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 basinial black shale-dominated facies of western to central New York); and 3) the laterally equivalent Mount Marion Formation (=upper Marcellus subgroup basinial 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 (Ettenson, 1985a) and eustatic sea level rise (Johnson et al., 1985) during a second active tectophase of the Acadian Orogeny (Ettenson, 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, 1989). 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)
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 dactyloconarid faunas, the Kakak-atomari 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 interdigitate 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
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 Catskill 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 it 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.
c) **Raise the rank of Oatka Creek Member to formational status (western to central New York); and retain the name Mount Marion Formation for its eastern New York facies equivalent:** Our proposed usage of the Oatka Creek as a formational rank unit is similar to the proposed usage of the Union Springs discussed above. In its present status, the Oatka Creek Member incorporates all strata of the proposed formation except the Cherry Valley Member, which is locally missing at the Oatka Creek type section. Again, it is a familiar term to various workers and its new usage should lead to little confusion and easy acceptance. As with the Union Springs, the Oatka Creek Member at present is equivalent to several members to the east (including those of the Mount Marion Formation in eastern New York). We also propose to retain the term the “Mount Marion Formation” in eastern New York for coarser, more proximal facies of the upper formation of the proposed “Marcellus subgroup.” The base of both the redefined Oatka Creek and laterally equivalent Mount Marion Formations will be designated as the basal contact of the Cherry Valley Member. This proposed boundary will be consistent with previous practice in the Hamilton Group wherein all higher formational boundaries were placed at the bases of widespread carbonate-dominated units. The coeval Oatka Creek and Mount Marion Formations comprise T-R cycle 1e of Johnson et al. (1985).

d) **Hurley Member (new):** The term “Hurley Member” is proposed for a key, distinctive unit found at all outcrops studied across New York into central Pennsylvania. The proposed Hurley Member occurs at the top of our “Union Springs Formation” and is composed of a very distinctive, richly fossiliferous limestone unit (Chestnut Street Beds of Griffing and Ver Straeten, 1991; =Wernoceras Bed of Rickard, 1952; =Proetid bed of Brett and Kloc in Anderson et al., 1986) and overlying shale-dominated strata. The Hurley in central to western New York and Pennsylvania is generally relatively thin (ca. 30-60 cm) but ranges up to approximately 7 m in thickness at its type section in eastern New York (along north side of NY Rte. 209 near Hurley and Kingston, Ulster Co.). The base is defined as the lowest carbonate-rich fossiliferous bed above: a) a massive sandstone at the top of the restricted Stony Hollow Member in eastern New York; or b) black shales of the redefined Bakoven Member west of the Albany region of New York. The top of the Hurley Member lies at the base of the Cherry Valley Member all across New York State. Two informal subdivisions will also be proposed, the Chestnut Street submember (lower, limestone) and the Lincoln Park submember (upper, shaly).

e) **Additional proposed changes to existing members include:**

   i) The Bakoven Member, formerly restricted to eastern New York, is revised to include all black shale-dominated strata in the proposed Union Springs Formation across New York State.

   ii) The Stony Hollow Member formerly represented all calcareous shale and sandstone above the Bakoven Member and below the Mount Marion Formation (Berne Member) in eastern New York. In our proposed scheme the Stony Hollow Member is restricted to strata that underlie rocks now assigned to the new Hurley Member (see above) and the revised Cherry Valley Member (see below) in eastern New York.

   iii) The Cherry Valley Member is expanded to include equivalent strata in eastern New York formerly placed in the upper part of the Stony Hollow Member. The revised Cherry Valley Member is composed of two lithosomes; an eastern sand-
dominated facies and a central to western carbonate-dominated facies. As noted above, it lies at the base of the upper part of the proposed Marcellus subgroup, in the Mount Marion Formation in eastern New York and the Oatka Creek Formation in central to western New York.

f) Member status of western black shales, Oatka Creek Formation: In raising the rank of the Oatka Creek to formational level, black shales above the Cherry Valley Member and below the Stafford Member of the Skaneateles Formation in western New York lack a member designation. Preliminary study of the upper part of the Marcellus subgroup in central to western New York indicates some revision is needed within the interval. Further work is required, however, to resolve problems and relationships within the Oatka Creek Formation. Therefore, at present we do not assign a member name to the western black shale facies of the formation, but do note that they resemble and are partly equivalent to the type Chittenango Shale Member of west-central New York.

GENERAL STRATIGRAPHIC DISCUSSION: MARCELLUS SUBGROUP

**Eastern New York**

In eastern New York, strata above the Onondaga Formation comprise a southeastwardly-thickening wedge of fine- to medium-grained clastics. Basal black shales of the Union Springs Formation, assigned to the Bakoven Member, underlie a wedge of calcareous shales to sandstones of the Stony Hollow Member. The Stony Hollow Member (revised) is approximately 68 m in thickness at Kingston in the southern part of the Hudson Valley outcrop belt; the unit thins to the northwest in part due to facies change with the upper part of the Bakoven Member, and is absent west of Albany County. The top of the Union Springs Formation across New York is characterized by a relatively fossiliferous interval of shales to calcareous sandstones or limestones (new Hurley Member) that include the widely distributed Chestnut Street submember (Chestnut Street beds of Griffing and Ver Straeten, 1991). From Cherry Valley to southwest of Kingston (ca. 140 km along outcrop) the Union Springs Formation expands from approximately 10 m to a known maximum of approximately 170 m (Rickard, 1989, Plate 22).

The overlying Cherry Valley Member at the base of the Mount Marion Formation in eastern New York is characterized by a cephalopod-rich limestone lithology that extends west of the Albany area, and terrigenous sand-rich strata south of Albany through the Hudson Valley outcrop belt. Black to dark gray shales above the Cherry Valley Member (i.e., Berne Member) are overlain by a distinctive coral-rich unit (Halihan Hill Bed of Ver Straeten, 1994) at the base of the overlying Otsego Member. The Halihan Hill Bed represents the first appearance of the classic fauna of the Hamilton Group in eastern New York. At Kingston the bed occurs approximately 85 m above the base of the Cherry Valley Member (= base of the Mount Marion Formation); near Cherry Valley the intervening strata are on the order of 30 m in thickness. In the Catskill Front, the remainder of overlying strata assigned to the Marcellus subgroup are over 400 m thick (based on Rickard, 1989), and include increasingly coarse marine (upper part of the Mount Marion Formation) to non-marine, fluvial-dominated rocks (part of the Ashokan Formation).

Griffing and Ver Straeten (1991) present a more detailed discussion of the Union Springs Formation and the Cherry Valley Member in eastern New York State. In addition, Ver Straeten (1994) outlines the microstratigraphy of parts of the overlying Berne and Otsego Members (Mount Marion Formation) across the same region.

**Central to Western New York**

These strata in central to western New York are the subject of this paper, and are summarized herein. The Union Springs Formation of central and western New York consists
primarily of black shales and concretionary to thin-beded limestones of the revised Bakoven Member. Although the Hurley Member is present, it is generally only represented by a thin bundle of skeletal limestone beds of the Chestnut Street submember, which are locally welded to the base of the overlying Cherry Valley Member. The Cherry Valley Member of east-central New York contains limestones with interbedded marlstones and shales, but is characterized further west as a compact skeletal limestone with few argillaceous interbeds. Both the Union Springs Formation and the overlying Cherry Valley Member of the Oatka Creek Formation pinch out west of the Rochester area. Rickard (1984, 1989) reports sporadic occurrences of the Cherry Valley Member west of the Genesee Valley, but the authors know of no existing outcrops in that region.

A thin fossiliferous bed of gray shale (informally termed the LeRoy bed of Brett and Baird, unpublished data; "gray bed" of Baird and Brett, 1986) is found within the lower part of unnamed black shales a short distance above the Cherry Valley Member across west-central to western New York. This bed marks the first occurrence of the classic Hamilton fauna in western New York and is thought to be the lateral equivalent of the coral-rich Halihan Hill Bed (discussed above) of eastern New York. Overlying strata of the Oatka Creek Formation in the central part of the state coarsen slightly upward but fine laterally into exclusively black shale facies in western New York.

PALEOGEOLOGIC SETTING

The Hamilton Group and equivalent strata occur throughout the Appalachian Basin, an elongate region of subsidence and sediment fill west of the Appalachian Orogen and east of a cratonward system of crustal uplifts and arches. The Appalachian Basin was the site of an extensive epicontinental seaway through early and middle Paleozoic time. Estimated paleolatitudes for the northern part of the Appalachian Basin during the Middle Devonian range from 25° to 35° south of the equator, in the tropical to subtropical climate belts (Wilzke and Heckel, 1988; Scotese and McKerrow, 1990). Thermohaline density stratification of the water column may have persisted in the deeper portions of the basin, which resulted in decreased sea floor oxygenation (Byers, 1977; Ettensohn, 1985b; Woodrow, 1985).

The Acadian Orogeny was the most significant event in the Devonian of eastern North America (Fall, 1985; Osberg et al., 1989; Roy and Skehan, 1993: Rast and Skehan, 1993). Uplift of the Acadian mountain belt was the result of collision between Laurentia and a microcontinent or a number of terranes (Rast and Skehan, 1993) referred to as Avalon. Subsidence of the Appalachian foreland basin, associated with thrust-loading in the adjacent mountain belt during a second Acadian tectophase (Ettensohn, 1985a), and a rise in eustatic sea level (Johnson et al., 1985) resulted in drowning of the Onondaga carbonate platform. Rocks of the overlying Union Springs Formation represent deeper water, organic-rich sediments initially deposited in the rapidly-subsiding foreland basin.

FAUNA

The Onondaga-Union Springs contact also marks a major paleobiological transition. Only a small portion of the Onondaga brachiopod fauna and very few of the associated trilobites, mollusks, or echinoderms persist into overlying strata. Faunas of much of the Union Springs Formation and similar parts of the overlying Mount Marion and Oatka Creek Formations consist of restricted, exaerobic to dyasaerobic, black shale-type assemblages (Brower and Nye, 1991) that characterize these facies throughout the Devonian. Shallower water, more aerobic sandstone to limestone facies, however, feature a distinctive fauna that is unique to the Union Springs Formation and differs from that of both the underlying Onondaga Formation and the overlying remainder of the Hamilton Group. Elements of this fauna occur in the Stony Hollow Member of eastern New York and in the widespread Hurley Member at the top of the Union Springs. The brachiopods Variatrypa arctica, Kayserella,
Carinatrypa, and Pentamerella cf. P. winteri, a small rugosan (Guerichiphyllum), and a trilobite (Dechenella haldemanni) are the most characteristic forms of this unique fauna. The Variatrypa arctica fauna was widespread throughout the Eastern Americas Realm during Union Springs time, including in Iowa (Spillville Formation; Day and Koch, 1994), the Michigan Basin (Rogers City Formation; Ehlers and Kesling, 1970), and the James Bay region of northern Ontario (Murray Island Formation; Sanford and Norris, 1975). Koch (1978) attributes the appearance of this fauna to a “limited migration” of Old World Realm brachiopods from Arctic North America during deposition of the Union Springs Formation. Koch (1988) states that the breakdown of paleobiogeographic boundaries may be due to continent-wide transgression at that time. Boucot (1990) associates this migration with a “geologically sudden lowering of the global climatic gradient” (discussed below) that resulted in dispersal of warmer water faunas into the Appalachian Basin during Union Springs time.

The classic fauna of the Hamilton Group first appears in central to western New York a short distance above the Cherry Valley Member. A richly fossiliferous bed of gray shale, informally termed the “LeRoy bed” or the “gray bed” (Baird and Brett, 1986) features a brachiopod-dominated fauna that includes Longispina, Mediospirifer, Athyris, and atrypids. Other common forms include small rugose corals, a variety of bryozoans, platyceratid gastropods, and rare Phacops trilobites. The LeRoy bed has been correlated from LeRoy in the west to east of Syracuse, and can be seen to rise stratigraphically upsection above the Cherry Valley Member toward the east. It appears to correlate with the previously mentioned coral-rich Halihian Hill Bed in eastern New York (Ver Straeten, 1994), in which the classic Hamilton fauna also first appears.

Late Elifelian-Early Givetian age rocks worldwide are marked by a key faunal extinction-radiation episode termed the Kacak-ottomari Bio-Event (House, 1985; Walliser, 1986, 1990; Chlupac and Kukal, 1986; Truyols-Massoni et al., 1990). The event occurs within the Tortodus kockelianus kockelianus conodont zone, and affects dominantly pelagic forms (goniatite cephalopods and nowakids). In the Appalachian Basin this interval is marked by the appearance and disappearance of the Cabieroceras and Agoniatites goniatite faunas of the upper part of the Union Springs Formation and the Cherry Valley Member and the later appearance of the Tornoceras goniatite fauna in the post-Cherry Valley lower part of the coeval Oatka Creek and Mount Marion Formations in New York (House, 1985; Chlupac and Kukal, 1986). Small, conical nowakid fossils associated with the event have recently been found in the Leroy bed of the Oatka Creek Formation and possibly in the Hurley Member of the Union Springs Formation (Chestnut Street submember; D. Lindemann, personal communication). The Kacak-ottomari Event has also been reported from the Barrande area of the Czech Republic, the Rheinisch Schiefergebirge of Germany, Thuringia and the Carnic Alps, northwest Africa, China, and the Cantabrian Mountains of Spain (Chlupac and Kukal, 1986; Truyols-Massoni et al., 1990).

BIOSTRATIGRAPHY AND AGE

Biostratigraphy of upper Elifelian strata in New York is very poorly resolved. Studies by Klapper (1971, 1981) indicate that the Bakoven Member occurs within the Tortodus kockelianus australis conodont zone and the overlying Hurley and Cherry Valley Members lie within the Tortodus kockelianus kockelianus zone. Conodont faunas of the overlying parts of the Mount Marion and Oatka Creek Formations have received little if any attention.

The goniatite succession through the Marcellus subgroup is discussed by House (1981), who recognizes three separate faunas: a) the Cabieroceras plebeiiforme zone, which comprises the upper part of the Union Springs Formation; b) the Agoniatites vanuxemi zone, which consists of the Cherry Valley Member; and c) the long-ranging Tornoceras uniangulare zone, which extends through the remainder of the Hamilton Group. Notably,
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. 824-825) 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, analogous 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 appear to represent long-term submarine condensation surfaces associated with transgression and sediment starvation-corrosion. 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 of 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 slates 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 rhizidistian Onychodus (both O. sigmoideas 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 arthrodiran Clarkeaosteus). Head shield armor of an even larger arthrodiran 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) hiatus deposits representing long-term accumulations concentrated by corrosion 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 hiatus 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 alkaline pore waters of organic-rich sediments (Burnett, 1977; Martill, 1991). Decaying organicss 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 corrosion 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 Kakak-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

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 conformable 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. Callicles 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 dysoxic 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.
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
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 (Griffin 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 Agoniatisites 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 Styloloma 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 Coleoicus aciculatum, minute rynchonellid 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 (Griffin and Ver Straeten, 1991; Griffin, 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 (Hurlay 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, stylolitic 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 Griffin (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 (cf. 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 rhynechnelid 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 Coelaulus 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 cephalopod 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.

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 stylolitinit-ccephalopod 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 stylolitinit-ccephalopod packstone facies and the nodular packstone/grainstone facies in parts of central and eastern New York. All these facies ultimately overstep the crinoid-stylolitinit-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 dysoxic 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, fenestrate, 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 Klaw, 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 hiatus 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 corrosion 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 corrosion of aragonitic goniatites and nautiloids is evident in the Cherry Valley Member, especially at erosional discontinuities. The current alignment of orthocenes and the coarse macrofossil hash/ reworked lag above scourd 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 corroded. Subsequent reworking led to further concentration and exposure of additional cephalopods to the destructive agents of the seafloor.

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 stylolitid-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 stylolitid 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
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 stylololids, 2) angular to rounded clasts of concretions and Chestnut Street packstones, and 3) abraded fish bone plates and fragmented cephalopod shells (including *Cabrioceras*). 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 corrosional 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 (easternmost 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 1d and 1e 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
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 (Dennis 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-section 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 typsum*, 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, soaply-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 correlative 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 (Faiil et al., 1973). 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 Selingsgrove 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 Selingsgrove 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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