STRATIGRAPHY AND FACIES RELATIONSHIPS OF THE EIFELIAN ONONDAGA LIMESTONE (MIDDLE DEVONIAN) IN WESTERN AND WEST CENTRAL NEW YORK STATE

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INTRODUCTION

The Middle Devonian Onondaga Formation of New York generally represents broad, carbonate platform facies that were deposited in the northern part of the Appalachian Basin during early to middle Eifelian time. Finer-grained, more basinal facies in central New York shallow laterally to the east and west into more biologically productive platform settings toward the Buffalo and Albany areas. Numerous biostromal to biohermal buildups, which include pinnacle reefs in the subsurface of southern New York, are rooted in the shallowest-water basal Onondaga facies.

Carbonates of the Onondaga Formation are characterized by calcarenitic to cherty to argillaceous limestones and minor shales deposited in a shallow epicontinental sea. The formation comprises a generally deepening-upwards succession, but apparently represents two major (third order) transgressive-regressive cycles. It is generally subdivided into four members across New York State (Edgecliff, Nedrow, Moorehouse, and Seneca, from the base upwards; Oliver, 1954; Rickard, 1975). A fifth member (Clarence) has been recognized only in western New York (Ozol, 1964; Oliver, 1966b); we herein designate the Clarence as a local facies of the Edgecliff Member.

The basal contact of the Onondaga Limestone is conformable in parts of eastern New York, but westward becomes unconformable and overlies increasingly older Devonian to Silurian strata. Throughout western and central New York State Eifelian-age strata are underlain by a major sub-Onondaga unconformity, commonly referred to as the Wallbridge Unconformity. The Wallbridge was recognized long ago by Sloss (1963), as one of the major sequence-bounding erosion surfaces in the Phanerozoic of North America. He used it to define the boundary between his Tippecanoe and Kaskaskia Megasequences. In actuality, the sub-Onondaga unconformity in Western New York State is a composite of two to three distinct erosion surfaces which are locally merged (Oliver, 1966c; see below). The nature of the upper contact has long been debated; it appears to represent a westward-younging, sediment-starved, submarine unconformity below overlying black shales at the base of the Middle Devonian Hamilton Group.

Underlying the Onondaga Formation in some parts of west-central to western New York are quartz arenites and minor carbonates of the upper Lower Devonian Tristates Group. These rocks, which include strata equivalent to the Oriskany Sandstone and/or the Carlisle Center and Schoharie Formations of eastern New York, occur sporadically across the region. In the Buffalo region a westwardly-thickening wedge of cherty limestone (Bois Blanc Formation) appears and thickens into southern Ontario.

Limestones of the Onondaga Formation (Figure 1) represent relatively tabular, clean, dominantly biogenically-derived sediments deposited in the northern part of the Appalachian Basin during a period of relative tectonic quiescence. Underlying and overlying clastics (Lower Devonian Tristates Group and Middle Devonian Hamilton Group, respectively) represent terrigenous sediments shed from a rising mountain belt in New England during two separate active "tectophases" of the Devonian Acadian Orogeny (Ettensohn, 1985). The concentration of altered volcanogenic strata (Tioga Bentonites/Ash Beds of Dennison and Textoris, 1970, 1978, 1987) in the upper part of the Onondaga Limestone heralds the

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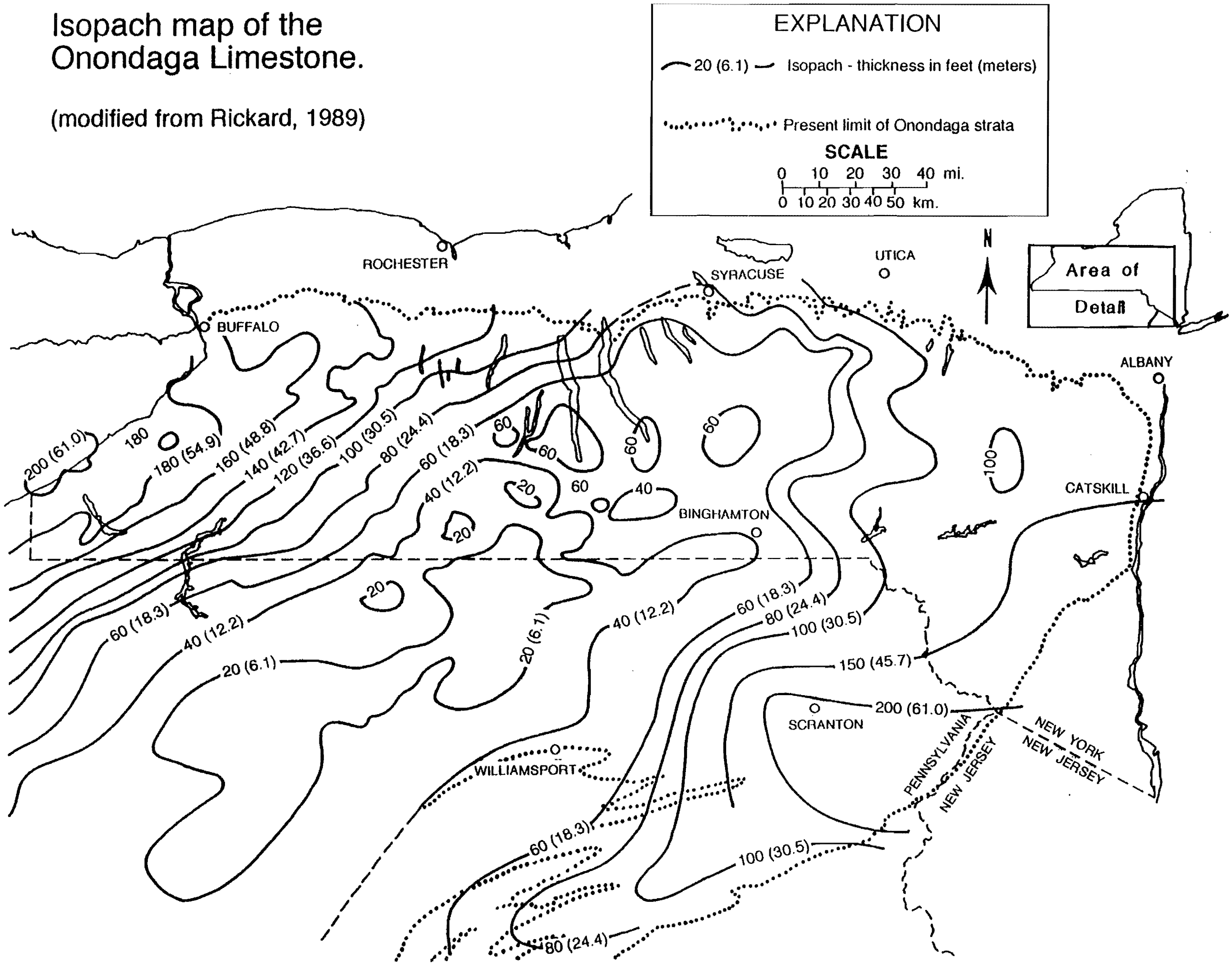
Isopach map of the Onondaga Limestone.

(modified from Rickard, 1989)



progradation of clastic sediments into the Appalachian foreland basin.

Interestingly, the area of maximum erosion and, presumably greatest uplift, during pre-Onondaga Emsian time experienced an inversion of topography in the early Eifelian. The main basin axis during deposition of the Onondaga Formation was a northeast-southwest oriented trough of active subsidence that intersects the New York outcrop belt approximately at the location of the central Finger Lakes (e.g., Seneca Stone quarry between Seneca and Cayuga Lakes = Stop 6 of this trip), but which migrated eastward through the Eifelian.

In this paper we will examine the following: 1) a new detailed stratigraphy for the Middle Devonian Onondaga Formation and associated underlying strata in western to west-central New York; 2) the occurrence of the Tioga Bentonites cluster in the Onondaga Formation; 3) apparent lateral shifts in more basinal facies through Onondaga time; 4) a sequence stratigraphic interpretation of the Onondaga and underlying strata of the upper Lower Devonian Tristates Group; and 5) a new regional synthesis of the Onondaga Formation and equivalent strata in the northern and central parts of the Appalachian Basin (New York and Pennsylvania).

GEOLOGICAL BACKGROUND

GEOLOGICAL SETTING

The Onondaga Formation of New York was deposited in the northern part of the Appalachian Basin during a time of relative tectonic quiescence in the early Middle Devonian. Basin topography across New York through much of Onondaga time consisted of three relatively shallow, gently dipping ramps, two in eastern New York that sloped to the southwest into Pennsylvania (Lindemann and Feldman, 1993) and westward into central New York, respectively, and a third that sloped eastward from western New York-Ontario into central New York. The latter two ramps gently dipped toward a central deeper, more basinal northern tongue of the central trough of the Appalachian foreland basin. The main basin axis during Onondaga deposition was a northeast-southwest trending area of more active subsidence that intersects the New York outcrop belt approximately at the location of the central Finger Lakes. Dennison (1985) likened the shape of the Appalachian Basin during much of the Devonian Period to the keel of a boat. The deepest portions of this basin lay south of the New York outcrop belt area, and are probably recorded near Altoona (west-central Pennsylvania) and in the subsurface to the west.

The eastern interior seaway during the earliest Middle Devonian was not restricted to the Appalachian Basin, however; carbonate-dominated strata equivalent to the Onondaga Limestone are widely distributed across eastern North America (Figure 2), from the James Bay region of northern Ontario to southeastern Quebec and Maine to southwestern Virginia to Illinois, and include such units as the Columbus Limestone of Ohio and the Jeffersonville Limestone at the classic Falls of the Ohio River (Koch, 1981).

PREVIOUS WORK

In the American Journal of Science in 1828, Amos Eaton (Eaton, 1828) first reported the "Cornitiferous Limerock" that constitutes the modern day Onondaga Formation. Subsequent work by the first New York Geological Survey (Vanuxem, 1839, 1840, 1842; Conrad, 1837; Hall, 1841, 1843; Mather, 1843) recognized two to four divisions of Eaton's Cornitiferous across New York State. In their final reports they noted three main

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◄ Figure 1. Isopach and outcrop map of the Onondaga Limestone and equivalent strata in the Northern Appalachian Basin (modified after Rickard, 1989).

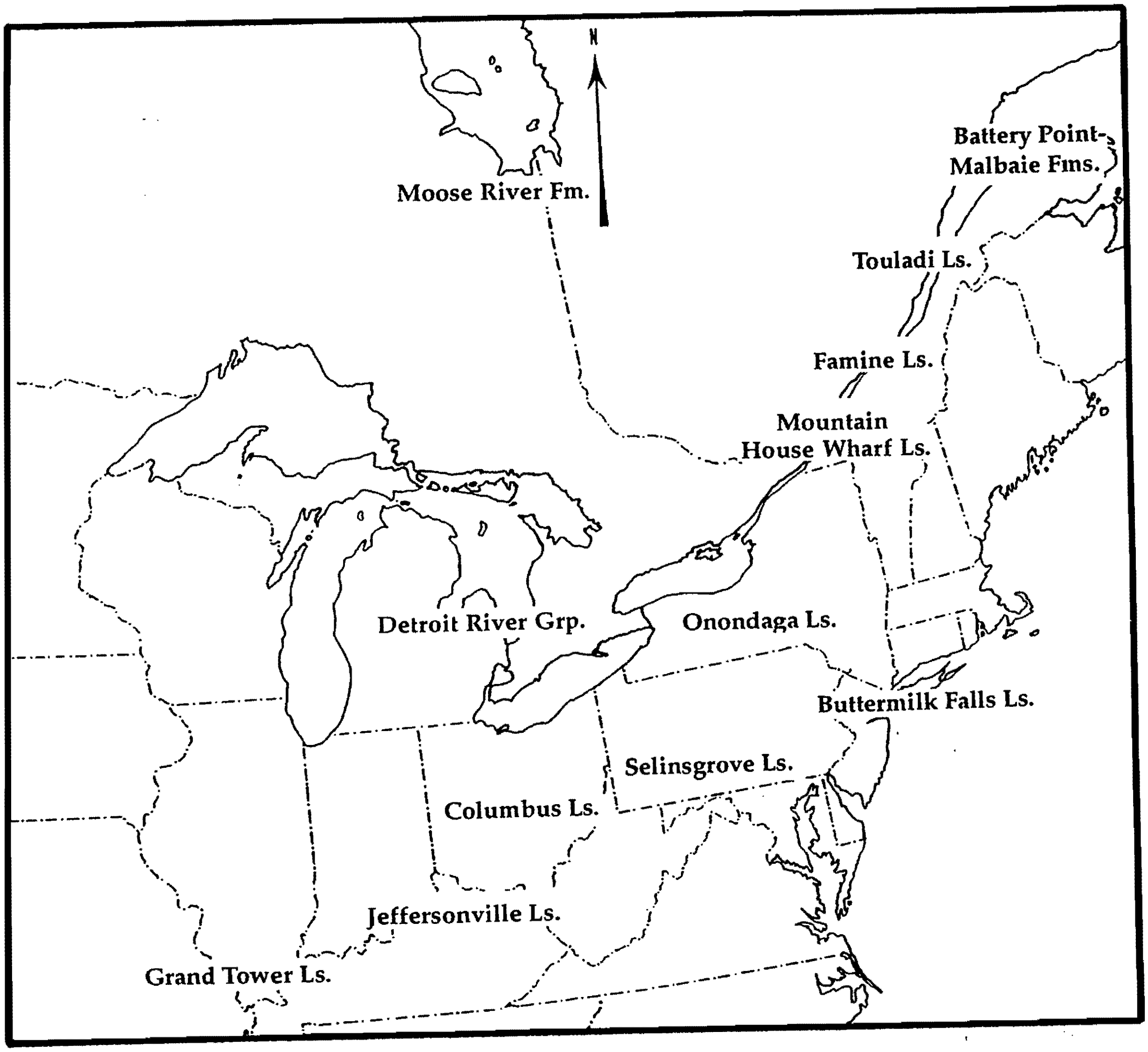

Figure 2. Map of Onondaga-equivalent strata across eastern North America (source=Koch, 1981).

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units: the "Onondaga Limestone" (coral-bearing, crinoidal limestone), the "Corniferous Limestone" (lower shaly and upper cherty units), and the "Seneca Limestone" (with relatively little chert and common chonetid brachiopods). The unit as a whole came to be termed the Onondaga near the turn of the century (for further discussion see Oliver, 1954; Chadwick, 1944).

The first modern stratigraphic and paleontologic study of the Onondaga Formation, upon which all recent study is based, was by Oliver (1954, 1956a; see Figure 3). Oliver subdivided the formation into four members that roughly correspond to the "Onondaga" (= Edgecliff Member), the two subdivisions of the "Corniferous" (=Nedrow and Moorehouse Members) and "Seneca" (= Seneca Member) Limestones of the first New York Survey.

James Hall's classic series, *Natural History of New York: Paleontology* (e.g., Hall, 1867, 1877) included the first comprehensive systematic study of the fauna of the Onondaga

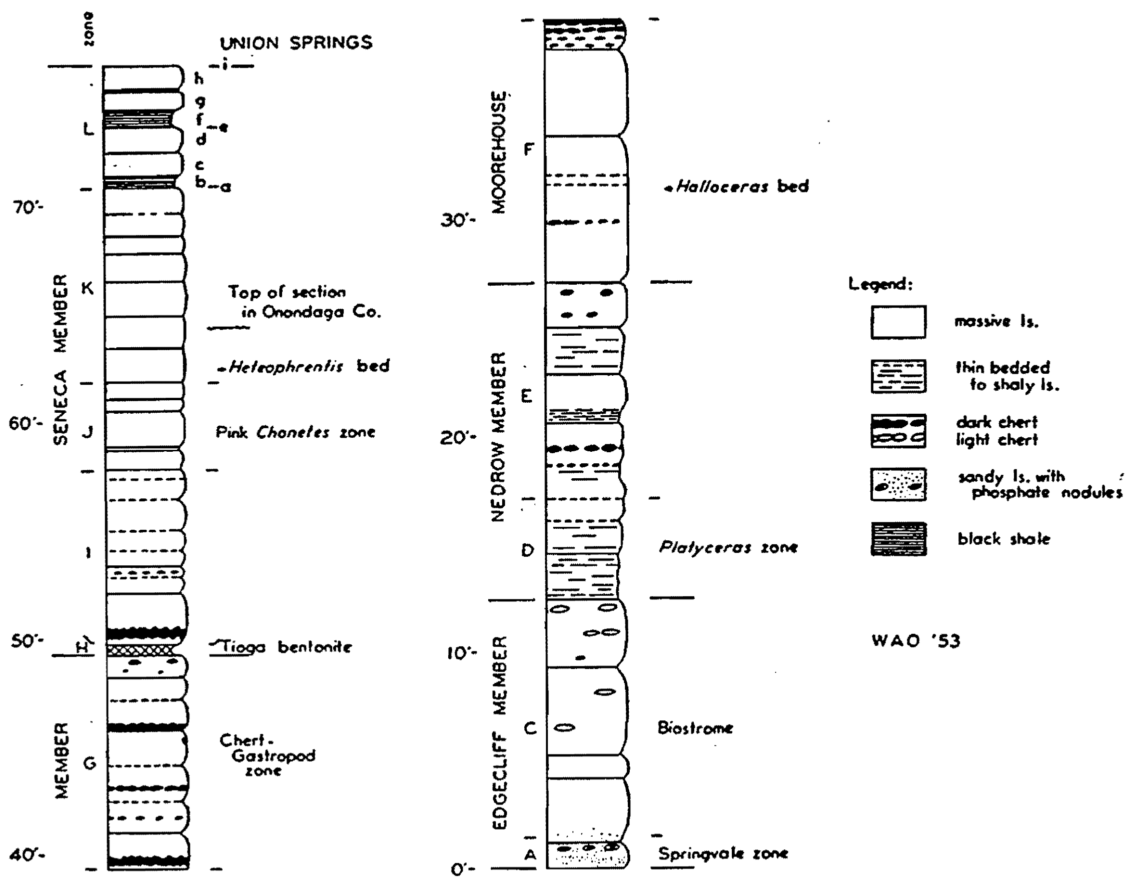

Figure 3. Oliver's (1954) composite section of the Onondaga Formation in the type area in central New York. Measurements in feet.

Limestone. Recent studies since Oliver's classic papers have chiefly focused on the corals (Oliver, 1960, 1976), brachiopods and brachiopod paleoecology (Feldman, 1980, 1985, 1994; Koch, 1981), and dacryoconariids and styliolinids (Lindemann and Yochelson, 1984). Lindemann (1980), Lindemann and Feldman (1981), and Feldman and Lindemann (1986) also examined the paleoecology of the Onondaga across New York and outlined a series of faunal communities.

Coral bioherms have been the focus of much study, in part due to the economic significance of pinnacle reefs in the subsurface of southern New York. Oliver's (1956b) report on bioherms and biostromes in eastern New York State was the first of many papers, most notably by Wolosz (1988, 1992), Wolosz and Paquette (1988), Kissling (1981), Kissling and Coughlin (1979), and Cassa and Kissling (1982); in addition, local bioherm buildups along the New York outcrop have been the subject of numerous master's theses since the 1960's (e.g., Coughlin, 1981; Poore, 1969).

Carbonate lithologies and detailed facies analysis of the Onondaga have been addressed by Lindemann (1980) and Lindemann and Feldman (1981). Additional petrologic study of the formation has focused chiefly on limestone (Lindholm, 1967, 1969a) and dolomite (Lindholm, 1969b; Selleck, 1985), chert (Ozol, 1964; Selleck, 1985; Maliva and Siever, 1989; Moyer, 1956), and clay mineralogy (April et al., 1984).

BIOSTRATIGRAPHY AND AGE

The Lower-Middle Devonian (Emsian-Eifelian) boundary was long placed at the base of the Onondaga Limestone in New York. Recent definition of the global Emsian-Eifelian stage boundary by the Subcommission On Devonian Stratigraphy, however, raises questions on its placement in New York. The latest statement, from Kirchgasser and Oliver (1993), places the boundary at or near the base of the formation, although they state that it could lie as high as the base of the Nedrow Member (the tenuous placement of the boundary is due to a lack of diagnostic conodonts in the Edgecliff Member).

Biostratigraphy of the Onondaga Formation is discussed in a series of papers in Oliver and Klapper (1981) and is summarized here. Goniatite biostratigraphy is poorly restrained for the Onondaga Limestone, with only one species reported. The entire formation is placed within House's (1981) goniatite Fauna #3. Klapper (1971, 1981) reports two conodont zones within the Onondaga, the "*patulus*" and "*costatus costatus*" zones. The former occurs within the lower part of the formation, from an unknown base (noted above) through the lower part of the Nedrow Member; the latter includes the upper part of the Nedrow Member through the top of the Onondaga. Klapper states that a fauna from low in the overlying Union Springs could be in either the *costatus costatus* or the younger *australis* zone.

The Edgecliff, Nedrow, and lower part of the Moorehouse Members occur in the upper part of the *Amphigenia* Assemblage Zone, in the upper of two subzones, the *Fimbrispirifer divaricatus* subzone (=large *Amphigenia* Zone; Dutro, 1981). Upper Moorehouse and Seneca strata are within the overlying *Paraspirifer acuminatus* zone. Oliver and Sorauf (1981) summarize the rugose coral biostratigraphy for the Onondaga Formation, and report two Assemblage Zones (*Acinophyllum segregatum* zone and an unamed zone). The first is broken into two subzones which include the Edgecliff (*Synaptophyllum arundinaceum* subzone) and the Nedrow-Moorehouse Members (*Eridophyllum seriale* subzone).

PALEONTOLOGY AND FAUNA

Brachiopods, corals, bryozoans, trilobites, and gastropods are more common elements of the fauna of the Onondaga Limestone. Their distribution varies throughout the formation with changes in lithofacies. Pelmatozoans, generally represented by disarticulated crinoid material, are common through parts of the formation, most notably in coarser facies where crinoid ossicles may be 1-2 cm in diameter and form crinoidal grainstones. Styliolinids are common in finer-grained facies, and may compose up to 95% of the rock (Lindemann, 1980).

Lindemann (1980) analyzed the fauna of the Onondaga and recognized nine communities within the formation across New York. Of these, two are dominated by corals, two by bryozoans, three by brachiopods, and one by trilobites; the additional community is split between a diverse brachiopod fauna and numerous corals. Lindemann also noted that the ichnofauna and degree of burrow-mottling varies throughout the formation. Coarser-facies communities feature occasional vertical burrows, while finer-grained, calcisiltite-rich assemblages may feature a diverse and abundant ichnofauna, generally dominated by *Chondrites.* Intense bioturbation occurs in some facies, and the ichnofauna is indistinguishable. Additional community analysis by Feldman (1980; Lindemann and Feldman, 1987) focuses specifically on the brachiopod communities of the Onondaga across New York.

Changes in communities through the Onondaga, as discussed above, are dominantly associated with tracking specific facies. Overall, the fauna of the Onondaga is very stable throughout the late Emsian to early Eifelian; Feldman (1994), in a recent monograph on the brachiopod fauna, states, "...taxa found in the Bois Blanc-Onondaga interval indicate a high degree of stasis." Dutro (1981) also recognizes, "the general unity of the Schoharie and Onondaga" brachiopod faunas, a fact he states was previously recognized by Cooper. Reportedly more than 80% of Schoharie brachiopod species persist into the Onondaga despite more marked changes in other taxa such as trilobites and cephalopods. A much smaller proportion of the brachiopods (no more than 10% of species) and very few of the trilobites, mollusks, or echinoderms of the Onondaga Formation, however, persist into the overlying Hamilton Group.

Several authors in recent years have interpreted a cooler, warm temperate setting for the Appalachian Basin during Oriskany to Onondaga time (Koch and Boucot, 1982; Boucot, 1990). Based on the lack of abundant stromatoporoids, stromatoporoid-dominated bioherms, oolites, dasycladacean or udoteacean algae, and a lower diversity gastropod fauna, Blodgett et al. (1988) infer a probable warm temperate environment for the Northern Appalachian Basin during the early Eifelian Stage. Koch and Boucot (1982) reach similar conclusions based on the paucity of gypidulinid brachiopod-dominated communities in the Oriskany to Onondaga Formations of the Appalachian Basin. Furthermore, in examination of Edgecliff reefs across New York and Ontario, Wolosz (1990a,b) reports a westward trend of increased size and abundance of stromatoporoids in the direction of the Devonian paleoequator.

Faunas across the Appalachian Basin from the Oriskany to Onondaga Formations show more affinity with colder, temperate Malvinokaffric Realm faunas than with warmer subtropical to tropical faunas of the more equatorward Old World Realm (Boucot, 1975, p. 327-331). This affinity breaks down, however, in the overlying Marcellus succession, and warmer subtropical faunas immigrate into the Appalachian Basin (see discussion in Ver Straeten et al., this volume)

THE LOWER DEVONIAN TRISTATES GROUP IN CENTRAL TO WESTERN NEW YORK STATE

Pragian- to Emsian-age strata of the upper Lower Devonian Tristates Group are poorly represented in west-central to western New York. In eastern New York these strata are chiefly represented by the Oriskany-Glenerie, Esopus, Carlisle Center, and Schoharie Formations and range up to 300 m in thickness (Rickard, 1989). The Tristates Group is thin to locally absent across the central to western part of the state and is generally represented by sand-dominated facies, with a wedge of limestone facies appearing in the Buffalo area that thicken westward into Ontario.

Quartz arenites of the Pragian-age Oriskany Formation and equivalent strata occur widely across eastern North America and comprise the basal sandstone of Sloss' (1963) Kaskaskia Megasequence. Large, robust brachiopods and other forms characterize the Oriskany Formation. Erosional remnants of the Oriskany Sandstone occur sporadically across west-central to western New York. Across much of the area, however, post-Oriskany processes removed and reworked the quartz sand during Emsian and/or earliest Eifelian time.

Younger, thin, upper Tristates sandstones, sometimes termed "Springvale Sandstone," also occur sporadically across the region. These are better exposed in the Syracuse region where they are represented by approximately 2-3 m of glauconitic and phosphatic to clean quartz arenites, which may locally be hematitic. Thin sandstones also occur locally at the base of the Onondaga Formation in the region (for more discussion, see below).

A thin wedge of upper Tristates limestone, the Bois Blanc Formation, occurs locally in western New York (Oliver, 1966a&c, 1967). The Bois Blanc is a dark gray, brachiopod-rich limestone (Boucot and Johnson, 1968) with numerous corals. It is finer grained than the overlying Edgecliff Member of the Onondaga Limestone. The Bois Blanc ranges from 0-1.3 m across western New York; it thicken westward into Ontario, and is 30 m in thickness at Woodstock, Ontario. The Bois Blanc Formation is equivalent to the Schoharie Formation of eastern New York.

THE ONONDAGA FORMATION IN WESTERN TO CENTRAL NEW YORK STATE

PHYSICAL STRATIGRAPHIC SUBDIVISIONS OF THE ONONDAGA LIMESTONE

Introduction

The subdivision of the Onondaga Limestone into members was completed largely as a result of the detailed studies of Oliver (1954; see Figure 3). Part of our work is focused upon the Nedrow-Seneca interval of the Onondaga in an attempt to correlate it westward from the type area south of Syracuse into western New York. This has resulted in discovery of several key marker beds, most notably a pair of dark shales and a fossil-rich bed overlain by thin clay-rich notches that may be K-bentonites. These markers have been correlated, not only into western New York, but subsequently into eastern New York State and into the Selinsgrove Limestone of central Pennsylvania. In the following sections, the various members of the Onondaga will be described in some detail, followed by a sequence stratigraphic interpretation of Onondaga stratigraphy.

Onondaga Formation - Overall Thickness And Facies

The Onondaga Formation in western and west central New York State (Figure 4) consists of approximately 18 to 50 m (Rickard, 1989; Figure 1) of light to medium gray-weathering and commonly cherty limestone. The lower Edgecliff Member and portions of the Moorehouse Member are characterized by a crinoidal pack- and grain-stone lithology with local micritic bioherms or patch reefs developed in the Edgecliff Member and biostromes of fasciculate corals, particularly *Eridophyllum* and *Synaptophyllum*, in the Moorehouse Member. These coarser-grained facies are typically non-cherty, or contain only small, gray chert nodules.

The most chert-rich portion of the Onondaga Limestone consists of up to 10 meters of micritic argillaceous wackestone (calcisiltite) interbedded with medium to dark gray cherts. This facies is particularly well developed within the upper part of the Edgecliff Member (Clarence facies) where chert nodule-rich beds and nearly continuous chert bands may constitute nearly 50% of the volume of the rock. Similar facies occur in the Moorehouse Member in western New York.

Lindholm (1967) recognized two fine-grained subfacies within the Moorehouse and Seneca Members based upon the percentage of clay; these were the fossiliferous calcisiltite with about 5% clay and biocalcisiltite with a smaller amount of clay and about 10 to 50% fossils. The latter facies appear to become dominant upward in the Moorehouse and Seneca Members of Western New York State, as well as in the upper Moorehouse of the Albany region. Finally, in the Nedrow Member, Lindholm recognized a fossiliferous calcisiltite with about 25% clay and less than 10% fossils.

Isopach maps for the Onondaga (Mesolella, 1978: Rickard, 1989; see Figure 1) demonstrate that the basin axis trend was associated with areas of minimal thickness for the Onondaga in south-central New York State. The outcrop expression of these more basinal facies indicates that they are composed mainly of argillaceous lime mudstones

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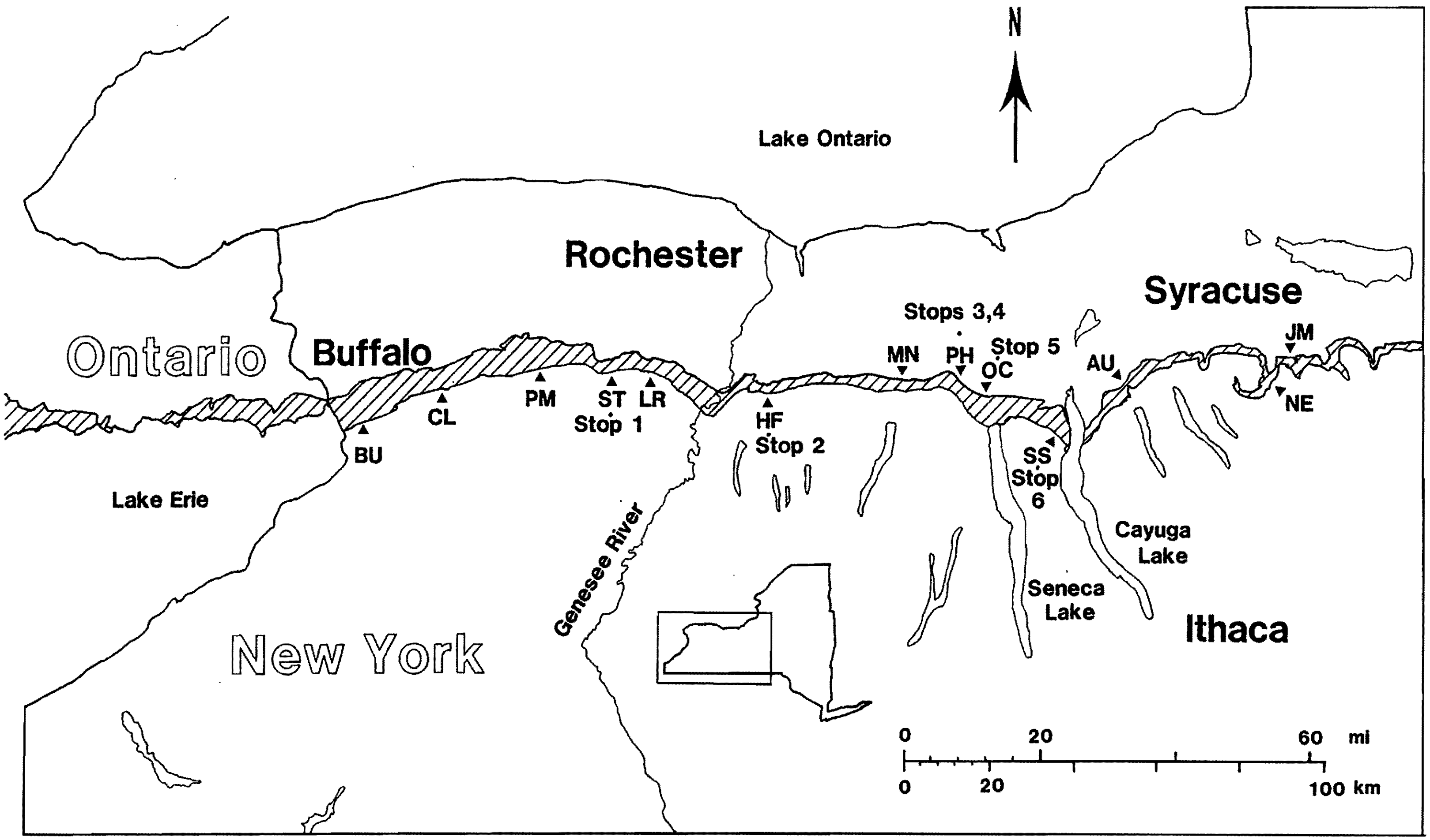
Figure 4. Outcrop map of the Onondaga Formation in west-central to western New York (modified after Rogers et al., 1990). Localities are as follows: BU=Buffalo, CL=Clarence, PM=Pembroke, ST=Stafford (Stop 1 of fieldtrip), LR=LeRoy, HF=Honeoye Falls (Stop 2 of fieldtrip), MN=Manchester, PH=Phelps (Optional Stops 3&4 of fieldtrip), OC=Oaks Corners (Stop 5 of fieldtrip), SS=Seneca Stone quarry (Stop 6 of fieldtrip), AU=Auburn, NE=Nedrow & Onondaga Indian Nation, JM=Jamesville.


N
Lake Ontario
Rochester
Syracuse
Ontario
Buffalo
Stops 3,4
Stop 5
MN
PH
OC
AU
JM
NE
CL
PM
ST
LR
Stop 1
BU
HF
Stop 2
SS
Stop
6
Lake Erie
Genesee River
Cayuga
Lake
Seneca
Lake
Ithaca
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0
20
60
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(biocalcisiltites or wackestones) interbedded with thin shales, particularly in the central portion of the Onondaga Formation. These light-weathering, micritic limestones are only slightly cherty relative to facies both east and west of the basin center area and carry a sparse fauna comprised mainly of dalmanitid trilobites and small brachiopods. Litho- and bio-facies of these more argillaceous rocks closely resemble the Onondaga-equivalent Selinsgrove Limestone (member of the Needmore Formation) exposed in cuts along the Susquehanna River at Selinsgrove Junction in central Pennsylvania, essentially due south of the Seneca Stone quarry. Indeed, detailed correlations (Ver Straeten, unpublished) reveal a precise correlation between meter-scale subdivisions of the Onondaga Limestone of the central Finger Lakes and those of the type Selinsgrove Member in central Pennsylvania. However, sections west of the type area, near the Allegheny Front, reveal that the Onondaga becomes even thinner towards the actual deepest portion of the sedimentary basin and is composed here of a larger portion of dark gray to nearly black shale, particularly in the upper beds (see below).

In the following section, we outline some of the new stratigraphic refinements to each unit of the Onondaga that have resulted from our recent field work. We emphasize those marker beds which can be correlated over considerable distances and which have utility for very detailed event and cycle stratigraphy within the Onondaga Formation.

Edgecliff Member

The Edgecliff Member is widely recognized as relatively coarse, coral to crinoidal-rich, non- to sparsely cherty strata in the lower part of the of the Onondaga Formation. Recent study across New York, and specifically in west-central to western New York, permits a new view of these strata. Our recent work demonstrates that much or all of the Clarence Member of the Onondaga Limestone (Ozol, 1964; Oliver, 1966b) in its type area of Erie County grades laterally into the middle and upper portions of the Edgecliff Member in its type area. Correlation of distinctive marker beds within the Nedrow Member across central to western New York demonstrate that the Nedrow overlies the Clarence throughout the region. Rickard (1975, 1989) originally noted this relationship based on subsurface log analysis. We have observed lateral gradations from non-cherty grainstone ("Edgecliff") to cherty packstone ("Clarence") facies within the wall of a single quarry (east wall of LeRoy Bioherm quarry; see Wolosz, this volume). Clarence facies is present and relatively thick (8.0 to 14 m) from Oaks Corners (Stop 4) westward to Buffalo. It is a very minor component of the Edgecliff interval from Seneca Falls (Seneca Stone quarry, Stop 6) eastward to Albany. However, thick, light-weathering, cherty, micritic facies reappear within the Edgecliff Member to the south of Albany along the Hudson Valley and into the Buttermilk Falls Formation in northeastern Pennsylvania. Because of the interfingering and lateral gradation of cherty, fine-grained limestone ("Clarence") and non-cherty crinoidal packstone, we choose to retain the term Edgecliff Member for the entire interval between the basal contact of the Onondaga Formation and the lowest shaly to argillaceous marker beds of the Nedrow Member. As such we retain the term "Clarence" as an informal name for the cherty, micritic facies that predominate in western <u>and</u> southeastern New York; we also propose the informal term "Jamesville Quarry facies" for the sparsely- to non-cherty crinoidal pack- and grainstones of central to eastern New York. A basal bed or "tongue" of the Jamesville Quarry facies is present in nearly all "Clarence facies"-dominated sections of the Edgecliff Member in New York and equivalent strata in northeastern Pennsylvania.

Near its type locality in the Syracuse area of Onondaga County (e.g., Jamesville quarry), the Edgecliff Member attains thickness of approximately 5.7 m. The member in its type area consists dominantly of chert-poor, crinoidal pack- and grainstone which we informally term the "Jamesville Quarry facies" of the Edgecliff Member. Chert occurs at two intervals locally, as a meter-thick package a short distance above the contact and as distinctive, yellowish-weathering, blue-gray chert nodules approximately 5 meters above the base of the member. The basal contact of the unit is sharp, but appears gradational because of the similar lithology of underlying uppermost Tristates Group strata. These upper 40 cm at the top of 2.2 m of post-Oriskany, Emsian-age strata (=Esopus?, Carlisle Center, and Schoharie Formations?) consist of silty to sandy packstone rich in large brachiopods such as *Amphigenia*. There is no basal Edgecliff fine-grained unit as appears in eastern New York sections (see Oliver, 1956a). The basal Edgecliff at Jamesville is rich in large crinoid columnals and also features a diverse rugose and tabulate coral assemblage. The upper boundary of the Edgecliff is sharply defined by a greenish-gray, silty, calcareous shale, which is rich in small corals, brachiopods, platyceratid gastropods, and other fossils. A similar thin shale layer occurs about 30 cm below the highest typical Edgecliff limestone, which suggests some interfingering of these two lithologies. A cherty interval near the top of the Edgecliff in the Syracuse area may correlate to a thin cherty band observed at the Seneca Stone quarry (see below).

To the west, the Edgecliff Member thins to a minimum of approximately 2.5 m at Seneca Stone quarry (Stop 6; see Figure 5). Here the unit is notably finer-grained, composed mainly of non-cherty, rather massively-bedded, wacke- to packstone. The Edgecliff, however, still carries large crinoid columnals near the base, and again near the top. The basal contact is clearly unconformable, although it appears gradational as a result of stratomictic processes. Lowest Edgecliff strata at Seneca Stone consist of a sandy conglomerate that includes clasts eroded from the Manlius Limestone and, more abundantly, dark, phosphatic sandstone cobbles derived from erosion of underlying Tristates Group strata seen preserved at nearby localities to the east. A thin biostrome just above the conglomerate in the basal portion of the unit is exceptionally rich in solitary and colonial rugose corals and small *Favosites*.

A distinctive 0.5 m-thick band of cherty calcisiltite (micritic limestone with black chert nodules) occurs 1.8 m above the base of the Edgecliff at the Seneca Stone quarry. This is the only trace of Clarence-like, cherty lithology at this section. The uppermost portion of the Edgecliff, which sharply overlies this cherty band, consists of crinoidal wacke- to packstone. The upper contact is sharply defined by an abrupt change to sparsely fossiliferous, medium dark gray, very shaly limestone of the Nedrow Member.

A most dramatic facies change within the Edgecliff Member occurs between the Seneca Stone quarry and the next major outcrop 21 km to the northwest near Phelps (Oaks Corners quarry, Stop 5). At this section (see Figure 5) the Edgecliff interval is much thicker, and

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Figure 5a. Four quarry sections of the lower part of the Onondaga Limestone and associated strata in west-central to western New York. Datum = Nedrow-Moorehouse Members contact. See Figure 4 for quarry section localities. Onondaga Formation lithology = limestone except where otherwise shown. Bold lines = datum or formational boundary; thin lines = member boundaries; dashed lines = various correlated beds. Key: 1=black shale, 2=dark, generally calcareous shale, 3=interval of pyrite nodules, 4=limestone nodules, 5=reworked phosphatic sandstone clasts, 6=nodular to bedded chert, 7=covered interval.

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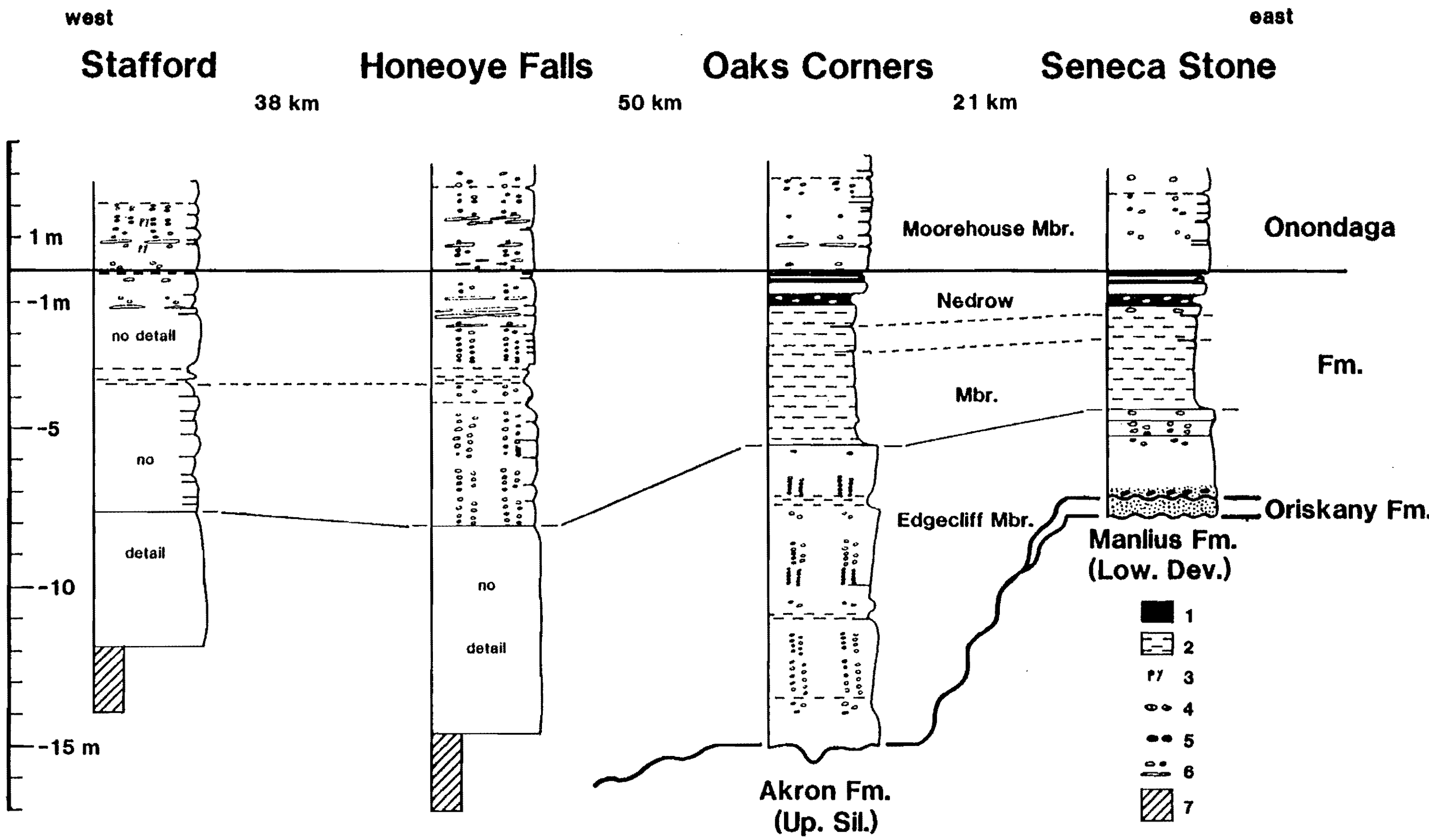
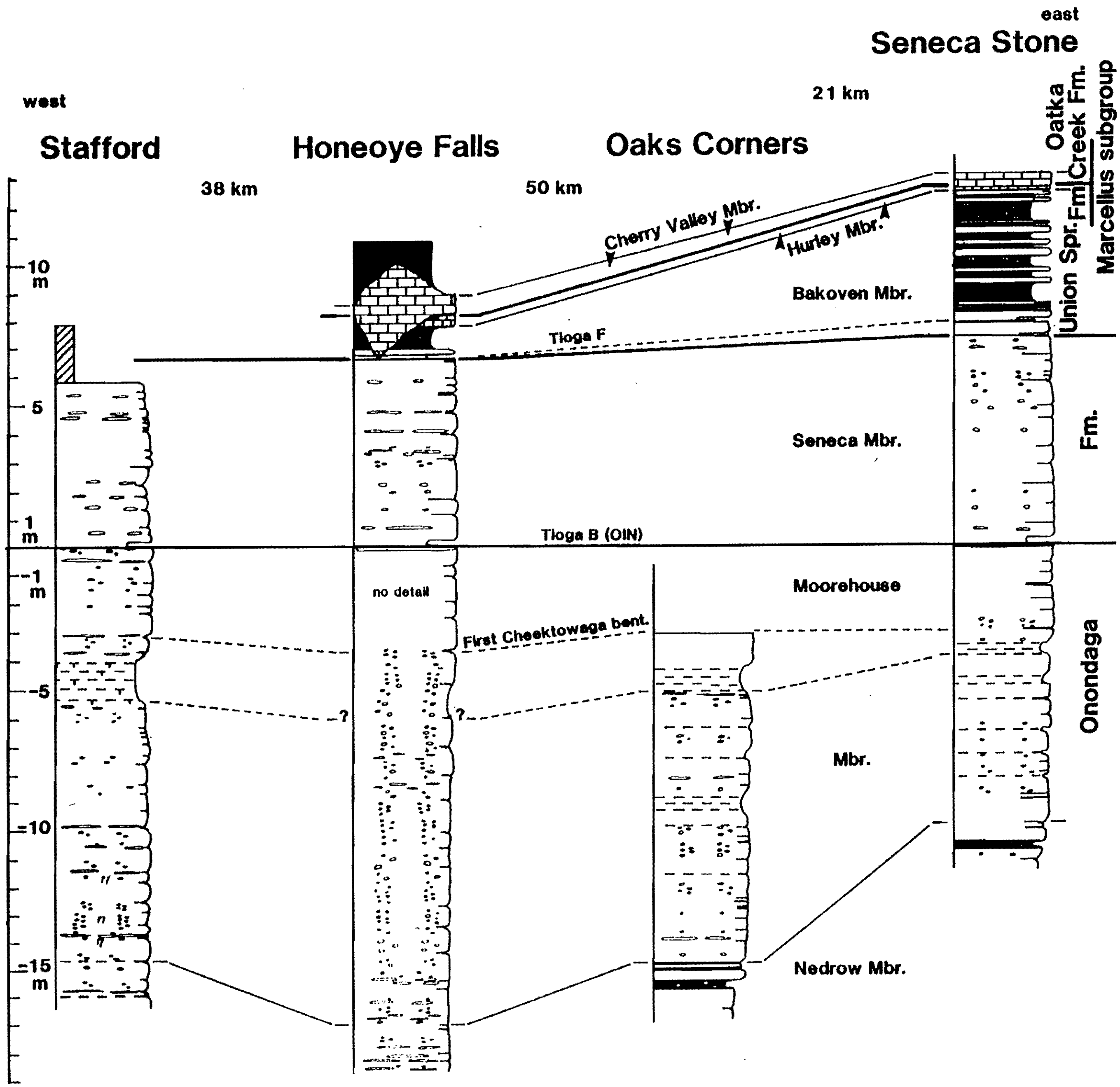
Figure 5b. Four quarry sections of the upper part of the Onondaga Limestone and lower part of the overlying Marcellus Shale in west-central to western New York. Datum = Tioga B (=OIN) Bentonite. Not all chert bands shown for Stafford quarry. Informal revised stratigraphy of the "Marcellus subgroup" after Ver Straeten et al., this volume. For Key see Figure 5a; arrows point to Tioga bentonite beds; q=shale bed with scattered quartz granules to pebbles at Seneca Stone quarry.


west
east
Stafford
Honeoye Falls
Oaks Corners
Seneca Stone
38 km
50 km
21 km
1 m
-1 m
-5
-10
-15 m
no detail
no
detail
no
detail
Moorehouse Mbr.
Onondaga
Nedrow
Fm.
Mbr.
Edgecliff Mbr.
Oriskany Fm.
Manlius Fm.
(Low. Dev.)
Akron Fm.
(Up. Sil.)
1
2
3
4
5
6
7


west
Stafford
38 km
Honeoye Falls
50 km
Oaks Corners
21 km
east
Seneca Stone
Oatka Creek Fm.
Union Spr. Fm.
Marcellus subgroup
Cherry Valley Mbr.
Hurley Mbr.
Bakoven Mbr.
Tioga F
Seneca Mbr.
Tioga B (OIN)
Moorehouse
First Cheektowaga bent.
no detail
Mbr.
Nedrow Mbr.
Onondaga Fm.
10 m
5
1 m
-1 m
-5
-10
-15 m

is comprised primarily of sparsely fossiliferous calcisiltites with abundant bands of dark gray to black chert, closely resembling the typical western New York Clarence facies. The total thickness of the Edgecliff Member ranges from about 8.5 to 9.2 m. This variability is a result of prominent channeling at the base of the unit. Channels with a relief of up to 70 centimeters are cut into the underlying Akron Dolostone. These low spots are infilled with more typical Edgecliff lithology which consists of crinoidal wackestone to packstone up to almost a meter in thickness, but in places as little as 30 cm thick. These are overlain by about a half meter of transitional stylonodular limestone with small, dark chert nodules. The next 3.5 m consist of distinctly cherty, micritic limestone which is capped by about 30 cm of light-weathering, crinoidal packstone which forms a distinct pale gray band in the quarry walls. This crinoidal packstone is abruptly overlain by slightly argillaceous, cherty micritic limestone, resembling that immediately below, which persists through another 2.1 m and is capped in turn by a second light-gray weathering crinoidal packstone that features very large crinoid columnals. This third coarser crinoidal interval is, in turn, overlain by about 0.5 m of dark, gray, non-cherty, argillaceous calcisiltite which closely resembles the typical Nedrow lithology seen higher in the section. This shaly interval weathers to form a distinct notch in the quarry face and is separated from the typical Nedrow by about 1.2 meters of additional Clarence cherty, micritic lithology capped by a sparsely fossiliferous crinoid-bearing wackestone. As at the Seneca Stone quarry, there is an abrupt change from this top bed of the Edgecliff Member into overlying nodular, non-cherty argillaceous Nedrow facies.

The details of the Edgecliff interval are not as clearly shown in quarries to the west. The interval is not exposed in a quarry near Manchester (13 km west of Oaks Corners quarry), and is poorly exposed near the base of the Honeoye Falls quarry south of Rochester. However, in the latter a somewhat comparable thickness of typical cherty Clarence facies has been observed overlying non-cherty Jamesville Quarry facies lithology.

Near Clarence, New York, in the Buffalo area, the Edgecliff Member is approximately 12 to 14 m-thick (Oliver, 1966b) and dominantly consists of the chert-rich Clarence facies. However, previous estimates of the thickness of the Edgecliff in western New York may have included a somewhat cherty, argillaceous interval at the top which we recognize as equivalent to the Nedrow Member to the east. Hence, the Edgecliff which appears abruptly between the Seneca Stone and the Oak Corners quarries, thickens some to the west, and then appears to maintain a more nearly uniform thickness from LeRoy to the area to Erie County . At present, it is not known whether the three small-scale cycles of the Edgecliff clearly recognizable at the Oaks Corners quarry, can be correlated over this region.

Nedrow Member

The Nedrow Member was defined by Oliver (1954) as a thin interval (approximately 4.5 m-thick by original definition) of argillaceous and typically rather fossiliferous limestone, characterized by platyceratid gastropods. The Onondaga Indian Reservation quarry in the Town of Nedrow, south of Syracuse was designated as the type section. The interval was correlated by Oliver, both east and west of this area; however, stratigraphers always encountered difficulty in tracing the unit into western (and eastern) New York. As previously stated, the Nedrow had been interpreted by some authors as laterally correlative with the "Clarence Member" (Clarence facies herein) in western New York (see Buehler and Tesmer, 1963, Oliver, 1966b.) However, later workers recognized that in west-central New York the Nedrow Member in places overlies cherty facies, comparable to Clarence (Rickard, 1975; Lindemann and Feldman, 1981). In most areas, from eastern New York at least to the Seneca Stone quarry (Stop 6), the thin Nedrow argillaceous limestone beds directly overlie pack- to wackestone deposits of the Edgecliff Member with a sharp, but conformable contact. Recently, we have recognized several marker beds within the Nedrow Member that facilitate detailed correlations into western New York sections, where they prove that the Nedrow indeed is a separate stratigraphic unit distinct from the underlying chert-rich strata (Clarence facies) of the Edgecliff Member. The same marker beds also permit correlation into the central part of the Appalachian Basin in Pennsylvania (Ver Straeten and Brett, 1994; see below).

Oliver's original description of the Nedrow-Moorehouse contact in the type area placed the member contact within an interval of interbedded shales and limestones. We have found that the specific bed at the contact is locally correlatable through a detailed bed-by-bed examination, but it is difficult to correlate very far. An informal criterion used to recognize the Nedrow-Moorehouse Member contact outside of the type area has been the position of the lowest dark chert above argillaceous strata; the lowest chert changes position, however, across facies changes, which makes it difficult to recognize a time-equivalent member boundary. The authors have recently recognized a pair of black to dark gray shale-dominated beds within the Nedrow Member that are widely correlatable across a large area of the northern and central parts of the Appalachian Basin (see Pennsylvania discussion below). Due to the ease of recognition and the widespread mappability of the two black shales, we functionally use them as the upper boundary of the Nedrow Member. We do note, however, that Oliver's original position of the Nedrow-Moorehouse boundary may be of significance; that bed has been located at the Seneca Stone quarry (Stop 6), where uncommon quartz pebbles and granules occur within a shaly layer.

Sections at the Oaks Corners and Seneca Stone quarries (Stops 5 & 6; Figure 5) display the Nedrow Member in its apparently most basinal facies along the New York outcrop. At the Seneca Stone quarry, the Nedrow is approximately 4.2 meters thick. It displays a relatively abrupt basal contact with the underlying upper wackestone unit of the Edgecliff Member. The basal shales are typically medium dark gray, but contain scattered fossils, particularly the brachiopods *Pseudoatrypa*, *Leptaena,* and small rugose corals, as well as pyritic burrows. The lower three meters of the Nedrow at this location consist of alternations of medium gray, sparsely fossiliferous, calcareous shales, and gray, somewhat nodular, highly argillaceous and noncherty limestones. Several distinctive crevices within the interval may represent K-bentonite beds.

About three to four meters above of the base of the unit at Seneca Stone, the Nedrow displays four thin (<5 cm-thick) bands of very dark gray shale. A thicker, nearly black calcareous shale band approximately 30 cm-thick forms a prominent marker bed 3.4 m above the base of the Nedrow. The black band locally contains two or more levels of small, ellipsoidal, black chert nodules and a thin middle limestone. This black marker unit, one of the most important regionally correlative beds within the Onondaga Formation, is overlain by a second important marker, a ledge-forming, light gray-weathering, somewhat fossiliferous wackestone 33 cm thick. This band, which is equally traceable, is overlain by an additional distinctive dark gray shale interval, up to about 20 cm in thickness. In detail this thin interval consists of two dark shales separated by a thin limestone bed. Unlike the lower dark to black shaly beds, this unit contains relatively abundant, small- to medium-sized brachiopods, particularly the orthid *Schizophoria*. This unit, informally referred to as the "*Schizophoria*" bed, has been located at least as far east as Syracuse and westward at least to the Manchester quarry. A similar, dark gray, relatively fossiliferous shaly band occurs to the west, and forms an easily recognized upper boundary for the Nedrow Member as defined herein. The triplet of the thick lower black shale, the light-colored middle micritic limestone, and the overlying thin, dark gray shale has recently been correlated throughout much of the northern to central Appalachian Basin (Ver Straeten and Brett, 1994; see below). It is identifiable in the Nedrow of the Syracuse region, in the middle portion of the Selinsgrove Limestone of central Pennsylvania, and in the Onondaga Limestone of the mid-Hudson Valley area of New York (Kingston region).

The Oaks Corners and Seneca Stone quarries (ca. 21 km apart), display very similar Nedrow sections. At Oaks Corners, however, the member overlies Clarence cherty facies as noted above. This quarry section is very significant in that it displays the complete Nedrow interval in context with the Clarence facies, and clearly demonstrates that the Nedrow is a younger stratigraphic unit, while "Clarence" strata represent Edgecliff-equivalent, chert-rich facies. At Oaks Corners, the Nedrow is somewhat thicker (ca. 5.4 to 5.5 m-thick) than in the section at Seneca Falls. The member displays the same distinctive marker beds seen at the Seneca Stone quarry. As previously noted, the basal shales abruptly overlie a crinoidal wackestone at the top of the Edgecliff Member. The Nedrow fauna at Oaks Corners is dominated by atrypid brachiopods, *Leptaena,* and small rugose corals. The lower four meters of the Nedrow consists of rhythmically interbedded calcareous shales and marly nodular limestones. These occur in clusters that appear to define four small scale (ca. 1.1 m-thick) shallowing-upward cycles. Each cycle contains four to five thin nodular limestones with interbedded medium to dark gray calcareous shales. In the upper part of the member there are about three thin, darker gray shale bands that are overlain by approximately 30 centimeters of black, chert-bearing shale, equivalent to the lower black shale marker bed seen at Seneca Stone quarry and elsewhere. The black bed is overlain by a prominent, light-weathering, noncherty micritic (calcisiltite) ledge which in turn underlies the upper marker unit of the Nedrow Member as defined herein, i.e., the *Schizophoria*-bearing dark shale unit. As at Seneca Stone quarry, this unit is characterized by two thin shales surround a middle, 10 cm-thick, argillaceous limestone bed. This horizon forms a prominent parting, and has been used as a lift level in the quarry which provides good exposures for examination of this shale and its small brachiopod fauna.

Excellent exposures of the Nedrow Member occur along Oak Orchard Creek immediately south of Route 96, just west of the Town of Phelps. These display the interval of the lower rhythmically-bedded calcareous shales and nodules (see description of optional Stop 4). The lower shaly beds along the creek contain abundant, well-preserved brachiopods and scattered small rugose corals. Among the prominent faunal elements are robust, articulated specimens of *Pseudoatrypa, Leptaena,* and *Pentagonia.* Upper thin argillaceous limestones and calcareous shales are only sparsely fossiliferous. The upper part of the Nedrow Member, including the black beds, is not exposed at this outcrop.

A comparable succession has been measured at the Manchester quarry, 13 km west of Phelps. Here, the prominent lower dark shale bed displays rusty weathering, somewhat larger, black chert nodules. Again, a shaly parting about 65 cm above displays abundant *Schizophoria,* and other small brachiopods.

To the west, correlation of the Nedrow Member becomes more difficult as the result of rather prominent facies change within the interval. However, at sections in the Honeoye Falls quarry (see Stop 1 description), and in quarries to the west near LeRoy and Stafford (see Figure 5), the interval is still recognizable. It is best displayed in the old Gulf Road quarries approximately 3 km northeast of LeRoy. Here the Nedrow Member is 7.7 m-thick and is distinctly cyclic in appearance. The lower part (ca. 6.0 m) consists of four alternations, which may correspond, in part, to the four small cycles observed at the Oaks Corners quarry. At LeRoy, the cyclic interval consists of fine, sparsely fossiliferous, medium gray calcisiltite with abundant dark gray to black chert nodules that alternate with lighter gray, crinoid- and coral-rich packstones with light gray chert. The base of the unit displays a relatively sharp contact with upper bed of the underlying Edgecliff Member, which carries an abundance of large, chert-replaced tabulate and rugose corals. The basal 20 cm of the Nedrow that overlies this coral bed is a dark gray, nearly barren argillaceous limestone, or very calcareous shale. A thin fossil-rich bed occurs at approximately one meter above the base of the Nedrow, and a second at about 2.5 meters above the base. A third, distinct, 20 to 40 cm thick, light-colored, very fossiliferous coral-rich limestone is overlain by an approximately 70 cm-thick, greenish, more argillaceous unit. This unit can be subdivided into a thin, coral-rich shale bed, a 10 cm nodular limestone and an upper, thin, less fossiliferous shale. Dark gray and somewhat shaly nodular chert layers and an 8-

cm-thick shale about 1.4-1.8 m above the green argillaceous unit are considered to be the probable equivalent of the lower black shale marker bed at the Seneca Stone, Oaks Corners, and Manchester quarries. The shale is overlain by a distinctly light buff-weathering, sparsely cherty limestone (ca. 90 cm-thick at LeRoy and ca. 1.0 m-thick at Stafford). This buff band, which may be subdivided into three intervals, contains scattered corals in a light micritic matrix. It is overlain, in turn, by another thin dark gray shale which appears to correlate with the *Schizophoria* bed at the top of the Nedrow Member at Seneca Stone quarry and other sites.

At present, the Nedrow Member has not been correlated west of the LeRoy-Stafford area. However, gamma ray logs correlated by L.V. Rickard (1989) show a similar signature at the top of the Edgecliff Member in the Buffalo area to that displayed in the known Nedrow section of the LeRoy to the Manchester area.

Moorehouse Member

The Moorehouse Member was named by Oliver (1954) for Moorehouse Flats near the Onondaga prison quarry southeast of Syracuse, New York. At that location, the Moorehouse consists of approximately 12.5 m of medium to dark gray, cherty, fine-grained limestone with thin, very calcareous shale beds and a thicker, more prominent shale about eight meters above the base of the unit. The thick shaly zone is recognized by the authors across New York State and in the Selinsgrove Limestone of central Pennsylvania and the Buttermilk Falls Limestone of eastern Pennsylvania (Ver Straeten and Brett, 1994; see below).

In the study area of west-central New York, the Moorehouse Member ranges from approximately 9.8 m-thick at the Seneca Stone quarry, one of its thinnest sections, to about 14.9 m in the Stafford-LeRoy area (see Figure 5). At the Seneca Stone quarry, the lower 6.4 m of the unit is composed primarily of burrowed, sparsely fossiliferous calcisiltite with a relatively small percentage of black chert. These are bounded by intervals of highly argillaceous limestone or very calcareous shale that seem to define at least six to seven small-scale cycles within the lower Moorehouse. The prominent shaly bands occur at about 1.5 to 1.7 m, 2.5 m, 3.3 m, 4,0 m, 5.0 m, and 6.0 m above the base of the unit. Notch-forming thin clays, which may represent K-bentonites, occur at several levels, notably at 0.95 m and 1.05 m above the base of the member. The thin shales tend to be relatively fossiliferous and contain skeletal debris of small crinoids, trilobites, and brachiopods. Rarely, articulated specimens of the trilobite *Odontocephalus* occur at those bedding planes. In some cases, these thin, fossil hash-bearing shales overlie irregularly burrowed surfaces that represent firmgrounds or possible hard grounds.

Chert becomes more prominent in the upper third of the Moorehouse, overlying the uppermost, prominent calcareous shale bed at 5.9-6.4 m above the base. This shaly unit, which we loosely term the "false Nedrow" shale, is medium to dark gray and somewhat more argillaceous than the remainder of the Moorehouse. In weathered outcrops, the "false Nedrow" appears shaly and is rich in pyritic burrows and small brachiopods. It appears to become somewhat more fossil-rich and more calcareous toward the top. The unit is widely traceable across the northern and central parts of the Appalachian Basin.

Two prominent notches that feature biotite-rich claystones occur at 3.0 m and l.3 m below the upper contact of the Moorehouse. These appear to represent the First and Second Cheektowaga Bentonites of Conkin and Conkin (1979, 1984; Conkin, 1987); the upper bed is the equivalent of the Tioga A Bed of Pennsylvania workers (Way et al., 1986). The highest beds of the Moorehouse Member, immediately below the Onondaga Indian Nation bentonite (OIN; = Tioga B bentonite of Way et al., 1986), contain specimens of the high-spired gastropod *Palaeozygopleura* and the enigmatic tubular fossil *Coleolus*.

At the Seneca Stone quarry, both the upper and lower contacts of the Moorehouse are sharply defined. The base can be drawn unambiguously at the top of the dark gray *Schizophoria*-bearing shale bed which is herein defined as the upper boundary of the Nedrow

Member. As previously stated, this definition of the Moorehouse base differs slightly from that used in the past. A thin shale approximately 2.5 m above the base, within which we have noted several quartz granules and pebbles, appears to correspond to the Nedrow-Moorehouse contact as originally defined by Oliver and shown in Figure 3. The upper boundary of the Moorehouse Member is readily identifiable here, as in most sections, as it is overlain by the 15 cm-thick Onondaga Indian Nation ("Tioga B") K-bentonite. This interval and an immediately underlying black, pyrite-rich, rusty-weathering chert bed form a distinctive marker in the wall of the Seneca Stone quarry. The OIN ash bed forms a prominent notch in the wall, and forms a clear separation from the overlying Seneca Member.

The section at Oaks Corners quarry displays an incomplete section of the Moorehouse Member. Again, its base is sharply defined at the *Schizophoria*-bearing shale beds of the top Nedrow as defined herein. Approximately 6-7 cyclic intervals, each capped by a prominent shale bed, can be recognized at this location and these appear to be correlative with cycles observed in the Moorehouse at the Seneca Stone quarry. The basal Moorehouse unit is a prominent massive limestone interval about one meter thick, overlain by twin beds in thin notches that represent possible K-bentonite beds. Prominent shale beds occur again about 2 and 2.5 meters above the base of the Moorehouse. The upper shale has yielded specimens of the stemless crinoid *Edriocrinus* and well-preserved bryozoans and sponges. A prominent, notch-forming calcareous shale interval about 80 cm-thick occurs at just over four meters above the base of the Moorehouse at this locality. The underlying and overlying beds are massive, light gray-weathering, fine-grained limestone (calcisiltite) with very prominent dark gray to brownish-gray chert nodules generally surrounded by buff weathering, dolomitic rims. A bed 1.4 m below the 80 cm shale carries abundant specimens of the large, coiled, frilled nautiloid *Gyroceras*.

Higher beds in the quarry, approximately 6 meters above the base of the Moorehouse, carry a diverse brachiopod fauna within argillaceous or shaly partings; particularly notable here are abundant *Atrypa*, *Leptaena*, and *Megakozlowskiella*. Trilobites, particularly *Phacops* and *Odontocephalus* are common in this horizon. This assemblage resembles the *Leptaena-Megakozlowskiella* community of Feldmann (1980). The widely recognizable Nedrow-like shale in the upper Moorehouse occurs approximately 10.5-11.5 m above the member base; the uppermost 1.2 m of cherty, fossiliferous limestone in the quarry represent the lower part of the coarser upper part of the Moorehouse Member.

Sections of the Moorehouse Member to the west, at Honeoye Falls and the LeRoy-Stafford area, not only display a thickening of the interval, but also an increased proportion of dark gray, chert-bearing beds, and several levels of crinoidal packstone or grainstone. Complete sections are displayed at both Honeoye Falls and Stafford quarries. At these sites again, the Moorehouse is delineated at its base by fossiliferous shales that correlate with the *Schizophoria* bed at the top of the Nedrow Member further east. The upper boundary is, as at all localities, sharply drawn at the base of the Tioga B-OIN bentonite. In these western localities, the Moorehouse clearly appears divisible into two submembers, separated by the very shaly "false Nedrow" limestone generally about one meter in thickness. The lower interval contains marker beds that appear to be correlative into the shaly caps of the six to seven cycles seen at Oaks Corners and Seneca Stone quarries. The first thin shale bed of the Moorehouse, about 90 cm above the top of the Nedrow Member, contains a diverse fossil assemblage. In the north quarry of the LeRoy Stone Company adjacent to Perry Road, this three cm-thick bed of dark gray, calcareous shale, has yielded an abundant and diverse fauna of brachiopods, including *Elytha, Schizophoria, Megakozlowskiella*, and others, as well as an abundance of small *in situ* stalked rhenopyrgid edrioasteroids (G.C. McIntosh, personal communication, 1990). The paired, thin, possible K-bentonite beds a short distance above the base in other sections may correspond to notches 2.3 and 2.6 m above the Moorehouse-Nedrow contact at the LeRoy quarries.

A prominent marker bed in the LeRoy and Stafford quarries, which occurs at 4.5 m above the base of the Moorehouse Member, is a recessive shaly and hackly-weathering dark chert bed. This may correspond to the interval of dark gray *Pacificocoelia*-bearing shales noted at the Oaks Corners quarry. The interval overlying this chert bed displays a distinctive coarsening-upward facies. About 2 m above the chert layer, in quarries at Stafford and LeRoy, is another very distinctive marker interval, consisting of biostromes of the fasciculate rugose coral *Synaptophyllum* and/or *Eridophyllum*. These thicket-like colonies occur in two beds over an interval of about 0.5 m. The beds are distinctive in that corals colonies are partially incorporated into dark chert nodules, in which the individual corallites stand out because of the contrast of their very light coloration to that of that surrounding chert. This marker bed was previously recognized by Oliver (1966c) and referred to as the *Eridophyllum* beds at Stafford. An interval overlying the coral biostrome bed, about l.25 to 1.5 meters thick, consists of crinoidal pack- and grainstones which are highly fossiliferous. The upper 30 cm of this interval is somewhat more argillaceous and has yielded abundant intact specimens of stalked rhenopyrgid edrioasteroids as well as relatively well preserved crinoids, primarily *Arachnocrinus*, *Tripleurocrinus* and *Schultzicrinus*.. These beds are overlain by argillaceous, *Zoophycos*-bioturbated limestone. This shaly, fine-grained, brachiopod-rich interval correlates with the prominent, thick, widespread, "false Nedrow" shale. Overlying this meter-thick interval of bioturbated, argillaceous limestone are about four to five meters of highest Moorehouse strata that feature chert nodules at several levels and, toward the top, intervals of crinoidal pack- and grainstone. At the Stafford quarry, the First and Second Cheektowaga Bentonites occur 3.6 and 0.5 meters below the top of the Moorehouse Member. As at more easterly localities, an abundance of gastropods and coleolids has been recognized in the highest beds of the member.

Seneca Member

The Seneca Member comprises the uppermost strata of the Onondaga Formation in New York. The name was first applied by Vanuxem (1839) for darker limestones with abundant chonetid brachiopods above the heavily chert-rich "Corniferous Limestone" of the old terminology. The Seneca Member as now defined (Oliver, 1954) is part of a general fining-upward trend that extends from the underlying upper part of the Moorehouse Member into the overlying Marcellus Formation. Smaller scale cyclicity is superimposed on this general deepening-upwards pattern, however. Lateral lithologic trends again show a general coarsening-outward east and west of the central New York trough. The Seneca Member is thickest in the central Finger Lakes Region. Regional trends laterally across the state show a slight thinning westward and a distinct bevelling and cutout of the Seneca Member eastward; the Seneca Member is reportedly absent from the Albany area of eastern New York, but pinches back in southward through the Hudson Valley and southwestward into northeastern Pennsylvania (Rickard, 1989).

The Seneca Member is less well exposed than the underlying Edgecliff-Clarence, Nedrow, and Moorehouse Members. The unit features a relatively low diversity fauna, especially toward the central New York trough. Chonetid and atrypid brachiopods may be abundant, along with less common *Leptaena* and other forms. Rugose corals are generally uncommon. Ostracod/minute brachiopod hash beds occur in some basinward sections. Fine to medium-grained wacke- to packstones dominate the Seneca Member, becoming finer-grained mudstones in parts of more basinal sections. In outcrop the member appears as thick-bedded to massive limestones separated by thin shaly to bentonitic partings. Light-weathering chert is common to rare in parts of the member, and disappears toward easternmost outcrops. Thin dark shales increase in number in the higher part of the unit.

The lower contact of the Seneca Member is sharply defined by the base of the prominent, 15-20 cm-thick bentonitic clay layer termed the Onondaga Indian Nation Ash (OIN; Conkin and Conkin, 1979, 1984; Conkin, 1987; = Tioga B bed of Pennsylvania, Way et al., 1986). It should be noted, however, that Conkin (1987) proposed a placement of the base of the Seneca approximately 0.47 to 1.25 m above the base of the OIN bentonite across New York at the position of a paracontinuity surface and biostratigraphic boundary.

The section at Seneca Stone quarry (see Figure 5) exposes the complete Seneca Member, which may be 7.1 or 8.4 m-thick dependent on the placement of the upper contact with the Union Springs Shale. The 20 cm-thick OIN bentonite lies at the base, overlain by two meters of argillaceous wackestones with a sparse fauna and scattered nodular chert. An overlying interval of upward-coarsening diminutive brachiopod or ostracod shell hash is capped by additional fine-grained limestones. Chonetid brachiopod coquinite beds of the "*Hallinetes* Zone" (Racheboeuf and Feldman, 1990; ="Pink *Chonetes* Zone" of Oliver, 1954) and an interval of small rugose corals that occur about 3-4 m above the base are widely correlatable through central New York. Thin dark shale interbeds begin to appear high in the section, above another coarsening-up package of limestone beds.

The position of the Onondaga-Marcellus contact in the type area of the Seneca Member is treated differently by different authors. The contact is well exposed at the Seneca Stone quarry (Stop 6), 8.5 km northwest the type section of both the Seneca Member and Union Springs Shale immediately south of the village of Union Springs. The debate centers around an interval of transitional strata between the two units which comprise Oliver's (1954) Zone L.

At 7.15 m above the base of the Seneca an apparent discontinuity occurs (base of Oliver's 1954 zone L). The surface of the bed is marked by a small-scale irregular topography and pieces of pinkish weathering, possibly hematitic limestone; overlying dark shale adhering to the surface exhibits scattered phosphatic fish bone fragments. The surface is overlain by fine-grained, dark, styliolinid-rich limestones and thin, interbedded black shales and bentonites that cap the carbonate succession; this post-discontinuity succession (Zone L) was assigned by Oliver (1954) to the Seneca Member. This transitional interval forms the top of the carbonate-dominated part of the section in the high walls of the Seneca Stone quarry. The beds were placed in the Seneca based on faunas found in apparently correlative strata 32 km to the east. Other authors have placed the contact lower in the section either at the 16 cm-thick parting associated with the upper, 12 cm-thick, Tioga "F" bentonite (Clarke, 1901; Cooper, 1930) or at the previously noted irregular burrowed surface 7.15 m above the base (Conkin and Conkin, 1979, 1984; Conkin, 1987). Conkin and Conkin (1979, 1984) also note a widespread bone bed (bone bed #7; Onondaga-Union Springs contact bone bed of Ver Straeten et al., this volume) and discontinuity on this same surface. The authors tentatively follow the usage of Conkin and Conkin, but more attention is needed to resolve the problem.

Two prominent Tioga K-bentonite beds occur: 1) at the base of the Seneca (OIN Ash = Tioga B of Pennsylvania workers); and 2) within the previously discussed transitional interval (7.6 m above OIN) at Seneca Stone quarry. Additional, thinner K-bentonites occur within the member also, chiefly concentrated in its upper part. As many as eight Tioga Ash Beds may occur in the Seneca Member at Seneca Stone quarry.

A complete section of the Seneca Member is also exposed at the Honeoye Falls quarry (Stop 2, ca. 75 km west of Seneca Stone quarry; see Figure 5). The Seneca is thinner at this locality (6.65 m-thick) and has become coarser-grained, composed of crinoidal wacke- to pack-stones; nodular to bedded cherts occur throughout the section. The fauna is more varied, but diversity still is relatively low. Chonetid brachiopods, characteristic of the member in central New York (including the "Pink *Hallinetes* Zone") have not been noted. More typical brachiopods of the Genesee Valley region include atrypids and *Leptaena*. A thin interval of corals occurs in the upper part of the Seneca Member at Honeoye Falls, closely associated with a five cm-thick bentonite bed approximately 1.3 meters below the top. Notably, the top of the Seneca at this locality is relatively coarse, and consists of crinoidal grainstones with numerous *Leptaena* brachiopods.

Approximately 6.65 m of wacke- to packstones of Onondaga-like lithology are capped by a discontinuity surface similar to that seen at Seneca Stone quarry. Resting on that surface in places is a thin veneer of dark shale overlain by approximately 15 cm of coarse, biotitic tuff to soapy, yellow-brown claystone and a thin (ca. 18 cm-thick) interval of styliolinid limestones. A prominent phosphatic lag deposit with scattered fish bone material occurs within the styliolinid limestones interval (discussed in Ver Straeten et al., this volume).

As at Seneca Stone quarry, as many as eight Tioga bentonites may be associated with the Seneca Member at the Honeoye Falls quarry, including the prominent OIN Ash bed and the previously mentioned 15 cm-thick biotite-rich bed in the base of the overlying Marcellus Shale. Notably, coarser-grained parts of the section appear, in some cases, to be concentrated about some K-bentonite beds. Several of the more notable thin K-bentonite beds in the Seneca at Honeoye Falls are discussed elsewhere in this paper with the Tioga Bentonites cluster.

Regional study of the Seneca Member across New York indicates a more complex picture than that of the underlying members. Of five complete sections studied between Honeoye Falls and Cherry Valley (ca. 235 km, west to east), the Seneca Member appears thickest at the Seneca Stone quarry in the central Finger Lakes area (7.15 m-thick). Westward the member thins somewhat to 6.65 m south of Rochester (Honeoye Falls quarry), but there does not appear to be any significant difference in the successions at each quarry. East of Seneca Stone quarry, however, the top of the member is progressively beveled off, from 5.0 m at Jamesville (south of Syracuse) to 3.2 m at Oriskany Falls to 2.0 m at the classic Cherry Valley exposures. No Seneca Member is reported east of Cherry Valley; Rickard (1989, Plate 31) projects a total absence of the unit in the Helderberg-Albany area, and its reappearance southward, where it thickens towards northeast Pennsylvania. Uppermost Onondaga strata are exposed at several localities in the Helderberg-Hudson Valley region in the east, but the prominent OIN bentonite has not been reported.

The junior author has recently found and positively identified several K-bentonite layers in the upper part of the Onondaga in eastern New York. In the Helderberg region two notable bentonites, approximately 8-10 cm-thick, occurs approximately 2-3 m below the top of the Onondaga and at the Onondaga-Union Springs contact. Either bed could potentially be the OIN-Tioga B ash; however, the OIN is generally on the order of 15-25 cm in thickness. On the other hand, all other K-bentonite beds in the Onondaga of New York are thin relative to these beds, rarely up to five cm-thick. At this time, no other marker beds that are associated with the OIN farther to the west have been identified in the Helderbergs. Further work is needed, but if the lower bed does prove to be the OIN, then it is the first report of the Seneca Member east of Cherry Valley.

The eastward cutout of the Seneca Member appears to be associated with a regional submarine unconformity, as stated by Rickard (1984). The progressive eastward loss of upper Seneca strata is confirmed by the disappearance of upper beds of the Tioga interval east of Seneca Stone quarry. It may be notable, however, that black shales of the Union Springs Shale overlie progressively coarser facies in an eastward direction, an indication that shallower platform conditions persisted toward the east through deposition of the lower part of the Seneca Member. The fact that fine-grained black shales overlie relatively coarse deposits in the east, that a phosphatic pebble-bone bed occurs at the contact, and that no bentonite layers have as yet been found in the overlying black shale succession seems to support the idea of a regional unconformity at the top of the Onondaga. The Onondaga-Marcellus contact is discussed in more detail in the accompanying paper by Ver Straeten et al. (this volume).

Reports of the thick, upper Tioga "F" (Tioga "restricted" of Conkin and Conkin, 1979, 1984; Conkin, 1987) immediately above the Onondaga as far east as Catskill are apparently erroneous; the bed appears to be cut out by the unconformity as far west as Jamesville, approximately 65 km east of Seneca Stone quarry.

TIOGA BENTONITES CLUSTER

Geologists' understanding of the package of volcanogenic strata collectively termed the "Tioga Ash Beds" or "Tioga Bentonites" has evolved rapidly over the last 15 to 20 years. Early reports and correlation of a single bentonite layer have now been superceded by recognition of a cluster of K-bentonite layers concentrated within, but not exclusive to, the upper part of the Onondaga Formation and equivalent strata across the Appalachian Basin and eastern North America.

Altered volcanic ashfall strata of Paleozoic age are generally termed K-bentonites (or metabentonites) due to the greater alteration of the original volcanic glass fragments to potassium-rich clays (mixed illite-smectite to illite). K-bentonite beds, generally considered to represent single volcanic ashfall events deposited on the order of hours to days, are ideal isochronous layers important to the stratigrapher. Their use in construction of a high resolution stratigraphy yields crucial data for a detailed basin analysis and for the timing of geologic and biologic events. Furthermore, bentonite layers in foreland basins adjacent to deeply-eroded mountain belts generally preserve the best record of paleovolcanic activity during an orogenic episode.

The prominent Tioga B-OIN bentonite bed that marks the Moorehouse-Seneca member contact in New York was first noted by James Hall (1843) who reported an "unctuous" clay layer in the upper part of the Onondaga Limestone. A possible volcanic origin for the bed was first suggested by Luther (1894). The term "Tioga Bentonite" was first used by Fettke (Ebright et al., 1949; Fettke, 1952) who recognized biotite-rich bentonite in well cuttings, which he used for subsurface correlation in Pennsylvania. Oliver (1954, 1956a) first recognized the bed now termed the OIN Ash (=Tioga B of Pennsylvania workers) in outcrops in New York and used it to mark the base of the Seneca Member.

Dennison was the first worker to specifically focus attention on the Tioga Ash Beds, initially in his Ph.D. work (1960, 1961) and subsequently in a series of papers that address such issues as distribution and isopach thicknesses of the Tioga Bentonites, potential volcanic sources, and even Devonian paleowind directions based on the Tioga ashfall record (Dennison, 1986; Dennison and Textoris, 1970, 1978, 1987). Conkin and Conkin (1979, 1984) have also made major contributions to Tioga studies, chiefly through recognition of numerous additional bentonites in the Tioga interval and their distribution from New York cratonward into Ohio, Indiana, and other areas.

The most detailed analysis of the cluster of Tioga Bentonites within the Appalachian Basin to date is from central Pennsylvania (Smith and Way, 1983; Way et al., 1986). Way et al. (1986) present a microstratigraphic correlation of seven Tioga Ash Beds (Beds A-G) across 280 km of the Valley and Ridge Province in central Pennsylvania (Figure 6). Rickard (1984) presented another correlation scheme for four bentonite beds in the Tioga Interval (Beds A-D) based on subsurface gamma ray log correlation (Rickard, 1984, p. 824, states that his beds B and C merge toward central New York. Field study shows this not

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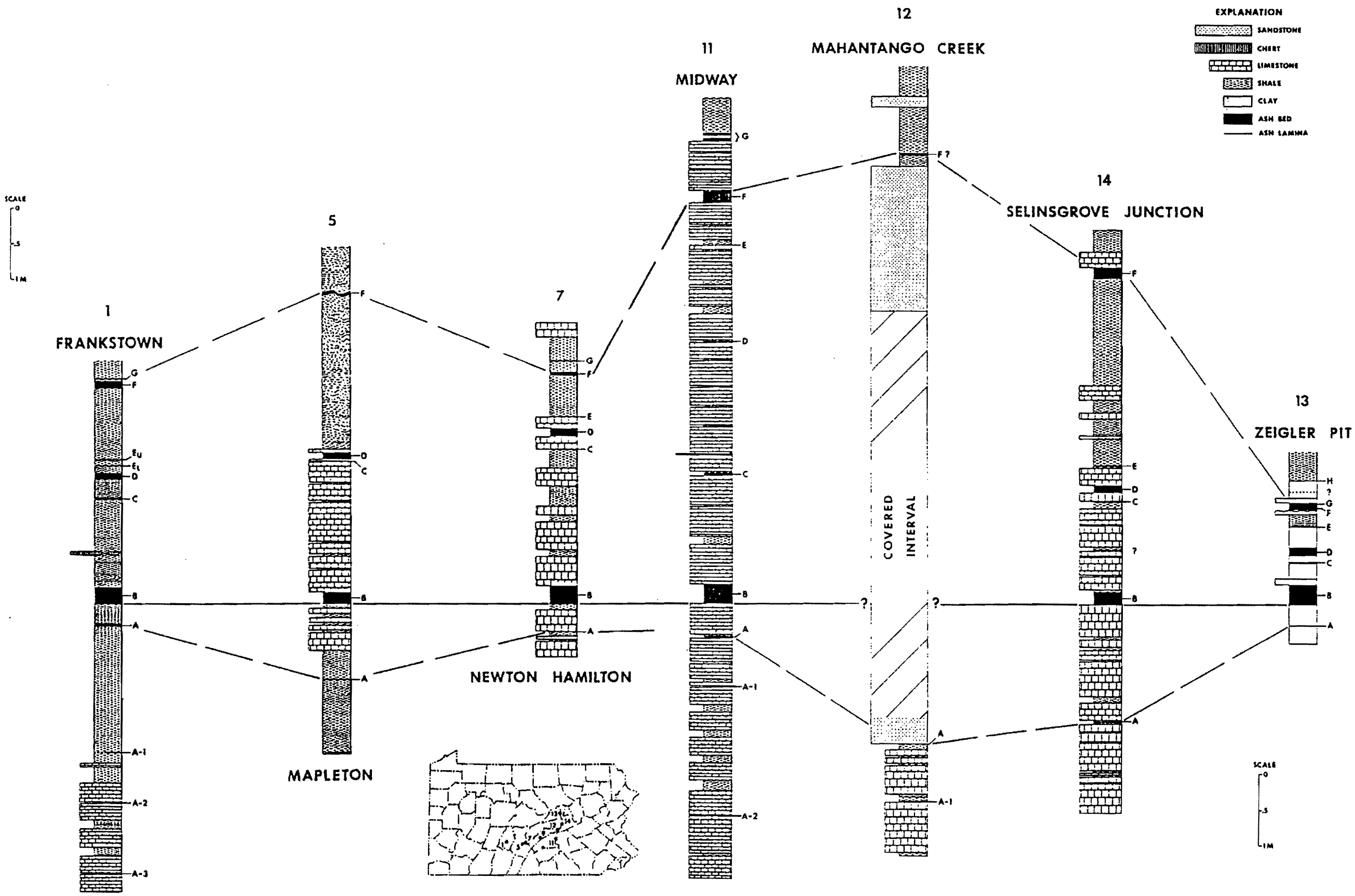
➤ Figure 6. Cross-section of the Tioga Bentonites Cluster across central Pennsylvania (modified from Way et al., 1986). Localities 5, 7, 11, and 12 correspond to Localities MP, MI, MH, and SJ of this paper (Figure 7), respectively.



EXPLANATION
SANDSTONE
CHERT
LIMESTONE
SHALE
CLAY
ASH BED
ASH LAMINA
SCALE
0
.5
1M
1
FRANKSTOWN
5
MAPLETON
7
NEWTON HAMILTON
11
MIDWAY
12
MAHANTANGO CREEK
COVERED INTERVAL
14
SELINSGROVE JUNCTION
13
ZEIGLER PIT
G
F
E_U
E_L
D
C
B
A
A-1
A-2
A-3
F ?
H
?

to be true). Way et al.'s (1986) terminology of Tioga beds A-G is utilized in this paper and is recommended for standard usage in favor of Rickard's scheme due to: a) the problems of translating well log thicknesses to cm-scale outcrop study; and b) the highly detailed resolution of the Pennsylvania workers scheme. The authors also recognize the usefulness of specific names for very distinctive, key beds (e.g., Onondaga Indian Nation (OIN) Ash of Conkin and Conkin, 1979, 1984; Conkin, 1987). The use of the name "Tioga" for a specific bed within the interval (e.g., "Tioga (restricted) Ash" of Conkin and Conkin, 1979, 1984; Conkin, 1987), however, should be suppressed.

Lithology of the Tioga bentonites ranges from coarse biotite crystal tuffs to tuffaceous clays to claystones that generally appear in outcrop as recesses between more resistant carbonate beds. Beds may appear dark to tan to gray or yellow, and leave a slippery, soapy feel when rubbed between the fingers. Biotite, which may appear bleached of color, is commonly recognizable in the field in some beds. Volcanogenic zircons, apatites, and beta quartz fragments are common accessory minerals that aid in positive identification of beds as altered volcanic ashfall layers. Preserved pumice may also be found. Some beds may show distinct layering, as if formed by several different ashfall events. Geochemical analysis of pristine glass inclusions that are found inside of volcanic quartz from the beds indicate a high-K rhyolitic composition of the source magmas (Schirnick and Delano, 1990, 1991).

A key aspect of recent Tioga studies is the recognition of a multiplicity of K-bentonite layers in Onondaga and equivalent strata in New York and across eastern North America. As previously noted, Conkin and Conkin (1979, 1984) and Rickard (1984) report four or more K-bentonites from the Onondaga Formation in New York. The junior author recognizes a number of additional possible K-bentonites in the Onondaga across New York (we state "possible" as some beds appear very similar to other known bentonite layers, but have not as yet been positively identified as such). Approximately eight possible Tioga bentonite beds occur in the Seneca Member and the base of the overlying Union Springs Shale at the Honeoye Falls quarry (Stop 2) and at the Seneca Stone quarry (Stop 6). The OIN bed and the thick bed in the base of the Union Springs (= Tioga "restricted" bed of Conkin and Conkin, 1979, 1984; Conkin, 1987) we correlate with the Tioga B and Tioga F Beds of Way et al. (1986; see Figure 6). Correlations of other beds in the Seneca between New York and Pennsylvania are tentative at this time.

Additional beds occur in underlying Moorehouse, Nedrow, and possibly the Edgecliff Members at these localities, including the First and Second Cheektowaga Bentonites of Conkin and Conkin (1979, 1984; Conkin, 1987) which occur in the upper part of the Moorehouse Member across New York, above the "false Nedrow" shaly interval in the middle of the member. Detailed work by the authors shows that the Second Cheektowaga Bentonite is the equivalent to the Tioga A of Way et al. (1986). Apparent K-bentonite layers in the lower three members of the Onondaga Formation tend to be relatively thin, generally on the order of 1-2 cm or less, rarely up to 5 cm in thickness.

In addition, one of the authors (CAV) has found several previously unreported bentonite beds in the upper part of the Onondaga Limestone of the Helderberg-Hudson Valley region of eastern New York (two of these are discussed with the Seneca Member above). These eastern beds, however, cannot at this time be correlated into central to western New York sections.

The Eifelian-age Tioga Ash Beds represent the youngest of three known Devonian ashfall-rich clusters in the Appalachian Basin. Lower Devonian bentonite-rich strata occur in the Lockhovian-age Kalkberg Formation (Helderberg Group; Bald Hill Bentonites of Smith and Way, 1988) and the late Pragian- or Emsian-age lower part of the Esopus Formation (Tristates Group; Sprout Brook Bentonites of Ver Straeten, 1992, ms. submitted; Ver Straeten et al., 1993) and equivalent strata across the Appalachian Basin. Notably, the Tioga and the Sprout Brook bentonite intervals mark major transitions between platform orthoquartzite-carbonate suites and overlying basinal dark gray to black shales (Onondaga

Limestone to Marcellus Shale and Oriskany Sandstone-Glenerie Limestone to Esopus Shale, respectively). In both cases deposition of ash-rich strata associated with an apparent increase in volcanic activity coincided with subsidence of the foreland basin (Ettensohn, 1985) and a eustatic rise in sea level (Johnson et al., 1985). These events were, in part, concurrent with a flush of fine-grained siliciclastics into the basin during the onset of two separate tectophases of the Acadian Orogeny (Ettensohn, 1985).

Rhyolitic volcanic rocks biostratigraphically equivalent to the Lower Devonian Bald Hill and Sprout Brook Bentonite intervals occur in the Northern Appalachians. However, no volcanic rocks equivalent to the Middle Devonian Tioga bentonites are reported from the Appalachians. Dennison and Textoris (1970, 1978), based on regional isopachs, project a potential source area for the Tioga Ash Beds in northeastern Virginia.

DISCUSSION

ONONDAGA FACIES GRADIENTS AND DEPOSITIONAL ENVIRONMENTS

Dark gray, sparsely fossiliferous, calcareous shales to very argillaceous limestones (Nedrow Member-type facies) appear to have accumulated toward the basin center. These were relatively starved of carbonate input. The source of the siliciclastics remains uncertain. However, the relative increase of shaly strata southward nearer to the main trough of the Appalachian foreland basin in central Pennsylvania suggests a possible southeastward source area. Indeed, the entire Onondaga interval appears to pass into shaly facies in northern Virginia and West Virginia (Dennison, 1960, 1961). The most distal Nedrow-type facies are represented by very dark gray to black, laminated calcareous shales. These facies carry a very sparse fauna of brachiopods (e.g., ambocoeliids), and styliolinids. Slightly lighter gray facies display abundant burrows of *Chondrites.* In places these calcareous shales contain a low diversity of brachiopod-dominated fauna with occasional small, solitary rugose corals, such as *Amplexiphyllum* and small *Heterophrentis.* These biofacies were referred to as the *Amplexiphyllum -chonetes* and *Amplexiphyllum-Odontocephalus* communities by Lindemann (1980); the brachiopod components are assignable to the low diversity *Atrypa* community and rarely to the *Pacificocoelia* community of Feldmann (1980).

The shaly Nedrow facies are interbedded with and grade laterally into argillaceous lime mudstones (calcisiltites) with sparse, typically fragmentary fossil assemblages, including minor crinoid debris, atrypid brachiopods, and, particularly the dalmanitid trilobite *Odontocephalus*. Such argillaceous limestones are typically non-cherty and form blocky tabular to slightly nodular bands, interbedded with calcareous gray mudstones. The sharp contrast in resistance between beds due to varying siliciclastic content has probably been diagenetically enhanced by early cementation of the more carbonate-rich intervals (for similar examples see Eder, 1982; Hallam, 1986; Ricken, 1991). These facies are typical of the Selinsgrove Limestone of central Pennsylvania (Inners, 1975) as well as parts of the Nedrow and Moorehouse members in portions of central New York State.

These fine-grained argillaceous limestones appear to grade laterally in some cases into sparsely fossiliferous lime mudstones which are less argillaceous and display layers and pods of gray chert. The latter typically appears to outline relatively large, branching burrow galleries of *Thallasinoides* type.

The Clarence facies of the Edgecliff Member is typically quite sparsely fossiliferous, although it locally contains medium-sized rugose corals, particularly *Heterophrentis,* fenestellid bryozoans, and brachiopods, such as *Atrypa.* Locally, these cherty facies appear to interfinger with and grade laterally in upramp directions into skeletal wacke- to packstones that are particularly rich in medium to large camerate crinoid columnals (Jamesville Quarry facies of the Edgecliff Member). Biostromes of fasciculate rugose and tabulate corals, such as *Syringopora, Acinophyllum, Synaptophyllum, Cylindrophyllum,* and *Eridophyllum* occur at some levels. These slightly muddy facies commonly display graded beds of skeletal debris passing upward into calcisiltites that suggest storm winnowing and deposition. Hence, these facies appear to have been deposited in areas below normal wave base, but above storm-wave base.

Finally, biostromal wackestone facies pass apparently upramp into coarse, typically winnowed and, in some cases, cross-laminated crinoidal pack- and grainstones of the typical Edgecliff lithology. These facies were deposited near normal wave base as implied by evidence of winnowing. Corals are abundant in these facies and include solitary rugosans such as *Heliophyllum, Siphonophrentis,* and large heads of tabulates such as *Favosites, Lecfedites,* and *Emmonsia.*

The spectrum of facies seen in the Onondaga Limestone from non-cherty calcareous shales and argillaceous nodular limestones to heavily cherty calcisiltites and fossiliferous calcarenites (wacke-, pack-, and grainstones) is repeated in a number of other units. For example, a similar sedimentary facies transition is observable in the Silurian Lockport Group and in the classic Lower Devonian Helderberg Group carbonates in the Hudson Valley. The classic Coeymans-Kalkberg-New Scotland transgressive succession documented by Rickard (1962) and Laporte (1969) displays the progression of crinoid pack- and grainstones to cherty micritic limestones, nodular non-cherty limestones, and, finally, highly argillaceous non-cherty limestones and calcareous mudstones.

Clearly, in part, the facies spectrum records decreasing environmental energy. Current- and wave-winnowing processes dominated in near-wave base facies (represented by grainstones) while muddy offshore facies were affected only by occasional intermittent storm action and, finally, deeper water shaly facies deposited below the effects of all but the most severe storms. A gradient from highly oxygenated to dysoxic environments is also suggested.

The most problematic feature of this carbonate facies spectrum is the presence of chert in a restricted facies belt between the high energy crinoidal shoal deposits and the most offshore muddy limestones that are typically non-cherty (see Maliva and Siever, 1989). Several key questions remain to be answered about the chert. First of all, what was the source and nature of the silica? Why is chert restricted to fine-grained but low argillaceous-content facies? Selleck (1985) provided an important working model to understand the occurrence of cherts within the Onondaga Formation. The source of silica, according to Selleck, was finely particulate silica, probably largely in the form of biogenic deposits, such as the opaline of sponge spicules. Such fine silica-rich sediment was winnowed from shallow shelf areas and, hence, typically transported into more offshore regions. Dissolution of the unstable opaline silica phases led to an enrichment of dissolved silica.

Perhaps the most enigmatic part of the story is the reprecipitation of this silica as cryptocrystalline quartz or chert (in particular, what caused reaggregation of this silica in local areas). The presence of chert bands suggests that enrichment of silica occurred intermittently or possibly periodically during deposition of parts of the Onondaga facies. Potentially, these cherts mirror certain surfaces of sediment starvation associated with minor climatic oscillations which temporarily reduced the amount of carbonate being produced within the system.

Another alternative is that carbonate within the cherty facies was deposited episodically as thin, storm-derived calcisiltite layers and that these depositional events were separated by much longer intervals of non-deposition in which the silica built up within near-surface pore waters. The common outlining of burrow galleries by chert suggests that special properties of the burrow fillings, including the increased porosity of the sediment filling, as well as possible geochemical alterations associated with decay of organic burrow linings, may have contributed to local aggregation of silica. The volume of silica at some levels, particularly in the Clarence facies of the Edgecliff Member, however, demands further consideration. One possibility is that the sediments became enriched with finely particulate silica as a result of volcanic ash input. Certainly, thin bentonites are known in the upper portions of the Onondaga and possibly as low as parts of the Nedrow and Edgecliff Members. However, any such possible ash beds are extremely thin within the Edgecliff Member, which is richest in chert. Note that this does not preclude the possibility of a general "background" input of finely particulate windblown volcanogenic silica. In the Moorehouse Member, there appears to be an association of thick, dark chert layers immediately below at least the thickest of the ash beds. However, again, other chert-rich intervals, particularly those of the Silurian Lockport Group, do not appear to be associated with times of volcanism.

Another very tentative possibility is that silica was locally concentrated by certain organisms, primarily siliceous sponges, whose spicules dissolved within the sediment to produce pore water solutions rich in dissolved silica or silicic acid (Maliva and Siever, 1989). Chert nodules in the Devonian Onondaga and Kalkberg, and the Silurian Lockport chert-rich intervals commonly display small spheroidal siliceous sponges (*Hindia*). External molds of spicules have also been observed in certain chert beds. These observations demonstrate at least that sponges were modestly common in areas where chert tended to form. However, such sponges are volumetrically relatively insignificant. Hence, if the chert-rich facies do represent belts of environments highly dominated by sponges, one must assume that the vast majority of sponge remains were completely dissolved and therefore that their fossil record has been almost eradicated. The absence of chert in the more argillaceous facies may reflect an absence of an appropriate source of opaline silica or may reflect the inhibitory effect of clay minerals in the reaggregation and precipitation of local masses of silica (see Selleck, 1985). In any event, our understanding of the depositional setting of these chert-rich facies remains very incomplete and will require much further study.

SEQUENCE STRATIGRAPHIC INTERPRETATION: TRISTATES GROUP AND ONONDAGA FORMATION

Overview

From the standpoint of sequence stratigraphy, the Tristates Group, Onondaga Formation and overlying Hamilton Group in central to western New York constitute a single large subdivision or "holostrome" of Sloss's (1963) Kaskaskia megasequence. This early phase or Tristates-Onondaga-Hamilton phase of the Kaskaskia is bounded by major unconformities. At the base, the sub-Oriskany Wallbridge Unconformity and a composite Wallbridge-upper Tristates-sub-Onondaga unconformity represent the major sequence boundary; at the top the sub-Tully or "Taghanic" unconformity bevels some portions of the upper Hamilton Group and forms the upper major sequence boundary for the holostrome. This is a second order depositional sequence in the terminology of Vail et. al. (1991). Detailed stratigraphic work permits resolution of a number of finer subdivisions within this major package that correspond approximately to third order depositional sequences as recognized by sequence stratigraphers (Vail et. al., 1977, 1991). Sequence stratigraphic study of the Tristates Group and Onondaga Formation is not as fully developed as that of the overlying Hamilton Group at this time, but some generalizations can be offered on the basis of detailed regional stratigraphy that is now nearing completion (Ver Straeten and Brett, 1994; Ver Straeten et al., this volume) In general, it appears that the Tristates-Onondaga interval can be subdivided into at least four third order sequences, each one comprising one to three million years in duration. However, the sequence boundaries between these stratal packages are not everywhere as clear cut as are found in other strata studied in the Appalachian Basin (e.g., Lower Silurian, Brett et al., 1990; Middle Devonian Hamilton and Tully Groups, Brett and Baird, in press).

Basal Megasequence Boundary

The Wallbridge Unconformity is one of five major Phanerozoic unconformities that define the boundaries of Sloss' (1963) "megasequences." It marks a major second order sequence boundary, associated with a major fall in relative sea level. The Wallbridge underlies basal quartz arenites/orthoquartzites of the upper Lower Devonian Oriskany Formation or younger strata across much of eastern North America. In western to west-central New York the Wallbridge Unconformity occurs as an irregular, karstified erosion surface at the top of the late Silurian Bertie or Akron Formations, or the overlying earliest Devonian carbonates of the Manlius Formation. This unconformity, which displays a relief of a few meters in some outcrops, is overlain locally by lenses of Oriskany Sandstone, by thin, sand- or limestone-rich strata equivalent to the Schoharie Formation of eastern New York, or directly by the lower Middle Devonian Onondaga Limestone.

Collectively, the overlying Tristates, Onondaga, and Hamilton strata, up to the major Taghanic Unconformity (below the Tully Limestone), constitute the first holostrome of the Kaskaskia Megasequence. This holostrome is divisible into a series of smaller-scale sequence-like units. Between these two scales, however, are two packages of strata, each bounded by unconformities.

The first succession is marked at its base by the Wallbridge Unconformity proper, which is overlain by transgressive Oriskany quartz arenites. Sandstones of the Oriskany Formation are composed of relatively clean, well rounded and frosted quartz sand grains, and commonly feature a fauna of large brachiopods and other forms. While the Oriskany Sandstone is missing at most localities in the west-central New York region, it does occur as a very thin quartz arenite in outcrops in the central Finger Lakes area, particularly at the Seneca Stone quarry (Stop 3), where the Lower Devonian Manlius Limestone is overlain by a 0-60 cm-thick lense of Oriskany Sandstone (Oliver and Hecht, 1994). The latter is rich in robust, thick-shelled brachiopods and favositid corals. Sands of the Oriskany may also locally be represented by thin neptunian dykes and fissure fillings on the Wallbridge karst surface. In places Oriskany sands may extend more than two meters downward into cracks within the upper Akron or Bertie dolostones. In the Hudson Valley, the Oriskany Sandstone grades laterally into sandy, cherty limestone of the Glenerie Formation. Together, the Oriskany and Glenerie Formations constitute an orthoquartzite-carbonate suite of sedimentary rocks that characterize not only the initial transgression of the Kaskaskia sea, but also an interval of tectonic quiescence prior to an episode of abrupt foreland basin subsidence and influx of a thick wedge of siliciclastic sediments.

The Oriskany Sandstone or Glenerie Limestone is overlain in eastern to east-central New York by dark gray to black silty and generally highly bioturbated Esopus Formation mudstone to sandstone. The latter is up to 100 m-thick in the Kingston area of the Hudson Valley but thins markedly to the northwest.

An erosional contact at the base of the Carlisle Center Formation appears to truncate upper beds of the Esopus Formation in a northwestward direction. West of Cherry Valley, New York, the Carlisle Center equivalent comes to rest directly on Oriskany Sandstone or other units below the Tristates Group and, consequently, below the Wallbridge Unconformity. Hence, the base of the Carlisle Center itself is a third-order sequence boundary. Again, a deepening upward succession (in eastern New York) from glauconite- and phosphate-bearing sandstones of the lower Carlisle Center and overlying calcareous, dark gray silty shales appears to record either another lesser tectonic pulse or an interval of eustatic deepening. However, this apparent deepening upward is reversed in the upper portion of the Carlisle Center which apparently grades upward into the overlying increasingly calcareous nodular to bedded shaly limestones of the Schoharie Formation. The upper Carlisle Center and Schoharie together appear to represent the highstand deposits of a second sequence developed above the Kaskaskia megasequence erosional boundary.

In the Hudson Valley, south of the Catskill area, the contact between the Schoharie and the overlying Onondaga formation appears to be conformable and perhaps gradational. However, as this boundary is traced northward into the region of Clarksville and westward beyond Cherry Valley, the basal Onondaga contact becomes distinctly sharp and the Schoharie Formation is progressively truncated. At Cherry Valley the basal Edgecliff Member of the Onondaga is comprised of some phosphatic and glauconitic material, as well as possible erosional clasts and sand derived from the underlying units.

Thin remnants of the underlying Carlisle Center and/or Schoharie Formations persist westward, at least to the Syracuse-Auburn area of central/west-central New York State. In these regions, the thin Tristates Group equivalent characteristically occurs as glauconitic silt- to sandstone (Carlisle Center Formation?) overlain by sandstone with large (up to 30 centimeters in diameter) dark gray to black phosphate-cemented sandy concretions (Mesolella, 1966; Schoharie Formation?). A 4-5 cm-thick bed of dark, non-calcareous shales is found locally at the base that may represent a thin remnant of the Esopus Shale. The upper bed of the Tristates immediately below the Onondaga carries a diverse and rich brachiopod and small coral fauna in a sandy limestone. This interval is sharply set off from the overlying Edgecliff Limestone. To the west, in the region near Seneca and Cayuga lakes (e.g., in the Seneca Stone quarry, Stop 5), the basal Onondaga unconformity becomes marked and the Edgecliff Member comes to rest on the Oriskany Sandstone with the underlying Tristates Group removed and/or cannibalized into the basal Edgecliff to form a sandy phosphatic conglomerate. At the Seneca Stone quarry the large phosphatic nodules from upper Tristates strata and pieces of phosphatized Oriskany Sandstone and Manlius Limestone have been reworked and accumulated as an erosion lag along the basal unconformity of the Onondaga Limestone. In west-central New York, the sub-Edgecliff unconformity locally merges with the Wallbridge to form one major disconformity, in which the Edgecliff rests directly upon the upper Silurian units. This composite hiatus ranges up to 20 million years in some areas where the Edgecliff Member may rest unconformably on the channeled upper surface of beds low in the Bertie Dolostone of Late Silurian (Pridolian age). However, still farther west, in Erie County and in the adjacent Niagara peninsula of Ontario, the Oriskany Sandstone and lateral equivalents of the Schoharie Formation reappear (Bois Blanc Formation) although they are still locally overlain with sharp contact by the Edgecliff Member. Therefore, as many as three unconformity surfaces may locally occur across New York; the sub-Oriskany Wallbridge Unconformity, a second pre-upper Tristates (Carlisle Center to Bois Blanc) unconformity, and a third sub-Onondaga unconformable surface.

The composite unconformity below the Onondaga Formation clearly represents a prolonged period of relative sea level lowstand, exposure, erosion, and karstification over much of New York State west of the Hudson Valley. However, the sub-Onondaga unconformity itself remains much more enigmatic. It is evidently not simply a case of non-deposition of the Tristates Group, as there is evidence for erosional truncation of some of the beds, including the phosphatic nodule-bearing interval in the Seneca Stone quarry. Furthermore, the contact between the Onondaga and the upper part of the Tristates Group (Schoharie Limestone in eastern New York and Bois Blanc Limestone in Ontario) appears to be conformable to nearly conformable. In those areas skeletal crinoidal grainstones of the Edgecliff Member appear to cap a shallowing upward cycle that commences within the underlying Schoharie-age interval. Yet, in much of western and west-central New York State, the base of the Edgecliff Member is very sharply defined and appears to truncate different levels within the Schoharie-equivalent, Emsian-age beds below. Indeed, over much of this region there is no vestige of the Tristates Group whatsoever, except for the occasional fillings of Oriskany sands into fissures of the underlying Silurian dolostones. Thus, there is tentative evidence that the central portion of New York State was subjected to uplift and erosion, perhaps under subaerial conditions, during the later part of the Emsian Stage. Simultaneously, marine deposition of silty limestone continued both to the east and west of this area. This suggests an intriguing pattern in which the central portion of New York may have been upwarped in a broad arch, possibly a forebulge produced as an isostatic response to crustal loading in the Acadian orogenic thrust belt in New England. These events would be associated with the development of an actively subsiding, narrow, Emsian-age foreland basin to the east and southeast in which a thick succession of dark gray shales of the Esopus Formation and the overlying, increasingly carbonate-rich Carlisle Center and Schoharie Formations accumulated during Acadian Tectophase I of Ettensohn (1985).

Edgecliff Member Sequence Stratigraphy

The Edgecliff Member is sharply bounded both at its base and top in nearly all localities in west-central to western New York. The basal erosional unconformity may or may not have developed under subaerial conditions, at least in the central portion of New York State. The sub-Edgecliff unconformity is interpreted as a third order sequence boundary. However, as discussed in the preceding section, the sub-Edgecliff unconformity may or may not have been produced by eustatic sea level drop.

In western and west-central New York State, the basal Onondaga Edgecliff Member clearly onlaps an irregular erosion surface in many places. For example, at the Oaks Corners quarry (Stop 2), there is nearly a meter of relief on the basal unconformity. Channel-like areas, no more than a few tens of meters across, are infilled with differentially-thickened pack- and grainstone deposits of the basal Edgecliff unit. Laterally, these units thin to nearly zero in areas between the channels.

This phenomenon also may occur on a larger scale. Apparently, the basal Onondaga deposits may thicken and thin more radically in association with topographic highs on the onlap surface. For example, the Edgecliff interval displays marked thickening between the Seneca Stone quarry and the Oak Corners quarry, approximately 21 km to the northwest (see Figure 5). This thickening is also associated with a relatively dramatic facies change, from dominantly crinoidal wacke- to packstone at Seneca Stone quarry into dominantly fine-grained, sparsely fossiliferous, and highly chert-rich calcisiltite of the Clarence facies. As noted in preceding sections, the Edgecliff displays a prominent cyclicity at both Seneca Stone quarry and Oaks Corners quarry. However, only two major cycles can be recognized at the former locality, whereas in the latter, much thicker section to the northwest, a total of four cycles, each one to three meters in thickness, can be discerned. Moreover, the cycles display distinctly different motifs. At Seneca Stone quarry, the cycles are dominated by sparsely fossiliferous, non-cherty, crinoid-bearing wackestone, capped by thin, crinoidal packstone beds. The dark, chert-rich, micritic bed is thought to represent the deepest water facies within the Edgecliff Member at the Seneca Stone locality. It closely resembles the majority of the Edgecliff interval (Clarence facies) in the adjacent Oaks Corners quarry. This cherty bed, in turn, passes abruptly upward into approximately 50 cm of crinoidal wackestone immediately underlying Nedrow Member calcareous shales. This latter clearly appears to represent a major marine flooding surface.

The two Edgecliff cycles at Seneca Stone quarry resemble PACs, (Punctuated Aggregational Cycles; Goodwin and Anderson 1985) and are interpreted in the light of sequence stratigraphy as parasequences. That is, each represents a more or less asymmetrical, shallowing upward cycle capped by crinoid-rich facies and abruptly overlain by deeper water cherty calcisiltites or calcareous shales.

By contrast, the four cycles in the Oaks Corners quarry, except for the lowest, are dominated by cherty, nearly barren limestones which closely resemble the cherty marker band at Seneca Stone quarry. Only the relatively thin caps of these cycles feature more fossiliferous crinoidal wackestones, which are more sparsely fossiliferous than the cycle caps at the Seneca Stone quarry and are similar to the main bodies of these cycles there. Cherty beds that immediately overlie the cycle caps are somewhat argillaceous; in the case of the fourth cycle, a dark gray, non-cherty calcareous shale that closely resembles the overlying Nedrow Member abruptly overlies the sparse crinoidal wackestone of the underlying cycle cap.

The overlying Nedrow Member displays a lesser degree of facies change between the Seneca Stone and Oaks Corners quarries and its internal stratigraphic subdivisions are readily correlated between the two sites. Therefore, in attempting to correlate the Edgecliff cycles, we have worked downward from the abrupt contact with the Nedrow. Using this approach, the upper cycle is only slightly thicker at the more westerly Oaks Corners locality than at Seneca Stone. However, its basal interval displays an apparent downslope facies transition from the cherty micrites at Seneca Stone quarry to the dark gray, Nedrow-like facies tongue at Oaks Corners, whereas the upper portion of the cycle becomes more distinctly chert-rich and much less fossiliferous at the Oaks Corners section. Assuming that this cycle is correctly correlated, the lower or first cycle at the Seneca Stone quarry represents only the third of four cycles at Oaks Corners. It, too, displays marked facies change, having become non-cherty in the distance between the two quarries. The coral-rich bed at the base of Seneca Stone quarry may correlate with the relatively fossiliferous cap of the second cycle at Oaks Corners. This latter interval is notable in carrying relatively large crinoid columnals and some favositid corals, even at Oaks Corners. This correlation scenario would suggest that the lower half of the Edgecliff interval exposed at Oaks Corners quarry, including the one-meter crinoidal lower cycle and bulk of the chert-rich second cycle, is completely absent at the Seneca Stone quarry. This pattern of apparent depositional pinch-out of units, together with the evidence of some thinning in the overlying beds and the above-noted facies changes, suggest that during Edgecliff deposition the area of Seneca Stone quarry lay in an up-ramp position with respect to sections to the west as in Oaks Corners. To the east, in and near its type section in the Syracuse area, the Edgecliff becomes increasingly fossiliferous and is composed of primarily pack- to grainstones. Although it again thickens in this direction, there is reason to suspect that this thickening is in a continued upramp direction.

The absence of basal Onondaga cycles I and II in the vicinity of Cayuga Lake may represent a lack of accommodation space in this region. As noted, tongues or pods of the Bois Blanc Formation of the Tristates Group occur eastward to the vicinity of Phelps, a few miles west of Oaks Corners quarry. And again, Tristates Group equivalents appear in the Auburn area, approximately 25 km northeast of Seneca Stone quarry. The vicinity of Seneca Stone appears to have experienced the greatest amount of removal of Tristates group in the sub-Onondaga unconformity. This fact, in turn, suggests that this particular area represented the topographically highest region of the sea floor during initial Onondaga transgression. If the basal Edgecliff units have any correlatives in this area, they lie within the reworked phosphatic conglomerates that sharply overlie the Oriskany at Seneca Stone quarry. In any event, it appears that the region to the west near Oaks Corners was much more actively subsiding in at least lower Edgecliff time. The Clarence cherty facies actually thickens somewhat from the Oaks Corners quarry westward at least to LeRoy but may thin again toward Buffalo where the lower Edgecliff again is represented by crinoidal pack- and grainstone facies. These facies are virtually absent at the Oaks Corners quarry, except for fillings of erosional channels at the very base of the Edgecliff Member.

Thus, a pattern of facies change, at least within the Edgecliff Member, indicates a local basin center in the Phelps to Manchester area (Ontario County, New York). This region appears to have been bordered both to east and west by shallow carbonate ramp transitional to shallow shelf, crinoidal shoal facies, both in the extreme west and in central portions of the state. The meter-scale parasequences observed within the Edgecliff member may represent minor eustatic sea level oscillations (see, for example, Goodwin and Anderson 1985), or minor pulses of subsidence, followed by progradational buildup of the seafloor by a few meters of carbonate deposition. However, the thinness of the cycles, together with evidence for abrupt shifts not only to deeper, but also to shallower facies (see, for example, the boundaries of the chert-rich marker bed at Seneca Stone quarry) suggest that progradation was probably not the chief mechanism for shallowing.

Overall, the three to four small-scale cycles or parasequences that make up the Edgecliff Member locally display an overall pattern of upward deepening or retrogradation. Thus, while each parasequence is a rather asymmetrical, generally upward-coarsening and -shallowing succession, the facies which overlie flooding surfaces at the tops of these small-scale cycles display a progressive trend from shallower to deeper water. This is particularly well seen in the four cycles of the Edgecliff Member at Oaks Corners quarry. The strata overlying the top of the basal meter-thick cycle are nodular, somewhat fossiliferous, and sparsely cherty. Those overlying the cap of the second cycle are thin-bedded, slightly argillaceous cherts. Strata overlying the third cycle cap consist of the Nedrow-like non-cherty argillaceous facies. Finally, the top of the fourth cycle is a major marine flooding surface at the contact between the Edgecliff Member and the overlying shaly Nedrow Member. This appears to represent the strongest deepening event of the four.

Overall, this retrogradational pattern is characteristic of a transgressive systems tract, as outlined by Van Wagoner et al. (1988) and Vail et al. (1991). It clearly appears that the Edgecliff was being deposited at a time of overall deepening of the facies and this pattern is seen at virtually all outcrops. We do note however, as discussed elsewhere in this paper, that the central New York region was also undergoing more rapid subsidence than other parts of the state during Edgecliff time.

Nedrow Member Sequence Stratigraphy

The Edgecliff-Nedrow Member contact is an extremely widespread, apparent deepening event. In many localities throughout western and central New York, it is marked by a dark gray to greenish-gray thin fossil hash-rich calcareous bed. Many of the fossils within this level appear heavily corroded and pitted, as though they had been exposed for prolonged periods on the seafloor. The greenish coloration of the shale suggests trace quantities of glauconite, which is commonly associated with sediment-starved intervals. In typical Nedrow outcrops, such as in the central Finger Lakes area, bundling of calcareous shales and thin to somewhat thicker, tabular, argillaceous micrite bands define at least five small-scale, slightly asymmetrical cycles within this unit. Again, these cycles appear to present a continued retrogradational pattern, at least up to the level of the distinctive upper Nedrow black shale marker bed. As noted, this black, laminated shale interval is extremely widespread throughout much of central New York, the south-central portion of the Hudson Valley, and into central Pennsylvania. We suggest that this episode of deposition of high dysoxic to anoxic laminated muds within the central portions of the Appalachian basin may represent one of the strongest pulses of deepening within the Onondaga succession.

Thus, while the Edgecliff to Nedrow contact is interpreted as a surface of sediment starvation, the thin shaly to nodular cycles of the Nedrow appear to constitute a condensed interval and the black shale band may represent a maximum flooding event. This sequence is somewhat unusual in that the maximum flooding surface and surface of maximum starvation appear to be offset from one another by at least four minor parasequences. Overall, the Nedrow is interpreted tentatively as an early highstand facies. The extremely widespread nature of the Nedrow black shale suggests that this may well have been an eustatic event, although it is not recognized as such on the well-known Devonian sea level curve of Johnson et al. (1985).

Some previous workers have interpreted the Nedrow as a shallow water facies. For example, Feldman (1980) argued that the *Pacificocoelia* community of the Nedrow Member in central New York represents one of the shallow water assemblages in the unit. However, this assemblage appears to be displaced in an upramp direction by more diverse brachiopod associations. Furthermore, *Pacificocoelia* appears in deeper water assemblages in other portions of the stratigraphic column. Moreover, the Nedrow Member is known to contain some of the more diverse offshore *Polygnathus* conodont elements that permit recognition of the *patulus-costatus costatus* zonal boundary (see Klapper, 1981). This contrasts with the typical shallow water *Icriodus* conodont biofacies represented in much of the rest of the Onondaga Limestone. The regional geometry of the Nedrow Member, with dark shales being confined to the more central portions of the Onondaga basin, also strongly suggests that the Nedrow represents one of the deepest intervals during Onondaga deposition.

In sections upramp from the basin center, the Nedrow interval becomes increasingly rich in limestone. Again, the more shaly intervals appear to pass laterally into light gray and dark chert-rich bands which display distinct cyclicity in quarries in the LeRoy to Stafford area (see Figure 5). In contrast, the nodular or tabular marly limestone beds of the cycle caps in the Nedrow of the basin center appear to pass upramp into fossiliferous wacke- to packstone lithologies, which bear increasingly diverse faunas of brachiopods, gastropods, and corals. The enrichment in fossils at the tops of some of these beds is spectacular and may reflect minor intervals of sediment starvation.

Understanding of facies trends in the Nedrow Member between the Seneca Stone quarry and the Oaks Corners quarry are somewhat ambiguous at this time. The sections are similar, although the Nedrow at Oaks Corners quarry is somewhat thicker than that seen at Seneca Stone quarry (see Figure 5). The dark marker bed is nearly black shale in both sections although thin beds of dark gray shale occur more prominently below the bed at the Seneca Stone quarry than at Oaks Corners quarry and the lower Nedrow at least appears to be slightly more fossiliferous in the latter than at the former. Certainly, facies trends in the overlying transitional Nedrow to Moorehouse interval strongly suggest a down-to-the-east ramp extending from Oaks Corners quarry to the Seneca Stone quarry. There is no doubt that the Nedrow undergoes a substantial lateral upslope change westward from the Oaks Corners quarry.

These lines of evidence suggest that the ramp deepened gradually from the area west of LeRoy through the area of Phelps to a deepest basinal position somewhere in the vicinity of the Seneca Stone quarry during Nedrow deposition. Certainly the higher beds of the Nedrow and the overlying Moorehouse strongly support this contention. While the Moorehouse is moderately fossiliferous and highly cherty at Oaks Corners quarry, it is thinner, much more sparsely fossiliferous and contains much less chert at the Seneca Stone quarry. Thus, in the time interval within lower Edgecliff deposition and the onset of Nedrow deposition, the basin center appears to have shifted slightly, by about 20 km, to the southeast from approximately the Phelps area to the Cayuga Lake region. This southeastward drift of the basin center may have continued into the later Eifelian during deposition of the higher Moorehouse and Seneca Members.

Moorehouse Member Sequence Stratigraphy

As defined herein, the base of the Moorehouse Member is drawn at the upper of the two dark shale marker beds ("*Schizophoria* bed"). Basal Moorehouse strata are among the most sparsely fossiliferous in most Onondaga sections, and consist of sparse echinoderm skeletal wackestone or lime mudstone with very scattered fossil debris. Weathered surfaces of beds low in the Moorehouse display markings diagnostic of the trace fossil *Zoophycos*. Hence, these rocks can be interpreted as bioturbated carbonate silt deposits that may have accumulated relatively rapidly and possibly under high turbidity conditions that were unfavorable to many benthic organisms. The appearance of abundant dark brownish gray chert nodules within the Moorehouse parallels situations seen in the Clarence facies of the Edgecliff Member and demonstrates the enrichment of silica, possibly from biogenic sources. Conceivably, these represent a sponge-rich facies which is nonetheless rather poor in brachiopods, corals, and other organisms. In contrast, the thin shaly intervals within the Moorehouse, which appear to record minor reversions to condensed Nedrow-like facies, display more diverse fossil assemblages with small rugose corals and relatively rich, brachiopod-dominated benthic communities.

A generally shallowing upward succession is seen in a series of approximately six to seven small-scale cycles in the lower to middle Moorehouse Member, that have been assigned by different authors to the upper part of the Nedrow Member (in part) or to the lower part of the Moorehouse Member. These cycles are represented by intervals of non-cherty to chert-bearing limestones capped by thin, dark gray to greenish-gray brachiopod-rich shales. The shaly beds are enriched in heavily fragmented or corroded fossil debris, suggesting sediment starvation associated with marine flooding events. The lower shale partings carry a modest diversity of *Pacificocoelia* and *Schizophoria* brachiopod assemblages in some areas. In contrast, some of the higher capping shales are richer in brachiopods and show a much higher diversity assemblage assignable to Feldman's (1980) *Leptaena-Megakozlowskiella* community.

In western sections this apparent shallowing-upward trend in the lower part of the Moorehouse culminates in approximately one to two meters of coral-rich, crinoidal packstone. Locally, in the Stafford-LeRoy area, this interval features one or more distinctive coral biostromes. In other units (e.g., Middle Silurian Lockport Group) similar biostromes commonly mark the caps of shallowing cycles, although they appear slightly below the coarsest beds in the middle Moorehouse Member.

The coral biostromal layers and associated crinoidal packstone interval is abruptly overlain by the "false Nedrow" calcareous shale to shaly limestone. Indeed, this argillaceous interval has been mistaken in some areas for the Nedrow Member (see Conkin and Conkin, 1979, 1984; Conkin, 1987). This shaly interval appears to reflect a marine flooding event or deepening that took place midway through deposition of the Moorehouse Member. This cycle has been overlooked by most previous workers on the Onondaga, but is recognizable not only in western New York, but also in central and eastern portions of the New York outcrop and southward into eastern and central Pennsylvania where it is commonly represented by a very dark gray shale interval that may resemble the Nedrow "black beds."

A fossil-rich crinoidal hash bed that occurs beneath this important marker may signify a condensed interval associated with the abrupt deepening pulse. However, in many sections it is abruptly overlain by coarser strata of the upper part of the Moorehouse Member. These strata comprise 3-4 m of crinoid-rich pack- and grainstone both in western and eastern New York State. In the central basin region (e.g., Seneca Stone quarry, Stop 6) the interval is a more chert rich and less argillaceous micritic limestone. It is typically rich in fossil mollusks, particularly high-spired gastropods.

These more fossiliferous facies of the upper Moorehouse Member extend upward to the Tioga B-OIN Bentonite that demarcates the top of the Moorehouse. Very similar facies occur in the lower part of the Seneca Member immediately above the Tioga B in most sections. In some sections (e.g., Seneca Stone quarry, Stop 6) the Tioga B bed is overlain by a thin interval of dark gray shale that grades upward through argillaceous limestone into wacke- or packstone of the lower Seneca. Hence, at least a small scale deepening-shallowing cycle appears to be associated with the bentonite. This and other evidence suggests that the Tioga B may represent a type of condensed bed and flooding surface. On the other hand there is no major shift in facies at this juncture; as stated, lowest Seneca strata immediately above the Tioga B are similar to upper Moorehouse strata.

Seneca Member Sequence Stratigraphy

Contrary to previous suggestions, the Seneca Member does not form a simple fining-up/deepening-up succession. Details of the member at Seneca Stone quarry (see Figure 5), where it appears most complete, show two larger scale cycles within the Seneca. An apparent deepening is recorded approximately one meter above the base at a transition from fossiliferous wackestone to finer-grained micritic limestone. Coquinas of *Hallinetes* (= "pink chonetid") brachiopods signal shallowing that culminates in a bed with small rugose corals 4.0 m above the base of the Seneca. The recurrence of finer-grained *Hallinetes*-rich limestones above mark a second deepening interval, but these in turn pass into somewhat more fossiliferous beds with small rugosans and a slightly more diverse brachiopod assemblage. The uppermost 0.5 m of Seneca marks a return to more finer-grained, sparsely fossiliferous facies. The upper contact of the Seneca Member as defined in this paper is marked by a thin, apparently widespread lag bed with fish bone material. This bed and the transition upward through the lower part of the Bakoven Member (Union Springs Formation) is discussed further in Ver Straeten et al. (this volume. Although correlative beds are uniformly coarser and more fossiliferous to the west, these overall patterns of change through the Seneca Member are reiterated at western New York localities (e.g., Honeoye Falls and Stafford quarries, Stops 2 & 1, respectively).

SYNTHESIS OF LOWER MIDDLE DEVONIAN CARBONATES, NORTHERN AND CENTRAL APPALACHIAN BASIN

Middle Devonian carbonates equivalent to the Onondaga Limestone of New York State occur widely across eastern North America (Koch, 1981). As previously noted, they range from the James Bay region of northern Ontario to southeast Quebec and Maine to Georgia and Illinois (Figure 2), and include the Columbus Limestone of Ohio and the Jeffersonville Limestone of the classic Falls of the Ohio River at Louisville, Kentucky. Within the Appalachian Basin, however, the relations between the Onondaga Limestone of New York and correlative strata has been somewhat obscure. The faunally diverse, cherty, carbonate platform-setting of the northern part of the Appalachian Basin (New York) in the lower Middle Devonian gives way southward to thinner, increasingly argillaceous strata (upper part of the Needmore Formation) across much of the rest of the basin. Poor biostratigraphic and lithostratigraphic resolution of more mud-dominated facies across central Pennsylvania into the Virginias has hindered detailed correlation and understanding of time-rock relationships between the Onondaga Limestone and its equivalents across the Appalachian Basin (Figure 7).

In the course of fieldwork during 1993, a series of distinctive, correlatable marker beds were found within the lower Middle Devonian Selinsgrove Limestone of central Pennsylvania. This microstratigraphic framework can be correlated across a minimum of 400 km of the Appalachian Basin into the Onondaga Limestone of central New York. As a result, we recognize that: 1) the Selinsgrove Member of the Needmore Formation in central Pennsylvania is the direct equivalent of the Onondaga Formation of New York; and 2) four recognizable subdivisions of the Selinsgrove Member are directly equivalent to the Edgecliff, Nedrow, Moorehouse, and Seneca Members of the Onondaga Formation of New York.

The Selinsgrove Member of central Pennsylvania is the uppermost of three members of the Needmore Formation (Inners, 1975). It is comprised of relatively thin, non-cherty,

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Figure 7. Map of the Onondaga Limestone in New York and equivalent Buttermilk Falls and Selinsgrove Limestones in Pennsylvania (modified after Inners, 1975). Key localities are as follows: [New York] CL=Clarence, HF=Honeoye Falls, SS=Seneca Stone quarry, AU=Auburn, JM=Jamesville, CV=Cherry Valley, CL=Clarksville, CA=Catskill, KI=Kingston; [Pennsylvania] ST=Stroudsburg, WB=West Bowmans, SW=Swatara Gap, MI=Midway, DL=Dalmatia, SJ=Selinsgrove Junction, NH= Newton Hamilton, MP=Mapleton.

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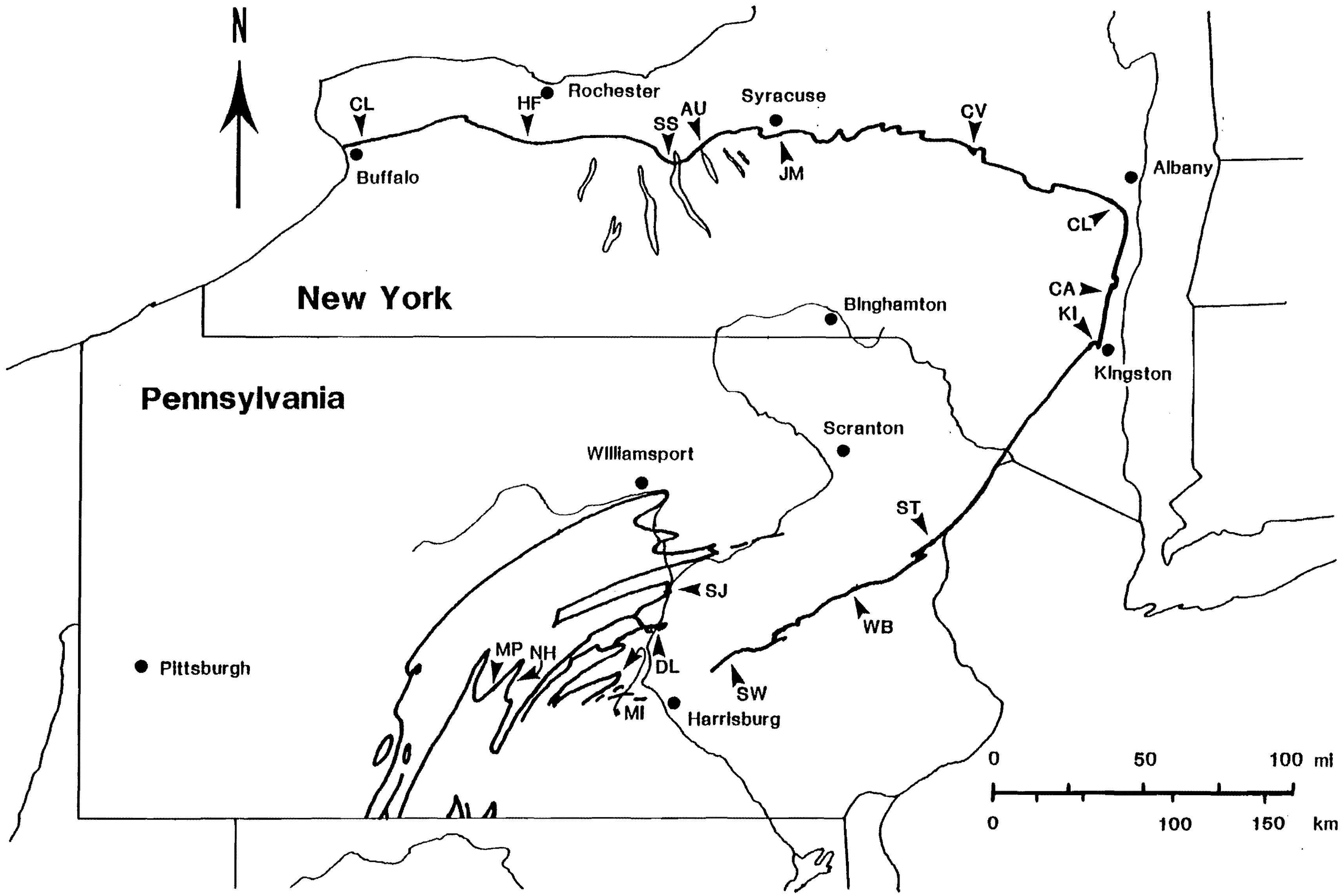
Figure 8. Microstratigraphic correlation of the Selinsgrove Limestone (central Pennsylvania) and the Onondaga Limestone (central New York).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CL
HF
Rochester
SS
AU
Syracuse
CV
Buffalo
JM
Albany
CL
New York
CA
Binghamton
KI
Kingston
Pennsylvania
Scranton
Williamsport
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SJ
WB
MP
NH
DL
Pittsburgh
SW
MI
Harrisburg
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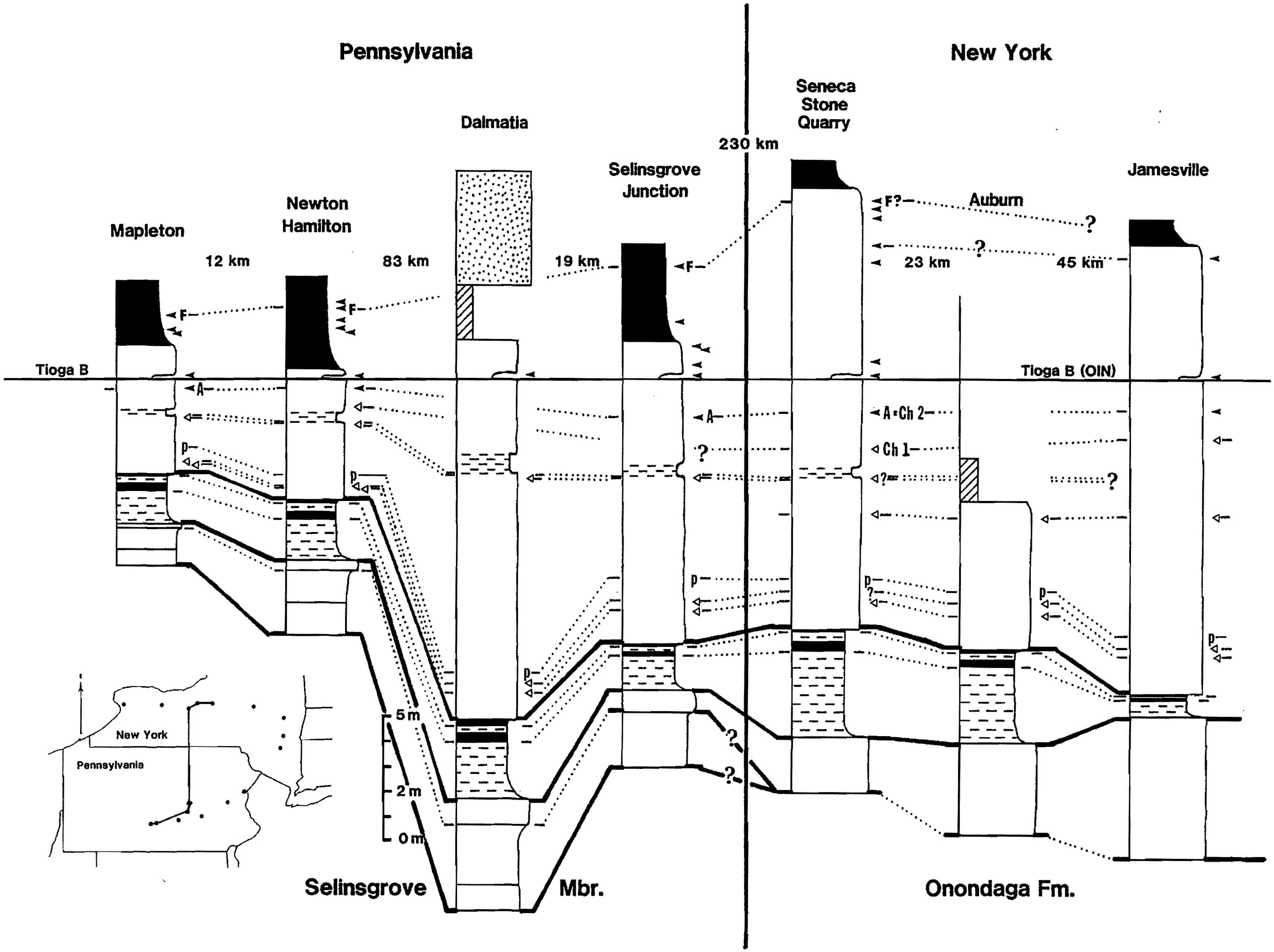

Pennsylvania
New York
Mapleton
Newton Hamilton
Dalmatia
Selinsgrove Junction
230 km
Seneca Stone Quarry
Auburn
Jamesville
12 km
83 km
19 km
23 km
45 km
Tioga B
Tioga B (OIN)
F
A
A=Ch 2
Ch 1
5 m
2 m
0 m
New York
Pennsylvania
Selinsgrove Mbr.
Onondaga Fm.

interbedded argillaceous limestones and calcareous shales. The Selinsgrove Limestone is characterized by low diversity faunas that include small brachiopods (chiefly *Ambocoelia*, *Pacificocoelia*, and other diminutive forms), trilobites (dominantly two species of *Odontocephalus*), ostracods, and dacryoconariids (Inners, 1975).

Subdivision and microstratigraphic correlation within the Selinsgrove Member in central Pennsylvania is possible through recognition of a number of distinctive lithostratigraphic marker beds. These marker beds include: 1) a thick-bedded to massive limestone, locally with large crinoid ossicles, in the lower part of the member; 2) shale dominated intervals; 3) several thin black shales; 4) the Tioga Ash Beds; 5) thin (ca. <1-5 cm-thick) clay beds that appear to represent additional K-bentonite beds; and 6) pyrite nodule-rich intervals. These beds occur in similar stratigraphic succession along at least 110 km of the central Pennsylvania outcrop belt (see Figure 8).

This microstratigraphic succession is directly correlatable from the type section of the Selinsgrove Member along the Susquehanna River in central Pennsylvania northward 230 km into the Onondaga Limestone at Seneca Stone quarry (Stop 6). At Seneca Stone and nearby central New York localities the same succession of lithostratigraphic marker beds is found (Figure 8). Among the marker beds recognized are the lower and upper (*Schizophoria*) black shale beds at and near the top of the Nedrow Member in New York and an overlying pair of yellow to tan soapy clay beds that appear to represent K-bentonites. The previously noted thick-bedded to massive limestone in the lower part of the member is equivalent to all or part of the Edgecliff Member in New York. The shaly Nedrow Member and the "false Nedrow" shale in the middle of the Moorehouse are also both recognizable in the Selinsgrove Member. The Tioga bentonite cluster is recognized in both regions (see Figure 6 and discussion above), although correlation of some beds from Pennsylvania to New York is problematic at this time.

The term "Onondaga" has at times been used erroneously as a synonym for the Needmore Formation in Pennsylvania. However, as shown here, only the Selinsgrove Member of the Needmore is the direct equivalent of the Onondaga Formation in New York. The two underlying members of the Needmore Formation in Pennsylvania are correlative with strata of the Lower Devonian Tristates Group (Esopus and Schoharie Formations) of eastern New York.

Wider correlation of this microstratigraphic framework into coarser, more shallow-water facies east and west of the central New York trough appears to be more difficult; preliminary work indicates, however, that at least some of the distinctive marker beds are widely recognizable. For example, at Kingston, in the southern part of the Hudson Valley outcrop belt (eastern New York), a distinct dark interval of argillaceous limestone occurs near the top of the Nedrow Member. A short distance above the dark beds occur two thin, clay-rich crevices that may represent K-bentonite layers. This succession corresponds to the two black shale beds and overlying twin clay beds found in the upper part of the Nedrow and lower part of the Moorehouse Members in central New York and equivalent strata in central Pennsylvania.

Preliminary work in eastern Pennsylvania shows a number of the same marker beds occur in the greatly thickened (ca. 83 m-thick), Onondaga-equivalent Buttermilk Falls Formation near Stroudsburg, Pennsylvania. Four members have been reported for the Buttermilk Falls Limestone (Epstein, 1984; Inners, 1975); a lower, relatively coarse, chert-rich limestone (Foxtown Member), an overlying shale-dominated interval (McMichael Member), another chert-rich limestone unit (Stroudsburg Member), and an uppermost Echo Lake Member. A prominent, 30 cm-thick K-bentonite in the upper part of the Stroudsburg Member corresponds to the Tioga B-OIN Ash bed in New York and central Pennsylvania. Recognition and microstratigraphic correlation of the distinctive marker beds shows that the four members of the Buttermilk Falls Formation in eastern

Pennsylvania are equivalent to the Edgecliff, Nedrow, Moorehouse, and Seneca Members in New York.

With all of this in mind, we can see a broader synthesis of lower Middle Devonian carbonates in the northern and central parts of the Appalachian Basin. Figure 9 (a&b) represents dominantly east-west cross sections of Onondaga equivalent strata along approximately 900 km of the outcrop belt in New York and Pennsylvania. Strata equivalent to the Edgecliff-Clarence, Nedrow, Moorehouse, and Seneca Members of the Onondaga Formation in New York are recognized all along the outcrop, except along the Auburn Promontory northeast of Harrisburg, Pennsylvania (Epstein et al., 1974), which represents the southeastern shoreline/margin of the Appalachian Basin during the early Eifelian.

The next stage of this study will extend the research into southern Pennsylvania, Maryland, and the Virginias, to test whether this microstratigraphic framework is correlatable into the southern portion of the Appalachian Basin, and if so, to compare and contrast the sedimentary record across the entire basin during the earliest Middle Devonian.

SUMMARY

The Middle Devonian Onondaga Formation of New York State represents shallow marine carbonates deposited in the northern part of the Appalachian foreland basin. Relatively shallow shoal to shelfal environments in eastern and western New York gently sloped toward a northern tongue of the central Appalachian basinal trough in the central Finger Lakes region of the State. Recent study shows that this basinal tongue shifted through Onondaga time and, in fact represented a center of subsidence in the position of a late Early Devonian uplifted peripheral bulge.

Four members of the Onondaga Limestone are widely recognized across New York State (in ascending order, the Edgecliff, Nedrow, Moorehouse, and Seneca Members; Oliver, 1954). The lower of these, the Edgecliff Member, is characterized by relatively coarse crinoidal to coral-rich packstone to wackestone facies that are locally chert-rich. Coral biostromes and bioherms, which include pinnacle reefs in the subsurface of southern New York, are rooted in a widespread coral-rich zone in the base of the Edgecliff Member. We herein informally propose two dominant, widespread facies of the Edgecliff Member, a cherty, micritic "Clarence facies" (formerly Clarence Member of western New York) and a coarse crinoidal, non- to sparsely cherty "Jamesville Quarry facies."

Overlying calcareous shale-dominated strata and laterally equivalent argillaceous limestones above the Edgecliff are assigned to the Nedrow Member. Chert is generally uncommon to rare in the dark shale facies but is relatively more abundant in laterally equivalent, more carbonate-rich facies of the member. The Nedrow is commonly associated with a diverse brachiopod fauna and numerous platyceratid gastropods. Recent fieldwork indicates that the Nedrow Member is a distinctive interval, correlatable into western New

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Figure 9a. Cross-section of the Onondaga Limestone across New York State. Upper part of Onondaga Formation at Kingston is generally covered and is unknown to the authors.

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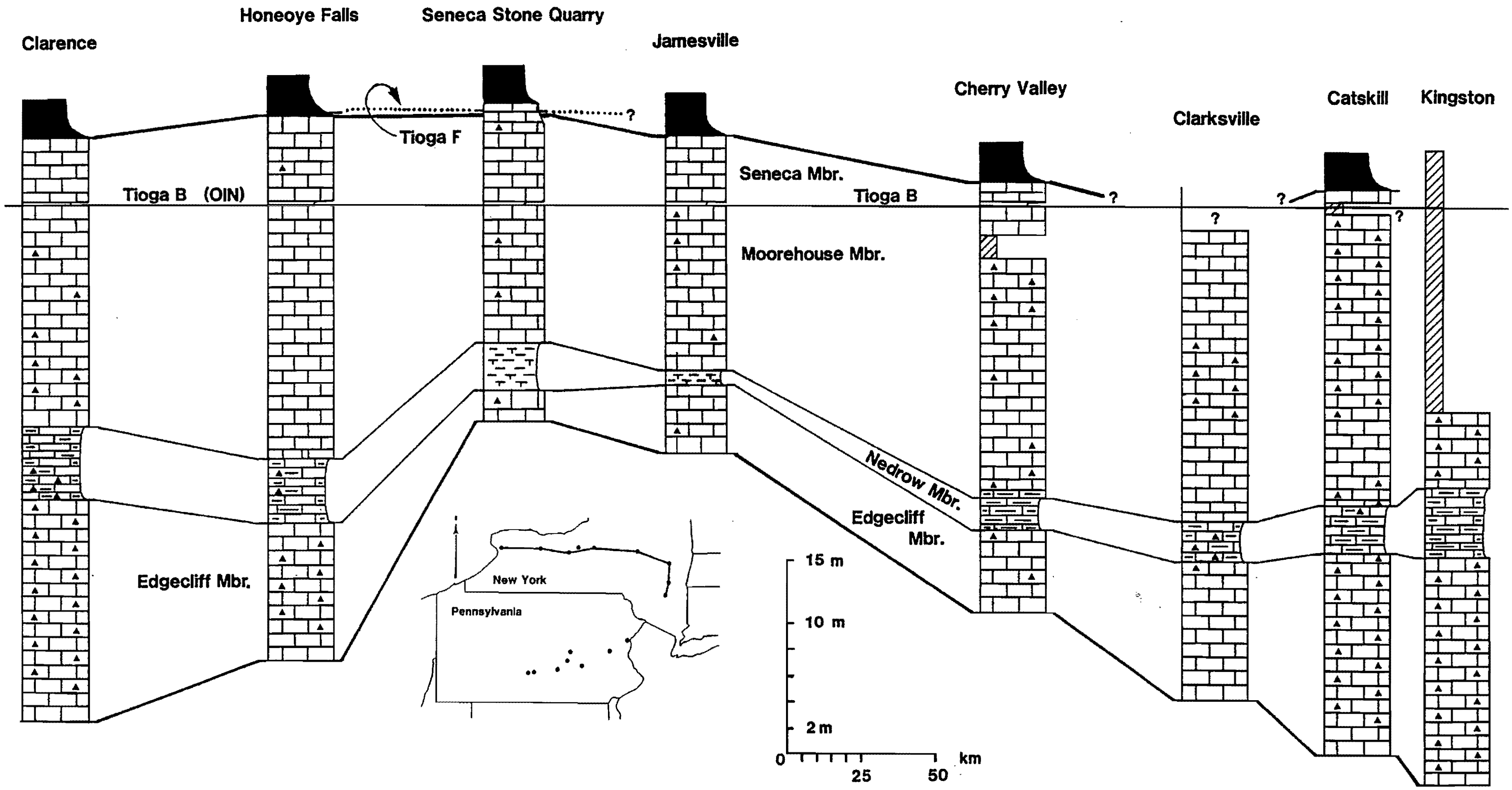
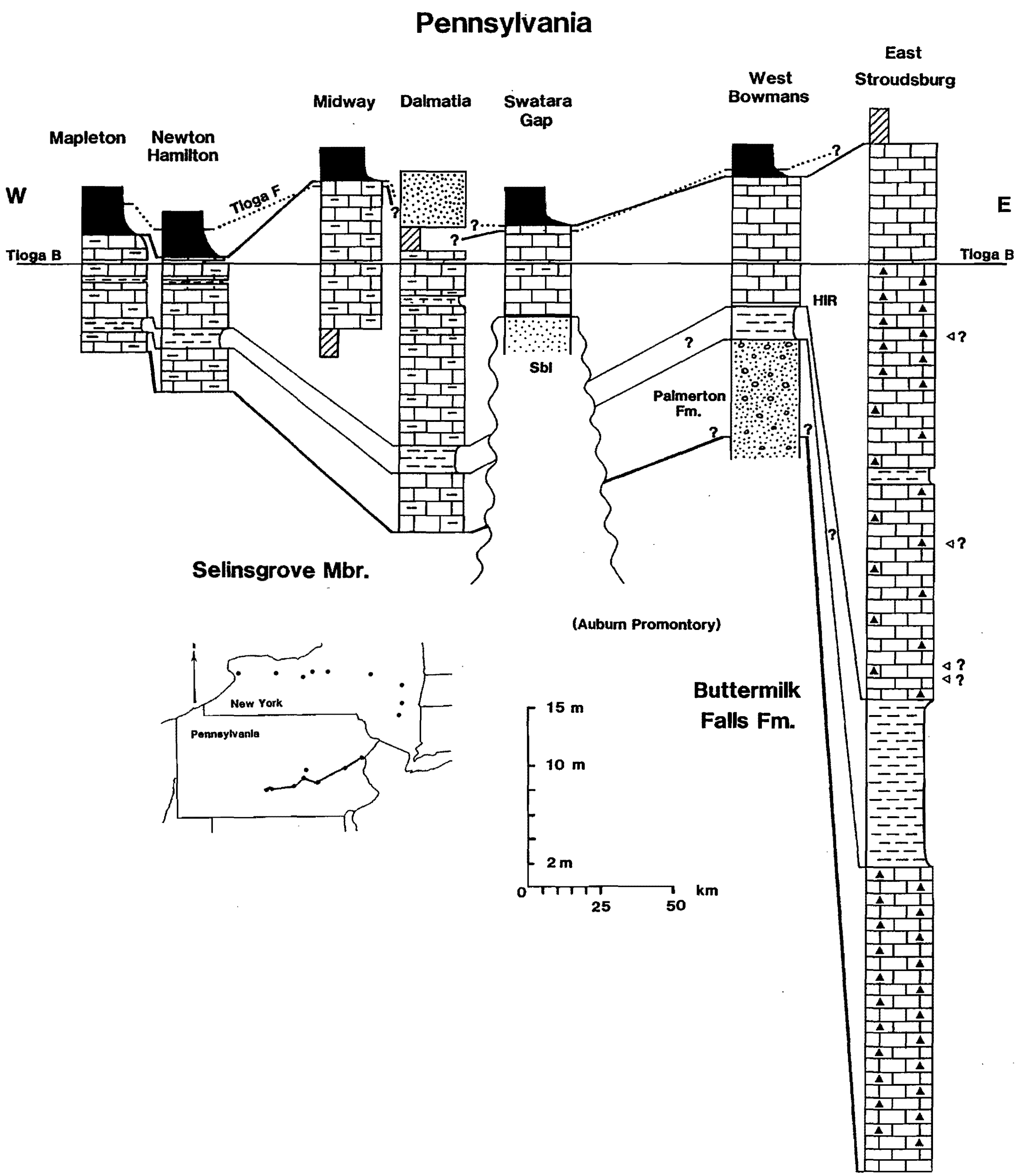
Figure 9b. Cross-section of the Onondaga-equivalent Selingsgrove and Buttermilk Falls Limestones across Pennsylvania. The Selinsgrove is dominantly comprised of interbedded argillaceous limestone and calcareous shale; the Buttermilk Falls chiefly consists of cherty to non-cherty limestone. Thicknesses from Swatara Gap and West Bowmans after Inners (1975) and Epstein et al. (1974). Note thinning and facies change in center of diagram, related to proximity of southeastern shore of Appalachian basin near the Auburn Promontory (see Epstein et al., 1974).

New York


Clarence
Honeoye Falls
Seneca Stone Quarry
Jamesville
Cherry Valley
Clarksville
Catskill
Kingston
Tioga F
Tioga B (OIN)
Seneca Mbr.
Tioga B
Moorehouse Mbr.
Nedrow Mbr.
Edgecliff Mbr.
Edgecliff Mbr.
New York
Pennsylvania
15 m
10 m
2 m
0
25
50
km


Pennsylvania
W
E
Mapleton
Newton Hamilton
Midway
Dalmatia
Swatara Gap
West Bowmans
East Stroudsburg
Tioga F
Tioga B
Tioga B
HIR
Sbl
Palmerton Fm.
Selinsgrove Mbr.
(Auburn Promontory)
Buttermilk Falls Fm.
New York
Pennsylvania
15 m
10 m
2 m
0
25
50
km

York where it overlies Clarence cherty facies of the Edgecliff Member. A pair of black to dark gray shale-dominated beds within the Nedrow Member are widely correlatable across a large area of the northern and central parts of the Appalachian Basin. These beds occur below Oliver's (1954) original position of the Nedrow-Moorehouse Members contact; however, due to the ease of recognition and the widespread mappability of the two black shales, we functionally use them as the upper boundary of the Nedrow Member.

Overlying strata of the lower part of the Moorehouse Member are characterized by poorly fossiliferous limestones, commonly interbedded with thin shales. A widespread calcareous shale near the middle of the member is succeeded by coarser facies in the overlying upper part of the Moorehouse. These rocks generally consist of pack- to wackestone facies similar to parts of the Edgecliff Member. Nodular to bedded chert occurs throughout the member but is more concentrated toward the top of the unit.

Uppermost strata of the Onondaga Formation are represented by medium- to fine-grained limestones of the Seneca Member. The Seneca is marked by a generally lower diversity fauna, and a lesser percent of chert than the underlying Moorehouse Member. Numerous altered volcanic ash beds of the Tioga Bentonites cluster are chiefly concentrated in the Seneca Member.

The contact of the Onondaga Limestone and the overlying Marcellus Shale in the type area of the Seneca Member is treated differently by different authors. The authors herein tentatively follow the usage of Conkin and Conkin (1979, 1984; Conkin, 1987) and place the contact at the position of an apparent discontinuity marked by fish bone material, pieces of hematitic limestone, and a small-scale irregular topography. Overlying interbedded styliolinid limestones, dark shales, and K-bentonite beds (Oliver's 1954 Zone L) are recognized as part of the overlying Marcellus Shale. The Onondaga-Marcellus contact is diachronous across New York State, as seen by the eastward truncation of the Seneca Member below an apparent submarine disconformity at the base of the Marcellus Shale.

Detailed microstratigraphic study across New York and Pennsylvania indicates that the four members of the Onondaga Formation in New York State are widely recognizable across the northern and central portions of the Appalachian Basin. For the first time it is shown that the Selinsgrove Limestone (upper member of the Needmore Formation) in central Pennsylvania is the direct equivalent of the Onondaga Limestone in New York. Underlying strata of the Needmore Formation in Pennsylvania are therefore equivalent to the older Esopus to Schoharie Formations of eastern New York. Furthermore, it is shown that four members of the Buttermilk Falls Limestone of eastern Pennsylvania are directly equivalent to the Edgecliff, Nedrow, Moorehouse, and Seneca Members of New York.

The Edgecliff to lower Moorehouse Members in New York State appear to represent a relatively large-scale sedimentary cycle, probably comparable to those seen in the lower and upper halves of the Helderberg Group, perhaps spanning up to two to three million years. This deepening/shallowing cycle is interpreted as a third order depositional sequence, comparable to those mapped by seismic stratigraphers. It commences with an erosional sequence boundary and combined transgressive surface at the base of the Edgecliff member. The Edgecliff represents a transgressive systems tract while the overlying Nedrow, separated by a surface of maximum sediment starvation early highstand interval; finally the higher Nedrow and its transition into the lower Moorehouse as previously defined by Oliver (1956a) represents a later highstand or regressive interval. However, the upper portions of the Moorehouse and lower parts of the Seneca Member in many areas display a return to coarser skeletal wacke- or even grainstone facies somewhat resembling those of the Edgecliff Member. This abrupt shallowing succession probably reflects a second third-order sequence in the Onondaga Formation as a whole. As in other parts of the Onondaga, the upper Moorehouse and Seneca interval is comprised of a number of smaller-scale cycles. Overall, these display a deepening upward trend, at least above the lower part of the Seneca Member. Bone beds associated with the top of the Seneca Member (see Ver

Straeten et al., this volume) record sediment starvation associated with a major deepening event. This event marks the onset of the second great tectophase of the Acadian Orogeny.

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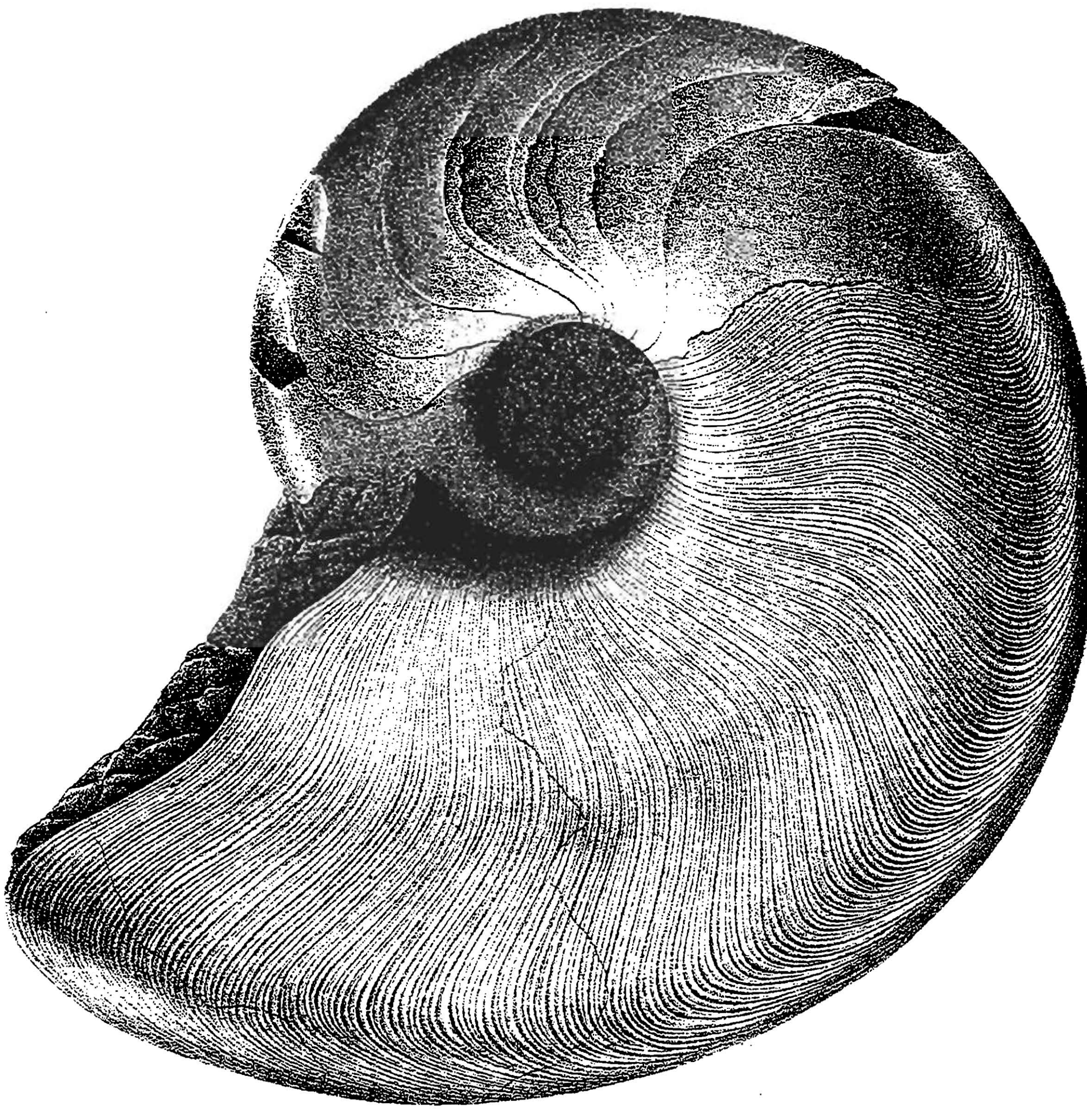
NOTE: Roadlog and stop descriptions for this fieldtrip follow Ver Straeten et al. (this volume).



Agoniatites vanuxemi

[From Hall, 1879, Natural History of New York: Palaeontology, Vol. V, Part II, Plate LXVI, Figure 1]

THE LOWER PART OF THE MIDDLE DEVONIAN MARCELLUS "SHALE," CENTRAL TO WESTERN NEW YORK STATE: STRATIGRAPHY AND DEPOSITIONAL HISTORY

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INTRODUCTION

A major succession of Middle Devonian siliciclastic rocks (Hamilton Group), which ranges from 90 m to approximately 1000 m in thickness, overlies carbonates of the Onondaga Limestone all across New York. The lowest part of these clastics is composed of black shale-dominated strata with minor limestones, and eastwardly coarsening, more sand-dominated, progradational strata, presently referred to as the Marcellus Formation. The Marcellus Formation is the lowest of four formations in the traditional subdivision of the Hamilton Group in New York State (Cooper, 1930, 1933, 1934).

Part of this fieldtrip will concentrate on lower Marcellus strata, which across New York consist of black shales, some thin limestones, and in eastern outcrops, calcareous shale to sandstone facies. These strata range in thickness from zero to less than one meter southwest of Rochester to over 180 m in southeastern New York near Kingston (Figure 1). Recent detailed work across the state indicates that the lower part of the Marcellus Formation comprises a fifth major cycle within the Hamilton Group, which is best developed in eastern New York (Brett and Baird, in press). In addition, the fauna of this interval is distinctly different from that of underlying and overlying rocks. With this in mind, we would like to present an informal preview of a new revision of the lowest part of the Hamilton Group that recognizes the significance of these strata. The revised stratigraphic nomenclature will be formally proposed elsewhere. In this revised scheme, the "Marcellus Formation" will be raised to subgroup status and subdivided into three formations: 1) the Union Springs Formation (=lower part of the "Marcellus subgroup"); 2) the Oatka Creek Formation (=upper Marcellus subgroup basinal black shale-dominated facies of western to central New York); and 3) the laterally equivalent Mount Marion Formation (=upper Marcellus subgroup basinal black shale to shoreface sandstone facies of eastern New York). Uppermost Marcellus strata in eastern New York are represented by non-marine, fluvial-dominated sandstones of the Ashokan Formation (Rickard, 1975, 1989).

The transition from the relatively shallow marine carbonates of the Onondaga Formation to clastics of the Marcellus subgroup marks a substantial reorganization of the Devonian Appalachian foreland basin. Major changes in sedimentation, basin geometry, faunas, and paleoecology are associated with overdeepening of the foreland basin due to thrust load-induced subsidence (Ettensohn, 1985a) and eustatic sea level rise (Johnson et al., 1985) during a second active tectophase of the Acadian Orogeny (Ettensohn, 1985a).

Apparent extinction of some of the endemic Onondaga faunas and immigration of two successive biotas into the Eastern Americas Realm from Arctic Canada and Europe, respectively, are recorded in rocks of the Marcellus subgroup (Koch, 1988). The first migration is marked by a unique brachiopod and coral fauna found in the newly

Isopach map of the Union Springs Formation and the Cherry Valley Member of the Oatka Creek - Mount Marion Formations (Marcellus subgroup).

(modified from Rickard, 1989)

EXPLANATION

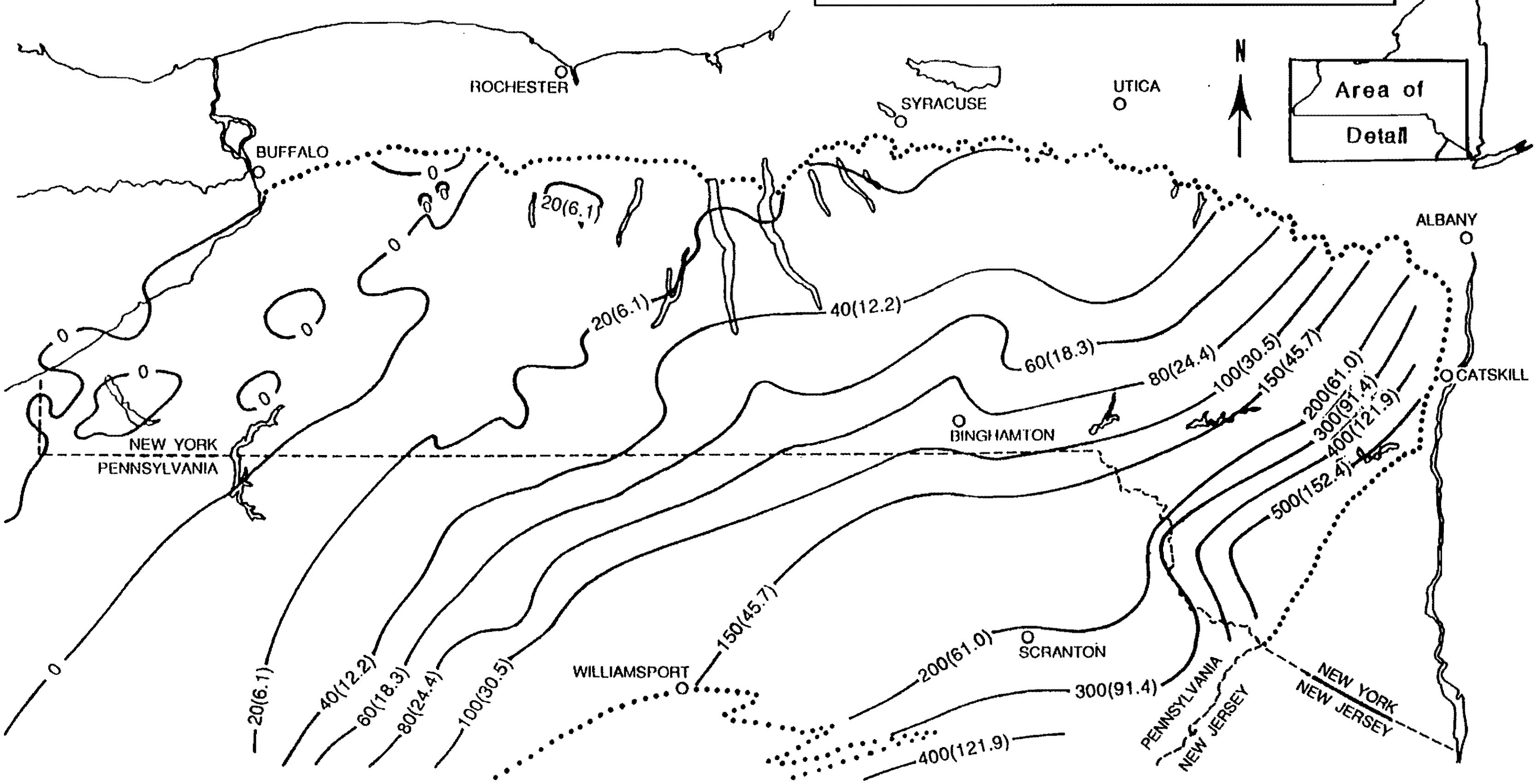
20 (6.1) Isopach - thickness in feet (meters)

Present limit of Marcellus subgroup strata

SCALE

0 10 20 30 40 mi.

0 10 20 30 40 km.



redefined Union Springs Formation in eastern New York. The first appearance of the classic Hamilton Group fauna occurs in the lower part of the overlying coeval Oatka Creek and Mount Marion Formations across New York. In addition, an important world-wide "extinction-radiation-extinction" bioevent involving pelagic goniatite and dacryoconariid faunas, the Kacak-*otomari* Event, occurs through this same time interval (Chlupac and Kukal, 1986; Walliser, 1986; Truyols-Massoni et al., 1990).

Analysis of laterally persistent discontinuities and macrofossil "hash" beds within skeletal limestones of the Marcellus subgroup (specifically those in the Bakoven, Hurley (new), and Cherry Valley Members) indicates condensation by short-term events which reworked long-term, time-averaged accumulations. Although the limestones of the Cherry Valley Member comprise distinctly different facies and represent relatively deeper-water deposition, they share a similar origin with younger Hamilton Group limestone members (Griffing, 1994).

One of the most significant changes between Onondaga and Union Springs/Marcellus time is the geometry of the foreland basin across New York. Deposition of the Onondaga Limestone and equivalent shallow marine carbonates in early Eifelian time was widespread and relatively uniform across much of eastern North America, which resulted in a broad, relatively tabular geometry to these carbonates. This is in contrast to the very distinctive eastward-oriented, wedge-shaped geometry that marks the overlying Union Springs Formation and the Marcellus subgroup as a whole (Figure 1). These key basinal changes were the result of thrust load-induced subsidence of the foreland basin toward eastern New York and uplift of a peripheral bulge in western New York and Ontario during early stages of Acadian tectophase II of Ettensohn (1985a).

Basal black shales and dark gray argillaceous limestones of the Union Springs Formation (Bakoven Member) overlie the Onondaga Limestone across all but westernmost New York. In eastern New York they interfinger with a thick package of calcareous shales to sandstones (Stony Hollow Member). A thin, widespread, fossiliferous package (the newly proposed Hurley Member) occurs at top of the Union Springs Formation along all of its New York outcrop.

The base of the overlying Oatka Creek and Mount Marion Formations is marked by cephalopod-rich limestones and equivalent sand-dominated calcareous strata in eastern New York (Cherry Valley Member). Black shales overlie the Cherry Valley all across New York; in eastern New York, however, they are succeeded by a thick package of progressively coarser, increasingly shallower, progradational clastics that are equivalent to black shale facies in the western part of the state.

Griffing and Ver Straeten (1991) presented the first detailed discussion of lower Marcellus strata in eastern New York. In this paper the authors will examine the equivalent rocks in west-central to western New York in detail, and discuss the larger scale implications of this major transition in the Devonian of the Appalachian Basin.

GEOLOGIC OVERVIEW

PRESENT GEOLOGIC SETTING

Outcrops of the Marcellus Shale/subgroup are exposed along an east-west trending outcrop belt spanning upstate New York from Buffalo to the Albany area. Near Albany the outcrop belt bends southward along the Catskill Front and farther southwest into

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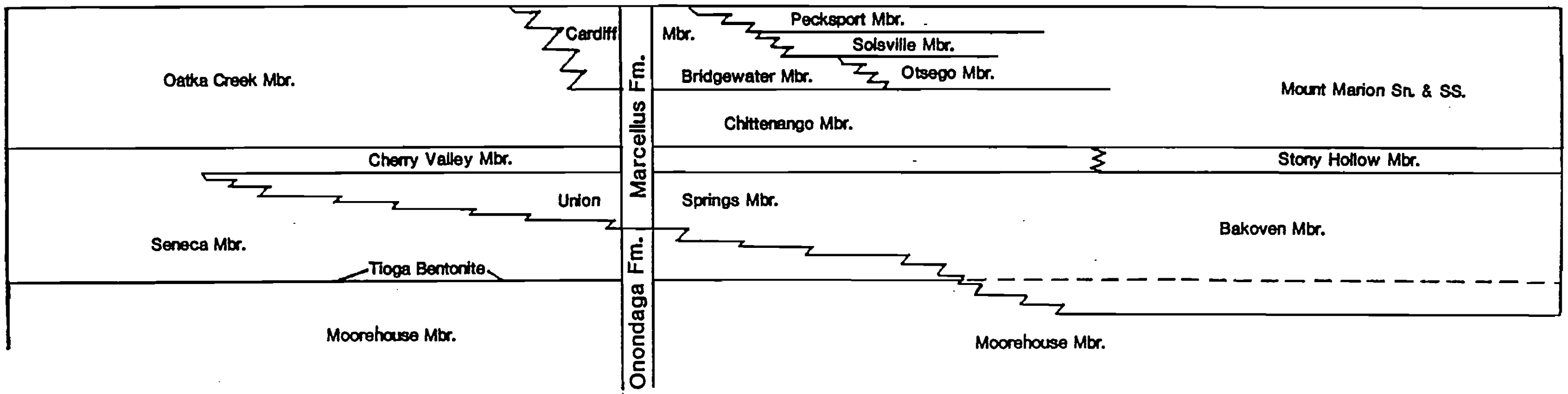
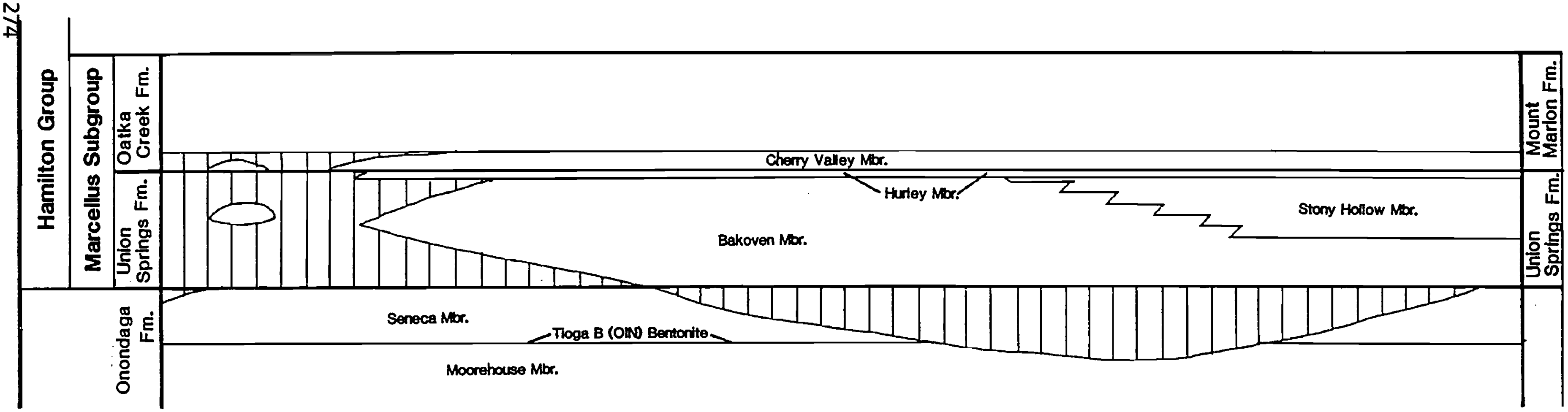
Figure 1. Isopach and outcrop map of lower strata of the Marcellus subgroup (Union Springs Formation and the Cherry Valley Member of the Oatka Creek and Mount Marion Formations) in the Northern Appalachian Basin (modified after Rickard, 1989).

after Rickard, 1975



Proposed Stratigraphic Revision



Pennsylvania, Maryland, and the Virginias through the Valley and Ridge Province.

These lower Middle Devonian strata are moderately to intensely folded and faulted in eastern New York and the central Appalachians (e.g., Bosworth, 1984a,b). Equivalent strata display little deformation in central to western New York; however, broad, low-amplitude folds and minor shear zones and thrust faults occur.

Most natural exposures of Marcellus strata lie in gullies or ravines, where streams have cut through intervals of poorly resistant shale, and where limestones and sandstones form cataracts and caps of waterfalls. Common usage of the underlying Onondaga Limestone for crushed stone in central to western New York also provides valuable quarry exposures of the lower part of the Marcellus Shale.

STRATIGRAPHIC REVISION

In the course of study of the Marcellus "Formation" in New York it has become apparent that this package of strata, which ranges in thickness from approximately 15 m on the Lake Erie shore (western New York) to over 580 m in the Catkill Front (eastern New York; Rickard, 1989), represents a more complex unit than has been previously recognized. A formal revision of these strata is presently in process (Ver Straeten et al., in prep), but the authors would like to take this opportunity to present it as an informal preview. The following is a brief outline and justification of the basis of the new stratigraphic scheme, which is summarized in Figure 2.

a) Raise the Marcellus "Formation" to subgroup status and split it into two formation-level subdivisions: The lower part of the Marcellus "Formation" represents a fifth major cycle in the Hamilton Group (the lowest of the five), equivalent in nature to the four previously recognized formations. Most notably in eastern New York its forms a distinctive succession of black shale to buff-weathering calcareous shale and sandstone easily distinguishable from overlying upper Marcellus strata. In addition, lower Marcellus strata feature a unique fauna related to other late Eifelian assemblages in eastern North America. This fauna is very distinct from those of the underlying Onondaga Formation and the overlying remainder of the Hamilton Group. Therefore, the term Marcellus, which represents rocks from the top of the Onondaga Formation to the base of the Skaneateles Formation, is raised to subgroup status. The Marcellus subgroup will consist of two formation-level packages of strata:

i) In the lower part of the Marcellus subgroup, the Union Springs Member is raised to the Union Springs Formation.

ii) The upper part of the Marcellus subgroup consists of the Mount Marion Formation in eastern New York State; in central to western New York the Oatka Creek Member is raised to formational status.

b) Raise the rank of the Union Springs Member to formational status: The Union Springs Member as previously defined incorporates all strata included in the proposed lower formation of the "Marcellus subgroup" in western to central New York. Raising the unit to formational rank maintains the usage of a familiar term which should lead to less confusion and easier acceptance among various workers. At present the Union Springs in western to central New York is the lateral equivalent of several members in eastern New York. The proposed Union Springs "Formation" would incorporate three members across New York State; black shales of the Bakoven Member (revised), calcareous shales to sandstones of the Stony Hollow Member in eastern New York (revised), and the distinctive Hurley

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Figure 2. Previous and revised stratigraphic nomenclature of the Marcellus subgroup in New York State.

this succession of goniatite faunas is known world wide, and recognized as part of the Kacak-*otomari* global bio-event.

Biostratigraphy of other forms (e.g., brachiopods and nowakiids) has received less attention up to the present. In addition, the previous studies have focused chiefly on the condensed and more black-shale dominated succession in central New York. We hope the new detailed stratigraphic work in the thicker and more complete eastern sections (Griffing and Ver Straeten, 1991; Ver Straeten, 1994; Ver Straeten et al., in prep.) will facilitate more highly resolved biostratigraphic study of these rocks.

Due to the lack of a detailed biostratigraphy of this interval, the Eifelian-Givetian boundary in New York is not well defined. Various authors place the boundary anywhere from the Cherry Valley Member (House, 1978) to the Skaneateles Formation above the Marcellus subgroup (Kirchgasser and Oliver, 1993). Rickard (1984) states that the boundary probably lies close to the Cherry Valley Member.

THE LOWER PART OF THE MARCELLUS SUBGROUP IN CENTRAL TO WESTERN NEW YORK STATE

BASAL CONTACT PROBLEM

The basal contact of the Marcellus subgroup with the underlying Onondaga Formation in New York has been widely discussed, and has been the source of long-standing debate. Previous workers have variously interpreted the contact to be: 1) diachronous due to lateral gradation of the limestones of the Seneca Member (upper part, Onondaga Formation) eastward into the black shales of the Union Springs-Bakoven Members (Clarke, 1901; Oliver, 1954; Rickard, 1975); 2) diachronous due to corrasion of upper part of the Onondaga Formation (Brett and Baird, 1990); 3) isochronous (Conkin and Conkin, 1984); or 4) diachronous and disconformable. Rickard (1984, p. 824-826) recently reviewed this problem, and on the basis of subsurface correlations, stated the Onondaga-Marcellus contact is a "major, regional (widespread) unconformity"; Chadwick (1944) and Lindemann and Feldmann (1987) also suggest a disconformable contact in eastern New York.

Detailed study of the Seneca Member of the Onondaga Formation and the overlying lower part of the Bakoven Member (Union Springs Formation) along the New York outcrop provides new insights into this long-standing problem. Brett and Ver Straeten (this volume) discuss the stratigraphy, geometry, and distribution of the Seneca Member in New York, and thus, these relationships will be summarized only briefly herein.

The Seneca Member is thickest and best developed in the vicinity of its type section in the central Finger Lakes region (e.g., Seneca Stone Quarry, Stop 5), where the member is 7.15 m-thick and is characterized by wackestones to packstones interbedded with thin dark shales and bentonites of the "Tioga Ash Zone." The member thins slightly to the west; south of Rochester (Honeoye Falls Quarry, Stop 1) the Seneca is 6.65 m-thick and appears to contain all strata found in the type area, except possibly a thin interval at the top. East of the central Finger Lakes, however, the Seneca Member progressively thins from 5.4 m near Syracuse to 2.0 m at Cherry Valley. No Seneca is reported from the Albany area of eastern New York (however, see Brett and Ver Straeten, this volume). Subsurface studies by Rickard (1989, Plate 31) indicate the Seneca Member reappears south of Albany and thickens into northeastern Pennsylvania.

One of the key features of the Onondaga-Union Springs transition is the occurrence of multiple, thin paleovolcanic deposits of the Tioga Ash Beds. In New York the Tioga beds occur chiefly within the Seneca Member. The Tioga bentonites cluster, as outlined by Way et al. (1986) for central Pennsylvania, appears to be complete in west-central New York (Honeoye Falls to Seneca Stone Quarries), where up to eight beds are associated with the Seneca Member; these include the prominent Onondaga Indian Nation Ash (OIN, Conkin and Conkin, 1984; Conkin, 1987; =Tioga B of Way et al., 1986) and the Tioga F bed near the

Onondaga-Union Springs contact (see Brett and Ver Straeten, this volume). East of the central Finger Lakes region toward Syracuse and beyond, however, the upper bentonites of the Tioga cluster appear to be progressively removed, associated with the top-downwards truncation of the Seneca Member (see Brett and Ver Straeten, this volume). Active search for the bentonite layers in the overlying black shales in eastern New York, analgous to their occurrence in central Pennsylvania (where the Tioga beds occur interbedded with Seneca-equivalent black shales; Way et al., 1986; see Figure 6 in Brett and Ver Straeten, this volume), has been unsuccessful; no Tioga bentonite beds have been found in the lower part of the Bakoven Member in east-central to eastern New York.

The interval of the Onondaga-Union Springs formational contact commonly features fish bone-phosphatic lag deposits. As discussed below, the bone beds appears to represent long-term submarine condensation surfaces associated with transgression and sediment starvation-corrasion. These lag deposits appear to be diachronous across the central to eastern New York outcrop belt, due to their occurrence on top of progressively older strata of the Seneca Member eastward.

BONE BEDS AND SKELETAL LIMESTONES OF THE MARCELLUS SUBGROUP

Bone Beds in central to western New York

Introduction

Several thin intervals of concentrated skeletal phosphate lie within limestones of the uppermost Onondaga Formation and parts of the overlying Marcellus subgroup in west-central New York. Three notable "bone bed" intervals occur: 1) in the Seneca Member at or near the Onondaga-Marcellus contact, 2) in the lower part of the Union Springs Formation, and 3) within the Oatka Creek Formation, at the contact of the Cherry Valley Member with overlying shales. Some these bone beds have been recognized previously, but preliminary analysis of their sedimentological and stratigraphic significance is presented in the following section.

Bone Bed At The Onondaga-Union Springs Contact

An interval of concentrated fish armor, fin spines, and teeth occurs at the contact of the Onondaga Limestone with the overlying Union Springs Formation in west-central New York. Conkin and Conkin (1975) contend that this bed correlates to bone beds that separate Onondaga and Marcellus equivalents in central Ohio, a distance of more than 670 km (Bone Bed 7 of Conkin and Conkin, 1975, 1979). This bone bed is perhaps best developed at the General Crushed Stone quarry, east of Jamesville, where it measures up to six cm-thick. A similar bone bed is recognized at Seneca Stone quarry, where it forms a thinner bone interval in erosional swales above the Seneca Member limestones, and at the Honeoye Falls quarry, where a thin bone interval directly underlies the Tioga F metabentonite.

The Onondaga-Union Springs contact (OUSC) bone bed at Jamesville quarry comprises crinoidal packstone-wackestone on top of otherwise skeletal-poor, bioturbated, dark gray, lime mudstones. Although bioturbated, several 3 to 10 mm-thick sedimentation units are faintly preserved and the basal contact of the bone bed locally forms a sharp, erosional discontinuity. The coarsest skeletal accumulations lie near the base of the bone bed.

The OUSC bone bed features completely disarticulated placoderm armor, large acanthodian fin spines (some *Machaeracanthus sulcatus* spines measure at least 26 cm-long), and individual denticles from the parasymphisial teeth of the marine rhipidistian *Onychodus* (both *O. sigmoides* and *O. hopkinsi*). The coarse, basal fish bone concentration is associated with abundant, large (commonly 1.0 to 1.5 cm-wide and 3 to 6 cm-long) micritic intraclasts which closely resemble rounded segments of the compressed, haloed, horizontal burrows observed within underlying strata. These intraclasts are interpreted as reworked portions of partially cemented burrows. Long segments of exhumed burrows show parallel alignment to each other and were probably exhumed by storm waves or currents. Small, rounded quartz pebbles are also a common component of the coarsest fraction of the bone bed.

In addition to phosphatized fish debris, small pelmatozoan ossicles and the valves of small chonetid brachiopods are phosphatized. Although black in color like unweathered phosphatic debris, the larger pelmatozoan ossicles (particularly large crinoid columnals) display various degrees of pyrite replacement instead. Most large pelmatozoan ossicles are disarticulated, slightly abraded and bored by endoliths, but some short, unworn, articulated stem segments also exist.

Bakoven Bone Bed

Another bone bed occurs within styliolinid grainstones and packstones in the lower black shales of the Bakoven Member (Union Springs Formation). Although several "black" styliolinid grainstones and packstones have been identified within Union Springs black shales at other west-central New York localities, styliolinid-rich bone beds are, at present, only recognized at the Honeoye Falls quarry (Griffing, 1994) and at the Seneca Stone quarry (Baird and Brett, 1986a). Although Union Springs strata are absent west of the Genesee Valley, Conkin and Conkin (1979, 1984) also correlate this bone bed with one in central Ohio (bone bed 8). This Bakoven bone bed occurs in the uppermost bed of a 15 to 19 cm-thick bundle containing 2 to 20 mm-thick, ripple cross-stratified, styliolinid grainstone/packstone beds which are separated by thin beds, drapes or partings of black shale. The interiors of many styliolinids within the grainstones are also filled with black shale. The small, low-relief ripples commonly contain wave discordant cross-laminae, but net migration direction appears to be to the east and southeast.

Like the OUSC bone bed, the Bakoven bone bed contains common disarticulated placoderm armor and *Onychodus* teeth. Also, abundant sand-sized, angular fragments of fish bone intermix with the styliolinids and highlight ripple foresets. Rare, rounded black shale clasts occur with the coarsest fish debris at the base of the bed.

Cherry Valley Bone Bed

A bone bed also occurs at the top of the Cherry Valley Member at several localities in west-central New York. Disarticulated fish armor is concentrated at and near the upper surface of a 1 to 3 cm-thick styliolinid packstone bed which also contains abundant, truncated goniatite and orthocone cephalopod shells. The bone-cephalopod bed overlies a firmground discontinuity that truncates another cephalopod-rich bed; it is directly overlain by fossil-poor black shales. This bone bed has been identified in Cherry Valley sections from Nedrow to Seneca Stone quarry, where it is best exposed. The bone bed occurrence coincides with the most condensed but complete sections of the Cherry Valley Member in New York State.

Most fish detritus consists of individual fish scales and disarticulated placoderm armor (particularly of the arthrodire *Clarkeosteus*). Head shield armor of an even larger arthrodire has been observed at Seneca Stone quarry exposures, where one fragment measured 56 cm in length (Griffing, 1994). Many of the placoderm plates found in this bed are disarticulated, but some remain partially articulated. The bone vesicles and the skeletal matrix of the uppermost Cherry Valley bed are extensively pyritized, and the upper surface of the bone bed forms a firmground or incipient hardground discontinuity. Rare, sub-rounded quartz and quartz sandstone pebbles are also present along the uppermost portion of the bone bed. Although reworked burrow clasts are not common in this bone bed, orthocones within this bed show a roughly unidirectional, offshore-directed current alignment and upper portions of *Rhizocorallium* traces have been eroded.

Discussion and Interpretation

A review of middle Paleozoic through Holocene bone beds by Antia (1979) demonstrates that there are many processes and pathways leading to bone bed formation. Disarticulated bone beds are commonly thought of as either: 1) hiatal deposits representing long-term accumulations concentrated by corrasion of less resistant skeletal, or 2) physically condensed deposits concentrated by hydrodynamic exhumation and density sorting.

Carbonate-hosted bone beds are common in the rock record. For example, a thin, marine vertebrate bone concentration capping the Santee Limestone (middle Eocene) of the South Carolina represents a diastem of several hundred thousand years duration (widespread) to millions of years in duration (locally where the Cooper Marl is absent and the Santee Limestone directly underlies the Pliocene-age Duplin Formation; Sanders, 1974). Personal examination of this long-term hiatal accumulation (by DHG) revealed bone fragments and shark teeth in various states of preservation; from extremely rounded and polished bone with abundant borings, to pristine, unabraded skeletal elements. Vertebrate skeletal material is directly associated with coated-grain phosphate and overlies a pitted, bored, abraded, and partially phosphatized hardground surface at the upper contact of the Santee Limestone. Partially articulated archaeocete whale skeletons from the upper Santee Limestone (Sanders, 1974) suggest that short-term event burial may also have contributed to bone bed concentration. The diverse skeletal assemblages and the rock types surrounding this bone bed indicate formation in very shallow, well-oxygenated waters.

Unlike upwelling models for phosphatization, phosphate enrichment of bone and phosphatization of calcitic skeletal debris can take place in the very shallow subsurface, during extremely slow background sedimentation (Baird and Brett, 1986). Phosphatization of bone can occur in alkalic pore waters of organic-rich sediments (Burnett, 1977; Martill, 1991). Decaying organics within sediments act as one source for the phosphate. Clasts already enriched with apatite (bone) make preferable sites for nucleation, but calcitic grains also provide good nuclei (Antia, 1979). Such "pre-fossilization" by apatite or pyrite may allow normally low density skeletal remnants to remain as part of the coarse lag developed from hydrodynamic reworking (Reif, 1982).

Like the Santee bone bed, Devonian bone beds often also represent diastems of long duration. The 4 cm-thick Upper Devonian North Evans bone-conodont bed of westernmost New York represents a reworked phosphate-rich aggregate of three conodont zones from the Middle and Upper Devonian (Huddle, 1981). The Middle Devonian bone beds of central and western New York may represent shorter diastems, but they comprise similar bone concentrations. Taphonomic and sedimentologic evidence suggests that short-term, event-driven hydrodynamic modification of the sea-floor played a critical role in condensation of these, and many other bone beds. Episodes of storm-generated reworking, mass mortality(?), and rapid deposition (triggering pyrite formation?) alternated with long periods of slow or no background sedimentation. Between episodic events, phosphatization of buried skeletal debris occurred accompanied by corrasion of carbonate skeletons that were exposed on the sea-floor. Later storm events probably disarticulated previously buried fish remains and mixed skeletal debris modified by rapid burial and non-depositional processes. Large quartz pebbles found in some of these bone beds more likely represent rare dropstones rafted in by plant/tree roots, rather than bedload transported sediment. The bone beds described here are all overlain by black shale facies and may represent lags formed during initial transgression or, more likely, during maximum transgression.

Limestones of the Chestnut Street submember (Hurley Member)

Introduction

A thin bundle of skeletal limestone beds form the base of the newly proposed Hurley Member of the Union Springs Formation from eastern New York to Honeoye Falls quarry, south of Rochester. Many of the distinctive elements of the Union Springs fauna which are recognized as part of the Kacak-*otomari* event (discussed above) are concentrated in the micritic packstones, wackestones, and minor grainstones of the Chestnut Street submember.

Lateral Extent and Thickness

The Chestnut Street submember acts as a widespread stratigraphic marker which not only extends across central New York but also persists from eastern New York into the central Appalachians (discussed below). At Kingston, New York, the Chestnut Street submember forms a 7 m-thick series of thin sandstones and interbedded silty shales. However, the entire bundle measures 20 to 43 cm-thick in eastern and east-central New York, where it contains from 2 to 7 individual limestone beds amalgamated into either one composite bed or into two shale-separated beds. The number of amalgamated beds and the overall thickness of the bundle decreases slightly across west-central New York, where it is overstepped by the Cherry Valley Member. The Chestnut Street submember reaches its minimum thickness at Flint Creek, near Phelps, where it forms a single 3 to 12 cm-thick bed which was scalloped and nearly removed by sub-Cherry Valley erosion. An anomalously thick (42 to 48 cm) Chestnut Street bundle of 3 to 4 beds is present along part of the

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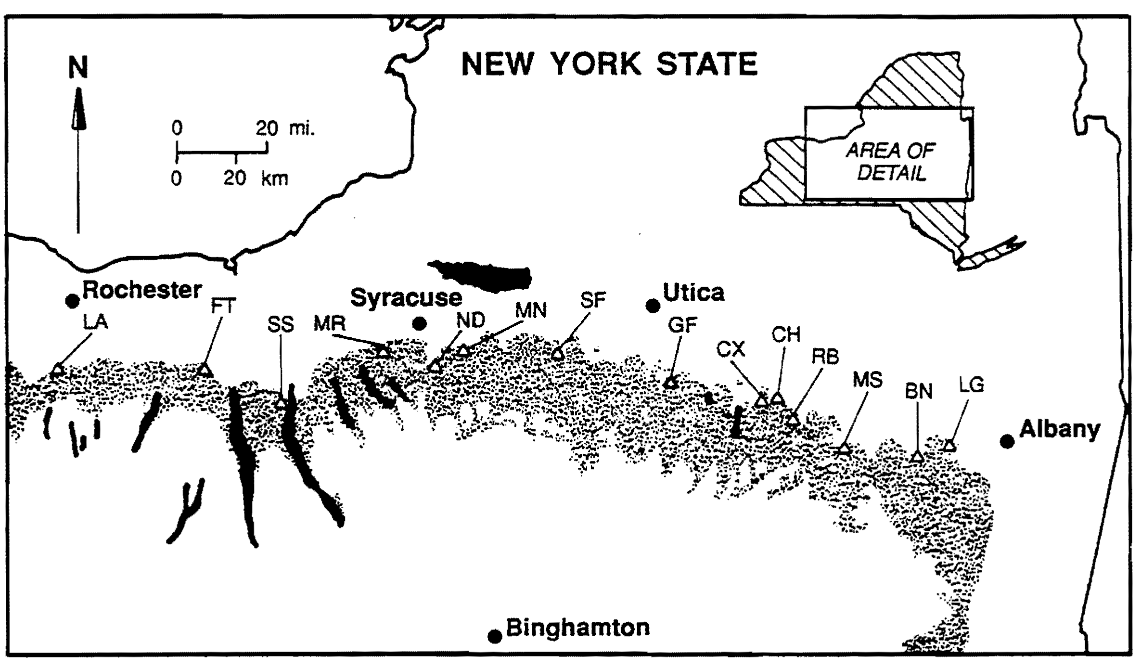
Figure 3. Map of selected outcrops of the Hurley Member (Union Springs Formation) and the Cherry Valley Member (Oatka Creek and Mount Marion Formations)between Albany and Rochester regions of New York State. Localities as follows: LA=Honeoye Falls quarry, near Lima, FT=Flint Creek, SS=Seneca Stone quarry, MR=Marcellus, ND=Nedrow, MN=Manlius, SF=Stockbridge Falls, GF=Gulf Road near East Winfield, CX=Cox Ravine, CH=Chestnut Street, RB=Rosenberg Road near Seward, MS=Mineral Springs, BN=Irish Hill near Berne, LG=Long Road near Thompson Lake.



exposures at the Honeoye Falls quarry. However, the unit is locally truncated to completely removed in other parts of the exposure (see below).

Contacts

The basal contact of the Chestnut Street submember manifests itself as an erosional discontinuity in western New York, where it truncates black limestone concretion beds of the Bakoven Member in places. The basal contact in east-central New York is obscured by "underbed" diagenetic modification, but minor downcutting is implied by reworked *Cabrieroceras plebeiforme* in the lower Chestnut Street beds. The upper contact is distinct but comformable in east-central New York, where overlying Hurley Member siltstones and black shales (Lincoln Park submember) separate the limestones of the Chestnut Street submember and the Cherry Valley Member. The upper contact with the Cherry Valley Member is sharp and forms a widespread disconformity in west-central and western New York.

Internal Stratigraphy

Scalloped hardground and firmground discontinuities separate two to three discrete beds of the amalgamated Chestnut Street submember in central and western New York State. These discontinuities, together with systematic vertical variation of rock types and faunal content, allow the correlation of individual Chestnut Street beds across this portion of outcrop (Figures 3 and 4). The lowermost one or two beds comprise fine-grained, burrow-mottled skeletal packstones/wackestones that weather a very light gray color. Calices of the minute crinoid *Haplocrinites clio* are most commonly found in these micrite-rich beds. These lower beds are separated by a locally manifested firmground contact and are capped by a highly irregular hardground surface. Relict sedimentation units within these lower beds appear to be normally graded. The uppermost bed or beds comprise coarser-grained, crinoid-rich skeletal packstones (and locally grainstones) with relatively more abundant fish bone and conodont remains. This crinoid packstone bed attains a maximum thickness of 11 cm at Pleasant Valley Road, in Marcellus, but most surrounding localities feature a 1 to 5 cm-thick bed that may be locally removed along individual outcrops. A scalloped, pyritized hardground surface forms the sharp contact between the welded Chestnut Street and Cherry Valley limestones in west-central New York (Figure 5). Clasts of the pyritic Chestnut Street crust that occur within overlying Cherry Valley Member limestones indicate synsedimentary pyrite formation.

Interpretation

The fauna of the Chestnut Street submember represents the most diverse fossil assemblage in the lower part of the Marcellus subgroup. Although the diminutive size of most benthic faunal elements in central to western New York suggests that some oxygen deficiency persisted throughout Union Springs deposition, the sea-floor was probably mildly dysaerobic to marginally aerobic in that part of the basin during Chestnut Street deposition. The Chestnut Street submember limestones occur directly above the Stony Hollow Member in eastern New York, which forms a coarsening-upward, calcareous shale-to-sandstone succession. The faunal assemblage, stratigraphic position and bedload transport features of this limestone bundle suggest a relatively shallow-water origin. The large micrite component (of algal origin?) of these limestones and the eastward

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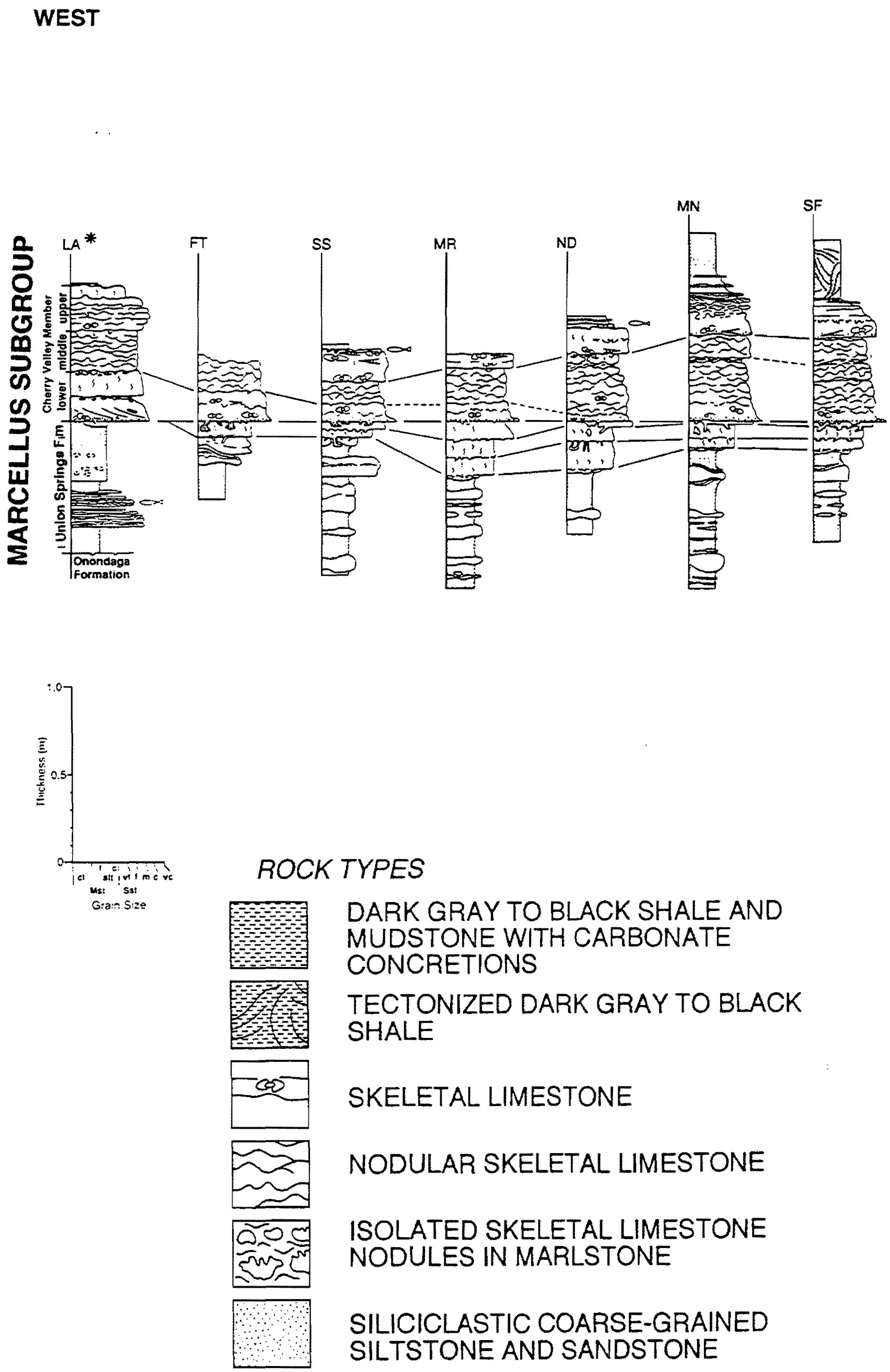
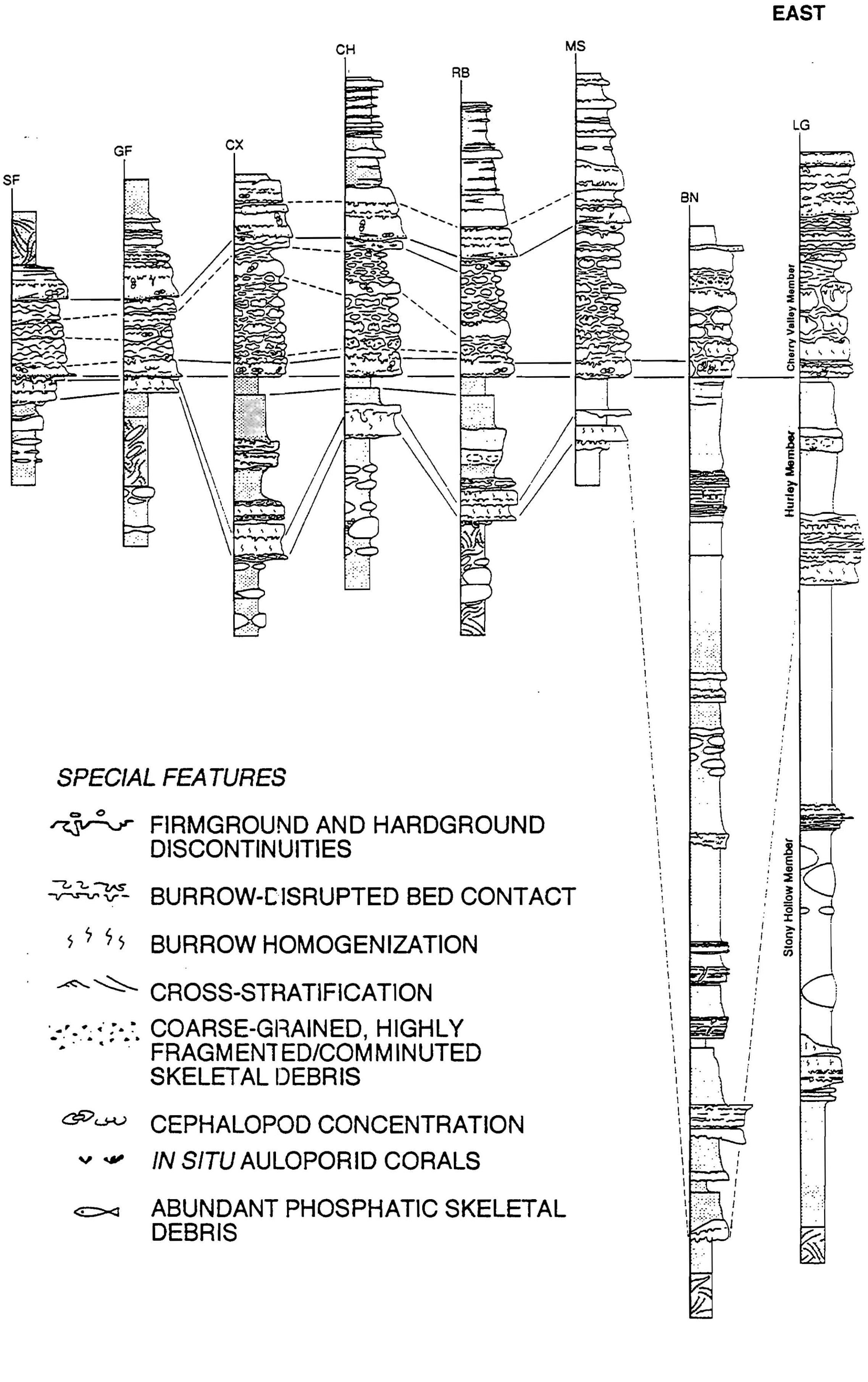
Figure 4. Stratigraphic correlation of the Hurley and Cherry Valley Members between selected sections in New York State. Datum is the base of the Cherry Valley Member (=base of Oatka Creek and Mount Marion Formations). Lower tie lines correlate limestones of the Chestnut Street submember. Localities are same as for Figure 3.



WEST
MARCELLUS SUBGROUP
Cherry Valley Member
lower
middle
upper
Union Springs Fm
Onondaga Formation
LA *
FT
SS
MR
ND
MN
SF
1.0
0.5
0
Thickness (m)
Grain Size
ROCK TYPES
DARK GRAY TO BLACK SHALE AND MUDSTONE WITH CARBONATE CONCRETIONS
TECTONIZED DARK GRAY TO BLACK SHALE
SKELETAL LIMESTONE
NODULAR SKELETAL LIMESTONE
ISOLATED SKELETAL LIMESTONE NODULES IN MARLSTONE
SILICICLASTIC COARSE-GRAINED SILTSTONE AND SANDSTONE


EAST
CH
RB
MS
LG
GF
CX
SF
BN
Cherry Valley Member
Hurley Member
Stony Hollow Member
SPECIAL FEATURES
FIRMGROUND AND HARDGROUND DISCONTINUITIES
BURROW-DISRUPTED BED CONTACT
BURROW HOMOGENIZATION
CROSS-STRATIFICATION
COARSE-GRAINED, HIGHLY FRAGMENTED/COMMINUTED SKELETAL DEBRIS
CEPHALOPOD CONCENTRATION
IN SITU AULOPORID CORALS
ABUNDANT PHOSPHATIC SKELETAL DEBRIS

overstepping of limestones over Stony Hollow siliciclastics suggest deposition during a hiatus. Relict graded beds even in bioturbated facies of east-central New York indicate event deposition (probably by storms) toward the basin center. The limited basinward expansion and broad facies distribution of both the Chestnut Street and Cherry Valley limestones suggests a broad, poorly-defined trough centered east of the Cherry Valley region with extremely gradual, basin-marginal slopes. Any major bathymetric asymmetry in the initial phases of the Marcellus basin was temporarily reduced before Chestnut Street deposition, probably by infilling of the more rapidly subsiding eastern portion of the basin by Bakoven and Stony Hollow sediments.

Despite aggressive erosional downcutting, thin limestone beds were preserved over hundreds of kilometers, due in large part to syndepositional cementation. Hardgrounds, incipient hardgrounds and firmgrounds formed resistant barriers to erosion during and after Chestnut Street deposition.

Cherry Valley Member in central to western New York

Introduction

A complex bundle of dark, organic-rich, skeletal limestones, marlstones, and shales known as the Cherry Valley Member forms the base of the coeval Mount Marion and Oatka

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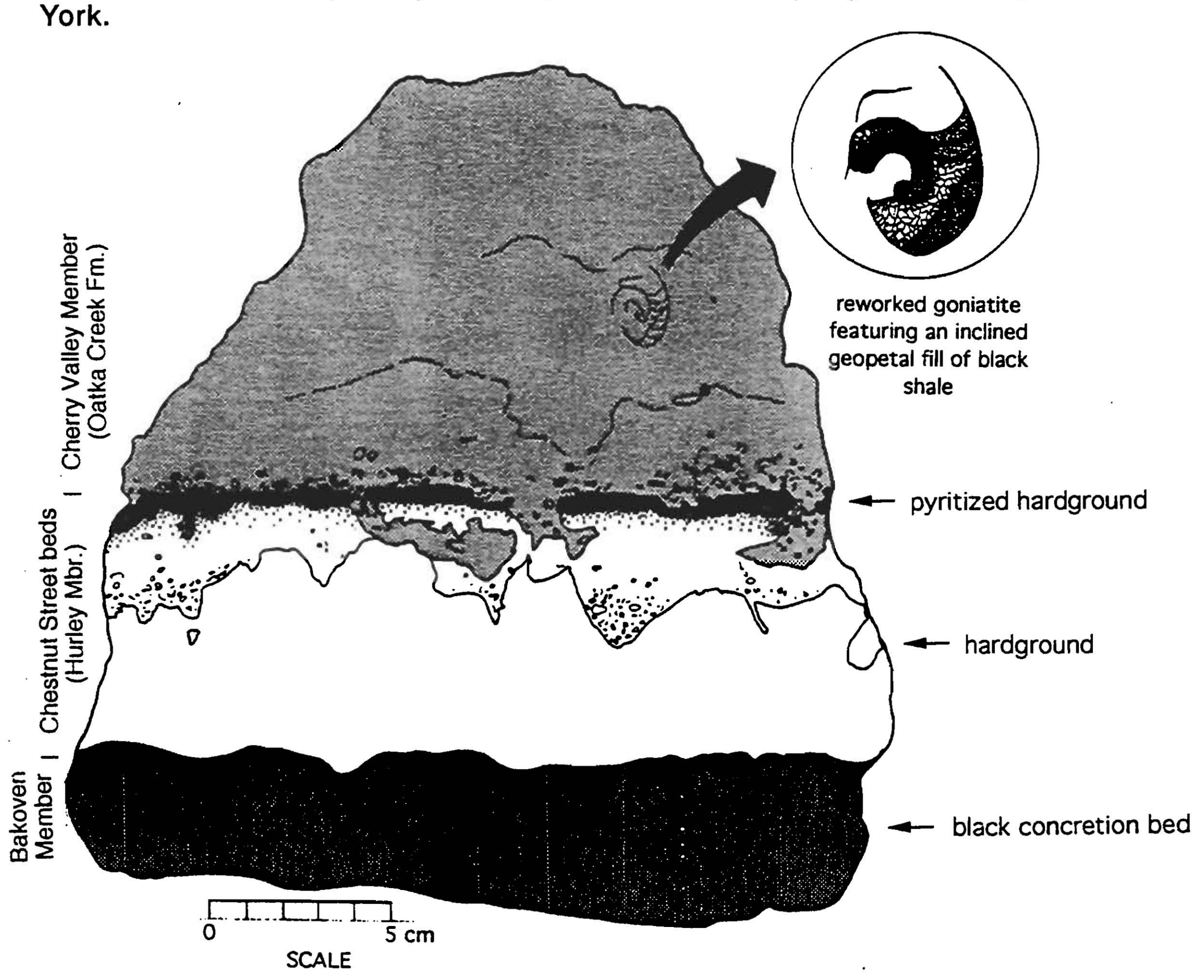
Figure 5. Sketch of polished slab from part of the welded limestone bundle (Chestnut Street submember and Cherry Valley Member) at Seneca Stone quarry, near Canoga, New York.



Creek Formations from Onesquethaw Creek, near Albany, to Honeoye Falls quarry, south of Rochester. Like the Chestnut Street submember limestones, the "Cherry Valley Limestone" (*sensu* Rickard, 1952) forms part of a carbonate-siliciclastic lithosome that extends into the central Appalachians (Griffing and Ver Straeten, 1991; see below). Both the carbonate and siliciclastic portions of the Cherry Valley Member contain a distinctive and widely known cephalopod fauna (Flower, 1936; Miller, 1938) highlighted by the ammonoids *Agoniatites vanuxemi, A. floweri,* and the orthocone nautiloid *Striacoceras typum.* Cherry Valley limestones consist of organic- and pyrite-rich, slightly neomorphosed packstones and grainstones which are dominated by the minute pelagic fossil *Styliolina fissurella* (17 to 39%, avg. 25% of total) and by disarticulated crinoid ossicles (1 to 33%, avg. 7% of total). The limestones also commonly contain remains of auloporid corals, the worm tube *Coleolus aciculatum,* minute rhynchonellid brachiopods, gastropods, nowakiids, ostracodes, bivalves and fish bone. The skeletal component and the common nodular fabric of these limestones is comparable to Devonian pelagic limestones of Europe and North Africa, such as the Cephalopodenkalk and the Griotte (Griffing and Ver Straeten, 1991; Griffing, 1994).

Lateral Extent and Thickness

The Cherry Valley Member thins rapidly along the eastern New York outcrop belt from a 10 m-thick siliciclastic-dominated interval at Kingston to a 1.76 m-thick sandy limestone at the south branch of Onesquethaw Creek. Westward thinning of the limestone bundle across eastern and central New York is very gradual, from 1.4 m-thick at Long Road ravine to about 41 cm-thick at Seneca Stone quarry (Figure 4; Stop 6). Even though the Cherry Valley Member is disconformity bound in west-central New York outcrops, the unit varies less than 10 cm in thickness along individual outcrops in central New York. The Cherry Valley at Seneca Stone quarry represents the thinnest section which contains all three submembers. Farther west the completeness and thickness of the unit vary considerably before disappearing altogether. The 37 cm-thick section at Flint Creek contains only lower and middle submembers below a hummocky erosional surface. The 0.40 m- to 3.15 m-thick section of the Cherry Valley Member at Honeoye Falls quarry (discussed below) demonstrates more thickness variation across a single outcrop than the unit does across the entire rest of central New York.

Contacts

The basal contact is sharp and paraconformable in east-central New York sections but represents a distinct erosional disconformity both east and west of the area. The sub-Cherry Valley disconformity in west-central and western New York is manifested by an irregular, scalloped hardground surface developed on the uppermost bed of the Chestnut Street submember (Hurley Member). Similarly, the upper contact is gradational and conformable with overlying Chittenango shales in east-central New York, as evidenced by the progressive vertical decrease in fossiliferous, calcareous black shale intervals and thin, styliolinid limestone beds. The upper contact becomes disconformable in west-central and western New York and is marked by a partially pyritized, scalloped, firmground or incipient hardground surface associated with cephalopod-bone bed pavements (see bone bed description).

Internal Stratigraphy

Rickard (1952) recognized a three-part subdivision of the Cherry Valley Member in east-central and eastern New York. It consists of: 1) a lower massive limestone, 2) a middle nodular limestone, and 3) an upper massive limestone. Submembers similar to Rickard's subdivisions are recognized by Griffing (1994; this article), but the placement of submember boundaries is based on bedding geometry and internal sedimentary fabrics, whereas Rickard's boundaries were based primarily on the weathering profile.

The lower submember consists of a single, laterally continuous, 9 to 15 cm-thick, bioturbated bed in east-central New York. This submember grades upward into large irregular, isolated to nearly continuous packstone nodules in marlstone (of the middle submember) in this area. Relict, burrow-mottled discontinuities separate several 1 to 3 cm-thick units within the bed in east-central New York. The lower submember thins to a minimum of 5 cm-thick between the Gulf Road and Marcellus localities, where it is commonly represented by a coarse skeletal hash directly above the basal hardground contact. The unit progressively thickens from the Marcellus locality westward, where it separates into at least two lumpy to tabular beds. The lower submember contains several distinctive skeletal concentrations which persist across large parts of central and western New York. The base forms the lowest cephalopod-rich horizon in the Cherry Valley Member. Rare, black shale-filled cephalopod steinkerns in the submember at Seneca Stone quarry suggest that black shales of the Lincoln Park submember (Hurley Member) were deposited and then removed by downcutting (Figure 5). The upper portion of the submember contains a persistent concentration of small, articulated rhynchonellid brachiopods. Patches of *in situ* auloporid corals locally occupy the upper contacts of individual beds within the lower submember at many outcrops across the state.

The middle submember is well-developed at all Cherry Valley localities but the facies vary systematically across the outcrop belt. The basal contact is gradational with the lower submember in central New York but forms a sharp, erosional discontinuity at the westernmost localities. In east-central New York the middle submember consists of several beds of isolated skeletal packstone nodules and a few laterally coalesced, discontinuous nodular to lumpy beds within skeletal marlstone. This packstone-marlstone facies is replaced to the west by a packstone/grainstone facies with small, tightly interlocked nodules and few argillaceous/marly partings. The middle "nodular" submember contains few widespread skeletal marker horizons and cephalopods are extremely uncommon in all but the largest nodules. Patches of *in situ* and fragmented *Aulocystis* are particularly common in the lowest and highest nodular beds in many central New York localities. The contact with the upper submember is sharp and forms an irregular, erosional discontinuity at some west-central New York localities, which is interpreted to be an incipient hardground.

The upper submember is widely identifiable and contains the greatest cephalopod concentrations in the Cherry Valley Member, especially in west-central and western New York. The basal contact is sharp and erosional everywhere and may locally display small scour channels into the underlying nodular limestones. The fining-upward, 35 to 38 cm-thick submember in the Cherry Valley region contains a series of amalgamated, 1 to 4 cm-thick, tabular beds separated by erosion or omission discontinuities. A macrofossil hash at the base of the unit directly overlies the scour surface and contains abundant fragmented and complete cephalopod conchs, gastropods, and fragments of auloporid colonies and *Coleolus* tubes. This cephalopod-rich interval can be recognized at all localities farther to the west. In addition, most of the individual beds within the upper submember bedset contain cephalopods shells, but concentrations in east-central New York are low. The submember thins to the west and these cephalopod beds coalesce into two closely spaced, highly concentrated cephalopod- and bone-rich pavements observable at the upper contact at the Seneca Stone quarry (see previous bone bed description). Truncated cephalopods or "half-cephalopods" occur on both subtle internal bed boundaries and more obvious firmground/incipient hardground discontinuities. Although uncommon, evidence of encrusters and endolithic borings within the interiors of half-cephalopods indicates that shell destruction was synsedimentary and only modified by later pressure solution along bed contacts. Endolithic borings in the upper portion of many complete cephalopod shells also indicate biogenic destruction of the exterior of exposed shell surfaces. Alignment of orthocone cephalopods in the upper submember cephalopod pavements indicate

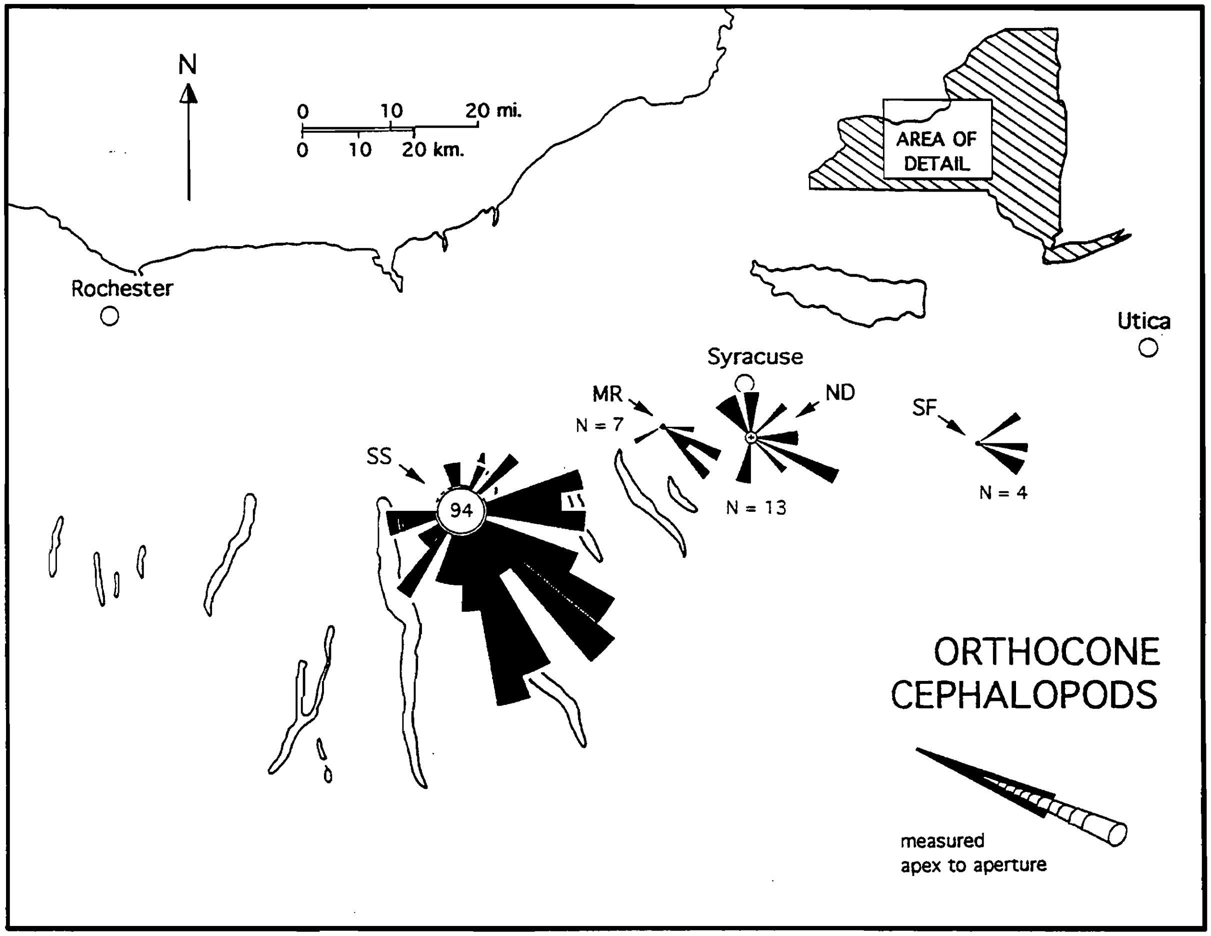


Figure 6. Paleocurrent map of aligned orthocone nautiloids in the cephalopod pavements at the top of the upper submember, Cherry Valley Member. Localities are as follows: SS=Seneca Stone Quarry, MR=Marcellus, ND=Nedrow roadcut, SF= Stockbridge Falls.

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unidirectional flows to the south or southeast, roughly perpendicular to paleodepositional contours (compare Figure 6 with Figure 1).

All three submembers have been identified in the westernmost known exposure of the Cherry Valley Member at the Honeoye Falls quarry (Stop 2), where the lowest beds appear to drape and thicken into erosional swales cut into the underlying Union Springs Formation (discussed below). The lower submember consists of an extremely coarse-grained, crinoid-styliolinid-fenestrate bryozoan grainstone facies which is overlain by the styliolinid-cephalopod packstones at this locality and at Flint Creek. Large-scale cross-stratification and the abundant crinoid content (33% of the total rock) in the coarse grainstones make the Honeoye Falls exposures very similar to the typical shallow-water "encrinites" in the Ludlowville and Moscow Formations. This is the only locality where articulated portions of crinoid skeletons and fenestrate bryozoan debris are commonly found in this limestone.

Systematic Lateral and Vertical Variation

The limestones and marlstones of the Cherry Valley Member represent two stacked, asymmetric, fining-upward intervals that are genetically linked. Although skeletal grain sizes do not vary much in east-central New York sections, a fining-upward trend is expressed by the progressive increase in clay content in the marlstones and by a decrease in nodule size. Farther west this fining-upward trend is expressed by decreasing skeletal grain sizes, whereas easternmost sections show a similar trend in both skeletal and quartz detritus. The lower fining-upward interval is represented by the lower and middle submembers combined. The upper fining-upward interval is represented by the upper submember and overlying dark shale-dominated strata. A sub-symmetrical appearance is given the entire bundle by the repetition: 1) of bedded cephalopod packstone facies in the lower and upper submembers, and 2) of fossiliferous nearly coalesced nodular beds at the base and top of the middle submember.

The nodular packstone-marlstone facies in east-central New York contains the least benthic skeletal component and the fewest hydrodynamic sedimentary structures of all Cherry Valley Member facies, and is interpreted to represent the more basinal facies within the Cherry Valley limestones. Much of the crinoid component in both nodular packstone-marlstones and the associated bedded styliolinid-cephalopod packstone facies in east-central New York is extremely fine-grained and may have been transported downslope. The nodular packstone-marlstone facies oversteps the bedded styliolinid-cephalopod packstone facies and the nodular packstone/grainstone facies in parts of central and eastern New York. All these facies ultimately overstep the crinoid-styliolinid-fenestrate grainstone facies (western New York) and the interbedded sandstone-packstone facies (eastern New York), both of which represent relatively shallow water deposition.

Discussion and Interpretation

The limited benthic fauna and the high organic content (1% organic carbon according to Brower and Nye, 1991) suggest deposition on a dysaerobic sea-floor, especially in more basinal areas. The westward increases in the abundance and size of crinoid ossicles in all facies may indicate increased sea-floor oxygenation upslope and/or closer proximity to skeletal production. In any case, the abundant crinoid ossicles (some partially articulated), articulated brachiopods, auloporids, fenestrates, and solitary cystiform rugosan corals present at Honeoye Falls quarry indicate local benthic production and aerobic sea-floor conditions during Cherry Valley deposition in western New York.

Facies of the Cherry Valley Member closely resemble many of the ancient, mixed pelagic- and benthic-derived skeletal limestones summarized by Tucker (1974), Franke and Walliser (1983), and Wendt and Aigner (1985). Although most commonly attributed to deep-water or open ocean settings, modern pelagic-rich sediments do occur in platform settings (Scholle and Kling, 1972). Sedimentary evidence indicates that many ancient "pelagic limestones" probably formed in shallow platforms in addition to deeper basinal settings. Such carbonates are interpreted to form as hiatal deposits which accumulated at extremely slow rates during periods of siliciclastic sediment starvation. The rate of taphonomic loss of skeletal hard parts in sea-floor environments often exceeds the rate of sedimentation (Cummins et al., 1986). It is unlikely that aragonitic cephalopod and gastropod shells would survive corrasion during long periods of sea-floor exposure associated with slow pelagic sedimentation, and yet both groups are well represented in the Cherry Valley Member. Sea-floor corrasion of aragonitic goniatites and nautiloids is evident in the Cherry Valley Member, especially at erosional discontinuities. The current alignment of orthocones and the coarse macrofossil hash/ reworked lag above scoured surfaces point to condensation by short-term modification and reworking of long-term accumulations, similar to bone bed formation in a lesser degree. Storm-generated mass mortality and rapid burial alternated with long periods of slow, gradual accumulation, during which partially exposed shells were corraded. Subsequent reworking led to further concentration and exposure of additional cephalopods to the destructive agents of the sea-floor.

Although limestone facies of the Cherry Valley Member differ markedly from other younger Hamilton Group skeletal limestone bundles, the overstepping of basinal facies over basin-marginal facies within the two stacked asymmetrical, fining-upward intervals in the Cherry Valley Member bundle resembles the facies pattern within the Tichenor Member-Deep Run Member interval or the basin-marginal portion of the Centerfield Member. The main phase of deposition for all these limestones appears to have followed submarine erosion/downcutting associated with peak regression. The limestones themselves represent the initial phase of transgression and relative starvation, as suggested by Brett and Baird (1990). A consequence of the depositional circumstances is that the first transgressive facies have a "shallow-water" appearance and represent more hydrodynamic condensation than later transgressive facies. Bedded styliolinid-cephalopod packstones and grainstones at the base of fining-upward intervals represent erosional lags and initial sediment starvation. Nodular facies appear to represent deeper water deposition in the continued absence of significant siliciclastic input. Sediment starvation persisted longer in west-central and western New York than farther east, as evidenced by the replacement of the gradational limestone-black shale transition with a bone bed/hardground surface. Sediment transfer by downslope currents (compensation currents) on the western slope is supported by the aligned orthocone cephalopods and by large channels preserved at the Honeoye Falls quarry.

LOWER PART OF THE MARCELLUS SUBGROUP AT HONEOYE FALLS QUARRY

Strata of the Union Springs and the lower part of the Oatka Creek Formations are exposed in the southern face of the Honeoye Falls quarry south of Rochester (Stop 1). Quarrying in the late summer and fall of 1993 exposed a discontinuous cross-section approximately 300 m wide along the uppermost bench of the south quarry wall. The section, which is not tectonically deformed, shows a remarkable amount of variation along the exposure in: 1) paleorelief (at two to three levels); 2) thickness of units; and 3) presence-absence of the Chestnut Street submember (Hurley Member) and underlying black shales of the Bakoven Member.

Six separate subunits within the Union Springs and Oatka Creek Formations overlie the Onondaga Formation along the exposure (from the base up): 1) the Tioga F bed (of Way et al, 1986 terminology ; ="Tioga restricted" of Conkin and Conkin, 1979, 1984; Conkin, 1987; see Brett and Ver Straeten, this volume), with a thin, mm-scale black shale at its base; 2) a package of thin, dominantly styliolinid limestones that also include the Union Springs bone beds discussed elsewhere in this paper and several thin, mm-scale, tan clay beds that may represent K-bentonites (Tioga G beds? of Way et al., 1986); 3) black shales (Units 1-3 are included in the Bakoven Member); 4) Chestnut Street Submember (Hurley Member); 5) the Cherry Valley Member (at the base of the Oatka Creek Formation); and 6) overlying black shales of the revised Oatka Creek Formation.

A significant amount of paleorelief occurs below and above the Cherry Valley Member at the Honeoye Falls quarry as shown in Figure 7. A pre-Cherry Valley erosional surface, including channel-like features that cut down through the Hurley and Bakoven Members, is exposed along the uppermost south face of the quarry. Geometry of the erosion surface in places resembles shale-floored submarine channels identified by Brett and Baird (1990) in other basin margin shale strata of the Hamilton Group. At one position along the exposure, almost the entire Union Springs Formation is cut out; only 7 cm of the 15 cm-thick Tioga F (subunit 1) at the base of the Union Springs remain below the Cherry Valley Member at that position. Overlying units 2 and 3 of the Bakoven and the entire Hurley Member (unit 4) is missing at that position; small, rounded limestone clasts are found at the base of the Cherry

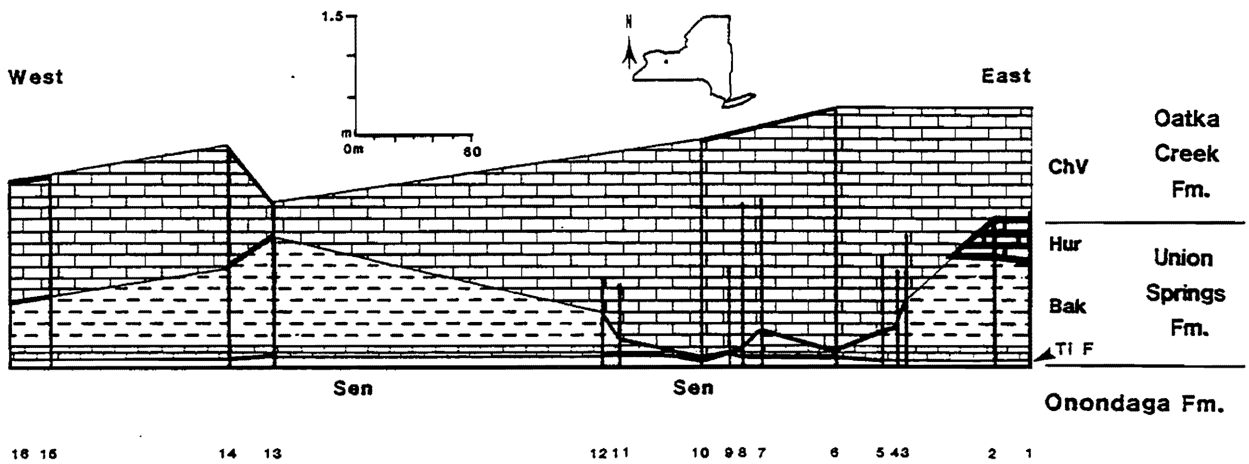

Figure 7. Cross-section of the Marcellus subgroup at Honeoye Falls quarry, south of Rochester (Stop 2 of fieldtrip). Note erosional cutout of strata at base and top of Cherry Valley Member. Bold lines mark known thickness; thinner lines represent projected thickness.

Valley. Elsewhere along the exposure the Bakoven Member ranges up to at least 1.7 m in thickness.

The Chestnut Street beds (Hurley Member) were reported by Griffing and Ver Straeten (1991) to be absent at the Honeoye Falls quarry. Recent excavations, however, show 42 cm of light, cream-colored limestone of the Chestnut Street submember in the eastern part of the exposure, approximately 1.4 m above the planar surface of the Onondaga Formation. The unit has not been found elsewhere along the exposure, except possibly in one area; the strata were apparently removed by pre-Cherry Valley erosion. Another possible surface of paleorelief may occur below the Hurley Member, but the small amount of exposure of the unit makes it very difficult to confirm this.

The Cherry Valley Member varies widely in thickness along the outcrop from as little as 40 cm to as thick as 3.15 m. Erosional downcutting and incorporation of winnowed lags into the basal Cherry Valley Member is evidenced by: 1) abundant black shale-filled styliolinids, 2) angular to rounded clasts of concretions and Chestnut Street packstones, and 3) abraded fish bone plates and fragmented cephalopod shells (including *Cabrieroceras*). As shown in Figure 7, thicker and thinner parts of the member do not necessarily correspond to areas of greater and lesser relief below the Cherry Valley because the top of the member, below overlying shales at the base of the Oatka Creek Formation, also shows variation in paleotopography along the outcrop. This contact across west-central to western New York has been previously discussed by Baird and Brett (1986), who associated relief on the top of the Cherry Valley Member with corrasional removal of carbonate strata during a period of transgression-induced sediment starvation in the region.

DISCUSSION

TECTONIC HISTORY, LATE EARLY TO EARLY MIDDLE DEVONIAN

During the late Early to early Middle Devonian the Northern Appalachian Basin was a dynamic system, marked by major changes in basinal geometry associated with several episodes of subsidence and "rebound." These episodes are associated with two early tectonically-active phases of the Acadian Orogeny in eastern North America (Tectophases 1 and 2 of Ettensohn, 1985a) and an intervening period of tectonic quiescence.

Different mathematical and computer-generated models have been proposed in recent years to describe foreland basin dynamics and stratigraphy associated with orogenic episodes (e.g., Quinlan and Beaumont, 1984; Beaumont et al., 1988; Jordan and Flemings, 1991; Sinclair et al., 1991). The basic premise of these models states that 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 are marked by relaxation and uplift of the foreland combined with subsidence of the peripheral bulge. The timing of subsidence and uplift differs in the models dependent upon an elastic or visco-elastic flexural response of the lithosphere.

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 these regional truncations of strata to reflect forebulge uplift and erosion associated either with episodic loading/tectonic rejuvenation in an adjacent fold-thrust belt or continuous loading of lithosphere of laterally varying flexural rigidity.

A model for the evolution of the Devonian Acadian Orogeny in eastern North America was presented by Ettensohn (1985a). Based on the stratigraphic record of the Appalachian Basin, he notes three to four phases of active tectonism in the late Early Devonian to Mississippian associated with oblique convergence of the eastern margin of North America and a landmass termed Avalon. Each "tectophase" is composed of a progression from stages of active tectonism to quiescence, recorded in the basin fill by a succession of clastic- to carbonate-dominated sedimentation.

Upper Lower Devonian, Emsian-age shales and minor sandstones to shaly carbonates of the Esopus, Carlisle Center, and Schoharie Formations (Tristates Group) show a distinctive, eastward-thickening wedge-like geometry that ranges from 0-300 m in thickness across west central to southeastern New York, respectively. These patterns are associated with an actively subsiding foreland basin adjacent to a probable active fold and thrust belt in the New England region during Ettensohn's (1985a) Tectophase I of the Acadian Orogeny. The absence of these rocks across west-central to western New York (Seneca Stone quarry to Buffalo) is the result of active uplift of a peripheral bulge in that region, possibly during later Emsian time (Schoharie Formation). Interestingly, the initial clastic-dominated part of the succession (shales to fine sandstones of the Esopus Formation in New York), which overlies widespread quartz arenites of the Oriskany Sandstone (see Boucot and Johnson, 1967), is restricted to the eastern margin of North America at that time (eastern most parts of the Appalachian foreland basin and deeper water facies in western New England; Rehmer, 1976). The Oriskany-Esopus transition at the base of the clastic wedge is marked by the occurrence of bentonite-rich strata (Sprout Brook Bentonites of Ver Straeten, 1992, ms. submitted; Ver Straeten et al., 1993)

Geometry of the basin was dramatically altered at the beginning of the Eifelian Stage (Onondaga Limestone). The Emsian-age trough of the basin in eastern New York was replaced by a less dramatically subsiding basin center in central New York, near the previous position of the uplifted peripheral bulge of Emsian time (Brett and Ver Straeten, this volume). Relatively deeper water environments in central New York, flanked on either side by relatively shallow carbonate ramps in eastern New York and western New York-Ontario, characterize the basin during deposition of the Onondaga Limestone. Rocks of the Onondaga Formation across New York range from approximately 20 to 60 m in thickness (Rickard, 1989; see Figure 1 in Brett and Ver Straeten, this volume), but nevertheless display a distinctly more tabular geometry than more clastic-dominated rocks of the underlying Esopus-Schoharie interval. Also note that carbonate-dominated, Onondaga-equivalent strata are very widespread across eastern North America at that time (Figure 2 of Brett and Ver Straeten, this volume). An apparent minor amount of volcanism during early Onondaga time (Brett and Ver Straeten, this volume) greatly increased through deposition of the higher part of the Onondaga, as indicated by the presence of as many as ten ash beds associated with the Tioga Bentonites cluster (Brett and Ver Straeten, this volume).

This increase in volcanism was accompanied by apparent subsidence of the eastern margin of the Northern Appalachian Basin that began in eastern New York during late Onondaga (Seneca Member) time. Initial sediment-starved conditions on the subsiding basin floor are indicated by a relatively minor, westward-younging, sediment-starved submarine unconformity at the Onondaga-Marcellus contact across the state.

Clastics of the overlying Union Springs Formation comprise another eastwardly, forelandward-thickening wedge of sedimentary basin-fill that characterizes the Middle Devonian Hamilton Group as a whole. More basinal environments occur in the subsiding trough of the foreland basin in eastern New York. Multiple erosion surfaces through the lower part of the Marcellus subgroup in west-central New York (i.e., Honeoye Falls quarry) give rise to a complete removal of Union Springs and lower Oatka Creek (Cherry Valley Member) strata west of the Genesee River. Strata equivalent to these rocks reappear to the west in the Delaware Limestone of central Ohio and other units as far cratonward as the Spillville Formation of Iowa (Day and Koch, 1994; Koch, 1978); their absence across the intervening region may indicate uplift on a peripheral bulge in western New York to southwestern Ontario and eastern Ohio at that time. The more westward position of this Middle Devonian peripheral bulge, in contrast to that of the late Early Devonian (Tristates Group) is probably associated with the westward migration of the foreland basin through time. Superimposed on this tectonic subsidence trend are two transgressive-regressive cycles that comprise the Union Springs and Oatka Creek-Mount Marion succession of the Marcellus subgroup (T-R cycles Id and Ie of Johnson et al., 1985).

To summarize, two major transgressions mark the upper Lower and lower Middle Devonian of the Appalachian foreland basin. Note, however, that these major transitions from relatively shallow marine orthoquartzites and carbonates to basinal black shales (Oriskany Sandstone into Esopus Shale and Onondaga Limestone into Marcellus Shale) are not due simply to a rise in eustatic sea level. In each case, the regressive, shallow marine orthoquartzite-carbonate suite comprises a relatively tabular body of rock that occurs widely across the Appalachian Basin and onto the eastern North American craton. In contrast, the deep basinal, major transgressive packages of siliciclastics consist of eastwardly-thickening wedge-shaped bodies that are concentrated along the eastern margin of the Devonian eastern interior seaway. These patterns point to a combined tectonic and eustatic control on the Appalachian Basin and the adjacent craton during two early tectophases of the Acadian Orogeny.

THE LOWER PART OF THE MARCELLUS SUBGROUP IN PENNSYLVANIA

Recent work in Pennsylvania shows that much of the same stratigraphic framework of the lower part of the Marcellus subgroup in New York can be recognized across Pennsylvania. In Pennsylvania, subdivisions of the Hamilton Group of New York are not generally recognized, and the usage of Marcellus Formation extends to all lower, black shale-dominated Hamilton-equivalent strata above limestones of the Onondaga-equivalent Selinsgrove Member of the Needmore Formation and the coeval Buttermilk Falls Formation (Ver Straeten and Brett, 1994; Brett and Ver Straeten, this volume; see Figure 8).

Black shales equivalent to the Bakoven Member of New York generally overlie the Selinsgrove Limestone in central and southern Pennsylvania and the Buttermilk Falls Limestone in eastern Pennsylvania. In central Pennsylvania, black shale facies may initially occur lower in the section within the Selinsgrove Member at more basinward

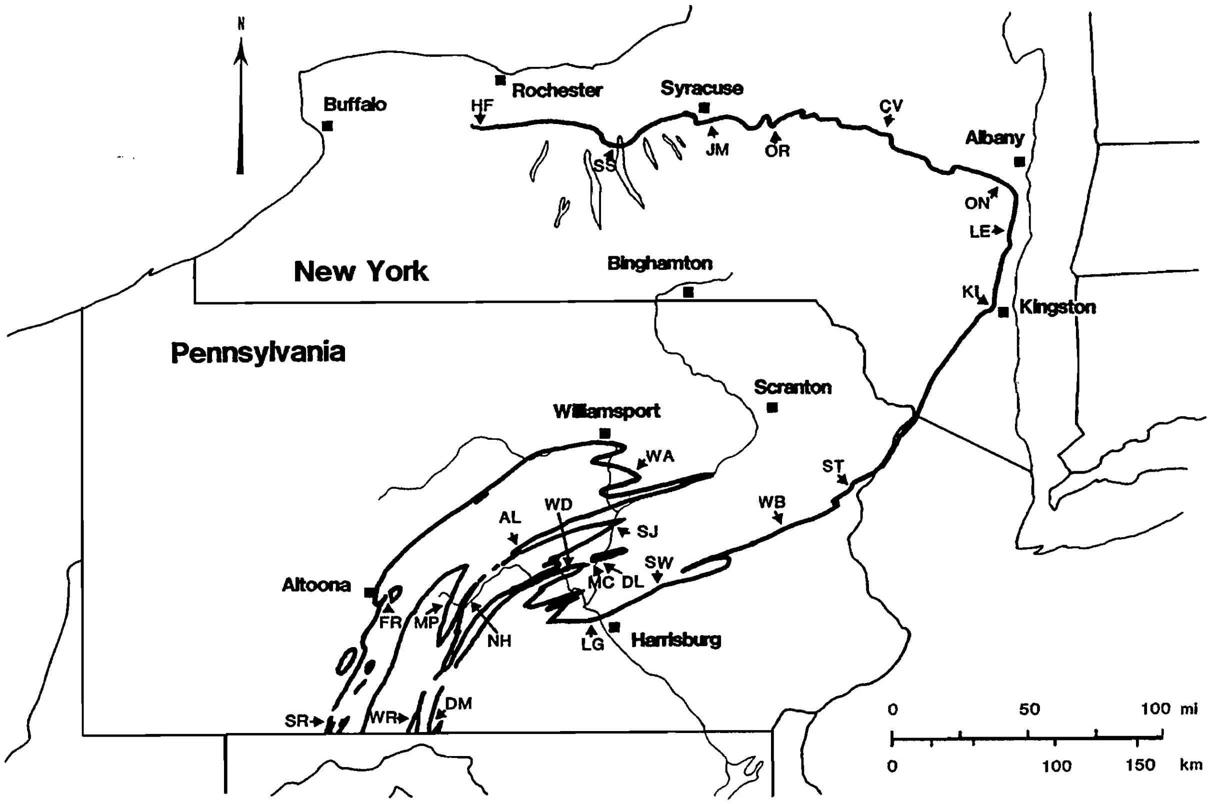

Figure 8. Outcrop map of the lower part of the Marcellus subgroup in New York and Pennsylvania (after Inners, 1975, and Berg, et al., 1980). Key localities are as follows: NEW YORK -- HF=Honeoye Falls quarry, SS=Seneca Stone quarry, JM=Jamesville quarry, OR=Oriskany Falls quarry, CV=Cherry Valley, ON= Onesquethaw Creek, LE=Leeds, KI=Kingston; PENNSYLVANIA -- ST=Stroudsburg, WB=West Bowmans, SW=Swatara Gap, LG=Lambs Gap, DL=Dalmatia, MC=Mahantango Creek, WD=Wardsville, SJ=Selinsgrove Junction, WA=Washingtonville, AL=Alfarata, NH=Newton Hamilton, MP=Mapleton, FR=Frankstown, DM=Dickeys Mountain, WR=Warfordsburg, SR=Stringtown.

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localities (e.g., Selinsgrove Junction and Frankstown, PA; see Figure 8 of Brett and Ver Straeten, this volume).

Calcareous shale and limestone with subordinate amounts of sandstone toward the middle of the Marcellus Formation in Pennsylvania, Maryland, and the Virginias are placed within the Purcell Member (Cate, 1963). The Purcell is generally reported to be equivalent to the Cherry Valley Member of New York (Dennison et al., 1972; Nuelle and Shelton, 1986; Way, 1993; however, see deWitt et al., 1993); detailed comparison between these strata and those of the New York section shows a more complex relationship, as discussed below.

Buff-weathering calcareous shales to sandstones similar to and equivalent, at least in part, to the Stony Hollow Member (Union Springs Formation) are recognizable in eastern Pennsylvania, notably in the Stroudsburg region, and locally through central Pennsylvania, as at Selinsgrove Junction along the Susquehanna River. The lower 11.5 m of strata formerly termed the "upper Selinsgrove Limestone" that are exposed at Selinsgrove Junction are directly equivalent to the Stony Hollow of eastern New York, and display the same set of lithofacies. Overlying strata at Selinsgrove Junction represent the Hurley and

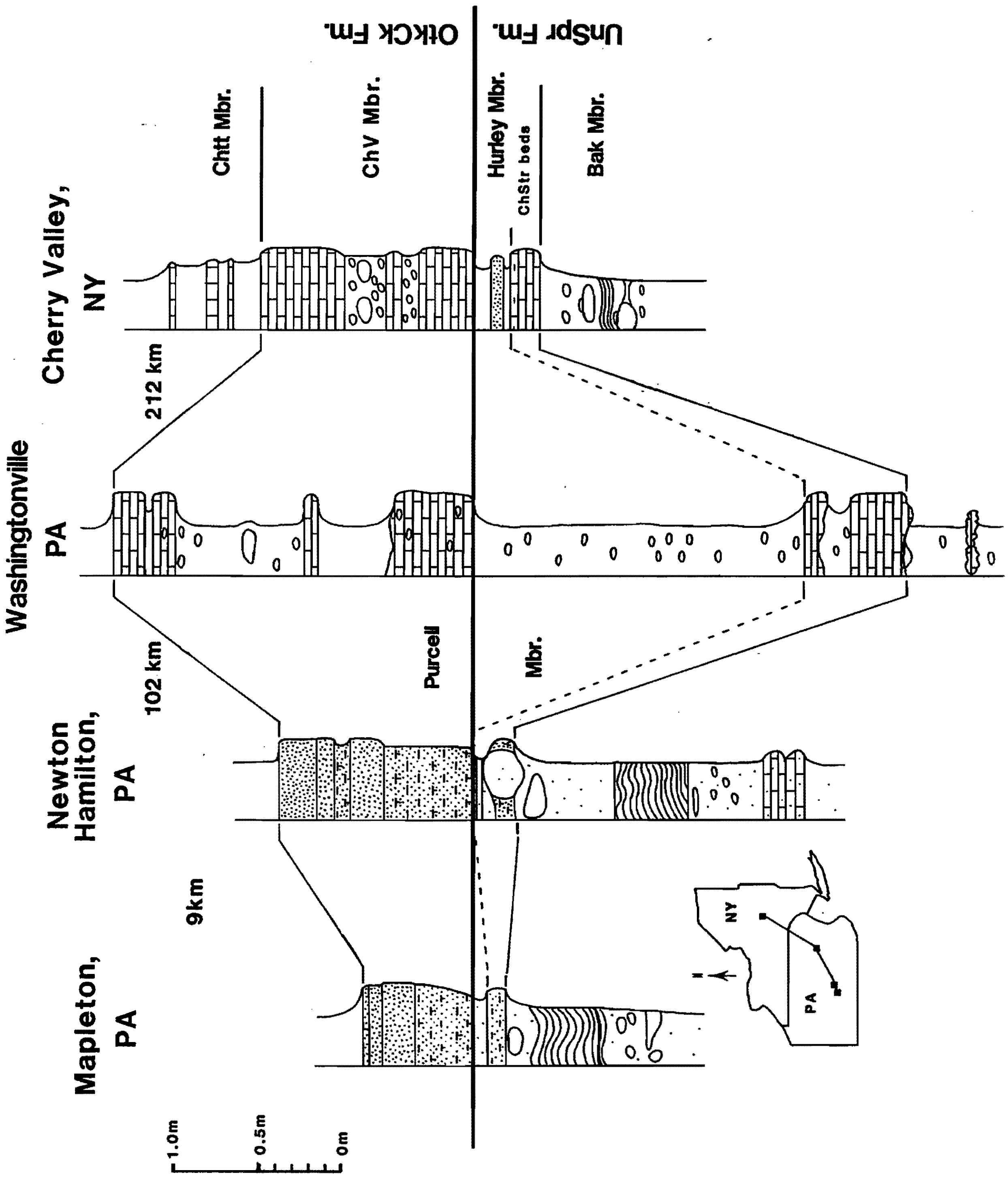

Figure 9. Cross-secton of the Bakoven, Hurley and Cherry Valley Members at Cherry Valley, New York and equivalent strata of the Purcell Member in Pennsylvania (thicknesses of strata at Washingtonville, PA from Way, 1993).

Cherry Valley Members of New York, and include both the proetid trilobite-rich carbonates of the Chestnut Street submember (below) and the classic cephalopod fauna of the Cherry Valley Member (above). In other areas, these Stony Hollow-equivalent strata may be represented by black shales or by dark, pyritic, silty shales to sandstones as can be seen at Newton Hamilton.

Strata correlative with the Hurley Member (Union Springs Formation) are recognizable across most of the Pennsylvania outcrop, most notably the proetid trilobite-bearing Chestnut Street submember (Figure 9). These beds can presently be correlated all across eastern to south-central Pennsylvania to the region along the Maryland border, where they have not as yet been identified. Recognition of the Hurley Member also permits positive identification of strata coeval with the Cherry Valley Member of New York (Oatka Creek and Mount Marion Formations of New York; see Figure 9). These Cherry Valley equivalents may, as in New York, be represented by limestone- or sandstone-dominated facies. The classic cephalopod fauna, dominated by *Agoniatites vanuxemi* and *Striacoceras typum*, is commonly found in more carbonate-dominated exposures.

Nodular to bedded barite, and a lesser component of nodular pyrite, is widely reported from the Purcell Member across the southern and central parts of the Appalachian Basin (Way and Smith, 1983; Nuelle and Shelton, 1986; Way, 1993). These deposits generally occur in the same position as similar, if more commonly pyritic, nodules that are found in the upper part of the Union Springs Formation in New York. Barite nodules in Pennsylvania outcrops are commonly golf ball-sized, although barite may also fill syneresis cracks in large limestone concretions, or even ammonoid cephalopods.

Across central Pennsylvania a previously unreported, widely recognizable K-bentonite bed, generally 3-6 cm-thick, occurs in the middle of the lower part of the Marcellus Formation. This bed often marks a transition from underlying black shales to slightly coarser silty mudstones to sandstones above. The bentonite typically appears as a honey-tan to light gray, soapy-feeling clay bed and forms a prominent, continuous recession along the outcrop. Bleached biotite crystals are visible in less weathered samples; locally the bed contains pyritic concretions up to 5 cm in diameter. This bed has not as yet been recognized in New York or eastern Pennsylvania, but has been found at a minimum of five key outcrops across central Pennsylvania.

This thin bentonite bed may be correlatable into the Harrisburg region of central Pennsylvania, where it commonly overlies typical black shale-dominated strata above the Selinsgrove Limestone and the Tioga Bentonites. Above the bentonite, however, thick-bedded to massive quartz-rich sandstones occur that are generally assigned to the Turkey Ridge Member of the Mahantango Formation (Faill et al., 1978). The Turkey Ridge commonly appears massive and undifferentiated , although in some localities the sandstones appear predominantly cross-bedded. The Turkey Ridge Member generally yields no fossils, which make it difficult to correlate with other strata. A complete section (28 m-thick) of the sandstones is exposed along Mahantango Creek, 40 km north of Harrisburg, west of the Susquehanna River. Roughly 5-10 m below the top of the Turkey Ridge at Mahantango Creek is an interval of sandstone nodules with a barium-rich cement matrix (F. Teichmann, Univ. of Rochester, pers. commun.). These seem to correlate with the barite and pyrite nodule-rich interval previously noted in the Purcell Member from Pennsylvania to the Virginias and in the upper part of the Union Springs Formation in New York. The Turkey Ridge at Mahantango Creek and other nearby localities is overlain by black shales. At least some sandstones assigned to the Turkey Ridge Member in central Pennsylvania, therefore, are equivalent to strata of the Stony Hollow and Hurley Members of the Union Springs Formation and the Cherry Valley Member of the Oatka Creek and Mount Marion Formations of New York.

At Mahantango Creek additional similar sandstones also occur below the thin K-bentonite layer, interbedded with black shales above the Selinsgrove Member. These lower strata, again, are for the most part equivalent to the black shales of the Bakoven Member in eastern

New York, where they occur overlain by the Stony Hollow Member. Across the Susquehanna River from the Mahantango Creek locality, near Dalmatia, the sandstones occur as low as the upper part of the Selinsgrove Member, in strata equivalent to the Seneca Member of the Onondaga Limestone of New York.

Along Interstate 81 at Swatara Gap, 35 km northeast of Harrisburg, 23 m of black shale above the Selinsgrove Limestone equivalent to the Bakoven Member of New York are overlain by a very thick section of sandstone. Plant root traces appear in the middle to upper part of the section. This thick sandstone body may be continuous from lower Marcellus strata (Turkey Ridge) upward into the post-Marcellus Montebello Sandstone within the section exposed; potentially, however, Union Springs-equivalent strata here may even be represented by non-marine facies.

Therefore, we believe we may now be able to widely correlate the New York members and identify a full facies spectrum throughout the lower part of the Marcellus subgroup across the northern and central Appalachian Basin. Much work remains to be done, including refinement of our work in New York and Pennsylvania and an attempt to correlate this new stratigraphic scheme into the southern part of the basin in Maryland and the Virginias.

SUMMARY

Lower strata of the Marcellus Shale comprise a fifth major cycle within the Middle Devonian Hamilton Group of New York State. In this light we informally raise the Marcellus to subgroup status and recognize three formations. They are: a) the Union Springs Formation, comprising strata from the top of the Onondaga Limestone to the base of the Cherry Valley Member all across New York; b) the Oatka Creek Formation, which consists of black shale-dominated upper Marcellus strata in central to western New York (from the base of the Cherry Valley Member to the base of the Stafford Member of the Skaneateles Formation); and c) The Mount Marion Formation, the lateral, progradational shale to sandstone equivalent of the Oatka Creek Formation in eastern New York.

In contrast with the southeasterly thickening wedge of siliciclastics in the lower part of the Marcellus subgroup in eastern New York, this interval is represented in central to western New York by a more tabular, westward thinning body of black shales and skeletal Limestones. Detailed study of the fabric of the limestones of the Bakoven and Hurley Members (Union Springs Formation) and the Cherry Valley Member (base of Oatka Creek and Mount Marion Formations) indicate conditions of long term accumulation of skeletal carbonate modified by short term events. Condensation and submarine erosion/corrasion increased westward across New York associated with a relative decrease in deposition of fine-grained siliciclastics on the distal, cratonic margin of the Middle Devonian Appalachian foreland basin.

Lower strata of the Marcellus subgroup are widely recognizable across the Northern and Central Appalachian Basin. Carbonate-rich strata of the Purcell Member of the Marcellus Formation and underlying black shales in Pennsylvania are shown to be equivalent to the Bakoven, Stony Hollow, and Hurley Members of the Union Springs Formation and to the Cherry Valley Member of the Oatka Creek and Mount Marion Formations of New York State. Furthermore, proximal marine sandstones (Turkey Ridge Member) near to the southeastern margin of the basin appear to be equivalent to more basinward rocks of the lower part of the Marcellus subgroup.

The base of the Marcellus subgroup marks a major reorganization of the Northern Appalachian Basin from a broad, gently sloping carbonate ramp to a rapidly-subsiding foreland basin during a second active tectophase of the Devonian Acadian Orogeny. Subsidence of an eastern trough adjacent to tectonic highlands was accompanied by gentle uplift of a cratonward peripheral bulge in western New York and adjacent parts of southern Ontario. Tectonic flexure of the basin was accompanied by two separate transgressive-

regressive cycles that divide the Marcellus subgroup into two distinctive successions, the Union Springs Formation and the coeval Oatka Creek and Mount Marion Formations. Each of these cycles was accompanied by a major faunal immigration into the Appalachian Basin from the Old World Realm. The second fauna, which first appears in the lower part of the Oatka Creek-Mount Marion succession, became well established and thrived throughout the remainder of the Middle Devonian Hamilton Group.

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FIELD TRIP LOG

C.E. Brett, C.A. Ver Straeten, and D.H. Griffing

NOTE: This roadlog accompanies papers by Brett and Ver Straeten and Ver Straeten et al. (this volume) on the revised stratigraphy and depositional history of the Onondaga and Marcellus Formations. In these accompanying papers, we document the details of sequence and event stratigraphy within the Eifelian Onondaga and Marcellus Formations in western and west-central New York State, and provide an interpretation of the sequence of physical and biotic events that these rocks document.

The early Middle Devonian Eifelian age was a time of significant reorganization within the Appalachian Basin both in terms of its tectonic evolution and the evolutionary ecology of its fossil assemblages. This field trip surveys the the revised stratigraphic and facies relationships of early Middle Devonian Onondaga Limestone and the highly disparate Marcellus black shale facies in western and west central New York State, roughly from LeRoy to Seneca Falls, New York.

Detailed stratigraphic correlation of the Onondaga and Marcellus Formations has recently been undertaken on a regional scale. The rather precise event and cyclic and stratigraphic correlations provide a far more refined framework than does biostratigraphy, and in turn permit rather precise resolution of the timing and dynamics of tectonic and sea level events within the Appalachian foreland basin. This detailed stratigraphic framework is also a key to understanding the dynamics of biotic change during the early Middle Devonian interval.

For a mapview of fieldtrip localities in west-central to western New York State, refer to Figure 4 of Brett and Ver Straeten, this volume. Stratigraphic sections of Stops 1, 2, 5, and 6 are shown in Figures 5a and 5b in Brett and Ver Straeten, this volume.

0.0	0.0	Leave parking lot south of Hutchison Hall; turn left (west) out of lot.
0.05	0.05	Junction with Wilson Boulevard; turn left (south) and get into right lane.
0.1	0.05	Junction with Elmwood Avenue; turn right (west).
0.15	0.05	Cross over Genesee River.
0.5	0.35	Bear slightly to left onto Scottsville Road (end of Elmwood Avenue).
0.9	0.4	Cross over Barge Canal; Immediately over bridge bear right onto I-390 North entrance ramp.
1.35	0.45	Merge onto I-390 North.
3.3	1.95	Cuts in upper part of highly fossiliferous Penfield Dolostone (Middle Silurian Lockport Group); Gates quarry in Penfield and Eramosa (Oak Orchard) Formations to left.
4.0	0.7	Bear left onto I-490 West entrance ramp.
4.4	0.4	Merge onto I-490 West.
4.7	0.3	Cuts on right and in median in lower sandy dolostone of Penfield Formation.
5.5	0.8	Exit for NY Rte. 531; continue ahead on I-490. Outcrops on both sides of highway in upper Penfield and basal Eramosa Formations.
17.2	11.7	Cross over Black Creek at Churchville exit; continue ahead on I-490.
20.1	2.9	Leave Monroe County, enter Genesee County.
23.15	3.05	Enter Town of LeRoy.
23.6	0.45	Exit from I-490 West to NY Rte. 19 and LeRoy.
23.9	0.3	Junction with Rte. 19; turn right onto Rte. 19 southbound.
24.4	0.5	Cross over NY State Thruway (I-90).
24.6	0.2	North Road, Frost Ridge Campground to left.
25.4	0.8	Begin ascent of Onondaga Escarpment.

25.6	0.2	Camillus Shale (Upper Silurian Salina Group) cuts on Rte. 19 and adjacent road to right.
26.2	0.6	Railroad underpass; walk down track to left (east) to Buttermilk Falls of Oatka Creek, a spectacular falls capped by Clarence facies of the Edgecliff Member of the Middle Devonian Onondaga Limestone.
26.3	0.1	Randall Road, route to the LeRoy Bioherm Quarry, site of one of Sunday's trips (see Wolosz, this volume).
27.1	0.8	Enter village of LeRoy.
28.0	0.9	Mill Street on left; route to Oatka Creek exposure of Onondaga-Marcellus contact. Continue ahead on Rte. 19.
28.3	0.3	Bacon Street on left; route to Oatka Creek exposure of Oatka Creek Formation (type section) and contact with overlying Stafford Limestone of Skaneateles Formation. Continue ahead on Rte. 19.
28.4	0.1	Junction with NY Rte. 5; turn right (west).
28.9	0.5	Railroad underpass.
29.3	0.4	Bethany-LeRoy Road on left; road to classic Middle Devonian Hamilton Group localities.
29.4	0.1	Leave village of LeRoy.
32.1	2.7	Enter village of Stafford.
32.65	0.55	Junction with NY Rte. 237; continue west on Rte. 5.
32.8	0.15	Cross Black Creek.
33.1	0.3	Leave village of Stafford.
33.4	0.3	Berms of quarry visible on left.
33.5	0.1	Stone house on left.
33.75	0.25	Genesee-LeRoy Stone Corp. quarry entrance; turn left (south) into quarry.
34.2	0.45	Check in at quarry office; from office proceed left (east) on gravel road.
34.25	0.05	Turn left (north) and descend quarry ramp road.
34.3	0.05	Continue straight ahead on quarry road.
34.6	0.3	Park cars in northwest corner of quarry and walk down ramp to lower part of quarry.

STOP 1. GENESEE-LEROY STONE COMPANY QUARRY, STAFFORD.

This relatively large quarry provides an excellent overview of the middle and upper parts of the Onondaga Limestone (Clarence facies of the Edgecliff Member, Nedrow, Moorehouse and Seneca Members; see Figure 5 of Brett and Ver Straeten, this volume). This stop serves as a reference section for western facies of the Onondaga Formation.

The quarry operates in five main lifts. The lowest two are commonly below water level but the second is exposed during drier seasons. Walls of the sump pit below the second lift exhibit heavily cherty Clarence facies of the Edgecliff Member. The overlying platform displays numerous large, spheroidal, chert-replaced heads of *Favosites* which are overlain by a thin shaly parting. This contact is thought to represent the base of the Nedrow Member at Stafford. It is overlain by an approximately four m-thick interval with distinctly cyclic alternations of dark gray chert-rich micritic limestone and pale pinkish-gray crinoidal limestone with light gray chert and abundant rugose corals.

The next platform is floored by one of the most distinctive marker beds in the western outcrops of the Onondaga; a greenish-gray argillaceous limestone with skeletal hash of crinoids, bryozoans, and brachiopods in addition to abundant and diverse tabulate and rugose corals. Because of its shaly nature, well-preserved fossils are easily obtained from this bed. It is interpreted as a condensed, time-rich fossil bedwithin the Nedrow Member.

The base of the third lift (5 m high) consists of 1.6 m of dark gray, very cherty, micritic limestone that weathers shaly toward its top and is capped by a 5 cm-thick shale bed. This shale and overlying less cherty, coral-rich, light weathering limestone are also readily correlatable in the Stafford-LeRoy area. The interval is interpreted here as the upper portion of the Nedrow Member. The upper part of the cherty limestone and the 5 cm-thick shale are thought to correlate with the lower, thick black shale bed of the upper Nedrow of central New York (Stops 5 & 6). The overlying light-weathering, slightly cherty limestone and succeeding thin shale appear to represent the white limestone and *Schizophoria* shale bed of the uppermost Nedrow Member as defined herein.

The third lift is capped by another persistent crinoidal hash and coral-rich shaly bed that forms a major platform in the quarry. An old road in the northwest corner of the quarry provides access up to some of the higher beds of the Moorehouse Member. Much of the lower parts of the wall consists of sparsely fossiliferous cherty micritic limestone with dark brownish gray chert. A particularly distinctive bed occurs approximately 1 m below the fourth platform of the quarry. This is a biostrome of thicket-type (fasciculate) rugose corals (*Synaptophyllum* and/or *Eridophyllum*). The light-colored corals contrast with surrounding large, dark gray, ellipsoid chert nodules. Slightly higher on the fourth platform, a variety of solitary and colonial rugosans and large favositids are exposed in the quarry floor. This coral-rich interval and immediately overlying crinoidal pack- and grainstones appear to represent the first of two major cycles in the Moorehouse. Slightly above the fourth platform is a distinctly non-cherty, slightly argillaceous and medium gray lime mudstone unit approximately 1.6 m-thick. This unit displays abundant spreiten of *Zoophycos* (which appear on weathered joint surfaces as gently curved laminae) and thin hash beds of brachiopods. This non-cherty interval weathers with shaly fissility and correlates to a middle Moorehouse shaly, "false Nedrow" interval that occurs widely throughout the Appalachian Basin (see Brett and Ver Straeten, above). It is sharply overlain by coarse-weathering, slightly cherty (pale gray chert) crinoidal pack- and grainstones of the upper Moorehouse, including strata that feature abundant large *Paraspirifer* brachiopods. This upper 3 m-thick interval comprises the *Paraspirifer acuminatus* zone recognized by previous workers. It represents the second major shoaling cycle of the Moorehouse. This crinoidal-rich facies yields excellent specimens of the crinoids *Arachnocrinus* and *Schultzicrinus*. Two prominent, clay-rich partings in the upper part of the Moorehouse (above the Nedrow-like shaly unit) represent the First and Second Cheektowaga Bentonites (Conkin and Conkin, 1979, 1984; Conkin, 1987; 2.7 and 0.5 m below the base of the Seneca Member, respectively).

Highest beds in the Stafford Quarry are in the Seneca Member of the Onondaga Formation. A distinctive, thick (ca. 20 cm-thick) clay bed that is traceable around the quarry represents the Tioga B or Onondaga Indian Nation Ash Bed that marks the base of the Seneca. The member is comprised of crinoidal wacke- to packstones with a relatively minor number of horizons of large, brownish-weathering chert nodules. The upper beds are exceptionally rich in brachiopods which tend to weather pale-cream to pinkish in color; *Leptaena*, *Megastrophia*, *Atrypa*, and *Megakozlowskiella* are all abundant here.

No upper contact of the Seneca Member has been observed here. However, dredge piles of black shale south of the quarry suggest that the contact with the overlying Marcellus subgroup lies a short distance above the upper platform of the quarry at Stafford.

To leave quarry, turn around and retrace route;

34.95	0.35	turn right (west) onto small quarry road.
35.0	0.05	Check out at quarry office on left; then turn right (north) onto main entrance road.
35.4	0.4	Turn right (east) onto NY Rte. 5 (return to LeRoy).
36.05	0.65	Reenter village of Stafford.
37.05	1.0	Leave village of Stafford.

40.0	2.95	Reenter village of LeRoy.
40.8	0.8	Intersection with NY Rte. 19; continue ahead (east) on Rte. 5
40.85	0.05	Turn right (south) into "McDonalds"; **10 minute rest stop**.
40.9	0.05	Leave McDonalds; turn right (east) onto Rte. 5 and continue eastbound.
41.1	0.2	Cross over Oatka Creek; falls over Stafford Limestone immediately north of bridge.
41.9	0.8	Leave village of LeRoy.
42.85	0.95	Perry Road on left; route to 5 or 6 large quarries in the Onondaga Limestone along Perry Road and adjacent Gulf Road.
44.1	1.25	Enter village of Limerock; site of famous stone fences where paleontologists since James Hall have collected crinoids and other fauna of the Onondaga Formation.
44.5	0.4	Church Road; eastward access to Onondaga quarries along Gulf Road to north.
45.2	0.7	Leave Genesee County, enter Livingston County.
47.2	2.0	Enter village of Caledonia.
47.85	0.65	Junction with NY Rte. 36 South; Rte. 36 joins Rte. 5.
48.3	0.45	Center of Caledonia; bear right on Rte. 5 (Rte. 36 turns left).
49.0	0.7	Leave village of Caledonia.
50.3	1.3	Quarry Road on right; old quarries in Onondaga down the road.
53.7	3.4	Descend onto floodplain of the Genesee River.
54.4	0.7	Junction with US Rte. 20; Rtes. 5 and 20 merge; continue straight (east) on combined Rtes. 5 and 20.
54.8	0.4	Bridge over Genesee River.
54.9	0.1	Enter village of Avon.
55.3	0.4	Junction with Wadsworth Avenue; south to classic Middle Devonian Hamilton Group outcrops. Continue straight on Rtes. 5 and 20.
55.5	0.2	Proceed around circle in center of Avon; bear right halfway around circle and continue east on Rtes. 5 and 20.
56.4	0.9	Leave village of Avon.
57.1	0.7	Enter village of East Avon.
57.7	0.6	Junction with NY Rte. 15; turn left (north) onto Rte. 15.
59.95	2.25	Leave Livingston County, enter Monroe County.
60.45	0.5	Intersection with Honeoye Falls #6 Road; turn right (east) onto Honeoye Falls #6 Road.
60.6	0.15	Cross over I-390; view of three drumlins to the left (north).
62.3	1.7	Five Points Road on left; continue straight ahead.
63.2	0.9	Cross Works Road; small outcrop of Onondaga Limestone on right along Works Road.
63.9	0.7	Entrance to General Crushed Stone Corporation, Honeoye Falls quarry, at town of Mendon line; turn right into entrance and bear right.

STOP 2. GENERAL CRUSHED STONE QUARRY, HONEOYE FALLS PLANT. (Five Points quarry).

64.1	0.2	Quarry office; stop and check in.
64.35	0.25	Turn left at high tanks; proceed past white brick building on right.
64.4	0.05	Turn right past building.
64.5	0.1	Descend into quarry on ramp road.
64.6	0.1	Turn left at base of ramp road and proceed under conveyor; note diagonal joints beautifully exposed in lower Moorehouse to left.

64.7 0.1 Fork left around crushed stone piles and proceed down ramp.
64.8 0.1 Turn to right at bottom of small ramp and park.

Stop 2a. Lower part of Honeoye Falls quarry.

This relatively large and active quarry in the southeastern corner of Monroe County exposes an essentially complete section of the Onondaga Limestone and lower strata of the Marcellus Shale subgroup, including the Cherry Valley Member (see Figure 5 of Brett and Ver Straeten, this volume). Strata in this quarry are slightly deformed (Alleghenian?), and rocks display a gentle dip roughly to the south at a steeper angle than the regional 0.5^{o} dip. Two prominent sets of nearly vertical joints occur in the quarry; the middle portion of the Onondaga also shows a distinctive pattern of diagonal jointing oriented at approximately 080-31S and 080-50S. The Honeoye Falls quarry is the only site in the western portion of the state that displays the entire Onondaga Formation (although the Edgecliff Member is only poorly exposed). The Onondaga Limestone at Honeoye Falls is typical of western exposures. The quarry is particularly notable for the unusually coarse facies of the Cherry Valley Member (Oatka Creek Formation) and for the distinctive channeling beneath it that in places chops out nearly the entire Union Springs Formation.

Mining operations work from six main lifts in the Honeoye Falls quarry. The lowest rocks exposed occur in a small, approximately 6.5 m deep sump pit in the northeast portion of the quarry. These rocks are rarely well exposed, commonly covered by water or by a muddy coating. The Upper Silurian (Akron Formation) - Middle Devonian (Onondaga Formation) unconformity is reportedly present in the lower part of the pit (General Crushed Stone Corp. records) although, based on regional trends, we would estimate the contact to lie some meters below. The sides of the small pit are composed of the cherty Clarence facies of the Edgecliff Member. The walls of the overlying larger pit expose a complete section of the Nedrow Member. The base of the Nedrow essentially forms the floor of the large pit in the northeast area of the quarry. Overlying micritic limestones interbedded with more fossiliferous crinoidal wacke- and packstones are characterized by alternating light gray and dark cherts. The middle part of the member features two distinctive subunits; lower, relatively coarse crinoidal pack- to grainstones with scattered corals, somewhat similar to the Jamesville Quarry facies of the Edgecliff Member, and a distinctive interval of greenish-gray argillaceous limestones and green shales 2.8-3.4 m below the Nedrow-Moorehouse Member contact. The green shales are rich in coral and crinoid material, and are correlative with similar strata at the Stafford quarry (Stop 1). The top of the green argillaceous interval occurs at the top of the second wall and forms the base of the third main platform within the quarry, similar to the Stafford quarry. Ellipsoidal and elongate nodular to bedded cherts, which may feature dolomitic rinds, occur scattered throughout generally light gray micrites of the upper Nedrow. A prominent hackly dark chert bed 1.6 m above the green argillaceous interval is probably associated with a prominent, dark to black shale in the upper Nedrow noted widely throughout parts of New York and Pennsylvania.

The Moorehouse Member, as defined herein, begins 2.8 m above the base of the third lift and is relatively thick at this locality (ca. 17 m) Limestones in the lower portion of the member (ca. 5.5 m-thick) appear increasingly fine-grained up to the level of the fourth lift. Nodular chert bands and several layers of bedded, hackly-breaking chert are common. Thin shaly to clay-rich interbeds are also found. Faunal diversity is rather low through the lower part of the Moorehouse.

The middle to upper parts of the Moorehouse at the Honeoye Falls quarry show a general coarsening-up trend. The upper part of the member is generally inaccessible in the high walls of the south face of the quarry, below the Onondaga Indian Nation bentonite (OIN;=Tioga B of Way et al., 1986). Comparison with nearby sections (e.g., Stafford quarry, Stop 1) indicate a rapid coarsening up above a thick, notably more argillaceous unit that occurs above the middle of the Moorehouse (this argillaceous unit is widely recognized across the Appalachian Basin throughout New York and Pennsylvania into at least northern West Virginia; see discussion in Brett and Ver Straeten, above). Where accessible the upper beds of the member are highly fossiliferous and yield well preserved brachiopods and some crinoid crowns (particularly *Arachnocrinus)* on weathered surfaces. These strata represent the coarsest facies of the upper part of the Onondaga Formation.

Return to cars and proceed back up small ramp; retrace route to the high tanks .

65.0	0.2	Drive beneath conveyor again, and immediately turn right and ascend ramp road and continue straight to white brick building.
65.2	0.2	Turn left at white brick building toward high tanks.
65.3	0.1	At main quarry road, turn left and proceed toward old equipment area onto narrow road along north rim of quarry.
65.65	0.35	Fork of lower and higher quarry roads.
65.7	0.05	Enter higher road onto top of Onondaga Limestone (do not drive onto berm pile at back).
65.9	0.2	Park cars.

Stop 2b. Upper part of Honeoye Falls quarry.

The Tioga B (Onondaga Indian Nations bentonite) forms a prominent break within the quarry at the base of the overlying Seneca Member. The Seneca is characterized by 6.6 m of dominantly tabular wacke- to packstones with minor pale gray cherts. Thin clay-rich partings, most notably at 1.75, 3.05, 3.95, 4.7, and 5.4 m above the base of the Seneca, represent altered volcanic ashes (K-bentonites). The upper bed of the Seneca Member, which consists of relatively coarse crinoidal and brachiopod rich limestone is capped by a sharp lithologic break with the overlying Union Springs Formation.

A thin, mm-scale black shale at the Onondaga-Union Springs contact overlies a relatively minor but widespread submarine unconformity across New York. Overlying strata comprise basal deposits of the Middle Devonian, siliciclastic-dominated Hamilton Group. Recent quarry operations in 1993-1994 have exposed a fascinating cross-section of lower strata of the Marcellus Shale subgroup (see Figure 7 and text of Ver Straeten et al., this volume). The rock exposed comprise the Bakoven and Hurley Members of the newly redefined Union Springs Formation and the Cherry Valley and overlying black shale facies of the also newly-redefined Oatka Creek Formation. The Honeoye Falls quarry represents the westernmost known exposure of the Cherry Valley Member and underlying Union Springs strata in New York State (NOTE: terminology used for Marcellus strata above the Onondaga Formation in this field trip guide follows the as yet informal stratigraphic revision presented in Ver Straeten et al., above).

A 15 cm-thick coarse, biotite-rich tuff of the Tioga F bentonite bed immediately overlies the thin skim of black shale at the Seneca-Bakoven Member contact. Overlying thin styliolinid limestones and black, platy, laminated shales of the Bakoven represent deposition under relatively deep, oxygen-starved conditions. A prominent phosphatic fish bone bed that yields abundant conodonts and fish remains, including onychodid teeth and dermal armor of arthrodires (discussed above) occurs within the package of thin limestones above the Tioga F. The Bakoven Member varies in thickness from 7 cm to at least 1.7 m along the outcrop as a result of extensive channeling along the discontinuity surface at the base of the overlying Cherry Valley Limestone.

A relatively thin, light-weathering, richly fossiliferous limestone found toward the eastern part of the Union Springs-Oatka Creek exposures represents the widespread Chestnut Street submember of the new Hurley Member (Union Springs Formation). Pygidia and cephala of the proetid trilobite *Dechenella haldemanni* are the most diagnostic fossils from this unit. Also present are small to medium-sized brachiopods, auloporid corals, sponge spicules and calyces of the diminutive crinoid *Haplocrinites*. The upper and lower contacts of this bed are sharply defined.

Along most of the exposure the Chestnut Street submember appears to have been removed, along with varying amounts of the underlying Bakoven Member by an extensive, channeled erosion surface that underlies limestones of the Cherry Valley Member. The Cherry Valley is extremely variable in thickness in this quarry, ranging from just over 40 centimeters upwards to over three meters along 300 meters of outcrop exposed in fall 1993-spring 1994. It is represented a very atypical facies for the unit, which consists dominantly of crinoidal pack- to grainstones with lesser amounts of fenestrate bryozoan and styliolinid material. As previously stated, the basal surface of this unit is extremely irregular and the Cherry Valley appears to fill low spots cut into the underlying Union Springs Formation. In contrast to most other localities, cephalopods are generally not particularly common at this location, although poorly preserved conchs of *Agoniatites* as well as some orthoconic nautiloids (e.g., *Striacoceras*) have been obtained. The upper surface of the Cherry Valley Member is also quite sharp and distinct; it commonly appears as a pyrite-coated corrosion surface. It displays an abrupt contact with overlying black shales assignable to the Berne Member.

To date, the highest beds observed in the quarry consist of barren, black, laminated shales with minor styliolinid hash beds. This interval at nearby localities (e.g., bed of Oatka Creek at LeRoy) features a richly fossiliferous bed of brachiopods and small corals that represents the first occurrence of the classic Hamilton Group fauna informally termed the LeRoy bed (= gray bed of Baird and Brett, 1986; see Ver Straeten et al., above); the LeRoy bed has not as yet been found at the Honeoye Falls quarry and likely occurs in strata above the erosional contact of the Oatka Creek Formation with overlying glacial till deposits.

As previously noted, the basal contact of the Cherry Valley Member shows significant paleorelief across the quarry exposure, including distinctive channel-like structures. The cause of the channeling is unknown; in all other localities the Cherry Valley displays a nearly planar, although sharp, basal contact. We presume that the erosional scour was developed as a result of submarine channeling by gradient currents during a relative low stand in sea level. Similar erosional furrowing associated with maximum regression and subsequent earliest transgression has been observed at other localities in younger Middle to Upper Devonian strata (for example, see Brett and Baird, 1990).

Return to cars and turn around; retrace route to quarry entrance.

66.1	0.2	Turn right (east) onto quarry road and proceed along north rim of quarry.
66.4	0.3	Drive through old equipment and bear left toward main quarry road.
66.5	0.1	Bear left onto main quarry road.
66.7	0.2	Check out at quarry office.
66.9	0.2	At quarry entrance, turn left (west) onto Honeoye Falls #6 Road.
67.7	0.8	Turn right (north) onto Works Road.
68.7	1.0	Cross Five Points Road.
69.4	0.7	Fork to left; Works Road becomes Phelps Road.
70.9	1.5	Intersect with NY Rte. 15A (Rush-Lima Road).
71.4	0.5	Enter village of Rush.
71.7	0.3	Rte. 15A bends to the right.
71.8	0.1	Cross over Honeoye Creek.
72.05	0.25	Junction with NY Rte. 251; turn left (west) onto Rte. 251.
72.6	0.55	Leave village of Rush.

73.4	0.8	Junction with NY Rte. 15; turn right onto Rte. 15.
73.5	0.1	Bear right onto I-390 North entrance ramp.
75.9	2.4	Rochester skyline view.
76.7	0.8	Exit from I-390 at Exit 12 and proceed to NY State Thruway.
77.0	0.3	Bear left at fork toward Thruway.
77.5	0.5	Toll booth of NY State Thruway; collect ticket.
77.65	0.15	Bear left at fork onto Thruway (I-90) east, toward Albany.
78.1	0.45	Merge onto Thruway eastbound.
89.9	11.9	Exit 45, I-490/Victor; continue east on I-90.
93.7	3.8	Exit 44, Canandaigua.
100.9	3.2	Exit 43, Manchester; exit off of I-90.
101.4	0.5	Toll Booth of Thruway.
101.4	0.1	Junction with NY Rte. 21; turn right (south) onto Rte. 21.
101.6	0.1	Junction with NY Rte. 96; turn left (east) onto Rte. 96.
101.8	0.2	Cross Canandaigua Outlet Creek.
104.1	2.3	Intersect Ontario Co. Rte. 7 at Manchester town hall; continue on Rte. 96. Manchester quarry in Onondaga Limestone is 1.6 mi. south along Rte. 7.
106.2	2.1	Intersect Ontario County Rte. 25; continue ahead.
108.1	1.9	Enter village of Clifton Springs.
109.4	1.3	Enter village of Phelps. Mobil gas station on left is opposite small road to right that leads across Flint Creek. Pull off to right.

Stop 3 (Optional). FLINT CREEK, WEST OF PHELPS.

The bed and banks of Flint Creek just west of Phelps provide an excellent exposure of the lower and middle parts of the Nedrow Member in its typical west-central New York facies. The banks expose medium gray, soft, bioturbated mudstones alternating with thin (up to 30 centimeters thick) tabular, somewhat argillaceous, fossiliferous wackestones. Bedding here appears rhythmic and some bundling of limestone beds is evident toward the top of the exposure. The shales near the stream level are extremely rich in well-preserved brachiopods, particularly robust specimens of *Pseudoatrypa*, *Leptaena*, and *Pentagonia*. Scattered crinoid debris and small rugose corals are also present.

The rhythmic bedding within the Nedrow Member may represent minor climatic oscillations. Neither the carbonate nor the mudstones appear to represent major event deposits. The limestone and mudstone bands both consist of multiple beds, some of which may represent thin event deposits, but with bedding largely obscured by bioturbation. Contacts of the interbedded limestones and shales appear to be relatively gradational and generally burrowed by *Chondrites* traces. Hence the alternations are thought to represent variations in the input of siliciclastic mud. The sharp contrast between of varying siliciclastic content has probably been diagenetically enhanced by early cementation of the more carbonate-rich intervals (discussed in Brett and Ver Straeten, above).

Return to cars and continue east on NY Rte. 96.

109.9	0.5	Railroad crossing opposite old Silver Floss sauerkraut plant.
110.0	0.1	Junction with NY Rte. 88 – turn left (north) onto Rte. 88 and continue to roadcuts just south of NY State Thruway overpass.
110.5	0.5	Pull off along road side just south of Thruway overpass.

Stop 4 (OPTIONAL). ROADCUT ON NEW YORK ROUTE 88, PHELPS.

Rock cuts on both sides of this north–south road display a Silurian–Devonian carbonate section. Because of the relatively strong component of southward dip, a relatively long section is exposed here. The lower part of the outcrops just south of the New York State Thruway bridge are in the upper part of the Upper Silurian Bertie Group that display an unconformable contact with the overlying Devonian strata. The unconformity overlies the Scajaquada Formation of the Bertie Group. Medium to slightly reddish gray shales and shaly dolostones display distinct small casts of salt crystal cubes, but few, if any fossils are obtainable from these beds.

The erosional Silurian-Devonian contact at the Wallbridge Unconformity is marked by thin stringers of quartz arenite, apparently of the Lower Devonian Oriskany Sandstone. Thin fissure fillings or neptunian dykes also of Oriskany quartz sand extend 30 to 40 centimeters downward below the upper surface of the Scajaquada Shale. The contact is overlain by a conglomeratic bed containing phosphatic or cherty clasts within a sandy limestone matrix. This bed is only a few centimeters thick, and is overlain conformably by brownish gray-weathering, very cherty micritic limestone (wackestone). Dark bluish-gray chert nodules up to fist size (10 to 20 cm in diameter) occur within these limestone beds. The rock is sparsely fossiliferous, but contains fragments of brachiopods, corals, and echinoderm debris. This unit is clearly not typical of the lower Edgecliff Member of the Onondaga Limestone; it is tentatively assigned to the upper Lower Devonian Bois Blanc Formation. Oliver (1963) reports minor exposures of apparently similar cherty, micritic limestone along the New York State Thruway in the vicinity of Phelps. The contact of the Bois Blanc and the underlying lenses of the Oriskany Sandstone represents a second, post-Wallbridge and pre-Bois Blanc unconformity.

The highest beds exposed in this roadcut consist of pale, pinkish gray-weathering crinoidal grainstone. These strata appear to be in sharp contact on the underlying Bois Blanc and are assignable to the basal Edgecliff Member of the Onondaga Limestone; this contact represent a third sub-Onondaga unconformity. In addition to the abundant crinoid skeletal material, the lower Edgecliff strata contain scattered solitary rugose and tabulate corals. The basal Onondaga contact contrasts markedly with the basal Devonian contact observed in the Oaks Corners (Stop 5) approximately 5 km to the southeast (discussed below).

110.7	0.2	Return to cars and continue north and turn around in drive north of Thruway overpass; retrace Rte. 88 back to Rte. 96.
111.4	0.7	Junction with NY Rte. 96; turn left (east) and continue through village of Phelps.
112.2	0.8	Cross over Flint Creek; outcrops of Upper Silurian Bertie Group.
114.1	1.9	Leave village of Phelps.
114.3	0.2	Cobblestone house; Scotch Highland cattle on left.
114.7	0.4	Junction with Ontario Co. Rte. 6 (Pre-Emption Road); turn right (south) onto Pre-Emption Road.
115.6	0.9	Entrance to Oaks Corners quarry; turn right (west) into quarry and check in at office; then return to Ontario Co. Rte. 6 (Pre-Emption Road) and turn right (south) on Pre-Emption Road.
115.7	0.1	Junction with Cross Road; turn right (west) onto Cross Road.
115.85	0.15	Pull off along roadside and park; walk down farm lane to quarry to the north (right).

Stop 5. OAKS CORNERS QUARRY, SOUTH WALL.

The old south wall of the active Oaks Corners quarry displays an excellent section ranging from the basal contact of the Onondaga Formation up through the lower two-thirds of the Moorehouse Member (see Figure 5 of Brett and Ver Straeten, this volume). The quarry can be approached by walking through a narrow strip of field just north of Cross Road at about 0.2 miles west of the junction of Ontario Co. Rte. 6 (Pre-Emption Road). Beds exposed at the level of the field and road are in the upper part of the Edgecliff Member (Clarence cherty facies) near its contact with the Nedrow Member. These flats are some 12-15 m above the base of the quarry. By walking to the left (west) and carefully proceeding down an abandoned quarry road from the upper platform it is possible to examine the lower part of the Onondaga down to the contact of the Edgecliff Member with the underlying Upper Silurian strata.

At the Oaks Corners quarry, in contrast to the Route 88 roadcuts (Stop 3), the Onondaga Limestone generally rests directly on beds of the Upper Silurian Akron Formation, a massive, dark brownish buff-weathering saccharoidal dolostone. J.W. Scatterday (personal commun.) reports a thin, locally-occurring sandstone in part of the quarry similar to that seen at Stop 4; it is presently unknown whether these strata are related to Oriskany or Tristates Group sandstones ("Springvale"). Where the sandstones are absent, the Akron-Onondaga contact is typically marked by rust staining, as a result of weathering of pyritic crusts that occur along the erosional surface. The unconformity is approximately four to five meters higher in the Silurian section than at the Rte. 88 exposures (Stop 3), where the unconformity surface is cut down to the level of the older Scajaquada Shale. In the Oaks Corners quarry, the unconformity displays relief of up to one meter. Large channel-like depressions, up to several meters across, occur along this boundary. Again, in contrast to the Route 88 cuts, where possibly four to five meters of Bois Blanc Formation occur above the unconformity, the Bois Blanc is missing at this location and the basal beds of the Edgecliff Member occur within hollows on the combined Wallbridge, sub-Bois Blanc (?), and sub-Onondaga unconformities.

The lowest unit of the Edgecliff Member is a fine- to medium-grained crinoidal grainstone, typically pinkish-weathering, which ranges from 40 to 120 centimeters in thickness as a result of the irregular topography at its base. The transition to chert-rich strata (Clarence facies) is abrupt but gradational and consists of cherty, crinoidal pack- to wackestones. The remainder of the Edgecliff Member is dominated by the Clarence cherty facies, and consists predominantly of pale gray-weathering micritic limestone with 20 to 30% dark gray chert. Skeletal wacke- and packstones, which feature large crinoid columns and tabulate and rugose corals, occur approximately three and six meters above the base. These form two light pinkish gray-weathering bands in the wall of the quarry and thus constitute important markers as well as represent the apparent tops of minor shallowing-up cycles. A 46 cm-thick, medium dark gray, sparsely fossiliferous and very calcareous shale occurs high in the Edgecliff Member. This interval closely resembles the higher Nedrow Member, but it is separated from the latter unit by 1.2 meters of micritic cherty limestone typical of Clarence facies. The Edgecliff is approximately 8.5 m-thick at the Oaks Corners quarry.

A sharp limestone-shale contact at the top of the Edgecliff marks the base of the Nedrow Member. Lowest shales of the Nedrow contain a relatively abundant fauna of *Pseudoatrypa*, *Leptaena*, small rugose corals, and other fossils. The Nedrow Member itself is approximately 5.3 m-thick at this location and consists of medium to dark gray, very calcareous shale or mudstone that alternate with argillaceous lime mudstones or wackestones. Some of the rhythmic bedding and bundling of limestones observed along Flint Creek in the corresponding interval (Stop 2) is also apparent here, although somewhat more subtle in this outcrop. The upper portion of the Nedrow Member contains a distinctive dark gray to black shale interval with small black chert nodules. This black shale marker bed has proved to be very widespread across the Appalachian Basin and is recognized at present across parts of New York to southern Pennsylvania (see above). A 40 cm-thick, light-weathering limestone bed with minor pyrite separates this bed from an overlying brownish-gray shale interval that contains a thin nodular limestone bed rich in the brachiopod *Schizophoria* sp. This bed forms the floor of the second highest lift near the abandoned quarry access road along the south wall of the quarry, where the brachiopod fauna and spectacularly weathered *Chondrites* burrows can be observed.

The Moorehouse Member in the Oaks Corners quarry consists dominantly of medium- to thick-bedded micritic limestones (slightly argillaceous fossiliferous wackestones). Several intervals of medium to dark gray chert occur within this section. Particularly heavy cherty beds occur approximately four to five meters above the base of the Moorehouse. Thin intervals of medium to dark gray, very calcareous shale that closely resemble the Nedrow Member (particularly the *Schizophoria* bed) occur approximately 2.2 and 3.0 m above the base of the Moorehouse. A relatively thick calcareous shale (80 cm-thick) that features well-preserved specimens of *Pacificocoelia* as well as *Schizophoria* occurs 5.4 m above the base of the Moorehouse and is well displayed in a cut along the side of a second, more westerly abandoned roadway that leads into the quarry along the south side. A cherty micritic limestone bed approximately 1.5 m below the *Pacificocoelia* shale contains abundant coiled nautiloid cephalopods (*Gyroceras*) which are well displayed on a glacially-polished surface just east of the second access road.

Highest beds of the Moorehouse are quite fossiliferous, and are particularly rich in brachiopods. Argillaceous beds about one meter below the top of the quarry contain a fauna dominated by atrypids and other brachiopods such as *Megakozlowskiella, Leptaena, Schizophoria*, and others. Trilobite material is rather common in the upper shaly beds and includes specimens of *Phacops* and *Odontocephalus.* Echinoderm material is relatively sparse, although rare specimens of an undescribed stalked rhenopyrgid edrioasteroid have been obtained from the shaly beds. Overall, the Moorehouse appears to have at least four to five minor shallowing-up cycles, each of which commences with calcareous shales and culminates in more massive, cherty, micritic limestones that may contain corals such as *Acinophyllum*. The upper part of the Moorehouse Member and the entire Seneca Member are absent at this location due to post-Devonian erosion.

The lower part of the Onondaga Formation at Oaks Corners is similar to more western sections in that the Edgecliff Member is dominated by Clarence cherty facies. Only a relatively small proportion (approximately 10% of the member) consists of the more classic chert-poor crinoidal packstones characteristic of the Jamesville Quarry facies (see body of paper) of the Edgecliff. The remainder of the member is relatively cherty, although not as chert-rich as the Clarence in Erie and Genesee counties. The Edgecliff here (ca. 8.5 m-thick) contrasts markedly with that seen at the Seneca Stone quarry (Stop 5; 21 km southeast) where the member is quite thin (< 3 m-thick) and consists mainly of the crinoidal wackestone facies with only a single band of cherty micritic limestone (see stop description below). The Nedrow Member at Oaks Corners is considerably shalier and less fossiliferous than the equivalent beds seen at the Honeoye Falls quarry (Stop 1; 50 km west) where the member is composed of micritic limestones with light gray to dark chert and greenish-gray argillaceous limestones rich in a diverse assemblage of rugose and tabulate corals, gastropods, brachiopods and other fossils. At the Oaks Corners quarry the Nedrow is only sparsely fossiliferous and carries a fauna dominated by a few species of brachiopods. Moreover, the upper portion of the member contains the distinctive black marker bed, which in the Stafford and Honeoye Falls quarries (Stops 1&2) appears to be represented by fossiliferous greenish shales. The Nedrow interval at Oaks Corners is, on the other hand, quite similar to that seen at Seneca Stone quarry (Stop 5).

The Moorehouse Member at Oaks Corners displays features suggestive of an intermediate setting between those seen in the Honeoye Falls and Seneca Stone quarries (Stops 1&5). It is thicker, more chert-rich, and more fossiliferous than the equivalent interval at Seneca Stone quarry. However, it contains considerably less crinoid material and is dominated by brachiopod-rich wackestone lithologies as opposed to the crinoidal wacke- and packstones of the Moorehouse at the Honeoye Falls quarry. It carries a fauna rich in brachiopods assignable to the *Megakozlowskiella*, *Atrypa*, and *Pacificocoelia* communities recognized by Feldman (1980).

Overall, the Onondaga appears to be uniformly of more fine-grained, more argillaceous, and probably deeper water facies than those seen in the corresponding intervals at and to the west of the Honeoye Falls quarry (Stop 1). However, the relationship of facies to those of the Seneca Stone quarry is not so clear cut. The lower Edgecliff Member appears to be distinctly finer-grained, more cherty, and less fossiliferous than the equivalent strata at Seneca Stone quarry. We suggest that only the upper beds of the Edgecliff at Oaks Corners quarry are continuous into the Seneca Stone quarry, where the lower units have pinched out over the irregular topography below the combined Wallbridge and sub-Onondaga unconformities. Those upper Edgecliff beds show distinct facies changes between Oaks Corners and the Seneca Stone quarry 21 km to the southeast. In particular, the chert-rich intervals appear to grade southeastward into crinoidal wacke- and packstones, whereas the dark gray Nedrow-like shale interval approximately 7.3 m above the base of the Edgecliff appears to grade into a single chert-rich micritic bed at the Seneca Stone quarry. Hence, it would appear that the Edgecliff Member is uniformly of deeper water character at Oaks Corners than at Seneca Stone quarry, which suggests a more basinal setting to the west at that time. The Nedrow Member appears very similar at both localities. The Moorehouse Member, in total contrast, appears to represent distinctly shallower water facies at the Oaks Corners quarry than it does at the Seneca Stone quarry, a complete reversal of the trend seen in the Edgecliff Member. This suggests that the basin axis or center of subsidence shifted through time from a more westerly position (probably west of Oaks Corners) eastward to the vicinity of the Seneca Stone quarry during deposition of the Onondaga Limestone.

Return to vehicles and turn around on Cross Road, then retrace route to Pre-Emption Road.

116.0	0.15	Intersection with Pre-Emption Road (Ontario Co. Rte. 6); <u>Continue straight</u> across (east) on Cross Road.
116.1	0.1	Railroad crossing.
117.1	1.0	Large gravel pit on left.
117.8	0.7	Intersection with NY Rte. 14; continue straight on Cross Road.
118.6	0.8	Junction with Town Line Road; leave Ontario County, enter Seneca County.
119.0	0.4	Intersection with NY Rte. 96. <u>Turn right (southeast)</u> onto Rte. 96.
121.9	2.9	Cross Whiskey Hill Road; continue on Rte. 96.
124.1	2.2	Junction with North Road, Rte. 96 turns right (south). <u>Proceed straight east</u> onto North Road.
124.8	0.7	Seneca County Fairgrounds.
126.0	0.8	Junction with NY Rte. 414. <u>Turn right (south)</u> onto Rte. 414.
125.95	0.35	<u>Turn right (west)</u> into "McDonalds;" **<u>10 minute rest stop</u>.** Return to Rte. 414 southbound.
126.0	0.05	Junction with Rtes. NY 5-U.S. 20; continue straight (south).
126.1	0.1	Bridge over Seneca River.
126.15	0.05	Junction with River Road; <u>turn left (east)</u> onto River Road.

127.8	1.65	Junction with Kingdom Road (opposite lumber yard); turn right (south) onto Kingdom Road.
128.8	1.0	Junction with County House Road, jog left; name changes to Disinger Road. Continue south.
129.8	1.0	Intersect Tom Allen Road; Continue straight on Disinger Road.
130.8	1.0	Junction Yellow Tavern Road; turn left (east) onto Yellow Tavern Road.
131.6	0.8	Junction NY Rte. 414, continue east on Yellow Tavern Road (Seneca Co. Rte. 21).
132.0	0.4	Bend in road; name changes to Canoga Springs Road.
132.7	0.7	Entrance to Seneca Stone Quarry; turn left (north) into quarry and check in at office, then proceed straight (north) into quarry.
133.1	0.4	Fork left onto ramp road, beyond sheds on left. Proceed to lower level.

STOP 6. SENECA STONE QUARRY.

The Seneca Stone quarry is another relatively large quarry that exposes a complete section from the upper part of the Lower Devonian Manlius Limestone to the top of the Middle Devonian Cherry Valley Member of the Oatka Creek Formation (Marcellus subgroup; see section in Brett and Ver Straeten, this volume, Figure 5). Strata within the quarry generally appear undeformed, with the exception of a prominent north-directed thrust fault that cuts up through the upper part of the Onondaga Formation (visible in the southeast and southwest parts of the quarry).

Limestones of the Lower Devonian Manlius Formation (Helderberg Group) are found in a small sump pit in the bottom of the quarry, overlain unconformably by quartz arenites of the Lower Devonian Oriskany Formation (lower part of the Tristates Group). These two units are separated by the true Wallbridge Unconformity that marks the base of the Kaskaskia Megasequence. Clasts of the older Manlius Limestone are visible in the base of the Oriskany, where they may be overgrown by tabulate coral colonies. The white quartz arenites of the Oriskany Sandstone also feature numerous large, robust brachiopods (including *Costispirifer arenosus*, *Rensselaeria*, and *Hipparionyx*), platyceratid gastropods, and rare rugose corals.

Twenty-five km northeast of the Seneca Stone quarry, at Auburn, sand-dominated strata of the upper part of the Tristates Group (Carlisle Center and Schoharie Formations) are present, similar to strata reported for the Syracuse area (see Brett and Ver Straeten, above). At Seneca Stone quarry, however, these rocks are absent except as reworked phosphatic cobbles in a basal sandstone bed of the Edgecliff Member (Onondaga Formation). Reworked, phosphatized clasts of the Manlius and Oriskany Formations are also found in the basal Edgecliff sandstone bed.

A thin interval of coral-rich limestone is succeeded by two cyclic packages of Edgecliff strata that appear to be equivalent to the two upper Edgecliff cycles seen at Oaks Corners (Stop 5). Well developed fine-grained, cherty Clarence facies are only developed within the lower part of the second cycle at Seneca Stone; the Edgecliff member in general here appears coarser than equivalent strata at Oaks Corners (Stop 5).

A sharp change into overlying calcareous dark shale-dominated strata marks the base of the Nedrow Member. The Nedrow and lower to middle parts of the overlying Moorehouse Member are best exposed in the east wall of the quarrybelow the third platform. The lower part of the Nedrow consists of alternating dark shales and argillaceous wackestones. Several distinctive crevices within the middle to upper Nedrow here may represent altered volcanic ash beds. The distinctive "black bed" in the upper Nedrow, which at Seneca Stone quarry consists of black shale with several bands of black chert nodules, is highly visible in the eastern wall. The bed, as observed at the previous locality (Stop 5), is overlain by a light weathering limestone and the dark "*Schizophoria* bed" at the top of the Nedrow.

Overlying strata assigned to the lower part of the Moorehouse Member consist of alternating calcisiltite limestone beds (< 1 m-thick) interbedded with thin (ca. 5-15 cm-thick) calcareous shales. This interval is relatively similar to facies that characterize the Onondaga-equivalent Selinsgrove Limestone of central Pennsylvania. Two paired crevices approximately 0.9 and 1.0 m above the *Schizophoria* bed represent apparent K-bentonite beds that are widely traceable across the central part of the Appalachian Basin (see Brett and Ver Straeten, above). Quartz pebbles and granules have been noted in a 14 cm-thick calcareous shale bed 2.5 m above the base of the Moorehouse. A 45 cm-thick argillaceous unit 6 m up in the Moorehouse, just below a platform on the east wall, correlates with the prominent "false Nedrow" shale seen at Stafford (Stop 1) and other localities across much of the Appalachian Basin (see Brett and Ver Straeten, above).

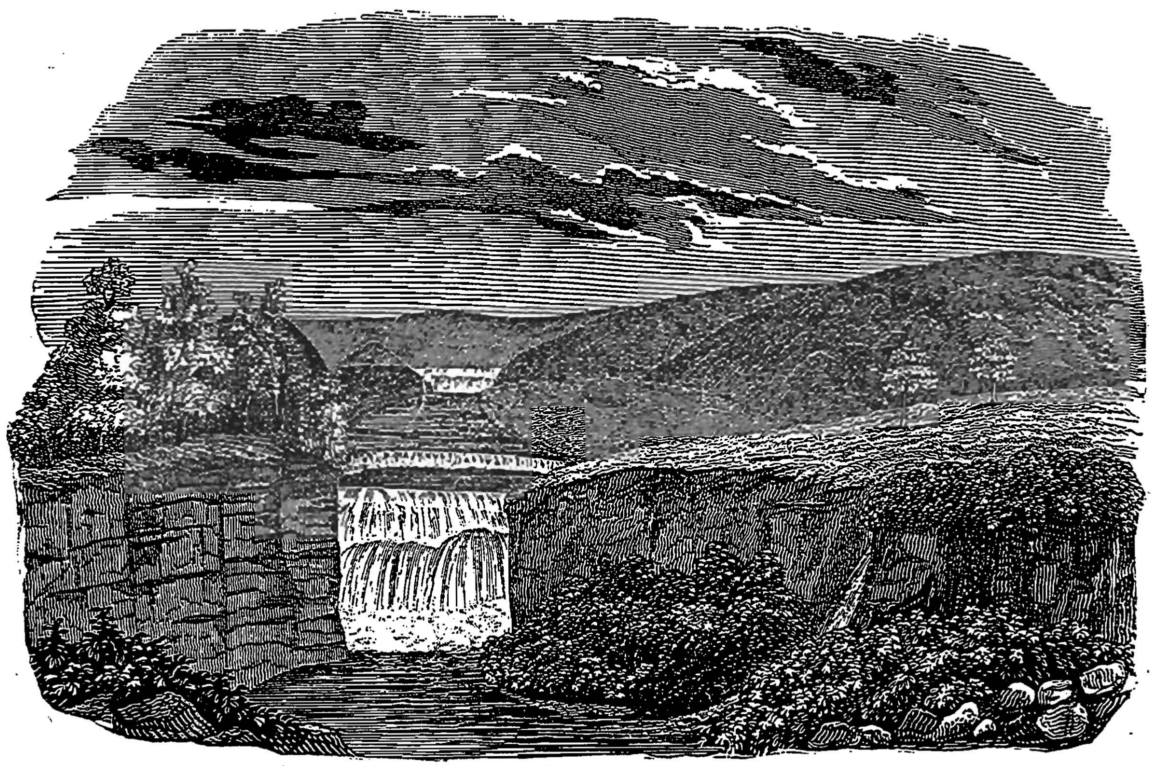
More resistant, coarsening-up strata of the upper Moorehouse Member Form the wall of the lift above the Nedrow-like shale unit up to the thick Tioga B-OIN Bentonite bed at the base of the overlying Seneca Member. Two conspicuous crevices, which feature biotite-rich claystones, represent the First and Second Cheektowaga Bentonites of Conkin and Conkin, (1979, 1984; Conkin, 1987). A 10 cm-thick, dark chert bed forms the cap of the 9.8 m-thick Moorehouse Member at Seneca Stone, immediately below the Tioga B-OIN bentonite bed.

The Seneca Member represents a general fining-up trend from the relatively coarse upper part of the Moorehouse Member. The Tioga B-OIN bentonite marks the base of the member. Five and possibly seven additional bentonites occur within the Seneca Member and the base of the overlying Union Springs Formation at Seneca Stone. Two fining- to coarsening-up cycles within the Seneca represent relatively smaller scale cycles superimposed on the general deepening-up trend (see Brett and Ver Straeten, above). Lithology of the member ranges from poorly fossiliferous wackestones to low diversity brachiopod-rich packstones (e.g., "Pink *Hallinetes* (formerly *Chonetes*) Zone," 3.2-4.0 m above the base). Nodular cherts and impure dolomitic cherts occur scattered throughout the member. The Seneca Member, as defined herein, totals 7.15 m in thickness. The upper contact of the Seneca Member at Seneca Stone quarry as defined herein is marked by a distinctive bedding plane with large horizontal burrows, scattered fish debris, and some pinkish weathering, apparently hematitic, limestone "clasts." The bed is immediately overlain by eight cm of black shale and a thin (3 cm-thick) k-bentonite bed. Overlying dark, fine-grained, styliolinid limestone beds are assigned herein to the Bakoven Member of the Union Springs Formation. The prominent, rusty-weathering Tioga F bentonite (ca. 12 cm-thick) occurs 65 cm above the base of the Bakoven at Seneca Stone.

The lower 1.3 m of the Bakoven is dominated by the previously mentioned thin styliolinid limestone beds. Black shales become more prevalent above, but occur interbedded with numerous thin (ca. 2-20 cm-thick) micritic limestone beds. The top of the Union Springs Formation at Seneca Stone quarry is represented by the richly fossiliferous Chestnut Street submember of the Hurley Member. The Chestnut Street beds, with their characteristic lighter-weathering color and fauna (e.g., proetid trilobites and the microcrinoid *Haplocrinites clio*), form a thin ledge of limestone approximately 10 cm in thickness that is firmly welded to the base of the overlying Cherry Valley Member (Oatka Creek Formation).

The Cherry Valley Member at Seneca Stone is more typical of its occurrence along much of its outcrop west of the Albany area. Three subdivisions, a lower massive, middle nodular, and upper massive limestones comprise an approximately 50 cm-thick section of organic-rich, pyritic, bedded to nodular wacke- to packstones. The classic goniatite and nautiloid cephalopod fauna of the Cherry Valley, which includes *Agoniatites vanuxemi* and *Striacoceras typum*, is well displayed on the excellently exposed upper bedding plane seen above the south wall of the quarry. Truncated cephalopod shells, fish bone material, and scattered pebbles, along with the development of a firm- to incipient hard-ground and pyritic crusts on the upper surface of the Cherry Valley Member, indicate a period of submarine sediment starvation prior to deposition of overlying shales. Overlying strata are not at present exposed, but Baird and Brett (1986) report dark shales that include a distinctive bed (LeRoy bed=gray bed of Baird and Brett, 1986; see Ver Straeten et al., above) in which the classic fauna of the Middle Devonian Hamilton Group makes its first appearance in the Appalachian Basin.

END OF TRIP. To return to the University of Rochester, retrace route to NY Rte. 414 at "McDonalds"; continue north on Rte. 414 past North Road and past intersection with NY Rte. 318 to entrance onto NY State Thruway (I-90). Take Thruway west (toward Buffalo) to exit for I-390 at Rochester and proceed north on I-390 to the University of Rochester.



Upper and Middle Falls of Portage. Sketch by Mrs. Hall
[From Hall, 1843, Geology of the Fourth District, Figure 96, p. 224]