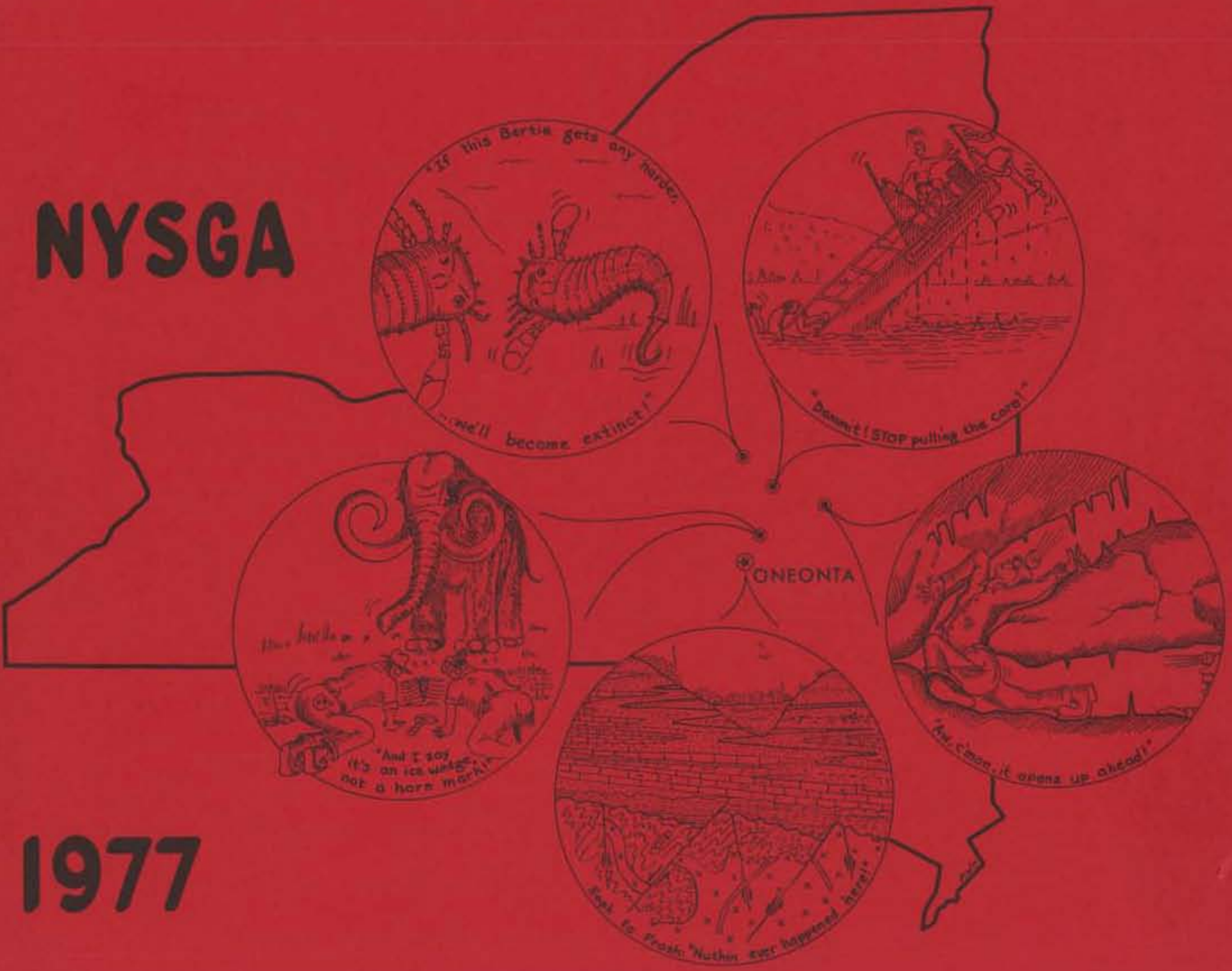

1977

49th Annual Meeting

STATE UNIVERSITY COLLEGE
AT ONEONTA

GUIDEBOOK

to

FIELD EXCURSIONS

conducted at the

49th ANNUAL MEETING

of the

NEW YORK STATE GEOLOGICAL ASSOCIATION

(September, 1977)

Philo C. Wilson, Editor

Host:

Earth Science Department
State University College at Oneonta, N. Y.

Additional copies of this guidebook may be purchased from the secretary of the New York State Geological Association: Dr. Daniel F. Merriam, Department of Geology, Syracuse University, Syracuse, N. Y. 13210, or from the editor.

DEDICATION

This Field Guidebook is affectionately dedicated
to
All Students of Geology:
past, present, and future;
from pebble pups to polished professionals;
for
it is their interest, enthusiasm, insights,
and progress that make conferences and guidebooks such as this worthwhile.

ACKNOWLEDGEMENTS

Without the time, effort, dedication, and professionalism of a number of individuals, neither the meeting nor the Guidebook would have been possible.

The responsibility for the planning, organization, and arrangements for both the meeting and the field trips fell on the shoulders of this year's president, Dr. P. Jay Fleisher. To a large extent, any successes enjoyed by either ventures are due to his efforts.

The contributing authors and field trip leaders (in most cases, the same individuals) are owed a huge debt of gratitude by both the current membership of the association and future users of the Guidebook. Without their generous donation of time and expertise, the heart of the meeting and this lasting record of its more important proceedings would be missing.

Behind the scenes, others have made significant contributions. We are indebted to the college for providing its facilities for the smoker and banquet. The editor is especially grateful to Ron Embling in the college's IRC department for extensive expert advice on the illustrations and for careful preparation of the quality metal plates used to print some of them; to Charles Winters for much of the photographic work; and to Joanne Ruteshouser for some of the redrafting required. Our heartfelt thanks go also to Moira Greiner who really put this finished product together by typing the introductory portions; snipping, pasting, composing, and retyping portions of the text; and providing the pagination as the final touch to each manuscript. Finally, we are all grateful to Jim Sheff in the College Print Shop who ran off the Guidebook copies, to the college, again, for allowing us to use their printing facilities - thereby greatly reducing the Guidebook costs, and to the student help who will be returning from summer vacations to assist in the arduous collating and binding processes...even though they don't know it as of this writing.

TABLE OF CONTENTS (continued)

Trip No. and Pages

Sunday, September 18th

CARBONATE AND TERRIGENOUS SEDIMENTARY FACIES OF TIDAL ORIGIN, EASTERN NEW YORK

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Department of Geology, R.P.I.

INTRODUCTION

This is a field trip to study sedimentary facies of tidal origin. 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. In this kind of approach the name and age of the formation becomes secondary; hence this field trip has been designed irreverently; it pays no heed to formation boundaries. Facies analysis will proceed within the boundary conditions of each single exposure.

During Cambrian to Lower Ordovician time, most of the North American continent was a shallow epeiric carbonate shelf, like the present-day Bahama Bank. At the eastern margin of this shelf, i.e. at the eastern margin of this continent, a relatively steep slope existed down which carbonate sediment moved by slides, slumps, turbidity current, mud flows, and sand falls to oceanic depths (Sanders and Friedman, 1967, p. 240-248; Friedman, 1972). We shall visit shallow-water carbonates shelf deposits which accumulated 30 to 40 miles west of the steep paleoslope which existed during Cambrian to Lower Ordovician times. These shallow-water epeiric carbonate sediments, located in such close proximity to a major ocean, were under the effects of tidal currents. On this field trip we shall examine products of tidal sedimentation on this Cambrian to Lower Ordovician carbonate shelf. For details on the stratigraphy of these carbonate deposits reference should be made to Fisher (1954, 1965) and Braun and Friedman (1969), and on the depositional environments to Braun and Friedman (1969), Friedman (1972), Buyce and Friedman (1975), and Friedman and Braun (1975), and Mazzullo and Friedman (1975, 1977).

Coincident with and after the Acadian orogeny during Middle and Late Devonian times huge river systems of a "tectonic delta complex" (Friedman and Johnson, 1966) drained the area which is now the site of the Catskill Mountains. Devonian rocks, of braided and meandering stream origin, interfinger with those of tidal, nearshore and offshore origin. We shall examine the tidal deposits, all of which are terrigenous. For details on the stratigraphy and depositional environments of the rocks of the tectonic delta complex reference should be to Johnson and Friedman (1969); some reinterpretations have been offered by Friedman (1972).

ITINERARY

Each stop describes and interprets the sedimentary facies; hence each stop should be regarded as self contained. Figure 1 is the road log and shows the location of all the six stops visited.

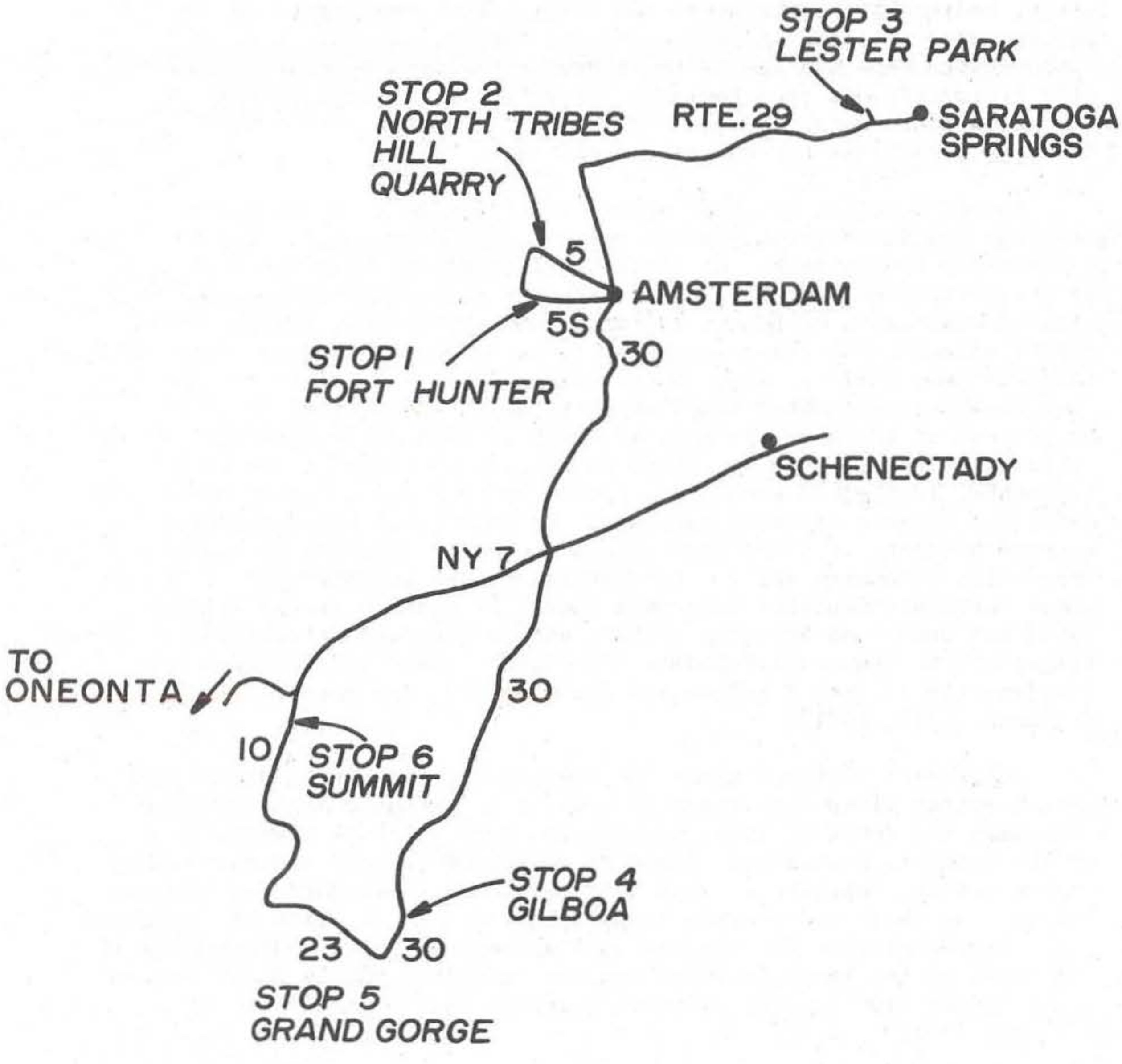

Fig. 1. Road log with stops. Scale: 1 inch = approximately 12 miles. Numbers refer to Highways.

Miles from last point	Cumulative Miles	
0.0	0.0	Depart Oneonta and follow NY 7 to junction NY 30.
4.1	4.1	Turn left (north) on NY 30; cross NY 20.
13.7	17.8	Continue on NY 30 to junction with NY 5S on outskirts of Amsterdam and close to entrance of New York Throughway.
4.0	21.8	Turn left (west on NY 5S and proceed to Fort Hunter; Fort Hunter, turn right (north) on Main Street;
0.2	22.0	Turn right (east) to Queen Ann Street.
0.9	22.9	STOP 1. 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).

Stop 1. Products of Tidal Environment: Flat Algal Mats

Stromatolites in the Fort Hunter Quarry consist almost entirely of dolomite and feldspar 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 2 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. 2).

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

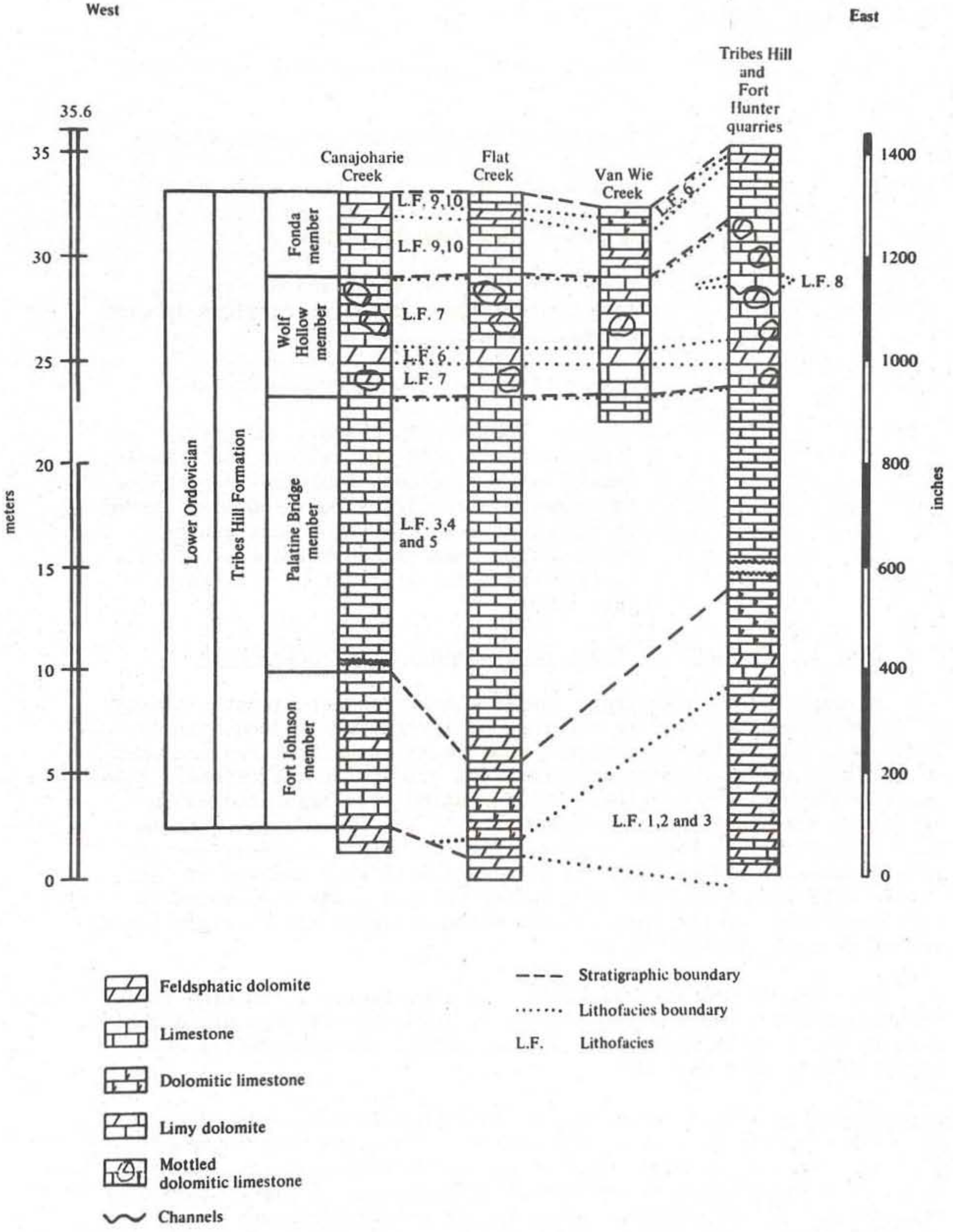

Fig. 2. Columnar section showing the relationship of ten lithofacies to four members of Tribes Hill Formaticn (Lower Ordovician) (after Braun and Friedman, 1969; Friedman, 1972).

feldspar (microline) is ubiquitous throughout this lithofacies; its identity as alkali feldspar was determined by x-ray analysis and staining of a thin section 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") as well as disturbed and discontinuous laminations. 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).

Trip Continued

Miles from last point	Cumulative Miles	
		Turn around and drive back to Main Street, Fort Hunter.
0.9	23.8	Turn right (north) into Main Street, Fort Hunter.
0.1	23.9	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.

Miles from last point	Cumulative Miles	
0.6	24.5	Cross Mohawk River.
0.5	25.0	Turn right (east) on Mohawk Drive (town of Tribes Hill).
0.4	25.4	Turn left (north) on Stoner Trail.
0.2	25.6	Cross Route 5 and continue on Stoner Trail.
2.7	28.3	Turn right on NY 67 (east).
1.5	29.8	Fulton-Montgomery Community College; continue on NY 67.
1.6	31.4	STOP 2. NORTH TRIBES HILL QUARRY (on left).

Stop 2. Products of Tidal Channels

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. Lodged within the channels are limestone blocks of variable shape ranging in diameter from about one to three feet (fig. 3). 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. 2; 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 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.

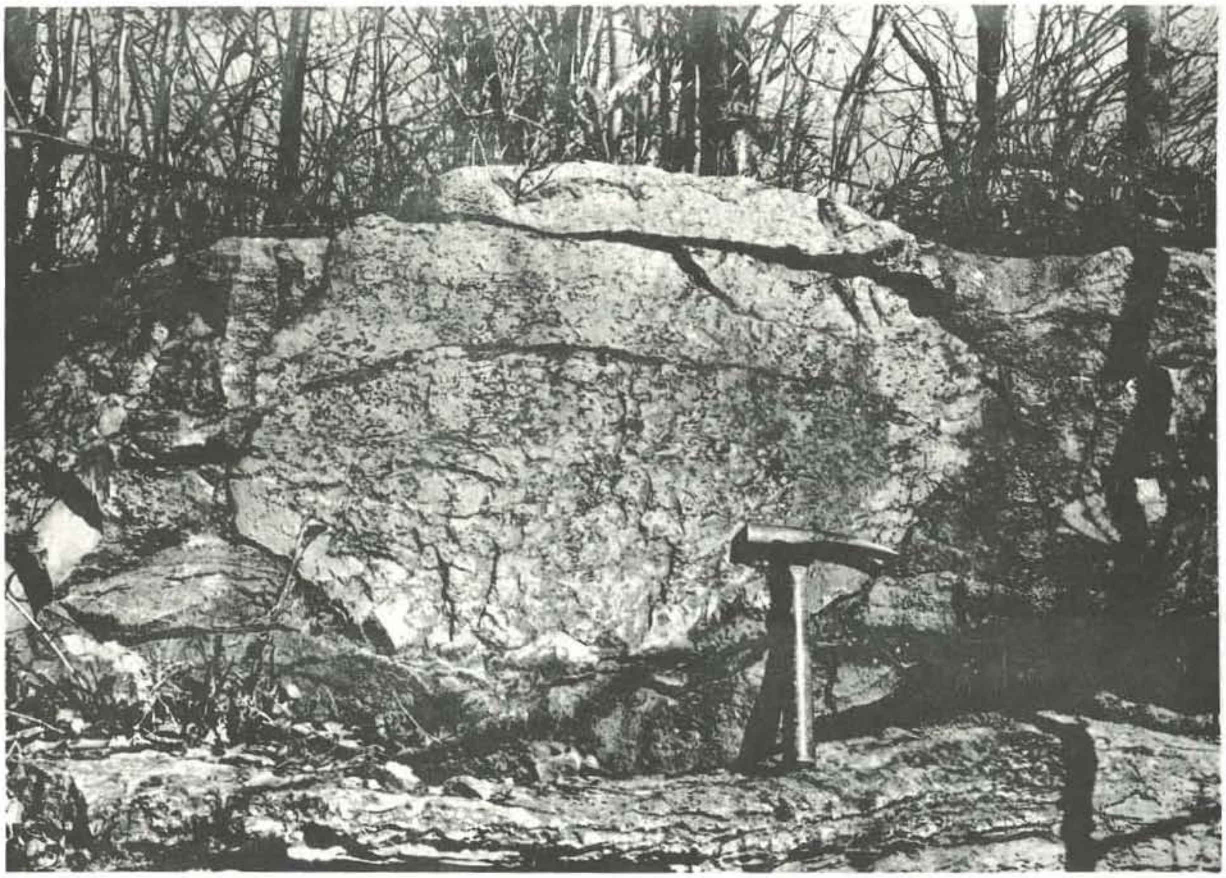

Fig. 3. View perpendicular to strata of limestones showing worn and abraded block (light gray) of mottled dolomitic micrite (lithofacies 7 of Tribes Hill Formation, Lower Ordovician, of Braun and Friedman, 1969, and Friedman and Braun, 1975) which is thought to have foundered from eroded bank of ancient tidal channel. Darker gray enclosing rock is intrasparite and biointrasparite (lithofacies 8 of Tribes Hill Formation of Braun and Friedman, 1969, and Friedman and Braun, 1975). North Tribes Hill Quarry (Stop 2).

Trip Continued

Miles from last point	Cumulative Miles	
		Continue east on NY 67 (through Village of Fort Johnson);
1.8	33.2	Turn left (east) on NY 5;
1.0	34.2	City of Amsterdam; turn left (north) on NY 30
6.3	40.5	Turn right (east) on NY 29
19.1	59.6	Continue on NY 29 to Petrified Garden Rd. Drive past "Petrified Gardens" to Lester Park.
1.2	60.8	Alight at Lester Park

STOP 3. LESTER PARK

Stop 3. Products of Intertidal Environment: Domed

Algal Mats, (Cabbage Heads). 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 algal layers. 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; Owen, 1973). The algal heads are composed of discrete club-shaped or columnar structures built of hemispheroidal algal mats expanding upward from a base, although continued expansion may result in the fusion of neighboring colonies into a Collenia-type structure (Logan, Rezak and Ginsburg, 1964). The algal mats are part of the Hoyt Limestone of Late Cambrian (Trempealeauan) age. Their intertidal origin has been inferred by (1) observations in the rocks, and (2) by analogy with similar modern algal heads.

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 criteria on recognition of tidal limestones, see Friedman, 1969). The analogy with modern environments relates to the occurrence of cabbage-shaped algal heads in the intertidal zone of Shark Bay, western Australia, in which the height of the domes is controlled by the degree of turbulence (Logan, Rezak and Ginsburg, 1964; Hoffman, Logan and Gebelein, 1969). With increasing wave and current energy the height of the domes increases; the relief of the domes decreases landward towards quieter water conditions.

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 algal mats 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 grapesteons 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-magnesium 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-magnesium 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-magnesium calcite.

Trip Continued

Miles from last point	Cumulative Miles	
		Turn around and drive back (south) to NY 29.
1.2	62.0	Turn left (west) on NY 29
19.1		
6.3	87.4	City limits of Amsterdam
1.4	88.8	Cross bridge over Mohawk River
13.7	102.5	Continue on NY 30; junction with NY 20
4.1	106.6	Cross NY 7; continue on NY 30
4.5	111.1	Schoharie
4.7	115.8	Cross NY 145 at Middleburg; continue on NY 30

Miles from last point	Cumulative Miles	
7.0	122.8	Cross Schoharie Creek
5.9	128.7	North Blenheim
6.5	135.2	Turn left (east) on road to Gilboa; stop before bridge
1.1	136.3	STOP 4. GILBOA FOREST

Stop 4. Tidal Marsh Facies

No examples of this tidal marsh facies have been found in situ. However giant seed ferns of the Gilboa Forest (Goldring, 1924, 1927), which grew in a marsh environment, were discovered in the now inactive Riverside Quarry near here (Fig. 4). More than 200 stumps were taken from this single quarry; some of these have been placed at this site, others are now preserved in museums (New York State Museum, Albany; Geological Museum, Rensselaer Polytechnic Institute). The "trees" of Gilboa Forest are among the world's oldest; they grew in a tidal marsh environment of the Catskill Deltaic Complex. The bulbous bases of these fossils were found in place in dark-colored shale; the upright trunks were encased in olive-gray, cross-bedded sandstone of probably tidal origin. The age of the "trees" is latest Middle Devonian.

Trip Continued

Miles from last point	Cumulative Miles	
1.1	137.4	Return to NY 30
0.7	138.1	Turn left (south) on NY 30
		STOP 5. GRAND GORGE SECTION

Stop 5. Intertidal Facies: Tidal Flats and Tidal Channels

The rocks at this exposure are medium gray, fine-grained graywackes; tabular cross-beds are ubiquitous; parting lineations are common. The most interesting single feature at this exposure are the tidal channels (Fig. 5). These channels are small, about 2 to 10 feet in cross section; they truncate the underlying strata. The channel fill consists mostly of a lag concentrate of transported spiriferid brachiopod shells. Usually the shell material is abundant enough to rate for the channel the name "coquinite." Holes in the coquinites are molds of brachiopods. Interestingly, brachiopod shells are confined only to the coquinite lenses; they are not found in the surrounding rock. Hence the brachiopods were treated by the channels as pebbles that were washed in from the open marine environment. In analogous modern tidal channels typical open sea species are washed into the channels by flood tides (Van Straaten, 1956).

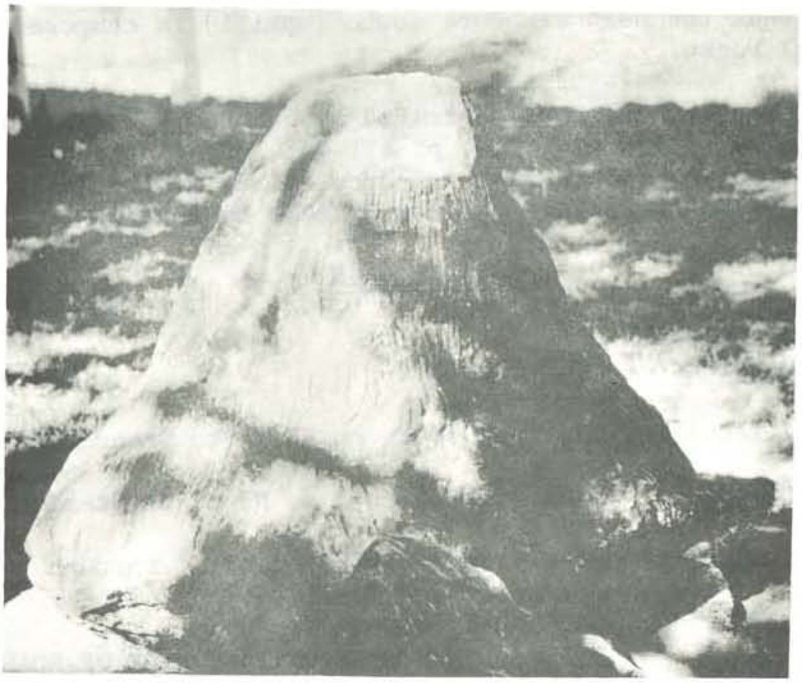

Fig. 4. Bulbous base of giant seed tree which grew in tidal marsh of Gilboa Forest. Latest Middle Devonian. Stop 4.

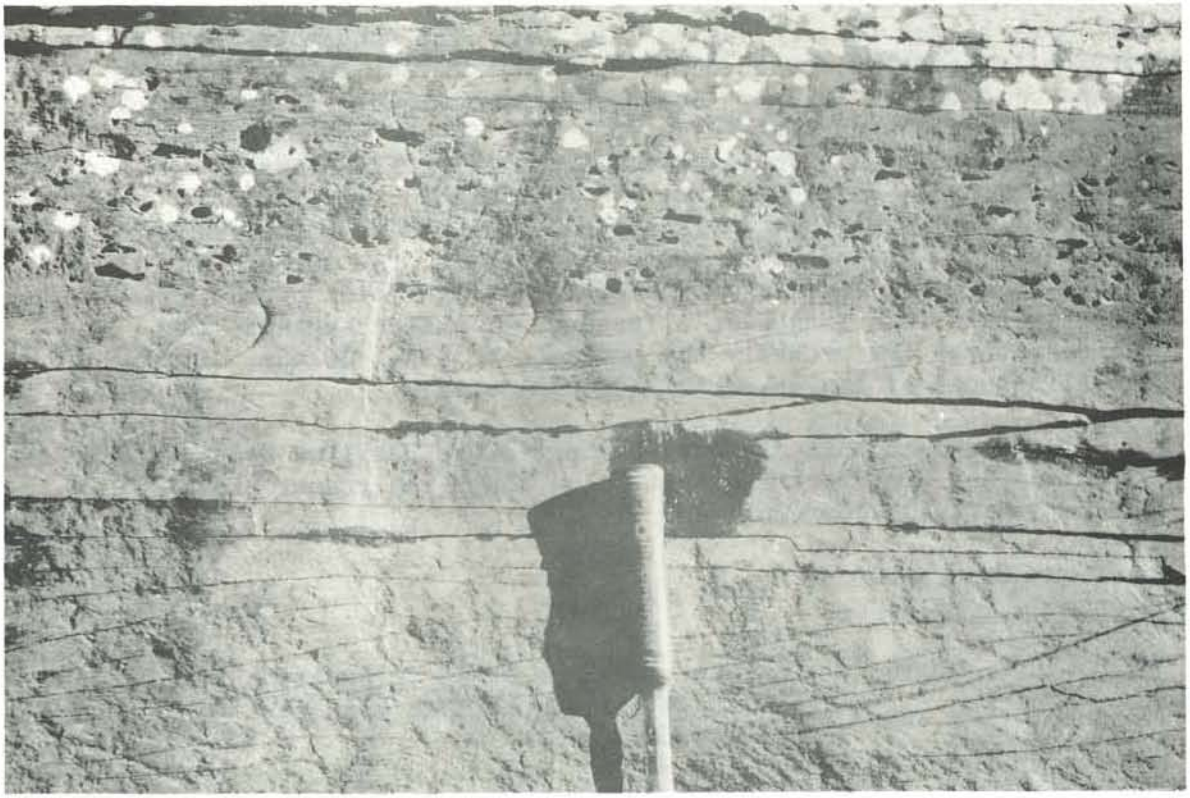

Fig. 5. View perpendicular to strata of sandstones showing low angle cross-bedding (lower part of photograph) and lag concentrate of transported spiriferid brachiopod shells with abundant molds (upper part of photograph). Inferred tidal channel. Early Late to latest Middle Devonian. Stop 5.

Note that the next exposure south (uphill) is composed of red fluvial rocks.

This exposure has been described by Johnson and Friedman as part of their section 43 (1969, p. 471-475, especially figs. 22 and 23). These rocks are the clastic correlatives of the Tully Limestone (early Late Devonian or latest Middle Devonian).

Trip Continued

Miles from last point	Cumulative Miles	
2.0	140.1	Continue south on NY 30 to Grand Junction
8.4	148.5	Turn right (west) on NY 23 to Stamford
17.2	165.7	Turn right (north) on NY 10 through Jefferson and Summit
		STOP 6. EXPOSURE ON EAST SIDE OF ROAD
		(Richmondville; 3.5 mi. north of Summit)

Stop 6. Deposits of Tidal Deltas and Lagoons

At this exposure lenticular sandstone bodies interfinger with dark-gray siltstones and shales (Fig. 6). The sandstones have a vertically shingled, or en echelon, configuration relative to one another. Even the thickest sandstone, approximately 6 feet thick, thins and pinches out laterally (see fig. 25, p. 478 in Johnson and Friedman, 1969). The sandstones contain marine fossils and wood fragments. In places they are crossbedded; ripple marks are locally present. In the siltstones and shales wood fragments are abundant. The presence of marine fossils, the absence of channels, and the lenticular geometric configuration of the sandstones within interfingering siltstones or shales suggests that the sandstones are probably the products of tidal deltas. If so, the siltstones or shales are of lagoonal origin.

The rocks at this exposure belong to the Hamilton Group (Middle Devonian) and are about 600 feet below the stratigraphic level of the Tully clastic correlatives.

Miles from last point	Cumulative Miles	
35.0	201.0	Continue north on NY 10 to junction with NY 7 (1.5 miles) and then head west on NY 7 to Oneonta.

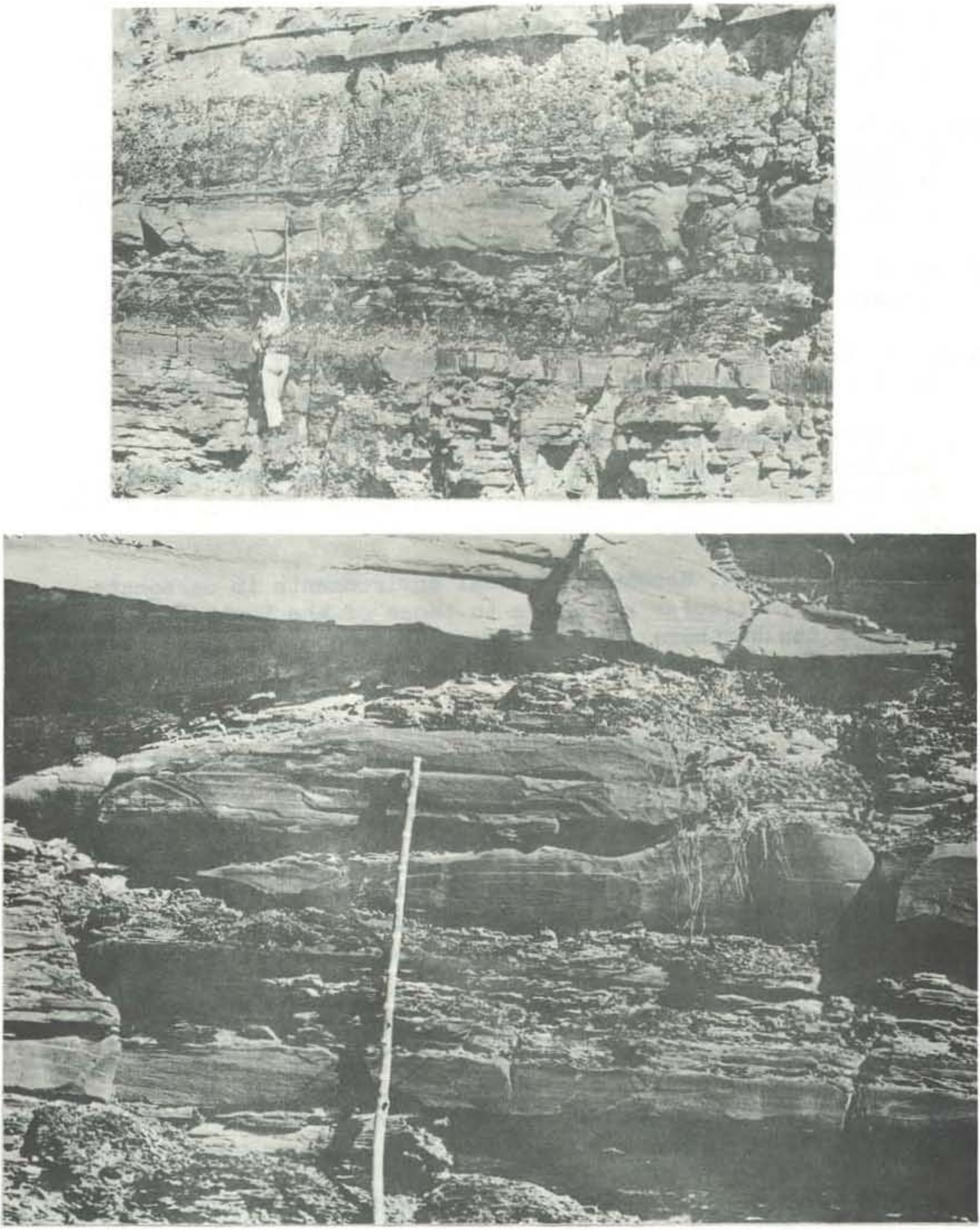

Fig. 6. Two views perpendicular to lenticular sandstone bodies interfingering with dark-gray siltstones and shales. The sandstones are inferred to be the products of tidal deltas; the sandstones and shales are thought to be of lagoonal origin. Hamilton Group (Middle Devonian). Stop 6.

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ICHNOFOSSILS

of the

TULLY CLASTIC CORRELATIVES IN EASTERN NEW YORK STATE

by

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&

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INTRODUCTION

Within the clastic correlatives of the Tully Limestone in eastern New York State there occurs a remarkably complete spectrum of ancient sedimentary facies (Johnson and Friedman, 1969; Johnson, 1968, 1970, 1972, 1976). These beds, which evolved during a transgressive pulse in the building of the great Catskill deltaic system, are part of a 3000 meter (10900') sequence that constitutes the standard for the Devonian System of North America (Figs. 1 and 2). They are exposed at the northeastern end of the Allegheny Synclinorium, are essentially undisturbed and, for the most part, very fossiliferous. Laterally transitional between those beds that are clearly of marine origin and those that are clearly non-marine are sandstones and shales that have sedimentary structures, lithology, geometric relationships with adjacent units and biogenic structures that indicate that they evolved in tidal and shallow sub-tidal environments.

The purpose of this field trip is to focus on one aspect of the evidence used to develop environmental assignments for the Tully clastic correlatives; namely, biogenic structures.

LITHOFACIES
of the
MIDDLE AND UPPER DEVONIAN

Three general lithofacies are recognized in the Devonian deltaic system of New York State (Fig. 2). The Catskill lithofacies, which consists of non-marine red and green-gray shales, sandstones and conglomerates, overlies and interfingers westward with littoral and shallow marine, very fossiliferous, gray sandstones and shales of the Chemung lithofacies. The Chemung, in turn, overlies and interfingers westward with deeper-water, sparsely fossiliferous, black shales of the Portage lithofacies. All of the exposures to be examined during this trip are within the eastern Chemung lithofacies. Stops 1 through 5 are in the Schoharie Valley, around Schoharie Reservoir. Stops 6 through 10 lie between the Schoharie Valley and the Unadilla Valley to the west.

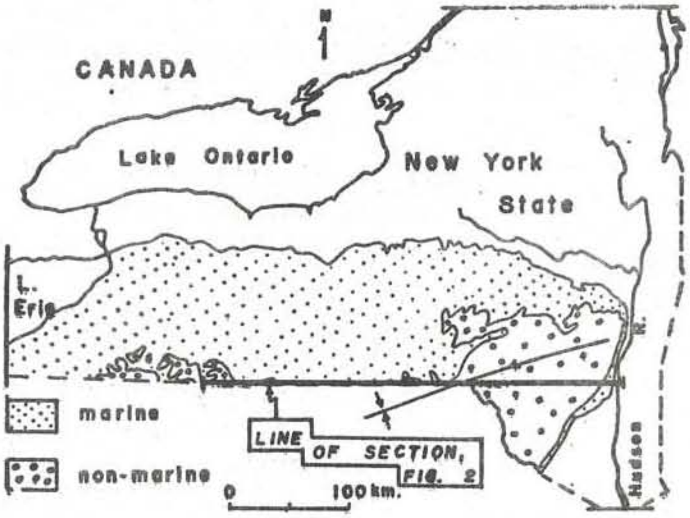

Figure 1 - Devonian bedrock of New York State (after Rickard, 1964).

CHARACTERISTICS OF EASTERNMOST CHEMUNG LITHOFACIES

In the Schoharie Valley the Catskill and Chemung lithofacies are interbedded and well exposed. The following represents a summary of the lithologic, sedimentologic and paleontologic characteristics of the Chemung beds in the vicinity of Gilboa Dam.

Lithology

Lithologies within the Chemung lithofacies are interlensing medium gray (N4) to dark gray (N3), micaceous siltstone and shale and medium gray (N5), very fine-grained sandstone with subordinate, medium gray (N5 and N6) coquinite lenses (color terminology is that of Goddard, 1951). All of the sandstones of the lithofacies are submature and immature graywackes following the usage of Folk (1954, 1965). They contain sporadic accumulations of shale pebbles as well as moderately common, small pyrite nodules. A few polymictic pebble conglomerates containing pebbles of light gray and greenish gray quartzite, medium gray slate, red and olive siltstone, and subordinate medium gray limestone are present. Siltstones and shales of the lithofacies are dark gray in color due to a high content of fine organic material. They are very micaceous and variably thinly cross-laminated to occasionally fissile.

The coquinites, or in most examples more correctly coquinoid sandstones, occur as elongate lenses ranging from a few centimeters thick by 1 or 2 m long to 15 to 45 cm thick by lengths of up to some 15 meters.

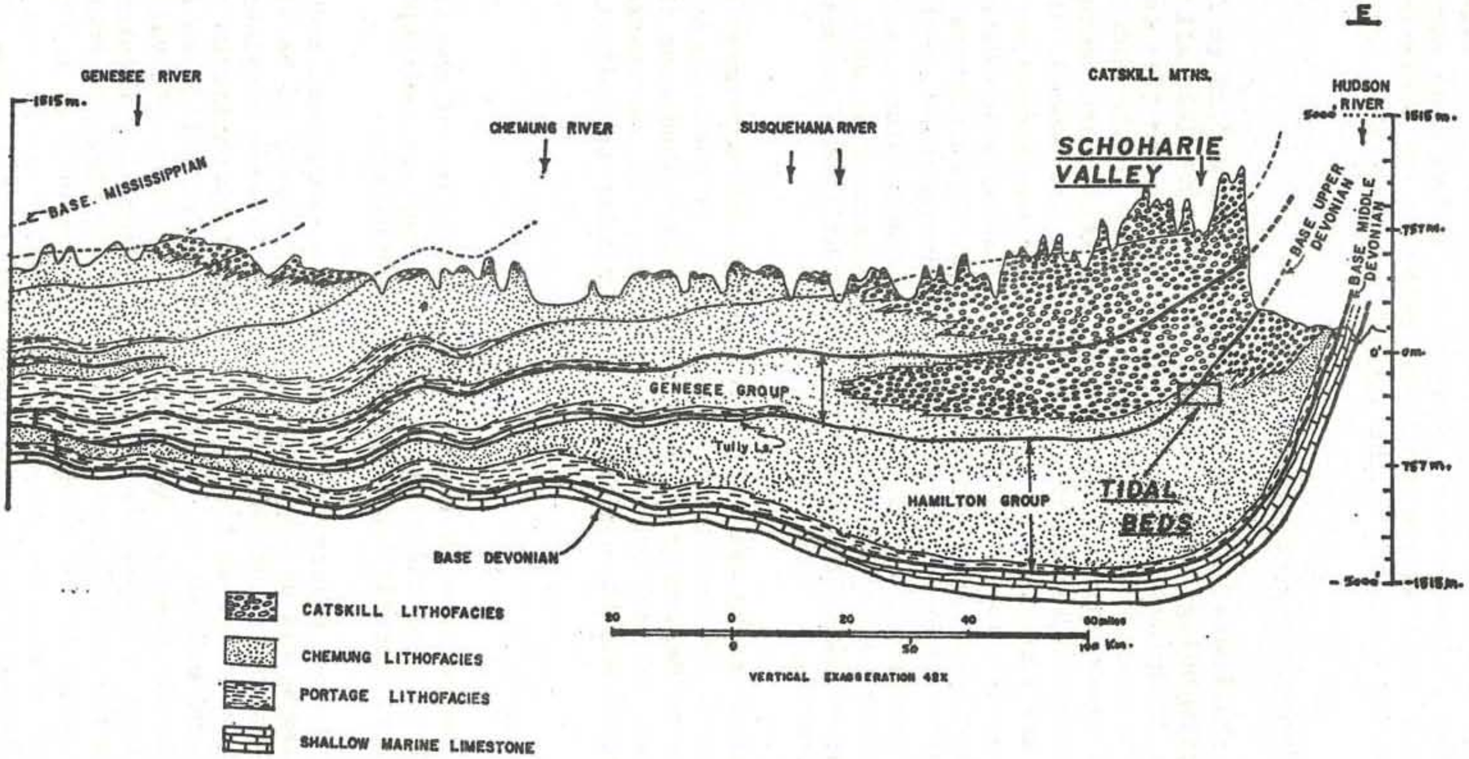

Figure 2 - Cross section of Devonian System along New York-Pennsylvania border (modified after Fig. 17, Broughton and others, 1962).

Thickness within a given lens is variable and they rest in channelled contact on underlying beds. Shell material in the lenses consists mostly of large spiriferid brachiopods, which in most fresh exposures are composed of calcium carbonate. Some of the lenses also contain pelecypod fragments as well as red siltstone pebbles. No preferred orientation of valves is apparent in the lenses, although some valves suggest imbrication.

Inorganic Sedimentary Structures

Bedding thickness of sandstones ranges from medium to thick and very thick (terminology after Ingram, 1954). Virtually all of the strata in the lithofacies, with the exception of the fissile shales, are cross-bedded or cross-laminated. Even the very thick-bedded sandstones, which in some cases appear homogeneous, are well cross-laminated. Interference, oscillation and current ripple marks are common. Interference ripple marks are expressed as a low-amplitude unevenness on bedding surfaces. The current and oscillation ripple marks, which have wave lengths of several centimeters and amplitudes of only 2 centimeters or less, provide reliable and plentiful evidence of sedimentary strike and direction of transport. Cross-bedding is of both planar and trough types and in most cases the inclination of foresets is well in excess of the 10 degree lower limit used by Pettijohn (1962) to denote high-angle cross-bedding.

Dessication cracks are well developed in the uppermost part of the Hamilton Group in the Schoharie Valley. Most of these occur as polygonal patterns of medium gray, very fine-grained sandstone infill on bedding surfaces of dark gray shaly siltstone. In one instance numerous sandstone infills extend some 15 cm perpendicular to bedding into a shale ledge.

Biogenic Structures

Biogenic structures in the Chemung lithofacies of the Gilboa Dam area are of three general types - (1) brachiopod and pelecypod body fossils, (2) ichnofossils and (3) fossil seed-ferns.

Brachiopods and pelecypods occur in both sandstones and shales as isolated specimens and as concentrations that appear to be allochthonous. Those found in allochthonous arrangements were considered, for purposes of this study, as biological sedimentary particles occurring in lithified sediment not necessarily that of their life environments. Ichnofossils in the Chemung lithofacies of the Schoharie Valley occur on bedding planes of sandstone as shallow, generally circular and ovoid depressions, which are slightly darker in color than the enclosing lithology. These occur in two sizes; those only about 1 cm in diameter, and those 2.5 cm or more in diameter. The smaller of the two extend downward perpendicular to bedding a distance of up to some 15 cm. At one locality abundant vertical burrows are 30 cm in length. A few of the burrows have a Y or U pattern.

Fossil seed-fern stumps are present at three stratigraphic levels in the upper Hamilton beds near Gilboa Dam. Over two hundred stumps were taken from the lowest of these levels during quarrying operations just north of the dam (Goldring, 1924, 1927). They occur in light olive-gray (5 GY 6/1), tabular and trough cross-bedded, fine-grained sandstones some of which contain vertical burrows up to 30 cm long. The beds are thick and very thick bedded, are in part slightly calcareous and, at certain levels, contain abundant casts of large spiriferid brachiopods.

ENVIRONMENTAL SYNTHESIS

The spectrum of Tully interval sedimentary environments includes sandstone bodies of alluvial channel origin which truncate underlying beds, contain basal shale-pebble lag-concentrates, are well trough cross-bedded, texturally immature, and display a "fining-upwards". The alluvial strata of overbank origin are horizontally laminated, red and green siltstones. Strata of the marsh facies consist of black organic lenses containing abundant plant remains some of which are "coalified." At the distal margin of the alluvial plain, just below the Tully interval, a swamp environment is represented by three levels of abundant fossil seed-ferns.

Sedimentation that resulted in strata of tidal origin within the Tully interval was of the Wadden-type. The tidal flat facies consists of gray, very finely cross-laminated muddy siltstone and very fine-grained sandstone, which contain allochthonous brachiopods and locally well developed mud-cracks. Sedimentary structures of the tidal channel facies are essentially identical to those of the alluvial channel facies, but can be distinguished by the unique character of the basal lag-concentrate, which is coquinite or coquinoid pebble conglomerate consisting largely of allochthonous brachiopod shells.

Strata of the nearshore facies consist of thick bedded bar sandstone bodies interbedded with very thinly bedded and laminated, fossiliferous siltstone that becomes increasingly calcareous westward and grades into the very argillaceous eastern extension of the Tully Limestone. Well developed trends of change in texture, general biologic character, and type and scale of sedimentary and biologic structures are present in both the nearshore (bar and lagoon) facies and the offshore facies.

Synthesis of the environmental pattern of the Tully interval indicates that (1) Tully sedimentation occurred during the transgressive phase of a transgressive-regressive cycle, (2) terrigenous material was trapped east of a submarine topographic high, thus permitting deposition of carbonate material in a basin that was for the most part being overwhelmed by clastic influx, and (3) landward migration of the strandline during the transgressive phase caused river mouth drowning and resulted in more widespread estuarine (tidal) conditions than were present immediately prior to and following Tully time. In addition, the transgression raised the base level of streams that were flowing westward across the deltaic plain, thus causing alluviation of fine-grained sediment in quantity greater than that deposited directly preceding and following Tully time.

The distribution of the environmental facies of the Tully clastic correlatives is shown on Figure 3.

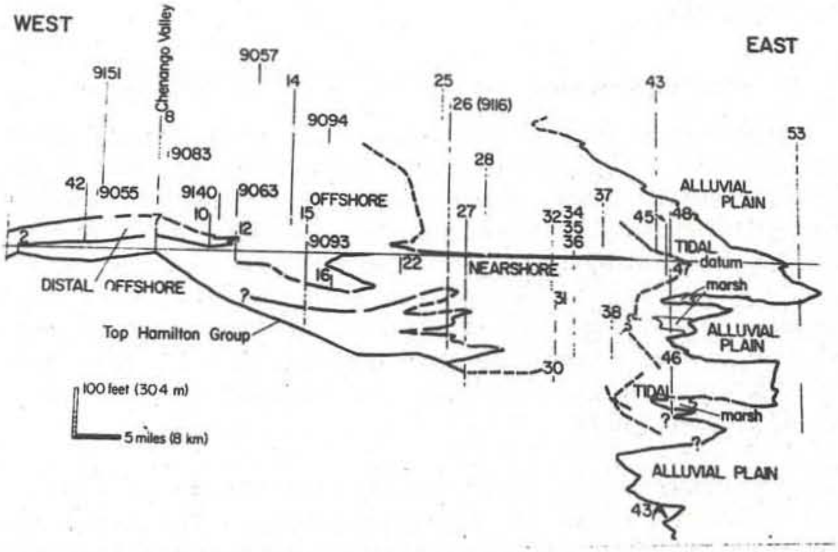

Figure 3 - Cross-section of Tully clastic correlatives. The section extends from East Windham on the northeastern front of the Catskill Mountains northwest to Georgetown in the Otselic Valley. Two-digit stratigraphic section designations are those of Johnson (1968). Four-digit designations are those of Thayer (1972).

BIOGENIC STRUCTURES

Biogenic structures are structures produced by organisms moving or living in or on the sediment. They include trace fossils, which are discrete tracks, trails and burrows. In the last 25 years biogenic structures, particularly trace fossils, have been used as aids in interpreting ancient depositional environments. The application of trace fossils in paleoenvironmental analysis has been based on a theoretical model developed by Seilacher (1964, 1967), in which the distribution of trace fossils, representing animal behavior, is related to factors which change with water depth. In high energy nearshore environments food is suspended in the overlying water rather than deposited in the sand substrate, resulting in a predominance of permanent dwelling burrows of suspension-feeding animals. In more quiet water offshore conditions, potential food particles are included in the fine-grained sediments; here horizontal feeding burrows are more common. Recent workers, including Rhoads (1967), Howard (1972), Frey (1975), and others have emphasized that local energy and substrate conditions and environmental fluctuations are more important than depth in determining the distribution of trace fossils.

The Tully clastic equivalents and related rocks contain moderately diverse and abundant biogenic structures. Trace fossils are found in siltstones, sandstones and limestones of alluvial offshore facies. They occur scattered throughout in low densities, concentrated along sandstone-shale interfaces, and in great abundance in some beds. It is difficult to recognize horizon or thin bed with large numbers of trace fossils, especially horizontal structures, if the exposure is a vertical face. With a few exceptions, trace fossils are seen most completely on bedding planes; good trace localities are therefore those with large exposures of bedding surfaces. Of the outcrops of the Tully equivalents and related rocks, the best outcrops for trace fossils are generally old quarries, where scraped bedding planes and quarried blocks provide large surface areas. Stream exposures are poor, for the few bedding planes exposed are commonly covered with overgrowth; likewise, few bedding surfaces are exposed in road cuts. The diversity of trace fossils from a given facies is, therefore, partly a function of the number of available quarries. In all outcrops, most of the trace fossils were collected from float. For this reason the locations of biogenic structures within the sections are not given precisely.

Because of sampling difficulties imposed by the trace fossil distribution, the type of exposures, and the impossibility of defining what constitutes one specimen of some trace fossils, no quantitative estimates of the abundances of biogenic structures in each facies have been made. However, although some of the biogenic structures, including the small type of Arenicolites, Spirophyton, ? Teichichnus and large vertical burrows are restricted to rocks of the tidal and alluvial or tidal and nearshore facies, most of the others range from alluvial or tidal to offshore facies or from proximal nearshore to distal offshore. In addition, many of the biogenic structures are found in diverse rock types - siltstones, sandstones, and limestones. This indicates that in the Tully clastic correlatives the distribution of the trace fossils is not related clearly to the inferred depositional environments.

Descriptions of trace fossils

Ten major types of trace fossils occur in the Tully clastic correlatives, and there are probably many more kinds of less common or less readily identifiable biogenic structures in the unit. In the descriptions below, trace fossils which have been given formal ichnogeneric names are discussed in alphabetical order, followed by the types which have not been given formal names.

Arenicolites: (Plate 1H, 2B, F). Specimens of Arenicolites are vertically oriented U-shaped burrows without spreiten. (A spreite is a layer of U-in U-shaped lamellae. It may have any orientation within the rock.) Two types of Arenicolites occur in the Tully clastic correlatives: 1) long, narrow burrows with fill darker than the surrounding rock, (Plate 2F) and 2) larger specimens with burrow fill similar to that of the surrounding rock (Plate 1H, 2B). Arenicolites is thought to be produced by a polychaete worm (Hantzschel, 1975; Janssa, 1974). The small type closely resembles burrows produced by spionid (polychaete) worms in uppermost intertidal zones in southern Californian lagoons. Although generally restricted to shallow water, high energy environments (Crimes, 1975), Janssa (1974). The small type closely resembles burrows produced by spionid (polychaete) worms in uppermost intertidal zones in southern Californian lagoons. Although generally restricted to shallow water, high energy environments (Crimes, 1975), Janssa (1974) reported Arenicolites from deeper water deposits. In the Tully clastic correlatives, the small type of Arenicolites is restricted to sandstones of the tidal and nearshore facies. The larger type occurs, but is rare, in rocks deposited under tidal and offshore conditions.

Bifungites: (Plate 1G). Appearing as a dumbbell-shaped structure on a bedding plane, Bifungites is interpreted as the cross-section of a spreite-bearing, vertically oriented U-shaped burrow (Osgood, 1970). Commonly considered to be a shallow-water structure, in the Tully equivalents it occurs in rocks of the tidal, nearshore, and offshore facies but is nowhere common. Like Arenicolites, it probably represents the dwelling burrow of a worm-like animal.

? Phycodes: (Plate 1E). Vertical sections of sandstones and siltstones of the nearshore and offshore facies show clusters of small (1 mm or less in diameter) horizontal burrows filled with lighter material than the surrounding rock. These are tentatively identified as Phycodes and probably are feeding burrows. Many modern deposit-feeding polychaete worms are very long and narrow and might produce similar burrows.

Planolites: (Plate 1C, D, F). Unbranched horizontally oriented burrows are included in the ichnogenus Planolites, if the burrow fill differs from the surrounding rock (see Osgood, 1970; Alpert, 1975 for discussion). Many of the Tully equivalents specimens are surrounded by a dark burrow lining (Plate 1C). If specimens are not oriented and sectioned, it is difficult to distinguish Planolites from the molds of trails made as surficial grooves. Planolites is one of the most abundant trace fossils in the Tully equivalents. A small type (less than 0.5 cm in diameter) is especially common (Plate 1F), although the larger form (larger than 0.5 cm in diameter) can be found at many outcrops (Plate 1C, D). Planolites is classified as a feeding burrow (Seilacher, 1964); the animal is thought to have ingested sediment and filled its burrow with the undigestible remains. In the Tully clastic correlatives and associated rocks, Planolites ranges from the tidal to offshore facies. This concurs with its designation as a facies-crossing trace fossil (Seilacher, 1967).

Skolithos: (Plate 1I, 2D). Vertical cylindrical burrows which may or may not be closely packed are included in the ichnogenus Skolithos. Two types of Skolithos occur in the Tully clastic correlatives: 1) a large type, greater 0.5 cm in diameter, which occurs in rocks of the alluvial to offshore facies, but is most common in sandstones of the nearshore facies (especially section 36) and 2) a smaller form, less than 5 mm in diameter which occurs in sandstones, and siltstones of all of the facies (Plate 1I, 2D). The small type of Skolithos is the most common trace fossil in the Tully clastic correlatives. Skolithos is interpreted as the dwelling burrow of a suspension feeding animal (Alpert, 1975). It is common in sandstones deposited under high-energy tidal and nearshore conditions (Seilacher, 1967; Crimes, 1975).

Spirophyton: (Plate 2A). Simpson (1970) defined Spirophyton as consisting of a central vertical tube around which a speite is spirally wound and only differing from Zoophycos in its smaller size. In the Tully equivalents Spirophyton occurs as circular areas (horizontal layers of the spreite) on bedding planes surrounding a central tube (Plate 2A). Seilacher (1964) designated the similar Zoophycos as indicative of middle depth deposition, but it has been found in shallower water deposits (Osgood and Szmuc, 1972; Kern and Warme, 1974; Thayer, 1974). In the Tully equivalents, however, Spirophyton is restricted to siltstones of the tidal and alluvial facies; it is abundant in some horizons in the tidal facies. Simpson (1970) interpreted Spirophyton and Zoophycos as resulting from the feeding activity of a bilaterally symmetrical animal. Other interpretations of the ichnogenera as plants (Loring and Wang, 1971) or body fossils (Plicka, 1970) are not widely accepted.

? Teichichnus: Generally horizontal burrows with vertically oriented spreiten extending above or below the burrows are included in Teichichnus. Because specimens in the Tully equivalents and related rock are more curved than most, they are only tentatively assigned to that ichnogenus. Well preserved specimens of ? Teichichnus were found in sandstones of the tidal facies; questionable specimens were found in sandstones of the offshore facies. Teichichnus is generally found in rocks deposited under more offshore conditions (Crimes, 1975) and is interpreted as the feeding burrow of a deposit feeding animal.

Zoophycos: (Plate 1J, 2C). Zoophycos is similar to Spirophyton but larger in diameter (Simpson, 1970). In the Tully equivalents, only the expressions of the spreiten on bedding planes have been recognized; these are lobate to nearly circular in outline (Plate 2C). On polished vertical surfaces chevron shaped lamellae within the spreiten are visible (Plate 1J). Zoophycos is rarely found in place, as it is difficult to recognize on vertical weathered surfaces. Where it is found in place it may cover a bed a foot or more thick. Generally, however, Zoophycos is not as abundant in the Tully clastic correlatives as it is in the Schoharie Formation in the Hudson Valley or Carlisle Center Formation, especially near Cherry Valley. Zoophycos occurs in siltstones, sandstones and limestones of the nearshore and offshore facies. This and other occurrences in New York State (Thayer, 1974; Marintsch and Finks, 1976; Rehmer, 1977) are additional evidence that the producers of Zoophycos were not restricted to bathyal depths.

Arthropod produced trails and trackways: (Plate 1K). A variety of arthropod produced lebensspurren occur - but are not abundant in - siltstones and sandstones of tidal to offshore facies of the Tully clastic correlatives and associated rocks. These are of diverse morphology and include resting tracks (Rusophycus), trilobite-crawling tracks (Cruziana), and smaller trackways (Isopodichnus) (Plate 1K). All, however, are bilobed and show transverse markings interpreted as scratch marks. Isopodichnus has been considered to be restricted to be restricted to nonmarine rocks (Trewin, 1976). The distinction between it and Cruziana is arbitrarily (Hantzschel, 1975) based on width of the trail.

Large vertical burrows: (Plate 2G). Very large (greater than 5 cm in diameter) vertical burrows with or without burrow linings are found in the sandstones of the tidal and nearshore facies (Plate 2G). Modern cerianthids (coelenterates) produce large deep vertical burrows, and actinians (anemones) capable of producing burrows of that size are infaunal inhabitants of modern nearshore sediments. These probably are, therefore, the dwelling burrows of suspension feeding animals.

Large horizontal traces: Although not abundant, very large (greater than 2 cm in diameter) horizontal burrows occur in fine sandstones of the nearshore and offshore facies (Plate 2E). Some of these may be molds of surficial trails, but several were probably produced intrastratally. Possible producers include burrowing trilobites or soft bodied deposit-feeding animals such as holothurians.

Surface trails: (Plate 1A, B). Some specimens are indistinguishable from Planolites on bedding surfaces are clearly molds of surficial trails, for on polished vertical sections laminations extend into the trace (Plate 1B). These are common and widespread in the Tully clastic equivalents, occurring in siltstones and sandstones of the alluvial to offshore facies.

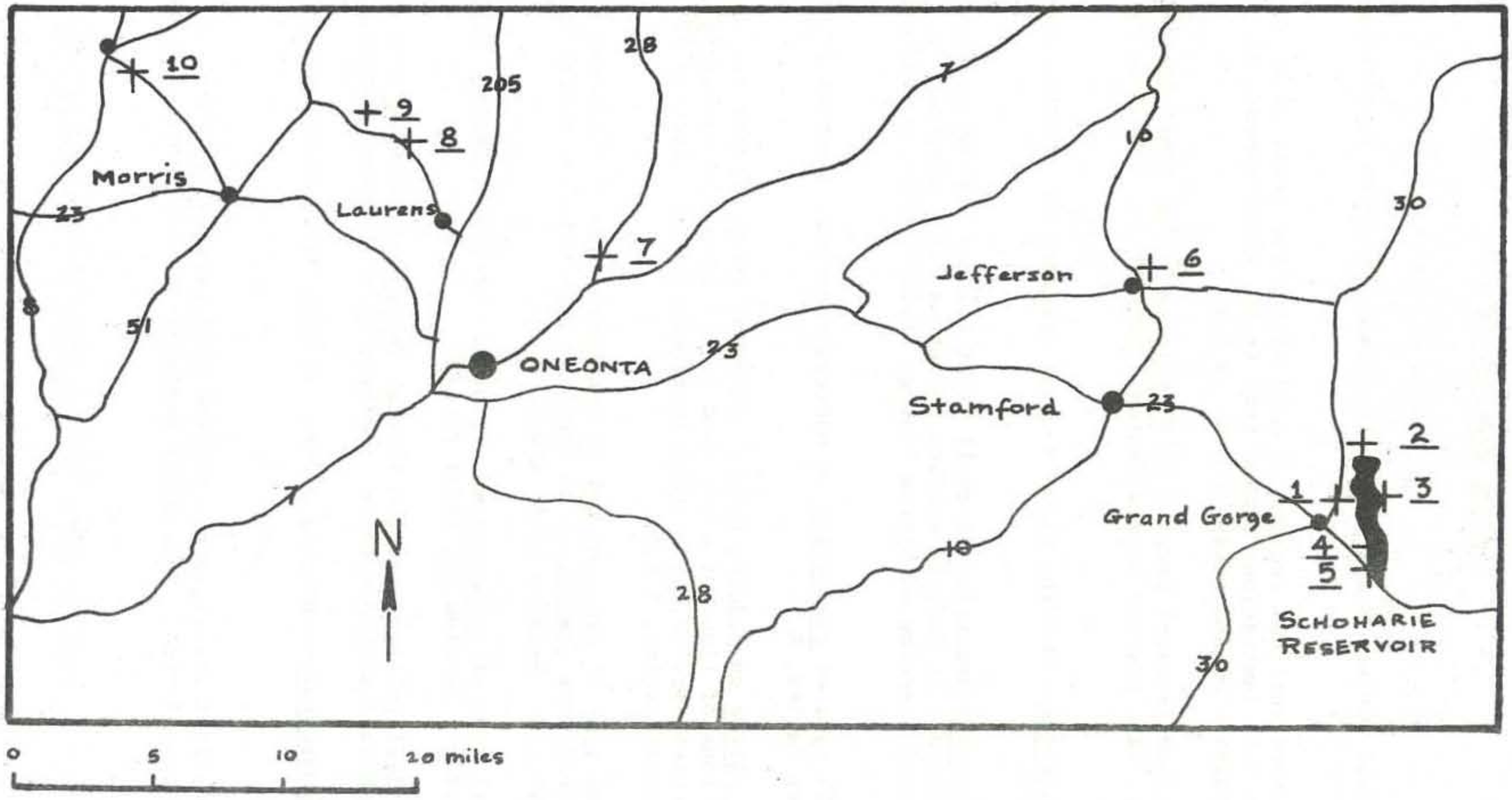

Figure 4. Locations of Field Trip Stops

PLATE EXPLANATION *

Plate 1

A. Mold of surface trail on bedding plane. Section 1, offshore facies X 1.

B. Polished vertical section of mold of surface trail shown in A. Note that laminations extend into trace, which appears as depression on underside of bed. X 1.3.

C. Polished vertical section of _Planolites_ (large type) showing dark, fine grained burrow lining. Section 27, nearshore facies, X 1.

D. _Planolites_. Bedding plane view of specimen in C before sectioning. X 0.7.

E. ? _Phycodes_ appearing as small light colored burrows occurring in clusters. At left is section through a large specimen of _Skolithos_, showing layering of burrow lining. Section 9057, offshore facies, X 1.

F. Small type of _Planolites_ on underside of bed. Section 27, nearshore facies, X 1.

G. _Bifungites_ on bedding plane. Enlarged areas at ends are cross-sections of limbs of a U-shaped burrow connected by vertically oriented spreite, also shown in cross-section. Section 9094, offshore facies, X 1.5.

H. Large type of _Arenicolites_ in weathered face of sandstone of tidal facies; note similarity to specimen from offshore facies in Plate 2 B. Section 43 A, X 0.5.

I. Small type of _Skolithos_ in weathered vertical section. Disc is a quarter. Section 43, tidal facies.

J. Vertical polished section through _Zoophycos_, showing dark chevrons (lamellae) within spreite. Gilbert Lake, offshore facies, X 1.3.

K. _Isopodichnus_ on bedding plane. Section 9063, offshore facies, X 2.

* Two-digit stratigraphic section designations are those of Johnson (1968). Four-digit designations are those of Thayer (1972).

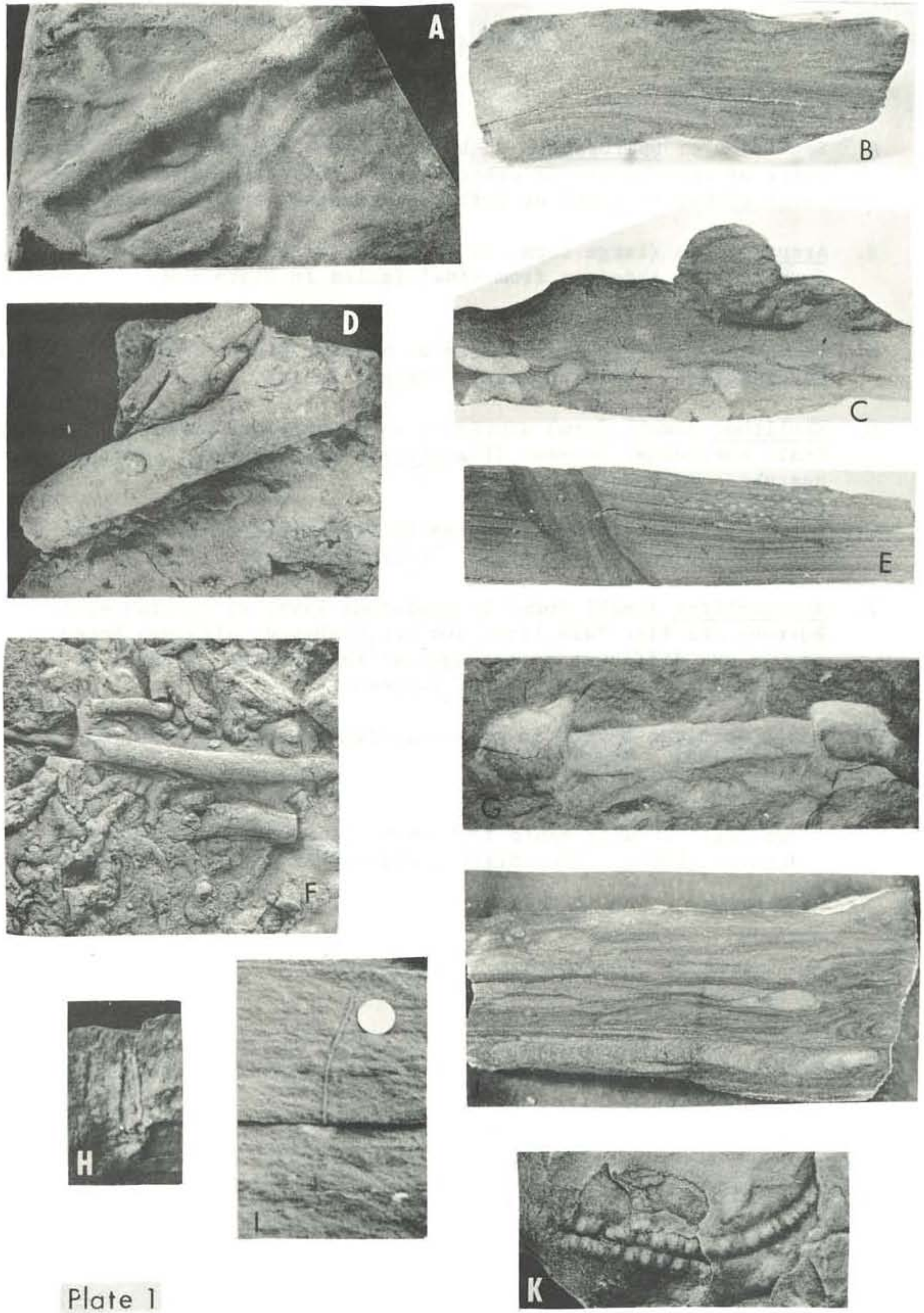

Plate 1

PLATE EXPLANATION*

Plate 2

A. Specimens of Spirophyton on bedding plane. Each specimen is one swirl of spreite around central tube. Lamellae within spreite swirl either to right or left. Section 47, tidal facies, X 0.5.

B. Arenicolites (large form) in sandstone of offshore facies. Compare with specimen from tidal facies in Plate 1 H. Gilbert Lake, X 1.

C. Zoophycos. Portion of spreite on bedding plane. Vertical burrows cut lamellae. Gilbert Lake, offshore facies, X 1.

D. Skolithos (small form) expressed as depressions on bedding plane. Small horizontal burrows (Planolites) also present. Section 27, nearshore facies, X 1.

E. Large horizontal traces on slab in stream bed at section 15. Lens cap in center for scale. Offshore facies.

F. Arenicolites (small form) in sandstone layer at section 43-A. Burrows are fine dark lines and are U-shaped, although bases of U's are difficult to see even at the outcrop. Pencil at upper right for scale. Tidal facies.

G. Large vertical burrow in cross-section on bedding plane at section 43-A. Tidal facies.

*Two-digit stratigraphic section designations are those of Johnson (1968). Four-digit designations are those of Thayer (1972).

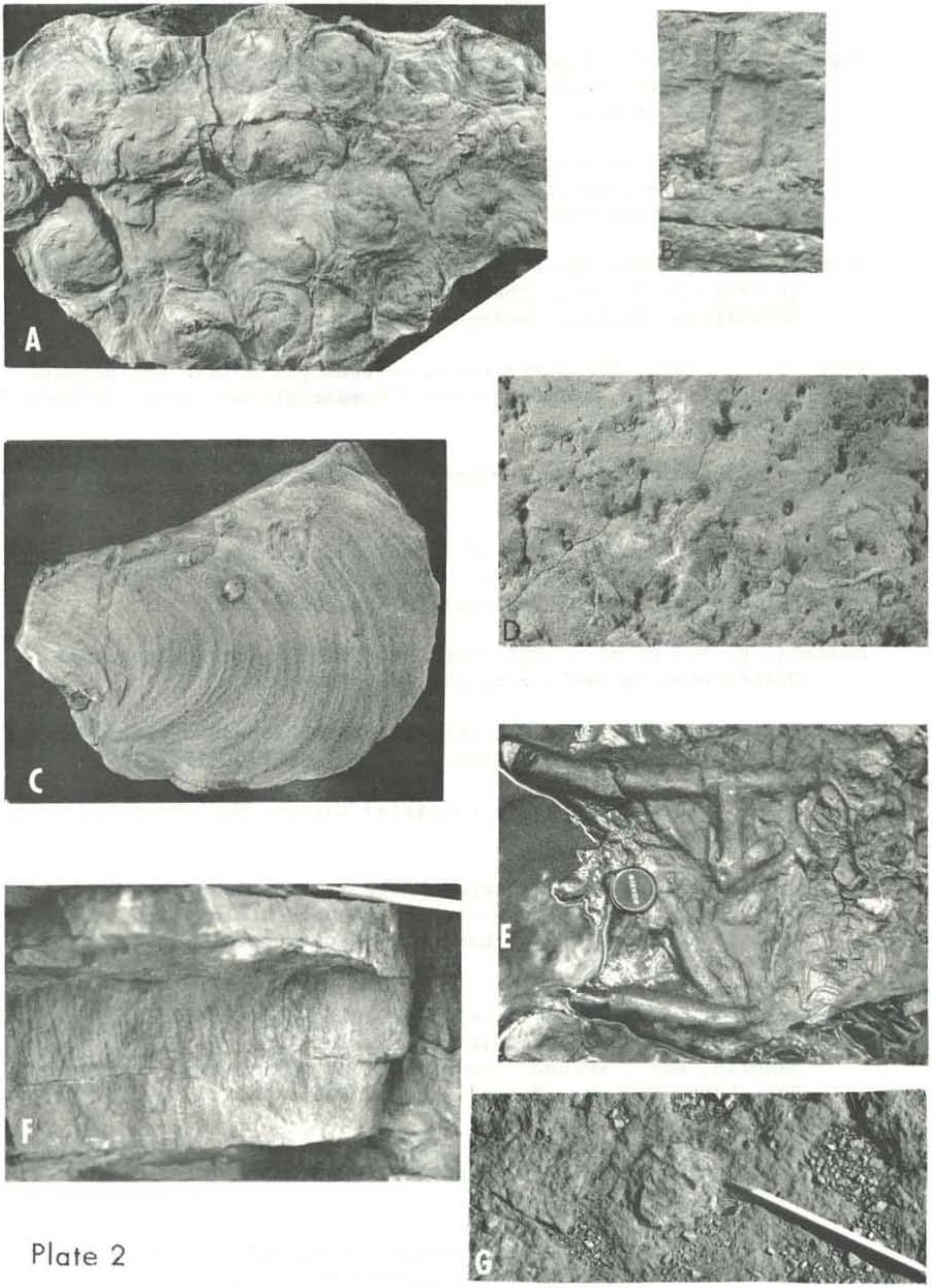

Plate 2

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TRIP A-2

Ichnofossils of the Tully Clastic Correlatives in Eastern New York State

ROAD LOG

Miles Between Points	Total Miles	Descriptions and Directions
0	0	LEAVE SUCO Campus. Turn left on West Street. Proceed down hill.
		ON RIGHT - HARTWICK COLLEGE.
0.6	0.6	Stop light. TURN LEFT onto Rts. 7 and 23 (Chestnut Street).
0.3	0.9	Stop light on Main Street. TURN RIGHT on Rts. 23 and 28.
		Cross SUSQUEHANNA RIVER.
0.6	1.5	BEAR LEFT. Proceed east on Rt. 23.
1.0	2.5	ON LEFT - Susquehanna River.
0.8	3.3	ON RIGHT - Holiday Inn.
0.1	3.4	ON LEFT - Notice flat-topped crest of hills. Streams are eroding into horizontally bedded rocks of Catskill lithofacies.
1.8	5.2	ON LEFT - VW dealer.
1.4	6.6	On left - road to WEST DAVENPORT.
1.1	8.7	Enter DAVENPORT CENTER.
4.2	12.9	Enter DAVENPORT.
1.5	14.4	BUTTS CORNERS.
6.3	20.7	ON RIGHT - Kame and kettle topography.
4.9	25.6	Enter VILLAGE OF STAMFORD
0.2	25.8	Intersection Rts. 23 and 10. CONTINUE EAST ON RT. 23.
4.7	30.5	Enter Delaware County.

Miles Between Points	Total Miles	Descriptions and Directions
2.8	33.3	Enter GRAND GORGE.
0.5	33.8	Intersection Rts. 23 and 30. TURN LEFT (North) onto Rt. 30.
1.0	34.8	Enter Schoharie County.
0.5	35.3	ON RIGHT - Top of Grand Gorge Section 43 of Johnson, 1968). Exposure consists of alluvial channel sandstone resting on red overbank shale.
		PROCEED DOWN HILL
0.4	35.7	Top of tidal channel facies.
		CONTINUE TO BOTTOM OF HILL
0.2	35.9	PARK on right side of road. Walk back to tidal channel outcrops. BE VERY CAREFUL. THIS IS A NARROW SPEEDWAY WITH POOR VISIBILITY.

STOP 1 (Gilboa & Prattsville 7½' Quads.) Outcrop is cross-bedded sandstone of tidal channel facies with lag-concentrates of shallow marine spiriferid brachiopods.
Ichnofossils:
2nd exposure above base (begins approximately 50 feet above base of section): Intermediate-sized (3-5 mm) specimens of Skolithos, large vertical cylindrical structures (rare, near top) molds of surface trails on undersides of beds.

3rd exposure above base: some Skolithos; also nondescript bioturbation, but this difficult to determine because of poor definition of lamination.

Upper section: abundant medium and small sized specimens Skolithos in siltstone float; Planolites also common. Well preserved specimens of Spirophyton are rare, but incomplete specimens are fairly common. Much of rock is highly bioturbated.

Miles Between Points	Total Miles	Descriptions and Directions
		CONTINUE NORTH ON RT. 30
0.1	36.0	ON RIGHT, in distance - Large quarry from which much of stone for Gilboa Dam was taken. Completion of dam impounded waters of Schoharie Creek, forming Schoharie Reservoir; a part of New York City water supply system.
0.6	36.6	TURN RIGHT on road to GILBOA.
0.5	37.1	AHEAD - View north down Schoharie Valley.
0.6	37.7	GILBOA. On right - display of seed-fern stumps taken from quarry just to southwest. Some 200 specimens were found during the quarrying operation. These seed-ferns are thought to have grown to heights of some 60 feet in swamps along the seaward margin of the Catskill deltaic plain during late Medial Devonian time. They were buried during a minor oscillation of the marine shoreline in tidal channel or bar sand deposits. DO NOT CROSS BRIDGE. TURN LEFT (NORTH) ONTO STRYKER ROAD (County Rt. 13).
		PROCEED NORTH ALONG SCHOHARIE CREEK.
1.3	39.0	PARK ON RIGHT *STOP 2* (Gilboa 7½ Quad.)- Ledges on west bank of Schoharie Creek consisting of burrowed Hamilton Group sandstones. *Ichnofossils*: Lower part of section: Underneath re-entrant are specimens of *Planolites*, *Isopodichnus*; small paired burrows of *Arenicolites* can also be seen. Larger U-shaped burrows (*Arenicolites*) and *Skolithos* occur in overlying bed. Under a re-entrant on the upstream side of the outcrop is ? *Teichichnus*; other specimens occur at about this layer. Upper bedding surfaces: 2 sizes *Skolithos*; sediment scoured from around larger burrows. Larger vertical burrows are common; horizontal burrows (*Planolites*) less so. Specimens of *Arenicolites* and *Isopodichnus* are rare.

Miles Between Points	Total Miles	Descriptions and Directions
		TURN AROUND. RETURN TO GILBOA BRIDGE.
1.3	40.3	GILBOA BRIDGE. TURN LEFT (EAST) AND CROSS BRIDGE.
		CLIMB HILL. STAY ON SURFACED ROAD.
0.5	40.8	ON RIGHT - Gilboa Dam.
0.3	41.1	ON LEFT - Gilboa Central School
0.9	42.0	ROAD FORKS. TAKE RIGHT FORK TOWARDS PRATTSVILLE. CROSS MANORKILL BRIDGE.
0.1	42.1	PARK ON RIGHT (at south end of bridge). Walk down path to mouth of Manor Kill. STOP 3 (Gilboa 7½' Quad., Section 46 of Johnson, 1968). The beds exposed in the Manor Kill Gorge are within the upper part of the Hamilton Group. Those in the lower part of the section, adjacent to the Schoharie Reservoir, are trough cross-bedded, burrowed, medium-grained sandstone of the Chemung lithofacies assigned to the tidal channel facies. Some of these sandstones are rich in plant material and in a few places, during low water stages of the reservoir, fossil seed-fern stumps, in growth position, may be seen. The remainder of the section upstream consists of interbedded red and green shales, dark gray shales and medium gray, shallowly cross-bedded, fine-grained sandstone; interpreted, respectively, as distal alluvial plain, tidal flat and tidal channel facies. Ichnofossils: Base (below spring water level): Ripple marked bed covered with small specimens of Skolithos, abundant Planolites and Skolithos in float. (just above spring water level): Arenicolites, Skolithos, Planolites, Bifungites (rare) and Cruziana in blocks of float at water level.
		TURN AROUND. RETURN TO GILBOA BRIDGE, THEN TO RT. 30.

Miles Between Points	Total Miles	Descriptions and Directions
3.0	45.1	TURN LEFT (South) ONTO RT. 30.
0.5	45.6	TURN LEFT ONTO "ROAD SEVEN" (unsurfaced).
		Proceed south along west side of Schoharie Reservoir.
3.2	48.8	ON LEFT - Road to Intake Building of Schoharie Reservoir. PARK ON RIGHT. WALK DOWN ROAD to Intake Building STOP 4 (Gilboa 7½' Quad., Section 47 of Johnson, 1968). The lower 17' of section consists of dark gray siltstone and shale; above this is 114' of lighter gray, in part shallowly cross-bedded, fine-grained sandstone of tidal or very shallow sub-tidal origin. Ichnofossils: Base: Abundant specimens of *Spirophyton* in ditch outcrop behind Intake Building; also some fine sandstone above this is highly bioturbated.
		About 50' above base (at level of birch post): *Cruziana* (?) on underside of sandstone bed.
		Middle: few layers with molds of surface trails exposed on undersides of beds up hill from road.
		CONTINUE SOUTH ON "ROAD SEVEN".
1.0	49.8	PARK ON LEFT BEFORE CROSSING BRIDGE. STOP 5 (Prattsville 7½' Quad., Section 48 of Johnson, 1968) - At this point Bear Kill drops over Hardenburg Falls and flows into Schoharie Reservoir. Beds here are assigned to the tidal channel and tidal flat facies. The tidal channel facies is represented by gray, cross-bedded, fossiliferous sandstones and the tidal flat facies by very dark gray, very thin-bedded, in part conglomeratic, shales. Lag-concentrates in both facies are rich in shallow marine brachiopod shells. Ichnofossils: Base: Rare *Skolithos* and *Planolites*; very rare large cylindrical burrows.

Miles Between Points	Total Miles	Descriptions and Directions
		About 8' above base: *Skolithos*
		Above falls: thin bedded siltstone with rare *Planolites*.
		CROSS BRIDGE AND CONTINUE TO RT. 23
0.3	50.1	TURN RIGHT (WEST) ONTO RT. 23.
2.4	52.5	ENTER GRAND GORGE.
0.5	53.0	JUNCTION RTS. 23 & 30. CONTINUE WEST ON RT. 23.
6.9	59.9	ENTER VILLAGE OF STAMFORD.
1.0	60.9	JUNCTION RTS. 23 & 10. TURN RIGHT (NORTH) ONTO RT. 10.
1.0	61.9	ON LEFT - Department of Environmental Conservation Regional Headquarters.
1.9	63.8	ON LEFT - Outcrop of Catskill lithofacies.
4.0	67.8	ENTER JEFFERSON
	68.1	STOP SIGN. TURN RIGHT AND CONTINUE NORTH ON RT. 10.
		TURN RIGHT ON UNSURFACED ROAD.
		ON LEFT - Small house on left just below prominent sandstone ledge. **STOP 6** (Summit 7½' Quad., Section 36 of Johnson, 1968) - In roadside quarry, about 0.2 mile east of house, shales of offshore facies. Behind house are sandstones of probable bar origin.
		Ichnofossils: Lower quarry: Several layers with interference ripple marks cut by *Skolithos* and *Planolites* with coarser burrow fill.

Miles Between Points	Total Miles	Descriptions and Directions
		Section behind house: Abundant large Skolithos. Note that a few burrows intersect. Some of the burrow walls are clearly defined, others not. A few layers contain small sinuous specimens of Planolites as well. A poorly preserved specimen of Cruziana has also been found here. Burrows formed in the relatively coarse sand would have been more likely to collapse than those formed in more fine grained sediments.
		TURN AROUND. RETURN TO RT. 10.
4.3	72.4	TURN LEFT (SOUTH) ON RT. 10.
1.0	73.4	IN JEFFERSON, TURN RIGHT (WEST) ONTO "MAIN STREET".
0.6	74.0	Leave JEFFERSON.
3.4	77.4	Enter NORTH HARPERSFIELD.
4.5	81.9	TURN RIGHT (WEST) ONTO RT. 23.
4.2	86.1	Enter DAVENPORT
4.3	90.4	Enter DAVENPORT CENTER.
2.8	93.2	TURN RIGHT ONTO DELAWARE COUNTY RT. 11 TO WEST DAVENPORT.
0.5	93.7	Stop Sign. TURN LEFT.
2.4	96.1	Cross SUSQUEHANNA RIVER.
0.3	96.4	Cross over Rt. I-88.
0.2	96.6	JUNCTION WITH RT. 7 & 28. TURN RIGHT (NORTH-EAST) ONTO RT. 7 & 28.
2.1	98.7	Enter COLLIERSVILLE.
0.3	99.0	Rts. 7 & 28 Separate - TURN LEFT (NORTH) ON RT. 28 TOWARDS COOPERSTOWN.
0.9	99.9	PARK ON RIGHT SHOULDER AT Goodyear Lake Dam. ON LEFT EXTENSIVE OUTCROP.

Miles Between Points	Total Miles	Descriptions and Directions
		STOP 7 (Milford 7½' Quad., Section 22 of Johnson, 1968) - This outcrop contains an example of the flow-rolls which are locally common in the Chemung lithofacies. These occur as beds of internally disturbed structure underlain and overlain by horizontal, well-bedded strata. Within the flow-roll beds are nodule-shaped, concentrically laminated masses of medium gray, very fine-grained sandstone enclosed in slightly darker colored siltstone. The laminar structure is due to concentric, extremely thin, dark laminae composed largely of very fine plant fragments. The enclosing siltstone commonly has a diapiric relationship to adjacent pillows. This outcrop is at the distal edge of the near-shore facies. Ichnofossils: Base: Specimens of Skolithos and Planolites are present, but not common. They are most easily seen on shale partings. Note the absence of trace fossils near the flow structures. About 10 feet above flow structures: Specimens of Skolithos and Planolites and molds of surface trails rare to common on shale partings. TURN AROUND AND RETURN TO I-88 VIA RT. 7 & 28.
0.8	100.7	RT. 7 & 28. TURN RIGHT (SOUTHWEST).
2.1	102.8	Enter EMMONS.
0.3	103.1	Stop light near drive-in movie. TURN LEFT AND ALMOST IMMEDIATELY TURN RIGHT (WEST) ONTO RT. I-88.
2.0	105.1	Exit for Oneonta Colleges and State Police. CONTINUE WEST ON I-88.
2.8	107.9	Exit for Rt. 205 and MORRIS. TURN NORTH ONTO RT. 205.
1.6	109.5	JUNCTION RTS. 205 and 23. CONTINUE ON RT. 205 & 23.
0.6	110.1	Caution light. Rt. 23 swings left (west). CONTINUE STRAIGHT AHEAD ON RT. 205.

Miles Between Points	Total Miles	Descriptions and Directions
4.0	114.1	ON RIGHT - Road to Oneonta Airport.
0.6	114.7	TURN LEFT onto road to LAURENS.
0.2	114.9	Enter LAURENS.
0.2	115.0	Stop Sign - TURN LEFT.
		CONTINUE THROUGH LAURENS.
0.4	115.4	TURN RIGHT onto Gilbert Lake Road.
1.1	116.5	Fork in road. TAKE RIGHT FORK.
2.4	118.9	ON RIGHT - Entrance to Gilbert Lake State Park.
0.5	119.4	PARK ON RIGHT. WALK UP SERVICE ROAD TO ROCK QUARRY. *STOP 8* (Morris 7½' Quad., Section 9094 of Thayer, 1972) - Although well above the Tully clastic correlatives, these fossiliferous, interbedded gray sandstones and shales exhibit typical characteristics of the eastern New York Chemung lithofacies. *Ichnofossils*: Near base: Abundant specimens *Zoophycos* with diverse forms. It is recognizable in vertical section as a series of horizontally oriented chevrons. Specimens of *Planolites* and *Skolithos* are abundant; *Cruziana*, *Bifungites*, large horizontal burrows and *Arenicolites* are rare, but present. Note specimen of *Arenicolites* on vertical surface of piece of float about seven feet above quarry base. Upper portion of quarry: Abundant specimens of *Planolites*, *Skolithos* and some of *Zoophycos*. Highly bioturbated sandstone is interbedded with laminated sandstone, implying influxes of sediment. CONTINUE TOWARDS NEW LISBON.
2.9	122.3	Four corners (NEW LISBON). TURN RIGHT (NORTH) ONTO OTSEGO COUNTY RT. 14.

Miles Between Points	Total Miles	Descriptions and Directions
0.9	123.2	ON RIGHT - Unsurfaced road. ON LEFT - house and barn. PARK ON SHOULDER AND WALK UP unsurfaced road to roadside quarry. STOP 9 (Morris 7½' Quad., Section 15 of Johnson, 1968) - Beds exposed in this unnamed tributary of Stony Creek and adjacent abandoned quarry are assigned to the offshore facies of the Tully clastic correlatives. Ichnofossils: Base: Planolites - rare to common; Skolithos common to abundant in siltstone; Bifungites rare. Zoophycos absent. In stream bed: Abundant float (fine to very fine sandstone) with abundant Zoophycos. Note diversity of shapes - from nearly elliptical to strongly lobate. Specimens Planolites and Skolithos are also common, as large horizontal burrows. Zoophycos rarely occurs on same slab with other trace fossils. TURN AROUND. RETURN TO FOUR CORNERS.
1.0	124.2	Four corners. TURN RIGHT (WEST) ONTO OTSEGO COUNTY RT. 12.
0.6	124.8	RT. 51. TURN LEFT (SOUTH) TOWARDS MORRIS.
3.8	128.6	Stop light in center of town. Bank on left and Morris Inn on right constructed of Chemung lithofacies flagstone. TURN RIGHT ON N. BROAD ST.
2.4	131.0	ON LEFT - quarry in Chemung lithofacies.
3.7	134.7	ON LEFT - Small quarry directly adjacent to highway. PARK ON RIGHT. STOP 10 (New Berlin South 7½' Quad., Section 9063 of Thayer, 1972). The shale beds in this quarry and in one directly above it are representative of the offshore facies. Ichnofossils: Base: In lower quarry thinly bedded siltstone has abundant specimens of Skolithos and Planolites. Isopodichnus is present, but rare. Sandstone in float is packed with specimens of Zoophycos. Note that central tube extends

Miles Between Points	Total Miles	Descriptions and Directions
		upward (or downward) from bedding plane and that spreiten extend laterally from this tube. This layer is exposed at the intersection of the quarry road and main road.
		Upper quarry: Abundant *Skolithos*, *Planolites*; rare *Bifungites*, *Arenicolites* and possibly ? *Teichichnus*. *Zoophycos* common on some surfaces. Note abundant ripple marks.
		TURN AROUND AND RETURN TO CENTER OF MORRIS.
5.8	140.5	Stoplight at Center of MORRIS. GO STRAIGHT AHEAD ON RT. 23.
9.1	149.6	Enter WEST ONEONTA
0.3	150.9	Junction Rts. 23 and 205.
0.7	151.6	Stop light. TURN LEFT. CONTINUE ON RT. 23.
0.3	151.9	Junction Rts. 23 & 7. CONTINUE STRAIGHT AHEAD.
0.4	152.3	Enter ONEONTA.
1.2	153.5	Stoplight. TURN LEFT ONTO WEST STREET.
		CLIMB HILL.
0.6	154.1	TURN RIGHT ONTO SUCO CAMPUS (Ravine Parkway).

END ROAD LOG

PALEOENVIRONMENTS OF THE MARCELLUS AND LOWER SKANEATELES FORMATIONS OF THE OTSEGO COUNTY REGION (MIDDLE DEVONIAN)

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INTRODUCTION

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

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

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

The Middle Devonian Hamilton Group of New York State is structurally simple and highly fossiliferous, thereby lending itself to detailed stratigraphic, paleontologic, and paleoecologic studies. In eastern New York it consists of approximately 1,650 feet of shale, siltstones, and sandstones in the Unadilla Valley, 1950 feet in the Susquehanna Valley and 2,285 feet near Richmondville (Cooper 1933).

The Marcellus Formation in the Otsego County region thickens eastward from about 600 feet in the Unadilla Valley, to nearly 820 feet in the Richmondville area in western Schoharie County. The base of the Mottville Member is generally taken to be the top of the Marcellus Formation east of the Cayuga Lake meridian. However, east of the Unadilla Valley, the Mottville loses its identity, thereby making the boundary between the Upper Marcellus and Lower Skaneateles almost impossible to delineate with precision. Therefore, criteria to determine the exact thickness of the Marcellus Formation across most of Otsego County is lacking.

The senior author, using the Mottville Member as a datum, obtained a dip of approximately 85 feet per mile to the southwest for the Lower Hamilton in the Unadilla Valley. Cooper (1933) indicates steeper dips of 90-100 feet to the southwest in the Susquehanna Valley and 100-137 feet per mile to the southwest in the Schoharie Valley.

PREVIOUS WORK

Lardner Vanusem (1842) in his report on the third geological district of New York laid the foundation for all later work in central and eastern New York west of the Catskills. Prosser (1895, 1899) furthered our knowledge of Middle and Upper Devonian rocks in central and eastern New York (Chenango Co. to Albany Co.). Grabau (1906) included some remarks on Hamilton strata in the Schoharie Valley to the east of the present region of study. The stratigraphic relations of the Hamilton Group as now understood were first clarified by Cooper's classic papers (1930, 1933). Rickard and Zenger (1964) provided the first detailed geologic maps of the Richfield Springs and Cooperstown Quadrangles and Rickard (1975) summarizes recent correlations for the New York Devonian.

During earlier investigations dealing with the facies and faunal control of the different sediment phases of the classic "Catskill Delta", the cyclic repetition of these phases was also recognized (Chadwick, 1933; Rich, 1951; Rickard, 1964; Wolff, 1965).

Through the use of faunal associations (Cooper, 1930, 1933) and thickening rates as well as the earlier descriptions of faunal and sediment features, various correlation and environmental subdivisions were extended. This has been particularly so for the transgressive units (McCave, 1968; Wolff, 1969; Johnson & Friedman, 1969), and for the growing evidence for the tectonic control of many depositional phases through contemporaneous uplift or subsidence for various parts of the Devonian basin in New York and Pennsylvania (Fletcher, 1963; Wolff, 1965, 1969; Sutton, et al., 1970; Walker, 1971; McCabe, 1973) and the recognition of the "Catskill Delta" as a tectonic deltaic complex (Friedman and Johnson, 1969).

With some modification, these phases and their inferred depositional environments within the Marcellus Formation in this area are indicated in Figure 1.

STRATIGRAPHY

General

The regional and local tectonic control of the depositional phases was outlined by Wolff (1969) and McCave (1973). Of significance is the Adirondack axis, which continues to act as a submarine barrier (arch) in this region during most of the period associated with the deposition of the Hamilton Group. The area between Richmondville and Schoharie Valley separates two marine basins and acts as a local shoal which enables the winnowing of marine sands during the short transgressive intervals; McCave (1973) reports four other sediment highs west of this region. These shoals permit the development of linear, en-echelon lenses of sand as "offshore bars" and separate the open marine platform and slope environments west of this area (the stops of this field trip) with the more restricted marine, lagoonal, and marginal channel and sand flat environments east of here (Wolff, 1969).

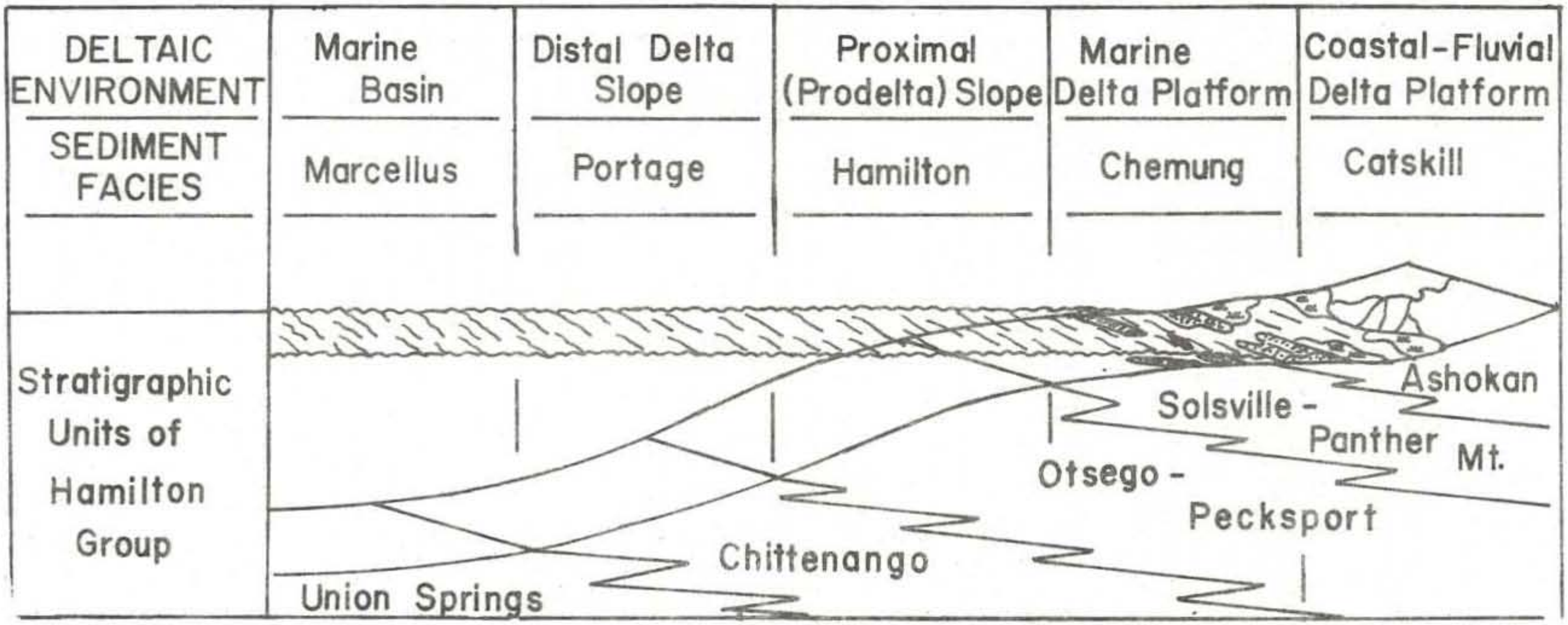

Fig. 1. Depositional environments and formation equivalents of the Marcellus

The features associated with the sediment facies of Rickard (1975) are described below. The modification for the Marcellus Formation is to divide these phases into the categories originally described by Rickard (1964), making the following associations: Marcellus=Cleveland, Portage=Chagrin, Hamilton=Big Bend, Chemung=Smethport. The alluvial associations (Catskill) will not be seen on this trip and are not included.

A. Marcellus Facies (Union Springs-Chittenango Members). The principle feature is the thin-bedded black, fissile, calcareous shales with thin bedded black micrite or micrite concretions. The sediments were deposited or precipitated in an anaerobic environment below wave base. The strata are sparsely fossiliferous, consisting of low diversity pelagic and epipelagic types.

B. Portage Facies (Lower Pecksport, Lower Solsville, Upper Bridgewater). Here the fissile laminated shales grade into massive laminated mudstones and thin-bedded homogeneous siltstones (distal turbidites). The proportion of micrite decreases rapidly vertically through the section. The deposits are not as deep since the sparse fauna now includes benthic as well as epipelagic and pelagic types.

C. Hamilton Facies, Otsego. The major lithology is knobby, irregular-bedded dark gray mudstone (from burrowing) with some siltstones or fine-grained gray sandstones (proximal turbidites). The sandstones become planar crossbedded and laminated higher in the section, and ball and pillow structures become more common. The sandstones exhibit scour and fill contacts and some ripples within the associated gray shales. This environment is now below and within the zone of wave base and includes a moderately diverse fauna of benthic and epipelagic types.

D. Chemung Facies Upper Solsville, Upper Pecksport, Mottville, Delphi Station, Panther Mt. Now the lithology and contacts become more variable and discontinuous. Thick sets of gray-light gray, medium-grained crossbedded sandstones are interbedded with horizontal bedded siltstones and dark gray shales. The important structures include low angle planar crossbedding, oscillation and current ripples and megaripples, scour and fill structures, burrow mottles, current lineation, and horizontal laminations. Coquinites are common in this area, but are uncommon south of Albany where pebble beds are more characteristic. This is a shallow marine environment near or within the zone of breaking waves (onshore-offshore transport). It contains a highly diverse fauna of brachiopods, pelecypods, worms, and plant fragments.

The sediment structure associated with the Mottville horizon (emphasized in the road log) indicate the presence of a sandy, well agitated marine platform with low angle crossbedding and low amplitude ripples. The crests of the current structures trend northwest and southwest while current lineation and crossbedding trend west and northeast. This suggests a west-northwest current system with a northeast-southwest onshore-offshore component.

Marcellus Formation

Although considerably revised since Hall (1839) first named the Marcellus, this formation has long been recognized as basal Hamilton. Cooper (1930) was able to subdivide it into a number of members based on stratigraphic position and lithology.

Due to facies changes within the Marcellus and overlying Skaneateles Formations it seems best to subdivide these formations differently between western and eastern Otsego County. The stratigraphic sections in Figure 2 reveal this variance in subdivision along with the position and thickness of exposed units for each of the field trip stops.

<u>Union Springs Member</u>. The Union Springs Member (Cooper 1930) consists of 25 to 35 feet of black fissile shales and thin black limestones lying between the Cherry Valley Member above and the Onondaga Limestone below. The dominant fauna of the Union Springs (Plate 1) is not a diverse one, consisting primarily of planktonic or epiplanktonic forms of cephalopods (<u>Tornoceras</u> sp., <u>Agoniatites</u> <u>nodiferus</u>), the pteropod <u>Styliolina</u> <u>fissurella</u>, the possibly epiplanktonic, <u>"Leiorhynchus"</u> limitaris and the hitchhiking bivalve <u>Lunulicardium</u> (Nye, et al. 1975). The Union Springs is best exposed at Cox's Ravine just Northwest of Cherry Valley - Stop 8.

<u>Cherry Valley Member</u>. The Cherry Valley Limestone has long been famous for its contained cephalopods. Originally known as the Agoniate Limestone (Vanuxem 1842), Clarke (1903) first applied the geographic name by which it is presently known. Sandwiched between the weak Chittenango Shale above and Union Springs Shale below this 5 feet of hard resistant limestone forms waterfalls and terraces. The type section is at Cox's Ravine, .7 miles northwest of Cherry Valley (Stop 8). An orange-red iron stain is characteristic of the Cherry Valley in outcrop.

The high diversity of cephalopods, nearly 30 species across the state, has been documented for many years (Clarke,1901; Flower, 1936; Rickard, 1952). The precise age of the Cherry Valley Limestone is in dispute as correlations with the European Eifelian-Givetian boundary have not been resolved (Rickard, 1975). <u>Agoniatites</u> <u>vanuxemi</u> and <u>Striacoceras</u> <u>typum</u> are common cephalopods. Other forms found include the tabulate coral <u>Aulopora</u> and the trilobite <u>Proetus</u> <u>haldemani</u>. (Plate 2-3)

<u>Chittenango Member</u>. The Chittenango Shale (Cooper, 1930) is a black, fissile, nearly barren shale totaling approximately 150 feet. Concretions, many septarian, occur throughout the unit. <u>Styliolina</u> <u>fissurella</u> and small tentaculitids are the only conspicuous fossils. The Chittenango will not be examined on the trip.

<u>Bridgewater Member</u>. This name was applied by Cooper (1930) to the shales between the Chittenango Member and Solsville Member. It was

Large bivalve mollusks and mostly pedunculate brachiopods dominate the assemblage. Minor constituent taxa include mobile epifaunal gastropods and trilobites. The problematical ichnofossil Taonurus is also very abundant.

The fauna is dominated by filter feeders (73%), while deposit feeders account for 15% of the assemblage and mobile carnivores, scavengers, and grazers (mostly gastropods and trilobites) account for roughly 12%.

The bivalves include the epibyssate Limoptera, Mytilarca, Cornellites, and Pseudaviculompecten, the endobyssate Modiomorpha, Actinodesma (Glyptodesma), Goniophoia, and Cimitaria and the mobile infaunal suspension feeding Grammysia and Cypricardella.

Camarotoechia, Mucrospirifer, Paraspirifer, Mediospirifer, and Tropidoleptus are the dominant brachiopods.

Vagrant benthonic forms include gastropods Bembexia and Paleozygopleura (Loxonema), and the trilobites Greenops and Dipleura. The relatively high frequency of gastropods may be indirect evidence of abundant plant growth.

In summation, the community is characterized by fixed and free, epifaunal filter feeders, and mobile and fixed, infaunal filter feeding bivalves. Vagrant benthonics are strikingly conspicuous.

Lithologically the lower Delphi Station is a calcareous arenaceous shale and siltstone or subgraywacke. Some areas contain megaripples with low angle planar crossbedding 6-8 feet long and 1-6 inches thick.

The inferred environment of the Limoptera Community was closer to shore than the previously described types, probably inhabiting the middle delta platform. Current activity was moderate to high, normal marine conditions prevailed, and the substrate was probably stable and firm. Sufficient organic detritus was in suspension and in the substrate to support the varied adaptive types described above.

Analogs are probably represented by a blend of McGhee's (1976) Leptodesma-Tylothyris and Atrypa-Cypricardella Communities and the Bellerophon Community of Bowen, et al. (op. cit.)

Portions or all of the Panther Mountain and Solsville Members are also representative of the middle delta platform in this area. The weakly developed Limoptera Community in these units, if present at all, may be due to greater rates of sedimentation from time to time on the middle delta platform. Portions of these units, especially the Solsville, may represent the unstable, shifting, substrates of the near shore delta platform.

ACKNOWLEDGEMENTS

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The junior author would like to thank Hofstra University for its "Faculty Research Award" used to defray field, laboratory, and drafting expenses. He also appreciates the efforts of Connie de Prado and William O'Brian in assisting with field and lab work.

PLATE 1

2a

2b

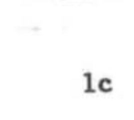
3a

3b

4

1a

1b



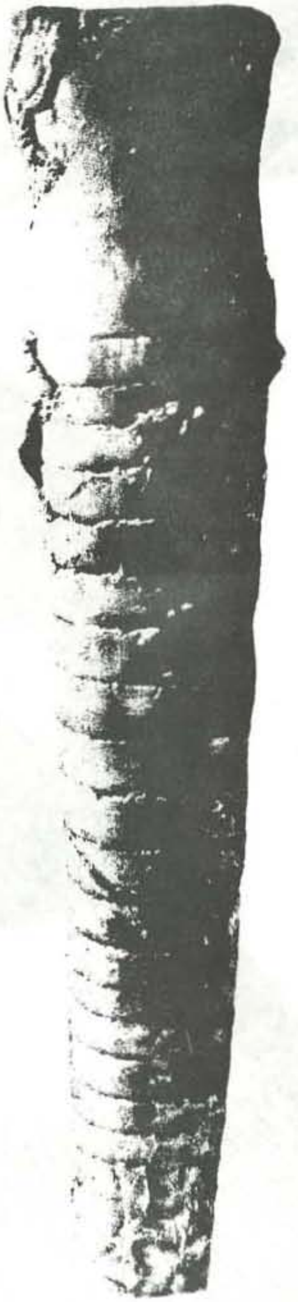
1c

UNION SPRINGS

Fig. 1a-1c	"Leiorhynchus" limitare	**Fig. 3a-3b**	**Styliolina fissurella**
Fig. 2a-2b	Lunulicardium marcellense	Fig. 4	**Agoniatites nodiferis**

PLATE 2

1



2b

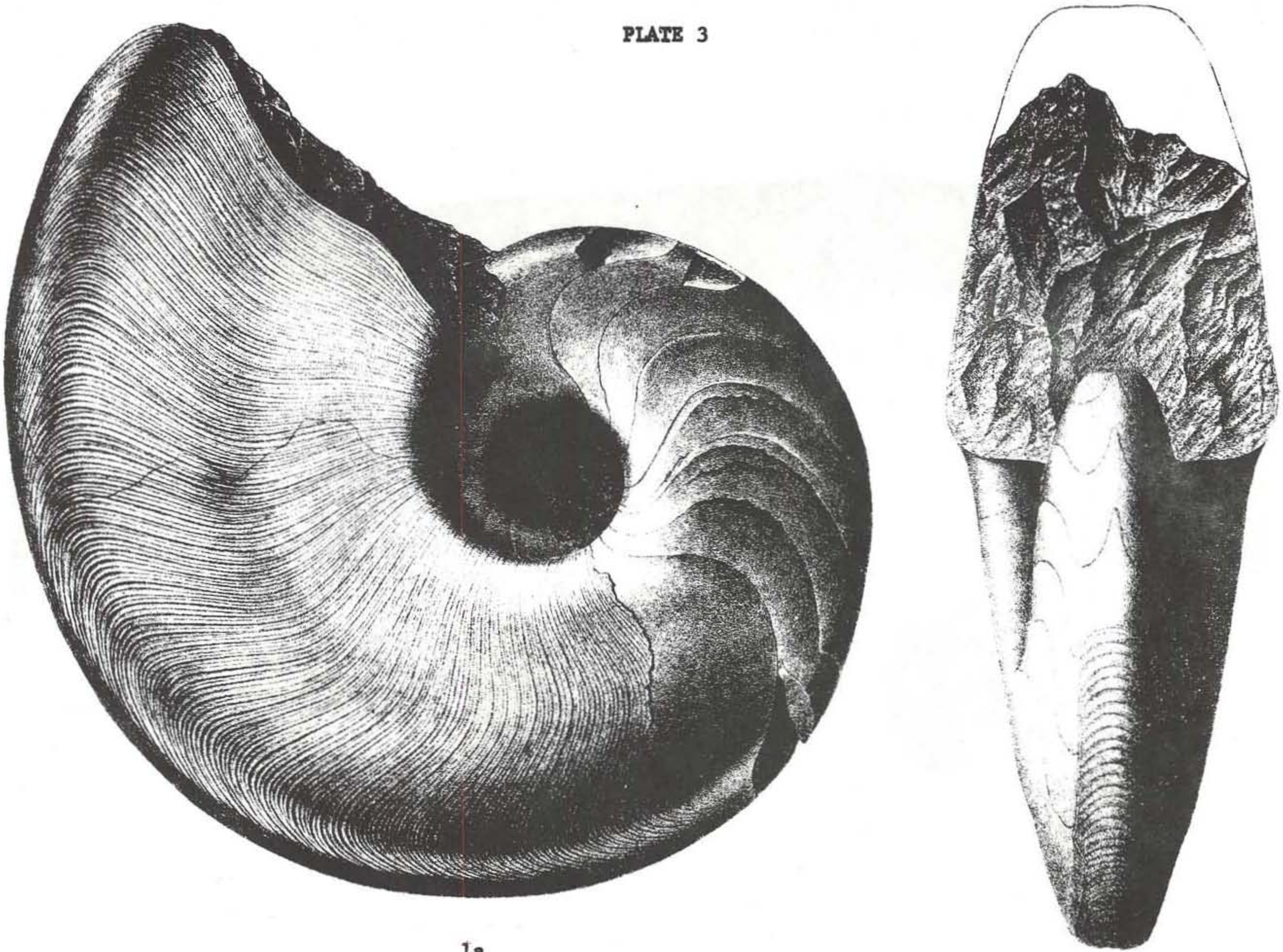
2a

3

CHERRY VALLEY

Fig. 1 Aulopora sp.
Fig. 2a-2b Striacoceras typum
Fig. 3 Proetus haldemani

PLATE 3



1a

1b

Fig. 1a-1b Agoniatites vanuxemi

PLATE 4

1a

1b

2a

2b

3a

4a

3b

4b

5a

5b

OTSEGO

Fig. 1a-1b Rhipidomella vanuxemi

Fig. 2a-2b Chonetes coronatus

Fig. 3a-3b Athyris cora

Fig. 4a-4b **Mucrospirirer mucronatus**

Fig. 5a-5b **"Leiorhynchus" multicostum**

PLATE 5

SOLSVILLE

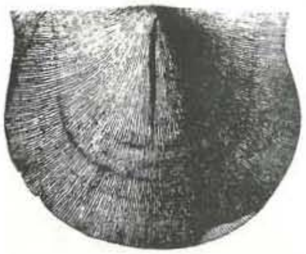
Fig. 1a-1b	Protoleptostrophia perplana
Fig. 2	Goniophora hamiltonensis
Fig. 3a-3b	Modiomorpha subalta
Fig. 4	Actinopteria bodyi
Fig. 5a-5b	Cornellites flabellum

PLATE 6

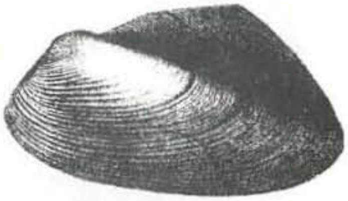
Solsville

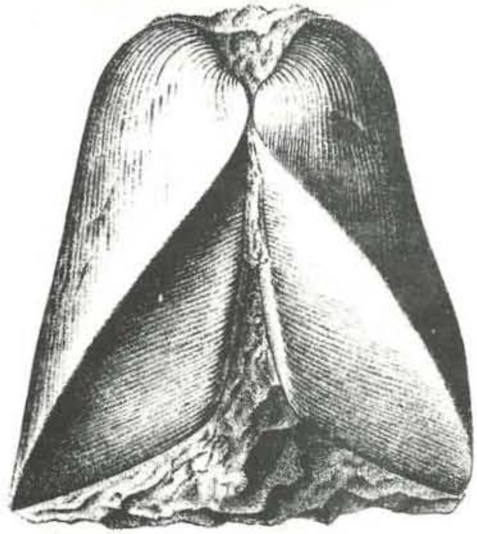
Fig. 1a-1b	Gosselettia triqueter
Fig. 2	G. oviformis
Fig. 3a-3b	Nephriticeras sp.

PLATE 5


1a


1b


3a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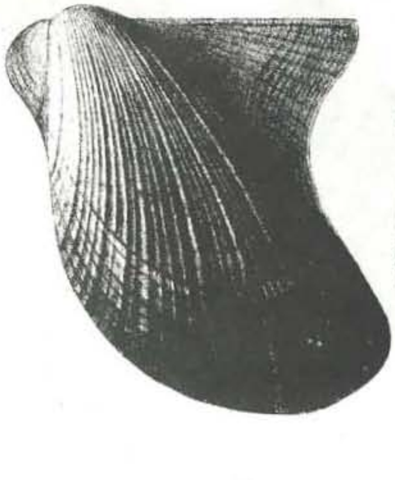
3b


4


5a


5b

PLATE 6

1a

2

1b

3a

3b

PLATE 7


1a


1b


2


3a


3b


3c


4a

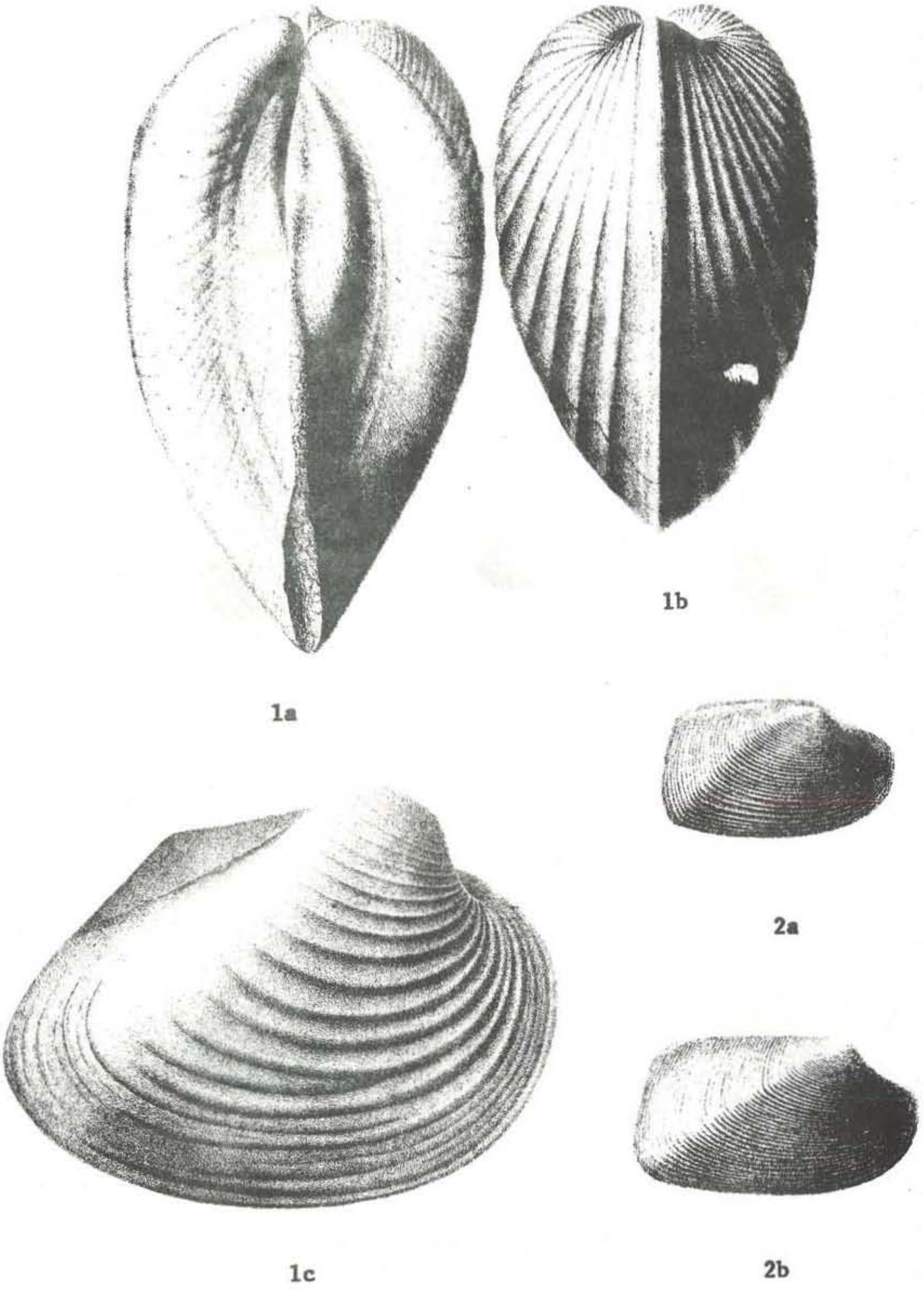

4b


4c

PECKSPORT

Fig. 1a-1b Ambocoelia praeumbona
Fig. 2 A. umbonata
Fig. 3a-3c Chonetes scitula
Fig. 4a-4c "Leiorhynchus" laura

PLATE 8



PECKSPORT

Fig. 1a-1c Grammysia alveata
Fig. 2a-2b Cypricardella bellistriata

PLATE 9


1a

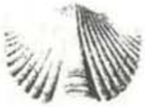

1b


1c


2a


2b


2c


3a


3b


4a


4b


5a


5b


6


7a


7b

MOTTVILLE

Fig. 1a-1c	Paraspirifer acuminatus	Fig. 5a-5b	"Camarotechia" congregata
Fig. 2a-2c	Mucrospirifer mucronatus	Fig. 6	"C." horsfordi
Fig. 3a-3b	Allanella (Spirifer) tullius	Fig. 7a-7b	"C." sappho
Fig. 4a-4b	Tropidoleptus carinatus		

PLATE 10

DELPHI STATION

Fig. 1a-1b	Conularia undulata
Fig. 2a-2b	Paracyclas lirata
Fig. 3a-3b	P. elliptica
Fig. 4a-4b	Mediospirifer audaculus

PLATE 11

Fig. 1a-1b	Actinodesma (Glyptodesma) erectum

PLATE 12

DELPHI STATION

Fig. 1a-1b	Limopteria macropteria
Fig. 2	Leiopteria dekayi
Fig. 3	Lyriopecten orbiculatus

PLATE 13

DELPHI STATION

Fig. 1	Actinopteria decussata
Fig. 2a-2b	Pseudaviculopecten princeps

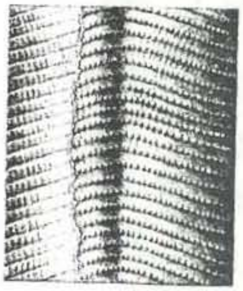
PLATE 14

DELPHI STATION

Fig. 1a-1d	Goniophora hamiltonensis
Fig. 2a-2b	Mytilarca oviformis
Fig. 3a-3b	Cypricardella bellistriata

PLATE 10

1a



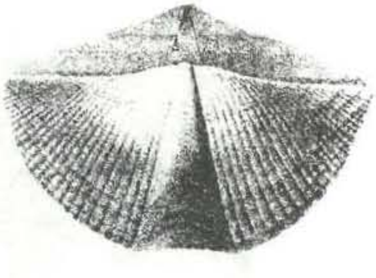
1b (6X)

2a

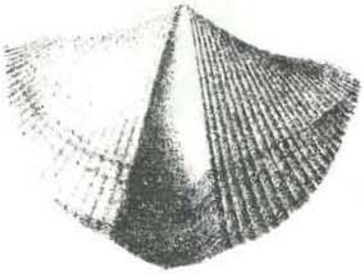
2b

3a

3b

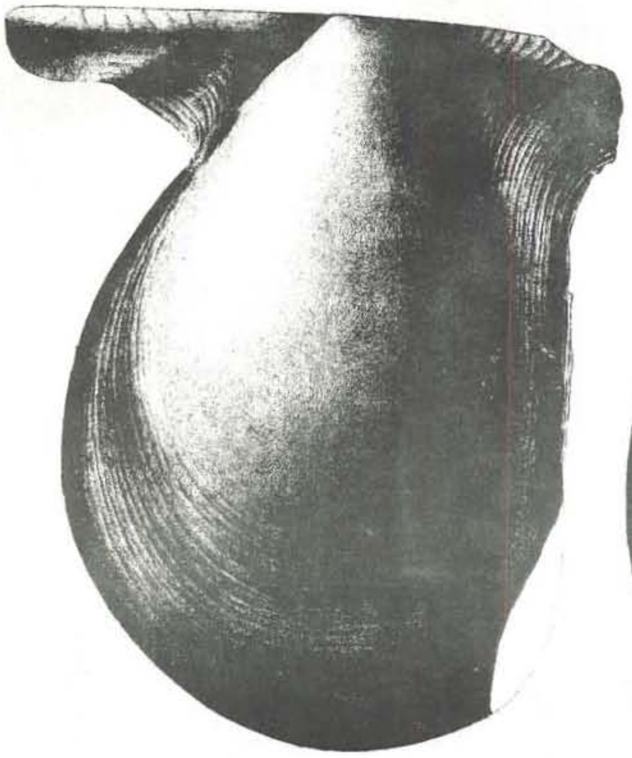


4a



4b

PLATE 11

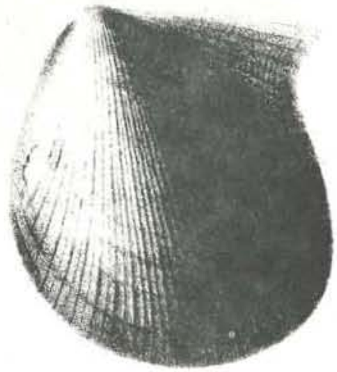


1a

1b

PLATE 12

1a



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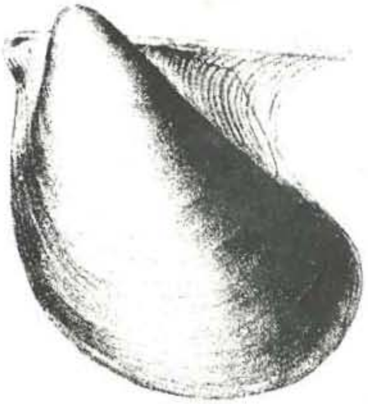

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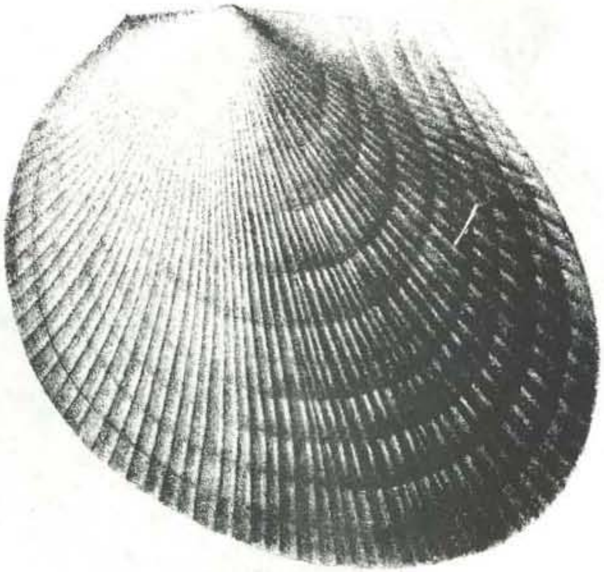

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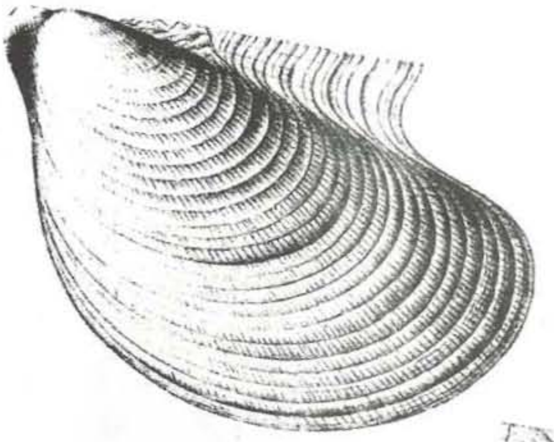
PLATE 13



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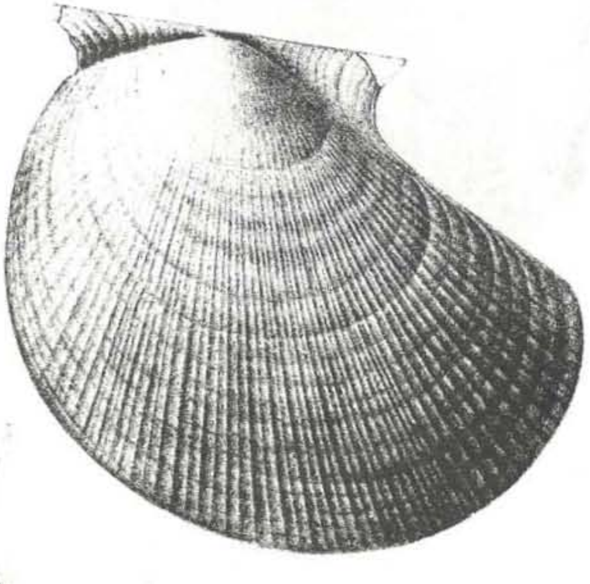
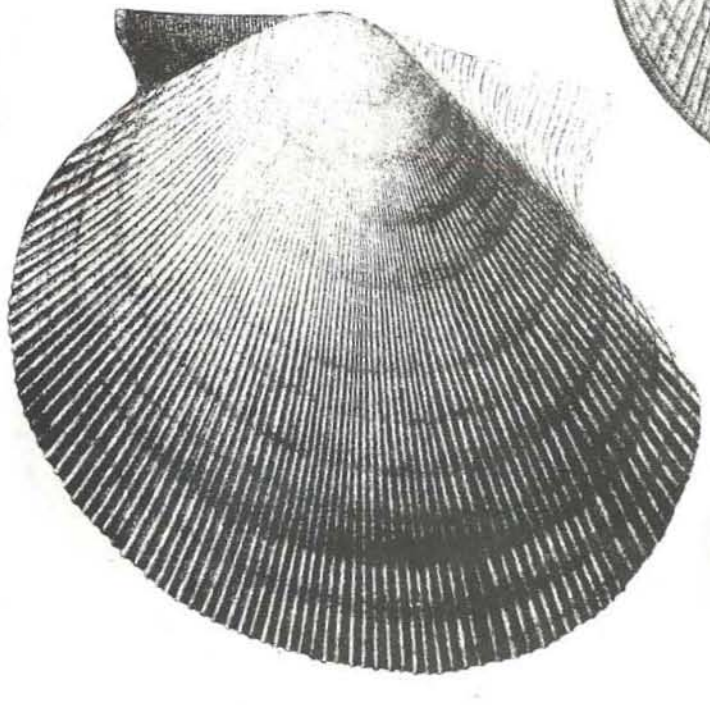


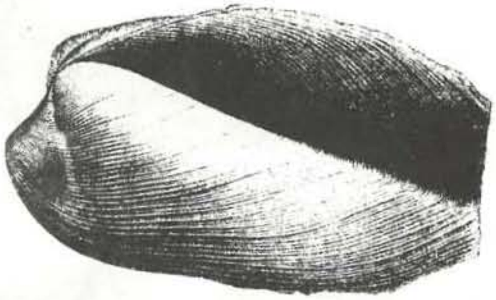
2a



2b

PLATE 14

1a



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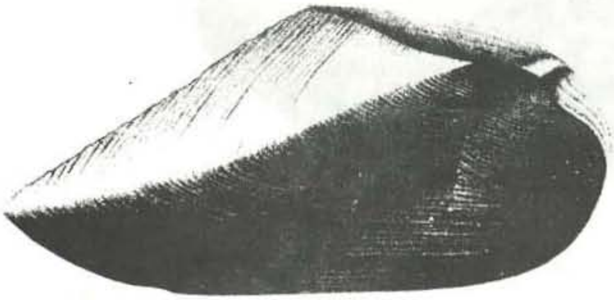


1c

1d

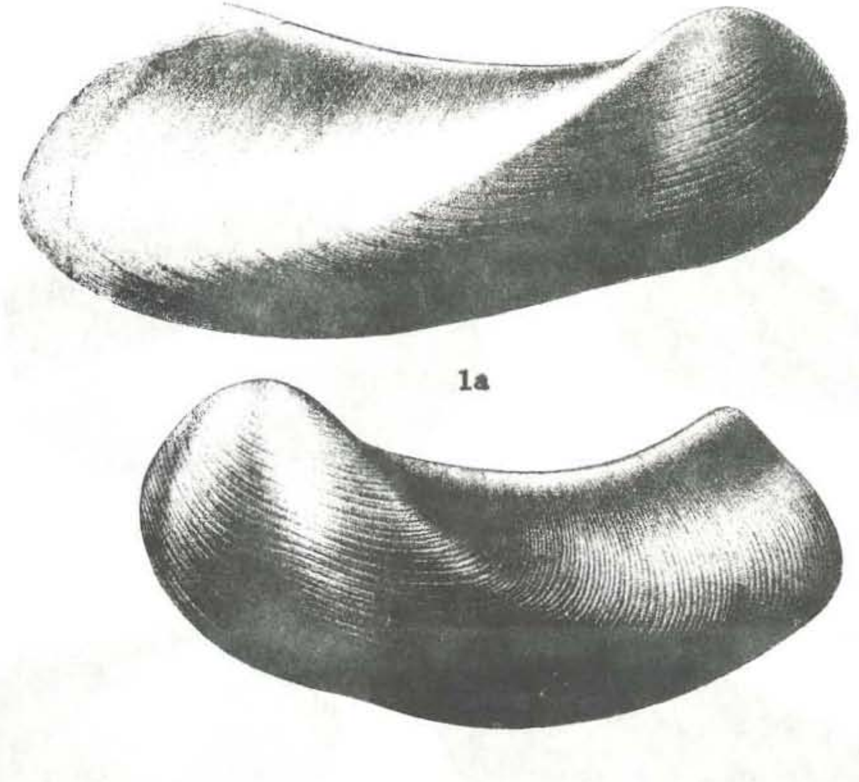
2a

2b

3a

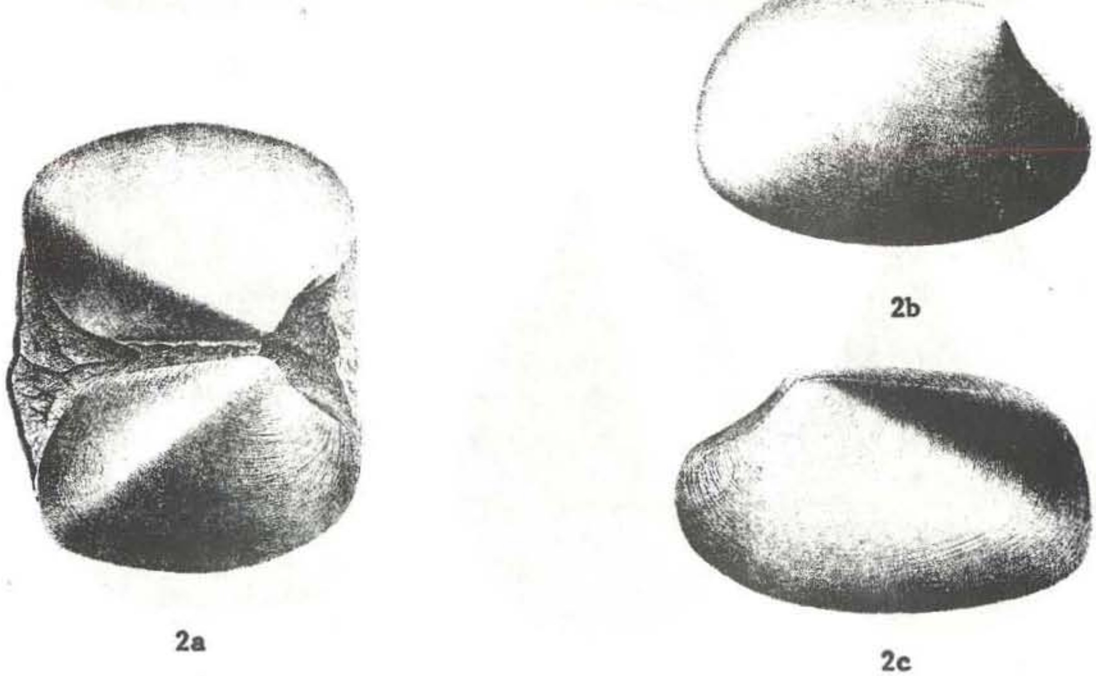
3b

PLATE 15



1a

1b



2a

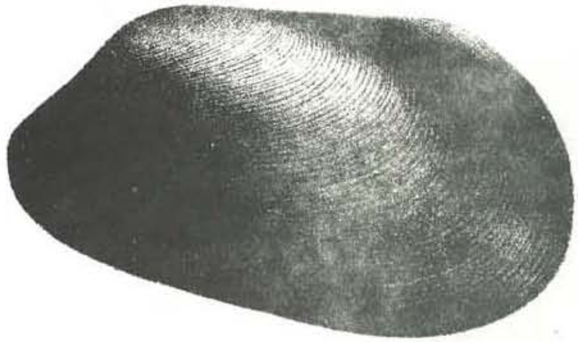
2b

2c

DELPHI STATION

Fig. 1a-1b Cimitaria recurva
Fig. 2a-2c Cypricardella tenuistriata

PLATE 16



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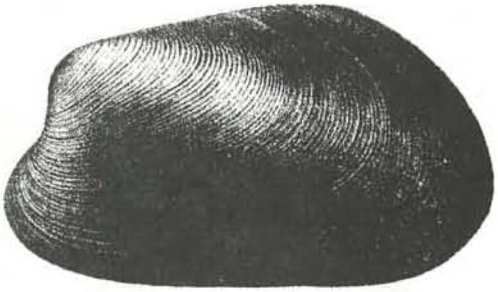

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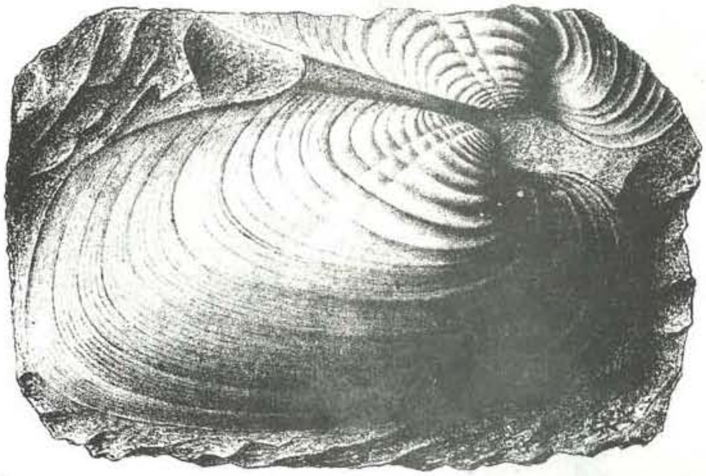
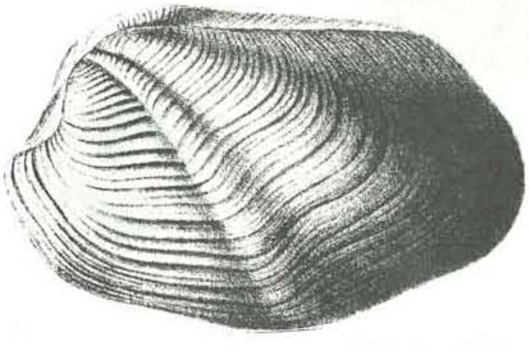


2a

3a



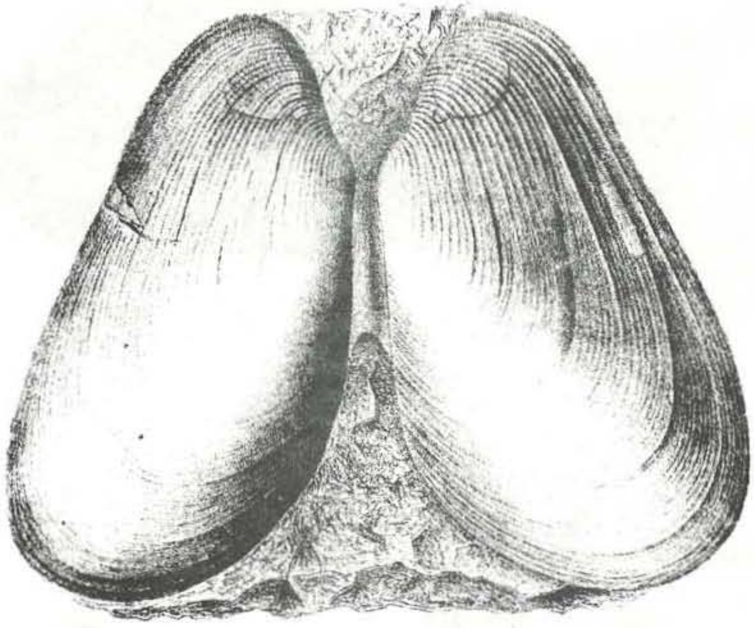
2b

3b

DELPHI STATION

Fig. 1a-1b Modiomorpha sp.
Fig. 2a-2b Grammysia bisulcata
Fig. 3a-3b Modiomorpha concentrica

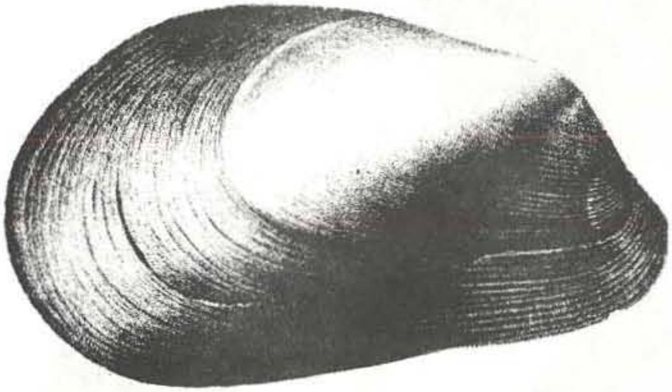
PLATE 17



1a

2a

2b



1b

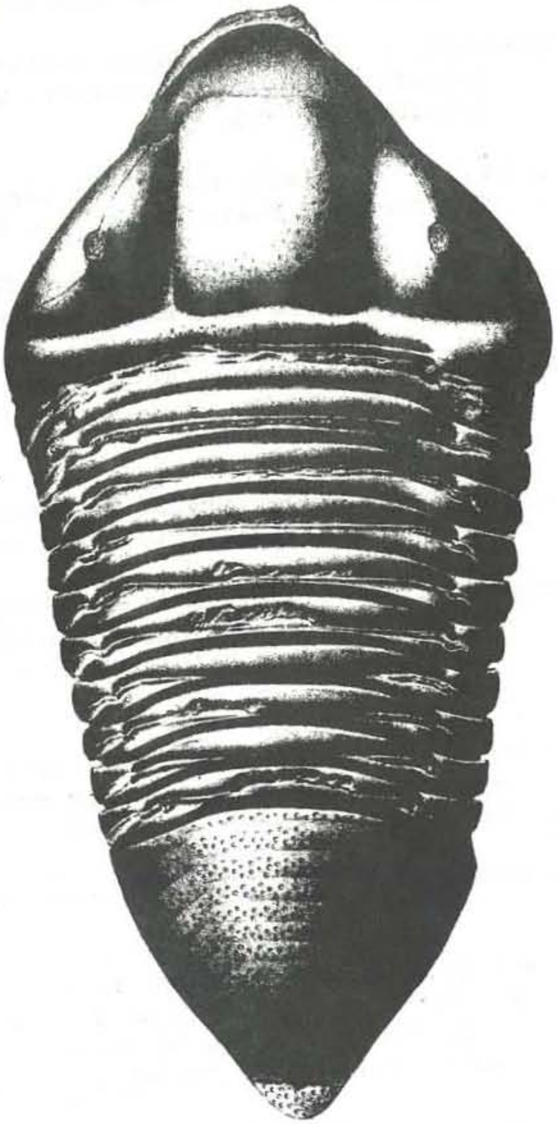
2c

DELPHI STATION

Fig. 1a-1b **Modiomorpha mytiloidea**
Fig. 2a-2c **Bembexia sulcomarginata**

PLATE 18

1a



1b

2

DELPHI STATION

Fig. 1a-1b **Dipleura dekayi**
Fig. 2 **Greenops boothi**

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Bridge
MOHAW
Sprakers
Creek
1000
1296
Sharon
4 LAN
1500
145
Pynesville
10
p 10
chmondville
Rossm
Lake
2000

ROAD LOG

NOTE: Quadrangles referred to are 7 1/2 minute. Mileage from Oneonta to Stop 1 and that from Stop 10 back to Oneonta are approximate.

Miles from last point	Cumulative Miles	
0.0	0.0	Oneonta-proceed West on NY 7
2.0	2.0	Enter West End
0.5	2.5	Jct. NY 23-proceed West on NY 23
2.0	4.5	Jct. NY 205-proceed West on NY 23
2.0	6.5	West Oneonta-proceed West on NY 23
14.0	20.5	Enter Morris
0.5	21.0	Jct. NY 51-proceed West on NY 23
8.0	29.0	Enter South New Berlin
0.3	29.3	Jct. NY 7-turn right (North)
8.0	37.3	Enter New Berlin-proceed North on NY 8
12.0	49.3	Jct. South Beaver Creek Road-turn left (West)
6.0	55.3	Enter Village of Brookfield
0.2	55.5	Jct. Main Street (Skaneateles Tpk.)-turn right (East)
0.1	55.6	Jct. North Beaver Creek Road-turn left (North)
1.8	57.4	STOP 1 - Road cut on West side Beaver Creek Road about 2 mi. North of Village of Brookfield. (Brookfield Quad.)

Units Exposed: Mottville (1' - Elev. top 1500'), Delphi Station Mbr. (45').

Here the Mottville represents the Camarotoechia-Mucrospirifer Community and delta front sand environment.

The overlying Delphi Station indicates a median delta platform environment. The Limoptera Community is well represented here. Fossils are extremely abundant.

---	---	Return South on Beaver Creek Road
1.8	59.2	Enter Brookfield
0.2	59.4	Jct. Main St. (Skaneateles Tpk.) turn left (East)
0.5	59.9	Jct. Dugway Road turn right (South)
1.6	61.5	Jct. Button Falls Road at Five Corners turn left (East)
1.5	63.0	STOP 2 - Button Falls - Falls on Button Creek down from Button Falls Road on the West side of the Unadilla Valley about 1 1/2 mi. SW of Leonardsville (Brookfield Quad.)

Units Exposed: Solsville (8' - Elev. top 1200'), Pecksport (90'), Mottville (10' - Elev. top - 1300'), Delphi Station (7').

The lithology, sedimentary structures and fauna of the Upper Pecksport assign it to the distal (outer) platform. The slightly sorted sands, sinuous and linguoid ripples, and lag concentrate conquinites of the Mottville probably represent a period of reworking or transgression forming the delta front sands. Camarotoechia and Mucrospirifer also occur in the upper Pecksport and probably represents the same community as the Mottville.

---	---	Proceed E on Button Falls Road
0.5	63.5	Jct. NY 8 turn left (North)
0.2	63.7	Solsville Ss. on left and in abandoned quarry
1.0	64.7	Enter Leonardsville
0.2	64.9	Jct. Huey Road - turn right (East)
0.2	65.1	Cross Unadilla River
0.7	65.8	Jct. Otsego Co. Road 18 - turn left (North)
1.2	67.0	Jct. Otsego Co. Rd. 21 (Skaneateles Tpk.) at Lloydsville-turn right (East)
3.4	70.4	Plainfield Center
0.2	70.6	Sharp curve to left (North)
0.4	71.0	STOP 3 - Plainfield Center Quarry just West of Otsego Co. Rd. 21; .3 mi. N of Plainfield Center (Unadilla Forks Quad.)

Units Exposed: Solsville (10' - Elev. top 1620'), Pecksport (80'), Mottville (5' - Elev. top 1700').

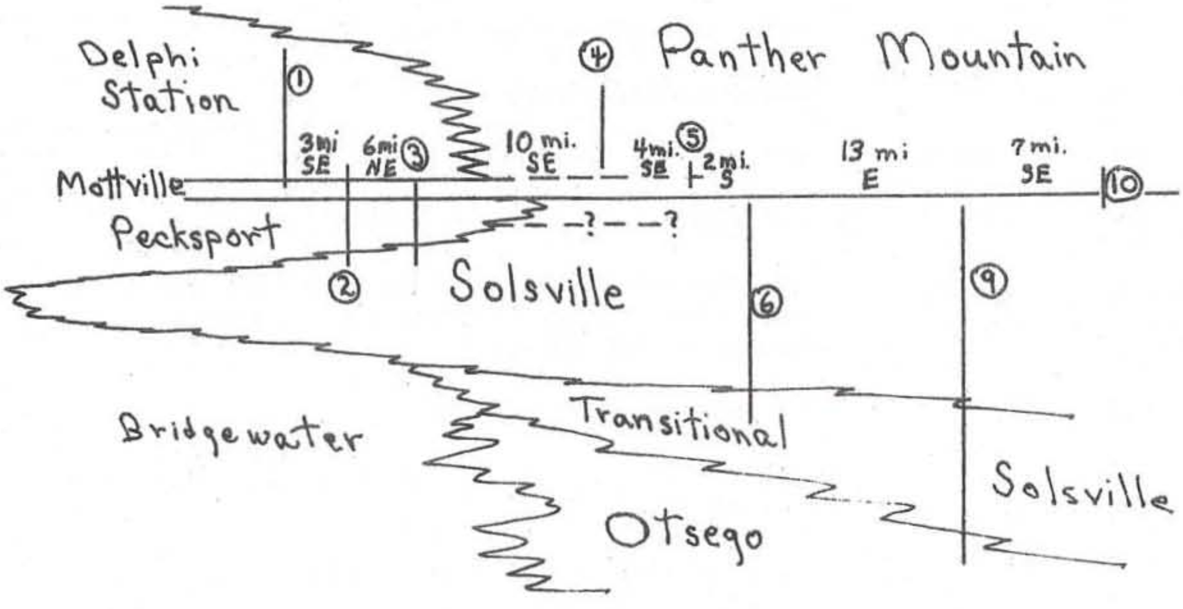
The Pecksport is here a horizontal to irregular bedded siltstone exhibiting some ripples, burrowing, and cross laminations of the distal (outer) delta platform or in part delta front sands. The Mottville caps the quarry and contains a 5 inch basal conquinite horizon. Large scale, low angle, crossbeds and ripples 1-2 inches thick and trending N 40°E as well as SW are present. Dipolar crossbeds suggest a series of migrating ripples deposited during a period of winnowing and reworking of the delta front sands on the distal (outer) delta platform.

---	---	Proceed N on Co. Rd. 21
0.05	71.05	Pecksport in abandoned quarry
0.05	71.1	Solsville top on left
0.9	72.0	Jct. NY 51 turn left (North)
1.6	73.6	Enter West Winfield
0.5	74.1	Jct. US 20 turn right (East)
10.3	84.4	Enter Richfield Springs
0.7	85.1	Jct. NY 167 Proceed East on US 20
0.8	85.9	Village water supply reservoirs on right
0.2	86.1	Jct. Allens Lake Road (Otsego Co. Rd. 26) turn right (South) - first right after Fountain View Motel.
1.7	87.8	Allen Lake on right
0.5	88.3	Jct. Otsego Co. Rd. 26 - turn right (West) toward Fly Creek
0.3	88.6	Curve to left (South) at "Walnut Grove" sign
2.1	90.7	Jct. Twelve Thousand Road - turn right (West) (sign to "Fieldstone Farm")
0.5	91.2	Solsville Member on right in pasture
0.2	91.4	STOP 4 - Twelve Thousand Rd. Quarry 1.5 mi. NE of Twelve Thousand - (Richfield Springs Quad.)

Units Exposed: Panther Mountain (22') or Delphi Station - Mottville interval.

About 22' of dark gray shales and siltstones are exposed here. The lithology and fauna are very similar to the Delphi Station at STOP 1. The assemblage is interpreted as being representative of the Limoptera Community with abundant sessile epifaunal and infaunal filter feeders, mobile infaunal types, non-sessile epifaunal filter feeders and vagrant benthonics.

The top of the quarry is approximately 40' above the Solsville exposed in the pasture .2 mi. to the east. If this exposure is equivalent to the lower Delphi Station, then the Mottville must lie below the floor of the quarry and very near the top of the Solsville. The top of the Solsville must therefore be getting younger eastward from the Brookfield Valley (STOP 1). A high diversity assemblage everywhere occurs above the Mottville from Central New York to Otsego County near below. Therefore, it would seem that the assemblage exposed here is indeed the lower Delphi Station. However, one cannot discount the possibility that a community similar to the Limoptera of the lower Delphi occurs somewhat earlier in time to the east. If we accept this interpretation, the Mottville would be at the top or just above the top of the quarry at this stop. The former interpretation is illustrated below.



---	---	Return east on Twelve Thousand Rd.
0.7	92.1	Jct. Otsego Co. Rd. 26-turn left (North)
2.5	94.6	Jct. Allens Lake Road (Otsego Co. Rd. 27)-proceed straight (East) Otsego Co. Rd. 27
0.9	95.5	Sharp bend to the Southeast

1.1	96.6	Jct. NY 80 turn right (South) and continue along West side of Otsego Lake
1.7	98.3	Hickory Grove Inn on right
0.9	99.2	Five Mile Point
0.1	99.3	Jct. Mohican Canyon Road (Otsego Co. Rd. 28) turn right (West)
---	---	Exposures of Otsego Shale along Mohican Canyon Rd.
0.7	100.0	Pierstown - turn left (South) on Otsego Co. Rd. 28
0.6	100.6	Solsville Sandstone on right
0.5	101.1	<u>STOP 5</u> - Roadcut about 1 mi. South of Pierstown (Richfield Springs Quad.)

<u>Units Exposed</u>: Panther Mountain (15')

This exposure lies approximately 45' above the top of the Solsville. The fauna contains <u>Paraspirifer</u>,large <u>Tropidoleptus</u>, and <u>Camarotoechia</u> in coquinite lenses. This may be the Mottville equivalent. The environment is delta platform.

---	---	Proceed South on Otsego Co. Rd. 28
2.2	103.3	Jct. NY 80-turn left (North)
0.1	103.4	<u>STOP 6</u> - Leatherstocking Falls on Leatherstocking Creek up from NY 80 about 2 mi. North of Cooperstown (Cooperstown Quad.)

<u>Units Exposed</u>: Solsville (100')

The upper portion of the transitional Solsville occurs in the lower part of the falls, while the true Solsville forms the lip. Fossils are rare. A marine delta platform environment is represented by the upper Solsville. Some massive, horizontal bedded and low angle crossbedded sands at the very top of the exposure may represent the Mottville horizon, although this conclusion is very tenuous at best.

---	---	Proceed North on NY 80
1.0	104.4	Three Mile Point - LUNCH STOP
---	---	Return South on NY 80
2.8	107.2	Enter Cooperstown

0.6	107.8	NY 80 turns to the right proceed straight on Lake St.
0.3	108.1	End of Lake St. - turn right (South) on River St.
0.1	108.2	Jct. Main St. - turn left (East) The Clinton-Sullivan Campaign (1779) embarked from this point down the Susquehanna. General Clinton's troops built a dam at the mouth of Otsego Lake, which when broken cleared out the upper portion of the Susquehanna, thereby allowing easier passage of his army on rafts. Clinton's army joined Sullivan's near Elmira to begin a retaliatory campaign against the western Iroquois (Seneca's) in the Finger Lakes-Genesee Region as a reprisal for the Iroquois-Tory attacks on settlements in and near the Mohawk Valley. (Cherry Valley Massacre)
0.2	108.4	Bend to North
0.1	108.5	Jct. Dugway Rd. (County Rd. #31) take left fork onto Dugway
4.2	112.7	STOP 7 - Roadcut on Dugway about 4 mi. North of Cooperstown. (Richfield Springs Quad.)

Units Exposed: Otsego 20'

This outcrop contains the massive to thin bedded dark gray shales and arenaceous shales typical of the Otsego. The fauna is of moderate to low diversity of attached and free epifaunal filter feeders. These are the rocks that yield the definite fauna of Cooper (1933). The environment represented is outermost delta platform on upper prodelta slope. Mucrospirifer and Chonetes, unattached epifaunal filter feeders, are very abundant and were adapted to the soft substrates of this environment.

---	---	Proceed North on Dugway (County Rd. #31)
0.5	113.2	Bend in road to the East
1.9	115.1	Glimmerglass State Park on left
4.0	119.1	East Springfield - Jct. US 20 turn right (East)
0.5	119.6	Jct. Otsego Co. Rd. #54 - (Old US 20) Cherry Valley - turn right (South)
3.3	122.9	STOP 8 - Cox's Ravine - .5 mi. West of Cherry Valley on County Rd. #54. (East Springfield Quad.)

<u>Units Exposed</u>: Union Spring (21'), Cherry Valley (5'), Chittenango (7')

The Cherry Valley Limestone forms the lip of the falls and is divisible into a lower and upper division. The <u>Agoniatites nodiferus</u> and <u>Werneroceras plebeiforme</u> Zone occur in the upper Union Springs about 2 feet below the Cherry Valley.

The Cherry Valley Limestone may not always represent a euxinic basin deposit but may represent oscillations of the O-Eh surface sometimes above the sediment - water interface and sometimes below or coincident with that interface. If below the sediment water interface, benthonic forms could become established. (Cottrell 1972, personal communication).

---	---	Proceed east on Otsego Co. Rd. 54
0.4	123.3	Enter Cherry Valley This was the site of the Cherry Valley Massacre. On the morning of November 11, 1778 a band of Tories and Indians under the infamous Mohawk chieftain Joseph Brant and the Tory Captain Walter Butler attacked the village, resulting in the dealths of 48 or more residents, mostly women and children. This and other attacks on frontier outposts precipitated the Clinton-Sullivan campaign of 1779.
0.3	123.6	Jct. NY 166 - turn right (South)
3.8	127.4	Enter Roseboom
0.2	127.6	Jct. NY 165 - turn left (East)
1.7	129.3	Enter Pleasant Brook - proceed E on NY 165
3.0	132.3	Enter South Valley - proceed E on NY 165
2.0	134.3	<u>STOP 9</u> - Roadcut on NY 165 up Weaver Hill 2 mi. East of South Valley (South Valley Quad.)

<u>Units Exposed</u>: Solsville (250'), Otsego (50')

A nearly complete section of Solsville is exposed here. The lower portions of the section represent prodelta slope and outer (distal) delta platform deposits. The upper part of the exposure represents the middle or inner (proximal) delta platform environment.

---	---	Proceed East on NY 165
1.2	135.5	Enter Schoharie County

1.4	136.9	Enter Dorloo
0.3	137.2	Jct. Schoharie Co. Rd. 33 (West Richmondville Road) - turn right (South)
5.1	142.3	Enter West Richmondville, cross railroad
0.1	142.4	Jct. NY 7 - turn left (East)
1.9	144.3	Enter Richmondville
0.9	145.2	Jct. Depot St. and NY 10 - turn left (North on Depot St.)
0.1	145.3	STOP 10 - Railroad cut on Delaware and Hudson Railroad at old depot station. (Richmondville Quad.)

Unit Exposed: Solsville (6')

This outcrop consists of 1-3 inch horizontal and planar cross-bedded and laminated subgraywackes contained within a set of large (1-2 ft.) ripples. The sandstones are not as sorted as those of other stops. Brachiopod coquinites occur in lenses near the base and at the top of the section. The Solsville here probably represents a nearshore zone of the inner (proximal) delta platform.

0.4	145.7	Return to NY 7 - turn right (West)
33.0	177.7	Proceed on NY 7 back to Oneonta

GEOLOGIC SETTING OF UPPER SUSQUEHANNA AND ADJACENT MOHAWK REGION OF NEW YORK STATE

by

David M. Hutchison
Hartwick College

INTRODUCTION

The outcrops and surficial features observed on this trip have been selected (1) to show students the change in lower Paleozoic stratigraphy through time (2) to illustrate several sedimentary and topographic features (3) to help students gain a better understanding of the geologic framework of this area.

The trip starts at the large Upper Devonian flood plain channel behind the F. W. Miller Science Building on the Hartwick College campus in Oneonta and ends in Precambrian garnet gneiss six miles east of Canajoharie. Progressively older beds are exposed to the north because of three factors: the gentle southerly dip of the beds, the erosion by the Mohawk River and the uplift, tilting and erosion of large fault blocks associated with normal faults in the Mohawk River Valley.

The clastic sediments are the result of the Middle Ordovician Taconian Orogeny (470-435 m.y. ago) and the Middle and Late Devonian Acadian Orogeny (385-355 m.y. ago) (Fisher, 1965). Both of these times of crustal unrest and uplift east of the Hudson River and in New England provided an influx of clays, silts and sands into the Ordovician and Devonian seas which occupied the area of this field trip. The carbonate rocks were deposited by these seas during periods of quiescence between orogenies.

GEOLOGIC HISTORY OF THE AREA

(Modified from Fisher, 1965)

During Precambrian time a thick sequence of geosynclinal sediments was deposited. The geosyncline was folded and regionally metamorphosed into a mountain range during the Grenville Orogeny (1,100 m.y. ago). For the next 500 million years the area was eroded and the mountains were beveled down exposing the metamorphic rocks in their roots.

By Late Cambrian time these Precambrian metamorphic rocks were covered by transgressing shallow seas which deposited the Little Falls sandy dolostones and dolostones forming a nonconformity. The Precambrian gneiss and Late Cambrian dolostone are exposed in a railroad cut six miles east of Canajoharie along the Mohawk River.

Shallow seas continued to deposit dolomitic rocks into Early Ordovician time. The Chuctanunda Creek Dolostone exposed in the gorge of Canajoharie Creek represents deposition at this time. After deposition of this dolostone the seas withdrew.

In Middle Ordovician time shallow seas again covered the area and deposited the Kings Falls and Sugar River argillaceous limestones on top of the Lower Ordovician Chuctanunda Creek Dolostone forming a disconformity. The thin beds of black shale in the limestones and the dark color of these argillaceous limestones reflect crustal unrest many miles to the east in the area of the present Taconic Mountains. This was the beginning pulse of the Taconic Orogeny. A thick black shale, the Canajoharie Shale, which overlies the limestones represents increased unrest during the Taconic Orogeny. These Early and Middle Ordovician sediments are well exposed in the gorge of Canajoharie Creek.

During Late Middle Ordovician time there was extensive erosion of the mountains. The detritus was deposited to the west as a thick sequence of shales and sandstones which are exposed in a few scattered outcrops between Sharon Springs and Canajoharie. The best exposure is just north of Sharon Springs.

Throughout most of Silurian time this area was emergent. If there are any Silurian rocks present, they are not exposed along the field trip route.

In Early Devonian time shallow seas encroached into the area and deposited a thick sequence of limestones (Helderberg Group) which are exposed north of Cherry Valley along Route 20 east to the vicinity of Sharon Springs.

Later in Early Devonian time there was uplift and erosion which resulted in the deposition of the Esopus Shale and Carlisle calcareous siltstone. This uplift was followed by another period of submergence when the Onondaga Limestone was deposited. These three formations are exposed on Route 166 north of Cherry Valley 1/4 mile south of Route 20.

During Middle and Late Devonian time the Acadian Orogeny was taking place in New England. This mountain building episode provided a vast supply of sediments which formed the thick sequence of sandstone, siltstone and shale which are exposed between Cherry Valley and Oneonta. These sediments were deposited as part of the extensive Catskill delta and flood plain deposits.

Since Late Devonian time the area has been subjected to erosion and the development of the Mohawk River, the Susquehanna River and their tributaries. In the Pleistocene glaciers moved into the area. The ice enlarged the river valleys and deposited morainic material in the valleys. Some of this material was reworked by later advances of the ice to form drumlins or was redeposited by meltwater to form kame terraces along the valley walls. The area is currently being drained by the Mohawk River which joins the Hudson River north of Albany and the Susquehanna River and its tributaries which flows south through Pennsylvania and enter the Atlantic Ocean in Chesapeake Bay.

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STRATIGRAPHIC SECTION OF FORMATIONS ON TRIP

(adapted from Rickard and Zenger, 1964 and Fisher, 1965)

Upper Devonian (Senecan Series)	Thickness	
Oneonta Formation	200'	Stop 1
Gilboa Formation	460'	Stop 2
Middle Devonian (Erian Series)		
Cooperstown Shale	410'	Drove by (after stop 2)
Portland Point Limestone	5-6'	Not observed
Panther Mountain Formation	800'	Not observed
Solsville Sandstone	290'	Not observed
Otsego Shale	260'	Not observed
Chittenango Shale	150'	Stop 5
Cherry Valley Limestone	5'	Stop 5
Union Springs Shale	25'	Stop 5
Onondaga Limestone	120'	Stop 3
Lower Devonian (Ulsterian Series)		
Rickard Hill Limestone (Scoharie)	0-1'	? Stop 3 ?
- ? disconformity ? -		
Carlisle Center Shale	10-40'	Stop 3
- ? disconformity ? -		
Esopus Shale	0-20'	Stop 3
- ? disconformity ? -		
Oriskany Sandstone	0-2'	Not present
- unconformity -		
Lower Devonian (Helderbergian Series)		
Kalkberg Limestone	15-50'	Stop 6
Coeymans Limestone	90-100'	Stop 7
Manlius Limestone (lower Thacher member)	30-40'	Stop 4
Upper Silurian (Cayugan Series)		
Cobleskill Limestone	10-12'	Not observed
- ? disconformity ? -		
Brayman Shale	100-200'	Not observed
Vernon Shale	0-80'	Not observed
- unconformity -		

Middle Silurian (Niagaran Series)

Herkimer Sandstone	0-40'	Not observed
Kirkland Hematite	0-2'	Not observed
- ? disconformity ? -		
Willowvale Shale	0-30'	Not observed
- ? disconformity ? -		
Sauquoit Formation	0-130'	Not observed
Oneida Conglomerate	0-15'	Not observed
- unconformity -		

Middle Ordovician (Mohawkian Series)

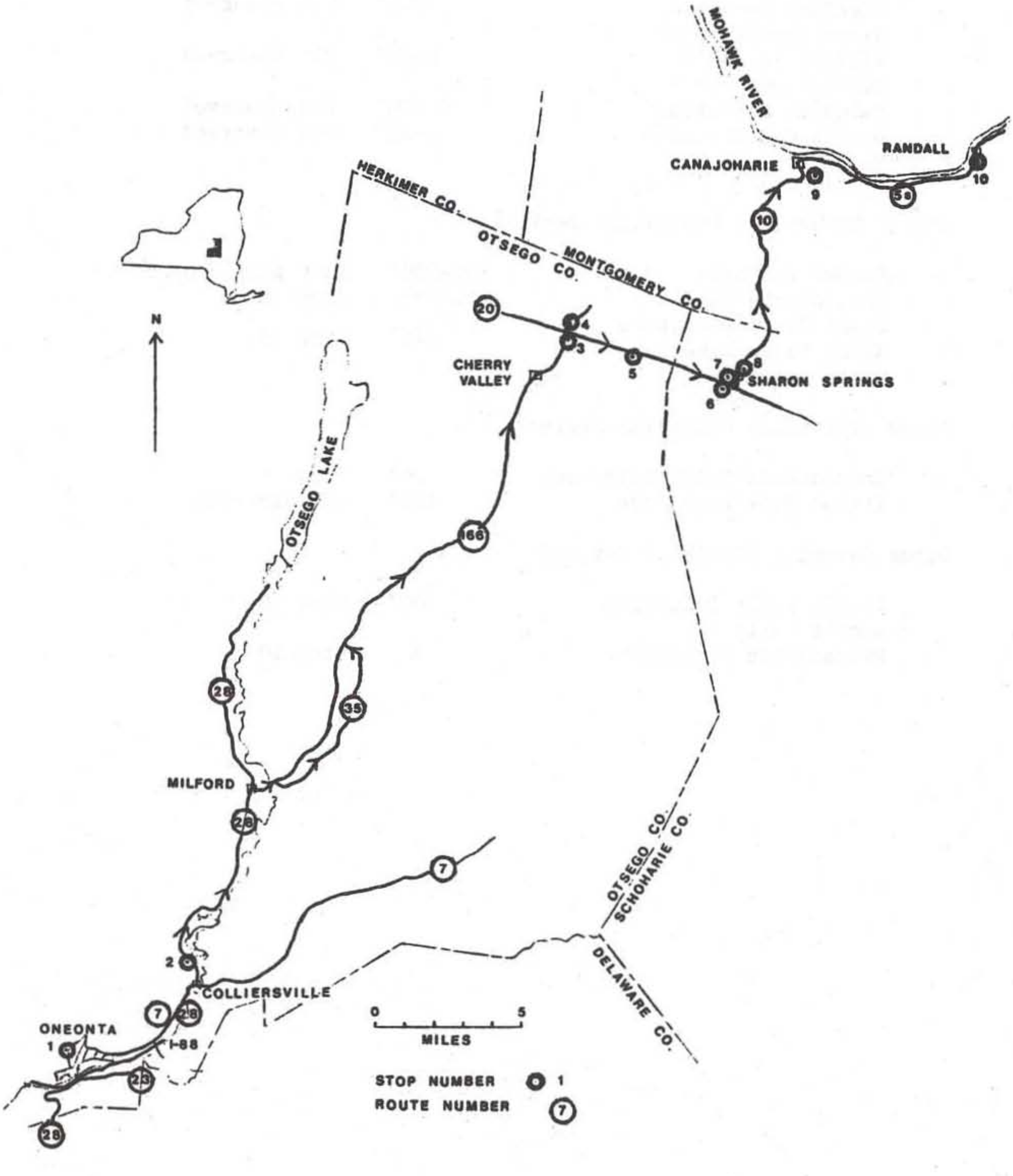
Frankfort Shale	500-800'	Just past stop 8
Canajoharie Shale	200'(?)	Stop 9
Sugar River Limestone >	15'	Stop 9
Kings Falls Limestone		
- unconformity -		

Lower Ordovician (Canadian Series)

Chuctanunda Creek Dolostone	20'	Stop 9
Tribes Hill Limestone	100'	Not observed

Upper Cambrian (Croixian Series)

Little Falls Dolostone	500'	Stop 10
- unconformity -		
Precambrian gneisses	?	Stop 10


MOHAWK RIVER
CANAJOHARIE
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9
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HERKIMER CO.
OTSEGO CO.
MONTGOMERY CO.
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CHERRY VALLEY
7
8
6
SHARON SPRINGS
OTSEGO LAKE
166
28
35
MILFORD
28
7
OTSEGO CO.
SCHOHARIE CO.
DELAWARE CO.
2
COLLIERSVILLE
7
28
ONEONTA
1
I-88
23
28
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5
MILES
STOP NUMBER
1
ROUTE NUMBER
7

ROAD LOG

GEOLOGIC SETTING OF UPPER SUSQUEHANNA AND ADJACENT MOHAWK REGION

Miles from Last Point	Cum. Milage	Route Description
0.0	0.0	ASSEMBLY POINT: Hunt Union Parking Lot at State University College at Oneonta (SUCO).
		Departure: At 8:30 A.M.
		Proceed southwest down Ravine Parkway to the main entrance of SUCO campus at West Street.
.7	.7	TURN LEFT ON WEST ST. until you come to the entrance of Hartwick College.
.2	.9	TURN RIGHT INTO THE HARTWICK COLLEGE CAMPUS at Hartwick Drive, proceed up the hill, veer left at the chapel house and continue going through the large parking lot to the outcrop behind the F.W. Miller Science Bldg.
.4	1.3	STOP 1 Upper Devonian Oenonta Formation

This outcrop consists of dark grey shales, thinly bedded siltstones and sandstones. A massive sandstone which fills in part of a Devonian stream channel is well exposed for about 150 feet at the left end of the outcrop. There is an erosion surface between the underlying shale and the overlying massive sandstone. This surface which marks the bottom of the channel rises stratigraphically to the right. Interference ripple marks are exposed just below the road level. Plant materials are abundant in some layers and a possible log cast was found at the far right end of the outcrop under the overhanging ledge, but much of this has weathered away. A few galena crystals about 1 mm across have been found in the thinly bedded sandstone.

Trilobites, marine pelecypods and brachiopods of the Gilboa Formation have been found in beds stratigraphically 75 feet below this outcrop.

A clean sandstone which shows extensive through-type cross bedding overlies this outcrop. Red mudstones and shales with root casts, worm burrows and ripple marks are exposed at the top of the hill in new exposures that have been uncovered by recent excavations for a new soccer field.

The view down the valley is looking southeast to Mt. Utsayantha in Stamford (about 30 miles map distance). The broad U-shaped valley is the result of Pleistocene glaciation. The Susquehanna River flows in from the north (out of your view) and through the city of Oneonta. The terraces on either side of the valley are kame terraces. Red beds are exposed near the top of the hills across the valley.

LEAVE STOP 1 AND GO BACK DOWN HARTWICK DRIVE TO WEST STREET.

.4	1.7	TURN RIGHT ON WEST STREET and continue going down hill.
.2	1.9	TURN LEFT ONTO CENTER STREET which is immediately past the Lutheran Church. (This is called "crash corner" for obvious reasons.)
.6	2.5	CONTINUE ON CENTER STREET FOR .6 MILE TO WALLING AVE. TURN RIGHT. Walling Ave. is the first street to the right immediately after you cross Oneonta Creek at the entrance to the park.
.2	2.7	TURN LEFT AT FRIENDLY ICE CREAM you are now on Main Street and Route 7 & 28. (Stay on this road for 4.8 miles to Colliersville)
.1	2.8	Fox Hospital on your right.
1.2	4.0	Small kettle hole on right. This has been partially filled in to make a parking lot for Pyramid Mall.
.4	4.4	View to right showing kame terraces across valley.
.6	5.0	Access to I-88 (continue going straight).

1.2	6.2	On right across valley gravel pit in delta kame.
1.4	7.6	TURN LEFT ONTO ROUTE 28 IN COLLIERSVILLE AT JUNCTION OF ROUTE 28 AND 7.
.9	8.5	STOP 2 Stop directly across from dam at Goodyear Lake.
		The Upper Devonian Gilboa Formation with horizontal sandstones and siltstones is exposed here. The well developed flow-rolls are of interest. It is apparent that these are primary structures (formed while the sediment was still "soft") rather than secondary structures (formed after lithification), but there is some question as to their origin. There are brachiopods, bryozoans, crinoids and pelecypods.
4.9	13.4	Outcrop of Middle Devonian Cooperstown Shale at curve in road. Good view ahead of broad U-shaped valley. The Susquehanna River flows south from its headwaters in Otsego Lake (Cooperstown) in this valley.
2.5	15.9	TURN RIGHT IN MILFORD ONTO ROUTE 166.
.8	16.7	Cross Susquehanna River. Clays indicate a glacial lake occupied this area.
.3	17.0	TURN RIGHT ONTO OTSEGO COUNTY ROAD 35 and take metal bridge over Cherry Valley Creek.
.2	17.2	Bear left at junction.
1.7	18.9	Meander scar of Cherry Valley Creek is visible to left.
2.1	21.0	Westville Cemetery on left.
.9	21.9	TURN LEFT AND CROSS CHERRY VALLEY CREEK. After crossing the creek NOTE THE EXCELLENT hummocky morainic deposits showing numerous kettle holes and knob and kettle topography.
1.0	22.9	TURN RIGHT AND GO NORTH ONTO ROUTE 166.
8.7	31.6	Town of Roseboom.

4.3	35.9	Cherry Valley - The town was settled about 1740. On November 11, 1778 over 40 people were killed by Tories and Indians in the infamous Cherry Valley Massacre.
1.3	37.7	STOP 3 (Pull off road to left and park in Highway Department gravel and salt storage area.) Topographically this spot is a break in the Helderberg escarpment. Fairchild interpreted this as a glacial spillway formed at a time when ice filled most of the Mohawk Valley. Meltwater was blocked from draining north and "spilled over" the escarpment eroding the valley (Fairchild, 1925). Fleischer (personal communication and elsewhere in this Guidebook) feels that the valley is the result of glacial scouring of a through valley. Three formations are exposed here. The lowest formation (exposed about .1 mile down the road) is the Esopus Shale. This is overlain by the Carlisle Center calcareous siltstone which contains numerous worm burrows *Toanurus cauda-galli* (Rickard and Zenger, 1964). About .1 mile south along the road the Carlisle Center siltstone is overlain by the Middle Devonian Onondaga Limestone which contains abundant crinoids, corals and brachiopods. The upper part of the Onondaga contains abundant chert. Jointing is very obvious at this outcrop. LEAVE STOP 3 AND CONTINUE GOING STRAIGHT AHEAD AND GO UNDER ROUTE 20.
.9	38.6	STOP 4 The Lower Devonian Manlius Formation (lower Thacher Member) crops out on the right. This laminated micrite contains some ostracods, tentaculitids and stromatoporids. Some mud crack marks are present. This is the intertidal facies of LaPorte, 1967. The Coeymans Formation rests on top of the Manlius Formation. TURN AROUND AND GO SOUTH TO ROUTE 20 EAST
.8	39.4	GO EAST ON ROUTE 20

2.7	42.1	TURN RIGHT OFF OF ROUTE 20 ONTO BLACKTOP ROAD AND PROCEED TO THE OUTCROP VISIBLE TO THE RIGHT.
.2	42.3	STOP 5 Three Middle Devonian formations are exposed here. The lower most formation is the Union Springs Shale which is a black fissile shale containing calcareous concretions. There is a thin limestone near the top of the shale. This is overlain by the Cherry Valley Limestone which is about 7 feet thick and contains a cephalopod fauna. More than 100 feet of the jet-black Fissile Chittenango Shale rests on top of the Cherry Valley Limestone. At the east end (left) of the outcrop the Union Springs Shale has been broken up and sheared indicating some minor faulting.
.2	42.5	RETURN TO ROUTE 20 AND CONTINUE GOING EAST
1.8	44.3	Schoharie County Line
1.8	46.1	STOP 6 Pull off road and stop at down going slope of hill. The Lower Devonian Kalkberg Limestone is exposed in a fresh outcrop. This is a medium grained thin to medium bedded limestone with abundant chert. There are numerous brachiopods, bryozoans, some corals and trilobite fragments. A 2" thick layer of bentonite is exposed near the eastern end of the outcrop.
.4	46.5	IN SHARON SPRINGS TURN LEFT AT STOPLIGHT ONTO ROUTE 10 AND PROCEED NORTH FOR .1 MILE TO OLD QUARRY NEXT TO BOWLING ALLEY.
.1	46.6	STOP 7 (in old quarry) The Lower Devonian Coeymans Formation consists of a coarse grained thickly bedded limestone with abundant brachiopods, crinoids and corals.
		LEAVE THE QUARRY AND PROCEED DOWN THE HILL.
.6	47.2	STOP 8 (STOP AT PARK NEXT TO OLD BATHS) Stop to look at springs and tufa deposits in the city park at the north end of the village of Sharon Springs. There is a strong odor of H_2S from the spring water. This is probably caused by the water passing through the underlying thick black shales.

.2	47.4	Upper Middle Ordovician Shales and Sandstones exposed in cliff at left.
3.0	50.4	Two drumlins are in view to the left.
6.7	57.1	IN CANAJOHARIE TURN RIGHT AT THE FIRST STOPLIGHT ONTO MONTGOMERY STREET.
.1	57.2	CROSS OVER CANAJOHARIE CREEK AND TURN RIGHT ONTO MOYER STREET CONTINUE ON MOYER STREET.
.3	57.5	TURN RIGHT ONTO FLORAL AVENUE AND PROCEED TO THE TURN-AROUND AT END OF ROAD.
.2	57.7	STOP 9 Four Lower and Middle Ordovician formations are exposed in Canajoharie gorge. The lower most formation is the Chuctanunda Creek Dolostone. This is unfossiliferous except for the "hippopotami backs" which are dolomitized hemispherical stromatolites (algal mounds) (Park and Fisher, 1969). Large potholes have formed in the dolostone (Canajoharie is the Iroquois name for the "Pot that washes itself") (Park and Fisher, 1969). The Middle Ordovician Kings Falls and Sugar River black limestones overlay the dolostone forming a disconformity. These limestones and the thin black shales in them contain abundant trilobite fragments, bryozoans, brachiopods and crinoids. The limestones are overlain by more than 100 feet of Middle Ordovician Canajoharie Shale.
.2	57.9	RETURN TO JUNCTION OF FLORAL AVENUE AND MOYER STREETS. TURN LEFT AND GO DOWN HILL.
.3	58.2	CROSS MONTGOMERY STREET AND GO ONTO MITCHELL STREET (WHICH IS 30 FEET LEFT AND PARALLEL TO CANAJOHARIE CREEK).
.1	58.3	CROSS RAILROAD TRACKS AND TURN RIGHT ONTO ROUTE 5S AT THE BEECHNUT FACTORY. Continue on Route 5S. En route to the next stop note the cliffs of Upper Cambrian Little Falls Dolostone.

6.5 64.8 STOP 10 Rusty weathering Precambrian garnet gneiss exposed along the south side of the road and in railroad cut.

FOLLOW THE FOOT PATH AT THE EAST END OF THE OUTCROP TO THE RAILROAD CUT. BEWARE OF POISON IVY ALONG PATH AND AT RAILROAD CUT.

The folded Precambrian gneiss is overlain by the Upper Cambrian Little Falls Dolostone. The dolostone is brecciated for several feet above the contact with the gneiss. Apparently there was movement along the unconformity during Ordovician time when the normal faults in the Adirondack Mountains and the Mohawk River Valley were formed.

PROCEED EAST TO OBSERVE THE FAULT-LINE SCARP OF NOSES FAULT FROM THE VEHICLES.

.5 65.3 There is a good view of the fault-line scarp on the overpass of Route 5S over the railroad tracks. Note that west of the Noses fault-line scarp the Mohawk River Valley has steep cliffs of Little Falls Dolostone. These are caused by the down cutting of the Mohawk River on the upthrown western side of the fault. East of the fault-line scarp on the downthrown side of the fault-line scarp there are no cliffs.

.5 65.8 END OF TRIP AT RANDALL.

GLACIAL MORPHOLOGY OF UPPER SUSQUEHANNA DRAINAGE

P. Jay Fleisher
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INTRODUCTION

The geomorphology of east-central New York State reveals the cumulative erosional effects of multiple glacial events, but the deposits of only the last ice sheet are known. Evidence for pre-Wisconsin glaciation has long been recognized along the glacial limit in Pennsylvania and from isolated and widely spaced localities in New York. However, the glacial chronology of the eastern Appalachian Plateau is confined to subdivisions of the Wisconsin Glaciation as displayed in the landforms and stratigraphy. Those factors that influenced glacier pulses, flow regime, and ice-marginal activity were widely variable across New York State, resulting in problems of correlation and chronology. In spite of this, a comprehensive picture has been developed through the combined efforts of many contributors who have concentrated on specific areas, drainages, and problems.

Within the area of the upper Susquehanna drainage are the deposits of mid-Wisconsin to late Wisconsin deglaciation. A characteristic assemblage of depositional landforms constitutes the valley floor morphology and represents a particular environment of deglacial processes. The valley walls and divides are, for the most part, examples of the combined effects of erosional and depositional conditions of a different glacial environment. The emphasis of this report will be to consider the glacier environments of deposition as represented by the landforms and their stratigraphy.

The area under consideration lies within Otsego County, along the upper reaches of the Susquehanna River from Wells Bridge to Otsego Lake. This discussion will include areas represented in part by the Unadilla, Otego, Franklin, Oneonta, Mt. Vision, Hartwick, West Davenport, Schenevus, Milford, Cooperstown, Westford, and Cherry Valley quadrangles, as illustrated in figure 1. Beginning in Wells Bridge and moving upstream along the Susquehanna the main tributaries are Otego Creek from the north at West Oneonta, Charlotte Creek from the east at Emmons (east of Oneonta), Schenevus Creek from the northeast at Colliersville (also east of Oneonta), Cherry Valley Creek from the northeast at Milford, and Oaks Creek from the northwest near Cooperstown.

Various aspects of the Quaternary geology within this area and adjacent parts of the Appalachian Plateau have been investigated and reported by several past workers. In addition to the general overview treatment given by Fairchild (1925) and Rich (1935), Coates (1974) and Coates and Kirkland (1974) considered the regional significance of main drainage ways and the general distribution of ice-marginal deposits. Krall's work (1972) included the drumlins near Richfield Springs and the occurrence and correlation of various moraines through this area. The work of Whipple (1969) also contributed to an understanding of the Quaternary geology north of Cooperstown. The Chenango drainage to the west has been studied by Cadwell (1972), who not only suggested a conceptual model for stages of deglacial events, but also provided an absolute age that has helped to establish a correlative chronology with other parts of the state. To the east is the Schoharie drainage, in which Le Fleur (1969) considered the unique aspects of Wisconsin glacial pulses into a north flowing river system and the northern Catskill slopes. Additional details of Catskill glacial history are contained in the work by Kirkland (1973) in the West Branch of the Delaware River of Delaware County to the south.

The purpose of this report is to present a general overview of the geomorphic development of the upper Susquehanna area, with special attention given to the glacial landforms and deglacial events. Hopefully, this will serve to fill the central gap between adjacent areas.

REGIONAL SETTING

This portion of the Appalachian Plateau is characterized by deeply dissected middle to upper Devonian clastic stratigraphy. Bedrock strata include interfingered and discontinuous beds and lenses of sandstone, siltstone, shale and sparse conglomerates of the Hamilton and Genesee Groups. The regional dip is to the south-southwest at angles typically less than 10°. In general, the bedrock of the region is well expressed by the topography. Some divides and broad, arcuate questas are capped by more massive parts of the stratigraphy and the subtle structural configuration can be seen on a regional scale.

The topography shows the compound influence of a fluvioglacial origin with the Susquehanna River as the main trunk stream. The present drainage was glacially modified from an elongate and incised dendritic pattern to an ice-scoured system of enlarged valley troughs and through valleys, with associated berms, umlaufbergs, and truncated spurs. Ice-scoured bedrock and thin lodgement till characterizes the uplands, however isolated occurrences of stratified drift are known to exist also. Large scale plucking of competent rock types has produced scattered basins in which upland lakes and bogs have formed.

Local relief typically reaches 600 to 700 feet. However, if one considers the drift that chokes the valley floors to thicknesses that generally range between 200 to 300 feet (Randall, 1972, Gieschen, 1974), the erosional relief is seen to be considerably greater. The drift is almost entirely sorted, even in moraines, and consists of glaciofluvial and glaciolacustrine gravel, sand, silt and clay.

Two large lakes (Canadarago and Otsego) dominate the headwater valleys of the Susquehanna River. Both are vestiges of ice-contact lakes that occupied moraine dammed basins. Otsego Lake, the larger of the two, currently occupies a considerably deeper basin with a maximum depth of 166 feet compared with 44 feet in Canadarago (Weir and Harman, 1974). Sometime following deglaciation the spillways of both lakes breached their impounding moraines and the lakes receded to approximately their present positions. A similar geomorphic situation can be interpreted for other parts of the drainage that are completely free of lakes today.

DRAINAGE DEVELOPMENT

Preglacial Geomorphology

The Susquehanna River and others of similar antiquity in the northeast have been the subject of geomorphic conjecture through decades of published literature. The age and evolutionary development of the Susquehanna along its full course through the Valley and Ridge, Piedmont and Coastal Plain Provinces remains a classic conundrum. However, here near its present head on the Appalachian Plateau, the situation seems somewhat less complex.

Although pre-tertiary paleogeomorphology is difficult to decipher and remains speculative at best, the tectonic history of central New York provides a framework upon which a geomorphic history can be pieced together. The earliest possible origin for the upper Susquehanna drainage dates back to the last marine emergence of this region. With late Paleozoic erosional remnants capping undeformed Devonian strata of western New York and adjacent Pennsylvania, it appears as though regional erosion and drainage development did not begin prior to late Permian or early Triassic time. It would have been at about this interval that the Hudson Valley began to take shape as the ancestral Hudson River flowed south along the trace of the Taconic thrusts and Acadian age fold structures. As this drainage and its tributaries developed, the Mohawk Valley was carved in similar less resistant lower Paleozoic strata. It is suggested that subsequent headward erosion eventually captured the original Susquehanna headwaters from the Adirondack flanks and diverted them into the Hudson Valley. As a result, the Susquehanna River was beheaded and its new divide shifted southward in a series of hanging valleys. Further development of the Mohawk and its tributaries established the Schoharie drainage in competition with the easternmost Susquehanna. A schematic representation of this general development is shown in figure 2.

Although repeated glacial erosion has modified this original drainage system, some valleys oriented perpendicular to the general ice flow remained relatively unaltered and still retain vestiges of their pre-glacial character. This is the case along that part of Ouleout Creek which flows northwesterly through East Sidney before joining the Susquehanna. Here, the valley morphology consists of well preserved small scale engrown meanders that are modified only by a shallow valley train. Even along many of the main drainageways subparallel or parallel to ice flow, the glacially modified sweeping curvatures of large meander remnants can still be recognized as part of the pre-glacial morphology. Several good examples of this can be seen along the Susquehanna near Otego and again at Milford Center, as well as along Schenevus Creek. When viewed in detail, the large scale streamlining effects and over steepening of slopes resulting from glacial erosion can be readily seen, however the unmistakable meander morphology is well preserved.

Figure 2

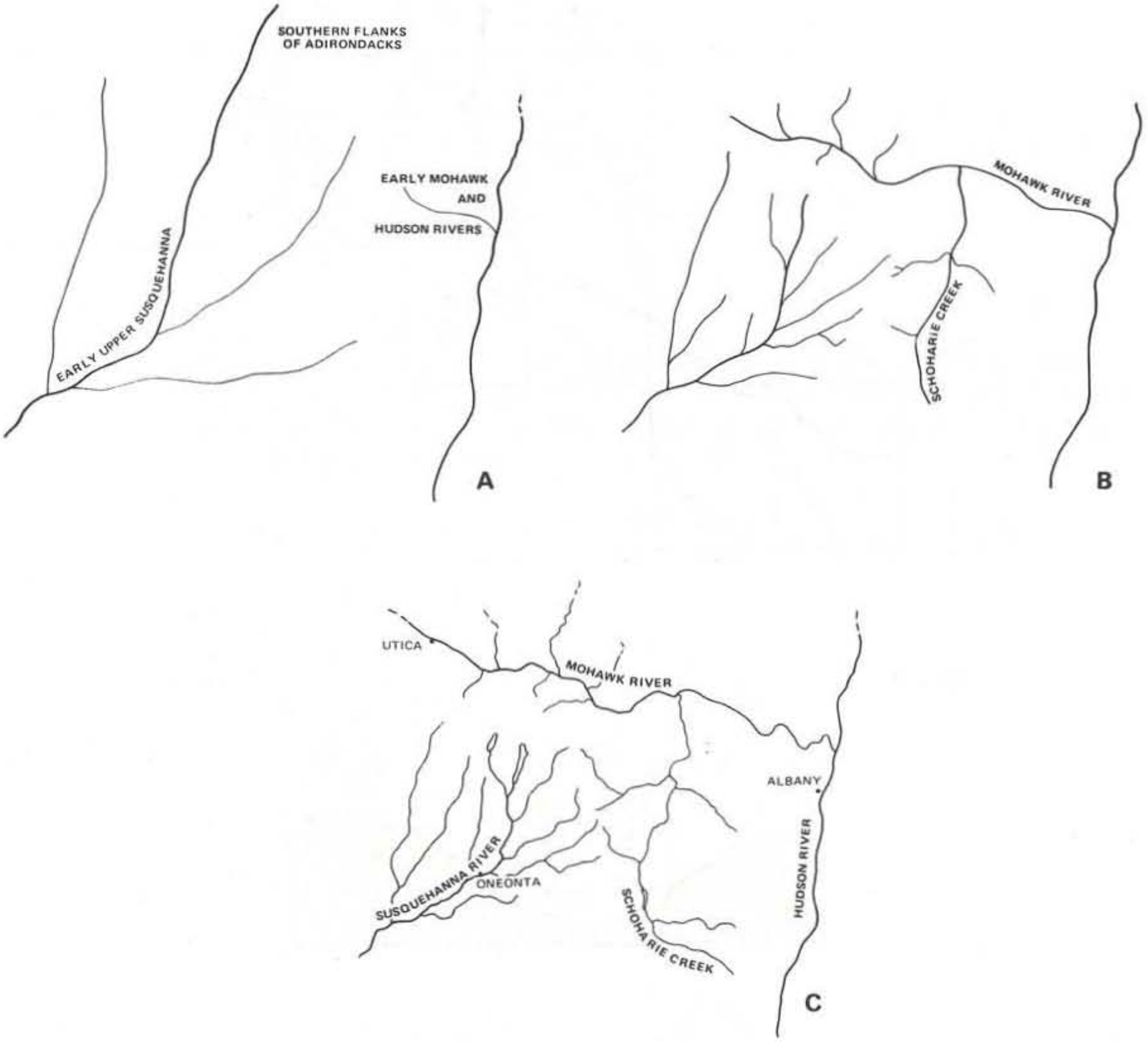
SOUTHERN FLANKS
OF ADIRONDACKS
EARLY UPPER SUSQUEHANNA
EARLY MOHAWK
AND
HUDSON RIVERS
A
MOHAWK RIVER
SCHOHARIE CREEK
B
UTICA
MOHAWK RIVER
ALBANY
HUDSON RIVER
SUSQUEHANNA RIVER
ONEONTA
SCHOHARIE CREEK
C

Figure 4

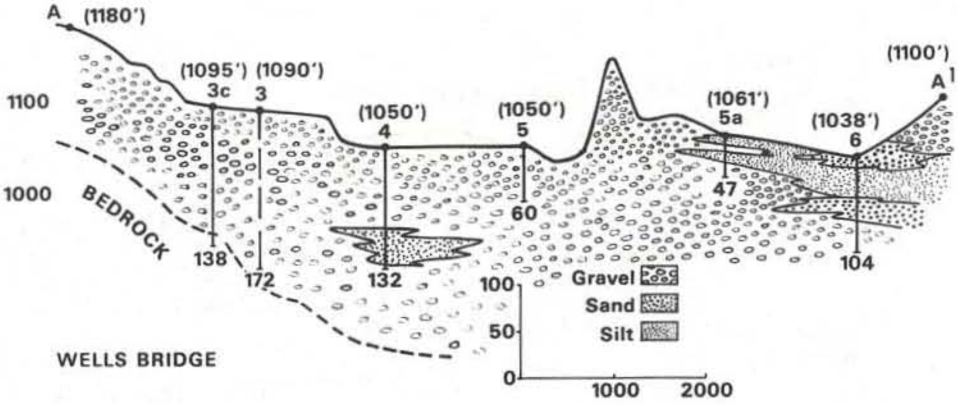

Figure 6

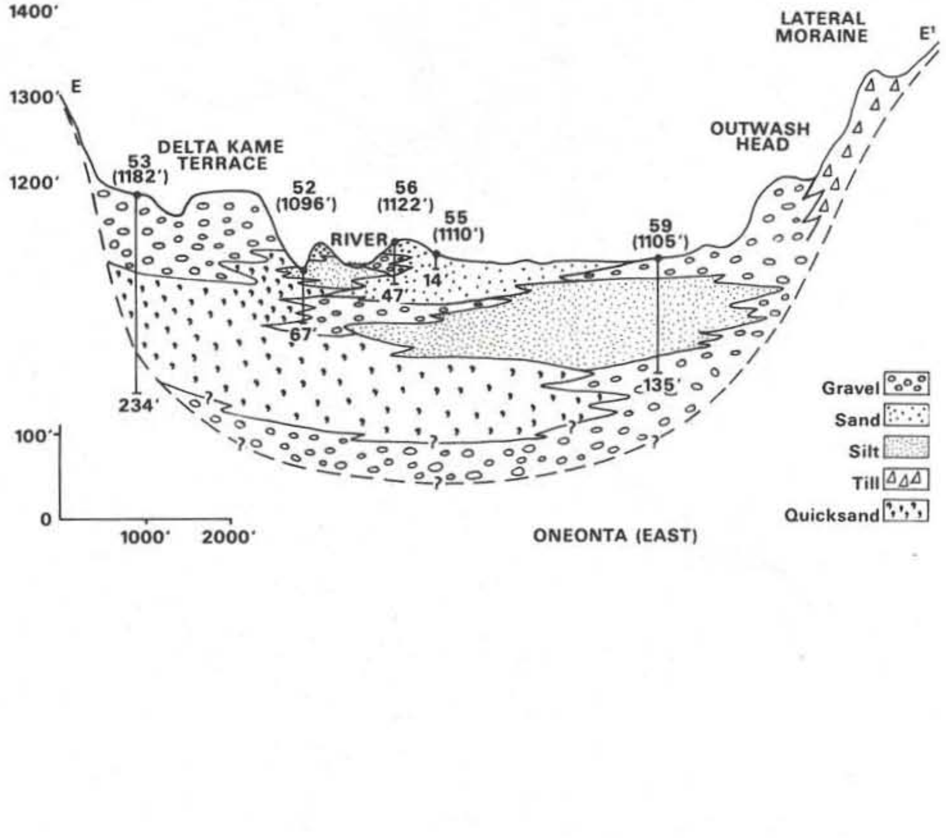

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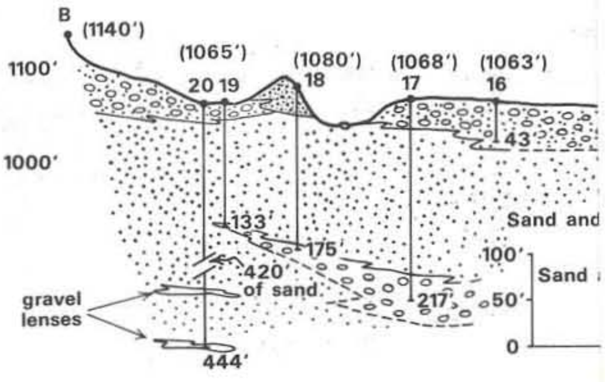
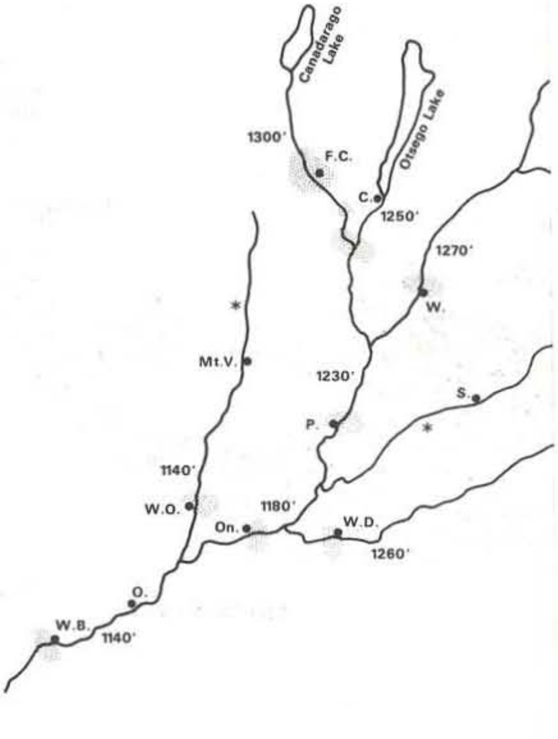
Figure 5



OTEGO

Figure 7



ROAD LOG: GLACIAL GEOMORPHOLOGY OF THE UPPER SUSQUEHANNA DRAINAGE

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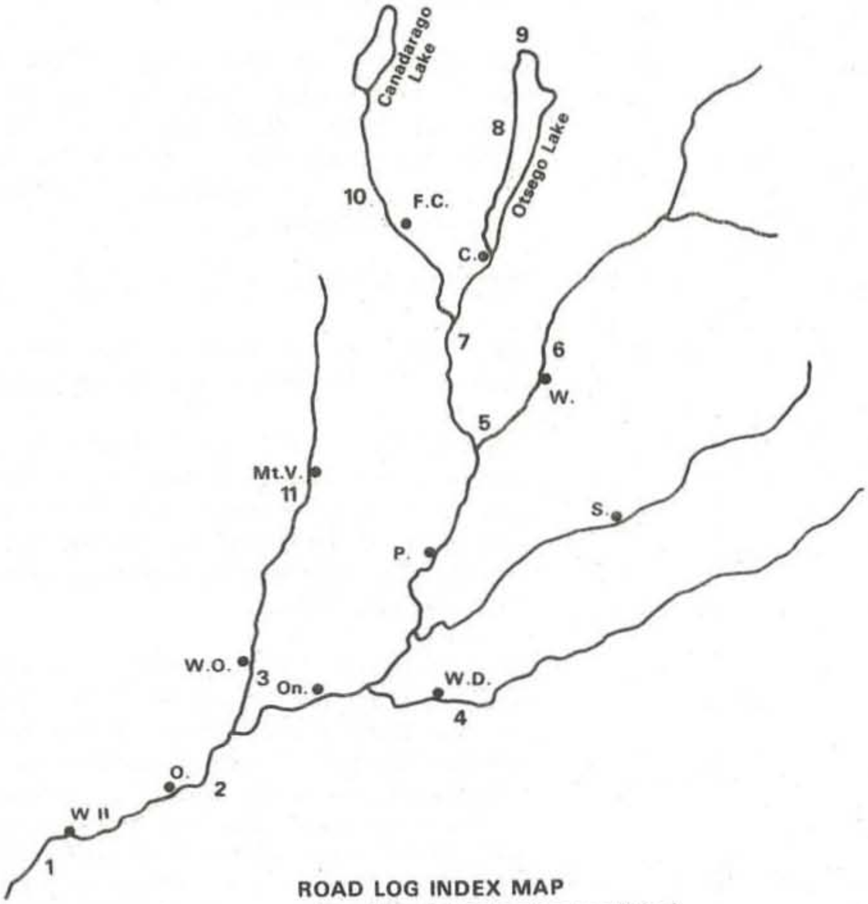
INTRODUCTION

The purpose of this field trip is primarily to examine the evidence for the glaciolacustrine environment at several different places along the upper Susquehanna drainage. The main stops will emphasize the landforms that characterize the salient aspects of a moraine impounded, ice-contact lake. Included will be various types of moraines and associated outwash, lacustrine plains, hanging deltas and delta-terraces, and strandlines.

The field trip will begin in Oneonta and cover the main Susquehanna Valley between Wells Bridge to the west and Oneonta to the east. The lower reaches of the Charlotte Creek Valley will also be considered. From there the route will mainly follow the Susquehanna north to its headwaters at Cooperstown, with a short diversion into Cherry Valley along the way. From Cooperstown the route will cross a short divide to the west and enter the drainage of Oaks Creek, and continue west and south to traverse the complete Otego Creek Valley. The road log index map shows the general location of each stop.



ROAD LOG INDEX MAP
(numbers indicate stop localities)

ROAD LOG

(Field trip log begins and ends at the
I-88 Oneonta [Rt. 23,28] interchange)

Miles from last point	Cumulative Miles	
0.0	0.0	Proceed west on I-88 from Oneonta (Rt. 23,28) interchange. I-88 parallels the Susquehanna River for the next 2.4 miles. Much of the area adjacent to the highway on the right (north) was under water during the spring flood of 1977 (probably a 25 year flood).
4.1	4.1	The valley floor to the north and south of the interstate was flood to within three feet of covering the highway here during the flood.
1.5	5.6	The highway rises above the valley floor and provides a good view of the modern flood plain and the abrupt change in valley trend that is a remnant of a preglacial engrown meander. The ridge on the horizon to the right (north) protrudes into the valley along the inside of the meander bend.
0.2	5.8	The location of STOP 1 is on the left (south), but we won't stop now. Access to this area is possible from County Rd. 48 (locally referred to as the Otego-Wells Bridge Rd.), which we will take on our return to the Oneonta area from Wells Bridge.
3.3	9.1	Continue west on I-88 past Rt. 7 & Otego exit.
1.3	10.4	Good view to the west of the valley plug formed by the Wells Bridge moraine.
1.7	12.1	View to the right (north) across the valley includes the back of the Wells Bridge moraine and associated outwash head terrace. The next 1.2 miles provides an excellent overview of the moraine and the breach carved by the Susquehanna River.
1.2	13.3 STOP 1	Exit I-88 into Rest Area. The eastern end of the parking lot looks over the hummocky relief on the down valley side of the moraine. The common border of the Franklin and Unadilla Quadrangles passes directly through the moraine. This moraine completely blocked the valley following glacier retreat permitting the damming of a continuous body of water, referred to as

Miles from last point	Cumulative Miles	
		Lake Otego, from Wells Bridge to Oneonta. Figure 3 of accompanying paper illustrates the topographic and subsurface aspects of the valley in this area. The moraine is assumed to have been implaced about 16,000 years BP and breached about 14,000 years BP. We will consider the field evidence for an 1140 feet lake level at the next two stops. Field work in the Unadilla and Sidney areas indicates that the Upper Susquehanna Lake Chain has greater down valley extent than will be covered in this road log. Return to I-88.
1.5	14.8	Cross Ouleout Creek.
0.5	15.3	Leave I-88 at exit for N.Y. 357, Franklin and Unadilla. Turn right on Rt. 357-West.
1.2	16.5	Cross Susquehanna River and turn right on Rt. 7 - east. Highway parallels the river for one mile.
1.7	18.2	Railroad overpass. Highway climbs onto outwash terrace near mouth of Sand Hill Creek.
1.8	20.0	Highway drops into Sand Hill Creek incision of outwash and immediately climbs to follow the Wells Bridge moraine - outwash contact.
0.6	20.6	Crest of moraine on the left, breach on the right.
0.4	21.0	Village of Wells Bridge. Turn right (south), cross Susquehanna and turn left (east) at the end of the bridge on Otego-Wells Bridge Rd., which becomes Otsego County Rd. 48. It was within the breach of this moraine that Bob Funk uncovered charcoal while excavating an archeological site in point bar silts that yielded a date of 13,000 to 14,500 years BP. This provides the younger limiting age of Lake Otego. Road parallels river for 0.6 miles before rising onto outwash head terrace. A correlative terrace can be seen across the valley to the north at an elevation of about 1140 feet.
1.1	22.1	Excavation for house on the right exposed fine sand under gravel with the contact at the base of the building, a few tens of feet below the terrace surface.

Miles from last point	Cumulative Miles	
1.9	24.0	Cross over I-88. White house across the valley to the north is situated on a terrace at about 1120 feet. Other planar landforms can be found along the valley that suggest a second level for Lake Otego below 1140 feet. This may be an interesting prospect to consider as a group. Entering Otego Quadrangle.
0.7	24.7	Access to I-88 on left. Continue straight ahead.
0.6	25.3	Fork in road, bear left.
0.3	25.6	Pass under I-88.
0.1	25.7	Intersection at end of bridge, turn right remaining on County Rd. 48.
0.2	25.9	Gravel excavation on right contains deltaic foreset and topset beds indicating current direction to the west down valley.
0.2	26.1	Similar exposure in excavation on the left.
0.6	26.7	Road drops to modern flood plain, which is superimposed on Lake Otego lacustrine plain. Lacustrine plain to the left and right for about a mile.
1.1	27.8	Kame on the right. Prior to construction of I-88 a similar but smaller feature could also be seen to the northeast.
0.2	28.0	Stop 2 is situated to the right, across I-88, on the lower valley wall slope marked by gullys and below "treeline". Proceed to I-88 overpass (.5 mile).
0.5	28.5 STOP 2	Park on the right beyond the overpass and walk south between I-88 and the forested slope of the valley wall. (Access permission may be requested at the farm directly across I-88 to the west.) Walk beyond the truncated spur to a gullied area on the left, about 300 yards south of overpass and upslope from the fence. At an elevation of approximately 1120-1140 feet (2/3 the way up the forest-free slope) pebbly coarse sand, fine sand, silt and a few clay seams were exposed along a gully wall in June 1977. Fluvial channel structures with

Miles from last point	Cumulative Miles	
		small scale foreset beds inclined into the slope and down valley rest upon finely laminated, rippled and cross bedded silt and fine sand. A distinct topographic break in slope can be seen up slope producing a clearly defined bench along the valley wall. A test pit to a depth of 2 to 3 feet revealed well sorted sand lacking stratification and containing occasional pebbles. This was noted repeatedly along this bench at an elevation of about 1140 feet. Another test pit upslope a few tens of feet and farther onto the bench revealed similar sand, lacking stratification as before, but no pebbles. These sands are interpreted to have formed along the strandline of Lake Otego by wave generated currents that moved into this valley wall alcove. The sand above 1140 feet lacks pebbles and is considered to be of eolian origin, blown up slope from the beach. Continue east on County Rd. 48.
1.3	29.8	Road drops back down to the lacustrine plain at an elevation of 1060 feet. Entering Oneonta Quadrangle.
1.5	31.3	Turn left on access to I-88,cross river and I-88, and proceed to Rt. 205 north.
0.5	31.8	Go straight through traffic light at Rt. 7 intersection. The highway traverses an outwash/alluvial bench between 1100 and 1120 feet at the confluence of Otego Creek and the Susquehanna River.
0.8	32.6	Continue straight through traffic light.
0.3	32.9	Junction of Rt. 23 from the right. Continue straight on Rt. 205-23.
0.7	33.6	Bear left on Rt. 23 at blinking light fork.
0.3	33.9 STOP 3	Turn right into gravel quarry just short of Otego Creek bridge in West Oneonta. The material exposed here has been consistantly similar to what can be seen here now. Massive foreset beds of coarse pebbly sand and washed gravel are inclined down valley and define to topographic slope to the south. Above are more poorly sorted topset gravels that vary in

Miles from last point	Cumulative Miles	
		thickness between 5 and 10 feet. The upper surface is planar and can be traced to the east, where it becomes irregular across Rt. 205. The northern side of the feature drops in elevation to join a terrace and eventually the flat, poorly drained valley floor. Interbedded and laminated silt and clay dominate this slope and show collapse structures. Occasional rafted clasts can be found within these deposits. By the nature of the material, its internal structure and topographic expression, this feature is referred to as the West Oneonta delta moraine. The topset-foreset contact is placed at about 1140 feet. Leave quarry and turn left on Rt. 23. Back track to Rt. 7 intersection and I-88 interchange.
2.3	36.2	Turn left on I-88 East and proceed to next exit.
2.7	38.9	Exit I-88 at Oneonta Rt. 23 and 28 interchange. Turn right on Rt. 28 East and cross river. Turn left (east) at stop sign on Rt. 28 East.
0.4	39.3	A large kame delta complex begins here on the right and continues for one mile. This may be part of a once larger delta moraine that extended farther into the valley.
1.0	40.3	To the right beyond the Holiday Inn and at the base of the valley wall can be seen the broad crest of a partially disserted left lateral moraine at an elevation of 1340 feet. Its up valley extent can be traced for about a mile, where it is in association with an outwash terrace (probably outwash head) at 1200 feet.
1.0	41.3	Both the moraine and the terrace can be clearly seen on the right (south). Coe Hill Rd. (dirt) crosses both of them and offers access. On the left (north) side of Rt. 23 is a lacustrine plain at 1100 to 1120 feet.
0.8	42.1	Highway climbs the kettled margin of the 1200 feet terrace. Kettles suggest an ice-contact origin. Within the next mile the highway will rise again on the down valley portion of the West Davenport moraine. Entering West Davenport Quadrangle.

Miles from last point	Cumulative Miles	
1.6	43.7	Intersection with road on the left that traverses the moraine across the valley and through the Charlotte Creek breach. The hummocky surface of the moraine can be seen along Rt. 23 as you proceed east.
2.5	46.2	Enter the downtown portion of Davenport Center and turn right (southeast) off Rt. 23 onto Delaware County Rd. 10 across from the general store. Proceed for 0.1 mile and turn left into gravel quarry within a hanging delta.
0.1	46.3 STOP 4	This excavation provides a look into a large hanging delta that was graded to Lake Davenport at 1260 feet. The lake was dammed behind the dual crested West Davenport moraine and flood the Charlotte Valley for a number of miles to the east. The difference between the internal sedimentary structures of this delta and those in a delta moraine reflects the contrasting sedimentary environments of the two. Here discharge is less variable, less sporatic and less energenic. Well sorted toeset sand displays a variety of delicate cross bedding, ripples and draped laminations reflecting the progressive decrease in current velocity and increase in water depth. The best exposures can be found along the northern portion of the excavation. Watch your step when climbing on the exposure and try to keep the dust down. Return to Davenport Center and intersection with Rt. 23.
0.2	46.5	Proceed straight across Rt. 23 and the clay rich lacustrine plain of Lake Davenport. Cross Charlotte Creek via two small bridges at 46.7 and 46.8, and bear left on Pine Lake Rd. Road climbs off the lacustrine plain and onto the back side of the dual-crested West Davenport moraine. Pine Lake is a kettle hole pond in the moraine.
0.4	46.9	Turn left at stop sign onto Delaware County Rd. 11. The road traverses the moraine, and part of the lacustrine plain for the next 3.2 miles.
2.2	49.1	Stop sign in West Davenport. The road to the left takes you back to Rt. 23, but we will proceed straight ahead on Delaware County Rd. 11.

Miles from last point	Cumulative Miles	
0.9	50.0	Entering Town of Oneonta. The road traverses part of the dissected and pitted outwash associated with the West Davenport moraine. The outwash surface blends with the 1180 feet terrace at the Susquehanna-Charlotte Creek confluence.
0.9	50.9	Morningside Drive on the left leads to the Oneonta Land Fill, where deltaic foreset beds within the 1180 feet terrace are inclined to the southeast indicating a current direction up the Charlotte Creek Valley. This is interpreted to mean the Charlotte was free of ice before the Susquehanna.
0.3	51.2	Entering Oneonta Quadrangle. Hemlock Rd. joins Otsego Co. Rd. 47 from the right. Proceed straight ahead. There are three large gravel excavations equally spaced north of Hemlock Rd. over a distance of two miles. Each reveals deltaic internal structure indicating current flow down valley and toward the valley center. Three distinct lobate aspects of the terrace here suggest coalesced lateral deltas that have formed a delta terrace at 1180 feet.
0.3	51.5	Cross Susquehanna River and I-88 interchange.
0.5	52.0	Intersection with Rt. 7 and 28 at Emmons traffic light. Turn right (east).
1.2	53.2	View across the valley to the south shows that the 1180 feet terrace position is nearly continuous across the valley floor. This illustrates the lobate nature of the terrace margins in this area and provides a view of the delta-terrace.
1.3	54.5	Entering West Davenport Quadrangle. Turn left at blinking traffic light (Lorenzo's Homestead Restaurant on the left) and follow Rt. 28 north.
0.8	55.3	Goodyear Lake on the right. Entering Milford Quadrangle.
1.5	56.8	Entering Milford Center, where well data from points across the valley indicate the bedrock floor lies more than 336 feet below the present lake level, and is predominantly occupied by quicksand.

Miles from last point	Cumulative Miles	
1.0	57.8	Enter Portlandville.
0.3	58.1	Turn right at Blue Bonnet Antiques and cross the Susquehanna River. Proceed across the poorly drained, pitted outwash for 0.2 mile and cross railroad tracks.
0.2	58.3	Turn left beyond tracks on Otsego County Rd. 35. For the next 2.4 miles we will be traversing the outwash and ablation moraine (Portlandville moraine) that dammed the Susquehanna to form Lake Milford at 1230 feet. This lake extended up valley to Hyde Park and into the mouth of the Cherry Creek Valley.
0.5	58.8	Wrightman Rd. intersects County Rd. 35 at white farm house and leads to the Crumhorn Mt. wedge locality discussed in this field guide under the title Wedge-Shaped Structures in Bedrock and Drift. In order to reach this site from here, take Wrightman Rd. and climb the valley wall for 1.1 miles; turn sharply to the left (northeast) on Boy Scout Rd. and follow the sign toward the Crumhorn Mt. Boy Scout Camp. Proceed northeast for 0.5 miles to a small rock quarry situated on both sides of the road. Park at the first exposure on the right. Although more than a dozen wedge structures were exposed during the progress of excavation only two remained clearly visible in June 1977. They can be found in a south-facing exposure on the east side of the road. Look for the characteristic upward flexure of bedrock that occurs adjacent to the wedges. In order to continue the road log mileage, back track and return to Otsego County Rd. 35. The mileage to and from Crumhorn Mt. is not included in this log.
3.0	61.8	Good view of the Lake Milford lacustrine plain to the left.
1.7	63.5	Stop sign intersection. For the past couple of miles the road has primarily been on the lacustrine plain. Turn left at stop sign. Proceed for 0.2 miles across Cherry Valley Creek and to intersection with Rt. 166.

Miles from last point	Cumulative Miles	
0.2	63.7 STOP 5	Intersection of Rt. 166 and County Rd. 35 Turn right and park. Exposed here on the west side of the highway is 33 feet of interbedded gray and tan clay under 14 feet of interbedded sand and coarse pebbly sand. The sand forms a discontinuous bench at 1230 feet and is interpreted as a Lake Milford strandline. Proceed north on Rt. 166.
1.5	65.2	Surface of hanging delta at 1230 feet formed by tributary to Lake Milford. False gain by alluvial fan deposition gives delta a gently inclined up surface.
1.5	66.7	Entering Cooperstown Quadrangle at the Cooperstown-Westville Airport. From here north for about 2 miles the highway is on pitted outwash.
1.5	68.2	Note morainic topography beginning to develop on the right.
0.4	68.6	Turn right onto Norton Cross Rd. (unmarked) that crosses Cherry Valley and traverses the hummocky surface of a moraine near Westville. This is the southeastern extension of the Cassville-Cooperstown moraine which is in the Susquehanna Valley to the west.
0.7	69.3 STOP 6	Cross Cherry Valley Creek where it breaches the moraine. Pull off to the right just beyond the bridge near the top of the hill. At the time of implacement this moraine blocked the valley to an elevation of about 1170 feet forming a dam for Lake Middlefield, a body of water that drowned Cherry Valley for nearly its entire course. The field evidence for Lake Middlefield is in hanging deltas at the mouths of tributary streams, a delta moraine at Middlefield and associated kame delta, and the large lacustrine plain across which the drainage presently meanders. In addition, well data indicate lacustrine sedimentation and the accumulation of thick clay deposits. The hummocky topography yields down valley to a pitted outwash that was incised by the drainage of Lake Middlefield to form valley train terraces. Up valley the moraine loses relief and joins the lacustrine plain.

Miles from last point	Cumulative Miles	
		Clean exposures in this road cut have revealed the moraine to consist of stratified sand and gravel and not unsorted drift. Proceed southeast across Cherry Valley on Norton Cross Rd.. Leave Cooperstown Quadrangle, enter Westford Quadrangle.
0.2	69.5	Turn left (north) at yield sign on County Rd. 35. Up valley extent of moraine can be seen on the left for the next 0.4 miles to where it finally joins the lacustrine plain.
0.8	70.3	Road crosses a dissected hanging delta at the mouth of a tributary. Barn on the left is situated on the delta surface at about 1270 feet.
0.4	70.7	Good view of poorly drained lacustrine plain.
2.1	72.8	Enter Village of Middlefield, turn left at stop sign and continue on County Rd. 35 to the northeast.
0.2	73.0	Cross Cherry Valley Creek and lacustrine plain.
0.1	73.1	Turn right on Moore Rd. just beyond the bridge and proceed north onto the front of a delta moraine.
0.1	73.2	Inactive quarry on right at one time revealed stratified sand and gravel with fluvial cross bedding. The road traverses the kettled back portion of the moraine for the next 0.5 miles.
0.5	73.7	Intersection with Rt. 166. Turn left and proceed southwest.
0.3	74.0	The hummocky slope on the right suggests the extension of the delta moraine at the base of the valley wall.
0.4	74.4	Dirt road on the left leads to a delta kame that can be seen standing above the lacustrine plain to an elevation of slightly above 1280 feet. Present excavation reveals distinct gravel foreset beds inclined down valley.
1.0	75.4	Road crosses a dissected hanging delta/alluvial fan at a B.M. elevation of 1275 feet.

Miles from last point	Cumulative Miles	
0.5	75.9	Turn right on Otsego County Rd. 52 to Cooperstown. Return to Cooperstown Quadrangle.
1.4	77.3	Road descends valley wall and provides a good view of morainic topography downslope. This may be the upland facies of the Cassville-Cooperstown moraine.
1.3	78.6	Enter Bowerstown. The road crossed morainic topography over much of the last mile. Turn left (south) on Beaver Meadow Rd.
0.7	79.3	Once again the road crosses what appears to be the upland facies of the Cassville-Cooperstown moraine. Note the morainic topography for the next 0.4 mile and discontinuously for the next 2 miles.
2.1	81.4	Stop sign. Intersection with County Rd. 33. Turn right.
0.3	81.7	Turn left on County Rd. 11 C (stonehouse and barn 100 yards down 11C). This is the outwash portion of the Cassville-Cooperstown moraine.
0.3	82.0	Railroad crossing and bridge over Susquehanna River.
0.4	82.4	Intersection with Rt. 28 at Hyde Park. Turn right (north).
0.3	82.7	Enter Village of Index.
0.4 STOP 7	83.1	Pull off to the right next to St. Mary's Cemetary. To the northwest (across the highway) is the characteristic topographic expressive for the Cassville-Cooperstown moraine. It can be traced in that direction for 5 miles up Oaks Creek to Oaksville. However, from here eastward across the Susquehanna Valley the moraine shows less relief, yet maintains an elevation of about 1250 feet. As the ice retreated from this position a lake remained impounded behind the moraine and grew in size. It is referred to as Lake Cooperstown and reached an upper limit of about 1250 feet. At this elevation it would have been somewhat larger than Lake Otego, which maintains an elevation of 1195 feet at present.

Miles from last point	Cumulative Miles	
		Well data from the vicinity of Hyde Park indicate the bedrock valley floor is in excess of 265 feet below the modern flood plain. The fill is almost entirely quicksand. This depth is consistant with gravity surveys run across the valley between the moraine and the Village of Cooperstown. Continue north on Rt. 28.
0.4	83.5	Moraine yields to outwash head and tributary deposits.
1.4	84.9	Enter Village of Cooperstown.
0.1	85.0	Bear right across railroad on Rt. 28.
0.4	85.4	Junction of Rt. 28 and Rt. 80. Continue straight on Rt. 80 east.
0.3	85.7	Traffic light at intersection of Rt. 80 and Main Street. Baseball Hall of Fame is two blocks to the right. Continue through intersection on Rt. 80.
0.1	85.8	Stop sign. Turn left.
0.6	86.4	Farmer's Museum on left, golf course and Otsego Lake on right. The golf course is situated on part of a small moraine and outwash surface that bulges slightly into the lake.
1.3	87.7	Beginning here and for the next 0.1 miles the road crosses a partially dissected and incised hanging delta at Brookwood Point. The most easily recognized strandline features of Lake Cooperstown are found along the western side of the valley where tributary drainages are larger.
1.1	88.8	Three Mile Point. Large brown and yellow house on the left occupies the surface of a hanging delta at an elevation of about 1250 feet.
0.7	89.5	Enter Richfield Springs Quadrangle.
0.8	90.3	Road climbs onto the hanging delta at Five Mile Point, which also stands at about 1250 feet.
1.0 STOP 8	91.3	Pull into the small parking area on the right next to the sign for the Lakeview Motel and

Miles from last point	Cumulative Miles	
		Cottages. Cross Rt. 80 and walk to the excavation at the back of the Lakeview Motel. Distinct foreset-topset structure can be seen in very coarse gravel. The upper surface was measured to be 66 feet above Otsego Lake and determined to have an elevation of about 1255 feet. This being the distal end of the delta lobe there is probably a minimal addition of false gain. Directly across the lake is Hyde Bay, into which Shadow Brook drains. A gravity survey run across that valley just 0.1 miles from the bay indicates a depth to bedrock of 69 feet. A single water well 0.2 miles up Shadow Brook logged 8 feet of gravel and 62 feet of clay, silt and sand, with the lower contact of the gravel at 1247 feet, indicating that Lake Cooperstown rose to at least that level. Furthermore, Shadow Brook flows across bedrock just 0.5 miles from this well, suggesting a buried channel up valley from Hyde Bay. Proceed north on Rt. 80 past Six Mile Point, which is also situated on a hanging delta graded to the level of Lake Cooperstown.
0.3	91.6	Enter Town of Springfield.
1.4	93.0	Rt. 80 traverses another hanging delta at about 1250 feet for 0.4 miles and shows a good example of modern incision. From here north the valley widens and relief diminishes. This is the open end of the Susquehanna through valley.
1.7	94.7 STOP 9	Turn right on Otsego County Rd. 53 and park. Walk back to intersection and clean up drainage ditch on southern side. Extremely fine laminated clay in varve-like form was exposed in June 1977. The elevation here is 1220 feet, which would have placed this area under about 30 feet of Lake Cooperstown water. Since leaving the Otsego Lake trough 2 miles back the terrain has become much more subdued and gentle. The modern sedimentary condition along the northern lake shore is considered to be a good analog of the environment in which these clays accumulated. Turn around, turn left and back track south on Rt. 80.
4.2	98.9	Five Mile Point. Turn right on Otsego County Rd. Rt. 28.

Miles from last point	Cumulative Miles	
0.8	99.7	Stop sign. Turn left, still on County Rd. 28.
2.0	101.7	Turn right at white house onto Armstrong Rd. (unmarked). SPCA sign at intersection.
1.8	103.5	Turn right at Tanner Hill Rd. (unmarked).
1.2	104.7	Road ends at intersection with County Rd. 26 (unmarked). Turn left. Road descends into the valley of Fly Creek.
1.1	105.8	Cross Fly Creek and the lacustrine plain of a small lake that was ponded behind a moraine at the Village of Fly Creek 3.5 miles down valley (to the left).
0.6	106.4	Bear left and remain on County Rd. 26. Road now parallels the valley and provides a good overview of the lacustrine plain on the left.
1.7	108.1	Enter Cooperstown Quadrangle.
0.3	108.4	Road climbs a moraine and follows it for 2 miles to Village of Fly Creek. This is part of a large moraine complex that blocked the drainage at Fly Creek and Oaksville.
2.0	110.4	Enter Fly Creek. Stop sign at intersection with Rt. 80 and 28. Turn right. Proceed west along the continuation of the moraine to Oaksville. This is the western extension of the Cassville-Cooperstown moraine that blocked Oaks Creek and dammed Lake Oaksville in the Canadarago Valley.
0.7	111.1	Enter Oaksville and Hartwick Quadrangle.
0.3	111.4	Cross Oaks Creek.
0.3	111.7 STOP 10	Pull off to the right and walk into the gravel quarry situated toward the back side of the moraine. Exposed are sorted and stratified sand and gravel, as is typical of moraines in the upper Susquehanna. Although the surface expression is hummocky and irregular, massive foreset beds characterize the internal structure of this part of the moraine. Possibly this accumulated in a delta moraine fashion as the ice retreated from the main moraine position.

Miles from last point	Cumulative Miles	
		The moraine reaches an average elevation of between 1300 and 1320 feet and controlled the water level in Lake Oaksville. Strandline features at this position can be seen in a number of places around Canadarago Lake and at Richfield Springs to the north. Although Canadarago is much smaller and shallower than Otsego Lake (44 feet vs. 166 feet), well information and gravity data indicate it occupies a bedrock basin comparably deep. Proceed north on Rt. 80 and Rt. 28.
0.4	112.1	Road descends back of moraine. Lacustrine plain of Lake Oaksville lies ahead.
0.2	112.3	Turn left and remain on Rt. 80 west and Rt. 205 south. Road climbs off the lacustrine plain and across the divide to the drainage of Otego Creek.
1.9	114.2	Turn left on Rt. 205 south.
2.8	117.0	Road descends onto flat floored valley.
0.7	117.7	Two kames and an area of dead ice topography can be seen on the left.
1.2	118.9	Cross Otego Creek and enter Village of Hartwick. Continue south on Rt. 205.
1.1	120.0	Truncated spur on left as road climbs large hummocky terrace form. This terrace, which continues for about a mile, appears to be a complex of dead ice terrain and tributary fan/delta deposits from adjacent short valleys.
1.1	121.1	Road drops to valley floor and what appears to be a lacustrine plain. Enter Mt. Vision Quadrangle.
2.4	123.5	Road climbs a bedrock controlled terrace and continues across a glaciofluvial terrace of uncertain origin. This and other similar features can be seen repeatedly along the valley. They are thought to be associated with static or stagnant ice condition that characterized this drainage.
0.9	124.4	Enter Town of Mt. Vision. Continue south on Rt. 205.

Miles from last point	Cumulative Miles	
1.8	126.2	Turn to the right on Blood Mills Rd. (unmarked), just short of sign for Circle S Farm.
0.3	126.5	Cross Otego Creek and turn right on dirt road that parallels the creek. Road leads to Otsego County gravel quarry.
0.2	126.7 STOP 11	Unload at gate and walk in. At various times during excavation a consistantly well defined deltaic internal structure has been observed. Massive foreset gravel and sand dip down valley and are covered by more poorly sorted topset beds, which range in thickness up to 30 feet. This deposit is practically at the center of the valley and has lateral extent. The creek cuts through to the east, where it is forced against the base of a truncated spur. A small tributary enters the valley from the west and joins Otego Creek slightly to the north. This feature has the topographic expression of a hanging delta at an elevation of about 1200 feet, but may well be part of a delta terrace deposit or kame delta. Collapsed wedge-shaped structures have been found at various times in the topset beds. Their occurrence and possible origin are discussed in this guidebook under the title Wedge-Shaped Structures in Bedrock and Drift. Return to Rt. 205.
0.4	127.1	Turn right on Rt. 205 south. The road crosses an extensive and continuous terrace level from here south to Laurens and beyond. The terrace scarp maintains an irregular trend marked by several undercut banks where the creek has meandered against the base of the terrace. In spite of this the terrace scarp expresses a lobate trend unrelated to meander scars. This feature is interpreted as a delta-terrace formed by terminal discharge in an ice-contact lake and not considered to be a kame terrace.
2.9	130.0	Highway traverses a small moraine that extends into the valley and deflects Otego Creek westward.
1.9	131.9	View of lacustrine plain to the right. Enter Oneonta Quadrangle.

Miles from last point	Cumulative Miles	
1.6	133.5	Highway crosses the lateral extension of the West Oneonta delta moraine, which can be seen to the right.
0.2	133.7	Junction of Rt. 205 with Rt. 23 at stop sign and blinking red light. Bear left and proceed south.
1.9	135.6	Traffic light intersection with Rt. 7 and I-88 interchange. Proceed across Rt. 7 to I-88.
0.3	135.9	Turn left on I-88 East.
2.7	138.6	Exit I-88 at Oneonta (Rt. 23 and 28) interchange.

END OF FIELD TRIP

A-6

PRELIMINARY GEOLOGICAL INVESTIGATION OF OTSEGO LAKE

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INTRODUCTION AND ACKNOWLEDGEMENTS

This report is a synthesis of the contributions of several workers. All of the ecological aspects, underwater sampling, bathymetry as well as some of the geological interpretation are the result of an impressive ten-year research effort by Bill Harman and his students working at the SUCO Biological Field Station. Use of the field station research vessel as well as the logistics for the lake tour and the lake log are also Harman's contribution. Breuninger contributed the sedimentology and Melia the Paleomalacology in two short studies done in 1974. Fleisher contributed material on the glacial geology and the glacial landforms map and accompanied Sales on an initial reconnaissance of the lake perimeter. Sales pulled together most of the general geology, stratigraphy, physiography and structure and did the actual writing of the shore road log, leaning heavily on the interpretations of Fleisher on the glacial geology. While not contributing specifically to this report, the bedrock mapping done by Rickard and Zenger (1964) provides a firm foundation for many of the interpretations. In pulling the paper together and in fitting other workers' concepts to the local situation, Sales may have distorted some of the concepts of the other workers. Much of this contribution represents preliminary ideas that will require further substantiation and modification. Parts of this paper were updated from Sales, et al., 1972.

GENERAL DESCRIPTION OF THE LAKE (LOCATION AND PHYSIOGRAPHY)

Otsego Lake (Figs. 1 & 2) is in northern Otsego County, New York, 57 kilometers (35 miles) southeast of Utica and 89 kilometers (55 miles) west of Albany. The village of Cooperstown is at its south end and the smaller towns of Springfield and Springfield Center lie a few miles north of the lake. It is within the northern part of the Appalachian (Allegheny) Plateau physiographic province in the extreme northeastern part of the Susquehanna watershed. It is considered to be the source for the Susquehanna River although the actual drainage divide separating Susquehanna from Mohawk River drainage lies about 8 kilometers (5 miles) north of the lake. The Plateau Province is a maturely dissected upland with local hill elevations from 550-670 m. (1800-2200 ft.). Valley elevations are in the 300-430 m. (100-1400 ft.) range. Bedrock under the major valleys lies below 30-90 m. (100-300 ft.) of glacial fill (Gieshen, 1974). There is a NNE-SSW topographic grain, possibly basement controlled, that may have been enhanced by glacial erosion so that the area is dominated by over-steepened and over-deepened troughs with intervening subparallel ridges. Otsego Lake lies in one of these troughs, as does its slightly smaller sister lake-Canadarago-just to the west.

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BEDROCK GEOLOGY

The lake is eroded in the Middle Devonian Panther Mountain formation and the subjacent lower members of the Hamilton Group. A prominant dip slope on the Lower Devonian Onondaga Limestone floors the valleys at the north end of the lake and dips gently SSW under the lake surface at a rate of about 90 ft./mile. All other formations in the region also take part in this regional dip (Figs. 1, 3c).

The details of outcrop pattern and lithology are well discussed in Rickard and Zenger's 1964 paper on the Cooperstown and Richfield Springs Quadrangles.

GLACIAL GEOLOGY

Glacial features associated with Otsego Lake and its surroundings are quite diversified and include a well developed moraine and drumlins, as well as hanging deltas, clays and sands representing a previously higher lake stand, here termed Lake Cooperstown (see Glacial contribution by Fleisher for additional detail beyond this summary and for a more regional perspective).

The Cassville-Cooperstown moraine trends southeasterly down Oak Creek valley and crosses the Susquehanna valley 2 miles south of Cooperstown and the Otsego Lake outlet,appearing again in Cherry Valley, the next valley to the east. This moraine completely fills the Susquehanna valley to an elevation of 1250 feet, except for a sharply incised cut at Phoenix Mills, through which the present Susquehanna River flows. This cut provides a logical damming mechanism that could have held Lake Cooperstown elevations at approximately 1250 feet prior to breaching. As a possible alternative,the lake may merely have been graded to the highest terrace level representing graded flood plain at that time. Large terrace remnants at 1250 feet are preserved at Hartwick Seminary and the County Home 2 miles below the moraine.

Several of the deltas along the west (more gentle) side of the lake are not graded to the present lake level, but are strongly incised in their upper areas with smaller present-day deltas below them graded to the present lake and with a noticeable break in slope in between. Upper areas of these deltas (Brockway, Three Mile, Five Mile, Six Mile, and Allen Lake) vary considerably in smoothness and preservation, but seem to be graded to a level of about 1250 feet. An exceptional exposure has been dug in the front of one of these hanging deltas between Five and Six Mile Points on the west side of the lake to accommodate the Lake View Motel and parking lot behind it. This clearly shows very coarse gravels and cobbles with little matrix foreset toward the lake below a nearly level surface at about 1255 ft. elevation. Down the dip of the foresets, sands of similar foreset attitude interfinger with the cobbles. At the top of the coarse foresets there is no sharp transition to horizontal topset strata.

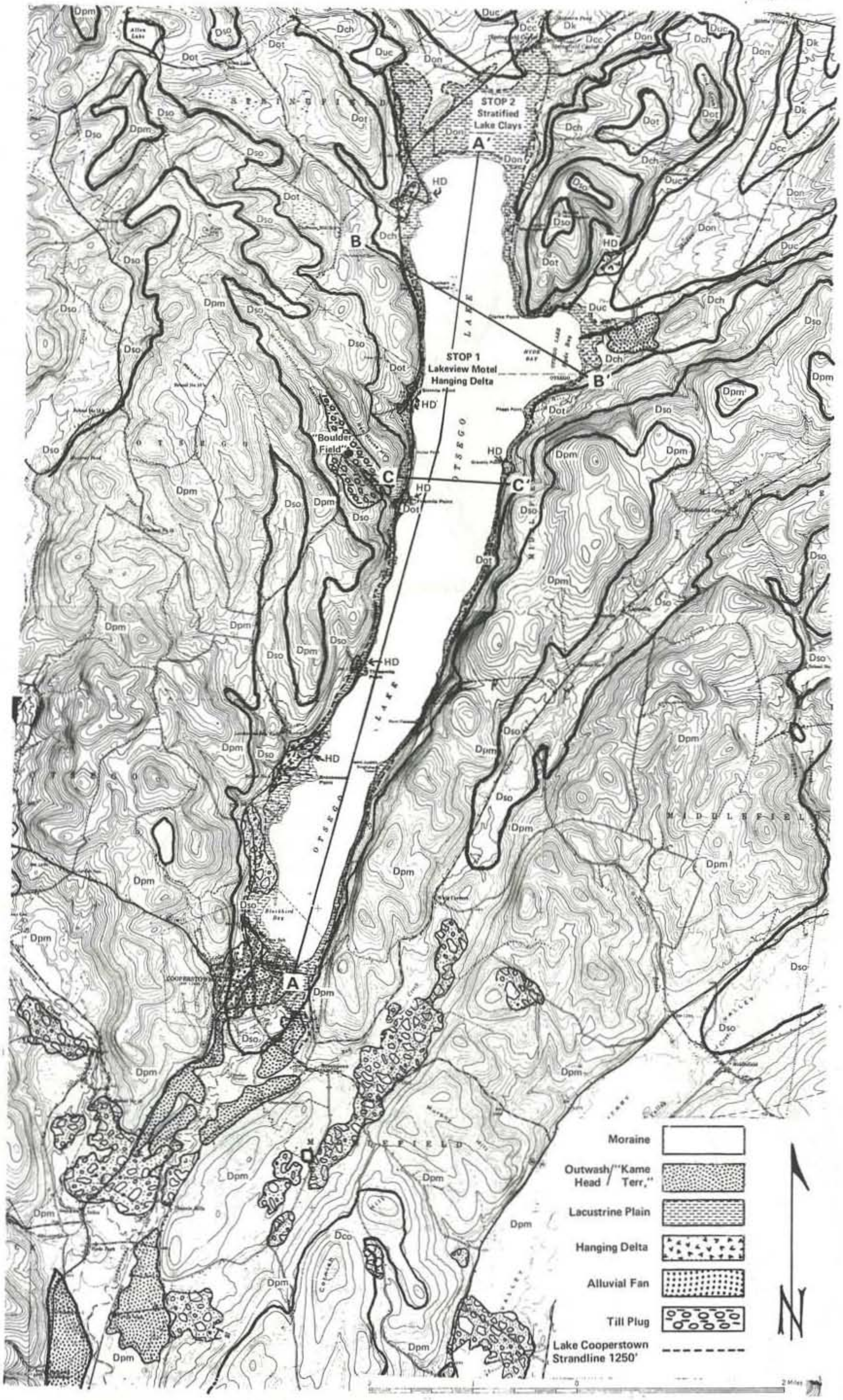


Figure 1. Composite topographic, Glacial Landform and Bedrock Contact Map of Otsego Lake area. Bedrock contacts taken from Rickard and Zenger, 1964. Glacial Geology taken from unpublished Reconnaissance maps by Fleisher and modified from Melia (1975). Mohican Canyon till plug to County Home - Hartwick Seminary terrace area added by Sales during reconnaissance for the road log.

Fig.2

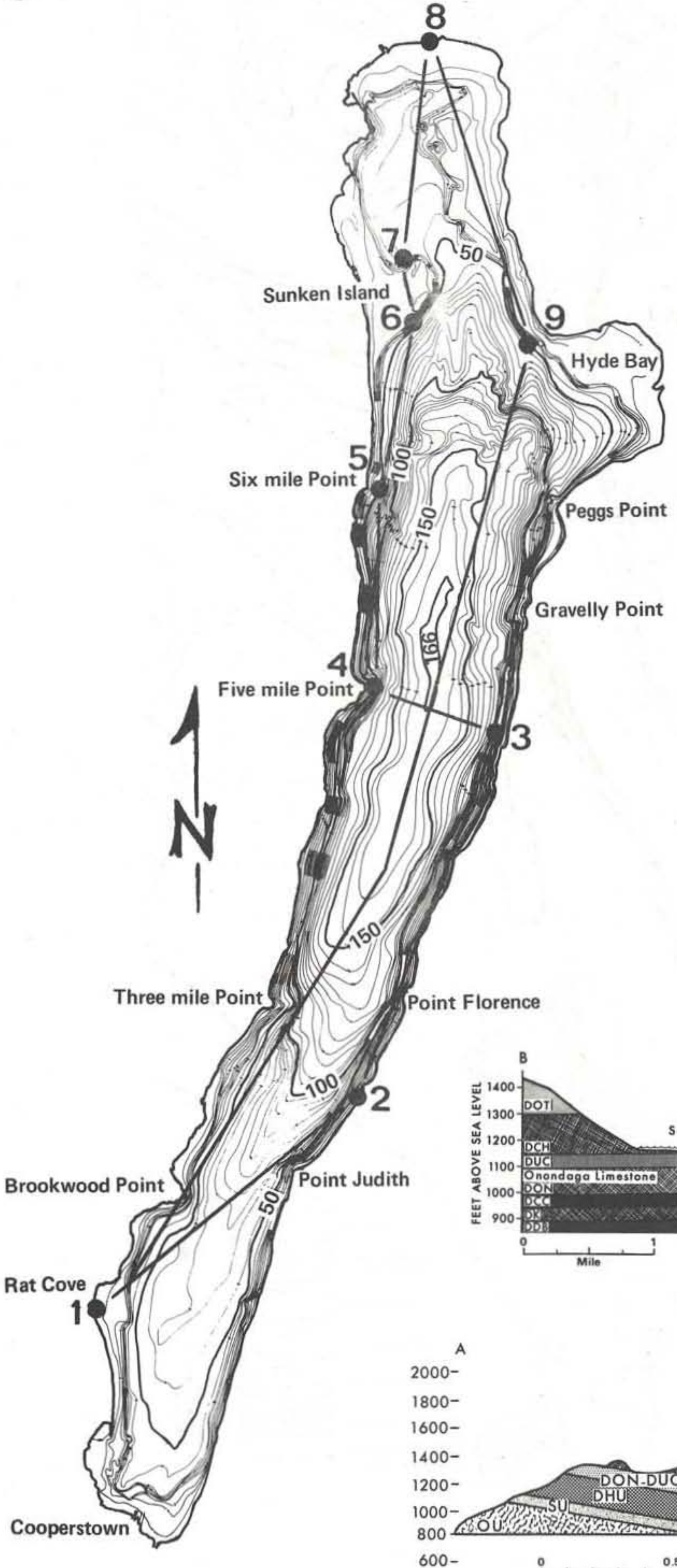
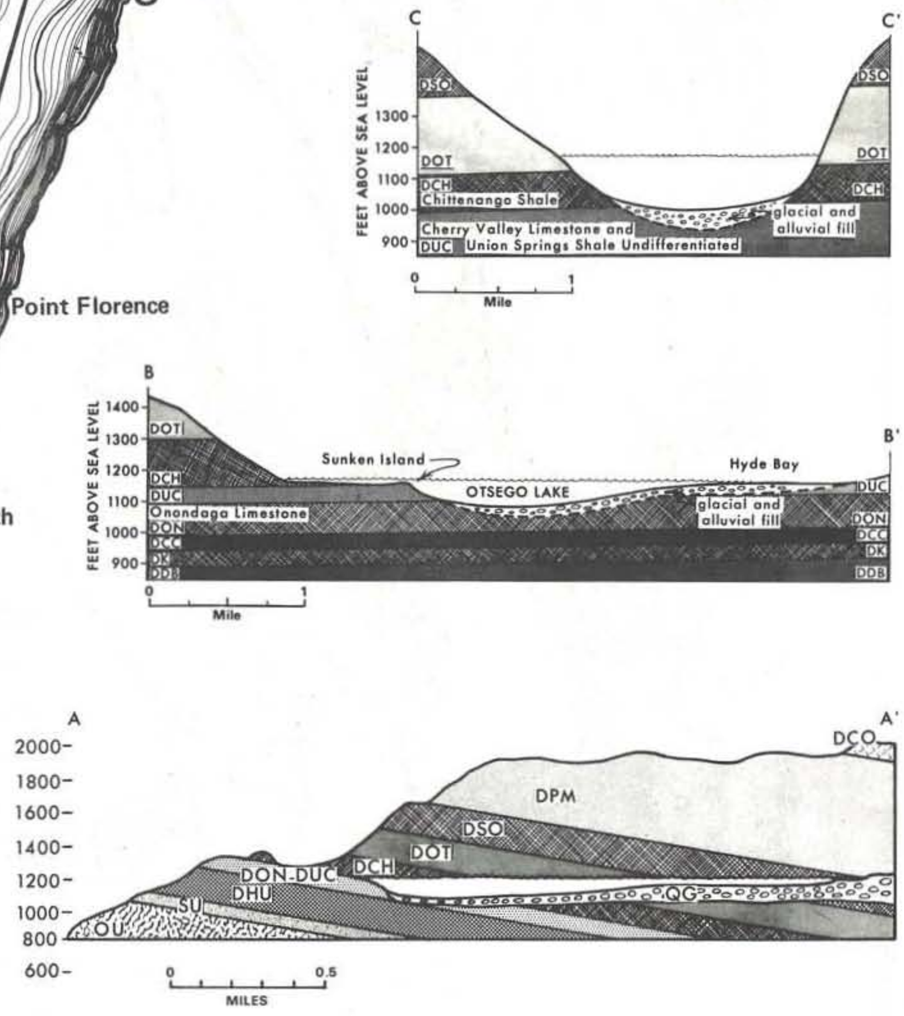


Fig. 3 - Diagrammatic cross sections of Otsego Lake.



Very finely and well-laminated lake clays are exposed at an elevation of 1240 feet at the intersection of Rt. 80 and County Route 53, in the ditch on the SE corner of the intersection approximately 1 mile north of the north end of the lake. These must be lake bottom pelagic clays deposited in quiet, protected water and below wave base under conditions (colder water?) that precluded bioturbation - all recent lake bottom clays and silts taken in cores from the present lake bottom are nearly non-laminated and apparently strongly bioturbated.

It is common that preglacial drainage oriented transverse to ice flow is often partly or completely filled with till during ice advance. Because of its hanging position above the lake trough, and because of incision by the postglacial Mohican Canyon, the till plug exposed there is an interesting and well exposed example. It may also be used indirectly to gain an estimate of amount of glacial downcutting in the main valley. The base of the till plug and elevation of the preglacial (interglacial?) valley floor is at about 1320 ft. elevation about one mile from the axis of the trunk valley. If we take the gradient of the former side valley floor as amoderate 100 feet/mile the confluence with the trunk stream should have been at about 1200 feet elevation, which is very close to the present lake level. Paul Gieschen (1974) found an average of 250 feet of fill below the general 1200-1250 ft. level of the present valley floors. Assuming that the same depths to bedrock prevail under Otsego Lake (except that water is substituted for some of the fill) there has been about 250 ft. of glacial downcutting below the preglacial valley bottom. This depth is, of course, much greater if computed at the truncated spurs. The end of Red House Hill at 1600 feet has been also removed in the trunk valley to this same common depth (±950 feet), giving over 600 feet of downcutting by ice at the interfluves.

CAUSES OF THE REGIONAL TOPOGRAPHY

The regional topography is the result of the interplay between: 1) SSW dipping rock units of varying erosional competence, 2) interfingering of hard and soft SSW plunging rock tongues, 3) SSW trending basement faulting seen in the Southern Adirondacks and plunging southward under the area and transmitted subtly to the surface by joint development, 4) Cenozoic through Recent epiorogenic uplift of the entire Appalachian region that provided erosion potential, and 5) Pleistocene continental glaciation which deepened south trending valleys, filled cross trending valleys, and partially filled valleys with a combination of morainal and glacial fluvial debris. The first two of these topics are discussed in detail below.

Stratigraphic Control of the Topography

The Catskill Delta of Devonian age has long been considered a world classic example for the progradation of a clastic apron over the marine deposits of a shallow sea. The net result of this geometry is the upward and westward shift of facies from marine through littoral through continental as the delta grew. The marine facies is dominated by thinly bedded and fine grained shales, especially the Chittenango shale, which are the least resistant to erosion of the rocks in the Plateau. At the other extreme, the continental facies is dominated by well indurated, coarse grained and massively bedded sandstones and conglomerates which by contrast are very competent and slow to erode. The littoral facies is stratigraphically, geographically and in terms of erosive competence, intermediate between the two extremes, being dominated by sandstones and siltstones of moderate bedding thickness.

The regional southward dip in combination with the regional southeastward rise in topography cause the marine facies to outcrop dominantly in the north and west areas of the Plateau, the continental facies to outcrop dominantly to the southeast in the Catskill Mountains, and the littoral facies to outcrop in between. Since, in an area of slow epiorogenic uplift such as the Tertiary Appalachians, erosion and uplift approach a steady state, elevations closely reflect rock resistance. In the Plateau the slow and steady rise of topography southeastward into the Catskills is caused by and is a reflection of rock resistance.

In detail, however, the stratigraphy in the Catskill Delta is famous for its interfingering facies tongues, reflecting a cyclic advance and retreat of environments within the overall westward progradation. The interfingering is locally seen in local stratigraphic sections as a vertical interlayering of sandstone and shale or conglomerate and sandstone or all three. The scale is extremely variable with major tongues being many tens of kilometers long and hundreds to tens of meters thick stratigraphically, with many minor thinner tongues. In general, the ends of these facies tongues should parallel the long axis of the Appalachian Sedimentary Basin, though in detail they must show the same lobate disposition seen in many present day low lying shorelines, reflecting contributions from irregular source areas into irregular depocenters.

This internal geometry of the Catskill Delta in combination with the superimposed regional southward dip dictates several very important geometric relationships: 1) the intertonguing relationships must intersect the surface of the Plateau, 2) since dip is low a geologic map of the Plateau is essentially a vertically exaggerated cross section which, if viewed in a south to southwesterly direction at a low angle, is restored to an undistorted (down structure) cross section, 3) geometry demands that in a situation such as the top of the Panther Mountain tongue more competent sandstone-conglomerate facies, tongues wedge out westward and plunge southward to southwestward. This may be responsible for the tendency for west and north facing valley walls built against these tongues to be slightly steeper, 4) geometry also demands that more incompetent shaly tongues of a more marine facies die out eastward. This in combination with the regional dip requires that valleys cut in these incompetent tongues, in a transgressive situation, when followed eastward or northeastward should rise and blend into the upland surface beveled on the adjacent harder unit where the softer tongues wedge to nothing, 5) cuestas should have the same en echelon arrangement on the Plateau surface that facies tongues have in the classic cross section.

A facies tongue cuesta should grow westward or southwestward above a developing soft tongue valley, turn slightly southward or southeastward as the tongue thins, and plunge under the next soft valley to the south.

It is here suggested that the east walls of the valleys of Canadarago Lake, Fly Creek, Otsego Lake, Red Creek, and Cherry Valley Creek are basically facies tongue cuestas held up by resistant tongues in the Panther Mt. formation and straightened by ice flow. The valleys themselves are cut in shale tongues of the lower Hamilton Group. Valleys of Otego Creek, Fly Creek, and Red Creek rise and blend into the upland, suggesting that they are shale tongue valleys. The valleys of Canadarago Lake, Otsego Lake, and Cherry Valley Creek, however, have been overdeepened by glacial erosion. They have breached the Plateau front and been deepened into through-going troughs. This facies tongue control has to have occurred quite high, at least above any glacial trough downcutting.

LAKE DIMENSIONS AND GEOMETRY

The lake has a normal pool elevation of about 361 m. (1194.5 ft.) controlled by a small dam in the Susquehanna River just downstream from the outlet. According to Palmer (1974) the lake may attain levels .5 feet below and 2 feet above this mean elevation. Sohacki (1974) made a study of discharge within the watershed and from the lake, finding a lake discharge of about 2,400,000 ft.^{3}/24 hours. It is about 13 km. (8 miles) long and averages about 1.5 km. (1 mile) wide, with east-west width increasing from about 0.8 km. (0.5 miles) near the south end of the lake to roughly 2.4 km. (1.5 miles) at Hyde Bay near the north end.

Maximum depth of 50 m. (166 ft.) occurs about two thirds of the way toward the north end of the lake, about N45°E (Fig. 2, Fig. 3c) of Five Mile Point, which is located on the west side of the lake.

There is east-west symmetry below water level. The deepest part of the lake is almost perfectly centered between the east and west shores. This symmetry below water level is noteworthy because there is a pronounced asymmetry both in the Otsego Lake trough above water level and in the adjacent major valleys both to the east (Red Creek and Cherry Valley Creek valleys) and to the west (Fly Creek and Oaks Creek valleys) (compare Figs. 1 and 2). The regional map suggests that the asymmetry is a general feature of the region. In east-west profile the lake basin below water level has the noticeable U shape of glacial troughs. This contrasts with the much flatter bottoms of the valley trains in adjacent glacial valleys. It is not known what proportion of this profile is attributable to erosion and what to deposition.

ORIGIN OF LONGITUDINAL BASIN GEOMETRY

The longitudinal profile of the lake basin is asymmetrical (Fig. 2) with a steeper and more irregular northern or south-facing end and a more gentle southern end, and with the basin deep 2/3 of the way toward the northern end. The northern end, below a prominent shallow bench. is both steeper and more irregular than its southern counterpart, suggesting that the same type of plucking that takes place on the lee sides of glaciated bedrock knobs may have been instrumental in removing the resistant Onondaga-Helderberg Limestones on this lee slope. Down-dip projection suggests that those formations should underlies that slope.The prominant gentle slope that floors the northern arm of the lake below the shallow bench is in the correct position to be an extension of the equally prominant dip slopes that occur on the Onondaga north of the lake.

The configuration of the south half of the lake is characterized southward by the flat basin deep, a gentle but very noticeable steeper slope up to about 65 feet depth and then a noticeably flatter area up to about 40 ft. depth, which is the base of the shallow bench.

There are two very different possible interpretations of this south half of the lake: (1) it is dominantly an erosional configuration caused by glacial scour of bedrock units of varying resistance, with only a conforming mantle of glacial fill; (2) it is a depositional configuration due to glacial fill above an essentially flat bedrock floor profile 200-300 ft. below lake level. A bedrock controlled configuration is supported by the fact that the mode of topographic expression of the bedrock units that should intersect the lake floor in this area correlates well with the topographic expression of the same units on the cuesta fronts northeast and northwest of the lake. Thus the basin deep would be etched in the very soft Chittenango shale,the same unit that has been stripped to form the Onondaga bench. The noticeably steeper midslope would correlate with the first subcuesta of the overall Panther Mt. cuesta, or the one held up by the relatively resistant lower Otsego shale. This unit forms the lower first cuesta above the Onondaga bench northwest of the north arm of the lake, and the same unit supports Cape Wykoff, Shankley Mountain, and Piney Cobble northeast and north of the lake, respectively. The higher flat on the lake bottom would correlate well with the line of swales in the upper Otsego shale aligned with Allen Lake northwest of the lake and with the saddles south of Cape Wykoff and Piney Cobble. Arguing against a bedrock carved profile and for a glacial fill profile for the configuration of the southern half of the lake is the fact that Gieschen (1974) has graviametrically computed depths to bedrock through Cooperstown village that suggests 279 feet of fill above bedrock. To honor this and still maintain a bedrock controlled erosional profile for the south half of the lake is nearly impossible, and suggests a more or less flat longitudinal bedrock profile some 100 feet below the bottom of the basin deep, with control of topography caused by amounts of glacial fill over this flat floor. As Gieschen, 1974 (p.44) points out, Fairchild (1924) has already suggested this "drift barrior" as the cause of the lake.

If this second (fill-dam) hypothesis holds true,it supports interesting speculations about the basic cause of the lake - why it is water rather than glacial fill: almost all wasting glacial tongues restricted in a confining valley debauch into a proglacial lake of some extent - it takes time after retreat of a glacier front to fill the glacial trough from its empty condition to a condition in which drainage is over the graded top of the accumulated valley fill. If fill contribution is locally small but previously deposited volume of valley fill downstream is great, a long lake develops. If local availability of fill is more than ample to fill the area immediately in front of the ice with debris up-grade of the outwash plain below, there is no lake at all. Thus there is a dynamic equilibrium at play with rapidity of retreat and build up of the downstream graded profile tending to increase volume of the lake, and sediment supply, especially downstream from the glacier and especially from side-entering tributaries, tending to decrease the volume of the lake. This concept applied to Otsego Lake suggests that as the glacier retreated northward and freed Oak Creek and Red Creek successively, such a large volume of sediment was dumped into the trunk Susquehanna that it was filled to grade, forming a very stable dam at that elevation. Excess material may even have extended the north facing slope of the fill northward to its present position. Contribution from the small clustered west slope streams along the southwest quarter of the lake between Leatherstocking Falls and Cooperstown may have supplied enough material to create the hump in lake bottom at Brockway Point. While the ice was being cleared from the main part of the lake and north along the Onondaga bench, the lake wasn't filled because there weren't enough large tributaries (of the calibre of Red and Oak Creeks) to supply this volume of sediment. Before the volume required could accumulate break-through of a lower outlet along the Mohawk diverted sediment discharge. Interestingly it should have also drastically and immediately cut the discharge of the Susquehanna and shifted the equilibrium from the high level grade, represented by the high terrace with kettles at 1250 feet, toward down cutting and terrace formation which as of today has lowered the river some 50 feet below its previous high stand.

DEVELOPMENT OF THE SHALLOW WATER BENCH

One of the most noticeable features of Lake Otsego bathymetry is the shallow water bench that rims much of the lake. The bench correlates in degree of development with the assumed sediment influx potential as reflected in the on-shore drainage area behind the bench (Sohacki, 1974). Thus it is best developed at the north end of the lake where the Allen Lake, Weaver Lake-Young Lake-Cripple Creek, and Hyden Creek drainages are bounded by divides as much as 9 km. from the lake shore. Its second best development occurs in the Hyde Bay where Shadow Brook also has its source several miles from the lake. Its development at the south end of the lake correlates well with the large subdrainage area provided by Glen Creek and the several creeks which enter the west side of the lakes between Cooperstown and Brookwood Point.

By contrast those areas of the lake basin which have no appreciable drainage area behind them and which show little postglacial dissection are nearly devoid of a bench. This includes the entire east side of the lake northward to Gravelly Point and the middle west side of the lake between the northern limit of the Brookwood Point Delta and the southern limit of the Sunken Island Platform. As a generalization those areas which do not have a wave built bench of soft sediment offshore have a tendency to have a small wave cut terrace developed at lake level.

There is also a good correlation between development of the bench and slope of the lake floor on which it is built. The generalization appears valid that wherever the slope of the floor approaches the average slope of the bench face no bench is present.

The bench appears to be best developed in areas where the shore behind it is both gentle and apparently constructional, being built of either glacial-fluvial or morainal deposits or postglacial alluvial-deltaic aprons. This raises the possibility that the bench is merely the sub-lake extension of the alluvial aprons developed on shore regarded to present wave base. The correlation of the bench lip with the 15 ft. contours suggests a depth control mechanism, but it is not sure whether this is mechanical wave base, a light, or chemical control of the sediment trapping aquatic plants,or some unknown mechanism.

There are areas of special interest with regard to bench development. 1) <u>Sunken Island</u>: Sunken Island near the northern end of the lake represents both one of the most elevated and most lakeward promontories of the shallow water bench. Depths on top of it are less than 2 m. and it is sometimes awash during prolonged dry spells. Among other possibilities, it may owe its origin to (a) an abnormal organic build-up if the general bench is organically built; (b) a high standing bedrock core either of roche moutonnee origin or of possible thickening in the underlying Cherry Valley Limestone due to Devonian reef buildup; (c) a lake-leveled drumlin core. Two somewhat similar features at Canadarago Lake--Deowongo Island and the Sunken Island near the west side of the lake--may have a common origin. Morphologically both of these appear to have a drumlin origin. Deowongo Island has a series of large (up to 2 m. in long dimension) boulders off its south end, visible on the lake floor. These could be a concentration of large erratics, exposed by winnowing out of till. There is some possibility, however, that they are large joint blocks plucked from the lee end of a roche moutonnee which cores that island. Thus the origin of these features and of Sunken Island in Otsego Lake could possibly be resolved by coring and sampling but at present is open to multiple interpretation.

The origin of the very flat area between Sunken Island and the shore likewise is unresolved. If beds in the bench area are of organic origin, the bench may merely represent favorable environment for carbonate secreting charophyte algae. If on the other hand it should be made up dominantly of clastic material, it may represent a "tombolo bar" mechanism with the material derived either from beveling of Sunken Island or from southward longshore drift of clastics winnowed from the Allen Lake Creek Delta front. Harman has pointed out on aerial photographs a noticeable counterclockwise drift in the lake, displayed in sediment plumes eroded off headlands. This is apparently common to most of the Finger Lakes and is usually attributed to Coriolis effect. This may, however, be due to a prevailing southwest wind bypassing the hilly western shore and creating a northward vector of drag along the east shore, with passive return flow south along the relatively sheltered west shore. There is, of course, no reason why the "organic" and "tombolo" mechanisms could not augment each other.

2) The Allen Lake Creek Delta: The Allen Lake Creek Delta at the northwest corner of the lake is unique in that the subaerial delta front extends all the way to the edge of the bench face in an area otherwise dominated by extensive bench development. This raises the dual possibilities that the subaerial delta (a) is merely a raised and perhaps non-beveled but otherwise normal portion of the more extensive underwater bench, (b) is later and physically overlies a normal and genetically different segment of the bench. Brookwood Point Delta seems similar. Coring on the delta might resolve this.

3) Bench segment west of Mt. Wellington: The bench segment west of Mt. Wellington on the east side of the north arm of the lake is interesting on several counts. It is the largest in the lake. It shows a noticeable inner linear depression parallel to the shore and an elevated outer lip. Depths in the inner depression are in the 5-7 m. range while those on the outer lip are in the 3-5 m. range, with an area less than 3 m. deep at the north end. The inner depression is bounded on either end by sharp declivities which appear to be erosional in origin. If these are subaerially eroded canyons, they would prove a previously lower water stand. If they are of submarine origin, they suggest effective cutting by some combination of density and/or longshore drift currents. There is a very sharp isolated high and an associated low at the outer edge of this bench segment which could possibly shed light on the orgin of the general feature. Tentatively they might be: algal buildups, large erratics, preserved kame and kettle topography, or bedrock outliers. Noticeably linear segments of this bench face might be joint controlled if the bench is partially of bedrock origin. If the bench has a constructional origin, the mechanism should be compatible with these straight segments. Some segments of this bench face appear to approach verticality which may enhance the possibility of exposure of the internal makeup of the bench.

SEDIMENTOLOGY

In an attempt to define sedimentological factors in the lake, 3 cores have been taken: one (A-1, 1.5 m. long), just north of the bench face in about 11 m. (30 ft.) of water about 100 m. (300 ft.) out from the town dock in Cooperstown, and two (A-2, 3.5 m.; A-3, 0.97 m.) from the lake deep in 50 m. (166 ft.) of water off Five Mile Point. These latter two cores come from the lake's deepest point as shown on Harman's (1974) bathymetric map (Fig. 2), and as located by sonar.

Two of the three sediment cores obtained in October, 1974 were cut into sections 0.1 m. long and examined petrographically.

Core A-1. During analysis grains larger than 1 mm. were sieved out and identified with a binocular microscope. Abundant aquatic snails, which occur throughout the core, have been described separately under the heading paleomalacology.

The lower section of the core, from 0.3 to 1.5 m. was grayish-white limy silty clay with abundant gastropods and gastropod fragments. At 0.8-0.9 m. in the cores were a few blackened twig fragments; otherwise there were no grains greater than 1 mm. in diameter. This part of the core represents relatively uniform biogenic sedimentation plus clays from suspension.

Sediment in the upper 0.3 m. of the core was limy gravely clay, with abundant snails. In the greater-than-1 mm. sieve fraction, 321 grains (excluding snails) were counted. Of these, 39% were fine grained sandstone and siltstone, brown to black in color; 16% were weakly consolidated brown silty clay clasts, 14% were twigs, seed hulls and other plant fragments; 8% were slag, presumably from railroads or the steam ferryboat which used to ply the lake; 2% were chert; and 1% were quartz and metamorphic rock fragments. The sandstone and siltstone grains were derived from the marine Devonian formations which crop out in the hills on either side of the lake. The chert grains probably came from limestones of the Onondaga and Helderberg Groups exposed along the Mohawk Escarpment to the north of the lake. The metamorphic rock fragments most probably come (via glacial transport) from the Adirondack Mountains.

Manmade slag first appeared in the core at exactly the same stratigraphic level as did non-manmade, natural grains such as sandstone, siltstone, chert, and quartz. This suggests that all, not just the slag, were recently introduced into the lake by man, rather than by completely natural sedimentary processes. (Plant remains such as twigs, however, occur both above and below 0.3 m.)

Core A-2. This core was cut into 10 cm.-long sections which were examined with a binocular microscope. The entire core consists of noncalcareous silty clay, olive black (5y 6/1) to olive gray (5y 4/1) in color, with less than 1% sand. The clay has a poor horizontal parting. There are slight changes in sediment color and in amount of decomposed black organic material (mostly bits of wood and leaves) which might allow lithologic subdivision of future cores into correlatable units. Colors cited are of moist, not dry, sediment, and follow the terminology of the Rock-Color Chart published by the Geological Society of America, New York (1963).

PALEOMALACOLOGY OF CORE A-1

Laboratory Procedures and Fossil Identification

This short (1.5 m.) core contained an abundance of aquatic pulmonate and prosobranch snails as well as much fragmental shell material. The core was sectioned into lengths which were placed in polypropylene vials and covered with 50% ethanol to prevent the sediment from drying out and to combat the growth of molds.

All intact snails and clamshells recovered from the core were counted and identified to species. Where possible shells were extracted by washing through a nest of sieves (2 and 1 mm.). Between 40 and 200 (the average being 100) shells were counted for each 0.1 m. interval and the results were incorporated into a general mollusk diagram (Fig. 4). Most shells smaller than 1 mm. in diameter were immature, hence the lower sieve size in the nest was 1 mm. For the identification of the mollusks the key by Harman and Berg (1971) was used.

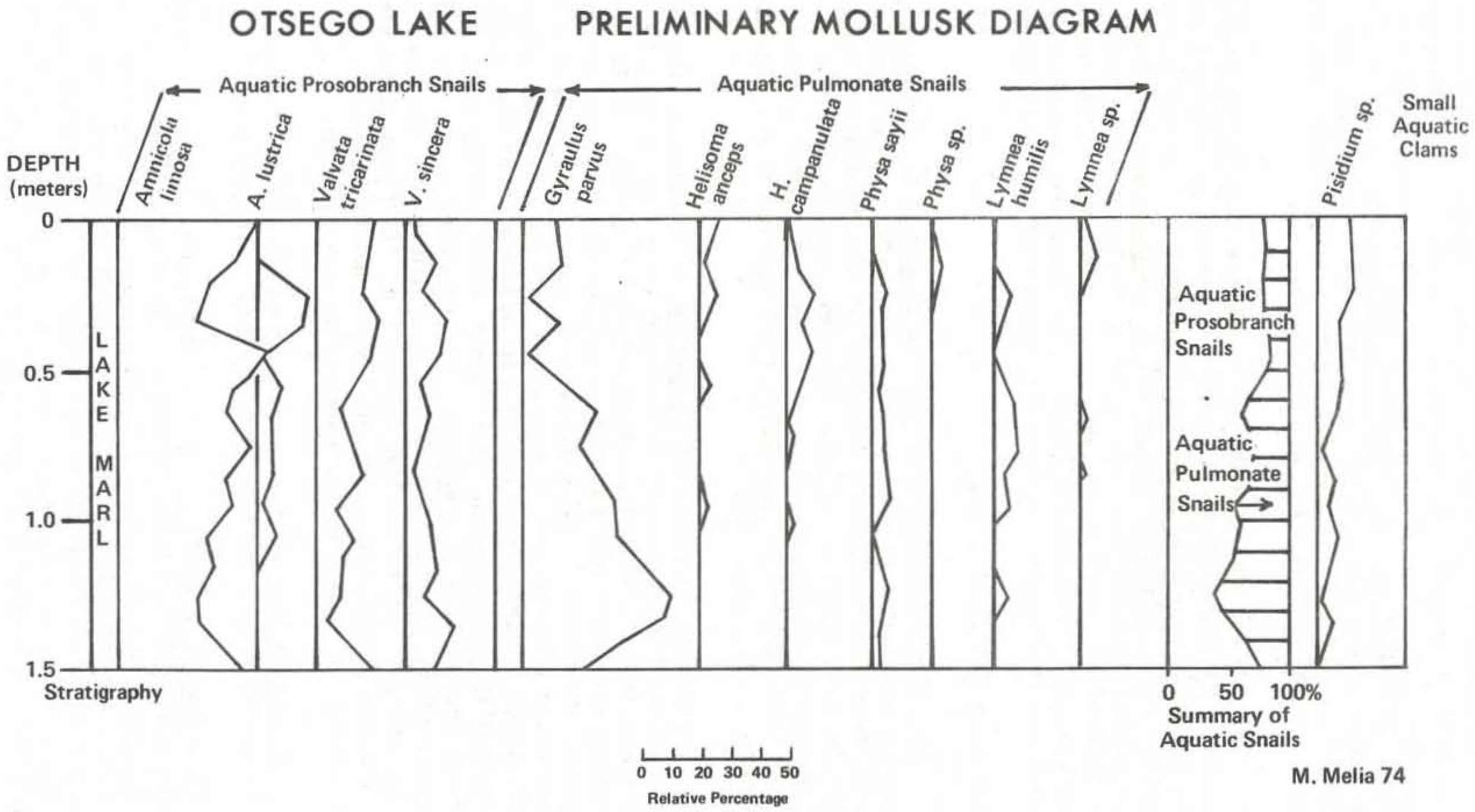


Figure 4. Preliminary Mollusk Diagram of Otsego Lake from Sales, et al., 1974.

Mollusk Stratigraphy

Prosobranch species were by far the most abundant mollusks in the core, and generally showed an increase in relative percentage upwards to the top of the core. Here they accounted for 70% of the total mollusks present. Amnicola limosa was by far the most numerous of these and accounted for at least 30% of all mollusks present (see Fig. 4). Similar observations were noted by Watts and Bright (1968) in a core from Pickerel Lake, South Dakota.

The most abundant pulmonate snail was Gyraulus parvus. This species, however, showed a marked decrease in relative numbers toward the surface from a maximum (51%) between 1.2 m. and 1.3 m. in core depth. Both Helisoma anceps and H. campanulata increased in relative percentage towards the top of the core, as did the small clam Pisidium sp. No terrestrial pulmonate snails were observed in the core. The mollusks only reported to genus were immature specimens whose species could not be determined with any degree of reliability.

Tentative Interpretations.

The great abundance of Amnicola limosa and Gyraulus parvus in the core is not surprising since they are both common species in the littoral zone where they are 'typical of the autochthonous organic matter association' (Harman, 1972). However, the decrease in relative numbers of G. parvus to the surface may reflect a recent decrease in the amount of bottom vegetation upon which this species lives (Harman, 1975, personal communication).

The greater numbers of G. parvus in the lower part of the core may reflect their greater resistance to being crushed by increased lithostatic load with increased depth of burial. This species is pseudoplanispiral and generally smaller than the other conispiral species in the core, therefore, a G. parvus shell with a small surface area would undergo less compression and consequently less crushing with depth. During sieving it was observed that the larger shells (especially Helisoma sp. broke apart more readily than the smaller shells (especially G. parvus). On the other hand, the relative numbers of G. parvus do decrease near bottom of the core and approach a percentage similar to that above 1 m. A 'Gyraulus maximum', then, related to environmental or ecologic conditions in the lake during the recent past may be represented on the diagram.

G. parvus may be over-represented in the core because of an overabundance of immature specimens of this species.

An Amnicola lustrica maximum between 0.2 m. and 0.4 m. in core depth may reflect recent interspecific competition on the parts of A. lustrica and A. limosa. Bottom vegetation, and hence snail populations, may have been disturbed by soft-sediment slumping or by the introduction of coarse sand and gravel of terrigenous origin, as noted in the section on sedimentology, this report. A. lustrica is less dependent on vegetation than is A. limosa, and thus would better maintain its population with changes in the substrate. At this point no positive explanation can be given for the demise of A. lustrica; it is still an inhabitant of the lake today (Harman, 1972).

Suggestions for Further Study

Clearly more information must be gathered before any firm conclusions about post-glacial changes of the mollusk population in Otsego Lake can be drawn. From a single 1.5 m. core which at best only spans a few centuries, a good reconstruction of the paleomalacology can not be gained. With more cores for correlation and perhaps some C-14 dates on the organic matter within the cores, a better picture might be perceived.

If pollen stratigraphy of the future cores is also obtained, the cores may be fit into the postglacial time framework where C-14 dates are not available.

Geochemical data must be obtained from the pore waters of the sediments in the lake in order to gain insight into the paleolimnological conditions and the influence of lake waters on the chemical solutions of shells. (Most shells in the present study were heavily pitted but were not abraded to any appreciable extent.)

Studies of the recent changes in the diatom populations of the lake should also provide paleoenvironmental information. Recent work by Del Prete (1972) has shown that diatom death assemblages may provide information about the postglacial depositional environments in lakes. Correlations between the diatom frequencies and geochemical analyses of the lake cores may also shed light on past lake conditions. Such a study was recently completed for Utah Lake, Utah (Bolland, 1974).

OTSEGO LAKE: CONTEMPORARY ECOLOGY

This contribution was written to provide background materials so that a better understanding of observable features noted in the log of the research vessel ANODONTOIDES can be understood from a biological point of view, and to explain, in a simplistic way how the results of processes now at work in Otsego Lake can confuse the characterization of ancient lakes.

It should be obvious that a lake is more than a hole in the ground filled with water. Aside from its morphology, every lake has its characteristic color, transparency, temperature regimes, combination of chemical compounds in solution, and not the least important, plant and animal populations. All of these (and more) interact in various complex ways to make each lake a unique environmental entity.

The distribution and abundance of living organisms drastically effects lake characteristics. For example; they modify oxygen levels, which in turn alter water chemistry which is extremely important in the building or degredation of sediments. Another example;

the reduction of the molar action of waves on shorelines and the concomittant trapping of silt and detritus in shallow areas for extended periods before it slumps into the deeper parts of the basin. Another, the precipitation of carbonates or silicates in the presence of various organisms directly forming sedimentary compounds.

Living things are dependent on inorganic nutrients (e.g.,phosphorus and nitrogen) in proper combinations and amounts to maintain viable populations. These nutrients cycle through ecosystems,often becoming trapped for extended periods and therefore unavailable for use. Their availability to organisms is affected not only by their presence in parent rocks, but by a lake's chemistry, morphology, and climate (and importantly in these times, populations of organisms living in the watershed). Therefore, we have come full circle. Initial action and resultant interaction cannot be distinguished.

Contemporary biologists spend much time discussing the potential productivity (the amount of protoplasm that can be grown there) of lakes. They call this the lakes trophic (energy) status. Bodies of water that are typified by great populations of algae and rooted macrophytes, turbid waters, and deep anaerobic organic sediments are considered very productive (eutrophic). Those with few plants, clear waters, and rocky bottoms are not productive at all (oligotrophic). Natural changes over time tend to turn oligotrophic lakes into eutrophic lakes because nutrients leached from parent rock are used by organisms, and recycled again and again, while more and more continue to be extracted from the bedrock (organic pollution is simply the result of the addition of "excess" nutrients from other ecosystems speeding up these natural changes).

However, lakes like Otsego are often called chemically eutrophic and morphometrically oligotrophic. Typical lakes in this climate (like Canadarago just to the west) with nutrient inputs similar to Otsego's are much shallower. When vast populations of algae in Canadarago die they fall to the sediments and are decomposed, during that process all of the oxygen in the lower waters is removed forming anaerobic sediments that release the nutrients for reuse by more algae when fall overturn (the breakup of thermal stratification) occurs. This results in greater populations of algae the next year and chronically reducing sediments.

Otsego is much deeper with a much greater volume of hypolimnion to surface area than Canadarago. The same amounts of nutrients entering would be used by algae (if not immediately lost into deep water). The algae would die and fall to the bottom, but since the volume of oxygenated water is so much greater, the oxygen is not completely used, sediments remain aerobic, and during fall overturn most nutrients remain chemically bound and are not returned to the surface organisms. This results in the maintenance of only small algae populations. Therefore in Otsego the greatest part of the lake appears oligotrophic but shallow isolated bays have superficially eutrophic characteristics.

A geologist 10,000 years from now coring Otsego Lake sediments could be extremely confused by taking a few cores scattered randomly throughout the basin. He could find fine and coarse grained anaerobic and aerobic sediments. Areas of $CaCO_3$ precipitates, and those where carbonates had been dissolved away. He could find fossils of organisms typical of eutrophic and those typical of oligotrophic waters. In order to determine the actual lake's characteristic, a knowledge of the distribution and abundance of those organisms present and a thorough knowledge of their ecological requirements (and restrictions) would be invaluable. Further, and I expect of more interest to geologists, the observations and analysis of sediments now being deposited in the presence of various biotic communities should be undertaken to use for comparison with their older counterparts.

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BOAT LOG - RESEARCH VESSEL ANODONTOIDES

Time from last point	Time Underway	(estimated at a research vessel cruising speed of approximately 2.5 miles/hour)
0:00	0:00	Biological Field Station, Rat Cove (Station 1). Shallow protected bay exhibiting surficial sediments of decomposing organic matter and precipitating $CaCO_3$ associated with *Chara vulgaris* and the rooted macrophytes. Surficial substrates oxidized and exposed to high (23°C) summer temperatures. Sediments and included subfossils illustrate population distribution of rooted plants according to their compensation points. Complexity of plant community and large standing crop is indicative of high potential productivity (eutrophy) and late stages in limnological succession.
0:05	0:05	Leaving the littoral area of Rat Cove. After the depth has exceeded the compensation point of *Potamogeton crispus* no more aquatic benthic plants can exist (profundal zone). Sonar indicates a rapid drop into the main basin which is practically flat bottomed as is typical of overdeepened glacial valleys. Note possible slump feature.
0:10	0:15	Deepest area long this transect. Must be underlain by 100 to 150 feet of fill above bedrock.
0:10	0:25	Kingfisher Tower. Bottom appears highly irregular as minor undulations are traversed parallel to the eastern shore.
0:05	0:30	Wave cut terraces derived from exposed bedrock (Station 2). No building possible because of sheer drop into basin.

Time from last point	Time Underway	
0:10	0:40	Wave built terraces. Stones sorted to size can be observed along entire terrace.
0:05	0:45	Pathfinder camp (Station 3). Start of transect across deepest point in lake (166 feet).
0:05	0:50	Center of basin.
0:05	0:55	Five mile point (Station 4). Contemporary delta. Angle of repose about 50°.
0:10	1:05	Lakeview Motel (Station 5). Walk to view delta formed in glacial Lake Cooperstown.
0:10	1:15	Sunken Island (South) (Station 6). Assorted boulders on lee of glacial advance. Formation may be a drumlin or a solid block of Cherry Valley limestone.
0:01	1:16	Sunken Island (North (Station 7). $CaCO_3$ nodules in association with blue-green algae. It's not known whether the algae are affecting the precipitation or if they are simply living in an inorganic precipitate.
0:14	1:30	Eel and associated "Islands". Possible blocks of limestone plucked from bedrock to the east.
0:10	1:40	North Shore (Station 8). Eroding sand beach. Illustrating effects of fetch of 8-9 miles from the south on a substrate similar to Rat Cove's over glacial till and/or coarse lacustrine deposits.
0:20	2:00	Clarke Point (Station 9). Eroding glacial till from the flanks of Mt. Wellington. In the spring, during ice break up, ice has been observed pushed up the shore to a height of 20 feet.
0:30	2:30	Ekman dredge sample from deepest point in the lake (166 feet). Essentially anaerobic silts covered with aerobic surficial sediments with tremendous amounts of organic oils and trapped nutrients. Constant 4-6°C temperatures year around.
0:30	3:00	Return to Rat Cove (Station 1).

ROAD LOG - OTSEGO LAKE

Road log starts from the Museum parking lot on the east side of Rt. 80 at entrance to Biological Field Station about 1/2 mile north of the Fenimore House and Farmer's Museum. It then proceeds north up the west side of Otsego Lake on Rt. 80. General bedrock geology covered in Rickard and Zenger, 1964.

Miles from last point	Cumulative Miles	
0.0	0.0	This entire area seems to be built on an undulating surface of low relief that averages 50 feet above lake level. Because of degree of undulation it is classified as moraine. There is some possibility that it may be a poorly developed distributive hanging delta into the shallow end of the lake from the several streams entering this general area of the lake. Bedrock rise across the road is a ledge of Solsville sandstone which is well exposed a few hundred feet to the south.
0.9	0.9	Road entering from the left passes close by Leatherstocking Falls of James Fenimore Cooper fame. A pullout 0.2 mile up this road affords a good view of the falls when water is high and leaves are off. The falls are, however, hard to see in summer. Leatherstocking Falls is caused by the same resistant ledge of upper Solsville sandstone seen on the golf course at mileage 0.
		Large open field on the right side of the road represents the undulating top of the Brockway Point hanging delta. This undulating top may possibly indicate continued growth and regrading during periods of water level fluctuation.
0.1	1.0	Bench mark on bridge over Leatherstocking Creek at 1251 ft. elevation can be seen to be approximately level with the top of the hanging delta.
0.35	1.35	Tennis court next to the lake is on the modern Leatherstocking Creek delta graded to the present lake level. Between here and the previous stop the creek can be seen to be incised below the older delta level.
		More or less continuous exposures of the lower Solsville shales on the west side of the road for the next several hundred feet. (Fossil list contained in Rickard and Zenger, 1964, p. 78.)

Miles from last point	Cumulative Miles	
0.65	2.0	Entrance to Three Mile Point. If open, this point affords one of the best views of the lake. The over steepened eastern wall of the glacial trough is very apparent and,if lighting is right,the consistent southward regional dip (approximately 100 feet/mile) can be seen in the foliage pattern, reflecting the ledges and benches and changing chemistry of the various rock units. The contact of the Solsville shales over the Otsego shales is about at road level on both sides of the lake and passes under lake level a few hundred feet to the south. Kingfisher Tower, a well known scenic landmark can be seen slightly to the south and across the lake at the water's edge. On the west side of the road the large house sits on what appears to be the top of the Three Mile Point hanging delta. Leveling up from the benchmark in the wall near the road suggests this elevation again to be very close to 1250 feet.
0.8	2.8	Terrace Motel for reference.
0.1	2.9	Exposure of bouldery till on west side of road. Nearly all of the large erratics are from the several resistant limestones which crop out along the Onondaga-Helderberg escarpment several miles to the north, with almost no contribution from the local bedrock which, being Otsego shale,can only be pulverized and contribute to the clay matrix.
0.1	3.0	Discontinuous outcrops of the Devonian Otsego shale on the west side of the road.
0.1	3.1	Wide open views of the lake but no good pull offs. Five Mile Point visible northward up west shore. Max. depth (166 feet) occurs in the center of the lake just off this point.
0.55	3.65	Crossing Five Mile Point delta contributed by Wedderspoon Hollow Creek via Mohican Canyon. A new delta graded to present lake level forms the point, with older elevated delta remnants up at road level at about 1250 feet. The stream is still incised into bedrock on the east side of the road so the area of the delta is rather small, perhaps because it is built on a very steep area of the glacial trough wall.

Miles from last point	Cumulative Miles	
		The delta front falls off very steeply to the lake deep and according to Harman who has dived along the front is made up of very coarse cobbles with abundant coarse plant debris. This intersection is the start of Auxiliary side trip up Mohican Canyon on County Rt. 28. Main log continues north on Rt. 80 - readjust your mileage if you take this side trip.
0.75	4.40	Lakeview Motel. Obtain permission to drive up behind motel to an excellent exposure of a cross section of a hanging delta. This shows coarse cobbles (apparently similar to those being deposited today on the front of Five Mile Point delta) foreset toward the lake and grading and interfingering with sands deposited lower on the delta front. While the top of the delta is very level there is no sharp contact internally between horizontal topset cobbles and the inclined foreset cobbles, but rather a blending. Leveling up from the water suggests an elevation of about 1255 feet for the upper level surface. This is the most significant exposure proving the former high lake stand.
1.0	5.40	Remains of Sunken Island sign. From here Sunken Island (of James Fenimore Cooper fame and awash with 3-6 feet of water)is located nearly half way across the north arm of the lake and slightly to the north of a line to Clarke Point which separates the north arm from Hyde Bay. See Lake Log for considerable additional detail.
1.1	6.50	Bridge over Allen Lake Creek. Benchmark in the middle of east bridge wall (1253 feet) provides excellent control for leveling the noticeably flat surface of the elevated delta just to the south of the bridge.
0.4	6.90	Clark Pond-Cripple Creek bridge.
0.4	7.30	Well defined NE-SW trending drumlin on west side of road upon which the Episcopal Conference Center is built.

Miles from last point	Cumulative Miles	
		This is one of the southern most representatives of the well known field of east-west trending drumlins that sits on the Onondage bench to the north. It was deposited by ice moving westward up the Mohawk Valley. Flow lines of the drumlins suggests that ice flow curved smoothly southward into the Otsego Lake trough.
0.5	7.80	Turn east on County Rt. 53 and stop. Lake clays of the former high lake stand preserved in drainage ditch on the southeast corner of the intersection. These are very well laminated (varved?) and are at an elevation of 1240 feet. At the 1250-55 ft. lake stand these should have been well out from shore and just below wave base on this very flat area of the Onondaga bench. It is interesting that all modern sediments taken from the lake, while equally fine grained, are strongly bioturbated and nonlaminated.
0.4	8.20	Excellent view south over former flat lake bottom, presumably underlain by the high-stand lake clays, south into the Otsego Lake trough. Mt. Wellington, the "sleeping lion", at two o'clock rises from the Onondaga bench and is capped by the Solsville formation.
1.0	9.20	Near top of pass at north end of Mt. Wellington (Wow! - sounds like the Canadian Rockies) stop and look back. Good view of the topographic break between the drumlin covered Onondaga bench to the north and the ledgy cuestas of the Panther Mountain-Solsville escarpment to the south. Rum Hill (Mt. Otsego), 2100 ft. and the highest point on the escarpment is directly in line with the road.
0.6	9.80	Intersection with Griggs Road. Overview of Shadow Brook valley. Piny cobble at 10 o'clock. If light is right several drumlins can be seen along and parallel to the base of the Panther Mtn. escarpment that forms the southeast side of the valley. They may have been shaped from the underlying Chittenango shale outcrop along the base of that escarpment. This soft shale may have provided the clay rich matrix material for the till. Foreground flat is not true valley bottom, but a southerly extension of a well-developed dip slope cut on the upper contact of the resistant Onondaga limestone as the Union Spring-Chittenango shales were stripped off.

Miles from last point	Cumulative Miles	
0.2	10.00	Intersection with Continental Road. Continue straight across bench, around sharp curves and off edge of Onondaga bench.
0.7	10.70	Bridge over Shadow Brook running on bedding in Onondaga. Notice that while the very low dip is typical, the strike here (North 85°East) is atypical, since in general regional strikes are very consistent at about North 70°West.
0.3	11.00	Well at yellow house logged a thickness of lake sands that may require some further down cutting below the levels exposed in the stream, although the anomolous strike and dip should help accommodate this depth of fill.
0.2	11.20	Turn south onto County Rt. 31 and return to Cooperstown via east side of lake.

Summary of East Shore Geology (No mileage or specific stops.) The extreme steepness of the east side of the lake in combination with its very forested nature make the geology less diversified and harder to see. While mostly hidden in the trees, some of the resistant bedrock members form prominent cliffs and ledges on the hillside. One of these contains Natty Bumpo's cave of James Fenimore Cooper fame. The upper Solsville (C) sandstone creates some high waterfalls in some of the very sharp and steep gorges draining this glacially over-steepened slope. The best, easily accessible bedrock exposure is along the first side road branching to the right as you drive north out of Cooperstown up the east side of the lake. A large but over grown quarry on the right several hundred feet up this road provides good exposures of the Panther Mountain lithologies (best exposures are way to the right as you enter the quarry and hidden around a corner). Bedrock is well exposed intermittently at lake level, where a small wave cut bench can sometimes be seen at present lake level with prominent underwater cliffs outward from the bench (see lake log). Driving the road one gets the impression that it may be partially built on a similar wave cut bench related to the former high water stand, especially just north of Kingfisher Tower, but this may be just a case of a bedrock ledge intersecting road level at this point.

Optional Side Trip
Mohican Canyon-Wedderspoon Hollow

Zero speedometer at intersection Rt. 80 and County Rt. 28

Miles from last point	Cumulative Miles	
0.0	0.0	Start Auxiliary Log.
0.0	0.0	Continuous exposure of the upper beds of the Otsego shale. Better and more picturesque exposure available at stream level, including a 10 ft. water fall.
0.15	0.15	Contact of Otsego shale and upper Mohican Canyon till plug exposed on both sides of road cut at an estimated elevation of 1320 feet.
0.2	0.35	Road and stream lower sharply in gradient at approximately 1330 feet onto the floor of the Wedderspoon preglacial valley. All exposures in the walls of Mohican Canyon above this elevation appear to be lodgement till. Subtracting this 1320 ft. elevation from the noticeably gentle surface at an elevation of ±1500 feet at the top of Mohigan Canyon suggests a 180 ft. thick till plug.
0.32	0.67	Large turn out on south side of road. Bedrock till plug contact exposed at stream level below turn out but with considerable slumping of till into stream.
0.45	1.12	Good exposure of clay-rich lodgement till with 6 foot limestone erratic. More or less continuous exposure of till on high side of road for the rest of the way up the canyon.
0.52	1.64	Cross culvert over creek. Immediately across the creek is the "Piorstown Boulder field", an area of solid erratics with no matrix covering an area about 50 feet square. Most of the rocks exceed two feet and some are as large as 4 feet in diameter.
		About 90% of the field including the largest and best rounded erratics are Adirondack crystallines. Less than 10% are limestone (averaging smaller and less well rounded) with only a very small <5% contribution of smaller cobbles from the local bedrock.

Miles from last point	Cumulative Miles	
		Size of the erratics suggest that this may be a natural winnowing process. It may, however, have been dumped there in clearing the large flat field that defines the top of the till plug above the boulders. In either case, it is an excellent sample of erratics characterizing the till plug.
0.05	1.69	Intersection of Rt. 28 and Wedderspoon Hollow Road at the top of till plug exposure.

Options from Intersection

1.) Return directly to Rt. 80 via same route.

2.) Small quarries in the upper Solsville (C) Ledge forming sandstone are exposed 0.3, 0.5, 1.5 miles south of this intersection (left turn).

3.) A right turn at intersection plus another right turn on a dirt road 0.1 miles after that takes you over Red House Hill and back down to Rt. 80 with a high scenic view of the north end of the lake from the crest of the hill.

A-7

PHYSICAL STRATIGRAPHY, SEDIMENTOLOGY AND ENVIRONMENTAL GEOLOGY OF THE UPPER DEVONIAN STREAM DEPOSITS OF THE CATSKILL MOUNTAINS OF EASTERN NEW YORK STATE

A GUIDED TOUR OF SOME OF THE NON-RENEWABLE NATURAL RESOURCES OF THE CATSKILL MOUNTAINS

by

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PALEOECOLOGY AND STRATIGRAPHY OF THE ORDOVICIAN BLACK RIVER GROUP LIMESTONES: CENTRAL MOHAWK VALLEY

by

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INTRODUCTION

Introduction

For over 150 years the Ordovician rocks of the Mohawk Valley have been under study. Some of the leading geologists and paleontologists of the 19th and 20th centuries studied the limestones, shales, and fossils of the Medial Ordovician Black River and Trenton groups in the Black River, West Canada Creek, and Mohawk River valleys (see Kay, 1937, for historical review). As a result, these rocks have become well-known as part of the Medial Ordovician standard reference section of North America.

The purposes of this field trip focusing on the limestones of the Black River Group of southern Herkimer County, New York, are to:

1) Demonstrate the stratigraphic succession and its lateral variations.
2) Discuss and evaluate the age relationships and time correlations of the various formations by
    a) Examining the diverse faunas and
    b) Demonstrating the lateral continuity of major lithic and biologic characteristics.
3) Examine and evaluate the criteria for determining the extent and significance of the disconformity along the Black River-Trenton boundary.
4) Examine and evaluate the criteria for determining the environments of deposition and paleogeography.

This field trip guide will summarize some of the previous work on the Black River Group in the Little Falls and Utica 15' quadrangles of Herkimer County and incorporate new data supporting reinterpretations of the stratigraphy in this area. The order of localities has been chosen as conveniently as possible for economy of travel along a southeast to northwest traverse.

Geologic setting

The Little Falls and Utica quadrangles are located along the southwestern margin of the Adirondack Mountains and include part of southern Herkimer County (Fig. 1). Good exposures of Medial Ordovician limestones are to be found along the Mohawk River, West Canada Creek, and East Canada Creek valleys and those of their tributaries (Fig. 1). Many small abandoned limestone quarries in both quadrangles contain exposures of the Black River-Trenton boundary.

Lower Paleozoic strata dip gently to the southwest from the Pre-Cambrian on the northeastern part of the Little Falls Quadrangle (Cushing, 1905), and Precambrian inliers occur at Middleville and Little Falls (Cushing, 1905; Young, 1943; Kay, 1953). The Late Cambrian Little Falls Dolomite underlies the Ordovician rocks and overlies the Precambrian basement complex. A few northeast-southwest trending normal faults cut Paleozoic and Precambrian rocks, e. g., near Little Falls and Dolgeville (Cushing, 1905; Kay, 1937).

BLACK RIVER GROUP: BACKGROUND

Rock units

Vanuxem (1842) was the first to use the name Black River for some of the limestones of Medial Ordovician age. The Black River Group has its type area in the Black River Valley in northwestern New York State. Although not originally, it is now composed of four formations: Selby, Watertown, Lowville, and Pamelia formations (Cameron and Mangion, 1977) (Fig. 2). The group occurs in the Champlain Valley, Mohawk Valley and extends northwestward to the shores of Lake Ontario beyond Watertown, Jefferson County, and thence westward into Ontario, Canada. It is also exposed in the Ottawa Valley and St. Lawrence Lowland of Ontario and Quebec (Kay, 1942; Wilson, 1946).

The Watertown and Pamelia were both thought to disappear somewhere south of Boonville, Lewis County; however, Cameron and Mangion (1977) have extended the Watertown southeasterward to the Newport area for what was previously considered to be Rockland (Kay, 1953; Cameron, 1969). The Watertown Limestone is the Youngest unit of the Black River Group in the field trip area (Central Mohawk Valley) and ranges from zero to seven feet thick (Fig. 2). The name Watertown was used by Cameron (1968) and Kay (1968) to replace the original name, Chaumont Formation, which Kay (1929) first applied as a time-stratigraphic term. The Pamelia Formation is the oldest unit and averages about 150 feet thick in northwestern New York. It is a dolostone that nonconformably overlies the Precambrian basement complex or the Cambrian Potsdam Sandstone in northwestern New York.

The middle formation of the group, the Lowville Limestone, which

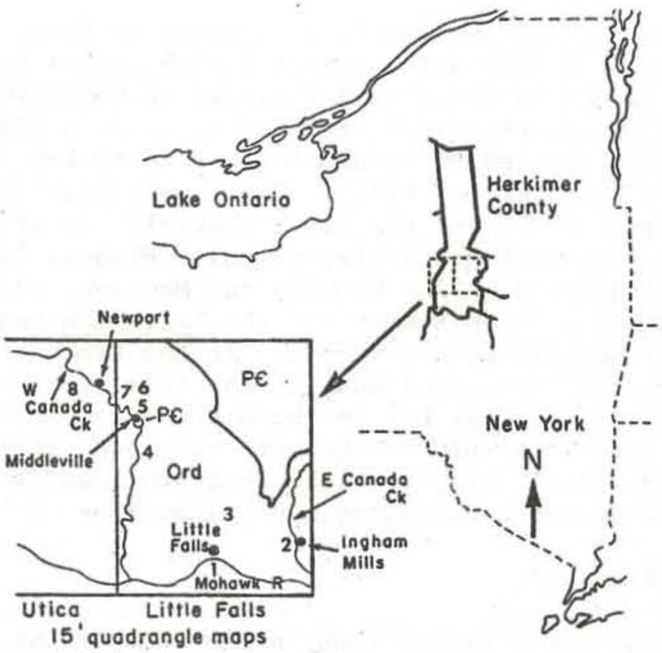

Fig. 1. Partial map of New York State with index maps showing location of quadrangles and field trip stops (numbers).

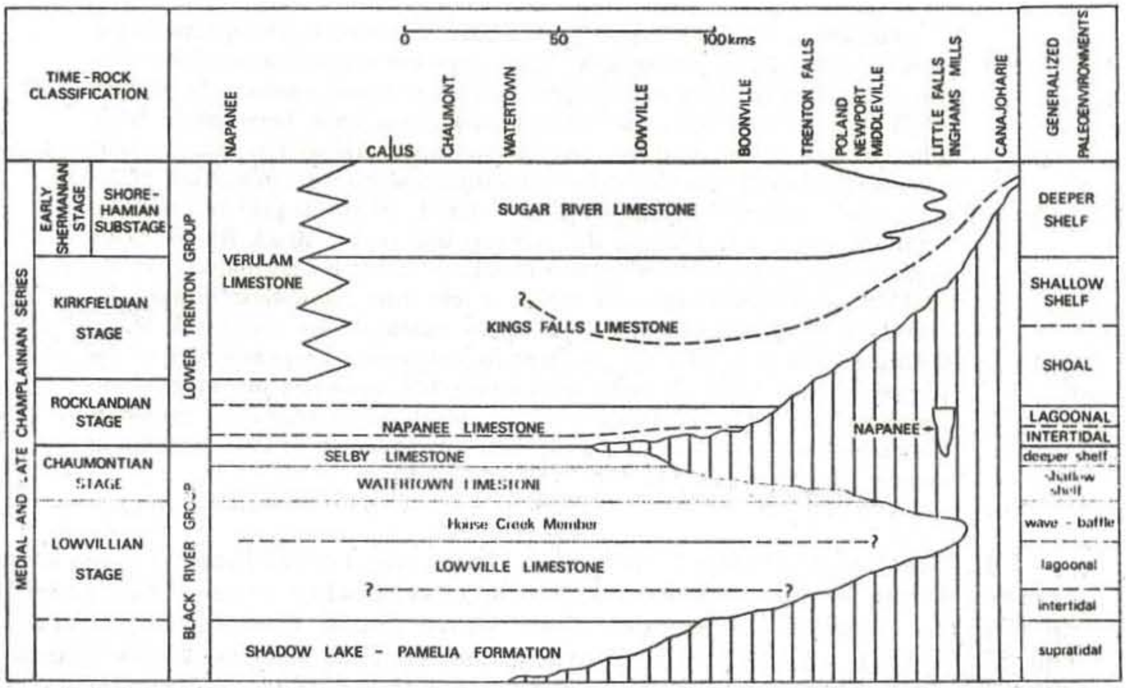

Fig. 2. Generalized correlation chart of Black River and lower Trenton groups from the central Mohawk River Valley in New York to southeastern Ontario. The width of each unit approximates relative thickness which is an estimate of time. Generalized paleoenvironmental framework is shown in the right hand column. Note the ambiguous and problematic portrayal of the Black River Group in the southeast, i. e., central Mohawk River Valley (From Cameron and Mangion, 1977, p. 489).

averages about sixty feet thick, was, prior to 1899, known as the "Birdseye Limestone." Clarke and Schubert (1899) called it the Lowville Formation for exposures in and around the town of Lowville, Lewis County, New York. However, they also referred to it as a stage or time-rock unit which has resulted in terminological confusion (Kay, 1968; Cameron, 1969; Cameron and Mangion, 1977). The "Lowvillian" stage is ambiguous outside its type area, and the term "Lowville" is still the most widely used term for the rock-stratigraphic unit (Fisher, 1962, in press; Walker, 1973; Rickard, 1973; Cameron and Mangion, 1977). Walker (1973) proposed the House Creek Member for the Tetraduim-bearing upper Lowville limestones of northwestern New York. In the field trip area the Lowville Limestone comprises most of the relatively thin (26 to 37 feet) Black River Group, and it has not been formally subdivided into members. However, at least two informal members have been described (Kay, 1953; Cameron, 1969; Kamal, 1977): a lower buff-colored, sandy and dolomitic limestone and an upper dove-gray, pure limestone.

Correlation Problem

Some controversy exists today as to whether the rock units of the Black River Group and Trenton Group in New York and Ontario are time-stratigraphic, i. e., the same age throughout their geographic distribution. This problem was summarized by Cameron and Mangion, (1977, p. 488) as follows:

> Walker (1973) and Barnes (1967) have reviewed three current hypotheses of Black River stratigraphy. The argument revolves around whether the formations are time-stratigraphic or facies of one another. As Walker (1973) has pointed out, the various viewpoints have been made from different spatial orientations: one follows the trend of the outcrop belt whereas the others show hypothetical onshore-offshore relationships. However, when the paleogeography is considered, all the hypotheses may be regarded as correct. That is, the outcrop belt in the Black River Valley more or less parallels the ancient strandline, and it is reasonable that the contacts of the formations are more or less time lines. Furthermore, by following Walther's Rule, all the facies exhibited by the Black River Group should be laterally equivalent in a direction perpendicular to the paleoshoreline. Unfortunately, the outcrop belt geometry precludes showing this relationship. Walker (1973) has also shown stratigraphic evidence, a metabentonite, that confirms the near synchroneity of the formational contacts in part of northwestern New York.

In northwestern New York, the limestone formations of the lower Trenton Group are also believed to be essentially time-stratigraphic in nature. However, they have been shown to be time-transgressive in the field trip area in the central Mohawk River Valley where the paleoshoreline is eastward along the north-south trending Adirondack Arch near Canajoharie, New York (Fisher, 1962, in press; Kay, 1968; Cameron, 1972, 1973; Mangion, 1972; Cameron, Mangion, and Titus, 1972; Mangion and Cameron, 1973; Titus, 1973, 1974; Titus and Cameron, 1976; Cameron and Mangion, 1977). The Black River Group in this area, on the other hand, appears to be time-stratigraphic, indicating that its local paleoshoreline is northward towards the Adirondack Dome.

Environmental Framework

The environmental stratigraphy and paleoecology of the Black River Group in northwestern New York has received much attention in recent years (e. g., Textoris, 1968; Walker and Laporte, 1970; Walker, 1972, 1973; Cameron and Mangion, 1977). "In the type area of northwestern New York it represents a somewhat restricted (Walker and Laporte, 1970) submergent cycle with (1) supratidal dolomitic mud flats of the Pamelia at the base, (2) intertidal lagoonal, and wave-baffle limestone facies of the Lowville in the middle, (3) level bottom, subtidal, pelletal limestones of the Watertown..." (Cameron and Mangion, 1977, p. 495) representing relatively deeper, though still shallow, water deposits, and (4) slightly deeper subtidal, more argillaceous, Selby limestones at the top. "The shoaling conditions in the uppermost Selby are consistent with the shoaling conditions of the middle Bobcaygeon of south-central Ontario (Liberty, 1969), the apparent diastem between the Selby and Napanee of southeastern Ontario and northwestern New York, and the widening bite of the Black River-Trenton unconformity along the western and southern Adirondack border (Fig. 2)" (Cameron and Mangion, 1977, p. 497).

Black River-Trenton Unconformity

The lower Trenton limestones of central and northwestern New York represent a transgressive sequence in which a late-Medial Ordovician sea transgressed the western Adirondack Dome from west to east according to the northwest-southeast outcrop belt. One result is a disconformity between the Black River Group below and the Trenton Group above in central New York that narrows to a diastem in northwestern New York (Fig. 2).

Evidence for this transgression and unconformity can be found in the litho- and biostratigraphic relationships of the upper Black River-lower Trenton formations. The northern basal Napanee Limestone pinches out southward before reaching the field trip area where the lower Trenton formation is the Kings Falls Limestone (Fig. 2). West of the Adirondacks in the Black River Valley, the Selby Limestone at the top of the Black River Group (Fig. 2; Cameron and Mangion, 1977) pinches out southward while the underlying Watertown Limestone decreases in thickness. The latter also pinches out still farther south in the Mohawk River Valley (Fig. 2).

The age of the base of the Kings Falls becomes progressively younger to the southeast because its basal Rocklandian-aged beds disappear (Titus and Cameron, 1976), indicating that the lower Kings Falls in central New York is Kirkfieldian in age (Fig. 2). Conglomeratic beds also sporadically occur at its base, such as at Inghams Mills (Stop #2). In addition, the Kings Falls decreases in thickness eastward to disappearance east of Canajoharie (Park and Fisher, 1969).

In the area of Middleville, a thin metabentonite layer (an altered volcanic ash) in the lower Kings Falls occurs progressively lower in the section towards the southeast, being at nine feet at Buttermilk Creek (Stop #6), seven feet a quarter mile south at City Brook (Stop #5), two feet three miles farther southeast at Stop #4 and at Stoney Creek

(Kay, 1953), and absent farther east. If this persistent clay represents a synchronous time surface at each of these localities, then the base of the Kings Falls is onlapping the top of the Black River Group and becoming younger eastward (Fig. 3).

Other indications for an early Trentonian transgression come from paleoenvironmental evidence. For example, the lower Trenton Group represents another submergence event with progressively deeper water formations upwards in the section (Titus and Cameron, 1976; Cameron and Mangion, 1977) (Fig. 2).

BLACK RIVER GROUP: HERKIMER COUNTY

Lithologies

The Watertown and Lowville Limestone formations of the central Mohawk River Valley are composed of a complex of ten interbedded and somewhat gradational lithologies, seven of which are volumetrically important (Fig. 3) (Kamal, 1977). The three minor lithologies are (1) a thin metabentonite composed of cream-colored clay resulting from alteration of volcanic ash, (2) medium gray clay seams, and (3) thin calcareous shales.

The seven major lithologies and some of their variations are described below:

<u>Lithology 1</u>: Medium- to thick-bedded, massive, very light to light gray weathering, medium gray, quartzose, pelletiferous, dolomitic, calcarenitic limestone. This lithology characterizes the lower member of the Lowville Limestone.

<u>Lithology 2</u>: Thin- to medium bedded, yellowish gray weathering, medium gray, wavy, mudcracked, dolomitic, extensively stylolitized, laminated micrite; ostracodes rare. A variation is a pelletiferous micrite.

<u>Lithology 3</u>: Medium- to thick-bedded, light gray weathering, medium to dark gray, vertically burrowed, mudcracked, stylolitized biomicrite; ostracodes rare to common.

<u>Lithology 4</u>: Thin-bedded, yellowish gray weathering, medium gray intrasparite; ostracodes common. When the ostracodes and other ofssils are common, the lithology is an intrabiosparite.

<u>Lithology 5</u>: Thin- to medium-bedded, pale yellowish gray weathering, dark gray micrite. These micrites grade into biomicrites, micrites with a minor sparry fraction, or a combination of all three. This lithology is very mottled. The mottling is thought to be the result of horizontal burrow-reworking.

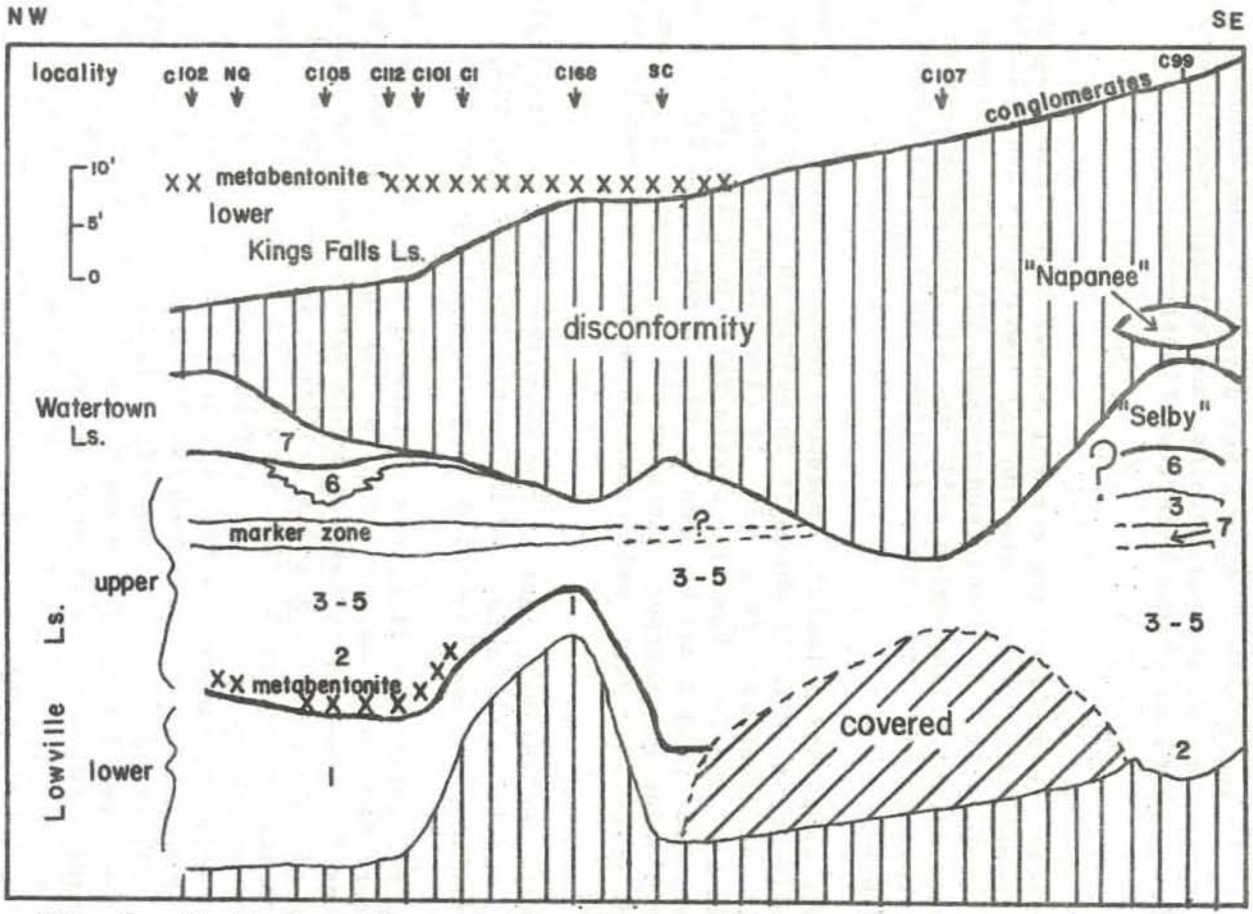

Fig. 3. Preliminary "correlation-thickness" chart for the Black River and lower Trenton groups in the central Mohawk River Valley. Thicknesses are shown along with disconformities (vertical lines). Horizontal time lines are assumed to be the upper metabentonite and the argillaceous marker zone; the lower metabentonite would also be a horizontal line on a true correlation chart. See Figure 5 for a guide to symbols and abbreviations. Numbers refer to lithologies described in text.

Lithology 6: Thin- to medium-bedded, yellowish gray weathering, medium gray, bioclastic limestone. This Tetradium (tabulate coral)-bearing lithology ranges from a biomicrite (or fossiliferous micrite) to a biosparite.

Lithology 7: Thick ledged, cherty, lumpy and wavy bedded, thoroughly horizontally burrow-reworked biomicrite, pelmicrite, and micrite. Sparse but diverse fauna, including corals, stromatoporoids, and straight nautiloids. Typical of the Watertown Limestone.

Stratigraphy

The Lowville Limestone of the central Mohawk River Valley can be subdivided, in ascending order, into the (1) lower sandy and dolomitic limestone (lithology 1), (2) middle mudcracked, vertically burrowed, dove-gray calcilutite (lithologies 2-5), and (3) Tetradium-bearing limestone (lithology 6). Above these is lithology 7 of the Watertown Limestone (Fig. 3).

The lower sandy and dolomitic limestone member occurs in the Newport and Middleville areas (Fig. 1) where it is nearly 16 feet thick, but east of Middleville it disappears (Fig. 5). It disconformably overlies the sandy dolomites of the Late Cambrian Little Falls Dolomite (Fig. 5). The relief at this contact can be seen at City Brook (Stop #5). A metabentonite or prominent reentrant occurs at the top of the lower member at City Brook (Stop #5), Buttermilk Creek (Stop #6), and Newport (Stop #8) (Fig. 5).

The middle and thickest part of the Lowville contains lithologies 2 through 5, but it is characterized by vertically burrowed, mudcracked, sparsely fossiliferous, and laminated (algal? mats) calcilutites.

The upper Lowville, or lithology 6, resembles the House Creek Member of northwestern New York. Walker (1973, p. 11) introduced the House Creek as being "...composed of Tetradium bioclastic limestone with a central zone of colonies of Tetradium in life position." This thin bioclastic facies is apparently discontinuous in the field trip area, occurring (1) in the upper 2' 4" at locality C105 to the north at Diamond Hill (Fig. 5; Cameron, 1969), (2) in the upper three to five inches in the south Newport-north Middleville area (localities C112, C112A, C101, C1; Stops 5, 6, & 7; see Figs. 1, 5, & 8; Cameron, 1969), and (3) in the upper 8 feet at Inghams Mills (locality C99; Stop #2). Upright Tetradium colonies are present at two localities (C99, Stop #2, Fig. 8 of Cameron, 1969; C112, Stop #7, Fig. 8 herein). This facies is apparently absent at Newport (Stop #8) and at exposures in Poland, the next town to the north.

Correlation

The nearshore carbonate lithologies of the Lowville Limestone are complexly interbedded. This interbedding is indicative of "yo yo oscillation" (Friedman, 1975) across the shoreline, such as in sabkhas. Such interbedding makes correlation very difficult. Furthermore, much of the strata was deposited in local areas (lenses) and, as such, may not be directly correlative with strata of the same lithology at a geographic distance. Lithological similarity has remained, therefore, the major method of correlation, using marker beds, metabentonites and geometric relationships.

Correlation of the lower strata of the formation was done through recognizing the lower sandy and dolomitic member (lithology 1). In three of the sections (Stops 5, 6, & 8), the member is topped by a two to four inch metabentonite or a reentrant whose unique position favors its acceptance as a suitable time line (Fig. 5).

A marker zone of thin, shaly and argillaceous limestone about two or more feet thick near the top of the Lowville stands out physically with a definite lumpy weathering appearance. It is traceable among eight of the sections and serves as a correlatable horizon for the upper part of the Lowville (Fig. 5).

The marker zone, the metabentonite and the Tetradium-bearing bioclastic facies appear progressively higher in the sections eastward. This and the fact that the Watertown Limestone above the Lowville pinches out eastward (Cameron, 1969; Cameron and Mangion, 1977) indicates that (1) the top of the Lowville Limestone is older eastward and (2) the unconformity of the Lowville Limestone with the overlying Trenton Group is larger eastward. Inghams Mills (Stop #2) appears to be an exception because a nearly complete section is preserved locally (Fig. 3).

Paleoshoreline

A time-stratigraphic relationship is postulated in the east-west direction for the Lowville in the study area (Fig. 3). Because the transgressive sequence does not cross time-lines, the outcrop in central New York is postulated to have been parallel to a paleoshoreline to the north. Walker (1973) concludes that the Lowville Limestone in northwestern New York is time-stratigraphic in the north-south direction parallel to the outcrop belt, but postulates a time-transgressive relationship in an east-west direction at right angles to the outcrop belt. In central New York, on the other hand, such a time-transgressive model would be in a north-south direction. Most likely, the paleoshoreline was north-south along the western side of the Adirondacks and east-west along the southwestern side of the Adirondacks. Connecting these two areas suggests a paleoshoreline that may have encircled an Ordovician low lying landmass - Adirondackia of Kay (1937).

Paleoenvironments

Seven nearshore to offshore carbonate environments of depostion are recognized in the transgressive Black River Group as inferred from lithofacies distributions. Although the seven lithofacies occur most often in pure form, they are best considered as ideal end members. Lateral gradations occur between some of them and vertical gradations are common. The environments of depostion of these lithofacies are inferred on the basis of lithology, textural features, sedimentary structures and paleontologic considerations (Kamal, 1976, 1977) (Fig. 4).

Supratidal environments (lithology 2) are characterized by nonfossiliferous, layered, mudcracked, dolomitic, pelletal dismicrites and dolomitic quartzose calcarenites (lithology 1).

High intertidal environments (mostly lithologies 3 and 4 and some 2) are characterized by vertically burrowed, well-bedded, mudcracked, pelletal, laminated (algal?) biomicrites and biopelmicrites. Intrasparites are common. Fossil debris, mainly large leperditid ostracodes are rare to common.

Low intertidal environments (some of lithologies 3, 5, & 6) are characterized by sparsely fossiliferous, poorly bedded, laminated (algal?) micrites. This facies is readily recognized by combinations of mottling, vertical burrows, and pelloids.

Shallow subtidal or lagoonal environments (mostly lithology 5) are characterized by sparsely to commonly fossiliferous and horizontal burrow-reworked micrites. Fossils range from a few ostracodes to skeletal debris mainly containing snails, trilobie fragments, coral fragments and cryptostome ectoprocts.

Shoal environments (lithology 6), or wave-baffles of Walker (1973), are composed chiefly of biomicrites and, occasionally, biosparites. The tabulate coral *Tetradium celluloseum* in life position (Fig. 8 herein; Cameron, 1969, Fig. 8, p. 15-16), is common in this facies (Stops 2, 6, & 7).

Open marine, shallow "level-bottom" environments are characterized by thorough horizontal burrow-reworking, obscured bedding, and diverse and abundant fossils. This facies is represented by the Watertown Limestone. The major fossils include tabulate and rugose cup corals, normal salinity requiring ectoprocts, brachiopods, and echinoderms, and mollusks, such as nautiloids, snails, and clams. Uncommon calcareous algae, micrite envelopes of possible endolithic (shell-boring) algal origin, and algal(?) borings indicate deposition within the photic zone, while the burrow-reworking indicates depths below wave-base (e. g., 10 meters or more).

Deeper subtidal environments are represented by the shaly, very fossiliferous, Selby-like lower "Napanee" at Inghams Mills (Stop #2). This was probably deposited in still deeper water than the Watertown (lithology 6), but rare micrite envelopes indicate depths still within the photic zone.

ACKNOWLEDGMENTS

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Fig. 4. Litholgic-Environmental Model for the Black River Group

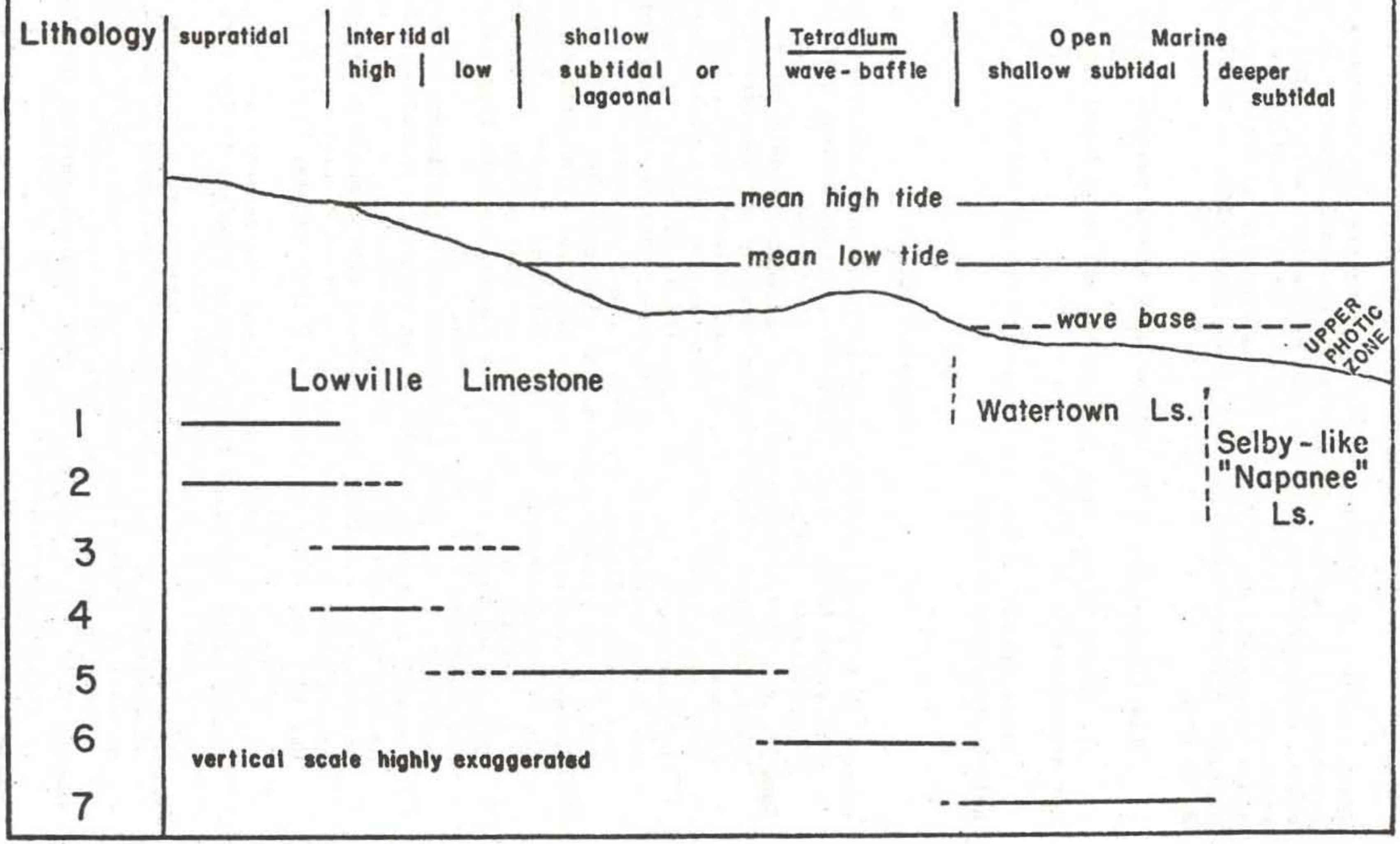

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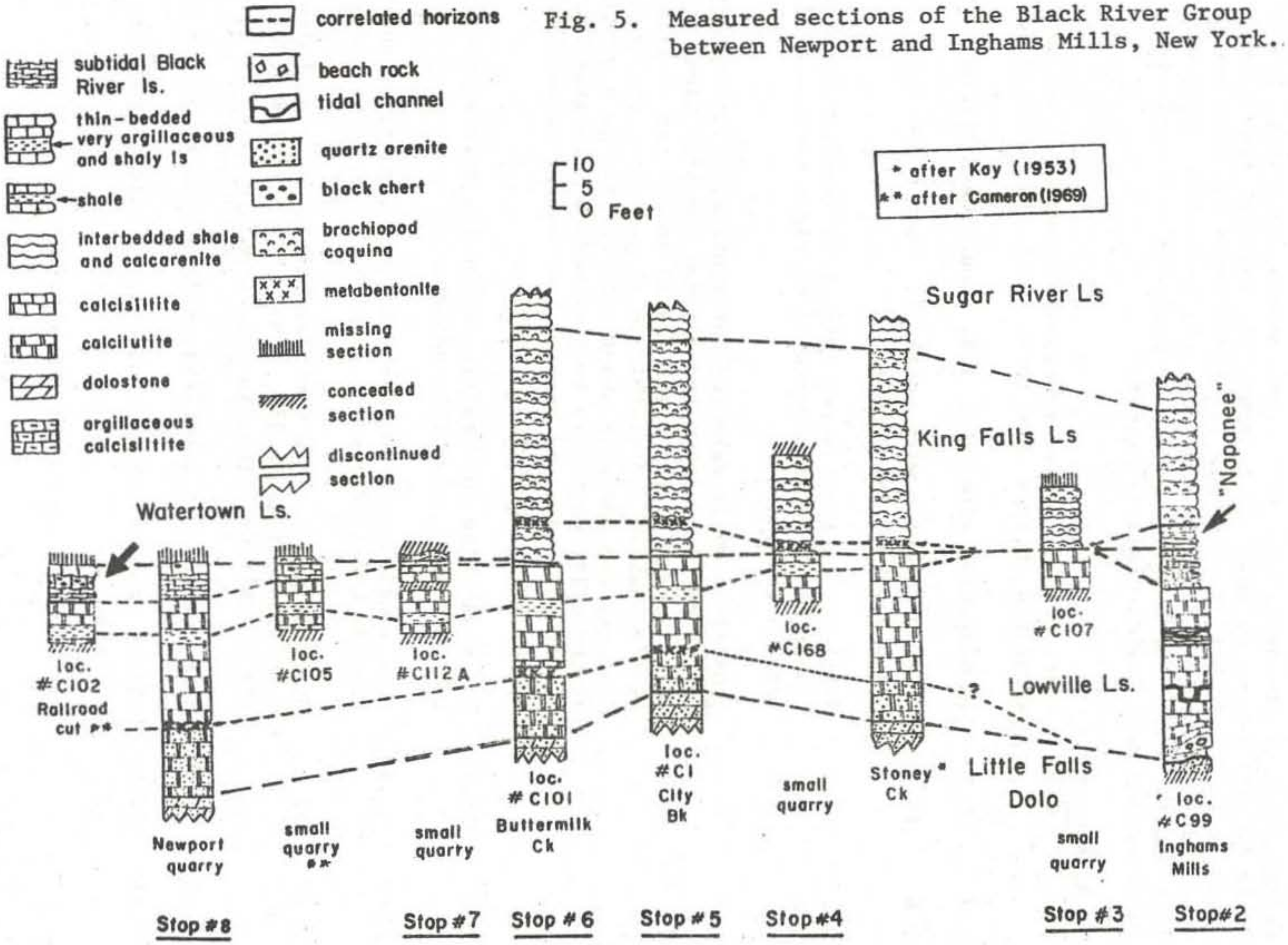
Fig. 5. Measured sections of the Black River Group between Newport and Inghams Mills, New York.



Mileage Log

This mileage log is designed to start in Richfield Springs at the intersection of Routes 20 and 167. From Oneonta, take Route 205 north to Route 80, drive east on Route 80 to Route 28, and then take Route 28 north to Richfield Springs. As you intersect Route 20, from Route 28, turn right (east) onto Route 20. Go 0.4 mile to traffic light where a left (north) turn starts this road log on Route 167. A road sign at this intersection says "Little Falls 17 miles."

*In Mi	**Cu Mi	
0.00	0.00	Traffic light at intersection of Routes 20 and 169 in Richfield Springs, New York. Go north on Route 167.
9.9	9.9	Intersection with Route 168. Continue north on Route 167.
5.6	15.5	"T"-intersection with Route 5S. Turn right (east) onto Route 5S and drive uphill.
0.8	16.3	Small vegetation covered outcrop of Trenton limestones (upper Kings Falls Limestone) on right side of road. Park on the shoulder.
		<u>Stop #1</u>: While watching for traffic, cross highway to the small clearing and descend the bank along the small stream at the right (east) end of the clearing. (The stream is not visible until you enter the brush.) Cross stream and walk about 100 feet to the near end of the cliff where 2.5 feet of medium dove gray Lowville Limestone is exposed beneath the coarse, cross-laminated, shelly lower Kings Falls Limestone.
0.0	16.3	While watching for traffic, carefully make a "U"-turn and head west, downhill, on Route 5S.
0.85	17.15	Intersection with Route 167 north. Turn right and head towards Little Falls.
0.05	17.2	Outcrops of the late Cambrian Little Falls Dolomite on both sides of Route 167. This unit directly underlies the Black River Group in this area.
0.25	17.45	More outcrops of the Little Falls Dolomite on the right.
1.45	18.9	Cliffs of Little Falls Dolomite, a thick formation, on the right.
0.1	19.0	Bridge crossing Mohawk River Canal.

*In Mi = Incremental Mileage
**Cu Mi = Cumulative Mileage

0.05	19.05	Bridge crossing Mohawk River.
0.1	19.15	Stop sign. Continue straight after checking for traffic.
0.05	19.2	Stop sign at "T"-intersection. Turn right and stay in right lane.
0.1	19.3	Stop sign. Turn right and get into the left (turning) lane.
0.05	19.35	"T"-intersection with Route 5, a divided highway. Turn left onto Route 5 and head east.
0.45	19.8	Traffic light at intersection with Route 169. Proceed straight on combined Routes 5 and 167.
0.2	20.0	Precambrian gneiss on both sides of highway. This unit underlies the Late Cambrian Little Falls Dolomite in this area.
0.3	20.3	Get into left lane in preparation for a left turn.
0.1	20.4	Blinking yellow traffic light. Turn left onto Route 167 north.
0.9	21.3	Turn right into scenic view parking area.
0.1	21.4	North end of parking lot by sign explaining this historic part of New York. A nice view of the Mohawk River Valley to the east can be seen from this upthrown side of the Little Falls Fault (Cushing, 1905, p. 38).
0.2	21.6	Outcrop of Little Falls Dolomite on left side of road.
1.45	23.05	Proceed straight ahead, leaving Route 167. Pass Exxon Station on your left. Now on Dockey Road.
0.15	23.2	Intersection with Bidleman Road. Proceed straight ahead.
0.4	23.6	"Y"-intersection after small bridge. Bear left onto Inghams Mills Road.
0.75	24.35	Intersection with Snells Bush Road (once East Creek Road). Continue straight on Inghams Mills Road.
0.75	25.1	After driving down hill, continue straight onto dirt road (a dead end sign marks it). (Do not turn right and go onto the large bridge over East Canada Creek.) Note: Poor roadside exposures of Rocklandian and Kirkfieldian (lower Trentonian) limestones and shales to the left. If the power company (Niagara-Mohawk) does not permit trespassing, park and walk across the large bridge. Descend the left (upstream) side to the large limestone exposures at the inside of the meander to see all but the base and top of the Lowville Limestone. The 4 foot thick, burrow-reworked, Watertown-like, subtidal facies caps the exposure.

0.05	25.15	Turn right and cross small wooden bridge.
0.04	25.19	After crossing wooden bridge, take right fork in dirt road.
0.02	25.21	Turn left in front of building.
0.02	25.23	Turn left back onto dirt road.
0.05	25.28	Park on grass along right side of dirt road.

Stop #2. Inghams Mills (locality #C99):

Walk to the right, through the grass, and proceed to the right of the tall chain-link fence, walking beneath the powerline tower. At the stone wall along the edge of the field, bear left and walk along the fence. (CAUTION: Poison ivy often grows in abundance along this path.) Opposite the brick building, turn right and proceed very carefully over the boulders and across the creek towards the base of the outcrop. The boulders you will have to walk over to get to this exposure are sometimes unstable and move when stepped on. Some are sharp and dangerous.

Four formations of Medial Ordovician age are excellently exposed along with the top of the Late Cambrian Little Falls Dolomite(?) below the dam on East Canada Creek. Lithologies, unusual sedimentary structures, fossils, formation boundaries, and disconformities can be carefully examined.

Little Falls Dolomite(?). Only 2 feet of the Late Cambrian Little Falls Dolomite are exposed at the base of the exposure. This unit is represented by relatively thick-bedded, light to medium brown weathering, quartz arenitic, pyrite-bearing dolostone with thin interbedded shale layers.

Lowville Limestone. About 29.5 to 30 feet of Lowville Limestone are excellently exposed with a thick dove gray shaly limestone at the base. The lowest 2 to 3 feet exhibit a slump and boulder beachrock (Figs. 5-6) containing limestone blocks up to 2.5 feet in diameter, that probably formed as a result of instability over the irregular depositional surface of the Little Falls Dolomite. This might be a channel margin slump, e. g., bank collapse deposit.

The next 16.5 feet contain horizontally laminated (algal?), dove gray calcilutites with abundant vertical burrows (Phytopsis), a few ostracodes. and frequent stylolites. Frequent mudcracks confirm an intertidal origin. A tidal channel (Figs. 5,7) is wholly exposed on the west side of the outcrop (old stream channel).

Fig. 6. Beach-rock at base of Lowville Limestone at Inghams Mills (locality C99; Stop #2). Hammer is scale.

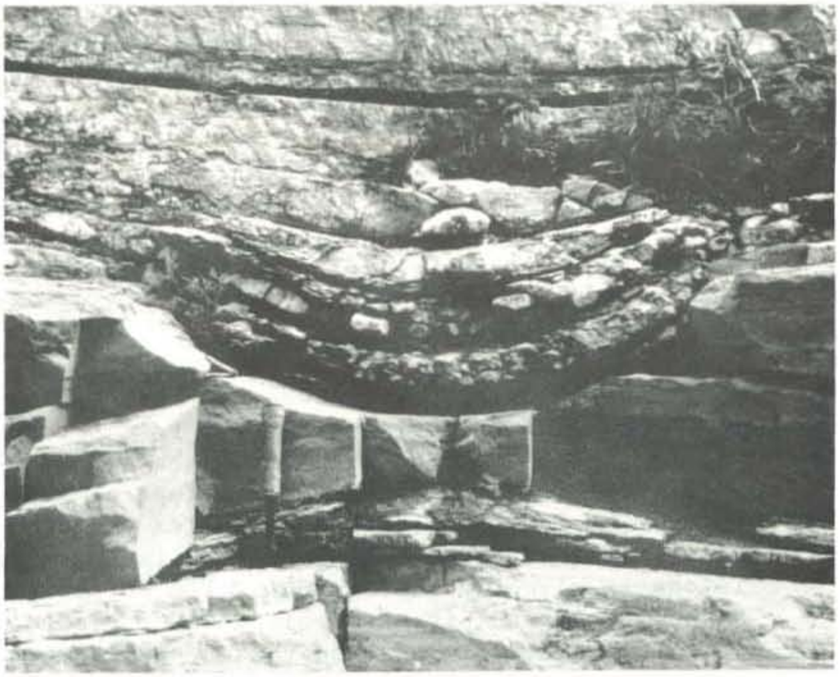


Fig. 7. Tidal channel cutting intertidal lithologies in the middle Lowville Limestone at Inghams Mills (locality C99; Stop #2). Hammer is scale.

Between 16.5 and 21.5 feet an apparently subtidal, irregularly burrowed, essentially non-laminated, massively bedded, dark gray to black calcisiltite zone contains Foerstephyllum halli, Lambeophyllum profundum, Hormotoma, Loxoplocus, Isotelus, cryptostome bryozoa, straight nautiloids, and pelmatozoan debris. This resembles the subtidal Watertown Limestone to the northwest.

Immediately above these deeper water sediments, the intertidal facies begins to reappear. This is a vertically burrowed, horizontally laminated (algal?), limestone intraclast-bearing, fossiliferous calcilutite and calcisiltite zone. Fossils from this interval include Tetradium cellulosum, Eoleperditia fabulites, Lambeophyllum profundum, Isotelus, cryptostome bryozoa, and pelmatozoan fragments. Near the base of this zone a sediment-filled tidal meander(?) or channel (Cameron, 1969, see Fig. 7) up to 7 feet wide and 2 feet deep is excellently exposed in 2 faces of the outcrop. Note the structure and composition of the sediments filling it.

At about 27 feet, a 9 inch thick calcilutite bed contains scores of whole Tetradium cellulosum colonies in life position that cover 50% to 90% of the bed which contains a thin veneer of limestone pebble conglomerate. One can readily see how the fine-grained sediment was trapped in and around these delicately branching tabulate corals. This is also equivalent to Walker's (1973) wave-baffle lithology and it resembles his House Creek Member of the Lowville Limestone in northwestern New York (Fig. 8; see Fig. 8 of Cameron, 1969).

The top of the Lowville Limestone is riddled with burrows (dominantly vertical) partially filled with the black lustrous carbonaceous mineral anthraxolite. Several inches of irregular relief over the top of this bed may mark a disconformity between the Black River Group and the Trenton Group.

Trenton Group. The lowest 13 feet of the Trenton(?) limestones can be divided into 7.5 feet of chocolate brown weathering interbedded calcareous shales and argillaceous calcisiltites at the base and 5.5 feet of medium gray weathering interbedded thinner shales and less argillaceous calcisiltites above. The contact between these 2 subdivisions is slightly gradational. The surfaces of the limestone layers exhibit extremely well-developed loading casts. In addition, the lower subdivision contains an unusually well-developed and fully exposed intraformational fold similar to those described by Chenowith (1952) from the Sugar River Limestone in northwestern New York. Fossils are common. The fauna of the lower 7.5 feet is that of the uppermost Black River Group, i. e., the Selby Limestone of northwestern New York (Cameron and Mangion, 1977), while the fauna of the upper 5.5 feet resembles that of the lower Trentonian Napanee Limestone. Overlying these limestones is the 38 foot thick Kings Falls Limestone with basal conglomerates.

0.0	25.28	Drive straight ahead on the dirt road.
0.02	25.3	Turn left onto dirt road leading from power plant.
0.05	25.35	Bear right, crossing small wooden bridge. Then, bear left.
0.05	25.4	Intersection with Inghams Mills Road. Proceed straight, uphill. (Do <u>not</u> turn left and cross bridge.)
0.8	26.2	Intersection with Snells Bush Road. Turn right.
2.15	28.35	Intersection with Route 167. Turn right onto Route 167, heading north.
0.4	28.75	Turn left onto Bronner Road.
0.65	29.4	Intersection with Murphy Road. Continue straight on Bronner Road.
0.6	30.0	Bear right where Bronner Road turns right (intersection with Davis Road).
0.2	30.2	"Y"-intersection. Bear left, continuing on Bronner Road.
1.25	31.45	Park on right side of road.

Stop #3. Small quarry (locality #C107):

Walk into small old quarry about 100 feet into field from right side of road.

The Black River-Trenton boundary is well-exposed along the contact between 8 feet of upper Lowville Limestone and 13 feet of lower Kings Falls Limestone. The very shaly lowest 13 feet of Trenton(?) limestones seen at Stop #2 is absent and pebbles of the Lowville Limestone can be seen in the lowest few inches of the Kings Falls. There is little relief along this contact to suggest a disconformity.

The thickest section of the Lowville occurs at the axis of the fold at the far end of the quarry. Shales are rare. Fossils are uncommon but include Isotelus, Eoleperditia fabulites, small ostracodes, Liospira, and cryptostome bryozoa. Tetradium cellulosum is absent.

The very fossiliferous Kings Falls Limestone exhibits the somewhat typical cyclic nature of burrowed finer-grained calcarenites and calcisiltites alternating with cross-laminated, coarse-grained calcarenites and coquinites.

0.0	31.45	Proceed straight ahead (west).
0.15	31.6	Intersection with Burrell Road. Turn left (south).
0.1	31.7	Exposures of Shorehamian limestones (Trenton Group) on both sides of Burrell Road.
0.2	31.9	Intersection with Yellow Church Road. Turn right (west) onto Yellow Church Road.
0.7	32.6	Intersection with Route 170. Proceed straight ahead. Yellow Church Road changes name to Top Notch Road.
0.7	33.3	Intersection with dirt road. Bear right, continuing on paved road.
0.45	33.75	Intersection. Continue straight ahead.
1.05	34.8	Intersection with Cole Road. Continue straight ahead. Top Notch Road changes name to Rockwell Road.
0.75	35.55	Acute angle intersection with Route 169. Proceed north on Route 169.
4.6	40.15	Crossing Stoney Creek in a relatively narrow stream valley.
0.6	40.75	Park on right side of road by entrance to quarry uphill from small creek and outcrop of Little Falls Dolomite.

Stop #4. Small quarry (locality #C168):

Walk along dirt road into small old quarry (now a private dump about 100 feet into woods from right side of road (Route 169)).

At this stop, we shall (1) examine metabentonites at the base of the Kings Falls Limestone and (2) reexamine the Black River-Trenton boundary between the upper Lowville and lower Kings Falls limestones. The top of the Lowville has 1 to 2 inches of relief, possibly due to scouring since bedding laminae are truncated. The shaly and argillaceous limestone interval between 2 and 3 feet appears to form a marker zone that can be traced from here northwestward to Newport. *Tetradium* is absent. The 4.5 foot sandy lower member can be seen in the lower quarry. The Lowville is about 11.5 feet thick at this locality.

The fossiliferous Kings Falls contains cream-colored, sticky, 2 to 3 inch thick metabentonites at 12 and 29 inches. A similar 2 inch thick clay has been reported at 2 feet from Stony Creek one-half mile to the southeast (Craig, 1941; Kay, 1943, 1953). We shall evaluate the significance of these clays for time-correlation at the next stop.

0.0	40.75	Proceed downhill (north), continuing on Route 169.
1.05	41.8	Stop light. Downtown Middleville. Proceed straight ahead onto Route 28 North.
0.7	42.5	Quarry on right is in Little Falls Dolomite.
1.1	43.6	Turn right onto paved road. Drive straight uphill (<u>not</u> a hard right turn).
0.25	43.85	"Y"-intersection. Bear left, going downhill, onto Old City Road.
0.15	44.0	Park on either side of road before bridge over City Brook.

<u>Stop #5</u>. City Brook (locality #C1):

Walk onto bridge and look upstream towards the falls. This outcrop has been <u>CLOSED</u> to trespassers, but we can look and talk here.

The characteristics of the Lowville and lower Trenton limestones will be compared with those at previous stops. The Lowville Limestone lies disconformably on the quartz arenite-rich Late Cambrian Little Falls Dolomite below the bridge. The lower falls is supported by the upper Lowville Limestone, and the upper falls (Craig, 1941, Fig. 5; Kay, 1953, Fig. 11) is supported by the middle Kings Falls Limestone.

<u>Lowville</u> <u>Limestone</u>. The lower 7 feet are tan weathering, gray, quartz arenite-rich, ostracode-bearing, impure, thick-bedded, medium-textured, dolomitic, argillaceous limestones interbedded with a few calcareous shales up to 3 inches thick. Vertical burrows are abundant. A 3 inch thick metabentonite occurs at 6' 9" (Kay, 1943, 1953). Kay (1953) correlated this with a prominant reetrant at the top of this lower member at Newport Quarry (Stop #8, Fig. 5).

The upper 19.5 feet of the Lowville is composed of relatively pure, light gray weathering, dove gray, conchoidally fracturing calcilutite (sublithographic) and some calcisiltites. Stylolites are abundant from 11 to 16 feet. Thin shales are frequent between 13 and 16 feet, at the 18th foot, and especially between 19.5 and 21.5 feet where the limestones are very argillaceous (argillaceous marker horizon). Vertical burrows (Phytopsis) are abundant between 11 and 16 feet and in the top foot. Mudcracks occur above and below the 25th foot. An intertidal origin seems probable for these limestones. Tetradium is extremely rare in the upper few feet.

Kings Falls Limestone. Sediment from a coquinal calcarenite bed at the base of the Kings Falls fills some of the burrows in the highly burrow-reworked calcilutite bed at the top of the Lowville. The Kings Falls is characterized by coquinal calcarenites, as at previous localities. Cross-laminated and pararippled beds are frequent.

At 7 feet a deep reentrant marks where a metabentonite is weathering out. Less than a mile north, at Buttermilk Creek (Stop #6), this clay is 9 feet above the base of the Kings Falls (Kay, 1953). If this altered volcanic ash near the base of the Kings Falls between Stony Creek and Buttermilk Creek is part of a single bed, then it represents a synchronous time surface indicating that this formation is onlapping the Lowville eastward. Therefore, the base of the Kings Falls becomes progressively younger eastward, increasing the gap in time marked by the Black River-Trenton boundary in that direction (Fig. 3).

0.0	44.0	Proceed straight ahead, crossing bridge.
0.05	44.05	(Herkimer diamonds are common in the Little Falls Dolomite downhill to the left.)
0.5	44.55	Turn sharp, acute, right onto White Creek Road.
0.4	44.95	Buttermilk Creek. Carefully park on the shoulder. Do not block the driveway.

Stop #6. Buttermilk Creek (locality #C101):

Descend to the creek from the bridge and walk upstream. The Little Falls Dolomite comprises the streambed at the bridge. As you walk upstream, you will walk through the Lowville Limestone and eventually reach the Trenton limestones (Kings Falls).

The lower sandy member (11-12 feet) of the Lowville can be seen roughly between 2 broad flat areas in the streambed. The 23-24 foot thick upper Lowville is fully exposed as you walk further upstream. The argillaceous marker horizon (about 2 feet thick) occurs 6 feet below the top. From 2 to 5 inches below the top there are pieces of the colonial tabulate coral Tetradium. Beneath the Tetradium, vertically burrowed calcilutites dominate down to the marker horizon. The uppermost 1 to 2 inches contain a strophomenid-rich layer resembling the top of the Watertown Limestone at the next stop (Stop #7).

The Kings Falls Limestone, disconformably overlying the Lowville, is shelly, shaly, pararippled, cross-laminated, and sheet-laminated. A metabentonite, reviewed at City Brook (Stop #5), occurs at 9 feet above the base. The Trenton Group at this outcrop is described in more detail by Cameron, Mangion and Titus (1972).

0.0	44.95	Continue north on White Creek Road.
0.3	45.25	Intersection with Elm Tree Road. Turn right.
0.05	45.3	Barbed wire gate to "car graveyard." Park on shoulder of road.

Stop #7. Small hillside quarry exposures (locality #C112A):

Open gate, go through, CLOSE GATE, and walk uphill to last major exposure in field (about 100 feet from road). Return to cars by way of gate. Be sure it is closed when you leave.

The Watertown burrow-reworked lithology first appears as about a 1 foot thick, but recognizable, lithology at this locality. It can be distinguished from the subjacent vertically burrowed calcilutites of the Lowville and the superjacent calcarenites of the Kings Falls. Large tabulate corals (Foerstephyllum halli) and rugose solitary corals are present, as in some exposures farther northwest, but black chert is absent here. Only the 2 inch thick strophomenid brachiopod-rich bed at this locality is represented at Buttermilk Creek less than a half mile south.

Whole Tetradium cellulosum colonies can be found in the uppermost five inches of the Lowville whose argillaceous limestone marker bed is exposed 6 feet below the top. Between the Tetradium and the marker zone, vertically burrowed calcilutites predominate, as at Buttermilk Creek (Stop #6). This upper Tetradium horizon resembles the upper Tetradium beds at Inghams Mills (Stop #2) and Walker's (1973) House Creek Member of the Lowville of northwestern New York.

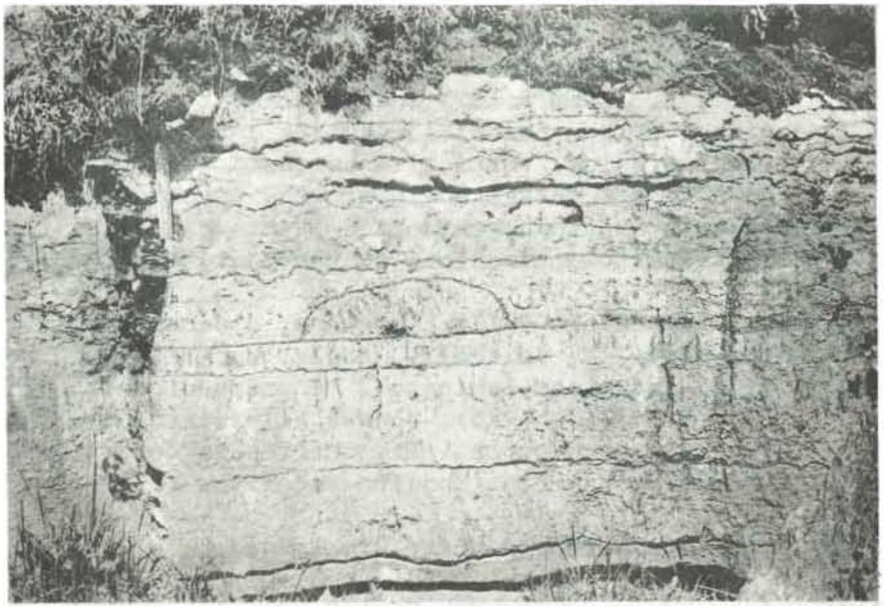


Fig. 8. Tetradium in life position (outlined) in lithology 6 (outlined) at the top of the Lowville Limestone, at locality C112 (Stop #7) in southern Newport. The thin Watertown Limestone is above lithology 6. Six inch ruler is scale.

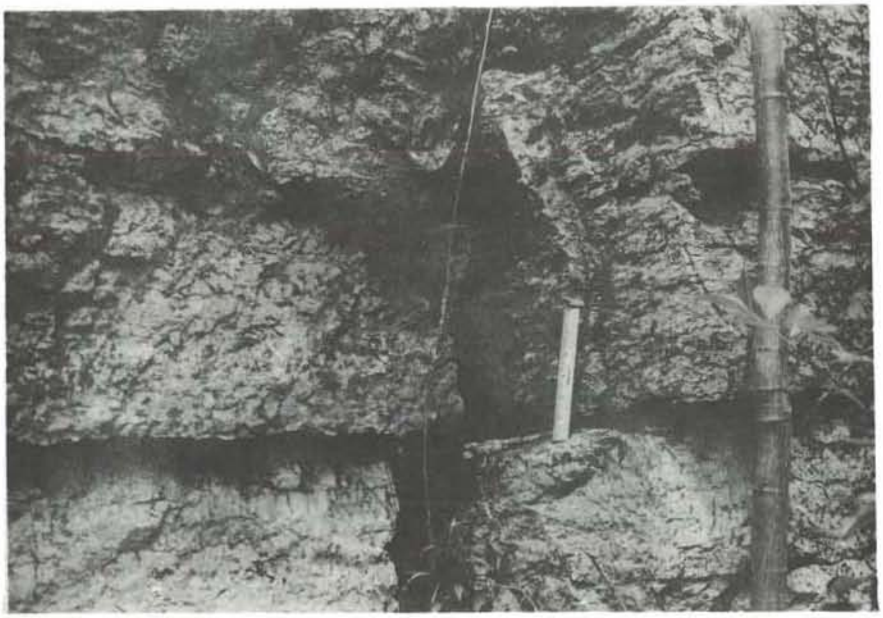


Fig. 9. Highly burrow-reworked, subtidal Watertown Limestone (lithology 7) above vertically burrowed, intertidal Lowville Limestone at Diamond Hill (locality C105, Fig. 5). Six inch ruler at contact is scale.

0.0	45.3	Continue on Elm Tree Road (uphill).
0.1	45.4	Turn left into driveway in order to turn around and proceed back to White Creek Road.
0.2	45.6	"T"-intersection with Elm Tree Road. Turn left.
0.7	46.3	Intersection with Old City Road on left. Continue on White Creek Road.
0.65	46.95	"T"-intersection with Route 28. West Canada Valley Central Junior-Senior High School across the road. Turn right (north) towards Newport.
2.05	49.0	Flashing yellow traffic light in Newport. Turn left onto Bridge Street (=Old State Road).
0.15	49.15	Crossing bridge over West Canada Creek.
0.1	49.25	"T"-intersection with West Street (=Newport Road). Turn right (north).
0.75	50.0	Turn right into gravel road leading to a large, old quarry. Park in front of the gate, but do not block the entrance for trucks.

Stop #8. Northwest Newport Quarry (locality NPQ):

Walk about 150 feet along the gravel road and then descend the grassed slope to the upper quarry where the Watertown Limestone caps the quarry wall which is composed mostly of Lowville Limestone. The top of the quarry here is beginning to collapse, so stay well clear of the edge. Enter at your own risk. After examining the top of the Watertown, continue to descend the grassed slope (overgrown old road) to the quarry floor. Bear left to examine fallen blocks of the Watertown and upper Lowville. Bear right all around a promentory to the southeast part of the quarry where the lower and middle Lowville can be examined safely in the quarry wall. Climb up over the rubble to the gravel road to return to the cars.

The lower dolomitic and sandy member of the Lowville is about 15.5 feet thick. Its contact with the upper 21.5 feet is gradational. The 2 foot thick argillaceous marker horizon occurs about 6 feet below the Watertown Limestone. *Tetradium* have not been found in the upper Lowville here. The top of the Little Falls Dolomite presumably forms the quarry floor.

The Watertown Limestone is highly burrow-reworked, black chert-bearing and fossiliferous. The fauna is diverse but hard to collect. Corals are common as well as brachiopods and mollusks.

The contact with the Kings Falls Limestone is exposed in a quarry southwest of Newport (Kay, 1953), but not here.

0.0	50.0	Turn around in quarry driveway and head back to Newport.
0.75	50.75	Turn left (west) onto Bridge Street.
0.2	50.95	Flashing red traffic light at "T"-intersection with Route 28 (Main Street of Newport). Turn right (south) onto Route 28 South.
2.05	53.0	Passing school on right.
2.35	55.35	Traffic light. Downtown Middleville. Turn right and cross bridge over West Canada Creek, thus continuing on Route 28 South.
0.2	55.55	Bear left at fork in road, continuing south on Route 28.
8.15	63.7	Turn right (west) onto Route 5 (Routes 5 and 28 combine here for a short distance). Proceed into Herkimer.
0.7	64.4	Stop light. Intersection of Routes 28 and 5. Turn left (south) onto Route 28 South.
0.2	64.6	Stop light. Turn right, continuing south on Route 28.
0.25	64.85	Entrance to New York Thruway. Those returning to Oneonta, New York, continue south on Route 28 and retrace your way back (see beginning of road log).

- END OF TRIP -

PALEONTOLOGY OF THE LOWER TRENTON GROUP OF CENTRAL NEW YORK STATE

by

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INTRODUCTION

The lower Trenton Group contains a broad spectrum of carbonate environments ranging from shallow nearshore to relatively deep offshore facies. Well preserved, diverse and abundant fossil assemblages are found at all stratigraphic levels. Many good, easily accessable outcrops are available for field demonstrations of principles of fossil community analysis and marine paleoecology. These outcrops extend from Canajoharie to Watertown and beyond into Ontario. However most of the major facies can be visited within a short belt extending from Little Falls to Middleville. This field guide will focus on this area.

GEOLOGIC SETTING

Five formations make up the lower Trenton Group. These are, in ascending order, the Napanee Limestone, the Kings Falls Limestone, the Sugar River Limestone, the lower Denley Limestone and the Dolgeville Facies (Kay, 1937, 1968). These units were deposited in a transgressing sea associated with an inversion of topography which accompanied the Taconic Orogeny (Rodgers, 1971). As the seas swept eastward through New York State the following sequence of environments appeared at the various locations. First a nearshore lagoonal facies appeared represented by the calcisiltites of the Napanee and lower Kings Falls Limestone. This was a generally quiet water environment with normal marine salinities. Following the lagoonal facies is a wave swept shoal facies represented by the sparitic coquinal calcarenites of the middle Kings Falls Limestone. Primary physical structures including pararipples, cross bedding, sheet laminations and intraclasts indicate very shallow, turbulent conditions (Mangion, 1972). This nearshore lagoon to shoal sequence characterizes the lower Trenton Group northwest of Boonville. In this area seas were transgressing over a nearly horizontal landscape. As the seas approached the Adirondack Arch the slope of the transgressed landscape increased. As a result the shoal facies migrated shoreward at the expense of the lagoon facies which disappeared altogether. The shoal facies of the northwestern outcrops grades into the shallow, turbulent nearshore facies in the southeastern outcrops. This facies pattern matches depositional models described by Anderson (1971).

Succeeding the shoal facies is the shallow offshore shelf facies of the upper Kings Falls Limestone. This facies is distinquished from the underlying shoal facies by a scarcity of high energy primary

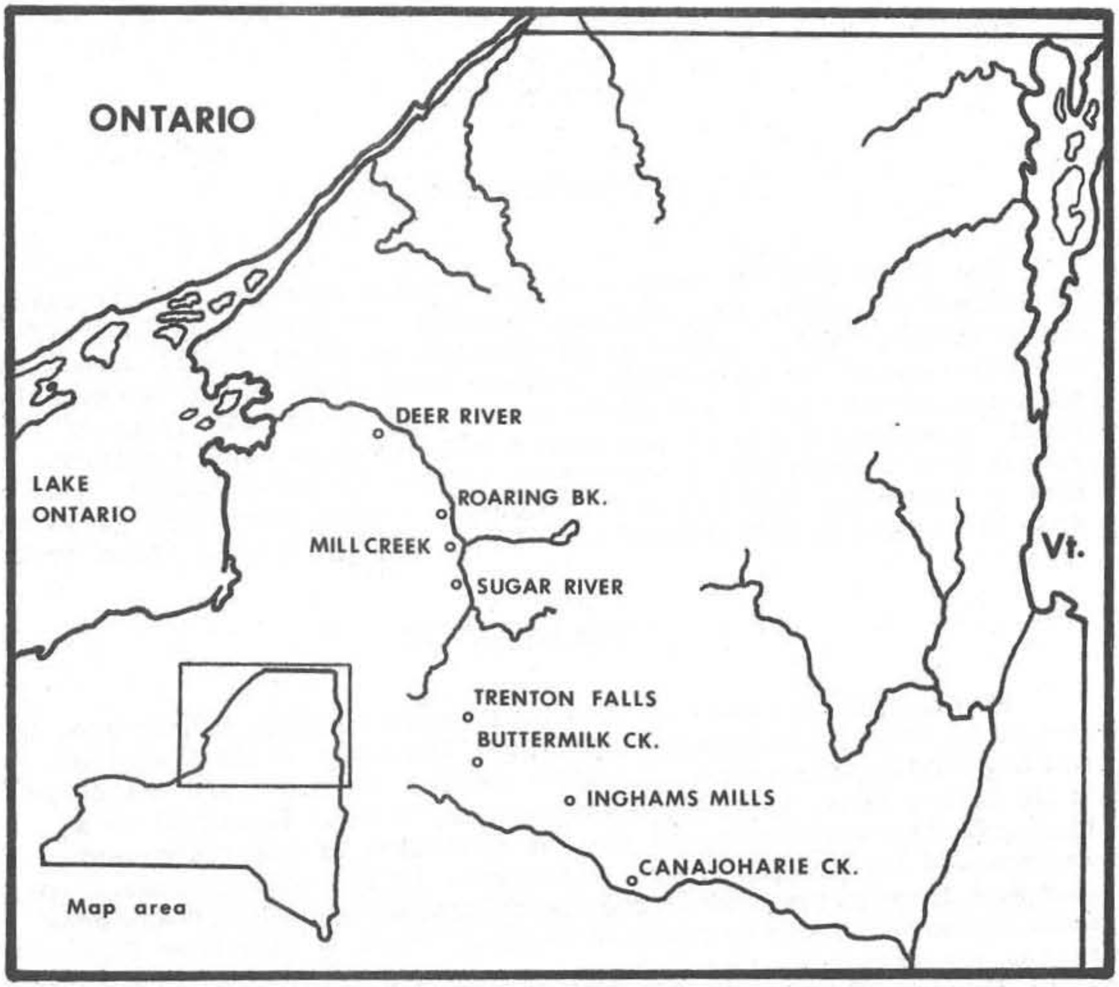
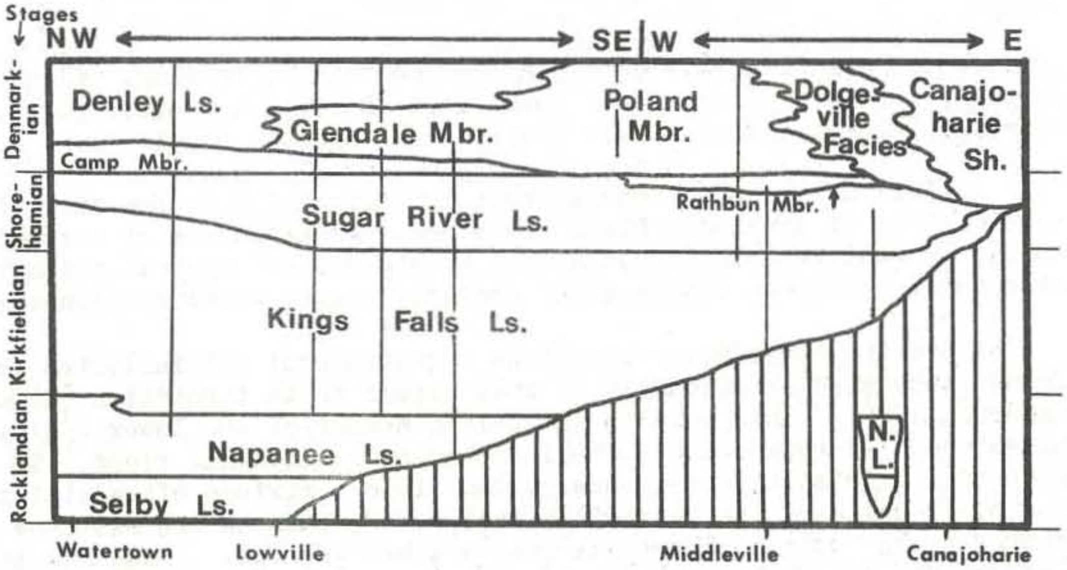
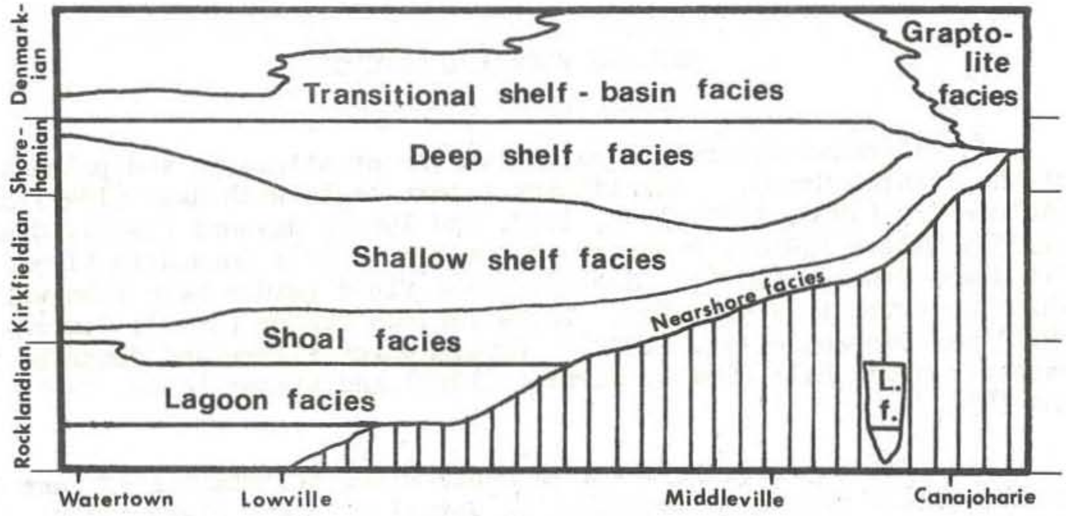
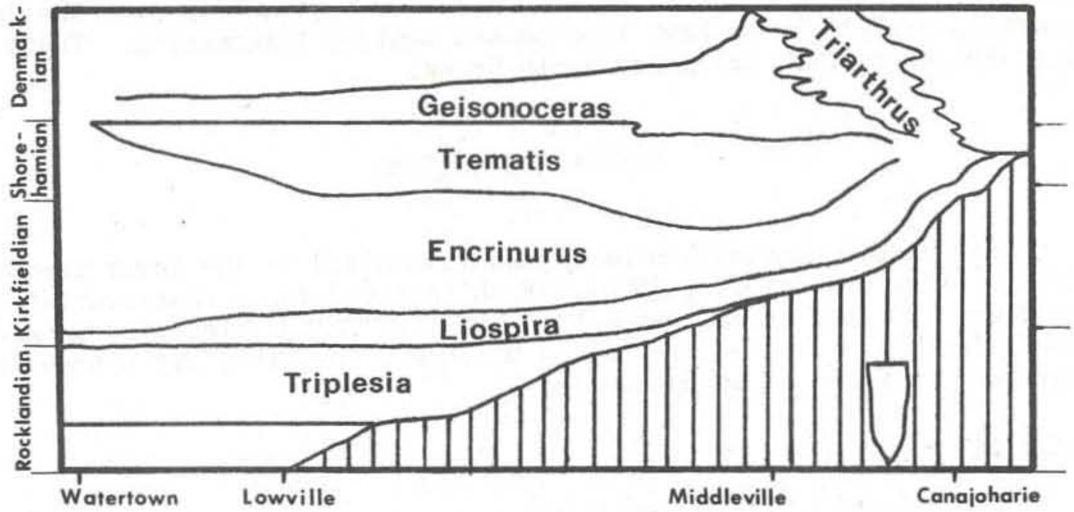


Fig. 1 (Above) Map of northwestern New York State showing major outcrops of Trenton Group.

Fig. 2 (To the right, next page) Three cross sectional views of the lower Trenton Group. View one (top) shows the stratigraphy of the lower Trenton Group. View two (middle) shows the stratigraphic distribution of the various facies of the lower Trenton Group. View three (bottom) shows the stratigraphic distribution of the various communities.


Stages
NW
SE
W
E
Denmark-ian
Shore-hamian
Kirkfieldian
Rocklandian
Denley Ls.
Glendale Mbr.
Poland Mbr.
Dolge-ville Facies
Canajo-harie Sh.
Camp Mbr.
Rathbun Mbr.
Sugar River Ls.
Kings Falls Ls.
Napanee Ls.
Selby Ls.
N. L.
Watertown
Lowville
Middleville
Canajoharie


Denmark-ian
Shore-hamian
Kirkfieldian
Rocklandian
Transitional shelf - basin facies
Grapto-lite facies
Deep shelf facies
Shallow shelf facies
Nearshore facies
Shoal facies
Lagoon facies
L. f.
Watertown
Lowville
Middleville
Canajoharie


Denmark-ian
Shore-hamian
Kirkfieldian
Rocklandian
Triarthrus
Geisonoceras
Trematis
Encrinurus
Liospira
Triplesia
Watertown
Lowville
Middleville
Canajoharie

structures, more micritic calcarenites and thinner bedding. Although still probably subject to occasional turbulence this was a deeper, farthur offshore, quieter and more stable environment than the shoal.

A still deeper shelf environment is represented by the micritic calcarenites of the Sugar River Limestone. An abundance of burrow reworked structures, thin bedding and an absence of physical primary structures indicates a more quiet probably deeper water environment.

Above the Sugar River Limestone a sequence of calcisiltites is found interupted occasionally by what appear to be turbidites (Titus and Cameron, 1976). This unit is the Poland Member of the lower Denley Limestone. It represents a shelf to basin transitional slope. To the east this calcisiltite sequence grades into a mixture of calcisiltites and black shales, the Dolgeville Facies. Furthur to the east the limestones pinch out and the black shales alone persist. These are the Canajoharie and Utica black shales.

EARLIER WORK AND OUTCROPS

An extensive literature exists on the stratigraphy and paleontology of the Trenton Group. Significant papers begin with Hall (1847) and include Kay (1933, 1937, 1943, 1953, and 1968); Raymond (1903); Cushing (1905); Miller (1910); Prosser and Cumings (1897); Chenoweth (1952) and Titus and Cameron (1976). Several other field guides have been written which describe this vicinity. These include Fisher (1966); Cameron (1969, 1972) and Cameron et al. (1972). Papers which figure and describe the faunas include Hall (1847); Raymond (1921) and Wilson (1946, 1947, 1951 and 1956).

The best outcrops in the area occur along tributaries of West Canada Creek. These have been described in detail by Kay (1943, 1953). Good, thick exposures are found along Stony Creek, City Brook, Buttermilk Creek, Shedd Brook, Rathbun Creek and elsewhere. Unfortunately over the past few years several of these have been posted against trespassing. These in-City Brook, Rathbun Creek and North Creek.

FOSSIL COMMUNITIES

Six fossil communities have been recognized in the lower Trenton Group (Titus and Cameron, 1976). Each is named for a characteristic species. In life these communities occupied belts which lied progressively farther offshore. Following Walther's rule they are exposed in a vertical sequence at each outcrop.

Triplesia Community

The *Triplesia* Community occupied the protected quiet mud bottomed facies of the Napanee and lower Kings Falls limestones. The community is named for the orthid brachiopod which serves as an index for the Rocklandian Stage (Kay, 1937; Cameron and Mangion,1977).

The Triplesia Community is much more heterogeneous than any of the others. It also has the longest faunal list (74 taxa). About a third of the species are brachiopods. Of these the strophomenids are most abundant. Sowerbyella is the most common form making up over 50% of the remains. At least 7 species of Rafinesquina and 3 of Strophomena are present. Orthids make up most of the rest of the brachiopods with Paucicrura and Hesperorthis being very common.

The bryozoa, especially trepostomes, are locally abundant. Prasopora and Amplexopora are the most prominent genera. Sometimes slabs are densely littered with the remains of these forms. The fanlike Phylloporina is sometimes common.

A number of groups are present in the Triplesia Community but uncommon elsewhere. Corals are rarely found outside this community. Streptolasma is the most abundant but also found are Columnaria and Foerstephyllum. Clams are more abundant here than elsewhere. Colpomya and Endodesma are locally abundant. Ostracodes are very abundant but few have yet been identified.

Also common are snails, nautiloids, trilobites and crinoids. Generally uncommon, but present, are conularids, algae and sponges.

The community is dominated by the low filter feeders which include brachiopods, bryozoa and clams. Grazers, including snails, trilobites and ostracodes are next most abundant. The only other significant trophic groups are the carnivores (nautiloids) and the high filter feeders (crinoids).

Generally community populations are scattered into dense localized clusters. Scarcity of suitable substrate in this muddy facies probably accounts for this.

Liospira Community

The Liospira Community occupied a wave swept shoal environment offshore from the Triplesia Community. In the Middleville-Little Falls area, however, the lagoonal facies is absent and the Liospira Community occupied an onshore facies. The community is named for the pleurotomarid gastropod which has a range which closely parallels that of the community.

Again the brachiopods are numerically dominant. Orthids are particularily common. Paucicrura makes up over 50% of the remains. Other common orthids include Dinorthis, Hesperorthis and Plectorthis . The strophomenids are still common with at least seven species present.

Gastropods are more abundant in this community than elsewhere. Hormotoma, Loxoplocus, Phragmolites, Sinuites and Liospira itself are found.

High filter feeding forms did not do well in the turbulent environment. Both the crinoids and bryozoa are relatively less common in this environment than elsewhere. However one crinoid, Schizocrinus nodosus, did thrive in this facies and is commonly represented by large round columnals.

Overall diversity of the Liospira Community is very high (71 taxa). Curiously, however, diversities of the individual bedding surfaces are generally very low. This apparent conflict between low bedding surface diversities and high overall diversity is resolved if the shoal facies is envisioned as being composed of many microenvironments each with a low diversity microcommunity. The sum of all of these microcommunity faunal lists produces the high overall diversity.

Equitability figures are consistantly low. Paucicrura averages 54% of the bedding surface assemblages and sometimes makes up over 90% of some assemblages. The low diversities and equitabilities of the bedding surface assemblages clearly indicate that the Liospira Community was a physically controlled community (Sanders, 1968).

The community is overwhelmingly dominated by low filter feeders and most all of these are brachiopods. The only other significant trophic group is the grazers represented by gastropods and trilobites.

Encrinurus Community

Lying offshore of the shoal facies was a shallow shelf which was occupied by the Encrinurus Community. The community is named for the phacopid trilobite which is most easily identified by its distinctive pygidium.

While the brachiopods Paucicrura and Sowerbyella still dominate the community (46% and 15% respectively) the importance of other groups is much greater than in the nearshore communities. Bryozoa in particular are abundant. Trepostomes, including Prasopora, Amplexopora and Eridotrypa make up the most obvious non-brachiopod components of the community. Cryptostomes, including Stictopora and Escharopora are also abundant.

Trilobites also reach their peak in diversity in this community. Besides Encrinurus there is found Ceraurus, Flexicalymene and Hemiarges. Crinoids too reach a peak in diversity. Unfortunately few fully articulated skeletons have been found but study of the stems and columnals has indicated the presence of Cupulocrinus, Dendrocrinus, Ectenocrinus, Glyptocrinus and Heterocrinus.

Conspicuously absent are the mollusks. Virtually no gastropods, nautiloids or pelecypods are known from this community.

Overall diversity of this community is high (61 taxa) but lower than was found in the more nearshore communities. This is surprising because bedding surface diversities reach a maximum in the uppermost beds containing the community. This problem can again be solved by considering the role that microenvironments and microcommunities play in the overall diversities of large communities. The shallow shelf facies must have been much more monotonous than was the case for the shoal. A corresponding lower number of microcommunities must have existed. The stable nature of the shallow shelf facies promoted high diversities within the microcommunities but with fewer of these microcommunities overall diversity was depressed.

Equitability figures for this community rise above the levels found in the Liospira Community. The most abundant form (Paucicrura) makes up an average of 46% of the bedding surface assemblages. Increased equitability apparently reflects the greater stability of the offshore facies. This was largely a biologically accommodated community.

There is also a more equitable distribution of the trophic groups in this community. The low filter feeders are still dominant but also common are the high filter feeders (crinoids and bryozoa). The grazers (trilobites) are also common.

Trematis Community

Moving offshore on the shelf depths gradually increased, current activity decreased, condition became more stable and the substrate became more muddy. This offshore shelf habitat was occupied by the Trematis Community. The community is named for the small inarticulate brachiopod which occurs in abundance. Another good guide fossil for the community is the trilobite Cryptolithus tesselatus.

About a quarter of the species of this community are brachiopods with Paucicrura once again dominating (38% of the assemblages). Bryozoa are numerically very important. Prasopora makes up about 20% of the assemblages. Also abundant are the genera Eridotrypa and Amplexopora.

Crinoids continue to be abundant here with the small pentagonal columnals of Iocrinus being diagonistic of the community. Trilobites are also abundant, especially Flexicalymene.

Gastropods and nautiloids continue to be quite scarce in this community as in the Encrinurus Community. Apparently the Shallow shelf environment was not suited to these groups. A few clams do appear and are sometimes locally abundant.

Overall community faunal lists become progressively shorter in an offshore direction. The 74 species of the nearshore Triplesia Community compare with 53 in the offshore Trematis Community. Again this is not reflected on the individual bedding surfaces. Diversities of these surfaces are among the highest found in the lower Trenton Group. Again, as in the Encrinurus Community, the environmental picture suggests a quiet, stable seafloor with uniformly high diversities and a small number of microcommunities.

Equitability figures reach a peak in this community. The most abundant species, Paucicrura, only makes up 38% of the bedding surface assemblages. This is the lowest level of dominance found in the lower Trenton Group. The high diversity and low dominance figures indicate that the Encrinurus Community was a biologically accommodated community.

Low and high filter feeders continue to dominate in this community. These are represented by the brachiopods, bryozoa and crinoids. The only other significant trophic group is the grazers represented by the trilobites.

Geisonoceras Community

The lower Denley Limestone was deposited beyond the carbonate shelf in a bank margin environment sloping to the east. In this facies the lithologies become dominated by calcisiltites as the calcarenites disappear. The Geisonoceras Community occupied this facies and reflects the mud bottomed substrate.

Only 7 species of brachiopods are found here but Paucicrura continues to dominate (44%). The bryozoa continue to thrive in the quiet water environment with at least 9 species present.

The most characteristic and interesting components of the community are the nautiloids, gastropods and crinoids. The lowermost beds which contain the community are extremely rich in nautiloids. Hundreds of specimens are found littering the bedding surfaces at this level. Genera include Trocholites, Endoceras, "Orthoceras" and most abundant Geisonoceras itself. Associated with these and especially common at the base of the Denley is the snail Sinuites bilobatus corrugatus. Above the nautiloid beds are encrinites rich in the remains of the crinoid genus Merocrinus.

Trilobites are represented only by Flexicalymene and Isotelus, with many whole specimens of the former commonly observed.

The overall faunal list is still shorter in this community. Only 49 taxa have been found. Bedding surface diversities had reached a peak in the strata near the boundary of the Encrinurus and Trematis community zones. Above this level diversities steadily decline to relatively low levels in the Geisonoceras Community zone.

Equitability levels decline in the Geisonoceras Community zone. Paucicrura reached a low level of dominance in the Trematis Community (38%) but then rebounded in importance in the Geisonoceras Community (44%). Evidently this community is at least partially physically controlled. A physical factor which may have introduced instability into this deep water community was the presence of turbidity currents. Graded beds which appear to be turbidites are common in the lower Denley Limestone. The low filter feeders are the dominant group but other trophic groups are important there as well. The carnivores (nautiloids) and the high filter feeders (crinoids and bryozoa) are significant members.

Triarthrus Community

The lower Denley Limestone apparently represents a slope descending from the carbonate shelf to a relatively deep basinal environment. At these greater depths the carbonates begin to interfinger with black shales. This sequence of alternating shale and limestone is known as the Dolgeville Facies and was inhabited by the *Triarthrus* Community. The community is named for the small trilobite which is often found in great abundance.

This is the only community not dominated by brachiopods. However several inarticulates are present and these include rare specimens of *Lingula*.

The dominant Group is the ostracoda. At least six species are found and they comprise nearly 90% of the individuals present. These include the genera *Aparchites*, *Primatia* and *Primatiella*.

The only other group of any significance in this community is the trilobita. *Isotelus*, *Flexicalymene* and *Triarthrus* are moderately abundant.

A number of planktic forms occur with the *Triarthrus* Community. These include graptolites, annelid worms (*Spirorbis* and *Serpulites*) and a brachiopod (*Leptobolus*).

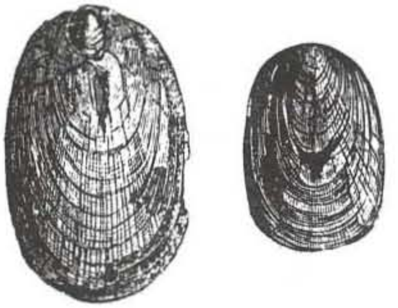
A number of thick beds are rich in forms that are usually only found in the shallow water communities. *Sinuites*, for example, is very abundant in a few beds. These are evidently transported remains, which probably rode turbidity currents into the deep water zones. Care must be taken when collecting in the Dolgeville Facies to recognize and avoid these beds.

Although the overall faunal list for this community is low, the fossiliferous slabs which are found often have fairly diverse assemblages on them. Equitability figures in this community are probably useless because many of the ostracode remains may represent molting during life rather than actually representing the body of a dead individual.

Table One - An abbreviated faunal list of lower Trentonian taxa. Listed are common visable fossils. Omitted are rare or microscopic forms.

Group Species	Community					
	Trip.	Lios.	Encr.	Trem.	Geis.	Tria.
Brachiopods						
Anazyga recurvirostris			X			
Dinorthis pectinella		X				
Doleroides pervetus		X				
Hesperorthis tricenaria	X	X				
Leptobolus insigna						X
Lingula curta						X
L. reciniformis				X	X	X
L. rectilateralis major	X			X		
Oepikina inquassa	X	X	X			
Parastrophina hemiplicata	X	X				
Paucicrura rogata	X	X	X	X	X	X
Platystrophia sp.			X	X	X	
Plectorthis plicatella		X				
Protozyga exiqua	X	X				
Rafinesquina trentonensis	X	X	X	X	X	
R. praecursor	X			X	X	
R. prestonensis	X	X	X	X		
R. robusta	X					
Rhynchotrema sp.		X				
Sowerbyella sericea	X	X	X	X		
Strophomena filetextra	X	X				
Trematis terminalis	X			X		
Triplesia cuspidata	X					
Bryozoa						
Amplexopora minnesotensis	X	X	X	X	X	
Corynotrypa inflata	X					
Eridotrypa mutabilis	X	X	X	X	X	
Escharopora recta	X		X			
Pachydictya acuta	X	X	X	X	X	
Phylloporina sp.	X		X			
Prasopora similatrix	X	X	X	X	X	X
Protocrisina exiqua			X			
P. perantiqua				X		
Stictopora blackensis	X	X	X	X	X	
Gastropods						
Hormotoma gracilis	X	X				
H. trentonensis	X	XX		X		
Liospira americana	X	X				
Loxoplocus sp.		X				
Phragmolites compressus	X	X	X			

Group Species	Community					
	Trip.	Lios.	Encr.	Trem.	Geis.	Tria.
Sinuites cancellatus	X	X				
S. bilobatus corrugatus					X	
Subulites elongatus	X	X				
Nautiloids						
Endoceras proteiforme	X		X	X	X	
Geisonoceras lineolatus					X	
G. tenuitextum	X				X	X
G. tenuistriatum	X				X	
"Orthoceras" amplicameratum					X	
Spyroceras bilineatum		X				
Trocholites ammonius					X	
Pelecypods						
Colpomya faba	X					
Ctenodonta levata		?	?	X	X	
Endodesma trentonensis	X					
Lyrodesma sp.	X	X				
Vanuxemia sp.	X	X				
Trilobites						
Bumastis porrectus	X	X	X			
Calliops callicephalus			X			
Ceraurus pleurexanthemus	X		X	X		
Cryptolithus tesselatus				X		
Encrinurus cybeliformis			X			
Flexicalymene senaria	X	X	X	X	X	X
Hemiarges paulianus		X				
Isotelus gigas	X	X	X	X	X	X
Triarthrus becki						X
Miscellaneous						
Primatia spp.						X
Primatiella unicornis						X
Schizocrinus nodosus	X	X				
Streptolasma corniculum	X	X				
Conularia trentonensis	X		X			



TREMATIS TERMINALIS

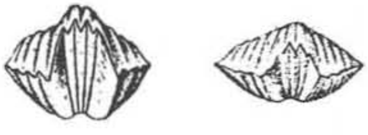
LINGULA RECTILATERALIS MAJOR

PAUCICRURA ROGATA

DINORTHIS PECTINELLA

HESPERORTHIS TRICENARIA

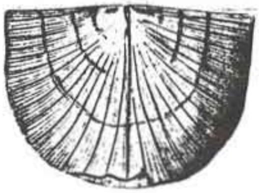
PLECTORTHIS PLICATELLA



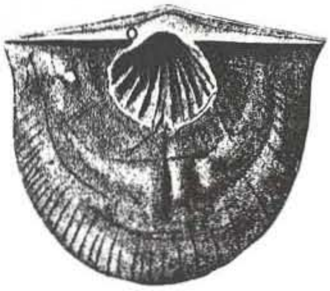
PLATYSTROPHIA SP.

TRIPLESIA CUSPIDATA

PARASTOPHINA HEMIPLICATA

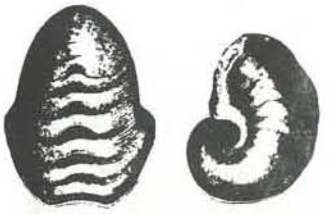


SOWERBYELLA SERICEA



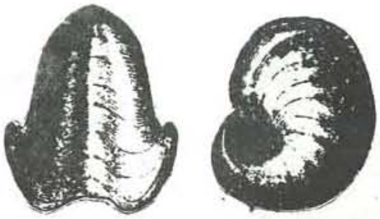
RAFINESQUINA TRENTONENSIS

STROPHOMENA SP.



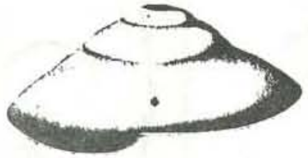
1. SINUITES BILOBATUS

2. HORMOTOMA TRENTONENSIS



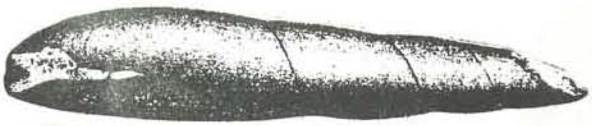
3. SINUITES CANCELLATUS

4. HORMOTOMA GRACILIS



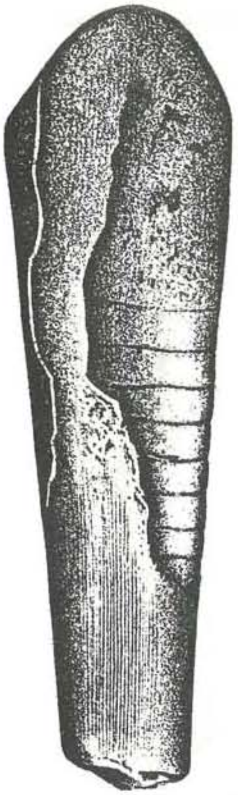
5. LIOSPIRA AMERICANA

6. PHRAGMOLITES COMPRESSUS

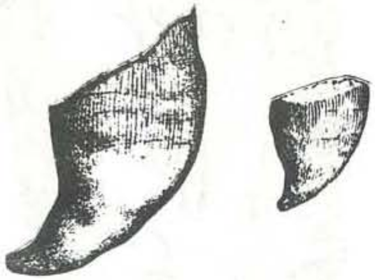


7. SUBULITES ELONGATUS

8. CONULARIA TRENTONENSIS



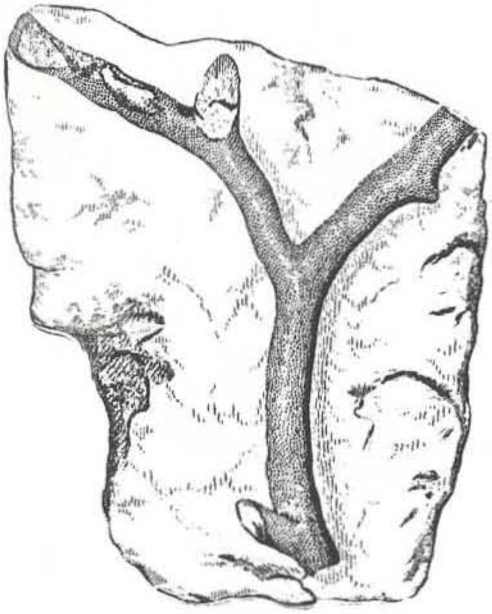
9. GEISONOCERAS TENUITEXTUM



10. STREPTOLASMA CORNICLUM

11. TROCHOLITES AMMONIUS

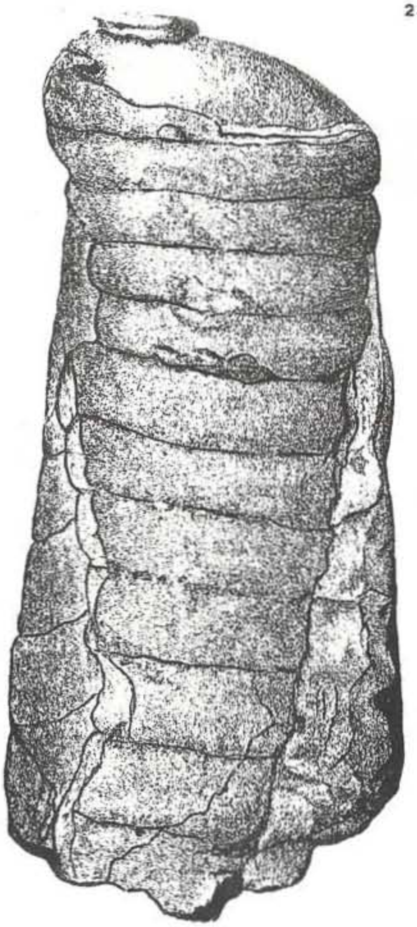
1. ESCHAROPORA RECTA



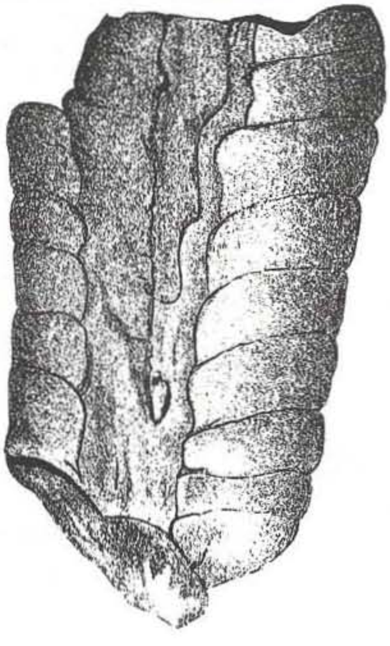
2. AMPLEXOPORA MINNESOTENSIS

3. PACHYDICTYA ACUTA

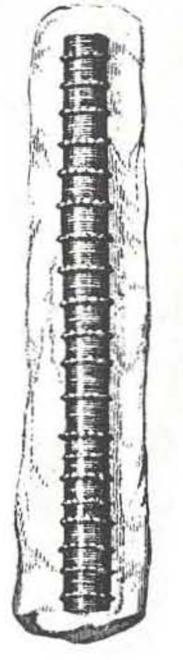
4. PHYLLOPORINA SP.



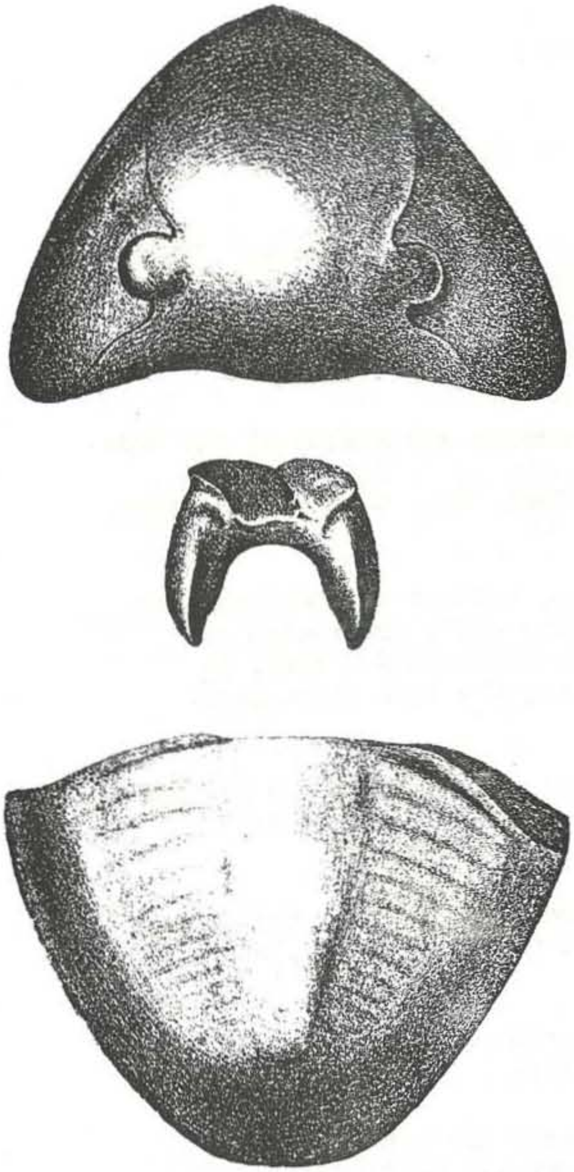
5. ENDOCERAS PROTEIFORME



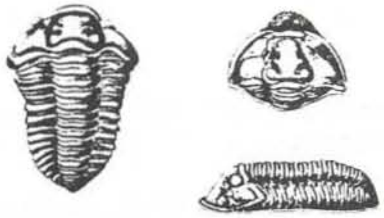
6. E. PROTEIFORME



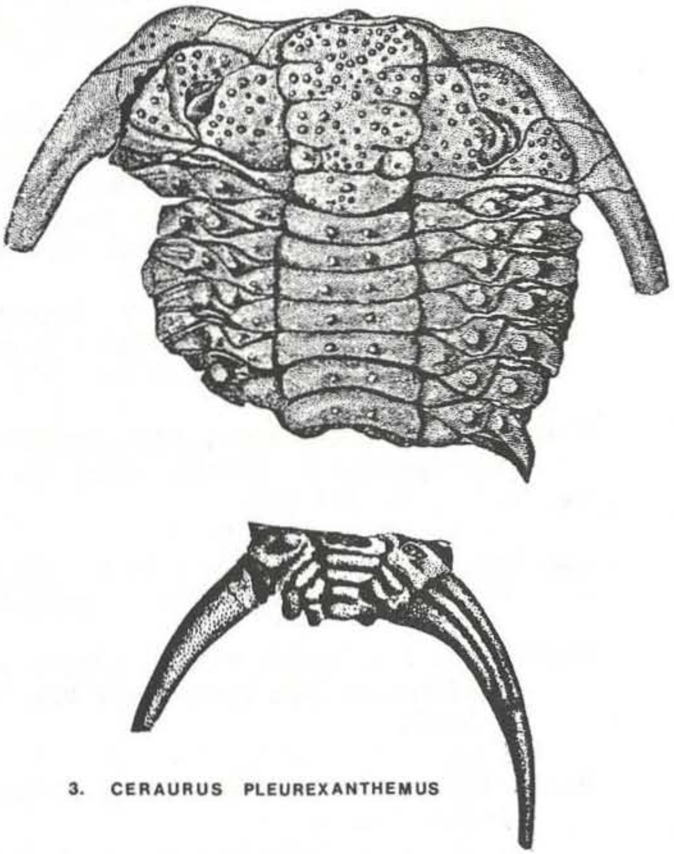
7. SHIZOCRINUS NODOSUS



1. ISOTELUS GIGAS



2. FLEXICALYMENE SENARIA



3. CERAURUS PLEUREXANTHEMUS

4. TRIARTHRUS BECKI

5. CRYPTOLITHUS TESSELATUS

MILEAGE LOG

This mileage log begins at the intersection of routes 28 and 5S in the town of Mohawk. This intersection is near to the Herkimer exit of the New York State Thruway (exit 30). This trip is within the Little Falls and Utica quadrangles.

InMi*	CumMi	
0.0	0.0	Proceed east on Route 5S.
6.2	6.2	Turn right on Route 167
0.8	7.0	Park alongside the road about 1 block short of the Thruway overpass.
		STOP 1: Outcrop along the road is an exposure of the Dolgeville Facies and contains remains of the *Triarthrus* Community. In the summer and early fall this outcrop is likely to be well grown over but in the spring it is an excellent exposure. The best fossil collecting is on thin brown shales where ostracodes are very abundant. Fissile black shales often yield abundant remains of *Triarthrus*, other trilobites and brachiopods. Also present at this outcrop are folds in the strata produced while the sediment was still soft. Above the thruway overpass is an excellent exposure of the Dolgeville Facies. Unfortunately the State Troopers will throw you off of this outcrop if they see you.
0.8	7.8	Turn around and proceed back to the intersection with Route 5S. Turn left on Route 5S and then immediately turn right onto Route 167.
2.1	9.9	Proceed north on Route 167 heading toward Little Falls. After crossing the Mohawk River turn right at Sam's Supe Service and then immediately turn left onto Route 169.
1.3	11.2	At this point there is an intersection marked by a sign for the Little Falls Junior/Senior High School. Turn right and proceed up the road one block. To the left beyond the bushes is an abandoned quarry.

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* InMi = Incremental mileage; CumMi = Cumulative mileage.

		Side trip A: We will not visit the quarry on this field trip because at this time of the year the quarry is badly overgrown and very difficult to get into. However, in the spring this is a good exposure of the lower Kings Falls Limestone. The quarry contains abundant remains of the *Liospira* Community.
0.0	11.2	*Continue north on 169*.
6.6	17.8	At this point we are crossing Stoney Creek. A large white farmhouse is on the left.
		Side trip B: Upstream are good exposures of the Poland Member of the Denley Limestone which contain very sparce remains of the *Geisonoceras* Community in generally baren calcisiltites. Downstream are good exposures of the Sugar River Limestone containing abundant remains of the *Trematis* Community.
0.6	18.4	*Continue north on 169*. A large abandoned quarry is found on the right hand side of the road.
		Stop 2. This is a larger quarry than at first appearance. Around toward the back of it is a good exposure of the Lowville Limestone. About 17 feet of this formation is exposed. Lying unconformably upon this unit is the Kings Falls Limestone. The lower beds are very shelly but overlying strata become finer grained. The lower five feet contain elements of the *Triplesia* Community (*Schizocrinus*, *Streptolasma* and a great abundance of *Sowerbyella*). Overlying these beds are strata containing typical *Liospira* Community faunas. A bentonite lies a few feet above the base of the Kings Falls Limestone. Towards the back of the quarry there is the waterfall of an intermittant stream. Following this stream bed one can see discontinuous exposure of nearly the whole Trenton Group. Beds containing assemblages from the *Encrinurus*, *Trematis* and *Geisonoceras* communities are exposed here.
0.0	18.4	*Continue towards Middleville on Route 169*. Enter downtown Middleville.
1.1	19.5	Turn right onto Route 29 east.
1.3	20.8	Proceed uphill on Route 29. Pass an exposure of the upper Little Falls Dolomite and then stop at a road outcrop of the Trenton Group.

Stop 3: This road outcrop shows an exposure of the Kings Falls and Sugar River Limestones. The lower 10 feet contain remains of the *Liospira* Community. The next 20 feet contain assemblages from the *Encrinurus* Community and the uppermost beds contain *Trematis* Community faunas. Just above the road outcrop Maltanner Creek crosses the road. Stream outcrops expose a complete section of the Trenton Group from its base to the lowermost Denley Limestone. This section is of historical interest because it was intensely studied by James Hall in the early 1840's. Probably 50 or more species were originally described from this outcrop. Unfortunately while this land is not posted the owner is apt to throw people off of his property.

0.0	20.8	Turn around and head back to Middleville.
1.3	22.1	Enter downtown Middleville and turn right onto Route 28.
4.4	26.5	Enter Newport and turn left on Bridge Street.
0.3	26.8	Cross the West Canada Creek and turn left onto Newport Road.
1.4	28.2	Park in dirt lot on left side of road. Beware of mud.

Stop 4: This is Shedd Brook which shows an exposure ranging from the upper Kings Falls Limestone to the Denley Limestone. Strata containing assemblages from the *Encrinurus*, *Trematis* and *Geisonoceras* communities are exposed. Of greatest interest are the beds just below the parking lot. These contain a great abundance of nautiloids most of which are of the genus *Geisonoceras*. These beds represent assemblages of the *Geisonoceras* Community. Also present are *Endoceras*, and *Trocholites* in moderate abundances.

End of trip. Retrace the road back to Newport and Route 28.

THE STRUCTURAL FRAMEWORK AND STRATIGRAPHY OF THE SOUTHEASTERN ADIRONDACKS

by

James McLelland
Colgate University

INTRODUCTION

The southeastern Adirondacks are herein defined as the topographic highlands (overwhelmingly Precambrian) that lie within a compartment whose corners are situated at: Speculator, Gloversville, Saratoga Springs, and Glens Falls (see fig. 3). The southeastern Adirondacks are part of a regional geologic framework that underlies the map area shown in fig. 1. The lithology and structure of this region is shown in figs. 3 and 4. The purpose of this trip is to show as many examples of this area's representative lithology and structure as time permits.

PREVIOUS WORK

Early mapping within the southeastern Adirondacks was done by William Miller (1911, 1916, 1920, 1921), Cushing and Ruedemann (1914), Bartholome (1956), Thompson (1959), and Hills (1965). Hall (1965) and his students prepared detailed geologic maps along the east flank of the Palmerton Range. In the mid-1960's McLelland (1969) began mapping with the Canada Lake area immediately west of Sacandaga Reservoir. This work was pushed eastward and northward in the early 1970's (McLelland 1974). The contiguous geology to the northwest of the southeastern Adirondacks represents the cumulative work of Cannon (1937), Nelson (1968), de Waard (1965), Lettney (1968), Geraghty (1977), and McLelland (1975, 1976). In addition to these contributors, a great deal of the area was reconnaissanced by Y. Isachsen for the 1961 edition of the N.Y. State Geological Map.

REGIONAL STRUCTURAL GEOLOGY

General Description

Four definite phases of regional folding have been recognized in the southern Adirondacks. A fifth phase of folding may be present as broad, gentle warps. All of these fold sets have large dimensions with the two earliest being of unusually great extent.

The earliest fold event is isoclinal and, overall, recumbent. It is referred to as F_1 and is best represented by the Canada Lake Nappe (fig. 4). F_1 folding is also represented by the Little Moose Mt. Syncline and the Wakeley Mt. Nappe. All F_1 folds have approximately E-W axial

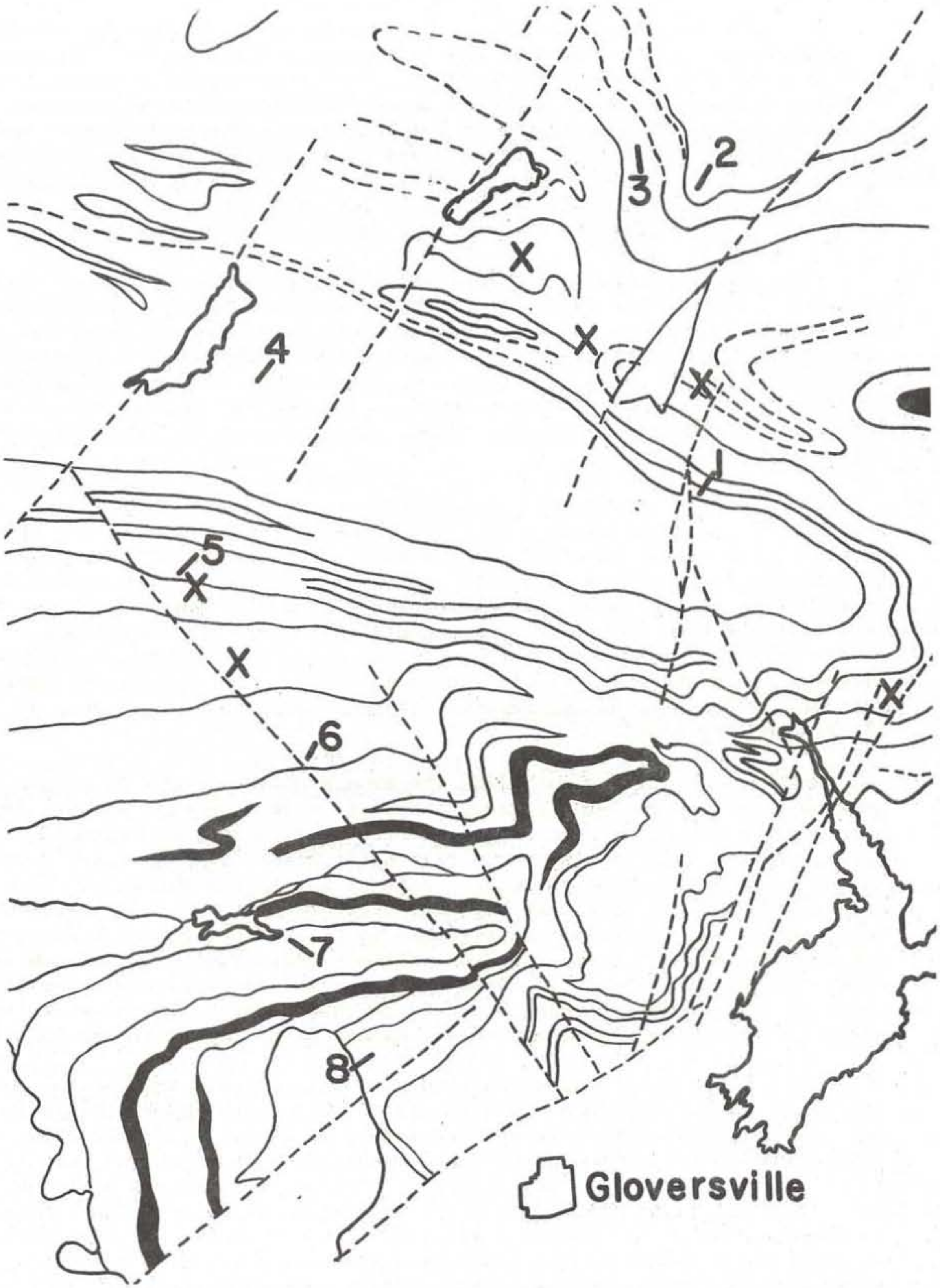

Fig. 10 - Field trip area enlarged from fig. 4. Stop numbers are shown. Large X's locate major anorthositic sills intrusive into de Waard and Walton's (1965) supracrustal sequence.

THE BASEMENT CONTROVERSY

In the early 1960's Walton and de Waard (1963) proposed an intriguing new hypothesis concerning Adirondack geology. They postulated that, together with associated charnockitic lithologies, the anorthositic rocks of the Adirondacks constituted a pre-Grenvillian basement complex. Prior to the Grenville Orogeny (~1.1 b.y.), this basement complex had been folded, metamorphosed, and eroded. Sometime during the Proterozoic the basement was unconformably overlain by the section of rocks that begins with the Lower Marble Fm. and is referred to as the supracrustal sequence. During the Grenville Orogeny, both basement and supracrustal sequence were folded together and metamorphosed. Subsequent erosion has left the basement exposed in the cores of domes, while the supracrustal rocks are preserved in synclinal keels.

The Walton-de Waard basement hypothesis was originally based upon the observation that the Lower Marble Fm. seems to overlie a number of different lithologies and appears, therefore, to be separated from these rocks by an unconformity. Presumably the unconformity was initially angular, but as in many other instances, the angular discordance has been erased by subsequent deformation.

There are several problems inherent in the basement hypothesis. The first is that a number of the so-called "older paragneisses" assigned to the basement complex are identical to lithologies lying above the marble. In this writer's opinion most of these should be included within the Lower Marble Fm. The fact that these units may often be discontinuous does not necessarily prove the existence of an erosional disconformity. The same affect could be produced by original variations in shallow water sedimentation. Equally probable is that boudinaging with the marble rich units would result in similar phenomena. It is widely recognized boudinage structures are common in this horizon (Stop 3). In places the marbles have been almost completely squeezed out, and the Lake Durant Fm. lies directly on quartzo-feldspathic gneisses of type "a", yet it is widely agreed that this sort of discordance is tectonic in origin.

A second point of importance concerns the status of the anorthositic gneisses as candidates for a pre-Grenvillian basement. Field work in the southern Adirondacks has resulted in the recognition of a large number of anorthositic sills that intrude at stratigraphic horizons lying far up into the supracrustal sequence. The locations of some of these are shown in fig. 10. One of these bodies will be visited at Stop 5. The existence of these sills represents serious negative information with regard to the hypothesis that the anorthosites of the Adirondacks are part of a pre-Grenvillian basement. It is possible, of course, to suppose that there was more than one episode of anorthosite intrusion in the Adirondacks. However, even the principle bodies of anorthosite to the north contain inclusions of lithologies identical to the Lower Marble Fm. and appear to cause what may be high temperature contact metamorphism in the latter, e.g. garnet-wollastonite deposits at

Willsboro Point.* Thus, all anorthosite bodies appear to post-date the Lower Marble Fm.

If we conclude that the anorthositic gneisses of the Adirondacks cannot be part of a Pre-Grenvillian basement, then it is still possible to hypothesize that the associated quartzo-feldspathic gneisses of type "a" constitute such a basement. Absolute age dating does not corroborate this hypothesis, and these gneisses may simply represent the next layer down in a continuous stratigraphy (Isachsen, McLelland and Whitney 1975). However, the status of the type "a" gneisses remains unresolved, and the identification of a pre-Grenvillian basement constitutes a major problem in Adirondack research.

IMPLICATION FOR ADIRONDACKS IN GENERAL

It is believed that the structural framework developed here for the southern Adirondacks may be extended to the entire mountain range. Figure 11 shows the manner in which fold sets F_1-F_4 can account for the outcrop pattern of the Adirondacks. Within the Northwest Lowlands Foose and Carl (1976) have already demonstrated that the alaskitic gneisses once thought to occur in phacoliths is actually exposed in the cores of structural culminations lying at the intersections of NNE and NW fold axes (F_3 and F_4 of this paper). Fishook terminations in these outcrops appear due to earlier fold noses.

In Fig. 11 the Arab Mt. Anticline has been extrapolated across the entire northern section of the Adirondacks. This, like many other extrapolations in fig. 11, is speculative and based upon a synthesis of data from earlier reports, aeromagnetics, etc. Nonetheless, the picture that emerges is not unreasonable and may serve as a working model for further research. It does appear likely that salients and re-entrants in the Marcy Massif (Saranac Basin, etc.) lie at the intersections of F_2 and F_3 fold axes. Similar interpretations appear likely for structural basins such as that mapped by Buddington and Leonard (1962) near Sabbatis, New York.

Fig. 11 suggests that the southern Adirondacks represents a large domical structure due principally to large F_2 and F_3 intersections, and underlain by extremely large F_1 nappes (Canada Lake-Little Moose Mt. Syncline and Wakeley Mt. nappes). Erosion has cut a window through this dome providing an excellent exposure through great, recumbent flaps of rock deformed and metamorphosed at some 20-25 km depth and 600-800°C (McLelland and Whitney 1977). Since the present Moho beneath the Adirondacks appears to be located near 35 km (Katz, personal communication), it seems likely that the Grenvillian orogeny represented by these P,T conditions may have been associated with events resulting in a double continental thickness.

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* It should be noted that Essene et al (1977) have proposed that the development of wollastonite may be due to lowering of the partial pressure of CO_2 by influx of H_2O in a two component vapor phase.

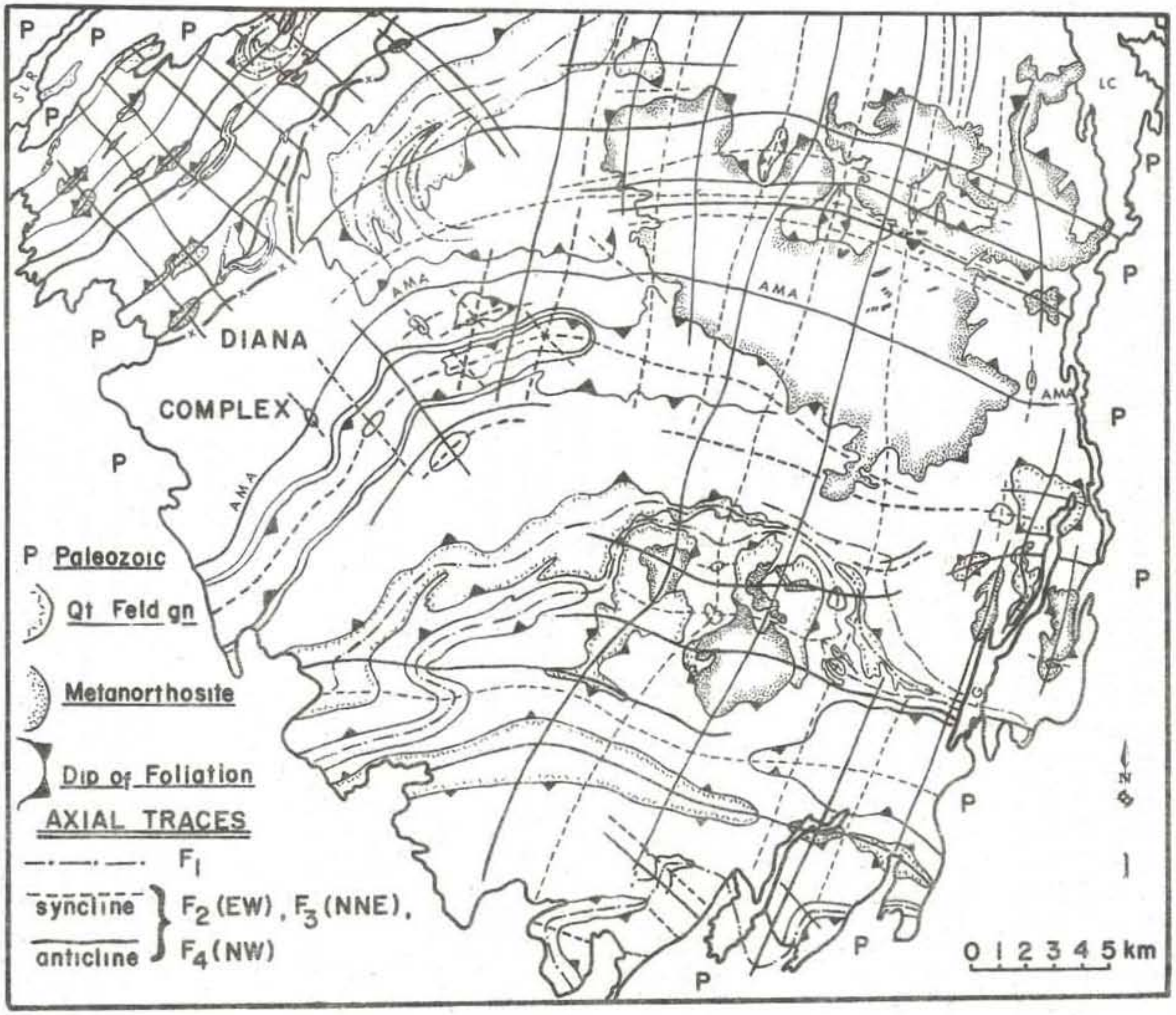

Fig. 11 - Hypothetical structural framework for the Adirondacks. AMA-Arab Mt. Anticline.

FAULTS

Three main systems of faults affect the Adirondacks. All are normal faults and many formed during the PreCambrian and were reactivated in Paleozoic time. The best defined topographically is the NNE trending set that has been further accentuated by glacial scouring. A great many lakes are oriented parallel to this fault set, e.g. Indian Lake, Lake George. The NNE faults are important in determining the eastern and southeastern margins of the Adirondacks where they have "stepped-down" the Paleozoic section to the east. A number of grabens also exist. Such grabens are present at the Sacandaga Reservoir area, the Lake George Graben which continues southward to the northwest of Saratoga Springs, and at the Paleozoic inliers in the vicinity of Wells, New York.

The NNE faults often have extensive breccias developed along them. An outstanding example exists at, and just south of, the junction of Rts. 8 and 30. Many of these faults must have substantial offset along them, but, thus far, mapping of the PreCambrian has failed to establish precise quantitative values for this displacement. The reason is that most of the larger NNE faults have major valleys associated with them, and it is difficult to extrapolate folded stratigraphy across these. A minimum offset is obtainable at the town of Wells where the Paleozoic inlier lies 1500 feet below the tops of the surrounding PreCambrian hills. The offset must have been at least this much with the downthrown side being to the east.

Offset along the NW faults has been easier to ascertain because they are less affected by glacial scouring and resultant valleys. Near Canada Lake the offset on the western NW fault shown on fig. 3 is approximately 2000' with the east side being downthrown.

Slickensides, breccia, closely spaced fracturing, and stratigraphic discontinuities indicate that the region has been affected by an almost E-W set of high angle faults. Offset along these has not been measured. The E-W fault system shows up well on ERTS imagery and appears to extend into the Paleozoics.

ACKNOWLEDGMENTS

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ROAD LOG

Mileage

0.0 West side of bridge leading from Rt. 30A into Northville, N.Y. Assembly point will be in boat launching area   miles north of bridge.

3.9 Cross the Sacandaga River. For the next 3.5 miles all exposures have been within the Sacandaga Fm. The large hills immediately to the south are underlain by vertically dipping paragneisses and metagabbros situated on the hinge line of the Canada Lake Nappe. Note the southerly dips of the Sacandaga Fm.; these define the southern limb of the Piseco Anticline.

7.4 Leaving Sacandaga Fm.; enter quartzo-feldspathic gneisses "a" of the Piseco Anticline. For the next 4 miles all exposures lie within these gneisses.

11.4 Stop 1 - 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. Here there is exposed the contact between the quartzo-feldspathic "a" gneisses of the Piseco Anticline and the overlying Sacandaga Fm. The hills to the south are composed of homogeneous quartzo-feldspathic type "a" gneisses coring the Piseco Anticline (note how ruggedly this massive unit weathers). The Sacandaga Fm. at Stop 1 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 metamorphosed soil profile can be discerned at the base of the Sacandaga Fm. However, this does not preclude the prior existence of an angular discordance. Intense deformation often erases all traces of earlier angular discordance (Balk 1936).

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.

13.7 Entrance to Sacandaga Public Campsite. On the north side of the road are quartzo-feldspathic gneisses and calc-silicates. These are probably within the Lower Lake Durant Fm. Anorthositic and gabbroic rocks have intruded here and locally steep dips may be related to this.

15.7 Enter town of Wells. Silver Bells Ski are to east. The slopes of the ski hill are composed of excellent gabbroic anorthosite and anorthositic gabbro. These appear to be intrusive into the Upper Marble Fm. These intrusives may be related to the Speculator Mt. anorthosite sheet and can be traced eastward into anorthositic rocks of the Tenantville Complex which is exposed in the region near Tenantville in the large saddle of the Piseco Anticline several miles to the east.

The town of Wells in underlain by Lower Paleozoic sediments which have been down dropped by a set of steep N20E faults that result in a local dome and graben complex. The mapped offset of PreCambrian stratigraphy across these faults indicates that, if the displacement vectors were vertical, the throw is of the order of 3500 ft.

19.2 Junction with Gilmantown Road. Continue north on Rt. 30. We are now near the hinge line of the Glens Falls Syncline.

21.5 Parking area on east side of highway. To the west are charnockitic gneisses assigned to the Blue Mt. Fm. Note the southerly dips as we are located here on the north flank of the Glens Falls Syncline.

22.2 Junction of Rts. 8 and 30. Continue north on Rt. 30. Beginning at the intersection are good exposures of garnetiferous leucogneisses of the Upper Marble Fm. Lithologically these are similar to the leucogneisses seen in the Sacandaga Fm. at Stop 1, however, they lack the good layering that characterizes the Sacandaga.

At the junction itself there are good exposures of fault breccia associated with one of the NNE faults responsible for the Paleozoic inlier at Wells.

For the next mile the highway passes just above the contact of the metastratified sequences and anorthositic rocks of the Oregon Dome. These anorthosites form the large hills across the stream valley to the northeast.

23.2 Leaving the Upper Marble Fm. On the north side of the highway are cuts through garnetiferous amphibolite, calc-silicates, marbles, and quartzites of this unit.

24.7 Small outcrop of quartzo-feldspathic gneiss in the Lake Durant Formation.

25.1 Stop 2. One half mile south of southern intersection of old Rt. 30 with new Rt. 30.

On the west side of the road small roadcut exposes a splendid example of Adirondack anorthositic gneisses that are 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 calc-silicate within the anorthositic rocks. These are believed to have been derived from the Lower Marble 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 pryoxenes. Recently McLelland 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 650-700° C respectively.

26.2 Long roadcuts parallel to strike through the lower porition of the Lake Durant Fm. These are characteristically composed of well layered pink quartzo-feldspathic gneisses, thin amphibolites, and calc-silicates. The quartzo-feldspathic lithologies are dominant and become increasingly so proceeding up from the basal units. At this locality the increase in quartzo-feldspathic material is accompanied by the development of K-feldspar megacrysts.

26.7 On west side of road are extensive cuts in the Upper Marble Fm. Quartzite, calc-silicate, and sillimanite-garnet-quartz-feldspar leucogneisses are especially well developed here. Some marble and charnockite are present. The large hills to the southeast consist of anorthositic gneisses in the Oregon Dome. The rocks exposed along the highway dip off the dome.

27.2 Stop 3. Northern intersection of old Rt. 30 and new Rt. 30, 3.3 miles east of Speculator. New York.

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

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

A variety of interesting lithologies are present in this roadcut. The marble itself contains diopside (now serpentinized), tourmaline, graphite, chondrodite, phlogopite, and a variety of pyrites. Interesting reaction rims, or selvages, exist between the marbles and quartz rich boudins. Presumably these selvages reflect the influence of compositional gradients during metamorphism.

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

Garnet + Hornblende = Orthopyroxene + Calcic Plagioclase + Water

This reaction is characteristic of the granulite facies wherein the <u>association</u> garnet plus hornblende is unstable (de Waard 1965).

Also present in the outcrop are various layers rich in calc-silicates. One of these contains coarse, pale diopside crystals several inches across. Others consist almost entirely of green diopside. Tremolite has also been found in some layers. Rusty weathering, metapelitic units are rich in graphite, calc-silicates, and pyrite. Grossularite, scapolite, and wollastonite, and sphene have been recognized in thin section.

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 Upper Marble, but not exposed here, are quartzites, kinzigites; sillimanite rich, garnetiferous, quartz-microcline gneisses; and fine grained garnetiferous leucogneisses identical to those characterizing the Sacandaga Fm. These lithologies may be seen in roadcuts .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 (1.1 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.

30.5 Junction of Rt. 8, 28, and 30 in village of Speculator. Head southwest on Rt. 8.

For the next 14 miles exposures are limited. For the most part, however, we shall be passing through the quartzo-feldspathic gneisses "a" that cover the Piseco Anticline.

44.5 Stop 4. Hinge line of Piseco Anticline near domical culmination at Piseco Lake. The rocks here are typical quartzo-feldspathic gneisses "a" such as occur in the Piseco Anticline and in other large anticlinal structures, e.g. 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 of K-feldspar may be seen. In the present outcrop these megacrysts appear to have been largely granulated and only a few small remnants of cores are seen. The open folds at this locaity 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. Often these 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 F_1 minor folds. Near the northeast end of the roadcut such F_1 minor folds are highly visible because the presence of quartzites in the stratigraphy enhances their visibility. Slabbed and polished specimens from this and similar outcrops demonstrates that these F_1 folds are exceedingly common in the Piseco Anticline. Examination of these F_1 folds shows that the dominant foliation in the rock is axial planar to them. Similarly, layer transposition is related to flattening parallel to the axial planes of F_1 folds. The intersection of F_1 axial plane foliation and earlier compositional surfaces helps to define the strong lineation in the outcrop. In addition to this a number of rod-like lineations are probably the hinge line regions of F_1 minor folds which are difficult to recognize because of apparent lithologic homogeneity. Lineation in the outcrop is further intensified by the fact the upright and relatively open F_2 folds are coaxial with F_1. Thus the intersection of the F_1 and F_2 axial planar foliations results in a lineation parallel to the two fold axes. Moreover, F_2 minor folds are often of the crenulation variety and their sharp hinge lines define a marked lineation in the F_1 foliation.

As described above, a number of parallel elements combine to produce an extremely strong lineation in the Piseco Anticline. Past observers have sometimes 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 more realistically explained as an intersection lineation of So, Si, and S_2 elements. Moreover, the intensity of the lineation is more the result of the early F_1 recumbent folding and flattening than it is of the later, coaxial F_2 Piseco Anticline.

46.5 Junction of Rt. 8 and Rt. 10. Turn south towards Canada Lake.

47.0 On both sides of Rt. 10 are red stained quartzo-feldspathic gneisses "a" that have been cataclastized by a large N20E fault zone. For the next 5.5 miles we shall pass through a number of road-curves as Rt. 10 makes its way through the core rocks on the south limb of the Piseco Anticline.

50.5 Cross into the Sacandaga Fm.

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

52.8 Stop 5 - 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. Thsse are believed to be F_1 and F_2. 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.

Further 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. About half-way down this roadcut there occurs a very large and impressive boudin of amphibolite and iopsidic gneiss. To the north of this boudin the quartzo-feldspathic gneisses are pervasively intruded by anorthositic gabbros, gabbroic anorthosites, and various other related igneous varieties. At the north end of the cut and prior to the metasoratified sequences these intrusives can be seen folded by upright F_2 axes. They are crosscut by quartzo-feldspathic material.

Three important conclusions emerge from study of this outcrop. The first is that the anorthositic suite is intrusive into rocks at, and above, the stratigraphic level of the Lower Marble or Sacandaga Fm. In the second place, while the anorthositic rocks are clearly involved in F_2 folding, they do not show, and in fact transect, F_1 foliation. Thirdly, the quartzo-feldspathic rocks intruded by the anorthosites appear to have undergone substantial anatexis in the vicinity of the intrusion. This is suggested by the cross-cutting quartzo-feldspathic material and by the overall appearance of the gneisses along the roadcut.

53.9 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.

54.2 Fine grained metagabbro on west side Rt. 10.

54.6 Excellent roadcut in coarse anorthositic gabbro. Ophitic to subophitic texture well preserved. Garnets are sporadically developed and tend to be associated with coarse gabbroic pegamtites showing mineral grwoth perpendicular to contacts. Compositional layering may be primary.

55.1 Small cut in megacrystic granitic gneiss on east side of highway.

55.3 Begin half-mile of roadcuts exhibiting intrusion of quartzo-feldspathic gneisses by members of the anorthositic gabbro suite, several phases of which appear to be present and in cross-cutting relationships. Source metasedimentary areas may be xenoliths. Pods of megacrystic gneiss may be anatectic in origin.

55.9 Kennels Pond - Avery's Fishing Site

56.0 Lake Catherine to east of highway; metasediments intruded by anorthositic gabbros in roadcut on west.

56.8 Avery's Hotel on west of highway at top of hill.

56.9 Steeply dipping kinzigites with white, anatectic layers.

57.7 On west side of highway at sharp bend are excellent examples of anorthositic gabbros intrusive into kinzigites. The gabbroic rock transect the principal foliation (F_1) and are folded by upright folds of the F_2 event.

57.9 Extremely garnetiferous kinzigites. Here the rocks dip gently to the north due to the presence of a mesoscopic F_2 synform.

58.5	Road sign: Canada Lake - 10 miles
59.0	Crossing Swamp
59.7	Crossing swamp that marks contact between the Sacandaga Fm. and megacrystic gneisses of the Rooster Hill Fm.
60.0	Megacrystic gneisses of Rooster Hill Fm.
60.1	Megacrystic gneisses of Rooster Hill Rm.
60.5	Kinzigite in Rooster Hill Fm.
61.2	Stop 6 - North end of Stoner Lake. Type locality of Rooster Hill Fm. The Rooster Hill Formation is characteristic of a wide spread lithology throughout the Adirondacks. Its most characteristic feature is the presence of striking 1-4" megacrysts of K-feldspar. These are almost always falttened within the plane of foliation. Nonetheless, a number of these megacrysts preserve evidence of approximately euhedral crystal outline. Compositionally the Rooster Hill megacrystic gneisses consist of orthopyroxene, garnet, hornblende, biotite, perthitic microcline, some plagioclase (oligoclase), and quartz. An igneous analogue would be quartz monzonite. The parentage of the Rooster Hill megacrystic gneisses is obscure. It is not known whether the megacrysts are phenocrysts or porphyroblasts. The fact these lithologies are conformable with the enclosing stratigraphy over broad areas is consistent with a metastratified origin but does not rule out intrusion as sills. The lack of substantial banding across units thousands of feet thick is less consistent with a metasedimentary origin than with an igneous one. However, the problem remains unresolved and requires further research. Regardless of parentage, the Rooster Hill Fm. appears to correlate with the Lake Durant.
62.0	Crossing contact of Rooster Hill Fm. and kinzigites of the Peck Lake Fm. Near the contact the Rooster Hill megacrystic gneisses become equigranular. This is probably due to cataclasis.
62.9	Kinzigites in the Peck Lake Fm.
63.8	Junction of Rt. 10 and Rt. 29A. Continue east on Rt. 29A-10.
64.8	Small roadcut of kinzite.

65.5 Canada Lake Store and Post Office Ledges on north side of highway consist of pyroxene-quartz-plagioclase gneisses (enderbites) assigned to Royal Mt. member of the Green Lake Fm. Scarce amphibolite layers are boudinaged, and near east end of the outcrop amphibolite pods have been broken and rotated by intrusive material. This material is of the same pyroxene-quartz-plagioclase composition as the enderbite and grades into it.

65.7 Crossing Green Lake on Rt. 10-29A. At east end of bridge and in woods are exposures of quartzites and leucogneisses of the Green Lake Fm.

66.2 Cross contact into charnockites of the Canada Lake Fm. These form large roadcuts along the highway.

66.8 Stop 7. Irving Pond Fm. in the Core of the Canada Lake Nappe. The units to be examined occur along the east side of the road.

The Irving Pond Fm. consists of some 2500' of quartzite and less abundant quartzo-feldspathic gneisses and calc-silicates. It has been folded back on itself in the core of the nappe, and its apparent thickness is therefore doubled. At this particular locality we will examine the Irving Pond near its lower contact with the Canada Lake Fm. In the outer 100-200' near this contact the Irving Pond becomes "dirty" and clean massive quartzites give way to garnetiferous biotite-quartz-feldspar gneisses (kinzigites). Both of these lithologies are well developed at this locality. Also present near the contact is an excellent set of F_1 minor folds showing axial plane foliation. These folds do not appear to fold an earlier tectonic foliation. Their axes parallel the Canada Lake Nappe.

67.7 Passing Nick Stoners Inn and Golf Course.

68.8 Passing Vroman's Hotel in town of Caroga Lake.

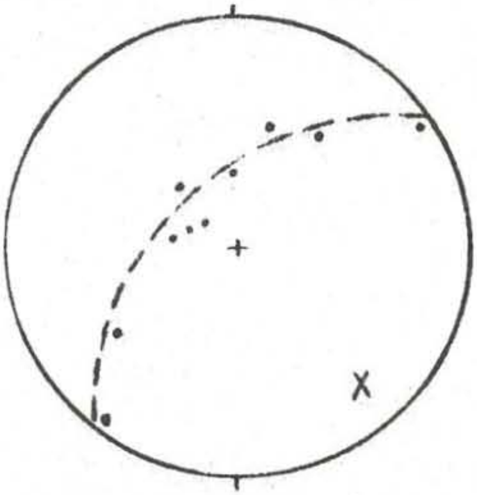
69.2 Junction Rt. 29A and Rt. 10. Continue south on Rt. 29A.

70.8 Enderbites and related gneisses of the Royal Mt. Member of the Green Lake Fm. The repetition of stratigraphy from the Canada Lake Store is due to recumbent, isoclinal folding about the Canada Lake Nappe.

71.7 Stop 8 - The Peck Lake Formation.

Roadcut of garnetiferous quartz-biotite-oligoclase gneiss with minor amphibolite and calc-silicate bands. These gneisses are the dominant lithology of the Peck Lake formation which is exposed here on the south limb of the F_1 fold. Needles of sillimanite can be seen in some specimens. White porphyroblasts are K-feldspars and pods of white quartzo-feldspathic material are probably anatectic.

In a little overhang near ground level there is an F_2 minor fold with an axial trend of N50W, plunging 15 SE. Axial plane cleavage and lineation cut across the compositional layering and earlier foliation of this fold. It appears that such folding and cleavage are prevalent throughout outcrops of Peck Lake gneiss. Often these features are obscurred by poorly developed compositional banding. Polishing and staining reveal both folds and cleavage in many specimens and, therefore, suggest that their abundance vastly exceeds their recognition.



The entire outcrop is a "large minor" fold. Note the change of dip from one end to the other. The accompanying equal area plot is for poles of foliation in this roadcut and in outcrops directly NE of the road.

The lithologies and structures represented in this cut are typical of the Peck Lake formation. It is the structural complexities that make the Peck Lake formation difficult to work with and subdivide. It is, by far, the least competent unit in the sequence.

72.5 Peck Lake

End Road Log

MINERALOGY AND GEOLOGY OF THE NEWCOMB AND SANFORD LAKE AREA

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INTRODUCTION

For many years the titaniferous magnetite ores of the Lake Sanford District constituted the largest source of titanium in the world. Today these deposits still rank among the world's greatest operative titanium ores. They are located within the Marcy metanorthosite massif. Within the field trip area adjoining metamorphosed rocks, especially the Grenville marble, provide interesting and diversified contrasts in mineral content and pose challenging problems as to formation and origin.

REGIONAL AND STRUCTURAL GEOLOGY

Most of the region to be visited is part of the Marcy massif which along with the Grenville complex forms the core of the Adirondack Mountains. On the flanks of these precambrian rocks are gently dipping Paleozoic rocks mostly of sedimentary origin. No paleozoic rocks other than glacially transported are present in the area to be studied. Figure 1 shows quadrangles in the field trip area with names of authors of geological publications.

Simmons (1964) made a detailed gravity survey of the Adirondacks and adjacent areas. His analysis of the data obtained is shown in Figure 2. He concluded that the metanorthosite massif was a slab 1200 square miles in area increasing in thickness from a maximum of 3 km in the west to 4.5 in the east with two roots extending downward about 10 km. The metasediments in the southwestern portion of the study area are marbles and quartzites of the Grenville series which Isachsen and Moxham (1968) believe are rock roofs or roof pendants which have undergone slight erosion. See Figure 2.

Primary structures such as foliation and flow lines are seen in the metamorphosed igneous rocks. Balk (1932) considers these features to have formed before solidification of the molten material.

Folds on the scale of a few feet are seen in the Grenville marble. No large scale folding of the marble is evident. The contortions indicate that the calcium carbonate must have been in a plastic state. There is much conjecture as to the large-scale structure of the area as considerable data must still be accumulated.

At least three faults occur in the area. The general strike is NNE. The most detailed study of faults was made by Heyburn (1960) in the McIntyre development where they are exposed much better than elsewhere in the area. Data concerning them were also obtained from drill holes. The dip is mostly about 65 degrees northwest. One fault had a strike of N 84 W and a dip of 54 degrees to the north (Heyburn, 1960). Shear zones and major topographic lineaments are also present.

Balk (1932) and Heyburn (1960) agree on the trend of the joint systems. They located two sets, one oriented N 30° W and the other N 50° W.

Dikes have been reported on a small scale in geological reports of the different parts of this area. Miller (1919) located an intrusion of granite 5 feet wide in metanorthosite of the Whiteface type. Its contact was not sharp. This is near the Blue Ridge highway 1.5 miles west of the Boreas river.

Avenius (1948) and Balk (1932) discovered diabse dikes. Heyburn (1960) observed not only diabase dikes but pegmatite dikes and DeMatties (1974) found two norite dikes. The width of the dikes varies from a few inches to 10 feet and the length from a few feet to over 50 feet. Most of the dikes strike NE-SW. DeMatties (1974) noted one that had a strike of N 65° W and dip of 27° NE.

During the pre-Paleozoic, the portion of New York state comprising the area to be visited was covered with sediments believed to have been of marine origin. While no fossils were found in them, their widespread occurrence in adjacent areas and the presence of graphite disseminated throughout the Grenville marble, quartzite, and some of the gneisses present in the Grenville series indicates that there was some type of life during that period. Graphite is not a constituent of limestone but the remains of living things like blue-green algae after having undergone decomposition to carbon or hydrocarbon could become graphite after metamorphism.

Blue-green algae as well as other forms of microscopic life have been found in Early, Middle, and Late pre-Paleozoic. Perhaps the decomposed remains of clusters of these organisms yielded graphite under conditions which converted the calcareous sediment of the ocean to the coarse crystalline calcite of today's Grenville marble.

The sediments making up what is called the Grenville Series began to undergo uplift, deformation, and intrusion by magma about one billion years ago and continued to be exposed to these forces for almost a third of a billion years. This event is called the Grenville orogeny. Sedimentary rocks were completely metamorphosed to marble, schist, and gneiss. The degree of metamorphism was too strong to produce slate. Isotopic studies have provided the dates of the Grenville orogeny (Dott and Batten, 1971), but the time during which the sediments were deposited has not as yet been determined because "dates obtained from such rocks (the metamorphic and igneous) generally record only the last readjustment of the isotopes during an episode of heating". (Dott and Batten, 1971) The conclusion is that the sediments were deposited longer than one billion years ago, but how much longer as yet is unknown.

Intrusions of the anorthosite and granite-syenite magmas into the limestone, shale, and sandstone took place during the orogeny with the entire mass then undergoing the metamorphic events. Evidence for this is seen in the inclusions of marble in some of the formerly igneous bodies and in the granulation, foliation, and other features of the metanorthosite and its phases.

Considerable erosion of the Grenville occurred since there are large areas, especially the high ones, where there is no Grenville today. In addition, marble is not very resistant to weathering or erosion under moisture conditions.

During the Paleozoic era, seas surrounded and perhaps covered the Adirondacks after the area had undergone subsidence. Remnants of the Potsdam sandstone, Little Falls Dolomite (?) (Miller, 1919) of the Late Cambrian occur south of the study area in the Schroon Lake quadrangle. To the east, outside of the study area in the Champlain Valley, Middle Ordovician rocks occur. However, within the study area no Paleozoic rocks in situ have been discovered. Balk (1932) believes that Paleozoic rocks were removed from the Newcomb quadrangle by erosion.

There is no evidence as to deposition for the remainder of the Paleozoic and the entire Mesozoic. However, considerable erosion occurred along with uplift, faulting, and jointing. Considerable evidence is present for glacial activity during the Pleistocene such as striations, even on the highest peaks, erratics, moraine, till, extinct lakes extant during the Pleistocene, and lakes formed by damming of rivers by deposition of glacial drift.

LITHOLOGY

Figure 3 shows the rocks in the field trip area.

Metanorthosite

Metanorthosite is the most abundant and most continuous bedrock in this region. It differs from anorthosite found in localities other than the Adirondacks in that it has undergone metamorphism. This nomenclature was first used by Isachsen and Moxham (1968). It has also been called Marcy anorthosite since it outcrops in abundance on Mount Marcy. Megascopically most of the rock is labradorite with grains of this plagioclase feldspar close to 1 inch long. Miller (1919) has reported lengths up to one foot on the ridge 1 mile north-northwest of Blue Ridge. (See map)

Heyburn reports that in the Sanford Lake area to the north the Marcy-type anorthosite is mostly porphyritic. The laboradorite or andesine phenocrysts are also very coarse attaining slightly over 3 inches in length, with only a very few reaching 10 cm. Just west of Sanford Lake Avenius (1948) noticed that labradorite phenocrysts were smaller with maximum size at 6 cm.

DeMatties (1974) who studied the geology in the area north of Miller and south of Heyburn and Avenius found very coarse labradorite up to 15 cm with many around 2.5 cm. In his area the color varied to greenish gray. He observed that "a relict porphyrytic texture" occurred locally in the metanorthosite.

Color varies from light to dark bluish gray. Polysynthetic twinning as evidenced by striations is often visible. Usually less than 10% of the metanorthosite consists of other minerals of two different sizes. The larger are hornblende and pyroxene, the smaller biotite, garnet, pyrite, pyrrhotite, ilmenite, and magnetite.

Isachsen and Moxham (1968) state that "gabbroic or noritic metanorthosite commonly (though not invariably) occur along the borders" of metanorthosite. De Waard and Romey (1968) define norite "as a plutonic rock, magmatic or metamorphic, which has the composition of a gabbro or diorite, and in which hypersthene is a major dark constituent." The terms gabbroic anorthosite, gabbroic metanorthosite, border phase anorthosite, and Whiteface-type anorthosite have all been used in the literature to describe the same rock.

It is lighter in color than metanorthosite, being whitish to greenish gray. On Whiteface Mountain it is the predominant rock. Labradorite phenocrysts average a smaller size than in Marcy-type metanorite and the maximum size rarely exceeds 2 cm so that the texture is finer. Foliation is often present. DeMatties (1974) considers the range of ferromagnesian minerals in gabbroic metanorthosite as between 10 and 22.5%.

The Whiteface-type anorthosite which has less than 10% mafic minerals megascopically is very similar to the Marcy-type anorthosite. However, the Whiteface-type anorthosite which has more than 10% ferromagnesian minerals but less than 22.5% can be considered as gabbroic metanorthosite (DeMatties, 1974). There is a gradation from one Whiteface type into the other, but microscopic examination for distinguishing each is essential. Microscopically both types exhibit more alteration, more crushing, more distortion.

Mineralogically the Whiteface and Marcy metanorthosites are quite similar. As the ferromagnesian minerals increase there is a decrease in the labradorite and an increase in sericite or scapolite or both.

Metanorite

A distinct area of metanorite has been mapped and described by DeMatties (1974). It may occur in other parts of the field trip area, but has not been mapped as an individual unit. It is mostly black, at times foliated, consisting of mainly pyroxenes (32-49.6%), plagioclase feldspar (12.5-32.8%), garnet (5.4-16.8%), opaque minerals (14.6-22.8%), amphibole (hornblende), chlorite, and apatite. The last three generally comprise well under 10% of the metanorite. The pyroxenes consist of clinopyroxene and hypersthene with the former usually the dominant of the two, the ratio of monoclinic to orthorhombic being from slightly over 4 to 1 to 0.85 to 1. Microscopically sericite, hematite, and alkali feldspar were noted. The type of plagioclase feldspar is andesine since its anorthite content varies from 35 to 56%. Included among the opaque minerals are magnetite, ilmenite, goethite, hematite, and sulfides.

There is a gradation from metanorite into anorthositic metanorite. DeMatties (1974) considers the boundary between the two as 35% ferromagnesian mineral content, under this value and over 22.5% being anorthositic metanorite and over 35% being metanorite. The decrease in ferromagnesian minerals is compensated by an increase in plagioclase feldspar content.

Charnockitic, granitic, and quartz syenitic gneisses

What Miller (1919) and Balk (1932) have called the syenite-granite series, today appear on the New York State Geological Map as "charnockitic, granitic, and quartz syenitic gneisses variably leucocratic containing varying amounts of hornblende, pyroxenes, biotite; may contain interlayered amphibolite, metasedimentary gneiss, migmatite."

Charnockite is defined (De Waard and Romey, 1968) "as a plutonic rock, magmatic or metamorphic, which has the composition of a granite and contains hypersthene." Within the northern quarter of the Schroon Lake quadrangle which comprises the lower part of the southeastern portion of the study area, Miller (1919) mapped two areas of granite. One is almost one mile southwest of Sand Pond and 1.4 miles due south of Wolf Pond to the south of Blue Ridge Road. The other body of granite is adjacent and to the south and west of Cheney Pond (the south Cheney Pond). Both granite stocks are separated by a mass of gabbro. An analysis of a specimen from the granite close to Sand Pond (Miller, 1919) revealed 62% microperthite, 30% quartz, 6% oligoclase, 1.5% biotite, with magnetite, apatite, and zircon present in very minor amounts. Its color when fresh is pinkish gray, and weathered it is light brown. Granulation and foliation may be present.

In the portion of the Newcomb quadrangle present in our area of study Balk (1932) found the syenite-granite series to be extremely variable in composition. He did not map separate regions of granite and syenite as Miller. It occupies parts of the southern and southwestern portion of the area to be visited. The color ranges on fresh surfaces from dark green to grayish white to pink depending upon whether or not much quartz is present. In general the granitic members are lighter (Balk, 1932). Weathered surfaces present a grayish white at times with a slight yellowish tint. In the more acid phase, quartz was most abundant, followed by microcline, orthoclase, and a small amount of hornblende and biotite. Just to the west of Newcomb outside our area a specimen of the more acid phase of the syenite-granite series yielded mostly quartz, microperthite, orthoclase, a little oligoclase, augite, and garnet. Also slightly outside of the area syenite grading into granite was observed (Balk, 1932), No difference in age could be determined from the outcrops. The granite had mostly quartz, then microcline, microperthite, biotite, and some hornblende.

Undivided and mixed gneisses

On the New York State Geological map designated under undivided and mixed gneisses is a hybrid rock mangeritic to charnockitic gneiss with xenocrysts of calcic andesine and locally xenocrysts of anorthosite. With increasing percentage of the anorthosite component, it passes gradationally into anorthositic rocks. In the lowest south central portion of the study area Miller (1919) mapped some of these rocks as the Keene gneiss. It consists of 75% oligoclase-labradorite, 8% garnet, 7% quartz, 4% monoclinic pyroxene, and 2% or less of each of the following: magnetite, zoisite, and apatite. Fresh rock has a greenish gray color and it weathers brown. It is medium-grained in texture and may have xenoliths of labradorite up to an inch in length. Miller (1919) believes that this gneiss is transitional between anorthosite and syenite-granite since its position falls between the two.

De Waard and Romey (1968) define mangerite as "a plutonic rock, magmatic metamorphic, which has the composition of a quartz monzonite and contains hypersthene." Megascopically it may be impossible to distinguish hand specimens from members of the syenite-granite series, but microscopically Miller claims that it is possible.

Balk (1932) has mapped the same type of rock as the Keene gneiss and called it syenite-granite with labradorite crystals, or phenocrysts.

Gabbro or Metagabbro

In the central part of the study area occur some outcrops of gabbro or metagabbro. Miller (1919) found that the composition of the Cheney Pond (southern Cheney Pond) stock was 45% labradorite, 20% hypersthene, 18% garnet, 6% biotite, 4% olivine, magnetite, and a very small quantity of pyrite. This rock could very well be termed a norite because of its hypersthene content. Miller believes the garnet to be of secondary origin. The texture of the gabbro is medium to moderately coarse. A fresh surface is dark gray to almost black and it weathers to a deep brown. In some specimens hornblende or ilmenite or both may be present. Typically it is not foliated. Interestingly, the labradorite has very minute dark inclusions. Other facies of the gabbro occur "as the highly foliated border facies amphibolite."

Balk (1932) reported that the augite, hypersthene, and olivine greatly diminish in quantity and may even disappear as the gabbros grade from their cores to their border into a schistose phase and amphibolites. There is an increase in the amphibole, garnet, and biotite as this transition progresses. Miller (1919) believes that the gabbro is younger than the anorthosite, whereas Balk (1932) disagrees. In the Newcomb area glacial deposits cover most of the amphibolite.

Grenville Marble and Quartzite

The Grenville Marble and Quartzite are present in the western eighth of the study area. Large outcrops of the marble are visible along Route 28 starting about 2 miles east of Newcomb and one mile east of the Hudson River. This marble differs from the Vermont marble of West Rutland and Proctor in that the calcite grains are considerably larger. Indeed, the could consider this calcite with inclusions. The individual calcite grains range to 1 cm in length. Graphite flakes and crystals ranging from 2 to 5 mm are disseminated throughout the marble. The marble is mostly white, but locally may be stained a light yellowish brown from oxides of iron. In one outcrop close to a schist and gneiss the marble has a black stain.

Occasionally parts of the marble are dominated by other minerals. A great variety of minerals have been reported (Balk, 1932) from the marble in this area including apatite, biotite, chondrodite, diopside, feldspar, garnet, graphite, magnetite, phlogopite, pyrite, pyroxene, pyrrhotite, quartz, scapolite, sphene, spinel, tourmaline, tremolite, and zircon. Most of these minerals are less than 1 mm in length but locally may be considerably larger. Balk (1932) described a deposit of tourmaline, unfortunately exhausted, on the south shore of Harris Lake at Newcomb. Brown and green tourmaline crystals up to 8 inches long, 4 inches wide, and having a girth of 12 inches occurred in the marble associated with albite, blue apatite, graphite, hematite, pyrite, pyroxene, scapolite, smoky quartz, sphene, and zircon.

Slightly west of the study area where the "old wagon road crosses the channel between Rich Lake and Harris Lake" at the dam is an outcrop containing small blue apatite crystals and wollastonite (Balk, 1932).

There is little quartzite exposed in the study area. Balk reports that most outcrops where the quartzite is found also have impure marble interbedded. The quartzite is stained yellow or brown because of iron oxides. Many of the minerals listed with the marble occur. In addition the apatite and sphene are locally more abundant.

GEOLOGY OF THE SANFORD LAKE MINERAL DEPOSITS

History

While hunting beaver in 1826 Louis Elija, an Indian guide, discovered an outcrop of iron ore at what is today Lake Henderson(named after the son-in-law of Archibald MacIntyre, both original developers of Elija's discovery). David Henderson was so impressed with the ore sample which Louis Elija had brought him that he accompanied him on a tiring journey to the wild and isolated outcrop. Hyde (1974) quotes from Henderson's letter to MacIntyre:

> "We found the breadth of the vein to be about fifty feet!--traced it into the woods on both sides of the river. On the one side went eighty feet into the wood, and digging down about a foot of earth, found the pure ore bed there--and let me here remark this immense mass of ore is unmixed with anything--in the middle of the river where the water runs over--the channel appears like the bottom of a smoothing iron--on the top of the vein are large chunks which at first we thought stone, but lifting one up and letting it fall it crumpled into a thousand peices of pure ore. In short, the

> thing was past all our conceptions--We traced the vein most distinctly--the sides parallel to one another, and running into the earth on both sides of the stream. We had an opportunity to see the vein nearly five feet from the surface of it on the side of the ledge which falls perpendicular into the water."

Ore was mined in the early 1830's and the first iron successfully produced in 1838. Ten years later titanium was discovered in the ore. In the 1850's mining and smelting reached a peak but became completely inactive with the financial panic of 1857. Activity resumed in 1894, but ceased in about 1913 because of problems including the presence of titanium which impaired the smelting processes then known (Gross, 1968).

National Lead Company, now called NL Industries, Inc. purchased the mining area for its titanium content in 1941. Ironically, the substance which once was very undesirable because of the metallurgical problems it posed, reversed its position and exceeded the iron in value. The MacIntyre Development has been in continuous operation since 1941 and for many years was one of the leading producers of titanium in the world. It "continues to be one of the principal sources of titanium dioxide in the world" (MacIntyre Development N L Industries, Inc., p. 1).

Relationship of Local Geology to Regional Geology

Basically the only differences between the geology of the 24 square miles of the Sanford Lake District and the regional geology are the lack of members of the Grenville Series and the syenite-granite series and the occurrence of the ore bodies. There may be ore bodies present outside of the Sanford Lake District in the field trip area, but as yet none have been discovered. DeMatties (1974) is of the opinion that they may occur to the south of the present mining area.

Ore Body Descriptions

Figures 4, 5, and 6 show the ore deposits and the rocks in which they occur.

Gross (1968) has established TiO_2 content for mapping purposes as follows:

Classification	% TiO_2
anorthosite	0.0 - 5.4
gabbro	5.5 - 9.4
low grade protore	9.5 -13.4
medium grade ore	13.5 -17.4
high grade ore	17.5 plus

Two major types of ore bodies occur. One is found in the anorthosite and the other in the gabbro. Both types occur in the Sanford Hill Pit and the South Extension Pit. Mining ceased in the former in 1966 and is now going on in the latter. The ore bodies are massive irregular lenses. A further distinction is that the anorthositic type of ore occurs in a footwall and the gabbroic type of ore occurs in a hanging wall.

In the footwall type of ore there are sharp contacts with the metanorthosite, whereas in the hangingwall type of ore there is a gradation into the gabbro (Heyburn, 1960). Each type of ore body contains very poor and high grade material, the ore in the gabbro occurs in the form of darker layers or bands to a content of 17.5% TiO_2. Generally, when this amount is exceeded, the gangue amounts to less than 30% and there are no ore layers. The layers of ore in the gabbro, according to Gross (1968) range from microscopic to tens of feet. Stephenson (1945) mentioned one locality where almost 200 feet of solid ore were found.

Gross, who has been associated with the mining of the titaniferous magnetite for more than 30 years, has observed (1968) that "all bodies of this ore are associated with gabbro masses...The one factor governing the location and form of the ore bodies is the presence and flow structure attitudes of the gabbro bodies."

The following are examples illustrating the content of ores and gangue: (Heyburn, 1960)

	*(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
sulfides	1.5	1.6	1.1	1.7	2.8	1.8	4.0	8.1	3.5	7.4	8.6	4.5
pyroxenes	6.6	3.0	7.7	4.7	6.3	9.8	17.1	15.2	24.8	20.8	19.4	23.9
amphiboles	2.3	3.2	3.1	1.5	3.0	1.7	5.9	16.2	9.9	6.7	9.1	4.2
biotite	0.8	1.0	1.2	1.1	0.5	1.0	2.0	4.3	3.9	5.0	1.4	2.6
garnet	8.1	3.0	4.0	3.4	4.7	5.7	21.1	15.0	13.1	14.8	14.4	13.7
feldspar	19.2	8.2	13.8	10.3	15.2	21.0	49.9	41.2	44.8	45.3	47.1	51.1
black opaques												
ilmenite	35.9	36.2	38.6	36.5	37.2	22.2						
magnetite	25.7	43.8	30.5	40.8	30.3	36.8						
TOTAL	100.1	100	100	100	100	100	100	100	100	100	100	100
TiO_2	18.9	19.2	38.6	18.8	19.5	20.6						
Fe	32.3	45.5	30.5	46.2	35.4	31.2						

*(1)(2)	North End Hangingwall Ore
(3)(4)	South End Footwall Ore
(5)(6)	Sanford Ore Body Extension
(7)(9)	Gangue Minerals in Hangingwall ore samples calculated from (1)(2)
(8)(10)	Gangue Minerals in Footwall ore samples calculated from (3)(4)
(11)(12)	Gangue Minerals in Sanford Body Extension calculated from (5)(6)

Stephenson (1945) has worked out the mineral paragenesis of the Sanford Lake District as follows:

plagioclase feldspar(earliest)

apatite

hypersthene

augite

hornblende

garnet

ilmenite-magnetite(latest)

Biotite is both primary and secondary. Gross (1968) states that as a primary mineral it forms after the garnet. As a secondary mineral it forms from hornblende. Other alteration minerals are chlorite, carbonates, and scapolite, which are post ore. The sulfides of iron-pyrrhotite and pyrite according to Gross (1968) are formed just after the ilmenite-magnetite.

Theories of Ore Formation

Stephenson (1945) assigns the origin of the ores to magmatic segregations in gabbro and magmatic injections in the anorthosite, both processes being related. He noticed that ore lenses in gabbro "are associated with all of the ore bodies." "The ore residuum of gabbro supplied the ore constituents which form large masses in the anorthosite." He believed that where the anorthosite had solidified it was replaced by the ore residuum.

Kays (1965) disagrees with Stephenson since he found (1) that the transition from anorthosite to gabbroic anorthosite to gabbro was gradational, (2) no evidence that there was intrusion by gabbro, (3) magnetite those to ilmenite ratios in anorthosite ores differed from in gabbros, thereby precluding differentiation of the gabbro to produce anorthositic ore, and (4) relations "between plagioclase composition and the amount of ferromagnesian silicates plus garnet."

Gillson (1956),believes that the anorthosite was solid before the ore was formed, and that the ore bodies were formed by pneumatolytic replacement. His supporting evidence includes (1) localization of ores which indicated that deposition was not widespread, (2) parallelism of the rock zones and faulting influenced ore deposition, (3) garnet and scapolite cannot have been formed by filter-pressing, (4) paragenesis indicated that the ore minerals formed after the plagioclase feldspar and garnet, whereas if there had been magmatic segregation, the ore minerals according to Bowen's studies would have formed prior to the other minerals, (5) the presence of veins containing plagioclase feldspar richer in Na than the labradorite illustrates the mechanism whereby "much of the original feldspar was replaced by andesine. This process he calls andesinization." Gillson states that the final step in the formation of the ores was by deposition from solutions whose access was structurally controlled.

Kays (1965) objects to parts of Gillson's conclusions in that (1) labradorite can be converted to andesine without the intervention of solutions rich in sodium. The formation of andesine "occurred when the initial plagioclase was granulated by the pervasive shearing that is associated with the localization of ore." (2) iron, magnesium, and titatinium were already present in the rocks and not introduced by solutions from outside these rocks.

In Kays' own words, "the Sanford Hill deposit is the result of two main events. The first, presumably magmatic event, determined the geochemistry of the area and the gross structure of the anorthosite; the second retrograde matamorphic event determined the mineralogical and structural details of the ore deposit." He advocated a redistribution of the iron, magnesium, and titanium with reactions producing the ferromagnesium minerals and resulting in a concentration of the magnetite and ilmenite.

Heyburn (1960), because of the close association between ore and gabbro which he noted, is of the opinion that they are either contemporanious or practically contemporaneous. He states, "The iron and titanium probably were intruded with the gabbro and segregated with the aid of volatiles to form the ore bodies." The ore in the anorthosite is younger and formed by replacement. Evidence of volatile activity according to Heyburn is "the occurrence of garnet along the contact between ore and anorthosite and also by the presence of secondary biotite."

DeMatties (1974) made a detailed petrographic, mineralogical, and quantitative chemical analysis of samples gathered from the region just south of the mining area, and found that there was an increase in concentration of titanium dioxide and iron to a maximum in the vicinity of the center of the metanorite and that there was no structural control involved. This observation constitutes part of his reasoning for classifying the ore deposit as late magmatic. He states, "Field relationships indicate that these bodies form both segregations as well as injections within metagabbro and metanorthosite respectively."

It is most informative to consider the views of Stanford O. Gross, chief geologist of NL Industries. He has studied the ore deposits for a much more extensive period than any other geologist. Gross (1968) states: "After many observations, it is clearly evident that many theories can be proved if only a portion of the conditions are, or can be, taken into consideration. After a number of years working at the operation, the question of ore genesis becomes more and more complex. No one theory can explain satisfactorily all of the rock and mineral relationships now in evidence."

MINERALOGY

In the following discussion, G refers to occurrence in the Grenville marble, S in the Lake Sanford district, and O in the field trip area other than Grenville and Lake Sanford.

Apatite $Ca_5(F,Cl,OH)(PO_4)_3$ Hexagonal Dipyramidal

Apatite generally occurs as blue crystals 1 mm and smaller
(Balk, 1932). "On the south shore of Harris Lake at Newcomb
was a famous tourmaline locality now exhausted, also found at
this spot were blue apatite, sphene, zircon, muscovite, smoky
G quartz, scapolite, albite, graphite, hematite, pyroxene, and
pyrite. Tourmaline crystals were brown and green 8 inches
long and 4 inches wide." Outside and to the west of the
field trip area occurs wollastonite and small crystals of blue
apatite in "the ledge at the dam where the old wagon road crosses
the channel between Rich Lake and Harris Lake."

Gross (1968) noted that apatite occurred in all rocks of
the Sanford Lake area as anhedral grains associated with
S labradorite and andesine usually present to the extent of less
than 1 per cent, but at times increasing to 10% by volume in
gabbro having a high ore content.

Biotite, muscovite, phlogopite

G Each occurs in very small amounts predominantly less than 1 mm in diameter.

The only mica observed was biotite. It was found in
S gabbro both devoid of ore and rich in ore as a primary mineral
and alteration product of hornblende. It rarely exceeds a
few percent.

South of the Lake Sanford Ore deposits DeMatties (1974)
O observed up to 4% biotite in Whiteface metanorthosite.
Biotite easily visible to the unaided eye forms a large part of
the amphibolite.

Calcite $CaCO_3$ Hexogonal Rhombohedral Trigonal Pyramidal

By far the most abundant mineral in the Grenville marble.
In samples studied in this area so far, it ranges from 51 to 85%
by weight. Crystals have not been observed, but it is certain
that they are present. Balk (1932) reported some calcite
G crystals several miles south of the field trip area in the
southern part of the Newcomb quadrangle. The calcite is a
creamy white. Occasionally there are yellow-brown stains due to
staining by goethite.

S It occurs as a secondary mineral along faults and joints.

Chlorite $Mg_3(Si_4O_{10})(OH)_6$ Monoclinic Prismatic

S It occurs as a secondary mineral along faults and joints.

Chondrodite $Mg_5(SiO_4)_2(F,OH)_2$ Monoclinic Prismatic

G Occurs as yellow-brown grains, usually 1 mm or less.

Garnet

A group of silicates most of which also contain Al. Those having Al also have either Mg, Mn, Fe, or Ca. Those not having Al have Ca and either Fe or Cr. The Mn and Cr types of garnet have not been reported from the field trip area.

Isometric Hexoctahedral Class

G Disseminated as anhedral red, orange, and orange-red grains 1 mm and less.

Present in all Lake Sanford area rocks mostly microscopic
S but can constitute up to 8.1% where rich in ore (Heyburn, 1960).
Composition is mixed grossularite-andradite-almandite (Gross, 1968).

Some of the outcrops along the Blue Ridge road contain
O megascopic garnet but not in crystals. Grains are up to 5 mm
in length.

Graphite Hexagonal Dihexagonal Dipyramidal

It is scattered throughout the Grenville marble, offering
a striking contrast with its silvery metallic luster and
perfect basal cleavage. When size greater than 10 mm, often
its luster is dull black and sooty, but in the smaller flake
G form always metallic. Since the graphite is so soft (hardness
ranging from 1 to 2), its crystal shape is easily distorted.
However, by dissolving away in dilute HCl (one part acid to
six parts water by volume) the surrounding calcite, usually
fine hexagonal crystals of graphite can be obtained.

The crystals are very thin, tabular, and have (0001) as the prominent face. Most of the flakes are smaller than 2 1/2 inches in diameter.

Amphiboles

The only amphibole other than hornblende reported in the
S Lake Sanford area was altered beyond recognition except for
its cleavage (Stephenson, 1945).

Hornblende Monoclinic Prismatic

Has been reported from all rocks of the Lake Sanford area
S being most abundant in the gangue associated with the ore

minerals. Its color is green and brown. It is a primary
S mineral and a secondary, the latter as an alteration product of pyroxene. The brown color is more abundant in the more basic rocks.

It is also present in the charnockitic, granitic, and
O quartz syenitic gneisses as well as the amphibolite facies of the gabbro.

<u>Tremolite</u> Monoclinic Prismatic

G Has been reported in the Grenville marble.

Hematite Fe_2O_3 Hexagonal Rhombohedral Scalenohedral

DeMatties (1974) reported hematite as a secondary mineral from the oxidation of magnetite. It may occur alone as a
S pseudomorph, or associated with magnetite forming rims around magnetite grains. It is a minor mineral, but locally may be present to the extent of 4.1%.

Pyroxenes

S The following pyroxenes have been found: augite, clinopyroxene, diopside, hypersthene, orthopyroxene, and pyroxene.

<u>Clinopyroxene</u> Monoclinic Prismatic

Present in all rocks of Lake Sanford area being up to
S 30% by volume of the gabbro and diminishing to less than 5% of the anorthosite (Gross, 1968).

<u>Orthopyroxene</u> Orthorhombic Dipyramidal

S Most abundant in gabbros rich in ore.

O Most abundant in metanorite (DeMatties, 1974).

<u>Diopside</u> Monoclinic Prismatic

Parts of the Grenville marble have abundant diopside, but in the field trip area crystals and gem variety diopside
G have not been found. The Grenville marble containing the crystals of gem variety diopside is located about 66 miles to the northwest near DeKalb. The diopside in the field trip area is dispersed as grains up to 2 mm in diameter.

Magnetite Fe_3O_4 Isometric Hexoctahedral

Magnetite intergrown with ilmenite and ulvospinel occurs in sizes ranging from microscopic to larger than 50 feet on
S edge. It can be easily separated from ilmenite, but not from ulvospinel. Crystals are unknown in the Tahawus and Blue Ridge area.

G It occurs in quartz in grains generally less than 1 mm in maximum dimension and is never megascopic.

Rocks such as gabbro and gneisses occuring along the Blue
O Ridge road have very small quantities of magnetite present mostly disseminated as grains, but occasionally massive enough to support a small bar magnet. Crystals have not been observed.

Maghemite Fe_2O_3 Isometric Hexoctahedral

This is a secondary mineral formed from magnetite. It
has not been reported as yet. Slightly softer than magnetite,
S brown, brown streak, ferromagnetic. Palache, Frondel, and
Berman (1944) state "the brown alteration product of many mag-
O netites, especially on specimens found near the surface, is
apparently maghemite." Ramdohr (1969) states that the color
may "even be bluish-black." When heated, the maghemite alters
rapidly to hematite. There is reason to believe that this
mineral is present especially since Ramdohr (1969) notes,
"impurities such as V and Ti appear to favor the formation of
maghemite from magnetite and make the maghemite more stable."

Ilmenite Fe_2TiO_3 Hexagonal Rhombahedral

Ilmenite is weakly magnetic. It occurs almost entirely intergrown with magnetite and ulvospinel. According to Gross (1968), its grains are smaller than magnetite's and it can be recognized megascopically only "in coarse-grained anorthositic ore by its high luster and conchoidal fracture compared to the dull luster and parting planes of magnetite." In addition, a tiny bar magnet held against the bottom part of a mass of ilmenite will not be supported and fall when the ilmenite is almost as large as the magnet, whereas if there are both ilmenite and magnetite of equal grain size, the magnet will be supported. Indeed, if the ore is fine-grained, it is not possible to distinguish the ilmenite and magnetite megascopically. The easiest method of finding the ilmenite is to use a small bar magnet about 1" x 0.2" x 0.2" and apply it to the specimen. A most generous supply of ore specimens is provided by N L Industries at the visitors overlook. However, since many are too large to carry, it is advisable to bring along a sledge hammer, chisel, and safety glasses. The specimens containing ilmenite in this size are scarce, but with patience the collector will be rewarded.

Ulvospinel Fe_2TiO_4 Isometric Hexoctahedral

Ulvospinel is a mineral which was first known synthetically, later suspected being present in some magnetites, and finally found in Swedish magnetite ores. Its occurrence has been reported in over 25 localities such as Africa, Australia, China, and the moon. However, special techniques employing oil immersion, magnification in the order of 1000 times, and meticulously polished surfaces are essential for its identification.

Ramdohr (1953) was the first to find ulvospinel at Tahawus. It has about the same magnetic intensity as magnetite so cannot be separated by this property. There may be MgO, Al_2O_3, and V_2O_3 present in very minute amounts in the ulvospinel. It occurs in magnetite to the south of Lake Sanford area in very minute veinlets (DeMatties, 1974), anhedral grains, exsolution lamellae, and exsolution nets. Ramdohr (1953) states that at times magnetite has been found to contain "as much as 30% of extremely fine grained ulvospinel."

Pyrite Isometric Diploidal

G Where exposed on the surface of the Grenville marble pyrite has been oxidized to goethite often staining the white calcite a rust color. Where embedded in the calcite so that it has been protected from chemical weathering, it often occurs as crystals cube, pyritohedron, modified cubes and pyritohedrons, metallic luster, brassy yellow ranging from microscopic to megascopic.

S Gross (1968) states that pyrite and pyrrhotite "are most frequently associated with minerals of the reaction zone between ore and anorthosite. Pyrite occurs as very thin late veinlets that cut ore and gabbro" mostly thinner than 0.6 inch. The sulfide minerals are widely disseminated in many of the Lake Sanford rocks, but rarely exceeds one per cent.

Pyrrhotite Hexagonal Dihexagonal Dipyramidal

G Metallic luster, dark brown on tarnished surface and pale bronze-yellow, almost silver on fresh surface; massive, in grains longer than wide, but mostly under 1 mm; ferromagnetic; may appear to be magnetite to the unwary, but color considerably lighter and much softer.

Quartz Hexagonal Trigonal-Trapezohedral

S A very minor mineral

G Occurs as grains disseminated in the Grenville marble. Most abundant in the quartzite member of the Grenville Series.

O Present in the charnockitic, granitic, and quartz syenitic gneisses.

Scapolite

A series of minerals ranging in composition from calcium aluminum silicate with chlorine, carbonate, and sulfate to sodium aluminum silicate with chlorine, carbonate, and sulfate. The last three can completely substitute for one another.

Tetragonal Dipyramidal

G Reported as being present.

S Stephenson (1945) found scapolite as an alteration product of plagioclase feldspar with the scapolite "occurring as scaly aggregates along the borders of the grains." It is also common in the "reaction zones between the ore and anorthosite."

Sphene $CaTiSiO_5$ Monoclinic Prismatic

G Wedge-shaped brown to very light brown crystals mostly smaller than 0.5 mm in diameter. Very difficult to see crystal faces. Largest size seen in this region are about 1 mm in diameter. The crystals are roughly circular in shape. One cleavage has been observed.

Plagioclase feldspar

Andesine 50-70% albite 30-50% anorthite

Present to a small extent in the metanorthosite making up some of the smaller and medium-sized grains especially in the groundmass;
S more abundant than labradorite in the metanorite (DeMatties, 1974), and in the diorite (Avenius, 1948). Heyburn (1960) found andesite of a brownish pink color in two pegmatite dikes.

Labradorite 30-50% albite 50-70% anorthite

This is the most abundant feldspar in the field trip area. It constitutes the major mineral in the ore-barren metanorthosite. It is also present in the ore as phenocrysts. The author has seen and
S collected magnificent specimens containing phenocrysts of labradorite exhibiting polysynthetic twinning embedded in titaniferous magnetite. Some of the plagioclase feldspar inclusions attain lengths of 6 inches. The color varies from blue to dark gray, almost black.

Specimens of labradorite may be collected in outcrops on the
O eastern half of the Blue Ridge road. They are also available in rounded pebbles, cobbles, and boulders in the gravel pits just east of Newcomb.

Potash Feldspar

Microcline $K(AlSi_3O_8)$ Triclinic Pinacoidal

Avenius (1948) reported this feldspar as being present in what he called diorite and others gabbro near northern Cheney Pond. Stephenson (1945) determined that microcline constituted about 1/4
S of the syenitic phase of the gabbroic anorthosite. DeMatties (1974) noted that it is present in the Whiteface metanorthosite facies. Potash feldspar has been found in all of the rocks of the Sanford Lake area, but only in a few places as mentioned above has it been identified as microcline.

Balk (1932) found microcline "medium-grained, in a well-foliated
G lime-silicate rock" visible only microscopically in a scapolite rock where "the main highway on the west shore of the Hudson crosses the 1500 foot contour line."

Orthoclase $K(AlSi_3O_8)$ Monoclinic Prismatic

O Miller (1919, p. 41) reported orthoclase in granite intruding anorthosite 1 mile south of Sand Pond.

Spinel

A group of Isometric Hexoctahedral oxides usually containing at least two of the following: Al, Cr, Fe, Mg, Mn, and Zn. Minor amounts of a green spinel which Stephenson (1945) identified as her-
S cynite $FeAl_2O_4$ with MgO bounds some of ore minerals, but width of grains is less than 0.5 mm. "Lamellar intergrowths of spinel parallel to the cube direction in magnetite may occur" (Stephenson, 1945). Undoubtedly this is ulvospinel that Ramdohr identified.

Pleonaste

An iron spinel and at times almost transparent. Also occurs
S in minute quantities in the Lake Sanford area ores. Ramdohr has identified it as being present. (Ramdohr, 1953)

Very minor amounts of spinel occur in the Grenville marble.
G The author has seen minute pink octahedrons (much smaller than 0.1 mm) in the Grenville marble between Whitehill and Ticonderoga, but they are very rare.

Wollanstonite $CaSiO_3$ Triclinic Pinacoidal

G Has been reported in the Grenville marble.

Zircon $ZrSiO_4$ Tetragonal Ditetragonal Dipyramidal

G Has been reported in the Grenville marble.

Among the very minor minerals reported from the Lake Sanford area are barite, chalcopyrite, epidote, leucoxene, molybdenite, orthoclase, prehnite, quartz, scapolite, and sphalerite.

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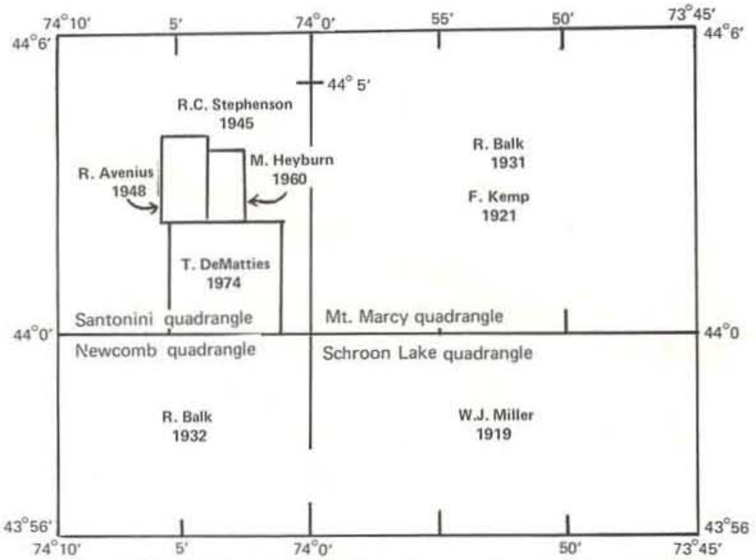


Figure 1. Quadrangles in field trip area with names of authors of geological publications

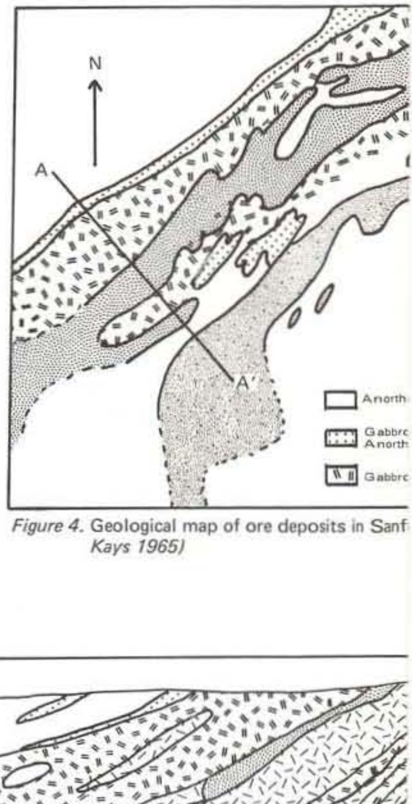


Figure 4. Geological map of ore deposits in Sanf
Kays 1965)

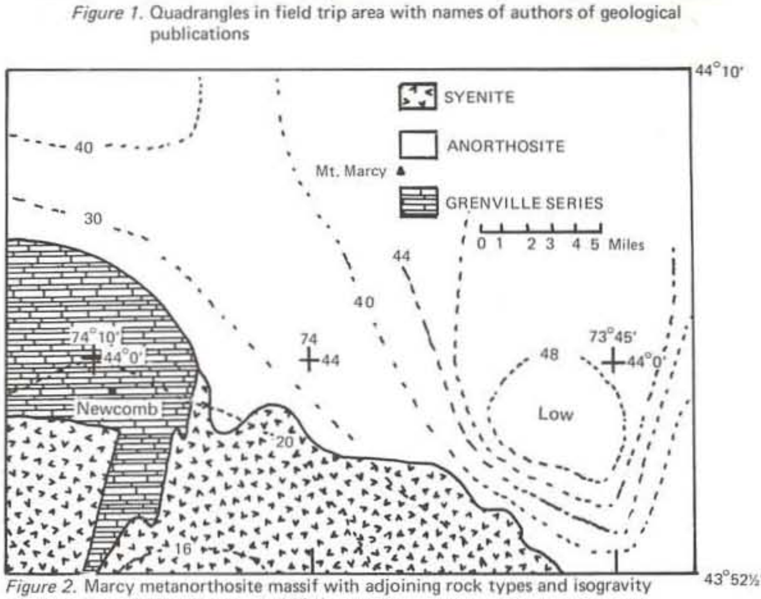


Figure 2. Marcy metanorthosite massif with adjoining rock types and isogravity lines. *(After Simmonds 1964)*

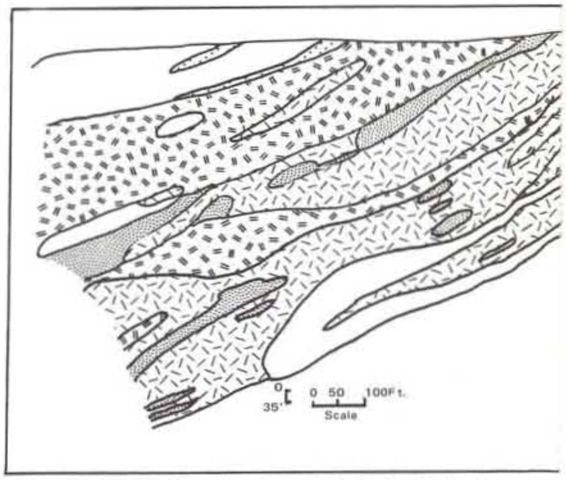
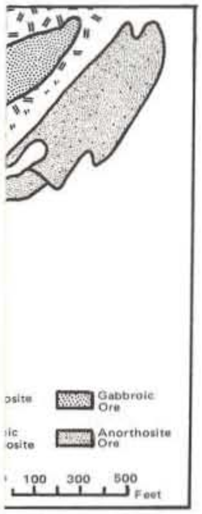
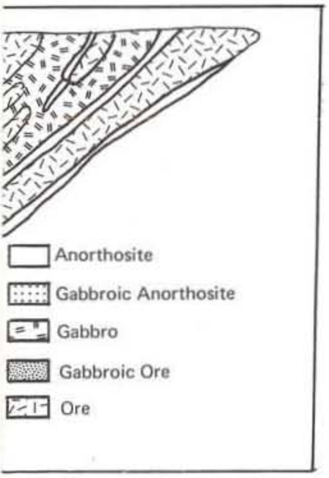


Figure 5. Cross section of ore deposits in Sanford Lake along area



ord Lake area *(After*



AA' in Figure 4 *(After Kays 1965)*

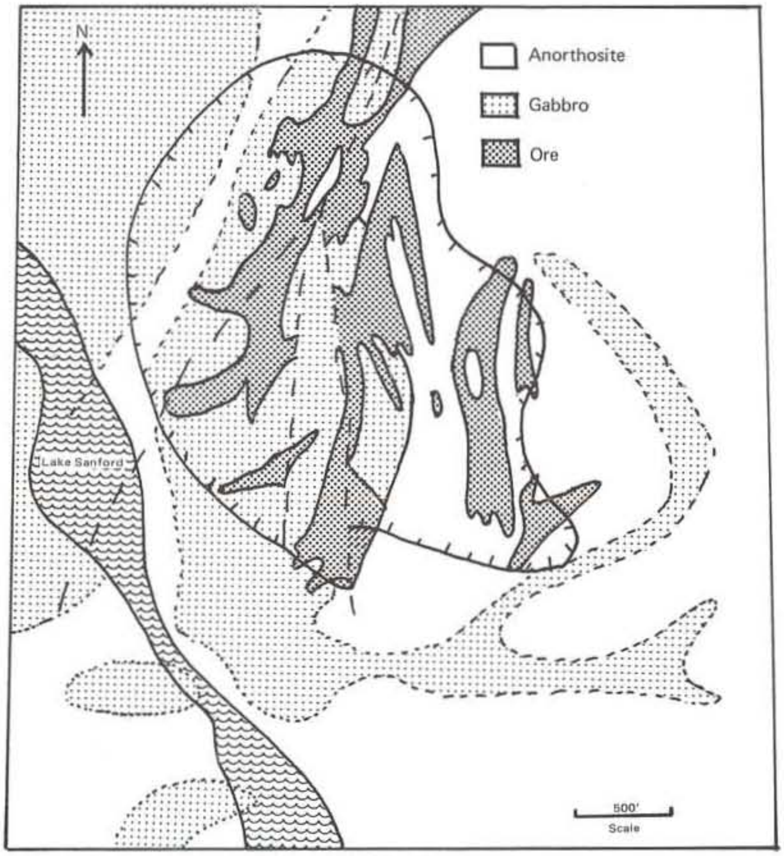
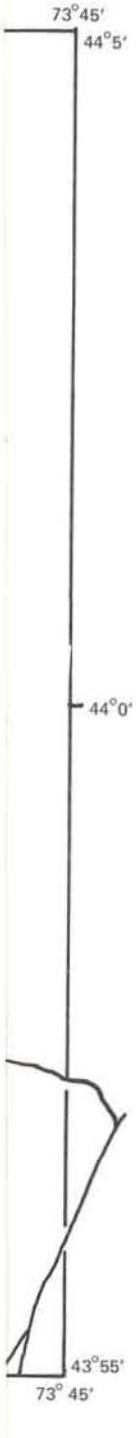


Figure 6. South extension pit Sanford Hill *(After Gross 1968)*



ROAD LOG

Mileage		
Point to point	Cumulative	Directions & Descriptions
0 73	73	LEAVE College, east on I-88, east on N.Y. 7 to Duanesburg right on U.S. 20 until I-87.
99	172	Left on I-87 (Northway). Leave at exit 29. Second sign reads Newcomb. Turn left under Northway going west.
3.1	175.1	Bruce's Blue Ridge Store (only one for miles) on right.
3.0	178.1	Small bridge. On left sign "Trail to Hoffman Road 8.5 miles, Big Marsh Pond 3.5 miles."
8.3	186.4	Sign on left reads "Trail to Irish Town via Minerva Stream and Lester Dam 11 miles." Parking area on left.
4.4	190.8	Triangle formed by road intersections; stop sign; turn right to Tahawus. There are no side paved roads. Stay on paved road.
6.7	197.5	Left is to trails to Mt. Marcy and high peaks.
0.6	198.1	NL Industries Mineral Collecting Area. Continue past this point to parking area near office building. STOP 1 The trip from Oneonta will take about 4 hours and 15 minutes. We will meet at the mine at 11:00 a.m. Our leader for this part of the field trip will be Stanford O. Gross of NL Industries, resident Geologist and Mining Engineer. We will be here until 1:00 p.m. You will have an opportunity to collect at the Mineral Collecting Area until about 1:30 p.m.
7.3	205.4	Road south to triangle. Turn right to Newcomb.
0.1	205.5	Railroad crossing.

Mileage		
Point to point	Cumulative	Directions & Descriptions
3.0	208.5	On left Finch Pruyn Co.
1.5	210.0	Crossing the Hudson River
1.1	211.1	Turn left and park in Newcomb Central School parking area. STOP 2 Marble outcrops on east side of parking lot; massive grayish-white calcitic; portions stained a light yellow-brown; Present are graphite, calcite, and in small grains pyrrhotite, garnet, and sphene. Turn right on highway (Route 28N) going east.
1.1	212.2	Hudson River crossing.
1.5	213.7	On right is Finch Pruyn Co.
1.8	215.5	On left is road to Tahawus.
0.3	215.8	On left is another road to Tahawus.
0.5	216.3	Enter gravel pit. STOP 3 Well rounded boulders, cobbles, and pebbles of metanorthosite, gneisses, and other rocks in the area occur in this fluvioglacial deposit along with sand.
0.1	216.4	Turn right after leaving gravel pit.
0.4	216.8	Turn right.
0.3	217.1	Triangle.
0.8	217.9	Crossing railroad tracks.
0.1	218.0	Keep right to Northway (I-87), but do not take left which is back to Tahawus.
1.6	219.6	STOP 4 On both sides of the highway are large outcrops of amphibolite weathered a deep brown. A fresh surface is medium-grained grayish-brown with nodules of hornblende scattered throughout the

Mileage		
Point to point	Cumulative	Directions & Descriptions
		medium-grained material. Some of the amphibolite has a pinkish tint when there is more garnet present. Also present are biotite, garnet, plagioclase feldspar, and quartz. Some of the amphibolite nodules have been elongated producing a gneissic appearance. Some of the amphibolite has been intruded by numerous dolomite veins less than 2mm wide.
2.9	222.5	STOP 5 Parking area on right. Sign reads Trail to Irishtown via Minerva Stream and Lester Dam. On both sides of road extensive outcrops of garnetiferous gneiss. Occasional magnetite present with some hornblende and pyroxene. Some gabbro is also present in which magnetite and ilmenite are abundant.
0.2	222.7	STOP 6 On left is garnetiferous gneiss with some magnetite.
0.6	223.3	STOP 7 On left gabbro with garnet, pyroxene, very small amounts of magnetite and ilmenite with plagioclase feldspar as metacrysts. Gabbro is lighter than stop 5 occurrence.
2.1	225.4	STOP 8 Metanorthosite outcrops, weathered and fresh medium-grained; weathered metanorthosite is white and fresh surface is dark gray.
1.7	227.1	STOP 9 On left outcrop of coarse-grained metanorthosite. Phenocrysts are much larger than in previous outcrop.
6.2	233.3	On left Bruce's General Store, Blue Ridge, N.Y.

Mileage		
Point to point	Cumulative	Directions & Descriptions
2.4	235.7	On right is sign reading Northway (I-87S) Entrance. STOP 10 Across the street to the left about 50 feet east of the sign stating speed 40 mph is Stop 10. Diabase dike intruding metanorthosite. About half way up the hill the contacts between the diabase and metanorthosite are readily visible with the width of the diabase about 3 feet. There appears to be another dike several feet to the west which is broader, but there are no contacts visible. The first dike strikes almost due north.
0.1	235.8	Turn right to go south on I-87 toward Albany. If you wish to go north, continue east to entrance to I-87 North. Field Trip is concluded.

KARST GEOMORPHOLOGY OF THE COBLESKILL AREA, SCHOHARIE COUNTY, N.Y.

John E. Mylroie, Murray State University, Murray, Ky.

Arthur N. Palmer, State University College, Oneonta, N. Y.

INTRODUCTION

The term "karst" refers to a landscape that has evolved primarily by the solutional weathering of bedrock. Karst landscapes, dominated by features such as sinkholes, caves, and cave springs, are most commonly found where calcareous rocks, particularly limestone, comprise a large percentage of the surface.

The Cobleskill area of east-central New York State (Figure 1) is a portion of the Helderberg Plateau, the very northeastern tip of the Appalachian Plateaus geomorphic province. This area contains limestones of Helderbergian (Lower Devonian) age, dipping 1-2 degrees to the south-southwest. Northeast of the village of Cobleskill (Figure 2), tributaries of the north-flowing Schoharie Creek have entrenched through the limestones, providing paths for ground water flow suffiecint for caves and other karst features to have developed to an extent seen nowhere else in the Northeast. Recent works by Kastning (1975), Baker (1976), M. V. Palmer (1976) and Mylroie (1977) have provided a detailed geomorphic and hydrologic examination of the karst in this area. To the layman, the area is known chiefly as the location of Howe Caverns, which is part of the largest underground drainage system in the state.

The stratigraphy of the region is shown in Table 1. A thick sequence of Ordovician clastic rocks are overlain by a thin Upper Silurian section consisting of the Brayman Shale, Cobleskill Limestone, and the lower beds of the Rondout Dolomite. The Silurian-Devonian boundary is transitional within the Rondout Dolomite in this locality (Rickard, 1975). The Helderberg Group of early Devonian age consists of the upper beds of the Rondout Dolomite and the Manlius, Coeymans, Kalkberg, New Scotland and Becraft Limestones. All the limestones except the New Scotland are rather pure, with the Coeymans, Kalkberg and Becraft being exceptionally good scarp and bench formers. Overlying the Helderberg Group is the Tristates Group, a section of Lower Devonian clastic rocks grading upward to the Middle Devonian Onondaga Limestone. The Onondaga is a cherty, resistant limestone that also forms benches and scarps. It is overlain by the Middle Devonian Hamilton Group, composed primarily of clastic rocks which include the youngest bedrock units of the Cobleskill area.

Karst features are well developed on the Helderberg limestones, particularly the Manlius, Coeymans, and Becraft. Although karst features are common in the Onondaga Limestone farther east, this rock unit is not exposed over a broad enough surface in the field-trip area to possess significant karst features.

A variety of Pleistocene glacial sediments overlie the bedrock in discontinuous and irregular patches, primarily in the form of till sheets and drumlins. Glacio-alluvial sands and gravels are common in the valleys, as are lacustrine clays related to glacial Lake Schoharie (LaFleur, 1969). Holocene sediments consist mostly of reworked glacial material and colluvial material derived from the Paleozoic rocks.

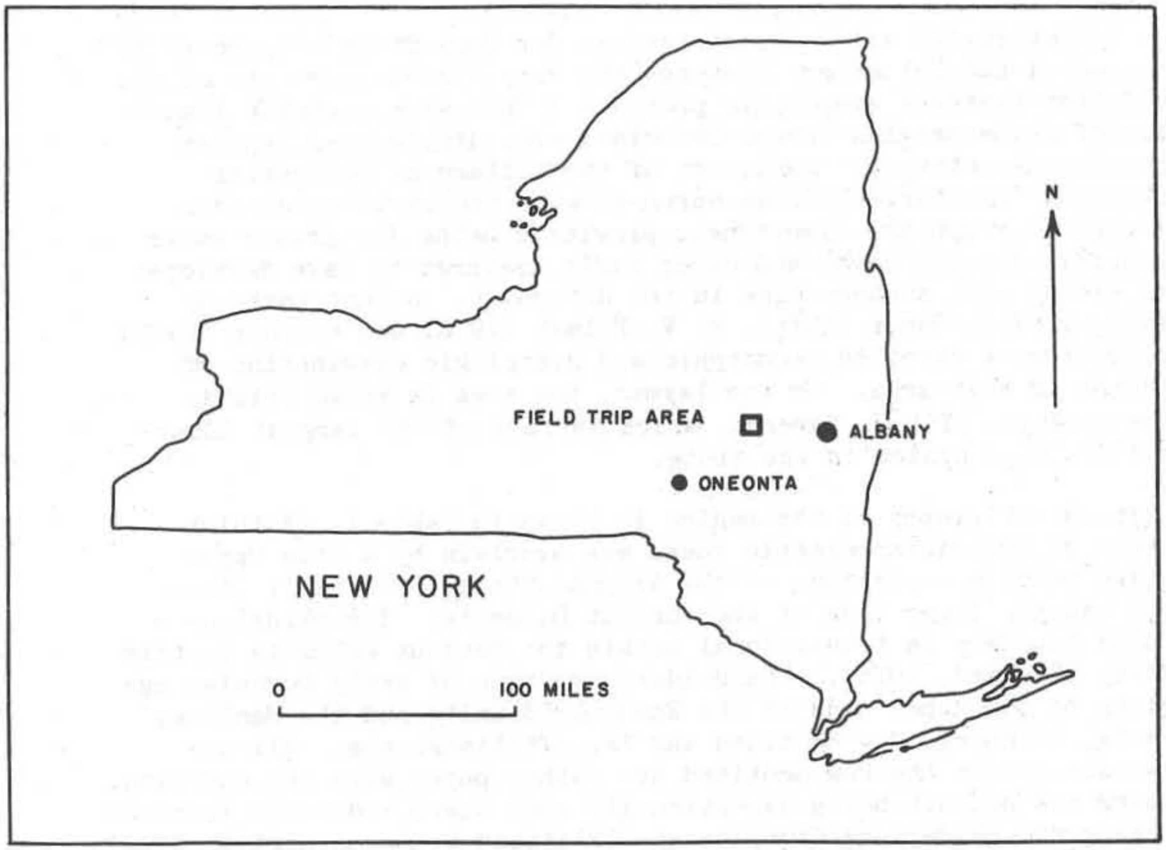


Figure 1 - Location map of the Cobleskill area, Schoharie County, New York.

System	Group	Rock Unit	Thickness at Howe Cave (feet)
Quaternary		alluvium	20 +/-
		sand and gravel (outwash)	0-20
		lacustrine sediments	0-100
		till and tillite	0-100+
Devonian	Hamilton	mainly sandstones and shales	340
		Onondaga Ls.	100
	Tristates	Schoharie Fm.(limy ss.)	8
		Carlisle Center Sh.	40
		Esopus Sh.	50
		Oriskany Sandstone	6
	Helderberg	Alsen Ls.	8
		Becraft Ls.	20
		New Scotland Fm. (shaly ls.)	-
		Kalkberg Ls.	104
		Coeymans Ls.	54
		Manlius Ls.	36
		Rondout Dol.	37
Silurian	Salina	Cobleskill Ls.	9
		Brayman Sh.	40
Ordovician		Indian Ladder Fm. (sandstone and shales)	100
		Schenectady Fm. (sandstone, graywackes, and shales)	1800-2000

Data compiled from Gregg (1973), Kastning (1975), Rickard (1975), Baker (1976) and Mylroie (1977).

Table 1 - Stratigraphic section in the Cobleskill area.

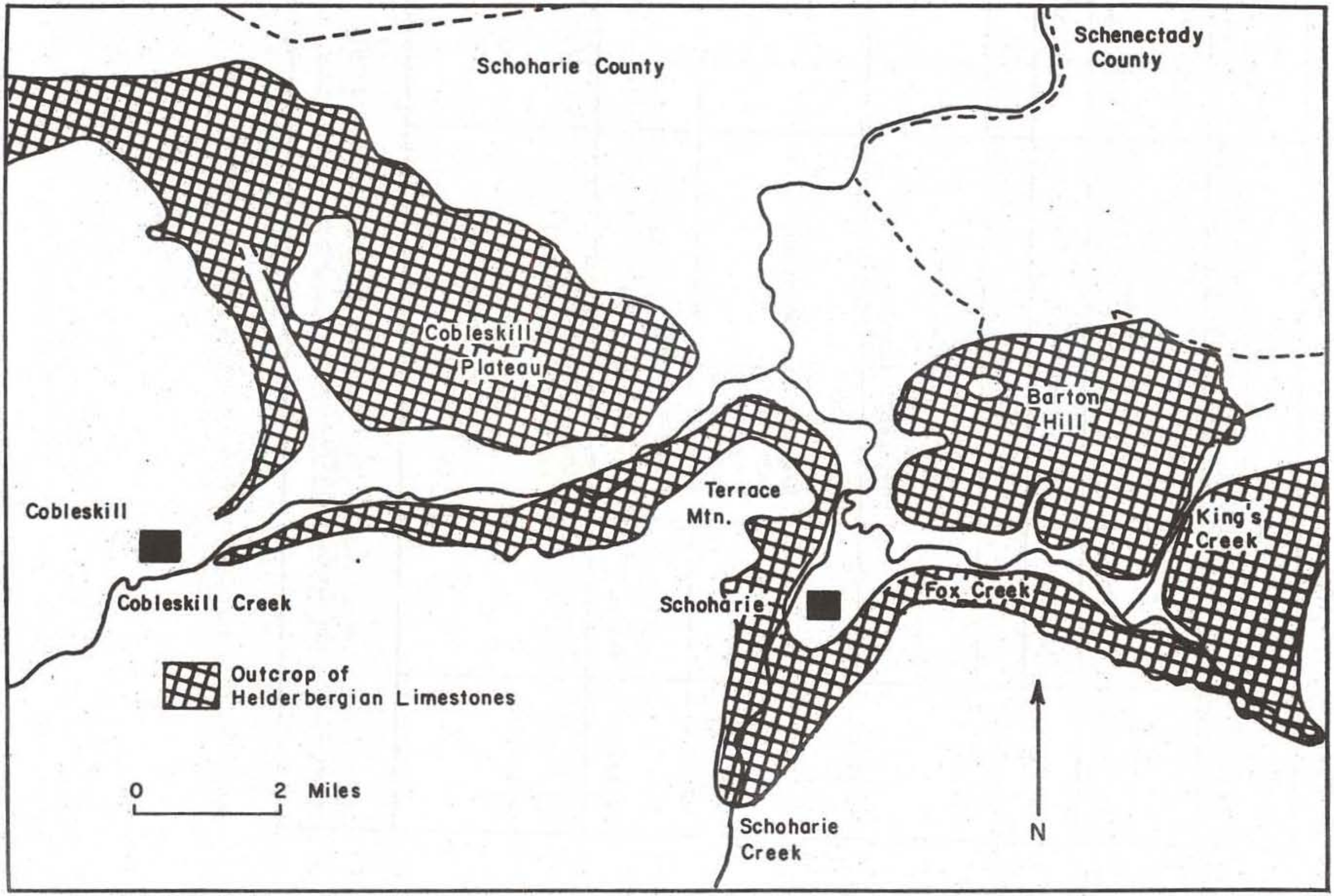


Figure 2 - Outcrop pattern of Helderbergian limestones in the Schoharie valley (modified from Berdan [1950]).

KARST FEATURES

A karst landscape consists of two environments, the surficial and the subsurface. Karst features of each environment can be classified according to their geomorphic relationships and hydrologic functions (Mylroie, 1977). This classification is outlined below, both to serve as a description of typical karst features to be found in the Cobleskill area, and to provide a convenient terminology for use in the remainder of the text. Details of this outline are explained in the paragraphs that follow.

- I. Surficial Karst Features
  - A. Exposed bedrock surfaces
  - B. Mantled bedrock surfaces
- II. Interface Features (connections between surface and subsurface environments)
  - A. Insurgences (zones of groundwater recharge)
    - 1. Diffuse
    - 2. Confluent
  - B. Resurgences (ground water emerges at the surface)
    - 1. gravity spring
    - 2. artesian spring
    - 3. overflow spring
  - C. Intersection features (fortuitous intersection of subsurface features by unrelated surface processes)
    - 1. Vertical
    - 2. Lateral
- III. Subsurface Features
  - A. Active cave passages (contain perennial streams)
    - 1. Tributary passage
    - 2. Master cave passage
    - 3. Diversion passage
    - 4. Tapoff passage
    - 5. Abduction passage
  - B. Abandoned cave passage (no longer contains perennial flow)

Surficial karst features form by the solutional etching of bedrock surfaces, both exposed and mantled with soil or sediment. These features form entirely within the surficial environment, without regard to the ultimate destination of the water that forms them. Such karst features as solution rills and solution pockets in the bedrock surface are examples of surficial karst features.

Interface features are the genetic connections between the surficial and subsurface environments. These include funnel-shaped depressions known as sinkholes, pits formed by ground water descending along fractures, sinking streams, and springs. Interface features can be divided into three main types depending on their hydrologic function: insurgences, or point of water input into the subsurface environment; resurgences or points of water output from the subsurface environment; and intersection features, or points of contact between the surficial and subsurface environments caused by predominantly non-solutional processes (such as collapse and scarp retreat) without substantial water exchange between the two environments.

Insurgences are basically of two types, diffuse and confluent. A diffuse input is the flow of water into the subsurface more or less uniformly over a large area, via primary porosity or fractures in bedrock. A confluent insurgence is the point where water enters the subsurface environment as perennial or intermittent streams.

Resurgences have three basic morphologies in terms of their hydrologic character: gravity springs, where water leaves the subsurface environment under free-surface flow; artesian springs, where water exits under hydrostatic pressure; and overflow springs, which can be either artesian or gravity springs, but which flow only in flood times, when the normal resurgences for a cave system cannot handle the entire groundwater discharge.

Intersection features comprise two basic categories; vertical intersection features, such as those formed by mechanical collapse of the roof of a solutional chamber, producing a collapse sinkhole; and lateral intersection features, where a retreating scarp or hillside breaches a pre-existing cave.

The subsurface environment forms the underground link between insurgences and resurgences. Solutional conduits, or caves, are classified by the hydrologic function they perform in completing this link. A "cave system" consists of those interface and subsurface features that are hydrologically integrated. Active cave passages are solution conduits that presently carry water, either perennially or seasonally. Abandoned cave passages no longer carry water, except perhaps during large floods, but they are preserved within the limestone as evidence of former paths of groundwater flow. Cave passages can be further subdivided as follows: tributary passages collect water from insurgences and carry it to the master cave passage, which is the main route connecting the insurgences to the resurgence(s). Diversion passages carry water around obstructions in the master cave. Tapoff passages convey water from master cave passages to relatively new springs as a result of local adjustments in base level, or other changes in the surface environment. Abduction passages represent connecting links between competing cave systems, where water flows from one cave system to another, as with surface stream priacy.

KARST OF THE COBLESKILL PLATEAU

The field trip described in this paper is limited to the area designated here, for convenience, as the "Cobleskill Plateau". It is bounded on the east by Schoharie Creek, on the south by Cobleskill Creek, on the north by the truncated up-dip edge of the Helderbergian limestones, and on the west by the line of disappearance of these limestones beneath the clastic Tristates Group (see Figure 2). This area is somewhat unique among the karst areas of the United States. The karst is highly developed, especially in the subsurface, and cave systems of several miles in length are known. However, because the area has been heavily glaciated, the impact of continental glaciation on karst topography and hydrology can be determined. Unlike the glaciated karst in alpine terranes, the Cobleskill Plateau is almost undeformed structurally. The lack of structural deformation allows a clear understanding of the effects of glaciation.

Pleistocene glaciation had a great effect on the surficial and interface karst features but a relatively minor effect on subsurface karst features. Glacial ice crushed, buried or quarried many of the surficial and interface features. Most surficial karst seen in the area today is post-glacial in origin. The greatest impact of glaciation has been in the deposition of till of varied thickness atop the pre-glacial topography. Where glacial till is thick (roughly more than 5 feet) it forms an impervious layer that allows surface runoff to collect and sink as large, confluent insurgences where the streams encounter exposed limestone. In areas where till is thin or absent, water tends to enter the limestone in a diffuse manner through solutionally enlarged joints. East of the Cobleskill Plateau, on Barton Hill (Figure 2), glacial till is generally thin or absent, and confluent insurgences are rare (Mylroie, 1977). In the vicinity of Cobleskill, however, till thicknesses vary greatly, and numerous drumlins are present. The greater abundance of till results in many confluent insurgences on the Cobleskill Plateau. The amount of glacial sediment thickens considerably toward the west on the plateau, having completely buried a northern pre-glacial tributary valley of Cobleskill Creek (Figure 2). Many of the largest closed depressions in this area are caused at least in part by glacial deposits. These depressions, instead of forming lakes, as in non-carbonate terranes, are kept fairly dry by the drainage of incoming water through solution conduits in the limestone exposed in their floors or walls. Although of glacial origin, these large depressions owe their continued topographic expression to solutional processes.

The valley of Cobleskill Creek has been filled with glacial drift to thicknesses as great as 100 feet, displacing the present stream from its original bed onto the limestone benches that once formed its south bank. The resistant limestone benches have prevented rapid downcutting of the creek into the less resistant glacial material. The glacially buried north bank of the valley contains a large artesian spring, known as Doc Shaul's Spring (Figure 3), which was originally a gravity spring in the valley wall during pre-glacial times. Piping by ground water under pressure has created a conduit from the bedrock upward through the overlying glacial sediment to the surface, forming an artesian karst spring.

Numerous sinkholes exist on the Cobleskill Plateau, formed by the subsidence of glacial material into solutional voids beneath. Many of these sinkholes feed vertical pits that extend through the Coeymans Limestone to caves in the underlying limestone. In this area, the size of a sinkhole tends to be proportional to the thickness of the glacial overburden and the capacity of the underlying solutional cavity to receive this material. Most sinkholes overlie active cave passages whose streams are able to remove material that subsides into them.

Glacial erosion and deposition has deranged much of the surface drainage on the plateau, resulting in the abandonment of some insurgences and the reactivation of others. In addition, many resurgences have been partly or completely occluded by glacial sediment. Despite these surficial changes, the subsurface conduits have not been significantly altered by glaciation. Many abandoned cave passages were filled with fine-grained silts and clays because of stagnant water conditions beneath the ice sheets. However, active cave passages flushed themselves clean of the finer sediments during and after ice withdrawal, with much of the coarser material remaining behind as lag deposits.

The major cave systems of the Cobleskill Plateau are apparently of pre-glacial origin, so their morphology and orientation have been determined by factors other than glaciation. The most important factor influencing the orientation and flow direction of the major cave systems in the Cobleskill Plateay and other nearby areas is the relationship between the regional dip and the altitudes of the master surface streams of the area (Fox, Schoharie, and Cobleskill Creeks). Groundwater in the limestones generally flows concordant to the strata, down the dip along favorable beds and bedding-plane partings, until it reaches the irregular and discontinuous top of the phreatic zone, roughly at the elevation of the local base level, where the water flows nearly parallel to the strike to the nearest available surface outlet.

The pattern of the major subsurface flow paths in the Fox, Schoharie, and Cobleskill valleys has been interpreted from cave exploration and from dye tracing of ground water. This pattern is shown diagrammatically in Figure 3.

In addition to the strike and dip of the beds and the interaction of the regional master surface streams with this structural geometry, there are several other geologic features of importance to the origin of caves in the Cobleskill Plateau. Joints, faults, and lithologic vatiations are of local importance in a cave system, even though the overall cave orientation is controlled by more regional factors. The main joint trends are sub-parallel to the dip and strike at roughly N20°E and N85°W respectively. The joints are therefore oriented parallel to the favorable flow paths and are often utilized by groundwater flow, which enlarges them solutionally into fissure-like passages.

Their influence is greatest upon interface features and tributary passages, which convey water underground from the surface, and which therefore must cut across the strata. Joints, because of their discordance to

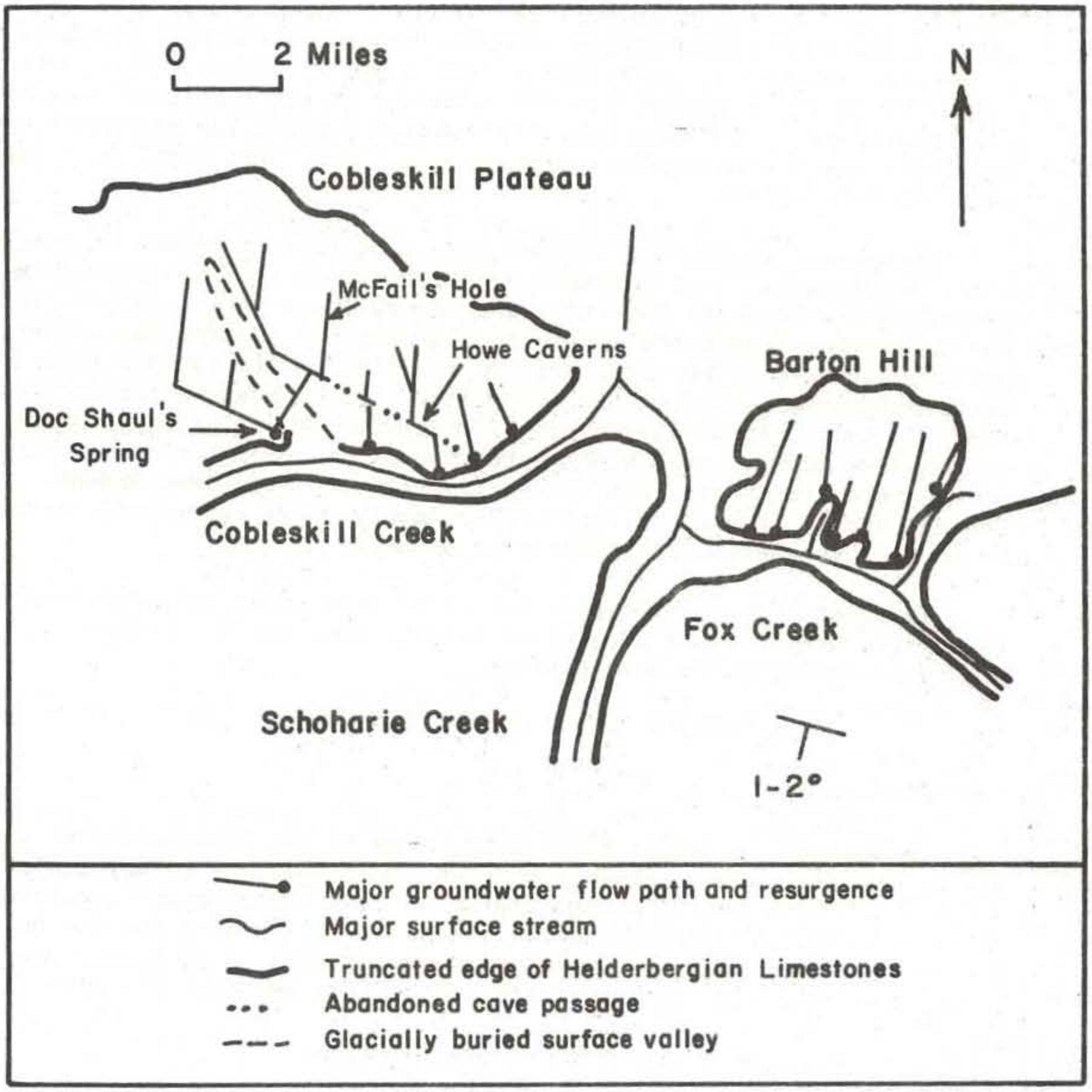


Figure 3 - Major paths of karst groundwater flow in the Cobleskill area.

the beds, are ideal for this function. Some single joints and joint swarms form cave passages that are almost perfectly linear for distances as great as 2000 feet. Joints seem to have less influence upon the low-gradient strike-oriented passages. Faults are occasionally utilized by ground water, in one case for nearly 2000 feet of cave passage. Faults are utilized as paths of groundwater flow for great distances only where they are oriented sub-parallel with otherwise favorable flow directions such as the dip or strike. Bedding-plane partings between contrasting rock types or textures are particularly favorable for groundwater flow and commonly form the initial zone of development of a cave passage. The contact between the massive Coeymans Limestone and the thin-bedded Manlius Limestone is of particular importance in this regard.

Lithologic variations between formations are important in controlling karst development. For instance, surface exposure of the nearly impermeable New Scotland Formation determines where water can sink into the underlying limestones and therefore helps to control the pattern of cave passages. The stratigraphic position of the various rock units is also of considerable importance. For instance, the impure, shaly Rondout Dolomite, which would otherwise be a poor cave former, contains extensive cave passages because of its position near the base of the pure limestones that are so favorable to cave development. Ground water in the pure limestones commonly forms entrenched canyons or tapoff passages in the underlying Rondout.

The features and processes described briefly in the preceding paragraphs are examined in greater detail, with specific examples, in the description of field trip stops.

DESCRIPTION OF STOPS ON KARST FIELD TRIP

Introduction

As with any geologic field trip, many of the features to be viewed are on private lands. It is important, therefore, to follow instructions exactly and to exercise a high degree of consideration and conservation at each locality. Detailed instructions are given here and in the road log as to where to go and where not to go at each stop; please obey them. The road log appears at the end of this report. See also Figure 4.

STOP 1 -- Physiography of the Cobleskill area.

From this location, the general physiography of the Cobleskill Plateau can be seen. Cobleskill Creek, the major surface stream of the area, flows eastward immediately below (north of) Stop 1. Further to the north lies the gently rolling Cobleskill Plateau, comprised mainly of Helderbergian limestones, its landscape morphology controlled both by glacial and by karst processes. The regional dip is 1-2 degrees SSW. South of Stop 1, the limestones disappear beneath Middle Devonian rocks, mainly of clastic lithology. To the northwest is a prominent flat-topped hill, Barrack Zourie, which is an outlier of the Middle Devonian rocks. North of the Cobleskill Plateau lies the Mohawk lowland, developed on pre-Silurian rocks. Looking eastward along Route 7, three major

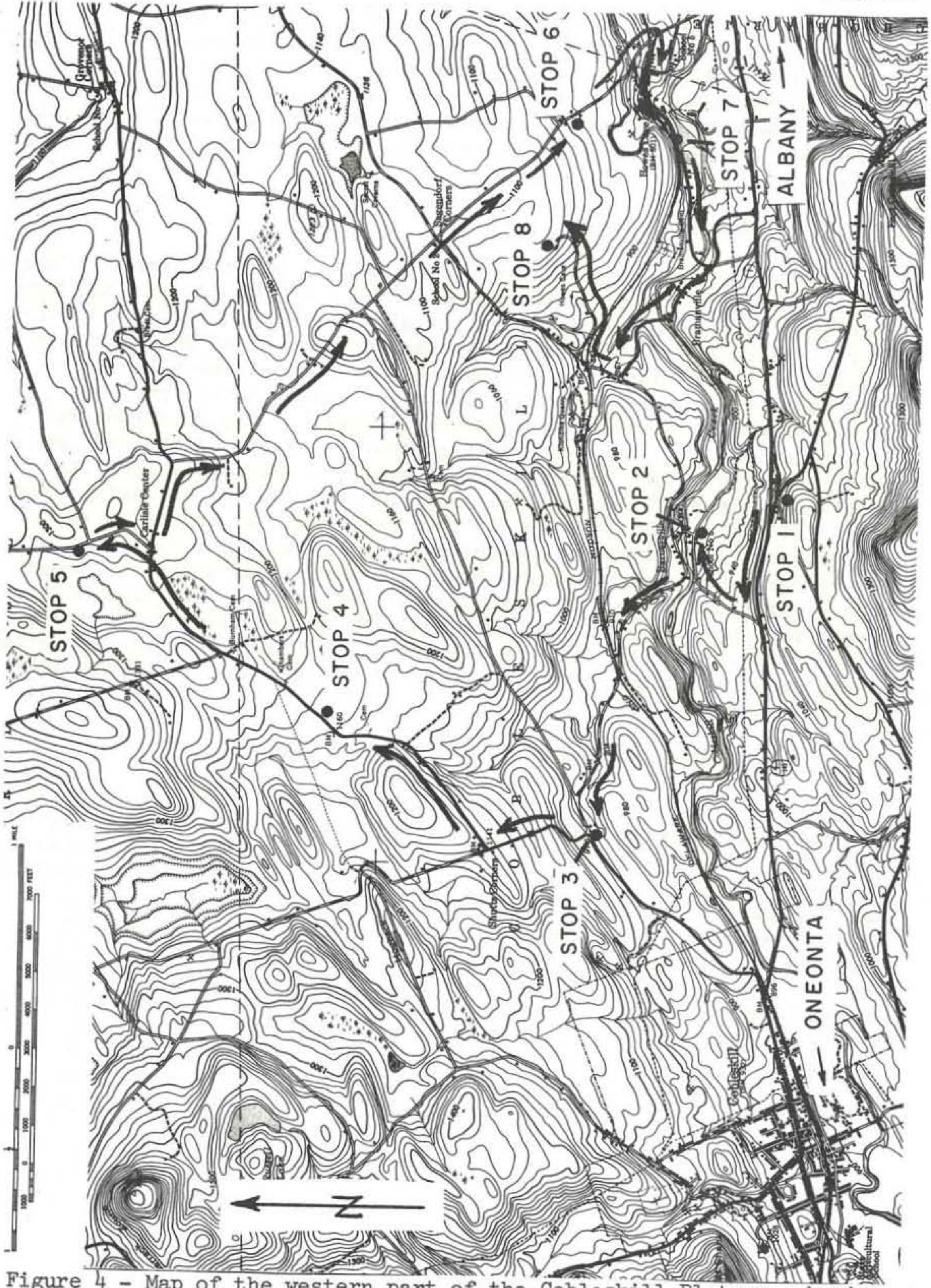


Figure 4 - Map of the western part of the Cobleskill Plateau, showing plan of karst field trip (from Cobleskill 7½-minute topographic quadrangle).

structural benches can be seen on the right (south). These benches are formed on resistant limestones and are not erosional terraces. The lowest one is formed on the Coeymans Limestone, the middle one on the Becraft Limestone, and the upper one on the Onondaga Limestone. The corresponding benches to the north of Route 7, across Cobleskill Creek, are for the most part obscured by thick deposits of glacial drift.

STOP 2 -- Cobleskill Creek

Cobleskill Creek, seen here, is the master surface stream of the area. Glacial deposits of Wisconsinan (and possibly earlier) age have displaced the creek from its pre-glacially entrenched valley onto the bedrock benches that form the south bank of the buried bedrock valley. Glacial till now forms the north bank and attains thicknesses of more than 100 feet in the pre-glacial valley. Looking downstream, the post-glacial superposition of Cobleskill Creek on the Helderbergian limestones can be seen. The south-southwesterly dip of the beds may have counteracted the tendency of the creek to shift back into its original sediment-filled valley. Part of the flow of Cobleskill Creek sinks into solutional openings in the south bank, at the point where the Cobleskill Creek first crosses onto the limestones, just west of the bridge. The water resurges 6000 feet downstream where the creek swings north and leaves the limestones. During low flow, this underground diversion route is capable of accepting the entire flow of the creek, so that the channel is left dry for the next 6000 feet. This subsurface diversion of a surface river is one of the longest in the Northeastern United States.

STOP 3 -- Doc Shaul's Spring

To the south of the intersection is Doc Shaul's Spring, a large artesian karst spring (Figure 5). This spring is located directly above the glacially buried northern bedrock bank of the pre-glacial Cobleskill valley and drains solution conduits in the Rondout, Manlius, and Coeymans Formations. When the bedrock valley was filled with glacial sediment, a resurgence located in the valley wall at this locality was buried. In response, the underground water piped a conduit upward through the glacial sediment to the surface following the retreat of the east glacial ice sheet. This artesian spring, with a peak discharge of more than 40 cfs, is one of the largest karst springs in the Northeast. It drains several square miles of the Cobleskill Plateau to the north, including the areas seen at stops 4 and 5 (see Figure 4). The elongate hill south of the spring is a drumlin lying along the axis of the buried pre-glacial valley of Cobleskill Creek. To the north of the spring is a steep hillside formed by the till-covered Becraft and Onondaga structural benches. No bedrock outcrop is known within a radius of more than 1500 feet in any direction from the spring.

STOP 4 -- Limestone pavements.

Along the east and west side of the road at this location are exposed bedrock surfaces developed along bedding planes in the Becraft

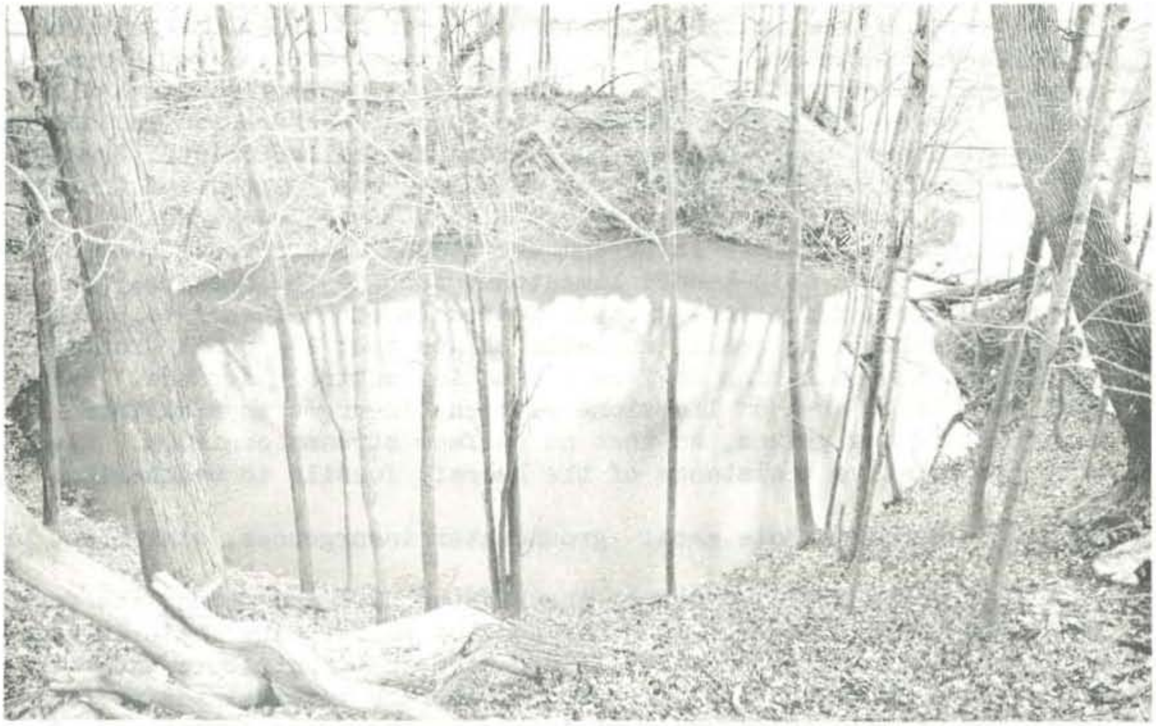


Figure 5 - Doc Shaul's Spring (Stop 3). Artesian conditions have resulted from the blockage of subsurface drainage by glacial deposits.

Figure 6 - McFail's Hole (Stop 5), a joint-controlled solutional pit in the Kalkberg and Coeymans Limestones.

Limestone. Bare surfaces of this type are called limestone pavements. In jointed limestones, such as those seen here, the joints become solutionally enlarged by infiltrating water to form fissures called grikes. Where the grikes intersect to form a checkerboard pattern, the blocks of limestone bounded by the grikes are called clints (Sweeting, 1973). In thick-bedded rocks such as these, the joints (and therefore the grikes) tend to be widely spaced (about 3 to 30 feet apart), and the resulting clints are large and are stable with respect to mechanical weathering. In a thin-bedded limestone, such as the Manlius, the joints and grikes are very closely spaced (about 3 inches to 3 feet apart), resulting in small, unstable clints that are easily rotated by mechanical weathering to form a chaotic, unstable surface. Rainfall on a large area of limestone pavement insurges in a diffuse manner along the grikes, so that no surface streams can form. Also note the relative resistance of the Becraft fossils to weathering.

STOP 5 -- McFail's Hole area: groundwater insurgences, sinkholes, pits.

Follow the field road from the highway down and around the farmer's field and follow the path into the woodlot below. The features seen here are confluent groundwater insurgences that contribute water to Doc Shaul's Spring (Stop 3). Most of them are vertical shafts formed by the solutional enlargement of joints in the upper formations of the Helderberg Group (Figure 6). They are named for some of the original explorers who descended the pits in search of caves.

A large number of insurgences are closely clustered in this area. This clustering is caused by two phenomena:

a) The area is a window of limestone in the surrounding clastic and glacial cover. Limestone is exposed to solutional processes from water draining off the surrounding impermeable uplands. The streams flow radially into the area and sink in a number of separate insurgences that all unite in the subsurface along a single drainage path.

b) The large amount of recharge available from the impermeable catchment area, plus the large sediment load carried in from that area, has blocked many of the insurgences, causing the formation of overflow routes to secondary insurgences, which further increases the complexity of the insurgence pattern.

Note: Permission to enter this property must be obtained from the National Speleological Society, 1 Cave Avenue, Huntsville, Alabama 35810. Visitors must be accompanied by a local member of the N.S.S.

Referring to Figure 7, locate and examine each of the features discussed below.

1. Wick's Hole - a large, occluded insurgence receiving the combined flow of three intermittent streams that unite here. The bedrock exposed in the walls of the sinkhole is the Kalkberg Limestone. Note the washed-in vegetal matter and sediment, and the overflow route to the south.

2. McFail's Hole - a large pit insurgence formed by solutionally enlarged joints (Figure 6). It overlies directly the cave passage that drains this area. Formerly 90 feet deep, its lower 30 feet has become

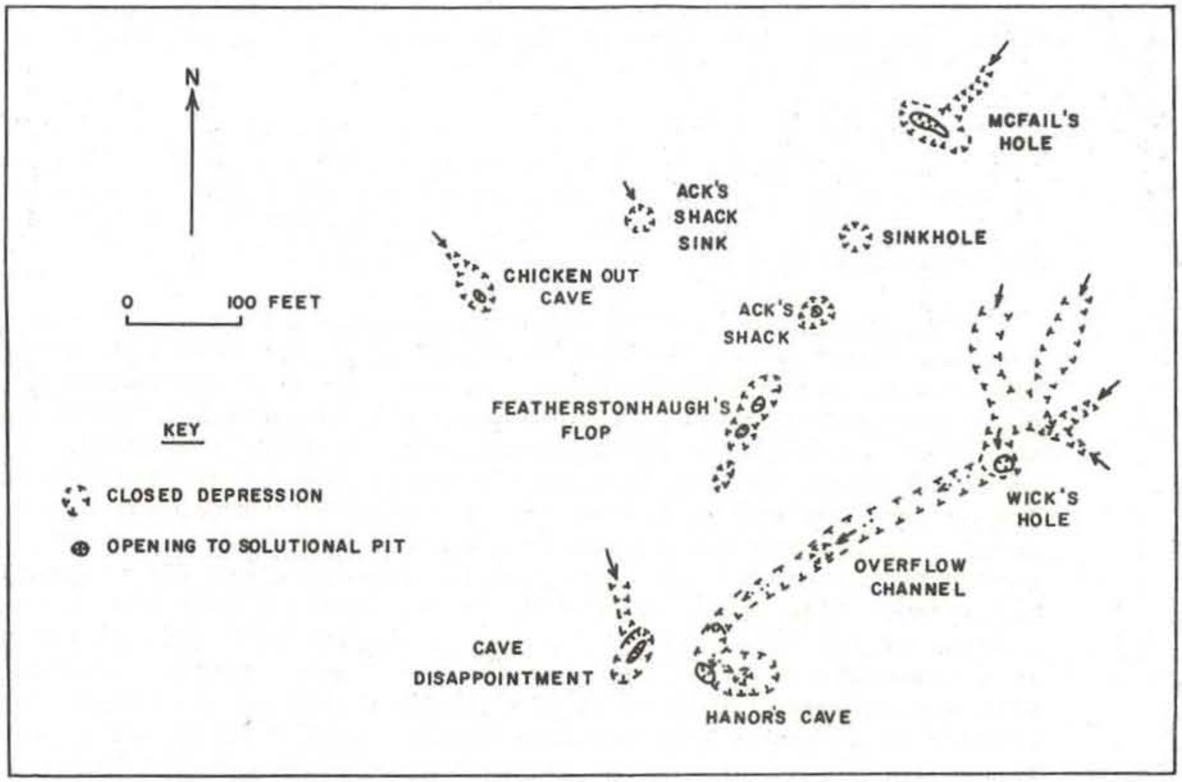


Figure 7 - Map of confluent insurgence points in the McFail's Hole area (Stop 5).

blocked in recent years by collapse material. The upper lip of the pit is in the Kalkberg Limestone, and the main part of the shaft is in the Coeymans Limestone.

3. Ack's Shaft - a pit insurgence 80 feet deep. It is narrower than nearby McFail's Hole, although it receives about the same flow of water. The water that utilizes this pit enters a small insurgence 200 feet to the northwest and flows to Ack's Shack through a shallow solution conduit about 10 feet below the surface. The water enters the wall of the pit near the top and descends to a narrow cave passage below. The top of the pit is an intersection feature, caused by the collapse of the 10 feet of rock directly over the pit. The upper part of the pit is formed in the Kalkberg Limestone, the lower part in the Coeymans and upper Manlius Limestones.

4. Cave Disappointment - a pit insurgence similar to McFail's Hole, fed by a perennial surface stream. This pit leads to a series of adjacent shafts, fissures, and low cave passages. The pit connects by way of these tributary routes to nearby Hanor's Cave. The pit is formed in the Kalkberg and Coeymans Limestones.

5. Hanor's Cave - an overflow pit insurgence for floodwater overflowing from Wick's Hole. Hanor's Cave transmits this water to Cave Disappoint-

ment. The cave, developed in the Kalkberg and Coeymans Limestones, fills to the ceiling with water during floods.

6. Walking north up the stream bed that feeds Hanor's Cave, note the solutional enlargement of joints in the exposed bedrock. Continue north to Wick's Hole, then follow the path <u>around</u> the field to the vehicles.

<u>STOP 6</u> -- Howe Cave Quarry.

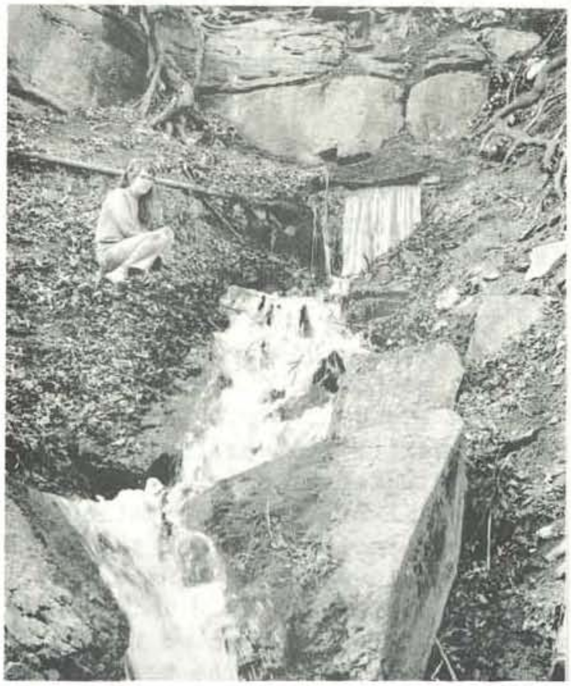
Stop along the road at the northeastern edge of the quarry. The Coeymans Limestone is exposed in the ditch on the west side of the road. Glacial striae can be seen on the rock surface, presently undergoing destruction by solution. Solutional denudation rates as much as a foot per 1000 years are common in karst areas (Sweeting, 1973). Cross the ditch (to the west) and climb to the top of the dirt ridge <u>but no farther</u>, and look down into the quarry. The quarry floor is located within the lower Manlius Limestone, and the quarry walls are formed by the middle and upper Manlius Limestone and the Coeymans Limestone. Note the thin bedding of the Manlius, compared to the thick bedding of the overlying Coeymans. On the far west wall of the quarry is a low-angle reverse fault (dipping 14 degrees south, striking N75°W) with approximately 1½ feet of displacement (Figure 8). It is subsidiary to a larger bedding-plane thrust located below the quarry floors, best seen within the natural-cement mine located beneath the quarry, which contains large gash veins of strontium and barium minerals (40 feet long, 3 feet wide, and 8 feet high) associated with the faulting.

Many of the joints near the top of the quarry wall are solutionally enlarged but become narrower with depth. The Howe Caverns master cave once crossed the area now occupied by the quarry, from west-northwest to east-southeast, but has been truncated by the quarrying operations. The western section of the cave extends through the salient of limestone that juts into the quarry from the west wall. The actual cave opening, located along the northeast wall of this salient, is obscured by quarry debris, as is the corresponding opening in the eastern wall of the quarry. A drainage tunnel has been dug into the cave from the south side of the salient, draining the cave water across the quarry floor to an artificial shaft in the middle of the quarry, which carries the water into the cement mine below.

<u>STOP 7</u> -- Gravity springs and openings to cement mine.

Park just west of the small bridge over the stream. At the bridge, look upstream at two grated openings, one rectangular and the other rounded in cross section. (Do not attempt to enter any of the features described in this stop; view from shoulder of road only.) This is the resurgence point for the water in Howe Caverns that was seen to flow across the quarry floor at Stop 6. These openings apparently represent the original, natural solutional resurgence for Howe Caverns, now altered by mining. The bedrock ledges exposed are the Rondout Dolomite, which has been mined as a "natural cement" (Cook, 1906). The Rondout

Figure 8 - West wall of the Howe Cave Quarry (Stop 6), showing thin-bedded Manlius Limestone in the lower third, overlain by thicker bedded Coeymans Limestone. A low-angle thrust fault can be seen dipping to the left (south-southwest), with a displacement of slightly more than a foot.



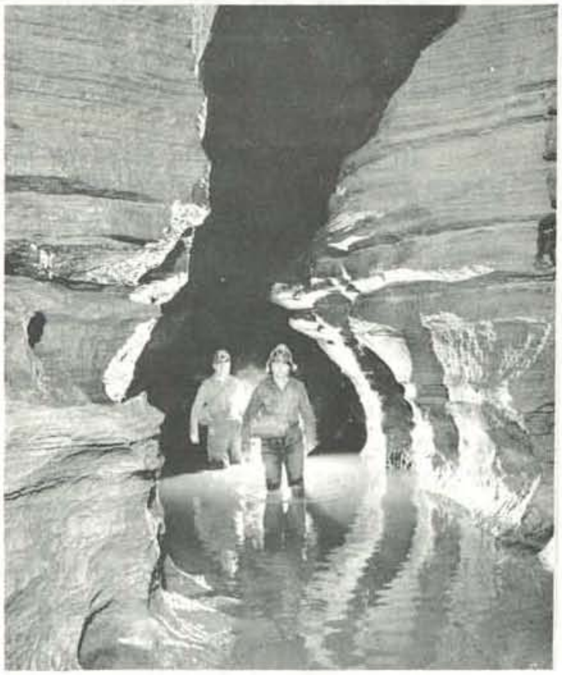


Figure 9 - Nameless Spring, a partly dammed gravity spring in the northern wall of the Cobleskill valley (Stop 7).

Figure 10- Typical cave passage (non-commercial variety) in the Howe Caverns area, developed within the thin-bedded Manlius Limestone. This is a typical canyon passage formed by a free-surface cave stream that has incised below the original solution conduit.

contains the Silurian-Devonian boundary in this part of New York State (Rickard, 1975). Proceding downhill (west), two more rectangular openings are seen. These also are openings to a cement mine in the Rondout. Farther downhill, the small ledge of thick-bedded rock is the type section of the Cobleskill Limestone. About 9 feet of Cobleskill Limestone occurs here, overlain by the Rondout Dolomite and underlain by the Brayman Shale.

Farther down the road on the north side is a small resurgence, Nameless Spring, a gravity spring in the Cobleskill Limestone (Figure 9). This spring has been dammed as a water supply. The small erosional re-entrant in the valley wall where the spring emerges is called a spring alcove. Immediately west of Nameless Spring is Nameless Spring Cave, an overflow spring for Nameless Spring. This cave is developed at the Rondout/Cobleskill contact and carries water only in flood times. Because of the larger spring alcove at the cave, it is possible that Nameless Spring is a fairly recent tapoff from Nameless Spring Cave.

STOP 8 -- Howe Caverns.

Park at the Howe Caverns parking lot and enter the lodge as a group. If the party is sufficiently large, it is possible to be admitted to the cave at the half-price group rate. (Advance notice must be given in order to receive group rates.)

In the following discussion, refer to Figure 11 for locations and place names in Howe Caverns. The elevators into Howe Caverns occupy an artificial shaft to the cave. The original entrance is located immediately southeast of the quarry seen at Stop 6. The elevators descend roughly 160 feet to the cave. Howe Caverns consists of a large master cave passage flowing southeast nearly parallel to the regional strike, with water contributed by dip-oriented tributary passages that enter from the north. Leaving the elevator, an abandoned passage (the West Passage) is seen to the left through the concrete portal. Although it once drained much of the Cobleskill Plateau farther west, it no longer carries a stream. It is terminated after a few hundred feet by collapse where it approaches the wall of a surface valley. This passage apparently formed prior to the incision of the valley that now truncates it. Straight ahead from the elevators is a natural chamber with an artificial tunnel heading north from it. This tunnel connects to the rear of the Winding Way and was constructed to provide a loop passage for smoother flow of tourist traffic. The tour follows the natural cave passage to a major junction. To the left, in the floor, a stream enters and follows the main cave to the southeast. Ahead and to the left is the entrance to a long tributary passage, the Winding Way, which will be discussed in detail later. The tour follows the main passage to the right. This passage is a large conduit composed of two basic parts: a large oval tube, 20 to 30 feet wide and 15 to 20 feet high, with a deep canyon cut in its floor, 6 to 12 feet wide and 10 to 15 feet deep, formed by entrenchment of the cave stream beneath the tube level (see Figure 10). The solutional ceiling is

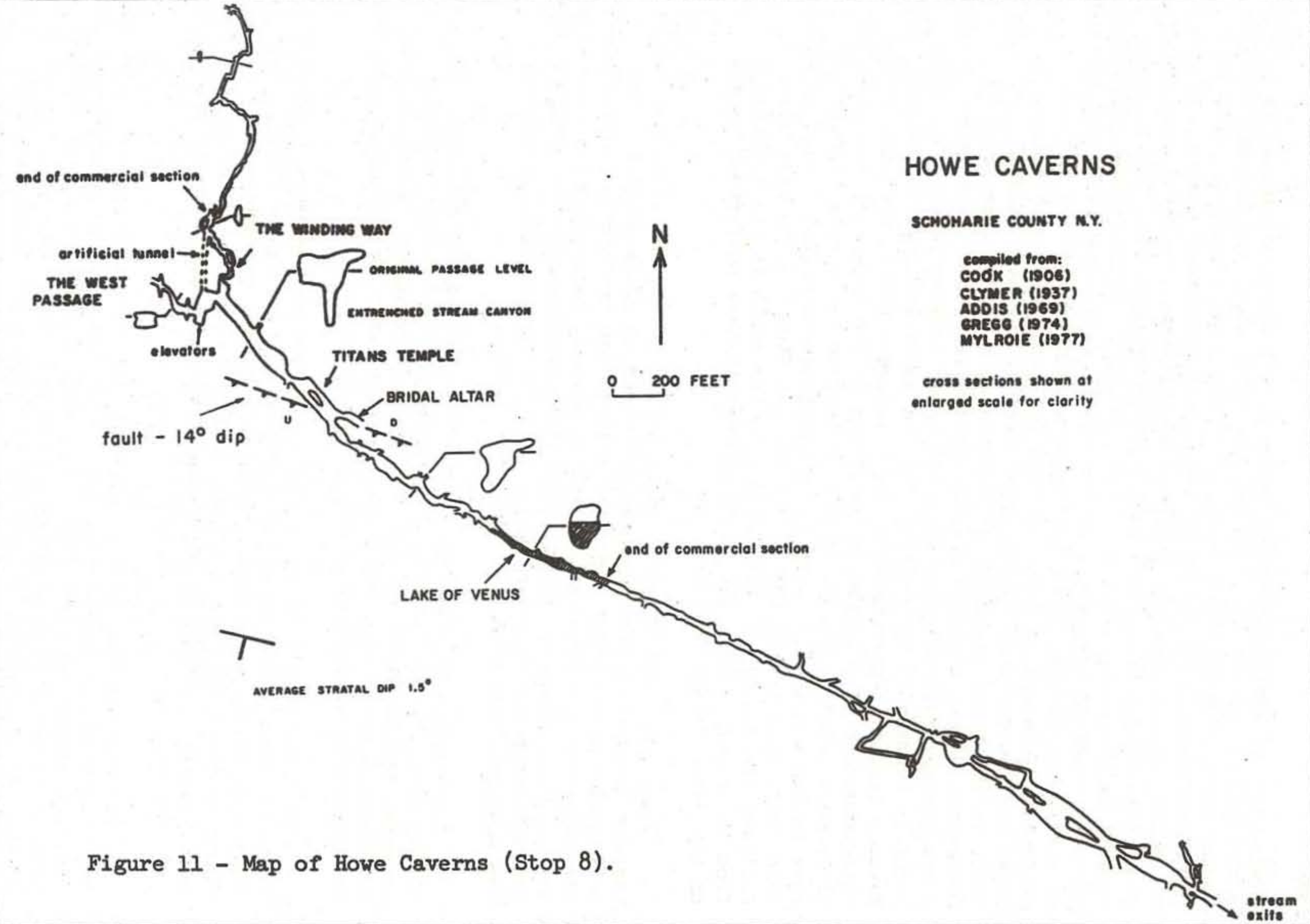


Figure 11 - Map of Howe Caverns (Stop 8).

located at the Coeymans/Manlius contact, and the cave passage is located in the Manlius Limestone. The ceiling rises above the Coeymans/Manlius contact only in areas where ceiling collapse has occurred. Note the difference between the smoothly sculptured solutional ceilings and the rough, planar ceilings produced by collapse. The cave continues downstream over a bridge and past a large collapse area to the largest chamber in the cave, known as Titan's Temple. In this chamber, evidence for each stage of the cave's origin can be seen. The passage originated as a solution conduit along the Coeymans/Manlius contact and was eventually enlarged by solution into the large tube with elliptical cross section now seen as the upper half of the main passage. At some point in the past, probably in response to a drop in the level of Cobleskill Creek, the cave stream cut downward to a lower level, forming a new passage that diverged from the upper tubular level. The upper level is terminated by sediment fill a short distance to the east of Titan's Temple. Upstream from the divergence point, the cave stream entrenched the deep canyon in the floor of the tube. At the point of divergence between the two levels, a reverse fault cuts through the cave having a dip of 14 degrees to the south-southwest. This is the same fault observed in the quarry wall at Stop 6. The cave water followed the dip of the fault plane to the south in its divergence from the upper level. The fault appears to have no further impact on the cave (Gregg, 1974).

Downstream from Titan's Temple in the lower, active level, the cave passage is generally rectangular or arched in cross-section. The rectangular areas occur where the thin-bedded and highly jointed Manlius Limestone has collapsed along bedding planes, destroying the curvilinear shape of the passage. Joints contribute small amounts of infiltrating water through the ceiling in this part of the passage, forming many stalactites aligned in rows along the joints.

A few small side passages enter this section of the cave. They are of two basic types: abandoned upper levels or loops of the main passage, and abandoned or active tributary passages. Nearly all the tributaries enter from the north, feeding water to the master cave from insurgence areas located in the up-dip direction.

The cave stream is ponded midway in the main passage, forming the "Lake of Venus" and causing alluviation of the bedrock floor. The boat ride on the lake demonstrates some of the explorational difficulties found in caves that are partially flooded. The Lake of Venus has been artificially deepened by the construction of a small dam at the end of the tourist route.

Returning along the main passage, the tour then enters the Winding Way. Although it is normally dry, water pours out of this passage into the main stream during floods. The Winding Way is a classic example of what is called a canyon passage, high and narrow with many twists and turns. As the passage is followed up-dip, the ceiling gradually ascends. The upper part meanders back and forth over the lower level of the canyon. The ceiling of the Winding Way cuts discordantly downward across the strata to merge in a graded manner with the solutional ceiling of the master cave. The discordant ceiling results from the transmission of water to the master conduit from stratigraphically higher insurgences.

The artificial tunnel branching from the Winding Way leads the tour back to the elevators. Notice the obvious difference between the solutional walls of the Winding Way and the blasted walls of the tunnel. Near its southern end, the tunnel intersects a large natural chamber. Along the east (left) wall of this room are some interesting calcite deposits (informally called "lilypads"). They mark the former water surface of a stagnant pool of water that was supersaturated with respect to calcite. Several different pool levels can be discerned, and some dogtooth spar is visible in places below the levels of the former water surfaces. Also along the east wall of this room is a solutionally enlarged fissure, 40 feet high, that extends nearly to the surface. This fissure is a source for the mud, water, collapse material, and glacial debris seen at this location. Cross the bridge, enter the elevator, and return to the surface.

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ROAD LOG FOR KARST FIELD TRIP

Miles from last point	Cumulative Miles	
0.0	0.0	STOP 1 - intersection of Routes 7, 145 and Mineral Springs Road; view of Cobleskill Plateau. From here, head west on Route 7 to
0.7	0.7	Barnerville Road; turn right on Barnerville Road. Note drumlins to the west, resistant limestone benches to the east. Continue on Barnerville road past Cobleskill Creek on the left (north) to
0.6	1.3	STOP 2 - Barnerville Methodist Church; view of Cobleskill Creek valley. From here, cross over Cobleskill Creek, heading north. Bear left at intersection immediately beyond Cobleskill Creek, and continue to
1.0	2.3	Railroad tracks. (Notice drumlins ahead and to left). Cross tracks and continue to
0.6	2.9	Intersection with Meyers road, which enters from the right (east). Bear left, continue to
0.2	3.1	STOP 3 - Doc Shaul's Spring (at road intersection). Observe spring from the south side of the road, but don't leave the road. From here, follow side road north (uphill) to
0.6	3.7	Intersection. Turn right (east) and continue to
0.6	4.3	Intersection. Bear left, following main road; continue to
0.5	4.8	STOP 4 - Bare limestone pavements on either side of road. Do not stray too far into the fields. From here continue north
0.6	5.4	Pass road on left; continue northeast.
0.2	5.6	Pass Runkle Cave (its resurgence can be seen across the field to the left (west), continue northeast.
0.6	6.2	Pass dirt road on left, turn left onto paved road at next intersection. Continue north to
0.4	6.6	STOP 5 - McFail's Hole area (confluent insurgences). Park cars along road, follow

Miles from last point	Cumulative Miles	
		the field road on foot from the paved road down and around the farmer's field, and follow the path into the wood lot beyond. Note: permission to enter this property must be obtained from the National Speleological Society, 1 Cave Avenue, Huntsville, Alabama 35810. Visitors must be accompanied by a local member of the N.S.S.
0.4	7.0	T-intersection. Bear left (east), continue east to
0.3	7.3	Intersection. Bear right (south), continue to
1.3	8.6	Myers Road on right; continue past this road to
0.2	8.8	Lawton Road on the left; continue past this road to
0.5	9.3	Crossroads (Sagendorf Corners). Continue straight through this intersection to the south, to
0.9	10.2	Robinson Road on the left. Continue past this road to
0.2	10.4	STOP 6 - Howe Cave Quarry on right (west). On foot, cross ditch to west and climb to top of dirt ridge to view quarry, but no farther. Return to cars, continue south to
0.3	10.7	Crossroads. Proceed straight (south) to
0.1	10.8	Railroad tracks. Cross tracks and turn sharp right to the west, past the small town of Howes Cave to
0.4	11.2	STOP 7 - (Gravity springs and cement mine) at "Fallen Rock" sign and small bridge over stream, just past large building on the north side of the road. From here continue west on road to
0.7	11.9	Bridge over Cobleskill Creek. Continue to
0.1	12.0	T-intersection. Turn right (north), following the Howe Caverns signs.
0.4	12.4	Re-cross Cobleskill Creek. Continue to
0.4	12.8	T-intersection. Turn right (north), and continue to

Miles from last point	Cumulative Miles	
0.1	12.9	Railroad overpass. Make an immediate right turn beyond the overpass onto the Howe Caverns Estate, STOP 8 - Take tour of Howe Caverns. Because of the large parking area, mileages back and forth along the Howe Caverns driveway will vary. Return mileages are calculated from the end of the Howe Caverns driveway at the railroad overpass. Return under the railroad overpass to the southwest and on to
0.2	0.2	Intersection. Bear right (southwest), and continue to
1.0	1.2	Intersection with Barnerville Road. Turn left (south) onto Barnerville Road, re-cross Cobleskill Creek, and continue on to
0.7	1.9	Route 7. From here parties may return to Oneonta by taking Route 7 southwest (to the right), or may go their own way. Albany is to the left (northeast).

SEDIMENTOLOGY AND PALEONTOLOGY OF PORTIONS OF THE HAMILTON GROUP IN CENTRAL NEW YORK

by

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INTRODUCTION

The richly fossiliferous marine sedimentary rocks of the Middle Devonian Hamilton Group of Central and Western New York (fig. 1) have been the object of paleontologic, sedimentologic and stratigraphic studies for nearly 150 years. The purpose of this field trip is to introduce participants to various lithofacies and faunal assemblages which characterize the upper portion of the Hamilton Group in the area of its type section. We further hope that observation and discussion of sedimentary structures, lithologies and fossil occurrences in field exposures will illustrate the excitement and frustration inherent in paleoenvironmental interpretation.

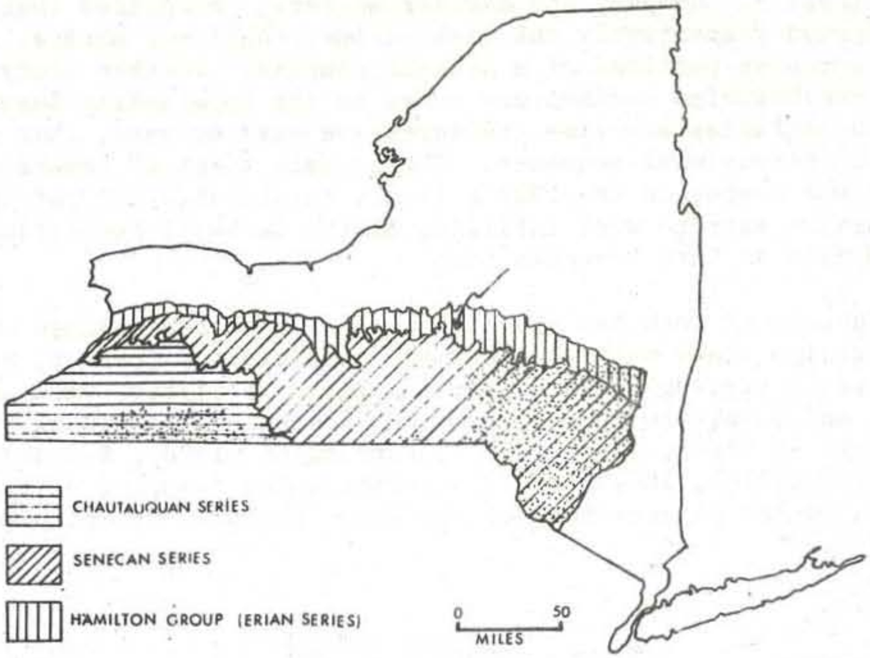

Fig. 1 - Distribution of Middle and Upper Devonian terrigenous clastic sedimentary rocks in New York State. Arrow indicates study area. (after Rickard 1975)

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PREVIOUS WORK

A list of early workers in Middle Devonian stratigraphy and paleontology of New York is graced by such eminent names as Hall, Clark, Prosser, Grabeau, and Cleland. These investigators recognized the major lithostratigraphic sequences of the Devonian and described the fauna, setting the stage for subsequent work. The studies of these men in the 1800's and early 1900's were carried out along strike of the major units. It was soon recognized that the faunal zones and prominent mappable strata that were easily recognizable in the western and central portions of the state were lost in less differentiable rocks to the east.

The work of G. Arthur Cooper in the late 1920's and early 1930's culminated in the definition of four formations which have since served as the basis for study of the Hamilton Group. Cooper (1930, 1933) based his subdivisions on three thin, but persistent limestone units which interrupted the terrigenous clastic sequence. Cooper further noted the existance of four major facies within the Hamilton Group: A "Marcellus" facies, consisting of dark shales with small, thin-shelled brachiopods and bivalves: a "Moscow" facies, consisting of blue-grey calcareous shales with an abundant and diverse marine fauna; a "Hamilton" facies, characterized by silty shales, siltstones and sandstones, bearing large brachiopods and bivalves; and a "Catskill" facies, consisting of red and green shales, siltstones and sandstones, often bearing non-marine plant fossils. Cooper, and earlier workers, recognized that these facies represented respectively the deep marine, shallower marine, transitional and non-marine portions of a deltaic complex. Further study of Middle and Upper Devonian sedimentary rocks in the Appalachian Basin revealed that these facies are time transgressive east to west, thus representing a large regressional sequence. The classic "facies" papers of Chadwick, Caster and Cooper in the 1920's firmly established the pattern of progressive east to west infilling of the Catskill depositional basin from Middle to Late Devonian time.

Subsequent work has shown that the faunal assemblages which characterize these major facies, and subdivisions thereof, are explicable in terms of varying water depth, turbidity, salinity, wave and current energy and substrate rheology in the original depositional environment. The works of Grasso (1970, 1973), Harrington (1970), Sutton, Bowen and McAlester (1970), Thayer (1973) are but a few examples of recent studies concerning the paleoecology of Mid-Upper Devonian deltaic sediments in New York.

TECTONIC SETTING

The paleotectonic regime of Mid-Upper Devonian time suggests that in the New York State region clastic sediments were shed from the rejuvenated Taconian mountains, uplifted during "Phase II" of the Acadian orogenic event. The miogeosynclinal basin which received these sediments was a rapidly subsiding downwarp on the edge of the continental crust. It is most probable that this basin formed as a result of isostatic adjustment to uplift to the east, in present-day New England. The

Catskill basin would therefore have formed via a "sea floor inversion" -- a process directly analogous to that described by Bird and Dewey (1970) for the Mid-Upper Ordovician of New York, resulting from the Taconian Orogenic event.

Devonian sedimentary rocks were deformed by the Alleghenian event in southeastern New York and adjacent Pennsylvania. This orogeny had only minor effect on the rocks of central New York. The only evidence of tectonic disturbance is a regional dip of 60-100 feet per mile (based on Skaneateles-Ludlowville contact) and a series of joints of unknown origin.

STRATIGRAPHY IN THE STUDY AREA

The Hamilton Group sediments in the Chenango Valley outcrop along the glaciated valley walls and in stream sections perpendicular to the north-south major valleys. More resistant sandstones and sandy limestones form caprocks of waterfalls in tributary streams. Excellent exposures of most of the units are also available in quarries and burrow pits excavated for road fill.

In all of New York State, the basal Hamilton Group sediments of the Marcellus Formation overly the Onondaga Limestone, apparently in a conformable fashion. In the study area the Marcellus formation consists of a basal black shale (Union Springs Member), succeeded by a black, cephalopod-bearing limestone (Cherry Valley Member), sandy shales (Bridgewater Member), sandy shales and siltstones (Solsville Member), and sandy shales, siltstones and sandstones (Pecksport Member).

The Skaneateles formation is made up of a basal thin shaley limestone (Mottville = Stafford Member to west) overlain by sandy shales and sandstone (Delphi Member), black shales and sandy mudstones (Pompey Member), dark sandy shales (Berwyn Member), a fine grained sandstone with blue-gray sandy shales (Chenango Member - Colgate sandstone of Cooper (1930)), and a capping thin, discontinuous crinoidal limestone (Stone Mill Member, probably equivalent to the Centerfield Limestone further to the west).

The Ludlowville of the study area was undifferentiated by Cooper, consisting in general of grey shales and sandy shales with one thick (15-20') sandstone unit. The stratigraphy of the Ludlowville in the Chenango Valley is presently under study by the authors.

The Moscow formation consists of a thin basal calcareous sandstone (Portland Point Member) overlain by a thick unit of dark grey sandy shales and siltstones (Windom Member). A summary stratigraphic column for the Chenango Valley is shown in fig. 2.

The overlying Tully Limestone marks the Middle-Upper Devonian boundary in this region. In the Chenango Valley, the Tully is characterized by thin beds of limestone with interbedded silty and sandy shales. This

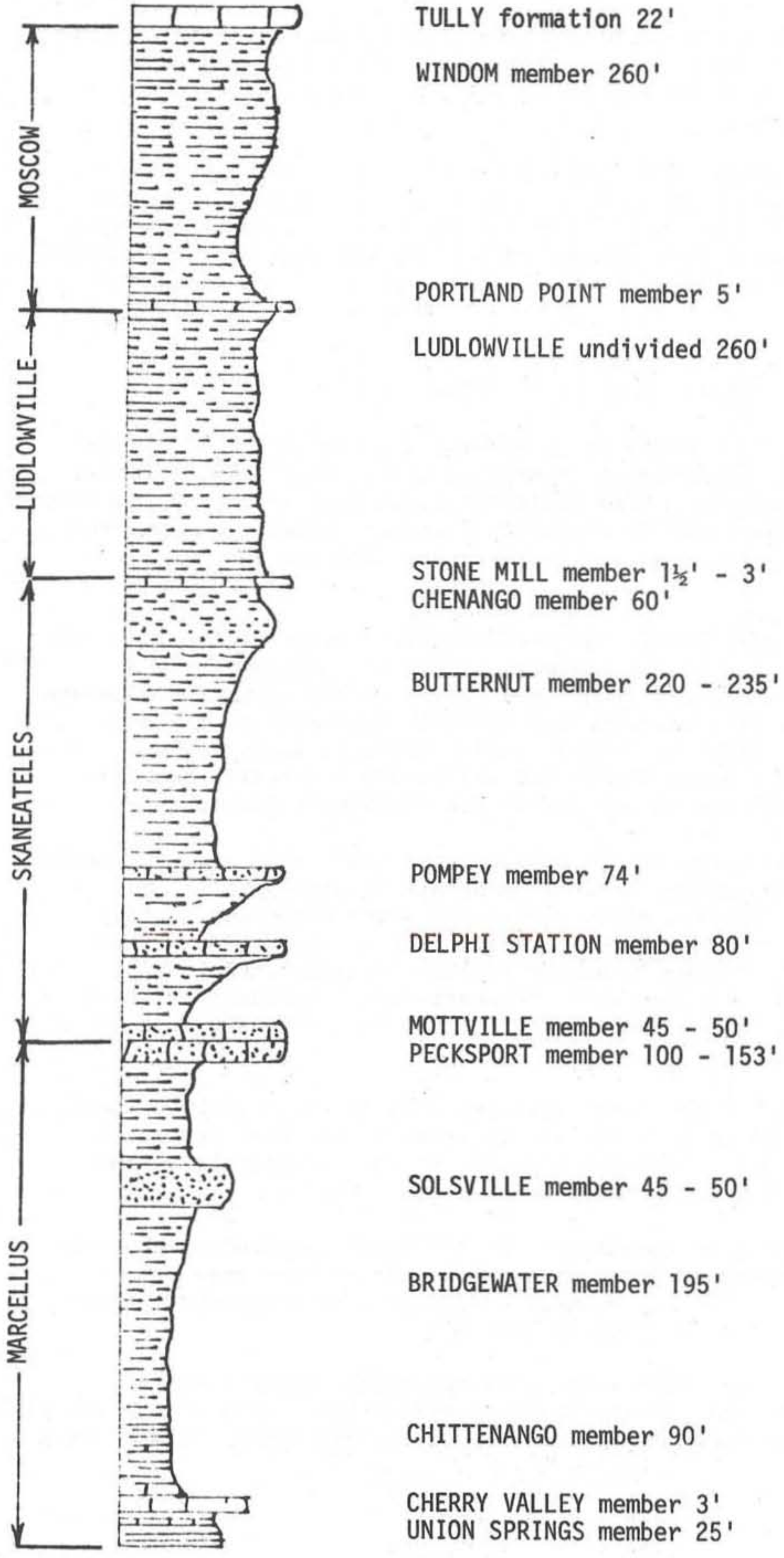

Fig. 2 - Stratigraphy of the Hamilton Group in the Chenango Valley

Adapted from G. A. Cooper (1930)

unit thickens into clastic correlatives to the east (Johnson and Friedman 1969), but thins and disappears into an erosional interval to the west (Rickard 1975).

SEDIMENTOLOGICAL FEATURES

To the casual observer, the shales, siltstones, and fine-grained sandstones of the Hamilton Group in Central New York are a rather monotonous series of rocks. The more spectacular primary structures characteristic of shallow water limestone and coarse-grained sandstones are generally absent, and the fine-grained texture of most lithologies precludes simple thin-section examination. However, a number of useful primary and penecontemporaneous features can be discerned upon careful observation. These structures may often then be used for paleoenvironmental interpretation. A list of common features of interest to the sedimentologist follows.

Primary Structures

(1) Crossbedding - Many of the fine-grained sandstones of the Hamilton Group contain trough crossbedding and ripple laminations. These features indicate wave or current transport of the sediment and paleocurrent directions.

(2) Scour and Fill - Truncation of earlier bedding and subsequent filling of depressions with sediment indicates current activity.

(3) Graded Bedding - Single thin siltstone or sandstone beds often contain size gradation from coarse to fine upward. Such grading is usually caused by a single depositional event, related to storm surges or perhaps turbidity currents.

(4) Ripple Marks - These structures indicate wave or current activity on the substrate.

(5) Biogenic Structures - Tracks and trails left by burrowing organisms are common in many lithologies in the Hamilton Group. In general, intense bioturbation of sediment results in loss of primary stratification and indicates conditions suitable for infaunal benthos (sufficient oxygen, stable substrate). Single vertical burrows often indicate that animals lived below the sediment for protection from waves and currents, whereas horizontal trails may indicate quieter water conditions where grazing was possible. The paleoenvironmental requirements of the organism responsible for the common "rooster-tail" structure called Taonorus will be discussed in the field.

(6) Slumping, Load Casting, Ball and Pillow Structures - These features indicate post-depositional instability in sediments. Usually differences in density of various sediment layers promote the plastic flow of water-rich sediment following deposition. Large-scale soft-sediment deformation may indicate deposition on an initial slope or might be caused by outside disturbances such as storms or earthquakes.

(7) Parting Lineation - In the Hamilton Group, this feature is found only in the sandstones. These faint parallel structures on bedding surfaces are caused by unidirectional current flow over the substrate.

(8) Intraclasts, Mud Chips - Clasts of partially indurated sediment may be ripped-up from the substrate, transported and redeposited. These clasts are usually chips of grey or green shale in the Hamilton Group, and are confined to the coarser (sandstone) lithologies.

(9) Groove Casts and Tool Mark Casts - Sole markings indicating current activity and paleocurrent direction.

THE FAUNA

Paleoenvironmental reconstructions based only on the physical and chemical characteristics of sedimentary rocks are, of course, incomplete. The use of fossil assemblages as representative paleocommunities is an integral part of interpretation of sedimentary environments. However, the significance of paleocommunity data is dependent to a great degree on the knowledge of life habits and thus environmental requirements of groups of organisms. This knowledge stems in part from study of analogous living organisms, coupled with detailed morphological study of fossil groups. Care must be taken in paleocommunity studies, especially in assuring that samples are representative of a fossil assemblage, not simply specimens selected by a biased collector searching for large or impressive fossils.

With some degree of certainty, major faunal elements in the Hamilton can be assigned to certain habitat/feeding groups. Each group has certain habitat requirements which may then be used to infer characteristics of the depositional environment. The following feeding types are recognized for the purposes of this study.

(1) Vagrant Herbivores and Carnivores - These organisms were capable of directed motion on the sea floor. Some may have been swimmers (nektonic). They may have been herbivores, carnivores or detritus feeders, and their only common environmental requirement is oxygenated water and a food source. Because of a lack of more specific habitat requirements, these organisms are not highly diagnostic of any particular set of original environmental conditions. For many elements in this group, preservational happenstance appears to be the most important control over presence or absence. This group includes the following Hamilton genera:

Gastropods: *Paleozygopleura*, *Bembexia*, *Ptomatis*, *Praematuratropis*, *Ruedemannia*
Trilobites: *Greenops*, *Phacops*, *Trimerus*
Cephalopods: *Orthoceras*, *Spyroceras*, *Tornoceras*
Asterozoa: *Devonaster*

(2) Epifaunal Filter Feeders - Attached to the substrate, or lying sessile upon it, this group was dependent on constant wave or current action to supply micro-organisms and organic matter, which they subsequently

filtered from the water. In general, the presence of members of this group indicates oxygenated bottom waters and sufficient water movement to provide food. However, large influxes of sediment, or extremely active current/wave conditions might have prevented colonization. This group is represented in the Hamilton by large articulate brachiopods such as Spinocyrtia, Mucrospirifer, Tropidoleptus and Devonochonetes; the smaller articulate brachiopods Ambocoelia and Chonetes; and the epibyssate bivalves Leiopteria, Pterinopecten, and Pseudaviculopecten.

(3) Infaunal Filter Feeders - Members of this group lived buried or partially buried below the substrate and filtered food from the overlying bottom waters. Bivalves such as Cypricardella, Leptodesma, Actinopteria, Goniophora and Modiomorpha were probably attached to the sediment by byssus (endobyssate habit, Stanley 1968). Other members of this group, such as the bivalves Orthonota and Cimitaria were likely capable of burrowing, as was the inarticulate brachiopod Lingula. In general, this group had environmental requirements similar to the epifaunal filter feeders, although the infaunal group was undoubtedly more tolerant to fluctuations in turbidity, temperature and salinity.

(4) Infaunal Deposit Feeders - This group consists of those organisms which fed on organic material contained in the sediment. As such they are often found in fine-grained shales deposited under rather quiet water conditions, because fine muds generally contain high concentrations of organic material. The palp-feeding bivalves Nuculites, Nuculoidea and Paleoneilo characterize this group.

(5) Turbidity-Intolerant Filter Feeders - This group, although not functionally separable from the epifaunal filter feeders, are sufficiently different (by analogy with modern groups) in turbidity tolerance to warrant attention. The organisms in this group required clear, well-oxygenated water, and were highly susceptible to sediment-clogging of their filter-feeding mechanisms. They are thus indicative of rather low rates of sediment influx and agitated water conditions. Examples from the Hamilton of the study area include the corals Microcyclus and Favosites, the bryozoans Sulcoretepora and Taeniopora and various crinoids.

Substrate Requirements

The lack of, or limitations of, attachment mechanisms in various sessile benthonic organisms may restrict certain groups to specific substrate types. For instance, the larger peduculate articulates such as Mucrospirifer and Mediospirifer were likely limited to firm substrates or those where shell material was available for attachment. In contrast, the spinose chonetids were well-adapted to a soft mud substrate, living snow-shoe-like on the soft bottom. The apparent lack of attachment mechanisms in the chonetids would preclude their existance in wave- or current-churned environments.

Species Density and Diversity

The density of a given species (number/unit volume of rock) is a rough indicator of the suitability of a given environment for that organism. However, one must use caution in interpreting such data, because preservational bias may selectively concentrate individuals of a given species.

Diversity refers to the numbers of different species found. Low diversity often indicates rigorous conditions which prevented the growth of all but a few species. High diversity generally indicates more suitable or less variable environmental conditions. Again, preservational bias may drastically change the original species diversity.

Fossil Occurrence

Fossils in all lithofacies of the Hamilton are found in two different types of occurrences; coquinite and non-coquinite assemblages. Coquinite assemblages occur within shell-rich lenses or stringers, whereas non-coquinite assemblages are characterized by single fossils more or less surrounded by sediment. Sutton, Bowen and McAlester (1970) speculated that the coquinite lenses of the Upper Devonian Sonyea Group of south-western New York were formed by the winnowing of finer sediment from previously deposited material, leaving a lag concentrate of shell material. Such winnowing of the substrate would have taken place during storm, spring tide or flood season situations.

Coquinite assemblages of the Hamilton Group appear to be of two types. One is similar to those described by Sutton, Bowen and McAlester (1970). These coquinites are seen at the base of large scours or channels and contain numerous disarticulated and broken shells. A second type of coquinite is commonly found in the dark silty shales of the Ludlowville and Moscow Formations. This type is characterized by concentrations of whole and articulated shells, with abundant small phosphate nodules. We theorize that this second type of coquinite represents a period of little or no clastic influx and a substrate inhabited by a dense benthic shelly fauna, with the phosphate nodules forming penecontemporaneously during the depositional hiatus. This second type of coquinite often contains small specimens of the colonial coral Favosites perhaps indicating low rates of clastic influx.

Faunal Lists

The faunal lists which follow are included to assist the collector in identification of specimens from the four major collecting stops. They are partial and generally include only the more common species at each locality. More detailed discussions of faunal distribution and abundances are included in the stop descriptions contained in the road log.

Faunal Distribution

Faunal counts to date are included in the description of each stop in the road log. Hopefully, their inclusion will provide a basis for substantive discussion in the field.

PARTIAL FAUNAL LIST - BRIGGS ROAD

Brachiopods

Ambocoelia umbonata
Mucrospirifer mucronatus
Spinocyrtia granulosa
Devonochonetes coronatus
Chonetes scitula
Tropidoleptus carinatus
Athyris sp.
Rhipidomella penelope
Schuchertella peruersa
Elita fambriata
Pustulatia pustulosa
Protoleptostrophia perplana
Stropheodonta demissa
Camarotoechia congregata

Molluscs
Bivalves

Paleoneilo muta
P. emarginata
P. plana
P. maxima
Nuculoidea lirata
N. bellistriata
N. varicosa
Cimitaria recurva
C. corrugata
Cypricardella bellistriatus
Nuculites triqueter
Grammysia arguata
G. alueata
Grammysia sp.
Leiopteria deskayi
Leiopteria sp.
Actinopteria decussata
Sanguinolites solenoides
Limoptera macroptera
Goniophora rugosa
Pterinopecten vertumnus
Parallelodon hamiltonae

Gastropods

Bembexia sp.
Ptomatus patulus
Paleozygopleura hamiltonensis

Cephalopods

Spyroceras crotalum
Tornoceras sp.
"*Orthoceras*" sp.

Arthropods

Greenops boothi
Phacops rana
Trimeris dekayi

Bryozoa

Fenestella sp.
Taeniopora exigua
Sulcoretopora sp.

Miscellaneous

Pelmatozoan debris

PARTIAL FAUNAL LIST - GEER ROAD

Brachiopods

Spinocyrtia granulosa
Mucrospirifer mucronatus
M. consobrinus
Mediospirifer audaculus
Ambocoelis umbonata
Athyris subtilita
Athyris sp.
Tropidoleptus carinatus
Schuchertella cf. *perversa*
Chonetes scitula
Chonetes sp.
Rhipidomella penelope
R. oblata
Protoleptostrophia perplana
Leptaena sp.
Stropheodonta sp.

Molluscs
Bivalves

Grammysia secunda
G. arcuata
Modiomorpha concentrica
M. regularis
Cypricardella sp.
Mytilarca gibbosa
Paracyclas elliptica
Nuculoidea corbuliformis
N. lirata
N. varicosa
Paleoneilo maxima
Leiopteria conradi
Pholadella radiata
Parallelodon hamiltonae

Gastropods

Ruedemannia trilex
Ptomatis leda
Loxonema delphicola

Cephalopods

Spyroceras crotalum
"*Orthoceras*" sp.

Arthropods

Greenops boothi

Coelenterates

Favosites sp.
Aulopora tubaeformis

Bryozoa

Fenestella sp.

PARTIAL FAUNAL LIST - PIERCEVILLE QUARRY

LUDLOWVILLE FORMATION, HAMILTON GROUP

Coelenterata

Aulopora elleri
Favosites sp.

Bryozoa

Sulcoretepora incisurata

Brachiopods

Petrocrania hamiltoniae
Lingula punctata
Lindstroemella aspidium
Mucrospirifer mucronatus
Spinocyrtia granulosa
Mediospirifer audaculus
Ambocoelia umbonata
Athyris spiriferoides
Tropidoleptus carinatus
Rhipidomella penelope
Protoleptostrophia perplana
Devonochonetes coronatus
Longispina mucronatus
Devonchonetes syrtalis
Chonetes vicinus
Spinulicosta spinulicosta
Cyrtina hamiltonensis
Elita fimbriata

Molluscs
Bivalves

Solemya vetusta
Orthonota undulata
Grammysia bisulcata
G. arcuata
G. cuneata
G. globosa
Nuculoidea corbuliformis
N. opima
N. lirata
Nuculites oblongata
N. triqueter
Palaeoneilo constricta
P. emarinata
P. fecunda
P. muta
P. plana
Parallelodon hamiltoniae
Ptychopteria (Actinoptera) decussata
A. boydi
Ptychopteria (P.) flabellum
Leptodesma (Leiopteria) sayi
L. rafinesquii
Pseudaviculopecten fasciculatus
Lyriopecten macrodontus
Pterinopecten undosus
Modiomorpha cencentrica
M. mytiloides
Pholadella radiata
Cypricardella tenuistriata
Cimitaria recurva
Goniphora hamiltonensis

Gastropoda

Ptomatis rudis
Naticonema lineata
Palaeozygopleura hamiltoniae
Ruedemannia trilix
Platyceras sp.
Dictyotomaria capillaria

PIERCEVILLE QUARRY (continued)

Cephalopoda

<u>Tornoceras</u> <u>discoidea</u>
"<u>Orthoceras</u>" sp.
<u>Spyroceras</u> <u>crotalum</u>

Hyolithida

<u>Hyolithes</u> <u>neapolis</u>

Tentaculitida

<u>Styliolina</u> sp.

Arthropoda

<u>Greenops</u> <u>boothi</u>
<u>Phacops</u> <u>rana</u>
<u>Dipleura</u> <u>dekayi</u>
<u>Echinocaris</u> <u>punctata</u>
<u>Rhinocaris</u> <u>columbina</u>

Annelida

<u>Taonurus</u>

Plants

<u>Protolepidodendron</u> sp.

PARTIAL FAUNAL LIST - DEEP SPRING ROAD

Brachiopods

Mucrospirifer mucronatus
M. consobrinus
Chonetes scitula
Athyris subtilita
Athyris cora
Athyris sp.
Devonochonetes syrtalis
Protoleptostrophia perplana
Ambocoelis umbonata
Mediospirifer audaculus
Spinocyrtia granulosa
Tropidoleptus carinatus
Rhipidomella penelope
Camarotoechia sp.
Rensselandia sp.

Molluscs
Bivalves

Nuculoidea lirata
N. bellistriata
N. randalli
N. corbuliformis
Paleoneilo muta
P. constricta
P. emarginata
Cypricardella bellistriata
Prothyris lanceolata
Nuculites oblongatus
Pholadella radiata
Leiopteria dekayi
Actinopteria sp.
Parallelodon sp.
Tellinopsis subemarginata
Pterinopecten vertumnus
Modiomorpha mytiloides
Orthonata carinata
Actinodesma erectum
Modiella pygmaea
Goniophora hamiltonensis

Gastropods

Ptomatis leda
Praematuratropis ovatus
Ruedemannia trilex
Dictyomaria capillaria
Platyceras carinatum
Loxonema hydraulicum
Loxonema cf. *laeviusculum*
Loxonema sp.

Monoplacophorans

Cyrtonella pileolus

Cephalopods

Spyroceras crotalum
"*Orthoceras*" sp.

Arthropods

Greenops boothi

Bryozoa

Taeniopora exigua

DEEP SPRING ROAD (continued)

Incertae Sedis
Hyolithidae

Hyolithes aclis

Coleolidae

Coleolus tenuicinctum

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ROAD LOG

Cumulative Mileage	Mileage from last stop	Location
0.0	0.0	Entrance to village of Hamilton, NYS Route 12B, heading north.
0.20	0.20	College Street entrance to Colgate University campus, turn right (east).
0.55	0.35	Intersection by Administration Building; turn right (south). Proceed up hill.
0.80	0.25	Second right; turn right (southwest).
1.10	0.30	Circular drive, park on grass. Walk east up entrance road to Colgate University quarry (approx. 450 yards).

<u>Stop #1</u>. Colgate Quarry - Chenango Sandstone (Upper Skaneateles Formation).

Remarks: Most of the buildings of Colgate University are constructed of the thin- to medium-bedded, fine grained Chenango sandstone (= Colgate sandstone of Cooper, 1930) exposed here. A series of nearly perpendicular vertical joints made quarrying a rather simple process.

Noteworthy feature, here are the large slump structures in the lower portion of the exposure. The fauna is largely dominated by <u>Tropidoleptus</u>, Mucrospirifer and numerous epifaunal and semi-infaunal bivalves. The asterozoan Devonaster has been reported, but is quite rare.

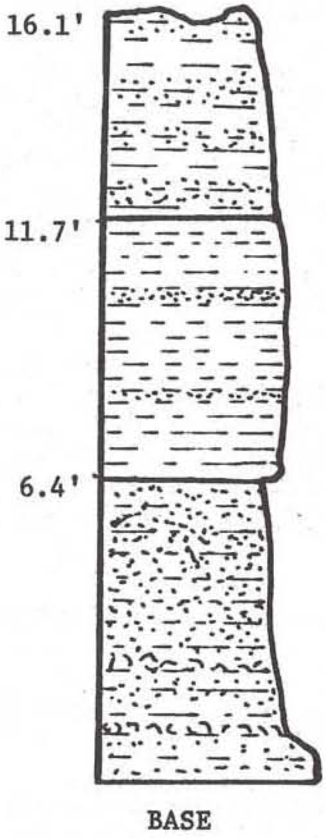
Return to Cars.

Cumulative Mileage	Mileage from last stop	Location
1.10	0.0	Return to NYS Route 12B.
1.95	0.85	Intersection with NYS Route 12B - cross NYS Route 12B, proceed west on College Street.
2.50	0.55	Intersection with Lebanon Street (becomes Hamilton Road). Turn left (south).

Note: Field trip begins at southern village limits, Hamilton, New York, on NYS Route 12B, heading north. Mileage to nearest 0.05 odometer miles.

4.15	1.65	Hamlet of Randallsville - bear right (west) at intersection. Continue west on Hamilton Road.
4.40	0.25	Intersection with River Road - turn left (south).
4.90	0.50	Intersection with Briggs Road - turn right (west).
6.45	1.55	<u>Stop #2</u>. Briggs Road Quarry - upper portion of Ludlowville Formation. (Description on following page.)
6.45	0.00	Continue SW on Briggs Road.
7.00	0.55	Intersection with Lebanon Center Road - turn right (west).
7.70	0.70	Intersection with Bastian Road - turn right (north).
8.05	0.35	Intersection with Reservoir Road - continue north (bear right).
8.50	0.45	Intersection with Lebanon Hill Road - continue north (bear left).
9.15	0.65	Intersection with Geer Road - turn left (west).
10.10	0.95	Quarry entrance - small dirt road on right. Park on shoulder, walk north approximately 150 yards. <u>Stop #3</u>. Geer Road Quarry - upper portion of Ludlowville Formation. (Description on following page.) Remarks: This quarry provides an opportunity to observe and contrast the two types of coquinites which are characteristic of the Hamilton in this region. Approximately 2.1 feet from the base of the section a phosphate nodule-bearing coquinite is exposed. A similar bed is present at 14.2 feet. Other (storm lag ?) coquinites are scattered throughout the section, especially from 15.5 to 20 feet in the section.
10.90	0.80	Intersection with Bradley Brook Road - turn right (north).

STOP #2 -- BRIGGS ROAD QUARRY

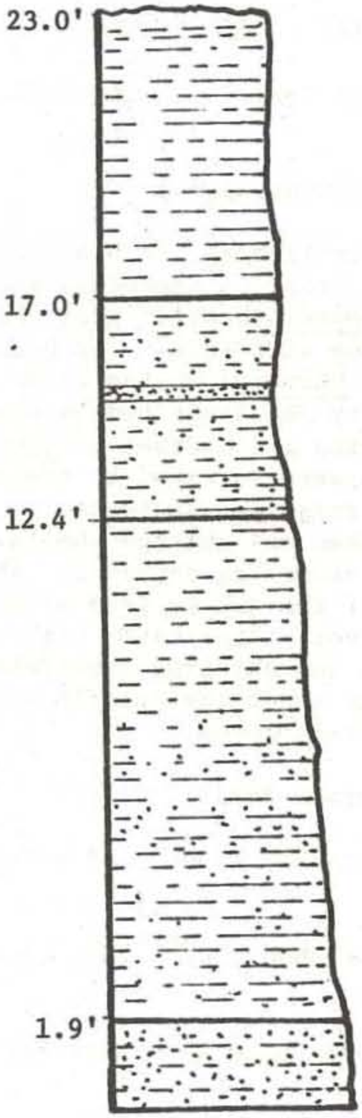


LITHOLOGY	FAUNA
Green-gray micaceous laminated siltstone with interbeds of gray calcareous shale.	Epifaunal F. F. - 78% Infaunal F. F. - 3% Infaunal D. F. - 15% Vagrant H.+C. - 2% Turbid-Int. F.F.- 2%
Gray silty shale with 1-3" thick beds of laminated and rippled siltstone.	Epifaunal F. F. - 77% Infaunal F. F. - 2% Infaunal D. F. - 12% Vagrant H.+C. - 4% Turbid-Int. F.F.- 5%
Gray micaceous siltstone	Epifaunal F. F. - 94% Infaunal F.F. - 2% Infaunal D.F. - 3% Vagrant H.+C. - 1% Turbid-Int. F.F.- 0%

DOMINANT GENERA

Upper siltstone:	Ambocoelia	- 20%
	Spinocyrtia	- 17%
	Elita	- 15%
	Nuculoidea	- 12%
Middle shale:	Ambocoelia	- 25%
	Chonetes	- 20%
	Spinocyrtia	- 17%
	Nuculoidea	- 8%
Lower siltstone:	Chonetes	- 37%
	Devonochonetes	- 19%
	Tropidoleptus	- 16%
	Mucrospirifer	- 9%

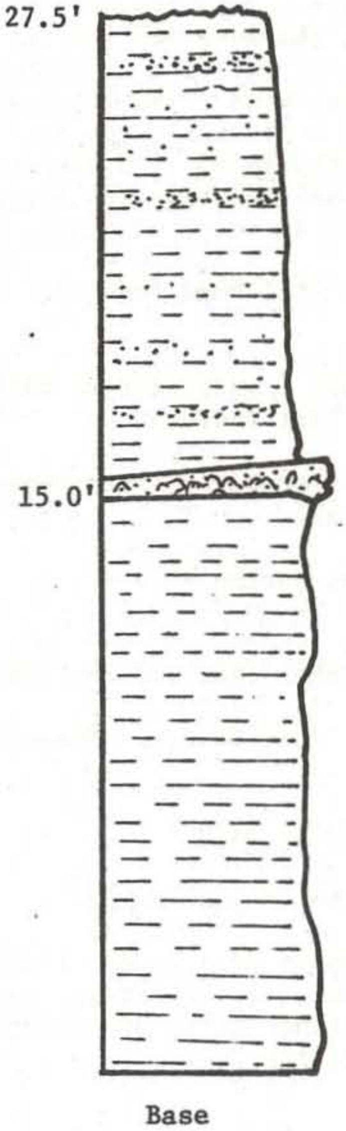
STOP #3 -- GEER ROAD QUARRY



LITHOLOGY	FAUNA
Crumbly to fissile gray shale.	Chonetes and Ambocoelia dominant
Gray silty shale with light brown laminated and rippled thin beds of siltstone	
Dark gray fissile silty shale grading upward into crumbly dark gray shale.	Chonetes and Ambocoelia abundant
Dark brown silty calcareous shale.	Bivalves abundant

11.80	0.90	Intersection with Soule Road - turn left (west).
11.90	0.10	Quarry entrance on left. Park on shoulder. *Stop #4*. Pierceville Quarry - Ludlowville Formation. (Description on following page.) Remarks: Three major lithofacies/biofacies are exposed at this stop. A *Chonetes*-bearing dark shale, a *Spinocyrtia*-bearing grey shale and a bivalve-bearing siltstone. The patchy distribution of the *Chonetes* in the lower section of the quarry was described by Linsley, et al. (1972). Strips and patches of *Chonetes* on bedding surfaces were ascribed to areas of grass-covered and grass-free sediment. Coquinites with broken and abraded shells were thought to be storm lag deposits. The uppermost portion of the quarry is a siltstone with abundant bivalves. Apparently higher rates of deposition and shifting substrates precluded the domination of the sessile epifaunal articulate brachiopods.
11.90	0.0	Return to Bradley Brook Road.
12.00	0.10	Intersection with Bradley Brook Road - Turn right (south).
14.75	2.75	Intersection with Lebanon Road - turn right (west).
18.50	3.75	Intersection with NYS Route 26 - turn left (south).
20.30	1.80	Georgetown Village - intersection with East Hill Road - turn left (east).
21.10	0.80	Outcrop on right - park on shoulder. *Stop #5*. East Hill Road - Georgetown. Moscow-Tully Contact. Remarks: The silty shales and siltstones of the uppermost Moscow Formation are seen here overlain by the Upper Devonian Tully Formation. The Moscow here is dominated by large articulate brachiopods and bivalves, with numerous, well-preserved trilobites, particularly *Phacops*.

STOP #4 -- PIERCEVILLE QUARRY



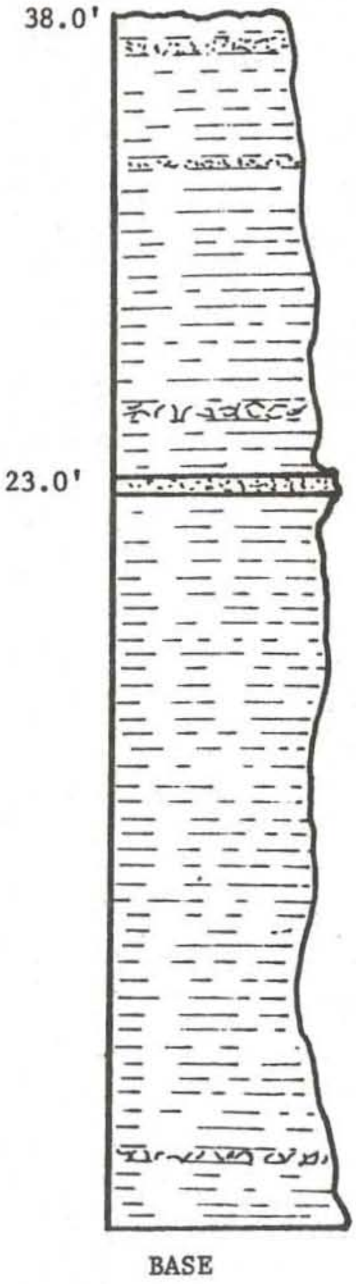
LITHOLOGY	FAUNA
Dark gray to brown shaley siltstone. Occassional rippled siltstone beds.	Various infaunal and epifaunal bivalves.
Gray calcareous shale	*Spinocyrtia* dominant
Crumbly to fissile dark gray shale	*Chonetes* dominant.

The contact is placed at the base of the first thin blue-grey limestone. Several thin (2-6") beds of limestone, separated by calcareous siltstone, characterize the Tully here. The Tully at this location is rather sparsely fossiliferous, with a few solitary argose corals and the colonial *Favosites* most prevalent. *Hypothyridina*, the diagnostic Upper Devonian Rhynconellid, has been reported in the Tully here, but is quite uncommon.

21.10	0.0	Continue east on East Hill Road (becomes South Lebanon Road).
24.75	3.65	Hamlet of South Lebanon - intersection with Campbell Road - turn left (north).
26.35	1.60	Hamlet of Lebanon - intersection with Lebanon Road - turn right (east).
28.00	1.65	Intersection with Deep Spring Road - turn right (south).
29.20	1.20	Quarry entrance on right - park on shoulder.
		Stop #6. Deep Spring Road Quarry - Moscow Formation.
		(Description on following page.)
29.20	0.0	Turn around - return to Lebanon Road.
30.40	1.2	Intersection with Lebanon Road - end of trip. (To return to NYS Route 12B, turn right (east) on Lebanon Road. Continue east approximately 4.5 miles to NYS Route 12B.)

End Road Log

STOP #6 -- DEEP SPRING ROAD QUARRY



LITHOLOGY	FAUNA	
Fissile dark gray silty shale. Occasional thin siltstone beds. Prominent coquinite at 27'	Epifaunal F.F.	- 92%
	Infaunal F. F.	- 0%
	Infaunal D.F.	- 6%
	Vagrant H.+C.	- 2%
	Turbid-Int. F.F.	- 0%
Brown siltstone with ripple laminations and groove casts.	Epifaunal F.F.	- 77%
	Infaunal F.F.	- 6%
	Infaunal D.F.	- 8%
	Vagrant H.+C.	- 9%
	Turbid-Int. F.F.	- 0
Dark gray to light gray fissile slightly silty calcareous shale. Phosphate-bearing coquinite near base.	Epifaunal F.F.	- 54%
	Infaunal F.F.	- 10%
	Infaunal D.F.	- 28%
	Vagrant H.+C.	- 8%
	Turbid.-Int. F.F.	- 0%

DOMINANT GENERA

Upper shale:	Chonetes	- 65%
	Spinocyrtia	- 14%
Middle Siltstone:	Chonetes	- 52%
	Mucrospirifer	- 20%
	Paleoneilo	- 8%
Lower shale:	Chonetes	-36%
	Nuculoidea	-20%
	Mucrospirifer	-11%
	Paleoneilo	- 8%

PHYSICAL AND BIO-STRATIGRAPHY OF THE ONONDAGA LIMESTONE IN OTSEGO COUNTY, NEW YORK

by Richard Lindemann, Dept. of Geology, R.P.I. and Skidmore, and
Robert T. Simmonds, Earth Science Dept., SUC, Oneonta

PURPOSE

The purpose of this article is to summarize the work which has been done on the Onondaga Limestone so as to provide a brief introduction, and a fairly comprehensive set of references for those who are curious about the formation. No stratling new discoveries will be revealed. The Onondaga formation has been the subject of study by numerous of the immortals of New York State geology, by three doctoral students and at least five students at the master's level. These studies have provided a wealth of information on the formation which has not previously been compiled into a comprehensive summary other than those which are so concise as to provide nearly no information at all. At present numerous aspects of the formation are being studies at the industrial, governmental, and academic levels. We know of several studies in the academic sector alone which are so near completion as to necessitate the modification of this summary almost before it becomes available. "So it goes." Kurt Vohnegut, Jr. (1970B)

INTRODUCTION

The Onondaga Limestone has long been recognized in New York and is one of the state's most extensively exposed and prominent formations. Its outcrop and characteristic escarpments extend for over 550 km from Buffalo to the Helderbergs and thence southward through Kingstone to Port Jervis (Fig. 1). This outcrop is dotted with hundreds of active and inactive quarries which have produced vast quantities of building stone and aggregate material. Since 1967, when the first large, subsurface, gas-bearing Onondaga "reef" was located, interest in the formation has waxed somewhat. Despite its prominence and economic import there is yet much to be learned about this formation, particularly in its more academic aspects.

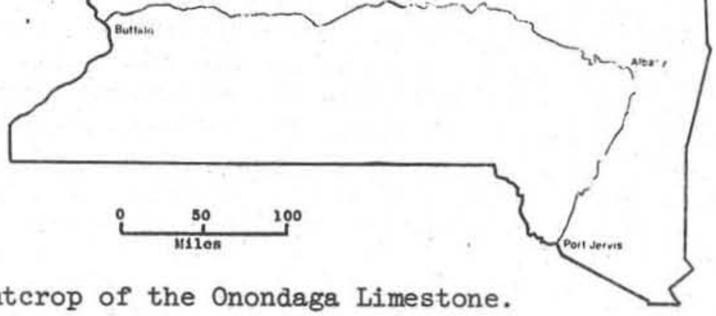


Fig. 1 - Outcrop of the Onondaga Limestone.

The Onondaga Formation is a coarse-to-fine-grained limestone, which ranges in thickness from 21.5 m (70') in central New York to in excess of 49 m (160') in the eastern and western parts of the state (Table 1). A variety of forms and colors of chert are common throughout. The formation was deposited during Eifielian time (lower Middle Devonian) (Rickard, 1975) just prior to and during the first clastic influx from the Acadian Orogeny. The Onondaga represents the last extensive carbonate and reef building phase in the region.

HISTORY OF GEOLOGIC STUDY

The Onondaga Formation figures prominantly in the history of New York State geology and it has a long and diverse history all its own. The first illustration of a fossil from the New York Devonian strata was a gyroconic nautiloid from the Onondaga. It was published in 1807 (Wells, 1963). Prior to the establishment of the New York State Geologic Survey in 1836, mention of those strata now known as the Onondaga Limestone consisted mainly of descriptions of its escarpments, fossils, and resistance to the efforts of the Erie Canal builders. One notable exception is found in the work of Eaton (Wells, 1963) who in his pioneer stratigraphic studies placed the long persistent name of "Cornitiferous Limerock" on the formation and recognized two subdivisions. In 1839, Vanuxum, working in central New York, divided the formation into four subdivisions, which roughly correspond to the present day members. The uppermost of Vanuxum's subdivisions received the name "Seneca Limestone" a label which persists today. In 1841 Hall (p. 156-158) recognized a three-fold division of the formation and introduced the term "Onondaga Limestone" for those beds now known as the Edgecliff Member. Following the time of these early studies the stratigraphy of the formation was in a state of flux for over a century. Oliver (1954, 1956), in a detailed state-wide study of the formation, established the type sections, descriptions, and extents of the Onondaga Formation and four members within it. Ozol (1963), working in western New York, established the presence of a fifth member and brought the stratigraphy of the formation to its present state.

STRATIGRAPHIC UNITS (Fig. 2)

Edgecliff Member

The type locality of the Edgecliff Member is Edgecliff Park, southwest of Syracuse (Oliver, 1954). The Edgecliff is a light-grey, coarse-grained, crinoidal limestone, with beds ranging in thickness from 15cm-1m. Crinoid columnals with diameters of 2 cm or more are diagnostic of this unit. The Edgecliff is characterized by a rich and abundant fauna of rugose corals and tabulates. Brachiopods, ectoprocts, gastropods, and trilobites are present though not usually common. The typical Edgecliff fauna and lithology can be traced from Buffalo to the Helderbergs. South of the Helderbergs, in the areas of Leeds and Kingston, the Edgecliff swells from its normal thickness of about 9 m to a maximum thickness of 11 m and becomes finer-grained,

LOCATIONS

MEMBERS	Buffalo	Leroy	Syracuse	Richfield Springs	Cherry Valley	Cobleskill	Helderbergs	Catskill-Leeds	Saugerties
Seneca	12.3m + 40' +	9.2m 30'	7.8m 25.5'	2.1m 7'	2.1m 7'	- -	- -	- -	- -
Moorehouse	17m 55'	17m 55'	7m 23'	22.9m 75'	22.9m 75'	21.3m 70'	21.3m 70'	11.3m + 37' +	30.5m + 100' +
Nedrow	uncertain	uncertain	4.3m 14'	3.7m 12'	3.7m 12'	4m 13'	4.6m 15'	13.1m 43'	10.4m 34'
Clarence	13.8m 45'	13.8m 45'	- -	- -	- -	- -	- -	- -	- -
Edgecliff	3.1m 10'	3.1m 10'	6.1m 20'	6.1m 20'	7m 23'	9.1m 30'	9.1m 30'	10.7m 35'	11m 36'
Totals	45.7m + 150' +	42.7m 140'	25m 82'	34.7m 114'	35.7m 117'	34.4m 113'	35m 115'	35m 115'	51.8m + 170' +

Table 1. Average Thicknesses of the Onondaga Limestone throughout N.Y.S.

darker, and less fossiliferous. Further south the member thins to about 4 m at Wawarsing, and, bearing a sparse fauna, can be recognized only by the presence of crinoid columnals.

The Edgecliff has been divided into three faunal zones the elements of which can be found in Oliver (1954, 1956). The zones are described as follows: Zone A is the basal unit at many localities west of Richfield Springs, where the Onondaga ceases to be transitional with the subjacent Schoharie Formation. Zone A is a brachiopod dominated unit with quartz sand and silt scattered about in the limestone. The abundance of quartz grains decreases upwards with the lowermost bed occasionally containing sufficient quartz to be a sandstone. The zone ranges in thickness from less than 2 cm to 1.2 m. Zone B is a discontinuous, coral cominated, limestone which is found only in western New York and Ontario. This zone has been found to represent 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 zone can be traced from Buffalo to Leeds, a distance of about 490 km. (300 mi.). East of West Winfield Quadrangle two subzones, designated C_1 and C_2, can be recognized. C_1, the lower of the two, is a medium grey, fine-grained, limestone with a non prolific coral (dominant) and brachiopod fauna. Subzone C_2 is the typical and predominant coarse-grained, light-grey, coraliferous Edgecliff Member.

Nedrow Member

The Nedrow Member is typically a thin-bedded, very fine-grained, argillaceous limestone. At its type locality, Indian Reservation Quarry south of Nedrow, N.Y., the unit measures 4.6 m (15') with an abrupt base and a gradational upper contact (Oliver, 1954). The member maintains its typical thickness over most of its recognizable range except in the vicinity of Leeds and Saugerties where it is 13 m (43') and 10.5 m (34') respectively. In eastern and western New York the Nedrow is difficult to recognize due to the absence or scarcity of argillaceous sediment. In westernmost New York Nedrow equivalent beds lie above the Clarence Member rather than the Edgecliff which it normally succeeds (Rickard, 1975). In the eastern part of the state the Nedrow is lithologically very similar to the Edgecliff Member and is recognizable only by its fauna and thin bedding.

The Nedrow bears a distinctive fauna by which it can frequently be identified despite its lithologic variability. The base of the member often consists of a 0.6 m - 1.5 m zone of very thinly bedded argillaceous limestone containing two species of rugose coral Heliophyllum halli and Amplexiphyllum hamiltonae, as well as a diversity of platycerid gastropods and brachiopods. This unit, designated Zone D by Oliver (1954), bears very few corals other than those mentioned above and is quite widespread throughout the state. Zone

E, which succeeds the latter, is thicker bedded, less argillaceous, and bears a low diversity, high density brachiopod fauna to the exclusion of most other taxa.

Clarence Member

Ozol (1963) designated that portion of the formation in western New York which overlies the Edgecliff Member and is 40-75% chert as the Clarence Member. The Clarence roughly corresponds to the corniferous limestone of Hall (1841) and the Nedrow black chert facies of Oliver (1954). The member is a medium to dark grey, 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 usually absent or very rare though occasionally the lower beds bear a fauna similar to that of the underlying Edgecliff Member. The Clarence is approximately 13.8 m (45') thick over most of its extent and can be traced from Buffalo, through its type locality in Clarence, New York to Avon, New York. East of Avon it apparently pinches out.

Moorehouse Member

The type locality of the Moorehouse is the Onondaga County Prison Quarry at Jamesville, New York (Oliver, 1954). Here the unit is a medium-grey, very fine-grained limestone with numerous shaly partings forming beds of 0.6-1.5 m in thickness. Chert is found throughout but is most abundant in the upper half of the member. The Moorehouse increases in thickness both westward and eastward from central New York where it is 6.3-7.7 m. In western New York it is about 20 m (65') thick, and near Saugerties over 31 m (100').

In central New York two 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 richest fauna of any unit in the formation. A diversity of brachiopods, gastropods, cephalopods, and trilobites is present and often quite abundant. Several mollusc species are characteristic of this zone.

Neither the typical Moorehouse lithology nor the two faunal zones are continuous across the state. West of Geneva the faunal zones are indistinguishable and are replaced by a fairly evenly distributed brachiopod fauna. Gastropods are nearly absent. In westernmost New York the "brachiopod facies" gives way to a "coral facies" which is coarser grained and contains several species of solitary rugose corals in addition to a well developed brachiopod fauna. In eastern New York the Moorehouse has an Edgecliff-like lithology with a diverse brachiopod, gastropod, cephalopod, trilobite, and coral fauna. Cephalopod species characteristic of central New York are absent. Several of the coral species are characteristic of Edgecliff faunas (Oliver, 1963). Between the Helderbergs and Kingston to the south, the Moorehouse is divisible into a lower non-cherty unit, a middle with dark grey to black chert, and an upper non-cherty unit (Oliver, 1956). To date the complex variations in fauna and lithology contained within the Moorehouse Member have not been documented in sufficient detail to display any pattern.

Seneca Member

The Seneca 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 and measures 7.8 m (25.5'). It is a fine-grained limestone which becomes darker and less fossiliferous upwards as it grades from a Moorehouse-like lithology below to a shale above. The Seneca and Moorehouse Members are separated by the Tioga Bentonite.

Oliver (1954, 1956) identified five zones within the Seneca Member. Zone H is believed to have resulted from a volcanic ash fall. Though there are several bentonites within the Onondaga (Rickard, 1976) this particular one can be traced across the state with a good degree of certainty. Zone I is a medium-dark grey limestone with a lithology similar to that of the upper Moorehouse Member but characterized by an abundance of Chonetes lineatus. Zone J, also called the "Pink Chonetes zone", is a very thinly bedded limestone. It is packed with Chonetes many of which are pink in color. Zone K is a dark grey limestone which rapidly darkens upward. It is characterized by Chonostrophia reversa with other species being rare and all fossils becoming scarcer toward the top. At its type area, the base of this zone is marked by a concentration of Heterophrentis. Zone L is a very dark grey limestone which is interbedded and intergraded with the overlying Marcellus Shale. This uppermost zone of the formation bears a low density, low diversity brachiopod fauna.

Despite rather poor and intermittent exposure the Seneca Member can be seen to exist in a gradational facies relationship with the overlying Marcellus Shale. The Seneca thins from over 12.3 m (40') at Buffalo to 2.1 m (7') at Cherry Valley. The eastward thinning is matched 30.5 cm for 30.5 cm (foot for foot) by the eastward thickening shale (Oliver, 1956). As the Seneca thins eastward from its type section in central New York, the upper zones are progressively lost. At Stockbridge Falls Zone L is absent and at Cherry Valley only the bentonite and Zone I are present. The member does not exist east of Cherry Valley and presumably the bentonite is enclosed within the Marcellus Shale. Though no exposures of this shale-bentonite relationship are reported from New York, a shale enclosed bentonite believed to be equivalent to the Tioga of central New York is known from eastern Pennsylvania (W.D. Sevon, pers. com.).

FORMATIONAL CONTACTS

Basal Contact

A slightly diachronous relationship is indicated by the contact of the Onondaga Limestone and its subjacent formations. Throughout eastern and southeastern New York a gradational contact exists between the Onondaga Formation and the calcareous mudstones of the Schoharie

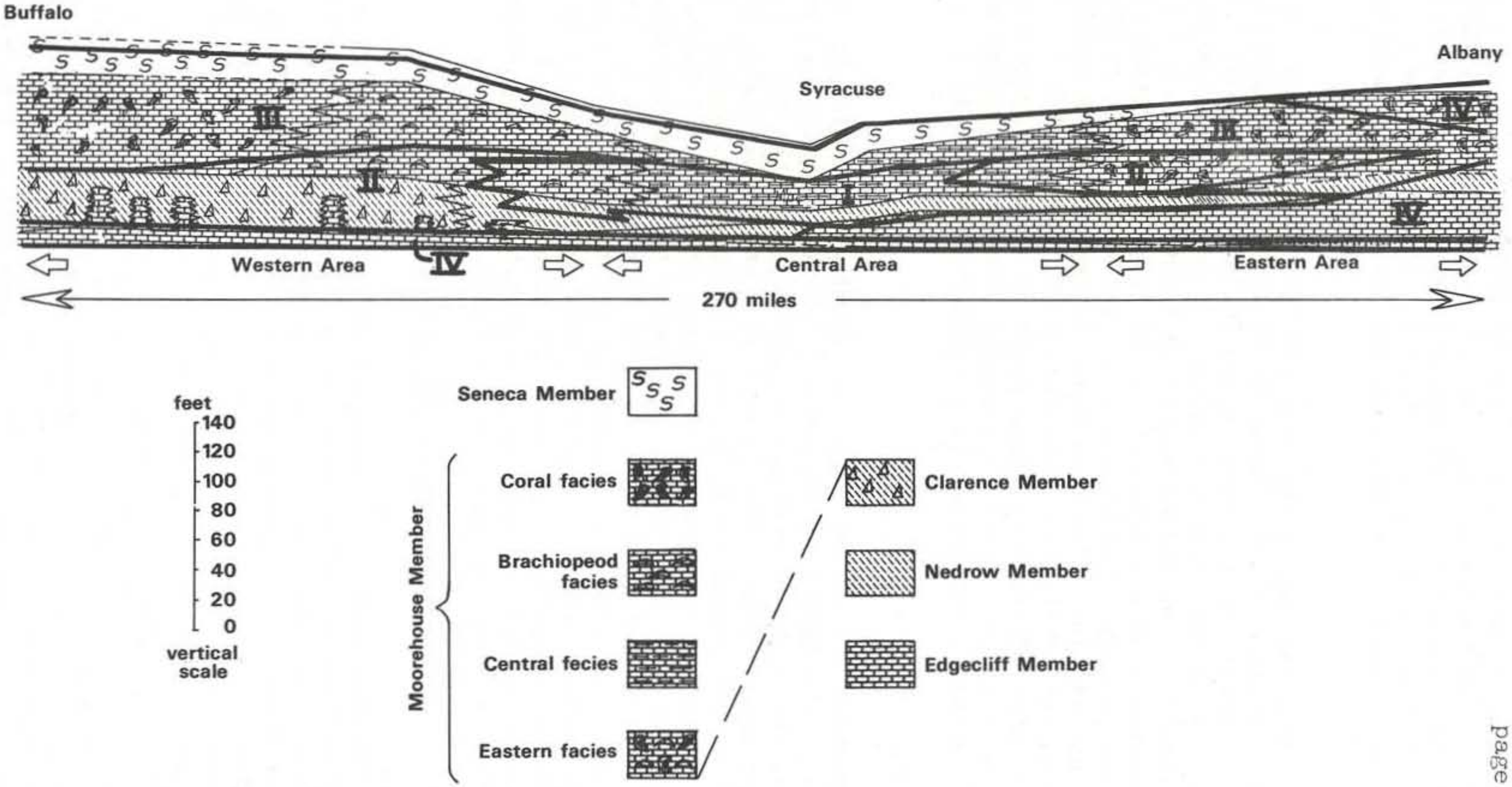


Fig. 2 - Cross section showing stratigraphic units and lithofacies (From Lindholm, 1967).

Formation. Between Sharon Springs and Richfield Springs the gradational contact is marked by phosphorite nodules and glauconite, indicating a slight unconformity. Westward from Richfield Springs the Onondaga rests unconformably on successively older formations. Often the contact is unmistakably erosional and the lower beds of the Onondaga contain quartz sand and lithiclasts reworked from the underlying formations.

At many localities in western New York the Onondaga rests unconformably on the Silurian Akron Dolostone. In some places, however, it rests on erosional remnants of the Early Devonian Bois Blanc Formation. At sites where the latter is the case the contact is marked by occasionally cross bedded quartz sand and is abrupt and undulatory, Sand concentrations are greatest in troughs of the contact indicating that its morphology is erosional in origin and not the result of post-depositional warping. The Bois Blanc Formation is the western New York equivalent of the Schoharie Formation (Oliver, 1967). Therefore, erosion of much of the Bois Blanc prior to Onondaga deposition indicates that the base of the latter is somewhat younger in western New York than in the east. Deposition in a transgressive sea is indicated.

Upper Contact

Throughout its entire range the Onondaga Formation is overlain by shales of the Marcellus Formation. Wherever exposures permit observation, the contact between the limestone and the shale can be seen to be gradational. When viewed on a statewide scale, the contact reveals a facies relationship between the upper two members of the Onondaga Formation and the Bakoven, Union Springs, and Oatka Creek members of the Marcellus Formation. Using the Tioga Bentonite and the base of the Cherry Valley Limestone as time planes it can be readily seen that limestone deposition was terminated as clastic mud prograded westward (Rickard, 1975). This diachronaity is so pronounced that limestone deposition had ceased in easternmost New York even before the first beds of the Seneca Member had been deposited in the more central and western parts of the state.

LITHOLOGY AND LITHOFACIES

The Onondaga Limestone lacks diverse allochems and is nearly devoid of sedimentary structures. As a result the carbonate petrology of the formation tends to be relatively monotonous in comparison with many other formations. Throughout most of the Onondaga, fossils, whole and fragmental, are the sole allochem constituents of any quantitative consequence and are usually the only ones present. The vast majority of particles recognizable in thin-section or polished-slab are crinoids, brachiopods, ectoprocts, trilobites, and corals. Microfossils, such as radiolarians, achritarchs, and sponge spicules are conspicuously absent in the limestone itself but can commonly be found in the chert (Ozol, 1963; Wicander and Schopf, 1974; Pfirman and Selleck, 1977). Other allochems such as pellets, ooids, and intraclasts are common at very few localities and only in the lowermost beds of the Edgecliff Member.

Taken as a whole the formation is volumetrically dominated by silt-size carbonate particles having a mean grain-size of between five and fifteen microns (Lindholm, 1967, 1969a). These silt-size particles are found to be lacking or absent only in the eastern part of the state and in the Edgecliff Member throughout. Noting that the carbonate silt particles are poorly-sorted, of variable shape, and frequently associated with terrigeneous silt, Lindholm (1969a) concluded that they are of detrital origin rather than the result of the neomorphic alteration of micrite to microspar (Folk, 1962). Lindholm further concluded that the calcisiltite was produced by the mechanical and organic breakdown of invertebrate shell material. Although the breakdown of shells is known to produce large quantities of lime mud (Matthews, 1966), the lack of positive identification of the calcisiltite's origin leaves the door open for other possible sources such as the production of lime mud by algae (Stockman, _et al._, 1967).

Lindholm (1967) reported the presence of several terrigeneous detrital minerals which occur in varying abundances throughout the formation. The clay minerals "illite" and chlorite are most abundant in central New York, where they can comprise up to 20% of the rock. Biotite, which never makes up more than 1% of the rock, is nearly ubiquitous. Quartz silt is found in many samples. Dolomite can often be found as euhedral to subhedral overgrowths on originally round to subround silt-size detrital dolomite grains. Noting strong correlations in both size and frequency distributions between dolomite and quartz, Lindholm (1967, 1969b) concluded that both are detrital in origin. He further concluded that, with the exception of the pronounced influx of terrigeneous mud which caused the deposition of the Nedrow and lower Moorehouse members in central New York, most terrigeneous components of the Onondaga are the result of aeolian transport.

Lindholm (1967) recognized four basic limestone types within the formation. They are identified on the basis of relative proportions of fossil allochems, calcisiltite, and sparry calcite. The lithologies (distribution shown in Fig. 3) are described as

1. Fossiliferous Calcisiltite - Composed of 1-10% fossil material in a calcisiltite matrix. Dominant fossil types include crinoids, brachiopods, and trilobites. The latter attain their peak abundance within this lithology. Terrigeneous clays can comprise up to 20% of the rock volume and anhedral quartz silt less than 7%.
2. Sparse Bioclacisiltite - Composed of 10-50% fossil material in a calcisiltite matrix. Fossil constituents commonly include crinoids, brachiopods, and trilobites. Quartz silt, dolomite, biotite, and clays are common though not abundant.
3. Packed Biocalcisiltite - Composed of fossil material in excess of 50% with a calcisiltite matrix. Fossil content is dominated by crinoids, bryozoans, and corals. Terrigeneous materials are scarce or absent.
4. Biosparite - Composed of fossil material with sparry calcite. Calcisiltite is absent. Fossil content is dominated by crinoids, bryozoans, and corals. Terrigeneous components are usually absent. In eastern New York and the Edgecliff Member throughout, biosparite is interbedded with packed biocalcisiltite.

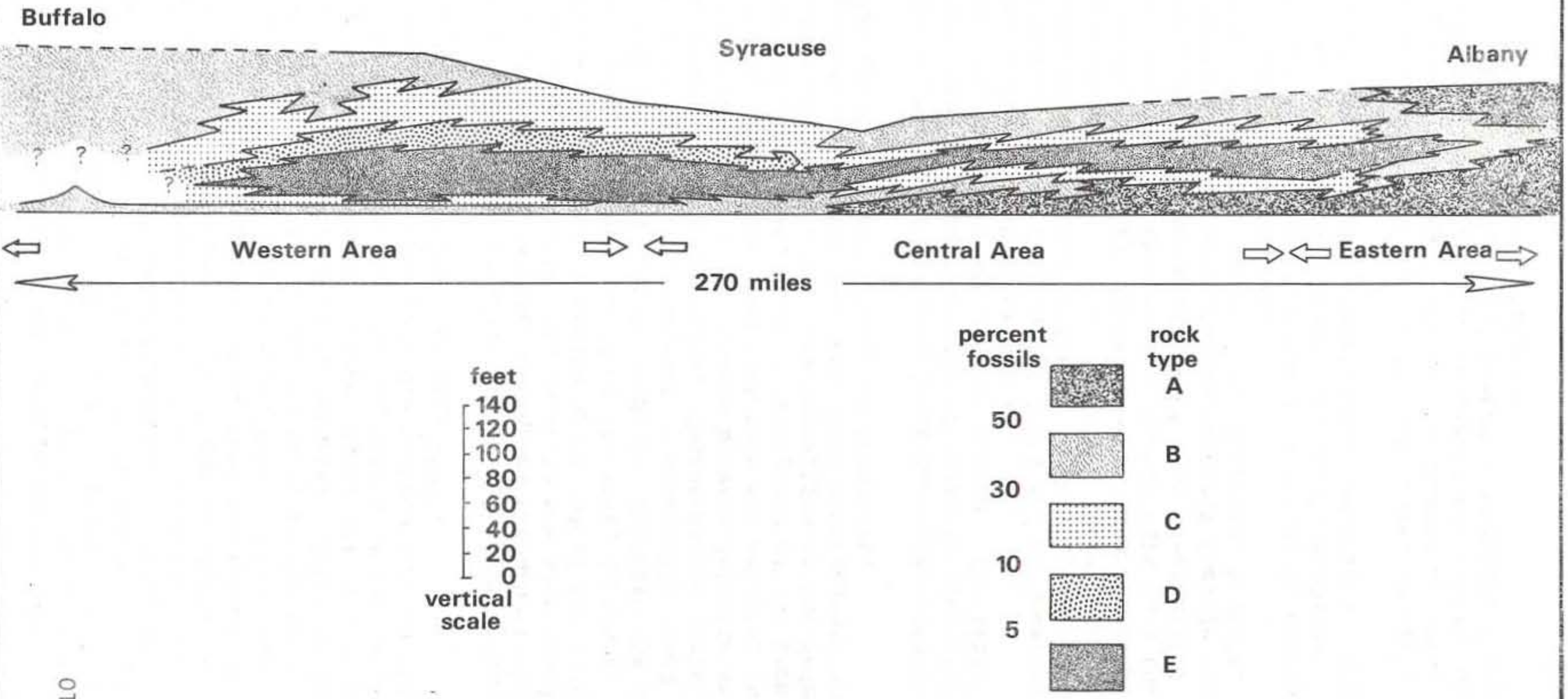


Fig. 3 - Cross section showing distribution of carbonate rock types (From Lindholm, 1967).

FACIES	I	II	III	IV
Fossil content	less than 10 per cent	less than 10 per cent	10 to 50 per cent	greater than 50 per cent
Dominant fossils	brachiopods trilobites crinoids	brachiopods trilobites crinoids	brachiopods trilobites crinoids	crinoids bryozoans
Dolomite content	10-20 per cent	5-10 per cent	less than 5 per cent (in western area up to 20 per cent)	less than 5 per cent
Clay content	5-25 per cent	2-5 per cent	2-5 per cent	less than 2 per cent
Biotite	present	none	none	none
Burrowing	distinct	distinct to vague	distinct to mottled	generally absent
Relationship to members	includes Nedrow and lower Moorehouse of central area.	Nedrow and lower Moorehouse of western area.	Upper Moorehouse and Seneca of central and western areas.	entire Edgecliff, as well as Nedrow and upper Moorehouse of eastern area.

Table 2. Composition of Lindholm's lithofacies. From Lindholm 1967.

Lindholm (1967) divided the formation into four lithofacies based on lithologic texture, composition, and mineralogy as well as spatial relationships. The compositions of the lithofacies are summarized in table 2.

Figure 2 compares and contrasts the distributions of Lindholm's lithofacies and Oliver's stratigraphic units. Lindholm (1967) suggests that discrepancies in spatial distributions between lithofacies and members are due the different observational scales used in the studies. Stratigraphic units were identified using macrofossils and overall lithologic character while lithofacies were identified using thin-sections. Lindholm further suggests that macrofossils were deposited at or very near their life sites while fine grained fossil debris underwent extensive transport. In reaching this conclusion Lindholm further supports his contention that the calcisiltite is indeed of detrital origin.

CHERT

Cherts occur commonly in many of the state's limestone formations. However, the cherts of the Onondage Formation are unusual in their occurrence and abundance. Though the chert content of any given interval or member is highly inconsistent between localities, there is a general tendency for increasing percentages to the west (Fig. 4). In general the Edgecliff Member contains ≤3% chert, the Nedrow 0-2%, the Clarence 40-75%, the Moorehouse 3-15%, and the Seneca ≤5% (Ozol, 1963). These percentages must be applied with caution due to rapid changes in form and abundance which the cherts undergo both vertically and laterally. Chert is unevenly distributed, tending to be concentrated in specific beds or intervals leaving others only sparsely chertified.

Morphologically, chert occurs as nodules, lenses, anastamosing networks, and beds. The nodules and lenses are usually scattered about within beds or in specific layers and are frequently elongate parallel to bedding. Nodules vary in shape from smooth and rounded to highly irregular with protruberences which transgress bedding. Irregular shaped nodules often coalesce with one another. Extensive nodular coalescence leads to the development of anastomosing networks which can result in intervals of massive chert enclosing small "islands" of limestone (Ozol, 1963). Discrete chert beds are not common in the formation. Those which do occur range in thickness from 5-25 cm and can be traced the full extent of the outcrop, but not between localities. Though no universally reliable association has been found between chert morphology and the texture or composition of the enclosing limestone, the more massive cherts are best developed in massively-bedded, homogeneous, fine-grained limestones (Ozol, 1963). This association appears to be confirmed by the recent work of Pfirman and Selleck (1977).

Chert in the Onondaga is primarily composed of microcrystalline quartz. Lesser amounts of chalcedony, cryptocrystalline quartz, megaquartz, and isotropic silica are also present (Ozol, 1963). Ozol has also noted that microcrystalline quartz usually occupies the former positions of solid parts of fossils while other silica minerals

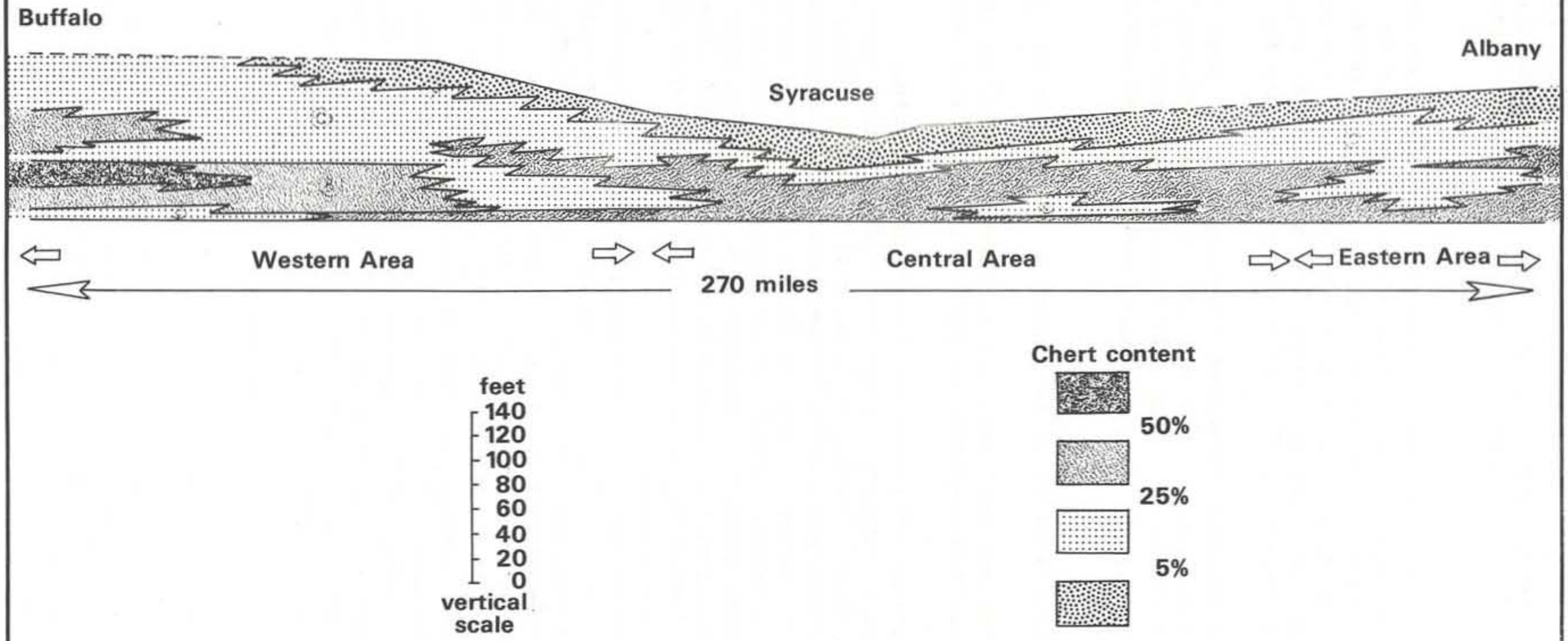


Fig. 4 - Cross section showing chert content (From Lindholm, 1967).

occupy the intersticies. Therefore the relative abundance of the various silica minerals within a given chert body may possibly be related to the original texture and composition of the limestone (or sediment).

In addition to silica minerals the cherts contain varying quantities of calcite, dolomite, limestone, minute vacuoles, and several minor accessory minerals. The former two minerals are often found as euhedral crystals up to 2 mm in size concentrated near the periphery of nodules. Among the minor accessory minerals found to be concentrated in the chert with respect to the enclosing limestone are Fe_2O_3 and TiO_2.

Chert in the Onondaga Formation originated by the post depositional silicification of carbonate sediments and the post lithificational silicification of limestone. Numerous items of evidence can be seen in the rock which support the replacement origin of the chert. Among others they include:

1. Partial silicification of the internal structures of corals and tabulates.
2. Fossils which are half enclosed in chert and half in limestone.
3. Fossils preserved as ghosts or partially silicified remnants within chert.
4. Isolated patches of limestone within chert nodules.
5. Preservation of original limestone bedding within chert.
6. "Incipient chert" (Ozol, 1963, p. 141) found as highly calcareous rims on nodules and nodular shaped patches of calcareous chert within the limestone. These zones of impure chert are believed to represent initial stages of silicification because they preserve original limestone textures more faithfully than the chert proper. When found as rims on nodules these zones often contain euhedral dolomite far in excess of that found either within the limestone or the chert.
7. In proximity to many chert nodules limestone laminae can frequently be seen to flare so as to pass above and below the nodule. The surfaces of some nodules bear slickensides-like lineations. These phenomena would occur only if the chert were a hard entity within a loose or semilithified sediment. They also support the contention of Shinn and others (1977) that carbonate sediments do indeed undergo compaction prior to cementation.
8. In a few instances styolites have been observed within chert bodies (Lindholm, 1967). Because styolites form within limestone and not within loose sediment, it is believed that some Onondaga cherts inherited these structures through the replacement of solid limestone.

BIOHERMS

Background and Description

Bioherms have been known to exist within the Onondaga Limestone since the mid 1800's when Hall (1859) described the present day Edgecliff Member as being composed of coral reefs. Hall and other early investigators who referred to reefs within the formation were probably impressed by the great abundance of coral in the Edgecliff Member and applied the term reef indiscriminately. Grabau (1903, 1906) provides the earliest mention of individual reefs complete with descriptions and locations. The first reef to be described was characterized as a domal mound with flanking beds dipping away at about 10°. This reef was located in the Fogelsanger Quarry in Williamsville, just east of Buffalo on Rt. 5. Quarry operations had ceased shortly after exposing this reef over its full extent. Unfortunately construction of the Youngman Expressway went directly through the reef and placed most of it, as fill, into a nearby swamp. The remaining exposures consist of only a small portion of the flanking beds, off-reef Edgecliff, and the overlying Clarence Member. A point of interest which may be worth noting is that this quarry was, for quite some time, a popular fossil collecting site for scientific supply houses, museums, and rock hounds alike. As a consequence, there are many fossils about bearing the citation "Onondaga Limestone, Williamsville, N.Y.". These are to be treasured as their point of origin no longer exists.

Between the time of Grabau's original work and the mid 1950s over 21 bioherms were found along the formation's outcrop. Oliver (1956) reported that all reefs with the exception of the one in Williamsville were located in eastern New York. Subsequent field work (Oliver, pers. com.) revealed nearly a dozen additional reefs in western New York and adjacent Ontario. Furthermore it appears that bioherms also exist in the central part of the state. Subsurface studies since 1967 have revealed the presence of several additional reefs in southwestern New York (Warters, 1972) and adjacent Pennsylvania (Piotrowski, 1976).

The bioherms, seen in outcrop, are generally round or ovoid in map view and domal or lensoid in cross section. They range from quite small to in excess of 370 meters (1200') in length and 22 meters (70') in thickness (Oliver, 1956). Oliver (1954, p. 636) reported finding several "micro-reefs" in western New York. These are less than 0.6 m (2') in height and 3 m (10') in diameter. They are individual coral colonies or thickets (Squires, 1964) which trapped lime mud and therefore appear quite different from the enclosing normal Edgecliff lithology. All size gradations exist between the "micro-reefs" and the full fledged bioherms which contain several coral species which are found nowhere else in the formation (Oliver, 1956). Flanking beds dipping away from the bioherms at 10-15° are well developed only on the larger bioherms. The fauna of these flanking beds grades from highly coraliferous near the mounds to a normal Edgecliff fauna at a distance. Oliver (1956) indicated that biohermal growth was, for the most part, therminated by the influx of terrigeneous mud which ended Edgecliff deposition and initiated the Nedrow Member.

The subsurface reefs of southwestern New York and adjacent Pennsylvania are quite different from those in outcrop. Despite their apparently similar faunas these reefs often exceed 55 m (180') in height (Piotrowski, 1976). They attain this height in areas where the entire formational thickness does not exceed 15 m (50') and therefore must project far above the remainder of the formation. Due to their inaccessibility little is yet known about the paleoecology of these subsurface reefs, however, it appears that they developed along a hinge line between a relatively stable epicontinental shelf to the north and a subsiding basin to the south (Warters, 1972).

Four Onondaga bioherms have been studied in detail to determine successional patterns, facies relationships, and paleoenvironments (Mecarini, 1964; Bamford, 1966; Poore, 1969; Williams, 1977). Each of these four investigators approached the problem with somewhat different view points, methods, and intentions. Despite this, their findings, though not identical, reveal quite similar successions of biofacies, or fauna-sediment associations, within the bioherms throughout the state. Poore (1969, p. 56) compiled the results of the first three above cited studies to develop a "typical" bioherm model which could be used in future studies. Though necessarily general in content, the "typical" Edgecliff bioherm appears to accurately depict the development of bioherms other than those which were used in its synthesis. A diagram of the model is shown in Fig. 5 and an annotated summary of the four basic facies is presented below.

1. Acinophyllum Facies. This, the lowermost unit of the bioherm, is dominated by the delicate compound rugose coral Acinophyllum. This branching coral baffled currents and trapped lime mud thus stabilizing the substrate and building upwards. This facies, which is the pioneer community of the bioherm, corresponds to the "basal stabilization zone" of Walker and Alberstadt (1975, p. 238).

2. Core Facies. This unit overlies the Acinophyllum facies and makes up the main body of the bioherm. The matrix material of this facies is predominantly lime mud however spar content increases upwards. The unit can frequently be divided into two subfacies. The lower subfacies has a low faunal diversity which is dominated by branching rugose corals or tabulates such as Cylindrophyllum or Coenites which trapped lime mud and continued building of the mound. This subfacies corresponds to the "overlying colonization zone" of Walker and Alberstadt (1975).

   The lower core subfacies grades into the upper core subfacies which, in addition to the branching rugose corals and tabulates, supports a well developed fauna of laminate to hemispheric tabulates of the Emmonsia and Favosites genera. This facies supports the highest faunal diversity of any on the reef. It corresponds to the diversification zone of Walker and Alberstadt (1975).

3. Flank-Cap Facies. This unit consists of those beds which both flank the bioherm,grading distally into the normal Edgecliff lithology, and override it. The bioherm cap contains sand and gravel size sediments with virtually no lime mud. Terrigeneous mud is also absent from this facies dispelling the contention that a terrigeneous influx killed off the corals.

4. Energy Shadow Facies. This unit is found on the "platform" side of the core facies. The Acinophyllum and Core facies of several bioherms contain corals which are strongly oriented in a direction

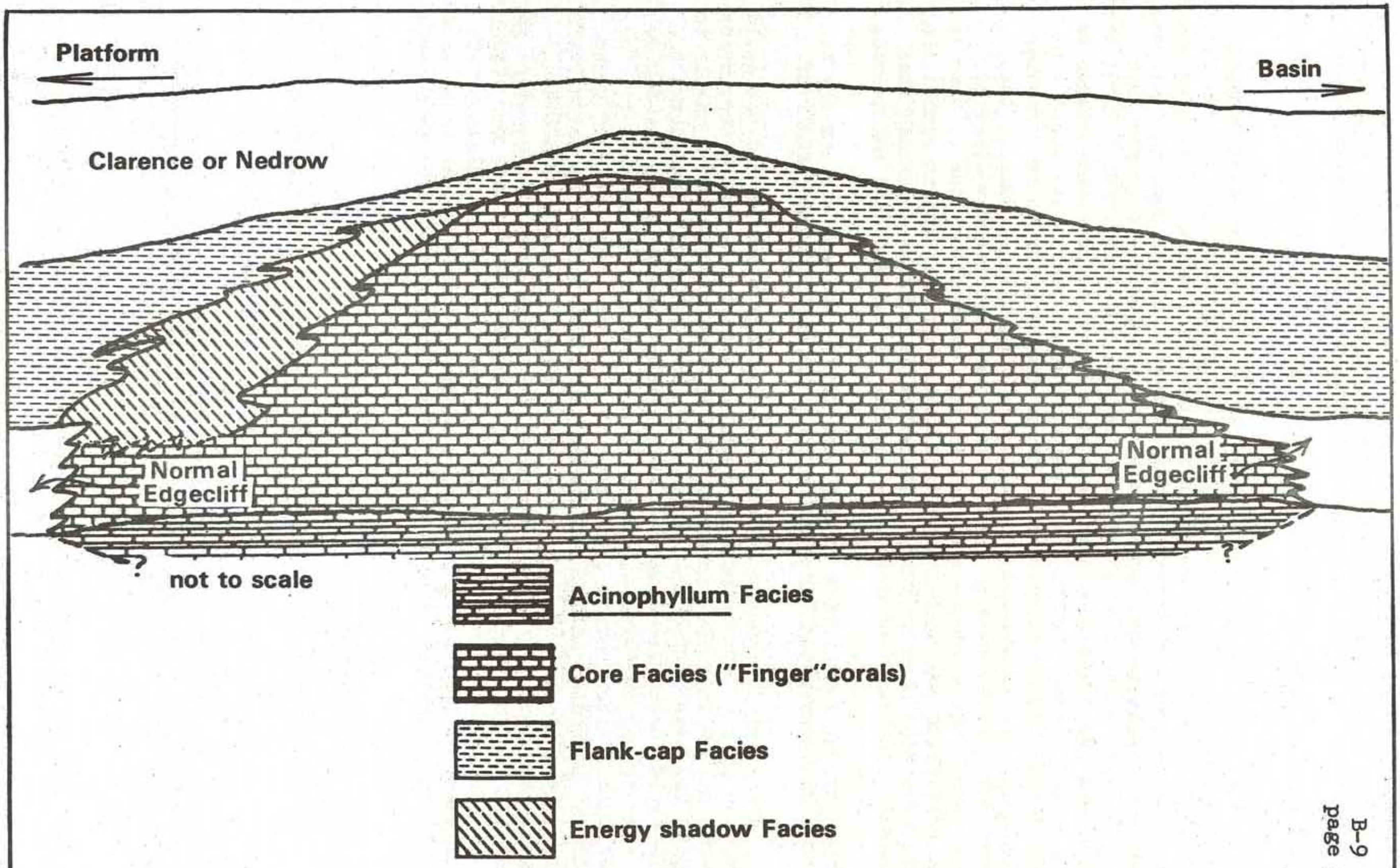


Fig. 5 - Cross section of a "typical" Edgecliff bioherm (From Poore, 1969).

interpreted as representing prevailing waves or currents. Opposite this direction is located the energy shodow facies which contains greater quantities of lime mud than "the core facies but less than the Acinophyllum facies" (Poore, 1969, p. 56). The fauna of this facies is interpreted as consisting of organisms tolerant of fluctuating and occasionally high turbidity levels.

Reefs or Bioherms?

It is the general consensus of those who have studied Onondaga bioherms that they contain discrete successional stages and result in the erection of a wave resistant topographic feature. Noting an upward increase in spar and corresponding decrease in lime mud, successional stages of bioherm development have been attributed to growth into successively higher energy waters. Walker and Alberstadt (1975), who developed the fourfold classification of reef successional stages to which the Onondaga bioherms correspond rather well, have stated the belief that faunal succession in those stages prior to the "domination zone" are principally biologically controlled. None of the previously cited Onondaga reef studies have described a stage of development which can be assigned to the "domination zone". This is the physically controlled zone initiated when reef growth enters the zone of strong wave activity. Therefore it must be concluded that Onondaga bioherms lacked a fauna capable of building and maintaining a true wave resistant structure. This conclusion appears to be supported by the recent work of Williams (1977) who was also unable to find a well developed "domination zone" in the Thompson Lake reef.

The above stated conclusion that Onondaga bioherms did not build into the zone of strong wave activity is almost a foregone conclusion. Ever since Wells (1957) reported that Paleozoic corals were unable to expand the basal attachment area, they have generally considered to have lived "below wave base". The question remains as to the degree of wave agitation Paleozoic reefs were capable of withstanding. The reef core facies contain quantities of lime mud comparable to those found in sediments on and immediately adjacent to Florida patch reefs which are subjected to hurricanes and frequent squalls (Lindemann, unpublished work). Part of the solution to the agitation question may lie in a current investigation, by the senior author, into the stability and wave resistance potential imparted to branching rugose corals by the entrapment of lime mud. To date, Onondaga bioherms appear to be more accurately described as bioherms (Cloud, 1952) rather than true reefs (Heckel, 1974).

The Mount Tom Bioherm

Oliver (1956, p. 20-22) described a group of seven bioherms in the vicinity of Richfield Springs. The one he designated as "Mount Tom No. 1 reef" is 215 m (700') long, 155 m (500') wide, and 22 m (70') high. This bioherm was the subject of Mecarini's 1964 study. The facies identified by Mecanini are summarized in Table 3, and are briefly described below. The spatial relations of the facies are shown in Fig. 6.

Facies →	Basal Facies	Core Facies			Flank-Cap Facies		Inter-reef Facies
Subfacies →		Acinophyllum Subfacies	Tabulate Subfacies		Typical Cap	Typical Flank	
			Ciacopore Unit	Emmonsia Unit			
Spar	6	2	9	18	24	8	2
Micrite	45	47	27	11	7	8	32
Quartz	-	-	-	-	-	-	2
<u>Acinophyllum</u>	1	40	5	-	-	-	-
Solitary Rugose corals	-	-	-	5	13	-	-
Emmonsia	-	-	-	14	-	11	-
Auloporids	-	-	2	2	1	-	1
Other Favositids	-	-	16	6	3	-	-
Crinoids	36	6	30	35	42	68	36
Ectoprocts	5	2	4	6	5	2	1

Table 3. Average percents of selected components as seen in thin-sections from Mt. Tom Reef from Mecarin, 1964.

Basal Facies. Consists of a tan and gray shale and limestone which grades upward into a crinoidal biomicrudite. The lower portion bears a fauna of platycerid gastropods and brachiopods, solitary rugose corals, trilobites, ostracods, and favositids. The maximum thickness of this facies is 3 m (9').

Core Facies. Forms the reef itself and is divided into two subfacies. <u>Acinophyllum</u> Subfacies - described as an <u>Acinophyllum</u> biomicrudite, this subfacies is dominated by <u>Acinophyllum</u> with a sparse fauna of crinoids and ectoprocts. It attains a thickness of about 4 m (12').

Tabulate Subfacies - Subdivided into two units.
<u>Cladopora</u> Unit. Ranges from a packed biomicrudite to a poorly washed, small tabulate biosparite. The percentage of spar increases upwards. In addition to <u>Cladopora</u> this unit contains a fauna of <u>Emmonsia</u>, <u>Thamnopora</u>, <u>Aulocystis</u>, and <u>Syringopora</u>. It attains a maximum thickness of 12 m (40').
<u>Emmonsia</u> Unit. This unit is a highly porous, coarsely crystalline, poorly to well washed, rich <u>Emmonsia</u>, crinoidal biosparudite. It

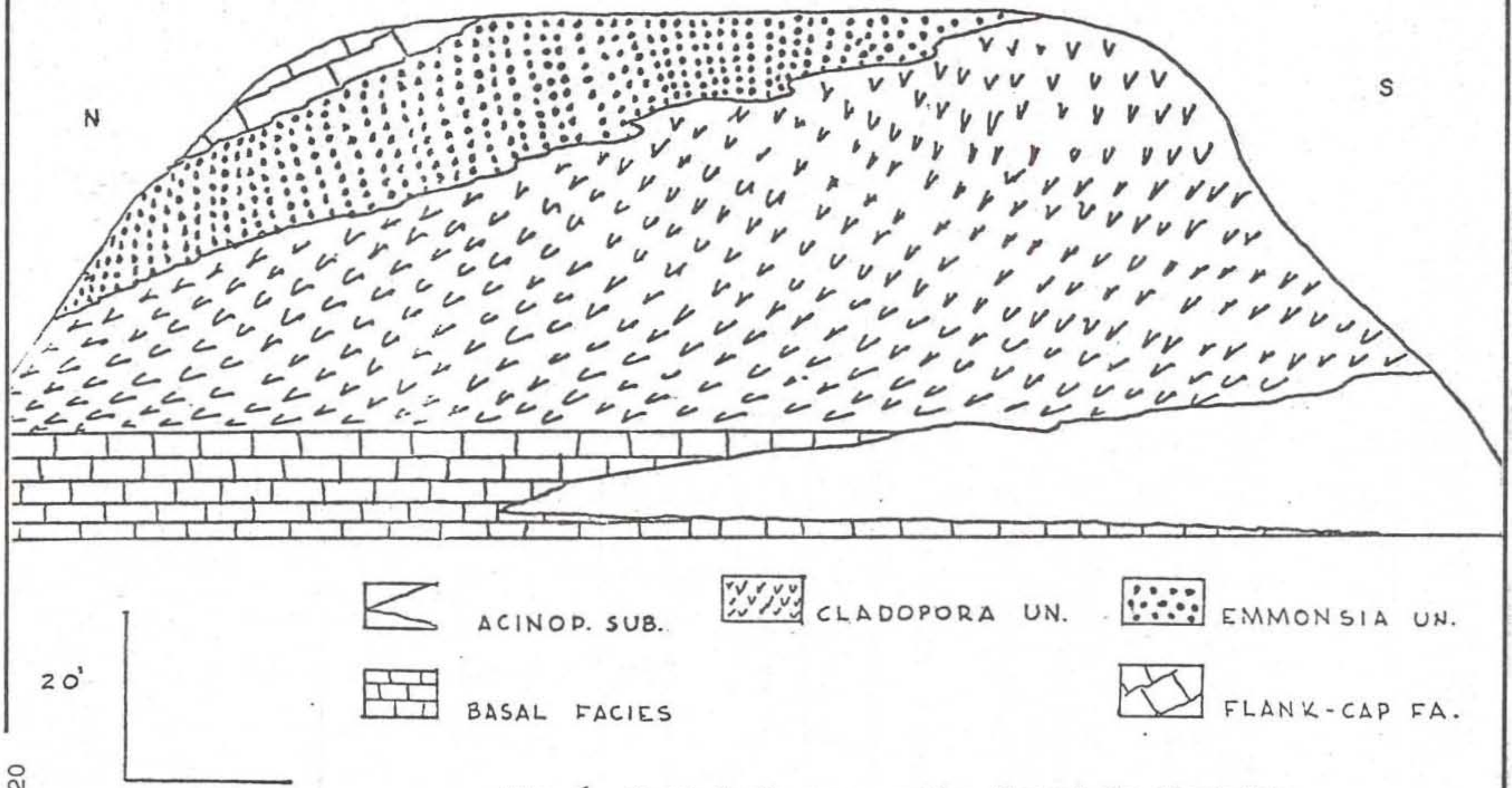


Fig. 6 - North-South cross section through the Mount Tom bioherm (From Mecarini, 1964).

bears a fauna of *Emmonsia*, *Cladopora*, *Aulocystis*, *Syringopora*, various ectoprocts, brachiopods, and particularly in its upper parts, *Heliophyllum*. It approaches 6 m (20') in thickness.

Flank Cap Facies. This facies overlies the core facies and is an extension of the flank deposits which dip away from the bioherm at 15°. The lithology ranges from an extremely coarse, crinoidal and solitary coral, biosparudite above the core to a poorly washed, gray, crinoidal biosparudite on the flanks. The fauna is dominated by *Heliophyllum* and *Cystiphyllum*.

PALEOENVIRONMENTS

The Onondaga Limestone was deposited in an initially shallow but subsiding epicontinental sea, within about 30° of the equator. A westward transgression of the sea across New York State is indicated by the base of the formation. The transgression resulted in the deposition of the Edgecliff Member in sahllow, wave-affected waters (Laporte, 1971). This is evidenced by the lithologic character and corals reefs of the member. Variations in turbidity and water agitation are indicated as major allogenic environmental controls on faunal character and distribution throughout the eastern half of the Edgecliff (Lindemann, 1974). Continued subsidence carried the sea bottom below the effects of waves and set the stage for deposition of the other members (Laporte, 1971). Deposition of the Nedrow Member took place during an influx of clastic mud which moved through a topographic depression or trough which then existed in central New York (Oliver, 1956; Lindholm, 1967). The source of the mud appears to have been quite some distance to the north, or possibly the south east, as indicated by clastic free deposition to the east and west, a rapidly subsiding basin to the south, and a general absence of nearby land (Wicander and Schopf, 1974). The Moorehouse Member marks a return to relatively nonturbid conditions. Unlike the Edgecliff the Moorehouse was deposited in quiet water. The Seneca Member was deposited during the westward progradation of the Marcellus shale. The gradational and interbedded relationship between the Seneca Limestone and the Marcellus Shale indicate that turbidity levels waves and waned for a time prior to the eventual inundation of the sea by clastic mud and termination of limestone deposition.

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ROAD LOG

Miles from last point	Cumulative Miles	Route Description
0.0	0.0	Leave the Oneonta State campus and proceed to Richfield Springs via West Street, Rt. 7, Rt. 205, and Rt. 28. In Richfield Springs remain on Rt. 28 until just north of Rt. 20. We will reassemble in the Flea Market parking lot on the east side of Rt. 28 just north of the intersection. Mileage will begin here.
2.8	2.8	Continue north on Rt. 28 to rock exposure on east side of road just north of Schuyler Corners.
		STOP 1. This exposure contains the uppermost Edgecliff and lowermost Nedrow Members. Though the contact cannot be seen, the pronounced differences in fauna and lithology are evident. Note the color and nature of the chert for future reference. The outcrop is typical of hundreds of other Onondaga exposures in extent and weathering characteristics.
2.8	5.6	Return to Rt. 20 and turn left (east) at the blinking light.
6.8	12.4	Remain on Rt. 20 until its intersection with Rt. 80 at Springfield Four Corners, turn left (north) onto Rt. 80.
0.2	12.6	Take the first left which is a winding, gravel-paved quarry entrance, and park on the first broad level area.
		STOP 2. Park in abandoned quarry entrance on left and walk up into quarry. In this quarry 57' of the formation are exposed; 19.5' Edgecliff, 12.5' Nedrow, 25' Moorehouse. The gradational beds between the Schoharie and Edgecliff can be seen in the road as you walk up into the quarry and in the pinnacle of rock to your left just as the road begins to level off on top. These beds grade from dark and glauconitic below into clean, coarse-grained, coraliferous Edgecliff above. The floor of the northern quarry section is in the transitional beds.
		The western quarry section which we will visit has exposed the upper Edgecliff, the entire Nedrow, and the lower Moorehouse. The main

Miles from last point	Cumulative Miles	
		floor of the quarry lies on the upper Edgecliff which can be recognized by its corals, large crinoid columnals, and pyrite. The water filled pit and ramp are entirely in the Edgecliff. The main quarry walls contain the dark, shaley Nedrow in their lower parts and the cherty Moorehouse above.
1.3	13.9	Leave the quarry headed north on Rt. 80 and take the second left onto Koenig Road.
0.7	14.6	Continue along Koenig Road to its juncture with Mt. Tom Road just beyond the large white house at the hill crest. Stop at house (Mr. Lamb) for permission to examine outcrops.
		STOP 3. The stop is the near (East) face of the knob directly ahead. Mount Tom Reef No. 1. This is the reef shown in Fig. 6 of the text. Study the reef zonation in the text before proceeding onto the reef. Exercise caution as much of the rock wall is unstable and footing can be tricky. The obvious characteristics of this, and all other bioherms in the Onondaga, are its massively unbedded nature and lack of chert. With patience and close examination you will be able to spot the different corals which comprise the framework of the reef. Examination reveals that the clear cut zonation shown in Fig. 6 is not nearly so clear cut in the reef itself. The matrix material between the corals consists mostly of lime mud, with the coarse crinoidal material typical of many Onondaga bioherms lacking.
1.0	15.6	Proceed west along Mt. Tom Rd. and stop just before reaching the long low hill which crosses the road from north to south.
		STOP 4. Another reef is exposed in the southern end of this hill. The exposure appears to be the "Core Facies" of a reef, but its actual position within the reef is uncertain due to lack of exposure. The reef seems to extend a considerable distance on the basis of the topographic expression.
0.6	16.2	Continue straight along this road until it terminates on Chyle Road and turn left.

Miles from last point	Cumulative Miles	
0.7	16.9	Take the right off of Chyle Rd. onto Merry Hill Road.
0.2	17.1	Go down Merry Hill Road and stop.
		<u>STOP 5.</u> The hill on the east side of the road is Mt. Tom Reef No. 7. Though it has been referred to as a bioherm, this hill is composed of bedded, cherty limestone: characteristics not found in biohermal structures. The fauna here is not typical of other bioherms or the "normal" Edgecliff. The fauna is dominated by small broken twigs of the branching tabulate <u>Coenites</u> and doesn't contain anything which could be considered a framework. At present the significance of these beds is uncertain.
0.2	17.3	Return to Chyle Rd. and turn right (west).
1.4	18.7	Take a left (south) onto Little Lakes Road at the first intersection.
2.2	20.9	Turn left (east) on Rt. 20 in Warren.
10.8	31.7	Stay on Rt. 20 until reaching the Parking Area just east of the Cherry Valley exit. Enter Parking Area.
		<u>STOP 6.</u> This exposure and its twin across the valley are two of the most continuous and complete exposures of the Onondaga Formation. Here the formation is exposed from its phosphoritic based transitional beds, through the shaley Nedrow, and into and including most of the cherty Moorehouse. For the thicknesses, fauna, and lithologies of the members refer to Figure and to the text. Figure 7 is provided to show member thicknesses here and at STOP 7 as well as the characteristics and continuity (or lack thereof) of chert bodies within the formation.
0.6	32.3	Continue east on Rt. 20.
		<u>STOP 7.</u> In many respects this set of exposures is quite similar to STOP 6. It is however significant in its continuity with STOP 6 and the differences between the two with respect to chert. This stop is further significant because it's the easternmost exposure of the

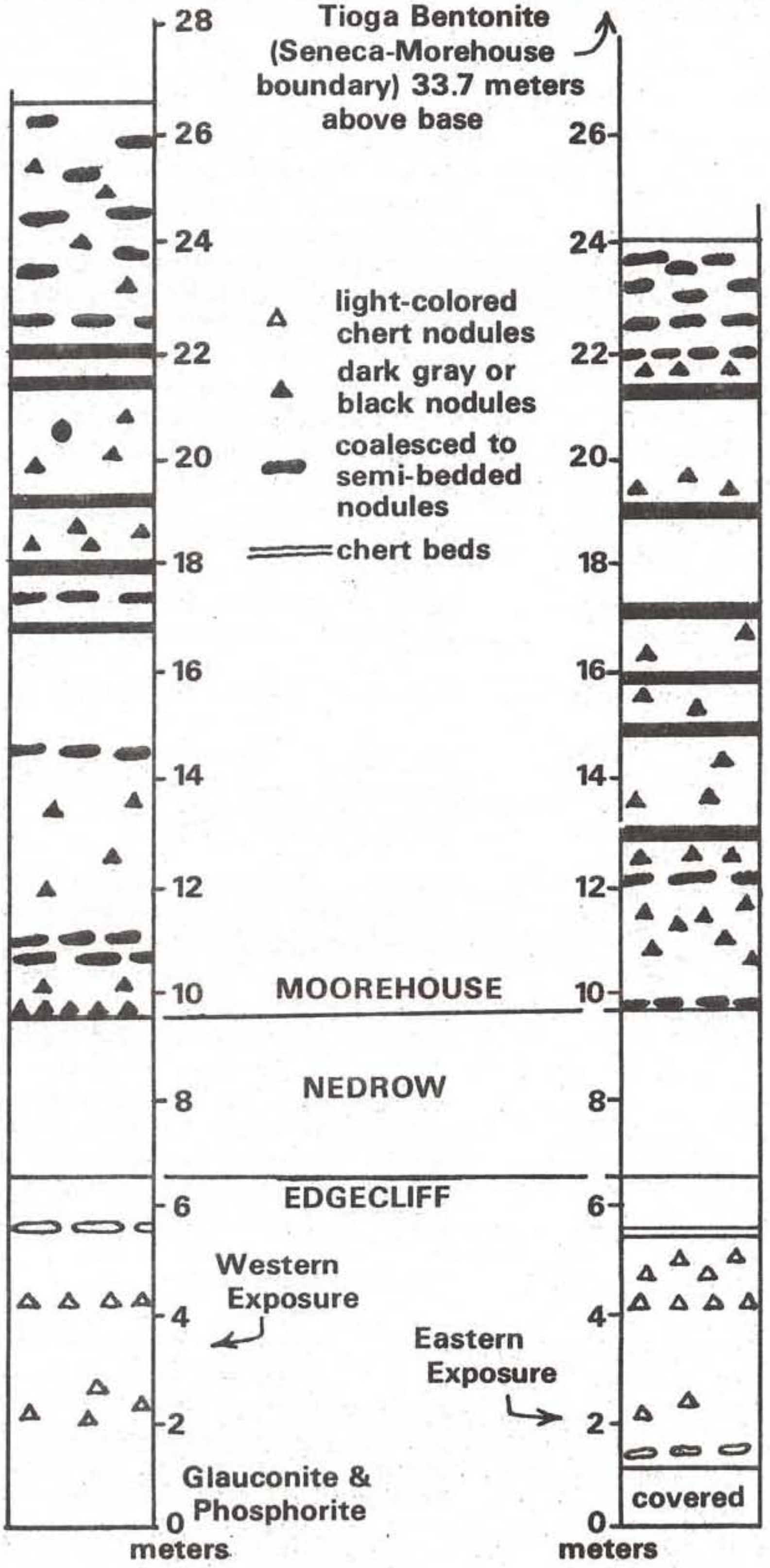

Fig. 7 - Exposures on Rt. 20 at Cherry Valley showing thickness of members and distributions of chert. Percentages not represented.

Miles from last point	Cumulative Miles

Nedrow Member as defined in central N.Y., the Tioga bentonite, and the Seneca Member. The latter two are exposed a half mile east of the rest area and can be seen to lie on about two meters of nearly chert-free Moorehouse. East of the uppermost member of the Onondaga is the Moorehouse.

End of field trip. Return to Oneonta via Cherry Valley and Rt. 166 to Milford; thence southwest on Rtes. 28 and 7.

THE PANTHER MOUNTAIN CIRCULAR STRUCTURE:
A POSSIBLE BURIED METEORITE CRATER

Yngvar W. Isachsen, Stephen F. Wright, Frank A. Revetta,[1]
and Robert J. Dineen

INTRODUCTION

We were led to a study of the Panther Mountain circular feature in the central Catskill Mountains, after discovering its striking appearance on satellite imagery. Our subsequent investigation to date does not permit us to explain the feature with any certainty, but it does enable us to narrow the range of possible explanations.

This article is a progress report which describes, in historical sequence, our investigations to date. Our work proceeded in the following, sometimes overlapping, stages: photogeology, gravity and magnetic measurements, conventional field study, and shallow seismic refraction profiling. A study of cuttings from a drill hole located inside the margin of the structure study is just beginning.

The structural geology of the region in which the feature occurs is not well known; the bedrock geology of the Phoenicia quadrangle, in which the Panther Mountain circular feature is located, has not been mapped in any detail. Chadwick (1936) shows a "preliminary map" of the Phoenicia and Kaaterskill quadrangles at very small scale (1:350,000), and the Geologic Map of New York by Fisher and others (1971) shows the geology only by projection. The formations shown on the State map, all continental clastic rocks of Upper Devonian age, are as follows: Walton Formation (shale, sandstone, conglomerate), which underlies the valley floor and most of Panther Mountain; the Slide Mountain Formation (sandstone, shale, conglomerate) which underlies the summit area, and the Honesdale Formation (sandstone, shale) which forms the summit itself. The colors of these rocks are red, green, and gray. The glacial geology of the region has been mapped and described by J.L. Rich (1934).

PHOTOGEOLOGY

The physiographic and drainage features of the Catskill Mountain region are remarkably well displayed on Landsat imagery (Fig. 1). The regional morphology reflects major geologic and tectonic provinces, as well as providing insights into the history of brittle deformation in the region (Isachsen 1973, 1974; Isachsen and others 1974).

The Allegany Plateau, with the Catskill Mountains forming its eastern projection, comprises all but the eastern portion of Figure 1. For the most part, the Plateau is marked by dendritic drainage, with major consequent streams flowing southwestward down the gentle (1^{o}-2^{o}) regional dip of Devonian continental and marine strata.

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Figure 1. Landsat 1 (ERTS) infrared image of Catskill Mountain region (portion of Image No. 1079-15124-7). Note how the circular form of Esopus Creek near Phoenicia contrasts with the general dendritic pattern of the region.

Esopus Creek, however, which drains into the Ashokan Reservoir, departs markedly from this dendritic pattern (Fig. 1, 2). Together with its uppermost tributary, Woodland Creek (Fig. 3), it forms an anomalous circular drainage feature 10 km in diameter. This drainage encircles Panther Mountain (el. 858 m, 2680 ft.), and is herein referred to as the Panther Mountain circular structure. Surrounding this structure is a series of interrupted arcuate ridges which together form an enclosing circular rampart of about twice the diameter of the Panther Mountain structure, and offset to the north. This circular alignment of ridges is open to the east. It can be discerned on Figure 1, but the ridge crest is better defined on a good drainage map (e.g. Isachsen, in press) where it shows up as a divide of gross circular dimensions. This outer circular feature has not been studied and will not be referred to further. Other arcuate features may be seen in the imagery, but these are much less striking, and may be fortuitous.

Another set of morphological features deserve mention, namely, the set of closely spaced NNE linear features which cross the prominent EW ridges of the Catskills at right angles. These may be zones of closely spaced joints produced as a result of reactivated basement faults (Isachsen and others, 1974). Be that as it may, we wish to point out for later reference that they occur both north and south of the Panther Mountain structure but, with one possible exception, do not pass through it.

The morphological details of the Panther Mountain structure can be seen in Figure 2, which is a high-altitude (U2) infrared photograph. For geographic orientation, see the topographic map at the same scale on the facing page (Fig. 3). At this scale, many irregularities can be seen in the circular rim valley, the most noteable being the right-angle bend of Woodland Valley in its upper reaches. Close examination of the photograph shows that much of the rim valley is actually made up of such north-south and east-west segments. Similarly, Figure 1 shows numerous examples in the general region of north-south and east-west tributary valleys which feed the major southwest-flowing streams. The north-south set appears to be longer (up to 15 km) and thus more prominent; their trends actually range from north-south to north-northeast. We will refer to these linear features later.

PREVIOUS RECOGNITION OF THE PANTHER MOUNTAIN STRUCTURE

Sometime after our photogeological "discovery" of the Panther Mountain feature, L.V. Rickard called our attention to an entertaining article by Chadwick (1950), written for the layman, in which he referred to the Panther Mountain mass as "a great rosette," and interpreted it as a "low dome." Chadwick referred to this "dome" in four unpublished consulting reports written in 1943, 1944, 1948 and 1951. We were unable to evaluate this documentation for his interpretation because maps were missing from each of the reports available to us. Another unpublished consulting report on the Panther Mountain feature, written by Ralph Digman in 1948, also lacked a reference map which incorporated both Chadwick's and Digman's strike-dip data. Digman was less certain of the validity of strike-dip measurements in the continental Catskill facies but concluded that "The domical structure for the area of the Panther Mountain massif is considered a strong possibility."

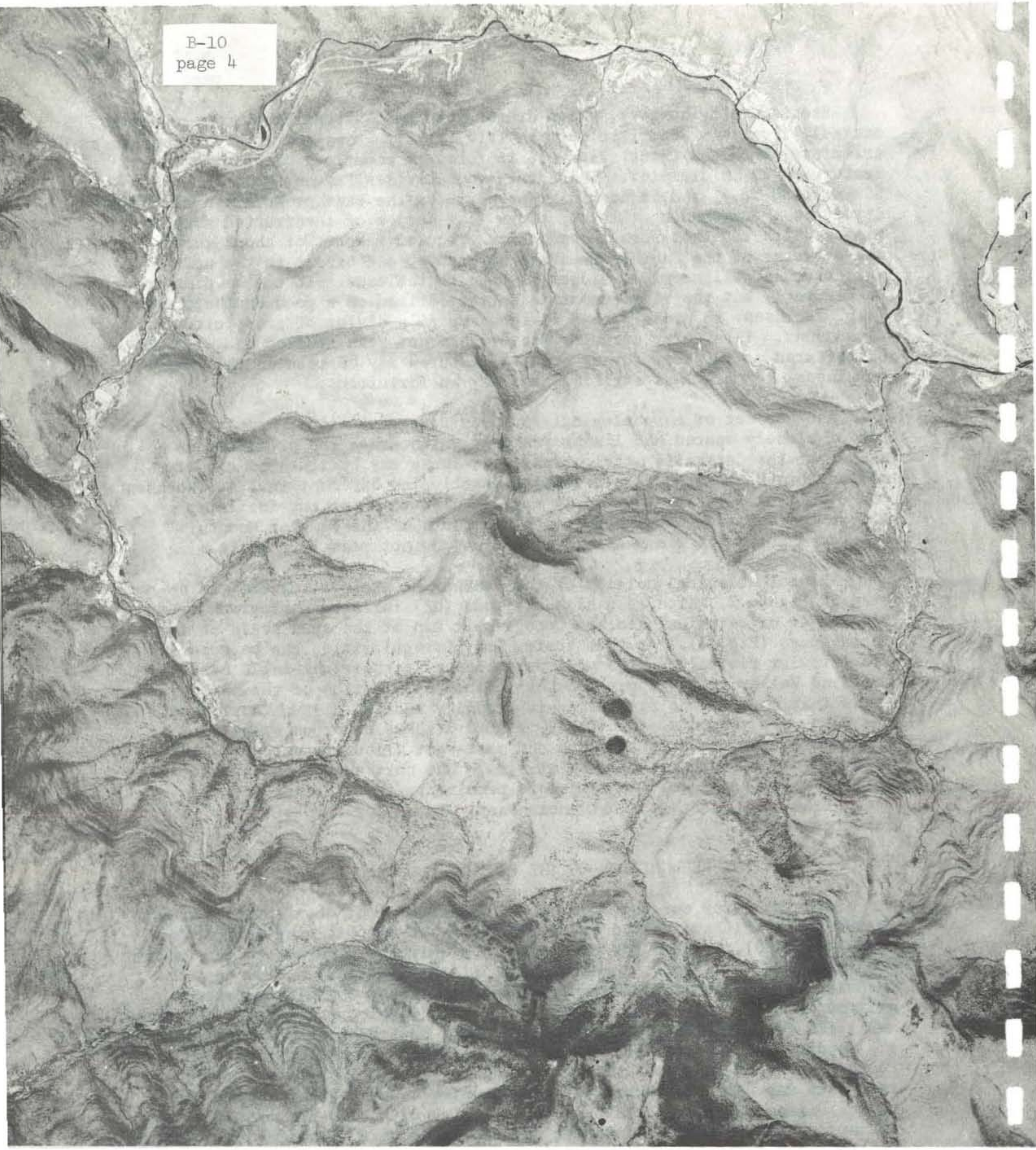

Figure 2. High altitude (U-2) infrared photograph of the Panther Mountain circular feature. Note the lack of lateral continuity of the continental clastic rocks which make up this region. For geographic orientation, see topographic map at same scale on opposite page. Ignore darkroom blemishes near center of photograph.

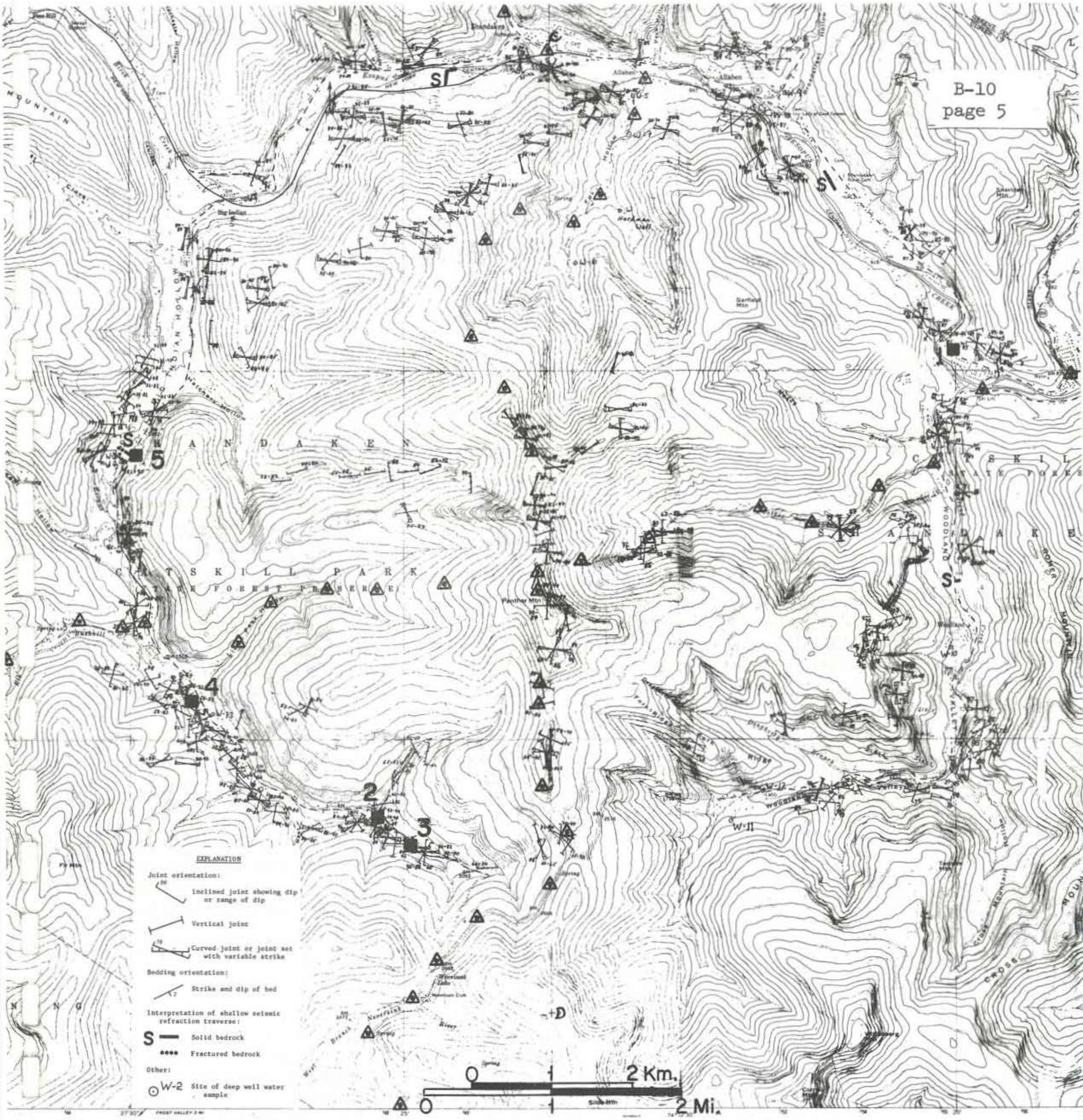

Figure 3. Reduced copy of joint work map of the Panther Mountain structure (7 1/2 minute topographic base from Shandaken and Phoenicia quadrangles). Triangles show locations of NS and EW gravity and magnetic stations, and squares with numbers indicate field trip stops. Sites of seismic refraction profiles are, in clockwise direction, Bedell Street, Golf Course Road, St. Vincent De Sales Cemetery, and Woodland Creek floodplain.

Several years after the submission of these consulting reports the Herdman well was drilled in Fox Hollow, near the northern edge of the Panther Mountain mass, to test for gas. The hole penetrated the Paleozoic section down to the Shawangunk Conglomerate in which it bottomed at 6400 feet. Selected cuttings from this well will be studied during the next phase of our investigation.

GRAVITY AND MAGNETIC STUDIES

Introduction

The above observations were made before any field visits to the area. Our first thoughts were that field study would show the structure to be either a very low-amplitude dome or basin. This led to the question: If it is a dome or basin, what might be the underlying cause? We decided that the best approach to this question would be to run two perpendicular gravity and magnetic surveys across the circular feature, and to extend them about one diameter beyond. A prior examination of the simple Bouguer gravity anomaly map at 1:250,000 of the region by Diment and others (1973) showed only that the circular feature was located on an elongate gravity gradient sloping 1 milligal/km to the southeast, without any associated perturbations.

Measurements

Gravity and magnetic measurements were made across the Panther Mountain circular feature at some 70 stations with a station spacing of approximately 1 km. Each traverse was about 30 km long, sufficient to extend across the 10 km diameter of the Panther Mountain mass and 6-10 km beyond in each direction. Figure 3 shows station locations within the area of the map.

The gravity measurements were made using a Worden Gravity Meter. For the measurements, a base station was established at Phoenicia which is tied to the U.S. Geological Survey network. Two readings were taken at each station to minimize errors due to drift and misreading the meter. Meter drift between readings was assumed to be linear, and corrected readings were determined from a drift curve plotted at the end of each day's work. Station elevations were determined by altimeter which was corrected for changes in temperature and barometric pressure. Four corrections were applied to the gravity measurements: free air, latitude, Bouguer, and terrain (32 stations).

The magnetic survey was made using an M50 magnetometer made by Varian Analytical Instrument Division.

Observations

Results of the gravity and magnetic surveys are summarized in Figure 4, with topographic profiles added for purposes of location and comparison.

It may be noted at the outset that the magnetic profile does not show any clearly anomalous characteristics over the Panther Mountain massif, nor over the rim valley. This indicates that if the Panther Mountain circular anomaly is controlled by some buried feature, that feature has

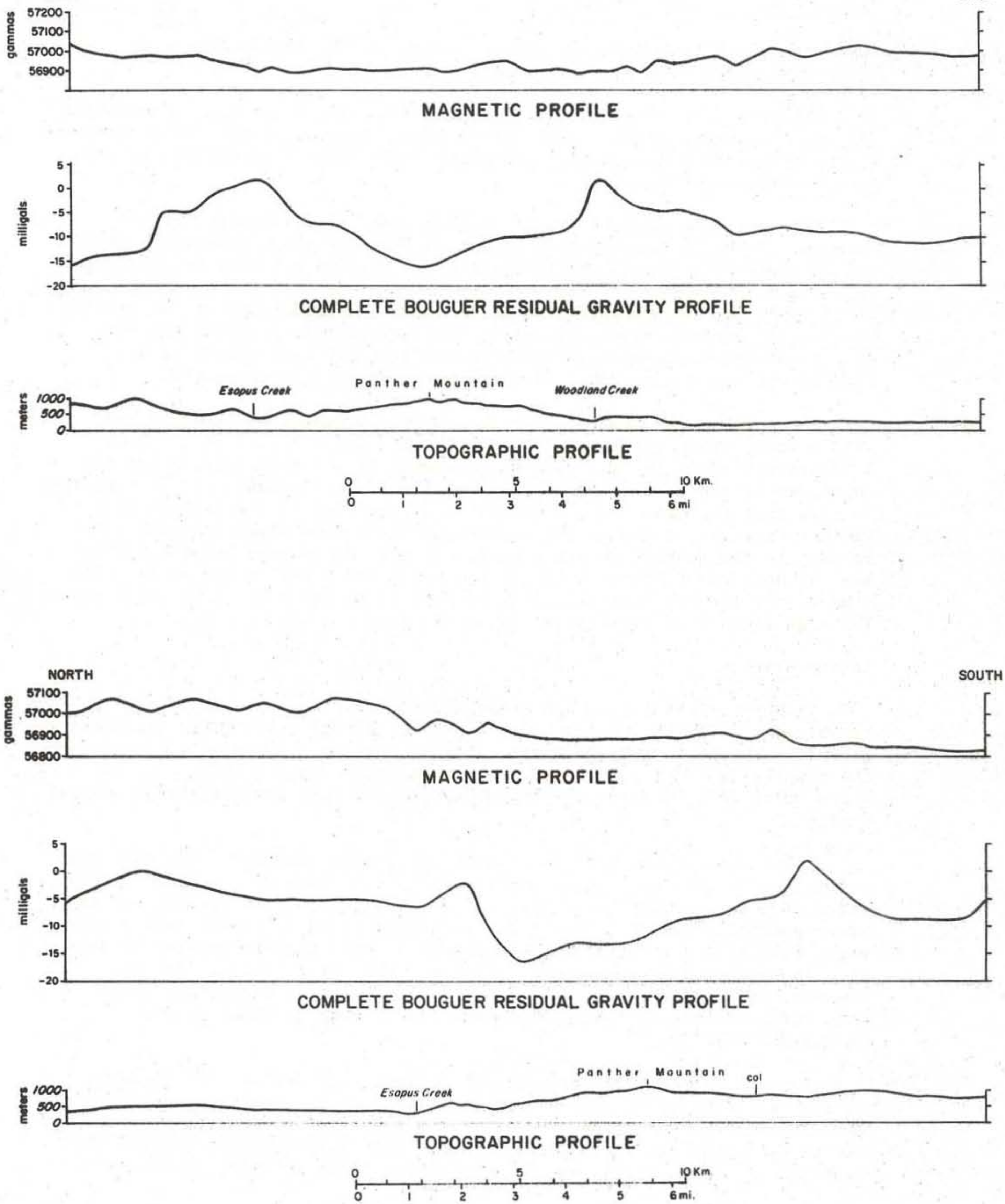

Figure 4. West-east and north-south topographic, gravity, and magnetic profiles across the Panther Mountain circular structure. Locations of geophysical stations are shown in Figure 3. See text for discussion.

essentially the same magnetic susceptibility as the surrounding area. We will refer again to this point later in the text.

The gravity profiles are more exciting in that they show a pronounced (18 mgal) negative anomaly over the feature. However, there are differences in the shapes of the west-east and north-south gravity anomalies, so they will be discussed separately.

The west-east profile shows a highly symmetrical negative gravity anomaly. It has a very steep gradient on the east and a moderately steep one on the west. These lead to an interior "bench" and then to a deeper depression in the center. The gravity relief from the rims to the bench is 12 mgal, and the total relief is 18 mgal. The remainder of the profile outside the Panther Mountain area is not particularly anomalous except near its western end where a steep gradient with 7 mgal relief occurs. This may be due to measurements which were not terrain-corrected.

The north-south profile is a pronounced, asymmetrical gravity low with a long, steep gradient on the north side and a relief of 18 mgal. A relatively small (9 mgal) low occurs north of the main anomaly but the remainder of the gravity profile is relatively featureless. It is important to note that the diameter of the gravity depression is the same as that of Panther Mountain, although the depression is shifted slightly south with respect to the Panther Mountain mass. In the topographic profile, this mass is bounded by Esopus Creek to the north and a col to the south. The rims of the gravity depressions on both sections are bounded by small peaks. The significance of these is still uncertain.

Interpretations

It appears clear from the gravity data (pending additional gravity traverses across the feature) that a high-magnitude gravity low coincides closely with the Panther Mountain circular feature. In addition, whatever the underlying "source," it has the same magnetic susceptibility as the surrounding rock, and hence must have about the same ferromagnesian mineral content.

There are several ways to explain the gravity anomaly. All call for a drastically less-dense mass underlying Panther Mountain, and the occurrence of this mass at a shallow level (1 km), in order to account for the steep gravity gradients. The first possibility, an intrusive salt diapir, might fulfill these requirements inasmuch as the specific gravity of salt is 2.16 vs an estimated value of about 2.7 for the Paleozoic section. However, the eastern edge of the Salina salt basin is known from drill hole information to be some 70 km west of the Panther Mountain area (Rickard 1969).

Two other categories of explanation were considered: 1) intrusion of foreign rocks of relatively low density, such as granite or rhyolite, into the Paleozoic section, and 2) severe brecciation of existing rocks, due to hypervelocity impact into the Paleozoic stratigraphic section and underlying basement rocks which would reduce their density. These two

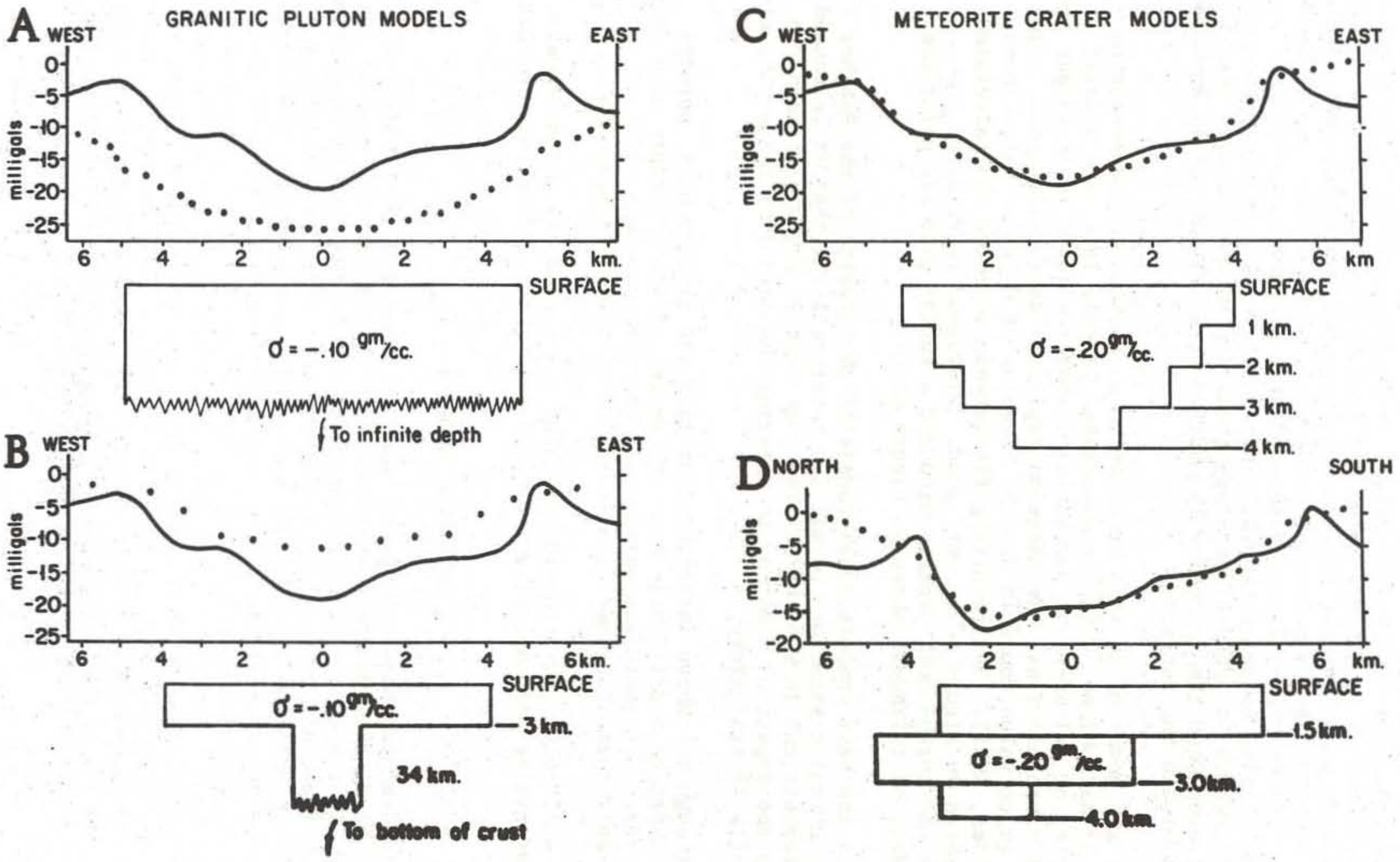

Figure 5. Gravity models that were tested for compatibility with measured values across the Panther Mountain circular structure. The modeled granitic plutons were chosen to simulate a stock (upper left) and an intrusive sheet and feeder pipe (lower left). Models of a near-surface breccia lens such as would be associated with a buried astrobleme are shown for both the west-east and north-south profiles. Solid lines show measured values, and dotted lines the computed gravitational attraction of the model tested.

were modeled in many configurations, and four of the better fits are shown in Figure 5. Profiles A and B show two of numerous shapes and dimensions of granitic plutons that were modeled. A density contrast of 0.10 gm/cc was used, based on an average value for granite (2.65 gm/cc) vs an estimated value of 2.75 gm/cc for the Paleozoic section and underlying Proterozoic rocks. Density figures were taken from Clark (1966). The poor correspondence between measured and calculated gravity values is obvious. The 0.1 gm/cc density contrast thought representative of a felsic pluton is not great enough to produce the steep gradients in the measured gravity profile, even when the intrusive is modeled as a cylinder of 10 km diameter, placed close to the surface.

For the model of in situ brecciation we chose a buried meteorite crater, or astrobleme, with its associated breccia lens, and modeled it as a series of cylinders of decreasing diameter stacked to represent the shape of a breccia lens. We chose an empirical density contrast, using the 0.2 gm/cc value found in drilled breccias of Canadian astroblemes (e.g. Innes, 1961). The resulting fit between measured and calculated values shown in Figure 5C is very good. Analogous modeling of the asymmetrical north-south profile produced a rather good fit using the arrangement of cylinders shown in Figure 5D.

Thus the best computational models of the gravity of the Panther Mountain circular structure permit the interpretation that it is caused by an asymmetrical lens of brecciated rock such as might have been produced by the impact of a meteorite entering the area from the south, with a low angle of trajectory.

Although the above interpretation fits the gravity data, perhaps nothing short of a drill hole near the center of the structure or a seismic profile across it would adequately test the idea - unless study of the Herdman well cuttings shows clear evidence of shock metamorphism.

We will return to a consideration of the buried-astrobleme model after describing and analyzing our field structural and seismic refraction studies.

STRUCTURAL GEOLOGY

A fundamental question we had hoped to resolve by field study was whether the Panther Mountain structure is slightly domical, basinal, or unwarped. That question remains unanswered due to the fluvial depositional fabric of the sedimentary rocks in the region. They consist largely of alternating continental sandstones and pebble conglomerates characterized by large-scale cross-stratification and erosional scour marks at the base of units. Overbank deposits of red silty shale make up the remainder of the section, but these units are generally obscured except at the base of some sandstone cliffs. When exposed, they are commonly scoured and channeled by the overlying sandstone units. Sub-horizontal bedding surfaces are very rare due to pervasive cross-bedding of sandstones and scouring of shale units. The few surfaces we were able to measure gave inconsistent results concerning possible flexing of the structure. We were probably measuring scoured surfaces of shale. Thus, we were unable to support or refute the previously mentioned conclusions of Chadwick that the Panther Mountain structure is a low dome.

Field studies, nevertheless, did provide a considerable amount of data relating to brittle deformation - specifically jointing. Some 500 individual joints or joint sets were measured at a total of 236 stations in an effort to determine whether the joints located within the circular valley differ in any way from those located away from the valley. Features examined included orientation, spacing, degree of curvature, surface irregularity, and host lithology. Two main features which characterize the majority of joints seen in individual outcrops are: 1) general lack, with some notable exceptions, of any single, dominant, through-going set against which other joints abut, thus making the systematic versus non-systematic classification inapplicable, and 2) the comparative rarity of planar as opposed to curved joint surfaces. Such curvatures occur in both the horizontal and vertical dimension. Even joints of the same set in a single outcrop or nearby outcrops differ markedly in their expression.

Where extensive joint faces are exposed, such as in the many old flagstone ("bluestone") quarries of the region, the degree of planarity can be seen to vary considerably over distances of a meter to a few meters. The character of these surfaces ranges from planar to broad, regular, cylindrical rolls through irregular, non-cylindrical curves, to local bumps and depressions. From such giant exposures one gains the impression that all, or nearly all, joints in the area are probably curved, and that "planar joints" are really only planar segments along larger, hidden, irregular surfaces.

Surprisingly, we could find no visible relationship between the curvature of joint surfaces and either the attitude of cross-lamination or the coarseness of grain size in host sandstones and conglomerates. Similarly, rare, extremely planar joints (or segments of curved joints?) cut through highly cross-bedded rocks without deflection.. We speculate that the joint-surface irregularities may be related to variations in cementation, but have not studied this question; the local control of joint curvature remains an enigma.

The considerable variation in strike and dip of joints in the region made the recording of strike-dip data more complicated than usual. Joint surfaces which curved in the horizontal plan were recorded as having a range in strike, the limits of which were usually at either end of the exposure. Dips were similarly recorded as a range of values. As always in joint studies, difficult decisions had to be made where outcrops were small, as to which surfaces should be classified as joints and which as irregular fractures.

The recorded data on joint orientations were plotted on a joint work map, which is reproduced as Figure 3. The joint azimuths, without regard for dips, were plotted on rose diagrams. Strikes were lumped into 10^{o} sectors to show azimuth frequency. Curved joints were given proportional representation in each sector covered by its range in strike. Thus,

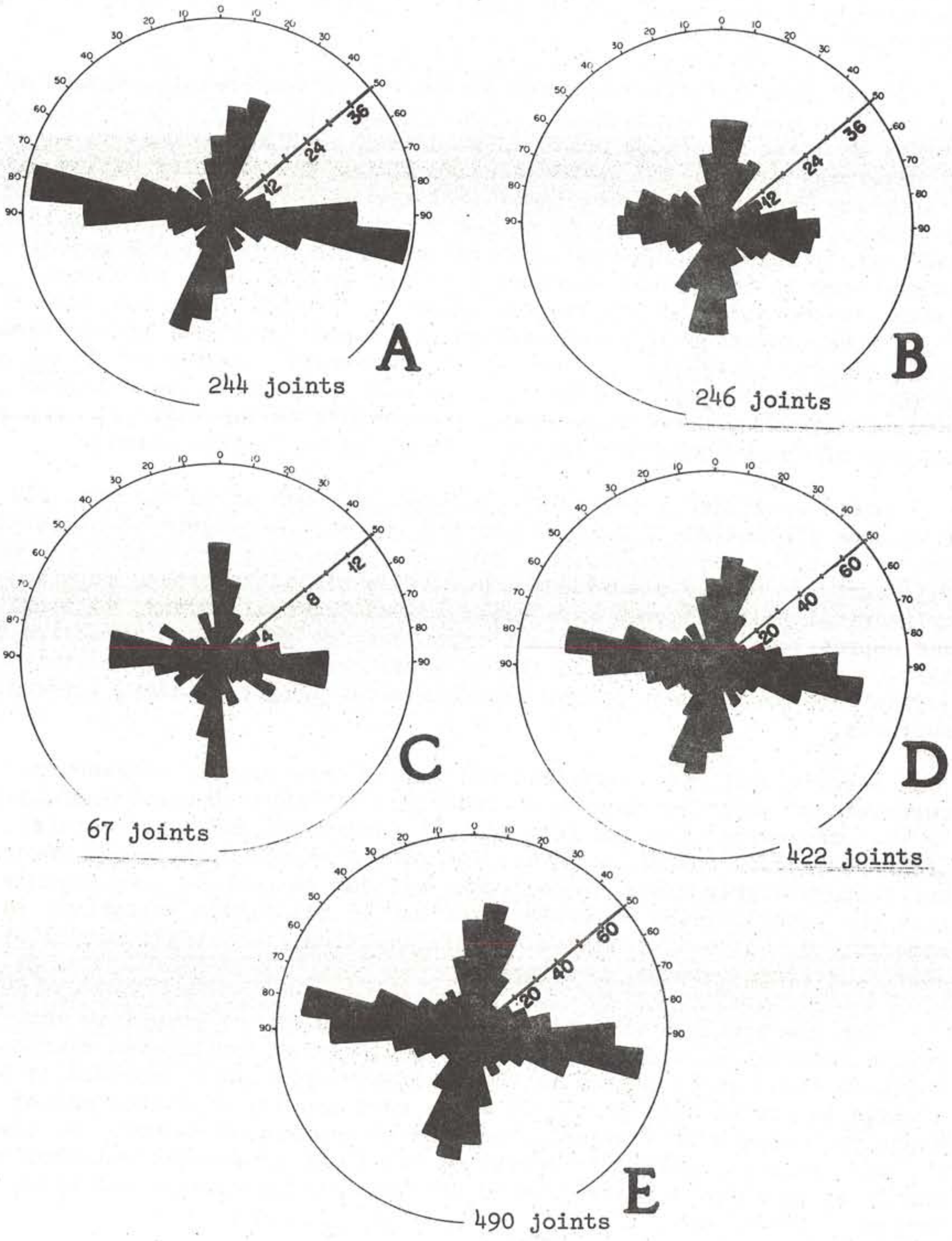

Figure 6. Joint frequency diagrams for: (A) joints of variable strike range (5°-30°), (B) joints of constant strike (range$<5^{\circ}$), (C) joints occurring in the center of the rim valley, (D) joints occurring at all localities other than the center of the rim valley, (E) total of all joints measured. Note scale differences. See text for discussion.

for example, a curved joint with a strike range of N10-30W was tabulated as 1/2 joint in the N10-20W sector and 1/2 joint in the N20-30W sector.

The joint measurements were plotted in five categories as shown in Figure 6:

A. Joints of variable strike ("curved joints"): range 5°
B. Joints of constant strike ("planar joints"): range 5°
C. Joints located in or near high-density joint zones
D. Joints located away from high-density joint zones
E. Total of all joints measured.

A comparison of rose diagrams 6A and 6B shows the following relationships:

1. The number of joints with constant strike equals those with variable strike.
2. The population of "curved joints" shows stronger maxima and less scatter than that of "planar joints." (Recall that these terms refer only to strike, not dip).
3. The "planar joints" form an orthogonal system, or "pairset" (Gay 1973), trending essentially NS and EW. The curved joints form a pairset trending NNE and WNW. Considering the great variabilities in curvature of individual joints described earlier, this apparent shift 10° clockwise may not be real, despite the clean appearance of the diagrams.

Rose diagrams 6C and 6D were constructed to compare the frequency distribution of joints in the center of the anomalous rim valley with those elsewhere in the area. Diagram 6C suggests that the rim joints are localized in a strong, equally developed, NS-EW pairset which shows very little dispersion. However, it must be acknowledged that the number of measurements made in the rim valley is relatively small. This is because exposures in the valley floor are restricted to the upper reaches of Esopus and Woodland Creeks (Fig. 3).

The non-rim joints shown in diagram 6D constitute essentially the same pairset, although with less sharp maxima, more prominent development of the EW set, and an apparent 10° clockwise rotation.

Comparing all five rose diagrams of Figure 6, it seems safe to conclude that one prominent pairset, ranging from N to NNE and W to WNW, characterizes the main-brittle deformation of the region.

These joint sets correspond extremely well with orientations of the numerous, earlier-mentioned, linear stream courses within the Panther Mountain structure, as well as with the short N-S and E-W segments of the Esopus valley and the larger rectangular corner of Woodland Valley (Figures 2 and 3). Thus it is clear that the major joint sets control much of the topography of the area. This is not to overlook the modifications produced by Pleistocene glaciation, of which an especially prominent example is the cirque at the head of Panther Kill.

It seems likely that the N to NNE and W to WNW linear tributary valleys in the greater Catskill region referred to earlier (Fig. 1) are also controlled in some way by the same orthogonal joint system. This has been discussed at greater length elsewhere (Isachsen and others, 1974).

It is now pertinent to ask if the circular rim valley is controlled by joint orientations. If so, it is not obvious in the frequency distribution of rim joints (diagram 6C). Observation of the joint work map (Fig. 3), however, does show jointing parallel to the stream course in nearly all exposures found in the rim valley or valley walls. However, the limited amount of outcrop in the center of the rim valley makes it difficult to determine whether joint orientation alone might control the circular valley. This is especially true in view of the N-S and E-W segmented nature of the valley in many places.

It is noteworthy that these segments are extremely short as compared to similar joint-controlled drainage within the structure and elsewhere in the region. This suggested that some factor other than joint orientation was responsible for the circular valley development, and that, quite likely, the cause was an increase in joint density due to an intensification of jointing along directions of the regional pairset.

Our field measurements of joint spacing confirmed this prediction. Aside from the center of the rim valley, joint spacing throughout the area consistently falls in the range 1.5-10 m, and commonly exceeds 2 m. This includes valley floors as well as slopes and summits. An example of this regional spacing is shown in Figure 7A, where joints are about 3 m apart in the massive sandstone unit above the excavated shale.

The opportunity to examine joint frequency in the center of the rim valley is, unfortunately, restricted to the heads of Esopus and Woodland Creeks where gradients are relatively high. Elsewhere in the valley the bedrock floor lies beneath a floodplain ranging in width from tens to hundreds of meters (Figures 2 and 3). Where outcrops are found, the spacing between joints is commonly 1 m or less, and, over short distances, as low as 2-5 cm. Figure 7B is a view of Stop 3 located in the upper reaches of Esopus Creek. The joints shown strike about N5E, and the spacing ranges from 5 to 50 cm. Note that these closely spaced joints or joint zones do not continue into the overlying beds. This is typical. These joint zones are restricted to the center of the rim valley but are localized within it both vertically (as shown here) and horizontally.

Figures 7C and 7D are photographs taken at Stop 4 of a joint zone in which a nearly orthogonal system is developed. The general spacing is 20-30 cm, with local zones having joints spaced only 2-4 cm apart. Dips of the joints range from 52°W to 60°E, suggesting that many could be classified as conjugate joints. Here, again, the joint zone can be see in the field to be limited in both horizontal and vertical extent.

For the sake of completeness, it should be added that bedding plane separations or "bedding plane joints" are common. However, they are interpreted as a response to erosional unloading, and were not recorded.

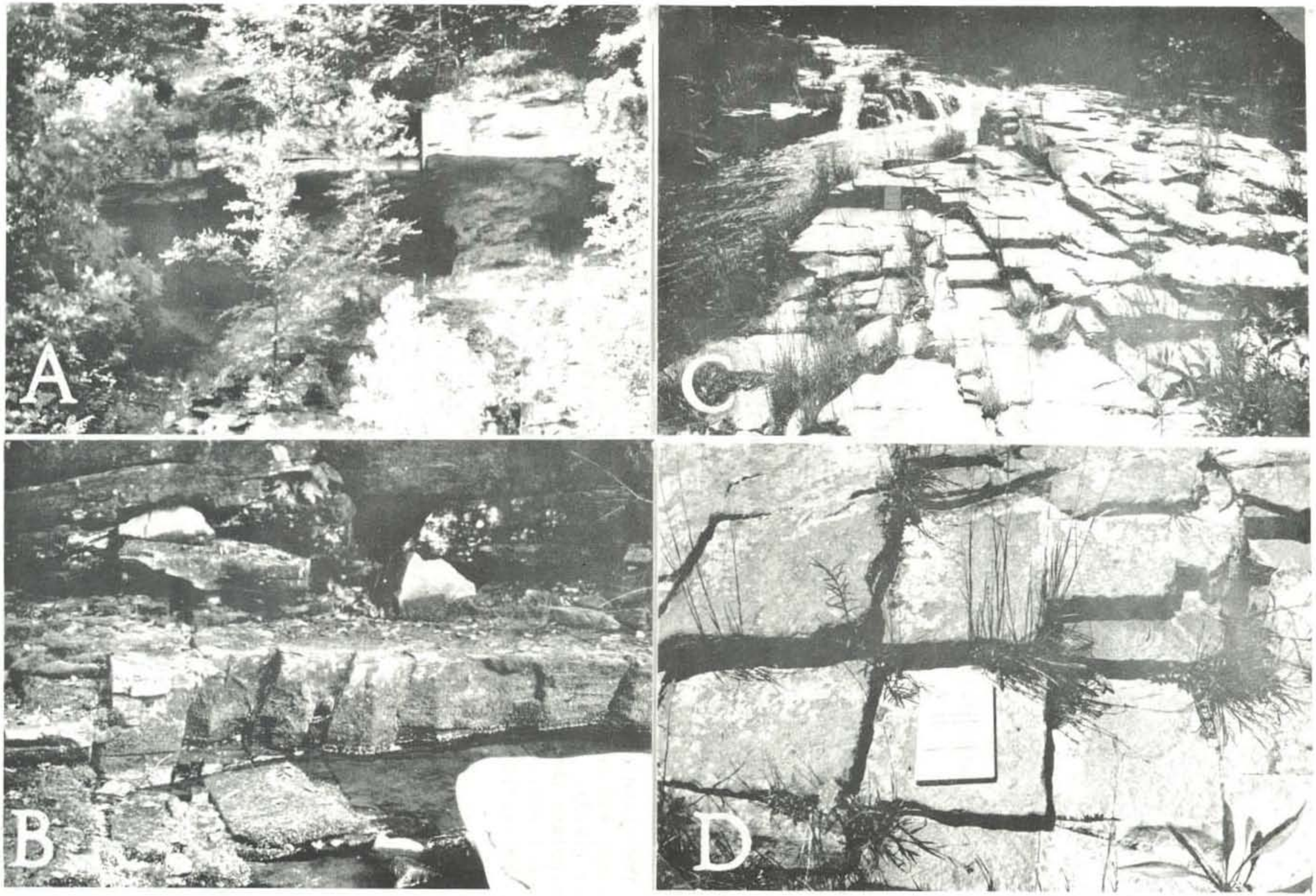

Figure 7. Photographs of joint exposures at: A, "Indian Cave Quarry" (at Roadlog mileage 7.8) showing joints with average regional spacing of 3 m; B, Stop 3 in center of rim valley, looking SSW at joint set with .4-.5 m spacing; C and D, Stop 4 in center of rim valley, looking SSE at pairset with .3-.4 m spacing.

SEISMIC REFRACTION STUDY

As is well known to field geologists, attempts to ascertain the relationship of valley development to bedrock structure are commonly thwarted by alluvial sediments which obscure bedrock at critical localities. Esopus Creek provides another fine example of this dilemma, as can be seen by the restriction of bedrock exposures to small portion of the valley rim (Fig. 3).

To obtain bedrock structural data beneath the extensive, alluvial-filled parts of the valley, we ran several shallow seismic refraction profiles across it. The goal was to search for a low-velocity zone in bedrock which would delimit a possible zone of intense jointing or other fracturing.

The seismic refraction data were gathered with a Huntec FS-3 single-channel seismograph, using a hammer-and-plate sound source. The hammer was a standard twelve-pound sledge, impacting on a ten-pound steel plate measuring 12 inches on a side and 1 1/2 inches in thickness. See Huntec, Ltd. (1970) for a description of the instrument and accessories.

The geophone position was held stationary and readings were taken of hammer blows spaced at ten-foot intervals. Traverses were reversed in order to eliminate the effect of interface slopes and inhomogeneous seismic layers.

The seismic refraction profiles were interpreted using the time-intercept and critical-distance methods, as described by Ewing (1960) and Mooney (1973). A Texas Instruments SR-56 programmable calculator was used to calculate the thickness, station offset, and true velocities of the seismic layers. The time-intercept method gave more consistent results than the critical-distance method in this area.

Four profiles were made across portions of the rim-valley flood plain. Their locations are shown in Figure 3. The sites were selected on the basis of ease of access, flat terrane, and avoidance of power line interference.

The seismic velocities of bedrock in two of the profiles (St. Vincent De Sales Cemetery and the floodplain of Woodland Valley) were found to be between 13,000 fps and 14,900 fps, values which fall in the normal range for sandstone and shale. These lines, therefore, define segments of the rim valley which are *not* abnormally fractured, and thus place spatial constraints on where a *rim* fracture zone might be.

The Bedell Street profile (Figure 8), on the other hand, shows an abrupt decrease in bedrock velocity from a normal sandstone-shale value of 14,500 fps on the east to 11,000 fps on the west. This low bedrock velocity is compatible with a zone of sandstone and/or shale having an abnormally high fracture density. Unfortunately this line is too short to show the full width of the low-velocity zone, but the zone appears to be at least 18 m (60 ft.) wide.

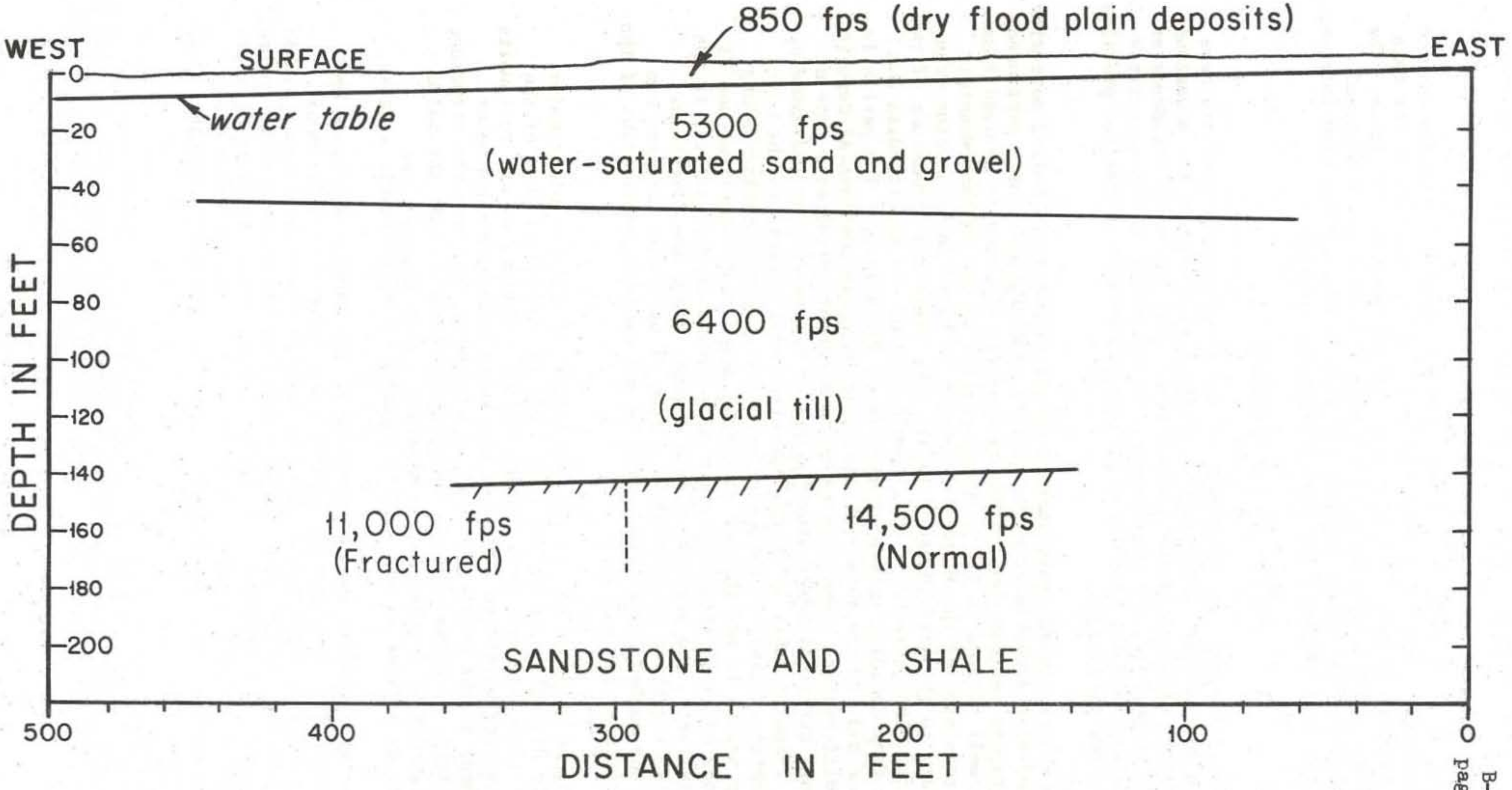

Figure 8. Seismic refraction profile along Bedell Street on the western rim of the Panther Mountain circular structure. Inferred lithologies for the four velocity layers are shown in brackets. The low velocity in bedrock is interpreted as due to closely spaced joints (joint zone) or other abnormal fracturing.

The profile along Golf Course Road yielded somewhat ambiguous results due to a "phantom" third-layer velocity in the data; analysis of the data using the critical-distance method yielded normal bedrock velocities. The time-intercept method, however, gave low values suggestive of abnormal-fracture density. The latter results are favored because the time-intercept method in this area produced the more consistent results.

"PUTTING IT ALL TOGETHER"

The interpretations given in each of the foregoing sections are here incorporated into a model which might satisfactorily explain the anomalous Panther Mountain circular feature. We believe that the model accommodates the observed morphology, the gravitational and magnetic fields associated with the feature, and the structural geology and seismic refraction profiles derived from our field work.

Figure 9 is a scaled cross-section of the hypothetical buried meteorite crater deemed most probable from the gravity modeling previously mentioned. The stratigraphic section down to the base of the Silurian is derived from the Herdman well located in the northern portion of the Panther Mountain mass. The remainder of the Paleozoic section is based on projection from deep well data to the west (Rickard 1973). The shape and dimensions of the modeled breccia lens were based on a combination of our gravity data and information from Canadian crater studies (e.g. Innes 1961). The partially eroded crater and rim are shown infilled with Devonian continental deposits. Subsequent differential compaction of these sediments produces a zone of high tensional stress directly over the rim of the crater, as indicated by arrows. We visualize this as having two structural effects on the overlying sedimentary rocks: 1) extension occurs via slight openings along pre-existing joints in the thicker sandstone units of the section, and 2) in the thinner beds, an intensification of jointing occurs parallel to the regional joint sets, and perhaps to some degree, along new directions. These effects, together, would produce a zone of erosional weakness congruent with the buried crater rim. This is one possible explanation of the anomalous, circular rim valley.

To date, no evidence exists for repetition of units, or other major stratigraphic disruption, in either lithologic or electrical logs of the Herdman well (L.V. Rickard, oral communication). Whether or not rock units within the section have been tilted is not known because no dip meter survey was made in the hole. The lack of a magnetic low over the structure is not surprising, because although brecciation would disrupt the paleomagnetic alignment of ferromagnesian minerals, such minerals are either absent, or present in very minute amounts, in the Paleozoic section.

The time of meteorite impact according to the above model would be Upper Devonian. The steep gravity gradient and large mass-deficiency beneath the structure require that the low-density source be located within 1 km of the present surface, thus further refining the stratigraphic control on time of impact. In addition, the model dictates that the crater itself must have been relatively young, with still well-developed crater rims, when entombed beneath Devonian sediments. It may thus be a remarkably well-preserved fossil crater.

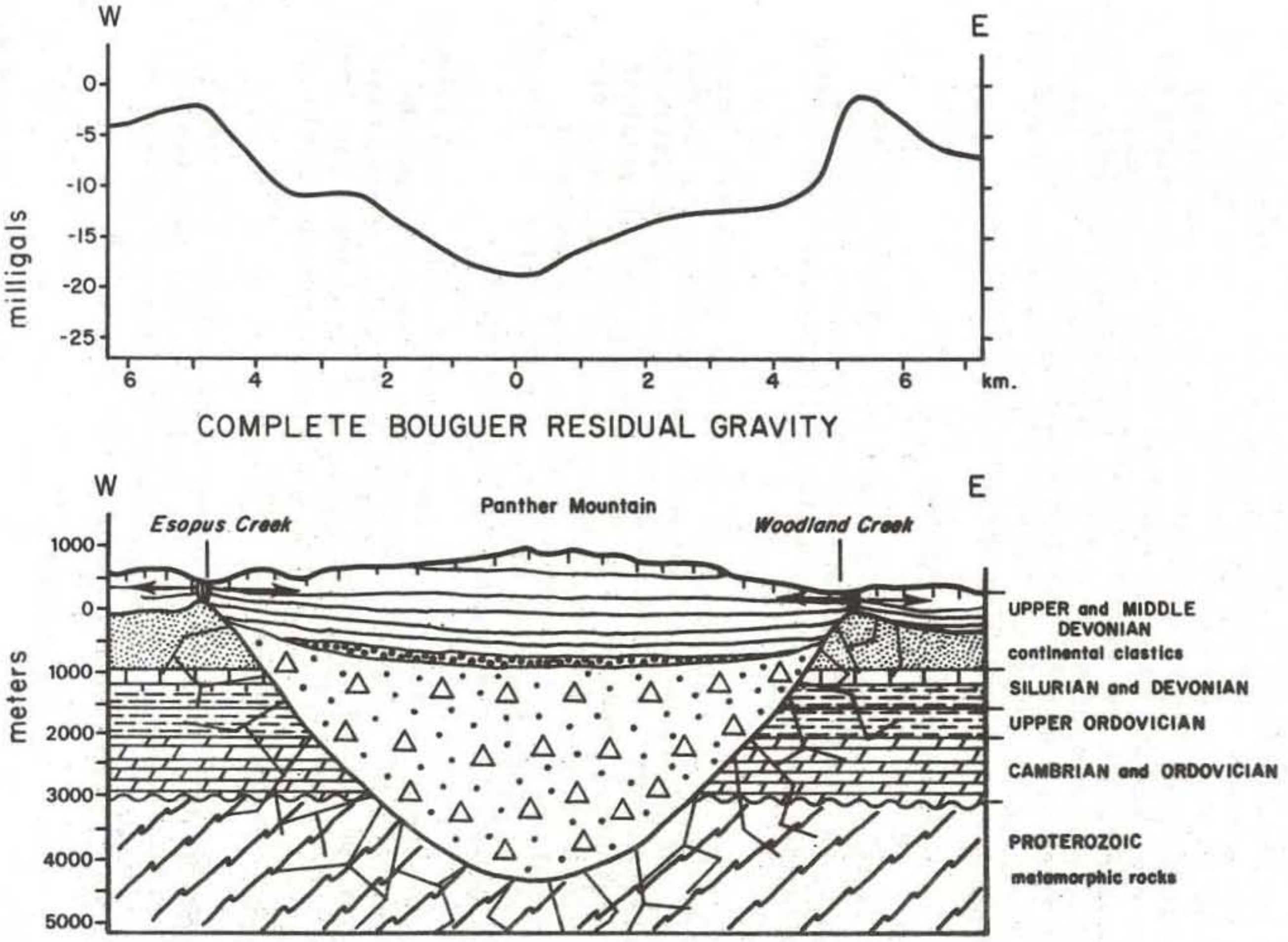

Figure 9. West-east gravity profile and scale drawing of possible buried astrobleme showing eroded crater infilled with Devonian sediments and underlying breccia lens. Draping of sediments over former crater rim exerts abnormal tensional stresses in the overlying rocks resulting in an increased joint density. Vertical and horizontal scales are equal.

As to possible associated flexing, we anticipate that, if it exists, it may exist as downwarping over the crater depression caused by differential compaction, rather than as doming. We would also predict that differential compaction might lead to the formation of a low-amplitude rim anticline located over the present rim valley.

In the section on photogeology, we noted the numerous NNE linear valleys which cross the prominent EW mountain ranges north of Panther Mountain. We referred to the suggestion by Isachsen and others (1974) that they might be zones where joints were intensified due to reactivated dip slip movement on pre-existing basement faults. Without reiterating the reasons for this interpretation, we wish to note here that these linear valleys, with one possible exception, do not pass through the Panther Mountain structure. This is consistent with the interpretation of a large breccia lens underlying Panther Mountain because such a lens would probably re-orient and/or absorb any such upward-propagated stresses.

ECONOMIC IMPLICATIONS

At the outset of this study, we thought that the Panther Mountain circular anomaly might be a domical surface expression of an underlying felsic pluton, similar to the Upper Devonian Peekskill granite body located 80 km to the southeast.

Such a pluton would produce sufficient heat through radioactive decay of uranium, thorium, and potassium to exist as a vast reservoir of thermal energy if the overlying rocks possessed sufficient insulating qualities to raise locally the geothermal gradient. If the resulting thermal gradient were sufficiently elevated, the area would have potential as a source of dry hot-rock geothermal energy. As shown by our modeling experiments (Fig. 5), however, a felsic pluton does not have a sufficiently low density to account for the enormity of the negative gravity anomaly.

Another possible energy source can be considered, however, with respect to the astrobleme model. The large brecciated lens associated with the astrobleme would provide a large reservoir for gas, and black shale source beds exist in the stratigraphic section. Subsurface astroblemes have been inferred in the Williston Basin, where they are either producing fields or potential hydrocarbon reservoirs (Swatsky 1975).

Only a limited quantity of gas was found in the Herdman well which is located at the northern edge of the 10 km structure, but this single well, located as it is near the rim of the structure, may not provide an adequate test for gas reserves beneath the Panther Mountain mass.

ACKNOWLEDGEMENTS

For technical assistance, we wish to express our thanks to Richard Major who made many of the joint measurements used in this study, and to Diane Sheldon, Margaret Guthrie, Gary Thompson, and Ed Kujawski who made the gravity and magnetic measurements, and reduced the gravity data.

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ROAD LOG

BIG INDIAN TO PHOENICIA

Mileage	Difference	
0.0	0.0	Big Indian is located between Kingston and Oneonta on N.Y. Rte. 28. Mileage starts at intersection of Rte. 28 and County Road 47 leading to Oliverea. Start trip by heading east on Rte. 28.
2.2	2.2	Golf Course Road. Edge of Gulf Course Road between Rte. 28 and creek was the site of shallow seismic traverse (Fig. 3). The seismic refraction data closest to the creek suggests a possible fracture zone in underlying bedrock. See text.
2.9	0.7	Large road cut and small quarry on south side of road at first R.R. crossing on Rte. 28 since Big Indian. Many examples of joints typical of the Panther Mountain area can be seen.
2.95	.05	Bridge on Rte. 28 crosses Esopus Creek just east of above outcrop.
3.15	.2	Junction Rte. 28 and Rte. 42 at Shandaken, crossing point for N-S gravity and magnetic traverse. Traverse continued north along Rte. 42, and south via Fox Hollow and trail across the Panther Mountain structure and to the south (Fig. 3).
5.55	2.4	St. Vincent De Sales Cemetery. Gravel pit behind cemetery is site of another shallow-seismic refraction survey. This seismic line essentially paralleled the valley. Interpretation showed bedrock to be unfractured.
7.4	1.85	<u>STOP 1</u>. Access to field trip stop is via a small, steep gravel road seen on the left as the highway takes a sharp left curve around a protruding kame. This rough access road switches back several times and passes a currently open gravel pit before reaching a large abandoned quarry. Total walking distance is slightly over one-fourth mile. This stop is included to display a series of well-developed joint faces in a large, fresh, man-made outcrop. These joints can be seen to be widely spaced, generally pervasive through this thick sandstone bed, and roughly planar in nature. Note the large amount of small-scale irregularities

		on even the largest and best developed joint faces. This is one of the many flagstone ("bluestone") quarries of the Catskill region which were operated in the early part of this century before being superseded by Portland Cement. It was quarries such as this which provided the old "sidewalks of New York."
7.8	0.4	"Indian Cave Quarry." Visible high on the slope through opening in trees on north side of road just opposite the junction of Rte. 28 and the Woodland Valley Road (see photo, Fig. 7A). The quarry was named locally for the cave-like nature of the holes created by the removal of red silty shale from beneath the overlying sandstone. We were not able to ascertain why the shale was mined, but its removal has allowed some shifting of the overlying sandstone blocks along joint planes. This allows easy observation of typical regional joint spacing (here about 3 m) in an outcrop near to, but not directly in, the rim valley.
8.4	0.6	Intersection Rte. 28 and Rte. 214. Turn left to enter Phoenicia. Rte. 28 continues to Kingston. At this point return to Big Indian for second leg of field trip along Big Indian Hollow.
16.8	8.4	Big Indian.

SECOND LEG OF FIELD TRIP - BIG INDIAN HOLLOW

0.0	0.0	Big Indian. Second part of field trip starts here. Turn south from Rte. 28 onto small road (County #47) and proceed south up Big Indian Hollow towards Oliverea.
2.85	2.85	Oliverea Shell Station and general store.
2.95	0.1	Small road to right crossing bridge over the Esopus Creek and heading up McKenley Hollow. The stream channel and broad alluvial floodplain are visible to the right. Downstream from this point, the stream meanders and braids across the valley. Nowhere in this area or further downstream is bedrock exposed in the stream channel.
3.75	0.8	Slide Mountain Inn. Located where small road branches west up the Bushkill Creek valley. The stream valley here is still deeply filled with alluvial sediments. Outcrop is limited to the very edge of the valley, where hillsides meet

the valley floor. This intersection is also a station point on the E-W gravity and magnetic traverse of the Panther Mountain structure. Gravity stations are often located at road intersections or other well defined and surveyed locations to minimize error when correcting the gravity data.

The Slide Mountain Inn is typical of many Catskill summer resorts in the area, a number of which have catered to the summer tourist for over one hundred years. Access to the area was formerly via the railroad line from Kingston to Oneonta which was abandoned early in 1977. Passengers left the train at Phoenicia or Big Indian and were met by carriages from the particular resorts at which they planned to stay.

6.3 2.55 STOP 2. Stop at large pull-off on right side of road, often used by the county to store road stone and gravel. Walk .05 mile to small hollow where road crosses tributary of the Esopus Creek. Just beyond the stream, take a small unmarked trail to the right which leads immediately to the tributary.

In this lovely little glen the small feeder stream plunges down to Esopus Creek via a series of cataracts and spill pool. The jointing here is typical of jointing observed at most localities on or near the Panther Mountain structure even though this outcrop is located within 50 m of the Esopus Creek rim valley (which at this point is bottomed in alluvial gravels). Many joint surfaces can be seen, with strikes ranging between N63W and N78-83E. Note the lack of any dominant joint set traceable throughout the outcrop. Most joints are non-through-going, generally abutting other joint surfaces in either horizontal or vertical directions or both. Note also the characteristic lack of any consistent relationship between cross-bedding and the curvature of joint surfaces. The stream has greatly modified joint surfaces in its channel. Note also that this steep-walled stream channel has undergone a considerable amount of erosional unloading without any increase in joint density or other observable brittle deformation in the channel. Similar observations have also been made in the larger non-rim valleys of the area. In short, erosional unloading of valley floors has not, in itself, been found to cause an increase in joint density.

Proceed to Stop 3.

6.8 .50 STOP 3. Look for an old brown house close to the left side of the road, and park where possible along the road margin. Exactly opposite this house, bushwack directly down to the stream (about 50 m) and the outcrop shown in Figure 7B should be visible on the opposite (SSW) stream bank. Here, two sets of very closely spaced joints can be seen at stream level, one striking N2-9E and dipping 63°-80°W and the other striking N30-34E and dipping 45°-56°SE. Joints in these sets are spaced from 50 cm apart to as little as 2 cm apart in a narrow (50 cm wide) zone in the outcrop. This outcrop of closely spaced jointing is very restricted in space. The jointing is not present in the thicker overlying sandstone nor in outcrops immediately up or down stream. Although joint spacing of about 1 m characterizes exposures present in the center of the rim valley, this outcrop and several others further downstream are the only ones observed in the entire Panther Mountain area which display this extremely dense jointing. Although outcrop control is limited, high-density fracturing appears to be the structural control on the arcuate pattern of Big Indian Hollow.

6.9 .3 TURN AROUND HERE. Bus or car turnaround. Small remnant of logging road on right just beyond culvert. Turn around and go back down the valley towards Big Indian.

9.5 2.6 STOP 4. A small field opens to the left. Walk down farm path which runs along the far edge of this field until the stream is reached, at about 200 m. The outcrop itself is a broad, flat exposure located on the opposite stream bank. In some seasons it may be necessary to wade the stream, although a less detailed view can be had from the opposite bank.

Two closely spaced, planar, nearly orthogonal joint sets are exposed here (Fig. 7C, D). The N60-70E set is systematic (generally through-going) in a strike direction and trends perpendicular to the stream course. Dips are mainly 68°-80°NW, but several are seen to dip 78°-80°SE. The N10-30W set is non-systematic. It trends parallel to the stream course and displays a range of dips suggestive of conjugate pairs. These dips generally have values of 60°-67°NE and 52°-76°SW though some are vertical. Joint spacing in both sets is consistently 30-50 cm and locally as little as 2 cm. Although we have found a general inverse relationship between bedding thickness and joint spacing, nowhere, regardless of bed thickness, have we seen such a display of closely spaced joints over this large an area.

This joint zone is limited in both horizontal and vertical extent. In the beds upstream, joint spacing increases to 1 m just above the waterfall. Similarly, joint spacing is 1 m or greater in the outcrop 20 m downstream and also in a large, thick-bedded outcrop located in woods 15 m southwest of the main exposure. At low water, joints in the N60-70E set can be seen to be only variably continuous into the underlying beds. This is another example where high-density joint zones seem to be restricted to certain beds in limited lateral positions along the rim. The significant fact is their restriction to the rim and, thus, their apparent control on stream development.

At the downstream end of this outcrop, jointing is extremely intensified in a narrow zone 40-50 cm wide, where the spacing is only 3-6 cm. This occurs within the N70-60E set. Note the resulting differential erosion between this zone and the remaining outcrop. Perhaps this illustrates, in microcosm, the way in which closely spaced joints control the circular rim valley that defines the Panther Mountain mass.

Continue driving down valley to Stop 5.

9.7	0.2	Green Bridge crosses the stream flowing in Little Peck Hollow.
11.05	1.35	Oliverea Bridge - on road to left over Esopus Creek.
11.65	0.6	STOP 5; BEDELL STREET. Small path crosses perpendicularly nearly the entire width of the valley. At this location and several others like it where the Esopus Valley is deeply filled with alluvial deposits, the shallow seismic refraction technique was used to search for zones of abnormal bedrock velocity. This is the site of our most definitive traverse. The near-level field provided

an ideal test site where few corrections were needed, and the ease of access to the entire valley width was excellent. Interpretation of this traverse has identified a bedrock zone of low seismic velocity, which we interpret to be a continuation of the abnormally dense jointing mapped upstream (Fig. 8). The seismic refraction method will be demonstrated here.

END OF TRIP.

GEOLOGICAL CONTEXTS OF ARCHEOLOGICAL SITES ON THE SUSQUEHANNA RIVER FLOOD PLAIN

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INTRODUCTION

Prior to the present decade, prehistoric archeological research in New York State had a long history going back over 50 years, focussing on major drainage systems (Parker 1922; Ritchie 1938b, 1944, 1951, 1965, 1969). Yet over this period relatively little attention was paid to the Upper Susquehanna Valley, including its major tributaries in the State. This neglect is surprising in view of the high archeological potential of the region, reflected in numerous recorded sites and surface collections, and a geographic position conducive to the study of many problems in cultural distribution and adaptation.

The first major attempt at professional exploration occurred in the 1920's, when a canoe flotilla carrying archeologists and laborers began at Cooperstown and surveyed for archeological sites well down into Pennsylvania (Moorehead 1938). Later, surveys were conducted by William A. Ritchie, who also excavated some sites of the late prehistoric Owasco culture (Ritchie 1934, 1938a, 1939, 1944:59-71, 1969:xxiv-xxvi). Sporadic work was carried out in the late 1960's by the New York State Museum and the State University at Binghamton, partly in connection with the State highway salvage archeology program (Wilcox n.d.a, n.d.b: Elliott and Lipe 1970; Funk and Hoagland 1972a, 1972b; Hesse 1968, 1971). A major interdisciplinary program of investigations into regional prehistory was initiated by the writer in 1971. Field work is expected to conclude with the 1977 field season and a final report will eventually be published. The project has involved personnel from several institutions, including the New York State Museum, the State University of New York at Albany, and the State University College at Oneonta. Preliminary reports have appeared (Funk, Rippeteau, and Houck 1973, 1974; Kirkland, et al 1976; Funk and Rippeteau 1977).

The fundamental objective of this project is to delineate the history of human adaptations to the postglacial Upper Susquehanna environment. This requires the acquisition of data on the sequence of prehistoric Indian cultures, their distribution in time and space, their subsistence and settlement patterns, and the various components of environmental change. To accomplish these goals, our methodological

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emphasis has been on stratified flood plain sites, where the discrete occupation surfaces are separated by the accumulation of overbank sediments. In such contexts, the mixture of debris from different periods of habitation is minimal or absent; the patterning of artifacts, hearths, pits, or refuse on each floor is undisturbed; and radiocarbon dates on organic materials from these floors can be attributed to the individual occupations with a great deal of assurance. Thus it is possible to construct a well-dated stratigraphically based regional sequence of artifact styles and cultural complexes, to study within-site patterning, and to make valid between-site comparisons.

Palynological data used to sketch a picture of floristic environments are acquired from bogs, occupation zones on archeological sites, or precultural levels in our excavations. Other paleoenvironmental data are contributed through studies of changing postglacial landforms, especially with regard to the flood plain. When all the data are analyzed, we should be able to present a synthesis of prehistoric culture change in relation to environmental change within the Upper Susquehanna drainage.

ACKNOWLEDGEMENTS

Many persons have contributed to the Upper Susquehanna Project. We are especially indebted to P. Jay Fleischer for his input on the geology of several sites; to Beth Wellman for her assistance in preparing this report and the processing of collections acquired in our excavations; and to Franklin J. Hesse by whose efforts many of the sites were located and tested.

THE ARCHEOLOGICAL SEQUENCE

An important result of our investigations has been the construction of a detailed framework for prehistoric Native American cultures in the valley. This framework consists of a sequence of cultures, identified and contrasted by means of distinctive artifact styles, which are solidly placed in relative time by recurrent stratigraphic associations and in absolute time by over 70 ^{14}C determinations.

The earliest known human groups, the Paleo-Indians, entered New York State from the south and west following the recession of Woodfordian ice. Radiocarbon dates from several sites indicate this event took place ca. 9000 B.C. and probably somewhat earlier. Generally believed to have subsisted largely on big game animals, some of which are now extinct, these people are identified chiefly by their "fluted" lanceolate projectile points chipped from high-grade flint. Although fluted points have occasionally been found on plowed fields in the Upper Susquehanna drainage, no habitation sites with in situ remains have so far been discovered there.

Throughout the eastern United States, the Paleo-Indian cultures apparently evolved into the Archaic cultures which represented adaptations to changing early postglacial environmental conditions. Exploiting the diverse resources of these surroundings, Archaic groups developed a considerable variety of subsistence patterns and artifact styles. This period lasted from approximately 8000 to 1500 B.C. For reasons yet obscure, few traces of the earlier Archaic occupations from 8000-4000 B.C. are known in the Northeast. One possible explanation is that the predominantly coniferous forests of 8000-6000 B.C. were relatively poor in food resources available to populations at a hunting-gathering stage of culture. We have located and excavated two sites of that age at Wells Bridge. These are the oldest Archaic sites on record in New York or New England north of the coastal region.

Middle Archaic developments from 6000-4000 B.C. are still relatively obscure, even though the pollen data suggest an improved environmental situation. By the time essentially modern ecological conditions prevailed -- the oak-chestnut-deer-turkey biome of Ritchie (1969: 32) -- the first important Late Archaic traces are referred to as Early Laurentian and ^{14}C dated ca. 4000-3000 B.C. Later groups are known in the study area in more detail, including the successive Lamoka, Vestal, Snook Kill, and Frost Island phases (Ritchie 1969; Ritchie and Funk 1973; Funk, Rippeteau and Houck 1974). Each complex is distinguished on the basis of diagnostic traits, usually projectile point types. There appears to have been a population surge during this period of ca. 2500-1200 B.C. By Frost Island times (ca. 1500-1200 B.C.) soapstone pots, a horizon marker across the Northeast, had been introduced, followed by the first true pottery.

We have little data on the succeeding Early Woodland and Middle Woodland manifestations, which elsewhere in the Northeast denote a time of ceramic innovation, and burial ceremonialism attained a high degree of elaboration. There may have been a decline in population throughout the Upper Susquehanna Valley between 1200 B.C. and A.D. 400.

A continuous development is indicated from the Middle Woodland cultures into the next major stage, the Late Woodland. By A.D. 1100 there is clear evidence that northeastern Indians were growing corn, beans, and squash (domesticated long before in Mexico). This revolution in subsistence brought with it changes in the social order, an accelerated population growth, and an increase in village size. These first New York agriculturists were the Owasco people (ca. A.D. 1100-1300) who in turn gave rise to the Iroquoian cultures whose historic representatives, the Five Nations Iroquois, played an important role in colonial history. Strangely, while Owasco sites are common in the Susquehanna Valley north of Pennsylvania, Iroquois sites are rare and of small size.

GEOLOGICAL CONSIDERATIONS

Of primary relevance to this field trip, our investigations on flood plain sites have enabled us to develop a detailed ^{14}C chronology for generally structureless overbank sediments at several sites between Oneonta and Wells Bridge. Not only have the occupation levels been dated, but in some cases underlying sands and silts rich in organics have also been dated.

The sedimentological picture is reconstructed as follows. With the retreat of Woodfordian ice, the Upper Susquehanna basin was the scene of numerous small lakes formed below successive ice marginal positions. These lakes were impounded on their southern borders by morainal dams. Wells Bridge was the site of one such "valley plug" creating a lake some 10 miles (16 km) in length. This lake was subsequently filled by over 400 feet (122 m) of lacustrine silts and clays (Fig. 1, data from Randall 1972). Lenses of gravel occur in the lake sediments at the junction of major tributaries. Their positions high in the lacustrine sequence indicate a very rapid lake infilling if these gravels are related to late stage ice melting in tributary basins, or they might possibly be contemporaneous with some climatic change or fluctuation. If there was a long period of infilling it was not accompanied by any recognized shoreline features.

A series of kame deltas at 1140 feet (347 m) indicate the former lake level during ice retreat. These kame deltas occur discontinuously along the sides of the river between Wells Bridge and Oneonta.

With the disappearance of the lake as a result of breaching of the morainal "plug," the Susquehanna River occupied the surface of the lacustrine deposits (at least by 12,000 B.C.) and began a period of considerable lateral movement. Some point-bar deposits were laid down during this period (one volume dated 11,910 B.C. at the Russ site at Wells Bridge). These deposits survive on the valley margins or below overbank accumulations.

At several of the sites examined between Oneonta and Wells Bridge (Camelot No. 1 and No. 2, Kuhr No. 1, Russ, Enck) lower sands and gravels appear to represent lateral accretion deposits whereas the upper silts are overbank deposits. At the Fortin site the overbank sediments directly overlie gravels which may be reworked glacial outwash. At Camelot No. 2, Kuhr No. 1, Kuhr No. 2, and Enck there are a series of terraces or meander scars; each successive one of these features away from the river is presumed to be older than those closer to the river. Local relief between these terraces is generally only on the order of a meter. In general, archeological sites are located in the terrace closest to the river or near the surface on the second terrace. Any occupation zones in higher terraces were obscured in the plow zone (upper 30 cm). Sedimentation rates for overbank silt deposits were determined for six sites (Fig. 2). In each case sedimentation rates were very rapid initially, becoming slower with time. These curves are similar in form to a curve hypothesized for Brandywine Creek, Pennsylvania, by Wolman and Leopold (1957). They based their curve on the average number of days per year on which a given flood stage is equalled or exceeded and a constant increment of sediment deposited each time the bank is overtopped by flood waters.

As sediment accumulation due to flooding is most rapid next to the river and decreases towards and up onto the adjacent terrace, living floors also trend up away from the river. These levels (time equivalent surfaces) are compressed away from the river, eventually becoming obscured

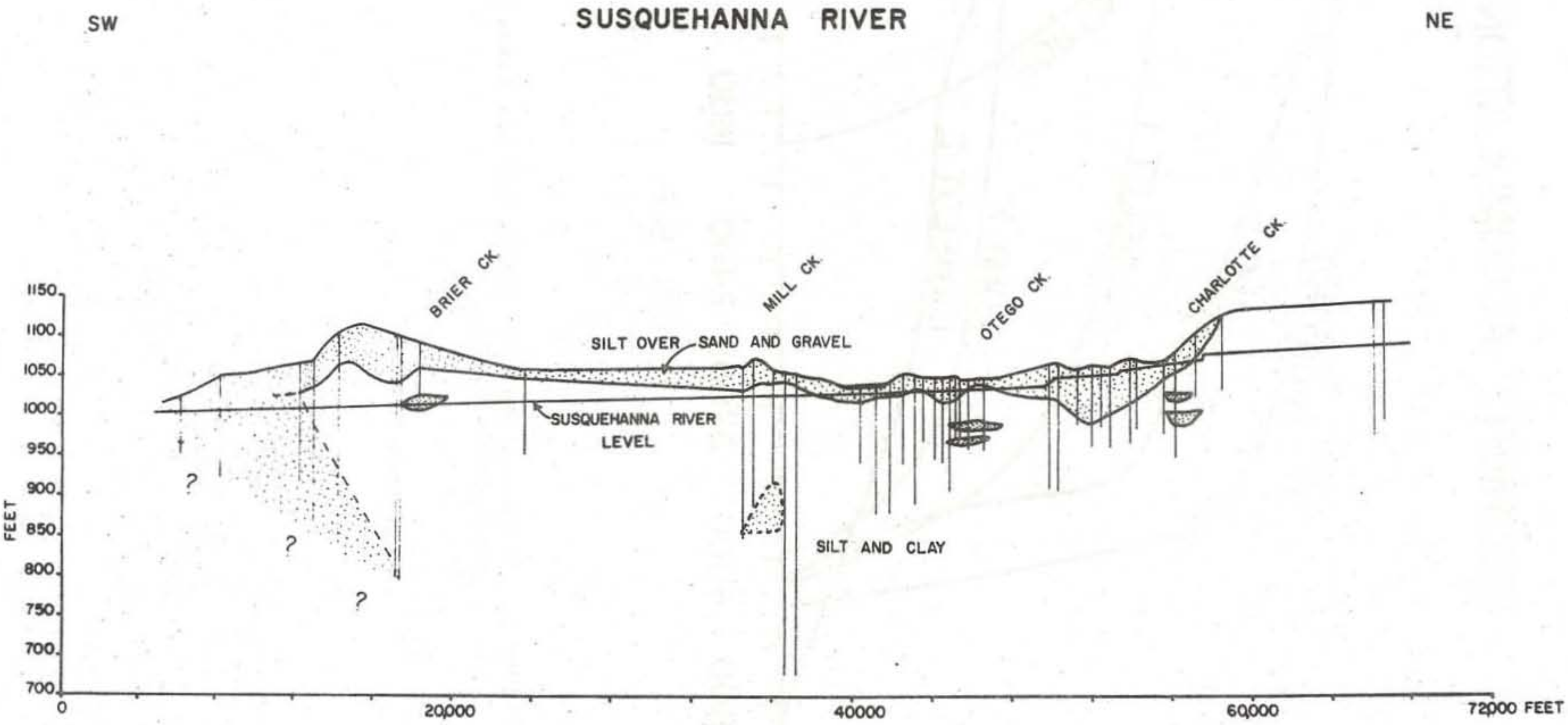

Figure 1. Longitudinal section of the Upper Susquehanna River from Wells Bridge to Oneonta.

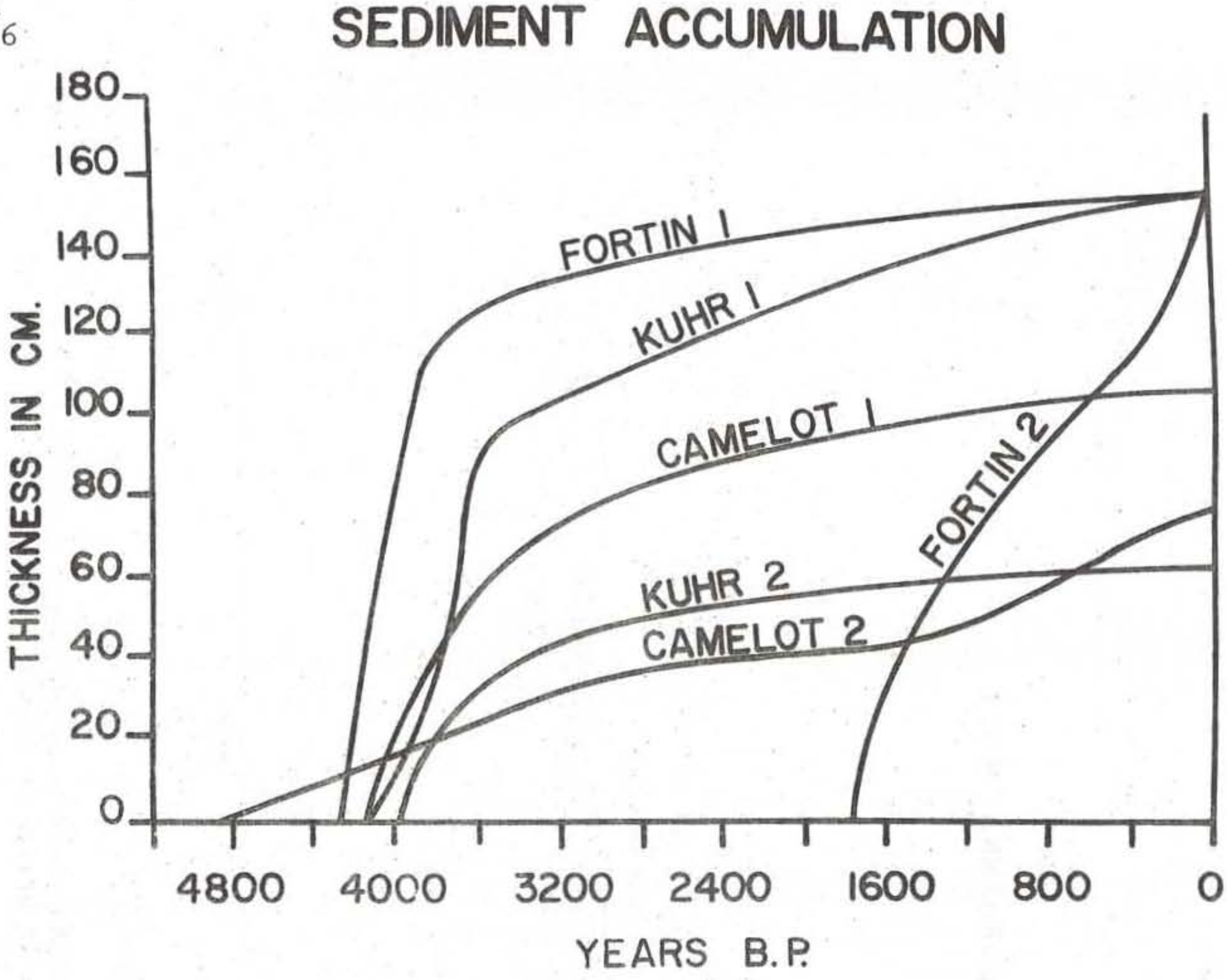

Figure 2. Sedimentation rate curves for six sites in the Upper Susquehanna Valley.

in the plow zone. No occupation levels occur below about 5000 y.a. on the first terrace at most of the sites. Older occupation zones are unlikely to occur on this terrace since they would have been close to the water table and therefore uncomfortably wet and subjected to more frequent flooding. Time rate accumulation curves for some of the sites are shown in Fig. 2. The form of these curves support Wolman and Leopold's concept of overbank sediment accumulation. The close proximity of the sites to the river suggests the lack of lateral migration by the Susquehanna River for several thousands of years in the immediate past. Further confirmation of this river stability can be seen when the configuration of the river from 1915 topographic mapping is compared with that from 1968 aerial photography (Fig. 3). In addition the proximity of the dated organics from lateral accretion deposits suggests an even older stability of the river approaching 7000 to 9000 years. Although much evidence for past meandering of the Susquehanna River is evident from scroll patterns (Fig. 4), we believe that the majority of these are the result of migrations that took place some 7000 to 9000 years ago and that few if any major changes have occurred in the river geometry in the past 5000 years.

The latter statement is supported by the data from the Russ and Gardepe sites, even though they contained very early Archaic occupation levels older than 5000 y.a. Probably they displayed a different pattern because they lie astride the Wells Bridge moraine. Here the river channel was largely confined by the drift, into which it incised itself soon after the local ice lobe receded from the vicinity. Following initial deposition of point-bar silts and sands ca. 12,000 B.C. at the Russ site, the river seems to have shifted slightly to the south, commencing deposition of overbank silts which attained a thickness of ca. 1 m beginning ca. 6300 B.C. and continuing to the present. In this southward swing it eroded away part of the Gardepe site where Indian occupancy began ca. 9300 y.a.

Incidentally, our study of scroll patterns may aid in the discovery of additional early occupational remains on the older terraces of sites similar to Kuhr No. 2 and Camelot No. 2.

CONCLUSIONS

A sequence of prehistoric Indian occupations extending to at least 9300 B.P. has been delineated by our investigations. Possibly due in part to unfavorable environmental conditions, little evidence exists of Archaic groups who lived between 10,000 and 6000 B.P.; much more information is available for Laurentian, Lamoka, Frost Island and other hunting-gathering cultures of 2500-1200 B.C., who collectively seem to represent a moderate population increase. After another poorly known period from 1200 B.C. to A.D. 400, the archeological record again seems more complete, and is understood in some detail through most of the Late Woodland (village agricultural) epoch. Most of our data on the pre-agricultural groups was obtained from stratified flood plain sites, which have also provided material for over 70 radiocarbon dates.

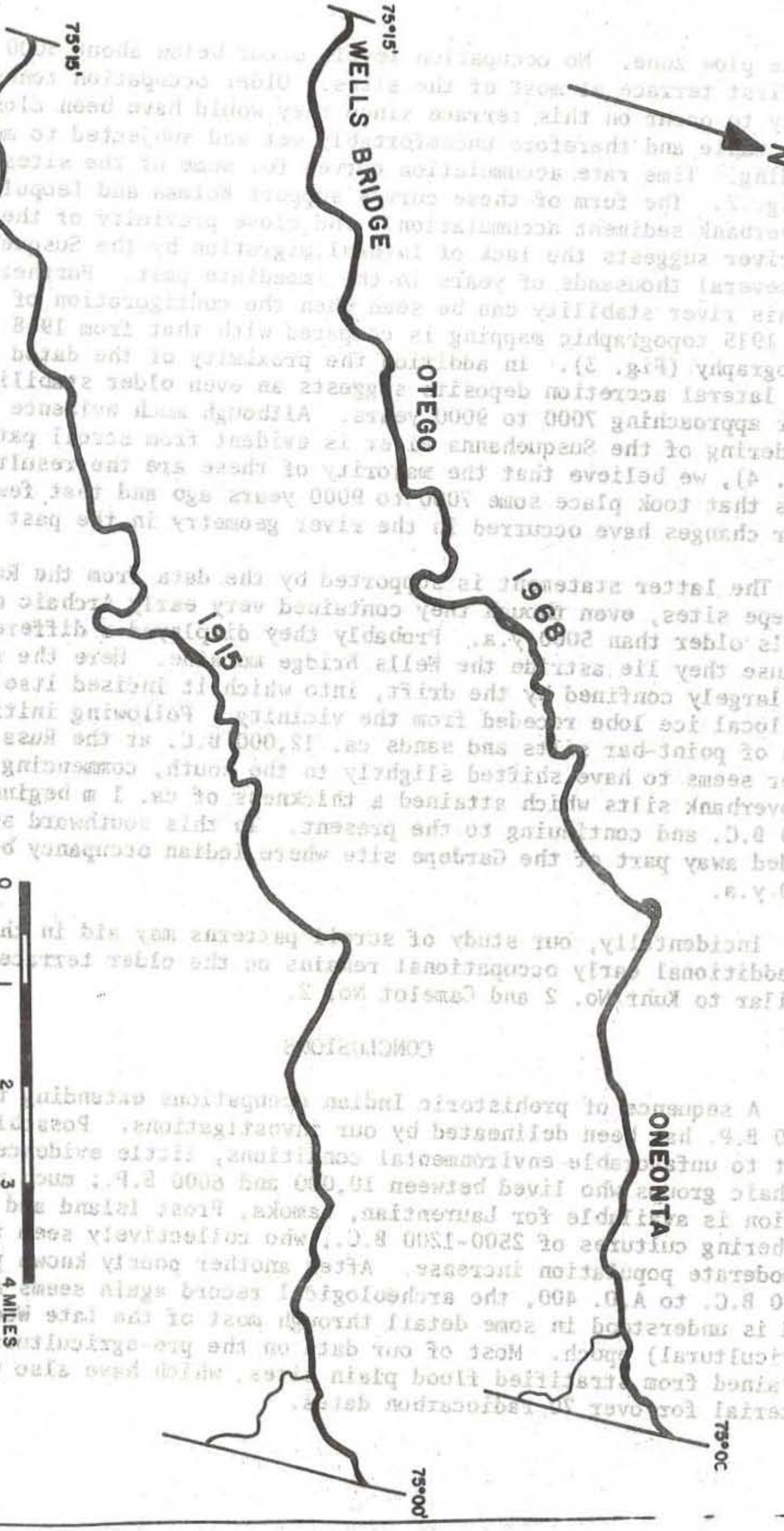

Figure 3. Comparison of Upper Susquehanna River geometry for 1915 and 1968.

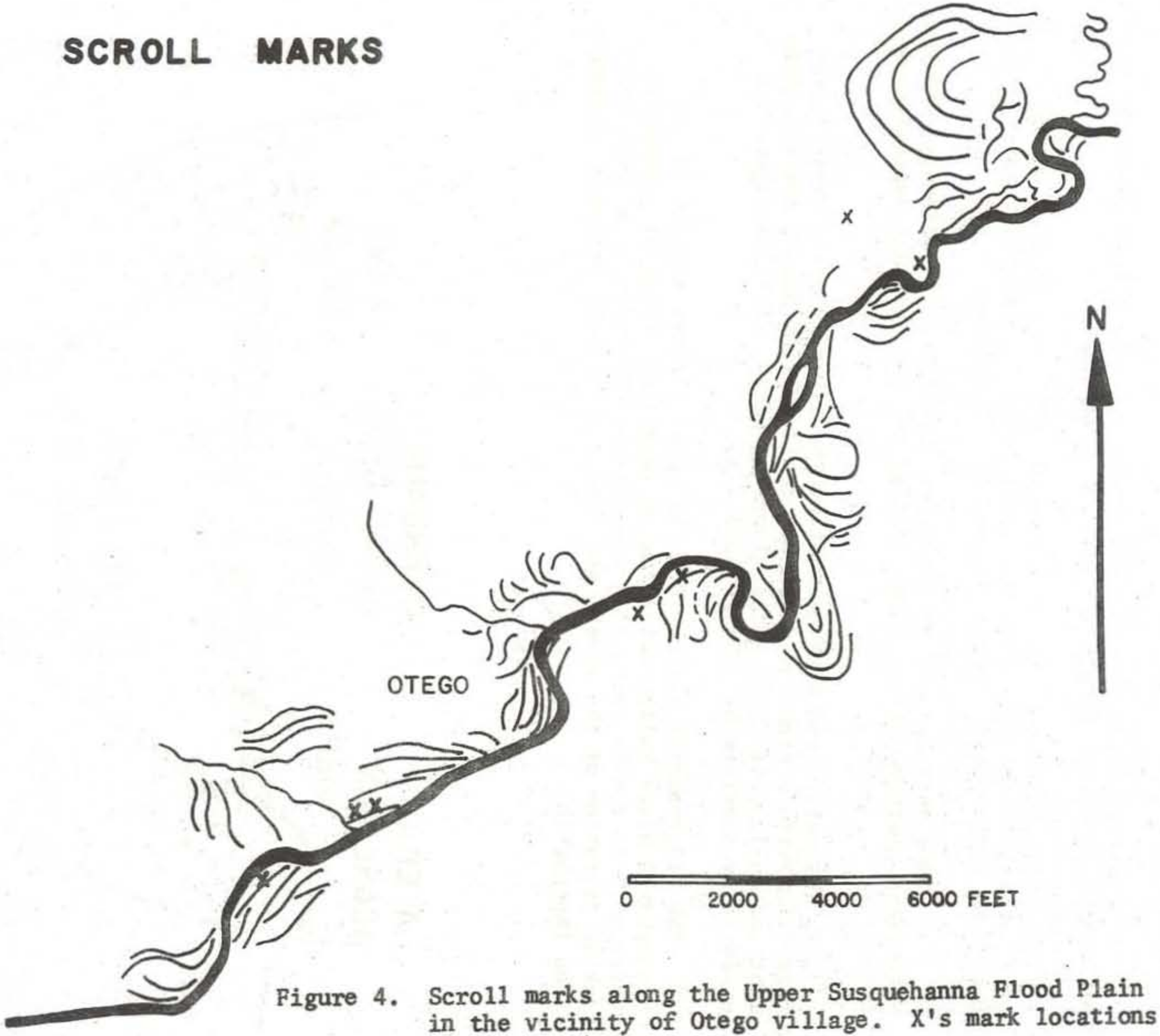

Figure 4. Scroll marks along the Upper Susquehanna Flood Plain in the vicinity of Otego village. X's mark locations of major archeological sites.

In light of the evidence presented herein we propose the following postglacial history for the Susquehanna River between Oneonta and Wells Bridge.

1. Initial deposition of lake sediments into a lake dammed by the Wells Bridge "valley plug" moraine.

2. Entrenchment of the dam allowing the river to flow on top of the lake sediments. At this time the river probably migrated readily across the whole flood plain. Period begins ca. 14,000 y.a.

3. Slow entrenchment of the river into the lake sediments. Each successive position of the river created its own overbank depositional terrace.

4. Migration and entrenchment of the river into its present configuration with a stabilized meander configuration due to the entrenchment and buildup of flood silts along the banks. This configuration essentially complete by 7000 to 9000 y.a.

The diagrammatic sketch (Fig. 5) shows a cross section of the Susquehanna River Valley detailing an idealized series of successive terraces. As can be seen, each successive terrace is at a lower level making migration of the river back into a previously occupied configuration improbable.

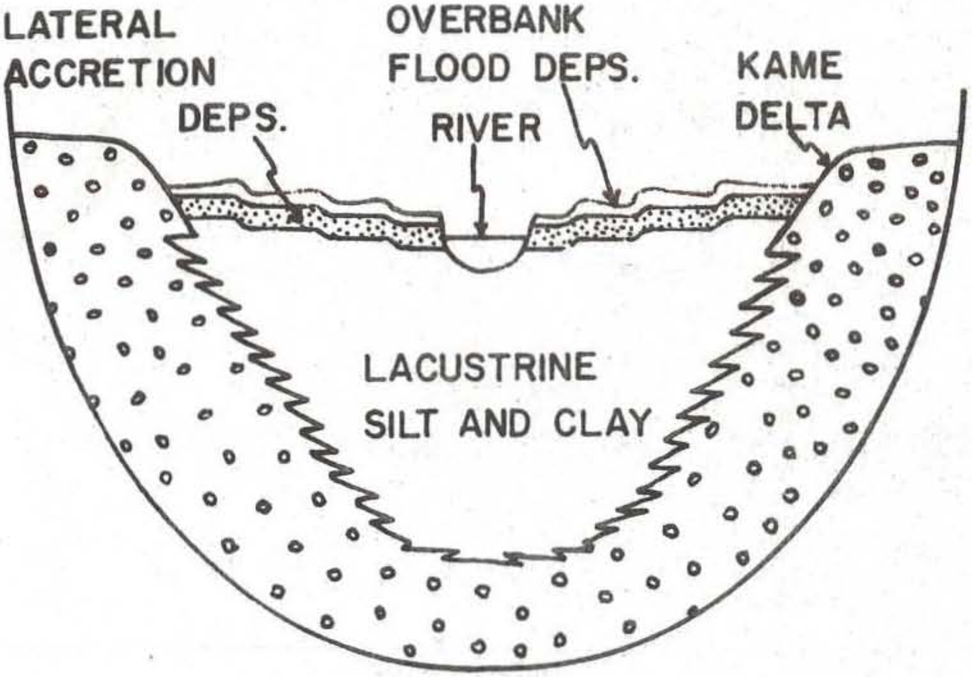

Figure 5. Idealized cross-section of Susquehanna River showing flood deposit terraces.

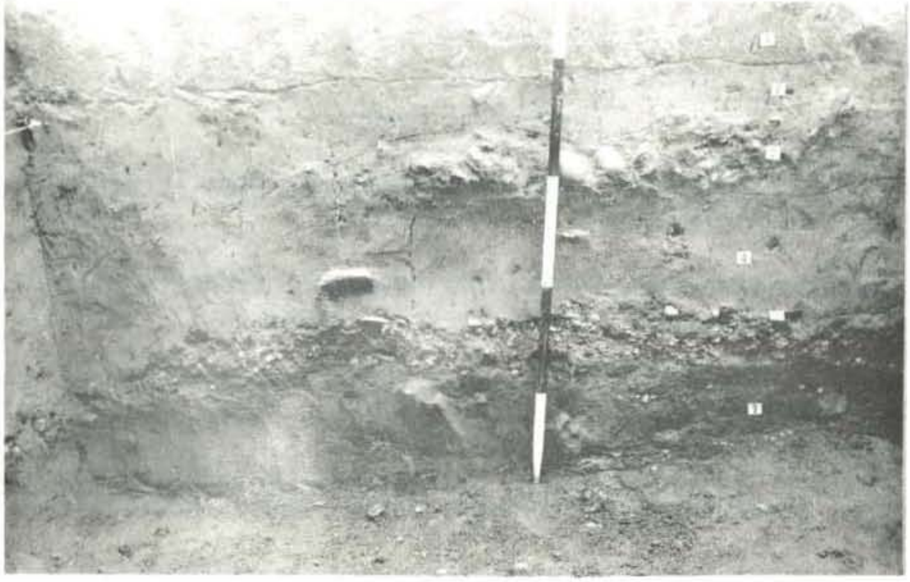

Figure 6a. East profile of section W50S10 at the Fortin site, Locus 1. Stratigraphic zones numbered with tages. Zone 1, plow zone (mixed occupation debris including modern trash). Zone 2, yellow-brown silt (Frost Island phase, 1330 B.C. ± 90 years, I-7097). Zone 3, living floor demarcated by fire-cracked rock, charcoal, thermally reddened silt (Late Archaic occupations dated between 1870 B.C. ± 95 years, Dic-207, and 1660 B.C. ± 95 years, I-6368). Zone 4, yellow-brown sandy silt (Late Archaic Lamoka phase, 1890 B.C. ± 100 years, I-6567, and 1800 B.C. ± 95 years, I-6369). Zone 5 is absent from this part of grid. Zone 6, gravel containing rare artifacts. Zone 7, interbedded sands and silts (Lamoka phase, 2235 B.C. ± 120 years, I-7098, and 2020 B.C. ± 100 years, I-6568). Tip of range pole rests on heavy gravel (outwash?).

Figure 6b. North and east profiles of section W20N10 at the Kuhr No. 1 site. Below the plow zone (top 30 cm) are easily visible dark bands representing prehistoric occupation zones within a matrix of yellow-brown silt. The oldest zones within a matrix of yellow-brown silt. The oldest occupation is dated 2570 B.C. ± 165 years (Dic-116) and the youngest just below plow zone is dated 380 B.C. ± 85 years (I-7093). Oldest (deepest) occupation level is dark band just one foot above tip of range pole.

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ROAD LOG

Cumulative Miles	Point to Point Mileage	Description
0	0	Depart from Hunt Union.
		Turn left from Union parking lot; go to East St., turn right, follow East to Center, right on Center, go to Maple. Turn left on Maple, continue to I-88, enter northbound lane. Take I-88 to terminus at Emmons-West Davenport Road. Turn right, cross iron bridge to F & F Airpark entrance on other side. Drive in to parking area on Fortin site next to hangars.
5.0	5.0	<u>STOP #1: Fortin site, Locus 1 and Locus 2:</u>
		Located at the junction of the Susquehanna River and Charlotte Creek near Oneonta, the Fortin site loci yielded one of the most complete cultural sequences of any of the sites examined. At Locus 1 eight occupation zones and a plow zone were contained within 1.83 meters of stratified sands, silts, and small gravels. These deposits rested on compact gravels which appear to be of ice-contact derivation, perhaps reworked by the river. The deepest occupation level (Late Archaic, Lamoka phase) dates to 4185 ± 120 years B.P. (I-7098) and the youngest level just below plow zone (Early Woodland, Meadowood phase) is dated 3180 B.P. ± 95 (I-6740).
		At Locus 2, there were five occupation floors in 1.83 meters of unstructured silt, again resting on heavy gravels. In this case however the deepest zone only dates to about A.D. 200. The cultural components range from early Middle Woodland to Late Woodland in affiliation.
		At both loci, occupations tended to concentrate on low rises which existed from the beginning (initially point bars?) and maintained themselves as perceptible topographic forms to the present.
		Return to I-88, proceed south to Otego exit. Turn right, go to Route 7, turn right again, drive into Otego. Turn

right at Church St., proceed to railroad tracks. Turn right and drive on raised path along tracks. Turn left at first crossing, follow tractor path through field, turn right along river to Kuhr No. 1 site near creek.

20.2 15.2 STOP #2: Kuhr No. 1 site:

Located in Otego village at the junction of Flax Island Creek and the river, this site displayed a highly sensitive archeological stratigraphy. At least 11 living floors were present, separated by culturally sterile silt where the overbank deposits were thickest (3-4 m) close to the river. The oldest identified occupation, of the Lamoka culture, was dated at 4520 ± 165 years (Dic-116). The field in which the site is located consists of four terrace-like long, low rises sub-parallel to the river. They occur in a south to north succession, with the highest being farthest from the river. The terrace presently adjoining the river is the youngest and presumably they increase in age away from the river, indicating successive positions of the river. The occupation levels occur mostly in the second terrace, and reach an average depth of 1.8 m. They trend upward onto the third terrace where they are compressed into the top .60 m of deposit, eventually feathering into the plow zone (upper 25 cm.).

A backhoe trench excavated to a depth of 4 m in the third terrace exposed 2.5 m of sterile silt below the deepest occupation level. At its base was the water table. In turn this deposit rested on a coarse blue-gray sand at least 30 cm thick containing wood fragments, leaves, acorns, and pine cones. A wood sample yielded dates of 8970 ± 110 and 9020 ± 85 years B.P. (Dic-113, 120). Test pits into sands and gravels 4 m below surface on the fourth terrace failed to yield organic remains.

Return to Route 7, turn left, proceed south and west on Route 7 to Wells Bridge. At first hill on west edge of Wells Bridge village, turn left on gravel road, go across railroad tracks. Park alongside road on left side next to trees. Russ site is in field behind trees.

25.6 5.4 STOP #3: Russ site:

The archeological levels at this site overlie the Wells Bridge moraine on the north side of the river where it swings southward in the first leg of a crescentic bend. Here in some places .7 m of late-glacial lacustrine deposit overlie the moraine; in other parts of the field what appear to be river deposited sands rest atop the moraine. On the northeastern edge of the field 1.3 m of silts overlie the lake sediment and underlie a horizon dated $13{,}860 \pm {}^{750}_{-830}$ B.P. (Dic-750). These old silts may represent a very early stage of point-bar deposition, as they slope away to the south and west where younger silts have filled in following a slight southward shift of the river. This shift occurred at least 10,500 y.a. as indicated by a dated humic zone which caps the older sediment.

The more recent silts may be of overbank origin. By at least 8300 B.P. the first Archaic Indians occupied the site; the deepest living floors occurred at ca. 1 m. A *terminus ante quem* for the sub-plow zone silts is provided by dates on several hearths which extend below plow line from occupation surfaces destroyed by cultivation. These dates average about 4000 B.P. The plow zone itself contains artifact types ranging in age from 6000 y.a. to the present, so the silts immediately underlying the plow zone probably date to at least 6000 y.a.

Return to Route 7, turn right and proceed ca. 400 feet to bridge approach. Turn right, go across river, keep to right, proceed on road to gravel turn-off on right side next to drainage ditch. Drive in, park in field adjoining Firemen's Association pavilion. Gardepe site is across drainage ditch.

26.7 1.1 STOP #4: Gardepe site:

This site is located on the south side of the river near the middle of the bend. Since the river has moved slightly southward in postglacial time, it has added to the deposits on the north side, but has cut into the banks on the south side. An undetermined portion of an archeological site has been destroyed in this way.

The major locus of occupation closely parallels the river near its bank. Behind this locus and also paralleling the bank is a low rise. Farther from the river are other features associated with the moraine, including a fair-sized kettle hole bog only 100 m from the river. This bog, 7 m deep, was sampled by Michael Melia and the data incorporated in his Master's thesis.

Occupational remains occurred within six definable strata near the river bank. The upper two zones relate to modern cultivation and contain much mixed Indian material. Zone 3 was partly disturbed by plowing; below it the various levels were undisturbed. The artifacts and radiocarbon dates from Zone 1 through 5 suggest Indian occupations ranging in age from ca. 4000 y.a. to A.D. 1100. The mode of formation of Zones 4 and 5 is a mystery; flood deposition may have played a part but downslope wash from the adjoining rise also seems to be a factor. Zone 6, a firm olive-brown silt, was ca. 3 m thick, resting on bluish clays of possible lacustrine origin, which in turn covered the morainal deposit. Zone 6 seems continuous with old silts which overlie the moraine everywhere on the site, including the edges of the bog. Presumably therefore it is of fluvial origin but the precise mechanism is not fully understood. A bifurcated-base projectile point was recovered, apparently in place, about 40 cm below the top of the zone. Three m from the point a hearth within the zone produced charcoal dated 9380 B.P. ± 100 years (Dic-261). The point is of a type dated ca. 8000 years old in the Southeast. Together with the dated hearth it suggests occupation by

		Early Archaic Indians concurrently with the late stages of formation of Zone 6.
41.0	14.3 (approx.)	Return to Hunt Union.

WEDGE-SHAPED STRUCTURES IN BEDROCK AND DRIFT, CENTRAL NEW YORK STATE

P. Jay Fleisher
SUNY, College at Oneonta

INTRODUCTION

Wedge-shaped structures resembling ice-wedge casts and fossil ice veins have been found in both bedrock and drift hosts on the eastern Appalachian Plateau of central New York. These features are exposed in the walls of four separate borrow pits at three different localities within the upper Susquehanna River drainage, south of the Mohawk Valley and northwest of the Catskill Mountains. All three localities are within Otsego County and can be found on the Milford, Richfield Springs and Mt. Vision quadrangles. The index map of figure 1 illustrates the location of each site as well as their general topographic setting. Based on their respective locations they are referred to as the Crumhorn Mountain, Fitch-Metcalf, and Laurens-Mt. Vision sites.

The purpose of this paper is to review the physical characteristics and occurrences of these wedge structures and consider what, if any, paleoclimatic significance they hold. A review of the literature indicates that previous authors have reported many features in various parts of the northeast as being related to periglacial processes. The main question under consideration is whether the structures discussed here are in any way related to permafrost processes.

A variety of permafrost and frost related features have been reported for the New England area by Denny (1951), Kaye (1960), and Koteff (1961). The work of Denny (1936), Smith (1949, 1953), and Wolfe (1953) suggest the significance of periglacial processes that once occurred in Pennsylvania and New Jersey. Clark (1968) documented the occurrence of sorted patterned ground associated with quartzite ridges from Pennsylvania to Virginia and West Virginia. Small scale bedrock deformation (up-warps) flanking vertically tapered till wedges in central New York has been reported by Cadwell (1973), and similar features in the same general area were initially interpreted to be of potential periglacial significance by Fleisher and Sales (1971). Late Wisconsin ice-wedge polygons have been reported in south western Ontario by Morgan (1972). More recently, Walters (1975) suggested polygonal patterns associated with vertically tapered ground wedges in outwash of central New Jersey to be possible ice-wedge casts. While the suggested effects of alpine glaciers and associated climatic conditions as far south as western North Carolina have been subject to contested debate since first presented by Berkland and Raymond (1973), it seems clear that a growing body of field evidence from the northeast suggests that this region may have been subjected to periglacial paleoclimate conditions of variable intensity at some time during the late glacial chronology.

WEDGE-SHAPED STRUCTURES

The terminology of the periglacial phenomena has developed over a period of decades and draws upon the nomenclature of several languages. In some cases purely descriptive terms are used, whereas others carry genetic implications. Some terms refer to only part of a three dimensional structure that has both vertical expression and a horizontal pattern, whereas others imply the entire feature. The lack of widely accepted terms with clear meaning and definite criteria for field recognition has led to confusion and independent usages. Black (1976) provided a much needed summary of terms and processes related to ice and soil wedges that will hopefully reduce problems in the future. In an effort to avoid the problem of usage and meaning, the following brief descriptions of wedge-shaped structures described by others is given. Since many of these suggest an origin through periglacial processes, it might be wise to begin at the beginning.

As suggested by Black (1966), the term periglacial is used to mean an area or region, commonly peripheral to a glacier margin, in which the climatic conditions favor intense frost action as a dominant process. While the potential for permafrost exists, it is not necessarily present. In this sense the term implies the potential for a very broad spectrum of frost related phenomena.

Ice-wedge cast

The most widely accepted term for the post-periglacial remnant of an ice-wedge (commonly considered part of a polygonal ice-wedge surface pattern) is an ice-wedge cast (Black, 1964 in Dylik 1966). Ice-wedge casts occur in association with a wide variety of host materials and represent various stages of past ice-wedge growth. Leffingwell (1919) proposed a two phase cycle of ice-wedge development controlled by the formation of frost-generated contraction cracks, in which spring meltwater carrying fine mineral matter would freeze. Summer warming resulted in the expansion of the host against the newly formed vein of ice causing lateral compression. Repeated cycles contributed to wedge growth and lateral deformation of the host. Climatic amelioration ultimately causes the ice-wedges to melt, with resulting collapse of overburden to fill the void and form a cast of the former ice wedge. Their size, shape, spacing, associated contact deformation, texture, composition, and fabric are all a function of the many parameters of ice-wedge growth and decay. Although strict criteria cannot be applied for unquestionable identification of ice-wedge casts in all possible occurrences, several authors give some characteristics which typically can be used to distinguish true ice-wedge casts from similar features that may have formed by a totally unrelated process.

Ice-wedge casts are generally 1 to 3 m wide at their tops and taper downward to depths of 3 to 4 m. Black (1976) points out that a polygon 10 to 40 meters in diameter can be anticipated, with wedges of non-uniform size ultimately forming small subdivisions.

They are commonly found in fine-textured stratified drift, but have also been reported in gravel, till and even bedrock. Stratification in the adjacent host is commonly deformed upward (Pissart, 1970a in Washburn, 1973) by lateral forces generated during ice-wedge growth or slumped downward as the result of collapse following melting (Washburn, 1973). Most often, the cast consists of a mineralogy and texture similar to the overlying material which has slumped into the void produced by melting. Portions of the adjacent host material may be incorporated and a distinctive collapse foliation may be found in poorly sorted casts (Black, 1965, 1969). The accurate interpretation of a true ice-wedge cast requires the recognition of collapse and filling from above (Johnson, 1959). In addition, Black (1976) advocates the need for supplemental "supportive evidence of permafrost", and further stresses the importance of establishing favorable meteorological conditions (limited snow, wet and cool summers) for ground ice development.

Sand-wedge

The term sand-wedge proposed by Pewe (1959), refers to a vertically oriented wedge of sand, approximately 1 meter wide and 3 meters deep, that is part of a polygonal surface pattern of shallow furrows. As with ice-wedge casts, upward marginal deformation of the host can be observed which causes them to look very similar to ice-wedge casts. However, there are several very important aspects that differ. In addition to being somewhat thinner, the filling of a sand-wedge displays much stronger vertical foliation and generally consists of much finer-grained material (Washburn, 1973). Sand-wedges require a similar thermal regime as ice-wedges but form under the restricted moisture supply of arid polar conditions. Whereas ice-wedges grow through an annual accretion of hoar-frost and summer meltwater along thermal contraction cracks, sand-wedges grow by the addition of sand grains that sift down the narrow contraction crack to form vertically oriented layers that constitute a distinct foliation (Black, 1969). No subsequent collapse occurs because no massive ice is present. A fossil sand-wedge is a true relict of a permafrost structure. The distinction between fossil sand-wedges and ice-wedge casts filled with sand or loess can be difficult and the two easily confused. (Black, 1965).

Washburn (1973) has used the term soil-wedge interchangeably with sand-wedge, which may lead to further confusion. While the purely descriptive nature of the term may at first seem appealing, it reduces the significance of the climatic implications, an important original consideration, and adds to the possible confusion with the term soil-tongue (Yehle, 1954), a feature of no periglacial significance. One possible solution would be to adopt the term ground-wedge, as suggested by Dylike (1966). This would permit the retention of the climate's significance but reduce confusion in the case of those wedges which are filled by something other than sand.

Composite wedge

An additional type of wedge, known as a composite wedge, is intermediate in form between an ice-wedge and sand-wedge, and consists of a mixture of ice and sand (Black and Berg, 1964). No known fossil forms have been reported to date, although some previously described ice-wedge casts and fossil sand-wedges may be of this type. Presumably the fill material would consist of a well foliated, fine-grained lower wedge and a somewhat more coarse-grained, collapsed upper portion. This configuration would depict an initial dry polar climate which ultimately yielded to more moist conditions. The reverse of this would result in the slump destruction of a more recent dry-climate sand-wedge as the deeper ice-wedge ultimately melted.

Soil tongue

An additional feature that is similar in form and may be confused with wedges of periglacial significance is what Yehle (1954) referred to as soil tongues. In cross-sectional view they resemble ice-wedge casts. However, inspite of their general appearance, several characteristics have been observed that serve to distinguish them from frost-related wedge forms. The outwash gravels in which they are found consist of a high percentage (65%) of carbonate lithologies (limestone and dolomite), whereas the vertically penetrating soil tongues have been leached of carbonates. In addition, stratification of the adjacent host may be traced through the tongue as an unbroken sag. Iron oxide along the tongue margins indicates the significance of chemical weathering during their formation. These characteristics and the lack of an associated horizontally continuous ground pattern suggest differential leaching and mild subsidence produced these features.

Pop-up

This rather graphic term has had limited application since first used by Cushing, et al. (1910) to describe a local form of bedrock deformation in the Thousand Islands region. A pop-up consists of fractured and tilted bedrock slabs that simulate a chevron style of buckling, broken at the crest and presumably of limited downward extent. Sbar and Sykes (1973) give a brief summary of known pop-up localities in New York State as related mainly through personal and written communication rather than published reports. Complete field descriptions are lacking except for those cases in which pop-ups have been observed to have formed in active bedrock quarries. Coates (1964) reported a case of buckling and upheaval of limestone that occurred suddenly along the floor of a quarry in Ontario. It appears as though such features can persist along trends several tens of meters long and rise in local relief several meters above the surrounding surface. The entire flexure may extend 10 to 12 m outward away from the crack. Of particular interest is the fact that the disturbed sandstone slabs that form the pop-up reported by Cushing show glacial striae and polish, which attests to their post-glacial origin. Considering the association of recent pop-ups with active quarrying, it seems reasonable to assume that they form in response to lithostatic unloading and may be expected to occur elsewhere as a result of glacial unloading.

Tension Cracks ("Tension Wedges")

Still another wedge form, similar in cross section to those reported and illustrated by many authors as ice-wedge casts, is considered by Black (1976) to be of nonthermal origin. These features have a limited width of about .5 m at their tops and thin downward to terminate at depths of 1 to 2 meters. Found in gravely outwash, they are interpreted by Black to be tension fractures in which collapse has occurred. A resulting vertical alignment of loose fill and downward deflection of adjacent beds provides the structural configuration that makes these wedge features conspicuous on quarry walls. Their isolated occurrence and lack of polygonal form are damaging characteristics to a possible periglacial interpretation.

Other alternatives

In addition to the features discussed, similar ground forms may result from a variety of processes unrelated to a periglacial regime. Various authors recognize the lateral expansion and contraction mechanism as a common result of alternate wetting and drying of expandable clays in soils. Seasonal frost action unrelated to permafrost areas is another process with the same mechanism. The most reasonable explanation for the formation of the wedge-shaped structures in Otsego County may involve one or a combination of the processes discussed. The determining factors should be the observable characteristics of each site and a consideration of other paleoclimatic indicators.

DESCRIPTION OF WEDGE STRUCTURES

Crumhorn Mountain Site (Milford Quadrangle)

Crumhorn Mountain forms the divide between the Susquehanna River and Schenevus Creek from their confluence and up valley for several miles. It has a general southwesterly trend, with glacially steepened flanks and a broad low-relief summit. Elevations along the summit generally range between 1780' and 1880' at its southern end and increase to 1900' on isolated knolls to the north. The wedge structures are located in a shallow borrow pit from which siltstone of the Oneonta formation (?) is occasionally taken by the town of Milford. The quarry includes exposures on both sides of Boy Scout Road at an elevation of approximately 1870', 1.2 miles south of Crumhorn Lake, which is situated along the mountain summit (see figure 1). A total of 14 wedge structures were well exposed along bedrock joint faces of the quarry walls at various times during normal excavation since 1970. Although several were consumed by quarry operations, several are currently well exposed, while others have been partially buried by colluvium. All wedges are oriented parallel to persistant joints sets, and it is assumed that all occur along one or the other of two dominant joint directions. The wedges are spaced at distances of approximately 6 to 10 m apart and intersect in the quarry walls to form a pattern that may be rectangular or polygonal, but cannot be seen through the shallow lodgement till that mantles the bedrock.

The wedges range from 30 cm to 1.5 m in width near the surface and taper downward to depths of 2 to 3 m where they thin to just seams. The enclosing siltstone host is sharply upturned adjacent to the wedges in a zone of marginal deformation which diminishes with depth. Slicken-sides within the deformed siltstone along bedding planes indicates displacement perpendicular to some wedge trends. The magnitude of deformation appears to be directly proportional to the thickness of the wedge and, in at least one case, involves overturned beds near the surface. In most cases the siltstone appears warped and smoothly flexured, while others are abruptly broken into tilted slabs. Most flexed beds are highly fractured, resulting in literally hundreds of small breaks which formed perpendicular to the bedding, extending its length and giving the rock within the zone of deformation the false appearance of being longer than it actually was prior to deformation. In all cases the deformation fades laterally within a few meters of the wedge.

The wedges themselves consist of a tightly compact clastic filling of tabular rock fragments in a clay and sand matrix. The lithologies represented by the larger fragments are similar to the adjacent bedrock and appear to be locally derived. The finer size fraction consists of sand and granual size erratic lithologies and minerals which were derived from the overlying lodgement till. These include frosted sand grains and lithic fragments of crystalline rocks. Each wedge displays a general vertical sorting with finer particles near the bottom and larger clasts at the top, and in many cases grain size decreases toward the wedge center. A few clearly show a thin seam of silt and fine sand down the center of the wedge when viewed in cross sections.

Two primary structures, foliation and collapse features, are clearly developed and may be significantly related to the origin of the wedges. Each is well developed but the foliation is most conspicuous. It consists of a strong alignment of platy clasts in an orientation parallel to wedge walls. Many of these clasts appear to have been derived from the adjacent bedrock host. All clasts are firmly held in the compact wedge matrix. The collapse structure is confined to the upper portions of the wedges and generally involves down-dropped masses of overlying till. In some wedges small semi-cohesive portions of the fractured host rock appears to have subsided during collapse. Generally, the foliated and collapsed segments of a wedge reveal contrasting colors. An olive-gray color (2.5 Y 4/2) typifies the foliated lower segment, whereas a yellowish-brown color (5YR 4/4) indicates the collapsed segment. Sketches and a photo depicting the characteristics of several well developed wedges is shown in figures 2 and 3.

Fitch-Metcalf Hill (Richfield Springs Quadrangle)

This locality is situated on the broad undulating divide between Five Mile Point on Otsego Lake to the east and the flat valley floor of Fly Creek on the west, approximately midway between Cooperstown and Richfield Springs. Elevations on this portion of the divide range between 1700' and 2000', with isolated summits reaching 2,100' (see figure 1). As with the Crumhorn Mountain locality, the wedges are exposed along the walls and floor of a small, inactive rock quarry from which highly fissile siltstone and shale of the Panther Mountain formation were quarried. A think veneer of till mantles the bedrock. The excavation is located at the western end of a dirt road that connects Fitch Hill and Metcalf Hill. It consists of two adjacent but separate quarries both on the north side of the dirt road at an elevation of 1920'. The western section of the excavation contains two well developed wedges along a south-facing bedrock wall. Six smaller wedge remnants were also observed along the low walls and floor of the eastern section during the summer of 1973.

The orientation of all wedges seems to be strongly controlled by the dominant bedrock joints, which are nearly vertically inclined and trend NNE and WNW. The three major wedges are spaced 10 - 15 m apart and do not intersect. Because no surface expression could be found in the overlying till it is assumed that the plan view pattern would probably display the rectangular orientation of bedrock joints.

The two major wedges are similar in appearance and overall character to those previously described for the Crumhorn Mountain Site. They exist within the interbedded sandstone and siltstone of the Panther Mountain formation, which is flexed and broken along the same style and scale as those previously described. In addition, the fillings consist of a coarse clastic assemblage of local bedrock fragments in a tight matrix similar to the matrix of the overlying till. Figure 4 illustrates the upper portion of one of the larger wedges found at this site. Based on the similarity of these wedges with those on Crumhorn Mountain, it is assumed that the same mechanism of formation was active in both localities and probably at the same time.

Laurens-Mt. Vision Sites (Mt. Vision Quadrangle)

Otego Creek flows through a broad valley in a south-southwesterly direction as the major drainage way on the Mt. Vision quadrangle. Valley walls are oversteepened in places as the result of glacial modification and are mantled by a veneer of lodgement till that is generally fairly thin. The broad flood plain of the valley is lined by semi-continuous paired terraces with an elevation of 1160' at the village of Laurens. Otego Creek meanders across a flood plain of variable width, undercutting terrace scarps of stratified drift in some places. Well logs (Randall 1972) indicate a subsurface stratigraphy of terrace sand and gravel overlying clay in lateral valley positions, and a dominance of clays and silts along the medial segment of the valley. Total thickness of drift is not accurately known from borings, but gravity data and projected cross-valley profiles (Gieschen, 1974) suggest bedrock to lie at depths on the order of 100 to 150 feet below present stream level.

It is within these deposits that two separate gravel pits have been semi-continuously worked between the villages of Laurens and Mt. Vision. The excavation of both localities has exposed an additional type of wedge-shaped structure at what is referred to as the Laurens-Mt. Vision site.

The Laurens site is situated between Route 205 and Otego Creek, .9 miles northeast of Laurens along a flat-crested linear land form 1/4 mile southwest of a prominent kettle. The excavation is within moderately to poorly sorted topset beds of a "delta terrace" at an elevation of 1160 feet. The host material consists of interbedded coarse sand, pebbly sand, and sandy gravel 3 to 4 m thick. Fluvial sedimentary structures include cut and fill, channel deposits, cross bedding and graded bedding. Foreset beds of better sorted but similar material lie below and a thin veneer of reddish-brown silt lies above. Seven separate wedge structures were observed at various stages of excavation at this site. They extended to depths of 1 to 2 m in a vertical to steep orientation. They taper downward from widths of 5 to 15 cm at their tops. A downward deflection of bedding at their margins indicates collapse occurred. This is further shown by the subsidence of surficial silt, which appears to have been illuviated downward giving the wedge a brownish color in contrast to the gray host. The pebbles and cobbles of the wedge fillings show a distinct fabric that parallels the overall structure. Bifurcation into compound wedges was also observed. The sketch in figure 5 characterizes the salient aspects of these wedges.

No surface expression could be seen and, as far as could be determined by excavation, the wedges were not part of a polygonal pattern. Their plan view orientation was in a general northerly trend.

The Mt. Vision site is located on the western side of Otego Creek one mile south of the village of Mt. Vision. It is situated within a segment of a deltaic feature that protrudes eastward across the flood plain, constricting the valley floor. For this reason it may be interpreted as a delta moraine, but associated hummocky terrain is lacking. Possibly, delta-kame would be a reasonable alternative. Its broad upper surface lies at an elevation between 1160 and 1180 feet. At various stages of excavation strongly developed, moderately sorted, foreset beds and less well sorted topset beds 6 to 8 m thick were exposed.

Eight wedge structures have been exposed in the upper wall of this gravel quarry over the past several years. However, in almost all cases the exposures were short-lived and consumed by further excavation. In many respects the wedges here are of the same size, scale, description, orientation, and general occurrence as those previously discussed at the Laurens site. One notable exception was a single wedge structure of considerably greater size than all others. Its uppermost width was 1.5 m and exposed depth was 3 m, where it was covered by colluvium. Projecting its downward taper yielded an estimated concealed depth of 6 m. It too revealed collapse features, including the downward deflection and thinning of host stratification along its margins and a tongue of overlying silt that protruded downward into the upper wedge, as well as a distinct internal fabric.

INTERPRETATION

Salient Characteristics

From the foregoing discussion it is clear that the general characteristics of these features are in part similar to other wedge-shaped structures found in various geologic settings. Although superficially they may resemble any one of several possible structures with a variety of possible origins, a comparison of specific salient characteristics helps to eliminate some alternatives and isolate the most logically related feature(s). Such a comparison is made in table 1.

Crumhorn Mountain and Metcalf-Fitch Hill Sites

Of the various structures listed, only those of the Crumhorn Mountain and Metcalf-Fitch Hill sites and pop-ups are specifically confined to a bedrock host. However, ice-wedge casts do occur in bedrock on occasion (Davies, 1961) and may be confined to existing joints (Black, 1976). Host deformation, size, and filling represent additional similarities between the wedges of these sites and ice-wedge casts. Unfortunately, pop-ups have not been exposed in cross sectional view and a comparison of these characteristics is not possible. Since pop-ups are thought to result from lithostatic unloading, man-made and through deglacial release of stress, it seems reasonable to assume that they would be fairly common features in glaciated regions. Perhaps their subtle expression has for the most part simply gone unnoticed. On the basis of the physical characteristics displayed by the Crumhorn Mountain and Metcalf-Fitch Hill wedges, an association with ice-wedge casts and pop-ups remains equally strong.

One means of testing this association further would be to consider other paleoclimatic indicators for clues to the possibility of permafrost playing a role in the formation of these wedges. In a study of local pollen from bogs in the surrounding terrain, Melia (1975) established a climatic chronology in agreement with previous studies in correlative areas. The pollen record of late glacial time taken from a bog in Maryland, a few miles south of Crumhorn Mountain, consists of A zone (spruce zone) vegetation. Additional pollen data from other localities in the area provide a record of Band C zones (pine and hemlock respectively), which are considered to represent post-glacial conditions. The bedrock wedge structures are considered to have formed during late or post-glacial time because their fillings were derived in part from the overlying till and the deformed bedrock adjacent to the wedges extends upward into the till. If these

TABLE 1 - SUMMARY OF SALIENT CHARACTERISTICS

Wedge Structure	Host	Host Deformation	Width at Top	Depth of Penetration	Filling	Occurrence	Pertinent Associations
Wedges of Crumhorn Mt. & Fitch Metcalf Hill	siltstone, sandstone	flexed & broken upward	generally less than 1m, up to 2m.	2 to 3m.	similar to overlying till, compact strong fabric, collapsed near top	intersect along bedrock joints	filled in part by collapse of overlying till; deformed bedrock extends into overlying till
Wedge of Laurens and Mt. Vision	stratified drift	collapsed downward	generally 5 to 15cm., up to 1.5m.	generally 1 to 2m, up to 6m.	loose drift, with collapse fabric soil tongue	singly, no polygonal pattern noted	proximity to Otego Creek, trend semi-parallel to valley
Ice-wedge cast	drift and bedrock	forced upward	as much as 3m.	as deep as 10m.	varies with setting, slump fabric, evidence of collapse	polygonal pattern	other permafrost features
Sand-wedge	drift	forced upward	8cm to 1.3m	.3m to 3m	structureless sand, vert. oriented crossing sand bands	polygonal pattern	permafrost, but arid conditions
Composite wedge	drift	forced upward	similar to ice-wedge cast	similar ice-wedge cast	composite of ice-wedge and sand-wedge	polygonal pattern	intermediate to ice & sand-wedge
Soil tongue	drift	collapsed downward	less than 1m	as deep as 2 to 3m	loose drift, distorted bedding and collapse fabric, soil tongue	circular, linear and branching	soluble carbonate clasts, humid temperate climate
Pop-up	sandstone limestone	flexed & broken upward	overlapping to 1m.	est. to be several meters	not exposed, may not exist	individual linear buckles	unloading of bedrock excavation sites
Tension Crack	stratified drift	collapsed downward	less than 1m.	1 to 2m.	loose drift collapse fabric and soil tongue	singly, linear	host drift undercut by adjacent stream causing mass wasting

structures are a form of ice-wedge cast (or possibly sand wedge or composite wedge) one would expect to find evidence of tundra conditions condusive to ground ice formation represented in the pollen record. This has not been clearly demonstrated, but tundra-like openings within the spruce forest remain a possibility, as pointed out by Melia. The arid conditions necessary for sand wedge formation seems less likely.

Laurens-Mt. Vision Sites

The four most definite aspects of the wedge structures described at these sites are host deformation, size, occurrence, and pertinent associations. As shown in table 1, ice-wedge casts (and related sand and composite wedges), soil tongues, and tension cracks all share a common host material with these structures. The nature of host deformation and size suggest the elimination of any form of ice-wedge cast as a possible origin. Furthermore, the plan view polygonal pattern is also lacking. These structures are,therefore, considered to be of an alternate origin. Of the two remaining possibilities one seems more likely based on occurrence and pertinent associations.

As described by Yehle (1954), soil tongues originate through subsidence as a result of solution and removal of support. The soil tongues he described can occur in a variety of patterns, including linear and branching, but were restricted to outwash with a relatively high carbonate pebble count, such as 66% for the host and 10% within the tongues. While the wedges of the Laurens-Mt. Vision site may be similar in size, shape, and occurrence to soil tongues, they occur in a host that is deficient in soluble calcareous clasts (a few percent or less). However, a comparison with tension cracks described by Black (1976) yields very favorable results. The physical appearance of the wedges, their singular occurrence, and topographic setting all support an origin related to small scale subsidence along tension cracks formed in response to undercutting by an adjacent stream.

SUMMARY

A group of vertically oriented wedge structures are exposed in the walls of four separate excavations in bedrock (sandstone and siltstone) and stratified drift. Two bedrock exposures contain 25 structures that range in width from less than a meter to 2 m. at their tops and taper downward 2 to 3 m. The host adjacent to each is tilted and flexed upward with deformation decreasing with depth. Each wedge generally contains tabular rock fragments held tightly in a fine matrix. Vertical and lateral sorting is expressed by increasing grain size upward and outward. Several display two distinct internal textures consisting of a vertically foliated lower and collapsed upper segment, with sand-size exotics in each. All wedges occur along joints, but their trends do not project upward through an overlying thin lodgement till.

Eleven additional wedge structures were exposed in two closely associated excavations of a deltaic feature. They averaged about 10 cm.

across at their tops and penetrated 1 to 2 m. vertically. However, one much larger structure about 3 times this size was observed. All wedges were characterized by a distinct internal collapse fabric and surficial slump of overlying silty soil. A downward deflection of adjacent host stratification was indicative of subsidence. No surface expression was recognized at either locality and excavation failed to reveal a polygonal orientation.

Although these structures are similar to wedge-shaped features found in regions of past permafrost, there are several other mechanisms of origin that deserve consideration. Similar structures in other parts of New York State and New England have been reported and interpreted to have no particular paleoclimatic significance.

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CAPTIONS

Figure 1. Index map of wedge sites in Otsego County.

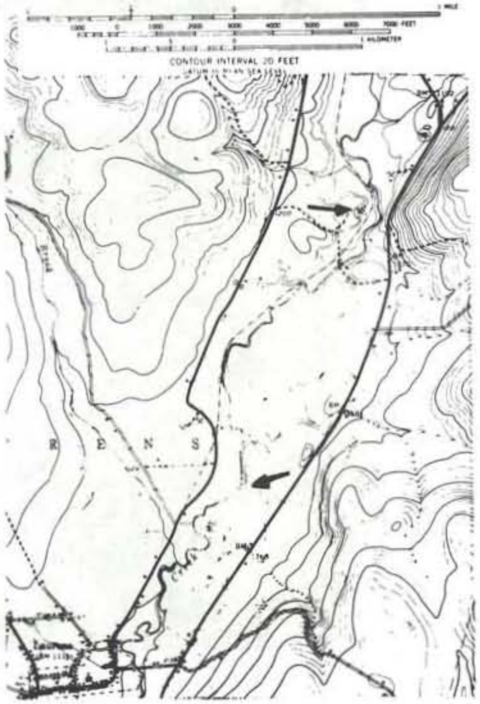
Figure 2. Sketches of wedges on Crumhorn Mountain. Illustrated are the salient aspects of the best developed wedges as exposed in 1972. Since then several have been consumed by the quarry operation, but two new ones are currently exposed.

Figure 3. Photograph of wedge on Crumhorn Mountain. Note that the flexed deformation of the bedding is proportional to wedge width and extends into the overlying till. This wedge extended to a depth of about 2 m and could be traced across the quarry floor.

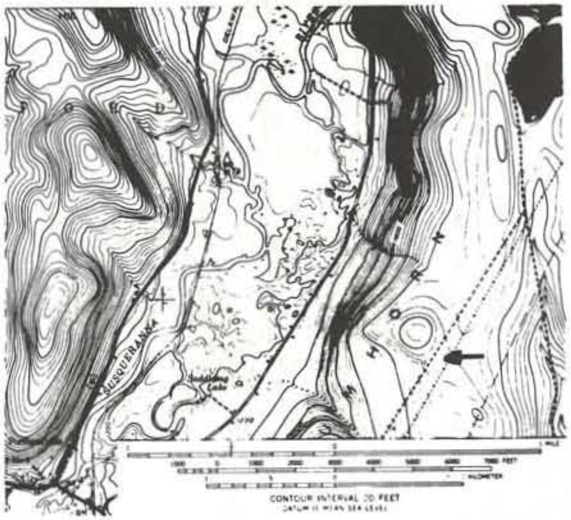
Figure 4. Photograph of wedge on Fitch-Metcalf Hill. This one of two well developed wedges with characteristics similar to those found on Crumhorn Mountain. Note the distinct upward break of host rock as opposed to the flexed deformation in figure 3.

Figure 5. Sketch of wedge at Laurens site. A distinct collapse foliation can be detected within the wedge, as well as in the adjacent host gravel. Note the hand shovel for scale.

Site 1 Laurens - Mt. Vision (Mt. Vision Quad.)



Site 2 Crumhorn Mountain (Milford Quad.)



Site 3 Fitch - Metcalf Hill (Richfield Springs Quad.)

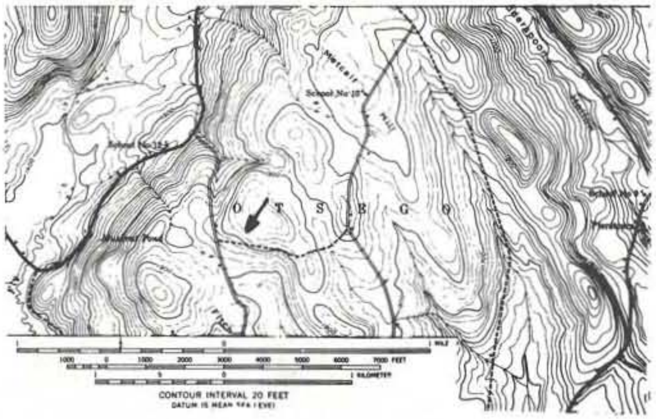


Figure 1

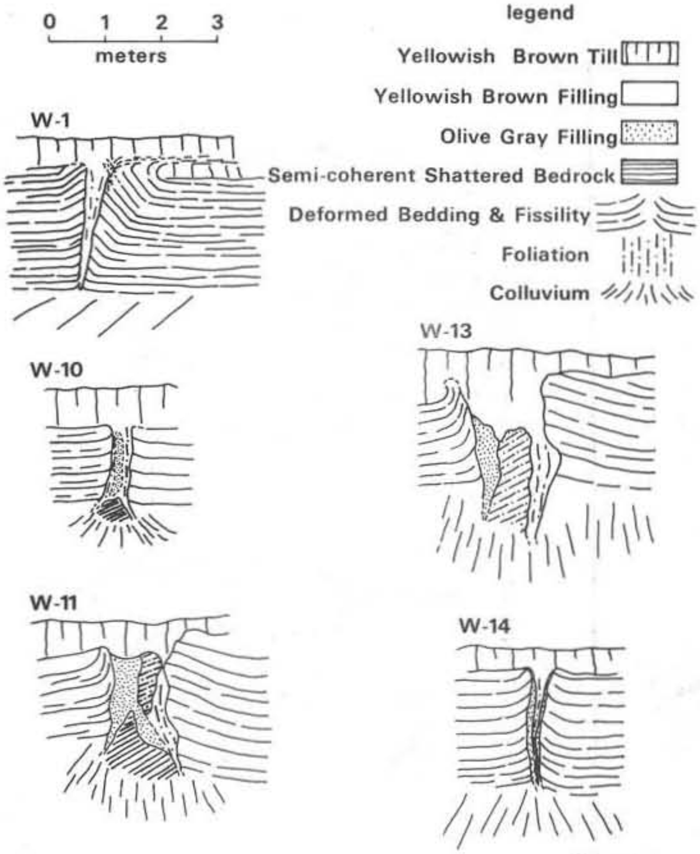


Figure 2

Figure 5

Figure 3

Figure 4

ROAD LOG: WEDGE-SHAPED STRUCTURES IN BEDROCK AND DRIFT

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INTRODUCTION

This log contains a description of the most convenient routes to the wedge localities discussed in the accompanying paper. Specific aspects of each of the three sites are described, but no attempt is made to document the geology between sites. This would be repetitious since the road log in this guidebook entitled Glacial Geomorphology of the Upper Susquehanna Drainage does this in some detail.

This field trip begins at the Route 7-Interstate 88 interchange 2 miles east of Oneonta in the community of Emmons and ends west of Oneonta at the Route 7 - Interstate 88 interchange in what is called the west end.

ROAD LOG

Miles from last point	Cumulative Miles	
0.0	0.0	Proceed east on Rt. 7 and 28 from the traffic light intersection with the I-88 interchange. A notable landmark for this intersection is the Del-Sego Drive-In.
2.5	2.5	Turn left at blinking light. Leave Rt. 7 and follow Rt. 28 north toward Cooperstown. Lorenzo's Homestead Restaurant will be on your left at this intersection.
2.3	4.8	Proceed on Rt. 28 through Milford Center.
1.0	5.8	Enter Portlandville
0.3	6.1	Turn right at Blue Bonnet Antiques on Otsego County Rd. 35, which crosses a bridge (Susquehanna River) immediately and a railroad within 0.2 miles.
0.2	6.3	Just beyond the tracks turn left and remain on County Rd. 35.
0.5	6.8	Turn right at white farmhouse and proceed up Crumhorn Mountain on Wrightman Rd. (unmarked). As the road climbs it provides an impressive view of the Susquehanna Valley.
1.1	7.9	Turn left near top of hill and follow sign that points the way to Boy Scout Camp. This is Boy Scout Rd.

Miles from last point	Cumulative Miles
0.5	8.4 STOP 1

Pull off to the right near the top of the hill in a bedrock quarry. The Town of Milford uses this rock for fill.

This is the Crumhorn Mountain Site. The quarry operation was much more active in the early 70's when more than a dozen wedge-shaped structures were exposed. Some have since been consumed by the operation or covered under colluvium, but two were well exposed in June, 1977. These can be found east of Boy Scout Road in the south facing wall of the excavation. They are most easily spotted by looking for the upward deformation of the siltstone bedding. Their deepest penetration has not been excavated, but judging from the amount of downward taper they are probably in excess of 2 m deep. These and all others occur along bedrock joints which seem to control their orientation.

Two sets of wooden pegs were emplaced in each of these wedges in order to determine whether their width varied seasonally due to temperature or moisture changes. The upper and lower portions of each wedge were monitored from April, 1976 to the present. The results are as follows:

	Wedge A (nearest the road)	
Date	dist. between upper pegs	dist. between lower pegs
4/21/76	50.0 cm	31.5 cm
5/15/76	50.2 cm	31.5 cm
7/16/76	50.0 cm	31.3 cm
8/17/76	50.0 cm	31.5 cm
9/11/76	49.7 cm	31.6 cm
3/11/77	49.8 cm	31.6 cm
5/31/77	49.8 cm	31.5 cm
	Wedge B (farthest from road)	
4/21/76	36.0 cm	22.2 cm
5/15/76	35.8 cm	22.0 cm
7/16/76	35.6 cm	21.8 cm
8/17/76	35.9 cm	22.0 cm
9/11/76	35.8 cm	22.0 cm
3/11/77	35.4 cm	22.1 cm
5/31/77	35.2 cm	21.9 cm

From these data it is concluded that no seasonal variation alters the width significantly.

The short upper segments of four other wedges may be detected through the colluvium along the east side of the road. Unfortunately,

Miles from last point	Cumulative Miles	
		the most impressive wedge remains buried by debris along the south facing wall of the operation to the west of the road. Most wedges are characterized by a highly compact filling that shows collapse foliation. However, a few small bedrock buckles can be found, in which little or no fill exists. Ice-wedge casts or pop-ups seem to be the main question here. Back track off Crumhorn Mountain to Otsego County Rd. 35.
1.6	10.0	Turn left and back track to Rt. 28.
0.7	10.7	Intersection with Rt. 28. Turn right and proceed north through Village of Portlandville.
4.0	14.7	Village of Milford
0.3	15.0	Blinking traffic light in Milford, proceed north on Rt. 28.
4.9	19.9	Village of Hyde Park
0.5	20.4	Village of Index
2.2	22.6	Village of Cooperstown
0.1	22.7	Bear right across railroad tracks on Rt. 28.
0.4	23.1	Junction of Rt. 28 and 80. Proceed straight on Rt. 80.
0.3	23.4	Traffic light intersection with Main Street. Proceed through intersection
0.1	23.5	Stop sign. Turn left and remain on Rt. 80.
2.0	25.5	Turn left on Otsego County Rd. 28 at Brookwood Point toward Leatherstocking Falls. The planar surface on your right at the turn is the upper surface of a hanging delta that was built into glacial Lake Cooperstown which stood about 20 m above the modern Otsego Lake level. (See paper and road log in this guidebook entitled Glacial Geomorphology of the Upper Susquehanna Drainage).
1.2	26.7	Turn left onto Armstrong Rd. (unmarked, but white house on left and SPCA sign on right).
1.7	28.4	Turn right on Tanner Hill Rd. (unmarked).

Miles from last point	Cumulative Miles	
0.7	29.1	Turn right just beyond large red barn onto Smith Cross Rd. (unmarked). Proceed for 0.2 miles to top of hill.
0.2	29.3 STOP 2	Pull over to the right, outcrop on the left. This is the Fitch-Metcalf Hill Site. There are two main wedges in this outcrop, but several others within walking distance up the road. These wedges are similar in many respects to those on Crumhorn Mountain. They are comparable in size and filling, but associated bedrock deformation appears slightly different. Here the rock is somewhat more massive and less fissile, which may account for why the rock appears broken upward here, as opposed to flexed upward at STOP 1. Here too joints define the orientation of the wedges and the bedrock is veneered by a till that collapsed to contribute to the wedge filling. Other much smaller wedges (or more accurately, buckles) can be seen in another excavation to the right (east). They can be reached by walking along the upper contour of the outcrop, through a raspberry patch and to a shallow excavation about 100 m away, or take the road if you're not a berry fan. Once again we are left with the question of whether these features are frost related or simply reflect the adjustment that occurred due to glacial unloading. Back track to Tanner Hill Rd.
0.3	29.6	Turn right on Tanner Hill Rd. and proceed north.
0.5	30.1	Road ends at intersection with Otsego County Rd. 26. Turn left. Road descends the valley wall of Fly Creek.
1.7	31.8	Bear left and remain on County Rd. 26.
4.0	34.8	Enter Village of Fly Creek. Stop sign at intersection with Rt. 80 and 28. Turn right.
0.7	35.5	Enter Oaksville.
1.7	37.2	Intersection of Rt. 205 south and 80. Turn left on Rt. 205 south and 80 west.
1.9	39.1	Turn left and remain on Rt. 205 south.

Miles from last point	Cumulative Miles	
4.7	43.8	Enter Village of Hartwick, continue south on Rt. 205.
2.2	46.0	Enter Village of Mt. Vision, continue south on Rt. 205.
5.1	51.1	Turn right just before Circle S Farm barn on Blood Mills Rd. (unmarked)
0.3	51.4	Cross Otego Creek bridge and take first right on dirt road that parallels the creek to the north.
0.2	51.7 STOP 3	End of dirt road at gate to Otsego County gravel excavation. This is the first of two locations, collectively referred to as the Laurens-Mt. Vision Site. At various times during the excavation of this deltaic feature (hanging delta or delta kame) massive gravel and sand foreset beds and poorly sorted topset gravels have been exposed. It is within the topset gravel that wedge-shaped structures have been observed. The largest reached a depth of 3 m and was 1 m wide at the top before being destroyed. Several smaller wedges have also been noted. In each case the wedges show a vertical orientation in a general N-S trend. They are characterized by downward collapse that includes the flanking gravels. A pebble count taken here included about 95% local lithologies and less than 1% limestone. However, chert at 1.7% is also present. Since the chert originated in a limestone host, it is assumed that much of the carbonate that was present has been leached. The lack of a polygonal wedge distribution rules out an ice-wedge mechanism for their formation. The evidence for leaching suggest that a soil-tongue forming process may have been active, but in other reported cases the carbonate content was much higher than would be anticipated here. This leaves the tension crack mechanism, which seems to have merit when one considers the juxtaposed location and trend of Otego Creek. Return to Rt. 205
0.4	52.1	Turn right on Rt. 205 south.

Miles from last point	Cumulative Miles	
1.2	53.3 STOP 4	Pull off to the right and walk in to a shallow gravel operation 0.2 miles off highway. This is the second of two localities described as the Laurens-Mt. Vision Site. Repeatedly during the excavation of this site a variety of small wedges, similar to those at the last stop, and vein-like structure (thin wedges) have been exposed. It is assumed that the similarity of features, topographic setting and host material would dictate a similar origin for both localities. Return to Rt. 205 and proceed south.
5.4	58.7	Junction of Rt. 205 with 23 at stop sign and blinking red light. Bear left and proceed south.
1.9	60.6	Traffic light intersection with Rt. 7 at I-88 interchange.

END OF FIELD TRIP