STORM-DOMINATED SHELF AND TIDALLY-INFLUENCED FORESHORE SEDIMENTATION, UPPER DEVONIAN SONYEA GROUP, BAINBRIDGE TO SIDNEY CENTER, NEW YORK

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INTRODUCTION

The Upper Devonian paleoshoreline of the Catskill clastic wedge in New York State has been interpreted for nearly a century as a complex deltaic sequence (Barrel, 1913, 1914; Chadwick, 1933; Cooper, 1930; Sutton, Bowen and McAlester, 1970; and many others). Friedman and Johnson (1966) envisioned this deltaic complex as a series of coalescing deltaic lobes that progressively filled the Catskill epeiric sea and existed as an uninterrupted deltaic plain from New York to West Virginia. In addition, some geologists believe that such epeiric seas were tideless owing to rapid tidal wave attenuation (Shaw, 1964; and Mazzullo and Friedman, 1975). Others presume that storm (wave) processes were dominant with little or no tidal influence (Dennison, 1985).

This study offers significant departures from these interpretations, by documenting nondeltaic environments with significant tidal influence along the Catskill paleo-shoreline. The purpose of this study (Fig. 1) is to delineate sedimentary environments spanning the nonmarine to marine transition in the Upper Devonian Sonyea Group and to test and challenge previous deltaic models of the Sonyea Group (Sutton, et al., 1970). Recent publications have introduced evidence for non-deltaic shoreline environments within the Catskill clastic wedge (Walker and Harms, 1971; 1975; Bridge and Droser, 1985; VanTassel, 1986; also see Sevon, 1985, Table 1, p. 83). Others have shown that tidal processes were significant in the Catskill sea (Slingerland, 1986; and Bridge, et al. 1985).

Figure 2 shows the paleogeography of eastern North America during Frasnian-Fammenian time. Paleogeographic reconstructions indicate that the Acadian Mountain range supplied large quantities of sediment westward, allowing a vast alluvial plain to develop. The alluvial plain was fronted by deltaic lobes which prograded westward into the Catskill epeiric sea.

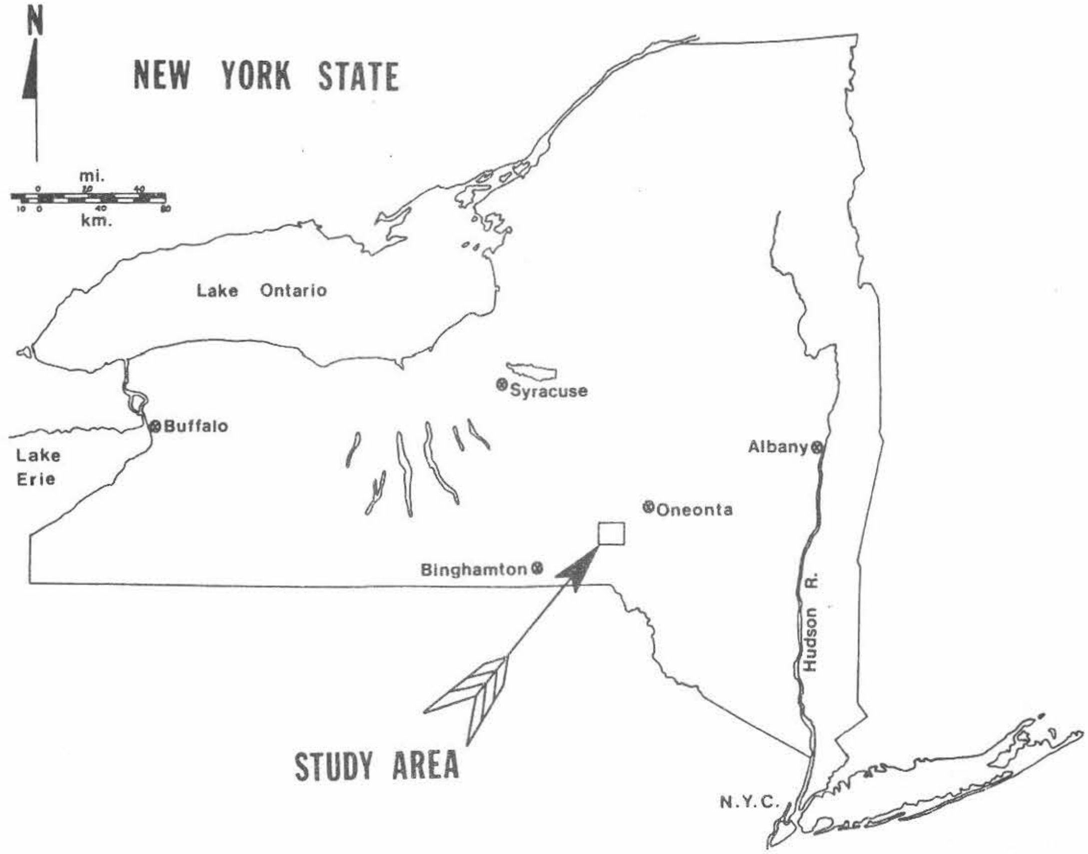


Figure 1: Index map of New York state showing the location of the study area.

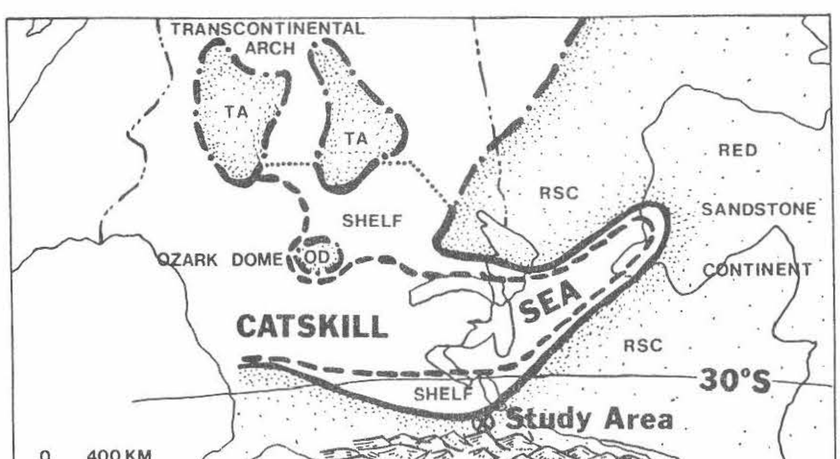


Figure 2: Palaeogeography of eastern North America during Frasnian-Fammenian time adapted from Haeckel and Witzke (1979), as cited by Slingerland (1986). The study area is shown in relation to the Acadian mountains and the Catskill sea. Notice the study area is positioned approximately 30 degrees south of the equator. OD= Ozark Dome; TA = Transcontinental arch; and RSC = Red sandstone continent.

Despite the compilation of a tremendous library of geologic information, very few papers specifically investigated the depositional environments along the paleoshoreline of the Catskill clastic wedge. Early workers may have biased the scientific community into thinking that deltaic lobes extended along all portions of the paleoshoreline (Barrel, 1913, 1914; Chadwick, 1933; Cooper, 1930; Friedman and Johnson, 1966). Such simplification is regrettable and is probably in error. The sequence of facies in this study suggests nondeltaic progradation of the Catskill clastic wedge during Sonyea time.

Location of Study Area and Methods

The study area is located in south-central New York in the extreme northwest corner of Delaware county and eastern-most Chenango county (Fig. 1). Most outcrops are located in the area of Bainbridge, Sidney, and Sidney Center, New York (Fig. 3).

Thirty-six outcrops were measured during the summer and fall months of 1987. Sequences of sedimentary structures and lithology, faunal content, biogenic structures, and soft sediment deformation were used as the basis for interpretation. Refer to Bishuk (1989) for detailed measured sections. Additional sections are being described by Applebaum (in prep.).

A Brunton compass and metric tape measure survey was conducted at the Sidney Center outcrops located at the intersection of Dunshee Road and Delaware County Route 35 (Fig. 4) to establish the stratigraphic succession of key outcrops in this area of limited exposure.

Stratigraphy

The Sonyea Group is the second oldest of seven groups in the Upper Devonian in New York State (Fig. 5). Present Sonyea Group stratigraphy was redefined by Sutton, Bowen, and McAlester (1970). The lower and upper group boundaries and several formational contacts are defined by thin, laterally persistent, black shale tongues. The Sonyea Group includes the rocks lying between the base of the Middlesex-Montour black shales and the base of the overlying Rhinestreet-Moreland black shales. The lithology and thickness of the Sonyea rocks between these black shale varies greatly with a general coarsening and thickening from west to east. The Sawmill Creek Shale divides the eastern portion of the Sonyea Group into two strikingly similar units, the Triangle Formation (lower), and the Glen Aubrey Formation (upper). Both formations consist of small-scale repetitive fining-upward sequences of marine shelf sandstone, siltstone, and shale. These formations differ only in their distribution, abundance, and type of invertebrate fauna. Below the Sawmill Creek Shale, the dominant taxa of the Triangle Formation include the brachiopods Productella, Mucrospirifer, and Leirorhynchus, the gastropod Bellerophon, and the bivalve Palaeoneilo (Sutton, et al., 1970). Above the Sawmill Creek Shale, the Glen Aubrey Formation displays a fauna that includes the bivalve Cypricardella, the brachiopods Cupularostrum, Tylothyris, Chonetes, Rhipidomella, Platyrachella, and Ambocoelia, and crinoid debris (Sutton, et al., 1970).

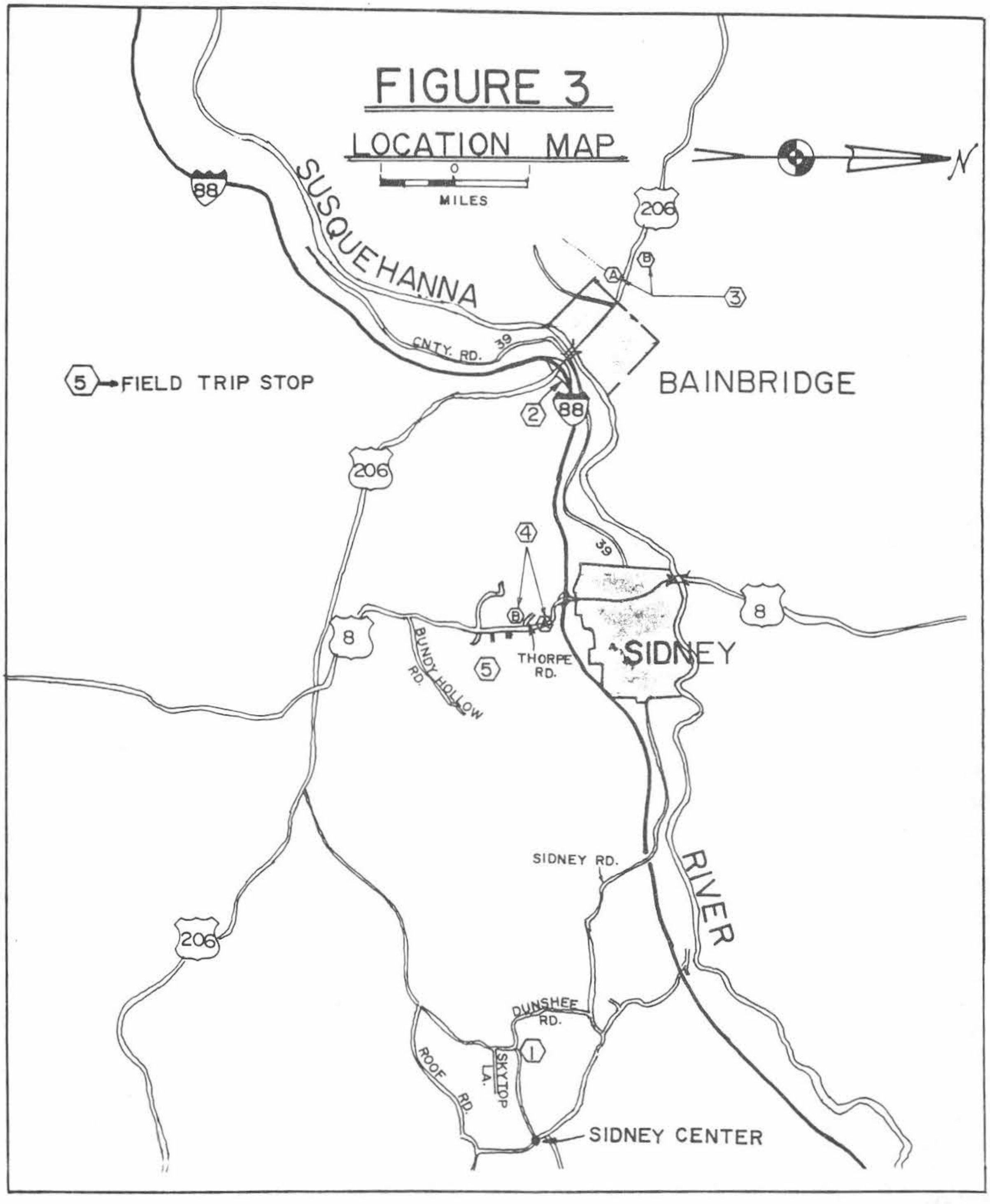
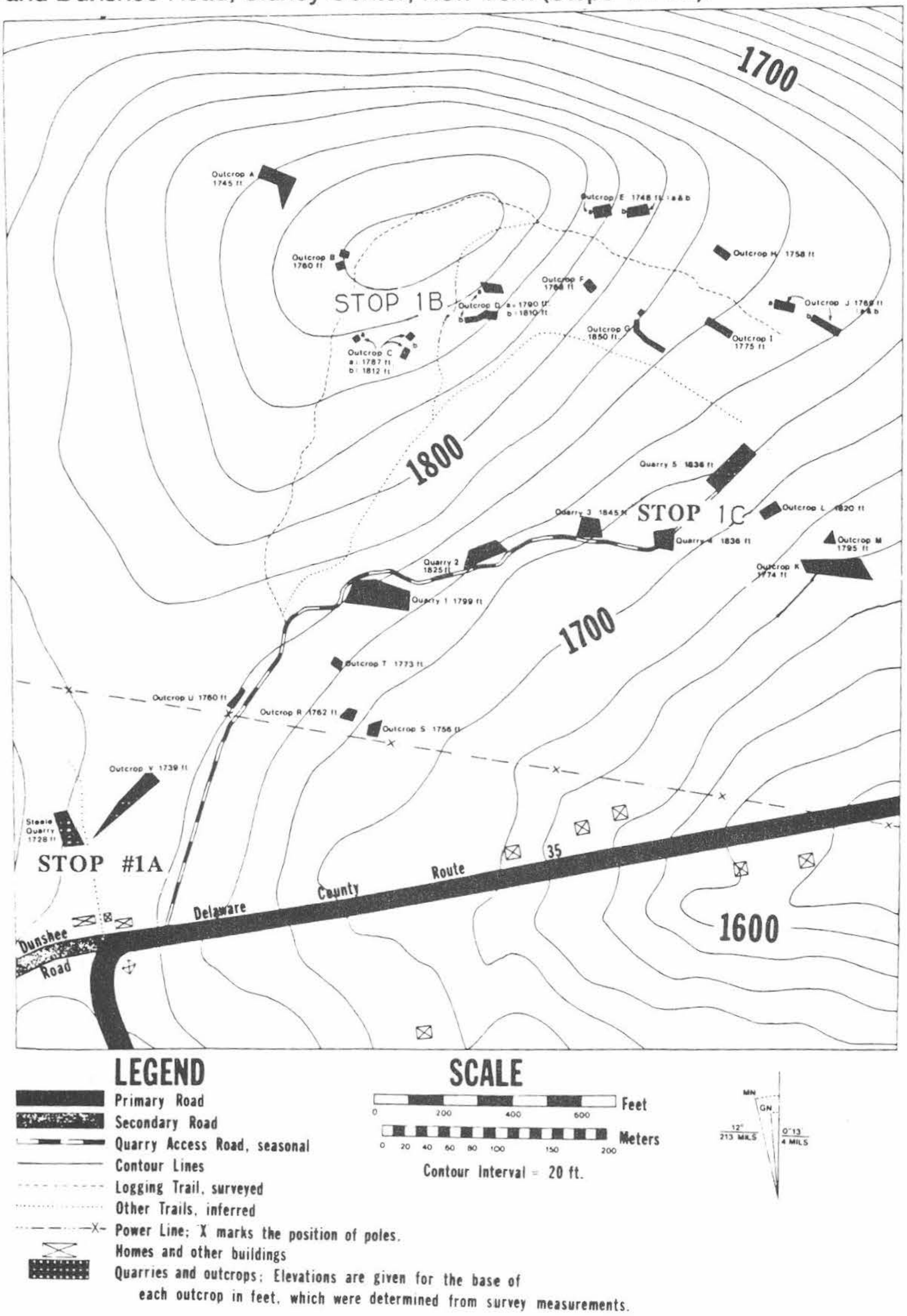


Figure 3: Roadmap of the Bainbridge, Sidney, and Sidney Center areas showing the location of the field trip stops.

Figure 4: Location of outcrops at the intersection of Delaware County Route 35 and Dunshee Road, Sidney Center, New York (Stops 1A-1C).



Black shales of the Sonyea Group are interpreted by Sutton and others (1970) as long transgressive intervals accompanied by low siliciclastic input to the shelf. Alternative interpretations of these units are included in this study.

Strata within the study area are probably assignable to the Glen Aubrey Formation (marine) based on faunal content, and the Walton formation (nonmarine) (Fig. 5). However, stratigraphic placement is difficult owing to limited exposure. Nonmarine to marine transition rocks are found within an unnamed unit assignable to the Cattaraugus facies (Fig. 5). Sections farther west at Bainbridge are likely in the Triangle Formation.

MARINE ROCKS (Chemung Facies)

Six facies that record fully marine to nonmarine transitional environments have been delineated from detailed measured sections of outcrops in the study area. These facies are shown in a composite section to show stratigraphic context and relative thicknesses (Fig. 6). See Bishuk (1989) for detailed measured sections of individual outcrops within each facies.

Two facies record deposition within the marine shelf of the Catskill Sea. These are: 1) the hummocky cross-stratified facies; and, 2) the dark gray shale facies. Exposures of these facies are more abundant than facies higher in the section, but all facies are still difficult to trace laterally. Limited exposure has made facies reconstruction difficult. Recent road construction has exposed several new outcrops since the study of Sutton, Bowen, and McAlester (1970) alleviating some of this difficulty.

Description of the hummocky cross-stratified facies

The hummocky cross-stratified facies consists of very fine sublitharenite, with common interbeds of siltstone and shale. Fine sand sublitharenite and conglomerate composed of shale and siltstone clasts are rare in the stratigraphically lower sections, but are dominant stratigraphically higher in this facies. Sandstones are moderately well- to well-sorted. The hummocky cross-stratified facies is the lowest unit in the stratigraphic sequence. It is present along Route 8, just south of Sidney, and at outcrops along Interstate 88 at Sidney and Bainbridge and points westward.

Hummocky cross-stratification is the dominant sedimentary structure. Hummocky cross-stratification is primarily found interbedded with siltstone and shale (Fig. 7), but also occurs as amalgamated beds of very fine sublitharenite (Fig. 8). Hummocky cross-stratified beds have sharp bases, with moderately rare directional sole marks such as flute and tool marks. Mean paleocurrent direction for flute and tool marks is 275 degrees.

Coquinite layers, coquinite-filled scours, coquinitic hummocks or ripple forms, graded bedding and conglomerate are commonly found at the base of hummocky cross-stratified sandstone. Coquinite layers are the most common of these features

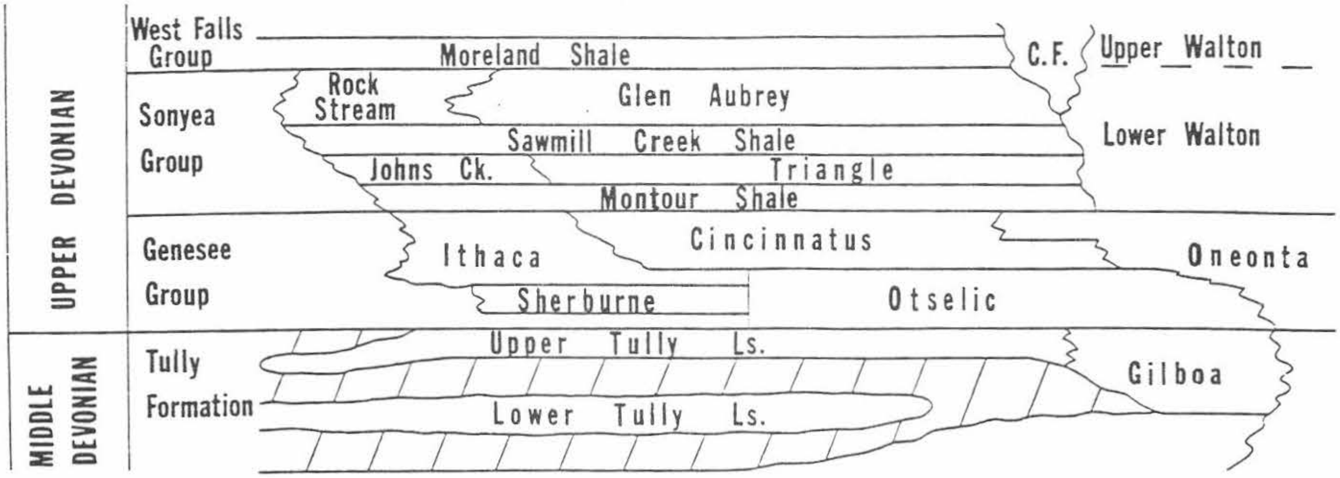


Figure 5: Stratigraphic correlation of part of the Middle and Upper Devonian in New York. Diagram simplified from Rickard (1975). The study was conducted within the Glen Aubrey and Triangle Formations (marine) and the Lower Walton Formation (non-marine). Nonmarine to marine transition rocks are best assigned to an unnamed portion of the stratigraphy designated as the Cattaraugus Magnafacies (C.F.). Diagonal ruling represents hiatus.

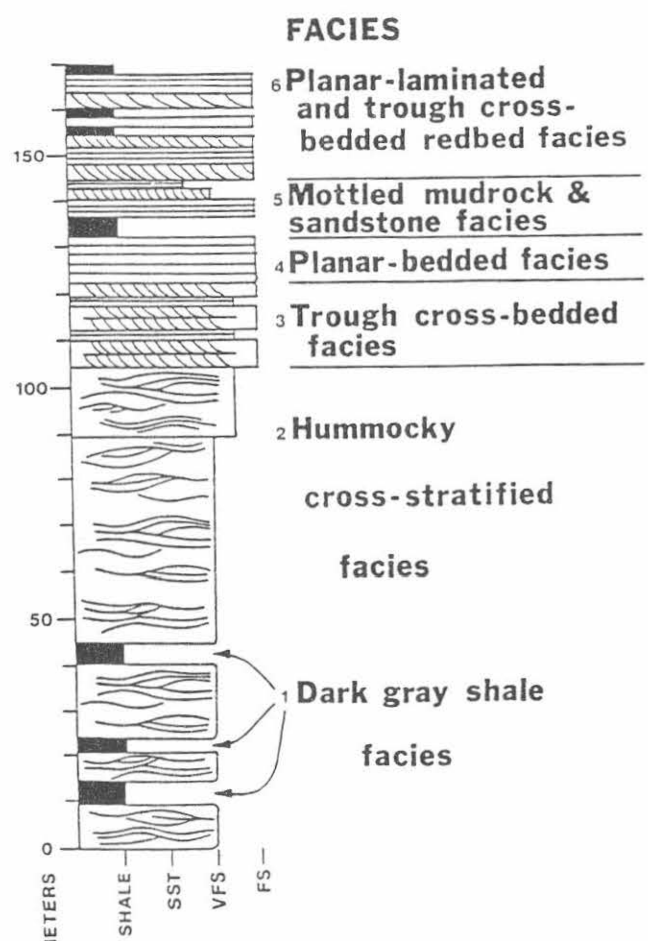


Figure 6: A 170 meter composite section illustrating the stratigraphic sequence of the six facies described in the study area.

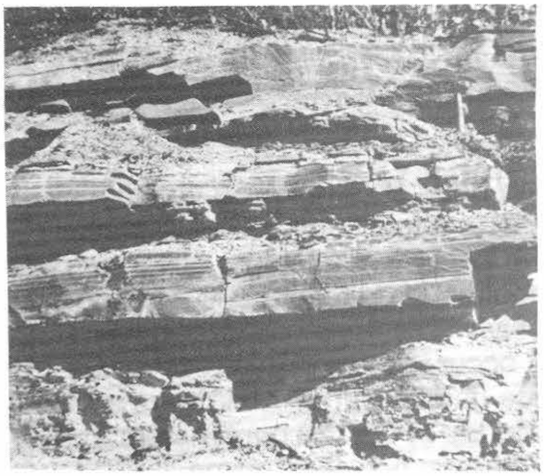
Figure 7: Interbeds of hummocky cross-stratified sandstone and shale. The top-most sandstone bed (next to hammer) illustrates an excellent hummock and concave-up and convex-up laminations. The bottom-most shale marks the position of the first reoccurrence of marine fauna at the top of Sidney Mountain quarry (see interpretation of mottled mudrock and sandstone facies for details). The hummocky cross-stratified facies disconformably overlies the planar-laminated and trough cross-bedded facies here, after a brief half meter covered interval (Stop 5).

Figure 8: A large, amalgamated, hummocky bedform with swale found in the amalgamated portion of the hummocky cross-stratified facies higher in the section. The crest to trough distance is 2.3 meters. Hammer and meter stick for scale (Stop 1A).

Figure 9: Close-up of Figure 8 showing internal structure of hummock. Climbing ripple cross-lamination in left-center of the photo are inclined at a steep angle of propagation, which suggests rapid deposition by a storm event with no post-storm reworking. Hammer for scale (Stop 1A).

Figure 10: A solitary wedge-shaped form is cut into shale and subsequently filled with shale. Basal surface of the wedge is listric in nature. This is a characteristic feature of the dark gray shale facies. Hammer for scale (Stop 4A).

Figure 11: Interbedded trough cross-bedding and planar-bedding found within the trough cross-bedded facies. Individual laminae on cross-beds are lenticular and occasionally rippled. Cross-bed sets are consistently inclined in the same direction (toward left side of page), which probably records the ebb flow tidal direction. Ripple cross-lamination resting on troughs are inclined in the opposite direction of the troughs. This strongly suggests current reversal induced by tides. Planar laminated interbeds are interpreted as swash bars within tidal inlets (Stop 1C).



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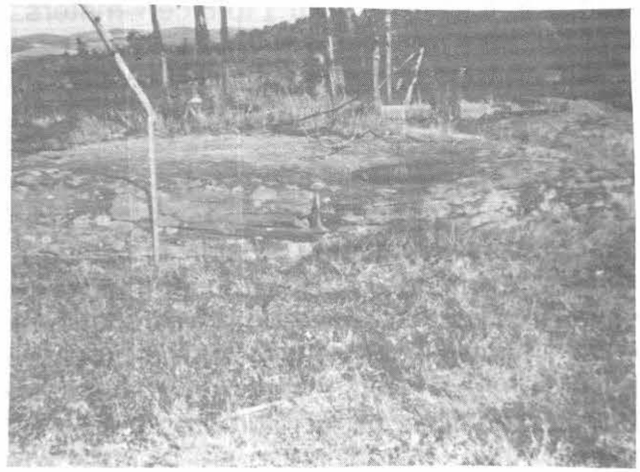

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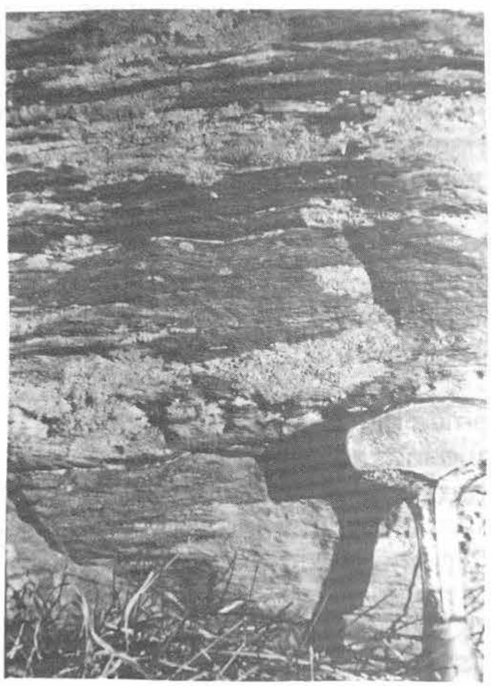

FIGURE 9

FIGURE 10

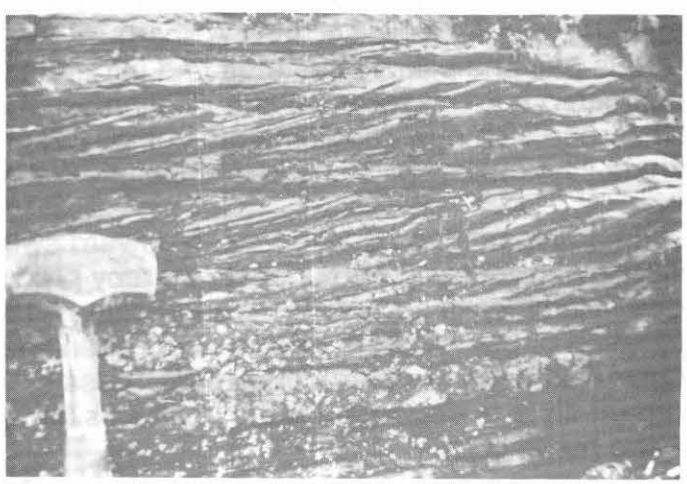

FIGURE 11

and range in thickness from 1 to 8 centimeters. These layers are not restricted to the base of hummocky cross-stratified beds. They occur less commonly as thin drapes or scour fills on tops of hummocks and swales and along truncations within amalgamated hummocky cross-stratified beds.

Laminations within hummocky cross-stratified beds show several variations, each with a regular sequence. Above coquinite layers, a few centimeters of planar lamination typically occurs. Planar lamination, with gentle undulations, often overlies low angle truncations. This is succeeded by low-angle curved laminae illustrating both concave- and convex-upward laminations, commonly with a form concordant style of deposition. Low-angle truncations may or may not occur. Hummocky cross-strata commonly dip less than 10 degrees. This sequence occurs within hummocks and swales of sandstone beds. Hummocks have amplitudes of 5 to 20 centimeters above adjacent swales. Wavelengths are typically 2 to 5 meters; however, some wavelengths of tens of meters have been observed. Hummocks and swales are commonly capped with slightly asymmetrical ripples and symmetrical wave ripples, which commonly contain transverse ribs or exhibit chaotic patterns. Paleocurrent readings on asymmetrical ripples average 260 degrees. Cross-lamination within ripples is usually not well preserved.

Lateral transitions are common within a single hummocky cross-stratified bed. The most common lateral transition is from hummocky cross-stratification as described above to planar laminae capped by wave ripples. Hummocky cross-stratification also changes laterally to wave-ripple laminae. Soft sediment slumps with internal hummocky cross-stratification and troughs with ball and pillow structures generally thin laterally to wave ripple-laminated beds or planar laminae capped by wave ripples. Craft and Bridge (1987) cite similar lateral transitions within hummocky cross-stratified beds.

Siltstone and shale interbeds are planar-laminated, blocky, or structureless, and commonly heavily bioturbated. However, siltstone interbeds may exhibit small-scale, current ripple cross-lamination, which is commonly discontinuous and cryptic.

The style of hummocky cross-stratification becomes dominantly amalgamated higher in the stratigraphic section. A sharp, scoured and loaded contact with numerous ball and pillow structures and intraformational conglomerate occurs where amalgamated hummocky cross-stratification commences. Very fine and fine sublitharenite with rare conglomerate composed of shale and siltstone clasts are dominant lithologies. Siltstone and shale interbeds are rare.

In amalgamated beds, concave-upward swaley surfaces pass laterally into convex-upward hummocky surfaces, thereby producing adjacent hummocks and troughs. Hummocks and swales are truncated laterally by hummocky cross-stratification or planar strata. Pebble lags often line these erosional surfaces. Most amalgamated beds are form-concordant. Less commonly, amalgamated beds show a discordant style of deposition with hummocks filling in underlying swales and swales overlying hummocks.

Heights of the hummocks are up to 20 centimeters above adjacent swales. Wavelengths range from 2 to 5 meters. Crests of hummocks are straight to slightly sinuous with a mean orientation of 128 degrees. Structures, internal to amalgamated hummocky bedforms, include climbing ripples with steeply inclined axes of propagation (70 to 80 degrees) along the flanks of hummocks (Fig. 9). The ripples generally show migration toward the crest of hummocks. However, there is evidence for rare current reversal recorded by ripple migration toward swales. Hummocks and swales commonly contain several horizons of Rhizocorallium (?) burrows and sinuous epichnial trails of Scalarituba in convex hyporelief. Amalgamated hummocky beds rarely have distinct sole marks along erosional bases. Where present, sole marks include flute casts, load casts, and a variety of tool marks.

Ball and pillow structures are abundant at or near the base of hummocky cross-stratified beds and display minimal penetration into underlying lithologies. Penetration and detachment of ball and pillow structures into underlying siltstone and shale interbeds and development of flame structures are less common, but occur in abundance along some horizons. Hummocky cross-stratification is preserved rarely within ball and pillow structures and soft sediment slumps.

Other structures of minor occurrence are generally found capping hummocks and swales. These minor structures include wrinkle marks (also known as "runzel marks"), asymmetrical ripples with or without transverse ribs (commonly found as ridges and furrows), and scour depressions with or without symmetrical wave ripples within depressions. Mean paleoflow from asymmetrical ripples is 359 degrees (Fig.13, Steele quarry locality). Paleoflow direction is indicated for scour depressions by their elliptical shape, with a mean directions of 160 or 320 degrees. Rare trochoidal ripples are only present at the Steele quarry in Sidney Center.

The hummocky cross-stratified facies has a diverse invertebrate fauna. All fossils have been transported and are never found in life position. However, articulated crinoid stems are common within coquinite lenses and intervening shale at the Bainbridge exit on Interstate 88 (Stop 2). Locally, Tentaculites are oriented with a mean paleocurrent direction of 245 degrees. Bivalves (Palaeoneilo, Nuculoidea, and Cypricardella), brachiopods (the productid, Productacea; the orthid, Tropidoleptus; the rhynchenellid, Cupularostrum; and the spirifers, Platyachella and Mucrospirifer) and carbonized plant fragments are also locally common in siltstone and shale interbeds.

The abundance of invertebrate fauna varies throughout the facies. Fauna are locally abundant, sparse or absent. This fluctuation in fossil content occurs in cyclic patterns within the facies, Spiriferids, rhychonellids, orthids, atrypids, bivalves, crinoids, gastropods, and Tentaculites dominate where fauna are abundant. The rhychonellid, Cupularostrum, and the spiriferid, Platyrachella, far outnumber all other taxa. Productids and diminutive individuals such as the bivalves Paleoneilo and Nuculoidea persist in the sparsely fossiliferous intervals.

Fossils decrease markedly in abundance and diversity where amalgamated hummocky cross-stratification dominates the section. However, carbonized plant fragments are abundant. The most common fossil is the rhynchennelid, Cupularostrum. Other fossils, in order of decreasing abundance, include the bivalve, Sphenotus, the spiriferid, Platyrachella, other unidentifiable brachiopod fragments, fish fragments, crinoid ossicles, and the bivalve, Cypricardella. The fossils are most often found associated either with loaded scour and fill bases as coquinite shelly lags or within intraformational conglomerates consisting mostly of flat shale intraclasts.

The cumulative thickness, in which amalgamated hummocky cross-stratification occurs, is approximately 7 to 15 meters. Similar thicknesses are reported by McCrory and Walker (1986) and Walker (1984).

Interpretation of the hummocky cross-stratified facies

Hummocky cross-stratification in the study area is interpreted as a storm-produced structure occurring below fair weather wave base and above storm wave base (Harms, 1975, and many others). The lower portion of the hummocky cross-stratified facies is therefore interpreted as representing deposition on a storm-dominated shelf.

Harms, Southard, and Walker (1982) state that hummocky cross-stratification forms under high-velocity oscillatory flow conditions as a continuum from 2-D wave ripples to hummocks of increasing wavelength to plane beds. Observed spatial variations in sedimentary structures are consistent with this interpretation. Climbing ripples, found within the amalgamated hummocky cross-stratified portion of this facies, augment an interpretation of rapid deposition of sediment by storms (Fig. 9). Steep inclination of climbing ripple propagation and the form-concordant style reflects vertical growth of hummocks with minimal migration, suggesting a dominant oscillatory flow and rapid deposition rate. Similar interpretations have been made by Craft and Bridge (1987) for rocks of the type Chemung facies.

The rare occurrence of current reversal in climbing ripples (Fig. 9) suggests disequilibrium in hummock growth with occasional migration down-flank toward swales. Rhyzocorallium (?) burrows are concentrated at various horizons within amalgamated hummocky beds (Fig. 9), which demonstrates the amalgamated nature of these intervals.

Sole marks are most easily observed in the lower portions of this facies where shaly interbeds are most common. Tool marks and groove casts trend east-west to east northeast-west southwest which is normal to the paleoshoreline in the paleogrogrpahic reconstructions of Barrell (1913, 1914) and Chadwick (1933). Rare flutes and asymmetrical tool marks record paleoflows which were directed offshore (west to west southwest). Following Duke (1990), we interpret these structures as recording high bed shear stresses produced by oscillatory flow in the inner boundary layer during storms (see also Duke, Arnott and Cheel, 1991). Offshore-directed structures record augmentation of bed shear stress on the offshore stroke of waves by geostrophically balanced coastal downwelling (Duke, 1990, Duke, et al., 1991).

Ball and pillow structures result from an inverse density gradient and low shear strength associated with high pore-water pressure (Allen, 1982, v. 2, p. 363). It is unclear from field evidence whether the high pore-water pressure was induced by rapid deposition and/or storm wave- or seismic-induced pressure pulses (Craft, et. al., 1987). The fact that some major ball and pillow horizons show minimal penetration into underlying lithologies is significant This lack of penetration suggests that the underlying siltstones and shales may have been at least semi-cohesive, which hampered soft sediment deformation. Detached balls and pillows in other parts of the measured section reflect rapid deposition causing liquefaction of underlying siltstones and shales and subsequent penetration of sand.

Most coquinite lenses are interpreted as postmortem storm-transport of shells to areas below fair-weather wave base (Sutton, et al., 1970). Articulated crinoid stems within coquinite lenses capping hummocks and swales and within intervening shale between hummocky cross-stratified beds suggests some in situ burial of crinoids. In addition, the presence of coquinite layers on both top and bottom of a single hummocky cross-stratified bed implies that the bed is amalgamated and that crests of hummocks may have been periodically modified by subsequent storms.

The cyclic patterns of fluctuation of invertebrate abundance, faunal change, and levels of biogenic activity is probably produced by fluctuations of the pycnocline (Byers, 1977), and may provide clues to relative rates of progradation and subsidence (Thayer, 1974). High diversity of taxa and moderate to low levels of biogenic activity indicate aerobic conditions and implies a relatively deep oxygen mixing depth. Low numbers of taxa and higher levels of biogenic activity indicate dysaerobic conditions and a shallower oxygen mixing depth (Byers, 1977). Marine transgressions are not likely to account for this cyclicity, because the cycles are too frequent. The cyclicity may have been induced by: 1) an event controlled cyclicity, in which storms dump fauna and oxygenated sediment into deeper dysaerobic zones; or 2) differential subsidence controlled by changing rates of progradation may also account for pycnoclinal fluctuations. Other less likely alternative explanations include sea-level rises that drove the shoreline eastward (Dennison, 1985) or sea-level rise in response to epeirogenic lithospheric downflexure causing basin-wide subsidence, along with interbasinal arches and domes, which existed in fluctuating submergent and emergent conditions (Quinlan and Beaumont, 1984).

The stratigraphic position of this facies, the predominance of fine sand sublitharenite, and a marked upward decrease in fauna suggest that the amalgamated hummocky cross-stratified portion of this facies occupies the lower shoreface. Siltstone and shale interbeds are rarely preserved, indicating that waves or currents (e.g., longshore-, tidal-, and storm-driven) had effectively winnowed the fine fraction (Swift, 1984). The abundance of amalgamated hummocky cross-stratification implies that storms were more frequent, thereby providing additional winnowing. The sharp, scoured and loaded contact at Thorpe road (Stop 4B) is interpreted as the contact between lower shoreface and shelf deposits. Paleoflow direction is consistently to the north, which may represent the longshore or geostrophic current direction. The marked decrease in faunal abundance indicates environmental stress associated with the nearshore zone (Thayer, 1974).

The hummocky cross-stratified facies is integrally involved in the overall progradation of the Catskill clastic wedge. Vertical upbuilding of hummocky cross-stratified beds at rates greater than the average rate of subsidence causes shallowing in the nearshore zone (Hamblin and Walker, 1979). This provides conditions conducive for rapid progradation of shoreface and foreshore deposits over the hummocky and swaley cross-stratified facies. The dominance of hummocky cross-stratified beds offshore warrants against an interpretation of deltaic deposits in the nearshore. Frequent storms would inhibit outbuilding of deltaic lobes and argues for a straighter shoreline.

Progradation ceased when interrupted by marine transgression and when tectonic conditions and/or the weight of nearshore deposits were sufficient to cause rapid subsidence. This is substantiated by hummocky cross-stratified beds overlying nonmarine, fluvial rocks at Sidney Mountain quarry (Stop 5, Fig. 7). Since hummocky cross-stratification is chiefly deposited below fair weather wave base, the nonmarine deposits subsided to an approximate minimum of 10 meters below sea level. Subsidence alone may not account for this, so it was probably coupled by a slight marine transgression. A major river avulsion and/or a directional change in dispersal of sediment from the source area may have contributed to abandoned or diminished nearshore deposition, which would allow subsidence to outpace accumulation.

The abrupt deepening apparent at Sidney Mountain quarry can not be attributed to Milankovitch cycles of the PAC hypothesis (Punctuated Aggradational Cycles, Goodwin and Anderson, 1985), because the study area lacks good stratigraphic control and exposure, which are essential criteria to establish PAC boundaries. Although Van Tassell (1987) established PAC boundaries in similar Frasnian-aged deposits of the Brallier, Scherr, and Foreknobs Formations in the Catskill Clastic wedge in Virginia and West Virginia, evidence is lacking in the Sonyea Group of New York.

Description of the dark gray shale facies

The dark gray shale facies occurs as three distinct intervals within the hummocky cross-stratified facies at Route 8 in Sidney (Stop 4A, Fig. 6). Lithologies are generally restricted to uniform dark gray shale and siltstone, with rare lenses of very fine sand sublitharenite. Biogenic structures and invertebrates are absent. Planar bedding is most common in this facies. Discontinuous, ripple cross-lamination in siltstone is cryptic, but occurs in all three shale units of this facies. Similar ripple cross-laminae are also reported by Hamblin and Walker (1979).

Trough and wedge-shaped forms characterize this facies. Basal surfaces truncate underlying planar-laminated shale, and are overlain by a wedge of shale (Fig. 10). Most of the truncation surfaces occur as solitary wedges, which are characterized by a sharp concave-up discontinuity surface. Truncation surfaces have a smooth, listric ("spoon-shaped") geometry. The shale is inclined along the discontinuity surface and is in angular discordance with underlying planar beds. Inclination of shale decreases to subhorizontal to horizontal planar laminations progressively upward within the wedges. Truncation surfaces also occur as facing pairs of intersecting, U-shaped troughs filled with shale that truncate each other (see route 8 measured section, 10.6-11.6 meters [Bishuk, 1989]). The shale that fills the U-shaped troughs conforms to its U-shape, and progressively flattens upward within troughs. Most wedges and troughs measure 5 to 20 meters in width, and truncate 1 to 2 meters of underlying shale. Applebaum (in prep.) has observed similar bedding geometries in mudstones at Bainbridge (Stop 2).

Similar truncation surfaces possessing a listric geometry have been reported by Davies (1977). However, there are two differences between the surfaces found in this study and those found by Davies (1977). The features in this study are much smaller in scale, and Davies (1977) does not recognize any facing pairs of U-shaped troughs.

<u>Interpretation of the dark gray shale facies</u>

The dark gray shale facies records three brief transgressive periods, which represent desposition on deeper portions of the shelf. This is substantiated by the complete absence of invertebrates and biogenic structures, and the predominance of silt and clay. The aerobic to dysaerobic conditions of the hummocky cross-stratified facies repeatedly alternates with anoxic conditions of the dark gray shale facies. Alternations are explained by fluctuations of the pycnocline to a more landward position, causing basinal anoxic conditions to briefly develop in areas which are normally oxygenated. Repeated shifts produced the alternation of euxinic environments of the dark gray shale facies and fossiliferous aerobic to dysaerobic sediments of the hummocky cross-stratified facies. Byers (1977) has reported similar pycnoclinal shifts within the Middlesex Shale in the distal portions of the Sonyea Group in western New York.

The factors that cause the pycnoclinal fluctuations are still problematic, so only some of the possible causes will be discussed here. Initial epeirogenic downflexure of the crust may have formed a deeper-water trough of the dark gray shale facies during the Acadian collision (Quinlan and Beaumont, 1984). The pycnocline adjusts simultaneously to this lithospheric downflexure by migrating to a more landward position. This was intermittently counteracted by sedimentation of the hummocky cross-stratified facies despite continued isostatic subsidence and sediment loading. Vertical upbuilding of hummocky beds and progradation rates were probably so rapid as to only record brief, euxinic conditions in the nearshore zone. During periods of frequent storms and rapid progradation rates, the pycnocline readjusted to a more seaward position. Similar interpretations of initial tectonic downflexure have been made in the Antler foreland basin of Nevada (Harbaugh and Dickinson, 1981) and in other groups of the Paleozoic Appalachian basin of the eastern interior of North America (Quinlan and Beaumont, 1984).

Other factors involved in oxygen mixing and density stratification associated with pycnoclines include control by wave base, tides, and climatic variability. Larger waves would allow deeper penetration of oxygenated water. The relation between oxygen decrease and depth is also influenced by any lateral influx of oxygenated water across a deep sill and by the input of organic material from surface production or sediment gravity flows from the basin margin which consumes oxygen at depth (Byers, 1977).

Isostatic and/or eustatic rise and fall of sea level may have also contributed to pycnoclinal fluctuations (Johnson, Klapper, and Sandberg, 1985). However, further evidence is needed to establish the magnitude and frequency of sea level change needed to account for frequent facies alternations. Eustatic marine transgression(s) operating alone is a less attractive explanation to account for the cyclic nature of the dark gray shale units. It would imply 3 transgressive-regressive events over a short interval of time. Frequent sea level change is not known to have occurred during Fammenian time (Haeckel and Witzke, 1979). Alternatively, the hummocky cross-stratified facies and the dark gray shale, facies represent laterally migrating, subjacent environments stacked vertically according to Walther's Law (Fig. 22).

The truncation surfaces that form shallow wedges and troughs are probably rotational gravity-slide failure scarps (Fig. 22). Large quantities of unlithified sediment were disaggregated during liquefaction and removed by gravity sliding, owing to the fact that large-scale breccia, rotated blocks, or crumpled or other disturbed bedding structures are absent in the sediment wedge above truncation surfaces. Trough-shaped truncation surfaces found in this facies are typical of submarine gravity slides. Overall, a gravity-slide mechanism is favored over an alternative interpretation of erosional channel forms that form a network of subaqueous distributaries for reasons defined by Davies (1977). A summarization of the criteria used by Davies (1977) that support a gravity-slide mechanism for this study include the following:

1) The listric geometry of the truncation surfaces is typical of landslide and other gravity-slide structures.
2) The sharp and regular truncations without any obvious local channels or erosional irregularities is best explained by shear rather than by current scour.
3) No radical change in depositional processes are detected from overlying fill to the truncated rocks, which both have a shale lithology. Therefore, there is no evidence for a period of increased current scour.
4) The absence of a coarse, basal lag above truncation surfaces discounts the formation of channels by a strong traction current and favors gravity-slide failure. Alternatively, coarse material may not have been present to form basal lags.

The rotational slumps were probably triggered by storm events, overloading, or seismic activity causing liquefaction and foundering of the sediment.

The occurrence of discontinuous ripple cross-lamination implies an environment above storm wave base. The cross lamination may also suggest reworking by storms which leave cryptic signatures in deep portions of the shelf during waning stages of storm events. Hamblin and Walker (1979) find similar ripple cross-lamination between hummocky cross-stratified beds of the Fernie Formation in the Rocky Mountains of Alberta.

The lowest shale unit depicted on Figure 6 is located at the Route 8 locality in Sidney and contains the darkest shale of all of the black shale units and lacks evidence of bioturbation. This unit bears closest resemblance to the characteristics of the Sawmill Creek Shale, a laminated and barren dark gray shale (Sutton, Bowen, and McAlester, 1970). The Sawmill Creek Shale is interpreted by Sutton and others (1970) as recording a marine transgressive event. We question the liklihood of unambiguous recognition of the Sawmill Creek in the study area because many shale intervals meet the general description of Sutton et al. (1970). A much more detailed definition is needed for this key stratigraphic marker.

Sutton and others (1970) place the Sawmill Creek Shale at the Sidney Mountain quarry (Stop 5) in Sidney. The only unit even closely reminiscent of the Sawmill Creek Shale at Sidney Mountain quarry is the siltstone-shale interval nearest the base of the quarry. We argue that correlation of black shale tongues of the Sonyea Group such as the Montour, Sawmill Creek, and Moreland Shales into the nearshore environments is difficult and probably erroneous. Many units of this study resemble the Sawmill Creek Shale. Therefore, it is more likely that the shale in question is separated by a higher frequency of storm units in the nearshore or proximal tempestite regime (see Brett, C. E., et al., 1986).

ROCKS AT THE NONMARINE TO MARINE TRANSITION (CATTARAUGUS MAGNAFACIES)

Rocks at the nonmarine to marine transition are assigned to an unnamed portion of the Cattaraugus Magnafacies (Fig. 5). This portion of the Sonyea Group stratigraphy is problematic and revision should be considered. We recognize three facies within the Cattaragus Magnafacies. They are: the trough cross-bedded facies, the planar-bedded facies, and the mottled mudrock and sandstone facies (Fig. 6).

Description of trough cross-bedded facies

The trough cross-bedded facies is a 7 to 15 meters thick unit that consists of moderately well sorted, fine sand sublitharenite. The trough cross-bedded facies is laterally traceable from the north-east at Delaware County Route 27 in Sidney Center to the south-west at Pine Hill Road on Sidney Mountain (Figures 3 and 4). Outcrops of this facies occur at similar elevations (approximately 1720-1780) throughout most of the study area. The trough cross-bedded facies is absent or covered near Sidney Mountain quarry.

The base of this facies is erosional and locally marked by a coarse sandstone-supported conglomerate and/or pebble lag. Carbonized stems, branches and occasional logs are common at the erosional base and are abundant throughout the facies. Locally, crinoid ossicles and Cupularostrum line the bottoms of troughs at and just above the erosional base.

Small- to medium-scale trough cross-bedding is the dominant sedimentary structure in the facies. Dip angles on trough cosets range from 14 to 25 degrees. Cross-beds commonly climb at low angles of propagation. Some cross-beds contain normally graded, lenticular laminae with asymmetrical ripples which oppose the dominant cross-bed paleoflow direction (Fig. 11). The trough cross-beds are largely unidirectional, but locally are multidirectional. Symmetrical and asymmetrical ripples are uncommon. Rare occurrences of reformed ripples with small-scale herringbone cross-lamination are found at Roof Road (Fig. 12). The herringbone cross-lamination is confined to scours at the crests of ripples marked by reactivation surfaces. These ripples are thought to be reformed, based on their asymmetry opposite the dip direction of the primary cross-lamination within the ripple. The geographic distribution of paleocurrent directions obtained from asymmetrical ripples and trough cross-beds are shown as rose diagrams in Figure 13.

In general, cross-bed set thickness thins upward within the facies. In addition, dip angles on troughs decrease upward in the facies. Dune bedforms are uncommon, occurring sporadically in the study area.

Trough cross-beds are interbedded with gently inclined and horizontal planar lamination. In general, planar-laminated interbeds become more common upward in the facies.

The trough cross-bedded facies closely resembles the planar-laminated and trough cross-bedded redbed facies positioned stratigraphically higher. It is differentiated from it by its sparse marine fauna, including the bivalve, Sphenotus, the rhynchenellid, Cupularostrum, the spiriferid, Platyrachella, and crinoid ossicles.

Interpretation of the trough cross-bedded facies

The trough cross-bedded is best explained as a laterally accreting, tidal inlet sequence of a barrier island and/or strandplain/tidal creek system (Fig. 22). This interpretation is based on the predominance of trough cross-beds, evidence of current reversals with differing flow magnitude, a sparse marine fauna, and the stratigraphic position of this facies. The trough cross-bedded facies occurs stratigraphically above the hummocky cross-stratified facies (storm-influenced lower shoreface and offshore deposits) and stratigraphically below the planar-bedded facies (foreshore beach/barrier deposits).

The tidal inlet study of Ossabaw Sound, Georgia by Greer (1975) describes a plausible modern analog to the trough cross-bedded facies. Similar interpretations of ancient analogs include Carter (1978) and Leckie (1985).

The small to medium scale trough cross-beds record deposition by migrating dunes within the inlet or tidal channel. Davidson-Arnott and Greenwood (1976) describe similar lunate dunes.

There is subtle, but unmistakable, evidence for tides in the trough cross-bedded facies. Asymmetrical ripples that climb larger scale foresets (Fig. 11) and reformed ripples with herringbone cross-lamination record current reversal induced by tides (Fig. 12). Some trough cross-beds, dune bedforms, and asymmetricai ripples on troughs, exhibit a rare multidirectional component, particularly at the Roof Road locality

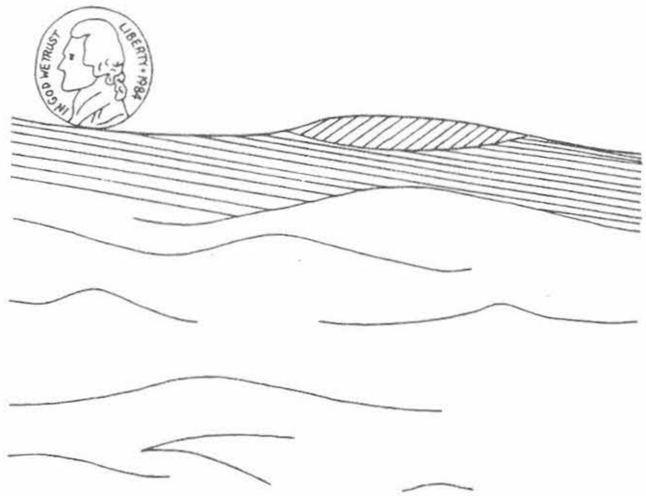

Figure 12: Reformed ripple with small-scale herringbone cross-lamination marked by a reactivation surace found within the trough cross-bedded facies. This reformed ripple suggests current reversal induced by tides. Other ripple forms shown are symmetrical to slightly asymmetrical. The diagram is a traced enlargement of a field photograph. Nickel for scale. Marvin residence, Roof Road, Sidney Center.

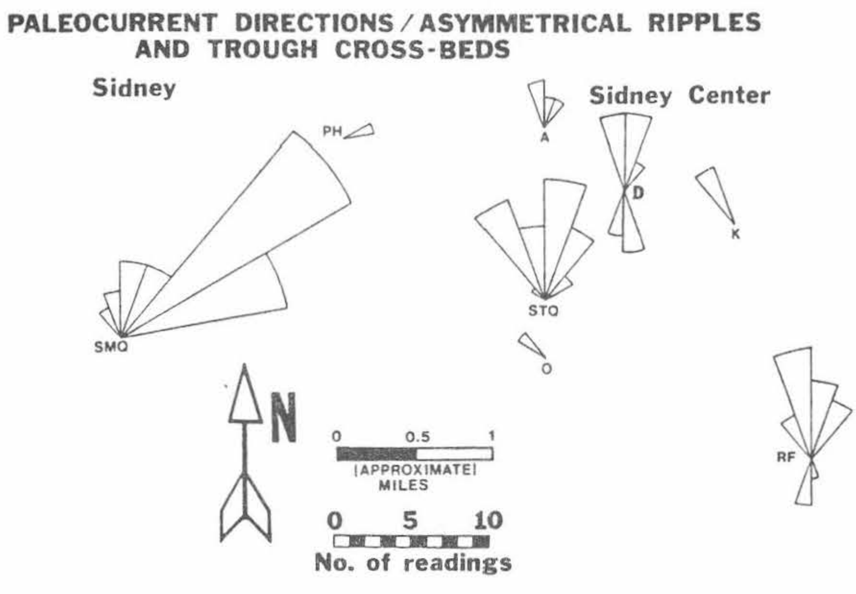

Figure 13: Rose diagrams depicting the geographic distribution of paleocurrent directions obtained from asymmetrical ripples and trough cross-beds (dune bedforms). The abbreviations represent outcrops in their approximate geographic location (see figures 3 and 4). A= Outcrop A, Figure 4 (trough cross-bedded facies); D= Outcrop D, Stop 1C, (trough cross-bedded facies) Figure 4; K= Outcrop K, Figure 4 (trough cross-bedded facies); O= Quarry #4, Figure 4 (Mottled mudrock and sandstone facies); PH= Pine Hill Road, Sidney Mountain (trough cross-bedded facies); SMQ= Sidney Mountain quarry, Stop 5, Figure 3 (planar-bedded facies); STQ= Steele quarry, Stop 1A, Figure 4 (Hummocky cross-stratified facies).

and Stop 1C of this field trip (Fig. 11). Asymmetrical ripples found on flanks of unidirectional trough cross-beds oppose the dominant northerly paleoflow, which indicates a subordinate southerly tidal current. This suggests an ebb-tidal delta deposit rather than a flood-tidal delta deposit within the tidal inlets (Reinson, 1984).

These structures lend credence to Slingerland's (1986) computer model, which proposed mesotidal to low macrotidal paleotide conditions in the Catskill sea during the Upper Devonian. Similar herringbone structures have been documented in the Becraft limestone of the Lower Devonian Helderberg Group (Ebert, 1987).

Figure 13 shows that paleoflow was dominant toward the north, with minor variations toward the northeast and northwest. Tidal inlets are therefore thought to have migrated in a northerly direction. This northerly paleoflow records either the dominant storm track, the prevailing wind direction and longshore current, or a flood tidal flow directed into headward portions of the Catskill sea.

Planar-laminated interbeds are interpreted as swash bars within tidal inlets, possibly representing spit development. Linear bars and swash bars exhibiting upper stage plane beds (areas of intense wave and current interaction) are common along the channel-margins of inlets (Reinson, 1984). Interbeds of subhorizontal planar-laminations showing opposing directions of inclination are strikingly similar to the seaward slope facies described by Davidson-Arnott, et al.,1976). These interbeds may represent complex interbedding of landward and seaward dipping, subhorizontal planar-lamination of an inlet bar. They are interpreted as fluctuations in the relative strength of waves and seaward flowing currents, forming complex interbeds where these currents interact.

Description of the planar-bedded facies

The planar-bedded facies is present at the Sidney Mountain quarry (Stop 5) in Sidney Center bluestone quarries 1, 2, 4, and 5 (Fig. 4), and at both the Skytop Lane and Sheetz bluestone quarries in Sidney Center. Rocks of this facies are also assignable to the Cattaraugus Magnafacies.

The planar-bedded, fine-grained sublitharenites of the Sidney Mountain and Sidney Center bluestone quarries are moderately well to well sorted. Planar beds are horizontal or subhorizontal. Subhorizontal planar laminations are gently inclined at angles less than 5 degrees. Bedding plane partings average 2 to 6 centimeters in thickness. Internal lamination is subtle and detectable only in thin section. Upper stage planar laminations are locally abundant. Structures such as parting lineation and aligned plant fragments show a dominantly NW-SE paleocurrent direction at all localities (Fig. 14). Inversely graded laminae (Fig. 15) are rare.

Bedding planes are commonly strewn with carbonized and pyritized plant fragments, small branches, bark, and rare logs. Discrete conglomerate beds consisting of flat shale intraclasts occur on some bedding surfaces as well (Fig. 16).

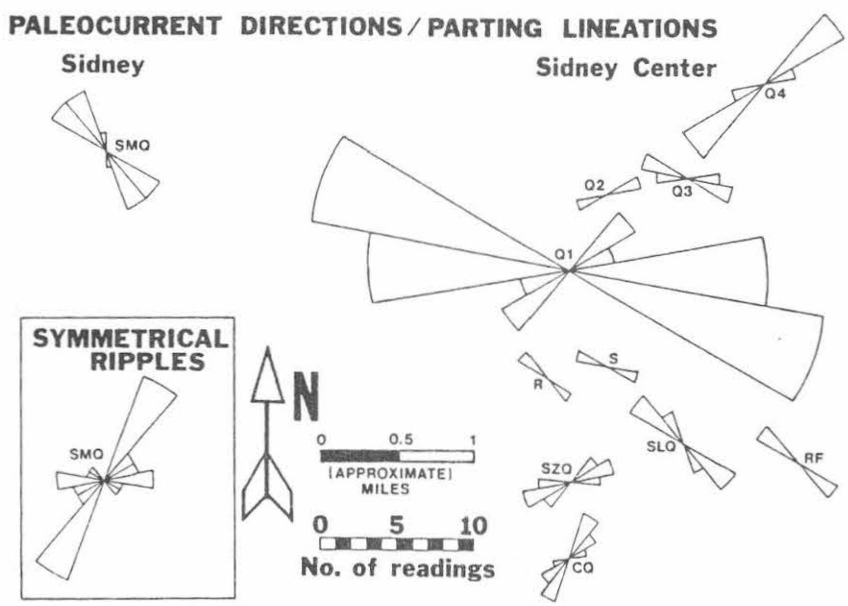

Figure 14: Rose diagrams depicting the geographic distribution of paleocurrent directions obtained from parting lineations. The inset at the bottom left corner is a rose diagram of paleocurrent directions obtained from symmetrical ripples at Sidney Mountain quarry. The abbreviations represent outcrops in their approximate geographic location (Figs. 3 and 4). CQ= Cardi quarry, Sidney Center (Planar-laminated and trough cross-bedded redbed facies; Q1= Quarry #1, Figure 4 (Trough cross-bedded facies); Q2= Quarry #2, Figure 4 (Planar-bedded facies); Q3= Quarry #3, Figure 4 (Mottled mudrock and sandstone facies); Q4= Quarry #4, Figure 4 (Planar-bedded facies); R= Outcrop R, Figure 4 (Trough cross-bedded facies); RF= Marvin Roof Barn, Roof Road, Sidney Center (Trough cross-bedded facies); S= Outcrop S, Figure 4 (Trough cross-bedded facies); SLQ= Skytop Lane quarry, Sidney Center (Planar-bedded facies); SMQ= Sidney Mountain quarry, Sidney (Planar-bedded facies); SZQ= Sheetz quarry, Cummings Rd., Sidney Center (Planar-bedded facies).

Figure 15: Subhorizontal and horizontal planar laminations are the predominant structure in the planar-bedded facies. Individual laminae are inversely graded as shown by alternating dark (very fine sand) and light (fine sand) laminae. Laminations are truncated by a reactivation surface at the top right of the photograph. Photograph of polished slab. Scale in centimeters (Stop 5).

Figure 16: Bedding plane strewn with flat shale intraclasts and the spirifer Platyrachella within the planar-bedded facies at Sidney Mountain quarry. Dime for scale (Stop 5).

Figure 17: Close-up of two molds of Barroisella campbelli. Specimen was found near the contact between the planar-bedded facies and the mottled mudrock and sandstone facies in Sidney Center. Scale in centimeters (Stop 1C).

Figure 18: The planar-bedded facies (lighter horizons at bottom and middle of photo) and the mottled mudrock and sandstone facies (darker horizons at shed and ladder and top of photo) are repeated twice at Sidney Mountain quarry. An unconformable erosional surface is located just above the top of the ladder. The second occurrence of the mottled mudrock and sandstone facies is present as a broad channel incised into the planar-bedded facies, which is filled with a fining-upward sequence of fine sand sublitharenite displaying low angle lateral accretion bedding grading to red-green mottled mudstone (Stop 5).

Figure 19: Examples of flaser and wavy bedding from near the top of the lower occurrence of the planar-bedded facies at Sidney Mountain quarry (See Fig. 18). Scale in centimeters (Stop 5).

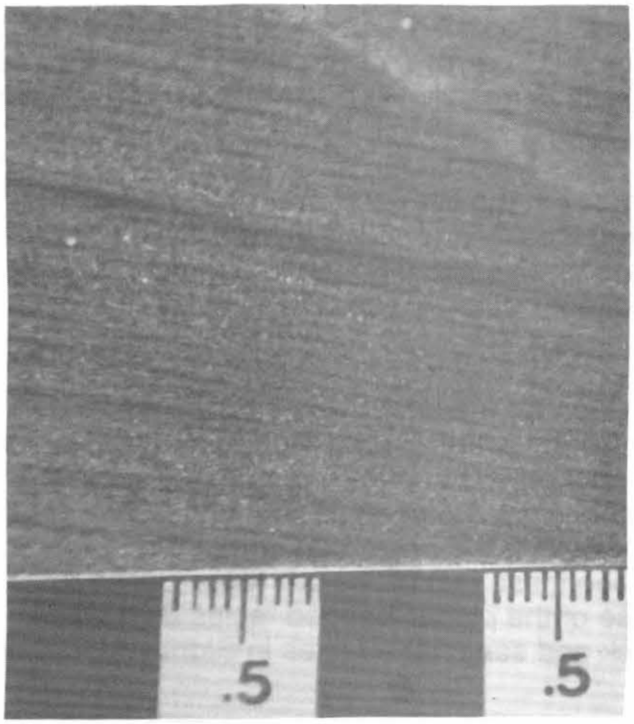

FIGURE 15

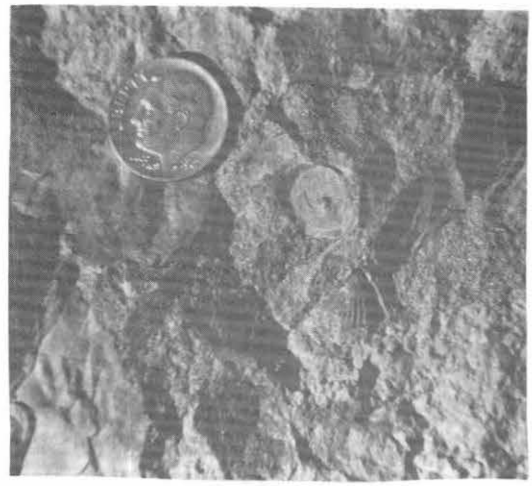

FIGURE 16

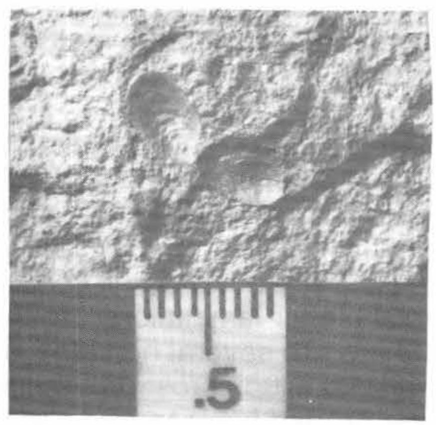

FIGURE 17

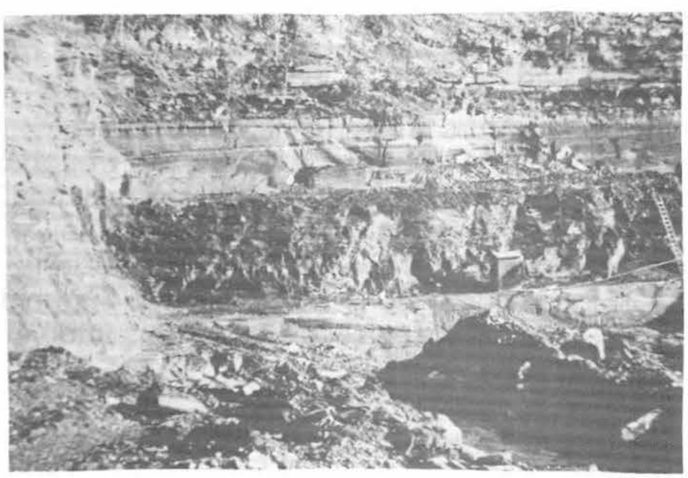

FIGURE 18

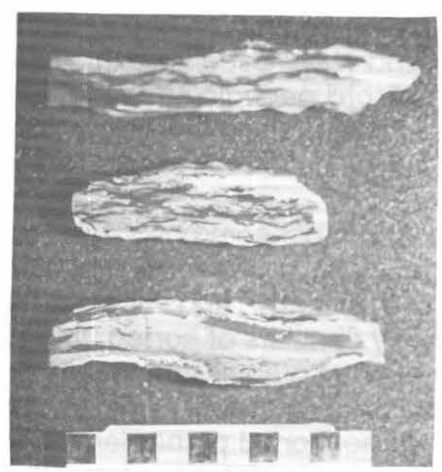

FIGURE 19

At the Sidney Center bluestone quarries (Stop 1), the uppermost half meter of the planar-bedded unit contains vertical, hematitic burrows of Skolithos and numerous shells of the inarticulate brachiopod Barroisella campbelli (?) (Fig. 17) associated with delicate plant leaves and stems.

Large, singular endichnial burrows occur in the float and are rarely found in the section. Similar burrows have been interpreted by Bridge, Gordon, and Titus (1985) as upward escape burrows of the nonmarine bivalve Archanodon occurring in fluvial and deltaic deposits. Gordon (personal communication, 1989) now thinks that they may be an indicator of brackish conditions.

The contact of the planar-bedded facies with the underlying trough cross-bedded facies is gradational in the Sidney Center area. Subhorizontal and horizontal planar laminations increase in abundance upward within the trough cross-bedded facies. In addition, subhorizontal planar laminations increase in abundance are much more common than horizontal planar laminations in the lower portions of the planar bedded facies. Contact relationships between these two facies are not exposed at Sidney Mountain quarry. However, the base of the planar-bedded facies is in sharp (erosional) contact with the mottled mudrock and sandstone facies in Sidney Mountain quarry (Stop 5).

At the Sidney Mountain quarry, the planar-bedded facies consists of two individual, fining-upward sequences with gently scoured and loaded bases. Each unit is interbedded with the mottled mudrock and sandstone facies (Fig. 18).

The first fining-upward unit consists of fine sand sublitharenite. Subhorizontal and horizontal planar laminations are the dominant sedimentary structures. Within the strata, there are several horizons of flat shale intraclasts, which rarely contain the rhynchenellid, Cupularostrum, the spiriferid, Platyrachella, and fish fragments (Fig. 16). Inversely graded laminae and numerous, highly abraded, arthropod fragments are common in this interval (Fig.15). Flaser bedding occurs commonly in this interval, which is characterized by discontinuous shale lenses which drape crests and troughs of ripples (Fig. 19). Wavy bedding with continuous shale lenses intervening between ripple cross-lamination occurs with flaser beds. Some of the shale surfaces of the flaser and wavy bedding exhibit sand-filled mudcracks with crude polygonal patterns, which record periodic subaerial exposure of these surfaces. A discontinuous linguoid rippled surface caps the fining-upward unit. Bioturbation levels are low in this interval. Burrow types are restricted to epichnial sinuous trails.

The most common sedimentary structure in the upper occurrence of this facies is large scale, subhorizontal planar laminations. This unit comprises the largest sand body in the quarry, and will be referred to as the main sandbody (fig. 18). The main sandbody consists of sorted, fine sand sublitharenite to quartz arenite. The subhorizontal planar laminations are inclined at angles of less than 5 degrees. These inclined beds alternate vertically and are truncated laterally by more mature (quartz arenite), horizontal planar lamination containing inversely graded laminae (Fig. 15). The cross beds also pass laterally into rare small channel forms with internal trough cross-lamination. The base of this sand body interval is gently loaded and scoured with occasional higher angle cross bedding. A variety of tool marks, flute casts, and load casts occur on the sole of the main sandbody. The base also contains numerous types of hypichnial burrows along with the rhynchenellid Cupularostrum and broken, unidentifiable brachiopod shells. Some of the hypichnial burrows include abundant vertical tubes, Cruziana arthropod trails, crescent-shaped burrows in convex hypo-relief Rhizocorallium (?), and "figure-8" burrows in convex hypo-relief.

Near the top of the main sandbody is a large, shallow scour 2 meters deep and approximately 50 meters wide. Sedimentary structures above this scour include numerous imbricated ball and pillow structures, climbing asymmetrical ripples, delicate shale interbeds (wavy bedding?), and lingoid ripples.

Numerous structures are found on the top bedding surface of the main sandbody. Lingoid ripples are common. These lingoid ripples are sometimes overlain by a secondary set of straight crested, asymmetrical ripples which have rounded to flat, planed-off crests with pointed and grooved troughs (Fig. 20). Other structures present at this horizon include symmetrical ripples and "ladder-back" ripples (Fig. 21). The ladder-back ripples consist of one set of symmetrical, oscillatory ripples and a second set of asymmetrical ripples within troughs formed at nearly right angles to the crest of the oscillatory ripples. In addition, a large block of silty sandstone was found in the float that contains large polygonal mudcracks which indicates periodic subaerial exposure of this surface.

The sequence of facies repeats throughout Sidney Mountain quarry. Also, two unconformable contacts exist: 1) between the mottled mudrock and sandstone facies and the planar-bedded facies in the middle of quarry (Fig. 18); and 2) between the planar-laminated and trough cross-bedded facies and the hummocky cross-stratified facies at the top of the quarry (Fig. 7).

Large scale planar cross-strata inclined at low angles at the top of the main sandbody are probably sand-filled channels (shallow and broad) exhibiting lateral accretion surfaces within deposits of the mottled mudrock and sandstone facies. Channel forms filled with lithologies of the mottled mudrock and sandstone facies are commonly incised into the top of the planar-bedded facies. The contact between these two facies is therefore sharp and erosional.

Figure 14 shows rose diagrams of paleocurrent directions measured from parting lineations at their respective geographic locations in the field.

Interpretation of the planar-bedded facies

The planar-bedded facies is interpreted as a prograding strandplain and barrier beach deposit (Fig. 22). There is subtle evidence for protective barrier islands, which are often associated with strandplain deposits. The absence of washover fans and backdunes makes it difficult to confirm a barrier setting. However, portions of the planar-bedded facies were probably consumed by lateral migration of tidal inlets of the trough cross-bedded facies, which gives barriers a low preservation potential.

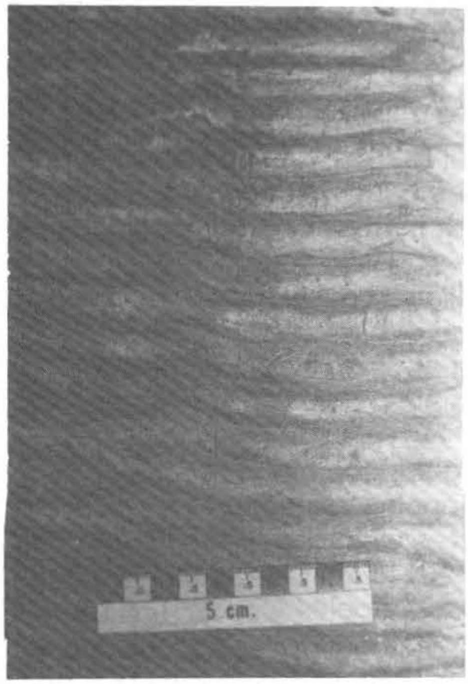

FIGURE 20

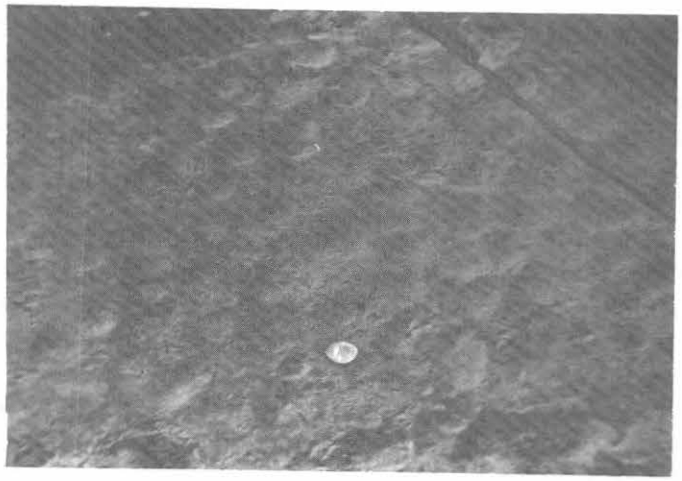

FIGURE 21

Figure 20: Flat-crested ripples. Asymmetrical ripples with rounded to flat crests and pointed troughs. These ripples are most likely the product of tide or swash reworking of symmetrical oscillatory ripples. Current direction is toward the bottom of the photograph (field azimuth= 50 degrees). Scale in centimeters (Stop 5).

Figure 21: Ladder-back ripples on the top bedding surface of the planar-bedded facies at Sidney Mountain quarry is clearly evidence of tidal influence (Stop 5).

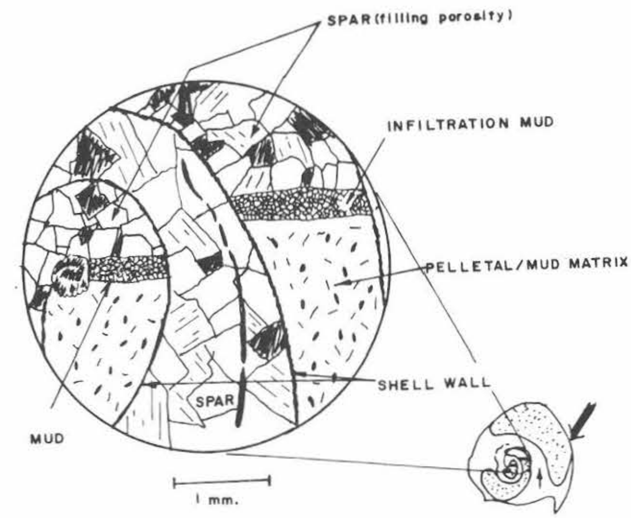

Figure 23: Sketch of photomicrograph showing infiltration mud filling shelter porosity inside the chambers of Bellerophon, float specimen from After, N. Y. Note the smaller depiction of the entire shell with the last whorl and body chamber completely filled by pelletal silty micrite. Shell has been reworked as evidenced by two layers of infiltration mud at the same orientation within smaller central chambers of the shell. Thicker arrow indicates original resting up position before reworking. Smaller arrow shows reoriented position following reworking.

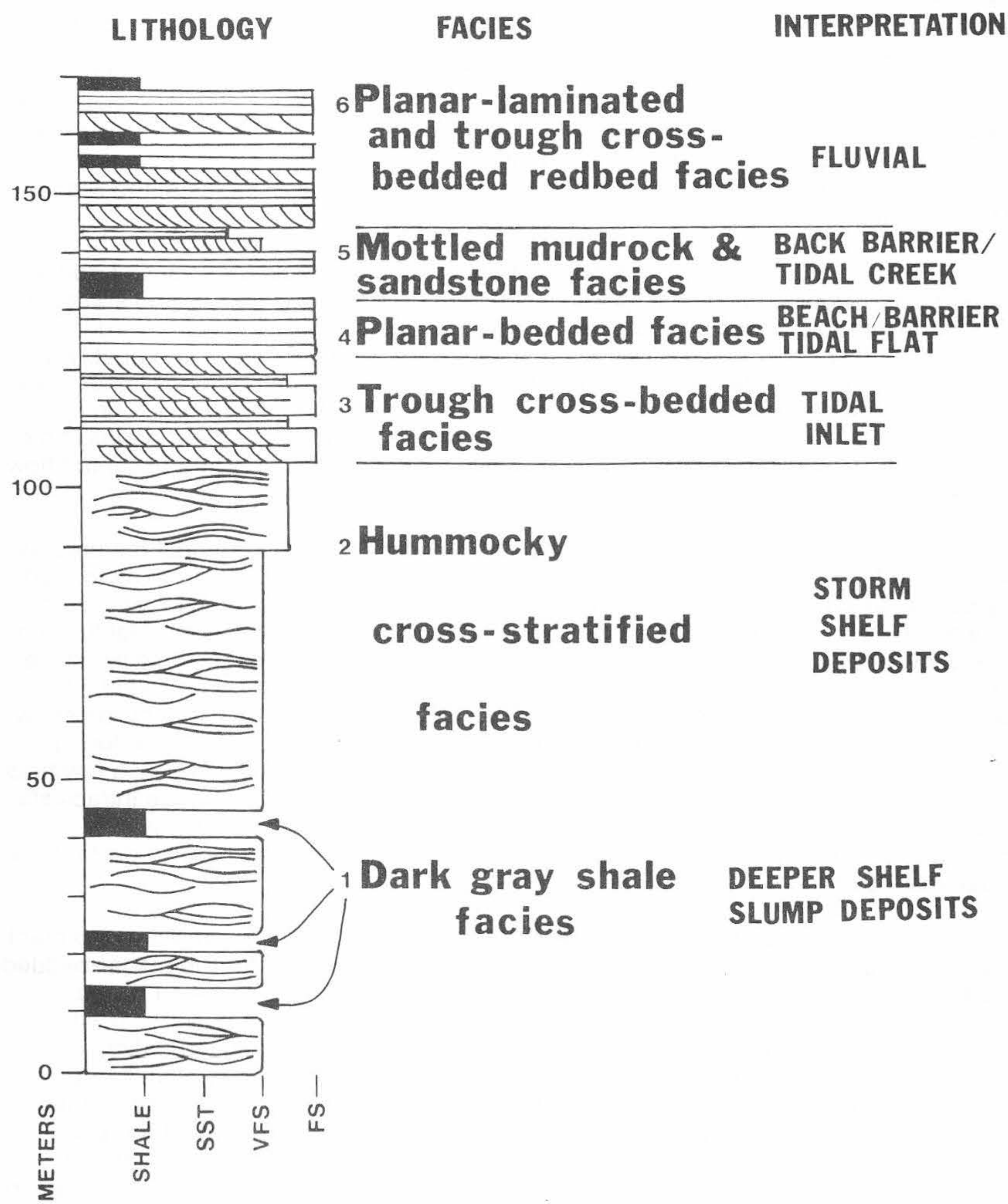

Figure 22: A 170 meter composite section illustrating the stratigraphic sequence and interpretation of the six facies units described in the study area. The overall sequence shows a coarsening-upward trend. Paleoenvironments of deposition are indicated in the right-hand column.

Close examination of the rose diagrams in Figure 14 has provided clues to reconstruct the morphology of the paleoshoreline. A dominant trend is present in a southeast to northwest direction. The paleoshoreline is oriented normal to this, in a northeast-southwest direction. This orientation is in agreement with past paleogeographic reconstructions of the Catskill sea (Haeckel and Witzke, 1984; Barrel, 1913, 1914; and Friedman, et. al., 1966). There is a slightly lesser component which parallels the shoreline orientation. This is interpreted as either an ebb directed tidal flow behind barriers or a flood-dominated flow seaward or barriers directed northeast into the Catskill basin. The orientation of symmetrical ripples at the Sidney Mountain quarry also supports this interpretation.

There is ample evidence for tidal activity in the planar-bedded facies. Ladder-back ripples suggest flood tidal flow with one set of symmetrical ripples and ebb tidal flow normal to this, which is preserved as asymmetrical ripples confined to troughs of the symmetrical ripple set. The secondary set of asymmetrical ripples is probably a late stage emergence feature formed as tidal currents drained off a depositional slope of a beach or tidal flat. Flat-crested ripples also record late stage tidal runoff on intertidal flats. Tidal currents caused planation of crests and subsequent deposition of reworked sediment into adjacent troughs. Field measurements indicate dominant flow to the north, which helps to confirm ebb flow behind barriers.

Flaser and wavy bedding (Reineck and Wunderlich, 1968) are tidal features as well, since they are found in close association with ladder-back ripples. They formed by settling of silt and clay from suspension at slack tide when current velocity is zero. The most likely location for flaser and wavy bedding to have formed is on tidal flats on the landward side of a barrier and adjacent to the back-barrier lagoon. The flat shale intraclast associated with horizons strewn with intraclasts, brachiopods, and plant debris may represent intraclasts derived from a local source, because the clasts show poorly rounded edges and clay clasts are readily weathered and destroyed during transport. Since the shale intraclasts are mostly concentrated in layers only a few tens of decimeters below flaser and wavy bedded units, it is likely that the shale intraclasts are derived from tidal flat sediment via spring tidal currents and/or strong storms. Similar suites of sedimentary structures in tidal flat settings are reported by deRaaf and Boersma (1971).

The association of Skolithos linearis, Barroisella campbelli?, and delicate plant leaves and stems strengthens a beach (foreshore) interpretation for the planar-bedded facies. Also, inverse graded bedding, highly abraded and highly rounded quartz grains, and abraded arthropod fragments are features common on beaches (Clifton, 1969). Inverse graded bedding is rare perhaps owing to infaunal bioturbation causing nearly complete sediment homogenization. An alternative explanation to account for homogenized beds is that the bluestones quarries in the Sidney Center area may represent an upper beach area landward of the swash zone where plant growth and soil development destroyed internal structure (Clifton, 1981). Another alternative is that much of the wave energy is dissipated just offshore on swash bars in the trough cross-bedded facies. This may prevent upper stage plane beds from forming intricate laminations owing to reduced swash agitation.

Thayer (1974) indicates that Cupularostrum and Platyrachella are abundant in the nearshore zone, because they are unusually euryhaline. The globose valves of Cupularostrum and the thick valves and compact shape of Platyrachella inhibited shell breakage in turbulent nearshore waters (Thayer, 1974). These brachiopods probably lived in subtidal environments of Sonyea tidal flats and/or just offshore, and were washed up onshore. Thayer (1974) also notes substantial numbers of bivalves, including Barroisella, in green silts and shales of estuarine, lagoonal, and tidal flat origin of the distal portions of the Oneonta Formation and within proximal portions of other marine formations of the Genesee Group. Barroisella was an infaunal burrower with a long, siphon-like pedicle and lived with its long axis vertical (Boucot, 1981). It probably lived in intertidal creeks and flats in the Sonyea Group.

In summary, the sedimentologic and paleontologic data of the planar-bedded facies best fits a depositional model of a prograding barrier island/strandplain and tidal creek system. Tidal features documented in this study are suggestive of a mesotidal range. These barrier islands probably were drumstick-shaped, which is the characteristic shape of barrier islands along mesotidal shorelines. The progradational tidal creek/drumstick barrier island system of Ossabaw Sound, Georgia (Greer, 1975) is suggested as a modern analog.

Some ancient analogs of regressive barrier island/strandplain and estuarine systems that are reminiscent of this investigation include: the Lower Cretaceous Notikewin Member (Fort St. John Group), northeastern British Columbia (Leckie, 1985); and the Upper Cretaceous Cardium Formation of the Kakwa Field and adjacent areas, Northwestern Alberta (Plint and Walker, 1987).

Heward (1981) contends that longshore and shelf sediment sources provide insufficient quantities of sediment to be maintained for extensive progradation of barrier island systems, despite a constant sea level over a long span of time. However, Leckie (1985) finds that the barrier island system of the Notikewin Member of the Fort St. John Group had prograded approximately 150 kilometers. A delicate balance between sediment supply and rate of subsidence would have been required for the back barrier lagoon to have migrated behind the barrier island complex and not have been filled in (Leckie, p.49, 1985). Also, a large sediment supply by rivers and a moderate wave energy are essential (Carter, 1978). Environmental constraints and processes similar to those described by these authors are thought to have operated during the Upper Devonian in the study area.

Tidal range apparently increased in the Catskill sea progressively toward the northeast. In central Pennsylvania, prograding muddy shorelines of weaker tidal influence (microtidal) have been described (Walker and Harms, 1975). In northern-most Pennsylvania, more abundant evidence for tides has been presented, which probably reflects increasing tidal range (Bridge and Droser, 1985). Sedimentary structures indicate significant tidal influence (mesotidal) within the study area. This trend supports the existence of a narrow, elongated embayment present at the north end of the Catskill sea (Heckel, et al., 1979; see Fig. 1). Tidal augmentation may have continued toward the headward portions of the Catskill sea, similar to modern tidal processes of the Bay of Fundy, Nova Scotia, Canada.

Description of the mottled mudrock and sandstone facies

The mottled mudrock and sandstone facies is characterized by red-green mottled mudstone, and less commonly, green-gray mottled shale. It is also assignable to the Cattaragus Magnafacies of the nonmarine to marine transition zone. This facies can be found at Sidney Center and Sidney Mountain quarry.

Exposure of this facies at Sidney Center consists of 1 to 3 meter fining-upward sequences of fine sublitharenite, sandy and silty mudstone, and mudstone (Fig. 18). Contact relations with the underlying planar-bedded facies is sharp and planar. Sedimentary structures within sandstone interbeds include alternating trough cross-bedding, planar-bedding, and rare asymmetrical ripples. Trough cross-beds are commonly inclined at low angles (5 to 17 degrees).

At Sidney Center, the lower half of the mudstone interval is green and featureless. Sparse, diminutive vertical burrows are present, which are possibly either Skolithos-like burrows or rootlets. The occurrence of this facies marks the first appearance of green and red coloration throughout the Sonyea stratigraphic section. This is significant, because sediments of the fluvial Catskill Magnafacies are dominantly green and red whereas open marine siltstone and shale are characteristically gray in color.

A distinct horizon of red-green mottling overlies the green featureless mudstone interval. The red-green mottled horizon is, overlain in turn, by dominantly red- to green-mottled, sandy- to silty-mudstone. This interval contains abundant fish plates, bone fragments and teeth of Bothriolepis and possibly Eusthenopteron(?). Also present are hematitic Skolithos burrows, and rare Barroisella campbelli(?).

At the Sidney Mountain quarry, the mottled mudrock and sandstone facies contains interbeds of siltstone and very fine sand sublitharenite. The mottled mudrock and sandstone facies is repeated twice at Sidney Mountain quarry (Fig. 18). It is interbedded with the planar-bedded facies, which also occurs twice within the quarry.

The first occurrence of this facies is bounded on top and bottom by sharp and loaded contacts. The siltstone and shale are planar-laminated or blocky, and dominantly green, gray or mottled green-gray. The sandstone is generally tan in color and exhibits planar lamination with rare parting lineations. Hummocky cross stratification is rare. Sandstone and siltstone interbeds are capped sporadically by symmetrical wave ripples and ripple cross lamination. Ball and pillow structures are present at and near the base of the interval. Fossils are restricted to carbonized and chalcopyritized plant fragments. Bioturbation is moderate to low.

The second occurrence of the mottled mudrock and sandstone facies at Sidney Mountain quarry, consists of one fining-upward sequence of fine sublitharenite and moderate to heavily bioturbated, mottled, red siltstone and mudstone. Channels commonly incise approximately one meter into the planar-bedded facies. Some of these channels are filled with sorted, fine sand sublitharenite exhibiting gently inclined planar-lamination interpreted as lateral accretion surfaces. Other channels are filled with moderate to poorly sorted, very fine sandstone, siltstone and shale. Siltstone and shale are characteristically red to red-green mottled.

Sedimentary structures include alternating planar-beds and trough cross-beds. Ladder-back ripples, symmetrical ripples, asymmetrical ripples and ripple cross-laminations are otherwise rare. Mudcracks occur throughout the interval but are rare. Asymmetrical ripples with superimposed mudcracks and ladder-back ripples occur rarely within siltstone lenses. Other dessicated surfaces are covered with various non-descript burrows with a red-green mottling. Wrinkle marks ("runzel marks") are found in close proximity to mudcracks. The bases of the siltstone lenses commonly have flute casts and structures that resemble small gutter casts.

Both the siltstone and mudstone contain abundant mud-filled root casts with macerated plant fragments. The casts are interpreted as roots rather than burrows, because the caliber of the opening shows a slight tapering on some specimens.

Interpretation of the mottled mudrock and sandstone facies

The mottled mudrock and sandstone facies probably represents a tidal creek and back barrier lagoon sequence, which partially dissects through a barrier island/strandplain system. Modern analogs to this sequence are described by Greer (1975) of the estuarine-marine transition of the Ogeechee river, Ossabaw Sound, Georgia. Ancient counterparts are suggested from work done by McCrory and Walker (1986).

The association of fish debris with inarticulate brachiopods and Skolithos, occurring directly above foreshore beach sediment of the planar-bedded facies, argues in favor of brackish water conditions. The mottled mudrock and sandstone facies may represent small, shallow, sluggish tidal creeks. Similar brackish water deposits, containing similar faunal associations, have been reported in the Devonian Catskill Magnafacies by Gordon and Knox (1989) and Thomson (1976). Gordon (1990, personal communication) is re-examining several genera of fish for possible habitation in brackish settings. It is suggested that the abundance of fish in the mottled mudrock and sandstone facies may suggest proximity to marine conditions and may reflect brackish conditions.

The fish debris at Sidney Center could be concentrated by one of the following mechanisms: a) by strong storms and/or floods, thereby producing a tempestite; or b) a channel floor lag deposit; or c) by processes related to tubidity maxima within estuaries, which causes concentrations of debris to be deposited at the nodal zone, where fresh and salt water prisms meet. Lateral migration of the nodal zone is known to accumulate concentrations of materials in modern estuaries and tidal creeks such as the upper reaches of Chesapeake Bay (Schubel, 1971a) and in the Demerara estuary of the coast of British Guiana (Schubel, 1971b). Similar processes could have operated in tidal creeks along the Catskill sea shoreline.

Several horizons at Sidney Mountain quarry suggest brackish to marine conditions. Ladderback ripples and asymmetrical ripples with superimposed mudcracks are found in close proximity along the same horizon. Ladderback ripples are clearly of tidal origin. Therefore, superimposed mudcracks on some ripples surfaces record intermittent emergences of the depositing surface during falling tides and/or discharge fluctuations. Wrinkle marks ("runzel marks") are also found in close proximity to these structures. The wrinkle marks can be interpreted here as another indicator of subaerial exposure when found in association with other dessication features. Reineck (1969) showed experimentally that such wrinkle marks develop when a strong wind blows over a partially cohesive sediment surface covered by a thin film of water, which deforms the sediment into wrinkles. These structures collectively record intertidal flat deposition along tidal creek margins.

The thickness of a fining-upward sequence approximates the depth of the tidal creek assuming that scouring into the mudstone by the planar-laminated and trough cross-bedded redbed facies was minimal. The tidal creeks in Sidney Center were probably not major streams but rather small and shallow, because the mudstone unit is only 3.36 meters thick. Some of the mudstone was stripped, because sandstones at the base of fining-upward sequences are commonly loaded and have scour and fill bases. However, at the Sidney Mountain quarry, the mottled mudrock and sandstone facies is 6.65 meters thick, which probably represents a larger tidal creek. The second occurrence of this facies at Sidney Center represents a smaller tidal creek, because it is only 2.2 meters thick.

Both the planar-bedded facies and the mottled mudrock and sandstone facies are repeated twice at Sidney Mountain quarry (Fig. 18). Initially, barrier island and barrier beach deposits of the lower interval of the planar-bedded facies prograded seaward. Tidal creek and back-barrier lagoon deposits prograded seaward as barriers/beaches prograded. A localized, brief marine trangression occurred, which produced a loaded, sharp erosional base followed by continued deposition of the planar-bedded facies. Soft sediment deformation structures at this locality are not of sufficient size, frequency, or penetration to account for the repetition of facies by subsidence alone. A combination of these processes probably occurred. Marine transgression may have been prompted by an episode of epeirogenic downflexure (Quinlan, et al., 1984). Again, tidal creeks and distal fluvial deposits prograded seaward as barriers/beaches prograded. A second marine transgression of greater magnitude is implied by rocks of the hummocky cross-stratified facies deposited unconformably on fluvial deposits of the planar-laminated and trough cross-bedded redbed facies located at the uppermost 4 meters of Sidney Mountain Quarry.

Red-green mottling in the mottled mudrock and sandstone facies is the product of one of the following mechanisms: a) biogenic activity by infauna or roots; b) salinity fluctuations in a brackish setting; or c) groundwater fluctuations in a terrestrial or coastal setting.

The mottled mudrock and sandstone facies is sharply in contact with, but lithologically similar to the planar-laminated and trough cross-bedded redbed facies. Placement of the contact between these two facies was difficult. It involved painstaking observations to locate evidence for tidal influence in the mottled mudrock and sandstone facies. This poses some problems. Tidal creek and fluvial sedimentary processes, lithologies, and resultant fining-upward sequenced are strikingly similar in many respects. Some intervals in this study remain problematic. It is not clear whether some intervals in the study area are estuarine or fluvial in origin. Within each of the problematic intervals, there is a lack of tidal features. However, root casts, vertical burrows, fish fragments, and plant remains are much more abundant in these intervals than in fluvial deposits of the planar-laminated and trough cross-bedded redbed facies higher in the section. Evidence for tidal influence may have been overlooked here.

Description and interpretation of the planar-laminated and trough cross-bedded redbed facies

The rocks of the planar-laminated and trough cross-bedded redbed facies represent nonmarine, fluvial Catskill Magnafacies of the Lower Walton Formation. These rocks bear close resemblance to Bridge and Gordon's (1985) study of fluvial fining-upward sequences of the Oneonta Formation of the Genesee Group, New York. Bridge and Gordon (1985) conclude that the Oneonta Formation was deposited by single, sinuous streams and rivers flowing over a lowland alluvial plain. The planar-laminated and trough cross-bedded redbed facies is thought to represent a similar environment of deposition. Other noteworthy investigations of fluvial Catskill Magnafacies include Bridge (1988) and Sevon (1985).

SUMMARY OF CONCLUSIONS

1. Figure 22 is a 170 meter composite section illustrating the stratigraphic sequence and interpretation of each of the six facies described in the study area.

2. The sequence of facies and the distribution of sedimentary structures suggest non-deltaic progradation of the Catskill clastic wedge during Sonyea (Frasnian) time.

3. Hummocky cross-stratification is a storm-generated structure formed under high velocity, oscillatory flow conditions. It is found between fair-weather and storm wave base. The abundance of hummocky cross-stratification along with the lack of small scale coarsening-upward sequences throughout the entire section warrants against an interpretation of deltaic deposits in the nearshore. Frequent storms would inhibit outbuilding of deltaic lobes and argues for a straighter shoreline.

4. Vertical stacking of hummocky cross-stratified beds produced nearshore shallowing. This provided conditions conducive for progradation of coastal deposits over the hummocky cross-stratified facies.

5. The dark gray shale facies represents deeper portions of the shelf. Anoxic conditions were produced by either pycnoclinal fluctuations or sea level rise or both. Pycnoclinal adjustment and/or sea level rise may be the result of epeirogenic lithospheric downflexure (Quinlan, et al., 1984) or eustacy. Listric truncation surfaces represent submarine slope-failure surfaces of soft sediment slumps.

6. The trough cross-bedded facies represents migrating tidal inlets of a barrier island or estuarine complex. Dunes show migration in a north to northeasterly direction, which probably indicates inlet migration in that direction. Northerly paleoflow records either dominant direction of longshore transport, tidal current direction, or storm track path. Planar-laminated interbeds may represent either swash bars or spit complexes within tidal inlets.

7. The planar-bedded facies represents either prograding strandplains or barrier beaches with associated intertidal environments (i.e., tidal flats, back-barrier salt marshes) in an overall barrier island complex. Paleocurrent data suggest a shoreline trend of southwest to northeast.

8. The mottled mudrock and sandstone facies represents estuarine and tidal creek deposits that partially dissect into the planar-bedded facies. Estuaries prograded seaward as beaches prograded.

9. Fluvial fining-upward sequences of the planar-laminated and trough cross-bedded redbed facies erosionally overlie coastal deposits of the mottled mudrock and sandstone facies. This facies is interpreted as fluvial Catskill Magnafacies of the Lower Walton Formation. Streams and rivers deposited sediment in a vast alluvial plain, which prograded seaward as transitional facies prograded.

10. Some sedimentary structures (i.e., flaser/wavy bedding, ladder-back and flat-crested ripples, and reformed ripples with herringbone cross-lamination) strongly suggest that tides were active in the Catskill sea.

11. Paleocurrent data and tidally-produced sedimentary structures suggest tidal augmentation in the Catskill sea progressively toward the northeast. This tends to support the existence of a narrow, elongate embayment present at the north end of the Catskill Sea.

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ROAD LOG FOR PROXIMAL STORM-DOMINATED SHELF TO TIDALLY-INFLUENCED FORESHORE SEDIMENTATION, UPPER DEVONIAN SONYEA GROUP, BAINBRIDGE TO SIDNEY CENTER, NEW YORK

CO-LEADERS: BISHUK, D., APPLEBAUM, R., AND EBERT, J.

Cumulative Mileage	Miles From Last Point	Route Description
0.0	0.0	Mileage begins at intersection of Main Street in Oneonta and Exit 14 onramp to Interstate 88. Take westbound onramp onto I-88.
7.3 and 10.6	7.3 and 10.6	To your left are exposures of fluvial deposits of the Oneonta Formation (Genesee Group). This formation is similar in many aspects to the Lower Walton Fm. (Sonyea Group) included in this study.
11.6-12.9	4.3	The Susquehanna river has incised through the Wells Bridge moraine (right). This moraine served as a dam, which impounded glacial Lake Otego. Upgradient of the moraine, 300 to 400 feet of lacustrine silts and clays underlie the valley floor. Downgradient, an outwash terrace can be seen at the rest area (13 mi.).
15.4-16.2	2.5	Immediately after exit 11, a sinuous, beaded esker can be seen at your right (extends for approx. 0.5 miles).
17.3	1.1	Take exit 10 off I-88 at Unadilla. Outcrops of Oneonta Fm. at left.
17.9	0.6	As you descend off of long off-ramp, make your first left onto River Road (located just before bridge over Susquehanna River). Glaciofluvial sand & gravel quarry to the left.
18.9	1.0	Make your 2nd (hard) left onto Delaware County Route 23 (east).

19.3	0.4	Reference marker: Quarry Rd.; Helderberg Bluestone Quarry at end of road; Excellent exposure of the Oneonta Fm. (Genesee Group). From Quarry Rd., count to the second road on your right (Dunshee Rd.).
20.5	1.2	Passing Road #13.
21.7	1.2	Turn right onto Dunshee Road.
22.2	0.5	Hummocky cross-stratified sandstones interbedded with shale of the Glen Aubrey Fm. (Sonyea Gr.).
22.5	0.3	Glen Aubrey Fm.(right); ball and pillow structures predominate the exposure.
23.2	0.7	Small quarry to the right consists of the amalgamated portion of the hummocky cross-stratified facies of this study (Glen Aubrey Fm.).
23.3	0.1	At intersection of Dunshee Rd. and Delaware County Route 35, bear left. Proceed less than a tenth of a mile past trailer home and make first left onto cobble driveway into an open field. Driveway leads to several bluestone quarries.
23.45	0.15	Park cars just before powerline.

STOP 1: SIDNEY CENTER OUTCROPS (See Figures 3 and 4)

STOP 1A: STEELE QUARRY AND PASTURE OUTCROPS OF THE HUMMOCKY CROSS-STRATIFIED FACIES (See Figure 4)

Location: Scattered outcrops and a small, inactive quarry are located in a cow pasture behind the Steele residence. All stop 1 outcrops can be found in the south-central portion of the Unadilla, New York 7.5 minute quadrangle, located at the intersection of Dunshee Road and Delaware County Route 35. Before visiting the Steele quarry, please ask Mr. and Mrs. Steele for permission to walk on their property. Since stop 1A is on private property, the authors ask that you do not use rock hammers on the outcrops or collect any samples.

Description: The Steele quarry and pasture outcrops (outcrop V) (Fig. 4) are stratigraphically positioned in the Glen Aubrey Formation, and are designated as the amalgamated portion of the hummocky cross-stratified facies. These exposures offer an excellent opportunity to examine hummocks and swales of HCS beds in plan view. The amalgamated portion of the hummocky cross-stratified facies is interpreted as dominantly sandy, storm deposits at or above fair weather wave base (consult text for details). Fossils are sparse and are restricted to coquinite lenses consisting of Sphenotus, Cupularostrum, Platyrachella, fish plates, and plant fragments. Sedimentary structures which cap hummocky cross-stratified beds include wrinkle marks crescentic scour depressions partially filled with very fine sand. These scours commonly exibit asymmetrical and symmetrical ripples within the depression.

An enigmatic shale unit is found in the center of the quarry. At approximately halfway up in the shale, there is a light colored and differentially weathered horizon which has rather high concentrations of dolomite. Since this shale can not be traced laterally, it is difficult to decipher its stratigraphic context and facies relationships.

At outcrop V in the cow pasture (Fig. 4), excellent hummocky bedforms are present. Within the hummocky cross-stratified beds, climbing ripple cross-lamination are inclined at a steep angle of propagation (Fig. 9). The ripples are slightly asymmetric in the direction of propagation toward the crest of the hummock (from left to right) suggesting that they migrated slightly up the flank. Steep inclination of propagation and the form-concordant style reflects vertical growth of the hummocks with minimal migration. This supports that hummocky cross-stratification formed under high velocity oscillatory flow conditions and rapid deposition rates during storm events.

STOP 1B: OPEN PIT AND FIELD OUTCROPS OF THE TROUGH CROSS-BEDDED FACIES (See Figure 4, Outcrops R and S)

Outcrops R and S represent the lowest portion of the trough cross-bedded facies, which sharply overlies the hummocky cross-stratified facies. The trough cross-bedded facies is assignable to the lowest facies unit of the Cattaraugus Magnafacies. Locally, an erosional base defines its base and near base, which is characterized by a coarse lithoclast, shelly, and plant debris lag. Contact relationships are not observable at this stop. The outcrops are positioned within a meter or two above the contact. However, a coarse lithoclast, shelly lag is present at outcrop R. The rhynchenellid, Cupularostrum, and the bivalve, Sphenotus, occur sparsely at this horizon. The sparse marine fauna is the best way to differentiate between the trough cross-bedded facies and the strikingly similar planar-laminated and trough cross-bedded facies (Lower Walton Formation) positioned stratigraphically higher. Trough cross-beds commonly climb at low angles of propagation and interpreted as dunes within tidal inlets within a barrier island/strandplain and tidal creek system. Planar laminated interbeds are interpreted as swash bars within the tidal inlets.

STOP 1C: LOGGING TRAIL OUTCROP OF THE TROUGH CROSS-BEDDED FACIES (Figure 4, Outcrop D-b)

Outcrop D is located approximately 40 feet higher within the trough cross-bedded facies than stop 1B. Trough cross-beds are spectacularly illustrated here owing to well developed differential weathering of the outcrop surface. Trough cross-beds exhibit normally graded, lenticular laminae, which probably reflect sediment supply pulsations induced by tides (Fig. 11). In addition, asymmetrical ripples on troughs commonly oppose the dominant, northerly paleoflow direction of trough cross-beds (Fig. 11). These asymmetrical ripples record a subordinate current reversal induced by tides within tidal inlets. Evidence of tidal activity in the Catskill Sea is only sparsely documented in the literature (Ebert, 1987; Walker, 1975; and Bridge and Droser, 1985) and has never been documented from the Sonyea Group.

STOP 1D: WOODLAND OUTCROP OF THE TROUGH CROSS-BEDDED FACIES (See Figure 4, Outcrop K)

Outcrop K is also assignable to the trough cross-bedded facies. Trough cross-beds are likewise spectacularly illustrated at this outcrop owing to well developed differential weathering of the outcrop surface. Trough cross-beds represent dunes migrating within tidal inlets. These alternate with planar-laminated interbeds, which represent swash bars deposited along the margins of tidal inlets. The trough cross-beds are unidirectional to the north and climb at low angles of propagation. Rare ripple cross-lamination on weathered surfaces is suggestive of current reversals, which offers additional supporting evidence for tidal influence.

STOP 1E: BLUESTONE QUARRIES #4 & #5 OF THE PLANAR-BEDDED FACIES AND THE MOTTLED MUDROCK AND SANDSTONE FACIES

The planar-bedded facies is sharply overlain at these quarries by the mottled mudrock and sandstone facies. The contact is planar and lacks incision by channels. The planar-bedded facies is extensively quarried for "bluestone" slabs used for sidewalk and construction purposes. Internal lamination within planar-beds is rare, but where it is present, it is often inversely graded. These structures are common on high energy foreshore beach/barrier setting. Also present are abraded arthropod fragments, and highly abraded and highly rounded quartz grains. The arthropod fragments may be either ostracods or trilobites. Near the upper contact of the planar-bedded facies, an association of Skolithos linearis, Barroisella campbelli, and delicate plant leaves and stems strenthens a beach (foreshore) interpretation for the planar-bedded facies. Barroisella was an infaunal burrower with a long, siphon-like peducle and lived with its long axis vertical (Boucot, 1981). It probably lived in intertidal creeks and tidal flats in the Sonyea Group.

The mottled mudrock and sandstone facies stratigraphically above has an association of abundant fish debris of Bothriolepis with Barroisella and Skolithos, occurring stratigraphically above foreshore beach deposits of the planar-bedded facies, argues in favor of brackish water conditions. The mottled mudrock and sandstone facies may represent tidal creek deposits.

STOP 1F (OPTIONAL): BLUESTONE QUARRY #1/ TRANSITION OF TROUGH CROSS-BEDDED FACIES WITH THE OVERLYING PLANAR-BEDDED FACIES (See Figure 4)

Bluestone quarry #1 occurs near the gradational contact between the trough cross-bedded facies and the planar-bedded facies. Planar-bedding dominates while trough cross-bedding is rare. The purpose for visiting this outcrop is to establish the contact relationship and to have an opportunity to collect plant fossils. Fossils of carbonized and pyritized plant stems, branches, logs, and bark can be readily collected at this location. Parting lineations and aligned plant fragments are abundant, which represents a strong onshore/offshore subtidal flow pattern.

23.45	0.0	Return to vehicles. Proceed back out to Dunshee Road.
23.6	0.15	Turn right onto Dunshee Road
25.1	1.5	Turn left onto Delaware county Route 23.
27.9	2.8	Turn right onto River Road.
28.9	1.0	Turn right onto I-88 onramp. Take I-88 westbound.

OPTIONAL FOR LUNCH

33.8	4.9	Take exit 9 from I-88 at Sidney.
34.1	0.3	Turn right onto Route 8 North.
34.6	0.5	Turn left at the first traffic light.
34.9	0.3	Turn left into McDonalds parking lot.

BREAK FOR LUNCH.

35.2	0.3	Return to vehicles. Proceed back out to Route 8. Turn right onto Route 8 south.
35.6	0.4	Turn right onto I-88 west

36.2-37.0	0.6	Exposures of the Triangle Fm. (Sonyea Group) consist of hummocky cross-stratified sandstone interbedded with shale.
38.8	1.8	Take exit 8 off I-88 at Bainbridge. Park cars on off-ramp at end of large outcrop.

STOP 2: HUMMOCKY CROSS-STRATIFIED FACIES, TRIANGLE FORMATION (?), EXIT 8 ONRAMP ON I-88, BAINBRIDGE (Figure 3)

Three outcrops afford ample opportunity to examine storm deposits. We will concentrate most on the largest exposure directly south of the eastbound lanes of Interstate 88. Storm beds, numerous soft-sediment deformation structures of variable scale, bioclastic mudstones and sandstones, and listric truncation surfaces are most easily identifiable at the exposure.

Please be extremely careful not to go out on the highway as this spot has limited sight distance for drivers. Also, vehicles are accelerating up the onramp onto the primary lanes. Please be alert at all times while at this stop. You may cross over to examine the middle outcrop north of the eastbound lanes. Be absolutely sure there are no oncoming cars as far as you can see down the lanes and around the bend before you cross the road. Vehicles are moving faster than they appear but if you are careful then tere is plenty of time to cross. Bedding planes are exposed at the very top of the outcrop displaying wave ripples and oriented fossils. They can be reached by carefully ascending the east end of the outcrop at the large culvert that passes under the road. Note also the numerous bedding surfaces with wave (?) or current(?) oriented Mucrospirifers and Tentaculites. East of the culvert are large slabs weathered out of the outcrop that contain numerous fossils and sedimentary structures. Collect all you wish from these loose slabs, but please do not collect in situ fossils or structures as ongoing research is continuing at this time. Please do not disturb any bedrock in place that has elevation or benchmark data recorded on it. These are reference markers for future study and should not be disturbed.

As we work our way up the large exposure, note the changes in lithology. Is the sequence fining or coarsening upward? What about the coarsest sandstone beds? Do they thicken upward over the entire vertical sequence or are there no discernable trends? Notice the slump scars (?) and what's directly above them. Could loading of several storm-deposited decimeter thick sandstone beds above the mudstone have contributed to the slump, or is some other mechanism warranted here such as seismic shaking (see discussion earlier by Bishuk, this paper). Are there any channel forms? We will try to answer these questions at the outcrop.

Note the variability in the morphology of the soft-sediment features. Relative size, orientation, internal stratification, and depth of penetration into underlying beds all vary throughout the section. Does there appear to be a correlation between the size of pillows and the thickness of the overlying sandstones. Are these all just balls and pillows? Consider the possibility of load casts, foundered ripples, and channel forms. Interpretation of these structures at this locality has been a source of lively discussion among the authors. Much work remains concerning the genesis of these sandstones.

Fossil coquinites and bioclastic mudstones are common at the base of storm layers, i.e. very fine to fine sublitharenites. This gives way to planar cross stratification, wave ripples, and thin mudstones with extensive bioturbation at the top of most sequences. These deposits are interpreted as tempestites by Applebaum (in prep.). Internal morphologies vary from one storm bed to another. For a recent discussion of vertical stratification sequences in storm-deposited beds see Myrow and Southard (1991).

39.3	0.5	Return to vehicles. Proceed to end of Bainbridge exit off-ramp. Turn right onto Route 206 westbound.
39.7	0.4	Junction 7. Continue west on Route 206.
40.2	0.5	Intersection of Rte 206 with Mt. Pleasant Road.
40.4	0.2	Reference marker: Road winds uphill to the left. On your left, look carefully for back of sign for eastbound traffic saying "Welcometo Bainbridge".
41.1	0.7	A guardrail can be seen on both sides of the road with a small outcrop on the left and a stream passing beneath the road. A gorge begins on the left. Park cars at the dirt pull-off on the right.

STOP 3A: STREAM GORGE EXPOSURE OF THE HUMMOCKY CROSS-STRATIFIED FACIES, GLEN AUBREY FORMATION (?), WEST OF BAINBRIDGE (Figure 3)

The exposures in the stream gorge south of Route 206 contain massive bedded sandstones, amalgamated sequences of balls and pillows, and most notably several key horizons of calcareous bioclastic conglomerates that may prove useful as lithostratigraphic or biostratigraphic "key beds". These shell beds are undoubtedly thanatocoenose assemblages and contain mostly crinoid columnals, brachiopods, gastropods, and branching bryozoans.

Numerous erosional surfaces within shell beds indicate amalgamation. Numerous reoriented geopetal structures (e.g. mud-filled gastropoda) suggest reworking of bioclastic materials by storms under waning flow conditions during the closing phases of the individual storm event. Fine mud resuspended by weak oscillatory wave currents settles out into areas of shelter porosity (underneath brachiopoda valves or inside Bellerophon chambers, see Figure 23). Similar fabrics have been documented by Kreisa and Bambach (1982).

41.1	0.0	Return to vehicles. Proceed westbound on route 206.
41.7	0.6	Outcrop can be seen on both sides of the road near crest of hill. Park cars on shoulder.

STOP 3B: HUMMOCKY CROSS-STRATIFIED FACIES, GLEN AUBREY FORMATION (?), WEST BAINBRIDGE (Figure 3)

This stop has some interesting features on the south side of the road. Of particular note are the high angle dips on some of the sandstone beds. Are these slump structures or channel forms? At the present time a definitive interpretation is unavailable. We welcome any suggestions. Surprisingly puzzling is the outcrop just north of the road, which contains no such distortion of bedding with all horizontal and undisturbed stratification. Can you explain the sudden change in attitude of the bedding over such a small distance, i.e. 10 meters.

41.7	0.0	Return to vehicles. Proceed on Route 206 eastbound back to I-88.
44.4	2.7	Turn left onto I-88 eastbound.
47.7	3.3	Take exit 9 off I-88 at Sidney. Bear right onto Route 8 south.
48.5	0.8	Large exposure of the Glen Aubrey Formation can be seen on both sides of the road. Turn right into large parking area.

STOP 4A: HUMMOCKY CROSS-STRATIFIED FACIES AND DARK GRAY SHALE FACIES, GLEN AUBREY FORMATION, ROUTE 8, JUST SOUTH OF SIDNEY (Figure 3)

Location: A huge exposure of the hummocky cross-stratified facies and dark gray shale facies can be seen on both sides of Route 8 located approximately 1 mile south of I-88 off-ramp.

Description: At this outcrop, we will look primarily at the dark gray shale, facies, which is found as three interbeds within the hummocky cross-stratified facies. The dark gray, facies records three brief transgressive periods, which represent deposition on deeper portions of the shelf. The hummocky cross-stratified facies represents storm deposits within storm base, and is similar here in many aspects to stops 2 and 3. The dark gray shale, facies is characterized by dark gray shale, a complete absence of invertebrates and biogenic structures, and locally abundant, listric truncation surfaces. The listric geometry of the truncation surfaces is consistent with submarine gravity-slide structures. The truncations are sharp and regular without any obvious local channels or erosional irregularities, which is best explained by shear rather than current scour. The rotational slumps were probably triggered by storm events or overloading causing liquefaction and foundering of the sediment.

48.5	0.0	Return to vehicles. Turn left onto Route 8 south and immediately get into right lane.
49.0	0.5	Turn right onto Thorpe Road.
49.2	0.2	Drive car to the end of the guardrail. Outcrop is at your left. At the end of the guardrail, make a 3-point turn and park cars single file along the right-hand guardrail.

STOP 4B (OPTIONAL): AMALGMATED PORTION OF THE HUMMOCKY CROSS-STRATIFIED FACIES, THORPE ROAD, NEAR CREST OF SIDNEY MOUNTAIN (Figure 3)

The sharp, scoured and loaded contact in the middle of the outcrop is interpreted as the contact between lower shoreface deposits (amalgamated hummocky cross-stratified facies-above fair weather wave base) and shelf deposits (hummocky cross-stratified facies-below fair weather wave base and above storm wave base). The predominance of fine sand sublitharenite above this contact, and a marked upward decrease in fauna suggest that the amalgamated hummocky cross-stratified portion of this facies occupies the lower shoreface and indicates increasing environmental stress associated with the nearshore. Siltstone and shale interbeds are rarely preserved, indicating that waves or currents (e.g., longshore-, tidal-, and storm-driven) had effectively winnowed the fine fraction. Hummocky cross-stratification is the predominant structure in all sandstone beds at the outcrop. The top surface of the outcrop displays excellent HCS beds in plan view and a variety of biogenic and sedimentary structures which cap HCS beds. Some of the observable features include wave ripples exibiting chaotic patterns, asymmetrical ripples with transverse ribs, conglomerate sheets consisting of flat shale intraclasts, paired vertical burrows of Arenicolites, and "figure 8"-shaped burrow of unknown ichnogenera. To reach the top of the outcrop, please walk around to the extreme right-hand side of the outcrop.

Near the base of the outcrop, an unusual interbed of grain-supported conglomerate grades to fine sand sublitharenite. The conglomerate is the coarsest unit found in the study area. Conglomeratic clasts are subrounded, with an abundance of siltstone and shale clast lithologies. These clasts commonly have Paleozoic weathering rinds. Other components include fish fragments, pockets of diagenetic galena, and plant debris occassionally replaced by galena. Graded bedding is the predominant structure consisting of alternating coarse sand and fine sand sublitharenite. Interpretation of this horizon is still pending, although it is suspected that it is a storm-generated deposit.

49.3	0.0	Return to vehicles. Turn right onto Route 8 south and get immediately into left lane.
49.6	0.3	Make first left onto Delaware County Route 4.
49.7	0.1	Bear right and proceed straight onto unnamed road. (Notice satellite dishes on unnamed road on the left).
49.8	0.1	Just after satellite dishes, bear left onto gravel and dirt road.
49.9	0.1	Bear left onto most used road and park cars at gate to Sidney Mountain bluestone quarry.

STOP 5: PLANAR-BEDDED FACIES, MOTTLED MUDROCK AND SANDSTONE FACIES, PLANAR-LAMINATED AND TROUGH CROSS-BEDDED REDBED FACIES, AND THE HUMMOCKY CROSS-STRATIFIED FACIES, SIDNEY MOUNTAIN QUARRY (Figure 3)

Location: From the gate described above in the road log, proceed on foot on dirt road for 200 meters. Walk around left side of quarry storage shed. Road will lead to the bottom of the quarry at its northern-most end. Each facies noted above can readily be seen by traversing back toward the south along the east wall of the quarry. Proceed with caution while walking on the quarry grounds. The terrain is rough and there is an open pit.

Description: Sidney Mountain quarry has the most complicated stratigraphy in the study area and exibits a multitude of sedimentary features. As a result of its complexity, we direct you to the sections on planar-bedded facies, mottled mudrock and sandstone facies, and hummocky cross-stratified facies (especially Fig. 7).