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

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INTRODUCTION

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

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

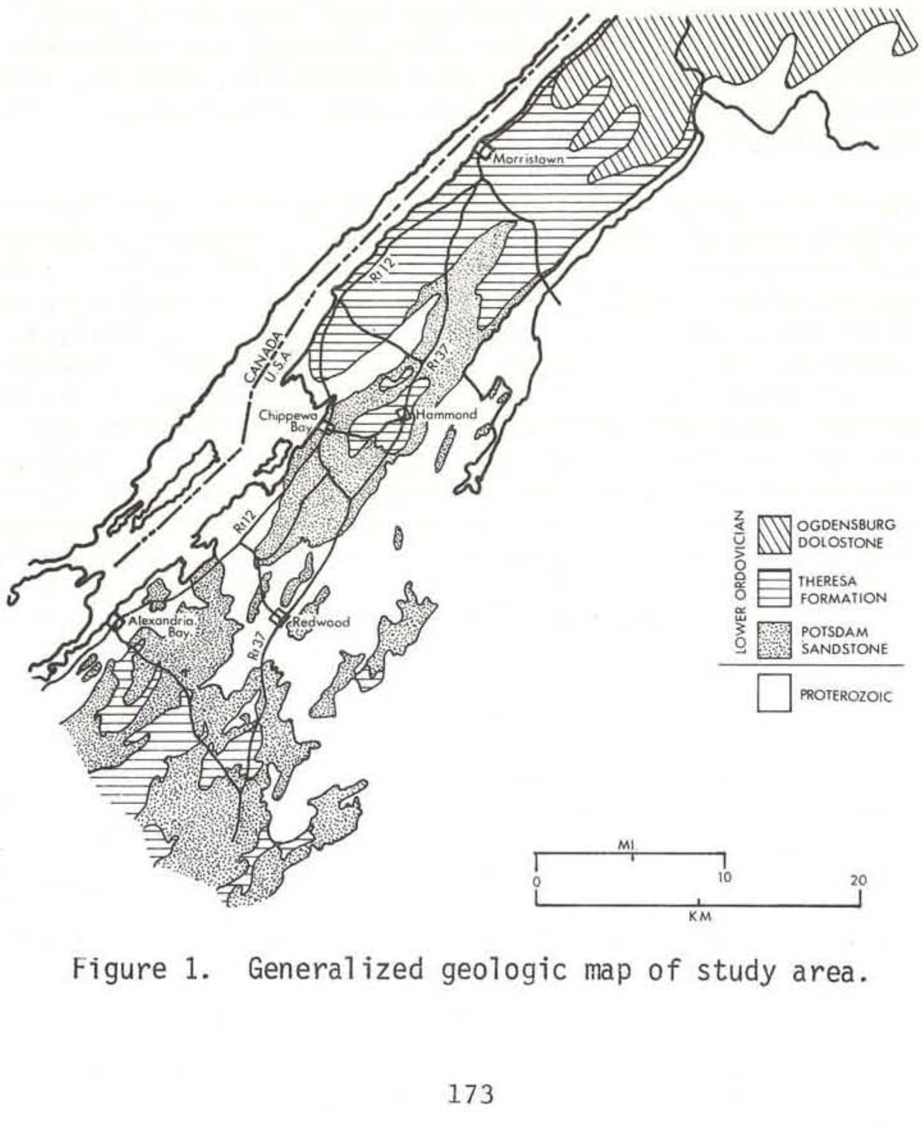

Figure 1. Generalized geologic map of study area.

PREVIOUS STUDIES

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

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

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

STRATIGRAPHY

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

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

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

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

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

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

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

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

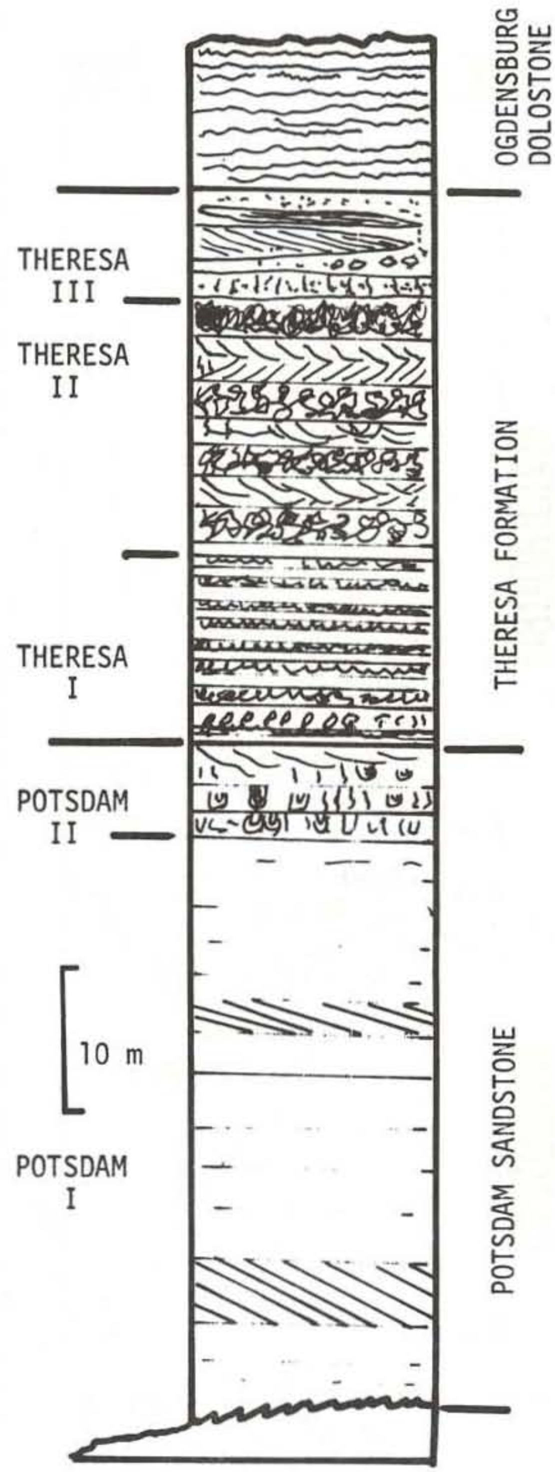

Figure 2. Generalized stratigraphic column for Potsdam Sandstone and Theresa Formation in study area.

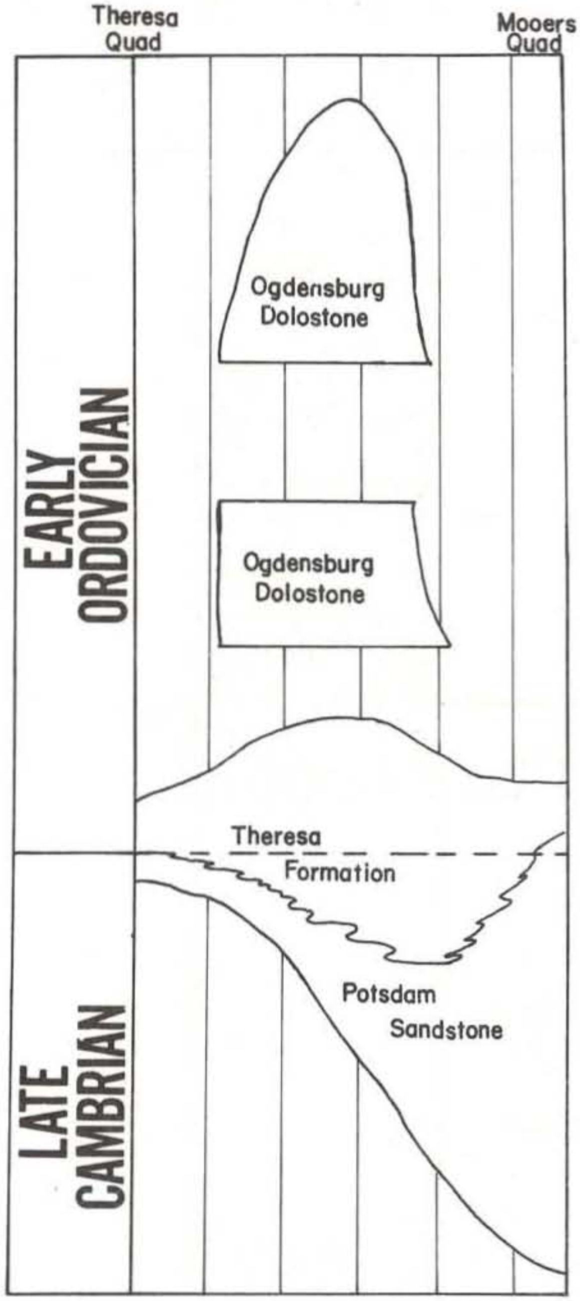

Figure 3. Stratigraphy of Cambrian and Ordovician of St. Lawrence Lowlands (after Fisher, 1977).

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

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

THE POTSDAM SANDSTONE

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

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

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

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

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

DEPOSITIONAL ENVIRONMENTS

Potsdam I

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

Potsdam II

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

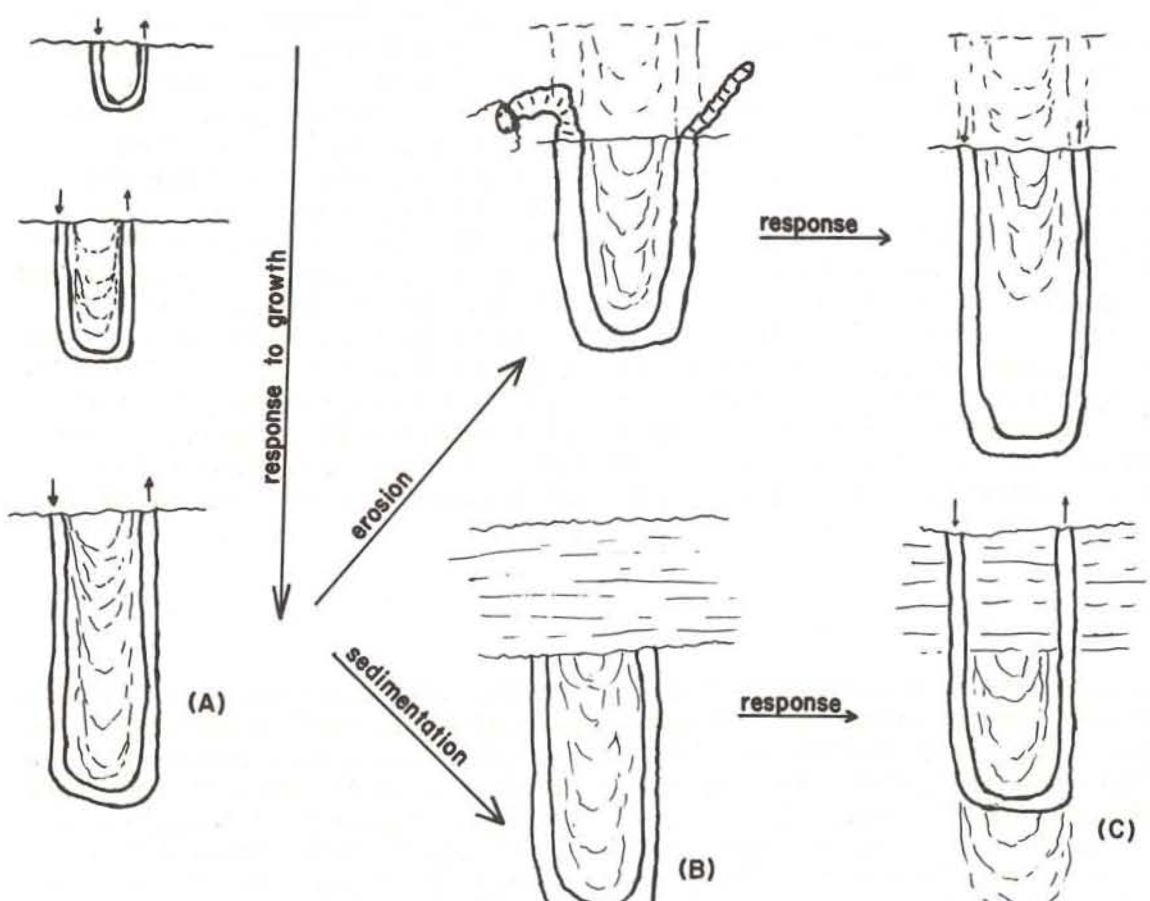

Figure 4. Burrow forms of Diplocraterion yoyo. A, is normal form in response to growth. B, is in response to erosion. C, is in response to sedimentation.

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

THERESA FORMATION

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

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

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

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

THERESA FORMATION: DEPOSITIONAL ENVIRONMENTS

Theresa I

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

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

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

Theresa II

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

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

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

Theresa III

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

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

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

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

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

ENVIRONMENTAL RECONSTRUCTION

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

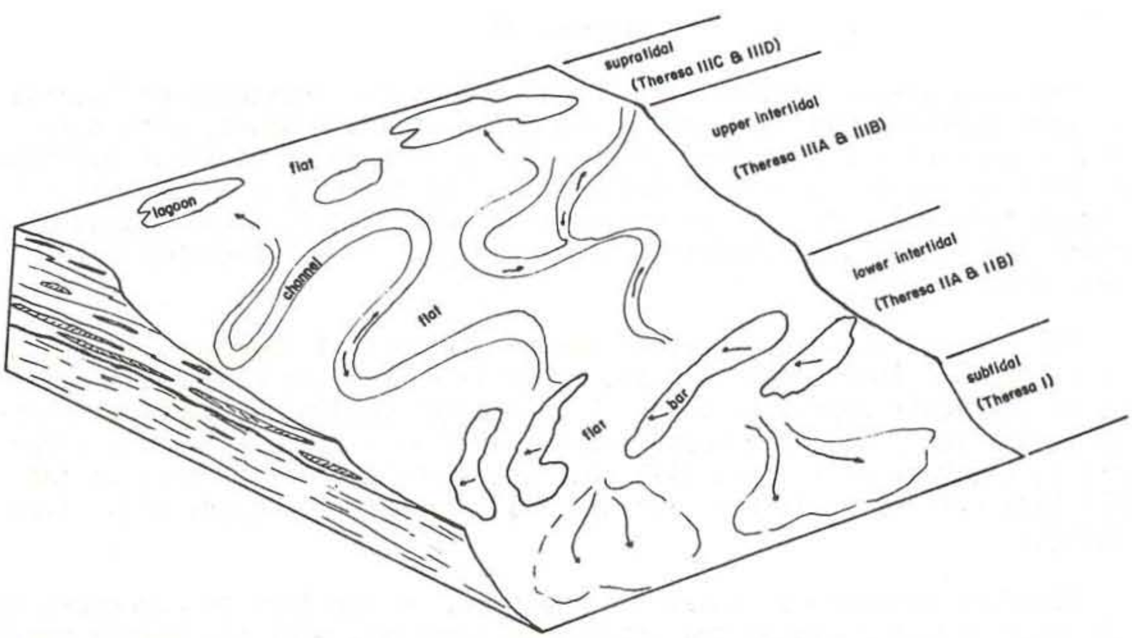

Figure 5. Environmental reconstruction of Theresa Formation.

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

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

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ROAD LOG*

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

*Mileage to nearest 0.05 odometer miles.

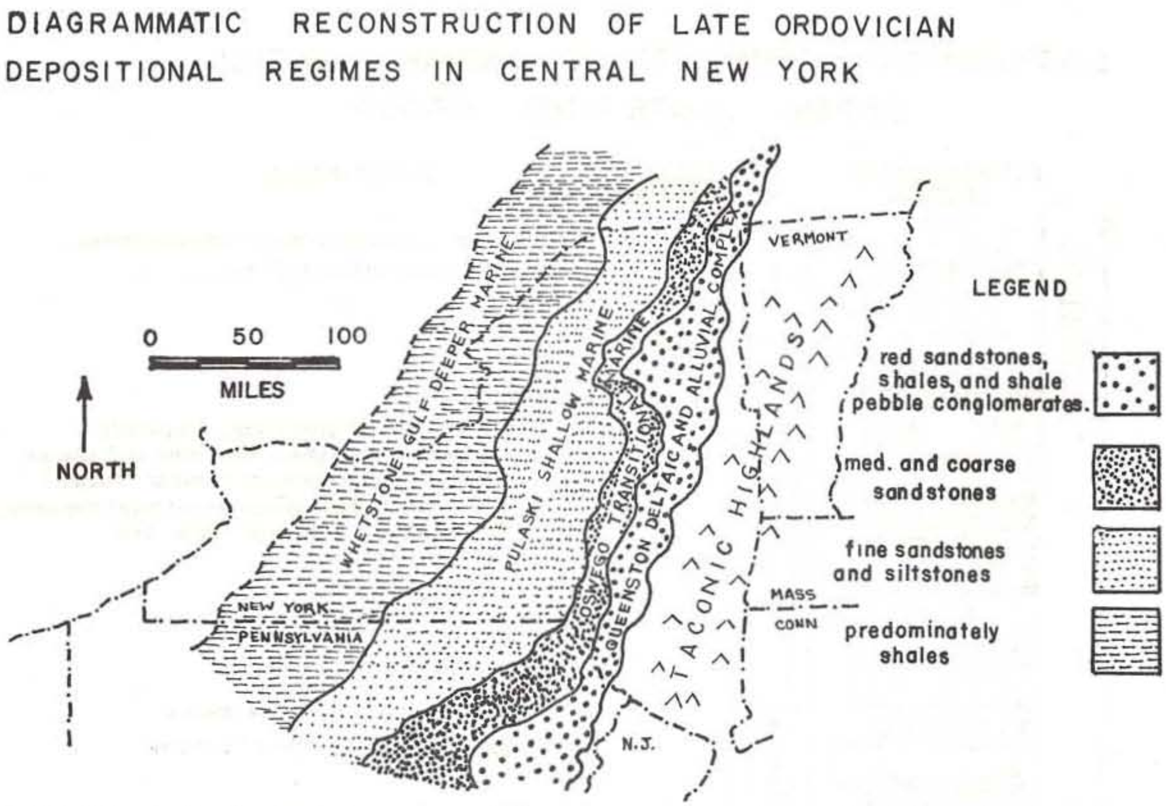

Figure 2. Late Ordovician depositional regimes (from Bretsky, 1970, after Broughton and others, 1962).

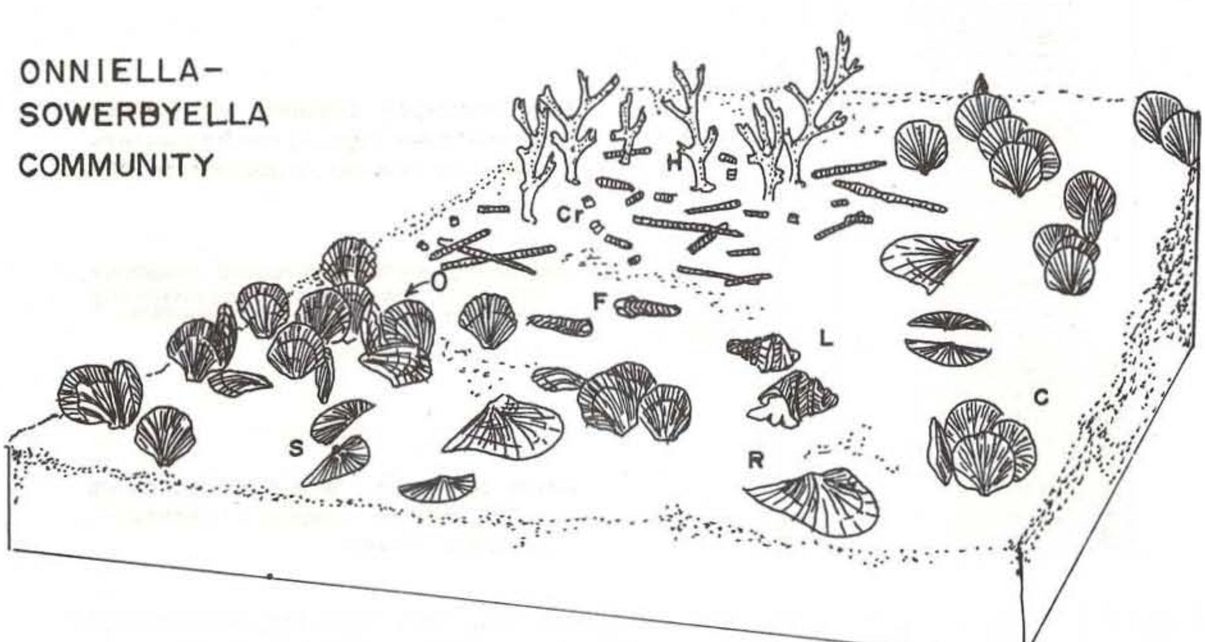

Figure 3. Reconstruction of Onniella-Sowerbyella Community (after Bretsky, 1970).

Nuculites-Colpomya Community

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

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

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

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

Ambonychia-Modiolopsis Community

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

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

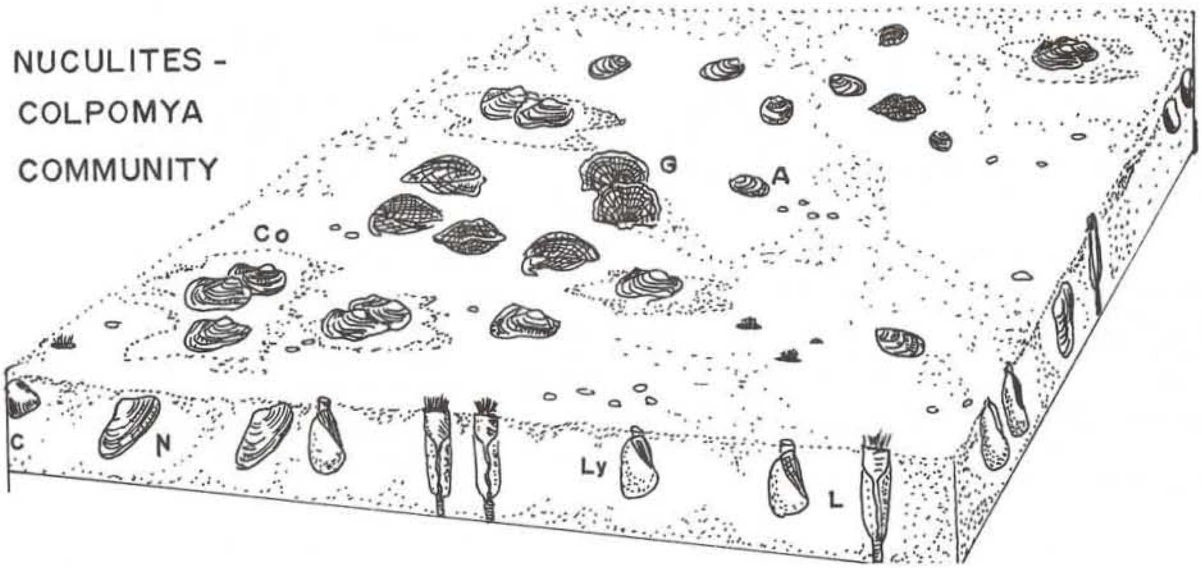

Figure 4. Reconstruction of Nuculites-Colpomya Community (after Bretsky, 1970).

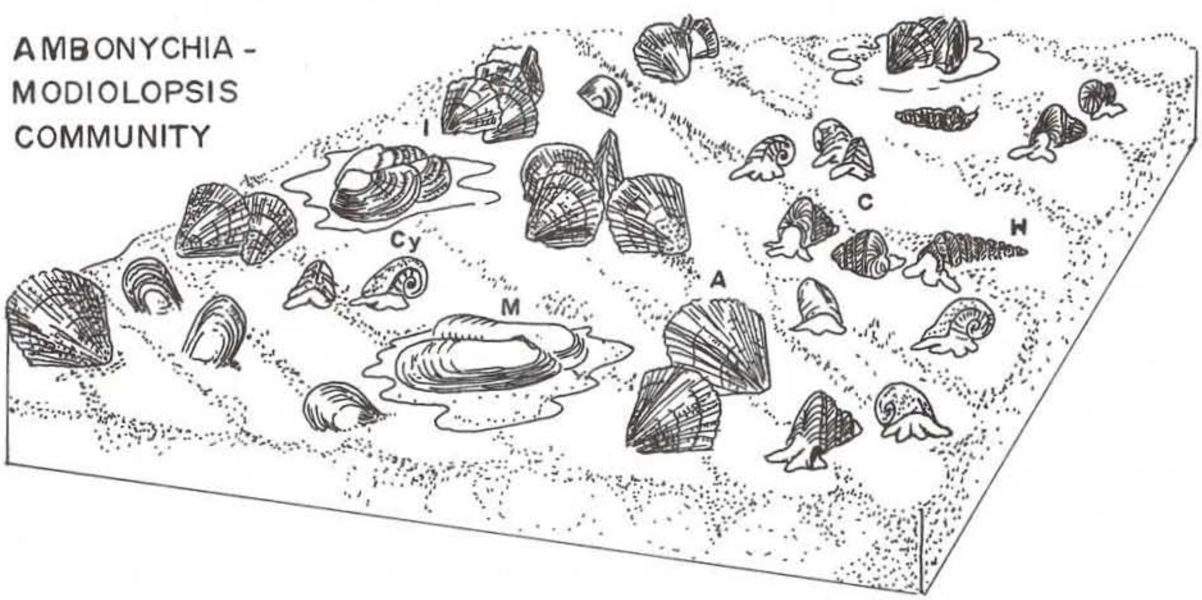

Figure 5. Reconstruction of Ambonychia-Modiolopsis Community (after Bretsky, 1970).

whole sequence grades upward into the unfossiliferous Oswego Sandstone.

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

BIOGENIC FEATURES

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

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

(2) Longitudinally striated burrows: intersect bedding planes at low angles; 4 to 5 inches long, $\frac{1}{2}$ inch wide; deeper than "turkey tracks"; occasionally filled with crinoid-bryozoan fragments.

(3) "U"-shaped tubes: dumbbell-shaped on bedding plane, usually $2\frac{1}{2}$ to 4 inches apart; found in massive-bedded orthoquartzites (Oswego-like sandstones); tubes filled with dark grey silty shales.

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

SUMMARY

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

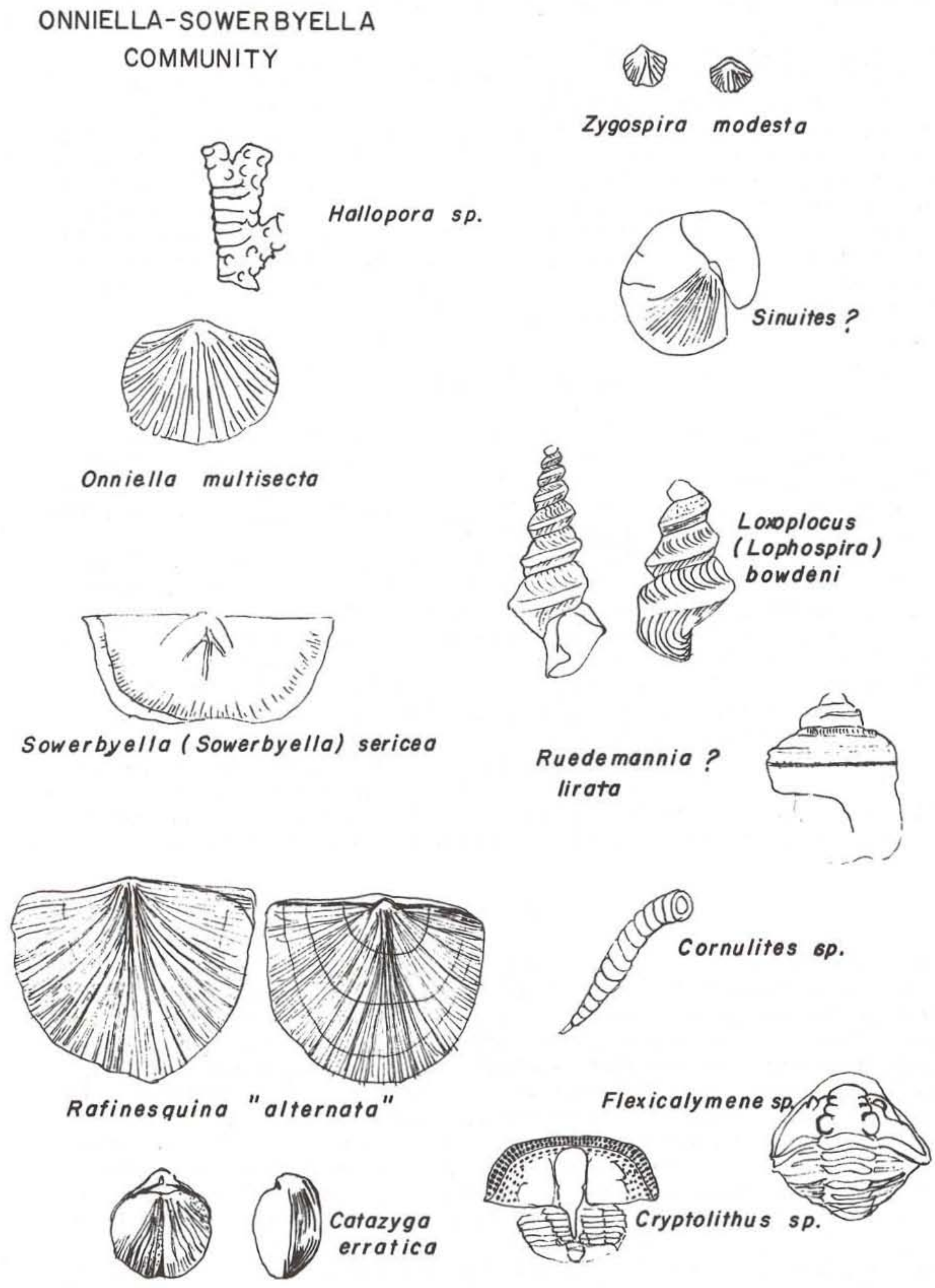

Figure 6. Representative fossils in Onniella-Sowerbyella Community.

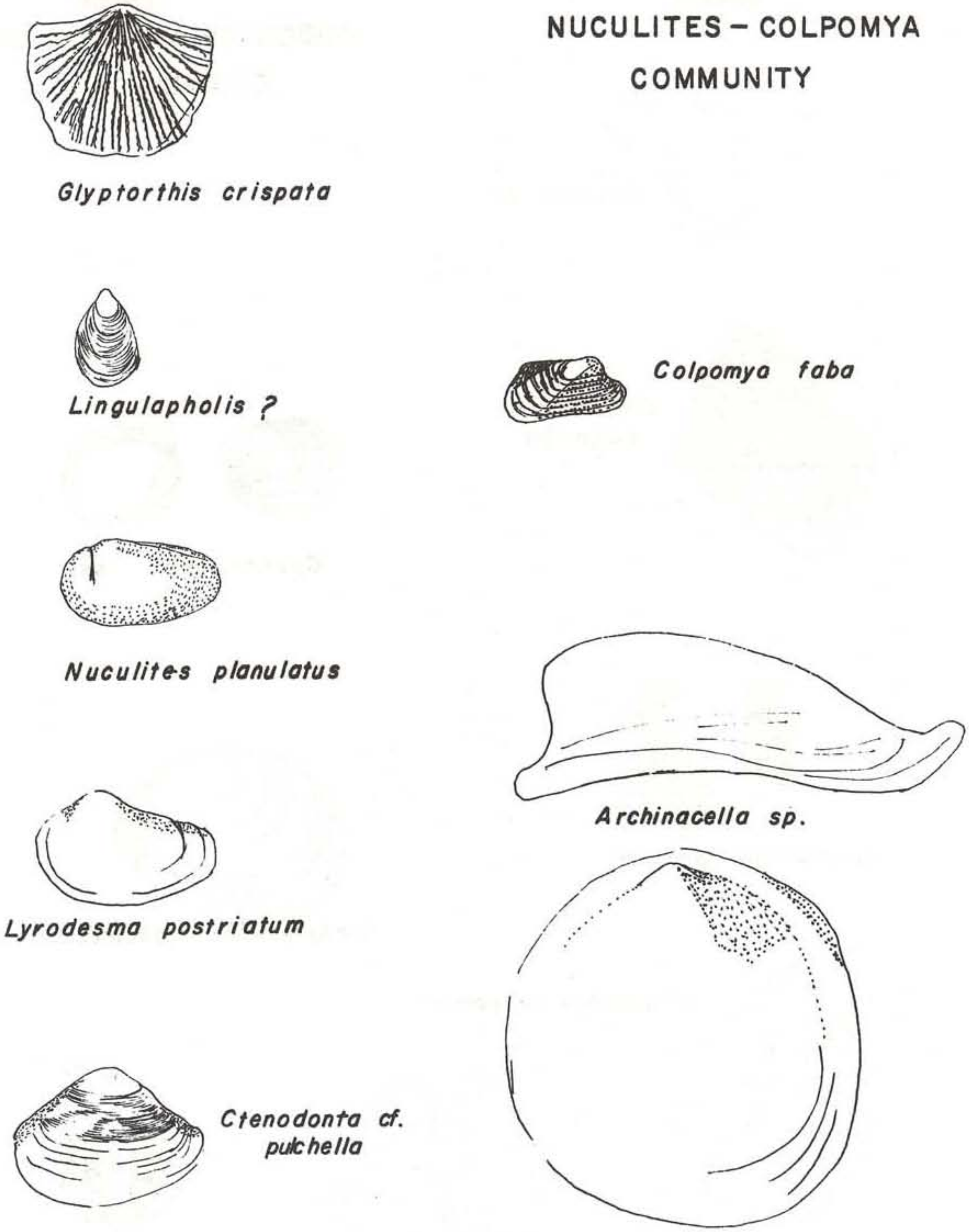

Figure 7. Representative fossils in Nuculites-Colpomya Community.

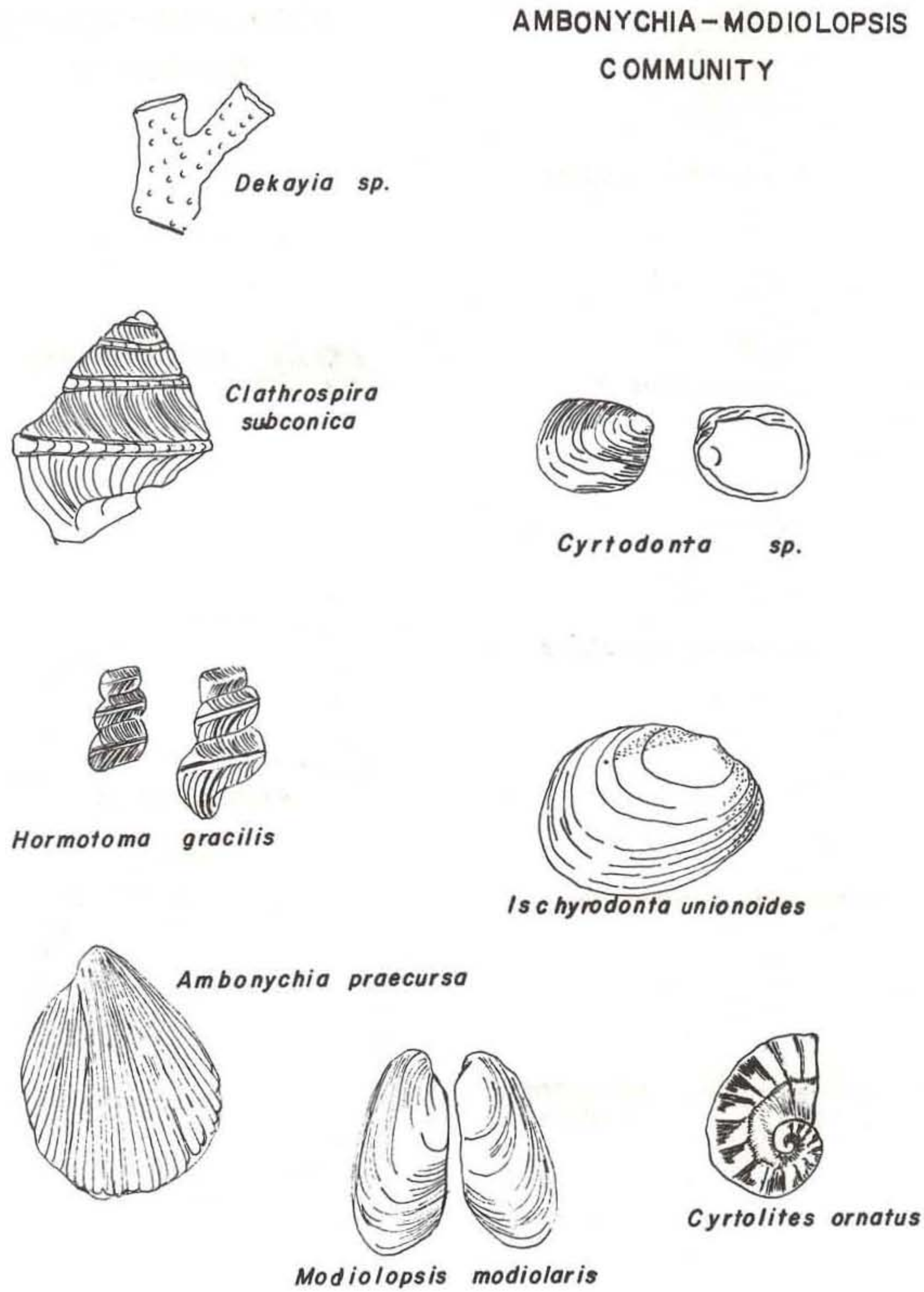

Figure 8. Representative fossils in Ambonychia-Modiolopsis Community.

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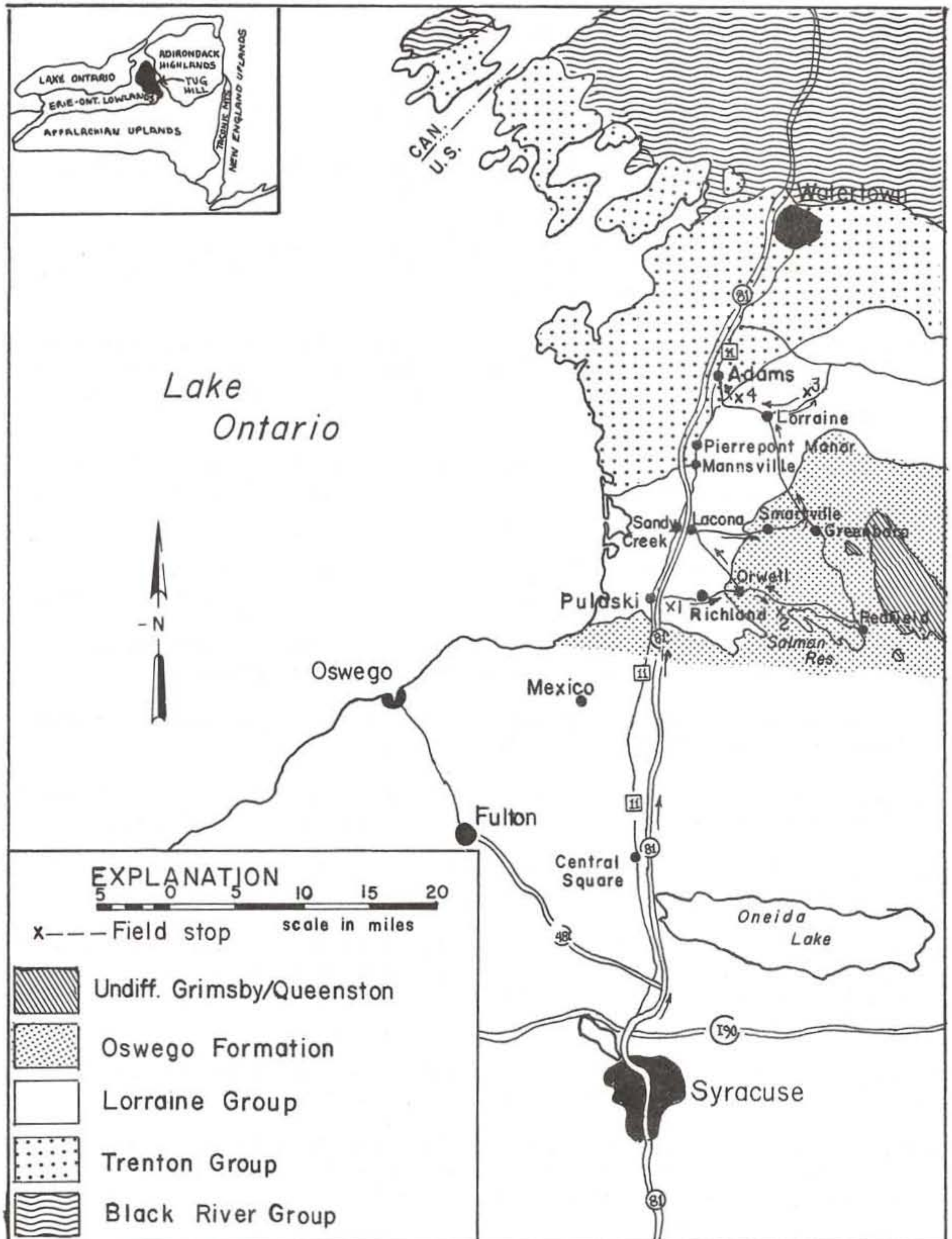

Figure 9. Field trip route with stops.

ROAD LOG

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

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

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

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

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

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

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

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

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

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

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

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