Middle Devonian near-shore marine, coastal and alluvial deposits, Schoharie Valley, central New York State

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INTRODUCTION

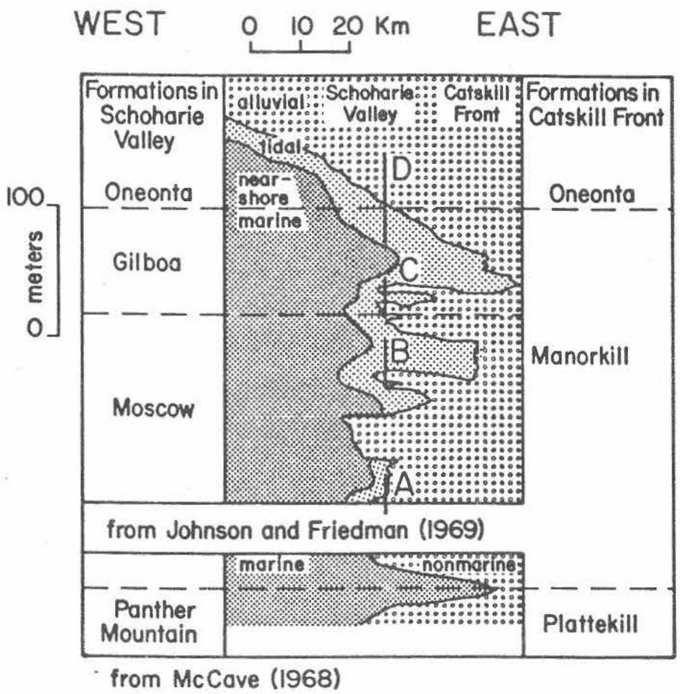
The mid-Devonian part of the Catskill clastic wedge in New York State is composed of fluvial deposits to the east along the Catskill Front and relatively thinner marine rocks to the west. Deposits of the Mid-Devonian shoreline occur in Schoharie Valley, central New York State, and provide an important record of changing marine to nonmarine depositional environments. The paleontology, stratigraphy and sedimentology of these rocks have been studied by many over a long period of time (eg. Goldring, 1924, 1927; Cooper, 1930, 1933, 1934; Cooper and Williams, 1935; McCave, 1968, 1969, 1973; Johnson and Friedman, 1969; Banks et al., 1972, 1985; Bonamo, 1977; Miller, 1979; Grierson and Bonamo, 1979; Miller and Johnson, 1981; Shear et al., 1984; Dannenhoffer and Bonamo, 1984). Sedimentologic variations within these deposits have recently been reevaluated with the goal of providing more detailed paleoenvironmental interpretations (Bridge and Willis, in press; Miller and Woodrow; in press).

The purpose of this field trip is to visit five outcrops which display the diversity of rock types exposed in Schoharie Valley. These deposits record a wave- and tide-influenced deltaic shoreline where the tidal range and degree of wave influence varied in space and time. During this trip we will focus on the relative influence of wave, tidal and fluvial currents in shaping this ancient coastline and nearshore sea bed.

STRATIGRAPHIC SETTING

Geologists have examined rocks in the Schoharie Valley since early in the nineteenth century. The current stratigraphic subdivision and correlation of the rocks (Rickard, 1975; Fig. 1) is due mainly to the work of Cooper (1930, 1933, 1934) and Cooper and Williams (1935). Formations were defined biostratigraphically in the absence of certain key species. As a result, formations are not well defined nor distinctive lithologically. This casts doubt upon lithostratigraphic correlations with the Catskill red beds to the east (Fig. 1).

Locations of outcrops and cores studied by Bridge and Willis (in press) are shown on Fig. 2. We will visit five of these outcrops on this trip. Outcrop positions projected onto a north-south line of section are given in Fig. 3. Stratigraphic dips in this area are generally to the south at approximately 1.5°. Such dip determinations allowed approximate lithostratigraphic correlations among the outcrops



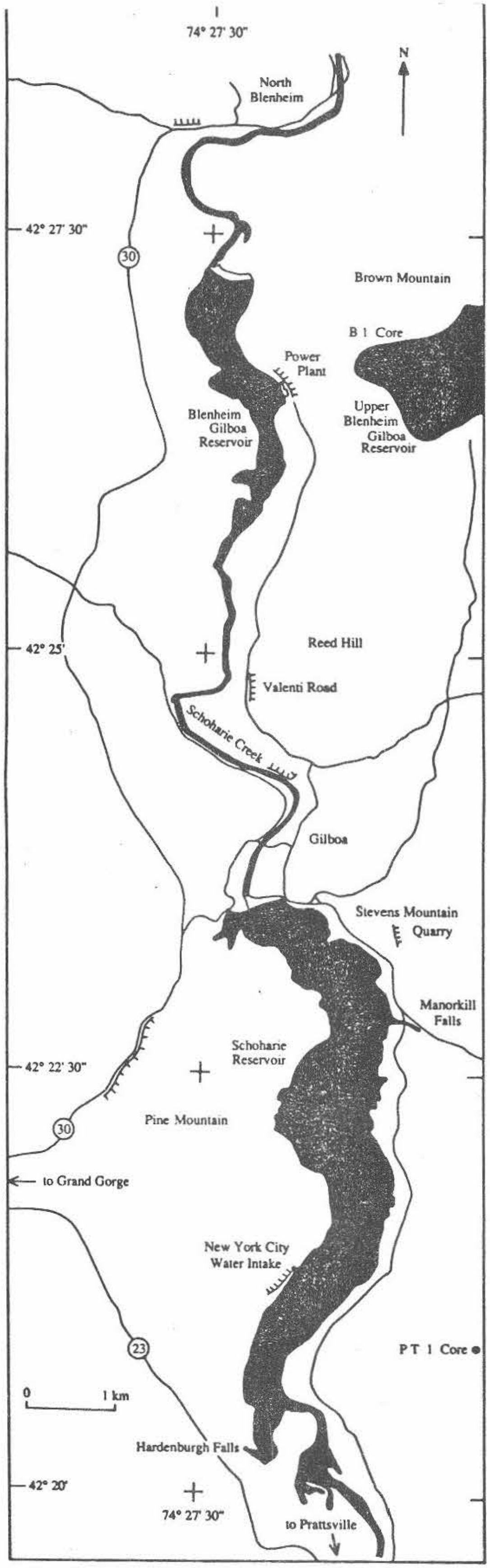


Figure 1. Stratigraphic section oriented E-W showing formations in Schoharie Valley, and their correlation with those at the Catskill Front. Interpretations of depositional environment are from Johnson and Friedman (1989) and McCave (1968). Lettered vertical sections refer to the stratigraphic positions of: (A) Schoharie Creek, near Gilboa; (B) Manorkill Falls, Schoharie Reservoir, (C) NY City Water Inlet, Schoharie Reservoir; (D) Stevens Mountain Quarry, Hardenburg Falls, and Route 30 N. of Grand Gorge. See Figure 2 for location map.

Figure 2. Location map of study area, showing position of outcrops and cores studied by Bridge and Willis (in press). Drawn from USGS 1:24,000 maps of Gilboa and Prattsville, N.Y.

and cores shown on the dip-parallel line of section (Fig. 3). Distinctive lithostratigraphic units on the order of tens of meters thick appear to correlate over distances of at least 10 kilometers. However, complex lateral lithologic variations inhibit detailed correlations within many stratigraphic intervals. The outcrops and cores include the lower part of the Oneonta Formation, the Gilboa and Moscow (Cooperstown) Formations, and part of the Panther Mountain Formation. The definition and characteristics of these formations are discussed in Bridge and Willis (in press). We have slightly revised the existing lithostratigraphic correlations with the thick fluvial successions at the Catskill Front, based on consistent vertical facies changes over 100's of meters of strata (Fig. 4).

Brachiopods from the Moscow and Panther Mountain Formations are typical Hamilton Group faunas (McGhee, pers. comm.). However, the top of the Hamilton Group (top Moscow, base Gilboa Formations) is difficult to define because characteristic fossils are absent. Preliminary palynological age determinations (Richardson, pers. comm.) suggest the Panther Mountain and Moscow Formations cover most of the *lemurata-magnificus* zones of Richardson and McGregor (1986), which corresponds to the upper *ensensis* to middle *varcus* conodont zones (early to mid Givetain). The Catskill Front alluvial sequence (which mainly includes the Moscow, Gilboa and Oneonta Formation equivalents) extends from the mid *lemurata-magnificus* to the mid *optivus-triangulatus* zones (mid to late Givetain) (Traverse et al., 1984, 1987). This is in general agreement with Rickard's (1975) biostratigraphic-lithostratigraphic chart. More detailed and extensive palynostratigraphic studies are in progress.

SEDIMENTOLOGICAL DESCRIPTION AND INTERPRETATION OF FIELD STOPS

There are complex vertical and lateral changes in the sedimentological properties of the rocks within each outcrop studied, making it difficult to describe them in a rigid facies framework. Although there are broad similarities among some of the outcrops, paleoenvironmental interpretation of these deposits rests critically upon integrating vertical and lateral sedimentological variations at individual outcrops. On this trip five particularly well exposed outcrops will be visited. Together they provide a representative view of depositional environments associated with the ancient Catskill shoreline.

STOP 1: Hardenburg Falls

Description

The lowest 6 meters of the exposure at Hardenburg Falls (Fig. 5) contains interbedded gray sandstones, dark-gray siltstones and shales. Lenticular-wavy bedded parts contain very-fine grained sandstone beds which fine up to mudstone. These sandstone beds are wave-ripple cross-laminated and have wave-ripple forms on their tops. Thicker sandstone beds (typically 0.1 to 0.5 meters-thick) have sharp, erosional bases overlain by intraformational shale fragments and disarticulated shelly fossils. They are fine to very-fine grained and fine upwards. Internal structures change upwards from

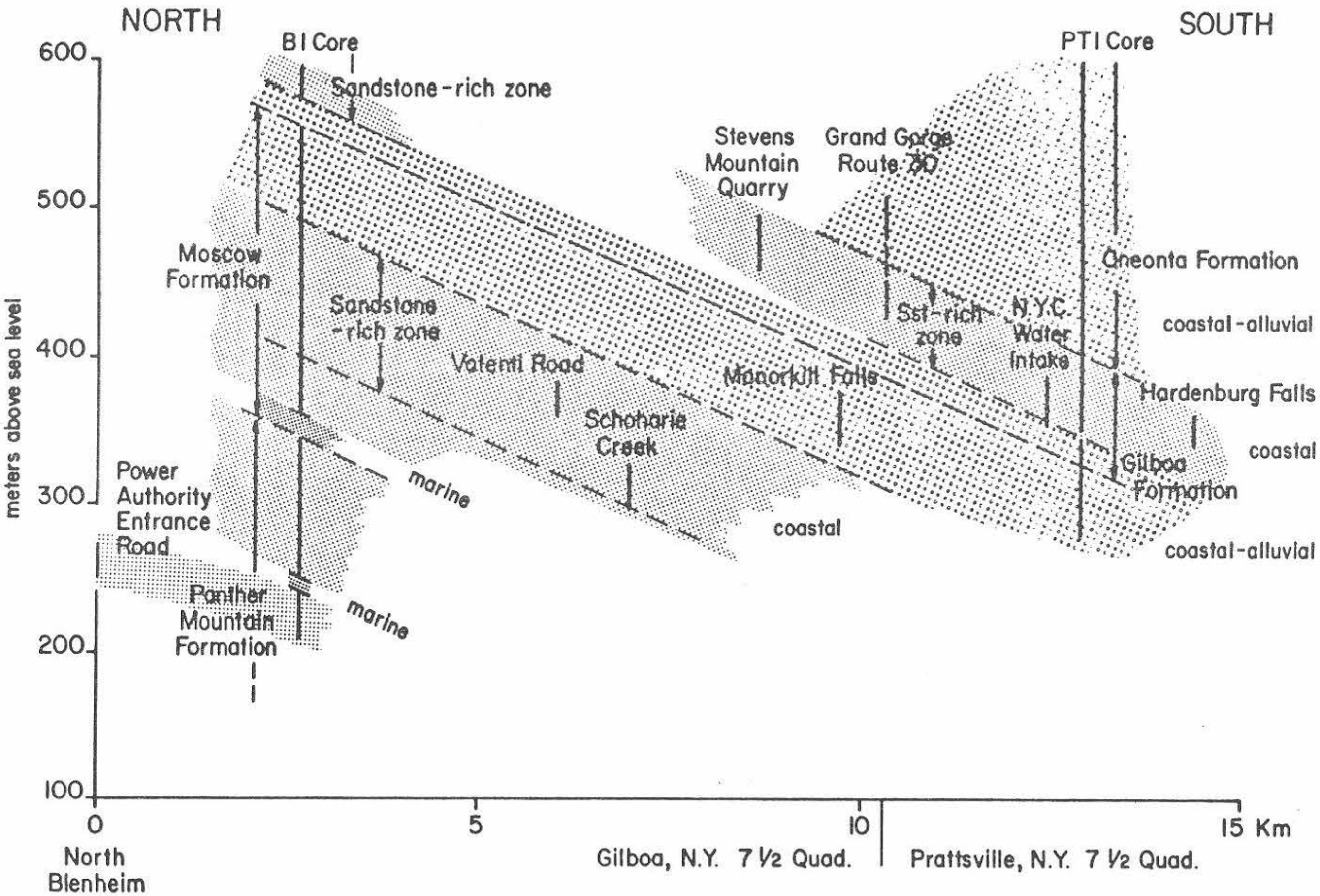


Figure 3. Stratigraphic section oriented N-S showing positions of outcrops and cores, and correlation of formations and other distinctive lithostratigraphic units within Schoharie Valley. Line of section approximately follows Blenheim-Gilboa and Schoharie Reservoirs (Fig. 2). Correlations were made based on a regional dip to the South at 1.5°. Broad paleoenvironmental interpretations are shown. The wide spacing of outcrops and cores precludes more detailed interpretations.

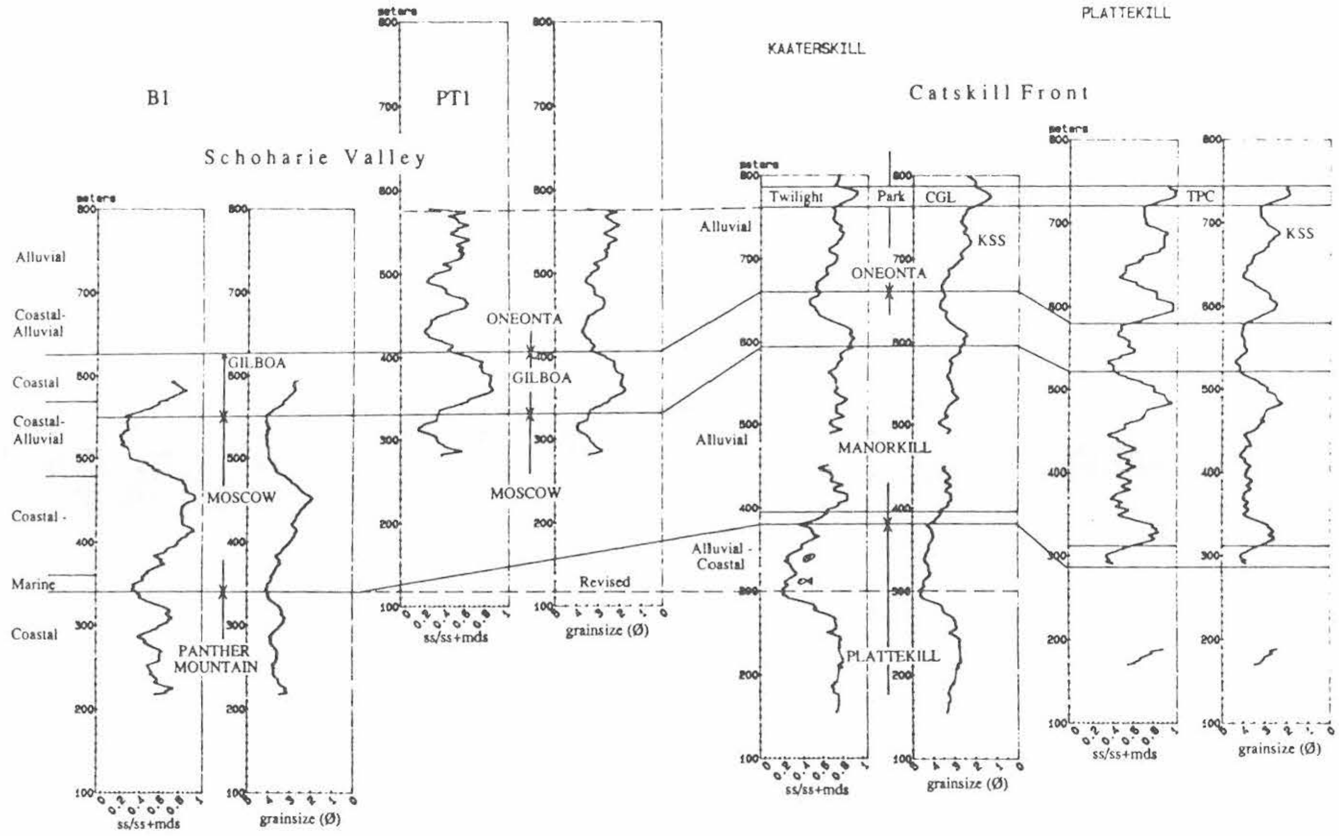
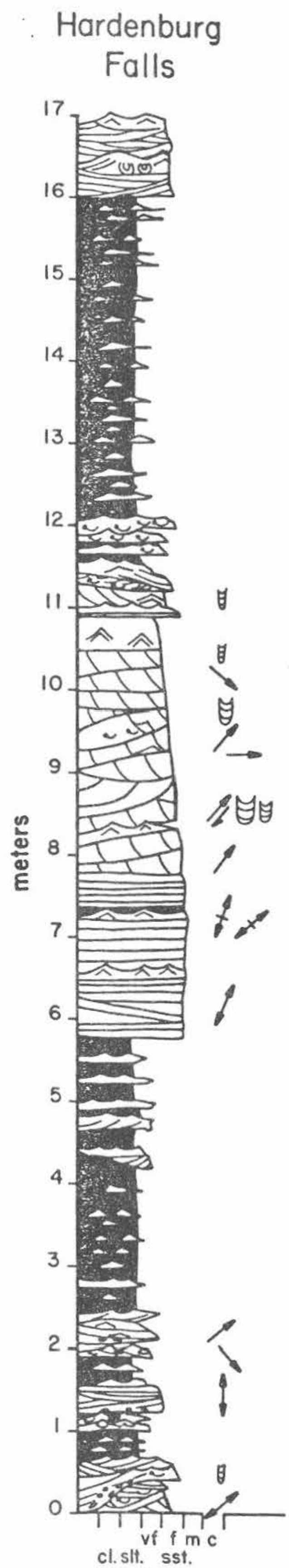
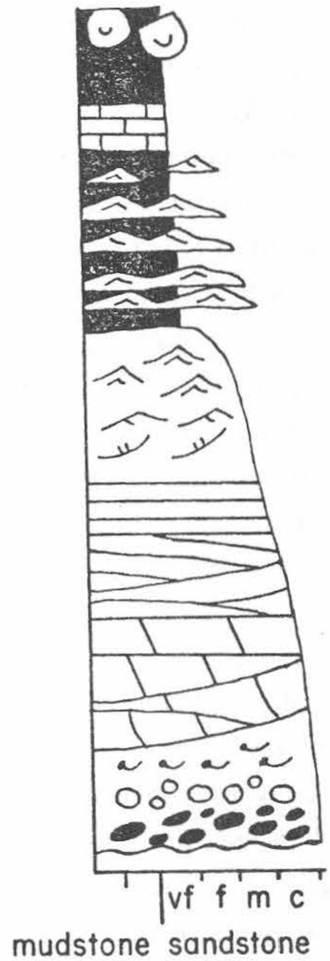


Figure 4. Revised lithostratigraphic correlations between Schoharie Valley and the Catskill Front, based on the proportion of sandstone and mean grain size in long cores and continuous stream sections. Existing formation boundaries and their correlations are solid lines. Schoharie Valley data are from this paper. Catskill Front data are from Willis and Bridge (1988). TPC = Twilight Park Conglomerate. KSS = Kaaterskill Sandstones.

Figure 5. Sedimentological log of Hardenburg Falls and key to sedimentological logs.



LEGEND



Load structures

Mudstone

Calcareous mudstone

Lenticular/wavy bedding with wave or current ripple marks

Flaser bedding

Small-scale cross-strata with wave ripples

Small-scale cross-strata with current ripples

Planar-strata

Hummocky/swaley cross-strata

Large-scale planar cross-strata

Large-scale trough cross-strata

Shell breccia
Extraformational pebbles
Intraformational breccia
Erosion surface

Fish fragments

Vertical and horizontal burrows

Meniscate burrows of various sizes

Chondrites

Spirophyton

U-shaped burrows

Branching burrows

Tree trunk cast

Plant fragments

Root casts

Rhizoconcretions

Calcareous nodules

mudcracks

= Fissile

\# Blocky texture

Disrupted

Pseudoanticlines

Unidirectional paleocurrent direction (N to top of page)

Orientation of parting lineation

Oscillatory paleocurrent directions

hummocky cross-strata or planar-strata to wave-ripple cross-lamination. Tops of beds are covered with wave-ripple marks (3-D, 2-D, and interfering types). Two-dimensional wave ripples indicate SW-NE paleocurrent oscillation. Some low-angle, hummocky cross-strata with superimposed wave-ripples and abundant shell fragments show a preferred paleocurrent direction to the NE. Rarely, such relatively coarse grained, shell-rich strata contain angle of repose cross-strata with SE paleocurrents. At the base of the section, amalgamated hummocky cross-stratified beds fill N-S oriented channels up to decimeters deep and meters wide. These beds contain rounded extraformational chert and quartzite pebbles, and intraformational shale clasts within a medium sandstone matrix.

Shell accumulations include the brachiopods *Spinocyrtia, Mucrospirifer, Mediospirifer,Orthospirifer, Cupularostrum*, the bivalves *Goniophora, Actinopteria, Palaeoneilo*, and crinoid ossicles. Most of the disarticulated shell fragments lie concave down along stratification surfaces and show little evidence of breakage or abrasion of fine detail. Some shell concentrations are markedly monospecific (e.g. *Cupularostrum*). Small, centimeter diameter vertical burrows occur in the tops of sandstone beds.

The 5 to 6 meter thick sandstone body in the middle of this section has a sharp base which is overlain by 2 meters of planar-stratified and swaley cross-stratified, fine to medium grained sandstone. These beds contain horizons of symmetrical and asymmetrical wave ripples with shale drapes. Parting lineation indicates NNE-SSW paleocurrents and asymmetrical wave ripples indicate a NE-SW oscillation with a preferred migration to the SW. These beds are overlain by about 2 meters of trough cross-stratified sandstone. Paleocurrents are towards the NE mainly, with the exception of a rare, oppositely directed cross-set. Wave and current ripples are superimposed on the large-scale cross-strata. One set of small-scale cross-strata indicates an easterly paleocurrent. Large-scale planar cross-strata occur above the trough cross-strata and climb up low-angle lateral-accretion surfaces; that is, inclined bedding surfaces dip to the NW (normal to the underlying trough cross-strata) and the planar cross-strata within beds dip to the SE. Vertical, meniscate burrows of varying diameter occur in this part of the sandstone body. The upper part of the sandstone body is wave-ripple laminated, very-fine grained sandstone, which contains sparse shell fragments. This is overlain by several beds of hummocky cross-stratified and wave-rippled, fine-grained sandstone with abundant shell fragments.

Interpretation

Interbedded shales and sandstones containing hummocky cross-strata, planar-strata, wave-ripple cross-laminae, wave-ripple marks, and abundant shelly-fossil concentrations are interpreted as nearshore marine deposits formed below fair-weather wave base (cf. Dott and Bourgeois, 1982; Harms et al., 1982; Hunter and Clifton, 1982; Swift et al., 1983). The sandstones are generally interpreted to be formed during storms by combined wave and unidirectional currents, whereas the shales generally represent fair-weather deposits or those formed below storm wave base. Oscillatory flows are generally directed alongshore, whereas the stronger undirectional currents represented by low-angle to angle-of-repose cross-strata are directed onshore (easterly direction). Although the shelly fossils in sandstone beds are clearly transported, their preserved detail precludes long periods or distances of transport. McGhee and Sutton (1985) believe that such shelly-fossil concentrations reflect the diversity of the indigenous infauna and epifauna (in this case typically nearshore marine), although their relative abundances do not reflect original population densities. Monospecific shell concentrations may well reflect only slightly disturbed original communities, as it is unlikely that hydraulic sorting could so perfectly separate shells of one species from other shells with similar hydrodynamic properties.

The thick sandstone body in the middle of this exposure is interpreted as deposits of a channel mouth bar associated with a tidal channel which prograded into a storm-wave dominated sea. Swaley-hummocky cross-strata, planar-strata and wave-ripples in lower beds but angle-of-repose cross-strata in upper beds, are evidence for variation in wave and unidirectional currents upwards. Lower down within the sandstone, amalgamated hummocky-swaley cross-stratified beds and wave-ripples overlain by shale drapes indicate periodic variation in combined-flow strength. Oscillatory currents associated with wave-ripples are generally to the NE and SW (alongshore). Upper beds with trough cross-strata directed alongshore (NE) to landward (E) (but rarely in the opposite direction) are most likely associated with sinuous crested dunes formed by strongly asymmetrical tidal flood currents. The SE-directed planar cross-strata may represent wave-formed swash bars or straight-crested tide formed dunes (eg. Hayes and Kana, 1976; Boothroyd, 1978; Fitzgerald, 1984). Superimposed wave- and current-ripples indicate periodic variation in current strength, and the presence of weak wave currents. Inclined bedding surfaces exposed near the top of the sandstone testify to lateral migration of the upper bar surface. The sparse fauna and low degree of bioturbation is typical of sandy deposits in coastal areas (Gould, 1970; Howard and Reineck, 1981).

Fossiliferous sandstones and mudstones above the channel mouth bar deposit indicate rapid return to marine conditions. Depositional environments at the shoreline probably depended on the position of tide-influenced channels which distributed sediment to the shoreline and near-shore areas. Avulsion of the channel from this area abruptly reduced local deposition rates, allowing the sea to transgress locally over this location.

Stop 2: Stevens Mountain Quarry

This quarry exposure is important because it provides continuous exposures from wave-dominated marine deposits to tide-dominated channel deposits. The extensive exposures also provide a better record of lateral variations than were exhibited at the last stop.

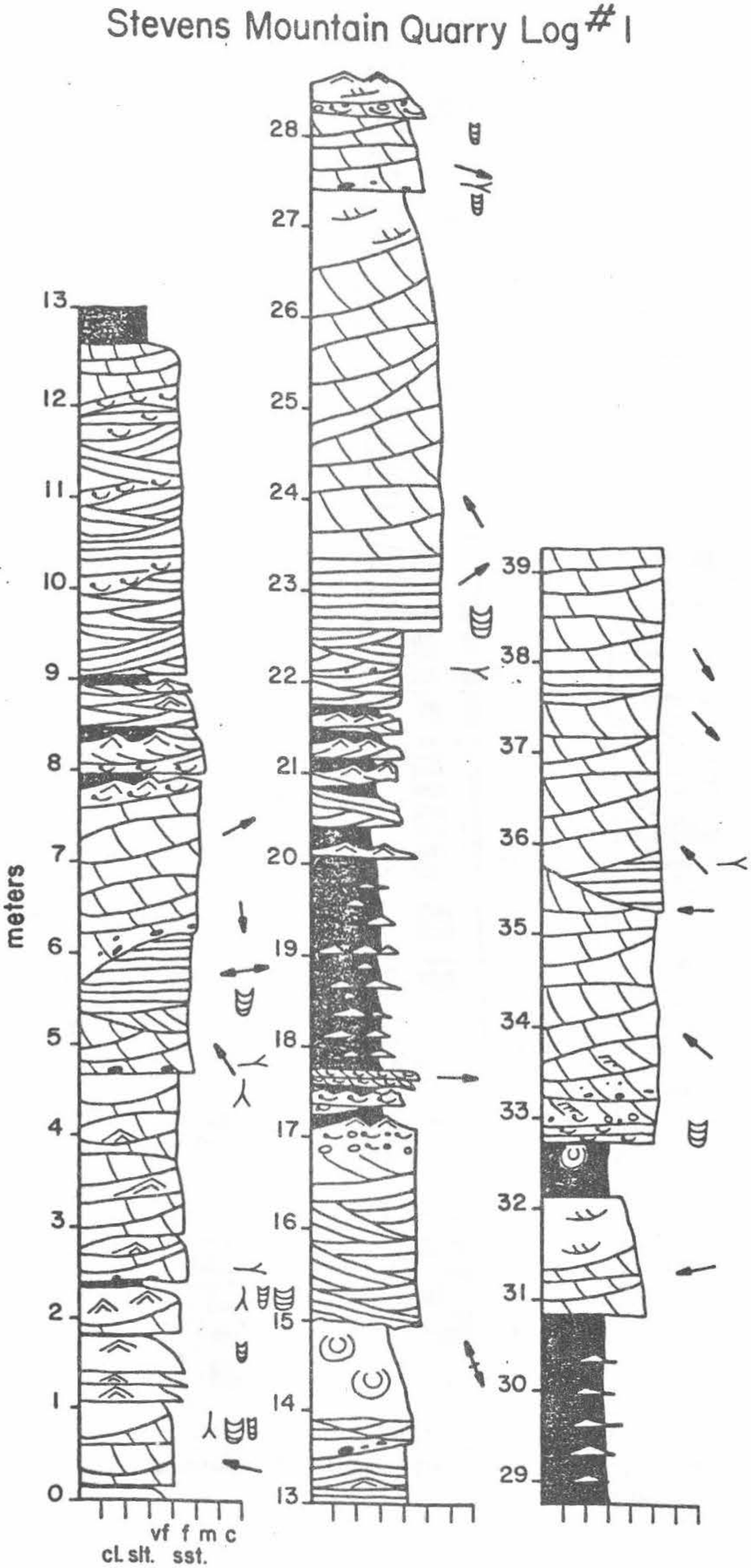
Description

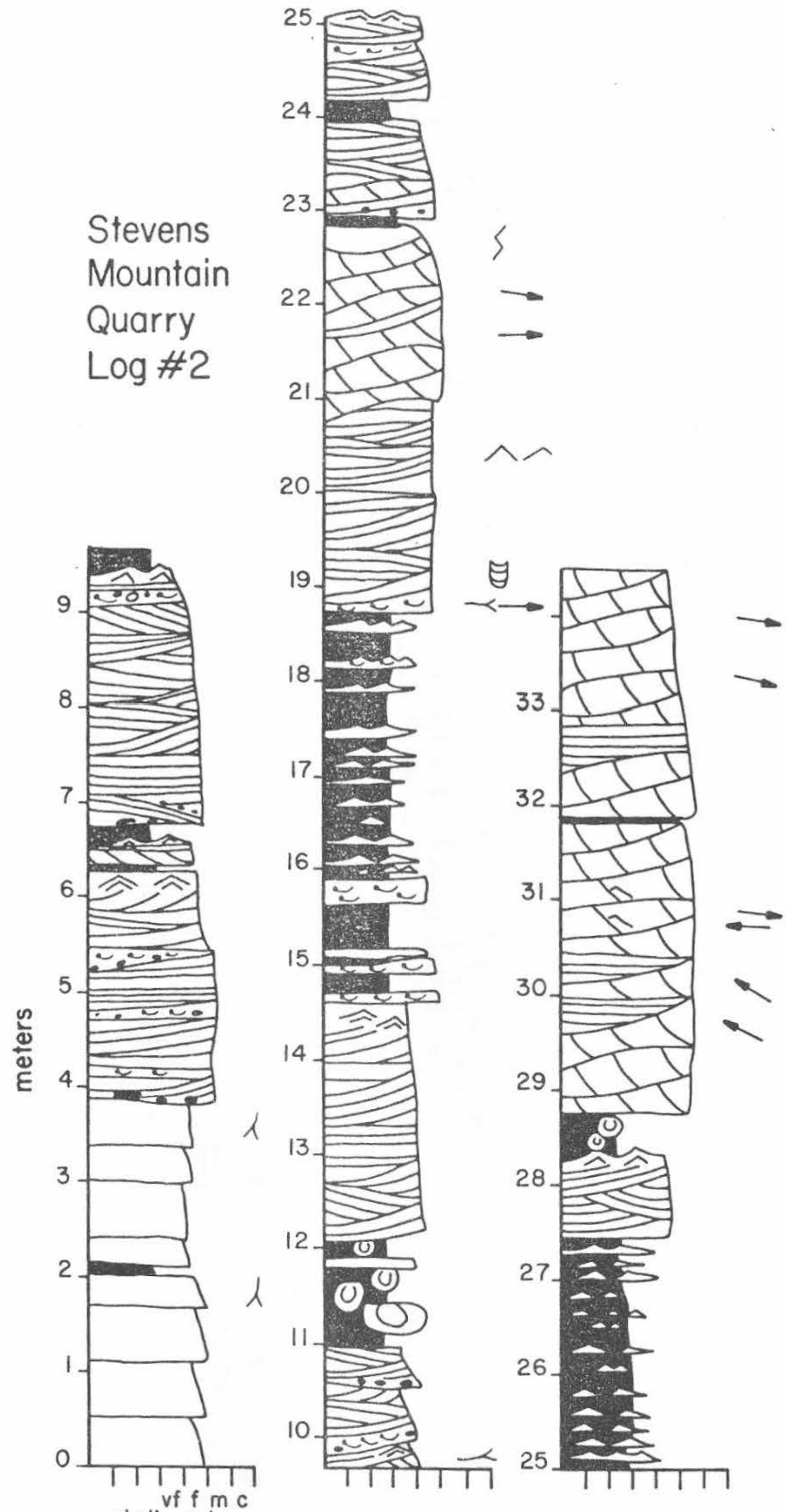
Much of the quarry exposure is composed of 2 to 6 meter thick, gray sandstone bodies separated vertically by mudstone dominated intervals of dark-gray shales interbedded with centimeter- to decimeter-thick gray sandstone beds (Fig. 6). The lowest 4 to 5 meters exposed above the quarry floor contains decimeter-thick beds of fine-grained sandstone with some centimeter-thick shale horizons. The sandstone beds have sharp bases overlain in places by drifted plant remains and shale chips. Internal structures are difficult to discern because of intense bioturbation by roots and burrows. However, large-scale cross-stratification (westerly paleocurrents) occur, and tops of beds have small-scale cross-strata and wave-ripple marks. Burrows are mainly vertical, sand-filled tubes which range in diameter from 2 to 10 centimeters: some have meniscate fills.

Within the overlying 11 to 12 meters of section (Fig. 6a, meters 5 to 17) occur several sharp-based, 2 to 3 meter-thick, fine-grained sandstone bodies separated by shale-dominated intervals with thinner sandstone beds. Bases of sandstone bodies show tool marks, and are commonly lined with plant remains, shell fragments and shale chips. The sandstone bodies are composed of decimeter- to meter-thick beds containing hummocky-swaley cross-stratification and planar-stratification. Individual beds in such amalgamated sequences are recognizable by their erosional bases overlain by shell concentrations of transported brachiopods, bivalves and *Tentaculites*. The upper beds within these sandstones are commonly shell-rich and contain intraformational shale chips and extraformational quartz pebbles. Angle of repose cross-stratification also is common in these upper beds, normally indicating an E to NE paleocurrent orientation. Wave ripples cap most sandstone bodies. The sandstone bodies vary in thickness and sediment type laterally. This change is most dramatic in the lowermost sandstone body in this succession. To the north, the sandstone body is about 3 meters thick and contains mainly large-scale cross-stratification and planar-stratification, indicating a range of paleocurrent directions (Fig. 6a, meter 5-8). To the south, this body thins to about 2 meters and contains mainly swaley cross-strata (Fig. 6b, meter 6 to 8). Shale-rich zones in the sequence contain decimeter-thick hummocky cross-stratified sandstone beds with wave-rippled tops. Load casts occur in distinct, laterally extensive horizons, particularly immediately beneath sandstone bodies.

The next beds contain 4 to 5 meters of interbedded shale and sandstone (Fig. 6a, meters 17-22). The lowermost decimeter-thick sandstone beds in this sequence (immediately above a sandstone body) are markedly lenticular, and rich in shells, intraformational breccia and extraformational quartzite pebbles. They contain hummocky cross-strata and, in places, angle of repose cross-strata with easterly paleocurrents. Wave ripple marks cap these sandstone beds. Most of the remainder of this interval is wavy and lenticular bedded, with very-fine grained sandstone occurring in centimeter-thick, wave-rippled beds. In the north end of the quarry, these lenticular-wavy beds coarsen and thicken upwards to decimeter-thick, hummocky cross-stratified, very-fine grained sandstone beds with wave-rippled tops, and

Figure 6. Sedimentological logs of the north (A) and south (B) ends of Stevens Mountain Quarry.




Stevens Mountain Quarry Log #2
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to amalgamated hummocky cross-stratified, fine grained sandstone beds with abundant plant remains and intraformational breccia.

These beds are sharply overlain by a 5 to 6 meter-thick fine to medium grained sandstone body (Fig. 6a, meters 23 to 28). It is dominated by large-scale trough cross-stratification (NW paleocurrent), with the exception of planar stratified beds above the erosional base and some small-scale cross-strata in the finer beds near the top. The top most decimeter-thick beds have abundant drifted plant remains, shells, intraformational shale and extraformational pebbles in their bases. Paleocurrents in these upper beds are to the SE. Large vertical meniscate burrows (5-10 centimeter diameter) occur in the lower parts of the sandstone body, but smaller (1-2 centimeter diameter) vertical burrows occur in the upper most beds. In the south end of the quarry this sandstone body is thinner (Fig. 6b, meters 19 to 23). Lower parts of the sandstone body are replaced by amalgamated swaley cross-stratified, fine grained sandstone beds, and the upper two meters are replaced by hummocky cross-stratified sandstone beds with wave-rippled tops and shale interbeds. Underlying beds are finer grained than to the north. The basal erosion surface contains flutes (E paleocurrent) and grooves, and is overlain by bivalve and brachiopod shells and plant remains. Paleocurrents in the central, coarsest part of the sandstone body are to the east.

Approximately 4 meters of interbedded sandstone and shale overlie this sandstone body (Fig. 6a, meters 29 to 33). The sequence is mainly wavy-lenticular bedded with centimeter-thick wave-rippled, very-fine grained sandstone beds. Within this succession to the south is a 0.9 meter-thick, hummocky cross-stratified sandstone bed with an erosional base and wave-rippled top (fig. 6b, meter 18). It occurs at the top of a coarsening/bed-thickening upward sequence. To the north, this bed changes laterally to a 1.3 meter-thick, fine to very-fine sandstone bed with large-scale cross-strata at the base (westerly paleocurrent) and small-scale cross-strata at the top (Fig. 6a, meter 31 to 32). This bed is in turn cut out laterally by a fine-grained channel fill. At the top of this sequence, immediately below the top most sandstone body, is an extensive zone of load casts.

The top most sandstone body in the quarry is approximately 6 meters thick (Fig. 6a, meters 33 to 39). The erosional base is overlain by intraformational breccia (shale blocks up to decimeters across) with brachiopod and bivalve shells in a medium sandstone matrix. The sandstone body is medium to fine grained and fines upwards in places. It is mainly large-scale trough cross-stratified, with some lenses of planar-stratification. Reactivation surfaces in the cross-strata of the lower part of the sandstone body are mainly erosional. Between laterally adjacent reactivation surfaces, cross-strata vary in dip. In places oppositely directed, asymmetrical ripple marks are preserved on foresets and reactivation surfaces, and shale drapes may also occur. Large vertical meniscate burrows also occur in these lower beds. Paleocurrents associated with large-scale cross-strata are towards the WNW in the lower half of the sandstone body, but towards the ESE in the upper half. Low angle, lateral-accretion surfaces extend through the sandstone body, and a sandstone filled channel cuts through the upper one third.

Interpretation

The sandstone body at the top of this exposure is interpreted as the deposits of a laterally-migrating tidal channel (see also Johnson and Friedman, 1969). River channels preserved in coeval Catskill facies to the east have generally north-westerly paleocurrents, but range from northerly to southerly (Willis and Bridge, 1988). Therefore paleocurrents with a westerly component are in the tidal ebb and river flow direction, whereas those with an easterly component are in the tidal flood direction. Variation in ebb paleocurrent orientation in various examples of this type of sandstone body suggest that channels had a range of orientations due to local channel curvature and/or a distributive channel pattern. Dominance of ebb-directed paleocurrents lower in the sandstone bodies, with flood currents and channel fills in upper parts is typical of the strongly asymmetrical tidal currents in tidal inlets, estuaries, and tide-influenced deltaic distributaries.

Variable dip angles of large-scale cross-strata, erosional reactivation surfaces and superimposed current ripples are further evidence of strong tidal-current asymmetry. They indicate growth of sinuous-crested dunes to 'full vortex' stage during the dominant tidal current, slackening of the current and modification of dune geometry, then erosion of the dune by the subordinate tide. Such features are commonly reported from mesotidal and macrotidal estuaries (eg Terwindt, 1981; Boersma and Terwindt, 1981; Dalrymple, 1984; DeMowbray and Visser, 1984). General absence of tidal bundle sequences and rarity of current ripples on reactivation surfaces suggests an erosional or nondepositional subordinate flood-tidal current and a dominant ebb-tidal current that may be reinforced by a fluvial current. Bioturbation is characteristically rare in such coastal sandstone bodies (eg. Howard and others, 1975). Large, vertical meniscate burrows are similar to those reported in fluvial and coastal channel deposits elsewhere (Thoms and Berg, 1985; Miller, 1979; Bridge, Gordon and Titus, 1986) and may be due to upward escape of bivalves. Brachiopod-bivalve fauna sparsely distributed through the sandstone bodies is also typical of nearshore communities (McGhee and Sutton, 1985; Sutton and McGhee 1985).

Sandstone bodies just below this top most sandstone body, with swaley-hummocky cross-strata, planar-strata and wave-ripples in lower parts, but angle-of-repose cross-strata in upper parts, are comparable to the sandstone body exposed in Hardenburg Falls (Stop 1). They are also interpreted to record evidence for combined wave and unidirectional currents of varying importance and intensity. Detailed interpretation of these deposits hinges critically on their lateral transition to thicker sandstone bodies dominated by angle-of-repose cross-strata and thinner sandstone bodies dominated by amalgamated hummocky-swaley cross-strata. It is also important that their bases are sharp in many places, but in others they occur at the top of coarsening-upward sequences with interbedded hummocky cross-stratified sandstones and shales immediately beneath. Furthermore, any evidence of channel fills or lateral-accretion bedding is restricted to their upper parts. These features suggest deposition on channel mouth bars which were prograding rapidly into a marine, storm-wave-dominated area. Such bars may be on the seaward side of tidal inlets (i.e. ebb-tidal deltas) associated with estuaries or barrier-beach shorelines, or associated with tide-influenced deltaic distributaries. Landward-directed (E, NE) trough cross-strata are most likely associated with sinuous crested dunes formed by strongly-asymmetrical tidal flood currents. Sets of planar cross-strata migrating to the NE, E or SE may represent wave formed swash bars or straight-crested tide-formed dunes (e.g. Hayes and Kana, 1976; Boothroyd, 1978; Fitzgerald, 1984). Wave and current ripples on dune/bar slipfaces and troughs indicate periods of tidal slack water and decreased tidal current strength, respectively. Sparse fauna and low degree of bioturbation (but dominance of the *Skolithos* ichnofacies) is typical of sandy deposits in coastal areas (Gould, 1970; Howard and Reineck, 1981).

Similar sandstone bodies in somewhat younger Frasnian rocks in the Binghamton (NY.) region were also interpreted as channel mouth bar deposits by Halperin and Bridge (1988). However, similar sequences reported from the Cretaceous Western Interior Seaway have been interpreted as due to deposition on prograding strandplains cut by estuaries (McCrory and Walker, 1986). McCrory and Walker (1986) and Hamblin and Walker (1979) interpreted amalgamated swaley-hummocky cross-stratified beds as beach and shoreface deposits, even though they rest sharply on interbedded hummocky cross-stratified sandstones and shale interpreted as offshore storm-dominated deposits. They interpreted this sharp contact as due to rapid progradation of the shoreface. Similar sandstone bodies occurring at the tops of gradational coarsening upward sequences have been interpreted as due to progradation of a wave-dominated deltaic shoreline (Chan and Dott, 1986; Swift et al, 1987). Swift et al.(1987) interpreted the amalgamated hummocky cross-strata as middle shoreface deposits, and angle-of-repose cross-strata as deposits on the upper shoreface by combined currents with an alongshore unidirectional component. A beach face origin for the sandstone bodies studied here is considered unlikely because of a lack of characteristic seaward-dipping planar-laminae with heavy mineral layers; alongshore directed cross-strata overlain by landward-directed cross-strata and planar-strata typical of ridge and runnel systems; and eolian cross-strata. The sharp base to many (but not all) of the sandstone bodies is hard to explain by rapid progradation of a beach face, but may be readily explained by rapid progradation of a storm-wave modified channel mouth bar which formed rapidly as a result of a channel diversion. Coleman and Prior (1982) show examples of distributary mouth bar sands that lie abruptly on offshore silts, and state that bases of sandstone bodies become sharper closer to the distributary channel.

Relatively thin sandstone bodies dominated by amalgamated swaley-hummocky cross-stratified beds are interpreted as more distal parts of channel mouth bars, which are completely dominated by storm waves (combined currents). The lack of mud suggests deposition above fair weather wave base. The common occurrence of load casts near their bases suggests rapid deposition of sand on mud. Such soft-sediment deformation features are common offshore from Mississippi delta distributaries (eg. Coleman and Prior, 1982). Paleocurrent indicators in the base of the sandstone bodies suggest a dominantly offshore directed unidirectional current, as is common in similar Frasnian rocks in the

Catskill region (Craft and Bridge, 1987; Halperin and Bridge, 1988). Lenticular sandstone beds on top of these sandstone bodies, with abundant shelly fossils, intraformational breccia, extraformational pebbles, and local channelling, are evidence of relatively strong unidirectional currents directed to the east and southeast (i.e. shoreward) superimposed upon wave currents. As there is no evidence of offshore directed currents, the unidirectional currents are not considered to be tidal flood currents but rather storm-wave associated currents. As these sandstone bodies are sharply overlain by interbedded sandstones and shales interpreted as deeper water nearshore deposits, these uppermost shelly sandstone beds are apparently associated with rapid abandonment of the channel mouth bar and reduction in sand supply. Johnson and Friedman (1969) interpreted these sandstone bodies as nearshore subtidal bar deposits, and Miller and Woodrow (in press) assigned an estuary mouth shoal origin.

Similar sandstone bodies elsewhere have been interpreted as wave-formed offshore bars or shoals (eg. De Raaf et al, 1977; Cotter, 1985). Wright and Walker (1981) have interpreted thin pebble layers at the tops of such sequences as transported by density currents. This is considered unlikely here. If such sandstone bodies do represent distal parts of storm-wave modified channel mouth bars, then their occurrence within sequences of deeper water sandstone and shales indicates channel switching (see also Swift et al, 1987). The overall sequence at Stevens Mountain Quarry indicates sandstone body deposition in progressively more landward parts of the channel-mouth bar complexes. Thus, this is an overall regressive sequence with superimposed variations in deposition related to local channel avulsion.

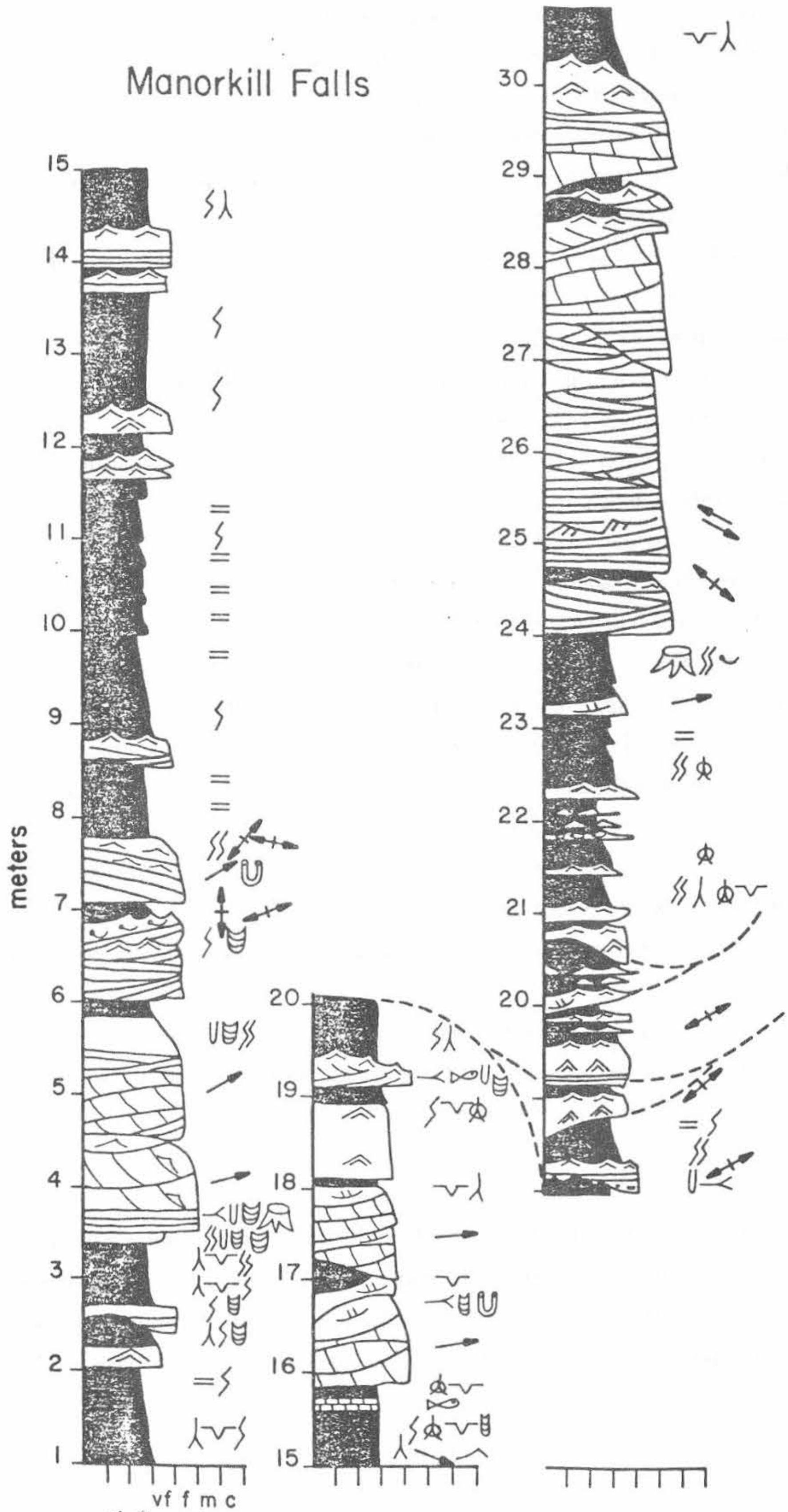
As implied above, interbedded shales and sandstones with hummocky cross-strata, planar-strata, wave-ripple cross-laminae wave-ripple marks, and abundant shelly-fossil concentrations are interpreted as nearshore storm-dominated marine deposits. These are interpreted in a similar way to those exposed within Hardenberg Falls (Stop 1). Sandstone beds near the base of the quarry were deposited mainly by N-NW directed unidirectional currents moving sand as dunes. Wave ripples in the upper parts of sandstone beds indicate deposition in standing water with weak wave currents. These characteristics, plus the abundance of burrows and roots, and the absence of marine fossils, suggest deposition by fluvial or ebb-tidal currents on a near coastal plain.

Stop 3: Manorkill Falls, Schoharie Reservoir

Description

Most of this section is composed of gray sandstone interbedded with red, green and gray siltstone and mudstone (Fig. 7). The lower part of this section contains two 10 meter-scale fining upward sequences (Fig. 7, meters 1 to 24). The lower 4 meter-thick interval within the first sequence has a high proportion of sandstone which sharply overlies intensely disrupted mudstones. These sandstone beds generally thin and fine upwards. Individual sandstone beds are sharp-based, sheetlike to lenticular, and centimeters to a meter thick. Thinner sandstones are very-fine grained, and small-scale cross-stratified with associated current ripples or (mainly) wave ripples. Thicker sandstone beds are

Figure 7. Sedimentological log of Manorkill Falls section, east side of Schoharie Reservoir.



mainly fine grained, and contain large-scale trough cross-strata, planar-strata, or (unusually) hummocky cross-strata passing upwards to small-scale cross-strata and associated current or wave ripples. Some thicker sandstone beds lower in the sequence show low-angle (<10°) inclined bedding surfaces extending throughout most of the thickness of the bed which dip in the direction the bed thins (i.e. to the east). Upper parts of these inclined surfaces are covered with straight crested and interfering wave-ripple marks, indicating oscillatory paleocurrents NE-SW and E-W. Oscillatory paleocurrent directions are quite variable throughout the sequence; however, a NE-SW orientation is common. Large- and small-scale cross-strata and current ripples consistently indicate an easterly paleocurrent.

Sandstone beds contain vertical burrows (including *Skolithos*), which range in diameter from a few millimeters to 7 centimeters; larger ones commonly showing meniscus structure. Horizontal meniscate burrows occur in places in the tops of sandstone beds. *Arenicolites* burrows also occur. Drifted plant remains are common in sandstones, and root casts occur in the top of some sandstone beds. There are two important occurrences of tree-trunk casts. Shelly fossils are rare. One shell-rich layer near the base of the section occurs near the top of a hummocky cross-stratified sandstone bed. This layer contains bivalves, brachiopods (eg. *Spinocyrtia, Allanella tullius*) juvenile crinoid fragments and bryozoa. Fish fragments are found in places.

Mudstones are either relatively unbioturbated and fissile, or bioturbated with abundant rootcasts, small vertical and horizontal burrows, and desiccation cracks. A nodular carbonate bed occurs near the top of the first sequence where calcareous rhizoconcretions are particularly abundant. This bed is similar to the one occurring at the New York City Water intake building.

The base of the second fining upward sequence is another sandstone-dominant interval (about 3 meters-thick), in this case dominated by large-and small-scale cross-strata (Fig. 7, meter 16 to 19). This interval is in turn overlain by an interval of overlapping channel fills. These channels are oriented E-W and are filled with alternating mudstone and sandstone beds. The sandstone beds are dominated by wave-ripple lamination, with rare planar and hummocky strata. Mudstones occurring adjacent to and above these channel fills are highly disrupted by mudcracks, burrows, rootcasts and in one location a tree trunk cast.

The sandstone body at the top of this section is similar to those occurring near the top of Stevens Mountain Quarry and the lower Grand Gorge route 30 section, and shows lateral-accretion surfaces. Paleocurrents near the base of the sandstone body are NW-SE.

Interpretation

In the Manorkill Falls section, desiccated, bioturbated siltstones with abundant root casts, rare tree trunk casts, and horizons of calcareous concretions, clearly represent floodbasins with a well developed flora which were periodically exposed and subjected to soil-forming processes. Sandstone beds overlying such deposits near the base of the section are distinctive and show evidence of easterly progradation of wedges of sand into at least temporarily standing water in which wave currents were active. The lowest bed buried and preserved the trunk casts. Two origins for this bed is considered possible: (1) a fluvial overbank sand splay, or (2) a back barrier washover deposit. Paleocurrent evidence supports the storm washover origin and deposits show many features in common with modern examples (e.g. Schwartz, 1982). However, there is little evidence in these rocks of the presence of beaches, so barrier islands seem unlikely. Although lateral migration of tidal inlets or other types of coastal channels may have removed the evidence of beaches, an overbank sand splay from a major channel is probably the most viable explanation.

Associated with the sandstone-dominated interval near the base of the section are sandstone beds showing evidence of strong wave currents, containing marine shelly fauna, and with a diverse assemblage of burrowing organisms. These deposits testify to the close proximity of the sea, and the onshore transport of marine fossils by storm waves. Furthermore, the overlying fissile siltstones with isolated hummocky cross stratified and wave-rippled sandstone beds indicate deposition of mud in quiet, standing water which was periodically agitated by waves. All of this evidence together suggest an upward transition from fluvial floodbasin/lacustrine conditions to a brackish interdistributary bay with access to fully marine waters.

A return to subaerial floodbasin conditions is signalled by desiccated mudstones with root casts, rhizoconcretions, fish fragments and a nodular carbonate-rich horizon (beds directly under the bridge; Fig. 7, meters 15-16). The overlying sandstone beds at the base of the second 10 meter-scale sequence record periodic deposition by temporally-waning unidirectional currents, probably associated with river floods. Desiccation cracks in the siltstones capping these sandstone beds and the lack of wave ripples, suggests subaerial exposure immediately following deposition. This sequence of interbedded sandstones and siltstones is interpreted as a crevasse-splay complex, but it is hard to dismiss flood tidal currents (storm enhanced?) as a depositional agent in view of the overall coastal setting.

The overlying sequence of interbedded sandstones and shales also has features indicative of mud deposition in an area of shallow water (but with periodic subaerial exposure) in which weak wave currents periodically deposited sand, and transported marine fossils into the area. The east-west oriented channel in this part of the section were apparently filled mainly by weak wave currents. The lack of evidence of reversing unidirectional sedimentary structures precludes a tidal-channel origin, and suggests instead a fluvial channel cutting across a floodbasin/interdistributary bay. Indeed, deposits typical of intertidal flats in mesotidal or macrotidal settings are notably absent throughout this outcrop. The sandstone body at the top of this section is similar to others viewed at previous stops and are interpreted as a channel-mouth bar deposits. Johnson and Friedman (1969) interpreted these deposits as interfingering alluvial marsh, tidal flat and channel deposits. They are also somewhat similar to the 'muddy shoreline' deposits of Walker and Harms (1971).

The 10 meter-scale sequences exposed at Manorkill Falls reflect relative sea level changes. Mudstone beds immediately below sandstone-rich intervals reflect floodplain emergence. Abrupt onset of sand deposition following fining indicates an abrupt change in depositional environment and the onset of a deepening trend. Such sequences may be related to channel switching which locally varied deposition rate at the shoreline.

Stop 4: Schoharie Creek outcrop

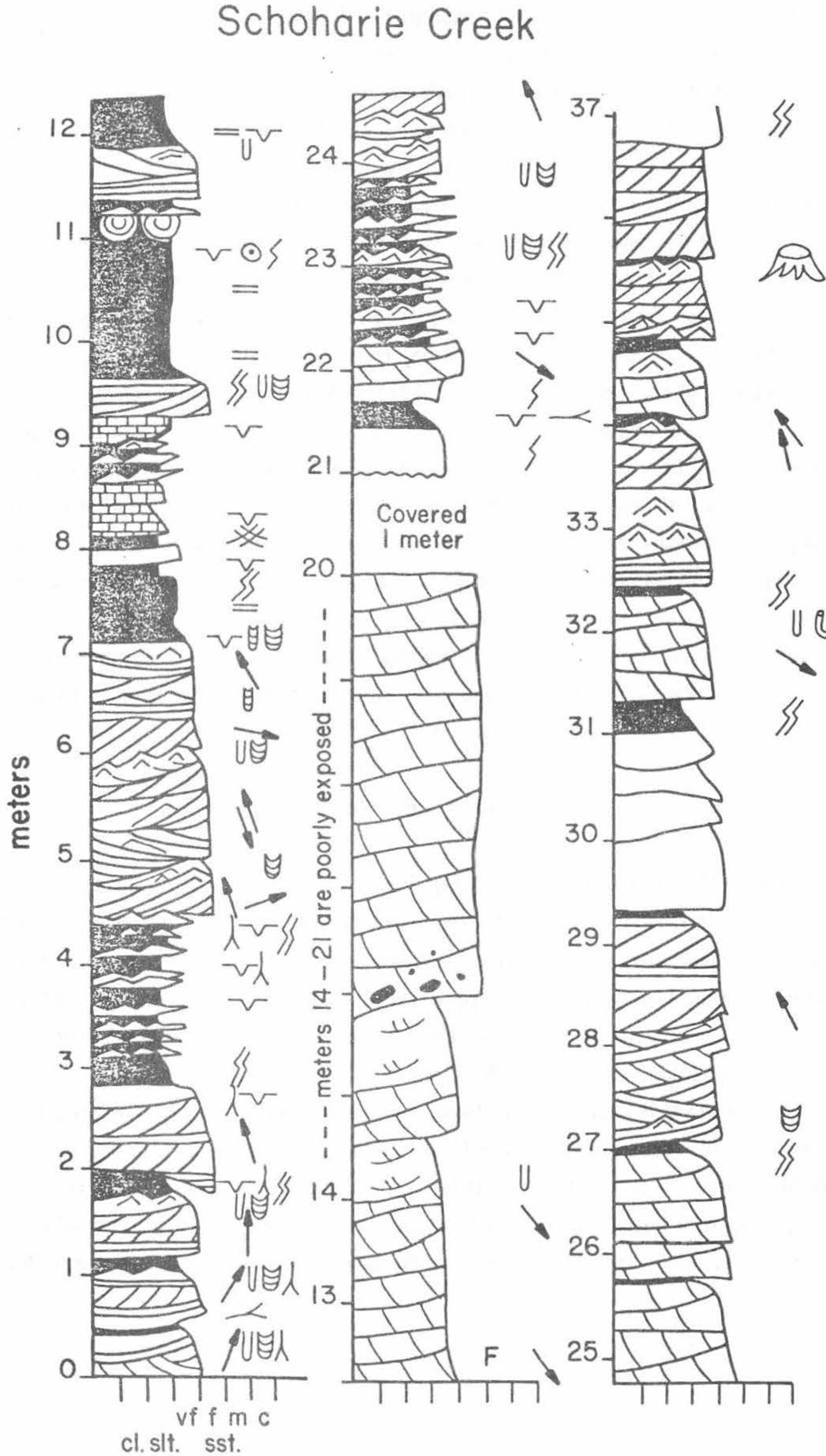
Description

The lowermost 11 meters of interbedded sandstone and mudstone in this stream and hillside section is, with the exception of the 2 to 3 meter thick sandstone body (Fig. 8, meters 4.5 to 7), similar to the lower parts of Manorkill Falls section (Fig. 8). Centimeter-thick, very-fine grained sandstone beds are mainly wave-rippled, whereas the decimeter-thick, fine-grained sandstone beds may also contain large-scale cross-strata (paleocurrents to N), planar-strata, and hummocky cross-strata. Tops of sandstone beds are normally wave-rippled and bioturbated by root casts and/or vertical, horizontal and U-shaped burrows of various sizes (millimeters to centimeters in diameter). Gray siltstones are bioturbated by roots and small burrows, and desiccation cracks are common. Calcareous concretions occur locally, and buff calcareous shale commonly fills desiccation cracks. There are several carbonate-rich mudstone beds near the top of this interval, in one case associated with pseudoanticlines. Some siltstones are relatively undisturbed and fissile.

The 2 to 3 meter thick, fine-grained sandstone body near the base of the section is somewhat unusual. It is dominantly large-scale trough cross-stratified, with some large-scale planar cross-strata and planar-strata. Large-scale cross-strata indicate paleocurrents to NNW and in a generally easterly direction. Wave-and current-ripples occur on reactivation surfaces, the current-ripples oriented in the opposite direction to the adjacent large-scale cross-strata. Ripple-marked surfaces throughout the sandstone body show vertical and horizontal meniscate burrows of various sizes centimeters in diameter).

Above poorly exposed sandstone bodies between meters 11 and 19 (Fig. 8) there occurs a 3 meter thick interval of sandstone and mudstone beds that are similar to those lower down. Above this interval is approximately 12 meters of section dominated by decimeter-thick fine to very-fine grained sandstone beds, with only small amounts of gray mudstone. Sandstone beds have erosional bases and are mainly large-scale cross-stratified, with minor amounts of planar and low-angle cross-strata. Upper parts of the beds are commonly wave-ripple laminated, with wave rippled tops. Paleocurrents from large-scale cross-strata are mainly to the NNW, but some are to the SE. Beds are intensely bioturbated with vertical and U-shaped burrows. A tree trunk cast occurs near the top of the sequence.

Figure 8. Sedimentological log of Schoharie Creek and hillside section just down stream of Gilboa bridge.



Interpretation

The lower part of the Schoharie Creek outcrop (Fig. 8, meters 1 to 11) is interpreted in a similar way to deposits exposed in the Manorkill Falls outcrop; that is, fine grained deposition in semi-permanent, near-coastal lakes or bays, with periodic emergence, plant growth and soil formation. Sand was introduced by unidirectional and/or wave currents and reworked by waves. Although trace fossils are abundant and diverse, marine shelly fossils are notably absent.

Evidence for strong tidal currents is generally lacking, with the exception of the 2 to 3 meter thick sandstone body near the base of the section. In this sandstone body bimodal paleocurrent directions in large-scale cross-strata, and wave-and current-ripples on reactivation surfaces all indicate deposition by tidal currents. However, the topmost part of the sandstone body shows more wave · influence. Its stratigraphic position between coastal bay or floodbasin deposits suggests deposition in a flood-tidal delta and/or tidal channel (c.f. Boothroyd, 1978). Wave-rippled and extensively bioturbated sandstones lower down in the section along Schoharie Creek are probably sandy tidal-flat deposits.

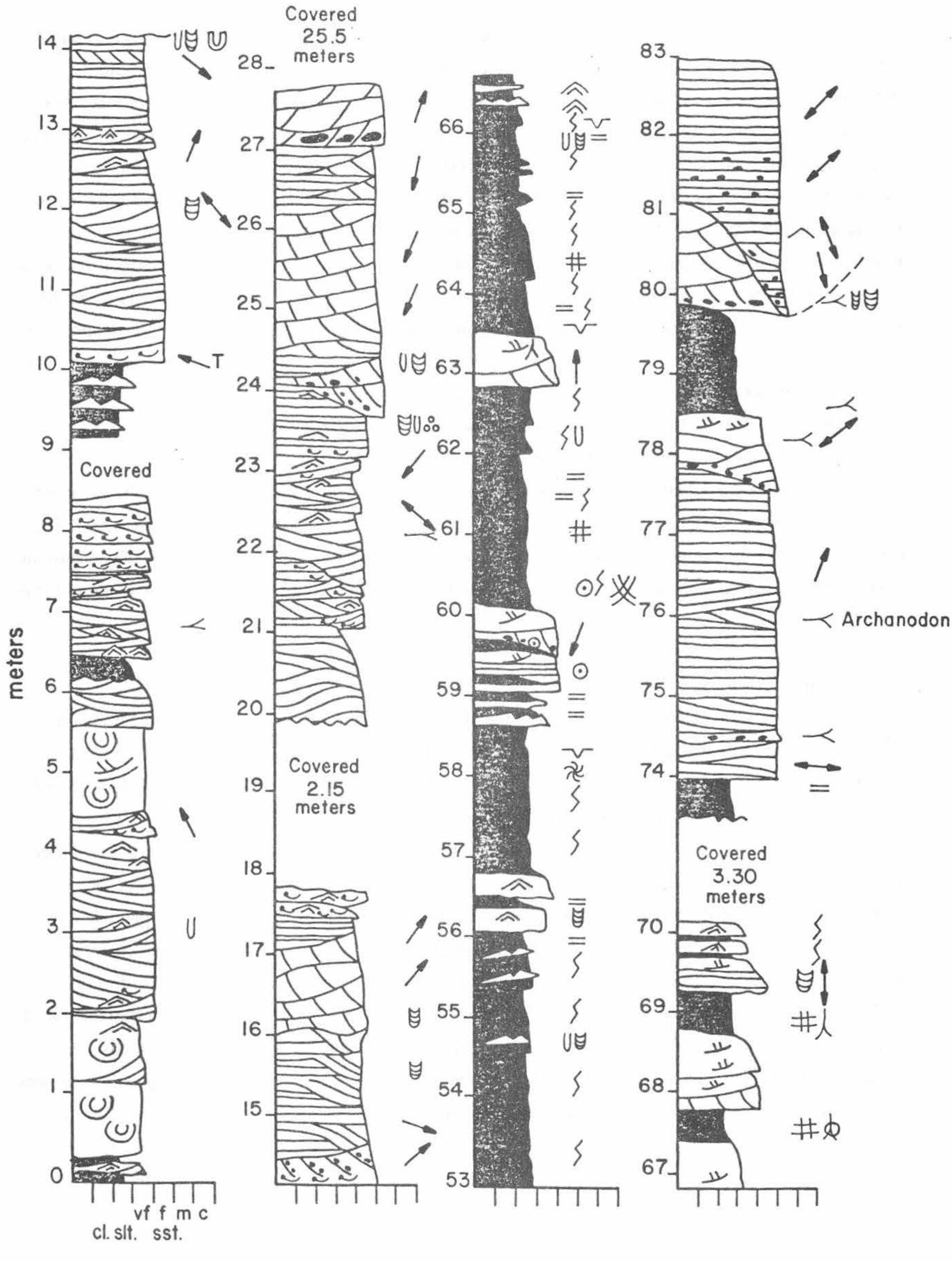
Sandstone beds in the upper 12 meters of section (Fig. 8) were deposited mainly by N-NW directed unidirectional currents moving sand as dunes. Wave-ripples in upper parts of many sandstone beds indicate deposition in standing water with weak wave currents. Stronger wave currents are indicated by swaley cross-strata near the base of some sandstone beds. These characteristics, plus the abundance of burrowing, lack of roots (except at the top of the section), and absence of marine fauna, suggests deposition by fluvial sheet-floods in a coastal body of standing water. Despite rare southeasterly paleocurrents, there is little evidence to suggest tidal currents. Johnson and Friedman (1969) assigned these rocks to the boundary between tidal and alluvial facies.

Stop 5: Grand Gorge Route 30

Description

The lowermost 28 meters of this section (Fig. 9) is closely comparable to the upper 30 meters or so of Stevens Mountain Quarry. In particular, sandstone bodies increase in thickness upwards and contain more angle-of-repose cross-strata relative to swaley cross-strata and planar-strata. There are also lateral transitions within the lower parts of the upper two sandstone bodies between angle-of-repose cross-strata, swaley cross-strata and planar-strata. Large-scale cross-strata in the upper parts of sandstone bodies indicate paleocurrents to the NNE and NE, whereas those lower down indicate S to SSW paleocurrents. However, solitary sets of planar cross-strata within the planar/swaley parts of these sandstone bodies indicated paleocurrents ranging from NNE to SE. Oscillatory current directions are commonly NW-SE. Large (5-10 centimeter-diameter) vertical meniscate burrows occur commonly in sandstone bodies, along with millimeter-wide *Skolithos*, *Arenicolites* and *Chondrites*. Load casts occur beneath sandstone bodies low in the section. Beds at the base of the section contain marine fossils.

Figure 9. Sedimentological log of Route 30 section, N of Grand Gorge.



Further up section, above a 25-26 meter covered interval, a 17 meter-thick sequence of red mudstones and red-gray very-fine to fine-grained sandstones are exposed (Fig. 9, meters 53 to 70). Mudstones are either fissile, or intensely disrupted and blocky-weathering with slickensided clay-lined surfaces between blocks. Desiccation cracks are common. Horizons of calcareous concretions (rhizocretions) occur rarely, as do pseudoanticlines. Bioturbation is pervasive and includes root casts and vertical burrows. One burrow type is 1-2 centimeters in diameter and has a meniscate fill. Others are 3 to 5 millimeters in diameter. The sandstone beds are sheetlike to lenticular, and range in thickness from centimeters to decimeters. Thinner beds are small-scale cross-stratified and have wave- or current-rippled tops. Thicker beds may be dominantly small-scale cross-stratified but can have large-scale cross-strata or planar-strata immediately above their erosional base. Sparse paleocurrent data indicate flow to the N or SSW. Large vertical, meniscate burrows (centimeters in diameter) occur in these sandstones but bioturbation is dominated by smaller burrows (1 centimeter diameter). Upper parts of sandstone beds may have root casts and rare calcareous concretions. Meter-thick upward fining and coarsening sequences occur in places (eg. Fig. 9, meters 58 to 60).

The upper part of the Grand Gorge road cut contains two erosional-based, fine-to medium-grained sandstone bodies. The lower one is dominated by low-angle cross-strata and planar-strata, but also contains angle of repose cross-strata. Along erosion surfaces occur drifted plant remains and a rare occurrence of the nonmarine bivalve *Archanodon* (internal mold, transported). The upper sandstone body shows lateral-accretion bedding passing laterally into a channel fill. Paleocurrents lower in the sandstone body are to the south. Vertical burrows of varying diameter occur in these lower parts.

Interpretation

The lower succession exposed along route 30 is comparable to the top of Stevens Mountain quarry, and is interpreted similarly. Red beds in the middle of the Grand Gorge Route 30 roadcut indicate a fluvial overbank sequence (see also Miller and Woodrow, in press). Desiccated, bioturbated mudstones represent floodbasin deposits. Blocky weathering mudstones with local calcareous concretions and pseudoanticlines indicate repeated wetting and drying, illuviation, and formation of ped structure typical of calcareous vertisols. Fissile mudstones indicate relatively minor influence of bioturbation and repeated exposure, and may represent relatively high deposition rates in perennially ponded areas. Wave-rippled sandstone lenses indicate periodic wave activity on such ponded areas. Sandstone beds with unidirectional sedimentary structures indicate periodic sand deposition during floods, either as individual sheet flood deposits within the floodbasin, or associated with progradation of levees or crevasse splays. The coarsening-upward sequence at meters 58 to 60 (Fig. 9) suggests progradation of a levee or crevasse splay into a floodbasin. Calcareous concretions and pseudoanticlines in overlying beds indicated subsequent rapid abandonment, reduction in deposition rate, and soil formation. The overall vertical sequence at Grand Gorge, Route 30 therefore is generally regressive, representing an upward transition from nearshore marine through coastal and fluvial deposits.

DISCUSSION OF DEPOSITIONAL ENVIRONMENTS

The Givetian rocks of Schoharie Valley show evidence of: 1) tide-influenced channels (estuaries of deltaic distributaries) with mouth bars and associated shallow-marine shoals; 2) muddy and sandy tidal flats and bays; and 3) river channels, floodplains and lakes (see also Johnson and Friedman, 1969; Miller and Woodrow, in press). The marine shelf was clearly storm-wave dominated. There is no evidence for beaches, intertidal sand-mud channel deposits with lateral-accretion bedding, nor well-developed tidal bundle sequences in cross-stratified sands. Therefore, the North Sea tidal flats may not be particularly good analogues for these deposits, as implied by previous workers (eg. McCave, 1968; Johnson and Friedman, 1969). Strongly-asymmetrical, ebb-dominated currents, possibly due to dominance of river flow during deposition, may explain the rarity of tidal-bundle sequences. Reactivation surfaces in cross-stratified sandstones generally indicate a nondepositional or erosional subordinate tide (c.f. Dalrymple, 1984; DeMowbray and Visser, 1984). Tidal range is difficult to estimate because tide-formed sedimentary features are not precise indicators of tidal range, and because tidal ranges and currents may have been enhanced by 'storm tides' or river floods during deposition. Furthermore, different parts of the coast may experience different tidal ranges, as is clearly evident in the North Sea and the Atlantic coast of the USA. This lack of beaches argues against a microtidal range, and many of the tide-formed sedimentary features in Schoharie Valley indicate higher tidal ranges (possibly mesotidal; see Slingerland, 1986). The lack of beaches along a coastline that clearly experienced strong storm waves may be the result of high rates of deposition of sand and mud near the mouths of a complex of channels. Switching (avulsion) of distributary channels was clearly an important process and controlled local deposition rates at the shoreline. It is recorded by the vertical alternations of channel sandstone bodies and the sandstone/mudstone successions. This implies the existence of a tide-influenced delta.

Storm-wave dominated marine shelf environments with submarine sand bars have also been reconstructed in the slightly younger Frasnian part of the 'Catskill clastic wedge' in New York and Pennsylvania (Craft and Bridge, 1987; Halperin and Bridge, 1988; Slingerland and Loule, 1988). Although wave-ripple crest orientations are variable, modal oscillation directions appear to be WNW-ESE (normal to the paleoshoreline) and NNE-SSW (alongshore), as observed in the Schoharie Valley. In Pennsylvania, Slingerland and Loule (1988) believe there is longshore drift to the SW. These workers all agree that tidal currents were only important depositional agents at the coast, but reconstructions of the nature of the paleocoastline differ.

It is generally agreed that beaches were not important in the Catskill clastic wedge (eg. Walker and Harms, 1971; Woodrow, 1985; Halperin and Bridge, 1988; Slingerland and Loule, 1988). Frasnian coastal deposits in central New York show evidence of distributary channels, mouth bars and interdistributary bays with little evidence of strong tidal currents (Sutton et al, 1970; Halperin and Bridge, 1988), but also of estuarine? channel bars and tidal flats with evidence for strong tidal currents (Bridge and Droser, 1985). Slingerland and Loule's (1988) reconstruction of the Frasnian shoreline in Pennsylvania is one of estuaries, tidal flats and shoals. Tidal ranges were considered to be high mesotidal, with strong flood domination. They saw no evidence for channel mouth bars, nor did they record tidal-bundle sequences in their cross-stratified estuarine sandstones. In contrast, Walker and Harms (1971) interpreted a Frasnian shoreline in Pennsylvania as being muddy with no shoreface sands, and only a few channel sandstone bodies. They took this to indicate low wave energy and low-tidal range (microtidal).

This diversity of different types of Givetian and Frasnian shoreline deposits should not necessarily be taken to reflect markedly different shoreline physiographies and sedimentary processes in different regions at different times. The common threads linking all of these deposits are: the presence of sandy channels with varying degrees tidal influence; the presence of extensive shallow bays and tidal flats where mud and sand were deposited; the rarity of beaches; and the storm-wave domination of the shelf. Much of the variability could be explained within the context of a wave-and tide-influenced deltaic coastline where location of distributary channels, tidal range, and wave activity varied in space and time.

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Apendix 1: Road log for Schoharie Valley field trip.

Start in Oneonta. Travel underneath Interstate 88 at exit 15 and turn left onto NY route 23, heading east. Approximantly 3 miles past Grand Gorge, turn left down a dirt road towards Hardenburgh Falls. Cross the bridge over Bear kill and park. Walk east down track on north side of the creek to exposures adjacent to the bridge.

Stop 1: Hardenburgh Falls

Return to NY route 23 and turn left (east) towards Prattsville. Travel for approximately 1.5 miles until the bridge over Schoharie Creek. Turn sharply left (north) immediatly after crossing the bridge along the road that follows the east side of Schoharie reservoir. Travel approximantly 0.6 miles as far as Gilboa- West Conesville Central School. Turn right immediately past the school, travel to the back of the school and park near the playing fields. Walk Southeast to the far corner of the playing fields and find the trail leading up the hillside to the quarry (about a 10 to 15 minite walk).

Stop 2: Stevens Mountain Quarry

Return to the main road by the school and travel south for approximately one mile to the bridge over Manorkill. Park on the south side of the bridge and find the trail leading down to the reservoir.

Stop 3: Manorkill Falls

Travel north approximately 1.5 miles (past the school again) and cross Schoharie Creek at Gilboa. Turn right immediately, along the left bank of Schoharie Creek, and travel approximately .5 miles. The outcrops to be viewed are rock ledges along the opposite side of Schoharie Creek.

Stop 4: Schoharie Creek

Return to Gilboa and turn right (do not cross the bridge again). Several Devonian tree trunk casts are displayed in a fenced area by this turn. This road joins NY route 30 after 1 mile. Turn left (south) on NY route 30 and travel approximately 1 mile until the road starts to climb up the west side of Pine Mountain. Park at the base of the hill near the first outcrops. Be careful of traffic by these road cuts.

Stop 5: Route 30, north of Grand Gorge

Continue on NY route 30 to Grand Gorge, and turn right (west) onto NY route 23, heading back to Oneonta.