SEDIMENTARY CYCLES AND LATERAL FACIES GRADIENTS ACROSS A MIDDLE DEVONIAN SHELF-TO-BASIN RAMP LUDLOWVILLE FORMATION, CAYUGA BASIN

CARLTON E. BRETT
University of Rochester
Rochester, N.Y. 14627

GORDON C. BAIRD
SUNY College at Fredonia
Fredonia, N.Y. 14603

and

KEITH B. MILLER
University of Rochester
Rochester, N.Y. 14627

INTRODUCTION

The Middle Devonian (Givetian) Hamilton Group of western and central New York State constitutes an eastwardly-thickening wedge of black and grey shales, mudstones and siltstones with thin, but widespread, carbonate and sandstone units. These sediments were deposited in the northern end of the stratified Appalachian Basin following early phases of the Acadian Orogeny (Ettensohn, 1985; Kent, 1985). Hamilton facies occur in distinct cyclic motifs of two sorts: subsymmetrical cycles centered on maximally-regressive, limestone facies in western New York, and upward-coarsening, dark shale-siltstone-sandstone hemicycles capped by maximally regressive storm-winnowed deposits in the eastern Finger Lakes region. Recent detailed study of Hamilton stratigraphy and facies distribution has demonstrated that the two types of cycles are correlative and intergradational, and that the carbonate rich beds in the subsymmetrical cycles are the direct lateral equivalent of the tops of the coarsening-upward hemicycles (Brett and Baird, 1985; Gray, 1984; Grasso, 1986); both motifs appear to be manifestations of large scale regressive-transgressive cycles and both carbonates and sandstones record relatively shallow water near wave base facies. This work further permits the development of models explaining the distribution of recurrent fossils associations - or biofacies along environmental gradients.

The Cayuga Lake Valley presents a unique opportunity to examine facies relationships within the upper Hamilton Group. This 42 mile-long valley produces a major southward deflection in the Hamilton outcrop belt allowing examination of strata well south of the prevailing east-west outcrop trend limit. Moreover, the effect is enhanced by the exposure of upper Hamilton beds along the crest of the Fir Tree anticline near the southern end of the lake. This structure, in effect, provides a "window" into the facies of the Upper Ludlowville and Moscow Formations in the Southern Tier, some 30 miles south of the main outcrop belt. Still more important is the fact that the present day Cayuga Valley appears to obliquely cross cut northeast/southwest-trending facies belts in the upper

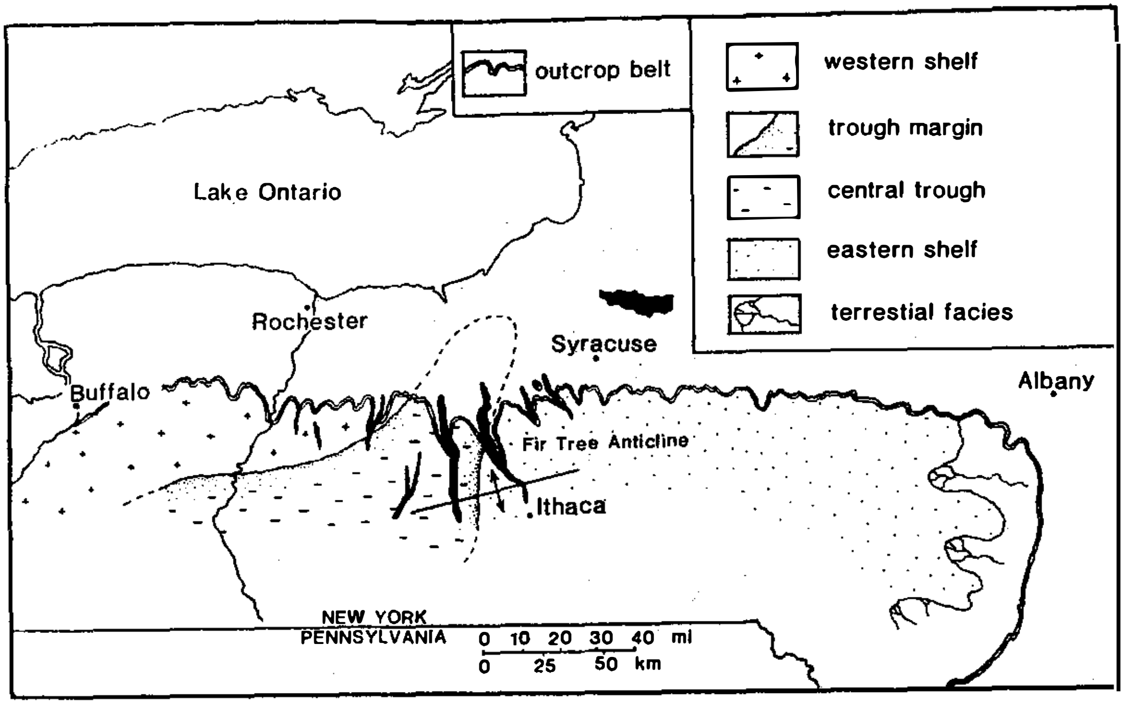


FIGURE 1.--Inferred paleogeography of the northern Appalachian Basin during Middle Devonian time showing northeast/southwest trending margin of the subsiding basin trough in the Cayuga Valley; note position of Fir Tree Anticline. Modified from Brett and Baird (1985).

Hamilton Group, which parallel the southeastern margin of the Appalachian Basin as it existed in Middle Devonian (Givetian) time (Fig. 1). Hence, unlike the exposures in the Seneca Valley, which display relatively little facies change along another extensive north-south transect (probably because this valley more nearly coincides with depositional strike), those of the Cayuga region exhibit marked changes in litho- and biofacies from north to south. Along the east side of the Cayuga Valley from Aurora, south to Lansing, one observes a progression from facies and stratigraphic successions resembling those of western New York into coarser clastic equivalents identical to those of the central New York region. Across a ten mile distance southward along the valley changes occur that parallel those seen 20 to 30 miles east of the Cayuga Lake meridian on the main (northern) east-west outcrop belt. This pattern indicates that facies strike in this area was approximately north-northeast to south-southwest, essentially transverse to the trend of Cayuga Lake.

The facies pattern in the Ludlowville Formation of the Cayuga and adjacent Owasco Valleys indicates that these environmental belts were aligned along a gentle northwest-dipping paleoslope or ramp that bordered a trough-like area of more active subsidence near the present-day Seneca Lake (Fig. 1). Lines of evidence supporting this inference include consistent northwestward changes of a) medium, brownish grey, silty mudstone facies into dark grey or black, fossiliferous shales; b) packstones or grainstone lithologies in carbonates to argillaceous wackestones; and c) differential northwestward thickening of several units. This suggests that the area of maximum subsidence and/or depocenter of the northern end of the Appalachian Basin lay in the Cayuga to Seneca region during much of Ludlowville deposition. However, facies and isopach patterns also imply that the precise area of deepest water (axis of subsidence) and the area of maximum thickness (depocenter) were not always exactly coincident; typically the depocenter lay to the southeast of the axis of subsidence. Moreover, neither depocenter nor deepest basin axis were fixed but, rather, both tended to shift northwestward through deposition of the Ludlowville and Moscow formations. This basin migration strongly influenced the lateral facies transitions observed at different levels. For example, along the northern parts of the outcrop belt, lower Ludlowville deposits display a major black to grey shale facies change between Owasco and Skaneateles Lakes, while in the middle Ludlowville (primary focus of this field trip) most abrupt facies and thickness change occurs between Cayuga and Owasco Lakes and, for the higher Ludlowville, this area of rapid change is displaced to the Cayuga-Seneca region.

This pattern persists throughout deposition of the overlying Moscow Formation, in which depocenters and deepest-water facies of successive members are displaced westward. This observation is consistent with a model proposed by Ettensohn (1985) for westward migration of the Devonian basin axis due primarily to Acadian tectonic thrust-loading and secondarily due to sediment wedge loading near the basin center. Superimposed on this pattern is a separate effect relating to sediment distribution. It appears that during transgressions the depocenter shifted southeastward away from the axis of subsidence due to the increased distance to source areas (flooding of shoreline areas) and the overall deepening of water which allowed more sediment to accumulate over more slowly subsiding shelf areas. This reduction in sediment supply resulted in accumulation of thin dark shale sequences in the sediment-starved basin center area and thicker, silty mudstones on the southeastern shelf. Conversely, during regressions, sediment tended to prograde northwestward toward the basin center and fine grained sediments tended to bypass the now-shallow shelf regions and to accumulate rapidly in the low energy trough, leaving winnowed sand or carbonate deposits on the shelves. The net result of these processes is that the basin axis and depocenter tended to nearly coincide during times of overall regression but to be offset from one another during deepening episodes; this effect is most directly the result of an energy threshold controlled by storm and/or normal wave base but it is also controlled by changes in sediment supply. Understandably, this complex pattern of facies change has led to nomenclatural problems, as noted below.

The primary focus of this fieldtrip is the examination of patterns of facies change expressed both vertically in the form of transgressive-regressive cycles and laterally within cycles as viewed north-to-south in the Cayuga-Owasco interlake region. To this end, we will proceed sequentially through an outcrop sequence up the inferred Ludlowville paleoslope; we will examine a regional facies spectrum, starting with basinal dark grey sequences and ending with shallow sublittoral fossil-rich sandstones. This will allow qualitative discussion of numerous biological and sedimentological changes that can be observed along this Paleozoic submarine ramp.

STRATIGRAPHY OF THE LUDLOWVILLE FORMATION IN THE CAYUGA LAKE REGION

General Background

Both the type section and the later proposed reference section of the Ludlowville Formation lie on the east side of Cayuga Lake. Hall (1839, p. 298) proposed the name Ludlowville for the shaley sequence between the base of what is now named Centerfield Member and "the Encrinal limestone" (now termed Tichenor or basal Portland Point Member, see Baird, 1979). Hall designated Salmon Creek in the town of Ludlowville, near the southern end of Cayuga Lake as the type section for largely aesthetic reasons. At that time he believed, incorrectly, that these beds were coeval with the Silurian Ludlow Formation and evidently felt it was an interesting and fortuitous twist that the supposedly equivalent strata cropped out at Ludlowville, New York. Ironically, however, the Salmon Creek section is very incomplete and atypical as only the upper 50' (~25%) of the Ludlowville Formation is exposed there. Consequently, Cooper (1930) designated a reference section on Paines Creek in the town of Aurora about 15 miles north of Ludlowville. This is also a poor type section in that structural complications give rise to uncertainties in measurements, particularly in the Ledyard Member. However, at least this creek exposes the entire sequence which in this area is about 80 m (250 ft) thick.

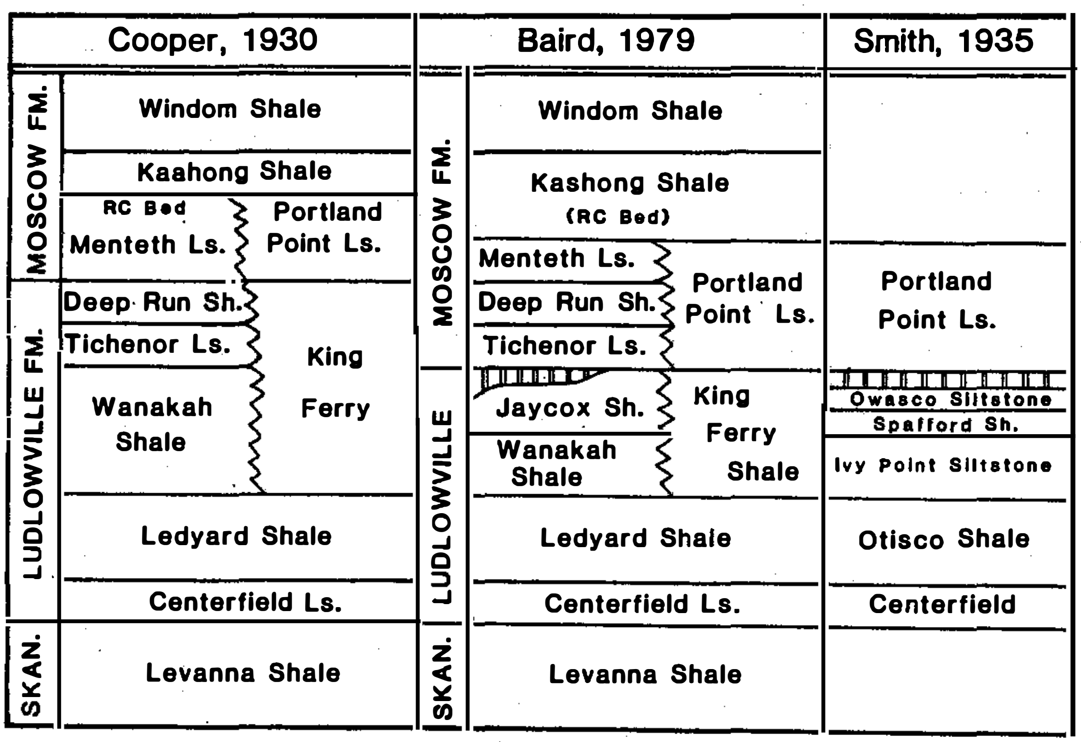


FIGURE 2.--Earlier stratigraphic terminology for the Ludlowville and Moscow Formations in the Cayuga to Skaneateles Lake area.

Detailed subdivision of the Ludlowville Formation into Members was formalized by Cooper (1930), who included, in western New York, five Members, in ascending order: Centerfield limestone and calcareous shale (Clarke, 1903) Ledyard black and dark grey shale, Wanakah grey shale (Grabau, 1917), Tichenor Limestone (Clarke, 1903) and Deep Run Shale. Cooper designated the upper contact of the Ludlowville at the base of the Menteth Limestone which he believed to be stratigraphically equivalent to the base of the Portland Point Member (Hall's "encrinal" bed) at the type area near Ludlowville in the Cayuga Valley (Fig.2). Cooper was unable to recognize the distinct Wanakah, Tichenor and Deep Run Members at Cayuga Lake and he proposed the name King Ferry shale for the supposedly equivalent interval between the Ledyard and Portland Point Members. Later work by Baird (1979), however, demonstrated that the Portland Point Member is, in fact, a condensation of the Tichenor-Deep Run-Menteth interval (see also Baird and Brett, 1981) and reset the base of the Moscow Formation to the base of the Tichenor Limestone (or basal "Portland Point limestone) throughout western and central New York. Baird further proposed a new unit, the Jaycox Member, for a calcareous, fossiliferous, shale at the top of the Ludlowville Formation, between a unique limestone (subsequently designated the Hills Gulch bed by Kloc (1983), and the erosional basal contact of the Tichenor Limestone, in western New York.

In this revision, one unit, the King Ferry Member was more or less left in limbo. Cooper's King Ferry Member was demonstrated to be equivalent to the Wanakah and Jaycox Members of western New York, but not to the Tichenor and Deep Run; further, the approximate contact of the Wanakah and Jaycox Members can be determined at Cayuga Lake. This seems to eliminate the need for the term King Ferry and it will not be used in the subsequent discussion. The presently accepted subdivision of the Ludlowville in western New York (see Rickard, 1975, 1981; Baird, 1979) is shown in Figure 3.

Working in the Skaneateles Quadrangle Smith (1935) independently provided a separate subdivision of the Ludlowville Formation into five members; in upward progression these are the Centerfield Member, Otisco Shale, Ivy Point siltstone (with upper and lower siltstone tongues separated by a middle shale), Spafford Shale and Owasco Siltstone, all below the Portland Point Limestone. The terminology of Smith has not been substantially modified except that Gray (1984) extended the name Chenango Sandstone to the Skaneateles meridian to replace the term Centerfield; Gray noted that this interval is lithologically a coarse siltstone and silty shale, not a limestone and is, thus, more similar to the Chenango Member than to the Centerfield although the two members are closely related and intergradational.

The duality of terminology for the Ludlowville between the Cayuga and Skaneateles areas reflects a persistent problem. Until recently no precise correlation existed between units west of Cayuga Lake and those of the Skaneateles area just 20 miles to the east. Initially there seemed little similarity between the Otisco-Ivy Point-Spafford-Owasco and the Ledyard-Wanakah-Jaycox sequence. Indeed, there is not a one-to-one relationship among them with the exception that the Otisco Member is the

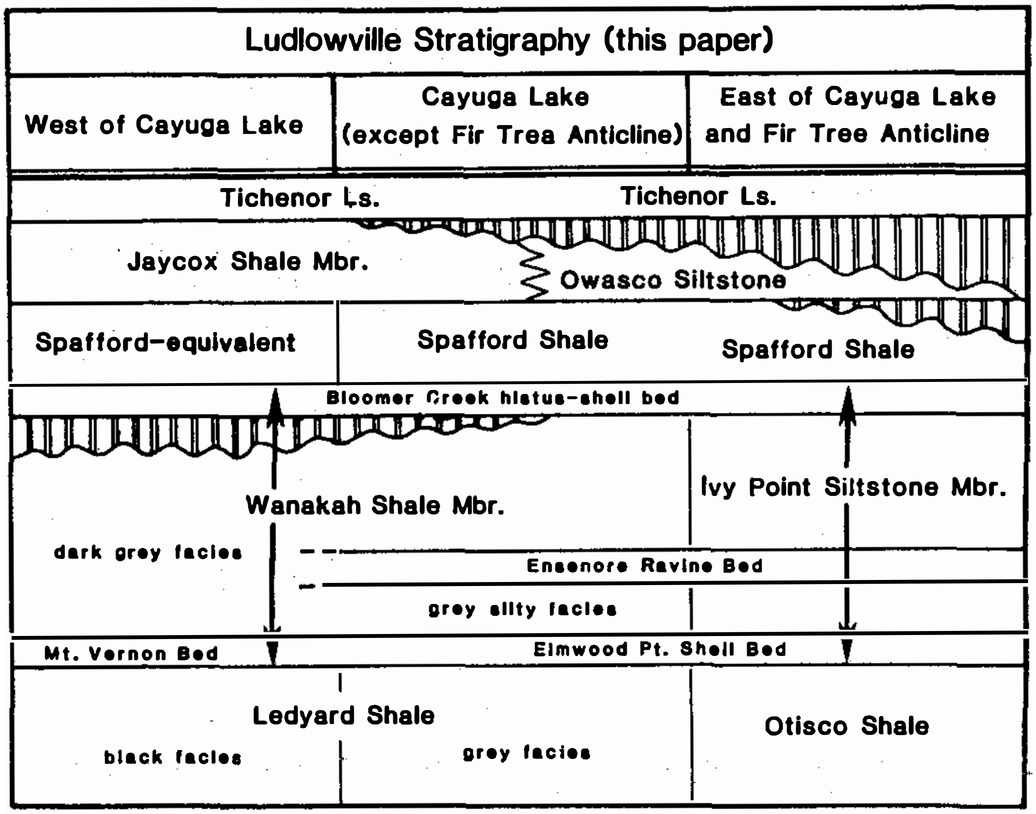


FIGURE 3.--Proposed stratigraphic terminology for Ludlowville Formations in Cayuga Lake and adjacent areas.

sole eastward correlate of the Ledyard Member. One thrust of our recent field studies of the Ludlowville Formation has been to establish detailed correlations between the persistent, easily recognized, and generally, more calcareous western Members and Smith's coarser clastic Members of the central New York region. The Seneca-Owasco Lake region has provided the most challenge in our correlation effort due to the complexity of these facies changes.

Detailed Correlation of the Ludlowville Members

Figures 3 and 4 illustrate our proposed correlations of the Ludlowville units. Our approach has been to locate thin key-beds in this region, both for correlation of surrounding deposits, and also as base lines for assessing lateral facies changes in these same units. These bounding layers are primarily condensed, complex shelly beds, some of which contain reworked fossils, hiatus concretions and phosphatic pebbles. Several of the beds display lateral faunal gradients, indicating that they cross-cut biofacies, despite their consistent thickness and position with respect to other such beds. These observations indicate that the beds formed during periods of widespread sediment starvation and/or erosion that affected major tracts of the sea floor. In most cases these beds also coincide with the tops or bases of small regressive cycles. The persistence of certain units is remarkable, for example, a thin (20-50 cm-thick) shell bed (Mt. Vernon-Elmwood Point bed) marking the base of the Wanakah Shale and equivalent Ivy Point Member, can be traced from Lake Erie nearly to the Tully Chenango Valley, a distance of over 150 miles; moreover, this bed is underlain everywhere, from Lake Erie to Owasco Lake, by a unique interval containing abundant *Phacops* trilobites, frequently as molt ensembles. Less persistent beds, apparently recording single sedimentation events (e.g. tempestites, distal turbidites), can be used for precise, isochronous correlation within limited areas; for example, Baird (1981) used the Mack Creek turbidite as a regional control marker in correlating outcrops of the medial (Wanakah-equivalent) part of the Ludlowville Formation around Cayuga Lake. A second correlation technique involves the matching of facies reversal points within small-scale cycles; as noted above, certain of these regressive maxima coincide with facies which are condensed and conspicuous. Using a network of such event beds and cycles we have made more refined (within-member) correlations across the critical Cayuga area. These are summarized as follows.

Centerfield-Chenango

As a result of detailed field studies, Gray (1984) established a direct connection between the Centerfield Member of western New York, and the Chenango Sandstone of the type Hamilton area. The interval is bracketed by a condensed shell-rich bed (Peppermill Gulf bed) below, which rests sharply on the underlying black shale of the upper Levanna or Butternut Members, and above by a phosphatic pebble-rich, shelly layer (Moonshine Falls bed) which locally overlies an erosion surface on the upper Centerfield or Chenango sandstone. A third unit that can be tentatively correlated is the Stone Mill Limestone which overlies the main sandstone bench of the Chenango Member (Earlville submember of Gray, 1984) this encrinite and coral-bearing unit can be traced into a coral bed that overlies the top of Centerfield calcareous mudstone in the Finger Lakes area.

Ledyard-Otisco Members.-- The base of the Ledyard Shale (and equivalent Otisco Member) is sharply demarcated from the Centerfield and Chenango beds by the Moonshine Falls bed; this shell and phosphatic pebble-rich layer can be traced from the Seneca Lake Valley eastward to the Chenango Valley. A series of higher connections can be made locally between the Skaneateles and Owasco Valleys; notable among these is a phosphatic pebble bed, associated with the Staghorn coral biostrome (Oliver, 1951), which persists a short distance across the transition from Otisco to Ledyard facies; we believe that a thin grey shale band in the lower black Ledyard at the type (Paines Creek) section marks this same horizon.

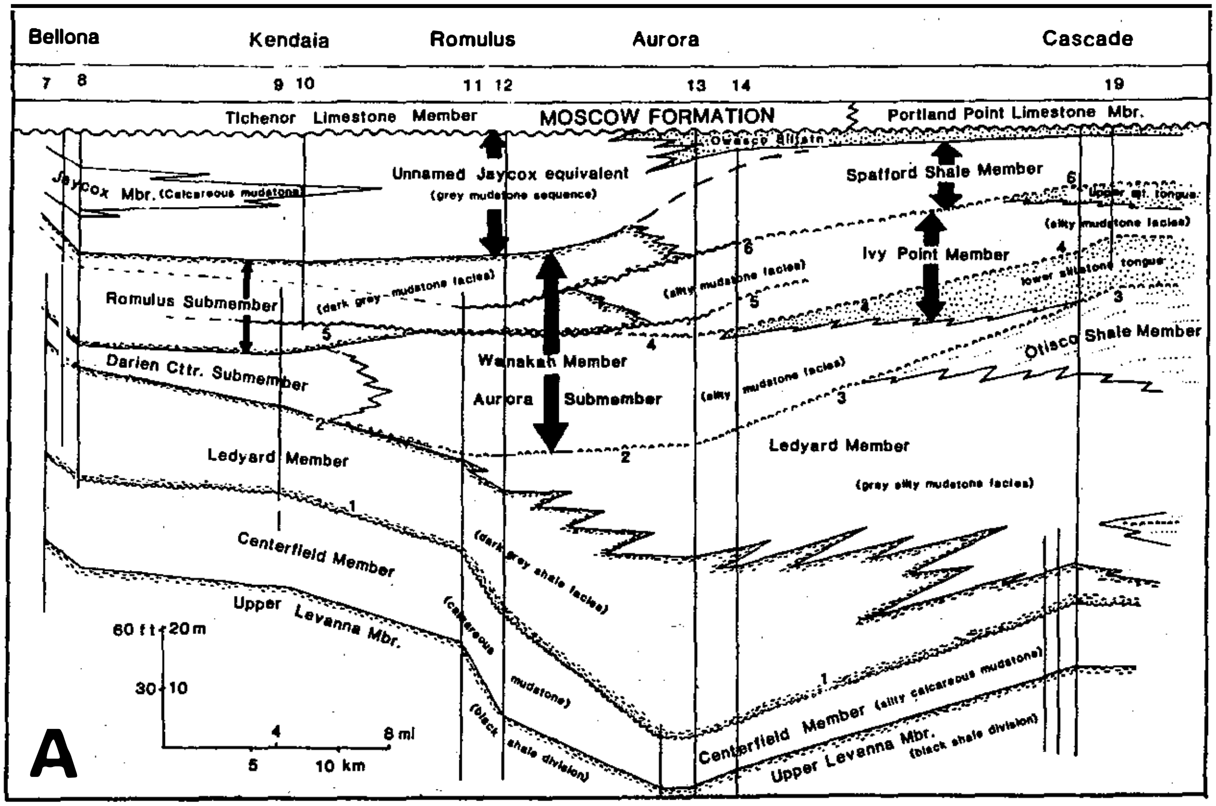
Toward the top of the Ledyard an interval of small carbonate nodules with well preserved cephalopods (Sheldrake beds) is traceable from western New York into the transition with the upper Otisco shales near Owasco Lake. Finally, the top of the Ledyard and Otisco shale is uniformly marked by a condensed shell-rich silty layer (formerly called the Strophalosia Bed; Cooper (1930), which is now termed the Mt. Vernon-Elmwood Point bed.

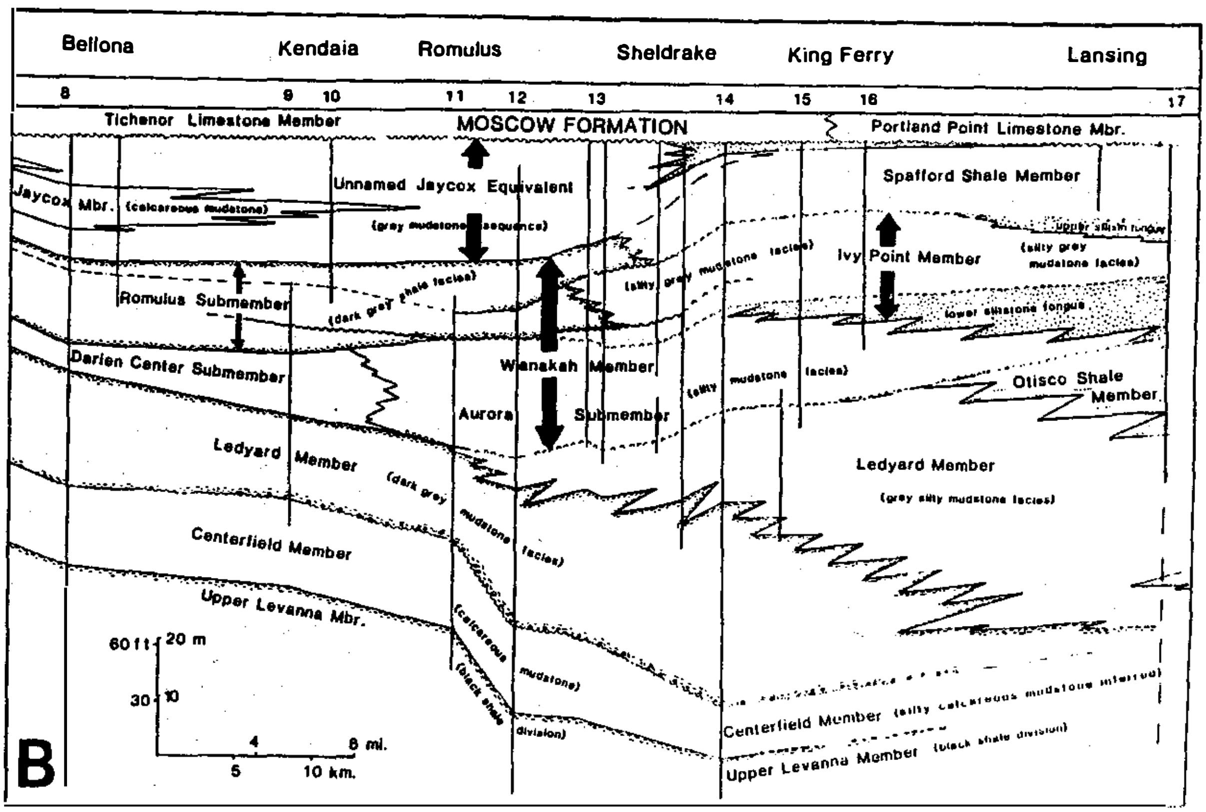
Wanakah Shale Ivy Point.-- The Elmwood Point shell bed establishes an important reference line between the basal Wanakah shale and Ivy Point Members. The Ivy Point Member, defined by Smith (1935), is a tripartite unit with lower and upper siltstone tongues, separated by a middle shale unit. Detailed correlation of the lower Ivy Point siltstone submember with the lower Wanakah beds (Aurora and Darien Center submembers) has been established by Miller (in prep.); he has noted three subcycles within the lower Ivy Point; these upward-coarsening hemicycles correspond respectively to the "Pleurodictyum beds," Darien Coral bed, and Murder Creek ("trilobite") Bed of the lower Wanakah Member. The middle Ivy Point shale contains a minor silty subcycle the top of which appears to correlate with Baird's (1981) Barnum Creek hiatus bed; overall, the middle shales correlate with a middle black shale lentil of the Wanakah in the Seneca Lake meridian.

Precise stratigraphic relationships of the upper siltstone submember of the Ivy Point with the upper Wanakah have been established because of the continuity of the Bloomer Creek hiatus concretion bed (Baird, 1981) with a rich shell-phosphatic bed at the abrupt upper contact of this higher upward-coarsening cycle. Minor subcycles within the upper siltstone submember have not yet been correlated westward.

Spafford Shale - Uppermost Wanakah black lentil.-- The Spafford Shale is rather clearly demarcated at its base by the Bloomer Creek-equivalent shell bed. On the basis of its position the Spafford can be correlated with a thin (1-2 m) dark grey to black shale lentil (Romulus submember) that overlies the Bloomer Creek bed westward from Cayuga Lake. About 10 m of soft grey shales exposed below an erosional contact with the Tichenor limestone at Salmon Creek (Ludlowville type section) and at Portland Point can be designated as Spafford shale as these shales overlie the Bloomer Creek bed.

FIGURE 4.-- A. Refined stratigraphy of Ludlowville Formation in an east-west direction across the central Finger Lakes region; this transect crosses depositional strike such that basinal facies in the western half of the section grade into shallow subtidal and possibly even lower shoreface deposits on the extreme right. Marker beds, indicated by numbers, include: 1) Moonshine Falls bed, 2) Mt. Vernon bed, 3) Elmwood Point bed (eastern equivalent of Mt. Vernon bed), 4) Ensenore Ravine bed, 5) Barnum Creek bed, and 6) Bloomer Creek bed.
B. Stratigraphy of the Ludlowville Formation in a northwest-to-southwest direction across the central Finger Lakes Region. Note the striking similarity of this profile with Figure 4A. Most of this lateral "basin-to-silty platform" facies change is visible in the Cayuga Valley because that lake trends essentially normal to Middle Devonian facies strike.


Bellona
Kendaia
Romulus
Aurora
Cascade
7 8
9 10
11 12
13 14
19
Tichenor Limestone Member
MOSCOW FORMATION
Portland Point Limestone Mbr.
Unnamed Jaycox equivalent
(grey mudstone sequence)
Spafford Shale Member
Jaycox Mbr. (calcareous mudstone)
Ivy Point Member
(dark grey-mudstone facies)
(silty mudstone facies)
Romulus Submember
Otisco Shale Member
Darien Cttr. Submember
Wanakah Member
Aurora Submember
Ledyard Member
(grey silty mudstone facies)
Centerfield Member
(dark grey shale facies)
Upper Levanna Mbr.
(calcareous mudstone)
(black shale division)
Centerfield Member (silty calcareous mudstone)
Upper Levanna Mbr. (black shale division)
60 ft 20 m
30 10
4 8 mi
5 10 km
A


Bellona
Kendaia
Romulus
Sheldrake
King Ferry
Lansing
8
9 10
11 12
13
14 15 16
17
Tichenor Limestone Member
MOSCOW FORMATION
Portland Point Limestone Mbr.
Unnamed Jaycox Equivalent
(grey mudstone sequence)
Spafford Shale Member
Jaycox Mbr. (calcareous mudstone)
Ivy Point Member
(silty grey mudstone facies)
Romulus Submember
(dark grey shale facies)
(silty grey mudstone facies)
lower siltstone tongue
Darien Center Submember
Wanakah Member
Aurora Submember
(silty mudstone facies)
Otisco Shale Member
Ledyard Member
(grey silty mudstone facies)
(dark grey mudstone facies)
Centerfield Member
Upper Levanna Mbr.
(calcareous mudstone)
(black shale division)
Centerfield Member (silty calcareous mudstone interval)
Upper Levanna Member (black shale division)
60 ft 20 m
30 10
4 8 mi.
5 10 km.
B

<u>Owasco Siltstone - Jaycox Member</u>.-- The Owasco Member is a thin bed (0.5 m) of coarse siltstone to fine sandstone which in some areas appears to have a gradational lower boundary with the underlying Spafford shale. Elsewhere the base is sharp and erosional. The top of the Owasco is sharply and erosionally overlain by basal Portland Point (= Tichenor) crinoidal grainstone. Locally, as in the area of Ludlowville and Portland Point, the Owasco is absent, presumably due to pre-Tichenor erosional truncation. Despite this bracketing, the exact western correlation of the Owasco is uncertain at this time. A calcareous, silty bed with a few corals occurs near the base of the Jaycox Member at King Ferry, New York. This suggests mutual correlation with the Owasco to the east and the basal Jaycox (Hill's Gulch) bed to the west. If so, the main body of Jaycox silty shales must have been erosionally truncated by pre-Tichenor erosion everywhere east of Cayuga Lake. This situation is reminiscent of that seen in western Erie where the Jaycox is erosionally truncated and the Tichenor limestone rests on Spafford- equivalent upper Wanakah shales (Baird, 1979).

In summarizing these correlations, it can be noted that nearly all of the conspicuous, fossil-rich, calcareous intervals of western New York can now be matched with upward-coarsing cycles in the east (Figs. 4, 6). Condensed capping shell pebble beds (i.e. Moonshine Falls, Staghorn, Mt. Vernon-Elmwood Point, Darien-Coral, Murder Creek-Ensenore, Barnum, Bloomer, and Hills Gulch) can be tentatively traced across major facies transitions (Fig. 4). These correlations establish a series of about six to seven major and minor transgressive/regressive cycles in the Ludlowville Formation which seem to cross-cut facies and are, therefore, probably allocyclic in nature (see below).

LUDLOWVILLE LITHOFACIES

Several distinctive facies recur in predictable sequences in the Ludlowville Formation of the Cayuga Valley area. These lithologies are described and interpreted in the following sections, arranged approximately in order of appearance of lithofacies within shallowing cycles.

<u>Lithofacies Descriptions</u>

A) Dark-gray to black shales.-- Dark, sometimes rusty-weathering, fissile to platey shales with millimeter-scale lamination, minor disseminated pyrite and rare carbonate concretions; fossils sparse to very common, poorly preserved, of low diversity, and dominated by small pelagic organisms.

These sediments are typical of the central Finger Lakes area; they grade laterally, into facies B and C mudstone. They appear to represent relatively deep, poorly-oxygenated environments of the basin center. Laminae represent slight differences in grain size, with thin, light colored silt and darker clay laminae; preservation of fine laminae is due to absence of bioturbation in minimally dysaerobic to anaerobic sediment (see Byers, 1977; Cluff, 1980; Aigner, 1980, for discussion of similar facies).

B) Medium to dark gray bioturbated mudstone.-- Thinly-bedded and fissile to massive and homogeneous, slightly calcareous to silty mudstones; with interspersed thin shell-rich horizons; and commonly contain scattered small brachiopods, nuculid clams, trilobites and nautiloids. Fine, threadlike to cylindrical pyritic burrow linings abundant; calcareous concretions ranging from 10 to 50 cm in diameter occur at numerous horizons within these deposits.

Detailed examination of Hamilton mudstones indicates that they are composed almost exclusively of pelleted mud, ranging upward to medium silt size (see Wygant, 1986; Brett, et al., 1986). The homogeneous, pelletal nature of the mudstone reflects persistent, though generally shallow, bioturbation that has destroyed most of the primary fabric. The occurrence of thin shelly layers may have resulted from minor storm winnowing. Pyrite aggregates and steinkerns indicate the presence of local, sulfidic microenvironments inside shells and burrows within the reducing, nonsulfidic muds; such microenvironments induced concentration gradients due to bacterial sulfate reduction and anaerobic decay of the contained organic matter (Hudson 1982; Dick and Brett, 1986). Rapid burial of organic matter may also have been a catalyst in producing carbonate precipitation (see Weeks 1957; Berner, 1968; Raiswell, 1971, 1976).

The color of these mudstones ranges from a very dark slate grey to medium grey in the central Finger Lakes region; although local variations in shale color reflect differences in organic content between beds, a regional, east-west color gradient appears to have a late diagenetic origin.

C) Bioturbated silty-calcareous mudstones.-- Massive 0.5 to 5 meter-thick calcareous to silty mudstones; conspicuously structureless except for abundant spreiten of Zoophycos and occasional shell beds or relicts of thin (2-5 cm), laminated siltstone layers; fossils rare and scattered, but typically well preserved.

The mudstone intervals record numerous rapid burial events; these siliciclastic-carbonate mud layers, presumably winnowed from nearby shallow shelf areas during storm events, were deposited in adjacent lower energy regions. However, pervasive and deeply-penetrating bioturbation, mainly by Zoophycos-producers, destroyed most primary lamination, leading to homogeneous, blocky mudstones. This facies forms the lower and middle parts of upward-coarsening cycles in New York State. These intervals tend to maintain prominent vertical joint planes, forming massive wall-like bluffs. Weathered joint facies display a distinctive pattern ("fretwork" surfaces) which reflect differential weathering of Zoophycos spreiten exposed in cross-section.

D) Cross-stratified, coarse-grained siltstones and sandstones.-- Thick-bedded to massive protoquartzite and subgraywacke units, ranging from one to five meters thick including amalgamated layers of hummocky cross-stratified, coarse siltstone to medium-grained sandstone. Surfaces typically display coquinites of disarticulated, convex-upward brachiopod and bivalve shells, as well as symmetrical and asymmetrical ripples. Sandstones are carbonate-cemented and contain horizons of large (up to 30 cm-across), spherical carbonate concretions. Persistent bands of soft-sediment deformation (ball and pillow structures) occur at certain levels. Bioturbation is minor where HCS bedding predominates but adjacent beds are usually intensely burrowed by Zoophycos.

The sandstones are interpreted as siliciclastic analogs of the condensed winnowed crinoidal calcarenite and they appear to grade laterally into the latter (Gray 1983, 1984). Sandstone deposits consist of amalgamated, storm reworked accumulations (cf. Aigner, 1985), usually developed within otherwise winnowed shelf sand. They form the upper beds ("roof beds" sensu Bayer et al. 1985) of coarsening-upward hemicycles in the southern Cayuga Lake area.

E) Shell-coral beds.-- Indurated, shell-rich (1-10 cm-thick) wackestone layers alternating with sparsely fossiliferous mudstones (Facies B,C). Thicker units typically display basal lag concentrations of finely-comminuted and corroded shell debris with well-preserved, articulated and unbroken skeletons concentrated along the upper surfaces. Shells on bed tops are preferentially oriented convex-upward and may display mud-sheltering. Certain shell beds pinch and swell along outcrops at wavelengths in the range of one to six meters. Intervening mudstone beds are sparsely fossiliferous, but may contain extraordinarily well-preserved fossils imbedded in, or attached to, the upper surfaces of underlying shell beds (see Brett, et al. 1983).

This evidence suggests that these shell beds are multi-event layers indicating relatively long-term accumulations of skeletal debris during times of minimal sedimentation. Skeletal accumulations were subjected to minor local currents and bioturbation during exposure.

Minor scouring at the bases of certain shell beds suggests brief intervals of erosion associated with the local shifting of skeletal debris across the seafloor during major storms. Shell beds were smothered during episodes of rapid mud accumulation (distal mud tempestites?) which buried groups of living organisms inhabiting the upper surfaces of the shell layers, usually as a single event.

F) Condensed beds; nodular phosphates and hiatus concretions.-- Thin (5-50 cm-thick), extremely widespread beds (traceable in outcrops for 150 to 200 kilometers); typically shelly, mud-supported beds containing a high proportion of disarticulated, fragmented and/or corroded skeletal material (rugose corals, thick-shelled brachiopods, crinoids, bryozoans and others), in addition to well-preserved fossils (Baird, 1978; 1981; Baird and Brett, 1983). Fossil diversity is high, but may reflect additive incorporation of taxa from several distinct communities. Thick-shelled brachiopods and corals commonly display loss of surficial detail and abundant micro- and macroborings, as well as encrustation by one or more generations of epizoans indicative of long-term exposure on the sea bed (Baird and Brett, 1981; 1983). Condensed beds may also contain small (usually less than 1 cm-diameter), rounded, black phosphatic nodules, some of which represent reworked, prefossilized steinkerns (Baird, 1978), and bored, encrusted and corroded hiatus concretions also occur at several localities (Baird, 1981).

Discontinuities and condensed beds are particularly associated with the tops of upward-coarsening, regressive hemicycles which occur east of the Finger Lakes Trough; condensation and erosion appear to be primarily associated with transgression events. Where condensed beds are sharply overlain by laminated black sediments, they may contain lags of reworked, tubular or steinkern pyrite (Baird and Brett, in press).

These beds clearly reflect widespread episodes of minimal net sedimentation and episodic bottom scour, for periods probably lasting 100's to 1,000's of years. In some cases significant erosion is evident, particularly where paleoslopes are indicated by other lines of evidence (Baird, 1981; Brett and Baird, 1982). The mixture of well-preserved and corroded fossils indicates complex histories for these layers, involving multiple episodes of rapid burial followed by exhumation and reworking. Bioturbation, predominantly by *Zoophycos*, also may have been significant in comingling sediment, fossils, and clasts of different ages, producing stratomictic discontinuities *sensu* Baird (1978; 1981).

LUDLOWVILLE BIOFACIES

Ludlowville beds have long been famous for their well preserved and diverse marine invertebrate fossils which form rather clearcut recurring associations (Cleland 1903; Cooper 1930, 1933; Smith, 1935). In the past two decades well over 70 fossil "communities" (also termed associations, or biosomes by some authors) have been recognized from the Hamilton Group, either qualitatively or as the result of multivariate analyses (Grasso, 1970, 1973, 1978, 1986; Miller 1986; Brower et al. 1978; Savarese et al. 1986; Gray 1984); however, many of these named communities are approximately synonymous and, until recently there has been little attempt to integrate the various studies. Synthesis of these studies with recent facies mapping of the Hamilton Group has permitted the development of a general biofacies model for these rocks (Brett et al. 1983, Miller, 1986, Gray 1983, 1984). This model incorporates and integrates the previous studies, as well as abundant unpublished data, to delineate generalized biofacies representing groups of closely related fossil associations (or paleocommunities). The model relates biofacies to one another and to inferred paleoenvironmental parameters.

Figure 5, modified from Brett et al. (1983) and Brett and Baird (ms. in preparation) depicts relationships among several recurring Hamilton biofacies. Adjacent biofacies on this diagram are those which most commonly border and intergrade with one another. The relative ordering of biofacies has been established on the basis of consistent vertical and lateral intergradation of fossil associations in five or six relatively complete sedimentary cycles of the Hamilton Group. In a general sense, the left hand side of the chart represents typical ordering of fossil associations in dark shale-carbonate, regressive cycles of the Hamilton Group in western New York, while the right side reflects the typical vertical sequence of associations in the correlative, upward-coarsening cycles in the eastern Finger Lakes region (see Figure 6). The lateral gradation of various portions of these two types of faunal cycles has been demonstrated in numerous sequences bounded by apparently isochronous beds.

Hence, the vertical axis of the diagram records changes in response to overall regressive (shallowing) episodes which affected both western and central New York. Changes in biofacies along this axis are thought to be the direct or indirect consequence of changing water depth. Factors actually responsible for community replacement may include oxygen levels (which should decrease in the deeper waters of a stratified basin), turbulence, light penetration, temperature, food supply, etc. The deeper-shallower polarity along this axis has been established by several lines of evidence including: 1) facies geometry (e.g., black, Leiorhynchus-bearing shales tend to occur nearest the presumed center of the Appalachian Basin and to grade concentrically outward into gray Ambocoelia-rich shale, then into Athyris or Mucrospirifer-dominated gray mudstones, etc.); 2) position within upward-coarsening hemicycles, in which sedimentary structures (e.g. hummocky cross stratification) unequivocally indicate decrease in water depth upward; and; 3) lateral

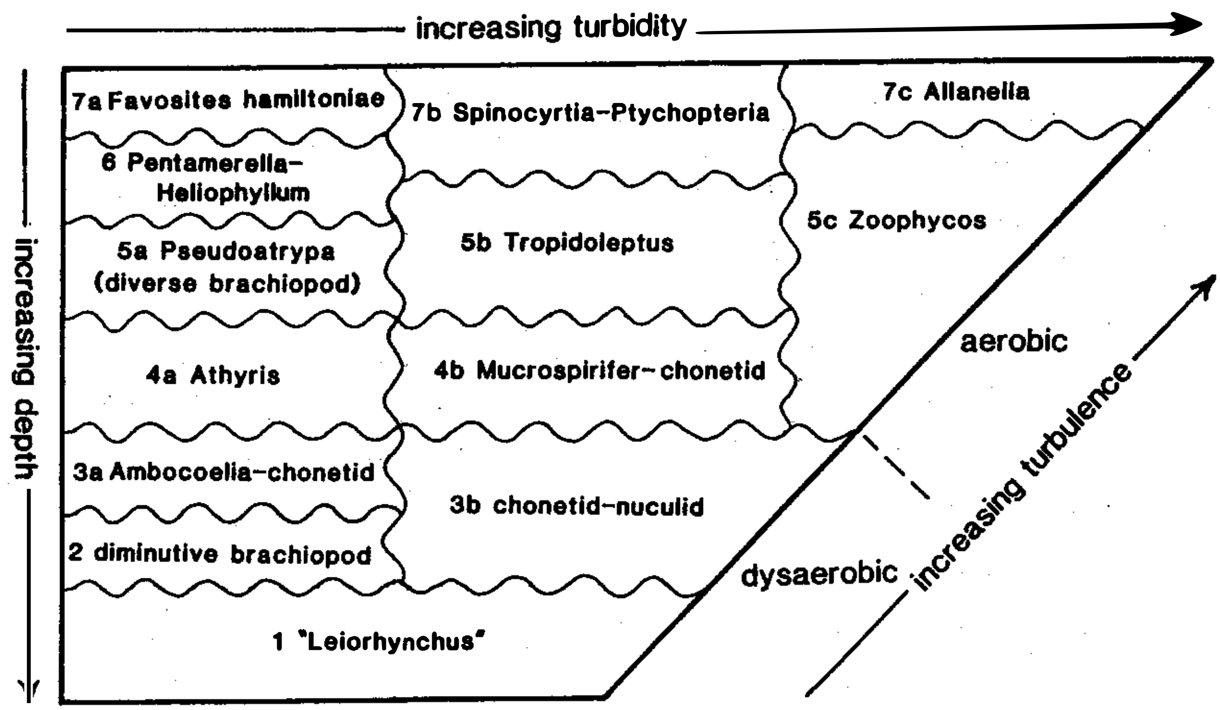


FIGURE 5.--Paleoecological model relating Ludlowville biofacies to inferred gradients of depth-related parameters and turbidity and/or sedimentation rates.

gradation within single isochronous condensed beds or intervals, which display upslope biofacies change in the relative order shown on the Figure.

Absolute depths can only be approximated at present. Evidence here is twofold: 1) evidence for position relative to the photic zone (e.g. indications of benthic algae or of visual systems in benthic organisms) and, 2) indications of position of biofacies relative to normal and storm wavebase (see Liebau 1980, for approximations of these depths) utilizing a proximality spectrum for storm generated beds (see Brett et al. 1986).

In general, most Hamilton facies, except perhaps the Leiorhynchus black shales, are thought to have been deposited within the photic zone (probably $\sim$50 m for a muddy epeiric sea), because of the abundance of phacopid trilobites with well developed eyes in most facies and circumstantial evidence for existence of benthic algae (herbivorous gastropods and evidence of possible algal substrates (see Brett et al. 1983). The large, complex eyes of Greenops and Phacops were quite possibly adapted for utilization of very low light levels so that these trilobites, (which are abundant, at least into the Ambocoelia-biofacies, though often lacking in Leiorhynchus associations), may have thrived in dysphotic settings. Finally, study of microendoliths produced by algae indicates that most Hamilton facies were deposited within photic depths; however, there is a marked increase in the abundance and diversity of microborings that correlates with overall faunal diversity increase (Vogel, et al, ms. submitted). This distribution pattern corroborates other evidence for the relative depths of the Hamilton biofacies.

A more refined subdivision of relative depths may be possible using evidence of tempestites (Brett et al. 1986). Amalgamated proximal storm beds are typical of the Favosites hamiltoniae and Allanella biofacies. Similar beds are forming today in shallow shelf settings generally at 10-20 m depths (Reineck and Aigner, 1982). Crudely graded proximal storm layers (coquinites, calcisiltites) are commonly associated with Tropidoleptus and diverse brachiopod biofacies; the lowest evidence for storm wave scouring (minor gutter casts) occurs in the Ambocoelia biofacies which may, therefore, have been deposited near the lower end of storm wave base (about 50-75 m; see Liebau, 1980), while only the most distal storm-generated currents apparently affected Leiorhynchus biofacies. In summary, then, the entire spectrum of Hamilton biofacies probably was developed in relatively shallow epeiric sea environments ranging from perhaps about 10 m downward to about 100 m. However, changes within this range appear to have exerted a strong control on fossil distribution.

The sequence of depth related biofacies is not identical in western and central New York, nor in every successive cycle in a given area. Certain biofacies (especially Leiorhynchus) persist with little change at an analogous position within any cycle from east to west. These are most probably the deepest water facies (see below) nearest the basin center, and, as might be predicted, they show the least effect of local conditions. However, other biofacies, particularly those toward the top of the diagram, appear to substitute for one another laterally at a given level within the cyclothem. Thus, for example, assemblages of diverse brachiopods and corals (biofacies 5A), in western New York, typically grade eastward into *Tropidoleptus*-dominated associations (biofacies 5B). The same type of substitution has also been observed vertically between lower and upper halves of a given cycle at a particular location.

Thus, the horizontal axis of the diagram (Fig. 5) records differences in communities, at a given position within the regressive cycle (and thus within a particular range of water depths), which are due to factors other than depth-related parameters; these may include substrate, turbidity, sedimentation rate, biotic factors, etc. However, the rather consistent association of biofacies changes with the eastward thickening and slight coarsening of cycle members strongly suggests that this change is related to sedimentation-controlled features. We believe that turbidity may have been somewhat more critical than absolute rate of sedimentation or substrate. The chemical composition (i.e., whether carbonate or siliciclastic) and grain size of the substrate appear to have exerted relatively little control, at least on the distribution of brachiopods, as we have seen nearly identical associations, at analogous portions of cycles (i.e. similar depths), developed in sandstones, mudstones or limestones. Similarly, although some biofacies changes are, in general, correlated with increasing thickness of a given sedimentary package, the same type of change can sometimes occur without substantial change in thickness of a bed; this tends to rule out net sediment accumulation rate as the critical factor. However, the biofacies substitutions almost always coincide with circumstantial evidence for increased turbidity, such as increased abundance of trace fossils (*Zoophycos*) and infaunal bivalves, decrease in presumed turbidity intolerant organisms (i.e. corals), and decrease in abundance of algal endoliths (Vogel et al. submitted).

Biofacies Descriptions

In the following sections we briefly characterize the various Hamilton biofacies from offshore (deepest) to onshore (shallowest).

1. *Leiorhynchus*.-- Low diversity (10-15 species), or even monotypic assemblages of poorly preserved leiorhynchid, chonetid and rare ambocoeliid brachiopods, nuculid bivalves, nautiloids, goniatites and *Styliolina*. Invariably associated with black to dark gray, laminated shales (Lithofacies A). Probably the deepest water assemblage (50-100 m); quiet dysaerobic water settings, sediments anoxic near to the sediment water interface, turbidity low to moderate; below storm wave base.

2. *Diminutive brachiopod*.-- Distinctive, low-diversity assemblages of diminutive brachiopods, particularly small (juvenile?) *Tropidoleptus*, *Truncalosia*, and *Ambocoelia nana*; small bivalves, including *Cardiola* and nuculids; archeogatropods, such as *Palaeozygopleura* and *Retispira*, and *Phacops* trilobites, associated with dark gray to black, fissile but non-laminated shales, with minor pyritic burrow fillings (Lithofacies A, B).

Slightly shallower and/or more aerobic than the Leiorhynchus association with dysaerobic to lower aerobic bottom waters and anoxic, shallowly-burrowed muds; low turbidity settings below storm wavebase; the occurrence of bedding planes covered with monotypic assemblages of small brachiopods may indicate mass mortality of spatfalls.

3A. Ambocoelia-chonetid.-- Low to moderate diversity (20-40 species) fossil assemblages, including abundant small, free-lying brachiopods (e.g. Ambocoelia, Devonochonetes scitulus); nuculid and modiomorphoid bivalves, archeogastropods, phacopid trilobites; rare small inadunate crinoids and blastoids, auloporid corals. Dark to medium grey, concretionary, pyritic shales and mudstones (Lithofacies B).

Relatively deep (~50 m), quiet water, moderately oxygenated with anoxic or dysoxic, nonsulfidic, shallowly-burrowed substrates; near storm wave base; at least dysphotic zone.

3B. Chonetid-nuculid.-- Low to moderate diversity assemblages dominated by Devonochonetes scitulus or Longispina, nuculid bivalves, archeogastropods, nautiloids and Greenops trilobites; rare small Zoophycos. Typical occurrence in dark to medium grey, bioturbated mudstones (Lithofacies B, C).

Depths, analogous to those for the Ambocoelia-chonetid association, but substrate probably more thoroughly bioturbated; turbid water conditons near sediment interface.

4A. Athyris. -- Moderate diversity assemblages (30-40) including stereolasmatid corals, fenestellid bryozoans, the brachiopods Athyris, Mucrospirifer, Devonochonetes, medium sized protobranch modiomorphoid and pterioid endobyssate bivalves, archeogastropods, phacopid trilobites and a few flexible and inadunate crinoids. Common in medium grey claystones to silty mudstones (Lithofacies B), sometimes concretionary or with nodular pyrite; commonly with shell-rich beds (Lithofacies F,G).

Moderate depths, within lower storm wave base (30-50 m), but normally rather quiet with low to moderate turbidity; bottom waters fully aerobic but upper sediments dysoxic.

4B. Mucrospirifer-chonetid.-- Moderate diversity assemblages (30-35 species) often largely dominated by Mucrospirifer and Devonochonetes brachiopods and/or bivalves such as Cypricardella, Paleoneilo; also minor trilobites, typical of medium grey, commonly silty mudstones and muddy siltstones (Lithofacies B,C,D), concretions and pyrite nodules uncommon.

Depths similar to the Athyris biofacies, with which it interfingers; fairly high sedimentation and relatively high amounts of silt; abundant shallow burrowing; probably high turbidity and instable substrate.

5A. Pseudoatrypa (diverse brachiopod).-- Moderate to high diversity fossil assemblages (40-60+ species); contains the highest brachiopod diversity of any Hamilton unit, including various atrypids, spiriferids (Mediospirifer, Cyrtina, Elita, Nucleospira, Spinocyrtia), strophomenids (Strophodonta, Pholidostrophia, Douvillina, Megastrophia), terebratulids (Centronella, and others); small- to medium-sized rugose corals (Stereolasma, Amplexiphyllum), fenestellid, and fistuliporoid bryozoans, various epi- and endobyssate bivales, trilobites, crinoids, blastoids. Primarily in medium to light gray, soft, commonly calcareous (marly) mudstone (Lithofacies B) with abundant thin shell-rich layers (Lithofacies E); minor Zoophycos bioturbation.

Shallower (20-30 m), fully aerobic muddy- to shelly-bottomed settings below wave base but well within storm wave base; upper sediments aerobic; moderate to deep burrowing; turbidity and sedimentation rates generally low.

5B. Tropidoleptus.-- Moderate diversity (30-50 species) assemblages, dominated by brachiopods (Tropidoleptus, Devonochonetes, Longispina, Mucrospirifer, Athyris, Meristella, Spinocyrtia). Pseudoatrypa and stophomenids may be present but usually rare, bivalves diverse and common, including Cypricardella, Modiomorpha, Ptychopteria, and Glyptodesma; rugose corals rare or absent but the tabulate Pleurodictyum may be common and large; varied ramose and fistuliporoid bryozoans; phacopid and proetid trilobites, often large; platyceratid gastropods; high diversity of crinoids and blastoids. Typifies medium to light bluish gray, soft, bioturbated, blocky and moderately to sparsely fossiliferous mudstones (Lithofacies B) or muddy siltstones (Lithofacies C); scattered coquinites, some with grading, gutter casts.

Analogous depths to Pseudoatrypa association, but with distinctly higher sedimentation rates and/or turbidity. Aerobic muddy to silty bottom areas, commonly affected by epeiric storm waves.

5C. Zoophycos. -- Zoophycos burrowing pervasive; very sparse, moderate diversity (20-30 species) but often large and well preserved body fossils, include various large clams (Actinopteria, Modiomorpha) and brachiopods such as Spinocyrtia. Associated with massive, bluff-forming, light gray, buff-weathering, bioturbated, silty mudstone or muddy siltstone (Lithofacies C).

Shallow, but low to moderate energy high turbidity settings, below normal wave base, probably affected by storm waves but most traces of bedding obliterated by Zoophycos; turbid and unstable substrates inhibited colonization by epifauna (trophic group amensalism) but those organisms which did colonize often grew to large size (abundant suspended food).

6A. Pentamerella (Heliophyllum).-- diverse (50 to 60+) coral-dominated fauna with many species of large turbinate and fasciculate rugosans (Heliophyllum, Cystiphylloides, Eridophyllum, and ramose to massive tabulates (Favosites, Alveolites, Cladopora); fenestrate, fistuliporoid and ramose trepostome bryozoans; brachiopods less common but represented by several genera, some of which (e.g. Pentamerella, Parazyga, Elita, Pentagonia) are largely confined to this facies; crinoids are abundant, but usually highly disarticulated; platyceratid gastropods and large pterioid clams locally common. May be biostromal; fossils commonly fragmented and heavily corroded.

Shallow, moderate to high energy settings approaching normal wave base (~20 m), well aerated, with abundant food supply; skeletal buildup on seafloor possibly inhibiting burrowing but favoring diverse epibiont communities; sedimentation rates very low. Light gray, commonly soft, crumbly, calcareous (marly) mudstone (Lithofacies B) to nodular argillaceous limestone, or, rarely, calcareous siltstone (Lithofacies C).

6B. Spinocyrtia (Ptychopteria).-- Low to moderate diversity (20-30 species) fauna concentrated in winnowed coquinite layers; heavily dominated by large epibyssate bivalves (Ptychopteria, Actinopteria, Glyptodesma), but with common large and/or robust brachiopods such as Spinocyrtia, Camarotoechia; Protoleptostrophia, Devonochonetes, Tropidoleptus, minor ramose bryozoans and crinoids; Dipleura trilobites; fossils usually preserved as uncompressed molds. Typical of blue gray, buff-weathering massive to laminated or cross laminated, coarse siltstones and fine grained sandtones, (Lithofacies C,D), with or without abundant Zoophycos burrowing.

Shallow (<20 m), high energy, silty to sandy bottomed environments; strongly affected by storm winnowing and approaching normal wave base; deep burrowing may be present or may be inhibited by movement of sand traction sheets.

7A. Favosites hamiltoniae-- A moderately diverse assemblage characterized by large hemispherical favositids, and rugose corals such as Eridophyllum, Heliophyllum, and Cystiphylloides, trepostome and fistuliporoid bryozoans, robust brachiopods (e.g. Megastrophia, Spinocyrtia, Rhipidomella, large bivalves, and abundant pelmatozoan ossicles; typically in crinoidal pack- and grainstone or coarse siltstone to fine, well-sorted sandstone (Facies D).

Very shallow, moderate to high energy, nonturbid settings near normal wavebase, with well-winnowed, firm substrates.

7B. Allanella.-- Low diversity assemblages, including the brachiopods Allanella tullius, Camerotoechia, Tropidoleptus, Schuchertella and large chonetids, large bivalves such as Ptychopteria and Glyptodesma may also be present; fossils commonly disarticulated, fragmented and/or moldic; associated with cross-bedded, commonly hummocky, rippled, coarse siltstone and sandstone, with intermittent coquinite beds;

Very shallow (10-15 m) high energy settings within, or close to, normal wave base; burrowing typically prevented by physical disturbance of silts and sands (Lithofacies D).

LUDLOWVILLE FACIES CYCLES

The Devonian System in the Appalachian basin, has already been examined for evidence of allocyclic and autocyclic depositional events; Dennison

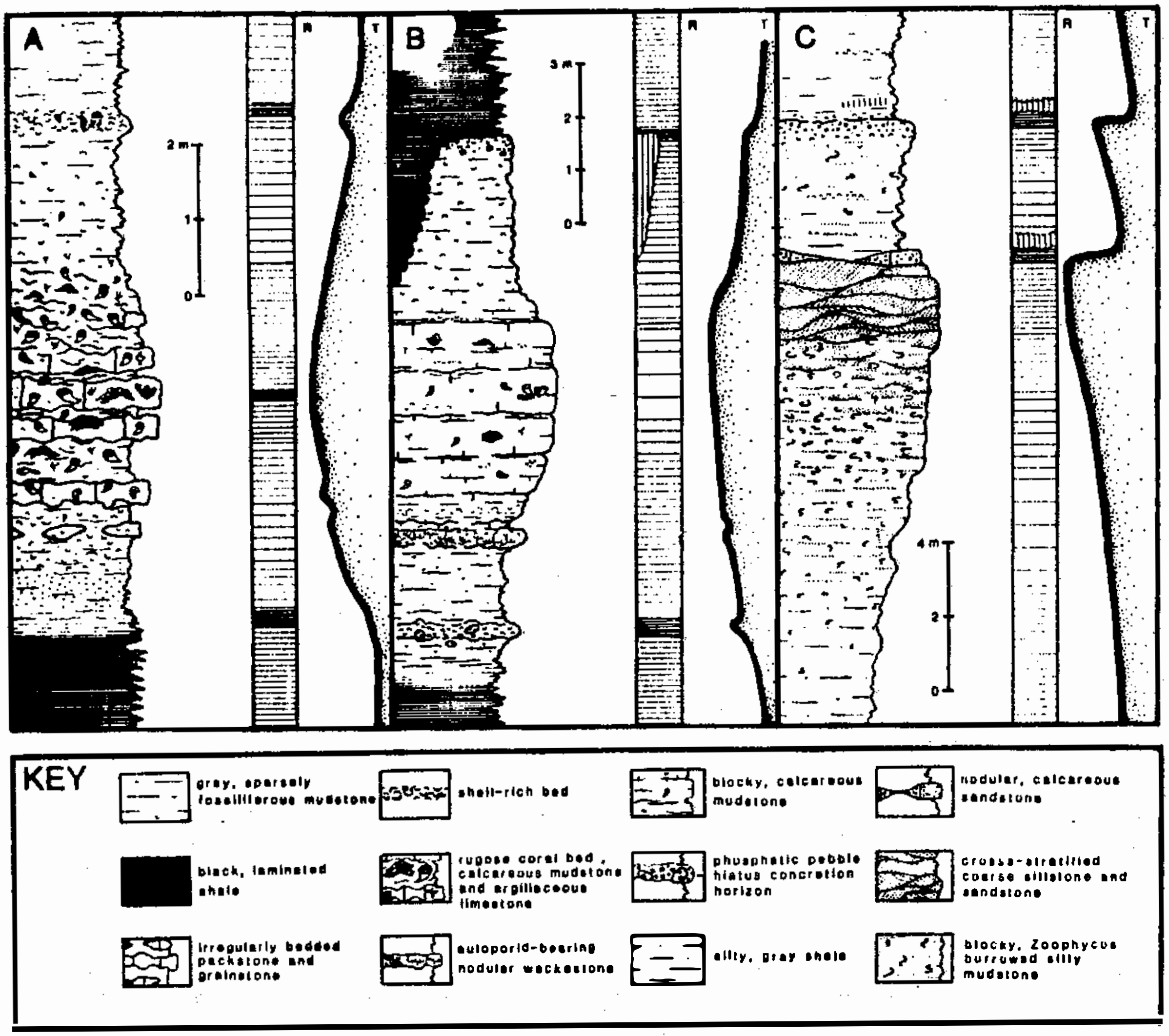


FIGURE 6.--Sections of a representative Ludlowville cycle, the Centerfield Limestone and equivalent Chenango Sandstone from A) Genesee Valley, B) Cayuga Valley, and C) Chenango Valley. Interpreted relative sedimentation rates and regression/transgression curves are shown for each section; within columns, close spacing of horizontal lines indicates slow net sedimentation; vertical ruling indicates hiatuses. Note change from subsymmetrical limestone centered cycle in the west to an asymmetrical, coarsening-upward cycle in the east.

and Head (1975), in summarizing intrabasinal correlations of the Devonian section, identified numerous eustatic fluctuations within the sequence. More recently, House (1983) and Johnson, et al. (1985) have presented intercontinental correlations of the Devonian system including deposits within the Appalachian Basin; these authors recognize the widely correlatable Devonian black shale deposits as marking eustatic transgression maxima, and House (1983) recognizes a three-fold hierarchy of cycle-magnitude (based on vertical thickness) in the Upper Devonian.

We recognize two scales of rather regular facies alternation within the Hamilton Group of the Cayuga Lake region. The two different orders of facies oscillations are differentiated on two bases: a) thickness, and b) magnitudes of lithofacies and, particularly, biofacies variation. Smaller (6th order) cycles, are relatively thin packages (generally <1 m in western New York and <3 m in thicker central New York sequences); moreover they display limited facies variation with a range of faunas reflecting only a portion of the total Hamilton biofacies spectrum; they may or may not be basinwide in extent. Conversely, larger-scale cycles are thicker (3 to 20 m) and display more nearly complete facies spectra (e.g. from black, fissile shales with *Leiorhynchus* to limestones with diverse faunas); these are invariably widespread.

We argue that these sequences are *cycles* in that they display a fairly regular, repeated and predictable sequence of litho- and biofacies, i.e. the sequence is not random (see Lukasik, 1984; Zell, 1986; Linsley, 1986; Savarese et al, 1986; Miller, 1986, for detailed study of individual cycles).

Whether or not cycles have similar durations is more difficult to ascertain because of a total lack of absolute dates. At present we can only note that the two levels of cyclicity each show rather similar thicknesses of strata per cycle in a given geographic area. If we equate rock thickness with time (a questionable assumption) then we would conclude that cycles have approximately similar periodicities. There does appear to be some discontinuity between small, 0.5-1.0 m-scale, cycles and larger 3-5 m, cycles. It is difficult or impossible to correlate some smaller cycles across very large areas, whereas all of the larger cycles can be traced regionally.

Finally, there is now strong evidence that the larger cycles are allocyclic in nature; not only can they be traced across facies boundaries within the Hamilton Group of New York (Brett and Baird, 1985), but several also can be tentatively correlated with transgressive-regressive cycles in the rest of the Appalachian Basin, the Cordilleran region and also in Europe, Morroco, and elsewhere, using conodont biostratigraphy for rough dating (see Johnson et al. 1985; House, 1983). This suggests a eustatic signature in these events.

The causes of smaller-scale oscillations are less certain. Some appear to be widespread, at least in western and central New York State; these also cross-cut facies and may be the result of allocyclic processes, probably either sea level or climatic fluctuations. Other small-scale, coarsening upward cycles appear to be restricted to central New York areas, and, therefore autocyclic mechanisms can not be ruled out. These might record episodic subsidence and tectonic adjustment of the southeastern basin margin or possibly local deltaic progradation (Selleck, 1983).

Large and small-scale, upward-coarsening cycles occur within the Ludlowville Formation in the Cayuga-Owasco area (Figs. 6, 8-10). They comprise distinctly asymmetrical, coarsening-upward hemicycles, ranging from 0.5 to 3 meters-thick. Each cycle begins with a thin (1-10 cm) shell-rich bed (Lithofacies F,G) containing diverse fossil assemblages, commonly dominated by the Athyris brachiopod biofacies (Athyris, Mucrospirifer, Spinocyrtia, various chonetids, the small rugose coral Stereolasma, and crinoidal debris). Most shells are disarticulated and some are fragmented and corroded. Small phosphatic pebbles (0.5 - 1.0 cm in diameter), including reworked phosphatic steinkerns, also occur in association with skeletal debris in some cases. Such roof beds usually abruptly overlie, but may be amalgamated with, the uppermost siltstones of the previous hemicycle.

The lower part of each hemicycle above the transgressive debris layer includes thin intervals of clayshale (Lithofacies B) with diverse brachiopod and bivalve faunas, including many of the elements of the underlying shell bed assemblage. Minor thin shelly layers alternate with Zoophycos-bioturbated claystone layers. Higher portions of the cycle consist of silty, thoroughly Zoophycos-bioturbated, massive mudrock with an (Lithofacies C,D) assemblage dominated by Tropidoleptus, Mucrospirifer (Biofacies III, V) and numerous bivalves. A zone of rusty-weathering, calcareous concretions, formed around the pyritized vertical shafts of Zoophycos, occurs toward the top of certain cycles. Thicker cycles may terminate in beds of coarse, laminated or bioturbated siltstone or fine grained sandstone (Lithofacies E), which contain layers of larger skeletons, particularly robust Spinocyrtia, and scattered, large rugose or tabulate corals. These coarse upper beds are more resistant to weathering than the underlying mudstone and tend to form waterfalls in stream exposures. Cycles commonly terminate with a flat, bench-like upper surface on which lies reworked shell and nodular phosphatic debris as well as succeeding softer mudstone beds.

Each cycle appears to record three major phases: First, an initial sediment-starved interval was associated with minor deepening, during which the basal shelly and phosphatic bed accumulated; this was followed secondly by a relatively rapid aggradation of the sediment surface to slightly shallower levels. Upward faunal changes record both the increased sedimentation rate and gradual shallowing. The third and last phase is recorded in the upper siltstone bed; this involved gradual decreases in net sedimentation rates coupled with multiple physical and biogenic reworking of sediment and bypass of fine-grained material (see Figure 6). Winnowing produced a relatively clean, condensed, coarse silt to medium-grained, sandy substrate and even permitted colonization by relatively turbidity-sensitive organisms such as tabulate corals.

CORRELATION OF LUDLOWVILLE CYCLES IN THE CAYUGA LAKE REGION:

FACIES PRECESSION

The present field trip examines not only the vertical relationship of facies within cycles but also the lateral variation of cycles across a distal-proximality spectrum. Walther's law predicts that the vertically stacked facies within a given cycle should grade laterally into one another across depositional strike. Hence, each analogous part of a given upward-shallowing cycle should display predictable lateral variation in a shoreward direction that is more or less in phase with, but consistently offset from that of the next overlying unit; (e.g. basal black shales of a given cycle should grade laterally upslope into gray mudstones, gray shales should grade to siltstones; siltstones to fine sandstones). We refer to this predictable facies change as facies precession.

In asymmetric cycles, the situation may be complicated in that facies present in the lower, shallowing, hemicycle are either absent or their homologs are quite different, in the upper, deepening, half cycle. In some cases, the upper half cycles typically condensed, undergo substantially less change than do the lower counterparts, especially in terms of biofacies. This may reflect variations in sedimentation rates at any given depth during the course of the cycle. During the regressive phase relative sea level drop apparently caused progradation of clastic sediments from southeastern source areas leading to marked differences in depth homologous members of the cycle from west to east approaching the area of maximum sediment deposition. In contrast, during transgressive phases the deepest basinal areas were more uniformly clastic sediment starved. Hence, differences from east to west were less accentuated and a more nearly uniform, thin package of sediments, with rather consistent biofacies, was deposited.

The Cayuga Lake transect provides excellent examples of facies precession within correlative cycles; the best examples come from the middle Ludlowville units, which undergo sufficient change to be designated as different members from northern to southern outcrops in the Cayuga Valley (See Figure 7 for geographic locations described in the following section).

In the King Ferry area (Stop 1) the Ledyard Member is dark gray to black fissile shale (Facies A), dominated by a diminutive brachiopod or chonetid-nuculid biofacies, with minor layers of chonetids and small Tropidoleptus and Ambocoelia. The Wanakah Member consists mainly of rather uniform silty mudstone and darker gray shales with thin horizons of concretions and condensed shell beds, several of which can be traced westward to the other side of Cayuga Valley and beyond.; there is a hint of coarsening-upward cycles, especially in the lower submember (Pleurodictyum beds of Grabau, 1899), and in the upper, Bloomer Creek interval. Most of the Wanakah Shale bears an Athyris or Mucrospirifer biofacies (4A,B), but the silty mudstones of the lower submember display Tropidoleptus or simply Zoophycos biofacies; the tabulate coral Pleurodictyum is abundant in this interval here, as it is west to Lake

Erie. The Spafford Shale overlying the Bloomer Creek shell bed, is sparsely fossiliferous, dark gray mudstone which passes upward into silty mudstone and minor siltstone in the Jaycox Member; the sequence is erosionally truncated by the Tichenor crinoidal limestone. The lower Spafford here yields a recurrent diminutive fauna with small Tropidoleptus, chonetids and nuculid bivalves, closely resembling that of the upper Ledyard shales, and the Jaycox siltstones are characterized by Zoophycos or Tropidoleptus biofacies.

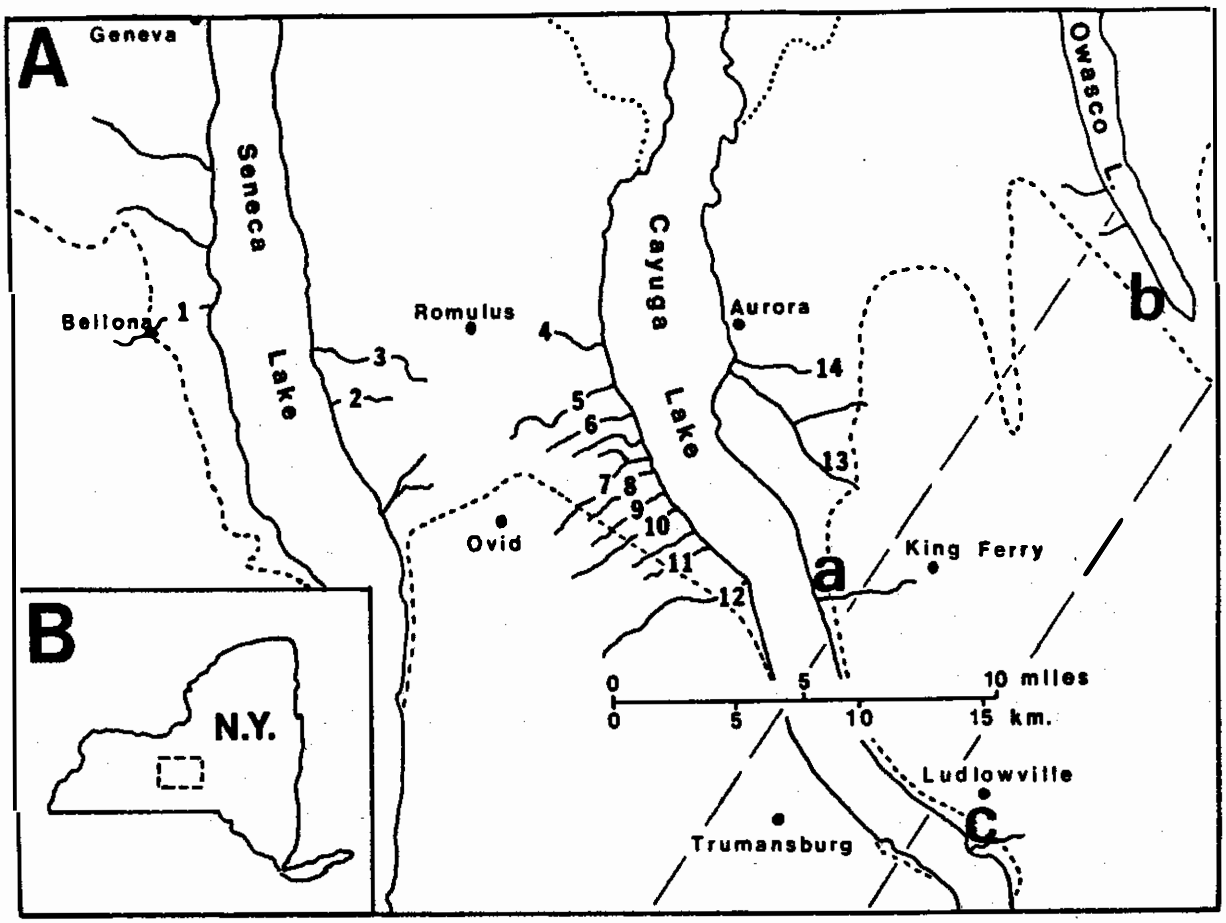


FIGURE 7.--Study area. A. Map of Seneca-Owasco Valley region. Figure shows the outcrop belt of the Hamilton Group (between dotted and dashed lines), including Fir Tree anticline exposures near Ludlowville on Cayuga Lake; large dashed diagonal lines show inferred depositional strike. Key Ludlowville outcrops are numbered, and include: 1) Kashong Glen; 2) Indian Creek; 3) Kendaia Creek; 4) Hicks Gully; 5) Big Hollow Creek; 6) unnamed creek; 7) Mack Creek; 8) Bloomer Creek; 9) Barnum Creek; 10) Powell Creek; 11) unnamed creek, 12) Sheldrake Creek; 13) Paines Creek; 14) Little Creek. Fieldtrip stops include: a) King Ferry Station; b) Cascade, Route 38 roadcut, and c) Portland Point.
B. Inset shows position of study area in New York State. Modified from Baird (1981).

At the Route 38 roadcut in Cascade, western Owasco Valley (Stop 2) most Ludlowville units have undergone substantial change, and display a more proximal aspect. The upper Ledyard interval, has changed from a black, fissile shale to a fossiliferous, silty, gray mudstone that can be termed Otisco Member; Ambocoelia and chonetid biofacies have been largely, but not entirely, replaced by Athyris biofacies. Within the Wanakah interval coarsening upward cycles at this locality are well developed, and are distinctly capped by platforms of relatively coarse siltstone. The fossil assemblages of these silty beds are more heavily dominated by Tropidoleptus, Zoophycos, and Spinocyrtia biofacies than those in corresponding beds at King Ferry.

Upper capping shell beds at the tops of cycles display relatively little change but are richer in larger brachiopods (e.g. Spinocyrtia). The Spafford Member has progressed to a relatively fossiliferous, grey, silty shale, with an Athyris to Tropidoleptus biofacies. The basal remnant of the Jaycox-equivalent interval is represented by a coarse, Zoophycos-burrowed to cross-laminated siltstone, of the Owasco Member, which contains coquinites of the low diversity Allanella biofacies.

Finally, at Portland Point (Stop 3) Ludlowville facies are still more proximal in aspect. The Ledyard-equivalent Otisco Member is a grey, silty mudstone with diverse brachiopod faunas resembling those seen in the lower Wanakah at King Ferry. The latter unit, in turn, has graded into burrowed to cross-laminated siltstone of the Ivy Point Member. The capping beds of coarsening upward cycles, which are composed of silty mudstones at King Ferry, are represented at Portland Point by hummocky cross-stratified to massive beds of coarse siltstone or fine sandstone, bearing Allanella coquinites. The lower Spafford Member bears a diverse Tropidoleptus biofacies, while upper beds contain Zoophycos-churned siltstone; the Owasco, if present at all, has been removed by pre-Tichenor erosion. Thus, all evidence points to considerably shallower-water conditions here than at Cascade, which, in turn, represents shallower conditions than at King Ferry. Nonetheless, all three areas were affected by the same shallowing-deepening cycles.

These observations add to the growing evidence for a gently northwestward-dipping ramp or paleoslope existing in the Cayuga Valley during deposition of the Ludlowville Formation (Figs. 1, 7; Baird, 1981; Baird and Brett, 1981). Some qualitative sense of the gradient on this ramp can be obtained by examination of the spectral facies changes within presumed time equivalent packages bounded by distinctive event beds.

One such interval is the Elmwood Point shell bed at the base of the Wanakah Shale (Figs. 8-10). This unit, probably the record of an interval of very low net sedimentation, displays gradational change in biofacies between King Ferry and Portland Point from a small brachiopod and mollusk-dominated assemblage to one containing abundant large spiriferid (Spinocyrtia) and strophomenid brachiopods and large bivalves (Ptychopteria). Thus, the lateral change with this narrow, precisely defined interval corresponds to nearly the full spetrum of biofacies change observed in a major cycle.

The biofacies change is paralleled by a gradation in lithofacies from dark grey slightlly silty mud and clay shales to coarse siltstones, with some evidence of winnowing; hence quiet water to near wave base positions are inferred. Based on the relative bathymetric inferences discussed under the biofacies section, we estimate that this might correspond to a depth difference of roughly 30-50 m in about 20 km.

Regional mapping of Ludlowville units demonstrates parallel, upslope gradients in biofacies along the northerly Cayuga to Skaneateles transect as well. The existence of the Fir Tree anticline section at Portland Point permits triangulation of facies belts (Fig. 7). Thus, for example, close resemblance of the Portland Point section to Ludlowville outcrops in the Tully Valley about 45 km (27 miles) to the northeast indicates that the regional depositional strike was approximately northeast-southwest. In contrast, marked facies differences between Portland Point and King Ferry sections only 20 km (12 miles) to the northwest indicate abrupt downslope environmental changes in this direction (Fig. 7). This pattern also explains the intermediate character of the Ludlowville facies at Cascade (Stop 2), relative to King Ferry and Portland Point. In actuality this outcrop is nearly 10 km (6 miles) north of the latitude of King Ferry; however, an imaginary NE/SW strike line projected from Cascade would intercept the Cayuga lake shore some distance southeast of King Ferry Station where the Ludlowville has dipped below the level of the lake, but north of the Fir Tree anticline exposures (Fig. 7). This evidence indicates that, at any given time, biofacies were arranged in elongate parallel belts that trended approximately NE-SW parallel to a gently (~1m/km) northwest dipping ramp.

The precise array of communities was variable depending upon: 1) overall water depth - controlled by transgressive/regressive cycles, and 2) sedimentation rate, as well as other factors. During transgression maxima (e.g. lower Ledyard) the biofacies transect would be as follows (deep to shallow; King Ferry to Portland Point areas): a) Leiorhynchus, b) Ambocoelia, c) Athyris (see Fig. 5).

In contrast, during times of peak sea level lowering the pattern would be either: a) Athyris, b) Pseudoatrypa (diverse brachiopod), c) Spinocyrtia, d) large coral (Pentamerella), if sedimentation rates were low, or: a) Mucrospirifer, b) Tropidoleptus, c) Zoophycos, and d) Allanella, under typical heavier sedimentation. In general, biofacies probably shifted laterally as tracking belts during transgressive-regressive cycles. However, differences in sedimentation between the half-cycles also produced some faunal asymmetries. Thus, the shallowing half-cycles are typified by low diversity Mucrospirifer- or Tropidoleptus-dominated assemblages, whereas the more condensed (sediment-starved) deepening hemicycle may display Athyris, Pseudoatrypa or large rugose coral biofacies , which are more typical of western New York calcareous ("clean-water") facies.

DISCUSSION

In summary, depositional strike within the Ludlowville section trends northeast-southwest nearly normal to the long axes of the Cayuga, Owasco, Skaneateles, and Otisco valleys; there is typically more facies change along these valleys than between them. This perception presents opportunities to examine the key depositional packages and fossil-rich event horizons, both within and between sedimentary cycles, in a new three-dimensional context of inferred Devonian paleobathymetry. It also allows us to predict the lithology and fauna of beds concealed in the subsurface.

A case in point relates to the Ledyard-equivalent Otisco sequence which is nearly entirely below lake level on the Fir Tree Anticline. From our surface mapping work we have found that the Staghorn Coral Bed in the Skaneateles and Otisco Valleys is associated with a spectacular northeast-southwest-trending, northwest-facing submarine escarpment (drop-off) which borders a thick, siltstone platform on which most corals rest (Brett and Baird, 1986). Since this escarpment and coral bed both occur within the lower Otisco Member in those valleys, and since the facies of the upper Ludlowville Formation here at Portland Point has precessed to facies identical to that overlying the Otisco at Staghorn Point, one could predict that the coral bed and possibly the submarine escarpment may be present below Portland Point or below Ithaca. The answer to this must wait because a complete subsurface drill core through the Hamilton section below Portland Point was recently destroyed before we knew of its existence. Future subsurface probes, however, could verify this prediction.

Our recognition of the Hamilton depositional strike trends within the Finger Lakes region, as well as our tentative correlations of numerous sedimentary cycles and event horizons within the Ludlowville and adjacent formations, will enable future students to fine-tune biofacies and taphonomic facies patterns along paleoslope gradients. Gradient analyses of these sequences and coenocorrelation techniques (see Cisne, and Rabe, 1978) will probably be the next steps in paleoenvironmental-paleoecological synthesis of this classic Paleozoic deposit.

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REFERENCES CITED

AIGNER, T., 1980, Biofabrics and stratinomy of the Lower Kimmeridge Clay, U. Jurassic, Dorset, England: Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, v. 159, p. 324-338.

AIGNER, T., 1985, Storm Depositional Dynamics: Dynamic stratigraphy in Modern and Ancient Shallow Marine Sequences: Lecture Notes in Earth Sciences, v. 3, 174 p. Springer-Verlag, Berlin, Heidelberg, New York, Tokyo.

AIGNER, T. and REINECK, H.E., 1982, Proximality trends in modern storm sands from the Helgoland Bight (North Sea) and their implications for basin analysis: Senckenbergiana Maritima, v. 14, p. 183-215.

BAIRD, G.C., 1978, Pebbly phosphorites in shale: A key to recognition of a widespread submarine discontinuity in the Middle Devonian of New York: Journal of Sedimentary Petrology, v. 48, p. 545-555.

BAIRD, G.C, 1979, Sedimentary relationships of Portland Point and associated Middle Devonian rocks in central and western New York: New York State Museum Bulletin, v. 433, 24 p.

BAIRD, G.C., 1981, Submarine erosion on a gentle paleoslope: a study of two discontinuities in the New York Devonian: Lethaia, v. 14, p. 105-122.

BAIRD, G.C., and BRETT, C.E., 1981, Submarine discontinuities and sedimentary condensation in the upper Hamilton Group (Middle Devonian): examination of marine shelf and paleoslope deposits in the Cayuga Valley, in, ENOS, P., ed., New York State Geological Association Guidebook, 53rd Annual Meeting, p. 115-145.

BAIRD, G.C., and BRETT, C.E., 1983, Regional variation and paleontology of two coral beds in the Middle Devonian Hamilton Group of western New York: Journal of Paleontology, v. 57, p. 417-446.

BAYER, U., ALTHEIMER, E. and DEUTCHLE, W., 1985, Environmental evolution in shallow epicontinental seas: sedimentary cycles and bed formation, in, BAYER, U., SEILACHER, A., eds; Sedimentary and Evolutionary Cycles, p. 347-381, Springer-Verlag Berlin, Heidelberg, New York.

BERNER, R.A., 1968, Calcium carbonate concretions formed by the decomposition of organic matter: Science, v. 159, p. 195-197.

BRETT, C.E., and BAIRD, G.C., 1982, Upper Moscow-Genesee stratigraphic relationships: evidence for regional erosive beveling in the late Middle Devonian, in, BUEHLER, E.J. and CALKIN, P.E., eds., New York State Geol. Assoc., Guidebook, 54th Annual Meeting, p. 19-63.

BRETT, C.E., and BAIRD, G.C., 1985, Carbonate-shale cycles in the Middle Devonian of New York: an evaluation of models for the origin of limestones in terrigenous shelf sequences: Geology, v. 13, p. 324-327.

BRETT, C.E., and BAIRD, G.C., GRAY, L.M., & SAVARESE, M.L., 1983, Middle Devonian (Givetian) coral associations of western and central New York State, in, SORAUF, J.E. and OLIVER, W.A., Jr., eds., Silurian and Devonian corals and stromatoporoids of New York, Fourth International Symposium for the Study of Fossil Cnidaria, Washington, D.C., p. 65-107.

BRETT, C.E. and BAIRD, G.C., 1986, Depositional events along a Devonian submarine escarpment: Staghorn coral bed (Ludlowville Formation), central New York: Geological Society of America, Abstracts with Programs, v. 18, p. 6.

BRETT, C.E., SPEYER, S.E. and BAIRD, G.C., 1986, Storm-generated sedimentary units: tempestite proximality and event stratification in the Middle Devonian Hamilton Group of New York, in, BRETT, C.E., ed., Dynamic Stratigraphy and Depositional Environments of the Hamilton Group (Middle Devonian) of New York State, Pt. I: New York State Museum Bulletin 457, p. 129-157.

BROWER, J.C., and others, 1978, Faunal assemblages in the lower Hamilton Group in Onondaga County, in, MERRIAM, D.F., ed., New York State Geological Association Guidebook, 50th Annual Meeting, Syracuse, p. 104-123.

BYERS, C.W., 1977, Biofacies patterns in euxinic basins; a general model, in, H.E. COOK et al., eds., Deep-water Carbonate Environments: Society for Economic Paleontologists and Mineralogists Special Publication, v. 25, p 5-17.

CISNE, J.L. and RABE, B.D., 1978, Coenocorrelation: gradient analysis of fossil communities and its applications in stratigraphy, Lethaia, v. 11, p. 341-364.

CLELAND, H.F., 1903, A study of the fauna of the Hamilton Formation of the Cayuga Lake section in central New York. U.S. Geological Survey Bulletin, v. 206, 112 p.

CLARKE, J.M., 1903, Classification of New York Series of geologic formations. New York State Museum Handbook 19, 1st edition, 28 p.

CLUFF, R.M., 1980, Paleoenvironment of the New Albany Shale Group, Devonian-Mississippian of Illinois: Journal of Sedimentary Petrology, v. 50, p. 767-780.

COOPER, G.A., 1930, Stratigraphy of the Hamilton Group of New York: American Journal of Science, v. 19, p. 116-134, 214-236.

COOPER, G.A., 1933, Stratigraphy of the Hamilton Group of eastern New York, Pt. 1, American Journal of Science, v. 26, p. 537-551.

COOPER, G.A., 1957, Paleoecology of Middle Devonian of eastern and central United States, in, H.S. LADD, ed., Treatise on marine ecology and paleoecology 2: Geological Society of America Memoir, v. 67, p. 249-277.

DENNISON, J.M. and HEAD, J.W., 1975, Sealevel variations interpreted from the Appalachian Basin Silurian and Devonian: American Journal of Science, v. 275, p. 1089-1120.

DICK, V.B. and BRETT, C.E., 1986, Petrology, taphonomy and sedimentary environments of pyritic fossil beds from the Hamilton Group (Middle Devonian) of western New York, in, BRETT, C.E., ed., Dynamic Stratigraphy and Depositional Environments of the Hamilton Group (Middle Devonian) in New York State, Pt. I: New York State Museum Bulletin 457, p. 102-128.

ETTENSOHN, F.R., 1985, The Catskill Delta complex and the Acadian orogeny: A model, in, WOODROW, D.L. and SEVON, W.D., eds., The Catskill Delta: Geological Society of America Special Paper, v. 201, p. 39-50.

GRABAU, A.W., 1898, 1899, Geology and Palaeontology of Eighteen Mile Creek and the Lake Shore Sections of Erie County, New York: Buffalo Society of Natural Sciences Bulletin, v. 6, pt. 1 Geology, Pt. II Paleontology, 403 p.

GRABAU, A.W., 1917, Stratigraphic relations of the Tully and the Genesee Shale in eastern North America: Geological Society of America Bulletin 28, p. 945-958.

GRASSO, T.X., 1970, Paleontology, stratigraphy, and paleoecology of the Ludlowville and Moscow Formations (Upper Hamilton Group) in Central New York, in, HEASLIP, W.G., ed., New York State Geological Association, Guidebook, 42nd Annual Meeting, Cortland, p. D1-D22.

GRASSO, T.X., 1973, A comparison of environments, the Middle Devonian Hamilton Group in the Genesee Valley, in, HEWITT, P.C., ed., New York State Geological Association Guidebook, 45th Annual Meeting, Rochester, p B1-B27.

GRASSO, T.X., 1978, Benthic communities of the Ludlowville and Moscow formations (Upper Hamilton Group) in the Tully Valley, Onondaga County, in, MERRIAM, D.F., ed., New York State Geological Association Guidebook, 50th Annual Meeting, Syracuse, p. 143-172.

GRASSO, T.X., 1986, Redefinition, stratigraphy and depositional environments of the Mottville Member (Hamilton Group) in central and eastern New York, in, BRETT, C.E., ed., Dynamic Stratigraphy and Depositional Environments of the Hamilton Group (Middle Devonian) of New York State, pt. 1: New York State Museum Bulletin 457, p. 5-31.

GRAY, L.M., 1983, Biofacies and depositional environments of the Centerfield "Member" in the northern Appalachian Basin: Geological Society of America Abstracts with Programs, v. 15, p. 170.

GRAY, L.M., 1984, Lithofacies, biofacies and depositional history of the Centerfield Member (Middle Devonian) of western and central New York State, Unpublished Ph.D. dissertation, University of Rochester, New York, 158 p.

HALL, J., 1839, Third Annual Report of the Fourth Geological District of the State of New York: New York State Geological Survey Annual Report, v. 3, p. 287-339.

HOUSE, M.R., 1983, Devonian eustatic events: Proceedings of the Ussher Society, v. 5, p. 396-405.

HUDSON, J.D., 1982, Pyrite in ammonite-bearing shales from the Jurassic of England and Germany: Sedimentology, v. 27, p. 639-667.

JOHNSON, J.G., KLAPPER, G. and SANDBERG, C.A., 1985, Devonian eustatic fluctuations in Euramerica: Geological Society of America Bulletin, v. 96, p. 567-587.

KENT, D.V., 1985, Paleocontinental setting for the Catskill Delta, in, WOODROW, D.L. and SEVON, W.D., eds., The Catskill Delta: Geological Society of America Special Paper 201, p. 9-14.

KLOC, G.J., 1983, Stratigraphic distribution of ammonoids from the Middle Devonian Ludlowville Formation in New York: MA thesis, State Univ. at Buffalo, 73 p.

LINSLEY, D.M., 1986, Cyclic deposition and stratigraphy in the upper Marcellus and Skaneateles Fms. in east central New York: Geological Society of America Abstracts with Programs, v. 18, p. 31.

LIEBAU, A., 1980, Palaobathymetrie und Ökofaktoren: Flachmeer Zonierungen. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, v. 160, p. 173-216.

LUKASIK, D.M., 1984, Stratigraphy, sedimentology, and paleoecology of the Kashong Shale (Middle Devonian) of New York: unpublished Ph.D. thesis, University of Cincinnati, 227 p.

MILLER, K.B.,1986, Depositional environments and sequences "Pleurodictyum Zone", Ludlowville Formation of western New York, in, BRETT, C.E., ed., Dynamic Stratigraphy and Depositional Environments of the Hamilton Group (Middle Devonian) of New York State, Pt. I, New York State Museum Bulletin 457, p. 57-77.

OLIVER, W.A., Jr., 1951, Middle Devonian coral beds of central New York: American Journal of Science, v. 249, p. 705-728.

PATCHEN, D.G. and DUGOLINSKY, B.K., 1979, Guidebook, Middle and Upper Devonian clastics in Central and Western New York State: U.S. Department of Energy-Eastern Gas Shales Project; West Virginia Geological and Economic Survey, 170 p.

RAISWELL, R., 1971, The growth of Cambrian and Liassic concretions: Sedimentology, v. 17, p. 147-171.

RAISWELL, R., 1976, The microbial formation of carbonate concretions in the upper Lias of England: Chemical Geology, v. 18, p. 227-244.

RICKARD, L.V., 1975, Correlation of the Silurian and Devonian rocks of New York State, Map Chart Series New York State Museum and Science Service, v. 24, 16 p., 4 charts.

RICKARD, L.V., 1981, The Devonian System of New York State, in, OLIVER, W.A., Jr. and KLAPPER, G., eds., Devonian Biostratigraphy of New York, Part 1: International Union of Geological Sciences, Subcommission on Devonian Stratigraphy, Washington, D.C., p. 5-22.

SAVARESE, M.L., GRAY, L.M. and BRETT, C.E., 1986, Faunal and lithologic cyclicity in the Centerfield member (Middle Devonian: Hamilton Group of western New York): a reinterpretation of depositional history, in, BRETT, C.E., ed., Dynamic Stratigraphy of Depositional Environments of the Hamilton Group (Middle Devonian) of New York State, Pt. I: New York State Museum Bulletin 457, p. 78-101.

SELLECK, B., 1983, Cyclic shallowing-upward sequences in the Hamilton Group of central New York: Geological Society of America Abstracts with Programs, v. 15, p. 70.

SMITH, B., 1935, Geology and mineral resources of the Skaneateles Quadrangle: New York State Museum Bulletin 300, 120 p.

WEEKS, L.G., 1957, Origin of carbonate concretions in shales, Magdalena Valley, Colombia: Geological Society of America Bulletin, v. 68, p. 95-102.

WOODROW, D.L., 1983, Topography and sedimentary processes in an epicontinental sea, in, STANLEY, D.J. and MOORE, G.T., eds., The Shelfbreak: Critical Interface on Continental Margins: Special Publication Society of Economic Paleontologists Mineralogists, v 33, p. 159-166.

WYGANT, G.T., 1986, Deposition and early diagenesis of a Middle Devonian marine shale: Ludlowville Formation, western New York, in, BRETT, C.E., ed., Dynamic Stratigraphy and Depositional Environments of the Hamilton Group (Middle Devonian) of New York State, Pt. I: New York State Museum Bulletin 457.

ZELL, P.D., 1986, Stratigraphy of the Middle Devonian Moscow Formation in the Chenango Valley, New York: Geological Society of America Abstracts with Programs, v. 18, p. 77.

ROAD LOG FOR LUDLOWVILLE FACIES FIELD TRIP

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Begin road log at junction of NY Route 34 and NY Route 13, at south end of Cayuga Lake in Ithaca. Turn right (north) on Route 34.
1.0	0.5-1.0	Climbing long upgrade on Route 34; note intermittent exposures of latest Middle Devonian Sherburne Siltstone (Genesee Formation); grade is nearly on dip slope of south limb of Fir Tree anticline.
3.25	2.25	Upper end of Shurger Glen.
4.3	1.0	South Lansing; junction Route 34/Route 34B; turn left (northwest) onto Route 34B.
5.0	0.69	Junction Portland Point Road on left (stop 3 is at end of this road); proceed north on Route 34B.
5.2	0.2	Leave town of South Lansing; top of hill
6.0	0.8	Road to Meyers Point at base of long hill.
6.2	0.2	Cross Salmon Creek (original Ludlowville type section).
7.0	0.8	Road to Ludlowville on right.
7.4	0.4	Top of hill above Salmon Creek Valley.
10.3	2.9	Lansing Fire Station.
12.15	1.85	Cross Lake Point ravine.
16.05	3.9	Junction Route 34B/NY Route 90; turn left (west).
17.05	1.0	Jump Corners; junction Route 90 and Clearview Road; turn left onto Clearview Road south of Triangle Diner (90 curves to right).
17.25	0.2	Intersection of Clearview Road with Lake Road; go straight on Clearview.
17.55	0.3	Cross upper King Ferry Creek (which exposes Genesee Formation).

18.25	0.7	Feedlot on left shows exposures of Tully Limestone
18.70	0.45	Sharp bend in Clearview Road.
18.75	0.05	Cayuga Lake shore; junction with lakeshore access road; turn right (north) and proceed (slowly) north. Narrow dirt road follows an old railroad bed along the lakeshore; it is bordered on the shore side by a row of cottages and on the other side by bluffs of Ludlowville shale (and outhouses!).
18.95	0.2	Small gully exposes lower Wanakah (equivalent to type King Ferry Member of Cooper, 1930); from here onward there are intermittent joint face exposures of the lower Wanakah.
19.15	0.2	Small gully; lenses of concretionary, fossil-rich mudstone are visible in wall.
19.25	0.1	More fossil-rich lenses visible in weathered joint face.
19.40	0.15	Stop and park at "Dead End" sign just south of Elmwood Point, for stop 1A.

STOP 1 KING FERRY STATION

Locality: Exposure along lake shore road extending from Elmwood Point, 1.6 miles south to near Cats Elbow Point, King Ferry Station, Cayuga Co., N.Y. (Sheldrake 7.5' Quadrangle).

References: Cooper (1930).

General Description: The south-dipping strata along the Cayuga Lake shore bluffs at King Ferry Station display the complete Wanakah Member (King Ferry Member of Cooper, 1930, in part), which is here somewhat over 30 meters thick (Fig. 8), over a lateral distance of about 1.6 miles. The Spafford and Owasco Members, comprising the uppermost 11 meters of the Ludlowville Formation are exposed at the southern end of this road near Cats Elbow Creek (Stop 1C). The King Ferry locality is the most basinward, and thickest of the sections being examined on this fieldtrip. A progressive northwest transition to an even thicker sequence of poorly fossiliferous, bioturbated, silty shales can be observed along the western margin of Cayuga Lake, as at Big Hollow Creek.

STOP 1A ELMWOOD POINT

Upper Ledyard Member.-- At section 1A we will examine the lower contact of the Wanakah shale at the base of a bed which we here designate the Elmwood Point bed for this locality. The uppermost two meters of the Ledyard Member can be seen below the Elmwood Point bed; the upper contact forms a prominent notch in the bank. These dark grey to nearly black shales contain common diminutive brachiopods (juvenile? Tropidoleptus, Truncalosia, Ambocoelia), nuculid and Modiomorpha bivalves, orthoconic nautiloids, and Phacops trilobites concentrated on thin bedding plane horizons. This characteristic biofacies, occupying the identical stratigraphic position, can be traced to the west as far as Lake Erie without significant change. A harder, more calcareous bed, about 0.5 meters below the contact, contains a somewhat richer fauna, including the brachiopod Athyris, which is absent to the west, and gives the first hint of facies change which becomes increasingly apparent to the east and southeast, as at Cascade (Stop 2).

Wanakah ("King Ferry") Member.

The base of this member is marked by the very widespread, mollusk-dominated Elmwood Point Bed (equivalent to the Mt. Vernon bed or "Strophalosia" bed; Grabau, 1898-1899; Cooper, 1930), which, at this locality, remains nearly unchanged from its appearance in western New York except for the common occurrence of the brachiopod Mucospirifer and the absence of Truncalosia ("Strophalosia"). A major coarsening-upward cycle, about 18 meters thick, overlying this stratigraphic marker bed, begins with dark grey silty shales and culminates in massive, fretted, Zoophycos-burrowed siltstone. This cycle can be subdivided into three subtle subcycles. The lowest is only about 1.5 meters thick. It consists of dark grey, sparsely fossiliferous shale,at the base, which grades upward into poorly fissile, burrowed, grey silty shales (Fig. 8).

This sequence is overlain by about 3 m of slightly harder silty mudstone, with numerous thin siltstone layers, and a moderately diverse assemblage of brachiopods, including large Spinocyrtia, Cypricardella and Modiomorpha bivalves, trilobites, and the small discoidal tabulate coral Pleurodictyum. Fossils tend to occur in local lenticular (pod-like), somewhat concretionary-aggregates which are visible along a weathered joint face just south of a bridge over a small gully about, 0.1 miles south of the parking area. These pods are interpreted as primary skeletal accumulations which have been enhanced by early diagenesis. Several fossil bands and pods here appear to have been terminated by silty tempestites. The abundance of siltstones in this portion of the section suggests a shallow water position, above storm wave base. These beds are the equivalent of the Pleurodictyum "zone" that can be traced to Lake Erie (Grabau, 1898, 1899; Cooper, 1930).

At Romulus, on the northwest side of Cayuga Lake, this same interval expands to a 4.5 meter-thick, coarsening-upward subcycle of dark grey silty shale with a sparse fauna of nuculids and Cardiola bivalves, orthoconic cephalopods, and small brachiopods and capped by Pleurodictyum-bearing beds.

		Return to vehicles and reverse route back to Clearview Road.
20.05	0.65	Junction Clearview Road; continue south on the lakeshore road to STOPS 1B and 1C.

20.1	.05	Cross King Ferry Creek; first outcrop south of the creek; shale here is about 6 m above the top of STOP 1A; a biostrome of rhomboporid and fenestellid bryozoans occurs here just above a thin siltstone, capping a second subcycle.
20.4	0.3	Pull off on wide area on left side of road adjacent to shale bank for STOP 1B.

STOP 1B KING FERRY STATION (SOUTH)

This bluff section displays the top of the lower Wanakah (Aurora submember) major cycle, which here forms a distinct bluff of massive siltstone; this unit shows a sharp upper platform because it is abruptly overlain by softer shale. The upper meter of the siltstone contains large spheroidal concretions associated with two lenticular, fossil-rich layers; the upper one, about 70 cm below the upper bench, contains the large rugose corals Heliophyllum and Cystiphylloides, together with a diverse assemblage of large bivalves, brachiopods, and bryozoans (Fig. 8). This appears to record maximal shallowing within the entire Wanakah. Winnowing and bypass of fine-grained-sediments produced a relatively clean, coarse-silt substrate which favored sporadic colonization by large corals.

An irregular, dense coquinite of brachiopods and Stereolasma corals immediately overlies the prominent siltstone bench and shows a hint of a minor coarsening upward cycle about 50 cm above that bench. This interval, here termed the Ensenore Ravine shell bed, is believed to

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Figure 8.--King Ferry Station Section. Note subtle development of shallowing subcycles, seen mainly in faunal change and upward coarsening from mudstone to silty mudstone or siltstone. This Ludlowville sequence is divisible into six sedimentary packages, corresponding to key divisions elsewhere (see text); these are: 1, Ledyard Member; 2, the lower Wanakah (Aurora Submember) which is equivalent to the Darien Center Submember (Mt. Vernon Bed to Murder Creek Bed interval; including the "Pleurodictyum zone" and "trilobite beds" of Grabau, 1899) in western New York; 3, short interval in the medial Wanakah capped by the Barnum bed of the central Finger Lakes region (see Baird, 1981); 4, overlying cycle capped by siltstone bed correlative with the Mack Creek bed; 5, upper Wanakah siltstone division; capped by the Bloomer bed; 6, coarsening-upward cycle of Spafford Shale Member. Numbered beds include: a, Elmwood Point shell bed; b, silty interval with lenticular fossil layers; c, Rhombopora-rich beds, overlying coarsening-upward subcycle; d, siltstone division of Aurora Submember with large rugose corals and large iron-stained concretions; e, Barnum bed; f, Mack Creek bed; g, Bloomer Creek bed interval; h, shaley bed with rich Jaycox-like fauna; i, sub-Moscow regional disconformity; j, Portland Point Member.

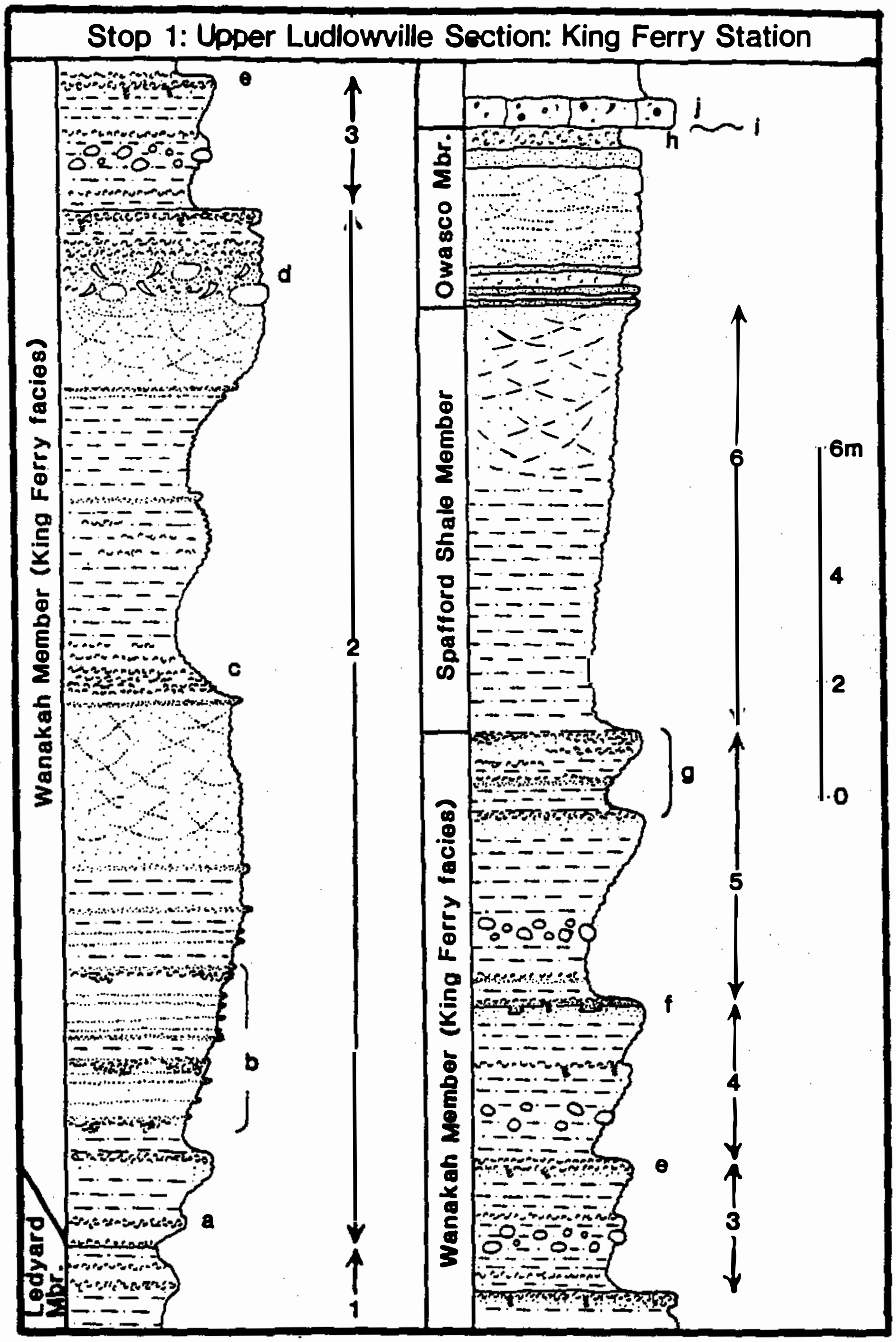

Figure 8.--King Ferry Station Section: See facing page for caption.

correlate with Grabau's (1898-1899) lower trilobite bed (Murder Creek bed of Kloc, 1983) in western New York, with which it bears striking faunal similarity.

Three other major coarsening-upward cycles, each with minor subcycles, occur within the remaining 9.5 m of the Wanakah Member (Fig. 8). The lowest of these sequences will be examined by walking about 0.15 miles south of the parking area. Each subcycle has a well developed interval of irregular, commonly rust-stained concretions near its base and is capped by a thin, silty brachiopod-dominated coquinite. These coquinites display scoured bases with pods or gutter casts and nested stacks of convex-upward shells.

The lower shell cap bed can be correlated with the Barnum Creek bed, the upper thick coquinites with the Bloomer Creek bed, both of which become subtle, but widespread, shale-on-shale, hiatus concretion horizons to the northwest (Baird 1981; Baird and Brett, 1981).

The middle shell bed level is capped by a 2-4 cm thick cross laminated siltstone which is traceable to the west side of Cayuga Lake as the Mack Creek turbidite (Baird, 1981).

Return to vehicles and continue south along the lake road.

20.6	0.2	Cross Cats Elbow Creek, which exposes a section of the Wanakah with overlying units.
20.65	0.05	Yellow 10 mph signpost; note excellent exposure of the Mack Creek turbidite siltstone.
20.85	0.2	Cross unnamed creek.
21.00	0.15	End of road; pull off in parking area and walk to shale bank behind cottages for STOP 1C.

STOP 1C CATS ELBOW POINT (SOUTH)

This bank provides an excellent view of the top of the Wanakah Member, here a sharp contact at the top of a 30 cm-thick, shell-rich argillaceous limestone, the Bloomer Creek bed. This bed caps a second prominent shallowing cycle in the upper Wanakah Shale; mimicking the Ensenore Ravine bed seen at STOP 1B; like the Ensenore bed the Bloomer bed contains a highly diverse brachiopod, bivalve, bryozoan assemblage with scattered large corals (Fig. 8). It correlates with a very shell-rich interval that is also traceable to Lake Erie (the <u>Stictopora</u> - <u>Demissa</u> zone of Grabau, 1898-1899; Blasdell beds of Kloc, 1983).

The Bloomer bed is sharply overlain by sparsely fossiliferous, dark grey shale of the lower Spafford Member. These shales coarsen upward into silty mudstone and siltstone, visible in the upper portion of this cliff section. Upper beds are 10 to 30 cm-thick, blocky, brownish-weathering, laminated siltstones with large concretions closely resembling the capping beds of the lower Wanakah (Aurora) cycle. This interval appears to be the northwestern equivalent of Smith's (1935) Owasco Member. It is separated from the Tichenor limestone in Cats Elbow Creek by about 40 cm of bluish grey mudstone with a very diverse fauna resembling the Jaycox Member west of Cayuga Lake. This section is critical in establishing a link between the lower Jaycox Member and the Owasco Member.

SYNOPSIS OF STOPS 1A - 1C.

In summary, this sequence of outcrops reveals the beginnings of a change within the upper Ludloville Formation from uniform dark grey to black shale with thin shell beds to a series of asymmetrical, shallowing-upward, muddy siltstone cycles and subcycles. In ascending order these cycles and their capping shelly or silty beds are: A) upper Ledyard: Elmwood Point bed; B) lower Wanakah (Darien Center- Aurora submember): Ensenore Ravine bed (and including three subtle subcycles); C) lower-middle Wanakah: Barnum Creek bed; D) middle Wanakah: Mack Creek bed; E) upper Wanakah: Bloomer Creek bed; F) Spafford Member: Owasco Siltstone. Most of these cycles are traceable, at least in western and central New York State, and appear to record allocyclic fluctuations in relative sea level.

		Reverse route and return to Clearview Road.
22.0	1.0	Junction Clearview Road; turn right (east) and retrace route uphill.
23.55	1.55	Triangle Diner and Jump Corners; proceed straight (gentle right) onto Route 90 east.
24.5	1.0	Town of King Ferry. Junction Route 90/Route 34B; proceed straight on Route 90.
25.8	1.3	Cross Little Salmon Creek.
27.6	1.8	Town of Genoa; cross Salmon Creek.
28.1	0.5	Junction Route 90/Route 34.
30.7	2.6	Junction Pine Hollow Road, Route 90 bends to the right. Go straight (gentle left) onto Pine Hollow Road.
31.9	1.2	Overlook into Owasco Valley.
33.3	1.4	Junction Route 90/Route 38, turn left (north) onto Route 38.
33.8	0.5	Cross Owasco Inlet Creek.
36.0	2.2	Fillmore Glen State Park on right.

36.1	0.1	Town of Moravia.
37.0	0.9	Junction of Route 38/38A; turn left staying on Route 38.
37.4	0.4	Cross Owasco Inlet.
40.3	2.9	Minor Otisco shale outcrop.
40.9	0.6	Town of Cascade; pull off on shoulder opposite road cut at junction of small side road and Route 38. Cautiously cross the highway for STOP 2A.

STOP 2. CASCADE; ROUTE 38 ROADCUT

Locality: Long roadcut along west side of N.Y. Route 38, on the west side of Owasco Lake Valley, town of Cascade, Cayuga Co., N.Y. (Moravia 7.5' Quadrangle).

Reference: Baird (1979).

Description: This roadcut provides an excellent exposure of the entire upper Ludlowville section from the upper Otisco Member through the Tichenor Limestone (Fig. 9). Most striking at this location is the clearly developed repetitive sequence of coarsening-upward cycles, capped by very diverse brachiopod-bivalve coquinites. These easily accessible beds, with extensive bedding plane exposures, are ideal for collecting a nearly complete suite of Hamilton fossils. The hierarchical pattern of subcyclic units is also very well displayed, here as are the iron-stained, concretionary intervals occurring toward the bases of the major coarsening upward cycles.

STOP 2A ROUTE 38 ROADCUT, CASCADE (LOWER)

Otisco Member and Elmwood Point Bed

The upper Ledyard Member-equivalent, here designated as upper Otisco Member, has changed noticeably in both litho- and biofacies, from dark, small brachiopod and mollusk-dominated shales seen at King Ferry to medium grey brachiopod-rich, silty shales here. Abundant *Mucrospirifer* and *Athyris* are associated with the bivalves *Cypricardella* and *Modiomorpha*, together with the more typical upper Ledyard nuculid bivalve-diminutive *Tropidoleptus* fauna.

The Elmwood Point bed can be seen at the top of the exposure along a side road intersecting Route 38. It is represented by a silty coquinite layer, up to 10 cm thick, with an irregular base (Fig. 9), which contains a moderately diverse assemblage dominated by the brachiopods *Mucrospirifer*, *Mediospirifer* and *Athyris* with associated strophomenid brachiopods and pterioid bivalves. The striking change from its appearance at King Ferry may be due, in part, to the condensation of the lowest, thin subcycle present at King Ferry onto the Elmwood Point bed continuing the eastward thinning trend from northwestern Cayuga Lake (Big Hollow Creek).

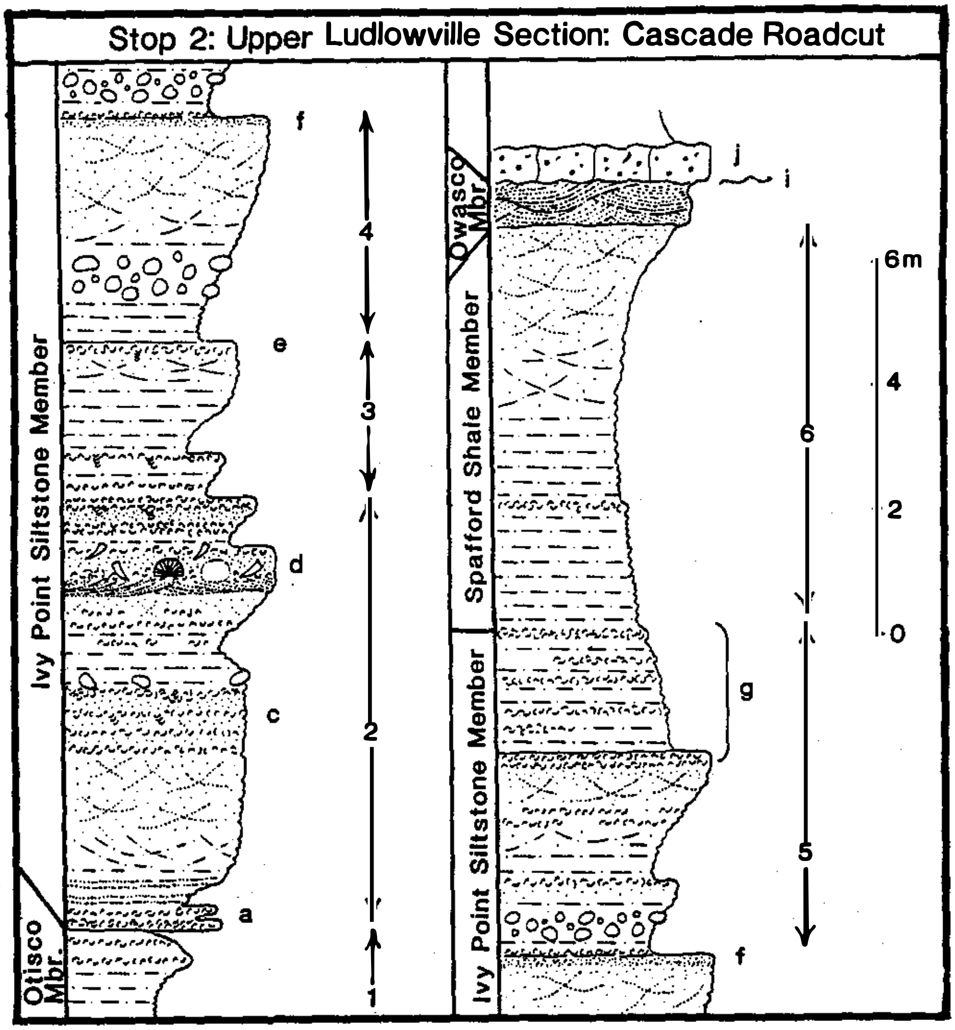

FIGURE 9.--Route 38 roadcut at Cascade. Note distinct upward-coarsening mudstone-to-siltstone cycles, capped by shell beds; also note distinct thinning of the lower Wanakah/Ivy Point interval as compared to that at King Ferry. Numbered intervals include: 1, Otisco Member; 2, lower Ivy Point/Wanakah (Aurora Submember); 3, short interval in the medial Ivy Point/Wanakah capped by the Barnum bed of the Central Finger Lakes region (see Baird, 1981); 4, overlying cycle capped by siltstone bed correlative with the Mack Creek bed; 5, upper Ivy Point/Wanakah siltstone division; capped by the Bloomer bed; 6, coarsening upward cycle of Spafford Shale Member. Numbered beds include: a, Elmwood Point shell bed; c, brachiopod-rich shell layers corresponding to Rhombopora-rich beds at King Ferry; d, siltstone division of Aurora Submember with large rugose corals and the hemispherical tabulate Favosites hamiltoniae; e, Barnum Creek bed; f, Mack Creek bed; g, Bloomer Creek bed interval; i, sub-Moscow regional disconformity; j, Portland Point Member.

41.3	0.4	Reboard vehicles and proceed uphill for 0.4 miles; prepare to make a u-turn across Route 38, at crest of hill; roadcut on west side of road is in upper Ludlowville and overlying Tichenor ("Portland Point") interval; reverse route downhill (south) for 0.2 miles.
41.5	0.2	Pull off along Route 38 at point opposite a small creek gully, disembark for STOP 2B.

STOP 2B ROUTE 38 ROADCUT, CASCADE (UPPER)

Wanakah/Ivy Point Member

This interval is dominantly muddy siltstone and is, thus, intermediate between the typical Wanakah and Ivy Point Members. Above the Elmwood Point bed the major lower cycle has both coarsened and thinned markedly to the east, being only about 7.5 meters thick at Cascade compared to over 17 meters at King Ferry (compare Figs. 8 and 9). This illustrates well our observation that sediment packages thicken basinward due to the rapid dumping of finer grained sediments bypassed from more proximal, wave swept environments.

Subcyclicity within the major lower cycle is more pronounced here than at either King Ferry or Portland Point (STOPS 1, 3). The lowest subcycle comprises 4-meters of highly bioturbated and sparsely fossiliferous silty mudstone contains several irregular, poddy fossil layers with a large brachiopod-bivalve fauna (including: Mucrospirifer, Mediospirifer, Athyris, Spinocyrtia, Protoleptostrophia, Tropidoleptus, Modiomorpha, Cypricardella, and Actinopteria). These beds likely correlate with the rhomboporid-rich interval at King Ferry. Above this is a 2-meter thick subcycle which coarsens upward into massive, locally hummocky cross stratified, coarse siltstone, indicating shallowing into normal wave base. Two prominent coraliferous horizons are present within the coarse upper unit which contain Cystiphylloides, Heliophyllum, and large hemispherical colonies of Favosites hamiltoniae. Certain of the solitary rugose corals show evidence of corrosion and reworking. This is clearly equivalent to the coral-bearing cap of the lower cycle at King Ferry. A thin (<1 meter) subcycle follows which is capped by a thin dense coquinite with an extremely diverse fauna. This bed is believed to be equivalent with the Ensenore bed which forms a prominent cap to the major lower cycle to the west as far as Sheldrake Creek on the west shore of Cayuga Lake.

The cycles capped by the Barnum, Mack, and Bloomer Creek beds are all siltier and more prominent than at King Ferry. Unlike the major cycle below, their thicknesses show little change from King Ferry; and the upper two cycles are even somewhat thicker. Most subcycles continue to be recognizable, and the upper two concretionary intervals are well developed. Abundant pyritized burrow tubes occur below the Barnum bed in a position analogous to the concretionary interval at King Ferry. The most easily identified interval in this cut is the rust-stained concretionary horizon below the Bloomer Creek shell bed. Each of the capping shell beds contains a diverse fauna, dominated by Athyris or Mucrospirifer.

Spafford Member and Owasco Members

The upper part of the Route 38 roadcut, near the crest of the hill, exposes the upper members of the Ludlowville Formation, and its contact with the overlying Moscow Formation (Fig. 9). The Bloomer bed at the top of the Wanakah/Ivy Point Member is not sharply defined but is represented by a series of closely spaced, discontinuous fossil coquinites with a very rich and diverse fauna, characterized by Athyris, Spinocyrtia, Pseodoatrypa, and Strophodonta demissa; these beds are considered to mark the top of the Ivy Point Member. The overlying the Spafford Shale Member is somewhat thinner than at King Ferry and contains a more diverse fauna, particularly typified by chonetid brachiopods and Tropidoleptus. The overlying Owasco Member displays marked coarsening and thinning due to the erosional truncation of the upper siltstones and Jaycox-like fossiliferous shales. We interpret this as the result of south-eastward downward cutting of the Tichenor Limestone Member which comes to rest directly on the Spafford at Portland Point. The Owasco shows distinctly more proximal facies than at King Ferry with Allanella-rich, sandy layers and hummocky cross-stratification.

The highest unit exposed in this part of the roadcut is the "Portland Point" Member; the Tichenor Limestone-equivalent is a coarse, crinoidal, coral rich packstone or grainstone. This unit is now considered to form the base of the Moscow Formation (Baird, 1979).

		Walk back downhill to vehicles; reboard and continue southward on Route 38.
46.7	5.2	Moravia. Turn right to follow Route 38; continue south.
50.45	3.75	Town of Locke; Junction Route 90 turn left (southwest) onto 90.
51.75	1.3	Junction road to West Groton; stay on Route 90.
51.95	0.4	Y-junction of Route 90 and Lamphier Road, North Lansing; turn left (west) on Lamphier Road; name changes to Lane Road.
54.7	2.8	Junction Route 34, town of North Lansing; turn left (south) on combined Route 34-34B.
61.25	6.65	Route 34 bends sharply to the right (west)
62.25	1.0	Junction Route 34/34B; turn right (north) onto Route 34B.

62.9	0.7	Junction road to Portland Point; turn left (west) onto Portland Point Road.
63.4	0.45	Entrance to Portland Point Quarry (in Tully Limestone) on left.
63.5	0.1	Pulloff on right is next to Minnegar Falls over Tully Limestone.
63.8	0.3	Pit in dark lower Windom Shale on left.
64.0	0.2	Cargill Salt Company mine on right; small Ludlowville outcrop on left.
64.25	0.25	Low outcrops of Ludlowville (upper Ivy Point) on left; pull off in parking area on right, just before white-painted building north of abandoned cement plant, for STOP 6. Proceed on foot from parking area to railroad track just below (west of) the road; walk northwest along railroad track for about 0.1 miles to large roadcuts at STOP 3A.

STOP 3A PORTLAND POINT; NORTHERN RAILROAD CUT

Locality: Exposures on railroad cut along east-shore of Cayuga Lake between Cargill Salt Company and abandoned cement plant, 0.1 to 0.3 km north of Portland Point, town of Lansing, Tompkins Co., N.Y. (Ludlowville 7.5' Quadrangle).

Reference: Patchen and Dugolinski (1979).

Description: This weathered railroad cut exposes about 12 m (40') of the lower Ivy Point Member and the underlying upper Otisco Shale Member near the crest of the east-west trending Fir Tree Anticline (Fig. 10). These are the oldest units exposed at the axis of this fold. This section and that in the adjacent mouth of Shurger Glen afford a direct look at facies far south of the normal east-west outcrop belt some 10 to 15 miles to the north of this area. The southward Ludlowville facies change (distinct coarsening of beds with pervasive shoreward biofacies transitions) along the Cayuga Valley clearly mirrors the eastward facies changes from the Aurora-King Ferry area to the Skaneateles Valley, and we use the terminology that Smith (1935) proposed for the Ludlowville Formation in the Skaneateles Valley in describing the section at Portland Point.

Otisco Shale Member

About 5 m of the upper Otisco Member consists of medium grey, highly fossiliferous, soft silty shale. Shell beds, especially near the top, yield abundant brachiopods, particularly *Athyris*, *Tropidoleptus*, *Spinocyrtia*, small bryozoans, and the rugose coral *Stereolasma*.

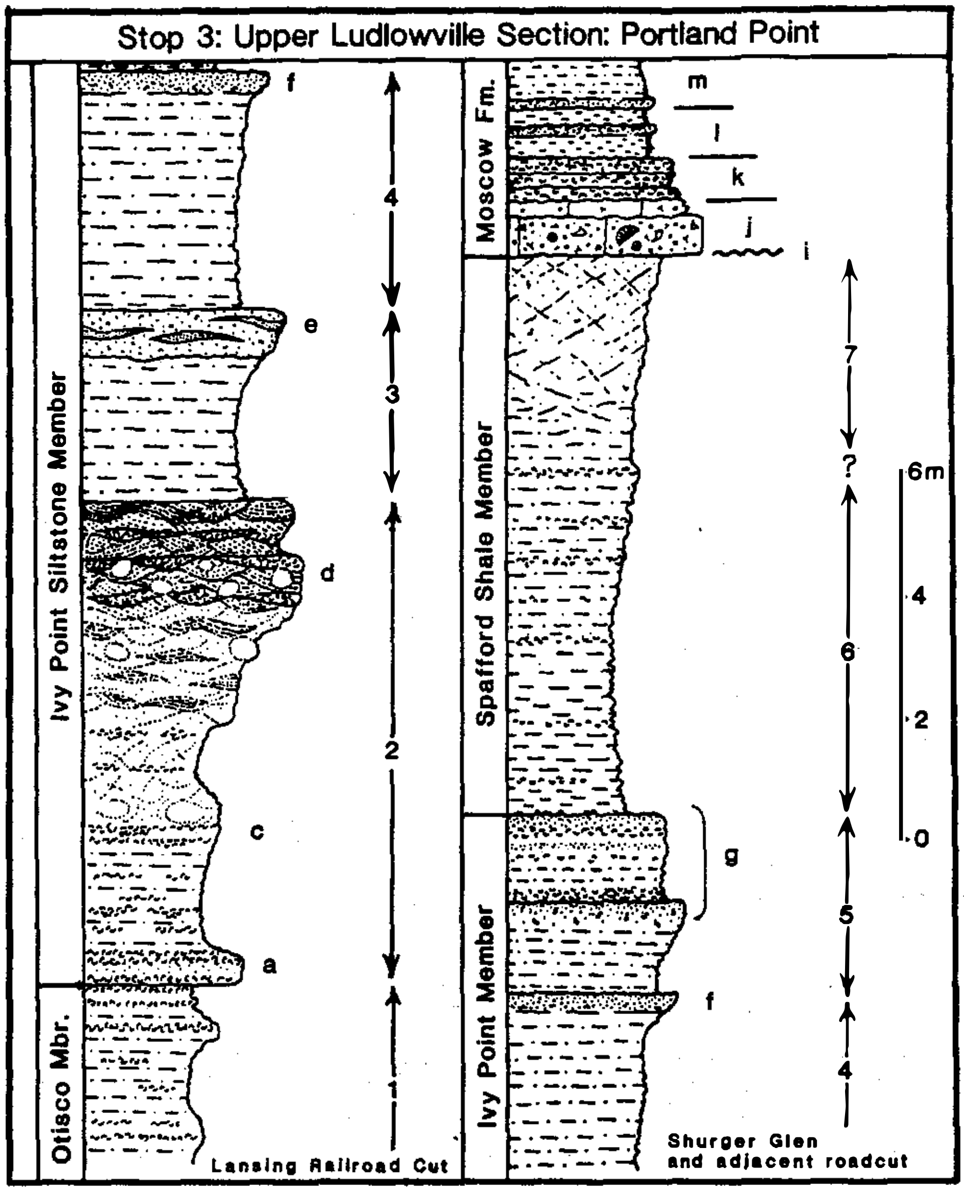

FIGURE 10.--Portland Point Ludlowville section at crest of Fir Tree anticline. Ludlowville stratigraphic terminology adapted from Smith, (1935). Note prominent development of regressive hemicycles capped by discontinuities and/or winnowed, condensed beds; also note that the upper beds of the lower Ivy Point tongue (interval d, equivalent to the coral-bearing upper beds at King Ferry and Cascade) is marked by hummocky cross-stratification, large concretions and coquinites of Allanella tullius. Based on faunal content, the upper part of the Spafford appears to match with the lowermost Jaycox Member in western New York and with beds immediately beneath the Owasco Sandstone in the Owasco to Tully Valley region. The Portland Point Member (j) rests directly on the Spafford, and is overlain by: k, the Rhipidomella-Centronella ("R-C") Bed of Kashong Shale Member; l, the upper Kashong beds including phosphatic pebble layer (see Baird, 1978, 1979); and m, the Windom Shale Member. (For explanation of other symbols see Figure 9).

Ivy Point Siltstone Member

The upper boundary of the Otisco shales with the Ivy Point can be located at the base of a distinctive 65-70 cm (2.1 ft.)-thick silty ledge that contains abundant large brachiopods and bivalves. This unit is the Elmwood Point bed noted at both previous stops. Here the bed contains large brachiopods, such as Spinocyrtia, and rugose corals; hence, in comparing the three sections, this bed displays a gradient of increasing diversity and a change from ambocoeliid to Athyris to Spinocyrtia biofacies. This bed apparently formed by sediment condensation along a paleoslope and thus it provides a natural transect of paleocommunities.

Above the Elmwood Point bed is an 8 meter- (26 ft.)-thick major coarsening-upward cycle which we term the lower siltstone tongue of the Ivy Point Member. It is clearly the interval equivalent of the lower Wanakah (or Aurora submember) cycle seen at Stops 1 and 2, but it is very distinctly coarser-grained. This sequence weathers with a distinctly recessed area near the base, where softer mudstone deposits overlie the Elmwood Point bed (Fig. 10). A remnant of the cap of the middle subcycle at King Ferry Station can still be recognized in several thin, Mucrospirifer- and Tropidoleptus-dominated shell beds associated with subconcretionary pods. Higher units include massive Zoophycos-churned silty mudstones; these, in turn, grade upward into laminated coarse siltstone, displaying evidence of local channeling.

The upper portion of the lower Ivy Point cycle consists of hummocky cross-stratified coarse siltstone and fine sandstone. Joint surfaces in the intensely bioturbated siltstone display a distinctive "fretwork"-type of differential weathering, controlled to some extent by textural and/or compositional differences between sediment within-and surrounding Zoophycos spreiten. Several layers of shell coquinite, composed mainly of the brachiopods "Allanella" tullius, Camarotoechia and minor shell hash, are visible near the top (Fig. 10). Large (up to 0.5 m diameter) calcareous concretions occur within a prominent 1.0 m thick, massive, buff-weathering coarse siltstone bed. This coarse bed caps the major regressive cycle and it is correlative with the coral-bearing siltstone bed at the top of the lower Wanakah cycle at King Ferry and Cascade (STOPS 1, 2); however, no corals have been found here, probably because this facies represents too unstable an environment. A meter-thick uppermost subcycle overlying the concretionary bed displays abundant fossil debris (mainly Allanella, Tropidoleptus, and Mucrospirifer) and is probably equivalent to the Ensenore Ravine bed; this subcycle is also capped by a coarse, slightly concretionary siltstone. Finally, this unit is overlain by softer grey and sparsely fossiliferous shale which grades upward, over about two meters, into another siltstone, probably the Barnum bed-equivalent.

Above the railroad cut, along the access road to Portland Point, a higher, but somewhat similar coarsening-upward cycle marks the position of the upper siltstone tongue of the Ivy Point Member, of Smith's (1935) terminology. This upper bench is capped by about half a meter of extremely shell-rich mudstone with abundant brachiopods, which is clearly correlative with the Bloomer Creek shell bed.

Walk back along the railroad and cross the Portland Point road at small bridge over Gulf Creek; walk upstream along the north bank of the creek for about 100'.

STOP 3B GULF CREEK (SHURGER GLEN)

Locality: Exposures along the gorge of Gulf Creek 0.1 km east of its mouth at Portland Point, Tompkins Co., N.Y. (Ludlowville 7.5' Quadrangle).
References: Cooper (1930); Baird and Brett (1981); Patchen and Dugolinski (1979).

Description of Units: The uppermost 11 meters (36') of the Ludlowville formation are exposed below a falls capped by Tichenor Limestone; these silty shales display a peculiar curved jointing pattern in the falls face (Fig. 10).

The top of the Ivy Point (or King Ferry) exposed near stream level, displays to advantage the Bloomer Creek shell bed which consists of two to three closely-spaced coquinite layers. Fossils at this level include the abundant brachiopods (e.g. *Athyris*, *Pseudoatrypa*, *Spinocyrtia*, *Strophodonta demissa*), bivalves (e.g. *Cornellites*, *Cypricardella*, and *Modiomorpha*), several bryozoans, and echinoderms, including the grapnel-like holdfast *Ancyrocrinus* and rare edrioasteroids. About 9 meters (29') of overlying, less fossiliferous, silty mudstone with occasional layers of coquinite is equivalent to Smith's (1935) Spafford Shale Member. The highest Ludlowville member (Owasco Sandstone), if ever present here, was apparently removed by the major sub-Tichenor erosion surface.

At the cap of the falls is Cooper's (1930) "Portland Point" Limestone Member, a very thin (0.9 m), condensed interval, with a basal (Tichenor-equivalent), crinoidal packstone ledge, and a middle silty calcareous shale division, which is equivalent to the Deep Run and Menteth Members of the Moscow Formation (Baird, 1979). Overlying this unit is another shell-rich bed (*Rhipidomella*-*Centronella* or "R-C" bed of the Kashong Member). A complete Windom Shale section and falls over the Tully Limestone are observable upstream from the first waterfalls.

DISCUSSION (STOPS 3A AND 3B): The Lansing railroad cut and adjacent Gulf Creek section display pervasively silty Ludlowville deposits which have a strong similarity to the upper Ludlowville sequence in the Skaneateles Valley near Spafford; Smith's (1935) Ivy Point and Spafford successions of the Skaneateles Valley are clearly discernable here. This similarity holds both for lithofacies and biofacies. It should also be remembered that most regional facies changes, and resulting difficulties of correlation, within the Ludlowville interval are encountered within 35 km (20 mi) along the northwest-southeast trending Cayuga Valley. Sparsely fossiliferous grey shales in the lower Wanakah section at Romulus transform southeastward to sandstones at Portland Point, and black shales in the northwestern upper Wanakah sections change to shell-rich grey silty mudstone lithology in this area.

End of field trip.