LOWER AND MIDDLE DEVONIAN FORELAND BASIN FILL IN THE CATSKILL FRONT: STRATIGRAPHIC SYNTHESIS, SEQUENCE STRATIGRAPHY, AND THE ACADIAN OROGENY

CHARLES A. VER STRAETEN AND CARLTON E. BRETT
Department of Earth and Environmental Sciences
University of Rochester
Rochester, New York 14627

INTRODUCTION

Modern stratigraphic study has come to be increasingly based on high resolution subdivision of the sedimentary record through detailed event and cyclic analysis. The recognition and correlation of unique single event horizons (e.g., altered volcanic ashes, shell marker beds, faunal epiboles and immigration events) and genetically-related depositional sequences permits microstratigraphic subdivision of the rock record at a finer scale than is possible through classical methods of bio- and lithostratigraphy. "Layer cake" stratigraphy , once the bane of stratigraphic thought, has again emerged in modified form through the application of "Event" (Kauffman, 1988) and "Sequence Stratigraphic" (Van Wagoner et al., 1988) methods.

The construction of a refined microstratigraphic framework of strata permits detailed analysis of the timing and nature of events in the rock record. Short term dynamics in the history of a basin are recorded by: sharp transitions between intrabasinal and extrabasinal sedimentation; clustered volcanogenic strata; condensed beds and minor unconformities; abrupt changes in faunas and short-term incursions of exotic faunas; cyclic sedimentation; and eustatic- and tectonic-controlled changes in relative sea level. A detailed, correlatable framework of large and small scale events helps unravel the history of a sedimentary basin.

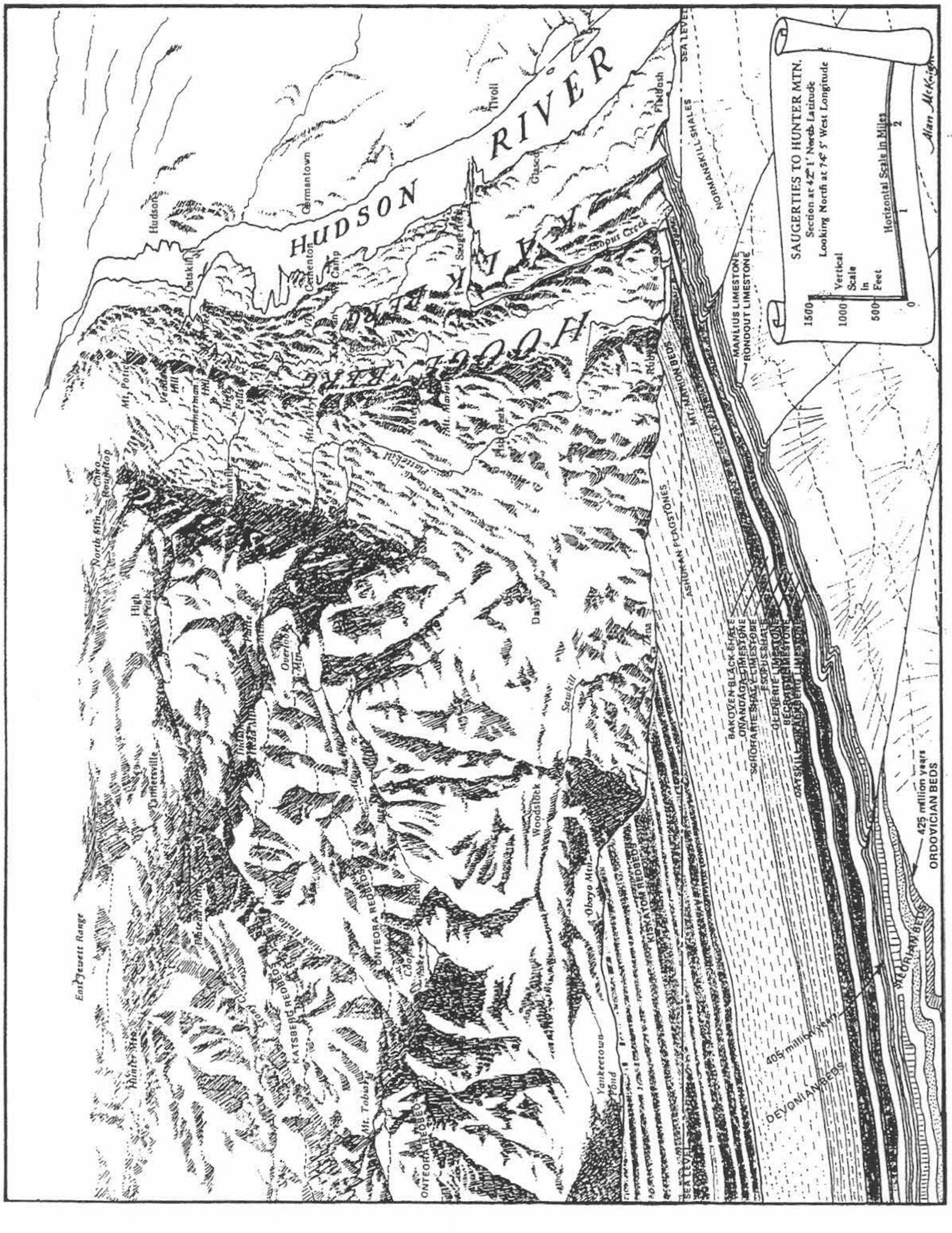
The late Early and Middle Devonian was a very dynamic time on the margin of the Eastern Interior of North America. A continent-continent collision, subsequent subsidence and infilling of an adjacent sedimentary foreland basin, and the evolution and migration of major faunas are recorded in the rocks of the Catskill Front in eastern New York State. The interaction of tectonically-induced flexure of the foreland basin and changes in eustatic sea level had a profound influence on the Northern Appalachian Basin at that time. Alternating tectonically active and quiescent stages of the Acadian Orogen (Acadian "Tectophases" of Ettensohn, 1985) resulted in major periodic alterations of subsidence and uplift, sedimentary style, faunas, and paleoecology. Superimposed over the tectonic influences are apparent changes in eustatic sea level (e.g., Johnson et al., 1985). As a result, the upper Lower and Middle Devonian foreland basin fill of New York is a complex succession of tabular to distinctly wedge-shaped bodies of carbonates and siliciclastics, shifting depocenters and basin centers, and marked unconformities.

This paper and field trip will examine the sedimentary record of the upper Lower and Middle Devonian rocks in the Catskill Front (see Figure 1). In addition to a review of member- and formation-level stratigraphy, the authors will present: 1) important new details and interpretations of strata of the Tristates Group, the Onondaga Formation, and the lower part of the Hamilton Group; 2 a discussion of the major and minor unconformities within the study interval; 3) the sequence stratigraphic framework for the upper Lower and Middle Devonian in New York State; and 4) stratigraphic trends and their implications for the evolution of the Northern Appalachian Basin and the Acadian Orogeny.

The Appalachian Basin and the Acadian Orogeny

The Appalachian Basin was a retroarc foreland basin that formed on the periphery of the eastern interior of North America associated with late Early to Late Paleozoic convergent margin tectonism (Quinlan and Beaumont, 1984). Collision of the Cambrian-Ordovician North American passive margin with an island arc in the Late Ordovician (Taconic Orogeny) resulted in formation of the Appalachian foreland basin. Relatively low-level tectonism throughout most of the middle to late Paleozoic Era was punctuated by large scale events, which include continent-continent collisions during the Devonian (Acadian Orogeny)

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. 313-356.


HUDSON RIVER
SAUGERTIES TO HUNTER MTN.
Section at 42° 1' North Latitude
Looking North at 74° 5' West Longitude
Vertical Scale in Feet
1500
1000
500
0
Horizontal Scale in Miles
1
2
NORMANSKILL SHALES
MANLIUS LIMESTONE
RONDOUT LIMESTONE
MT. MARION BEDS
ASHOKAN FLAGSTONES
DEVONIAN BEDS
405 million years
425 million years
ORDOVICIAN BEDS
ONTEORA REDBEDS
KATSBERG REDBEDS
Germantown
Tivoli
Woodstock
Saugerties

and Pennsylvanian (Alleghenian Orogeny). In each of these latter cases the Appalachian Basin was reorganized into a rapidly subsiding retroarc foreland basin into which synorogenic sediments were shed.

The Acadian Orogeny was the most significant event in the Devonian of eastern North America (Osberg et al., 1989; Roy and Skehan, 1993; Faill, 1985; Bradley, 1983). Collision of the North American landmass with a microcontinent or a series of terranes (Rast and Skehan, 1993; i.e., Avalon terrane) resulted in the formation of a large-scale mountain belt (referred to here as the Acadian Orogen) and renewed subsidence of the cratonward Appalachian foreland basin. Formation of a magmatic arc along the eastern margin of North America, best preserved in New England and Maritime Canada, was associated with major volcanism and plutonism, metamorphism, and deformation. Apparent southwestward migration of the orogeny through time (Rogers, 1967) is thought to have been associated with oblique convergence of Avalon with separate promontories on the eastern margin of North America with possible transpressional fault movement along a major system of dextral strike-slip faults (Williams and Hatcher, 1982; Ettensohn, 1985, 1987; Ferrill and Thomas, 1988). Alternating pulses of siliciclastic- and carbonate-dominated sedimentation in the adjacent Appalachian foreland basin indicate three to four active phases of Acadian tectonism occurred during the late Early Devonian to Early Mississippian (Tectophases I-IV of Ettensohn, 1985). Pulses of active tectonism, marked by overdeepening of the foreland basin and deposition of transgressive dark gray to black shales and volcaniclastic strata, alternate with periods of relative quiescence that are associated with regression, clastic progradation, and/or a return to more carbonate-dominated deposition.

Ettensohn (1985, 1987) proposed a model for the evolution of the Acadian Orogeny in eastern North America. Based on the stratigraphic record of the Appalachian foreland basin-fill, he projected three to four phases of active tectonism in the late Early Devonian to Early Mississippian associated with oblique convergence of the eastern margin of North America and a landmass termed Avalon. Successive collisions of Avalon with separate promontories in Quebec, New York, Virginia, and Alabama resulted in tectonic rejuvenation and the onset of separate "tectophases." Each of Ettensohn's tectophases is comprised of a progression from stages of active tectonism to quiescence, recorded in the rock strata by a succession of clastic- to carbonate-dominated deposition.

STRATIGRAPHY

Carbonate-dominated strata of the uppermost Silurian and lower part of the Lower Devonian (Rondout Formation and Helderberg Group respectively) are succeeded in eastern New York by a thick and complex interval of upper Lower and Middle Devonian siliciclastic and carbonate rocks. Strata of the Tristates Group (upper Lower Devonian) and the Onondaga Formation and Hamilton Group (Middle Devonian) are greater than a kilometer thick in the Catskill Front (see Figure 2) but thin to less than 25 m in parts of central New York. These rocks were subdivided by Rickard (1975) into five stages. These stages in ascending stratigraphic order are the Deerpark, Sawkill, Southwood, Cazenovian, and Tioghniogan Stages; the Sawkill and Southwood stages are referred to as the "Onesquethaw Stage" by some authors (e.g., Dennison, 1961, 1962; Inners, 1976). The overall vertical succession of rock consists of: (1) quartz arenites and carbonates (Oriskany, Glenerie, and Connelly Fms.), overlain by (2) siliciclastics (Esopus Formation), and mixed (3) siliciclastics and carbonates (Schoharie Formation). Overlying limestone of the Onondaga Formation is succeeded by thick, fine- to medium-grained, marine to non-marine clastic rocks of the Union Springs, Mount Marion, Ashokan, Plattekill, and overlying formations. The stratigraphy, lithology, biostratigraphy and fauna, and distribution of the individual units are discussed below.

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Figure 1. Physiographic map and cross-section of the Hudson Valley and Catskill Front, showing bedrock and relation to topography. Cross section at the southern boundaries of the Catskill and Kaaterskill quadrangles (Ulster Co.). Stratigraphic terminology of Figure 1 after Chadwick (1944); changes (from Rickard, 1975) include: Catskill Shaly=New Scotland; Kiskatom=Plattekill and Manorkill; Onteora=Oneonta; and Katsberg=Walton Formations. Onandaga=Onondaga. Note that the Mount Marion Formation includes most of the strata shown as Ashokan Formation. Original drawing by Alan McKnight.

Tristates Group: Deerpark Stage (Lower Devonian)

Oriskany Formation. The Oriskany Formation (Vanuxem, 1839) is the basal transgressive sandstone of Sloss' (1963) Kaskaskia Supersequence York. It overlies the Wallbridge Unconformity (Sloss, 1963), one of six major unconformities in the Phanerozoic of North America. The unit consists dominantly of mature quartz arenite that was deposited under relatively widespread, shallow-marine conditions across much of eastern North America (Boucot and Johnson, 1967). These shoreface to nearshore sandstones are characterized by abundant large, robust brachiopods ("Big-Shell Community" of Boucot and Johnson, 1967). The Oriskany Formation in New York ranges from 0 to < 3 m along the New York outcrop belt (Hodgson, 1970; up to ~30 m-thick in subsurface of Tioga Co., N.Y.; Rickard, 1989), and is up to 100 m-thick to the south in parts of Pennsylvania, Maryland, and West Virginia.

The Oriskany Sandstone sharply and unconformably overlies older Lower Devonian or Upper Silurian rocks along its outcrop belt in New York. The formation is thin in eastern New York and thin to absent in central New York, and is generally absent in the western part of the state. Locally, quartz sands of the Oriskany Formation fills fissures and karstic cavities in underlying carbonates (Brett and Ver Straeten, 1994). In eastern New York, the unit laterally grades into the Glenerie Limestone and Connelly Conglomerate (see below). The Oriskany Formation and equivalent strata are assigned to the *Icriodus huddlei* conodont zone and the *Costispirifer arenosus* subzone of the *Rensselaeria* brachiopod range zone (Lower Devonian; Klapper, 1981; Dutro, 1981). Previous work on the Oriskany Formation includes Hodgson (1970), Eaton (1921), and Oliver and Hecht (1994).

Glenerie Formation. The Glenerie Formation (Chadwick, 1908) represents limestone-dominated facies in eastern New York laterally equivalent to the Oriskany Sandstone. Siliceous to cherty limestones characterize the formation along its outcrop from southern Greene County (Catskill area; ~3 m-thick) southward through the Hudson Valley and to the Tristates area of New York, New Jersey, and Pennsylvania (~45 m-thick; Rickard, 1989). The formation extends in the subsurface across much of southeastern New York and northeastern Pennsylvania (Rickard 1989). In southern Greene County the base of the formation is marked by a phosphate pebble-rich lag immediately above the Wallbridge Unconformity. Southward (e.g., Kingston area), the basal-lag bed becomes quartz pebble-rich as the lower part of the Glenerie Limestone interfingers with the Connelly Conglomerate. In the Tristates area, the Glenerie Formation conformably overlies limestones of the Port Jervis Formation (Rickard, 1975).

The Glenerie Formation is generally richly fossiliferous; for example, ~100 species have been recorded from the Kingston area (Van Ingen and Clark, 1903), and Clarke (1900) reported 113 forms from a Devonian outlier across the Hudson River from Catskill. The fossils, which are commonly silicified, range from large, robust, Oriskany Sandstone-type brachiopods, to small, delicate forms that lived in more offshore facies represented by the Glenerie Limestone. Important references on the Glenerie Formation include Clarke (1900), Chadwick (1944), and Hodgson (1970).

Connelly Formation. The Connelly Formation (Chadwick, 1908) comprises quartz pebble-rich conglomerates in southeastern New York that are laterally equivalent to the Oriskany Sandstone. The unit crops out in the Kingston area (Ulster Co.), where it interfingers with lower strata of the Glenerie Limestone. The Connelly Conglomerate also occurs in the Skunnemunk Outlier, ~35 km southeast of the main outcrop belt in southeastern New York (Orange County; see below). In the outlier, the formation composes the entirety of the Oriskany interval, and has a maximum known thickness of 14 m (Boucot et al., 1970). Along the main outcrop belt in Ulster County, the unit is reported to range from 6.3 m (near Bloomington; Hodgson 1970) to a feather edge north of Kingston; in that area it unconformably overlies limestones of the Port Ewen Formation (Lower Devonian Helderberg Group). The fauna of the Connelly Formation is characterized by typical robust Oriskany brachiopods (Boucot, 1959). Previous studies of the Connelly Formation include Boucot (1959), Boucot et al. (1970), and most notably, Hodgson (1970).

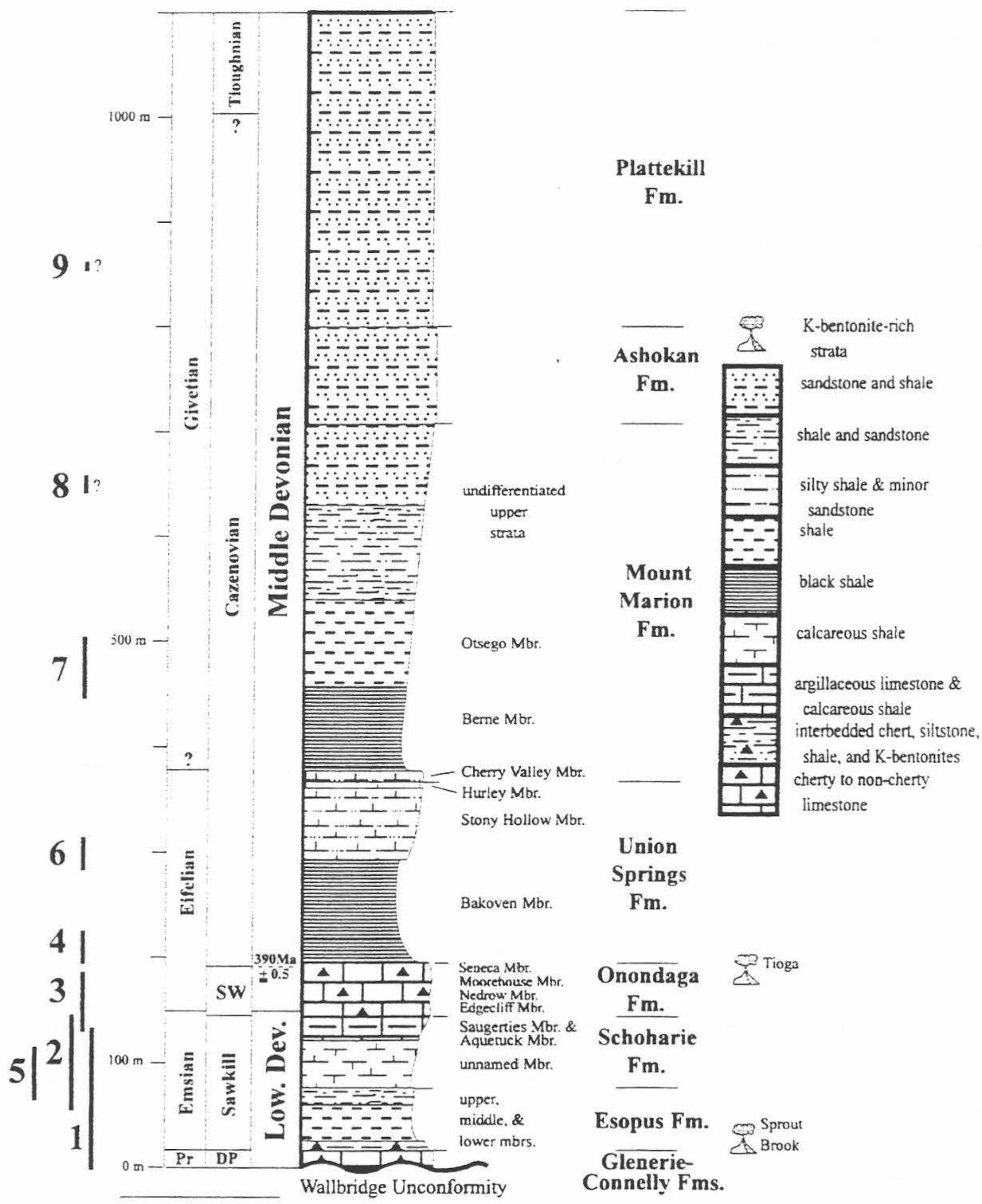

Figure 2. Composite section of upper Lower and Middle Devonian rocks in the vicinity of Kingston, N.Y. Bars on left side of diagram indicated intervals exposed at field trip stops 1-9. Absolute age of the "Tioga B" K-bentonite from Roden et al. (1990). Compiled from Ver Straeten (field notes), Rickard (1989), Hodgson (1970), Rehmer (1976), Feldman (1985), and Fletcher (1967).

Tristates Group: Sawkill Stage (Lower Devonian)

Esopus Formation. The Esopus Formation (Darton 1894; previously termed the "Cauda-galli Grit;" Vanuxem, 1842) of eastern New York, northern New Jersey, and eastern Pennsylvania is dominantly composed of dark gray shales and siltstones with lesser amounts of fine sandstone, chert, and K-bentonites. The formation crops out from east-central NY (Herkimer County) to eastern New York and southwestward into eastern Pennsylvania (Carbon Co.). The Esopus Shale is 0-100 m-thick along the outcrop belt (Rehmer, 1976), and is over 120 m in the subsurface (New York-Pennsylvania border area; Rickard 1989). Boucot et al. (1970) and Marintsch and Finks (1982) report as much as 185 m of Esopus in the Skunnemunk Outlier in southeastern New York (however, see Skunnemunk Outlier section below).

The Esopus Formation is generally unfossiliferous. Except for the Skunnemunk Outlier (see Boucot 1959; Boucot et al. 1970), the unit is typically barren, although it locally has a low-diversity macrofauna characterized by the brachiopod *Atlanticocoelia* (new genus, Koch in press; =*Pacificocoelia* of Boucot and Rehmer, 1977). The Esopus Formation is commonly extensively bioturbated, with common *Zoophycos* and/or *Chondrites* traces; Marintsch and Finks (1982) report over 16 different trace fossils from the Skunnemunk Outlier.

The biostratigraphy of the Esopus Formation is generally poorly documented; it is assigned to the *Etymothyris* brachiopod range zone (Lower Devonian; Dutro, 1981). Key references for the Esopus Formation include Rehmer (1976), Fenner (1971), Fenner and Hagner (1967), Boucot (1959), Boucot et al. (1970), Marintsch and Finks (1978, 1982).

Informal member-level stratigraphic schemes for the Esopus Formation have been proposed by several workers; Fenner and Hagner (1967), Fenner (1971), and Rehmer (1976) reported three subdivisions of the formation in the main outcrop belt. Boucot et al. (1970) proposed four members for the Esopus Formation in the Skunnemunk Outlier in Orange County. In each case the members were poorly delineated, most notably in the main outcrop belt. The authors herein propose a more rigorously defined member-level stratigraphy of three members for the Esopus Formation (main outcrop belt), informally termed the "lower, middle, and upper members."

The lower member of the Esopus Formation overlies the coeval Oriskany, Glenerie, and Connelly Formation along the New York State outcrop belt except in westernmost outcrops. Three subdivisions are recognizable in the lower member along the outcrop from Kingston to Cherry Valley: 1) a lower interval of interbedded siltstones, impure cherts, thin dark shales, and altered volcanic ash beds of the Sprout Brook Bentonites (see below); 2) a middle subunit of dark gray-black shales that commonly features large calcareo-phosphatic concretions; and 3) an upper siltstone to sandstone, generally 1-2 m-thick (to as thin as 0.1 m in western outcrops), with some fossils (including *Atlanticocoelia* and *Zoophycos*). Scattered glauconite has been noted in the upper subunit of the lower member.

These three subdivisions of the lower member of the Esopus are correlatable all along the main outcrop belt in New York (e.g., Kingston to Cherry Valley). Outcrops in the Hudson Valley range from 6-12.5 m in thickness. Along Rt. 23A near Catskill (Stop 2 of this fieldtrip) the lower member is 12.5 m-thick. The member thins in the northern Helderberg area, but thickens to the west. At Cherry Valley, the lower member (~4.3 m-thick) is represented by 3.6 m of interbedded siltstones, cherts, and k-bentonites that are overlain by rusty-weathering silty shales with scattered phosphatic grains (0.6 m). The upper siltstone-sandstone submember is represented by a thin (~10 cm-thick) siltstone bed. Overlying dark gray to purple and olive green shales and mudstones (1.7 m) at Cherry Valley represent lower strata of the middle member of the Esopus Formation.

The base of the middle member of the Esopus Shale is generally characterized by fine-grained, dark-gray to black shales and mudstones. The member grades upward through silty shales to a coarser cap of *Zoophycos*-churned argillaceous siltstones that immediately underlie the base of the upper member of the formation. Subtle-weathering dark and light bands can be noted on some outcrops; in general, however, the middle member appears massive and uniform.

Several workers including the authors (e.g., Inners 1975) have noted a distinctive interval of thinly laminated strata (>5m-thick) toward the upper part of the Esopus Formation between Kingston and Catskill. Near Catskill, the lower part of the interval consists of dark gray to black, rusty shales that pass upward into finely laminated ("pin-striped") shale-siltstone couplets. The upper part of the pinstriped unit in the Catskill area tends to be slightly coarser, and the thin siltstone to fine sandstone beds thicken and show planar to low-angle cross laminae. The upper part of the laminated unit in the Catskill area is also siliceous and resistant to weathering.

The stratigraphically highest rocks of the Esopus Formation consists of massive, gray to dark brownish gray siltstones to sandstones with pervasive, well-preserved *Zoophycos* spreiten. This unit abruptly overlies the laminated unit. The authors propose to place the base of the upper member at the bottom of the rusty shales in the lower part of the laminated unit, immediately above the previously noted *Zoophycos*-churned siltstone of the middle member. This places the base of each of the three members of the Esopus at a relatively abrupt transition to finer-grained strata (i.e., base of a sedimentary cycle) and, importantly, defines contacts that are distinct and recognizable in the field.

The authors' recent studies show that the laminated unit changes position with respect to the overlying contact with the Schoharie Formation. At Kingston (O'Reilly Street railroad cut, Stop #3 of Oliver et al., 1962) the top of the laminated unit lies 22.5 m below this contact. Thirty five km to the north, however, at Catskill (Rt. 23, Stop 1B of this fieldtrip) the laminated unit is directly overlain by the Schoharie Formation and the coarse, *Zoophycos*-churned sandstones that comprise the upper part of the upper member are absent. Twelve km farther north, near Climax, the laminated unit is also absent; basal strata of the Schoharie Formation overlie the *Zoophycos*-churned siltstone cap of the middle member of the Esopus Formation.

To the north and west across northern Greene County and Albany and Schoharie Counties the upper siltstone unit of the middle member forms the caprock of the Esopus Formation. At Cherry Valley (Otsego Co.; ~110 km along the outcrop belt) the upper siltstone unit is absent, and only the lower 1.7 m of the middle member remains. The middle and upper members are both absent west of Cherry Valley, and the Esopus Formation is represented by the lower member only. Twenty five km west of Cherry Valley (southwestern Herkimer Co.) the Esopus Formation pinches out (Rehmer, 1976).

Schoharie Formation. The Schoharie Formation (Vanuxem, 1840) comprises strata in eastern New York between the Esopus Shale and the overlying Onondaga Limestone. The Schoharie Formation is distributed across east-central to eastern New York, northwestern New Jersey, and eastern Pennsylvania. In eastern New York the strata generally consist of gray- to buff- weathering calcareous mudstones to argillaceous limestones; carbonate content increases upward through the formation. Three members are recognized in the Hudson Valley: 1) a lower unit of gray-weathering, bioturbated, calcareous silty mudstone to argillaceous limestone ("unnamed member" of this report = Carlisle Center Member of Johnsen, 1957, and Carlisle Center Formation of Rickard, 1975; see discussion below); 2) a middle unit of calcareous shale and nodular limestone, locally cherty/siliceous (Aquetuck Member); and 3) interbedded, buff- and cream-weathering, calcareous shales and limestones (Saugerties Member) that in the Hudson Valley grade upward into the Onondaga Limestone. A fourth member, recognized to the north in the Albany to Schoharie region, is composed of calcareous, quartz-rich sandstones (Rickard Hill Member). West of the Albany region undifferentiated Schoharie strata are herein assigned to the Carlisle Center Member (restricted; see below). Schoharie-equivalent strata in western New York are assigned to the Bois Blanc Formation; locally occurring, apparently equivalent strata in central New York have been termed the "Springvale Sandstone" (Baker, 1983; see Brett and Ver Straeten, 1994).

In outcrop, the Schoharie Formation and equivalent units range from zero to ~75 m between east-central New York and the Tristates area (Rickard, 1989); over 120 m of strata are reported from the subsurface of northeastern Pennsylvania (Rickard, 1989). The lower contact is generally abrupt, and is locally marked by glauconite, phosphate, and scattered quartz pebbles. The lower members exhibit low diversity/low density faunas that generally consist of ostracods (Fenner, 1971), small brachiopods, and dacryoconariids; upper strata of the formation are increasingly fossiliferous, especially the sandstones of the Rickard Hill Member;.

The Schoharie Formation is assigned to the *Eodevonaria arcuata* subzone of the *Amphigenia* brachiopod assemblage zone, the *Aemulophyllum exigum* coral assemblage zone, and questionably to the *serotinus* conodont zone (Lower Devonian; Dutro, 1981; Oliver and Sorauf, 1981; Klapper, 1981). References on the Schoharie Formation in New York include Johnsen (1957), Oliver et al. (1962), Inners (1975), and Goldring and Flower (1942).

An important aspect to the authors' new interpretations of the Esopus and Schoharie Formations is the recognition of a relatively cryptic, but substantial unconformity between the two units along the New

York outcrop belt (see below). This unconformity, which we term the "Sub-Schoharie unconformity" (="Pre-Upper Tristates unconformity" of Brett and Ver Straeten, 1994), was noted by previous workers as one of several glauconite- and phosphate-rich discontinuities in the lower part of the Schoharie Formation (Johnsen, 1957; Oliver et al., 1962). The authors herein informally propose a modification of the member-level terminology of Johnsen (1957) as outlined above.

Preliminary work on the Schoharie Formation in eastern to east-central New York suggests that strata previously termed the "Carlisle Center Member" in the Hudson Valley is not laterally equivalent to the Carlisle Center Member in its type area to the northwest (western Schoharie and Otsego Counties). Recent field study and recognition of the previously mentioned "Sub-Schoharie unconformity" suggests that the type Carlisle Center Member is equivalent to parts of the unnamed member, Aquetuck, and Saugerties Members of the Hudson Valley outcrop belt.

A part of Johnsen's (1957) reasoning for correlating strata of the type Carlisle Center Member with lower strata of the Schoharie Formation in the Hudson Valley was the apparent disappearance of the Aquetuck and Saugerties Members in the Albany area and west. Along NY Rt. 85 near Clarksville (Albany County) Johnsen (1957, p. 31-32) reported 6.1 m of "Carlisle Center" strata overlain by 0.9 m of richly fossiliferous, sand-dominated Rickard Hill Member. Restudy of the Rt. 85 outcrop, however, indicates that the lower unnamed member is present, but is much thinner than reported by Johnsen (1957). The Schoharie Formation there consists of: 1) 1.3 m of buff gray-weathering, bioturbated, calcareous, argillaceous siltstone (base of the member is covered at road level). A zone of chert nodules occur in the lower part of the unit, and scattered white quartz pebbles are found in the upper 0.5 m; 2) 4.7 m of increasingly calcareous silty to limestone-rich strata. The lower part of this unit (~2.6 m) consists of interbedded thin, silty, calcareous shales and bedded to nodular and knobby-bedded silty to argillaceous limestones. The strata are notably siliceous, and chert nodules occur in some beds. Strata above a 0.6 m-thick covered interval are characterized by interbedded calcareous shales and calcareous siltstone to limestone beds.; and 3) 0.86 m of richly fossiliferous calcareous quartz arenites of the Rickard Hill Member. The present authors interpret Unit 1 to be the lateral equivalent of the unnamed lower member of the Schoharie Formation of the Hudson Valley; the chert noted above may correlate with a distinctive black cherty bed reported from the unnamed member in the Hudson Valley (see below). Similarly, the white quartz pebbles appear to correlate with similar occurrences in the upper part of the unnamed member in the Catskill to Kingston region. The two subdivisions of Unit 2 appear to correspond to the Aquetuck and part of the Saugerties Members as they are developed in the Catskill vicinity and northward. Upper strata of the Saugerties Member is equivalent to the calcareous sandstone unit (Unit 3, Rickard Hill Member) that caps the Schoharie Formation in the Albany-Schoharie region.

The lower, unnamed member of the Schoharie Formation in the Hudson Valley is characterized by bioturbated, calcareous, silty shales and argillaceous siltstones. Basal strata of the unnamed member above the sub-Schoharie unconformity commonly feature abundant glauconite, phosphate pebbles, and scattered white quartz pebbles (see "unconformities" discussion below). A prominent dark siliceous band toward the center of the member ("black bed" of Oliver et al., 1962; ~0.6-1.0 m-thick) is correlatable throughout the Catskill to Kingston area, and may be recognized as far as Stroudsburg in eastern Pennsylvania (Inners, 1975). The unnamed member thickens southward through the Hudson Valley. At Catskill (Rt. 23, Stop 1 of this fieldtrip) it is 5.0 m-thick, but it is ~31.5 m-thick along N.Y. Rtes. 199/209 at Kingston (Stop 5 of this fieldtrip) and 43.75 m-thick in southwest Kingston, (O'Reilly Street railroad cut=Stop #3 of Oliver et al., 1962). The anomalous change in thickness toward the Kingston area is at present unknown, but may be associated with redeposition of upper Esopus sediments eroded from the north and northwest below the sub-Schoharie unconformity.

In the Catskill to Albany area, the overlying Aquetuck Member is characterized by fine-grained, dark gray- to buff-weathering cherty to siliceous shales with lesser carbonate. To the south, however, the siliceous aspect of the member disappears and the strata are more calcareous. One distinctive part of the member at Catskill is an interval of dark gray to buff siliceous shales 2.5-5.1 m above the base of the Aquetuck Member. These strata are represented by blocky-weathering, calcareous shales at Kingston (e.g., Rte 199-209) ~3-6 m above the base. This shaly interval in the lower part of the Aquetuck appears to be widespread, as it can be clearly distinguished in the middle of the Needmore Formation (submember 3 of the Hares Valley Member of Ver Straeten and Brett, in prep.) in central Pennsylvania. The same interval of dark gray to black shales is locally reported from the Needmore Formation of Virginia and West Virginia (upper tongue of Beaverdam black shale facies of Dennison, 1960, 1961).

West of the Albany area, strata equivalent to the Schoharie Formation are increasingly silt- to sand-dominated, as seen in the type Carlisle Center Member in east-central New York. At Cherry Valley (Otsego Co.), 5.9 m of the Esopus Formation (lower and lowest part of the middle members) are overlain by 13 m of *Zoophycos*-churned, glauconitic, medium-bedded to massive, quartz-rich calcareous siltstones of the Carlisle Center Member. The basal contact is very sharp and is marked by well-defined trace fossils (Miller and Rehmer, 1980; see below). The upper contact is placed at a deeply weathered, glauconite- and phosphate-rich clay layer interpreted to mark a pre-Edgecliff unconformity (Wolosz et al., 1991, p. 382-383; numerous abraided- and pristine-appearing zircons found in the clay layer by the present authors indicate the bed may be an impure K-bentonite layer). As noted above, the type Carlisle Center Member appears to be equivalent to parts of the unnamed member, Aquetuck, and Saugerties Members of the Hudson Valley outcrop belt.

Southwood Stage (Middle Devonian)

Onondaga Formation. The Onondaga Formation (originally "Cornitiferous Limestone" of Eaton, 1828) in eastern New York ranges from coarse crinoidal grainstones to fine-grained micritic limestones, with abundant chert and locally developed reef facies. Equivalent limestone-dominated facies occur widely across eastern North America, from the James Bay region of northern Ontario to southeastern Quebec and Maine to the Virginias to the Illinois Basin (Koch, 1981). Across New York, the Onondaga Limestone consists of four members (in ascending order): the Edgecliff, Nedrow, Moorehouse, and Seneca Members (Oliver, 1954, 1956). A fifth subdivision, the former Clarence Member (designation abandoned), is now recognized as a cherty facies of the Edgecliff Member (Brett and Ver Straeten, 1994). The lower subdivision, the Edgecliff Member is characterized by coarse crinoidal- and coral-rich to finer grained, chert-rich facies (Jamesville Quarry facies and Clarence facies, respectively; Brett and Ver Straeten, 1994). Biostromal to biohermal facies, including pinnacle reefs in the subsurface, are rooted in the lower part of the Edgecliff Member. In its type area, south of Syracuse, the overlying Nedrow Member is represented by calcareous shales and argillaceous limestones. In eastern New York, however, the Nedrow Member is characterized by argillaceous to fine-grained, generally non-cherty limestones that may be difficult to distinguish from underlying and overlying units. The third member (Moorehouse Member) is typified by chert-rich, fine to medium-grained limestones throughout New York State. The uppermost unit, the Seneca Member, features finer-grained, generally non-cherty limestones with thin shales and k-bentonite layers of the Tioga Bentonites cluster (see below). The Seneca Member is generally thin to absent in eastern New York (Rickard, 1975, 1989).

The Onondaga Limestone ranges in thickness from ~18-60 m in thickness across the outcrop belt in New York State; in the subsurface it may be as thin as 6 m (Rickard, 1989). The lower contact is disconformable across central to western New York, but is gradational with the underlying Schoharie Formation in the Hudson Valley outcrop belt in eastern New York.

The Middle Devonian Onondaga Formation is characterized by a diverse fauna dominated by brachiopods, bryozoans, corals, and echinoderm fragments, with additional trilobites, gastropods, and dacryoconariids. The lower part of the formation (Edgecliff Member) has abundant corals and echinoderms with local coral bioherms.

Biostratigraphically, Nedrow and questionably the Edgecliff Members are assigned to the *Polygnathus costatus patulus* conodont zone and the Moorehouse and Seneca Members to the *Polygnathus costatus costatus* zone (Klapper, 1981). The Edgecliff, Nedrow, and lower to middle parts of the Moorehouse Members occur within the *Fimbrispirifer divaricatus* subzone of the *Amphigenia* brachiopod assemblage zone (Dutro, 1981). The Nedrow Member in New York features the goniatite *Foordites buttsi* (House 1978, 1981). Oliver and Sorauf (1981) assign the Edgecliff Member to the *Synaptophyllum arundinaceum* subzone and the Nedrow and Moorehouse Members to the *Eridophyllum seriale* subzone of the *Acinophyllum segregatum* coral zone. The Seneca Member is assigned to the *Paraspirifer acuminatus* brachiopod assemblage zone and an unnamed coral zone (Dutro, 1981; Oliver and Sorauf, 1981). The Lower-Middle Devonian (Emsian-Eifelian) boundary is presently placed at or near the base of the Edgecliff Member, although, due to poor conodont control, it could occur as high as the base of the overlying Nedrow Member (Kirchgasser and Oliver, 1993).

The Onondaga Formation of New York has been the focus of numerous studies. Key works on the formation in eastern New York include Oliver (1956), Oliver et al. (1962), Lindemann (1979, 1980), Lindemann and Feldman (1987), and Feldman (1985). Recent field study augments this body of work and examines the regional relationships of Southwood-age strata in New York and Pennsylvania.

In the Catskill Front the Onondaga Formation is best exposed at the Saugerties exit of the New York State Thruway. A nearly complete section of the formation (50 m; Feldman, 1985) includes strata of the Edgecliff, Nedrow, and Moorehouse Members. The contact with the underlying Schoharie Formation (Saugerties Member is gradational. The lower 1.8 m and a thin interval 2.5-2.7 m above the base of the Onondaga Formation are relatively chert-free; the remainder of the Edgecliff Member (14.6 m total) features abundant layers of gray-weathering chert in fossiliferous pack- to wackestones.

The contact with the overlying Nedrow Member is marked by the disappearance of chert, an abundance of pyrite, and a thin shaly seam. Several distinctive and widely correlatable marker units found in the Nedrow in central to western New York and equivalent strata in Pennsylvania (see Brett and Ver Straeten, 1994) have been recognized by the authors at Saugerties. They include: 1) a thin clay parting 1.6 m above the base of the member (which possibly represents a thin K-bentonite layer) that may correlate with a similar bed in central New York; and 2) a subtle but distinctive darker interval 3.4-4.2 m above the base, also present at Kingston, that correlates with a pair of black shales at the top of the Nedrow Member in central New York and equivalent strata of the Selinsgrove Limestone throughout central Pennsylvania ("lower and upper black beds" of Brett and Ver Straeten, 1994).

The overlying Moorehouse Member at Saugerties has not as yet been examined in detail. Several key marker beds found in lower Moorehouse and correlative strata across New York and Pennsylvania are, however, recognized in the Thruway exposures. More detailed work on the Onondaga Formation at Saugerties is in process.

To the southwest, in eastern Pennsylvania, Onondaga-equivalent strata are represented by limestones of the Buttermilk Falls Formation. The four members of this formation (Inners, 1975; Epstein; 1984) are laterally equivalent to the Edgecliff, Nedrow, Moorehouse, and Seneca Members of the Onondaga Formation in New York. In general, the strata of the Buttermilk Falls Limestone is finer-grained than the Onondaga Formation of eastern New York State. A lower, crinoid rich, chert-rich unit with corals and a chert-free interval at its base is overlain by calcareous shales, similar to the Edgecliff and Nedrow Members in the central New York Finger Lakes region. Overlying limestones are characterized by dark chert (=Moorehouse Member). A prominent K-bentonite bed in the upper part of the formation is equivalent to the Tioga B-OIN bentonite that occurs at the base of the Seneca Member in New York. The Buttermilk Falls Formation is ~83 m-thick in the vicinity of its type section (East Stroudsburg, Monroe Co., eastern PA.). Lithologic and faunal trends throughout the Buttermilk Falls Limestone indicate that the Stroudsburg area represented deeper-water environments than eastern New York throughout its deposition. Lithologic and faunal trends clearly show that the Stroudsburg region was the basinward trough of carbonate-dominated ramps that extended from the Albany area in eastern New York and the Harrisburg vicinity of central Pennsylvania.

Hamilton Group: Cazenovian Stage (Middle Devonian)

Marcellus "subgroup." Relatively thin, black Marcellus shales above the Onondaga Limestone in western New York are the lateral equivalents of a thick, complex set of fine- to coarse-grained siliciclastics in eastern New York. These eastern strata, ~600 m in thickness (Rickard, 1989), range from basinal black shales that shallow upward to nearshore sandstones and alluvial-dominated brackish to freshwater continental environments. Recent work on these rocks show that this thick succession is separated into two separate subdivisions with distinct faunas, lithologies, and sea level histories. Recognition of these significant differences between the two units has lead to a revision of the Marcellus "Shale" (Hall, 1839) in New York (see Ver Straeten et al., 1994, in prep.) in which the Marcellus is raised to subgroup status, and the lower and upper subdivisions are assigned formational status. In this new stratigraphic scheme, the lower part of the Marcellus subgroup is termed the "Union Springs Formation". The upper subdivision is divided into two laterally-equivalent units, the "Mount Marion Formation" for the fine- to coarse-grained, progradational clastics in eastern New York, and the "Oatka Creek Formation" for black shale-dominated facies in western to central New York (see Ver Straeten et al., 1994 for more details). The contact of the Union Springs and

Mount Marion-Oatka Creek Formations lies at the base of the Cherry Valley Member across New York. Reasons for this stratigraphic revision include: 1) Recognition that lower and upper parts of the Marcellus subgroup each comprise a major sedimentary sequence, equivalent in stature to the other formations of the Hamilton Group (Skaneateles, Ludlowville, and Moscow Formations); 2) the lower part of the Marcellus subgroup features a unique fauna that is distinctly different from the overlying upper part of the subgroup and the remainder of the Hamilton Group.

Union Springs Formation. The Union Springs Formation (originally Union Springs "Member" of Cooper, 1930) marks the initiation of Middle Devonian clastic deposition in the Northern Appalachian Basin. Initial black shale-dominated strata (Bakoven Member) are generally in sharp contact with the underlying upper part of the Onondaga Formation; the contact is commonly marked by phosphate-rich fish bone beds. In eastern New York, the black shale facies of the Bakoven Member are overlain by buff- to dark gray-weathering, calcareous shales, siltstones, and sandstones of the Stony Hollow Member. The Union Springs Formation is capped across New York State by fossiliferous limestones and dark shales of the Hurley Member (Ver Straeten et al., 1994). The Union Springs Formation is best developed in southeastern New York (Hudson Valley, notably the Kingston area), where it is ~175 m-thick. The formation thins to the north and west and ranges from 10 m-thick to a feather edge across central to western New York. Union Springs strata are generally absent west of the Genesee River (Rochester area; for discussion see Rickard, 1984; Ver Straeten et al., 1994).

Barren to sparsely fossiliferous black shale-dominated facies of the Bakoven Member are characterized by pelagic to dysaerobic-type faunas dominated by dacryoconariids, nautiloid and goniatite cephalopods, and leiorhynchid brachiopods (Brower and Nye, 1991). More aerobic facies of the upper part of the formation (upper part of the Stony Hollow and the Hurley Members), however, feature a more diverse fauna, characterized by a unique assemblage of brachiopods, cephalopods, trilobites, corals, and crinoids. Elements of this fauna are associated with immigration of benthic forms dominantly from arctic Canada into the Appalachian, Michigan, Illinois, and Iowa Basins (Koch, 1978, 1988; Boucot, 1990; see Ver Straeten et al., 1994) and a global evolutionary event of pelagic cephalopods and dacryoconariids (Kacak-*otomari* Event; Truylos-Massoni et al., 1990; Chlupac and Kukal, 1986: Boucot, 1990; see Ver Straeten et al., 1994). This Union Springs fauna is very distinctive from both that of the underlying Onondaga Formation and the overlying remainder of the Hamilton Group. Key elements include the brachiopods *Variatrypa arctica*, *Warrenella*, *Kayserella*, and *Pentameralla*, the proetid trilobite *Dechenella haldemanni*, a rugose coral (*Guerichiphyllum*), and the microcrinoid *Haplocrinites*. Cephalopods of the Union Springs Formation associated with the global Kacak-*otomari* Event include *Cabrieroceras* and *Agoniatites nodiferous*. A detailed study of this fauna by A.J. Boucot and others is presently in progress.

The Bakoven Member is assigned to the *Tortodus kockelianus australis* conodont zone and the Hurley and questionably the Stony Hollow Members are placed within the *Tortodus kockelianus kockelianus* zone (Middle Devonian; Klapper, 1981). The Bakoven, Stony Hollow, and at least lower part of the Hurley Members feature *Cabrieroceras plebeiforme* goniatite faunas; the upper part of the Hurley Member (Lincoln Park submember) features *Agoniatites vanuxemi nodiferous* (House, 1978, 1981). The Union Springs Formation is not assigned a brachiopod zone at present, but recent study shows it features a unique fauna that is characterized by the brachiopod *Variatrypa arctica*. Key references for the Union Springs Formation in eastern New York include Goldring (1935, 1943), Chadwick (1944), Rickard (1952, 1985), Storm (1985), Griffing and Ver Straeten (1991), Griffing (1994), and Ver Straeten et al. (1994.

Griffing and Ver Straeten (1991) presented an initial detailed report of the lower part of the Marcellus subgroup in eastern New York. The subsequent revisions presented by Ver Straeten et al. (1994, in prep.) distinguish upper strata that Griffing and Ver Straeten (1991) retained in the Stony Hollow Member and assigns them to the new Hurley Member. Griffing and Ver Straeten also presented a series of key beds within strata now assigned to the Union Springs Formation. Two richly fossiliferous limestone dominated beds ("Proetid Units" of Griffing and Ver Straeten, 1991) with proetid trilobites occur in the upper part of the revised Union Springs formation in eastern New York. The higher bed, the "Upper Proetid Unit" of Griffing and Ver Straeten (1991) is now assigned to the Chestnut Street submember of the Hurley Member. It is separated from the overlying Cherry Valley Member by dark shales and minor sandstones of the Lincoln Park submember of the Hurley Member. The "Lower Proetid Unit" occurs in the upper part of the Stony Hollow Member, where it underlies a massive, resistant sandstone ("Massive

Sandstone Unit" of Griffing and Ver Straeten, 1991) that occurs immediately below the top of the Stony Hollow Member.

Mount Marion Formation. The upper part of the Marcellus subgroup in eastern New York is represented by the Mount Marion Formation and part or all of the overlying Ashokan Formation (Rickard, 1975). The Mount Marion Formation (Grabau, 1917, 1919) comprises a general coarsening-upward, progradational marine succession from basinal black shales to nearshore sandstones. The base of the formation, as redefined by Ver Straeten et al. (1994, ms. in prep.), is placed at the bottom of coeval limestones and calcareous sandstones of the Cherry Valley Member. Succeeding black to dark gray shales of the Berne Member are overlain by a prominent coral-rich unit (Halihan Hill Bed of Ver Straeten, 1994) at the base of the Otsego Member. Dark gray mudstones and thin sandstones of the lower and middle part of the Otsego Member grade upward into increasingly coarser, sand-dominated strata in the upper part of the formation. No member level subdivision has been proposed for the upper part of the formation beyond application of central New York terms (Solsville and Pecksport Members; see Wolff, 1967, 1969; Pedersen et al., 1976; Grasso and Wolff, 1977; Wolff and Buttner, 1979) which may or may not be correlative. In the Catskill Front the upper part of the Marcellus subgroup (= Mount Marion Fm. and all or part of Ashokan Fm.; Rickard, 1975) is reported to be in excess of 425 m (Rickard, 1989); equivalent strata of the Oatka Creek Formation (revised by Ver Straeten et al., 1994, ms. in prep.) in central to western New York thin to as little as 5 m (Ontario Co.; Rickard, 1989). Based on well log data from southwest of Catskill (Rickard, 1989, pl. 4) strata of the Mount Marion are probably in excess of 330 m-thick in the Catskill Front.

West of Albany, the Cherry Valley Member is composed of relatively fine-grained, bedded to nodular limestone, ~0.5 to 1.0 m in thickness. A pelagic fauna of cephalopods and dacryoconariids, as well as small brachiopods and small tabulate corals (auloporids) are characteristic of the unit (Griffing and Ver Straeten, 1991). South of Albany, however, the Cherry Valley Member becomes increasingly rich in terrigenous sand, and ranges up to 10 m in thickness (Griffing and Ver Straeten, 1991). Above the Cherry Valley, black to dark gray shales of the Berne Member are dominated by sparse, low diversity faunas of cephalopods, nuculid bivalves, and leiorhynchid brachiopods. The coral-rich Halihan Hill Bed (=base of Otsego Member) features a varied and highly diverse coral and brachiopod-dominated fauna (>70 forms) with abundant echinoderm debris. The overlying lower part of the Otsego Member is typified by low-diversity brachiopod assemblages that diversify upward into more mollusc-dominated faunas in the upper middle part of the formation. Diversity drops in the upper part of the formation; coarser, sand-dominated facies appear heavily bioturbated (*Zoophycos*) to laminar bedded (flagstone facies). Finer-grained facies in the upper part of the formation are dominated by low diversity *Mucrospirifer-Camarotoechia-Schizophoria-* (brachiopods) and bivalve-dominated faunas.

The Cherry Valley Member of the Mount Marion (and laterally equivalent Oatka Creek Formation) is placed within the *Tortodus kockelianus kockelianus* conodont zone and the *Agoniatites vanuxemi vanuxemi* goniatite zone (Middle Devonian: Klapper, 1981; House, 1978, 1981). Overlying strata of the Mount Marion Formation are assigned by Dutro (1981) to the *Mucrospirifer mucronatus* brachiopod assemblage zone and by Rickard (1975) to the *Mediospirifer audacualus* brachiopod zone; the formation lies within the *Tornoceras uniangulare* goniatite zone (House, 1981). Conodonts are not known from the formation. Oliver and Sorauf (1981) place the post-Cherry Valley strata of the formation in the *Heterophrentis ampla* coral zone. References for the Mount Marion Formation include Goldring (1943), Chadwick (1944), Wolff (1967, 1969), Pedersen et al. (1976), Grasso and Wolff (1977), Wolff and Buttner (1979), and Ver Straeten (1994).

Ashokan Formation. The Ashokan Formation (Grabau, 1917) marks the transition in eastern New York from marine to subaerial, fluvial-dominated deposition that characterizes the remainder of the Devonian in the Catskill Front. The formation consists of cyclic alternations of medium-grained subgraywacke sandstones and olive- to brown-weathering mudstones with dark gray shales. The Ashokan Formation is distinguished by the presence of channel-form sandstone bodies, the absence of normal-marine fossils, and the lack of continental redbeds. The sandstones appear cross-bedded to laminated and in the past were an important source of "bluestone" flagstones, utilized in building. Wolff (in Pederson et al., 1976) reports fluvially- and tidally-influenced sedimentary structures from the sandstones. Thickness of the unit ranges from ~150 m northwest of Kingston (type area) to a feather edge north of Catskill due to facies change with the overlying Plattekill Formation (Chadwick, 1944).

Fossils in the Ashokan Formation consist dominantly of plant material and ostracod and conchostracan crustaceans. The latter two forms are thought to be indicative of brackish water environments (Goldring, 1935) and occur through the overlying succession of fluvial-dominated environments (Chadwick, 1944, p. 120-121). Biostratigraphy of the formation is unknown. References on the Ashokan Formation include Chadwick (1944), Wolff (1969), and Pederson et al. (1976).

Hamilton Group: Upper Cazenovian-Tioghniogan Stages (Middle Devonian)

Plattekill Formation. The lowest Middle Devonian redbeds in the Catskill Front mark the base of the Plattekill Formation (Fletcher, 1962). The formation is composed dominantly of medium dark gray subgraywacke sandstones, siltstones, shales, and grayish-red shales, siltstones, and mudstones (Lucier, 1966). Fletcher (1964, 1967) and Lucier (1966) report a maximum thickness of 305 m in the Catskill Front, and subdivide the Plattekill Formation into two subdivisions, a lower unit (210 m-thick) dominated by medium dark gray shales, siltstones and sandstones with minor redbeds. The upper subdivision is almost entirely composed of grayish-red shales, siltstones, and claystones.

Willis and Bridge (1988) recognize two dominant facies for the Plattekill and overlying Manorkill Formations of the Catskill Front: 1) sandstone bodies, which represent channel bar deposits of aggrading, sinuous, migrating river channels; and 2) a sandstone-mudstone association, which was deposited over a low-relief alluvial plain during flood events. Bedding of the latter facies is generally obscured by bioturbation, desiccation cracks, and paleosol development.

Biostratigraphy of the non-marine Plattekill Formation is unknown. Key references for the formation include Chadwick (1933a, 1944; =lower part of his Kiskatom Fm.), Fletcher (1962, 1963, 1964, 1967), Lucier (1966), Willis and Bridge (1988), and Bridge and Willis (1994).

Overlying Middle and Late Devonian strata of the Catskill Front

Manorkill and Oneonta Formations. Subaerial, alluvial-dominated environments characterize the remainder of the Middle and Upper Devonian succession along the Catskill Front. Rocks of the overlying Manorkill and Oneonta Formations (including the Twilight Park Conglomerate) are, in general, similar to those of the Plattekill Formation but in general coarsen-upward, and have larger paleochannel sizes and thicker fluvial cycles (Willis and Bridge, 1988; Gordon and Bridge, 1987). These trends culminate in deposition of the Twilight Park Conglomerate, characterized by coarse pebble lithologies and thick sandstone bodies (Willis and Bridge, 1988; Bridge and Nickelsen, 1985). References for the post-Plattekill Middle and Upper Devonian strata of the Catskill Front include Chadwick (1933 a&b, 1944), Fletcher (1962, 1963, 1964, 1967), Lucier (1966), Bridge and Gordon (1985 a&b), Bridge and Nickelsen (1985), Bridge, Gordon, and Titus (1986), and Willis and Bridge (1988).

Strata of the Skunnemunk Outlier, Southeastern New York

Upper Lower and Middle Devonian strata also outcrop in an outlier ~35 km southeast of the main outcrop belt in Orange County, New York and northern New Jersey. The strata represent more shoreward equivalents to the strata in the Hudson Valley outcrop belt.

The Oriskany-equivalent Connelly Conglomerate lies at the base of the interval, where it sharply overlies sandstones of the Central Valley Formation (Lower Devonian Helderberg Group). Overlying dark mudstones, siltstones, and fine sandstones are assigned to the Esopus Formation. Four subdivisions of the Esopus Shale were recognized by Boucot et al. (1970) in the Skunnemunk Outlier; a lower siltstone (Mountainville Member), overlying dark-gray to black mudstones (Quarry Hill Member), fine sandstones and interbedded siltstones (Highland Mills Member), and an upper interval of black siltstones and mudstones (Eddyville Member). Overlying strata of the Pine Hill Formation (Boucot et al., 1970) consist of medium-bedded siltstones and fine sandstones (Woodbury Creek Member) and sandstones and conglomerates (Kanouse Member; Boucot et al., 1970). The Kanouse Member is shown by Kindle and Eidman (1955) and Boucot (1959, p. 734; pers. commun., 1995) to be laterally equivalent to the Middle Devonian Onondaga Formation of the main outcrop belt.

Boucot et al. (1970) reported four members of the Esopus in the Skunnemunk Outlier in southeastern New York. Lithological trends through their lower three members (Mountainville, Quarry Hill, and Highland Mills Members) mirror the relative coarser-finer-coarser trends of the lower, middle, and upper members proposed herein. The overlying fourth member (Eddyville Member) is finer-grained; this mirrors the trend in the main outcrop belt wherein strata of the lower part of the Schoharie Formation fine upward above the upper strata of the Esopus Formation. We herein project that Boucot et al.'s (1970) fourth member of the Esopus Formation in the Skunnemunk Outlier may represent lower strata of the Schoharie Formation (unnamed member) in the main outcrop belt. More work is needed to resolve this, however.

No limestone of Southwood (Onondaga)-age is reported in the Skunnemunk Outlier. The Onondaga Limestone is, at least in part, laterally replaced by quartz pebble conglomerates and quartz arenites of the Kanouse Member of the Pine Hill Formation (Boucot et al., 1970). The occurrence of large *Amphigenia elongata* brachiopods and the absence of smaller *Amphigenia*s indicate the member is equivalent to the Onondaga Formation of the main outcrop belt (Kindle and Eaton, 1955; Boucot, 1959; pers. commun, 1995). Interbedded conglomerates and sandstones in the lower part of the member fine upward into quartz-rich sandstones. Only the lower 7.6 m of the Kanouse Member is exposed in New York State (NYS Thruway at Highland Mills, Orange Co.); black shales of the Marcellus subgroup (Cornwall Formation) are exposed above a ~45 m-thick covered interval. The covered interval is not known from anywhere in the Skunnemunk Outlier.

The black Cornwall shales are overlain by offshore dark gray shales to nearshore and non-marine sandstone-dominated strata (Bellvale Formation). The top of the Devonian succession in the outlier (Skunnemunk Formation) is characterized by subaerially-deposited, conglomeratic fluvial-dominated facies. Thicknesses for the Cornwall, Bellvale, and Skunnemunk Formations range widely (~60-300 m;~300-900 m; and ~90-750 m, respectively; see Sulenski, 1969) No comprehensive stratigraphic study of the Hamilton Group of the Skunnemunk outlier has been reported (however, see Sulenski, 1969), and the member- and formation-level units of the Hudson Valley have not been recognized. Rickard (1975) however, correlates the Cornwall and Bellvale Formations with the Union Springs and Mount Marion Formations (terminology of this paper) and the Skunnemunk Conglomerate with the Plattekill and Manorkill Formations of the Catskill Front.

References for upper Lower and Middle Devonian strata of the Skunnemunk outlier include Kindle and Eidman (1955), Boucot (1959), Oliver et al. (1962), Finks (1968), Sulenski (1969), Boucot et al. (1970), and Marintsch and Finks (1982).

K-bentonites

Volcanic ash falls are a minor but very important part of the sedimentary rock record. Altered volcanic ash deposits of Paleozoic age, termed K-bentonites, can provide important information in a detailed basin analysis. K-bentonites represent isochronous deposits important to the stratigrapher and may yield absolute age dates for the timing of geological and biological events. Furthermore, they may represent the best record of ancient volcanism adjacent to deeply eroded mountain belts. They are a very important element in reconstructing the tectonics and evolution of an orogeny.

Two intervals of K-bentonite rich strata are known from the upper Lower and lower Middle Devonian rocks of the Northern Appalachian Basin. These strata represent multiple layers of altered volcanic ash that were erupted during Plinian-type volcanic eruptions in the adjacent magmatic arc of the Acadian Orogen. Dispersal of ash-laden clouds over the Appalachian foreland basin permitted deposition of water-lain ash beds that are generally thought to represent single eruptive events. Recognition and correlation of altered volcanic ash beds (K-bentonites of Paleozoic age) are key elements to detailed correlation of the foreland basin fill. Furthermore, they provide insights into paleovolcanism and orogenesis in the adjacent Acadian mountain belt.

Sprout Brook Bentonites (Esopus Formation). The lower member of the Esopus Formation is characterized by an interval of interbedded K-bentonites, cherts, siliceous siltstones, and dark shales. This recently discovered interval of altered volcanic ashes is termed the Sprout Brook Bentonites (Ver Straeten, 1992 a,b, in review; Ver Straeten et al., 1993). Up to 15 thin (mm-scale to ~15 cm-thick), tan-, green-, or gray-colored, soapy-feeling clay to claystone beds characterize the Sprout Brook Bentonites. The presence of euhedral zircons and apatites, diagnostic of volcanogenic strata, permit positive identification of the beds as altered volcanic ashes. The Sprout Brook Bentonites are best developed is New York State, but the interval is recognized across the Appalachian Basin through Pennsylvania into Maryland and the Virginias (Ver Straeten, 1992b, in review). They mark the transition from the shallow marine sandstones and limestones of the Oriskany-Glenerie-Connelly Formations and deeper, more basinal dark silty shales of the Esopus Formation.

Ver Straeten (in review) discusses potential volcanic sources for the Sprout Brook Bentonites in the Appalachian Mountains. One distinct possibility occurs 400-500 km to the northeast of the Hudson Valley in the Piscataquis volcanic belt of north-central to western Maine. Five volcanic centers in that region form a massive body of upper Lower Devonian pyroclastic ash flow tuffs. The largest of these deposits, the Traveler Rhyolite, has a estimated preserved volume of ~800 km^3 (Rankin and Hon, 1987). This is comparable in size to some of the larger Tertiary deposits in the western United States, which include the Timber Mountain and Paintbrush Tuffs of southwestern Nevada (900 km^3 and 1000 km^3 respectively) and the Lava Creek Tuff in the Yellowstone Caldera (1000 km^3; Christiansen, 1979, p. 31). Subadjacent to the Traveler Rhyolite is its comagmatic pluton, the Katahdin Granite, which has a surface area of ~1350 km^2 (Griscom, 1976). The upper Lower Devonian pyroclastic rocks of the Piscatiquis volcanic belt overlie shallow-marine sandstones of Oriskany age; marine rocks that overlie the pyroclastic rocks yield Schoharie-age marine faunas (Boucot, 1969). This large volume of Esopus-age pyroclastic source rocks and comagmatic plutons 400-500 km northeast of the Northern Appalachian Basin (Ver Straeten, in review) may have been the source area for the Sprout Brook Bentonites.

Tioga Bentonites (Onondaga Formation). The Tioga Bentonites (*sensu* Way et al., 1986) mark a second interval of Devonian pyroclastic-rich strata above the Wallbridge Unconformity. They have been the focus of numerous studies since their initial discovery in the 1940s (Fettke in Ebright et al., 1949; Fettke, 1952; Dennison, 1960, 1961; Dennison and Textoris, 1970, 1978, 1987; Conkin and Conkin, 1979, 1984; Way et al., 1986; Brett and Ver Straeten, 1994). The source area for the Tioga Bentonites is projected by Dennison and Textoris (1978) to be in the region of Fredericksburg in northeastern Virginia, ~500 km south-southwest of the Catskill Front.

Ten or more thin clay to claystone layers, which may feature abundant biotite grains (in addition to zircons and apatites), occur widely in the upper part of the Onondaga Formation and equivalent strata across eastern North America (Conkin and Conkin, 1979, 1984; Way et al., 1986; Brett and Ver Straeten, 1994). Brett and Ver Straeten (1994) discuss the Tioga Bentonites in New York State and the relationship to their occurrence in Pennsylvania, where they have recently been the focus of detailed work (Smith and Way, 1983; Way et al., 1986). The authors recognize ~eight Tioga beds in the Seneca Member and base of the Union Springs Formation in west-central to western New York. Additional thin K-bentonite beds occur in the underlying Moorehouse, Nedrow, and possibly the Edgecliff Members. Very prominent K-bentonites occur at the base of the Seneca Member (Onondaga Indian Nation Ash [OIN] of Conkin and Conkin 1979, 1984; Conkin, 1987; = Tioga B of Way et al., 1986) and at the base of the overlying Union Springs Formation (=Tioga F of Way et al. 1986) in west-central to western New York.

The Tioga Bentonites in eastern New York State are poorly developed and relatively undocumented. This is in part due to the progressive eastward bevelling of upper Onondaga strata, where most of the bentonites occur (Rickard, 1975, 1989 reports the Seneca Member as absent in the Albany area). Furthermore, outcrops of the upper part of the Onondaga Limestone are rare south of the Albany region, where the Seneca Member reappears and thickens into eastern Pennsylvania. The bentonites do not appear to pass laterally into the lower part of the overlying black shale of the Bakoven Member as projected by previous authors (Oliver, 1954; Rickard, 1975). Instead, they appear to be cutout at a submarine unconformity at the top of the Onondaga in eastern New York (Rickard, 1984; Ver Straeten et al., 1994). However, recent work has shown that thin Tioga Bentonites occur in the upper part of the Onondaga Formation in the Hudson Valley and the Helderberg Escarpment near Albany.

The authors have found two altered volcanic ash beds in the upper 2-3 m and at the top of the Onondaga on the Helderberg Escarpment southeast of Albany. Both K-bentonites are on the order of 8-10 cm-thick and have visible micas. Either bed could potentially be the Tioga B-OIN bed that occurs at the base of the Seneca Member from Cherry Valley to the west. However, the Tioga B-OIN bentonite is consistently on the order of 20-25 cm-thick. On the other hand, the beds may also correlate to thinner bentonites in the upper part of the Moorehouse Member to the west.

At Catskill (Stop 4 of this trip) a thin (~2 cm-thick) K-bentonite is present 0.3 m below the top of the Onondaga, in strata that Rickard (1989) considers to be the Seneca Member. This bed, similar to the layers on the Helderberg Escarpment, cannot be correlated into central New York at this time. Conkin and Conkin (1984) reported the Tioga F bed (=their "Tioga restricted" bed, designation abandoned) at the Onondaga-Marcellus contact at Stop 4. The authors, however, have not found any K-bentonite layer at the contact.

Unconformities In Upper Lower and Lower Middle Devonian Rocks, Eastern New York State

Unconformities are surfaces of erosion and/or non-deposition that mark significant breaks in the stratigraphic record. They occur within a sedimentary basin at different temporal and geographical scales, and may be of subaerial or submarine origin (Shanmugan, 1988). Their recognition is a crucial part of integrated basinal studies and are important to the stratigrapher for interpreting changes in relative sea level, defining depositional sequences, determining the timing of tectonic activity and flexure of the basin, and predicting the occurrence of economic deposits.

At least nine unconformities, listed below, of varying scales of magnitude and geographic distribution occur in upper Lower to Middle Devonian rocks of eastern New York State. In addition, some relatively conformable successions in the eastern part of the state may laterally be represented by unconformities.

1. Wallbridge Unconformity. The Wallbridge Unconformity is one of six major unconformities that bound six Phanerozoic supersequences of North America (Sloss, 1963). It marks the boundary between Sloss' Tippecanoe and Kaskaskia Supersequences. In eastern New York, the unconformity represents a relatively short part of the Lower Devonian; in the Tristates area of New York, Pennsylvania, and New Jersey the rock record is continuous, and no unconformity is recorded. Westward, across New York and toward the craton, missing time represented by the unconformity increases; in central to west-central New York, the entire Lower Devonian is absent, and Middle Devonian rocks overlie Upper Silurian strata.

In the Hudson Valley, the unconformity is marked by a quartz- to phosphate-pebble rich bed at the base of the Glenerie Formation (Stops 1A & 2). Upper strata of the Helderberg Group and the basal unit of the Tristates Group are progressively chopped out below the unconformity northward along the outcrop belt (for discussion of the Wallbridge Unconformity in central to western New York, see Brett and Ver Straeten, 1994, p. 248-250).

2. Basal Esopus Unconformity. A relatively minor unconformity occurs at the base of the Esopus Formation along its outcrop in eastern New York. Rehmer (1976, p. 68) reports that the basal contact is "everywhere abrupt and disconformable." No significant lag deposit has been noted at this position; the break is generally marked by the change from underlying quartz arenites or limestones into shales, siltstones, and cherts. To the south and southwest, however, the base of the Esopus is indicated by a sharp lithologic change from quartz arenites or quartz pebble conglomerates to shales (e.g., Skunnemunk Outlier, New York; eastern Pennsylvania).

3. Sub-Schoharie Unconformity (=Pre-Upper Tristates Unconformity of Brett and Ver Straeten, 1994). A depositional break between the Esopus and Schoharie formations was recorded by Johnsen (1957) and Oliver et al. (1962), who reported glauconite and scattered quartz pebbles at the contact in the Hudson Valley (see Rickard, 1975). The magnitude of this subtle but important unconformity was not previously recognized. As noted above, upper strata of the Esopus Formation are progressively truncated below the unconformity northward of Kingston (Stop 5). A lag deposit of glauconite, scattered quartz pebbles, phosphate pebbles, and fish bone material at Catskill (Stop 1) sharply overlies the thinly laminated interval in the upper Esopus that occurs 22.5 m below the contact at Kingston.

Further evidence of the erosive nature of this unconformity is shown along U.S. Rt. 20 at Cherry Valley (Otsego Co.) in east-central New York. Very finely-detailed trace fossils (e.g., *Cruziana*, *Fustiglyphus*, and scratch markings) are present on the base of the Carlisle Center Member (restricted) at Cherry Valley (Miller and Rehmer, 1982). The preservation of detailed scratch marks and individual trilobite appendage traces were interpreted to have been produced in semi-consolidated muds previous to deposition of the overlying glauconitic and pebbly sands of the Carlisle Center Member. Miller and Rehmer interpreted the break to represent a short depositional hiatus. A similar occurrence of "delicately sculpted" trilobite appendage traces and "remainie sediments" in the Middle Devonian of Ontario (Landing and Brett, 1987), however, clearly showed that preservation of the traces was directly related to excavation of disconformity-related, pre-compacted mud-firmgrounds at a major cycle boundary.

West of Cherry Valley the sub-Schoharie unconformity erosively cuts down through the middle member and then bevels away the entire Esopus Formation. It is possible that westward cutout of Esopus strata may in part be due to uplift of a peripheral bulge in central to western New York during Acadian Tectophase I/upper Tristates time. Its occurrence as far southeast as Kingston, however, appears to indicate some degree of eustatic influence is also involved. The unconformity, marked by a shell-rich fish bone and phosphate pebble lag bed, is also found at the correlative position in the lower part of the "calcareous shale member" (middle member) of the Needmore Formation in central Pennsylvania (e.g., Newton Hamilton, Mifflin Co., PA; Ver Straeten and Brett, in prep.).

4. Sub-Aquetuck Unconformity. The widespread occurrence of glauconite and scattered quartz pebbles at the contact of the unnamed and Aquetuck Members of the Schoharie Formation between Kingston (Ulster Co.) and Clarksville (Albany Co.) marks a relatively minor break in deposition (visible at Stop 1B).

5. Sub-Edgecliff Unconformity. The Schoharie-Onondaga contact across eastern New York is relatively conformable and represents a shallowing- to deepening-upward transition (Stops 1 and 3A & B). Across central to western New York, however, this unconformity represents a major break in deposition that locally becomes amalgamated with the pre-Schoharie and Wallbridge Unconformities (see Brett and Ver Straeten, 1994). In part, the unconformity in central to western New York is associated with an uplifted peripheral bulge from Acadian Tectophase 1 (Brett and Ver Straeten, 1994). The widespread transition from shallowing- to deepening upward in equivalent strata across the Appalachian Basin (Ver Straeten and Brett, 1994 a,b; Brett and Ver Straeten, 1994; Ver Straeten and Brett in prep.) appears to indicate that the unconformity is also related to a fall and rise in eustatic sea level.

6. Sub-Nedrow Unconformity. A subtle depositional break is recorded at the contact between the Edgecliff and Nedrow Members of the Onondaga Formation. This is generally indicated by a lithologic break from medium- to fine-grained limestones to more argillaceous strata, especially in central New York. Glauconite and pyritic nodules are found locally associated with the contact; pyritic crusts are also known to occur on the contact.

7. Onondaga-Union Springs Formational Contact. The contact of the Onondaga and Union Springs Formations represents a significant regional unconformity in New York State (e.g., Stop 4 of this trip). The contact is commonly marked by lag deposits of corrasion-resistant fish bone material and teeth and/or phosphate pebbles. The unconformity is shown to be older to the northeast by the cutout of upper Onondaga strata (Seneca Member) from the central Finger Lakes region and eastern Pennsylvania toward the Albany area (Rickard 1989). Along the New York outcrop Seneca Member strata are progressively cut out from the top as shown by the eastward absence of marker beds (bentonites, distinctive shell beds, etc.) toward the Albany area. Ver Straeten et al. (1994) recently discussed the Onondaga-Union Springs Unconformity in New York. It may be interesting to note that the contact across Pennsylvania is relatively conformable; sediment supply is presumed to have been more continuous in that area at that time.

8. Pre-Cherry Valley Unconformity. Across central to western New York the base of the Cherry Valley Member unconformably cuts downward through upper strata of the underlying Union Springs Formation, and generally lies directly on a resistant limestone ledge of the Hurley Member (Chestnut Street submember); south of Rochester, this erosional unconformity locally (at outcrop scale; see Ver Straeten et al., 1994, p. 293-294) cuts down through the Hurley and Bakoven Members to nearly rest directly upon the top of the Onondaga Formation. In eastern New York, however, the succession between upper strata of the Union Springs Formation (Hurley Member) and the base of the Cherry Valley Member is relatively conformable.

9. Top of Cherry Valley Unconformity. Similar to the previous horizon, this unconformity is poorly developed across eastern New York State. Across central to western New York it becomes more prominent, and southwest of Rochester it cuts out the entire Union Springs Formation and the Cherry Valley Member; lower strata of the Oatka Creek Formation in westernmost New York lie directly upon limestones of the Onondaga Formation.

DISCUSSION

Sequence Stratigraphy, upper Lower and Middle Devonian

The application of sequence stratigraphic methods to sedimentary basin studies provides a powerful tool for the analysis of time-rock relationships. It permits chronostratigraphic subdivision of the rock record into cyclic, unconformity-bound, genetically related successions of strata (Van Wagoner et al., 1988). A "depositional sequence" is the fundamental, meso-scale unit of sequence stratigraphy. A sequence is a coherent package of strata that is bound at bottom and top by unconformities or their correlative conformities (Mitchum et al., 1977). It is formed by a cyclic change in relative sea level through the interaction of tectonics, eustatic sea level change, and sedimentologic factors (Allen and Allen, 1990). A sequence can be subdivided into "systems tracts," composed of smaller scale cycles ("parasequences"), and are deposited during different stages of a transgressive-regressive cycle. Three systems tracts are recognized within a sequence: 1) A "Lowstand Systems Tract" at the base of a cycle, which consists of progradational to aggradational strata deposited during a fall to early rise in relative sea level. The lowstand systems tract of a sequence is not always well preserved; 2) a "Transgressive Systems Tract," which is deposited during a rapid rise in relative sea level. This results in onlap of sea level and sedimentation onto the basal unconformity of a sequence; depositional is retrogradational. Condensed sections are common within the transgressive systems tract and the lower part of the overlying highstand systems tract; 3) "Highstand Systems Tract" forms during the late stage of a rise to the early stage of a fall in relative sea level, which results in deposition of aggradational, sediment-starved to progradational strata. The base of highstand deposits occur associated with a "surface of maximum starvation" that may be marked by a smaller scale, submarine unconformity during a period of extreme sediment starvation.

Detailed field studies of upper Lower and Middle Devonian strata in New York and Pennsylvania indicate that the succession is composed of at least nine depositional sequences (see left side of Figures 3 and 4). Each sequence is bounded by basal unconformities or their correlative conformities at the base of the transgressive systems tract (e.g., unconformities 1,3,5 and 8 of the previous section); as noted by Brett and Baird (in press), the lowstand systems tract of the sequences are rarely preserved. Lesser unconformities may form at the base of the highstand systems tract (e.g., unconformities 2, 4, 6, 7, and 9 of the previous section. All strata discussed in this paper are part of Sloss's (1963) Kaskaskia Supersequence. The basal unconformity of DS1 represents the Wallbridge Unconformity-supersequence boundary.

Depositional Sequence 1. DS1 is composed of strata of the coeval Oriskany-Glenerie-Connelly Formations and the overlying Esopus Formation of New York State. The basal bounding surface of the sequence is the Wallbridge Unconformity (#1 of previous section). The lowstand systems tract of DS1 is not preserved, except potentially in the Tristates area near Port Jervis. The transgressive systems tract consists of the Oriskany Sandstone and its equivalents; it may also include in part lower strata of the Esopus Formation. The surface of maximum flooding may occur at the base of the Esopus Formation or within the lower member; the exact position is unclear at this time. In a general sense, the middle, relatively fine-grained member of the Esopus Formation comprises the early highstand of DS1; an overall coarsening-upward trend through the upper part of the middle member and the upper member is associated with late highstand conditions of siliciclastic progradation.

The Esopus Formation, however is also divisible into at least three major coarsening-upward successions (=lower, middle, and upper members). Each commences with dark gray to black shale and culminates in bioturbated argillaceous siltstone or fine-grained sandstone. The tops of the lower and middle members are capped by a sharply defined flooding surface. Smaller scale cyclicity may be manifest in parts of the formation by alternating 0.3-0.5 m-thick bands of lighter and darker gray-weathering mudstone.

Depositional Sequence 2. DS2 comprises strata of the Schoharie Formation (unnamed lower, Aquetuck, and Saugerties Members). The basal bounding unconformity of DS2 is the sub-Schoharie unconformity (#3 of previous section), that regionally erosionally truncates the underlying Esopus Formation. Again, a lowstand systems tract is not recognized at the base of the sequence. The unnamed lower member composes the transgressive systems tract. The discontinuity at the base of the Aquetuck Member (#4 of the above section) marks the surface of maximum flooding of DS2. Early highstand conditions characterize the Aquetuck Member; the maximum highstand of sea level appears to be represented by the widespread interval (New York and Pennsylvania) of dark shaly strata in the lower part of the member. A general shallowing upward trend through the upper part of the Aquetuck and Saugerties Members is indicative of late highstand conditions.

A particularly intriguing feature of DS2 is the strongly developed rhythmic bedding. This banding is similar to but better developed than that seen in parts of the Esopus Formation of DS1. Darker brownish buff calcareous mudstone layers alternate with cream-weathering, more carbonate-rich mudstone bands, calcareous nodules, or tabular limestone beds; these alternations show hints of bundling. This widely-known banded nature of the Schoharie Formation may represent small-scale, Milankovitch cycle rhythms comparable to those documented in Cretaceous and other age rocks (Kauffman, 1988, p. 639-644; Fischer, 1986, 1993).

Depositional Sequence 3. The third post-Wallbridge sequence consists of the Edgecliff, Nedrow and lower to middle parts of the Moorehouse Members of the Onondaga Formation of New York State. In eastern New York the base of the sequence is conformable; a laterally-equivalent erosive unconformity occurs across central to western New York. Lowstand conditions are not recognized, but may be found in the lower part of the Edgecliff Member, associated with initial growth of coral bioherms. The Edgecliff Member comprises the transgressive systems tract; the surface of maximum flooding is found at the base of the Nedrow Member (#6 of the previous section). Overlying fine-grained strata of the Nedrow member equal early highstand facies of DS3, which are succeeded by late highstand deposits of the lower to middle Moorehouse Member.

Smaller-scale cycles are not as readily recognizable in the Onondaga as in the Schoharie but may be discerned with careful study. Parasequence-scale cycles (~1 m-thick) reported in the Edgecliff Member in western to central New York (Brett and Ver Straeten, 1994) are difficult to distinguish in the coarser, less differentiated, chert-dominated facies of the member in eastern New York. The smaller scale banding seen in the underlying DS2 (Schoharie Fm.) is less evident in the Onondaga Limestone; rhythmic cherty and non-cherty couplets 0.1-0.4 m-thick could be a manifestation of the same type of cycles. The Nedrow Member in central New York displays alternations of more and less argillaceous carbonate beds that in some outcrops approach the weathered appearance of the Schoharie Formation.

Depositional Sequence 4. DS4 is marked at its base by a gradational change from shallowing- to deepening-up lithologic and faunal trends; the succession is conformable along the New York outcrop, associated with the widespread shallow ramp geometry of Onondaga strata across eastern North America. The laterally equivalent unconformity may occur in correlative shallower water deposits of the Detroit River Group in Michigan and Ontario. Upper Moorehouse strata may represent lowstand deposits of DS4; fining-upward trends through the overlying Seneca Member indicate a rise in relative sea level (transgressive systems tract). The prominent unconformity at the Onondaga-Union Springs contact in New York (#7 of previous section) represents a prominent marine flooding surface at the base of early highstand (note; this

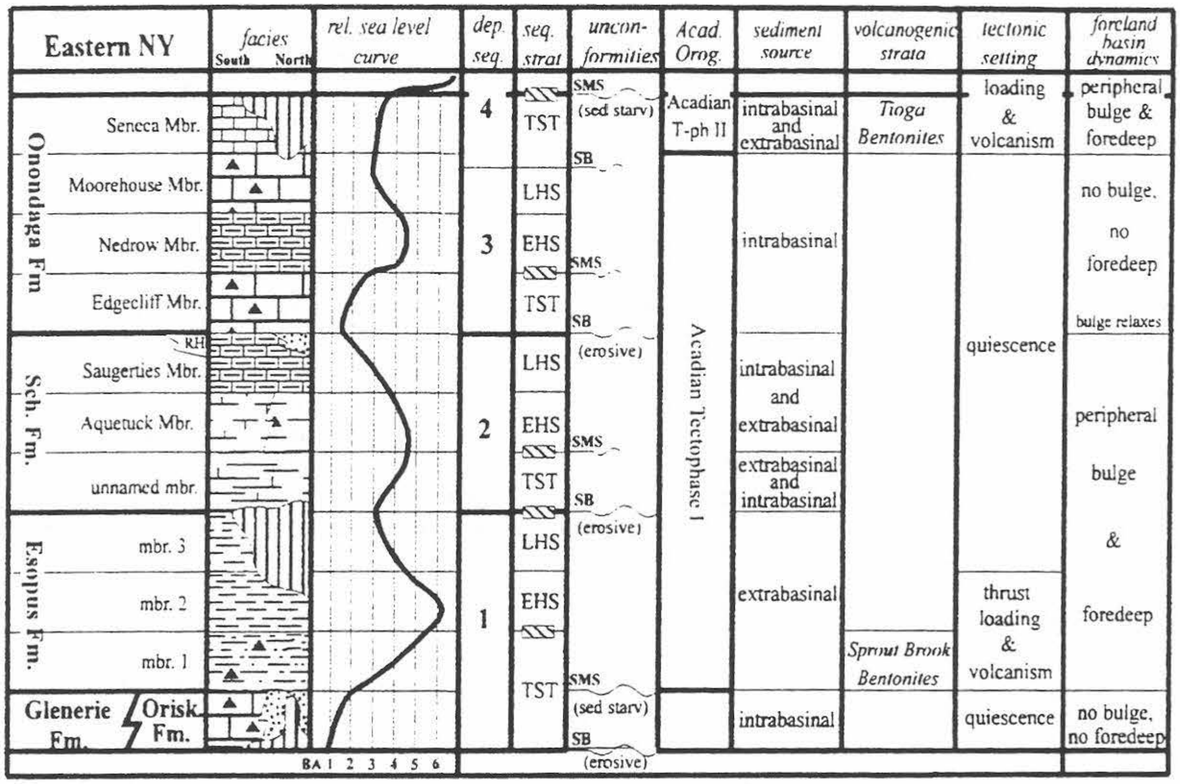

Figure 3. Stratigraphy, facies, sequence stratigraphy, and tectonic implications of upper Lower and lowest Middle Devonian rocks in New York State. Orisk.=Oriskany; Sch.=Schoharie; RH=Rickard Hill Member; WB=normal wave base; SWB=storm wave base; BA=Benthic Assemblages 1-6 of Boucot (1982). Dep.seq.=depositional sequence; TST=transgressive systems tract; EHS and LHS=early and late highstand systems tract; SB=sequence boundary; SMS=surface of maximum starvation of sequence stratigraphic terminology (see Van Wagoner et al., 1988). Erosive and sediment-starved unconformities as marked; cross-hatched boxes=condensed sections.

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major flooding surface is associated in part with the onset of basin subsidence and siliciclastic deposition during Acadian Tectophase II).

Early highstand deposits of DS4 are composed of black shales of the overlying Bakoven Member (Union Springs Fm.). Late highstand conditions are represented by calcareous shales to sandstones of the Stony Hollow Member; several scales of shallowing-upward cycles are displayed in the member. The overlying Hurley Member has the character of an intermediate-scale sub-sequence (parasequence set?) in which the Chestnut Street submember (with several internal cycles) represents an analog of a transgressive systems tract and the overlying Lincoln Park submember shales represent highstand systems tract-like deposits. The upper part of the Hurley Member sub-sequence is truncated below the a sub-Cherry Valley unconformity across much of central to western New York State.

Depositional Sequence 5. The overlying fifth depositional sequence comprises the Mount Marion Formation in eastern New York and the coeval Oatka Creek Formation in central to western parts of the state. The authors questionably place the sequence boundary at the base of the Cherry Valley Member, but note the transgressive nature of the skeletal limestones of the Chestnut Street beds at the base of the Hurley Member. In eastern New York DS5 is conformable, but the basal contact (base of Cherry Valley Mbr.) erosionally truncates the upper part of the underlying Hurley Member across central to west-central New York. West of Rochester, the basal Cherry Valley unconformity becomes amalgamated with the overlying maximum flooding surface unconformity (#9 of the previous section), which in part erosionally truncates

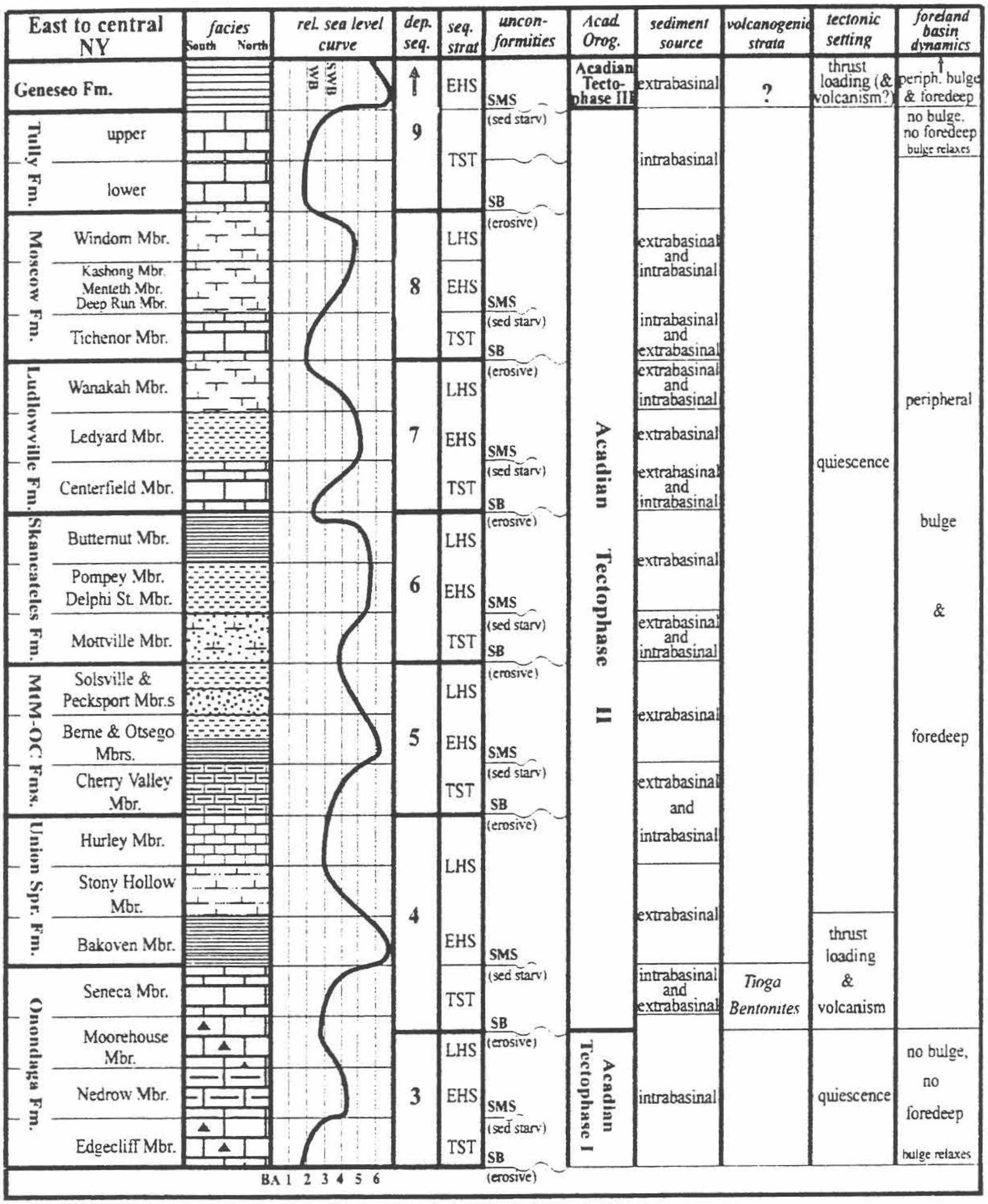

Figure 4. Stratigraphy, facies sequence stratigraphy and tectonic implication of Middle Devonian marine rocks in New York State. Abbreviations as in Figure 3. Skaneateles, Ludlowville, and Moscow Formations sea level-curve and sequence stratigraphy after Brett and Baird (in press).

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both the Cherry Valley Member and the highly condensed western New York highstand deposits of DS4; in that area highstand deposits of DS5 (lower part of the Oatka Creek Fm.) directly overlie the transgressive systems tract of DS4 (Seneca Member of the Onondaga Formation).

Black to dark gray shales of the Berne Member (Mount Marion Fm.) in eastern New York represent early highstand deposits of DS5. Thick overlying deposits of the Otsego Member and undefined upper Mount Marion strata represent progradational infilling of the preserved eastern foredeep of the basin; uppermost strata of DS5 are represented by fluvial-dominated strata of the Ashokan Formation (Rickard, 1975).

Parasequence-scale cycles appear to be represented in the upper Berne and lower Otsego Members by 3-8 m-thick successions of dark gray mudstones capped by thin shell beds as reported by Ver Straeten (1994). The cycle-capping shell beds represent sediment-starved flooding surfaces at the base of the parasequences. The base of the coral-rich Halihan Hill bed (=base of Otsego Mbr.) is locally unconformable (Ver Straeten, 1994) and marks the bottom of a key, intermediate-scale sub-sequence within the Mount Marion Formation.

Depositional Sequences 6,7,8, and 9. Sequences 6-9 of the New York Devonian are not recognized to poorly defined (e.g., DS9; see Bridge and Willis, 1994) in the fluvial-dominated, subaerial redbed succession of the Middle Devonian Plattekill and Manorkill Formations in the Catskill Front. These sequences, which have been discussed in detail for equivalent marine strata (Brett and Baird, in press), comprise the Skaneateles, Ludlowville, Moscow, and combined Tully and Geneseo Formations of central to western New York. These depositional sequences are characterized by a basal limestone-sandstone unit that overlies a sequence-bounding unconformity (e.g., Stafford-Mottville, Centerfield, and Tichenor-Menteth Members, DS6-8, respectively; Tully Formation, base of DS9). Flooding surfaces that cap the limestones are succeeded by dark, shale-dominated strata that in general coarsen upward to the base of the overlying sequence.

Basin Fill and the Acadian Orogeny

Foreland Basins Overview. Different mathematical and computer-generated models have been proposed in recent years to describe foreland basin dynamics and stratigraphy associated with orogenic episodes. Various approaches are based on thrust deformation and loading, sedimentary erosion and redistribution of the load, and an elastic (Jordan and Flemings, 1991; Sinclair, et al., 1991) or visco-elastic (Beaumont et al., 1988) flexural response of the lithosphere.

Quinlan and Beaumont (1984) and Beaumont et al. (1988) discuss a model of visco-elastic foreland basin flexure and its influence on stratigraphy of the basin fill over time. Loading of the lithosphere during episodes of tectonic thrusting leads to stress-induced subsidence of a proximal foreland basin and gentle uplift due to relaxation on a cratonward peripheral bulge. Subsequent periods of tectonic quiescence and unloading are marked by relaxation and uplift of the foreland. Beaumont et al. (1988) present a synthetic model of foreland basin fill and its implications for the magnitude of overthrust loads and the morphology of the inherited passive margin.

Sinclair et al. (1991) and Jordan and Flemings (1991) present computer-generated simulations of foreland basin stratigraphy that incorporate sedimentary erosion and distribution of tectonic loads. Sinclair et al. (1991) apply their model to the Cenozoic North Alpine Foreland Basin in Switzerland in an attempt to define possible controls on foreland basin stratigraphy during the evolution of an eroding thrust wedge. Assuming no eustatic sea level changes and elastic behavior of the lithosphere, they demonstrate that the foreland basin record of sedimentation and unconformities can be developed by changing the spatial distribution of a load.

Jordan and Flemings (1991) examine the foreland basin record through the interaction of subsidence, sediment flux, efficiency of sediment transport, and the period and amplitude of sea level changes. Variance of these parameters in the model generates distinct patterns of sedimentation and erosion associated with thrust-generated subsidence and changes of eustatic sea level.

Other recent work on foreland basin dynamics has focused on the sedimentary record of the basin. For example, Plint et al. (1993), in studies of upper Cretaceous strata in the Alberta foreland basin, note depositional patterns that include surfaces of erosive beveling at least 300 km cratonward of the present day Sevier deformation front. They interpret the regional truncation of strata to reflect forebulge uplift and erosion associated either with episodic loading/tectonic rejuvenation of an orogenic wedge or continuous loading of lithosphere of laterally varying flexural rigidity.

Patterns and implications of Acadian Sedimentary Fill, Northern Appalachian Basin. Figure 5 shows the geometry of the Oriskany, Esopus, Schoharie, Onondaga, and Union Springs Formations along ~450 km of the New York outcrop between Kingston and Buffalo. Distinctive wedge-shaped geometries characterize the Esopus and Union Springs Formations. This is in sharp contrast with the relatively tabular form of the Onondaga Limestone across New York. The Schoharie Formation, which lies between the Esopus and Onondaga Formations, exhibits an intermediate, modified wedge-shaped form. The geometry of the Oriskany and equivalent formations appears similar to that of the Schoharie Formation; the occurrence of Oriskany sands in karstic cavities and fissure fillings into underlying older Devonian and Silurian rocks across central to western New York appear to imply, however, a wider, and possibly more tabular distribution of the Oriskany Formation at the time of its deposition.

Strata equivalent to the Oriskany and Onondaga Formations are widespread across eastern North America. Rocks coeval with the Oriskany Sandstone occur continuously from Quebec and New Brunswick to Mexico and are found in the Appalachian, Michigan, and Illinois Basins (Boucot and Johnson, 1967, Figure 3a, p. 48). The Onondaga Formation is similarly widespread; it is found from the James Bay region of Ontario to southeast Quebec and Maine to Georgia and to Illinois (Koch, 1981; Oliver et al., 1967). The Schoharie Formation is also widely reported (Boucot and Johnson, 1967, Figure 5, p. 50), despite its absence across parts of central to western New York. In contrast, the Esopus Formation and equivalents are only reported from the Appalachian Basin (Esopus and Beaverdam shales; Ver Straeten, in prep.) and from the Lower Devonian of New England and Quebec (Boucot and Johnson, 1967, Fig. 4, p. 49; Rehmer, 1976, Fig. 12, p. 212).

The right side of Figures 3 and 4 summarize the succession of events during Acadian Tectophases I and II as recorded in the Appalachian foreland basin fill. The onset of tectonism during Tectophase I is indicated by: 1) a relatively abrupt change from widespread shallow marine, intrabasinal quartz arenites and carbonates (Oriskany-Glenerie-Connelly Formations) to deeper, extrabasinal siliciclastics (shale and siltstones of the Esopus Formation) shed from rising Acadian highlands; 2) volcanogenic strata preserved at the transition (Sprout Brook Bentonites), apparently associated with an episodic increase in volcanism in the adjacent magmatic arc of the Acadian Orogen; and 3) rapid subsidence of the proximal foredeep of the basin, accompanied by uplift of a peripheral bulge in central to western New York (timing of the uplift of the peripheral bulge is poorly constrained at this time, but is definitely post-Oriskany and pre-Onondaga).

Progradation of coarser extrabasinal siliciclastics into the northern part of the Appalachian basin was limited during Tectophase I and is generally restricted to the upper part of the Esopus Formation. Deposition of the overlying Schoharie Formation was associated with decreased clastic input and a gradational upward increase in intrabasinal carbonate influence. This decrease in clastic input is interpreted to indicate reduced supply of extrabasinal sediments and lowered relief in adjacent Acadian source areas during a period of decreased tectonism.

A return to fully carbonate-dominated deposition (Middle Devonian Onondaga Limestone and equivalents) across much of eastern North America, including within the Appalachian Basin, is indicative of relative tectonic quiescence and low relief tectonic highlands in the Acadian mountain belt. Thin K-bentonites occur at several horizons through the lower and middle parts of the Onondaga Limestone, however, indicating that minor volcanism continued throughout this quiescent subphase.

Geometry of the basin floor underwent major changes during early Southwood (Onondaga) time; Brett and Ver Straeten (1994) discussed the subsidence and/or migration of the Tectophase I peripheral bulge in central and western New York. The area of apparent highest relief on the bulge during latest Sawkill-earliest Southwood time (e.g., central Finger Lakes region of New York) underwent subsidence and became the Onondaga basin axis by Nedrow Member time.

The onset of Acadian Tectophase II is first indicated in the upper part of the Onondaga Formation carbonates. Similar to Tectophase I, the foreland basin fill records the following: 1) an abrupt change from widespread, shallow marine, intrabasinal carbonates to deep water, extrabasinal siliciclastics (black shales of the Bakoven Member, Union Springs Formation); 2) volcanogenic strata preserved at the transition (Tioga Bentonites), associated with a second period of episodic increase in explosive volcanism in the adjacent

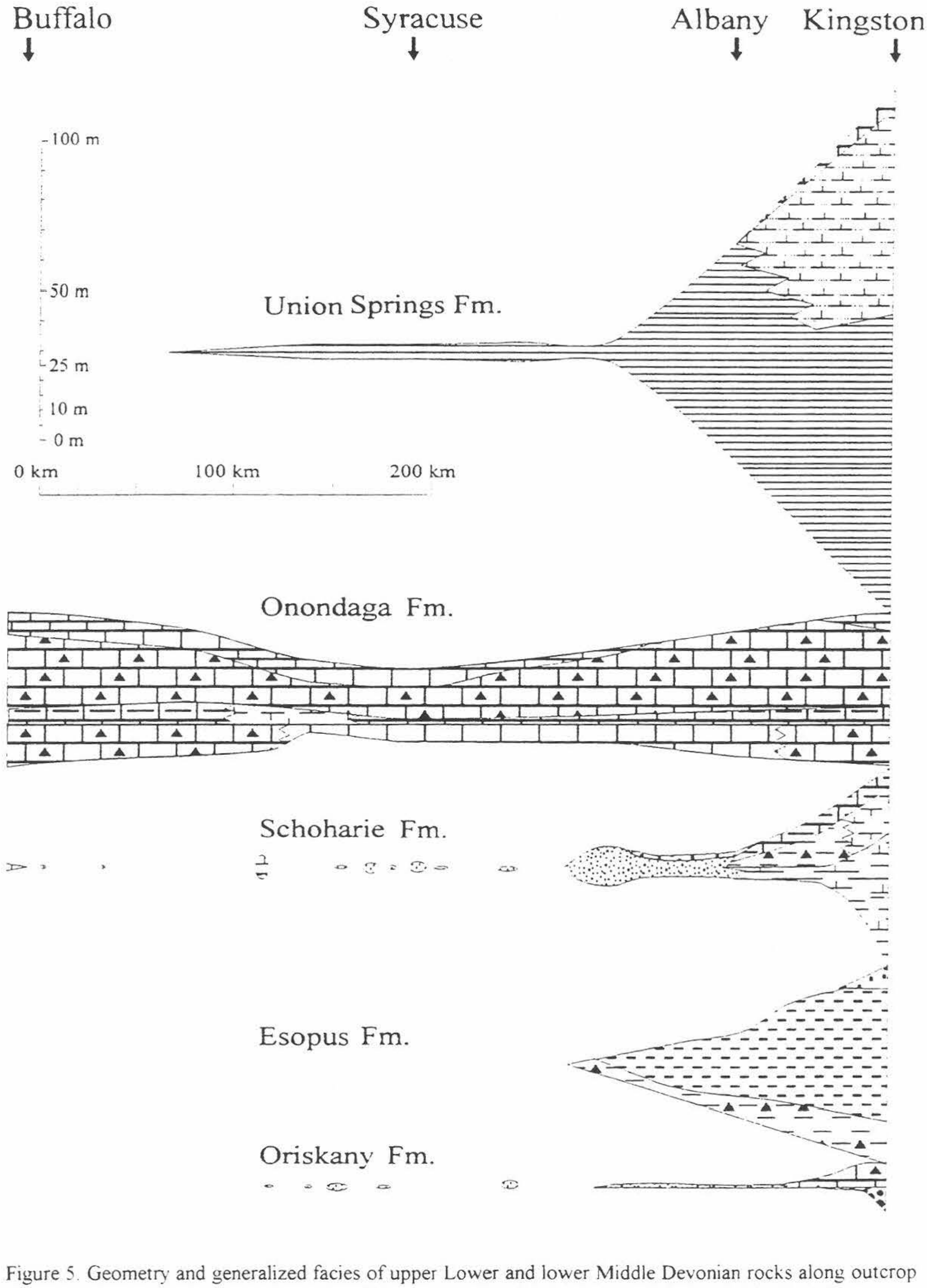

Figure 5. Geometry and generalized facies of upper Lower and lower Middle Devonian rocks along outcrop belt between Kingston (southeast) and Buffalo (west), New York. Note relatively tabular-shaped geometry of the Onondaga Formation in contrast to the distinct wedge-shaped geometry of the Esopus and Union Springs Formations. Thicknesses compiled from Ver Straeten (field notes), Hodgson (1970), Rehmer (1976), Johnsen (1957), Baker (1983), Oliver (1956), Feldman (1985), and Rickard (1989).

magmatic arc; and 3) rapid subsidence of the proximal foredeep (and associated sediment-starved conditions on the basin floor that led to the development of a submarine unconformity at the Onondaga-Union Springs formational contact) and uplift of a peripheral bulge in western New York and into southern Ontario. The uplift on the Tectophase II peripheral bulge appears to have begun in western New York at about the time of deposition of the Cherry Valley Member; Ver Straeten et al. (1994, p. 296) discuss multiple erosion surfaces in lower Marcellus strata and note coarse crinoidal grainstones in the Cherry Valley Member near Rochester. These occurrences are indicative of shoaling environments basinward of an area that was being uplifted as a general transgression occurred eastward along the remainder of the New York outcrop.

A decrease in tectonism during a medial stage of Acadian Tectophase II is marked by progradation and initial infilling of the foredeep of the basin by medium- to coarse-grained extrabasinal sediments in eastern New York (Mount Marion Fm.). Progradation of non-marine environments across eastern New York continued through deposition of the Hamilton Group (Ashokan, Plattekill, and Manorkill Fms.). An upward increase in intrabasinal carbonate content and dilution of extrabasinal clastics in equivalent marine rocks of the upper Hamilton Group (central to western New York) marks a progressive decrease in siliciclastic input from eroding highlands of Tectophase II. In this sense, the upper part of the Hamilton Group is similar to the Schoharie Formation during the early quiescent stage of Tectophase I.

A return to intrabasinal, limestone-dominated deposition of the Tully Formation is, similar to the older Onondaga Limestone, indicative of relative tectonic quiescence and lowered relief of tectonic highlands to the east in the Acadian orogen. Deposition of the marks the end of Tectophase II of the Acadian Orogeny.

Heckel (1973) reported a north-south striking anticlinal structure in central New York on the eastern margin of Tully Limestone deposition. This feature was a broad, low-angle area of topographic relief (~40-50 km across) that was active during deposition of the lower part of the Tully. In upper Tully time this feature subsided to form a topographic basin over the core of the breached anticline Heckel, 1973, p. 156).

This arch-like uplift to topographic basin progression during Tully time is strikingly similar to the dramatic subsidence of the Tectophase I peripheral bulge during early Onondaga time (central Finger Lakes region; Brett and Ver Straeten, 1994, see above). The authors postulate that Heckel's (1973) "anticline" of lower Tully time represents an uplifted Acadian Tectophase II peripheral bulge that subsided and/or migrated away by deposition of the upper part of the Tully Limestone.

The onset of Acadian Tectophase III is signified by a third abrupt transition from relatively widespread, shallow marine carbonates (Tully Formation) into overlying thick black shales (Geneseo Formation). This succession mimics those of the Oriskany to Esopus and Onondaga to Union Springs Formations. One exception to the previous depositional patterns is the absence of volcanogenic strata (K-bentonites) associated with this major transition. Closer inspection of this interval may yield another key cluster of Devonian K-bentonites associated with the initiation of the thick, Upper Devonian, Tectophase III clastic wedge of the Catskill Delta.

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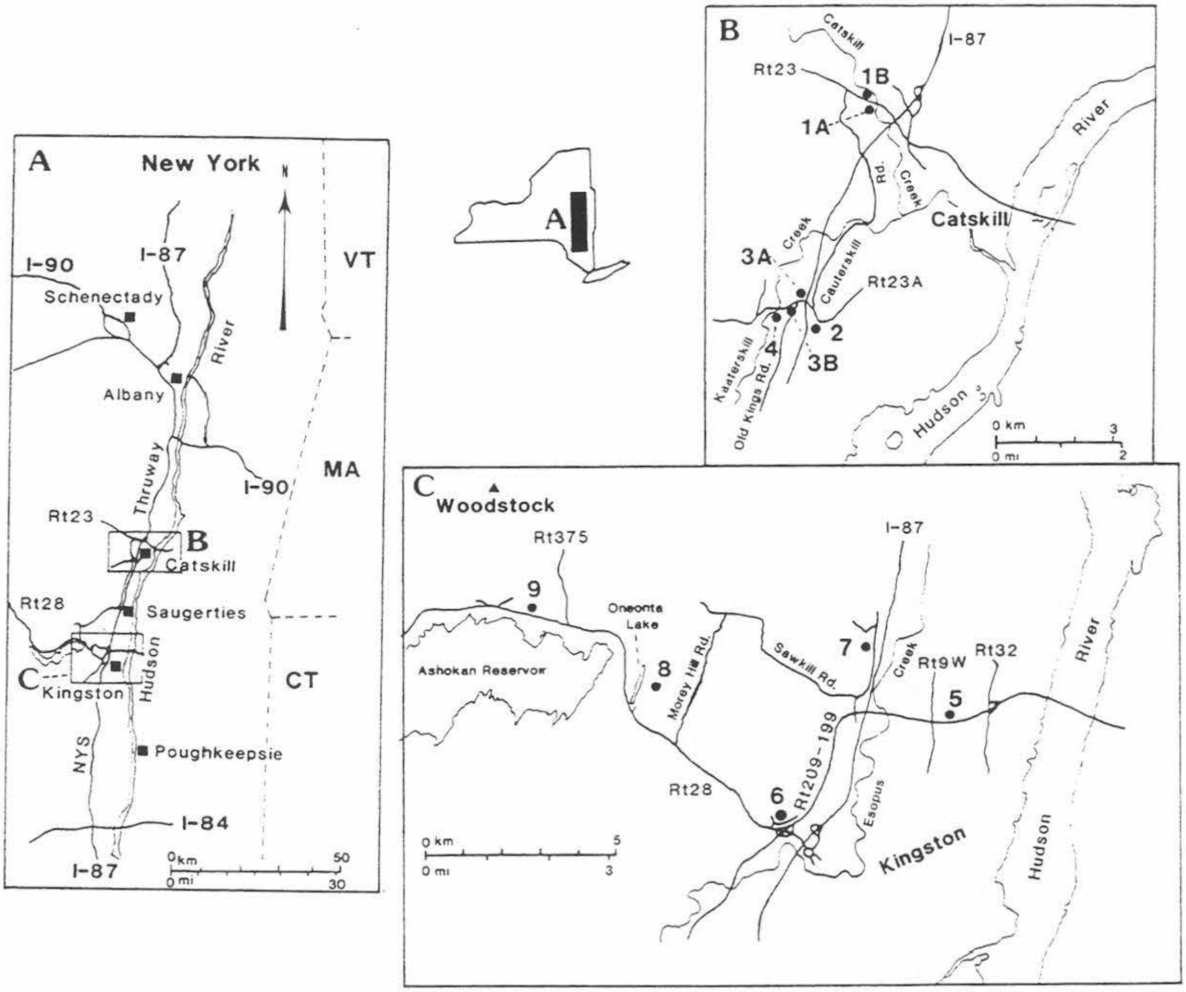

Figure 6. Maps of field trip area. A=eastern New York region with major highways. B=detailed map of Catskill (Greene Co.) vicinity; Stops 1A-4. C=detailed map of Kingston (Ulster Co.) area; Stops 5-9.

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FIELD TRIP LOG

0.0	0.0	Leave parking lot opposite gymnasium; proceed to intersection with Union Avenue; turn right onto Union Avenue.
0.0	0.2	Bear right at stoplight onto Union Street.
0.3	0.1	Turn left onto Nott Terrace at stoplight.
0.5	0.2	Observe west wall of Mohawk Valley in distance on right.
0.7	0.2	Proceed through intersection with State Street; Nott Terrace changes to Veeder Avenue.
0.9	0.2	Veeder Street angles to right and becomes Miller Street; proceed downhill.
1.1	0.4	Bear left onto Broadway Avenue.
1.2	0.3	Proceed into left lane to enter Interstate 890 East.
1.3	0.1	Turn left onto entrance ramp for I-890 East.
1.5	0.2	Merge with I-890 East.
4.5	3.0	View of Helderberg Escarpment, capped by Lower and Middle Devonian strata, straight ahead.
5.15	0.65	Tollbooth for New York State Thruway; get toll card and proceed to left lane for Interstate 90/NYS Thruway eastbound. Enter Thruway eastbound and proceed through the Albany Pine Plain, on late-glacial windblown sand dunes near the northwest shore of glacial Lake Albany.
6.3	1.1	Guilderland Service area on right.

10.3	4.0	Proceed straight on NYS Thruway past Exit 24; note that the Thruway changes from I-90 to Interstate 87.
11.6	1.3	Highway continues through the Albany Pine Plain; note vegetated sand dunes along Thruway.
15.4	3.8	Taconic Mountains visible in distance ahead; remnants of Ordovician overthrusted highlands of the Taconic Orogeny.
16.5	1.1	Exit 23; proceed straight on I-87 South.
17.2	0.7	Cross over Normanskill Gorge, near type section of Ordovician Normanskill Group.
17.6	0.4	Views of Helderberg Escarpment to right for next 17.5 mi.
19.8	2.2	Roadcuts in flysch-type sediments of Ordovician Austin Glen Formation (Normanskill Group) along NYS Thruway for next 15 mi.
23.9	4.1	Exit 21A (connector to I-90 and Massachusetts Turnpike; proceed straight on I-87.
31.9	8.0	Catskill Mountains, middle to Upper Devonian strata, visible ahead. Helderberg Escarpment on right, with limestone outcropping near crest of ridge.
32.9	1.0	Exit 21B (Coxsackie). Classic outcrop of "Dinosaur Leather", sole marks on base of Austin Glen Fm. turbidite bed visible 1.0 mi. north of Coxsackie exit along west side of N.Y. Rt. 9W.
35.1	2.2	Outcrops of Lower Devonian Kalkberg Limestone (Helderberg Group) visible on both sides of Thruway as you rise up onto the Helderberg-Kalkberg Escarpment. Exposures of Helderberg Group (Manlius, Coeymans, Kalkberg, New Scotland, and Becraft. Fms., in ascending order) for next 2.5 mi.
38.2	3.1	Long outcrop of middle part of Lower Devonian Esopus Formation (dark shale; Tristates Group) on right.
38.2	0.2	Strongly-dipping outcrop of Lower Devonian Glenerie Formation? (Tristates Group) on left.
38.9	0.7	New Scotland and Becraft Formations on left.
39.1	0.2	Esopus Shale on left.
39.6	0.5	Schoharie Formation on right; note dark band.
39.8	0.2	Low anticline on right.
40.2	0.4	Cherty Onondaga Formation (limestone) on both sides of I-87 for next 0.4 mi.
40.8	0.6	Cuts in Helderberg Group (Kalkberg, New Scotland, and Becraft Fms.) for next 3.0 mi.
42.8	2.0	<u>Bear right and exit</u> I-87/NYS Thruway at Exit 21-Catskill; note additional outcrops of New Scotland and Becraft Limestones along exit.
43.3	0.5	View of Catskill Mountains/ Catskill Escarpment in the distance to right.
43.5	0.2	Tollbooth at Catskill Exit; New Scotland Limestone to left.
43.7	0.2	Junction with NY Rt. 23B; <u>turn left</u> onto highway.
43.8	0.1	New Scotland, then Kalkberg Formations on right.
44.0	0.2	<u>Bear right</u> onto entrance ramp for NY Rt. 23 West. Exit ramp to left (east) shows angular unconformity of Ordovician Austin Glen Formation with uppermost Silurian Rondout Group; outcrop continues through Lower Devonian Manlius, Coeymans, Kalkberg, and lower part of the New Scotland formations. Faulted section along right side of entrance ramp repeats Manlius, Coeymans, and Kalkberg Formations.
44.2	0.2	<u>Merge</u> with Rte, 23; observe outcrops of Helderberg Group Limestones to right and left. For detailed discussion of structure of rocks along Rt. 23, see Marshak, 1990.
44.35	0.15	Bridge over I-87-NYS Thruway.
44.6	0.25	Crest of anticlinal structure in roadcuts.
44.7	0.1	Bridge over Catskill Creek; note high outcrop of Esopus Shale on right.
45.0	0.3	<u>Pull over to right</u> and <u>park</u> near green mile marker sign past guard rail.

Stop 1A (Optional). Wallbridge Unconformity in Catskill Creek at Austin Glen. To get to Optional Stop 1, walk back along Rt. 23 to bridge and walk down to creek along side of bridge. Turn right at bank of Catskill Creek and follow around to the natural dam in creek south of the bridge.

The natural dam at the mouth of Austin Glen is formed by the resistant base of the Lower Devonian Glenerie Limestone, underlain successively by limestones of the Port Ewen and Alsen Formations at the top of the Lower Devonian Helderberg Group. The basal bed of the Glenerie Formation is sand-rich, and features a prominent zone of reworked phosphate pebbles at its base. This phosphatic lag immediately overlies a prominent disconformity, the Wallbridge Unconformity (Sloss, 1963), which is one of six major unconformities in the Phanerozoic of North America. To the north and west, into central to western New York, this unconformity overlies progressively older rocks, as old as Late Silurian in western New York. South of Catskill the unconformity overlies progressively younger rocks in the upper part of the Port Ewen and Port Jervis Formations. In the Tristates area of southeastern New York, near Port Jervis, the succession from the Port Jervis Formation into the overlying Glenerie Formation is continuous and conformable (Rickard, 1975).

Downstream of the natural dam Catskill Creek runs through a gorge (Austin Glen) of the New Scotland and lower limestones of the Helderberg Group. The lower part of the gorge is the type section for the Ordovician Austin Glen Formation, seen previously on this trip in outcrops along the New York State Thruway. Upstream of the natural dam and the Rt. 23 bridge a high cliff of Esopus Shale is visible.

Return to the anticlinal outcrop adjacent to the vehicles.

Stop 1B. Esopus, Schoharie, and Onondaga Formations. Cuts on north side of N.Y. Rt. 23, west of bridge over Catskill Creek.

Highway cuts along Rt. 23 expose the upper part of the Esopus Formation, a complete section of the Schoharie Formation (unnamed lower, Aquetuck, and Saugerties Members), and the base of the Edgecliff Member of the Onondaga Formation in an antiformal fold west of Catskill Creek. The lower part of the exposure displays dark, rust-spotted, blocky-weathering silty shales of the Esopus Formation (Upper part of Depositional Sequence 2 of this paper). Along Rt. 23 the Esopus Shale is capped by a distinctive, 6.8 m-thick laminated unit that forms a distinctive marker at the base of the upper member of the formation. At Catskill the laminated unit is abruptly overlain by the Schoharie Formation; at Kingston, however, the top of the laminated unit underlies the Esopus-Schoharie contact by 22.5 m. The Esopus and Schoharie Formations thin laterally between Kingston and Catskill; however, the absence of upper Esopus strata above the laminated unit at Catskill appears dominantly to be associated with erosional truncation at a sequence-bounding unconformity below the Schoharie Formation (=base of Depositional Sequence 2 of this paper).

The sub-Schoharie unconformity at the base of Depositional Sequence 2 is marked by a sharp lithologic change and abundant glauconite, phosphate pebbles, fish bone material, and scattered white vein quartz pebbles. Five meters of calcareous, bioturbated argillaceous siltstone to silty mudstone of the lower unnamed member (formerly Carlisle Center Formation) overlie the contact. This contrasts sharply with up to 44 m of the unnamed member at Kingston. A 60 cm-thick, dark to black, rusty weathering, calcareous to cherty bed ("black bed" of Oliver et al., 1962) occurs near the middle of the member at both Catskill and Kingston. Glauconite and scattered quartz pebbles, apparently mixed downward from above by burrowing organisms, occur again in the upper part of the unnamed member at and below a lesser unconformity (=surface of maximum starvation in sequence stratigraphy terminology) at the base of the Aquetuck Member.

The Aquetuck Member along Rt. 23 (~12.7 m-thick) is characterized by fine-grained, buff- to olive-banded, cherty and siliceous to calcareous shales.. An interval of interbedded olive and dark gray strata 2.6-5.2 m above the member base represent the most basinal conditions in the Schoharie Formation. This interval at Kingston is represented by ~3.25 m of dark, blocky-weathering, calcareous shale and is correlative with a widespread interval of dark gray to black shale in the middle of the Needmore Formation in central Pennsylvania (see body of paper). Carbonate content increases and the siliceous aspect of the strata decreases through the upper part of the Aquetuck Member at Catskill. The lower part of the member is unfossiliferous; small brachiopods and other forms appear in the upper part of the member, and diversify and increase in abundance upward through the overlying Saugerties Member.

The contact with the Saugerties Member is gradational and is placed at the lowest continuous, light-weathering limestone band. Nine meters of fossiliferous, interbedded buff calcareous shales and light-colored limestones comprise the Saugerties Member at Catskill. The lowest strata of the Onondaga Formation (Edgecliff Member) are exposed near the west end of the outcrop.

Return to cars and proceed straight (west) on NY Rt. 23.

45.2	0.2	Turn left onto Cauterskill Rd.-Greene Co. Rt. 47 and proceed ahead.
45.6	0.4	Junction with Vedder Road; continue ahead on Cauterskill Rd.
45.7	0.1	Intersection with Vedder Mountain Rd.; continue straight ahead. Outcrops of Union Springs and Mount Marion Formations on the Hoogeberg Ridge to right.
46.5	0.8	Bridge over NYS Thruway; outcrops of Esopus to left along Thruway.
46.55	0.05	Outcrops of Schoharie Formation on left and right; note prominent cleavage.
47.5	1.0	Fine brown glacial sands exposed on right (possible shoreline sands of glacial Lake Albany?).
47.7	0.2	Bridge over Kaaterskill Creek; falls over Ordovician Austin Glen Formation on left.
47.75	0.05	Turn right and follow Cauterskill Road- Rt. 47 along Kaaterskill Creek.
48.4	0.65	Intersection with Cauterskill Creek Rd.; continue ahead.
48.7	0.3	Steeply-dipping Onondaga Formation on right.
49.0	0.3	Outcrop of Moorehouse and underlying Nedrow and Edgecliff Members of the Onondaga Limestone on left. Follow road to left past outcrop.
49.35	0.35	Fork to left on Cauterskill Rd.
49.4	0.05	Turn left onto N.Y. Rt. 23A
49.6	0.2	Pull over to right and park at abandoned NYS Thruway exit.

Stop 2. Port Ewen, Glenerie, and Esopus Formations, including the Wallbridge Unconformity. Abandoned exit of New York State Thruway at N.Y. Rt. 23A. The lower and middle parts of the outcrop are accessible; the upper part of the outcrop is along the New York State Thruway and can only be observed with written permission of the Thruway Authority.

This Lower Devonian outcrop exposes uppermost strata of the Helderberg Group, the Wallbridge Unconformity, the Oriskany-equivalent Glenerie Limestone, and the lower part of the Esopus Shale. The exposure extends southward ~300 m along the New York State Thruway, where middle and upper Esopus strata are overlain by more calcareous strata of the Schoharie Formation.

The Wallbridge Unconformity, one of six major North American Phanerozoic unconformities (Sloss, 1963) caps argillaceous limestones of the Port Ewen Formation as seen at Optional Stop 1A. The unconformity is marked by a thin (~10 cm-thick) phosphate pebble-rich conglomeratic lag at the base of the Glenerie Formation. This bed lies at the base of Sloss' (1963) Kaskaskia Supersequence, which extends from the upper Lower Devonian through the Mississippian Period, and marks the base of Depositional Sequence 1 of this paper. The Glenerie Formation at Rt. 23A (3.5 m-thick) consists of relatively fine-grained, fossiliferous, drab brown limestones and dark gray cherts. Oriskany-age brachiopods are visible in cross-section in some limestone beds; the highly diverse and abundant fauna known from the Glenerie Limestone locally, however, appears absent at this outcrop.

The limestones and cherts of the Glenerie Formation are gradationally overlain by strata of the Esopus Formation at Stop 2. The lower member of the Esopus, as defined herein, consist of a tripartite subdivision of strata: 1) a lower interval of interbedded, thin siltstones, cherts, shales, and K-bentonites. This interval includes the Sprout Brook Bentonites of Ver Straeten (1992b, in review; also Ver Straeten et al., 1993), which at this outcrop consist of up to 15 thin, altered volcanic ash layers; 2) a middle subunit of dark gray to black, banded shale with scattered medium-size (~10-20 cm), dark blue-gray calcareous-phosphatic concretions; and 3) an overlying coarsening-up interval of medium dark gray silty shales to buff-gray-weathering, slightly calcareous siltstones. Small brachiopods (*Atlanticocoelia* and/or *Leptocoelia*) and other uncommon fossils occur in the upper subunit, with scattered glauconite.

The lower submember (~6.6m-thick) of the member is highly deformed at this outcrop; disharmonic folds, shear zones, and prominent fractures and cleavage are associated by Marshak (1990) with movement of a detachment fault between the Glenerie and Esopus Formations. Bentonite beds along the outcrop pinch and swell between more resistant beds and form horizons along which faults slide. The overlying middle dark gray-black shale subunit (2.0 m-thick) in the upper part of the cliff shows prominent slaty cleavage. Subunit 3 of the lower member of the Esopus Formation along Rt. 23A totals 4.0 m in thickness; its capping buff-gray siltstone bed forms a prominent ledge around the corner from the anticlinal exposure.

The overlying middle and upper members of the Esopus Formation extend southward along the outcrop and consist of rusty, dark gray silty mudstones to argillaceous siltstones that total over 40 m in thickness. The upper member of the Esopus, unlike the previous stop, consists of the laminated unit and ~2.9 m of strongly *Zoophycos*-churned siltstones to fine sandstones. The base of the Schoharie Formation is marked by a prominent glauconite-rich bed with quartz pebbles. The overlying unnamed member of the Schoharie Formation is 9.2 m-thick along the Thruway cut and shows distinctive banding, as does the overlying Aquetuck Member (10.7+ m exposed; thicknesses for the Schoharie Formation reinterpreted from Johnsen, 1957). This banding may be related to Milankovitch cycles similar to those reported from Cretaceous and other age rocks (see discussion of Sequence DS3 in main body of paper).

The basal Glenerie phosphate pebble bed marks initial transgression during deposition of the first post-Wallbridge depositional sequence (=Sequence DS1 of this paper). Continued transgression coupled with the onset of tectonically-induced foreland basin subsidence (Acadian Tectophase I) marks the change into the overlying Esopus Formation. Shallowing and siliciclastic progradation through the upper part of the Esopus Formation is truncated by apparent erosion of upper Esopus strata (see discussion above) below an unconformity at the base of the Schoharie Formation (=base of Sequence DS2 of this paper).

Turn around and proceed back west along NY Rt. 23.

49.8	0.2	intersection with Cauterskill Rd.; proceed ahead on Rte 23A.
49.9	0.1	Bridge over NYS Thruway.
50.0	0.1	Intersection with Old Kings Rd.- Greene Co. Rt. 47. Pull over to right and park. Walk carefully back along Rt. 23A to bridge over the Thruway.

Stop 3A. Schoharie and Onondaga Formations. Highway cuts along NYS Thruway and NY Rt. 23A visible from Rt. 23A bridge. Access to exposures along thruway only through written permission of the Thruway Authority.

Highway cuts along Rt. 23 and the Thruway show extensive exposures of the Lower Devonian Schoharie and lower part of the Middle Devonian Onondaga Formations. Buff-orange, brown, and gray colors characterize the Schoharie Formation along the exposure. Light-weathering limestones, with common yellowish-weathering cherts, are typical of the Onondaga Formation. Very long exposures of the Schoharie are visible along the Thruway to the north. To the left, immediately north of the bridge, a darker, banded interval is notable in the lower part of the exposure. This interval of siliceous shales in the lower part of the Aquetuck Member (seen at Stop 1) is correlatable to a calcareous shale interval at the same position at Kingston; as previously noted, it is also recognized in the middle part of the Needmore Formation in Pennsylvania (see body of paper). Overlying strata on the northwest side of the bridge belong dominantly to the Aquetuck Member.

On the opposite side of the highway north of the bridge, alternating bands on argillaceous, buff-weathering limestones and purer, more calcareous limestone layers characterize the Saugerties Member of the Schoharie Formation. Overlying coarse, crinoid-rich, non-cherty to chert-rich limestones represent the Edgecliff Member of the Onondaga Formation.

Walk back to intersection of Rt. 23A and Old Kings Rd.

Stop 3B. Schoharie and Onondaga Formations. Cuts along N.Y. Rte 23A at and near its intersection with Kings Highway, ~0.0-0.3 mi. west of the bridge over the New York State Thruway.

Outcrops to the east and west of and along Old Kings Road on the south side of Rt. 23A expose argillaceous limestones of the upper part of the Schoharie Formation (Aquetuck and Saugerties Members) and a thick section of limestones of the Onondaga Formation (~44-m thick; Edgecliff, Nedrow and Moorehouse Members). The Schoharie-Onondaga contact is exposed on the east side of Old Kings Road, south of Rt. 23A. Buff- and light gray-weathering limestones with thin quartz sand stringers (Saugerties Member) are gradationally overlain by light gray, clean limestones of the Onondaga Formation (Edgecliff Member). The lower part of the Onondaga section exposed along Old Kings Road (basal 2.0 m-thick non-cherty interval and overlying chert-rich strata) comprise the Edgecliff Member (ca 16 m-thick). The lower 2.0 m of relatively chert-free, coral, brachiopod, and crinoid-rich pack- and grainstones ("Jamesville Quarry facies" of Brett and Ver Straeten, 1994) are capped by a thick section of medium-grained, cherty, crinoidal packstones ("Clarence facies" of Brett and Ver Straeten, 1994). Similar alternations of cherty and chert-free strata characterize the Onondaga Limestone in the Catskill area; chert-dominated facies are predominant locally, however.

The member level subdivisions of the Onondaga Limestone that are well-defined and easily recognized in central New York (see Brett and Ver Straeten, 1994) are less readily detectable in Hudson Valley outcrops. They can tentatively be separated by changes in chert and argillaceous content, and in bedding thickness.

A 6.6 m-thick covered interval, (which is exposed along Cauterskill Road, Mile 49.0 of this trip) at least in part represents the Nedrow Member. Overlying strata to the west along Rt. 23A comprise the Moorehouse Member. The coarse- to medium-grained, chert and crinoid-rich lithology of the Edgecliff Member below is replaced in the Moorehouse Member by finer-grained, cherty, wacke- to packstones characterized by brachiopod-dominated faunas. Calcite slickensides are common along bedding planes through the Moorehouse Member at Stop 3B; faulting, however, appears to be restricted along the bedding planes, associated with slippage of beds over each other during folding and overturn of the section.

The Onondaga Formation totals ~44 m at Stop 3B; uppermost strata of the formation are covered. Fifty meters of Onondaga strata are reported from outcrops along the NYS Thruway at Saugerties, 8.5 mi. to the south (Feldman, 1985); the top of the Saugerties section is thought to be close to the contact of the Onondaga Limestone and overlying clastics of the Union Springs Member (Stop 4, next locality).

A geologic overview of Localities 1-3 and 5 is summarized here (see Figure 3). Post-Wallbridge deposition of the Glenerie, Esopus, Schoharie, and Onondaga Formations represent a succession of, respectively, intrabasinal carbonates, extrabasinal siliciclastics, mixed siliciclastic and carbonate sediments, and a return to fully intrabasinal carbonates. These trends are associated with initial tectonic quiescence and carbonate-quartz arenite deposition above the Wallbridge Unconformity (Glenerie Formation), followed by: 1) a pulse of active tectonism in the Acadian Orogen, accompanied by volcanism and deposition of the Sprout Brook Bentonites, transport and deposition of fine- to medium grained siliciclastics, and subsidence of the foreland basin (Esopus Formation); 2) decreased tectonic activity and lowering of topographic relief in the mountain belt, associated with a decrease in siliciclastic input into the basin and deposition of calcareous shales and siltstones to argillaceous limestones (Schoharie Formation); and 3) a return to tectonic quiescence, marked by deposition of intrabasinal carbonates (Onondaga Formation). This succession of events 1-3 comprises Acadian Tectophase I as it is recorded in the foreland basin fill of eastern New York State.

Superimposed on these tectonically-related trends are three major depositional sequences (DS-1 to DS-3). These sequences appear to be dominantly controlled by eustatic sea level changes. The first sequence (DS 1) comprises the Glenerie and Esopus Formations. Initial deepening above the Wallbridge Unconformity continues upward through the Glenerie Limestone and lower to middle Esopus Shale (note: deepening during Esopus time is in part due to tectonically-induced subsidence of the basin). Upward shallowing through the upper middle to upper Esopus Formation is truncated by submarine erosion below a sub-Schoharie unconformity at the base of DS-2. Initial deepening through the Schoharie Formation culminates in deposition of widespread dark shaly strata represented at Catskill by an interval of dark, siliceous to cherty shales in the lower part of the Aquetuck Member. Overlying increasingly more calcareous strata are associated with a general shallowing-upward reaches a maximum at or near the Schoharie-Onondaga formational contact. Initial deepening at the base of the Onondaga Limestone marks the base of DS-3; transgression continued upward through the Edgecliff and Nedrow Members. Trends through the overlying Moorehouse Member indicate another major shallowing-upward trend during late highstand of DS-3. Transgression during the succeeding DS-4, which is dominantly represented by the overlying Union Springs Formation, was initiated during deposition of the upper part of the Moorehouse Member.

Return to the cars and proceed ahead west on NY Rt. 23A.

50.4	0.4	Cross over Kaaterskill Creek at Webber Bridge. Drive through the Bakoven Valley, with deeply eroded black shales of the Bakoven Member (Union Springs Formation) overlain by glacial sediments.
50.8	0.4	Turn left onto Underhill Rd., then turn around and return east of Rt. 23. Note outcrop of Stony Hollow Member (Union Springs Formation) at intersection; more outcrops of

		Stony Hollow Member northward along Underhill Rd and at the crest of Rt. 23A to the southwest.
51.3	0.5	Recross Kaaterskill Creek and pull over and park on right side of Rt. 23. Walk back along the highway and down steep bank to the creek.

Stop 4. Onondaga Formation and Bakoven Member of the Union Springs Formation. East bank of Kaaterskill Creek, below the N.Y. Rt. 23A bridge. Type section of the Bakoven Member. PRIVATE PROPERTY.

The stream bed and east bank of Kaaterskill Creek expose the upper 0.85 m of the Onondaga Formation and the lower 27 m of the Bakoven Member of the Union Springs Formation. The abrupt change from shallow marine carbonates to basinal black shales seen in the outcrop mark the onset of Acadian Tectophase II.

Light-weathering, relatively fine-grained limestones with atrypid brachiopods, small rugose corals, and other forms characterize the Onondaga Formation at this locality. The upper 35 cm of limestone appears slightly darker in color and overlies a thin (1-cm-thick) K-bentonite. Key upper Onondaga marker beds (e.g., the Tioga B-OIN bentonite at the base of the Seneca Member) are not seen at this outcrop; it is not known whether the exposed strata belong to the Moorehouse or Seneca Members. A thicker but partially covered outcrop (2.9 m-thick) of upper Onondaga strata occurs immediately north of Rt. 23 east of the bridge.

The Onondaga-Union Springs formational contact is abrupt, and features numerous bored phosphate pebbles and well-defined burrows that are visible in the creek when the water level is low. The contact is overlain by a thin (ca 2-3 cm-thick), highly condensed bed of phosphatized fossil debris (e.g., crinoid ossicles) and fish bone and teeth (NOTE: Please do not collect from the bone bed-this is a classic section and type locality). The bed marks a major sediment-starved flooding surface associated with tectonic subsidence of the Appalachian foreland basin at the onset of Acadian Tectophase II of Ettensohn (1985). For further discussion of this contact, see Ver Straeten et al. (1994) and Lindemann and Feldman (1987).

Overlying rusty-weathering, fissile black shales of the Bakoven Member represent deposition of fine-grained, organic-rich sediments in the proximal subsiding trough of the Appalachian foreland basin. Anaerobic conditions on the sea floor prevented colonization by benthic faunas; only rare leiorhynchid brachiopods and pelagic (?) dacryoconariids (*Styliolina*) and rare cephalopods occur in the shales. Three thin intervals of more calcareous strata (styliolinid packstones) occur upward through the section. The poorly resistant shale features numerous tectonized intervals (small shear zones and mesoscopic folds; Marshak, 1990) and fault surfaces, especially above the Onondaga Limestone in the lower part of the Bakoven Member.

The low valley to the west is floored by the Bakoven Shale, and is partially infilled with Pleistocene sediments. Roadcuts on the west side of the valley exposes the Stony Hollow Member of the Union Springs Formation (not the Mount Marion Formation as reported by Murphy et al., 1980; Marshak, 1990; Cassie, 1990).

Return to cars and proceed ahead (east) on Rt. 23.

51.5	0.2	Pass overturned to steeply-dipping Onondaga Limestone of Stop 3B.
51.6	0.1	Turn right onto Old Kings Rd.-Greene Co. Rt. 47.
51.7	0.1	Schoharie Formation on left.
52.9	1.2	Esopus (?) Formation on right.
53.4	0.5	Catskill Escarpment and Hoogeberg Ridge visible in far and middle distance to right.
53.6	0.2	High Falls Rd. on right; road to scenic High Falls on Kaaterskill Creek, an excellent section of Otsego Member of the Mount Marion Formation.
54.1	0.5	Catskill Escarpment and Hoogeberg Ridge to right.
54.4	0.3	Onondaga Formation on right.
55.7	1.3	Onondaga exposure behind house on left.
56.0	0.3	Watch for "beefalo" in pasture to left of road.
56.3	0.3	Excellent view of Catskill Escarpment, with Kaaterskill Clove visible to right and back a little.

57.5	1.2	Katsbaan Reformed Dutch Church, built 1732. Stone walls dominantly made of blocks of Onondaga Limestone, except front wall (brown-green sandstones of Austin Glen Formation).
58.2	0.7	Intersection with Ulster Co. Rt. 34; continue straight.
58.35	0.15	Turn left onto NY Rt. 32 southbound. Outcrop of Schoharie- Onondaga contact on right after turn (a left turn at the intersection would pass outcrops of the Onondaga Limestone, the Stony Hollow Member (Union Springs Formation), the Otsego Member and undifferentiated upper Mount Marion Formation, and lowest strata of the Plattekill Formation.
58.7	0.35	Saugerties Member (Schoharie Formation) on left.
58.8	0.1	Schoharie-Onondaga formational contact on right.
59.0	0.2	Schoharie-Onondaga formational contact on right.
59.2	0.2	Excellent Mexican restaurant on left.
59.6	0.4	Onondaga Formation on left.
59.7	0.1	Site of 1994 Woodstock Festival on right.
59.9	0.2	Turn left to enter NYS Thruway/I-87 southbound.
59.95	0.05	Get card at toll booth.
60.0	0.05	Merge onto I-87.
60.1	0.05	Long outcrop of the Saugerties Member (Schoharie Fm.) and most complete section of the Onondaga Formation in the Hudson Valley (along both sides of I-87).
60.8	0.7	Large quarry of dark, shale-dominated Berne and Otsego Members (Mount Marion Fm.) on north shoulder of Mount Marion to right.
61.6	0.8	Crest of Mount Marion, highest hill in the Hoogeberg Ridge. Type section of Mount Marion occurs at south end of the ridge, in a high south bank of Plattekill Creek.
63.9	2.3	Outcrop of Stony Hollow Member (Union Springs Fm.) on left.
64.3	0.4	Bridge over Plattekill Creek; outcrop of upper Stony Hollow Member (Union Springs Fm.) or Cherry Valley Member (Mount Marion Fm.) in creek bed on right.
64.9	0.6	Bear right onto exit ramp at Ulster Service Area -**REST STOP.**
65.1	0.2	Re-enter I-87 South.
66.8	1.7	Middle part of Berne Member (Mount Marion Fm.).
67.1	0.3	Cross over Esopus Creek.
67.4	0.3	Cross under N.Y. Rt. 209.
67.5	0.1	Outcrops of Stony Hollow Member along I-87 for next 1.7 mi..
69.1	1.6	Exit from I-87/NYS Thruway at Exit 19-Kingston.
69.9	0.8	Pay toll at booth.
69.9	0.05	Turn right onto traffic circle.
70.0	0.05	Fork right onto N.Y Rt. 28 West.
70.1	0.1	Cross over NYS Thruway/I-87.
70.3	0.2	Bear right onto entrance ramp for U.S. Rt. 209 North.
70.4	0.1	Merge With Rt. 209 North.
70.5	0.1	Long outcrop of Stony Hollow Member, both sides of highway.
70.7	0.2	Hurley Member (type section; Union Springs Fm.) and Cherry Valley Member (Mount Marion Fm.) exposed on left.
70.9	0.2	lower part of continuous section of Berne Member (Mount Marion Fm.).
71.3	0.4	Berne and Otsego Members (Mount Marion Fm.) boundary ~2/3 height up bank on both sides.
71.9	0.6	Berne and Otsego Members in high bank on right.
72.2	0.3	Cross over Sawkill Road.
72.4	0.2	Cross over I-87/NYS Thruway.
72.7	0.3	Bridge over Esopus Creek.
73.5	0.8	Cross over NY Rt. 9W.
73.7	0.2	Outcrops of Esopus and Schoharie Formations on both sides of highway.
74.05	0.35	Outcrops of (in descending order) Glenerie, Port Ewen, Alsen, and Becraft Formations.

74.25	0.2	Outcrops of (in descending order) New Scotland, Kalkberg, Coeymans, and Manlius Formations.
74.5	0.25	<u>Exit right</u> to N.Y. Rt. 32.
74.7	0.2	<u>Turn right</u> onto Rt. 32 and proceed under bridge.
74.8	0.1	<u>Turn right</u> onto entrance ramp for Rtes. 199/209 West.
74.9	0.1	Outcrops of Ordovician Austin Glen Formation on both sides of entrance ramp. <u>Enter</u> Rtes. 199/209 and proceed along road in opposite direction to which you just drove.
75.6	0.7	<u>Pull off highway</u> and park on right.

Stop 5. Esopus and Schoharie Formations. Synclinal exposure on north side of Rtes. 199/209 east of Rt. 9W, north of Kingston.

Outcrops on the north and south side of Rtes. 199-209 expose upper strata of the upper member of the Esopus Formation and the unnamed, Aquetuck, and lower part of the Saugerties Members of the Schoharie Formation. The north outcrop is less weathered, and better displays various features of the strata.

16.3 m of the upper member of the Esopus Formation are exposed at Stop 5. These strata represent siltstones to fine-grained sandstones that cap the formation locally. The laminated unit at the base of the upper member seen in the Catskill region (Stops 1B & 2) is absent at this outcrop, but is partially exposed 0.4 mi. south at the north end of the Hudson Valley Mall (east of Rt. 9W). The contact between the laminated subunit and the overlying bioturbated siltstones to sandstones is sharp at the mall exposure. A continuous, almost complete section of the upper member is exposed along a railroad cut north of O'Reilly Street in southwestern Kingston (Stop #3 of Oliver et al., 1962), where the member totals 27.5+ m in thickness; the contact with the underlying middle member is covered below 5 m of the laminated subunit. The overlying siltstone-fine sandstone subunit totals 22.5 m in thickness, in contrast with 2.9 m at Stop 2 and 0.0 m at Stop 1 in the Catskill area.

The top surface of the Esopus Formation is well exposed on a eastward dipping bedding plane on the outcrop, where well-preserved *Zoophycos* and other trace fossils are exposed. The contact with the overlying unnamed member of the Schoharie Formation is sharp. Scattered quartz and phosphate pebbles are visible in the succeeding strata. The unnamed member at Kingston consists of bioturbated, calcareous, silty mudstones to argillaceous siltstones that total 32 m in thickness. This contrasts with ~45 m at the railroad cut in Kingston and 9.2 m (Stop 2) to 5.0 m (Stop 1) in the Catskill area. Subtle banding is visible in the unnamed member along the outcrop. The prominent black, siliceous marker bed of the unnamed member (black bed" of Oliver et al., 1962; 0.7 m-thick) is visible in the middle of the member along Rtes. 199-209.

The contact with the overlying Aquetuck Member (Schoharie Formation) is gradational. The highest white quartz pebbles in the upper part of the unnamed member were used by Oliver et al. (1962) to define the top of said member. These occur just above the uppermost prominent white band of limestone in the middle of the outcrop.

The siliceous/cherty nature of the overlying Aquetuck Member in the Catskill area and north is replaced by more calcareous strata in the Kingston area. The dark, siliceous, shaly interval near the base of the member is represented by a 3.2+ m-thick interval of blocky-weathering shales and thin limestone bands ~3 m above the base of the member. Prominent "coffee and cream" banding is well-developed in the Aquetuck Member as well as the other members of the Schoharie Formation along the outcrop. White nodular limestone bands in the Aquetuck Member are replaced upward by more continuous, tabular limestone beds in the overlying Saugerties Member.

Return to cars and <u>proceed ahead</u> on Rtes. 199/209.

77.0	1.4	Recross over NYS Thruway.
79.0	2.3	<u>Exit right</u> onto ramp for NY Rt. 28 West.
79.5	0.2	Merge with New York Rt. 28 West.
79.6	0.1	<u>Turn right</u> at stoplight onto Forest Hill Rd.
79.65	0.05	<u>Make an immediate right turn</u> onto City View Terrace.
79.47	0.05	<u>Park</u> along roadside before guard rail across from outcrop.

Stop 6. Bakoven and Stony Hollow Members of the Union Springs Formation. Cut along City View Terrace immediately east of N.Y. Rt. 28.

This roadcut and a subadjacent cut along Rt. 28 expose the upper 10 m of the Bakoven Member and the lower 23 m of the overlying Stony Hollow Member (Union Springs Formation). The Bakoven Shale at Kingston consists of ~100 m of fissile black shale (Rickard, 1989, Ver Straeten et al., in prep.). Similar to Stop 4, the member is nearly barren of fossils; styliolinids, cephalopods, and *Panenka* bivalves comprise the dominant forms found here. The Bakoven Member features numerous deformational structures similar to those at Stop 4, which include several zones of sheared and mesoscopically-folded shales below the overlying resistant strata of the Stony Hollow Member.

The Bakoven-Stony Hollow contact is gradational at Kingston. Calcareous, buff-weathering, thinly laminated to burrow-mottled lower Stony Hollow strata also feature a low diversity, anaerobic to dysaerobic fauna of dacryoconariids and rare, small bivalves and brachiopods. Grain size increases upward through the Stony Hollow Member from laminated claystone-mudstone couplets in the lower part to fine-grained sandstones near the top of the unit. Biofacies upgrade from basinal anaerobic/dysaerobic dacryoconariid-dominated faunas to fully aerobic brachiopod-crinoid-trilobite shallow marine assemblages through the Stony Hollow and Hurley Members. A dysaerobic, dacryoconariid-leiorhynchid brachiopod-cephalopod assemblage in the overlying Cherry Valley Member indicates a return to deeper water conditions associated with transgression. The bottom of the Cherry Valley Member is a sequence boundary at the base of the Mount Marion Formation. The entire Stony Hollow and Hurley Members (type sections) and Cherry Valley Member (eastern clastic facies reference section) are exposed in the immediately adjacent area (see Griffing and Ver Straeten, 1991, p. 247-249).

Return to cars and proceed ahead on City View Terrace.

79.8	0.1	Turn around in parking lot of Potter Brothers Ski Shop and return to Forest Hill Rd.
80.0	0.2	Turn left onto Forest Hill Rd., then turn left onto Rt. 28 East at stoplight.
80.3	0.3	Proceed into right lane.
80.4	0.1	Bear right onto entrance ramp for Rt. 209 North.
80.5	0.1	Merge onto Rt. 209 North.
82.7	2.2	Bear right onto exit ramp for Sawkill Rd.
82.75	0.05	Turn left onto Sawkill Rd.
83.05	0.3	Cross Sawkill Creek.
83.1	0.05	Fork right onto Ulster Co. Rt. 31.
83.15	0.05	Berne Member on left.
83.4	0.25	Outcrop of Berne Member adjacent to outcrop along I-87/NYS Thruway (66.8 mi. of trip).
83.6	0.2	Berne Member on left.
83.7	0.1	Turn left into parking lot of Buzzanco's Greenhouses; park and walk to quarry exposure north of greenhouses.

Stop 7. Berne and Otsego Members of the Mount Marion Formation. Abandoned quarry along Ulster Co. Rte 31, north of Buzzanco's Greenhouses. PRIVATE PROPERTY: contact Mr. Buzzanco at the greenhouses. Locality 3 of Ver Straeten, 1994.

The upper part of the Berne and lower part of the Otsego Members of the Mount Marion Formation (Depositional Sequence 5 of this paper) are exposed in this abandoned shale pit). ~55 m of dominantly dark gray mudstones and claystones crop out in the quarry. Cyclically-occurring shell beds, generally separated by 3-8 m of unfossiliferous mudstones, feature distinctive brachiopod-dominated faunas that in general increase in diversity upward through the interval exposed. These small-scale cycles represent individual parasequences. The strata are also punctuated by packages of thin sandstone beds; recent work shows that most of the shell beds and clusters of thin sandstones have been successfully correlated along the outcrop belt along much of the eastern New York outcrop belt (> 110 km, Kingston to Schoharie; Ver Straeten, 1994).

The base of the quarry lies ~85 m above the top of the Union Springs Formation. Regionally the contact of the Berne and Otsego Members is marked by the occurrence of a richly fossiliferous coral-brachiopod biostrome (Halihan Hill Bed of Ver Straeten, 1994). This bed, which occurs ~12 m up in the quarry section, marks the first known occurrence of the classic fauna of the Middle Devonian Hamilton Group. Regional study indicates the bed represents initial flooding after a significant fall in relative sea level within Depositional Sequence 5; an abrupt contact of the Halihan Hill Bed with underlying claystones is due to local to regional submarine erosion of underlying sand-rich strata during sea level lowstand (Ver Straeten, 1994).

Overlying dark shale-dominated strata mark a return to deeper water settings associated with continued transgression. Low diversity shell beds, characterized by leiorhynchid and *Mediospirifer-Athyris* brachiopod associations characterize a 30 m-thick interval above the Halihan Hill Bed. Shell beds in the upper part of the quarry show an increase in diversity, apparently associated with a decrease in water depth. A package of thin sandstones at the top of the quarry are succeeded locally by a prominent, richly fossiliferous sandstone (up to 2.5 m-thick) that forms the caprock of waterfalls and ridges along the Hoogeberg Escarpment in eastern New York (e.g., High Falls of Kaaterskill Creek, SW of Catskill).

Return to vehicles and <u>return</u> along Rt. 31 to Sawkill Rd.

84.3	0.6	<u>Turn right</u> onto Sawkill Rd.
84.8	0.5	Otsego Member on right. Exposures of middle Mount Marion strata for next 1.0 mi.
85.2	0.4	Cross over Sawkill Creek in village of Sawkill.
85.5	0.3	Hill Rd. on left; road to extensive turn-of-the-century flagstone quarries in upper part of the Mount Marion Formation.
86.15	0.65	Intricately decorated house on right side of Sawkill Rd.
86.5	0.35	Jockey Hill Rd. on left; road to more abandoned flagstone quarries.
87.05	0.55	<u>Turn left</u> onto Morey Hill Rd.
87.5	0.45	Massive sandstones of upper Mount Marion Formation on right.
88.3	0.8	Quarry in upper part of Mount Marion on right behind houses.
88.7	0.4	Roadside cuts in upper middle part of Mount Marion Formation for next 1.0 mi.
89.3	0.6	<u>Turn right</u> onto NY Rt. 28.
89.9	0.6	Upper part of Mount Marion Formation for next 0.3 mi.
90.2	0.3	<u>Turn right</u> into entrance to abandoned flagstone quarries; <u>park and walk</u> up roadway past concrete barriers. Extensive exposures throughout the quarries. this stop will concentrate on rocks along the entrance road and in the upper quarry behind abandoned buildings on quarried cliff.

Stop 8. Upper part of the Mount Marion Formation. Abandoned flagstone quarry north of N.Y. Rt. 28 and east of Onteora Lake. PRIVATE PROPERTY.

This abandoned quarry features excellent exposures of nearshore marine to non-marine transitional deposits in the upper part of the Middle Devonian Mount Marion Formation. The upper strata of the formation are dominated by cyclic alternations of interbedded mudstone-sandstone facies and flaggy-bedded sandstone bodies on the order of 10 m total thickness. The coarser, sand-dominated strata may feature thin beds to lenses of quartz and chert pebble conglomerate. Normal marine faunas (brachiopods, bivalves, etc.) occur through most of the section; however, apparent plant-root traces in some beds indicate periodic subaerial exposure during deposition.

This locality was originally quarried around the turn of the century for bluestone flags that were used in New York City for sidewalks and curbstones; the quarry was reactivated during the 1970's for production of concrete aggregate (Banino, 1987). Two main levels were worked for quarry stone in the past. The main quarry face of the lower level exposes ~9 m of section, which is comprised of: a) a lower, 1.4 m-thick sandstone body; b) a middle 5.5 m-thick unit of interbedded dark gray mudstones and thin sandstones, which coarsens toward the top; and c) 2.0 m of flaggy-bedded sandstones at the top.

The upper level of the quarry features extensive lateral exposures of the flaggy-bedded sandstones. The top 0.5 m of the middle mudstone unit of the lower quarry face are exposed in the floor of the upper quarry, where scattered brachiopods (*Mucrospirifer* and *Devonochonetes coronatus*) and bivalves can be found. A large area of the upper quarry is floored by a 10 cm-thick quartz-rich sandstone with a symmetrically rippled top and common *Cruziana* trilobite traces on the underside of the bed.

The mudstone unit is overlain by conglomerate lenses and/or a pebbly, coarse sandstone bed at the base of the quarry face. The overlying interval (~1 m-thick) is characterized by thin- to medium-bedded sandstones and thin, black, fine-grained, organic- and pyrite-rich beds. These thin (~1-5 cm-thick), recessed interbeds contain abundant plant material, which include lenses of *in situ* root traces; yellow to white mineral crusts (Melanterite and Epsomite?) weather out of the crevices, probably associated with the decay of pyrite. Single valve rhynchonellid brachiopod shells also occur in some of the thin sandstones.

Overlying strata (ca 5 m-thick) are dominated by medium-bedded lithic arenites that appear planar- to cross-bedded. Pebbly lenses occur scattered through the section. Extensive bedding plane exposures of the flagstone interval are visible in the southern part of the quarries, where several unusual trace fossils have been found. A discontinuous but prominent crevice, ~halfway up the flaggy sandstone unit, is bounded by two lighter- and more smoothly-weathering sandstone beds. The upper bed (~40 cm-thick), which forms the caprock of the east wall, appears in side view to feature *in situ* plant root traces. Overlying sandstones are darker and flaggy bedded, similar to the beds below.

The top surface of the sandstone body is rippled (symmetric ripples) and is abruptly overlain by olive-gray colored, crumbly-weathering, sandy mudstones and thin sandstones. Relatively large *Camarotoechia* and *Mucrospirifer* brachiopods occur in the upper part of the sandstones (as densely packed lenses) and the overlying sandy mudstones. North of the quarry, in the woods, a relatively steeply-dipping body of thin, highly trough cross-bedded sandstones overlies the position of the olive-gray shales. It is not clear at present if this unit represents a submarine or subaerial channel-form deposit.

Return to the vehicles and <u>return</u> to Rt. 28.

90.3	0.1	<u>Turn right</u> onto Rt. 28 and continue westward toward the Catskill Mountains.
90.4	0.1	Upper Mount Marion strata.
90.7	0.3	Marine shales in uppermost Mount Marion in small quarry on right.
90.8	0.1	Top of marine section at quartz-rich sandstone at base of exposure on left hand side (= top of Mount Marion Fm.); overlying thick sandstones are in the succeeding Ashokan Formation.
91.3	0.5	Intersection with Zena (on right) and Rock (on left) Rds.
91.7	0.4	Exposure of Ashokan Formation on right side.
92.2	0.5	Intersection with NY Rt. 375 (to Woodstock); proceed straight on Rt. 28.
92.6	0.4	Outcrops of Plattekill Formation on left and right; lowest redbed exposures along Rt. 28.
92.7	0.1	Plattekill Formation on right.
92.9	0.2	<u>Pull off</u> to right side of road and <u>park</u> at outcrop.

Stop 9. Plattekill Formation. Cuts along N.Y. Rt. 28, 0.7 mi. west of intersection with N.Y. Rt. 375.

This outcrop of red, green, and olive mudstones (lower part) and medium-gray, cross-bedded sandstones (upper part) of the Plattekill Formation are a gross generalization of facies that characterize the remainder of the Middle and Upper Devonian of the Catskill Front. The lower 5 m of green, green-mottled red, and red mudstones feature calcrete nodules, indicative of development of paleosols on subaerial flood plains. Plant fossils and root traces are visible throughout much of the section; distinctive weathering styles appear to characterize different paleosol units along the outcrop. Overlying olive-weathering mudstones (~1.5-3.0 m-thick) are erosively capped by ~4 m of planar cross-bedded, lithic arenites that represent deposition within a migrating fluvial channel.

Pedersen et al. (1976) reported a zone of deformation in a paleosol horizon ~2.5 above the base of the section . These structures on close examination appear to resemble separate, low angle, basin- or bowl-shaped structures ~0.5 to 1.0 m in diameter. They are similar to "pedogenic slickensides" described from redbeds of Silurian-, Devonian-, and Pennsylvanian-age by Gray and Nickelsen (1989). Slickenlines on the bottom-side of the structures visibly radiate outward and upward through 180^0 laterally on the outcrop. Pedogenic slickensides form in modern vertisols associated with seasonal wetting and drying of expansive clays in the B soil horizon (Gray and Nickelsen, 1989; Ciolkosz et al., 1979).

The succession of events for Stops 4 and 6-9 and overlying strata are summarized here (see Figure 4). Six major depositional sequences are recognized above (and including) the top of the Onondaga Limestone in New York State (see body of paper above). These sequences correspond to five formation-level subdivisions of the Hamilton Group (upper Onondaga and Union Springs Fms., Mount Marion/Oatka

Creek Fms., Skaneateles Fm., Ludlowville Fm., and the Moscow Fm., Sequences DS4-8, respectively) and the overlying Tully and Geneseo Formations (Sequence DS9). In the Catskill Front, marine rocks of Sequences DS4 and DS5 feature recognizable transgressive and highstand systems tracts (see body of paper). Strata of the overlying Sequences DS6-9 are fully non-marine; no sequence stratigraphic framework for these fluvial-dominated rocks has been proposed (however, see Bridge and Willis, 1994).

A larger-scale set of trends related to Acadian Tectophase II are superimposed onto Depositional Sequences DS4-9. Widespread, intrabasinal carbonate deposition during the late, quiescent stage of Acadian Tectophase I (Onondaga Limestone) is succeeded by a thick, wedge-shaped body of siliciclastics associated with Acadian Tectophase II (Hamilton Group). The progression of Tectophase II is characterized by: 1) onset of renewed tectonism accompanied by increased volcanism and deposition of the Tioga Bentonites, subsidence of a proximal foredeep (eastern NY) and uplift of a peripheral bulge (western NY), and transport/deposition of initially fine-grained black shale. This was followed by the onset of progradation of progressively coarser clastic marine sediments into eastern New York (Union Springs and Mount Marion Fms.); 2) decreased tectonism in the Acadian orogen and progradation of non-marine facies into eastern New York (Ashokan, Plattekill, and Manorkill Formations). Decreasing siliciclastic input is indicated by a general upward increase in carbonate content in upper Hamilton Group strata in central to western New York (Ludlowville and Moscow Fms; this trend is analogous to general trends through the Schoharie Formation during Tectophase I); and 3) a return to tectonic quiescence and low relief of tectonic highlands in the late Middle Devonian, indicated by deposition of intrabasinal limestones (Tully Formation). Stages 1-3 comprise Acadian Tectophase II as it is developed in New York State. Onset of black shale deposition in the latest Middle Devonian (Geneseo Formation) marks the onset of Acadian Tectophase III.

END OF TRIP:

If traveling southbound, return east on Rt. 28 to I-87/NYS Thruway southbound.

If traveling north or east/returning to Schenectady, backtrack on Rt. 28 for 0.7 mi. and turn left onto Rt. 375. Follow Rt. 375 to T-intersection at Woodstock, then turn right onto NY Rt. 212 and follow to NYS Thruway northbound at Saugerties. Follow reverse directions of road log along Thruway north.

If traveling west, proceed west on Rt. 28 or follow directions back to Schenectady (above) and continue west on NYS Thruway.