

SUBMARINE EROSION ON THE DYSAEROBIC SEAFLOOR:
MIDDLE DEVONIAN CORRASIONAL DISCONFORMITIES IN THE CAYUGA VALLEY REGION

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INTRODUCTION

Many Devonian black shale units in New York and adjoining states are marked by erosional unconformities along their bases. Of particular note are distinctive lag accumulations of detrital pyrite, phosphatic debris, and bones along these discontinuity surfaces. This debris is derived from the scour of underlying units and it is often concentrated in erosional runnel-like depressions which explains the typical occurrence of this material as laterally discontinuous lenses in outcrops.

This reworked material is remarkable in that pre-formed pyrite was reworked as pyrite gravel; several lines of evidence in support of this include: similarity of reworked grains to underlying in-situ pyrite, distinctive patterns of pyrite grain breakage within lenses, and the reorientation of geopetal stalactitic pyrite. The absence of detrital carbonate allochems within debris lenses and the facies-specific association of these lenses with black shale deposits, indicate: 1, that detrital pyrite was stable on the anoxic or minimally dysaerobic sea floor; 2, that carbonate material (loose allochems on exposed limestone substrates) was prone to dissolution in these oxygen-deficient settings; and, 3, that strong episodic current activity was important in scouring the sea bed within the basin environment.

Where carbonate dissolution accompanies mechanical abrasion of the sea bed, we refer to the resultant erosion surface as a corrasional discontinuity; although this word has been used to describe several unrelated erosion processes, it has been introduced previously to describe submarine erosion by a combined process of abrasion and corrosion (see Gary et al. eds., Glossary of Geology, 1972).

We believe that discontinuities associated with black shale deposits, particularly those in the Genesee Formation, were produced by current processes operating in circumlittoral outer shelf and basin settings. Current processes probably include a significant component of deep-storm-generated turbulence, particularly on the mid- and upper basin margin slope. However, the occurrence of scour contacts and coarse debris along bases of even thin black shale deposits suggests that erosion may be

closely associated with impingement of the water mass boundary (pycnocline) with the basin margin slope. We include a discussion of the possible role of internal waves in generating these peculiar contacts and deposits during transgression events.

Black Shale Environments

A persistent myth regarding black shales is that they were deposited extremely slowly in "stagnant" settings by the gradual sedimentation of suspended sediment. Recent studies of black shale units indicate that basinal environments recorded in these deposits were more dynamic with respect to bottom circulation than the older "silled basin" model would imply. Williams and Richards (1984) note abundant evidence of current-induced graptolite alignment, as well as entrainment of silt in ripple bedforms in Ordovician black shales, a phenomenon which is also beautifully displayed in the medial Clinton Williamson Shale, an analogous Middle Silurian black shale in western New York. Likewise, Brenner and Seilacher (1978) and Kauffman (1981) cite evidence for moderate to strong (> 20 cm/sec) currents during deposition of the Jurassic Posidonia shales. Similarly, Devonian black shales in western New York display numerous levels of current-aligned, conical Styliolina shells, as well as thin beds of siltstone which contain bedforms suggestive of pervasive winnowing by bottom currents on a sediment-starved sea floor rather than turbidite deposition per se (Baird and Brett, in press). The presence of erosional unconformities and associated reworked pyrite gravel in this facies further indicates that strong currents were periodically active in this environment.

Most workers, including the present authors, interpret the Devonian black shales as offshore facies recording deposition in an intracratonic basinal setting; depth estimates for Frasnian and Famennian black shales range up to 530 meters (Lundegard, et al. 1980) but several authors favor depth ranges of 50 to 230 meters (Thayer, 1974; Broadhead, et al. 1982; Woodrow and Isley, 1983). The eastward facies spectrum from black shale, through greatly thickening turbidite wedges, into shell-rich, aerobic platform facies of the Catskill Delta Complex favors a deeper water (circumlittoral) interpretation for the black shale deposits (Thayer, 1974). Westward thinning of the Genesee deposits from 400 meters at Ithaca to 3 meters in eastern Erie County (deWitt and Colton, 1978) also indicates that black shale facies in western New York record extremely slow net deposition. The Devonian black shale sea was presumably stratified; this stratification may have produced a "silled basin" effect (e.g. model of Byers, 1977) with a strictly horizontal layering of water zones, but we feel that it may have been more a sub-horizontal, vertically-shifting pycnocline as proposed by Ettensohn and Elam (1985).

Discontinuities Flooring Black Shale Units

Discontinuities flooring black shales in New York State can be observed in the Middle Ordovician (Trenton Limestone-Utica Shale contact at several localities), the Middle Silurian Clinton Group (Sodus Shale-Williamson Shale contact in the Rochester region), and at numerous levels in

the Middle and Upper Devonian (Eifelian and Givetian) examples include the base of the Bakoven Shale Member in eastern New York (Goldring, 1943), the base of the Oatka Creek Member in western New York (this paper), the base of a black shale sequence in the medial Levanna Member in western New York, the base of the Ledyard Shale Member in the Seneca-Cayuga Valley (Brett and Baird, 1985; this paper), the base of the Genesee Formation (Taghanic Unconformity: Fig. 1) in western New York (see Brett and Baird, 1982; Baird and Brett, in press, numerous other authors), and at the base of thin black shales in the lower Genesee Formation in the Seneca Valley-Salmon Creek Valley region (Baird and Brett, 1986; this paper). Upper Devonian (Famennian) examples include the base of the Dunkirk and Cleveland black shales in western New York and Ohio, respectively (see Mausser, 1982; Baird and Brett, in press). The present field trip discussion and road log is an outgrowth of detailed studies of the Leicester Pyrite Member and two stratigraphically higher detrital pyrite occurrences within the lower part of the Genesee Formation.

Significance of the Leicester Pyrite

The Leicester project involved the study of lenses of pyritic debris (Leicester Pyrite Member) on the post-Hamilton-post-Tully (Taghanic) disconformity which separates richly-fossiliferous shales of the Upper Hamilton Windom Member (Moscow Formation) or Tully carbonates from overlying laminar black shale of the Genesee Member (lower Genesee Formation; see Fig. 1).

This erosion surface marks a hiatus which increases in magnitude westward from the Skaneateles meridian, where it is a mere omission horizon, to Lake Erie, where it is a regional disconformity below which the Tully Limestone and the upper beds of the underlying Windom Member of the Hamilton Group have been removed (Huddle, 1981; Brett and Baird, 1982). This unconformity is associated with a major eustatic transgression which began in the latest Givetian; it marks the Taghanic Onlap event in which basinal black shale deposits accumulated on variably bevelled older units (Johnson, 1970; Huddle, 1981; Johnson et al., 1985). The age of the basinal shales above the unconformity decreases westward from the Cayuga Valley to Lake Erie (Fig. 1); these beds become markedly younger into Ohio and Ontario such that up to four million years of diachroneity is revealed by conodont biostratigraphy due to regional onlap effect (Huddle, 1981; Uyeno, et al. 1982). Detailed mapping of strata within the lower Genesee Formation in western New York State corroborates biostratigraphic studies; individual beds are observed to converge and descend onto the Taghanic erosion surface as they are followed westward (Baird and Brett, 1985).

Findings from the Leicester study include the following: 1, most Leicester grains are reworked detrital pyrite; 2, Leicester pyrite lenses were deposited within the predominantly anaerobic environment recorded by the black shale; lenses are shingled within the basal few centimeters of this shale recording anywhere from one to several pyrite transport events in any given locality; 3, there is stratigraphic evidence for regional diachroneity of Leicester lenses, and, by implication, diachroneity of

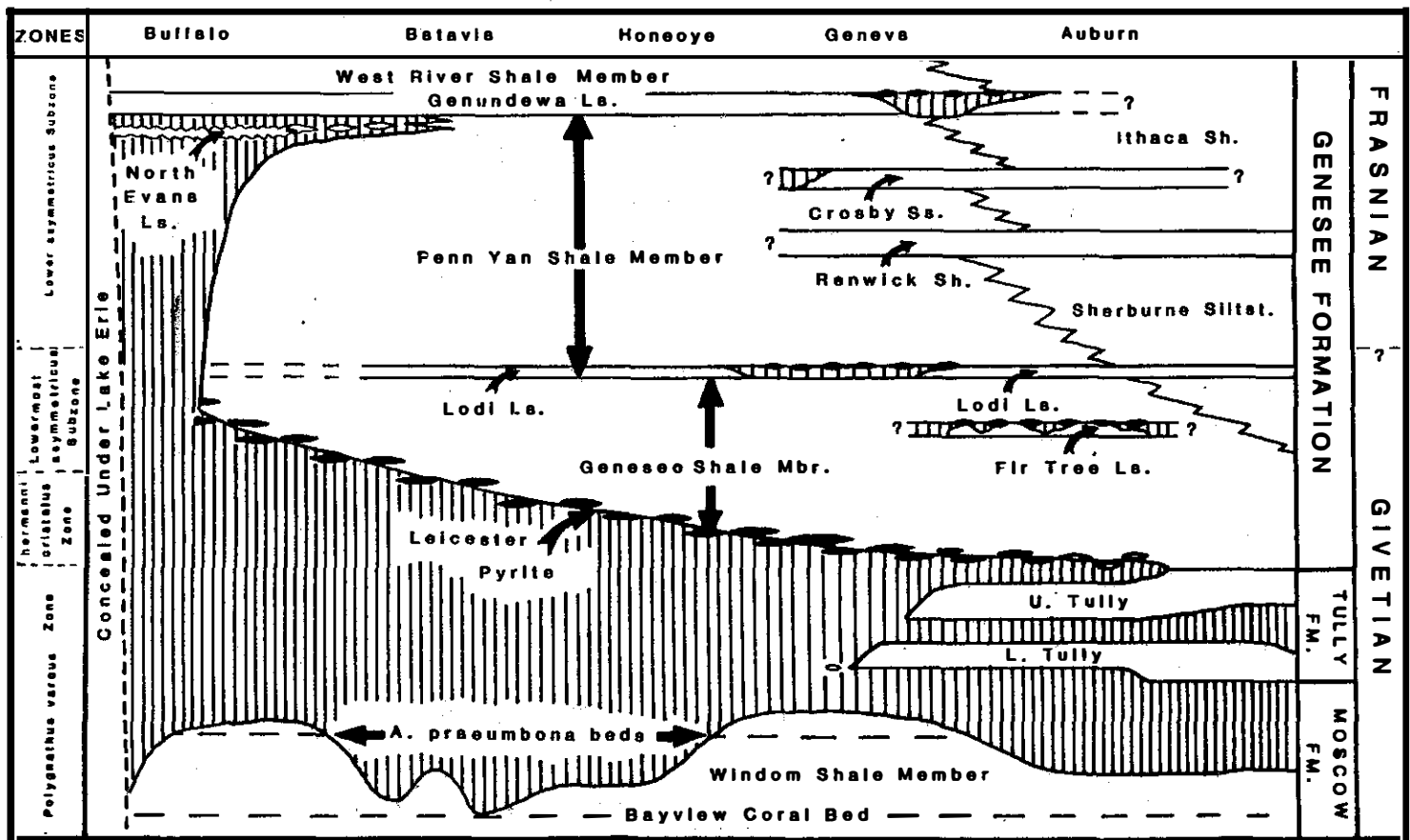


FIGURE 1.--Chronostratigraphic cross-section of lower Genesee Formation and subjacent Moscow Formation (Windom Shale Member). Note positions of the thin, and locally bevelled Fir Tree and Lodi limestone submembers. Large hiatus below the Genesee Formation marks the position of the Taghanic Unconformity; lenses of detrital Leicester Pyrite are derived from this erosion but were deposited through a long period of diachronous overlap of Genesee black muds upon this discontinuity. Based on Brett and Baird, 1982; Baird and Brett, in press, this paper.

basal Genesee muds, involved in the Taghanic Onlap event; this agrees with Huddle's (1981), biostratigraphic conclusions, summarized above (Fig. 1); and finally, 4, that the erosional process which entrained the pyrite and bones on the erosion surface was clearly an ongoing event both up to-, and even synchronous with, initial depositional onlap of Genesee black muds (Brett and Baird, 1982; Baird and Brett, 1985, in press).

Reworking of Pyrite Grains: Lines of Evidence

Examination of pyritic material within Leicester lenses and in the higher Genesee examples examined on this field trip, shows that the grains are essentially a detrital pyritic gravel breccia that was entrained and aligned by bottom currents (Fig. 2). Pyritic grains include nodules, tubular particles, and fossil steinkerns. Evidence for pyrite exhumation is fourfold. Firstly, Leicester tubular grain fragments correspond closely to in-situ pyritic burrow tubes in the underlying Windom Member. The absence of comparable pyritized lebensspuren in the Genesee black shale indicates that Leicester tubes are derived from below. Moreover, we have observed partially exhumed (upright) tubes both along the Taghanic unconformity and above two similar but younger discontinuities (post-Fir Tree and post-Lodi diastems discussed here) within the lower Genesee Formation (Fig. 2). The in-situ Windom tubes, corresponding closely to pyritized polychaete burrows described from Late Pleistocene Atlantic sediments (Thompson and Vorren, 1984), show evidence of early diagenetic pyritization in near-surface muds; Leicester tube debris was certainly pyritic at the time of erosion, up to approximately 500,000 years after its formation in Windom sediment, based on the zonal magnitude of the post-Windom hiatus.

Other types of pyritic grains in the Leicester also closely resemble those found in situ in the underlying shales. For example, reoriented, compressed, pyritic steinkerns of nautiloids in the Leicester correspond to in situ, vertically-flattened pyritic molds in the subjacent Windom (Baird and Brett, in press); in order for such molds to have been reworked, they would have to have been reinforced by diagenetic mineralization before exhumation. Leicester brachiopod and bivalve steinkerns additionally display "meniscus" collars of coarse crystalline exterior pyrite ("overpyrite") identical to those found in pyritized shells from the underlying Windom Shale. Regional species correspondence of Leicester steinkern fossils to those in successively bevelled Windom strata supports our contention that Windom-derived pyrite constitutes the bulk of Leicester grains (Brett and Baird, 1982; Baird and Brett, in press).

Secondly, pyritized steinkerns of tubes and fossils show arcuate, sharp-edged mechanical breakage surfaces, indicating that the grains were hard and brittle when broken.

Thirdly, to close any argument that Leicester grains may have been diagenetically altered to pyrite from a different earlier mineral, we document reorientation of early diagenetic geopetal pyritic stalactites identical to those described by Hudson (1982). We observe vertical

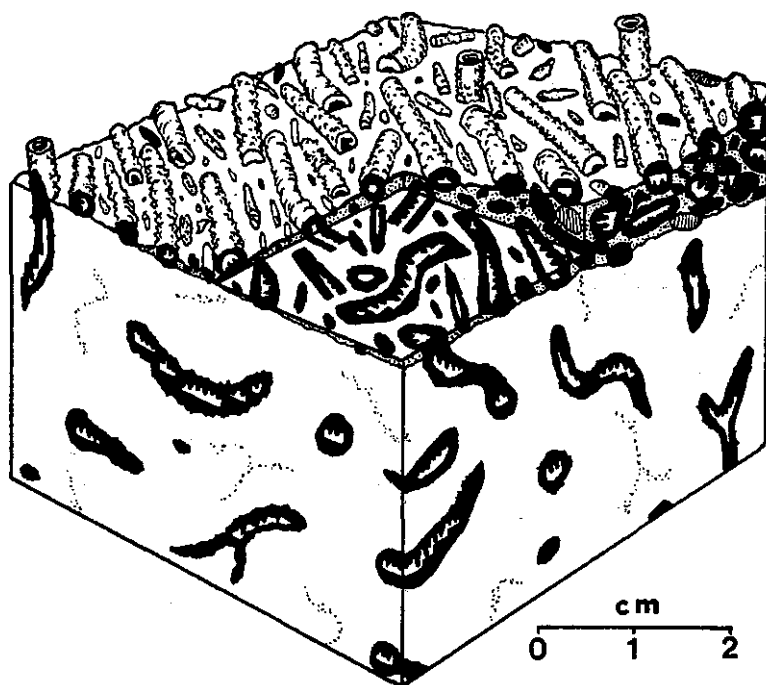


FIGURE 2.--Reorientation of pyritic geopetal structures on top Lodi discontinuity: schematic reconstruction. Note random attitudes of reworked burrow tubes above discontinuity.

stalactites within interior axial voids of in-situ pyritic burrow tubes below both the Leicester and a younger reworked pyrite accumulation associated with the Lodi Limestone Bed, higher in the Genesee Formation (this paper); tube fragments in the overlying lenses show stalactites in random orientations (Fig. 2).

Dissolution of Calcareous Grains

Pyritic lenses, conversely, generally show complete absence of calcareous grains associated with the pyrite although fish bones, phosphatic orbiculoid fragments, and conodont debris are typically abundant. Although the Leicester pyrite regionally oversteps the Tully Limestone as well as numerous underlying Windom concretion and shell beds, calcareous clasts are rare in lenses (Brett and Baird, 1982).

We hold that Leicester calcareous debris material underwent dissolution on the oxygen-deficient sea floor following exhumation. Where we observe occasional calcareous grains in lenses, they are almost always badly corroded. Examination of debris on the younger (basal Genesee) North Evans discontinuity (medial Genesee Formation; Fig. 1)) adds further support to our contention; where reworked debris is overlain by a limestone (Genesee Member) it is calcareous, but where a black shale

unit intervenes between the debris layer and the limestone, the reworked material changes laterally from a continuous blanket of pelmatozoan and hiatus-concretion debris to a thin, discontinuous deposit, rich in both nodular and tubular pyrite. This pattern suggests that the pyritic beds are chemical residues of a far greater volume of reworked material. Thus, Leicester, and analogous pyritic deposits are the chemical reverse of normal detrital carbonate accumulations; in aerobic settings, carbonate is stable but pyrite will oxidize and disintegrate. In the basinal settings discussed here, however, the pyrite is stable, and it is the carbonate fraction which is lost.

The precise process of dissolution remains to be determined. We believe that prolonged exposure of carbonate on the basin slope and floor combined with periodic development of low pH conditions are responsible for its disappearance. Similar interpretations have been made for other instances of fossil dissolution in black shale sequences (Seilacher, et al. 1976; Tanabe, et al. 1984). Reaves (1984) argues that repeated oxidation of pyrite or iron monosulfide produces sulfuric acid leading to dissolution of adjacent carbonate, and Sholkovitz (1973) interestingly shows that shells exposed on the anaerobic sea floor are better preserved than those found on dysaerobic substrates. Locally observed multiple-stacking (shingling) of Leicester lenses within basal Genesee black muds indicates that episodic strong currents swept the basin substrate; this suggests that prevailing conditions were anoxic but that brief periods of oxygen incursion could have lowered the pH level near the reworked materials.

Geologic Units to be Discussed

Three important and distinctive examples of submarine discontinuities associated with the onset of black mud deposition will be examined on this field trip; these examples, discussed in sequential-, and stratigraphically ascending, order, include: 1) the Cherry Valley Limestone-Oatka Creek Shale contact near the base of the Hamilton Group (corrasional limestone hardground); 2) the Centerfield Limestone-Ledyard Shale contact in the medial Hamilton Group (erosional concentration of phosphate nodules, shells, and detrital pyrite); and, lastly, 3) we describe and discuss the observed downslope erosional bevelling of two thin limestone units (Fir Tree and Lodi beds) in the lower Genesee Formation by discontinuities at the base of black shale units above each limestone.

On the field trip, the first four stops will illustrate both the downslope condensation of the Fir Tree Bed and the eventual downslope erosional overstep of this same unit below a black shale sequence; at stops 2 and 3 participants will also be able to observe and collect detrital pyrite on the discontinuity surface.

GEOLOGIC SETTING

Paleogeography and Tectonic Setting

The Hamilton Group and Genesee Formation are parts of a thick and largely terrigenous sequence within the Appalachian basin of eastern North

America. These sediments accumulated at the northern margin of this basin a few degrees south of the inferred paleoequator, based on paleomagnetic reconstructions (Ettensohn, 1985). The Acadian orogeny commenced during the Middle Devonian; convergent activity east and southeast of New York State involving oblique collision of one or more microcontinents (Avalonia) or possibly an island arc produced mountains in New England and in the Mid-Atlantic states (Dewey and Burke, 1974; Van der Voo et al., 1979).

Initial Acadian disturbance in New York is marked by an upward change from carbonate deposits (Onondaga Limestone) to the predominantly terrigenous succession of Hamilton formations; both the Hamilton and stratigraphically higher Genesee sediment sequence record erosion of the rising mountains to the east (Cooper, 1957; Rickard, 1981; Woodrow, 1985; Ettensohn, 1985).

The Genesee Formation and succeeding clastic divisions of the Upper Devonian record particularly rapid growth of the Catskill Delta Complex, a large tectonic delta system bounded by a sublittoral to uppermost bathyal basin to the west and northwest (Sutton, Bowen, McAlester, 1970; Broadhead et al., 1982; Woodrow, 1985); Genesee deposition coincides with a major pulse of orogenic activity which caused crustal diastrophism and locally high rates of sedimentation in the study area (Dennison and Head, 1975; Johnson et al., 1985; Ettensohn, 1985). The deepest part of the basin during Hamilton and Genesee time was probably centered in western Pennsylvania south of the study area (McIver, 1970; Lundegard et al., 1980), but the basin axis apparently shifted westward during the Frasnian and Famennian through processes of tectonic adjustment and isostatic effects (Ettensohn, 1985). The northern and western boundaries of the basin bordered low relief, cratonic shelf regions which supplied relatively little detrital sediment on that side of the basin; this is reflected in the almost exponential westward thinning of Genesee and higher sedimentary units to the west and northwest across the basin.

Depositional Setting and Facies

The present Finger Lakes Region is near the northern limit of the Devonian basin; during much of Hamilton time it was a variably well-oxygenated, infralittoral shelf which, at numerous different times, supported some of the highest Devonian invertebrate diversity recorded in eastern North America. Basal Hamilton (Marcellus) strata in western New York (see Union Springs and Oatka Creek Shale members: stop 5) are predominantly anaerobic and dysaerobic facies supporting minimal benthos, but numerous middle and upper Hamilton beds (see Centerfield Member: stop 6) are rich in invertebrate macrofossils, including rugose and tabulate corals, brachiopods, bryozoans, trilobites, bivalves and pelmatozoans; facies of this type record shallow subtidal shelf conditions with reduced turbidity (Baird and Brett, 1983; Gray, 1984; Brett et al., this volume).

During deposition of the Centerfield and most of the higher Ludlowville Formation, the New York shelf was bisected by a region of differential subsidence and slightly deeper water conditions (Finger Lakes Trough) which was centered in the Seneca-Cayuga Valley region and which

probably connected southward to more basinal settings in western New York and Pennsylvania, where the largely black Millboro Shale accumulated (Baird and Brett, 1981; Brett and Baird, 1982); conditions in the Finger Lakes Trough explain both the differentially thick and shaley condition of many Hamilton carbonates in this region and the black character of the Ledyard Shale Member at Stop 6, an interval which is grey and more fossiliferous both to the east and west of this area.

After deposition of the upper Hamilton Moscow Formation and succeeding carbonates of the Tully Formation, a period of erosion ensued which removed the Tully Limestone in western New York and up to half of the Windom Shale Member of the Moscow Formation in Genesee County (Brett and Baird, 1982). This pervasive bevelling probably occurred both prior to, and during the major post-Tully transgression event which saw the development of a deeper, stratified water mass across most of New York State. This period also saw the beginning of the Taghanic sedimentary onlap event, as black, laminated muds (Genesee Member) of the basal Genesee Formation began to accumulate in this basin which was apparently deepest in the Seneca Valley-Canandaigua Valley region. Continued filling of the basin by the prograding Catskill Delta accounts for the overall regressive character of the lower-to-middle Genesee stratigraphic section in the Cayuga Valley.

In contrast to the generally deep-to-shallow infralittoral facies spectrum of the Upper Hamilton Group which includes black or dark grey shales with diminutive fossils on the deep end and carbonate grainstones or shell-rich sandstones on the shallow extreme (see Brett and Baird, 1985 this volume), the Genesee spectrum in the Finger Lakes Region is dominated by less fossiliferous deeper water deposits. Above the Leicester pyrite or uppermost Tully beds, the Genesee Formation commences with hard, laminated, black shale (Genesee Member) followed by a prodeltaic wedge of dysaerobic, turbidite-rich, shale-siltstone facies (Penn Yan and Sherburne Members) which contains thin tongues of black shale and minor shell-rich layers such as the Fir Tree and Lodi beds discussed herein. Only further to the east in the Cortland-Chenango Valley region does the sparsely fossiliferous Sherburne pass into shallow subtidal, coquinite-rich siltstones and sandstones (Unadilla Member) comparable to the more pervasively fossiliferous Hamilton deposits.

CORRASIONAL HARDGROUND SURFACE: CHERRY VALLEY LIMESTONE-
OATKA CREEK SHALE CONTACT

Stratigraphy and Facies

The basal beds of the Hamilton Group which overlie the Onondaga Limestone Formation consist predominantly of black shale with lesser proportions of dark grey styliolinid-rich and concretionary limestone (Fig. 3). Most conspicuous among the limestones is the Cherry Valley Member, a thin (0.5 - 2.0 m thick) unit which is notably widespread across New York State and which is particularly famous for its goniatite and nautiloid fauna (see Flower, 1936; Rickard, 1952; Cottrell, 1972). Between Cherry Valley, New York and the "Five-Points" quarry, northwest of

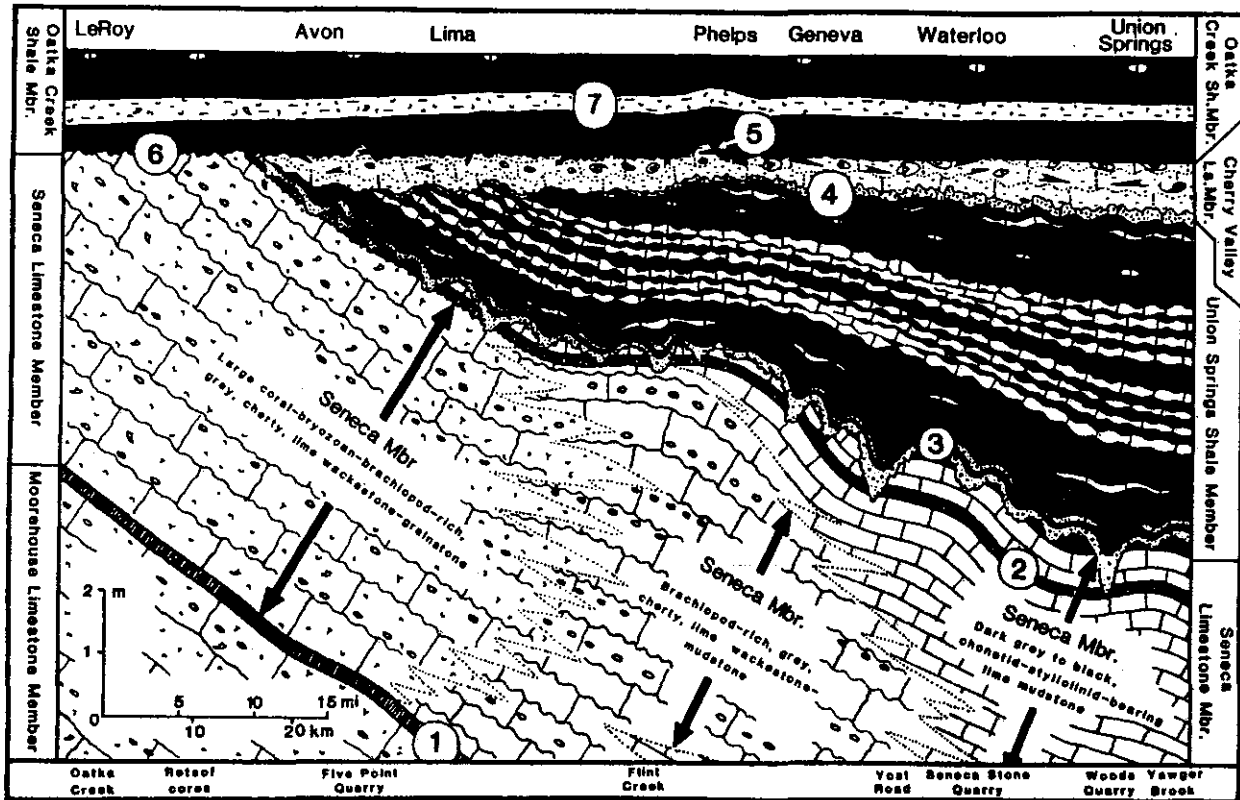


FIGURE 3.--Sub-Oatka Creek corrasion hardground and associated strata. Note conspicuous pattern of westward truncation of Seneca and Union Springs strata below the Cherry Valley and Oatka Creek Members; evidence for bevelling of units below the Oatka Creek is well displayed at Seneca Stone Quarry, Flint Creek near Phelps, Five-Points (Lima) Quarry, International Salt Company (Retsof) drill cores, and on Oatka Creek (see bottom of diagram). In addition, a conspicuous band of thin, bone and onychodid tooth-rich, styliolid limestone beds ("Bone Bed 7" of Conkin and Conkin, 1984), is observed to truncate the uppermost Seneca Member locally; varying completeness of the post-Tioga "A" to top of Seneca section in outcrops between Syracuse and the Five-Points Quarry suggests that the "Bone Bed 7" discontinuity is undulatory, as is shown on figure. Also shown is a conspicuous east to west facies change within the Seneca interval (see text). Units include: 1, Tioga "B" ash (Onondaga Indian Nation Metabentonite of Conkin and Conkin, 1984); 2, Tioga "A" ash ("Restricted Tioga" of Conkin and Conkin, 1984); 3, "Bone Bed 7" of Conkin and Conkin, 1984; 4, "Proetid Limestone Bed" at base of Cherry Valley Member; this unit is partly overstepped by Cherry Valley in this region; 5, corrasional hardground on top of Cherry Valley limestone deposit; raised bosses on this surface at Flint Creek are remnants of higher Cherry Valley deposits which escaped destruction before burial by black muds; 6, knobbly corrasional hardground on partly truncated Seneca Limestone; 7, unnamed, thin, grey, shell-rich bed within basal Oatka Creek Member, which is both widespread and rich in large, distinctive brachiopods.

Valley Member bears some resemblance to the Cephalopodenkalk limestones described from the Devonian of Europe and Africa (see Tucker, 1973; Wendt and Aigner, 1985), and it is similarly rich in pelagic (planktonic and nektonic) organisms, although some benthic taxa (aulopodid corals, bivalves, gastropods) also occur in this unit (Cottrell, 1972). As such, Cherry Valley facies accord well with overlying and underlying black shale sediments; Cephalopodenkalk deposits are generally interpreted as offshore transgressive facies, although not necessarily deep water (Tucker, 1973).

The cephalopod fauna, including large nautiloids and a diverse goniatite fauna, is the best known feature of this unit (see Clarke, 1901; Grabau, 1906; Flower, 1936; Rickard, 1952); one or more levels in the Cherry Valley are locally packed with phragmocones such that certain bedding surfaces are literally pavements of these shells. This is particularly the case for the topmost few centimeters of the Cherry Valley at Seneca Quarry; here, submarine erosion has neatly planed off the top of one of these layers revealing scores of truncated, prefossilized phragmocones at the discontinuity surface.

The juxtaposition of black shale beds on the Cherry Valley upper surface renders implausible the role of boring organisms as the principle erosive agent, as is normally seen on aerobic, organism-coated hardgrounds. Furthermore, the gross character and amplitude of irregularities on the erosion surface both at, and west of Flint Creek, suggest that some process other than burrowing or boring produced these features.

We argue that submarine corrasion of the pre-cemented limestone was an important erosive process prior to Oatka Creek black mud accumulation; current-induced scour was important in exposing the carbonate on the sea floor and in keeping it clear of covering sediment, but the peculiar isolated knobs and irregular, pitted and ridged terrain of the discontinuity surface at Phelps and further west does not resemble the smooth or runneled surfaces of limestones exposed to wave or stream erosion. Rather, it is more like pitted carbonate surfaces observed in areas where dissolution is known to occur (Freeman-Lind and Ryan, 1985; Williams et al. 1985). Additional evidence for carbonate dissolution is indicated by the concentration of phosphatic, but not calcareous, reworked debris on the erosion surface; this pattern is identical to that observed with the Leicester Pyrite, an accumulation of solution-distilled detrital pyrite and phosphatic debris that is similarly associated with initial black mud deposition or a submarine discontinuity surface (Brett and Baird, 1982; Baird and Brett, 1986, in press).

CENTERFIELD-LEDYARD BOUNDARY SURFACE

The Centerfield Limestone Member (basal Givetian) is a widespread key bed that marks the base of the Ludlowville Formation across western and west-central New York State. This unit, which is correlative with the Chenango Sandstone Member in central New York State (Gray, 1984) and probably correlative with the upper part of the Hungry Hollow formation in

Ontario (Landing and Brett, in press). The Centerfield, originally interpreted as being transgressive relative to overlying and underlying shales (see Cooper, 1957), is now known from biofacies and taphonomic evidence to record a regressive maximum in its medial beds (Gray, 1984; Brett and Baird, 1985).

Most significant within the Centerfield is a lithologic and biofacies sequence which is arrayed in a subsymmetrical pattern about the middle carbonate beds of this member (see Fig. 4A); in western New York, the medial beds of the Centerfield Limestone yield large rugose corals, domal Favosites colonies, and crustose stromatoporoids, as well as numerous bryozoans, brachiopods, and echinoderms. Both in the downward and upward directions away from the middle Centerfield limestone beds, there is a sequential outward biofacies transition from the above shallow subtidal fauna through respective intervals of large corals (Heliophyllum, Cystiphyllodes) in calcareous mudstone, in turn, through opposing belts of soft shale rich in small corals, fenestrate bryozoans, and diverse brachiopods, and finally to medium to dark grey dysaerobic shales above and below the Centerfield which yield a meager biota of diminutive brachiopods and mollusks (Gray, 1984).

This same regressive cycle is present in the Cayuga Valley area, except that the Centerfield sequence is much thicker in this region (Fig. 4A, B). It is also, distinctly less calcareous than the Centerfield Member of western New York, and is dominated by a greater number of mud- and silt-tolerant organisms than is observed in western New York Centerfield sections (Brett and Baird, 1985). Otherwise, a similar complete "mirror image" biofacies spectrum is observable both up and down from medial Centerfield calcareous mudstone beds in the Cayuga Valley with the sole exception of the Moonshine Falls section (Stop 6).

The type section of the Ledyard Shale Member, described by Cooper (1930), is on Paines Creek both at, and upstream from, Moonshine Falls; at this locality the lower 10 to 13 meters (33 to 43 feet) is a distinctly dark grey to black fissile shale which yields a sparse fauna consisting of the planktonic organism Styliolina, the rhynchonellid Leiorhynchus, diminutive nuculid bivalves, and flattened orthoconic nautiloids. At Moonshine Falls the Ledyard Member, above the Centerfield, resembles a typical black shale, although it may, in reality, represent a dark grey, dysaerobic deposit. Shale coloration in this region is deceptive; Hamilton shale deposits, west of the Rochester meridian all display a proportionately lighter color. The eastward darkening and hardening of shales as well as muddy limestones and siltstones is pervasive throughout the Middle Devonian section; one explanation, which we favor and which is a subject of ongoing study by the present authors, is that shales in this region experience higher late diagenetic burial temperatures. This effect makes it harder to prepare fossils collected in this region and further east, and it can fool inexperienced geologists into mismatching various units in correlation and misinterpreting paleoenvironments.

However, some regional color changes in the shales at this level reflect real paleoenvironmental controls; the Ledyard of this region

grades both to the west and east into various lighter colored, richly fossiliferous facies (Baird and Brett, 1985: Fig. 5). This pattern mirrors that in the overlying King Ferry and higher Ludlowville and Moscow units in this region, as well as within the underlying Centerfield Member; a region of differential subsidence and deeper-water conditions (Finger Lakes trough) was centered in this region during the deposition of these beds (see Baird, 1981; Baird and Brett, 1981; Brett and Baird, 1985). This feature explains the differentially darker color of the Ledyard and certain higher King Ferry shale units in the Cayuga Valley as well as the differentially thick and muddy character of the Centerfield Member in this area (see Brett and Baird, 1985).

The Centerfield-Ledyard contact in the Genesee Valley-Batavia area appears conformable and gradational, but in the Central Finger Lakes Region, the boundary is distinctly abrupt (Gray, 1984; Brett and Baird, 1985). Beginning to the west, at Wilson Creek and Kashong Glen near Geneva, this boundary is expressed as a layer of brachiopod and coral debris (Moonshine Falls Bed), suggesting minor scour or a period of nondeposition. East of Seneca Lake, the boundary is clearly erosional, but, in many sections, the horizon is cryptic; bioturbation activity timed with initial burial of the discontinuity at the beginning of Ledyard time, has essentially scrambled together top-Centerfield and basal Ledyard muds to the point that the discontinuity surface has been erased (Baird and Brett, in press). Such contacts, termed stratomictic (see Baird, 1981), typically cannot be found in a uniform shaly sequence by cursory examination. Depositional breaks of this type are frequently located when a biofacies discontinuity is first identified (see Baird, 1978) or when the stratomictic contact is correlative with a more readily identifiable unconformity such as is developed along the top of the Centerfield at Moonshine Falls (Stop 6). Hence, the minor Centerfield-Ledyard discontinuity (Moonshine Falls Bed) west of Cayuga Lake becomes more readily recognizable in the Aurora area, both because the magnitude of the erosion is greater and because the basal Ledyard shale above this break is distinctly darker than that observed above the contact at other localities.

In actuality, the Moonshine Falls section is quite anomalous when compared to outcrops in the immediate vicinity; virtually the entire upper transgressive part of the Centerfield section has been removed by erosion at this locality (Fig 4). In three nearby sections, respectively to the west, south, and north of Moonshine Falls, the 3 to 4 meter-thick resistant, medial Centerfield calcareous mudstone interval is succeeded by a comparable thickness of less calcareous, shaley mudstone (Gray, 1984). This sequence contains a biofacies succession recording transgression up to the relatively minor discontinuity horizon (Moonshine Falls Bed) below the Ledyard. At Moonshine Falls, this entire upper Centerfield transitional shale sequence is absent (Fig. 4); Ledyard black shale deposits are juxtaposed directly on the medial Centerfield, allowing a rare opportunity to study the spectacularly fossil-rich facies of the main Centerfield calcareous mudstone on a large clean bedding plane surface (see Road Log: Stop 6).

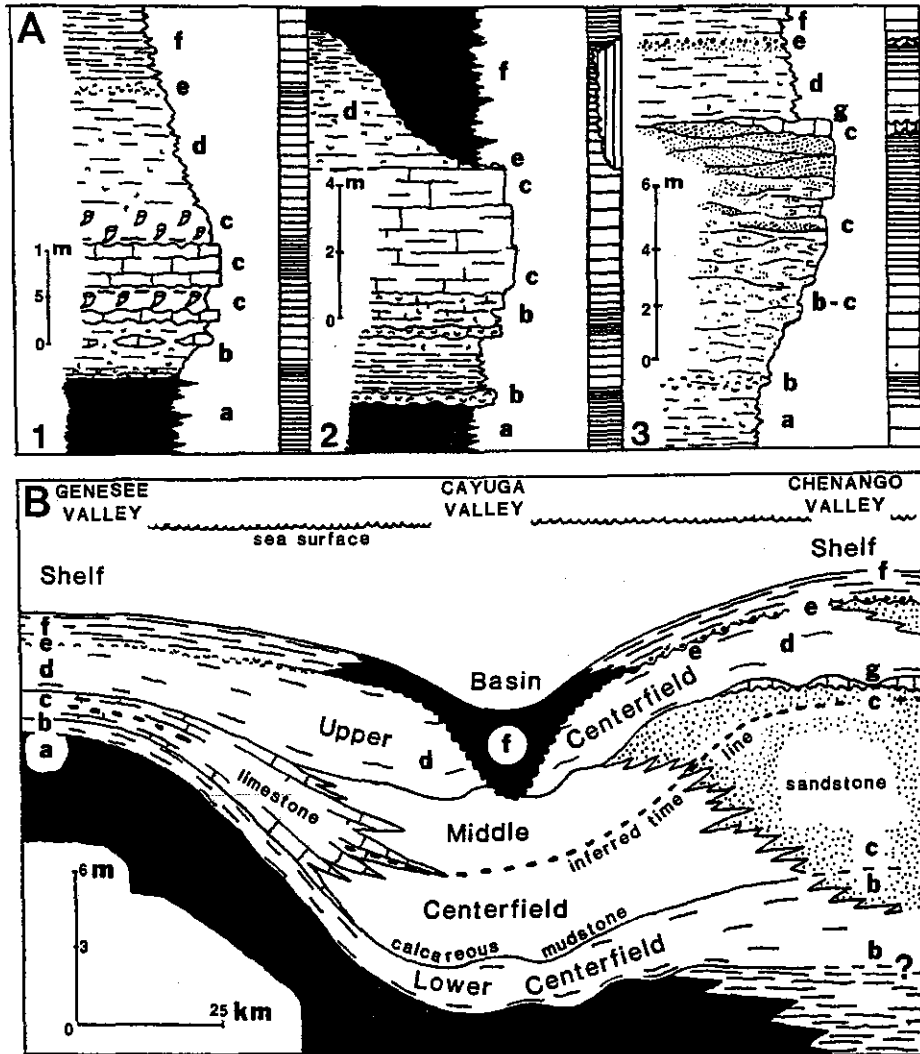


FIGURE 4.-- A) Representative sections of Centerfield Limestone and equivalent Chenango Sandstone in western, west-central, and central New York; spacing horizontal lines in narrow columns denotes relative rates of sedimentation; close spacing indicates slow net deposition; vertical ruling indicates hiatuses. Sections include (1) Genesee Valley, (2) Cayuga Lake Valley, (3) Chenango Valley. Lower-case letters designate coeval beds between sections; units include (a) pre-Centerfield black and dark grey shales; (b,d) transitional, calcareous grey mudstone and silt shale; (c) medial beds--argillaceous limestone (1), calcareous mudstone (2), and cross-laminated siltstone, sandstone (3); (e) discontinuity and associated condensed, phosphatic bed--note that this unit rests on an erosion surface (in 2); (f) dark grey to black shale; (g) sandy crinoidal limestone. B) East-west facies distribution at end of Centerfield deposition. Note abrupt gradation of western platform limestones and calcareous shales into thicker calcareous mudstone facies in trough, with further change eastward to upward-coarsening, siltstone-sandstone sequence on eastern shelf; black facies of overlying Ledyard Shale are restricted to basin center and rest on a local submarine erosion surface. Water depth is relative and not to scale; letters are as shown in A. From Brett and Baird (1985).

The cause for this local downcutting is problematic. Even in sections in the Owasco Valley further east, several meters of transgressive Centerfield shaley mudstone are always observed above the medial Centerfield sequence. However, we suspect that the Moonshine Falls area was very certainly not a single closed erosional depression into upper Centerfield beds. More likely, this erosional cut-out is the expression of an erosional channel or runnel into the Centerfield deposit which happened to coincide with this locality, or, conceivably, the differential bevelling of a local area of upfolded Centerfield beds. Although the explanation for this local anomaly remains enigmatic, the character of the erosion process can be deduced from the character of the Moonshine Falls Bed discussed below.

At all sections, from the vicinity of Aurora to the Chenango Valley, in central New York, the Moonshine Falls Bed is an easily identifiable horizon, marked by abundant phosphatic pebbles and fossil steinkerns, as well as by abundant reworked and highly corroded fossil fragments derived from Centerfield beds. Moonshine Falls is the best locality for sampling the phosphatic material, but Ensenore and Seward ravines on Owasco Lake also yield excellent pebbles and steinkerns at this level. On the west side of Cayuga Lake at Hicks Gully, Big Hollow Ravine, and in the unnamed brook adjacent to and downstream from the Poplar Beach shale pit (Optional Stop), broken pyritic borrow tubes, as well as phosphatic debris, occur within the Moonshine Falls Bed; these pre-cemented, pyrite-impregnated burrow castings show evidence of secondary disturbance by burrowing infauna which penetrated the mud-floored discontinuity surface (Baird and Brett, in press).

East of Skaneateles Lake the Moonshine Falls Bed thickens and splays into several discrete, shell-nodule debris layers which are most likely multiple-event storm (tempestite) beds. In this valley and eastward to the vicinity of Hamilton, New York, the Moonshine Falls Bed becomes more of a condensed sedimentary sequence than a simple erosion surface *per se*; this unit, both in this area, and also west of Seneca Lake, is thus believed to record little or no submarine erosion and minimal sediment accumulation.

The nature of the erosion process which produced the top-Centerfield discontinuity appears to be closely linked to the major transgression that began during deposition of the upper Centerfield; it seems likely that reduced sediment supply, associated with transgression-induced migration of coasts and sediment sources away from western New York, may have produced a situation in which erosion, not deposition, became the predominant process. During such a time, the burrowing activity of numerous organisms in surface muds would have served to soften and liquify these same muds, hence increasing their erodability under storm conditions; over a long period of time, repeated scour of these muds in shallow settings could have produced significant erosion and the conspicuous hydraulic concentration of phosphatic debris and shell fragments (see Baird and Brett, 1981: Stratomatic Erosion Model). In deeper areas within the Finger Lakes Trough, a greater proportion of the bottom erosion may have been produced by secondary, storm-induced bottom currents.

CORRASIONAL DISCONTINUITIES IN THE GENESEE FORMATION:
THE PROBLEM OF THE FIR TREE AND LODI LIMESTONE BEDS

Recent stratigraphic study of the lower and middle parts of the Genesee Formation (uppermost Middle- to lowermost Upper Devonian stages) by the present authors has produced important results and surprises. Much of this work has been a detailed stratigraphic study of the basal Genesee Leicester Pyrite Member, a well-known pyritic bone bed flooring the formation (see Brett and Baird, 1982; introduction to the present paper). However, our recent studies have been directed toward a microstratigraphic study of that part of the Genesee Formation (uppermost Genesee Member and lowermost Penn Yan and Sherburne Members) which contain the newly-described Fir Tree and the slightly younger Lodi Submembers (Figs. 1, 12, 13). These thin, fossiliferous, impure carbonate layers are closely associated with discontinuities which are produced by combined processes of abrasion and dissolution within a largely anoxic basinal environment; both of these limestones are clearly bevelled by corrasion in gently sloped settings. The chemical end products of this erosion, including reworked pyritic grains and bone fragments, serve as telltale markers of the resulting cryptic discontinuities developed within black shale facies where the limestone deposits have been destroyed.

Recent study of the Lodi interval by the present authors shows that two different carbonate-rich units had been lumped under the name Lodi in earlier work (see work of deWitt and Colton, 1978); these units, including a lower layer (Fir Tree Limestone Submember) within the upper Genesee Member and the true Lodi, which occurs slightly higher stratigraphically at the base of the Penn Yan and Sherburne Members, can be traced over large areas in the Finger Lakes Region (Figs. 1, 5-10).

The Fir Tree Submember, named for excellent cliff exposures at Fir Tree Point on Seneca Lake, is separated from the younger Lodi Bed by four to thirty meters of black to dark grey, silty shale which we designate the Hubbard Quarry Shale Submember for the complete and accessible exposure at Hubbard Quarry in Interlaken Township in Seneca County (see Stop 3: Fig. 13). This shale unit, equivalent to hard, black shale facies of the uppermost Genesee Member in western New York, thickens southeastward from 4.3 meters at Hubbard Quarry to 18 meters near Genoa, Cayuga County and to approximately 30 meters north of Renwick, Tompkins County. The lower part of the Hubbard Quarry submember is composed of black, laminar, silty shale usually rich in the inarticulate brachiopod Orbiculoidea lodiensis and the articulate brachiopod Leiorhynchus quadricostatum; the black shale facies grades both upward and southeastward to olive grey, silty mudstone and flaggy siltstone facies which contain, in addition to the above taxa, local bedding plane concentrations of auloporidae corals.

The Fir Tree Submember is a zero to ten-meter-thick, wedge-shaped deposit of interbedded concretionary, grey to chocolate brown, micritic limestone and shale which expands conspicuously southward in the central Finger Lakes Region (Figs. 5-7). The Fir Tree sequence becomes increasingly fossil-rich, calcareous, and condensed as its northern

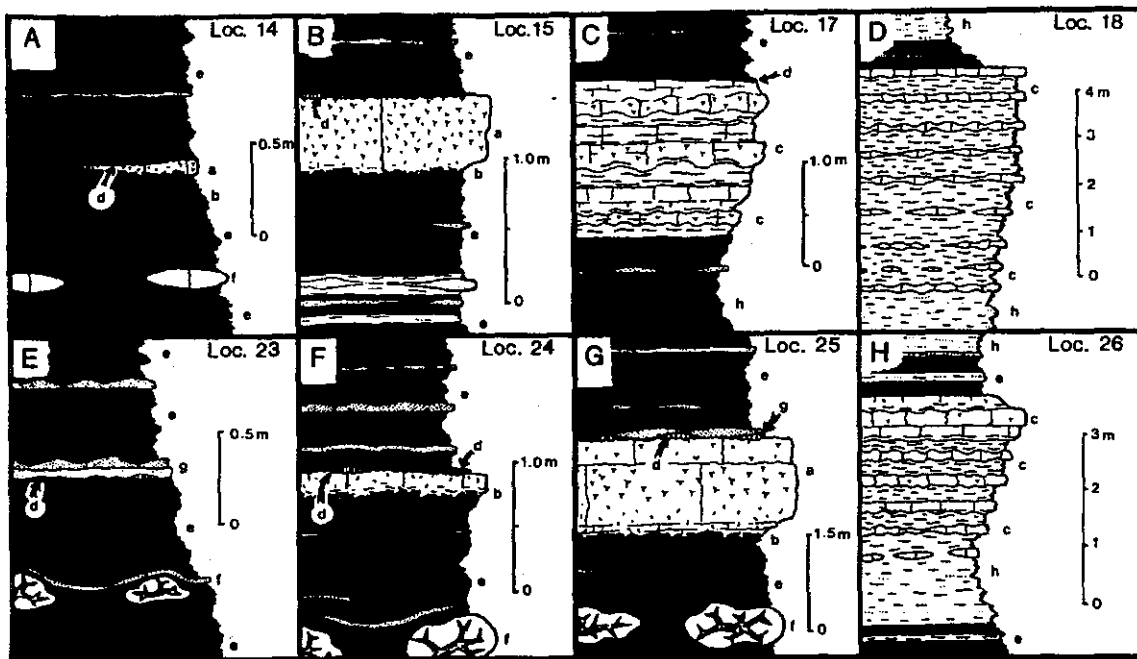


FIGURE 5.--Fir Tree Submember; selected sections along two transects normal to depositional facies strike. A-D is a transect from Hubbard Quarry southeastward to Trumansburg Creek (also see Fig. 6). E-H is a transect from Venice Center southward to Lansingville. Inferred upslope direction to the right. Note concurrent downslope condensation of Fir Tree beds and enrichment of these beds with auloporid corals; this paradoxical pattern is discussed in text; also note corrasional truncation of condensed Fir Tree section at the north end of both transects; a) condensed auloporid wackestone; b) thin, orbiculoid-rich, basal grey mudstone layer of Fir Tree Bed; c) thick, marginal facies of Fir Tree unit; sequence is mostly grey mudstone with sparsely-fossiferous concretionary lime mudstone layers; d) lenses of reworked detrital pyrite on top Fir Tree discontinuity surface; e) black shale facies with minor siltstone and grey mudstone interbeds; f) septarial concretions; g) siltstone bed draped over discontinuity and detrital pyrite; h) grey silty mudstone below thick Fir Tree deposits.

erosional margin is approached (Figs. 5-7: see stop sequence 1 to 4 in road log); thin (≤ 1 meter-thick), northernmost, Fir Tree sections consist of a dense, falls-forming ledge of impure limestone which contains bedding-plane mats and thickets of auloporid corals, small *Devonochonetes* sp., a sparse molluscan fauna, and numerous pyrite-suffused burrows (Fig. 5). This fauna disappears southward as the Fir Tree thickens exponentially, and the sequence becomes almost devoid of fossils as it changes laterally to a sequence of interbedded dark grey mudstone, concretionary "ribbon" limestones, and turbiditic siltstones (Figs. 5- 7).

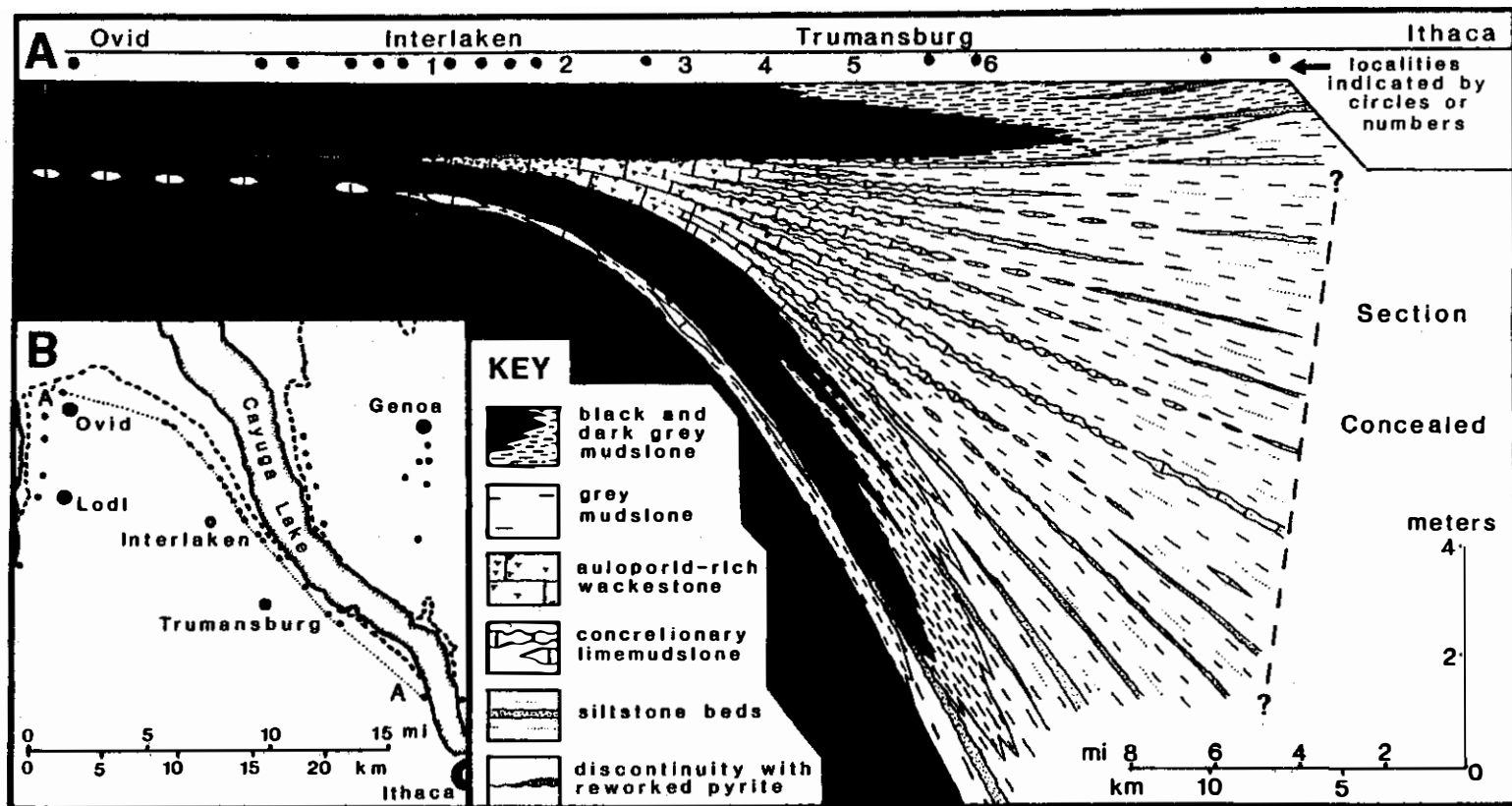


FIGURE 6.--Stratigraphic transect of the Fir Tree Submember approximately normal to depositional strike; note very rapid southwestward thickening and splaying of bed; presumed basinal direction toward northwest.

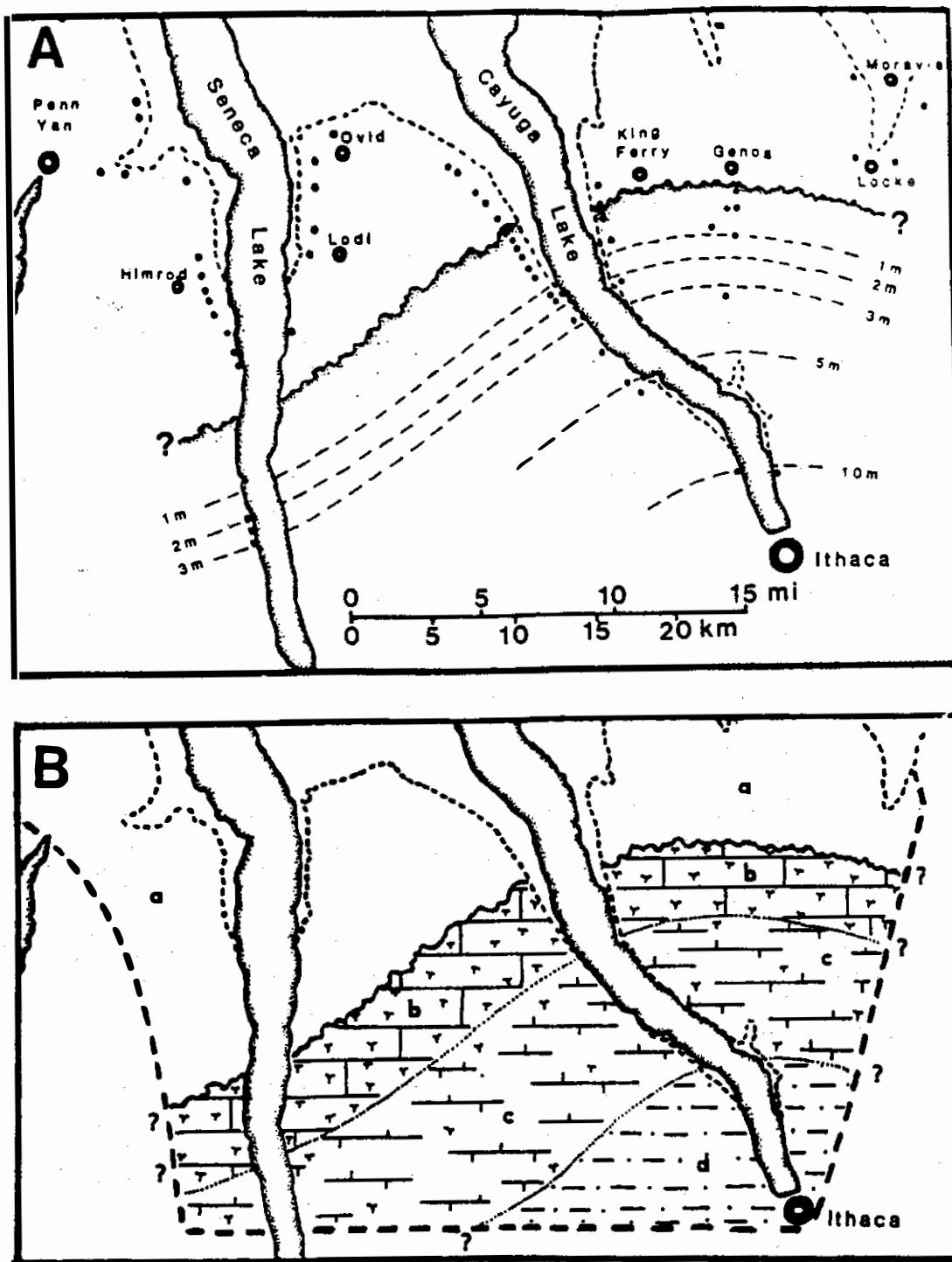


FIGURE 7.--A) Isopach map of Fir Tree Submember in the Seneca-Cayuga Valley region; note abrupt northward thinning due in part, to erosional truncation at top of bed; B) Facies map of Fir Tree Submember in the same region; symbols: a) black shale; b) auloprid-bearing limestone; c) sparsely fossiliferous calcareous siltstone.

As the Fir Tree Submember thins northward in the Cayuga and Salmon Creek valleys, its upper contact with the Hubbard Quarry Shale Submember changes progressively from gradational to abrupt and erosional along three south-to-north transects: from Little Point to Interlaken (west side of Cayuga Lake), Lake Point to King Ferry (east side of Cayuga Lake), and Lansingville to Genoa (east of Cayuga Lake), the Fir Tree is progressively cut out by a discontinuity that originates at the Fir Tree-Hubbard Quarry shale contact (Figs. 5, 6). North of the Fir Tree erosional limit this discontinuity persists within undifferentiated black shale facies of the Genesee Member (Figs. 5, 6).

The Lodi Limestone Submember (or Bed), named for a particularly good exposure on Mill Creek, Seneca County (see Lincoln, 1897; Kirchgasser, 1985), has now been found to be widely distributed throughout the Cayuga and Salmon Creek Vallies and is now known to extend continuously from the vicinity of Himrod, Yates County to the Skaneateles Valley (Figs. 8-10). This unit, like the Fir Tree Submember, is an impure, concretionary carbonate deposit that contains conspicuous bedding plane and thicket accumulations of auloporidae corals (Fig. 9). Also, like the Fir Tree, the Lodi displays lateral sedimentary condensation towards an erosionally bevelled margin in the Seneca Lake Valley, except that this concurrent condensation and truncation is in a northwestward rather than northward direction (Figs. 9, 10).

As with the Fir Tree, Lodi carbonate content and fossil diversity increases notably as the Lodi erosional limit is approached near Himrod, Yates County and Ovid, Seneca County (Figs. 8-10); at these places, the Lodi yields a moderate diversity fauna dominated by auloporidae corals, but also yielding Orbiculoidea lodiensis, the articulate brachiopods Pseudoatrypa cf. P. devoniana, Devonoconetes sp., Leiorhynchus sp., orthoconic nautiloids, the goniatite Ponticeras perlatum, pelmatozoan debris, and pyrite suffused burrows. This fauna becomes less diverse as the Lodi grades southeastward to silty mudstone and muddy siltstone lithofacies near Renwick, Tompkins County and at Locke, Cayuga County. Only further east, at New Hope Mills, Onondaga County, does a conspicuously diverse, shelly fauna appear in Lodi-equivalent siltstone and fine sandstone lithofacies (Fig. 8).

As with the Fir Tree deposit, the Lodi thickens away from its northeastward erosional margin, but unlike the Fir Tree, it reaches a maximum thickness of only one to two meters in the Cayuga and Salmon Creek valleys. The Lodi is closely associated with two to three recurrent beds of similar character which occur above the Lodi Bed proper (Fig. 9).

Both the Fir Tree and Lodi beds are missing in the northern Seneca Valley, in the vicinity of Penn Yan, Yates County, and in the Canandaigua and Bristol Valleys; in this region, their positions are marked by cryptic discontinuities within black and dark grey shale facies which have been identified at only a few localities (Fig. 9). In the Genesee and Honeoye Valleys, an auloporidae-rich concretionary limestone unit corresponding to the Lodi Bed is observed; this unit displays a southeastward erosional margin in the Honeoye Valley which closely resembles the northwestern

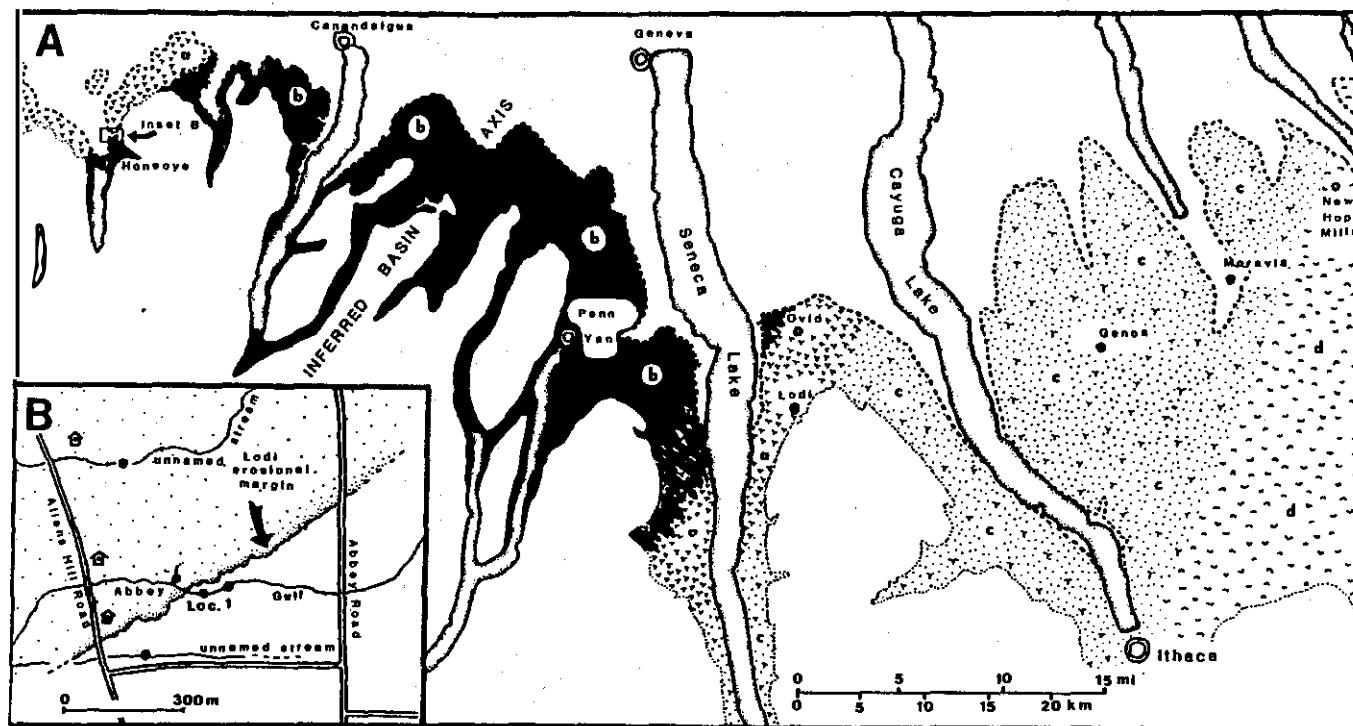


FIGURE 8.--A) Lodi facies belts and inferred basin axis. B) inset shows details of the eastern erosional limit of the Lodi Submember west of the basin axis; symbols: a) aulopod-bearing, concretionary wackestone; b) dark grey to black shale with minor bed of pyritic, bone-rich remanic sediment; area of basin axis; c) sparsely fossiliferous, aulopod-bearing, calcareous siltstone; d) fossiliferous, brachiopod-rich siltstone.

terminus of the Lodi (Fig. 8). Similarly a lower Genesee carbonate interval is recognized in the Genesee Valley; this unit may correspond to the Fir Tree level, but the correlation is only tentative at this time.

The northern Seneca Valley-Bristol Valley region is believed to mark the axis of a depositional basin during the time of lower Genesee deposition (Baird and Brett, 1985); the preponderance of monotonous black shale lithofacies and the absence of several grey shale sequences and fossiliferous horizons observable in the lower Genesee Formation, both to the east and west, suggest that the basin axis was probably centered in the Canandaigua-Geneva meridian. Paradoxically, the region of maximal erosional bevelling of the Fir Tree and Lodi beds is also in this area or bordering it; both of the limestone beds, and, at least, one additional limestone unit, are truncated in the basinward (downslope) direction such that black shale deposits overlying each limestone are juxtaposed on underlying black shales where complete bevelling of the carbonate units has occurred (Figs. 8-10).

Not surprisingly, the character of these discontinuities and of the associated lag debris upon them is distinctive, providing several clues as to the process of erosion which may have produced these breaks. Firstly, the top-Fir Tree and top-Lodi discontinuities, where developed, are overlain by laminated black shale deposits. These unconformities are only two of many similar submarine erosion surfaces which are overlain by black shale deposits (see Brett and Baird, 1982; Baird and Brett, in press). Where the Fir Tree and Lodi are overlain by grey mudstone, the upper contacts appear conformable, but where the grey facies grades laterally and downslope to black sediments, a discontinuity appears at the contact.

Secondly, both the Fir Tree and Lodi discontinuity surfaces, as well as a more minor intervening diastemic contact in the Bergen Beach ravine (Stop 2) near Interlaken, are littered with reworked detrital pyrite debris along with lesser quantities of bone, quartz sand, and orbiculoid fragments (Baird and Brett, 1986; this report). Much of this material consists of reworked, fragmental, pyrite-suffused castings of burrows derived from the bevelled, burrow-rich, limestone unit (Fig. 2). In a paper now in press, we present several criteria for the recognition of reworked pyrite; very important among these is observed one-to-one similarity of detrital pyrite grains, such as burrow tube fragments on the Fir Tree and Lodi, with in-situ pyritized tubes within these beds.

However, the one conclusive line of evidence for pyrite exhumation, best developed in the top-Lodi pyrite layer near Himrod, Yates County, is the aforementioned evidence of reorientation of geopetal pyritic stalactites (Fig. 2). Where early diagenetic, microbial sulfur-reduction occurs in voids such as in cephalopod chambers or in unfilled burrows, stalactites of framboidal pyrite often develop as projections from void ceilings (Hudson, 1982). Because no "stalagmites" develop from this process, the stalactites serve as a geopetal indicator. However, if pyrite grains have been exhumed and hydraulically concentrated on the sea floor, one would predict a random orientation for stalactites within these

grains. This prediction was fulfilled when cross-sections of top-Lodi pyrite lag grains were examined; stalactites developed in void spaces within in-situ Lodi burrows were always downwardly-oriented, while reworked tubes on the Lodi upper surfaces displayed stalactites oriented in all directions (Fig. 2).

The third distinctive feature of post-Fir Tree and post-Lodi discontinuity debris is the absence or rarity of reworked calcareous fossil fragments associated with the detrital pyrite. There is an abundance of tabulate coral, brachiopod, and pelmatozoan material within the underlying Fir Tree and Lodi source beds but almost none of this occurs with the detrital pyrite. This pattern is hardly an anomaly where black shales unconformably overlie fossil-rich strata; both the aforementioned Leicester Pyrite Member below the Genesee Member and the Skinner Run Bone Bed below the black Cleveland Shale Member are accumulations of detrital pyrite which contain little or no associated carbonate allochems (Brett and Baird, 1982; Mausser, 1982).

We believe that the absence of carbonate allochems is integrally related to the abundance of reworked pyrite. In essence, it is a direct consequence of the special basinal conditions within which this submarine erosion had occurred; under the predominantly anaerobic conditions recorded by the black shale deposits, exposed calcareous grains would have been unstable for the very reason that the pyrite was stable. Low pH conditions on the anaerobic or minimally dysaerobic basin floor would have produced conditions favoring the dissolution of exposed carbonate, particularly grains exposed for long periods of time on an erosion surface. Anaerobic conditions which could have produced a pitted corrosion surface on the Cherry Valley or Onondaga limestones in western New York localities, would have also produced distilled lag accumulations of pyrite and bone debris on discontinuities such as those in the Genesee Formation.

The last feature of the Genesee discontinuities discussed here is the fact that the pyrite lag accumulations always occur as laterally separated lenses when seen in outcrop profiles. This is also characteristic of the Leicester and Skinner Run pyrite accumulations, as well as other more minor deposits (see Brett and Baird, 1982; Mausser, 1982). This lensing is the two-dimensional perspective view of either tractional wave-bedforms of pyrite gravel or profiles of debris-fillings of erosional channels or runnels on the sea bed. In the instance of the Leicester pyrite study, we concluded that Leicester lenses were fillings of erosional runnels similar to erosional furrows on certain modern marine substrates (see Flood, 1983); we based our conclusion on the absence of foreset bedding in lenses, the overall width-dimensions of lenses, and the fact that the azimuths of current-aligned pyrite tubes usually paralleled the long axes of Leicester lenses. Whatever the correct interpretation of the Leicester lenses may be, it should apply similarly to the younger Fir Tree and Lodi pyrite lags since these display similar patterns of grain-current alignment and gross lens geometry.

When the distinctive features of the post-Fir Tree and post-Lodi discontinuities are reviewed collectively, a paradoxical pattern emerges - the submarine erosion appears to be intimately associated with the

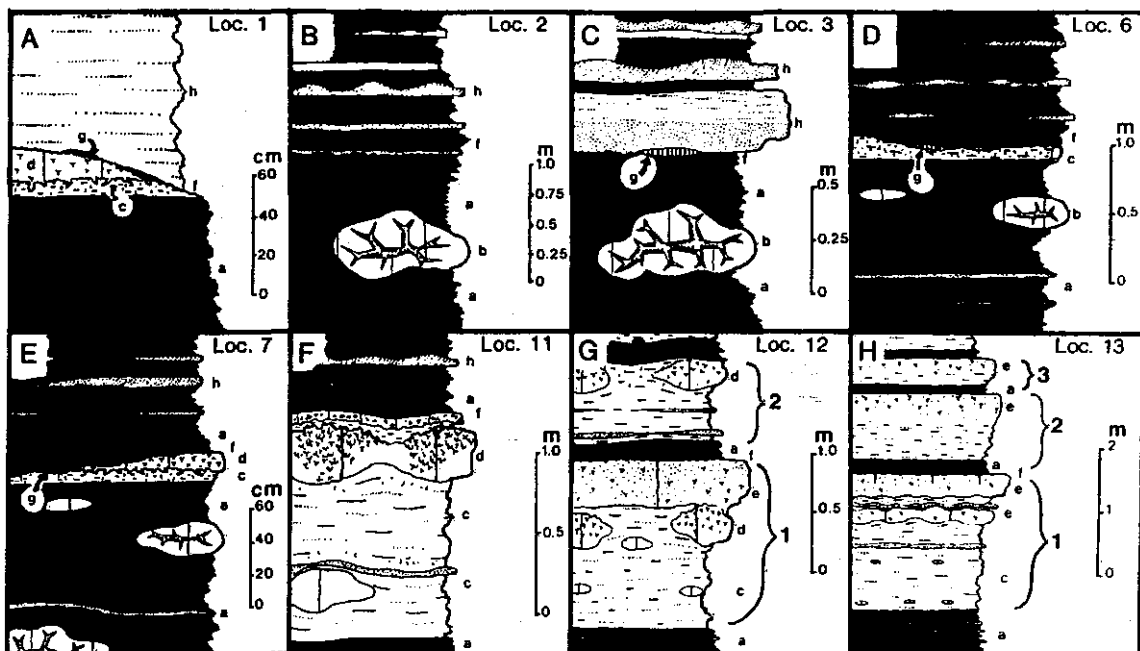


FIGURE 9.--Lodi Limestone Submember; selected sections along transect from the Honeoye Valley to Cayuga Lake. Sections F, G, and H are also shown on Figure 10. Note that section A (Abbey Gulf) displays the eastern erosional limit of Lodi deposits west of the basin and sections D and E show the northwest (downslope) limit of this unit southeast of the basin. Numbers in sections G and H denote Lodi (1) and two younger and similar sedimentary cycles which are developed concurrently at localities between Ovid and Interlaken. Key: a = black shale; b = septarial concretions; c = basal Lodi orbiculoid- and pyrite burrow-tube-rich grey mudstone; d = auloporida-rich concretionary limestone (good Lodi development); e = auloporida-bearing, calcareous, burrowed siltstone bench; f = Lodi discontinuity; g = lenses of reworked detrital pyrite on Lodi discontinuity surface; h = silty mudstone and current-rippled siltstone beds.

presence of overlying black shale deposits, and absent where the black shale tongues are absent. This intimate association of laminated black shale facies with hydraulically concentrated detrital pyrite and bone debris is similarly documented for the Leicester and it is most assuredly not a coincidence. The transgressive, upslope migration of the anaerobic lower water zone appears to have been closely associated with the onset of bottom scour and corrosion of the sea floor.

Two possible explanations for this erosion, one rather intuitive and the other much more theoretical and controversial, are provided here. The first is an oft-cited, but reasonable explanation - that the observed submarine erosion is related to the reduction in sediment supply during

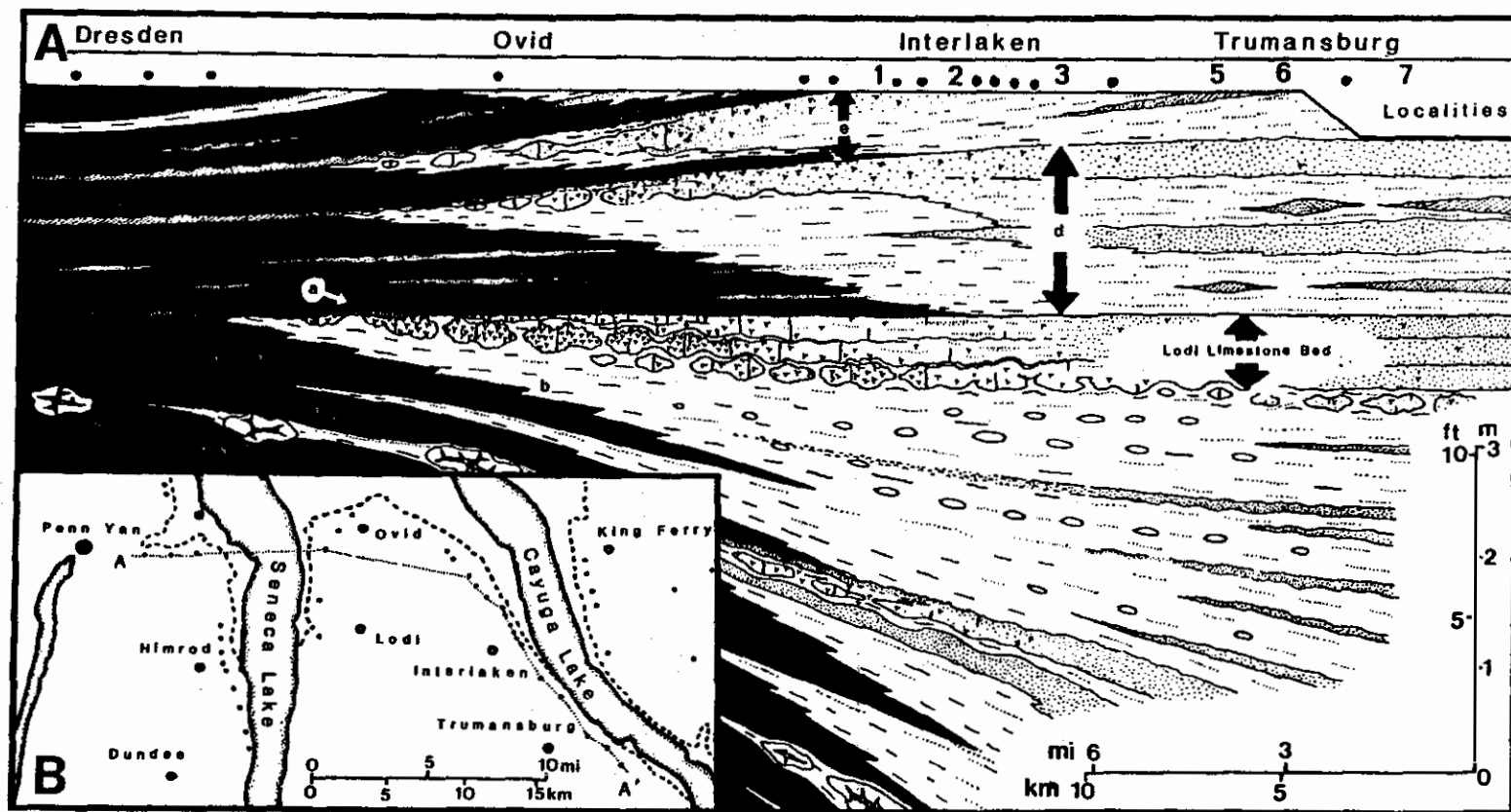


FIGURE 10.--Stratigraphic transect of the Lodi bed normal to depositional strike; symbols: a, pyritic lag deposit along truncated edge of Lodi Submember; b, d, e minor shallowing upward cycles which begin with grey bioturbated mudstone and culminate in silty limestone with auloporids.

transgression; a net rise of sea level would presumably cause an eastward migration of coasts away from the site of deposition resulting in nearshore alluviation of sediments which would have normally been deposited in the offshore Genesee basin (see McCave, 1973; Heckel, 1973 for application of nearshore alluviation model to explain episodes of Devonian carbonate deposition). In such an instance, a reduction in terrigenous mud supply to the Fir Tree or Lodi substrate during deposition could have shifted the sediment budget balance from net accumulation to nondeposition or erosion.

A more difficult and important question, posed by our data, can be stated as follows: what causal mechanism can account for the concentration of gravel-grade pyrite placers within a black shale environment? In the absence of a known modern analog we have to resort to specific known current processes which could partly explain deposits of this type. Three processes discussed here include: 1, bottom currents and turbulence generated by deep storm-generated gravity waves; 2, latent current activity in the deeper part of the basin, which is originally storm-generated, but which persists at depth long after the storm has passed; and 3, internal wave activity within the pycnocline which impinges against the basin margin slope.

The first two of these processes, storm-generated turbulence and latent storm-generated deep-water currents, are known to be important on the continental shelves and slopes as well as in large lakes; these are assumed to have been of some importance in particle transport in the Devonian shelf and basin settings. Deep storm wave turbulence is known to transport sediment to depths of 200 meters or more (Liebau, 1980) and storms can also generate boundary currents which can produce erosional furrows to depths of 200 meters as has been observed on the floor of Lake Superior (Johnson, et al., 1984). Furthermore, latent, storm-generated, cyclone-like disturbances are known to be important in scouring the sea floor and transporting sediment at bathyal depths (Hollister, et al., 1984). In particular, the episodic character of storm currents and latent, storm-generated current disturbances could explain the numerous, recurring levels of current-winnowed silt and sand which are characteristic of Devonian black shale deposits.

However, the erosional bases of the black shale units plus the occurrence of heavy, gravel-grade pyritic allochems on these discontinuities suggest that some process-specific erosion mechanism is associated with the transgressive upslope migration of the anaerobic water mass up the basin margin slope. The fact that both the Fir Tree and Lodi beds as well as their probable equivalents in western New York are differentially bevelled in the basinward (downslope) direction would seem to indicate that erosion may have been associated with the water mass boundary layer.

We believe, as do Ettensohn and Elam (1985) that a dynamic water mass boundary layer or pycnocline was developed in the Devonian slope and basin settings during periods of black shale deposition. Since pycnoclines are boundaries between layers of different temperature- and/or, salinity-related water density, they may behave, to a limited extent, like

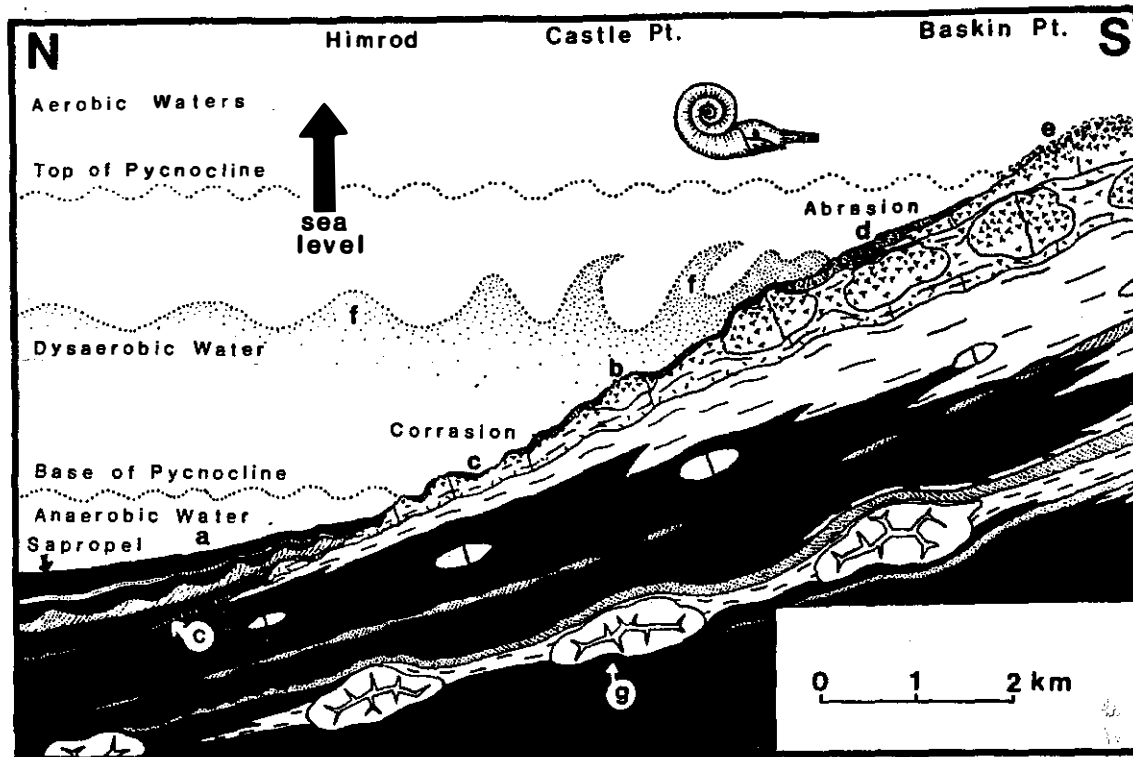


FIGURE 11.--Erosion model. Schematic shows process of mechanical erosion and corrosion of Lodi carbonate deposits during a transgression event. Internal wave-impingement on the paleoslope is believed to have been a significant factor in the submarine erosion process. As shown here these waves generate turbulence on slope, removing fines, and exposing carbonate material for corrosional attack in dysaerobic water. Residual early diagenetic pyrite and phosphatic fossil debris is concentrated as a tractional placer in lenses. Upslope migration of the pycnocline produces a widespread, gently-inclined unconformity which is progressively buried by overlapping black muds and silts as water deepens. Key: a) black muds; b) Lodi concretionary, auloporid-rich wackestone which is truncated by corrasion; c) reworked detrital pyrite (corrasion residue); d) top-Lodi veneer of mixed pyrite-calcareous debris; packstone; e) living auloporid thicket; f) Internal wave-train impinging paleoslope; g) septarial concretions marking stratigraphic position of similar Lodi-type cycle ("Bergen Beach") developed further upslope to southeast.

the air/water surface when the boundary is abrupt; energy transferred to the pycnocline will propagate along that layer in the form of waves; these internal waves are believed to be of some significance in transporting sediment on the outer continental shelf (Karl, et al., 1983).

In two recent papers, Woodrow (1983, 1985) has applied the internal wave concept in explaining a distinctive facies sequence within regressive, prodeltaic facies of the upper Genesee Formation in the Seneca Lake Valley. He attributes the formation of an interval of thick siltstone beds, which overlie a thick unfossiliferous turbiditic sequence and underlie fossil-rich, silty delta platform deposits to the impingement of internal waves against the upper prodelta slope during delta progradation.

In a tentative model presented here, we envision the impingement of internal waves against the basin-margin slope, during a period of net sea level rise and during a period of transgression-related sediment starvation on the basin slope as opposed to the progradation setting discussed by Woodrow. In this model, the zone of internal wave impingement on slope would migrate upslope during the transgression producing a continuous erosion surface which would extend to the maximum transgressive upslope limit reached by the lower water layer (Fig. 11). As erosion in the impingement belt proceeded, sediment fines would have been swept downslope (bypassed) onto the anaerobic lower slope to be deposited as laminated black mud and thin, winnowed siltstone layers above the discontinuity surface (Fig. 11). Exposed shells and concretionary carbonate would be destroyed by a combined process of abrasion and corrosion (corrasion) downslope from the belt of maximal internal wave impingement, but upslope from the low energy zone of black mud overlap on the discontinuity surface (Fig. 10).

In summing this process discussion, we believe that the Fir Tree and Lodi discontinuities, plus numerous other similar breaks below black shale deposits, may be a time-lapse record of the pycnocline position on the ancient basin slope. This explanation is still only a model, and it will probably remain so until a modern analog of these erosion surfaces is found. Such a discovery is anticipated, given the great increase in studies of modern basinal processes, and we believe that it will significantly change some of our views concerning the origin of black shale deposits.

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REFERENCES CITED

- 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., 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: *New York State Geological Association Guidebook*, 53rd Annual Meeting, Binghamton, 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.
- BAIRD, G. C. and BRETT, C. E., 1985, Reworking of sedimentary pyrite on euxinic seafloors, Devonian, western New York: (Abstract) *American Association of Petroleum Geologists Bulletin*, v. 69(2), p. 236.
- BAIRD, G. C. and BRETT, C. E., 1986, Submarine erosion on a Paleozoic anaerobic basin slope: fate of two Devonian limestone beds in the Genesee Formation of New York State: *Geological Society of America, Abstracts with Programs*, v. 189, p. 279.
- BAIRD, G. C. and BRETT, C. E., in press, Erosion on an anaerobic seafloor: significance of reworked pyrite deposits from the Devonian of New York: *Palaeogeography, Palaeoclimatology and Palaeoecology*.
- BRENNER, K. and SEILACHER, A., 1978, New aspects of the Toarcian Posidonia Shales: *Neues Jahrbuch fur Geologie und Palaontologie Abhandlungen*, v. 157, p. 11-18.
- BRETT, C. E. and BAIRD, G. C., 1982, Upper Moscow-Genesee stratigraphic relationships in western New York: evidence for erosive beveling in the Late Middle Devonian: *New York State Geological Association Guidebook*, 54th Annual Meeting, Buffalo, 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.
- BROADHEAD, R. F., KEPFERLE, R. C. and POTTER, P. E., 1982, Stratigraphic and sedimentological controls of gas in shale-example from Upper Devonian of northern Ohio: *American Association of Petroleum Geologists Bulletin*, v. 66(1), p. 10-27.
- BYERS, C. W., 1977, Biofacies patterns in euxinic basins; a general model, *in*, COOK, H. E. et. al., eds., *Deep-Water Carbonate Environments: Society for Economic Paleontologists and Mineralogists Special Publication*, 25, p. 5-17.

- CLARKE, J. M., 1901, Marcellus limestones of central and western New York: New York State Museum Bulletin, v. 49, p. 115-138.
- CONKIN, J. E. and CONKIN, B. M., 1984, Paleozoic metabentonites of North America: Pt. 1. Devonian metabentonites in the eastern United States and southern Ontario: their identities, stratigraphic positions, and correlations: University of Louisville Studies in Paleontology and Stratigraphy, v. 16, 135p.
- 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., 1957, Paleocology of the Middle Devonian of eastern and central United States, *in*, LADD, H. S., ed., Treatise on Marine Ecology and Paleocology: Geological Society of America Memoir, v. 67, p. 249-278.
- CORNELL UNIVERSITY, DEPARTMENT OF GEOLOGY, 1957, Geology of the Cayuga Lake Basin, Trip C: New York State Geological Association Guidebook, 31st Annual Meeting, Ithaca, p. 26-36.
- COTTRELL, J., 1972, Paleocology of a black limestone, Cherry Valley limestone, Devonian, New York: New York State Geological Association Guidebook, 44th Annual Meeting, Utica-Colgate Colleges, p. G1-G8.
- DENNISON, J. M. and HEAD, J. W., 1975, Sea-level variations interpreted from the Appalachian Basin Silurian and Devonian: American Journal of Science, v. 257(1), p. 1089-1120.
- DEWEY, J. F. and BURKE, K., 1974, Hot spots and continental break-up; implications for collisional orogeny: Geology, v. 2(2), p. 57-60.
- deWITT, W. and COLTON, G. W., 1978, Physical stratigraphy of the Genesee Formation (Devonian) in western and central New York: U.S. Geological Survey Professional Paper, 1032-A, 22p.
- 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 Papers, v. 201, p. 39-50.
- ETTENSOHN, F. R., and ELAM, T. D., 1985, Defining the nature and location of a Late Devonian-Early Mississippian pycnocline in eastern Kentucky. Geological Society of America Bulletin, v. 96, p. 1313-1321.
- FLOOD, R. D., 1983, Classification of sedimentary furrows and a model for furrow initiation and evolution: Geological Society of America Bulletin, v. 94(5), p. 630-639.
- FLOWER, R. H., 1936, Cherry Valley cephalopods: Bulletins of American Paleontology, v. 22, 95p.

- GOLDRING, W., 1943, Geology of the Coxsackie Quadrangle: New York State Museum Bulletin, v. 322, 374p.
- GRABAU, A. W., 1906, Guide to the geology and paleontology of the Schoharie Valley in eastern New York: New York State Museum Bulletin, v. 926, 386 p.
- GARY, M., McAFFEE, R., JR., and WOLF, C.L. (eds.), 1972, Glossary of Geology: American Geological Institute, Washington, D.C., 805 p.
- GRASSO, T. X., 1970, Paleontology, stratigraphy, and paleoecology of the Ludlowville and Moscow Formations (Upper Hamilton Group) in central New York: New York State Geological Association Guidebook, 42nd Annual Meeting, Cortland, p. D1-D22.
- 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, 158p.
- HECKEL, P. H., 1973, Nature, origin and significance of the Tully Limestone: Geological Society of America Special Paper, 138p.
- HOLLISTER, C. D., NOWELL, R. M. and JUMARS, P. A., 1984, The dynamic abyss: Scientific American, v. 250(3), p. 42-53.
- HUDDLE, J. W., 1981, Conodonts from the Genesee Formation in western New York: U. S. Geological Survey Professional Paper, 1032-B, 66p.
- HUDSON, J. D., 1982, Pyrite in ammonite-bearing shales from the Jurassic of England and Germany: Sedimentology, v. 27(5), p. 639-667.
- JOHNSON, J. G., 1970, Taghanic onlap and the end of North American Devonian provinciality: Geological Society of America Bulletin, v. 81, p. 2077-2106.
- JOHNSON, T. C., HALFMAN, J. D., BUSCH, W. H. and FLOOD, R. D., 1984, Effects of bottom currents and fish on sedimentation in a deep-water lacustrine environment: Geological Society of America Bulletin, v. 95, p. 1425-1436.
- 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.
- KARL, H. A., CARLSON, P. R., and CACCHIONE, D. A., 1983, Factors that influence sediment transport at the shelfbreak, in, STANLEY, D. J. and MOORE, G. T., eds., The Shelfbreak: Critical Interface on Continental Margins: Society of Economic Paleontologists Mineralogists Special Publication, v. 33, p. 219-231.

- KAUFFMAN, E. G., 1981, Ecological reappraisal of the German Posidonien-Schiefer (Toarcian) and the stagnant basin model, in . GRAY, J., BOUCOT, A. J. and BERRY, W. B. N., eds., Communities of the Past: Hutchinson and Ross Publishers, p. 311-381.
- KIRCHGASSER, W. T., 1981, Stop 15A - Taughannock Falls overlook, pp. 48-49, in, OLIVER, W. A. and KLAPPER, G., eds., Devonian Biostratigraphy of New York: International Union of Geological Sciences, Subcommittee on Devonian Stratigraphy, 69p.
- KIRCHGASSER, W. T., 1985, Ammonoid horizons of the Upper Devonian Genesee Formation of New York: legacy of the Genesee, Portage, and Chemung, in, WOODROW, D. L. and SEVON, W. D., eds., The Catskill Delta: Geological Society of America Special Paper, v. 201, p. 225-234.
- KLAPPER, G., 1981, Review of New York Devonian conodont biostratigraphy, in, OLIVER, W. A. and KLAPPER, G., eds., Devonian Biostratigraphy of New York: International Union of Geological Sciences, Subcommittee on Devonian Stratigraphy, Washington, D. C., p. 57-66.
- KRAMERS, W. J., 1970, The Centerfield Limestone (Middle Devonian) of New York State and its clastic correlatives: a sedimentologic analysis: Unpublished PhD. Dissertation, Rensselaer Polytechnic Institute, 335 p.
- LANDING, E. and BRETT, C. E., in press, Trace fossils and regional significance of a Middle Devonian (Givetian) disconformity in southwestern Ontario: Journal of Paleontology.
- LIEBAU, A., 1980, Palaobathymetrie und Okofaktoren: Flachmeer Zonierungen: Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, v. 160, p. 173-216.
- LINCOLN, D. F., 1897, Report on the structural and economic geology of Seneca County [New York]: New York State Geological Survey Annual Report, v. 14, p. 57-125.
- LUNDEGARD, P. D., SAMUELS, N. D. and PRYOR, W. A., 1980, Sedimentology, petrology and gas potential of the Brallier Formation: Upper Devonian turbidite facies of the central and southern Appalachians: U.S. Department of Energy, Morgantown Energy Technical Center, v. 5201-5, 220p.
- MAUSSER, H. F., 1982, Stratigraphy and Sedimentology of the Cleveland Shale (Devonian) in Northeast Ohio: Unpublished MSc. Thesis, Case Western Reserve University, 116p.
- McCAVE, I. N., 1973, The sedimentology of a transgression: Portland Point and Cooksburg Members (Middle Devonian), New York State: Journal of Sedimentary Petrology, v. 48, p. 484-504.
- McIVER, N. L., 1970, Appalachian turbidites, in, FISHER, G. W. et. al., eds, Studies of Appalachian Geology: Central and Southern New York. New York Interscience Pub., p. 69-81.

- OLIVER, W. A., 1983, Stop 20, Canoga Springs, Seneca Stone Co.. Quarry, p. 171. in, SORAU, J. E. and OLIVER, W. A., eds., Silurian and Devonian Corals and Stromatoporoids of New York: 4th International Symposium on Fossil Cnidaria, Washington, D.C., 180 p.
- PATCHEN, D. G. and DUGOLINSKI, B. K., 1979, Guidebook - Middle and Upper Devonian clastics, central and western New York State: Department of Energy, Eastern Gas Shales Project, West Virginia Geological and Economic Survey, Morgantown, W. Va., p. 167.
- REAVES, C. R., 1984, The Migration of Iron and Sulfur during the Diagenesis of Marine Sediments. Unpublished Ph.D. Thesis, Yale University, 413p.
- RICKARD, L. V., 1952, The Middle Devonian Cherry Valley Limestone of eastern New York: American Journal of Science, v. 250, p 511-522.
- RICKARD, L. V., 1975, Correlation of the Silurian and Devonian rocks of New York State: Map, Chart Ser., New York State Museum and Science Service, v. 24, 16p, 4 charts.
- RICKARD, L. V., 1981, The Devonian System of New York State: in, OLIVER, W. A. and KLAPPER, G., eds., Devonian Biostratigraphy of New York, Part 1: International Union Geological Sciences Subcommission on Devonian Stratigraphy, Washington, D.C., P. 5-22.
- RICKARD, L. V., 1984, Correlations of the subsurface Lower and Middle Devonian of the Lake Erie region: Geological Society of America Bulletin, v. 95, p. 814-828.
- SEILACHER, A., ANDALIB, F., DIETL, G. and GOCHT, H., 1976, Preservational history of compressed Jurassic ammonites from southern Germany: Neues Jahrbuch fur Geologie und Palaontologie Abhandlungen, v. 152, p. 307-356.
- SHOLKOVITZ, E., 1973, Interstitial water chemistry of the Santa Barbara basin sediments: Geochimica Cosmochimica Acta, v. 37, p. 2043-2073.
- SUTTON, R. G., BOWEN, Z. P. and McALESTER, A. L., 1970, Marine shelf environments of the Upper Devonian Sonyea Group of New York: Geological Society of America Bulletin, v. 81, p. 2975-2992.
- TANABE, K., INAZUMI, A., TAMAHAMA, K. and KATSUTA, T., 1984, Taphonomy of half and compressed ammonites from the lower Jurassic black shales of the Toyora area, west Japan: Palaeogeography, Palaeoclimatology Palaeoecology, v. 47, p. 329-346.
- THAYER, C. W., 1974, Marine paleoecology in the Upper Devonian of New York: Lethaia v. 7, p. 121-155.
- THOMSEN, E. and VORREN, T. O., 1984, Pyritization of tubes and burrows from Late Pleistocene continental shelf sediments off North Norway: Sedimentology, v. 31, p. 481-492.

- TUCKER, M.E., 1973, Sedimentology of Paleozoic pelagic limestones: the Devonian Griotte (southern France) and Cephalopodenkalk (Germany), in, HSU, K. J. and JENKYN, H. C., eds. Pelagic Sediments on Land and Under the Sea: International Society of Sedimentologists Special Publication 1, Blackwell Scientific Press, London, p. 71-92.
- UYENO, T. T., TELFORD, P. G. and SANFORD, B. V., 1982, Devonian conodonts and stratigraphy of southwestern Ontario: Geological Society of Canada Bulletin, v. 332, 55p.
- VAN DER VOO, R., FRENCH, A. N. and FRENCH, R. B., 1979, A paleomagnetic pole position from the folded Upper Devonian Catskill red beds and its tectonic implications: Geology, v. 7(7), p. 345-348.
- VAN DIVER, B. B., 1980, Upstate New York. Kendall/Hunt Geology Field Guide Series. Kendall/Hunt Publishing Co., Dubuque, Toronto, 276 p.
- WENDT, J. and AIGNER, T., 1985, Facies patterns and depositional environments of Paleozoic cephalopod limestones: Sedimentary Geology, v. 44, p. 263-300.
- WILLIAMS, S. H. and RICKARDS, R. B., 1984, Palaeoecology of graptolitic black shales, in, BRUTON, D. L., ed., Aspects of the Ordovician System: Palaeontological Contributions of the University of Oslo., v. 295, p. 159-166.
- WOODROW, D. L. and ISLEY, A. M., 1983, Facies, topography, and sedimentary processes in the Catskill sea (Devonian), New York and Pennsylvania: Geological Society of America Bulletin, v. 14, p. 459-470.
- 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: Society of Economic Paleontologists Mineralogists Special Publication, v. 33, p. 159-166.
- WOODROW, D. L., 1985, Paleogeography, paleoclimate, and sedimentary processes of the Late Devonian Catskill Delta, in, WOODROW, D. L. and SEVON, W. D., eds., The Catskill Delta: Geological Society of America Special Paper, v. 201, p. 51-63.

ROAD LOG FOR MIDDLE DEVONIAN CORRASIONAL DISCONTINUITIES
IN THE CAYUGA LAKE AREA

Cumulative Mileage	Miles from Last Point	Route Description
0.0	0.0	Begin trip at junction of Route 13-34 and Routes 79, 89-96 in town of Ithaca. Turn right (north) on Route 79-89-96.
0.2	0.2	Junction of New York Routes 89 and 96. Turn right (north) on Route 89.
0.2	0.8	Leave town of Ithaca, proceed north along west side of Cayuga Lake.
1.4	0.4	Tremain State Marine Park
1.5	0.1	Outcrops of Sherburne siltstone (Genesee Formation) on left.
3.5	2.0	Town of Ulysses.
4.6	1.1	Glenwood Creek; falls over Fir Tree beds (lower Genesee Formation) just east of road.
7.1	2.5	Cross Willow Point Creek; good exposure of Tully Limestone and Windom Shale.
9.2	2.1	Cross mouth of Taughannock Creek at Taughannock State Park. To the left (upstream) from the road bridge a low waterfall is visible; this section includes the Tully Formation (limestone) overlying the uppermost Hamilton Group (Windom shale); we will examine the gorge section upstream from this site.
9.4	0.2	Junction with road to Taughannock Falls overlook; turn left (west).
10.2	0.8	Parking area for Taughannock Falls overlook (Stop 1); pull off and walk down steps to viewing area.

STOP 1. TAUGHANNOCK FALLS

Location: Taughannock Falls Park overlook on north side of Taughannock Creek about 1 km southwest of N.Y. Route 89 town of Ulysses, Tompkins Co., N.Y. (Ludlowville 7.5' Quadrangle).

References: Cornell University Department of Geology (1959); deWitt and Colton (1978); Kirchgasser (1981, this volume).

Description: This overlook provides a spectacular view of the 66 m (215') high Taughannock Falls (purportedly the highest falls east of the Mississippi), a hanging valley at the end of about a mile long

post-glacial gorge (Fig. 12). The configuration of the falls is controlled by prominent joints; it is held up by resistant siltstone beds in the Sherburne Member.

In the early days of the silver screen, this locality and nearby glens were used as backdrops for early westerns, owing to the spectacular canyon-like walls in these gorges. Another interesting side light of this outcrop is the occurrence of thin (1-2 cm) dikes of Mesozoic kimberlite-like (actually alnoite) intrusive rock that crop out in the stream bed at the base of the falls (see Kay and Foster, this volume).

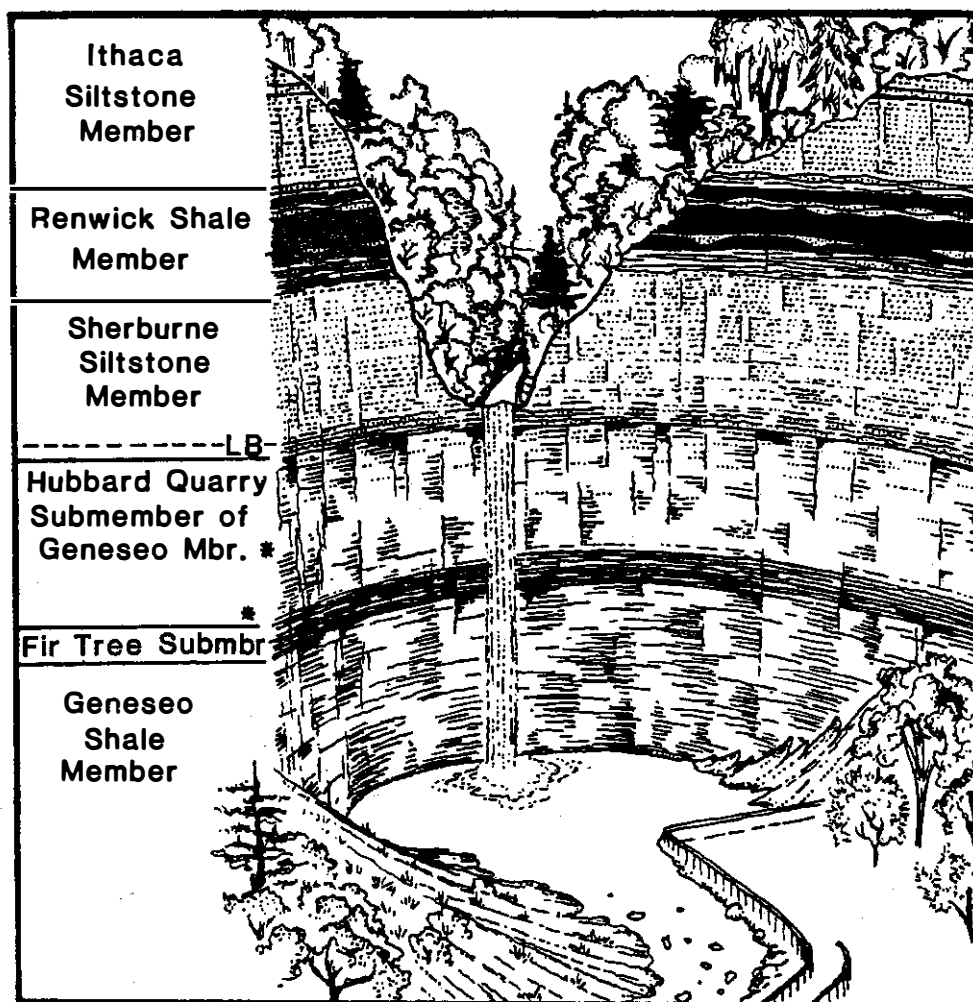


FIGURE 12.-- Great falls on Taughannock Creek showing key stratigraphic divisions and the positions of the Fir Tree and Lodi Submembers. Terminology used in figure and in text is modified from existing usage (see asterisks); the new designations (Fir Tree and Hubbard Quarry Submembers of the Geneseo Member) for the middle-upper part of the falls face correspond, respectively, to the Penn Yan Shale Member of deWitt and Colton (1978), Patchen and Dugolinski (1979), and to the lower part of the Sherburne Siltstone Member (see Kirchgasser, 1981). In this figure, the Renwick Member is shown as a black band to accentuate the lenticular siltstone beds distinctive to this interval.

Gorge walls, up to 120 m (200-400') high, expose shales and siltstones of the lower Genesee Formation of late Givetian to early Frasnian (latest Middle to earliest Late Devonian age). Depending upon the source, three or four members of the Genesee Formation are recognized at this locality. Black shales of the Genesee Member form the lowest exposed unit; the plunge pool level is about 3.8 m above the base of this member, the gradational lower contact with the Tully Formation being exposed downstream. The upper contact is about halfway up the face of the falls, 27 m (90') above the plunge pool and can be recognized by a change in coloration and bedding. The Genesee is nearly barren, platy to fissile black shale; it is largely covered by talus at the base of the gorge walls.

The overlying 26 m (80') unit in the falls face is readily recognizable as a lighter grey-weathering interval with several prominent bands (of silty limestone) near the base and a major system of smooth, vertical joints within the middle and upper parts of this division. This interval has been termed Penn Yan shale (deWitt and Colton, 1978; Patchen and Dugolinski, 1979) or simply lower Sherburne siltstone (Kirchgasser, 1981). In actuality, neither term is entirely appropriate as these shales are correlative with upper Genesee beds below the base of the Penn Yan or Sherburne elsewhere which has been placed at the Lodi Limestone bed. Recent study shows that the lower, 6-7 m (19-22') thick part of this unit, characterized by dark brown, rhythmically-bedded, silty limestone layers corresponds to a usually thin interval of auloporid coral-bearing carbonates termed the Fir Tree submember of the Genesee Member (Baird and Brett, 1986). In this particular area, however, the Fir Tree Submember is very thick and the limestone beds are very sparsely fossiliferous and seemingly turbiditic; this unit is the expanded equivalent of much thinner, condensed, and auloporid-rich, limestone facies to the north (see Figs. 6, 7, 13: stops 2 and 3). Above the Fir Tree interval is approximately 22 m (70') of silty shale which is largely black in the lower portion but which becomes progressively more silty towards the top. This sequence (Hubbard Quarry shale submember of the Genesee Member), like the Fir Tree below it, thins markedly to 4 m (13') at the type section, Hubbard Quarry (Stop 2) near Interlaken. Recently, conodonts of the disparalis zone (upper Givetian) have been obtained from the top of the Hubbard Quarry shale interval at the Lodi type section on Mill Creek (W.T. Kirchgasser pers. comm.). Ancyrodella rotundiloba, indicative of the lower asymmetricus zone, now accepted as the base of the Frasnian stage, has been observed from shales immediately overlying the Lodi horizon in westernmost Ontario County, N.Y. (Kirchgasser, pers. comm.). This indicates that the Middle/Upper Devonian boundary closely overlies the Lodi bed within the lowermost Penn Yan or Sherburne members. At Taughannock Falls the Middle/Upper Devonian boundary is probably at or near the lip of these falls.

Above the Hubbard Quarry submember is the 26 m (80') Sherburne siltstone member; the base of this unit can be seen as an abrupt change from the smooth joint-faced Hubbard Quarry interval to an irregularly-bedded and more resistant siltstone sequence about 9 m (30') below the falls lip. Although the lowermost Sherburne is obviously inaccessible at this locality, the basal 3 meters (10') of the member includes the silty, auloporid coral-rich interval of the Lodi unit, as can more easily be seen

beneath the Route 89 overpass bridge at a small, nearby creek (Loc. GEN 4 of deWitt and Colton, 1978) 0.65 miles northwest of Taughannock Point. In this region, the Lodi is composed of bioturbated calcareous siltstone which yields auloporids, small bivalves, and the diagnostic goniatite Ponticeras perlatum.

In the upper cliffs (about 11 m (35') above the level of the falls lip) the Renwick Shale Member forms a distinctive marker. It consists of dark grey-weathering shales with thick, light grey, highly convoluted turbidite siltstones. The Renwick Member, about 10 m (32') thick at this location, is considered to be an important stratigraphic marker. It consists of interbedded silty, black shale which is distinctly interbedded with lenticular and often channeloid sandstone bodies which appear to be of turbiditic origin.

The highest beds, overlying the Renwick to the top of the gorge are flaggy, brownish grey-weathering siltstones of the Ithaca Formation.

Interpretation: The visible Genesee section (lower middle Genesee-to-lower Ithaca) stratigraphic succession at this falls is equivalent to approximately 2 meters (6.5') of Genesee-Penn Yan section at Cayuga Creek in eastern Erie County; the tremendous southeastward expansion of this sequence shows the influence of Catskill Delta progradation in this basin setting.

The Genesee represents a major deepening event associated with the Taghanic onlap event. This transgressive event, occurring near the end of the Middle Devonian is recognizable nearly worldwide and is almost certainly eustatic in nature. In New York it is associated with major black shale deposition indicating anoxic bottom waters. The Fir Tree and Lodi intervals appear to record brief interruptions in the anoxia allowing colonization of the sea floor by a low diversity benthic fauna including aulopodid corals and small brachiopods and mollusks, whereas the Hubbard Quarry, parts of the Sherburne and Renwick reflect a return to more dysaerobic, perhaps deeper, water conditions. Superimposed upon these fluctuations of the aerobic/anaerobic water masses was a general increase in the impact of silty turbidites, associated with progradation of the Catskill Delta.

At this locality the 6 to 7 meter (19-22') thick Fir Tree section and the overlying 20 to 22 meter (65-70') thick Hubbard Quarry shale interval are greatly expanded equivalents of far thinner deposits some 6 miles to the north (see text) and stops 2 and 3. The Fir Tree submember thickens exponentially southward from the latitude of Interlaken, King Ferry, and Genoa and undergoes a profound facies change from a compact, aulopodid-rich, concretionary limestone bed in the north to a thick splayed succession of turbiditic concretionary "ribbon" limestone beds at Taughannock Falls (Figs. 5-7, 13). South of this locality, the Fir Tree interval continues to thicken, and this unit loses its identity into Sherburne facies before this interval dips below surface view, just north of Ithaca. The Lodi interval remains relatively thin through the Seneca, Cayuga, Salmon Creek, and Owasco Valleys, though it becomes coarser and, eventually, quite shell-rich east of the Owasco Valley.

Cumulative	Miles	
11.0	0.8	Return to Route 89, turn left (north).
11.75	0.75	Bridge over Trumansburg Creek; a large waterfalls east of the bridge exposes about 4 m (13') of interbedded limestone and shale at the Fir Tree position.
	2.4	Pull-off on right overlook on Cayuga Lake, note Lake Ridge Point and Milliken Power Station on east side of lake.
14.15	1.1	Little Point Road. Little Point Creek shows about 2.4 m (7') of Fir Tree interval (slabby limestones with shale interbeds, 8 m (26') of Hubbard Quarry shale, and 3 m (10') of Lodi aulopodid bearing calcareous siltstone.
15.25	0.85	Entrance to Rocky Dock Campsite on right. Rocky Dock Creek near campsite ground shows high waterfalls capped by Sherburne siltstone Fir Tree is 1.6 m (5.5') thick.
16.1	0.95	Bergen Beach Road on right; turn right (east) for Stop 2.
17.15	0.1	Outcrop of Sherburne siltstone in road ditch.
17.43	0.28	Pull off for Stop 2, on left side of road.

STOP 2 UNNAMED RAVINE NEAR BERGEN BEACH POINT

Location: Unnamed ravine south of Bergen Beach, 0.5 mi. west (upstream) of Bergen Beach Point, town of Covert, Seneca Co. (Trumansburg 7.5' Quadrangle).

Description: The waterfalls section on this small stream displays strata within the upper Genesee Member and the lowermost Sherburne Member of the Genesee Formation. Lower rock divisions (Windom Shale Member and Tully Formation) exposed both downstream and along the adjacent lake shore will not be examined here. This section is a greatly thinned lateral equivalent of the section exposed in the Taughannock Falls face; approximately 70 meters (215') of that section below the Lodi bed has thinned to less than half of that thickness here with most of the northward thinning taking place in the Fir Tree and Hubbard Quarry intervals (compare figures 12 and 13 of road log).

In the gently sloped floor of this creek, hard black, fissile to platy, Genesee black shale is exposed. The first prominent lip or ledge in the lower falls face, however, marks the position of the Fir Tree Limestone submember which is separated from the overlying, falls-capping basal Sherburne (Lodi) section by 8.5 meters (27') of the Hubbard Quarry Shale Submember. At this locality, the upper part of the Hubbard Quarry

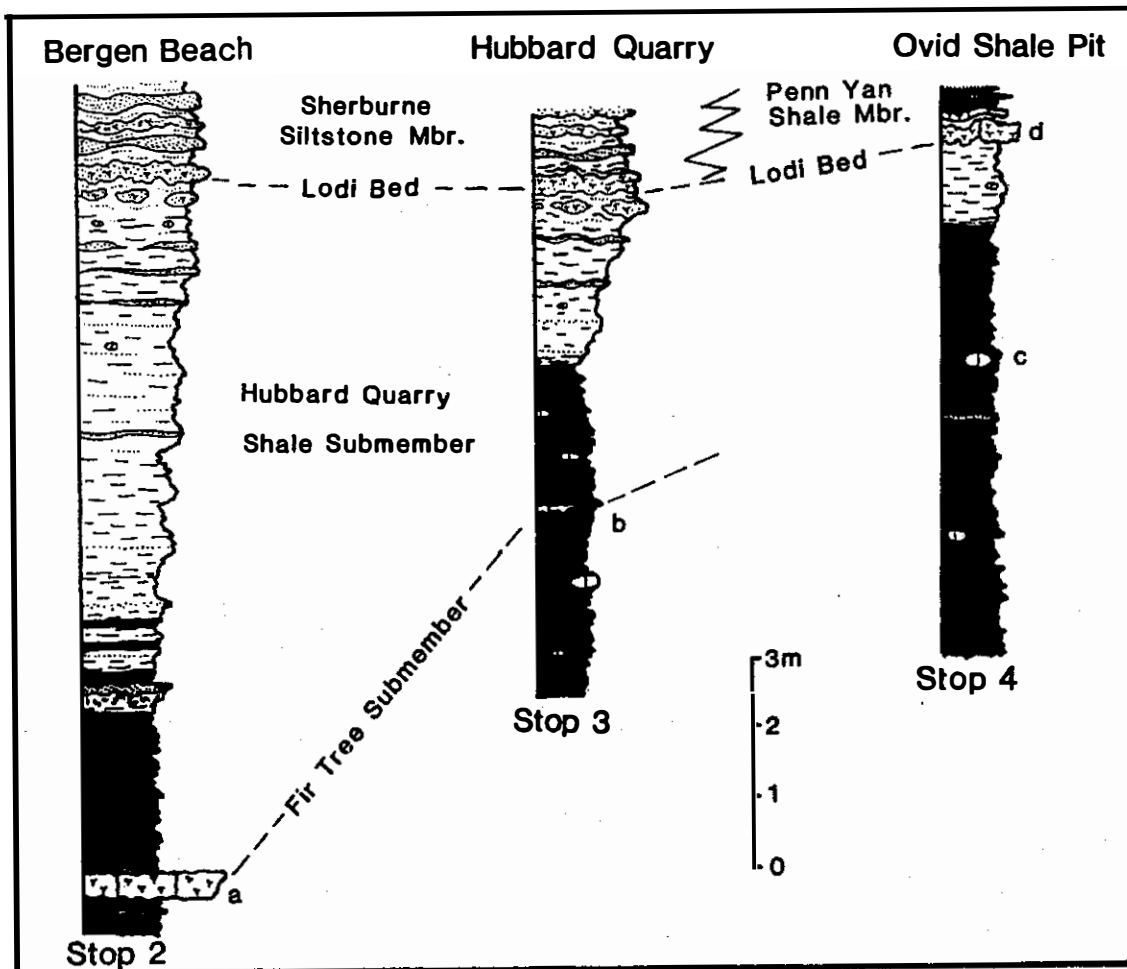


FIGURE 13.--Field trip stops 2-4: lateral changes within the Fir Tree-Lodi stratigraphic interval. Note northward truncation of Fir Tree Submember by discontinuity flooring Hubbard Quarry Submember. Units include: a, 0.5 meter-thick, aulopoid coral-rich bed of Fir Tree Limestone Submember; b, horizon of detrital pyrite and nearly completely truncated Fir Tree layers; c, concretionary horizon within undifferentiated Genesee black shale which is probably correlations with the Fir Tree Submember; d, calcareous Lodi bed, which resembles closely the Fir Tree layer at stop 2 (see discussion in text: Figs. 5-7).

submember and silty, hard, auloporid-rich strata of the Lodi Bed are inaccessible; we will observe this part of the section at STOP 3.

The Fir Tree Submember is markedly different at this section as compared with Stop 1; at Taughannock Falls and adjacent creeks the Fir Tree exceeds 5 meters (16') in thickness and consists of an alternation of dark shale and brown, concretionary to distinctly turbiditic, silty limestone beds. These sparsely fossiliferous "ribbon" limestones converge exponentially northward to form a thin, massive auloporid coral-rich impure limestone bed in this region (Figs. 6, 13). The allodapic limestone facies of the Trumansburg-Lansing area is replaced northward by increasingly fossil-rich, and bioturbated facies which is essentially identical to that of the Lodi Bed in the Seneca Valley region. The Fir Tree biota, through conspicuously auloporid coral-rich, is not really very diverse; we believe that the 0.6 meter (1.7')-thick Fir Tree Bed at this locality records an episode of reduced sediment supply and turbidity in a dysaerobic or minimally aerobic bottom setting. This would explain the absence of stereolasmatid corals, large brachiopods, and bryozoans in condensed Fir Tree deposits.

One feature of the Fir Tree Submember, however, stands out; its upper contact with black, laminated, silty shale beds of the lower Hubbard Quarry shale interval is sharp and planar. This marks the position of a submarine discontinuity, which first appears about 2.5 miles south of this locality. This break increases in magnitude northward along three separate southeast-northwest transects in the Seneca, Cayuga and Salmon Creek valleys, eventually overstepping the condensed Fir Tree deposit in each valley (see text, Stop 3: Figs. 5, 6, 13). This pattern of erosional overstep is strikingly similar to that observed at the Lodi level further to the northwest in the Seneca Lake Valley. This discontinuity, overlain by black Hubbard Quarry shale is distinctive for thin (0-0.8 cm-thick) accumulations of reworked pyrite, orbiculoide fragments, and occasional pieces of bone; this material can be skimmed up with a chisel from discontinuous debris lenses at the top of the Fir Tree Falls bench.

Above the Fir Tree Bench is a 2.5 meter (8')-thick sequence of lower Hubbard Quarry black shale facies which contains numerous Leiorhynchus quadricostata? and Orbiculoidea lodiensis on many bedding planes; above this level, the Hubbard Quarry Submember displays an upward-coarsening and upward-shallowing facies succession to the base of the Lodi Bed. Upper Hubbard Quarry beds are distinctly silty and ledge; these strata are usually variably bioturbated and diminutive molluscan material as well as occasional auloporid corals can be found at some levels.

At the top of the lower Hubbard Quarry black shale sequence, 2.5 meters (8') above the Fir Tree bench, is another erosional discontinuity which is marked by reworked pyrite. This is associated with a current-rippled siltstone layer which we informally term the Bergen Beach bed; this unit can be traced into surrounding gullies, and it may work the approximate position in this section of still a third Lodi-like unit which is developed within the Hubbard Quarry interval in the Seneca Lake Valley. Sectioned specimens of this siltstone bed at this locality show spectacular density-shape sorting of the pyrite grains into distinctive laterally-segregated lentils on the scour surface beneath the quartz silt.

17.7	0.38	Reverse route and return to NY87, turn right (north) and proceed.
18.2	0.6	Unnamed creek; here Fir Tree is 45 cm (1.5') thick and overlain by a pyrite layer up to 3 cm (1.5") thick.
18.3	0.1	Road to Interlaken on left.
18.5	0.2	South fork Interlaken Creek.
18.6	0.1	North fork Interlaken Creek; Fir Tree bed is compact 6" ledge here.
18.8	0.2	Interlaken Beach Road on right.
18.85	0.05	Lively Run Creek. Exposure of Lodi bed; Fir Tree level is inaccessible; prepare to stop.
18.95	0.1	Road into Hubbard Shale quarry (STOP 3) on right; pulloff on side of NY 89.

STOP 3 HUBBARD SHALE QUARRY

Locality: Small shale pit on east side of N.Y. Rt. 89 and about 0.3 km north of bridge over Lively Run Creek, town of Covert Seneca County, N.Y. (Sheldrake 7.5' Quadrangle).

References: Cornell Univ., 1951; deWitt and Colton, 1978; Kirchgasser, 1981; Van Diver, 1980; Baird and Brett, 1986; Hubbard Quarry Shale type section.

Description: The floor of this shale pit exposes very dark grey to black, platy shale of the Genesee Member (Genesee Formation). A layer of tabular, rusty stained carbonate concretions, containing auloporphid corals is exposed near the lowest (northeast) end of the quarry. This is the northern feather edge of the Fir Tree limestone Submember which is represented at Taughannock Falls by about 5-6 m (16'-19') of alternating tabular limestones and dark shale. Here the unit is condensed and has been almost completely truncated by submarine erosion (Fig. 13). Note the discontinuous sheet accumulation of reworked pyrite debris and orbiculoid fragments that marks the position of the discontinuity that cuts out the Fir Tree deposit. This same discontinuity can be followed locally within the undifferentiated Genesee black shale succession north past the Fir Tree bevelled margin; reworked pyrite and bone debris occurs locally, concentrated at the discontinuity position, usually as a lag concentration at the base of a bed of rippled, winnowed siltstone. Similar, nearly bevelled, Fir Tree deposits can be seen across Cayuga Lake southwest of King Ferry and in the Salmon Creek Valley just south of Genoa. This margin cannot be seen in the Seneca Lake Valley because it is below lake level north of the Fir Tree anticline, but we suspect that its position should be just south of Baskin and Caywood points on that lake.

The overlying black, fissile shale, here about 4.3 m (14') thick, has been designated the Hubbard Quarry submember (Baird and Brett, in prep.),

it contains bedding planes covered with the flattened specimens of Leiorhynchus quadricostatum and Orbiculoidea lodiensis. Two or three horizons of large septarian concretions, containing calcite and barite filled fractures, appear in the upper part of this division. The lower 2-2.5 meters (6.5-8.0') of the Hubbard Quarry Submember is a fissile to platy black shale. The upper part of this unit, below the Lodi beds, consists of grey to olive grey, silty mudstone which contains several thin siltstone beds; this interval, though poor in body fossils, is variably bioturbated suggesting deposition under dysaerobic conditions. The Bergen Beach bed of Stop 2 is not evident here.

The Hubbard Quarry shale is overlain by a nodular calcareous siltstone with very abundant auloporidae corals, which is the local representation of the Lodi Submember, marking the base of the Sherburne-Penn Yan Member (Fig. 13). As noted at Taughannock, this bed lies slightly below the Givetian/Frasnian (Middle/Upper Devonian) boundary. The Lodi grades northwestward into a more prominent and more fossil-rich concretionary silty limestone bed in the vicinity of Lodi and Ovid (see STOP 4: Fig. 13) before it, too, is bevelled below a black shale tongue still farther to the northwest.

		Return to vehicles; continue north on NY 89.
19.45	0.5	North Interlaken town line.
20.25	0.8	Kidders Gully north fork. Remnant pods of Fir Tree beds found here. Hubbard Quarry Shale is 4 m (13 ft.) thick.
20.65	0.4	South fork Sheldrake Creek in large water falls east of Rt. 96, Fir Tree bed is absent, Lodi caps falls.
20.95	0.3	North fork Sheldrake Creek
21.40	0.45	Road to Sheldrake on right.
20.6	0.2	Unnamed creek with good Hamilton exposures.
22.1	0.5	Powell Creek
22.55	0.45	Groves Creek. Tully/Window exposure is below road, in small quarry-water falls area.
22.85	0.3	Barnum Creek and shale pit in Window Shale Member on left. Prepare to turn.
22.95	0.1	Junction Route 89 and Co. Rt. 138 on left; turn left.
24.75	1.8	Junction Route 96, turn right (west).

26.75	2.0	Junction Route 96/96A turn right (north) on Rt. 96.
27.75	1.0	Junction Hayt Corners Road/West Blaine Road; turn left (west) onto West Blaine Road for STOP 4.
28.50	0.75	Gravel road leading into shale pit on left (south) side of West Blaine Road; lay down cable gate and drive in to end of road.

STOP 4 OVID SHALE QUARRY

Location: Shale pit 1.2 miles northwest of Ovid, Seneca County. North-south entrance road to pit is on the south side of West Blaine road 0.75 mile west of the Rt. 96-414/west Blaine road intersection in the town of Ovid. Ovid 7.5' Quadrangle.

References: This is locality OV-16: deWitt and Colton (1978).

Description: This borrow pit is excavated mainly into hard, fissile to platy, black shale facies of the Geneseo Member; the uppermost 10 meters (30') of this unit is visible here as is the basal contact with the overlying Penn Yan Shale Member (Fig. 13). This contact corresponds to the base of the 0.4-0.6 meter (1.2-1.8')-thick Lodi limestone bed which is exposed at the top of the south and east walls of the pit. The Lodi bed is easily seen in loose blocks around the quarry; it is composed of nodular concretionary grey limestone masses with associated calcareous, silty, gray mudstone. This unit contains framestone thickets of aulopodid corals which probably partly control the form and distribution of concretions within the bed. The Lodi fauna in this region is richer than at Stop 3; the aulopodid growth is more profuse here and additional taxa, including the brachiopod Pseudoatrypa devoniana, the gastropod Palaeozygopleura as well as numerous small bivalves and pelmatozoan debris, can be collected here. The Lodi here is overlain by rusty-weathering, silty, black shale facies comprising higher Penn Yan beds.

Discussion: This section displays an uncanny resemblance to those at stops 2 and 3; at those places an aulopodid rich unit was developed within a black shale sequence much like what we see at this stop. The deception here is that the aulopodid-rich beds at these stops seem to be all one and the same. In reality, we are looking at a repetition of the Fir Tree facies motif at the horizon of the Lodi; at this locality no Fir Tree beds are present and the Lodi has changed northwestward from a non-descript, rubbly siltstone deposit at Stop 3 to a more impressive fossil-rich ledge resembling the Fir Tree layer near its northern bevelled margin (Fig. 13).

This similarity becomes even more impressive due to the fact that the Lodi bed at this stop is close to its northwestward erosional margin; the Lodi is completely absent directly across Seneca Lake in localities near Dresden. An imaginary projection of the strike of the Lodi erosional margin (Fig. 8), based on its northeast-southwest alignment near Himrod west of Seneca Lake, would place the Lodi erosional limit less than a mile northwest of this pit.

As with the post-Fir Tree discontinuity, the erosion surface above the Lodi is marked by a discontinuous lag layer of reworked material which underlies black to dark gray, transgressive facies. At this locality a one to three centimeter (0.5"-1.5")-thick layer of transported aulopoid coral debris, pelmatozoan fragments, and subordinate detrital pyrite marks this contact at the top of the Lodi. In the vicinity of Himrod, this surface is marked by a discontinuous lag accumulation of reworked pyrite with little or no associated carbonate allochems.

Three meters (10') below the Lodi Bed in this section is a band of septarial concretions near the top of a meter-thick interval of dark gray chippy shale which is not as black as Geneseo beds above and below. We believe that the sharp upper contact of this interval with laminated black shale facies corresponds to the post-Fir Tree discontinuity within the Geneseo Member proper (Fig. 13). This contact shows that what may, at first, appear to be a homogenous and continuous black shale sequence may, in actuality, be a stacked, discontinuous succession of black shale packages bracketed by numerous internal erosion surfaces.

Return to vehicles and retrace route to

29.5	1.0	Junction Route 96-414. (<u>To continue on main route:</u> turn left (north) onto Route 96-414 and proceed for 1.6 miles to the junction of Route 96/Route 414 and turn right (north) on Route 414; then continue north for 0.45 miles to junction of Bromka Road where log for Optional Stop ends; route continues from that point. <u>To go to the optional stop:</u> follow the log below).
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LOG FOR OPTIONAL STOP

0.0	0.0	Go straight across intersection of 96-414 staying on West Blaine Rd. which becomes Hayt Corners Road.
4.60	1.6	Hayt Corners; continue straight eastward.
2.60	1.0	Hayt Corners Road bends sharply to the left (north); follow.
3.75	0.75	Intersection Stout Road; continue straight (Hayt Corners Road changes name to Iron Bridge Road.)
3.60	0.25	Road bends sharply to the left (west).
3.7	0.1	Road bends sharply to the right (north).

- | | | |
|-----|-----|--|
| 3.8 | 0.1 | Cross first unnamed creek. |
| 4.4 | 0.6 | Cross second unnamed creek; prepare to turn right into small gravel road to shale pit adjacent to creek. |

- OPTIONAL STOP. POPLAR BEACH SHALE PIT

Location: Shale borrow pit bordering the east side of Iron Bridge Road 0.7 mile southwest of Poplar Beach, Town of Romulus, Seneca County; pit also borders north branch of an unnamed creek which flows into Poplar Beach. Ovid 7.5' Quadrangle.

References: Baird, 1981.

Description: This shale pit is developed in medium to dark gray, chippy mudstone facies of the Wanakah (=King Ferry) Shale Member (Ludlowville Formation: Hamilton Group). This shale interval is sparsely fossiliferous and nearly homogeneous, with the sole exception of a layer of reworked calcareous hiatus-concretions which can be easily sampled on the service road leading into the pit and from the upper parts of the shale banks within the pit.

Discussion: This stop is included to show the great difference between submarine discontinuities developed under anaerobic or minimally dysaerobic conditions and those produced in aerobic settings. This discontinuity is one of two very similar horizons which were mapped within the King Ferry Member as part of a study of mechanical and bioerosional processes on a regionally sloped, mud-floored, Devonian sea floor (for details see Baird, 1981; Baird and Brett, 1981: N.Y.S.G.A. Binghamton Meeting: Discussion on road log). At this locality, we merely wish to emphasize that infaunal organisms play a disproportionately greater role in the erosion process on oxygenated substrates owing mainly to their burrowing and boring activity. It should be noted also that burrowing animals may erase sedimentary discontinuities in unconsolidated or minimally consolidated muds; this commingling or thorough mixing of the older and younger sediments changes the discontinuity from a discrete contact into a stratomictic interval of scrambled mud, shells prefossilized debris, and reworked concretions or small nodules.

At this locality, the level of hiatus-concretions and associated shell hash (Barnum Creek Bed) marks the position of a stratomictic erosional discontinuity; there is no obvious erosion surface associated with these nodules-rather the hiatus-concretions almost "float" in a slush of burrowed shell debris and mud. This is a good collecting stop for the bored and bioencrusted hiatus-concretions. Epizoans on the nodules include auloporid corals, the rugose coral Stereolasma, ctenostome bryozoans, and occasional pelmatozoan holdfasts. Distinctive flask-shaped borings are abundant on some nodules. Scratch marks on nodule exteriors, produced by burrowers colliding with still-buried concretions, are commonly found at this locality.

Return to Iron Bridge Road and turn right
(north).

4.75	0.35	T-junction with Swick Road, turn left (west).
5.70	0.95	T-junction with Marsh Corner Road, turn right (north).
5.75	0.05	Cross Big Hollow Creek.
5.95	0.2	Junction Bromka Road, on left, turn left (west).
Total		
7.60	1.65	Junction Route 414; turn right (north) and continue on main route.
		END OF OPTIONAL STOP ROUTE
		(Add 7.6 miles to route for extra stop)

30.55 (36.1)	2.05	Junction Bromka Road (end of optional stop route).
35.7	5.15	Junction Rt. 336; Peter Witmer historic farm.
36.1	0.4	Village of Fayette, cross Poorman Road; (a turn to left leads to Fayette town shale pit, a well known Centerfield/Levanna section 0.3 miles west of this junction). Continue north on Rt. 414.
38.5	2.4	Junction Yellow Tavern Road (Co. Rt. 121) turn right.
38.9	0.4	Note stone farm house on left.
39.1	0.2	Road bears right.
39.8	0.7	Entrance to Warren Brothers, Seneca Stone Quarry (STOP 5), on left; turn left into yard by office to obtain clearance to enter.
40.3	0.5	Proceed into quarry on gravel road, turn left on side spur; park near dump piles on south berm of quarry.

STOP 5 SENECA STONE QUARRY

Locality: Large quarry of Warren Brothers Co., 4 km SSE of Seneca Falls, just north of Yellow Tavern Road 1.5 km west of Canoga Springs, Seneca Co., N.Y. (Romulus 7.5' Quad.).

References: Oliver (1983); Rickard (1984); Conkin & Conkin (1984).

Description of Units: This active quarry displays an outstandingly complete sequence from the base of the Oriskany sandstone, through the complete Onondaga Formation and to the base of the overlying Marcellus Formation of the Hamilton Group. Oriskany Sandstone and its unconformable

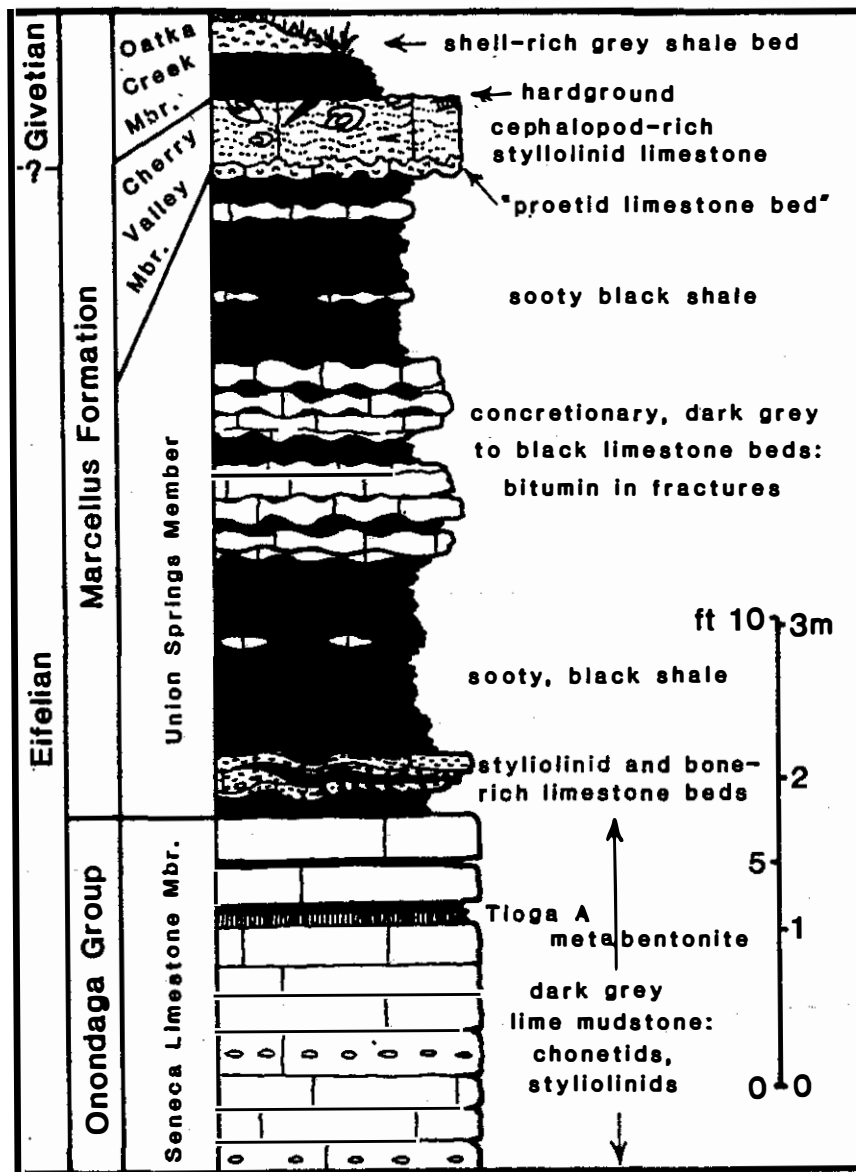


FIGURE 14.--Uppermost Onondaga and lower Marcellus strata at the Warren Brothers Seneca Stone Quarry. Key units and beds shown in figure are discussed in text. Note prominent bone-rich bed ("Bone Bed 7" of Conkin and Conkin, 1984) in the basal Union Springs Shale and conspicuous corrasional hardground on the top of the Cherry Valley Limestone Member.

contacts can be observed in the floor of the quarry; four members of the Onondaga, including ash layers are variably well exposed in the east wall of the quarry along an access road ramp. The lower Hamilton sequence including (in 1986) an excellent dip slope exposure of the top of the Cherry Valley Limestone, is well exposed on the south rim of the quarry. Considerable structure is visible in the walls of the quarry including minor gentle folding and a north-directed thrust fault which places Seneca Member over Marcellus black shales on the southeast side of the quarry. Our attention here is directed to the uppermost beds in the quarry, though many features within lower quarry units are worth the effort of a return trip.

Uppermost Onondaga and Marcellus Stratigraphic Units

Onondaga Group: Seneca Limestone Member

The highest division of the Onondaga Limestone includes 8.5 m (26') of dark gray to nearly black, micritic limestone which is separated from the underlying Moorehouse Member by a distinctive, 20 cm (8")-thick, cream-colored soft clay layer which is the expression of the middle Tioga ash bed which is termed the Tioga B layer (Rickard, 1984) or the Onondaga Indian Nation Metabentonite using terminology of Conkin and Conkin, 1984. The Seneca Member is a moderately fossiliferous wackestone with some chert nodules, chonetid brachiopods, dalmanitid trilobites, and gastropods in its lower part, but it is distinctly, darker, more argillaceous, and sparser in macrofossils towards the top; in the uppermost beds only a meager dysaerobic biota of Styliolina shells, diminutive chonetids, and the burrows Planolites and Chondrites is observed. The Seneca Member appears to grade upward almost continuously into the overlying Union Springs Member of the Marcellus Formation. The overall Moorehouse to Union Springs stratigraphic succession records a major transgression in this region; Moorehouse and lowermost Seneca aerobic facies is succeeded by higher dysaerobic Seneca beds which, in turn, pass upward into minimally dysaerobic to anaerobic Union Springs deposits (Figs. 3, 14). This transgression was probably eustatic in nature (see Johnson et al., 1985) and timed with the introduction of a considerable amount of siliciclastic mud (although much of the Union Springs is still carbonate rich and technically a very argillaceous, black limestone). In most areas of New York both east and west of the Cayuga Lake meridian, the Onondaga-Marcellus contact is unconformable and probably erosional, but here, near the presumed basin center it appears conformable. The overlying Union Springs muds reflect major uplift of Acadian source terranes, and the tectonism may have been propagated westward to form minor diastrophic uplift of the Onondaga, prior to subsidence.

About 62 cm (2') below the top of the Seneca facies succession is a second, yellow-weathering ash layer which is designated as the Tioga A bed (Rickard, 1984) or Tioga "sensu stricto" (Conkin and Conkin, 1984); on fresh, backpiled slab heaps along the quarry rim, one can often find crumbly, micaceous pieces of this ash mixed in with the other darker rock fragments. Both the Tioga A and B ash beds produce distinctive rust-staining on the quarry walls due to weathering and their levels can be seen easily from the quarry rim.

Hamilton GroupMarcellus FormationUnion Springs Shale Member

The Seneca Member is overlain by about 4.3 meters (13') of sooty, black, fissile shale which contains numerous brown-black, concretionary limestone beds, as well as thin Styliolina packstone layers near the top and base of the unit (Fig. 14). The biota of this unit is of very low diversity; the 1mm-long conical shells of Styliolina form the main component of tractional hash layers, and several other taxa including the brachiopods Ambocoelia and Leiorhynchus, the bivalve Pterochaenia, and cephalopods occur only sparingly in this interval. The Union Springs is distinctly sooty and fractures, along with the numerous joint and fracture surfaces within limestone beds, are filled with pyrobitumen. Thin bone-rich beds occur within a 15-20 cm (6"-8")-thick interval of Styliolina packstone layers just above the base of the Union Springs. This layer, designated "Bone bed no. 7" by Conkin and Conkin (1984) is a widespread key marker in the Union Springs Member; we have traced this unit from the Jamesville Quarry near Syracuse to the General Crushed Stone ("Five Points") quarry northwest of Lima, Livingston County (Fig. 3). Locally, this bed displays spectacular concentrations of onychodid teeth, placoderm armor, and spines, as can be seen at the Jamesville quarry near Nedrow. Bone beds such as this mark diastems and possibly even larger discontinuities within the black shale; this pattern is very similar to the style of submarine erosion which we observed in the Genesee Formation. Back-piled slabs of this bone-rich layer can be observed at this stop. The seemingly gradational nature of the Seneca-Union Springs contact in this region presents some difficulties in defining the top-Onondaga contact; Rickard (1984), places the Seneca-Union Springs boundary at the base of the upper ash bed, while Conkin and Conkin (1984), place it at a bone bed slightly below the ash. Neither of these layers truly coincide with the level where sooty Union Springs shale first predominates, further adding to the complexity of this problem.

Proetid Limestone Bed and Cherry Valley Limestone Member

Above the Union Springs is a distinctive, highly condensed limestone unit which can be traced in outcrop from the vicinity of Lima, Livingston County all the way into the Hudson Valley. At this locality this unit is a compact, 65 cm (2.2')-thick ledge which is actually composed of three amalgamated limestone subdivisions, two of which ("Proetid bed" and Cherry Valley Member, proper) are extraordinarily widespread. The basal few centimeters of the amalgamated ledge consists of a concretionary underbed which is actually a part of the Union Springs Member. This layer consists of large, brown, septarial concretions, which can be seen on large overturned blocks. Debris from the overlying "Proetid Bed" fills numerous cracks and solution pits which locally penetrate through the underbed.

"Proetid Limestone Bed": The next amalgamated division within the limestone ledge is a highly irregular, 5-15 cm (2-7")-thick

white-weathering, light grey, micritic unit which is sandwiched between the brown concretionary layer and the true Cherry Valley Limestone (Fig. 14). This white horizon contains scattered fossils, particularly, a few atrypid and rhynchonellid brachiopods, comminuted crinoid debris and calyces of the minute crinoid Haplocrinites clio, rare small rugose corals and proetid trilobites. Overall, this bed closely resembles a layer, informally termed the "Proetid bed" (Rickard, 1952). In the east the proetid bed is separated from the overlying Cherry Valley Limestone by 0.1 to 3 m of black shale and thus it represents a distinct carbonate unit. It appears to merge with the base of the Cherry Valley Limestone near the Chenango Valley due to pinch out and/or erosion of the intervening shale. At Seneca Quarry the top of the proetid bed is an irregularly sculptured hardground with a relief or nearly 10 cm. Darker grey matrix of Cherry Valley lithology infills pockets including undercut cavities on this limestone, indicating a period of induration and erosion of the surface prior to Cherry Valley deposition.

Cherry Valley Member: The upper two thirds of the carbonate ledge comprises the true Cherry Valley limestone, it is a dark grey, slightly pyritic, styliolinid and crinoidal packstone with abundant orthoconic nautiloids and large goniatites (Agoniatites). These cephalopods are particularly well displayed on the upper surface of the bed. Along the southwest rim of the quarry this upper surface has been glacially polished and striated; however on the southern edge it was covered by a thin veneer of overlying Oatka Creek shale. This shale has been bulldozed off on a large, gently-dipping surface on the south edge of the quarry, exposing the unweathered upper contact of the Cherry Valley bed. This surface is nearly planar and displays a large number of erosionally truncated nautiloids, goniatites and a few large fish bones. In some cases the bevelled edges of the phragmocones and the chambers on this submarine hardground are encrusted with drusy crystalline pyrite.

This appears to represent a regionally traceable cephalopod bed. Nautiloids are well preserved and show a prominent and highly significant northwest to southeast orientation. This seems to indicate that the cephalopods died shortly before original burial and were oriented by basinward-flowing currents on the sea floor. Very few specimens are vertically oriented.

Beveling of the fossils almost certainly took place on the Devonian sea floor after induration of the limestone. Examination of nearby sections indicates that a few centimeters of overlying Cherry Valley Limestone were removed from this surface exposing the prefossilized cephalopods. Erosional mechanisms probably included mechanical scour by traction sheets of residual debris and shells moved by currents (abrasion) and some component of submarine dissolution under anaerobic conditions prior to burial of this surface by Oatka Creek black muds (Baird and Brett, in prep.); evidence of this corrasion process becomes even more pronounced on this surface, further west at Flint Creek near Phelps, Ontario County and at LeRoy, Genesee County, where the discontinuity surface becomes distinctly irregular and pitted (see Fig. 3).

As noted for other submarine erosion surfaces (see discussion of Moonshine Falls), this erosive beveling apparently accompanied sediment

starvation associated with rapid transgression. The Cherry Valley is sharply overlain by black shale of the Oatka Creek-Chittenango members which records anaerobic conditions following Cherry Valley deposition.

		Return to office area, turn left (east) and proceed on Co. Rt. 121.
41.1	0.8	Sharp turn in road.
41.4	0.3	Bend in road at Canoga Springs.
42.4	1.0	Junction NY 89 Canoga Village; turn left (north) onto NY 89.
42.6	0.2	Leave Canoga Village
45.5	2.9	Entrance to Cayuga Lake State Park on right.
46.5	1.0	Defunct Eisenhower College on left.
47.9	1.4	Note raised stretch of road which follows a conspicuous narrow ridge.
51.85	3.95	Junction Rt. 89 and U.S. 20, turn right, (east) onto U.S. 20.
53.5	1.65	Entrance to Montezuma Wildlife Refuge; bridge over Cayuga Lake outlet.
53.9	0.4	Junction U.S. 20/Route 90; turn right (south) onto Route 90.
54.0	0.1	Slumped old roadcut in Camillus Shale (Upper Silurian).
57.4	3.4	Town of Cayuga.
58.3	0.9	Leave town of Cayuga.
63.9	5.6	Enter town of Union Springs
65.6	1.6	Leave town of Union Springs.
65.65	0.15	Woods Quarry, behind large garage building on left; has exposures of the Onondaga-Marcellus (Union Springs) contact; the same upper Tioga ash layer and fish bone bed seen in Seneca Quarry are present here.
67.25	1.56	Bridge over Great Gully; exposure of Mottville Limestone (Marcellus/Skanateles contact) visible in low falls east of road.

67.65	0.4	Bridge over Criss Creek; more Mottville exposure (visible from road during cold months)
68.95	1.3	Village of Levanna
69.5	.25-.55	Bluffs of Levanna along Cayuga Lake shore.
70.5	.55	Mouth of Dean Creek, base of hill going up into Aurora.
70.15	0.1	Enter town of Aurora.
71.45	1.3	Wells College on left.
71.8	.35	Junction NY 90/Poplar Ridge Road, turn left (east) onto Poplar Ridge Road.
72.55	0.75	Junction Fry Road turn right (south).
73.1	0.55	Junction Moonshine Road (gravel road) on right; turn right (south).
73.2	0.20	Bridge over Paines Creek (STOP 6). Park on left side of road just past bridge.

STOP 6 PAINES CREEK; MOONSHINE FALLS

Locality: Exposures on the bed of Paines Creek above Moonshine Falls 0.3 km west of Moonshine Road, south of Aurora, Cayuga Co., NY.

References: Cooper (1930), Grasso (1970); Kramers (1979); Gray (1984).

Description of Units: Paines Creek flows north westward on the dip slope between the bridge at Moonshine Road and the 12 meter (40')-high waterfalls, exposing extensive bedding planes of the upper Centerfield and the basal Ledyard shale. Strongly jointed, dark, fissile Ledyard shale crops out beneath the bridge and for 100 m above the waterfall. This contact and most of the Centerfield Member are re-exposed still further 400 m upstream from the bridge at the crest of a small anticline. The face of the waterfalls (largely inaccessible) exposes the upper 2 meters (6.5') of the black Butternut-equivalent part of the Levanna Shale Member, a disconformity at the top of the Levanna, and 10.7 m (35') of the lower Centerfield. This sequence can be examined by descending into the gorge along a small tributary gully north of the crest of Moonshine Falls.

Centerfield Member: A fossil hash bed containing scattered hiatus concretions, encrusted by bryozoans and auloporida corals, forms the base of the Centerfield and rests sharply on black, fissile Leiorhynchus-bearing shales of the Levanna. Overlying Centerfield gray shales contain small brachiopods (Ambocoelia, chonetids) and, at two levels, biostromes of auloporida corals. Higher beds show a transition to gray, calcareous mudstone with larger brachiopods, particularly Tropidoleptus, and a few larger rugose corals.

The highest beds of the Centerfield, exposed in the creek floor above

the lip of the waterfalls, are hard, light blue-grey, argillaceous limestones or very calcareous mudstones which are thoroughly bioturbated and display well-preserved large Zoophycos spreiten, typically with limonitic (originally pyritic) marginal tubes. Body fossils are abundant and very diverse but patchy in distribution. On the strongly jointed creek bed just above the waterfall are excellently exposed patches (biostromes) of ramose and foliose (fistuliporoid) bryozoans, some of which have associated brachiopods (rhynchonellids, Nucleospira, Elita, Vitulina as well as proetid and Phacops trilobites. Excellently preserved blastoids and crinoids are common in some bryozoan thickets at this level. Scattered large corals including solitary forms such as (Heliophyllum) and colonial taxa (Eridophyllum and Favosites) are also present.

Many localities show some 3 to 4 m of highly fossiliferous softer gray shales overlying the calcareous mudstone capping unit of Moonshine Falls which mark a transgressive facies transition into post-Centerfield deposits; however at this one locality these transitional beds are absent, apparently because of localized erosional truncation (Fig. 4). The upper contact of the Centerfield is disconformable here, as at adjacent localities, but the contact is very striking here owing to the lack of the sharply overlying black Ledyard shales. At the contact is a thin (1-2 cm) lag of crinoid debris with abundant fossils, derived from the underlying Centerfield; many of these are distinctly broken and corroded. This bed also contains abundant small phosphatic nodules, some of which are reworked fossil steinkerns (e.g. of conulariids and enrolled trilobites), fish bones and hiatus-concretions. Reworked, pyritized burrow tubes have been exhumed locally on this surface at some localities. However, where this has been observed, the tubes occur stratomictically commingled with shell hash in burrowed mudstone; these tubes, thus, show evidence of breakage and reorientation by infauna but no evidence of lateral current transport.

This lag bed, termed the Moonshine Falls Bed by Gray (1984) is an important widespread marker, which has yielded the conodont Polygnathus timorensis, diagnostic of the lower P. varcus zone of the Givetian stage; it is on the basis of these conodonts from this locality that Klapper (1981) has assigned the Centerfield to the base of the varcus zone; in actuality, no diagnostic conodonts have been obtained from the Centerfield proper, or from the underlying Skaneateles Formation.

Ledyard Shale: The basal 4 m of the Ledyard Member are exposed here, and this creek is the type section of that member. The lower beds are very dark gray to black, fissile shales with a Leiorhynchus-Styliolina fauna. A few thin stringers of crinoidal and phosphatic debris have been observed in the basal 10 cm of the Ledyard, these apparently have been reworked from lag debris overlying the erosional top of the Centerfield.

Interpretation: The Levanna-to-Centerfield sequence represents an abrupt change from deeper water black Leiorhynchus facies to fossil-rich calcareous mudrock, probably deposited in shallow water close to normal wave base, and within storm wave base. Although the sequence is gradational east of Syracuse meridian, here it is broken by a discontinuity that marks the sharp base of the Centerfield, Gray (1984) has interpreted this interruption in sedimentation to be the result of

local tectonic uplift of the sea floor near the Tully Valley. This updoming could have cut off sediment influx to the west, leading to slight erosion of the sea floor and condensation of shelly debris. Above this basal bed the Centerfield shows a gradual shallowing-upward sequence to the beds that cap Moonshine Falls; above this hard mudstone, in other localities there is a reversal and gradual transition back to deeper water facies (Fig. 4). However, again, the sequence was interrupted in this area by an abrupt jump to dark gray and black Leiorhynchus facies. As noted above, the upper Centerfield transitional shales have been removed, apparently by erosion associated with this interruption in sedimentation. Detailed mapping of the upper contact (Gray, 1984) proved that the transitional shales are present within 2 miles on either side of Moonshine Falls (i.e. both northeast and southwest of here). This further suggests that the erosion was localized (Fig. 4); the area of enhanced erosion may be in a channel-like depression no more than a mile across and perhaps oriented NW-SE, normal to the regional paleoslope. This erosion probably took place during an interval of general sediment starvation associated with rapid transgression at the onset of Ledyard deposition. We have observed similar erosional furrowing beneath blackshales at several other stratigraphic levels. That relatively strong currents persisted, episodically, even after the onset of black mud deposition, is indicated by the stringers of reworked Centerfield debris that occur just above the base of the black shale. Evidently, some dysaerobic settings were not entirely characterized by low energy.

Continue southwest on Moonshine Road.

73.6	0.3	Junction NY 90; turn left (south).
74.75	1.15	Junction Lake Road (to Stony Point campground) (stay on 90).
75.3	0.55	Junction Ledyard/Black Rock Road (stay on 90)
78.9	3.6	Triangle Diner; Stay on Route 90 going east. Junction Route 90/Route 34B. Turn right (south).
82.4	3.5	Enter Lake Ridge.
82.8	0.4	Cross Lake Ridge Point Ravine; here the Fir Tree Limestone is about 7' thick.
84.65	1.85	Pass Lansing Fire Station.
87.55	2.9	Begin descent into Salmon Creek Valley
87.95	0.4	Road to Ludlowville on left (stay on 34B).
88.75	0.8	Cross Salmon Creek; excellent upper Hamilton exposures are present in this creek.
88.95	0.2	Road to Meyer Point at base of long hill (stay on 34B).

89.75	0.8	Enter town of South Lansing.
89.95	0.2	Portland Point Road on right (stay on 34).
90.65	0.67	Junction Route 34B/Route 34, village of South Lansing. Turn right (south) following 34.
91.65	1.0	Upper end of Shurger Glen.
93.9	2.25	Start descent into Cayuga Valley (long down grade).
94.4	0.5	Exposures of upper Sherburne turbiditic siltstone in intermittent road cuts on left; long grade is nearly on dip slope of south limb of Fir Tree anticline; large lake bank section of upper Geneseo, Fir Tree equivalent siltstones, and Hubbard Quarry turbidites and shales is below west of road.
95.4	1.0	Base of long grade at lakeshore; twin glens expose Lodi beds near road level.
95.9	0.5	Junction Route 34/Route 13; large cuts on 13 are into lower medial divisions (Renwick-Ithaca mbrs.) of the upper Genesee Formation; city of Ithaca. (END OF ROAD LOG).