ORDOVICIAN ROCKS IN THE MOHAWK VALLEY: GEOLOGIC SITES FOR EDUCATION OF HIGH SCHOOL AND COLLEGE STUDENTS

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INTRODUCTION

The Mohawk Valley has outstanding bedrock geology and the stratigraphy of the Middle Ordovician rocks reflects the tectonic events associated with the Taconic orogeny (Figures 1-4). One advantage of teaching in this area is the ability to integrate the local stratigraphic record into classes concerned with stratigraphy, sedimentology, depositional environments, tectonics, and other geologic studies (Garver, 1992). Most of the Mohawk Valley is underlain by Middle Ordovician rocks that were deposited prior to and during the collision of the Taconic arc. This collision is clearly reflected in changes in the stratigraphic record, as well as structural and metamorphic events farther to the east (see Kidd et al. [this volume] for the structural aspects of the frontal thrust; see Hollocher [this volume] for the metamorphic aspects across the Taconic Orogenic belt). These changes include: 1) a deepening upwards trend that reflects tectonic subsidence; 2) lateral facies changes that reflect the basin geometry; and 3) paleocurrent trends that ultimately define the nature of coarse clastic infilling during the orogeny. The immediate focus of this field trip is on the stratigraphic record of the Taconic orogeny in the Mohawk Valley. In our examination we will look at separate pieces of the stratigraphy in ascending stratigraphic order - we will be traveling upward through time. We will examine changes in depositional environments and how these changes can be inferred from the rock record. We will also examine the lateral variation in the stratigraphy to infer changes in the basin geometry. Finally, we will use paleocurrent indicators to infer the shape of the basin and the flow directions of sediment fill during the Taconic orogeny.

This trip has two goals. The first goal is to gain an understanding of how to interpret depositional environments and how the changes in depositional environments can be used to infer tectonic events. The second, and perhaps most important, goal is to discuss how these different geologic sites can be used for the education of students. I have little experience with primary and secondary students on the outcrop, but I do have considerable experience with undergraduate students in the field and some of the challenges encountered in this arena certainly apply to younger students. Of the five sites on this trip, I use four of them in my course "Stratigraphy and depositional environments of New York", which I teach at Union College (for a complete description of the course, see Garver, 1992). These sites are advantageous because they focus on the most dramatic changes in the stratigraphy and they are easily accessible - most are in public parks.

WHY SHOULD STUDENTS SEE ROCKS?

In my mind there are several reasons that students should see rocks, but it is important to bear in mind that different students should see rocks for different reasons. Perhaps the first reason is to capture their attention. There is little doubt that fossil and mineral collecting trips stir that imagination of many young (and old!) students. In this regard, just "collecting stuff" is fine - these trips may lead some students to further inquiry. The second reason for showing student rocks may center around simply telling them a story. A third reason to show students rocks is to have them understand scientific inquiry and the methodology of the geological sciences. Many would argue that this final reason is far too esoteric for the average elementary or even high school student - I disagree. Primary and secondary school students can benefit a great deal if the second and third reasons are combined. Much of what we discuss during this trip involves some rather simple concepts and ideas that one can draw on from their own experiences.

When I teach *Stratigraphy and depositional environments of New York,* I combine reasons two and three above. The entire course centers around understanding tectonics through the stratigraphic and sedimentologic record by conducting weekly research problems aimed at understanding different parts of the stratigraphy. An important aspect of this approach is to have students observe and collect their own data, and to have each field project build on previous work. This week-to-week unity provides the students with an intriguing motivation that, in my opinion,

In Garver, J.I., and Smith, J.A. (editors), Field Trips for the 67th annual meeting of the New York State Geological Association, Union College, Schenectady NY, 1995, p. 357-375.

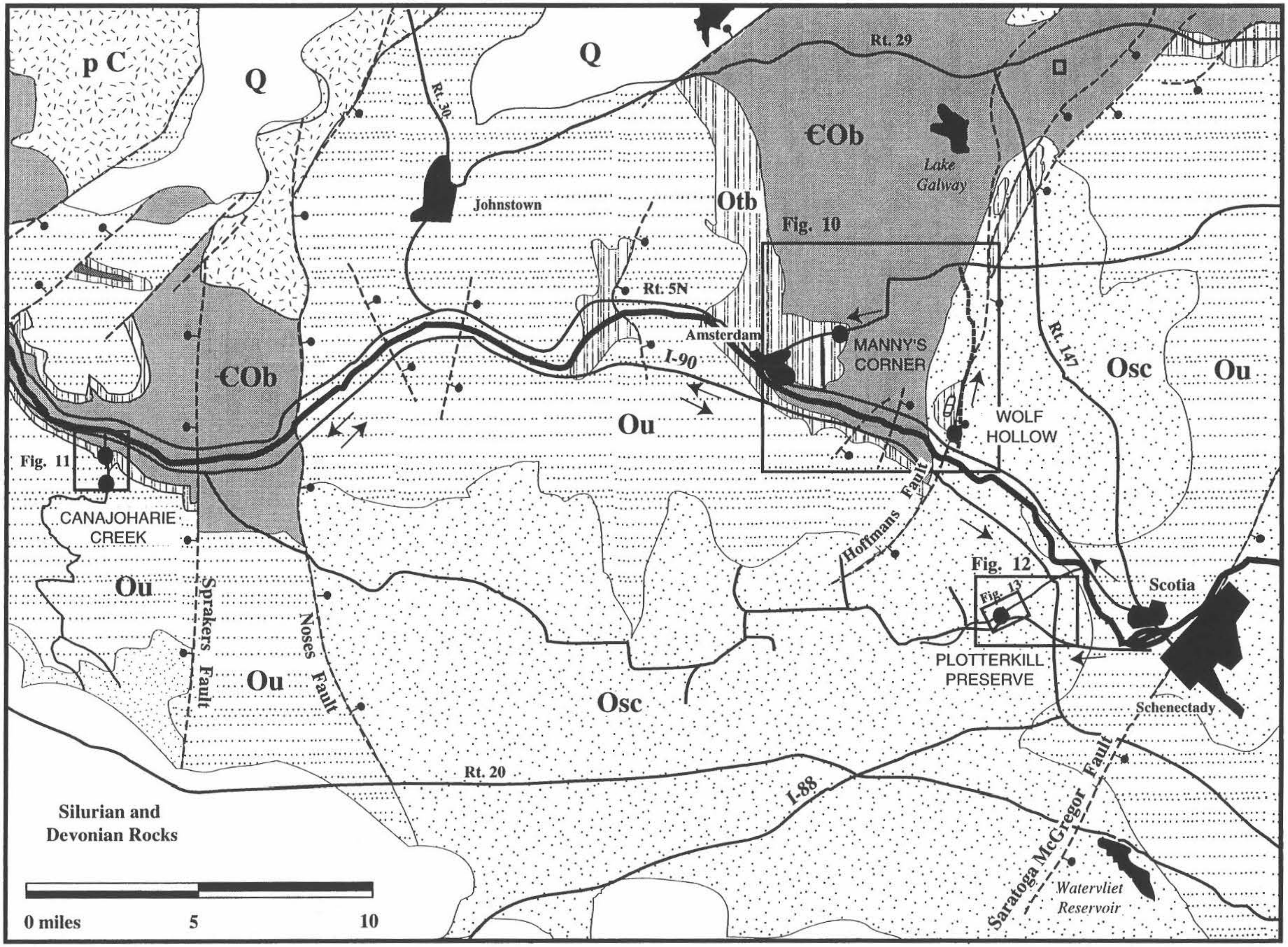

Figure 1: Simplified geologic map of the lower Mohawk Valley after Fisher et al., 1970, and Fisher 1980. Trip starts in Scotia, proceeds west on 5N to Wolf Hollow, north to Rt. 67 to expoures near Manny's Corners, then to Canajoharie Creek via Amsterdam and I-90. The last stop is in the Plotterkill Preserve near Schenectady. Normal faults shown with tick mark on the downthrown block. p€ is Adirondack basement; €Ob is the Beekmantown Group; Otb is the Trenton and Black River groups; Ou is the Utica Shale; and Osc is the Schenectady Formation. Younger rocks (Silurian and Devonian) and cover (Quaternary) are not shaded.

appears to accelerate the learning process. I have students write a formal lab report for each project. This weekly report writing and rewriting dramatically improves writing skills and crystallizes their understanding of the scientific method.

The approach of this course is to present the students with weekly field and lab exercises that have a common goal of deciphering the tectonic evolution of eastern New York through the stratigraphic record. A specific format and a detailed explanation of each project help the students organize their thoughts, manipulate the data, and interpret the significance of the data. The need for well-exposed, easily accessible field sites is obviously important. The field projects are not show-and-tell field trips; they include the investigation and data collection in a single area or outcrop toward a goal that is clearly outlined in an accompanying project description. The purpose of the field projects is not only to teach methodology, but also to confront them with real scientific problems that they must try to solve. In many cases there is no correct answer. I emphasize that it is not the answer that is important, but how you arrived at your conclusions. In this regard, their reports are aimed at persuading the reader that their interpretation makes sense in the context of the field observations.

GEOLOGIC FRAMEWORK FOR THE MIDDLE ORDOVICIAN STRATIGRAPHY IN THE MOHAWK VALLEY

The Middle Ordovician rocks in the Mohawk valley are now generally interpreted to reflect the tectonic events associated with the Taconic Orogeny. The Taconic orogeny is inferred to be a period of Arc-Continent collision where the west-facing Taconic arc (the subduction zone dipped to the east) collided against the passive margin of North America. This trip is designed to highlight some of the most important changes in the stratigraphy and depositional environments of the units that record this collision.

Beekmantown Group

The oldest unit of concern for this discussion is the Cambro-Ordovician Beekmantown Group (Figures 2-5). This is a thick sequence of limestone and dolostone that was deposited in shallow marine to supratidal environments. Different formations of the Beekmantown Group are well exposed in the Mohawk Valley and their correlatives are present both north and south along the eastern seaboard. These rocks are dominantly Upper Cambrian to Lower Ordovician and are punctuated by several unconformities (Fisher, 1977). This time span represents some 41 Myr of shallow shelf sedimentation with no evidence of tectonic activity (~517 to 476 Ma - see Harland et al., 1990). The depositional environments and ultimately the stratigraphy are dominated by changes in global sea level (eustatic sea level) as opposed to tectonic effects. This sequence of rocks probably represents a *Passive Margin* (or Trailing Margin) sequence that rifted away from another continental mass long before these sediments accumulated. A modern setting that probably resembles the depositional setting of these ancient rocks would be the southern and eastern coast of Florida today where carbonates and very mature clastic rocks (well-rounded quartz sandstone) are deposited together in a variety of depositional environments.

Middle Ordovician Limestones

Deposited above the upper units of the Beekmantown Group are several different limestone units - mainly the Black River Group and the "Trenton Limestones"[1] (Figures 2-5). The Black River Group contains the Lowville Limestone and the overlying Amsterdam Limestone (Fisher, 1977), both of which are generally fossiliferous and were probably deposited in a very shallow marine setting. We will use sedimentary structures and fossil content to make some inferences about their depositional setting.

The overlying limestones of the Trenton Group include, mainly, the Glens Falls Limestone[2]. This unit is abundantly fossiliferous and generally contains both limestone beds and interbedded calcareous shale. The depositional setting of this unit is a deeper-water shelf as compared to the underlying limestones of the Black River Group. The general upward trend in this stratigraphic sequence is a profound deepening (transgression). In the field, we will discuss possible ways to estimate depth during deposition for each of these units; once we have depth estimates, we

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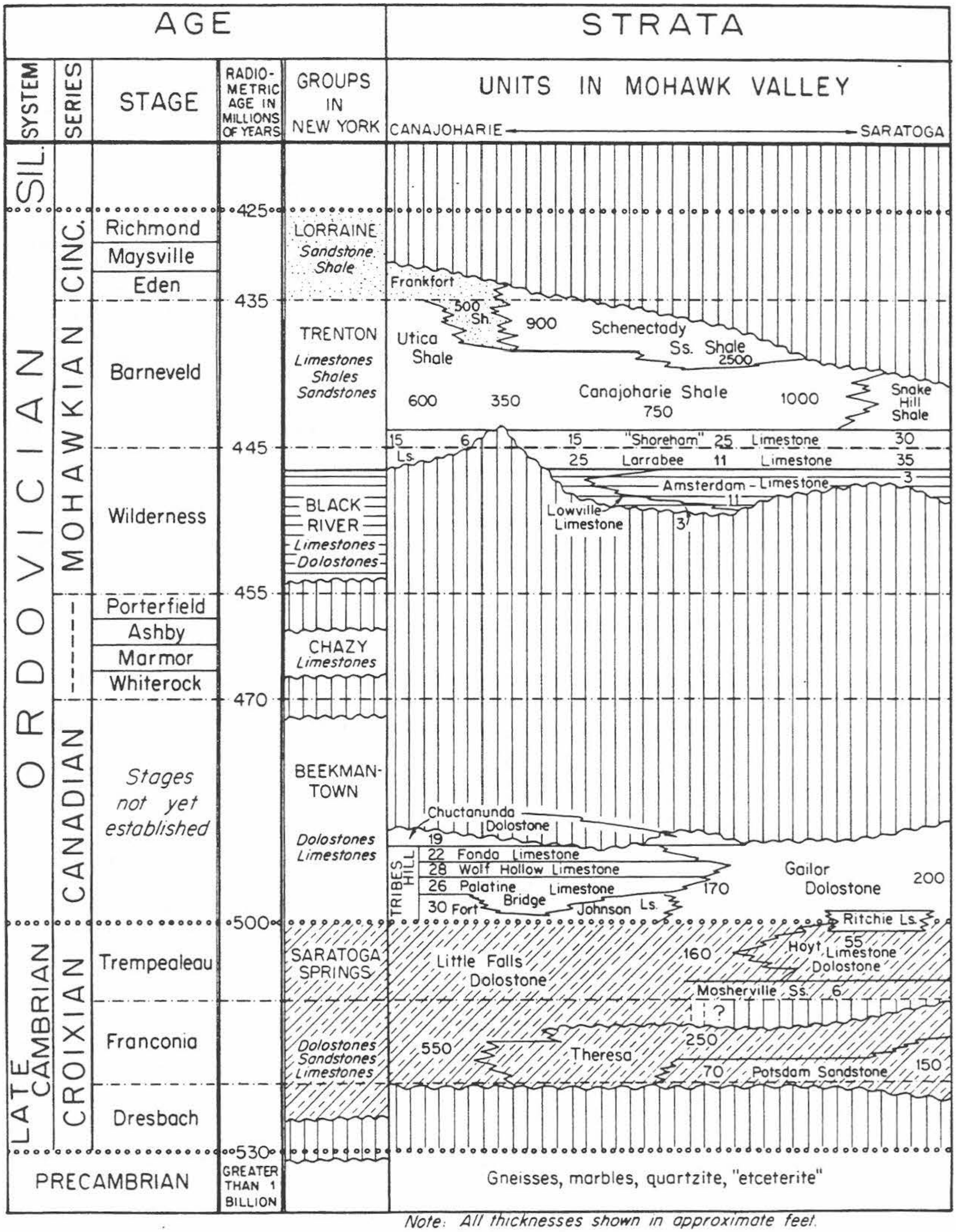
[1] There is some confusing nomenclature surrounding the Middle Ordovician rocks in the Mohawk Valley. To many geologists the Trenton Group includes the Utica Shale, but to others it does not. For the ease of discussion, I will refer to the Trenton Limestones and the Utica Shale separately.

[2] Locally the Glens Falls Limestone can be subdivided into a lower unit, the Larrabee Limestone, and an upper unit, the Shoreham limestone (see Fisher, 1977; 1965a,b)



Note: All thicknesses shown in approximate feet.

Figure 2: Generalized lower Paleozoic stratigraphy of the Mohawk Valley (from Fisher, 1965a,b). Thickness of units given in feet.

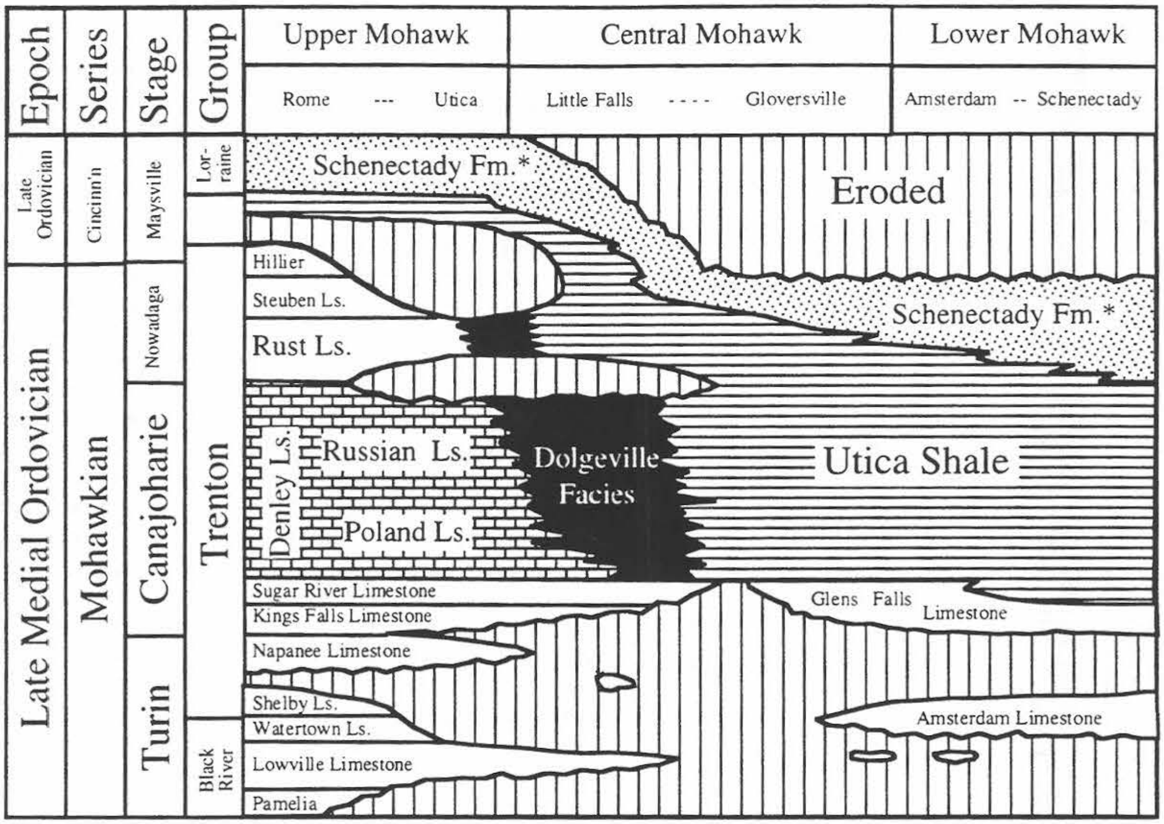


Figure 3: Generalized stratigraphic relationships in the Mohawk Valley showing biostratigraphic relationship between units (not thicknesses). Simplified from Fisher (1977). (*In this diagram the "Schenectady Formation" includes the Frankfort Formation.)

can make inferences about the influence of either sea level change (eustatic) or tectonic subsidence. I and others favor an interpretation in which the deepening trend is caused by tectonic flexure at the onset of the Taconic orogeny (see Baldwin, 1980).

Middle Ordovician Clastic rocks

The Utica Shale lies conformably above the transgressive limestones of the Trenton and Black River groups and reconstructions of depositional environments suggests that the transgression continued (Figures 2-5). The Utica Shale[3] is a thick sequence of black shale that is locally fossiliferous and locally calcareous. Two aspects of the Uitca Shale are noteworthy. First, it is extremely thick considering its age range (therefore the average accumulation rate must have been very high); it is about 300 meters thick in the Canajoharie area and it thickens to about 1000 m to the east of Schenectady. This rapid sedimentation rate implies that some tectonic mechanism was responsible for forcing the bottom of the basin downwards (as opposed to making sea level go up), allowing a thick sequence of sediments to be deposited. Second, it passes laterally into different units (Figure 5). Traced to the west, the formation becomes increasingly interbedded with limestone (Dolgeville facies) and much farther to the west it is passes laterally into limestone with no shale (Denley Limestone; see Fig. 5). Laterally, to the east, it passes into interbedded shale and sandstone of the Schenectady Formation and its equivalents. These ***Lateral Facies changes*** are extremely important in helping us determine the geometry of the depositional basin in which these rocks were deposited.

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[3] This name has also been somewhat controversial. It is generally agreed that the Utica Shale, Canajoharie Shale, and Snake Hill Shale are more or less lithologically correlative, but are slightly different ages (see discussion in Kidd et al., this volume)

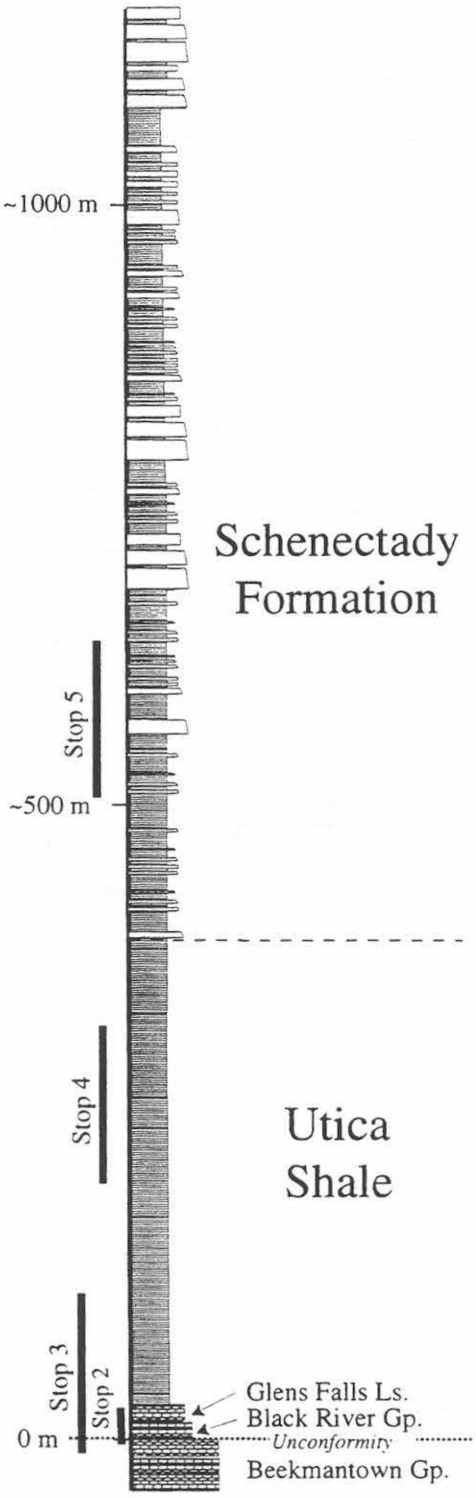

Figure 4: Generalized stratigraphic column for rocks seen on this field trip. Thicknesses are approximate (see Fisher, 1977). Approximate limit of the stratigraphy see at each field trip stop is shown on the left-hand side.

The Schenectady Formation[4] is a very thick sequence of interbedded sandstone and shale that is virtually unfossiliferous. The unit is very thick and is wedge-shaped, thickening dramatically from west to east (Fisher, 1977; see Figure 2). Unfortunately, because erosion has removed the upper beds of the Schenectady Formation, the true stratigraphic thickness of the Schenectady Formation is difficult to establish. In the Plotterkill area, the unit is greater than about 760 meters thick (Fisher, 1977). The Schenectady Formation is the foreland basin deposit that accumulated in an asymmetric basin in front of the advancing thrust complex associated with the Taconic arc. A ***foreland basin*** is a basin produced by flexure of the continental crust when a load (such as the Taconic arc) is placed on the edge of the crust (Figure 6). Perhaps tha best way to envision the geometry of a foreland basin is to hold one end of a meter stick on the edge of a table and push down on the free end, flexing the ruler downward. The hand that is pushing the ruler down is a load -- similar to a thrust complex. The ruler (if thick and wooden) behaves very much like "rigid" continental lithosphere. We know, however, that it is not this simple. When the continental lithosphere was pushed down by the forward-advancing load, the upper part of the continental crust responded by breaking along normal faults (Figure 7). Bear in mind that the load that was responsible for flexure of the crust was not static. Instead, it moved progressively to the west so the region of maximum flexure (the deepest part of the basin) also moved progressively from east to west. The relationship between lithospheric flexure and concurrent normal faulting in the Mohawk Valley is discussed in Bradley and Kidd, 1991. In the field, we will discuss the offset amounts, timing, and effect that these faults had on Middle Ordovician sedimentation.

An important aspect of basin studies is ***paleocurrent analysis***. A paleocurrent study involves determining the ancient flow directions (paleoflow) of sedimentary detritus in a basin. This sort of study is done to determine the position of the original source terrain, types of depositional environments, and lateral trends within a basin of deposition. If you work for an oil company, and you discover an oil-rich beach deposit, the direction and trend of that beach would be important information. Paleocurrent data from these beach sediments could help you make useful predictions about the lateral trends of this deposit. Many physical sedimentary structures are produced by traction currents and they commonly retain information about the direction of sediment transport. The sandstone beds in the Schenectady Formation represent turbidites that were deposited by fast-moving turbidity currents that moved downslope and were deposited in this part of the Mohawk Valley (Figures 7,8).

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[4] In this report, "Schenectady Formation" refers to the type Schenectady Formation as well as correlative units of interbedded sandstone and shale to the west and to the east (including deformed sequences). Notably, this would include the Frankfort (to the west) and parts of the Normanskill Formation (to the east).

Turbidity currents are sediment-laden currents that, because they are denser than water, flow downslope to the deeper parts of a sedimentary basin. When these currents reach the deepest part of the basin, or a break in slope such as is found at the base of the continental slope, they slow down and begin to deposit sediment. The decelerating current produces a very regular and systematic sequence of sedimentary structures that record the slowing of the current and the deposition of the sediment from the turbidity current (Walker, 1979). The deposition of a turbidite is very rapid (hours) and the downslope movement of the sediment may correspond to an earthquake, a storm, or any other mechanism capable of stirring up sands and silts in shallow water. Normally, deep-water environments receive only minor fine-grained sediment that rains down from the water column at extremely slow rates. It is common, therefore, for deep-water sediments to be composed of turbidites and interbedded shale with the former representing an instantaneous depositional event and the later representing the slow continuous accumulation of mud from the water column. Turbidites commonly have excellent paleocurrent indicators that can be used to reconstruct basin geometry.

In turbidite sequences, perhaps the most common ***paleocurrent indicators*** are found at the base of sandstone beds and represent the flow of the sand-rich turbidite over the muddy seafloor. Flutes and grooves are sole marks that commonly occur at the base of turbidite beds. Flutes are unidirectional sole marks that occur on the bottom of sandstone beds. They are caused by turbulence in the turbidity current striking the seafloor and moving forward at the same time. They look like inverted teaspoons with the sharp/steep side toward the source direction. Grooves are bidirectional sole marks. Grooves are elongate nearly straight marks on the base of sandstone beds. They are not asymmetric and they therefore simply indicate the orientation of the current but not the absolute direction. Paleocurrent indicators also occur in the main part of a turbidite bed. As turbidity currents slow and decelerate,

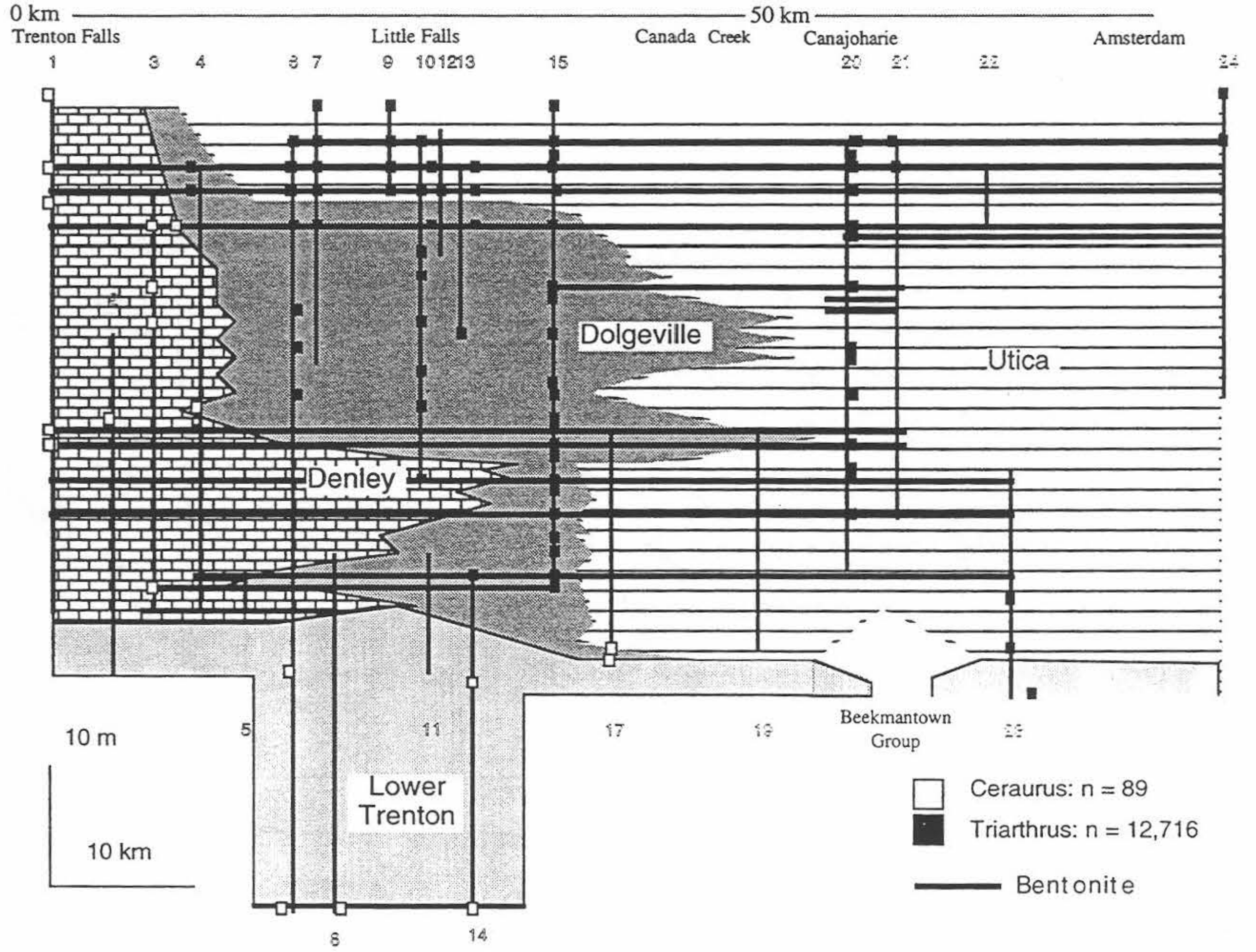

Figure 5: Relationship between bentonites (dark horizontal lines) and measured stratigraphic sections (vertical black lines) showing the distribution of Cerarus (open squares on the measured stratigraphic sections) and Triarthus (filled squares). Modified from the Macintosh Hypercard stack by Ray Gildner (unpublished).

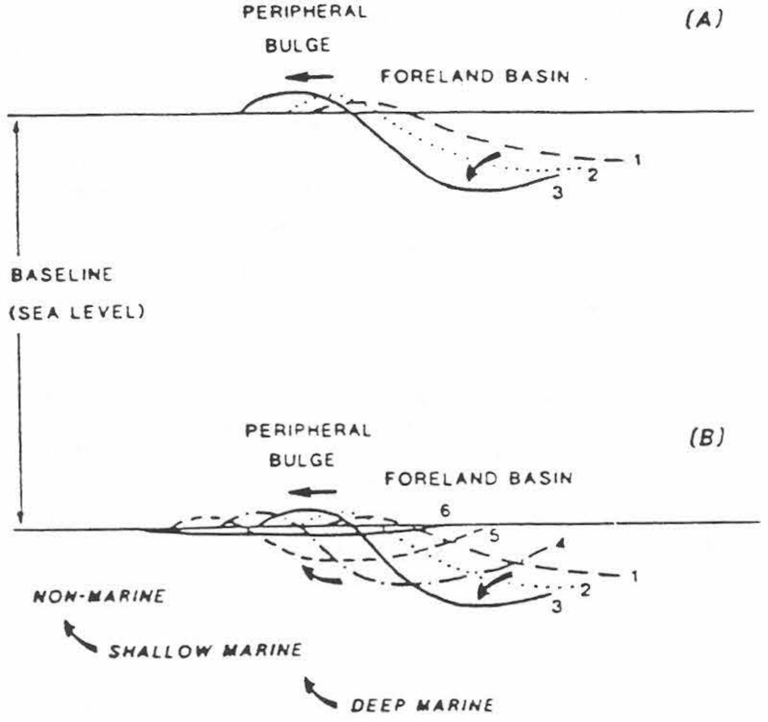

Figure 6: Development of lithospheric flexure due to thrust loading (from Pickering, 1977). Note that through time. the position of the maximum flexure (deep part of the basin) migrates forward with the advancing thrust complex [A]. Also note that at any one place that experiences this flexure, one can expect the environments to go from non-marine to shallow marine to deep marine. Locally, slight upwarping (the "peripheral bulge") can cause rocks to be uplifted above sea level.

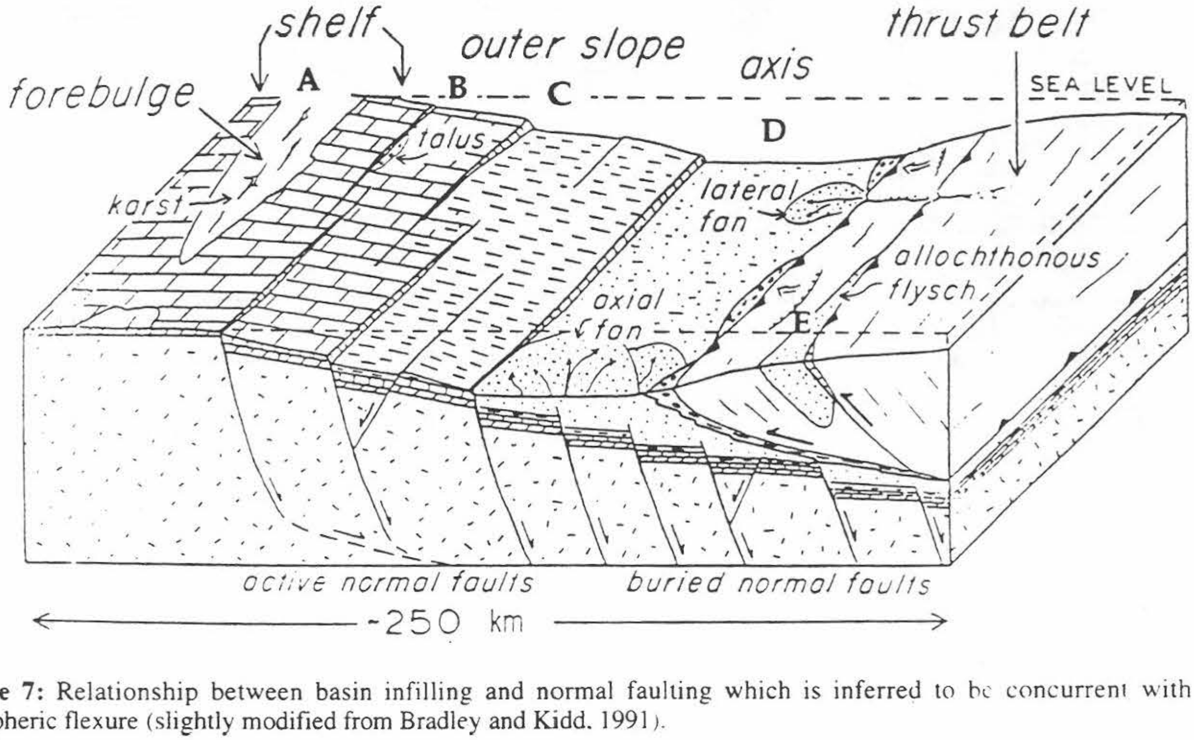

Figure 7: Relationship between basin infilling and normal faulting which is inferred to be concurrent with lithospheric flexure (slightly modified from Bradley and Kidd. 1991).

thus depositing their load, they produce planar laminated bedding. Parting lineation is a bidirectional current indicator that occurs on the split surface of parallel laminated sandstone beds. It occurs as a lineation parallel to the paleoflow direction and it is produced by mineral alignment during deposition. Eventually further slowing of the current produces rippling of the sand. At the top of a turbidite one can commonly observe ripple cross-lamination, which is a unidirectional current indicator. Unless exposures are excellent, however, it may be difficult to determine current direction. A cross-section of the ripples in a sandstone bed will display small (mm- to cm-scale) inclined foreset laminae that are inclined in the direction of ripple migration and current movement.

If you are interested in determining where the clastic came from, you would have to study the ***Provenance*** (source area) of the sediment. The provenance of the sandstones should give us a clue as to the composition of the highlands that eroded to fill the basin. In general, provenance studies of synorogenic clastic sediment are important because in other thrust belts the coarse-grained detritus is derived from the uplifted and eroding thrust complex and therefore the sandstone should provide a record of what collided. Thin sections of sandstones of the Schenectady Formation reveal that the sandstones are composed almost exclusively of quartz, feldspar, and sedimentary rock fragments (mainly fragments of limestone and sedimentary rocks and only minor metamorphic and volcanic rock fragments), and minor detrital mica. The grains of quartz are particularly interesting because many are well rounded multicycle grains. This observation suggests that the quartz grains are very mature texturally, and must have been reworked over and over in a stable tectonic setting - not typical of an active orogenic belt. Another important clue is the abundance of clasts of sedimentary rock fragments, which suggests that sedimentary rocks (including limestone) were common in the source area. Notable is the virtual lack of volcanic rock fragments. If the Taconic island arc collided with North America in the Middle Ordovician, then why aren't the sandstones rich in volcanic arc-derived detritus? The answer lies in what happens when an arc collides with the edge of a continent.

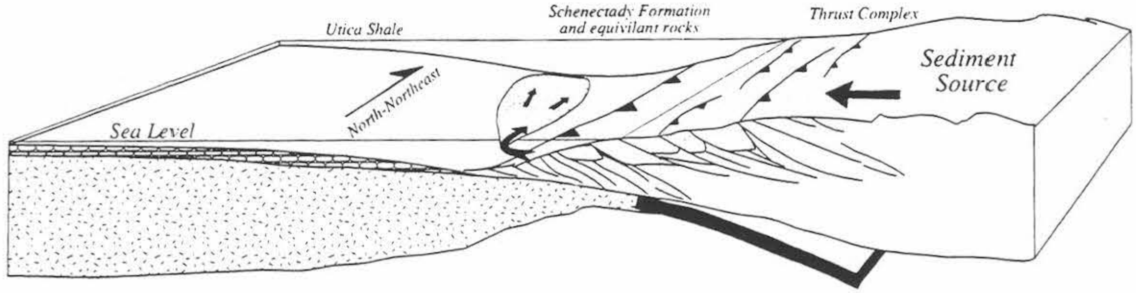

Figure 8: Large-scale relationship between flexure of the lithosphere and uplift of the thrust complex. The submarine fan drawn here emphasizes the axial transport of turbidites in the basin. From Garver and others (1996).

As we know from studies of modern arc-continent collisions (e.g. see Lundberg and Dorsey, 1988), the arc plows into the continental margin sediments (many of them deep-water) and imbricates them like a deck of cards in a rapidly growing thrust complex that separates the arc from the foreland basin (Figure 9). Because these continental margin sediments are the first to ride up onto the continental margin, they become rapidly uplifted and eroded, and the detritus then gets deposited in the adjacent foreland basin. Today, the thrust complex is well displayed in the Taconic mountains where deep-water (continental slope and continental rise) sediments have been internally imbricated and thrust over shallow water continental margin strata (Zen, 1961; Stanley and Ratcliff, 1985). The rocks in the Taconic allochthon are almost exclusively sedimentary rocks, including Cambrian and Ordovician units that are rich in well-rounded mature quartz sand (e.g. Poultney Formation, West Castleton Formation, and others) that was derived from contemporaneous units on the shelf (e.g. Theresa Formation) (Baldwin, 1983). The basement to the Taconic arc included ophiolites in many areas of the Appalachians. An ophiolite is a piece of ocean crust that includes basalt, gabbro, and ultramafic rocks. The ultramafic rocks are geochemically distinct because they contain far more chromium and nickel than any other rock common at the surface of the earth. Using the Cr and Ni geochemistry of the shale that is interbedded with the sandstone, Garver et al (1996) determined that ophiolites were not significant in the thrust complex that eroded to form the Schenectady Formation. They did find, however, that as one follows correlative sequences north to Newfoundland, the percentage of ophiolites in the source increased considerable. Similarly, they determined that sediments deposited very early in the collision reflect the nature of the Taconic arc, but that those deposited later in the collision are dominated by continental margin sediments.

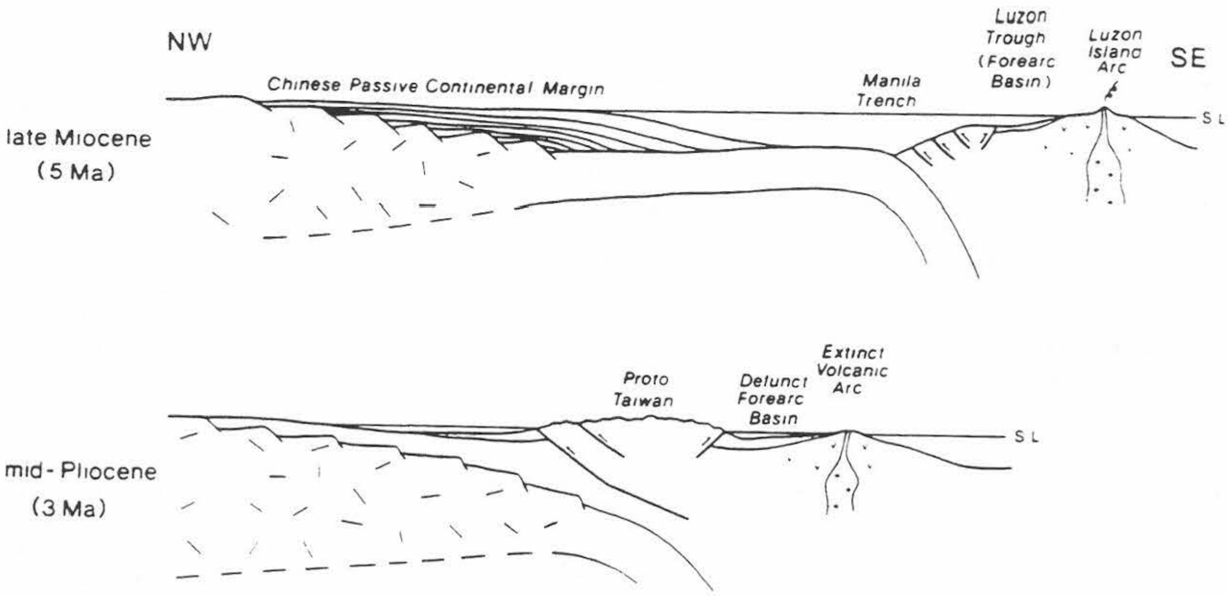

Figure 9: Inferred sequential development of the collision of Taiwan (from Lundberg and Dorsey, 1988). The west facing Luzon Arc is inferred to have collided with the passive margin of China only in the last 5 Million years. The inferred collision of the Taconic arc with the then passive margin of eastern North America was probably very similar. In the lower diagram (mid-Pliocene) note the development of "Proto-Taiwan" which is largely composed of imbricated sediments of the Chinese margin. Much of the sediment deposited in the foreland basin (to the west of Proto-Taiwan) is derived from the thrust complex and not from the Luzon arc - much the same scenario is envisioned for the collision of the Taconic arc.

As we examine the stratigraphy that records the collision of the Taconic arc, consider how these concepts of stratigraphy, sedimentology, depositional environments, and tectonics can be presented to students of all ages. I hope that the different experiences of the trip participants will come out as a lively and informative session that will help us all to be more effective in presenting rocks to students.

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ROAD LOG

Road Log starts at the Intersection of Rt. 50 and Rt. 5N on Mohawk Ave in downtown Scotia.

0.0	**0.0**	Continue westbound on Mohawk Ave through Scotia.
5.5	**5.5**	Canal Park and Lock 9 to the left.
7.6	**0.0**	Turn Right at Hoffmans on Wolf Hollow Rd.
8.25	**0.0**	Bear left and continue on Wolf Hollow Rd. Note historic sign telling of the displacement on the Wolf Hollow Fault.
8.4	**0.0**	Pull off to the left at sharp curve in the road - use caution because it is difficult to see oncoming traffic. Stop 1 (optional).

STOP 1: Hoffmans Fault

In Wolf Hollow a high-angle normal fault cuts the Schenectady Formation and older rocks (Figure 1 and Figure 10). This fault, which trends about 030 (north-northeast) is one of a family of high-angle normal faults that were probably active in the Middle Ordovician. Most of these faults dip to the east and the eastern block is downdropped - some notable exceptions occur farther to the west at the "Noses" (Figure 1). At this site one can see slightly tilted rocks of the Schenectady Formation (interbedded sandstone and shale) on the east side of the road. On the west side of the road are exposures of the Beekmantown Group - these are especially easy to see when the leaves are off the trees. Not visible from here are also exposures of the Trenton limestones and the Utica Shale, both resting above the Beekmantown Group. Using stratigraphic mismatch we can determine the apparent throw on the fault. Although the sign at the entrance to Wolf Hollow states that the fault has 1000 feet of displacement, is difficult to calculate the exact displacement because there are no clear stratigraphic markers in the Schenectady Formation. (See Locality 19 in Fisher, 1980). Using simple cross sections and reasonable stratigraphic thicknesses for these units, the apparent displacement is somewhere between 200 and 400 meters.

		Continue north on Wolf Hollow Road. Note the excellent exposures of the Schenectady Formation on the east side of the road along the entire length of the Hollow.
9.75	**0.0**	West Glenville Road - note exposures of the very fossiliferous Trenton Group limestones (Glens Falls Limestone) on the left (west) side of the road). Continue straight.
13.3	**0.0**	Rt 67. Turn left (west).
15.5	**0.0**	Several outcrops of carbonates of the Beekmantown Group (Wolf Hollow Limestone which is Lower Ordovician) along the right (north) side of the road.
17.0	**0.0**	Pulloff in small overgrown drive on left side of road to old abandoned quarry. This is private property. Please call Cranesville Block Company (518-346-5749) for permission to enter the "Manny's Corner quarry". See Figure 10.

STOP 2A: Quarry at Manny's Corner - Beekmantown , Black River, Trenton groups

In this quarry, the Cambrian to Lower Ordovician Beekmantown Group is disconformably overlain by Middle Ordovician carbonates of the Black River and Trenton Groups (see Locality 17 of Fisher, 1980). The floor of the quarry is composed of the Lower Ordovician Wolf Hollow Member of the Tribes Hill Formation. The Tribes Hill Formation is one of the upper units in the Beekmantown Group, a widespread and relatively uniform sequence of carbonates and dolomites found throughout eastern North America (for other stops in this unit see Friedman, 1972). Note that this unit is dolomitic, has algal mounds, and is replete with a single species of gastropod (*Ecculiomphalus*). The walls and nearby outcrops (north side of Rt. 67) are composed of the Lowville Limestone, the Amsterdam Limestone, and the Glens Falls Limestone (~Larrabee Limestone and the overlying Shoreham Limestone) all of which belong to the Black River Group and the Trenton Group (see Fisher, 1965; 1977). At this exposure, the unconformity between the Beekmantown Group and the overlying Middle Ordovician rocks is well displayed, and regional stratigraphic studies indicate that the upper part of the Beekmantown Group (the Lower Ordovician part) is missing. The Lowville Limestone is generally not fossiliferous, but it contains birdseye texture, a few vertical burrows, and mudcracks; locally it is dolomitic. The Amsterdam Limestone is irregularily bedded and the contact between the two units is marked by the first fossiliferous beds. These thin beds are very fossiliferous, with brachiopods, rugose coral, crinoids, and trilobites dominating the fauna. As you examine the outcrop from bottom to top, note the distribution of coral.

For students in *Stratigraphy and depositional environments of New York,* this project involves measuring a short (10 m) stratigraphic section, in which they describe the fossil content of the units, and interpret the depositional environments of these shallow marine rocks. As we will see, the interpretation of the depositional environments is aided by carefully noting the sedimentary structures and faunal content of each rock unit. After examining the rock we will have a brief discussion about relative sea level changes and the role of tectonic activity. The change in faunal content upsection indicates deepening through time and most students use their newly acquired knowledge concerning sea level changes and basin subsidence to explain this apparent transgression. As we will discuss, the deepening in the stratigraphic section may be related to tectonic subsidence. The goal of this phase of the project is to relate depositional environments and the unconformity to regional or global events that might have produced this particular sequence.

Continue west on Rt 67.
17.1 0.0 Pull off on right side of road to prominent outcrops on north side of Rt.67.

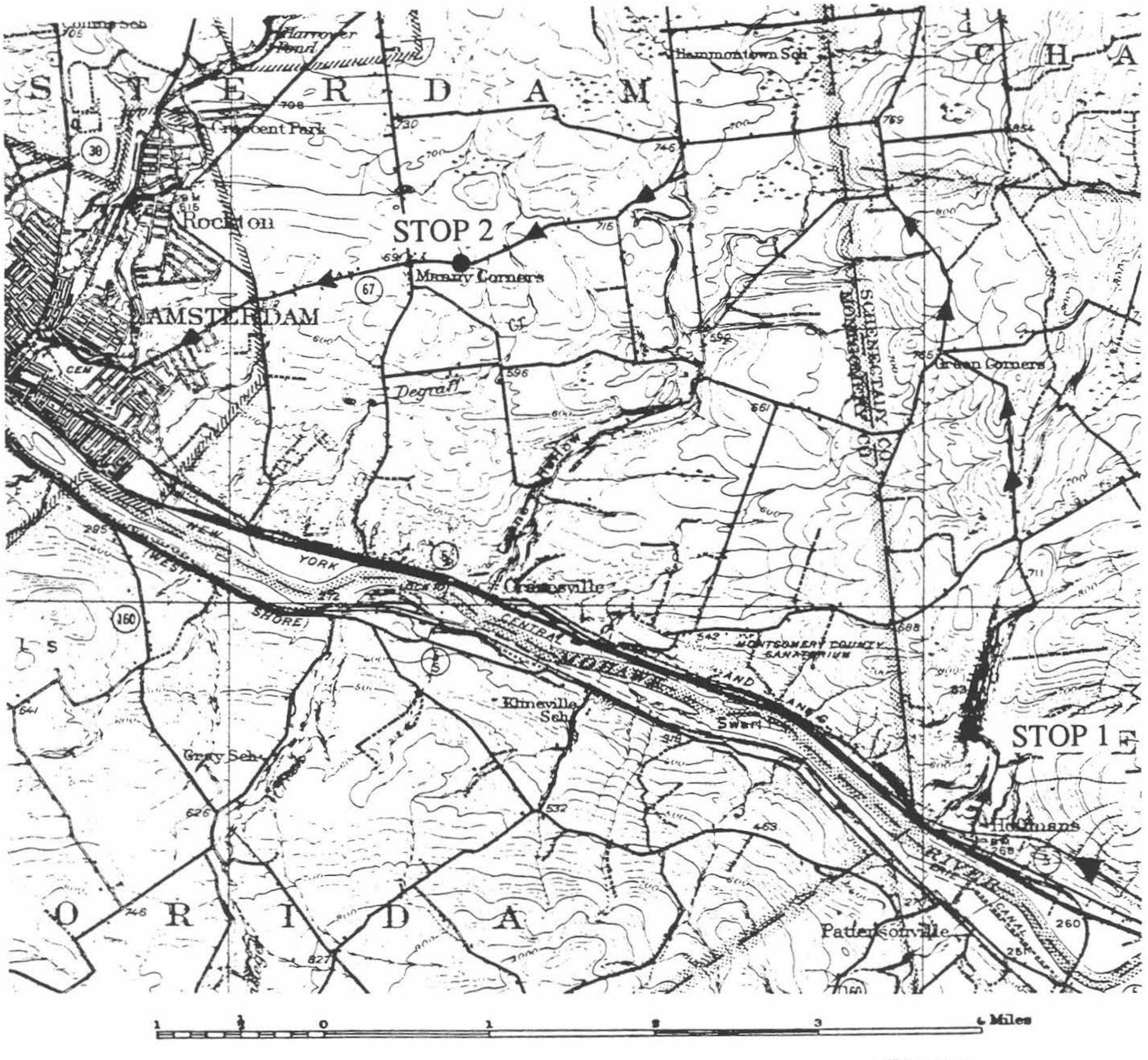

Figure 10: Topographic map showing the route and locations of Stop 1 (Wolf Hollow) and Stop 2 (Manny's Corners).

STOP 2B: Road cut across from Manny's Corner Quarry - Trenton Group Limestone

Exposed in the roadcuts along the nroth side of Rt. 67 are excellent exposures of the extremely fossiliferous Glens Falls Limestone. Note that these beds contain fossiliferous limestone (locally with scoured bases and graded beds) with interbedded calcareous shale which is also fossiliferous.

These rocks are replete with fossils; brachiopods, bryozoans, trilobites, crinoids, and others. Of particular note are two rather distinct trilobites. A small trilobite, *Cryptolithus tesselatus*, is common in the resistant limestone beds - they are typically the size of a fingernail. A much larger trilobite, *Isotelus gigas*, is common (unfortunately as fragments) in both the limestone bed and the calcareous shale. These are important index fossils. As we will see at Canajoharie Creek, geologists generally use fossils for either biostratigraphy or for reconstructing depositional environments. The concepts of biostratigraphic analysis are fundamental and are the basic tenet of the science of stratigraphy. As organisms evolve through time they change and new species eventually become extinct. By carefully studying the vertical distribution of distinct and common species, paleontologists have been able to determine fossil zones that are defined by the occurrence of a particular index fossil(s). *Cryptolithus tesselatus* is an index fossil for these beds. As we move upsection we will no longer see this fossil because it had become extinct. The distribution of index fossils and other more common and long ranging fossils is very closely related to depositional environments. (Good index fossils are found in many depositional environments). Some fossils can be used to determine the relative water depth. In the Mohawk Valley there have been very detailed studies of fossils with respect to water depth (see Cisnee and Chandlee, 1982; Cisne et al., 1982). As we will discuss at the outcrop, the assemblage of fossils in this outcrop suggests deeper water than does the assemblage in the underlying Amsterdam Limestone. Additionally, the occurrence of fine-grained calcareous shale suggests deposition below the normal wave base (the effective depth to which fairweather waves affect the bottom sediments). In this regard the stratigraphic section is deeper than that at the quarry. A deepening trend such as this is referred to as a transgression.

		Continue west on Rt 67.
18.35	**0.0**	Enter the town of Amsterdam
19.2	**0.0**	Intersection - Stay on Rt. 67 by veering slightly to the right.
19.95	**0.0**	(small public park [to left] with very nice exposures of the dolostone of the Beekmantown Group.)
20.0	**0.0**	Left to Rt. 30 south, follow signs to Interstate 90.
21.0	**0.0**	Left lane entrance to Toll Plaza for Interstate 90. Take I-90 west to Utica, Buffalo, etc. While merging (at about 21.3), note the exceptional exposures of the Utica Shale across the interstate in the exit ramp for the eastbound traffic.
32.0	**0.0**	Excellent exposure of limestones of the Middle Ordovician Trenton Group in the opposite lane. Above this exposure (on Rt. 5S) is the conformably overlying Utica shale. At the far end of the road cut on I-90, the uppermost beds of the Beekmantown group are exposed. Once again, the Knox unconformity separates the Trenton Group and the Beekmantown Group.
35.6	**0.0**	Cross the Noses fault (see Figure 10). This fault belongs to the family of normal faults that cut Middle Ordovician and older rocks in the Mohawk Valley, and is therefore similar in timing to the Hoffmans Fault. This fault and others to the west bound an upthrown block (horst) that exposes some of the oldest rocks in the Mohawk Valley. Note that this horst was probably a topographic high during the Middle Ordovician - as can be seen from the regional geologic map (Figure 1), the Trenton Group was not deposited on this block. Elevation of the horst above sea level may explain this distribution of rock units.
35.8	**0.0**	Across I-90 and along the barely visible Rt 5S are prominent exposures of the Precambrian Basement and the unconformably overlying rocks of the Beekmantown Group. The contact between these rocks, which can be seen along Rt 5S, shows evidence of structural disruption, and the interpretation of the contact is complicated by this disruption. The Precambrian rocks are provisionally assigned to the Peck Lake Formation, which is a garnet biotite gneiss about 1.1 Ga (billion years old). Although this contact may be faulted, in this area the Beekmantown Group is known to unconformably overly the Precambrian Basement. For a discussion of this area see Locality 12 in Fisher, 1980.
37.3	**0.0**	For about 0.5 miles there are very steep cliffs of the Upper Cambrian Little Falls Dolostone on the left (south) side of I-90. This unit, which is part of the Beekmantown Group, is stratigraphically lower than all of the ofther exposures of the Beekmantown Group that we will see on this trip. In places this unit has vugs containing doubly terminated quartz crystals locally known as the "Herkimer Diamond".
41.0	**0.0**	Take Exit 29 - Canajoharie/Sharon Springs, Rt. 10. Pay toll ($0.65 in 1995).

41.9	**0.0**	Right on 5S, enter town of Canojaharie.
42.0	**0.0**	Left onto Mitchell Street.
42.1	**0.0**	Cross Montgomery Street obliquely (slightly to left) and continue on Moyer St.
42.45	**0.0**	Turn right onto Floral Ave. (Opposite Barclay St.). Proceed to end.
42.6	**0.0**	Park at end of Floral Ave in dirt parking lot at the end of the street. Walk toward river and take foot path upriver for several hundred meters. Stop 3.

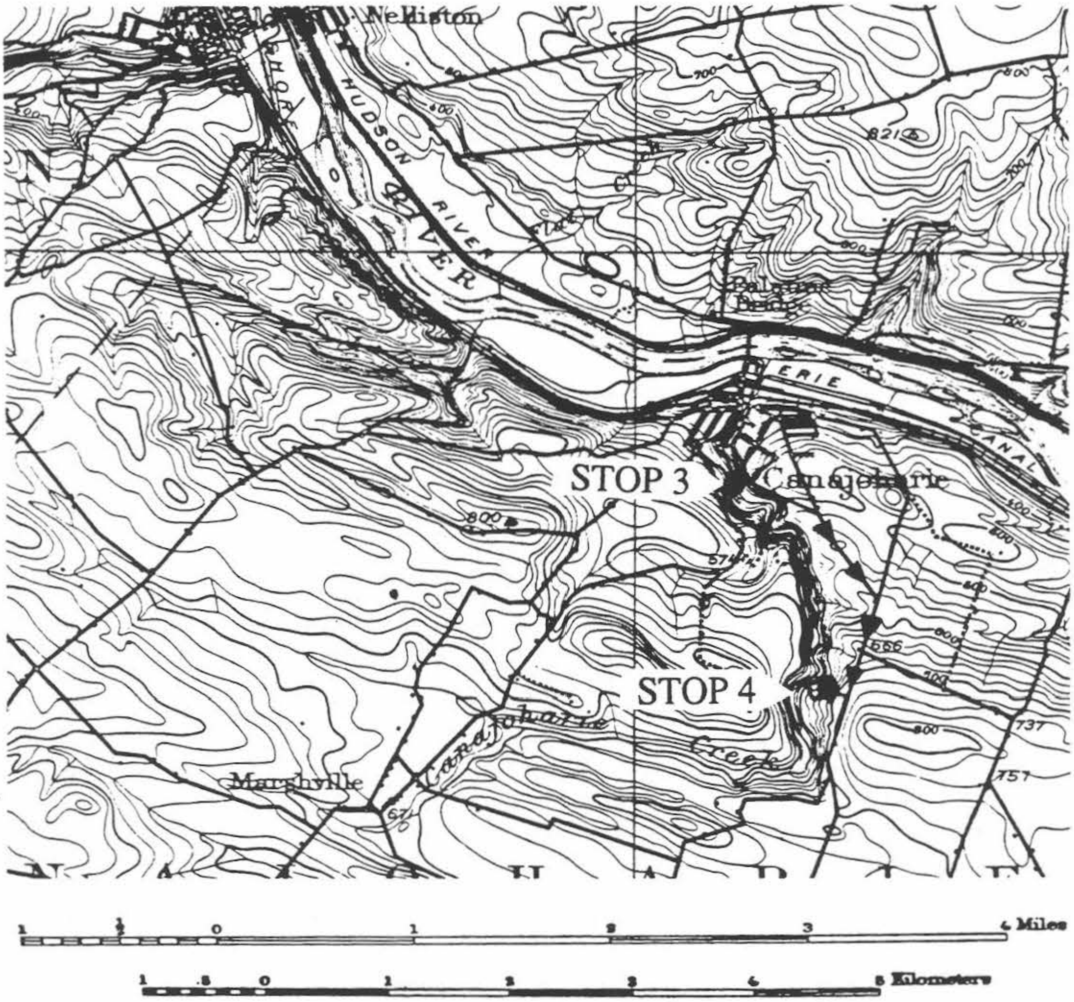

Figure 11: Topographic map showing the route and locations of Stop 3 (Canajoharie Creek on Floral Ave) and Stop 4 (Wintergreen Park).

STOP 3: Canajoharie Creek (Floral Avenue) - Beekmantown , Black River, Trenton groups

Similar to the exposures at Manny's Corners, limestone and shale of the Trenton Group disconformably overlie dolostone of the upper part of the Beekmantown Group in the river bed of Canajoharie Creek. This well-exposed and very fossiliferous stratigraphic section records important changes in the depositional history of the Mohawk Valley. Rocks in the Canajoharie Creek river bed include the Chuctanunda Creek Dolostone, which is part of the Beekmantown Group, and the disconformably overlying limestone and shale of the Trenton Group. Interbedded limestone and shale of the "lower Trenton Group" is conformably overlain by the Utica Shale, which is some 305 meters thick at this locality. All rocks of the Trenton Group were deposited during the Trentonian stage of the Middle- Late Ordovician (*circa* 448-458 Ma) and the rocks of the Chuctanunda Creek member of the Tribes Hill Formation were deposited during the Gascondian stage of the Early Ordovician (*circa* 505-488 Ma).

		Return to vehicles and drive down Floral Ave to Moyer St.
42.8	**0.0**	Turn right on Moyer St.
43.8	**0.0**	Veer right on Carlise St.
44.0	**0.0**	Keep right (straight) on Old Sharon Road.
44.1	**0.0**	Turn right into the entrance of Wintergreen Park.
44.2	**0.0**	Park at entrance gate in pulloff to the right. Walk down the park road to the Canajoharie Creek bed to exceptional exposures of the Middle Ordovician Utica Shale. (See Figure 11.)

STOP 4: Canajoharie Creek (Wintergreen Park) - Utica Shale

The second stop, which is near the top of the Utica Shale, can be accessed from Wintergreen Park (only open during the summer but it is possible to visit this locality yearround). Here the Utica Shale is a black, laminated and locally fossiliferous shale with minor thin (generally < 2-5 cm) seams of light gray and rusty weathering bentonite. The bentonites can be recognized easily because orange-red rusty streaks emanate from them. The rusty streaks are caused by the oxidation of pyrite which is common in the bentonitic seams. We will walk downstream to examine a fossiliferous section containing the trilobites *Triarthus* and *Isotelus*, as well as brachiopods and graptolites. Locally, very large nautiloids can be found in this outcrop. For pioneering work on the Utica shale (slightly to the west) see Kay, 1953.

The changes in depositional environments and basin geometry during the deposition of these rocks are well recorded in both the stratigraphy and lateral and vertical distribution of fossils. As you can imagine, individual organisms (fossils) preferred different depositional settings and therefore they commonly are found in only certain facies. For example, a thick-shelled pelecypod may inhabit a high-energy niche in the shoreface while a thin-shelled brachiopod may have found its niche in a deep-water environment. Once preserved in the geologic record, these individuals may serve as useful indicators of the energy level or water depth during deposition of a particular unit. In addition, the distribution of such fossils may provide important information concerning the original configuration and deepening trends within a basin of deposition. (see Cisnee and Chandlee, 1982; Cisne et al., 1982). From the enormous database collected by John Cisne and his co-workers, Ray Gildner has developed a Hypercard stack (Macintosh-based) that shows the distribution and occurrence of 10,000 fossils in the database. In essence, one can see the places where an individual fossil was observed in many stratigraphic sections. The distribution of two depth-sensitive individuals are shown in Figure 5. Here you can see that the distributions of *Triarthus* and *Cerarus* are very different; *Triarthus* is restricted to the eastern (deeper) sections and *Cerarus* is present only in the western (shallower) sections. From this we can see that the basin deepens to the west.

The occurrence of the bentonite is extremely important (Figure 5). Bentonite is commonly interpreted to represent volcanic ash. Therefore not only can these thin beds serve as chronostratigraphic markers (one bed is the same age everywhere), but they can also tell us that volcanic activity occurred nearby. Although the stratigraphy records this dramatic subsidence, this volcanic ash is the first direct sample of the Taconic arc to the east.

		Return to vehicles and drive out of park and retrace the route to I-90.
44.3	**0.0**	Turn left to Old Sharon Road
45.2	**0.0**	Turn left to Moyer St.
46.0	**0.0**	Cut obliquely across (left) Montgomery St. to Mitchell
46.1	**0.0**	Turn right onto Rt 5S.
46.2	**0.0**	Turn left to I-90 entrance. Get ticket and proceed on I-90 eastbound (Albany)
50.2	**0.0**	Again the Little Falls Dolostone is exposed to the right (south), but here you can also see a well exposed outcrop of the Precambrian basement across the Mohawk river on Rt. 5N. This exposure is also provisionally assigned to the Peck Lake Formation (circa 1.1 Ga) and is intruded by a dark-weathering basaltic dike that has been dated at about 700 Ma (see locality 12 in Fisher, 1980). Dikes of about this age are common in the Adirondacks.
55.8	**0.0**	Exposure of Trenton Group resting unconformably on the Beekmantown Group. Look closely because the unconformity is at the very beginning of the outcrop (west side).
72.2	**0.0**	Exposures of the Beekmantown Group on the right.
72.6	**0.0**	Cross the approximate trace of the Wolf Hollow Fault.
75.5	**0.0**	Excellent exposures of interbedded medium- to thin-bedded sandstones and shale of the Middle Ordovician Schenectady Formation. If observed from a distance, this turbidite sequence shows low-angle truncations that probably represent channeling on a submarine fan.
76.2	**0.0**	Exposures of the Middle Ordovician Schenectady Formation.

77.2	**0.0**	Exit at Exit 26 - Schenectady, I-890. Pay toll ($1.00 in 1995). Continue on I-890 east.
80.3	**0.0**	Take Exit 2 (Rt. 337 - Campbell Road).
80.4	**0.0**	Turn right on Rt. 337 south.
80.9	**0.0**	Turn right on Putnam Road.
82.7	**0.0**	Turn right on Rt. 159.
85.0	**0.0**	Turn right into the entrance/parking lot of the Plotterkill preserve. This is the Schenectady County Nature and Historic Preserve. Follow the Red trail (Figure 13) to the top of the waterfalls at the confluence of Rynex Creek and Plotterkill Creek. Stop 5.

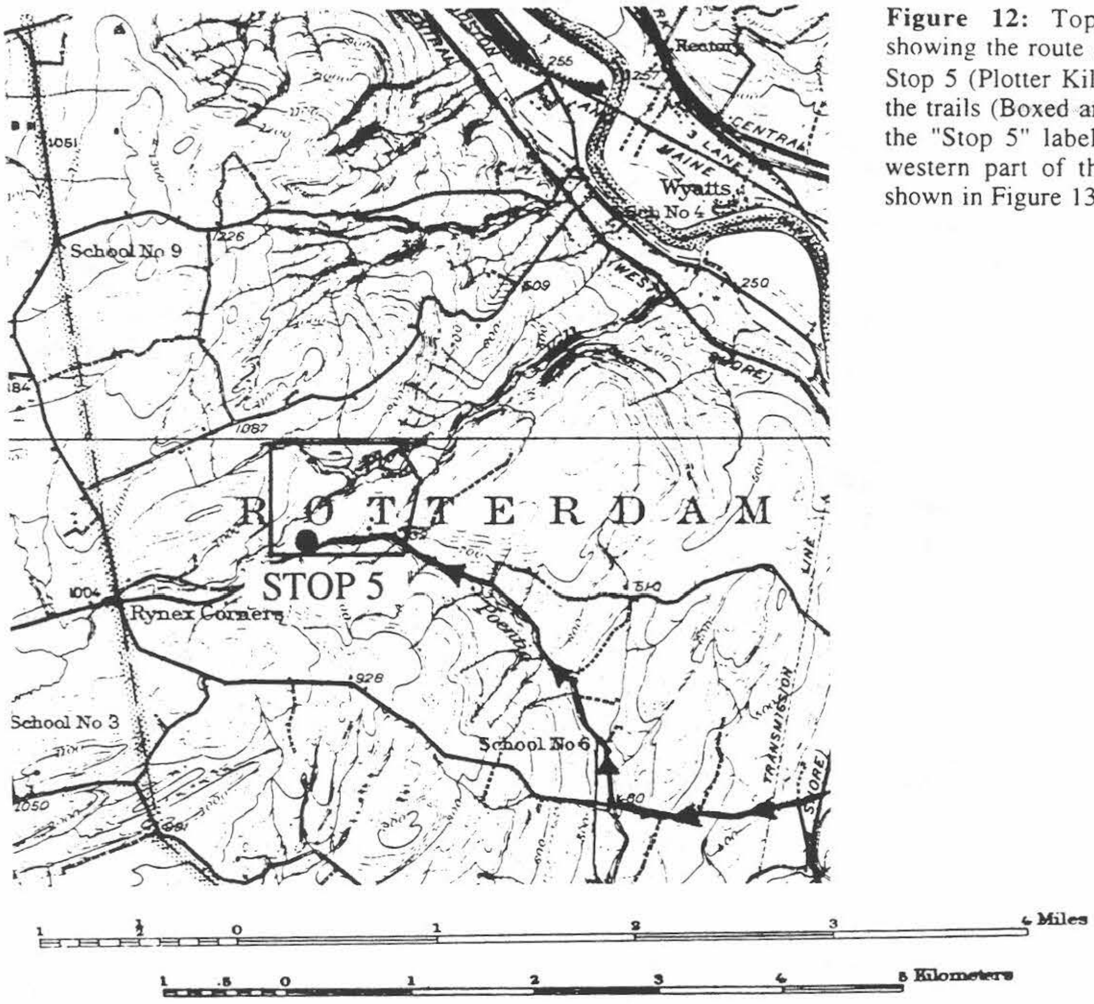

Figure 12: Topographic map showing the route and locations of Stop 5 (Plotter Kill). Location of the trails (Boxed area just north of the "Stop 5" label) in the south-western part of the Preserve are shown in Figure 13.

STOP 5: Plotterkill Preserve - Schenectady Formation

The Plotterkill Preserve is a private preserve that surrounds the lower reaches of the Plotterkill stream which drains north into the Mohawk River (Figure 12 and 13). The stream cuts into and beautifully exposes sandstone and shale of the Middle Ordovician Schenectady Formation (see Locality 30 in Fisher, 1980). The Schenectady Formation is Mohawkian in age (upper Middle Ordovician). Most of the formation (and the Utica Shale) is restricted to the Nowadagan stage but the lower beds belong to the Canajoharian stage (i.e., the top of the Mohawkian). In general the Schenectady Formation is composed of interbedded light-brown- to buff-weathering, medium- to fine-grained sandstone with interbedded gray to black laminated shale. The sandstones are laminated and rippled and locally graded. They commonly have flutes and grooves on their bases and ripples on the tops. The unit is virtually unfossiliferous with exception of uncommon graptolites. These sandstones are interpreted to have been deposited in very deep water and to have been transported to the site of deposition by turbidity currents.

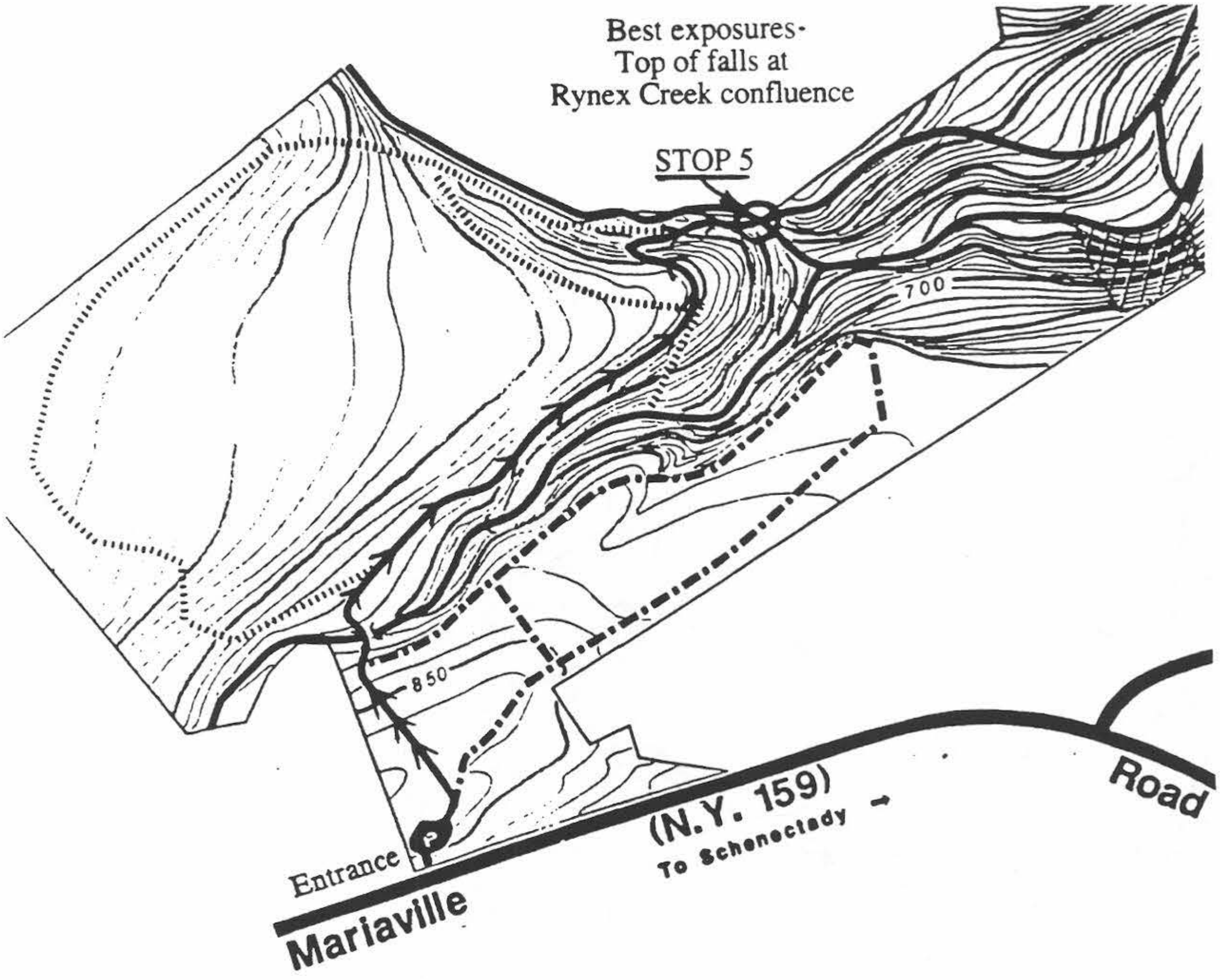

Figure 13: Trail map showing the route of the Red Trail which leads one to the confluence of Rynex Creek and Plotterkill Creek.

Although many geologists accept the notion that the clastic material had a source to the east, the paleocurrent data from this unit do not clearly support this contention. Using data collected from the Plotterkill Preserve and data from several other sites in the Mohawk Valley one can reconstruct the paleoflow directions within the basin during deposition. Virtually all of the pareocurents trend to the north-northeast. As exaplained above, these current directions may reflect sedimentation on a submarine fan that formed axial to the principal structural trend of the foreland basin.

For students in *Stratigraphy and depositional environments of New York,* this project involves measuring, plotting, and interpreting paleocurrents and relating this information to concepts of basin infilling. In the field, students spend several hours measuring flutes, grooves, and ripple marks from relatively flat-lying sandstone beds with a Brunton compass. Measurements are then entered into computer data files and plotted using Macintosh software. In addition to the data set collected by the students (all the data from different groups are merged), they are given two additional data sets from geographically separated outcrops of the same unit.

The Schenectady Formation has very good paleocurrent indicators - mainly flute and grooves. Virtually all of the paleocurrents in rocks of the Schenectady Formation in the Plotterkill preserve indicate flow from the southwest to the northeast (flow direction to about 020 to 030°) (see Figure 14). If these sediments were derived from the Taconic Arc to the east, then why do the ancient flow directions tell us that the sandstone flowed from the southwest? The answer lies in a possible interpretation concerning how turbidites flow in a basin and the shape of the basin. Turbidites flow downslope. If they encounter the deepest part of the basin, they tend to turn to flow along the basin axis as opposed to flowing upslope on the other side. In this regard, we recognize that foreland basins can develop two different types of submarine fans. The first, called a lateral fan, is composed of turbidites that accumulate directly off the edge of a large source terrain. In this case, all of the paleocurrents tend to record flow directly away from the source. The second, called an axial fan, records flow parallel to the source and possible parallel to the structures that influenced the source. This part of the Schenectady Formation was most likely deposited as an axial fan with a main feeder canyon somewhere to the south. It is interesting to note that the average paleocurrent direction in the Schenectady Formation is perpendicular to the direction of tectonic transport (thrusting direction) in the western Taconics (about 290 to 300° as determined at five localities). If thrusting in the Taconics was related to basin formation, then one would predict a foreland basin with a trough-like axis oriented at about 020-030° - exactly the orientation of the paleocurrents. A similar trend in sediment dispersal was recognized in correlative rocks in Pennsylvania, where the sandstones of the Martinsburg Formation indicate basin infilling by both lateral and axial submarine fans (McBride, 1962).

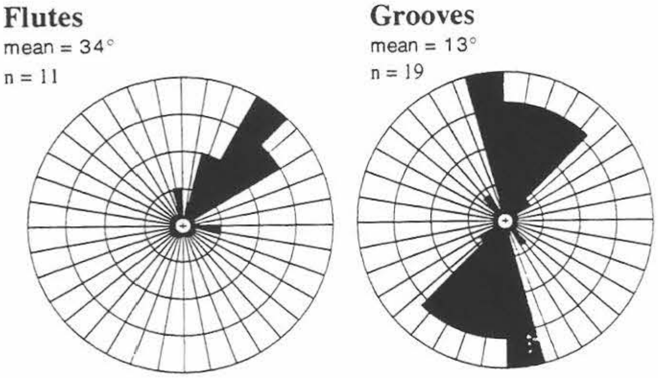

Figure 14: Paleocurrents from the Schenectady Formation in the Plotterkill Preserve (Stop 5). These polar histograms (or Rose diagrams) show the results of measurements taken in 1994 by the "Stratigraphy and depositional environments of New York" class at Union College. The diagrams can be read like a compass with north directly to the top, and east at 90°, etc. The flutes have a mean orientation of 34°, the grooves have a mean orientation of 13°; and together, if plotted all as bi-directional current indicators, they have a weighted mean of about 21°. From these data we can infer that the turbidites of the Schenectady Formation in the Plotterkill Preserve, were transported to the north-northeast. As discussed in the text, this orientation is inferred to be axial within a foreland basin.

In this area, the Schenectady Formation is underlain by the Utica Shale (i.e. Wintergreen Park), and together their thickness is nearly 1000 to 1800 meters. This shale/sandstone package thins gradually to the west and thickens dramatically to the front (east edge, near Troy) of the Taconic Range. The extreme thickness and the composition of these strata is an important sedimentation pattern. The thickness of strata preserved in a basin is generally a reflection of the relative depth or the amount of subsidence that occurred in the basin. This room for sediment is sometimes referred to as "accomodation space" because if there is not room for sediment (a basin), sediment tends to not accumulate. With this in mind, one could postulate that the basin was deepest, or experienced the most subsidence from here (Plotterkill) east to the Troy area where the unit thickens considerably. Shale that filled the basin has no obvious provenance or source area because the particles are so fine-grained. However, recent studies suggest that this shale reflects the changes in the composition of the thrust complex to the east (Garver et al., 1996). Sandstones contain coarse-clastic material that represents identifiable fragments of the source region. Because these and correlative sandstones have a distinct composition, workers have postulated that these sandstones had a source that lay to the east that was composed of mainly sedimentary rocks. Sandstones of the Schenectady Formation contain quartz, feldspar, and sedimentary rock fragments (with minor metamorphic and volcanic rock fragments), and a minor detrital mica.

The Schenectady Formation, therefore, was derived from the Taconic orogenic belt to the east - in this regard it is a synorogenic deposit. Paleocurrents indicate that the flow of sediment was to the north-northeast, which is exactly what we would predict if the structures presently preserved if the Taconic mountains produced a foreland basin. The sandstones and the shales were derived from the thrust complex and are therefore rich in sedimentary detritus and recycled grains - detritus directly from the Taconic arc is rare.

Exit parking area and retrace route. Turn left out of parking lot and follow Rt. 159 eastbound.
87.3 0.0 Turn left on Putnam Road.
89.0 0.0 Turn left on Rt. 337 north.
89.5 0.0 End of trip. Take I-890 east for Schenectady, Scotia, Albany and all points east (take take I-90 east at the end of I-890). Take I-890 west for all points west of Schenectady, exit I-890 at the I-90 interchange. To reach I-88 to Binghamton, take I-890 West, then take I-90 East and then exit for I-88 south.