THE WEST FALLS GROUP (UPPER DEVONIAN) CATSKILL DELTA COMPLEX: STRATIGRAPHY, ENVIRONMENTS, AND SEDIMENTATION

JAMES R. EHRETS
University of Rochester
Rochester, New York

INTRODUCTION

Since the last meeting of the NYSGA in Binghamton (Coates, 1963), significant advances have been made in the refinement of correlation and environmental interpretation of Upper Devonian strata in south-central New York. One purpose of this article is to summarize the updated stratigraphy in this region and to review how the stratigraphy has been developed. The main theme of the article is the result of recent study in the Binghamton area (Fig. 1). By tracing thin units of dark-gray shale to the east of Binghamton, a stratigraphic framework was developed which permitted further analysis of environmental and sedimentologic relationships of the Catskill delta complex in the area. Through the demonstration of the dark-shale framework and discussion of deltaic environments, a few of the interpretations are presented. The accompanying field trip is designed to illustrate a variety of deltaic environments and how they fit into the stratigraphic framework.

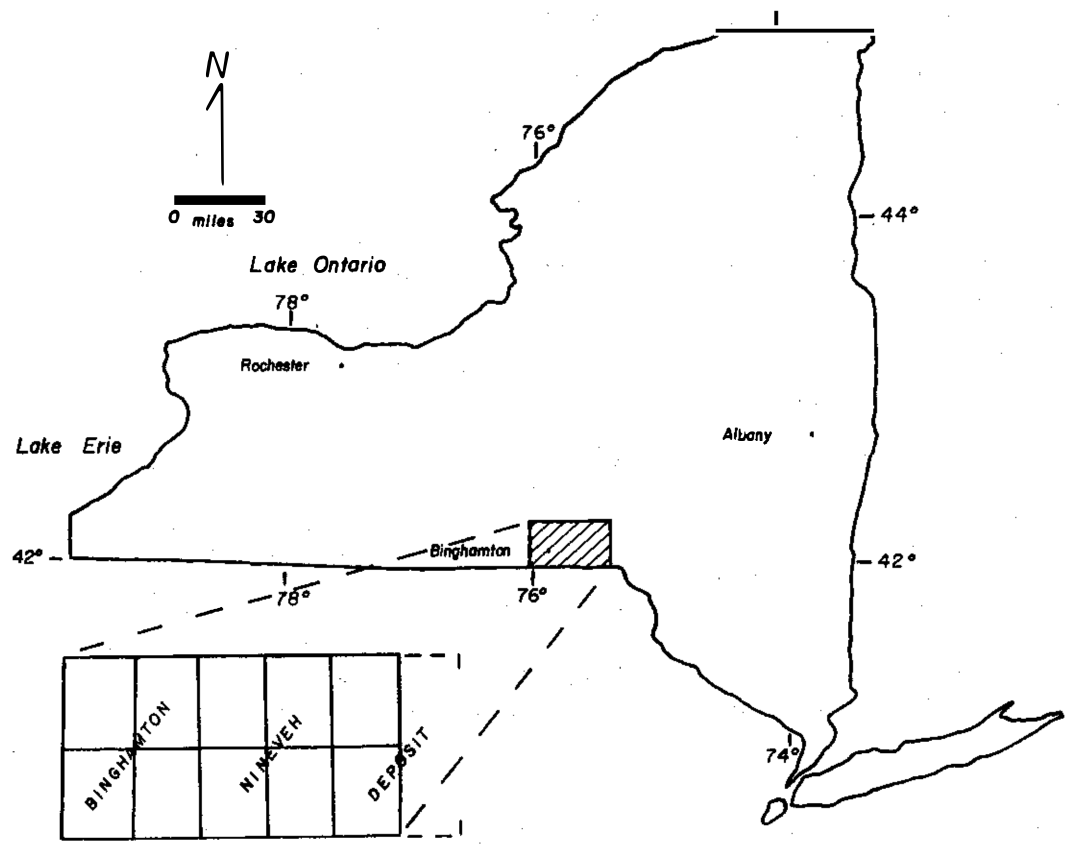


Figure 1. Study area location; inset shows included 15-minute quadrangles.

STRATIGRAPHY

Beginning about 1950, the use of dark shales for correlation in the Upper Devonian of New York has gained significant interest due to the discovery that certain units of dark shale parallel biostratigraphic zones. This has not only aided in the solving of some of the problems involved in correlating strata characterized by numerous facies changes but it has also facilitated the study of the interrelationships of the facies themselves. At present, four major dark-shale tongues are recognized in western New York: the Geneseo black shale, which defines (in part) the base of the Genesee Group as well as the base of the Upper Devonian; the Middlesex black shale, which defines the base of the overlying Sonyea Group; the Rhinestreet black shale, which defines the base of the next highest West Falls Group; and the Dunkirk black shale, the highest of the major shale tongues, which defines the base of the overlying Canadaway Group. These tongues, as well as a few intervening and overlying minor tongues, extend from the Ohio black shale which lies to the west of New York State (Fig. 2).

In a stratigraphic and structural study of the Dryden and Harford quadrangles which are located northwest of the Binghamton area, Sutton (1959) recognized two thin units of dark-gray shale which parallel the faunal zones he was tracing through the region. Sutton determined that the dark-shale units were more suitable for mapping purposes due to their persistence in the field. Following methods established by Sutton, Humes (1960), Nugent (1960), and Woodrow (1960) traced thin units of dark shale in the Ithaca, Watkins Glen, Elmira, Owego, and Waverly quadrangles located to the west and northwest of Binghamton. Two of the units were determined to be eastern equivalents of the Middlesex black shale: the Montour Member and the Sawmill Creek Member. Three such units were found to be equivalent to the overlying Rhinestreet black shale: the Moreland Member, the Dunn Hill Member and the Roricks Glen Member. Sutton (1963) later determined that a fourth shale member—the Corning Member—also extended eastward from the Rhinestreet. As the shale members were traced to the east the nomenclature for the intervening strata developed as new facies were encountered. The nomenclature at that time was summarized by Woodrow and Nugent (1963).

During later reconnaissance, Sutton (1964) and Woodrow (1964) determined that although the lithologic character differed from their respective type sections to the west, the shale members continued eastward and in fact intertongued with the nonmarine rocks of the Catskill facies. Shale members from the underlying Middlesex and Geneseo black shales were also shown to extend eastward into nonmarine strata (Sutton and others, 1970; Thayer, 1974). The most recent editions of the New York State Devonian correlation chart (Rickard, 1975) and the geologic map of New York State (Fisher and others, 1970) both include the dark-shale framework as a major feature in conjunction with biostratigraphic correlation.

With the exception of a small percentage of Sonyea Group strata which crop out in the valleys of the area, rocks within the Binghamton area are in the West Falls Group. A lithostratigraphic framework is

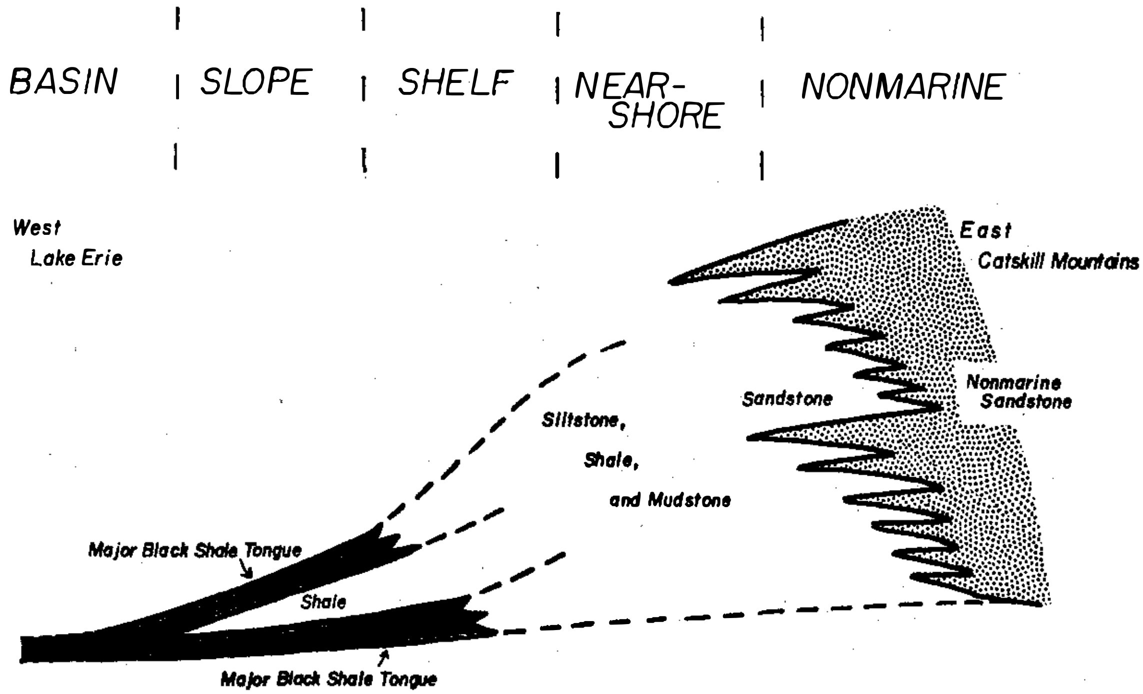


Figure 2. Generalized stratigraphic and environmental relationships of two consecutive tongues of black shale.

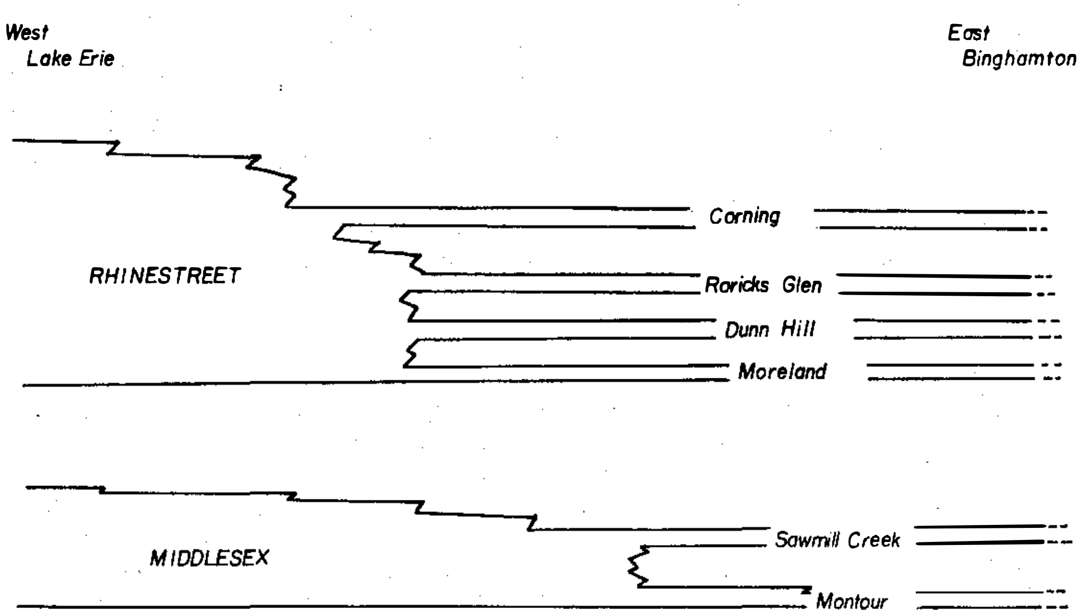


Figure 3. Time-stratigraphic relationship of dark-shale members of the Middlesex and Rhinestreet black shales. (after, Rickard 1975)

provided by the Moreland, Dunn Hill, Roricks Glen and Corning Members of the Rhinestreet Formation (Fig. 3). The nomenclature for the stratigraphic intervals between the shale members is established for rocks to the west of the Binghamton area (Fig. 4). The names Meads Creek, Beers Hill, and Millport, which have in the past been considered to define members of the Rhinestreet Formation in the Binghamton area, are now confined to strata within the Portage facies to the west of Binghamton (Rickard, 1975). Although new names are needed for rocks of the Chemung facies in the Binghamton area, no new names are proposed here. For discussion purposes, a specific interval will be referred to by the shale members which bound it above and below. For example, the rocks of the lowermost interval are referred to as the Moreland-Dunn Hill interval. Rocks occurring below the Moreland Member belong to the Glen Aubrey Formation of the Sonyea Group. Rocks overlying the Corning Member belong to the Gardeau Formation of the West Falls Group. All of these intervals and formations are composed of marine rocks of the Chemung facies as described by Rickard (1975). The marine rocks within the Binghamton area intertongue with nonmarine rocks of two formations within the Catskill facies. The Moreland-Dunn Hill and Dunn Hill-Roricks Glen intervals are correlative with the Upper Walton Formation while the remaining overlying rocks (Roricks Glen-Corning interval and the Gardeau Formation) are correlative with the Slide Mountain Formation (Fig. 4).

RECENT STUDY

Introduction. With the essential stratigraphic framework established by the dark-shale members of the Rhinestreet, the area between Binghamton and Deposit has been recently examined in detail in an effort to refine the framework and to develop an environmental and sedimentologic interpretation of the Catskill Delta complex for the West Falls Group (Ehrets, 1981). The Binghamton area provides excellent exposure of rock in the form of numerous road cuts and quarries for such detailed study. Of over 100 exposures in the area, 59 were chosen which were incorporated into a cross-sectional framework (Fig. 5). The most important aspect of the study centered around the tracing of the individual dark-shale members of the Rhinestreet due to their importance in the stratigraphic framework. The dark-shale members were traced through consideration of the stratigraphic and geographic relationships of scattered exposures of dark shale in the study area (see symbols, Fig. 5).

Structure in the Study Area. As a knowledge of possible structural complications is necessary to ensure the correct tracing of a particular shale member, it is important to briefly consider the geologic structure of the study area. Wedel (1932) determined the essential structural feature in south-central New York to be a gently flexed monocline which dips "practically due south at the rate of approximately 40 feet to a mile." The flexures in the monocline are the expressions of anticline (better described as series of aligned domes) and synclines which become more prominent to the southwest. Wedel traced the "Nichols syncline" (southernmost), the "Elmira anticline", and the "Horseheads syncline" (northernmost) east to Binghamton, observing that their existence east of Binghamton was questionable (Fig. 6). Woodrow (1968) added support to

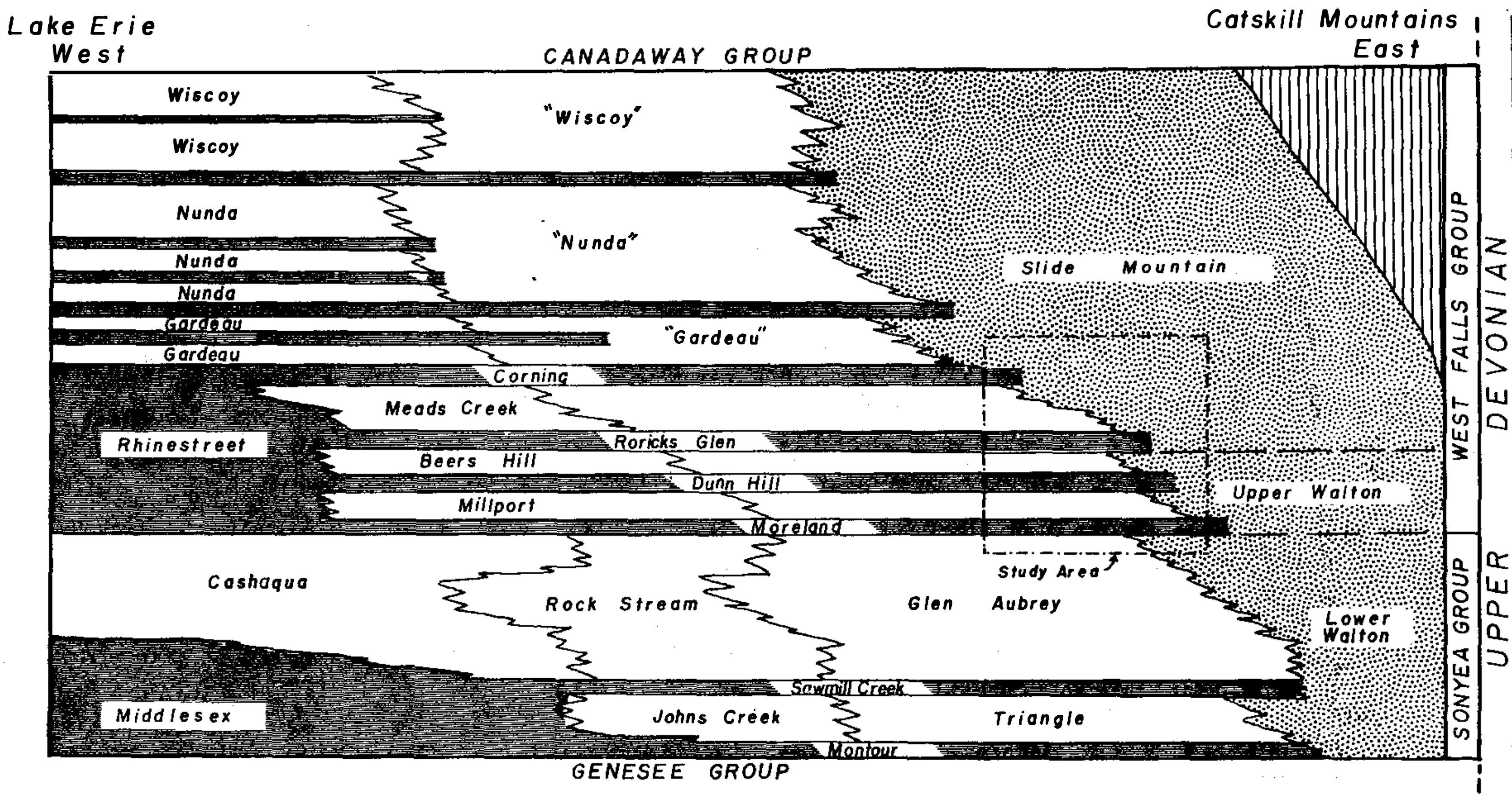


Figure 4. Summary of stratigraphic nomenclature and time-stratigraphic relationships for the West Falls and Sonyea Groups. Names in quotes are used informally. Closely ruled lines denote dark-shale members and black shale-formations; stipple denotes Catskill facies. (after Rickard, 1975)

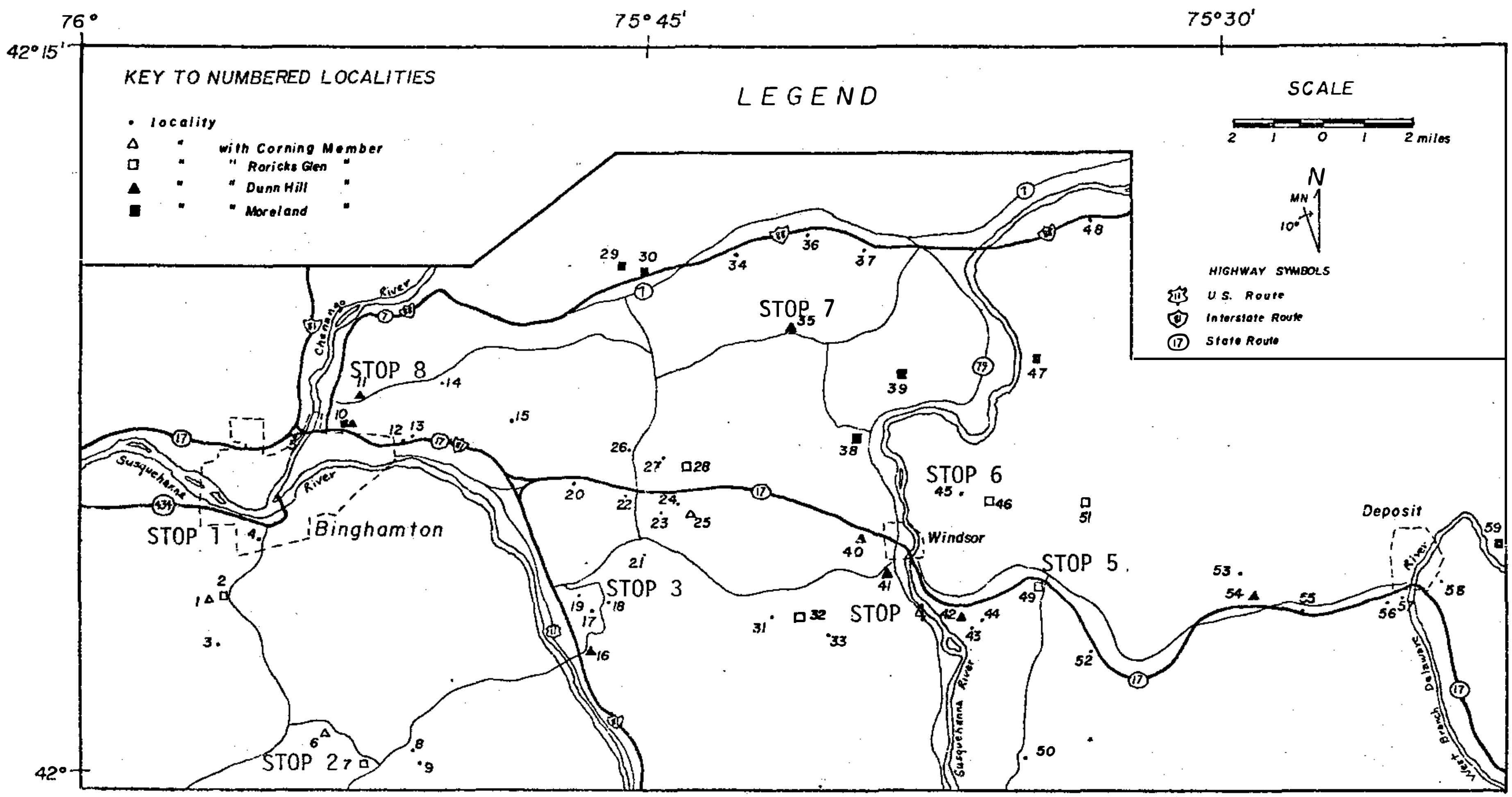


Figure 5. Geographic distribution of the 59 study area localities. Arrows indicate field trip route.

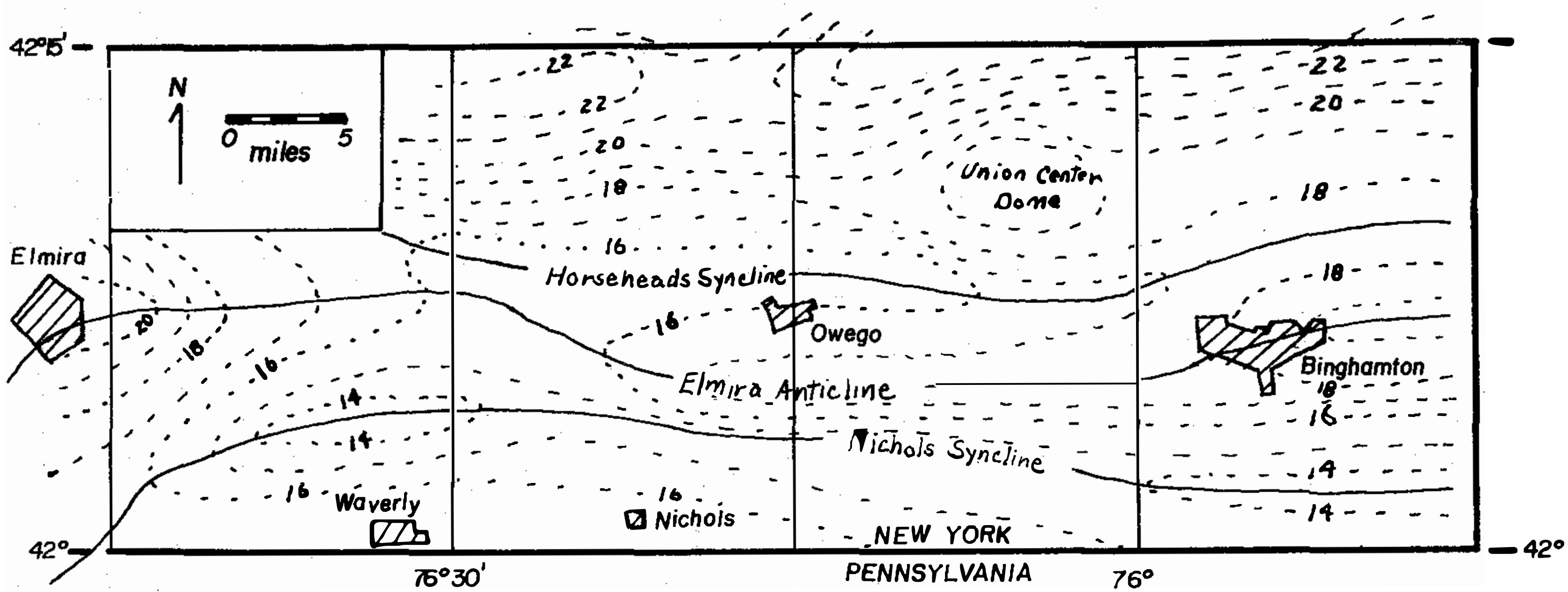


Figure 6. A portion of Wedel's (1932) structure-contour map of south-central New York showing the major structural features near and within the study area. Contour intervals are in hundreds of feet.

Wedel's work by observing that structural features in Bradford County, Pa. (southwest of Binghamton) indeed became more difficult to trace towards the northeast. Wright (1973) compiled deep-well data for much of New York and northern Pennsylvania from which a structure-contour map of the Tully Limestone (Middle Devonian) was compiled. General surface trends reported by Wedel and Woodrow are reflected in this subsurface map.

Using the elevation of exposures of dark shale, the writer employed simple construction methods to determine if the "surfaces" defined by the assumed exposures of individual dark-shale members showed inconsistancies which might either suggest the presence of structure or the incorrect tracing of the shales. The elevations of five assumed exposures of the Roricks Glen Member were found to define a nearly planar surface over a broad area in the central portion of the study area. The attitude of this constructed surface is N 77° W with a dip to the south of 47 feet per mile. This attitude agrees well with that reported by Wedel (1932). With the establishment of the Roricks Glen datum plane, the positions of the remaining dark shales were correlated with it. The results revealed that the other three shale members, within an east-to-west trending belt, defined planes essentially parallel to the Roricks Glen. Three anomalies were discovered, one in the west-central portion of the study area, where elevations of dark shale exposures ranged up to 50 feet higher than expected; and in the northwestern and southwestern areas, where dark shale elevations were on the order of 50 feet lower than expected. These anomalous areas coincide with the trends of the anticline and synclines which Wedel reported to extend into the Binghamton area. It was not determined how far east these features exist; however, due to the low magnitude of structural variation from the regional dip, it was concluded that no errors were made in the tracing of individual shale members.

With the geographic positions of individual shale members established, the 59 study area localities (Fig. 5) were projected onto a cross-sectional plane in a manner similar to that of Sutton and others (1970) and Thayer (1974) using exposures of dark-shale members as the basis from which all other localities were projected (Fig. 7). Since sedimentary-structure data indicates the general direction of sediment transport to be due west (Fig. 8), an east-west trend was chosen for the plane of projection, as this should best represent an average cross section of rock within the Catskill complex.

THE CATSKILL COMPLEX

Before describing the deltaic environments interpreted for the study area, it is important to briefly outline a few general environmental aspects which set apart the Catskill complex from modern deltas. Primarily, the physical nature of the complex as a network of coalesced alluvial plains and fluvial depocenters which paralleled the trend of the rising Acadian landmass is unequaled in modern physiography. In this light, the term "Catskill delta" is misleading as it implies a single river system. Individual delta "lobes" which existed contemporaneously have been recognized (Willard, 1939; Dennison and de Witt, 1972; Sevon, 1979), each of which can be interpreted as constituting a delta. The proximity of several fluvial systems to one another resulted in the lateral blending of

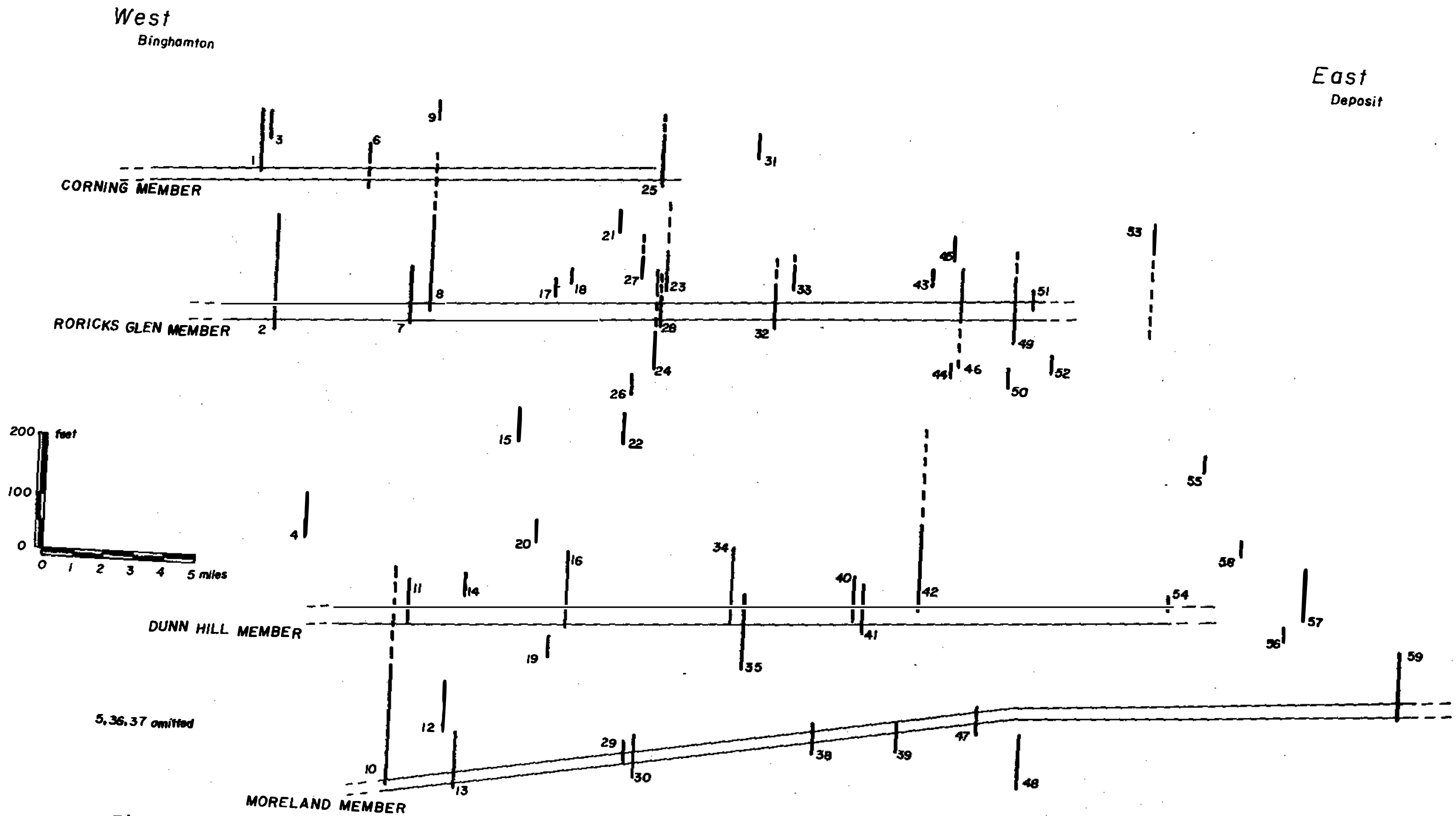
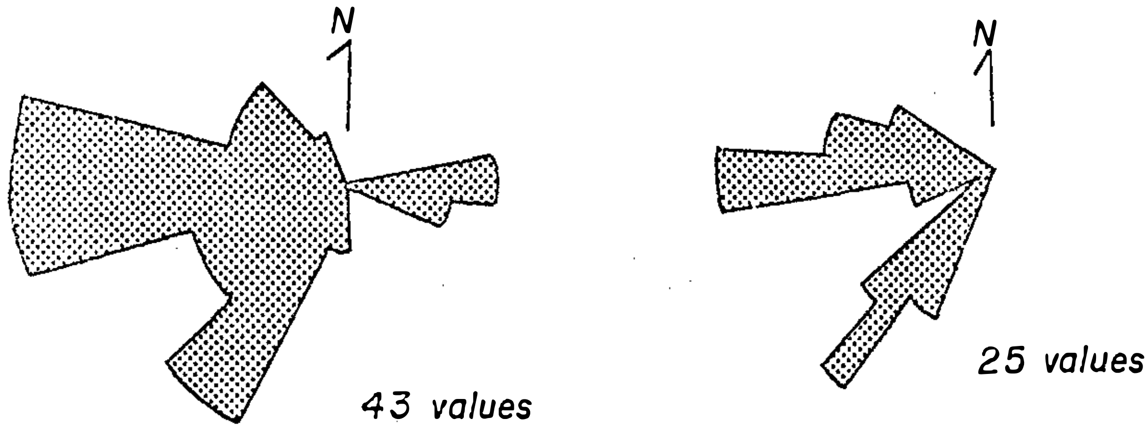


Figure 7. Cross-sectional summary of the stratigraphic and geographic distribution of the study-area localities. The cross section trends N 90⁰ W. Vertical lines represent extent of exposure (dashes indicate partially covered intervals).



(a) all sedimentary structures *(b) current ripples*

Figure 8. Summary of sedimentary structure data. The circular histograms were constructed using 10° class intervals.

their various environments along the prograding shoreline. In areas where fluvial systems were limited in number or size, "interlobe" or"nondeltaic" areas resulted. Thus extensive areas along the shoreline were entirely deltaic, entirely nondeltaic, or transitional in character.

Water depth, which is directly related to the width of the continental shelf in front of an advancing delta, strongly controls deltaic morphology (Kolb and Lopik, 1966; Coleman and Wright, 1975). Large deltas which build into deep water, as well as small deltas, in general, develop recognizable bottomset, foreset, and topset beds of the Gilbert-type delta (Moore, 1966; Morgan, 1970). However, large deltas building into water which is not directly underlain by a rigid basement are characterized by regional downwarping and local sediment compaction (Morgan, 1970). This results in the accumulation of a thick sediment pile which obscures the various beds normally associated with the term "delta". The Mississippi delta, the most commonly used modern example, is this type of delta. In addition, there is a significant difference between the modern Mississippi delta (Balize lobe) and its several ancient lobes. The ancient lobes were formed by progradation into shallow water and are termed "shoal-water deltas" (Gould, 1970). Distributaries of these deltas frequently plugged with sand which resulted in numerous bifurcations and the eventual formation of continuous "sheet sands" around the front of the deltas. In contrast, the Balize lobe is building out into relatively deep water near the edge of the continental shelf. The result is that this lobe differs drastically in size, configuration, and in sediment distribution from the ancient lobes. The Catskill complex is much more similar in character to the ancient lobes, thus making it impractical to use the modern Mississippi delta as a Catskill analogue.

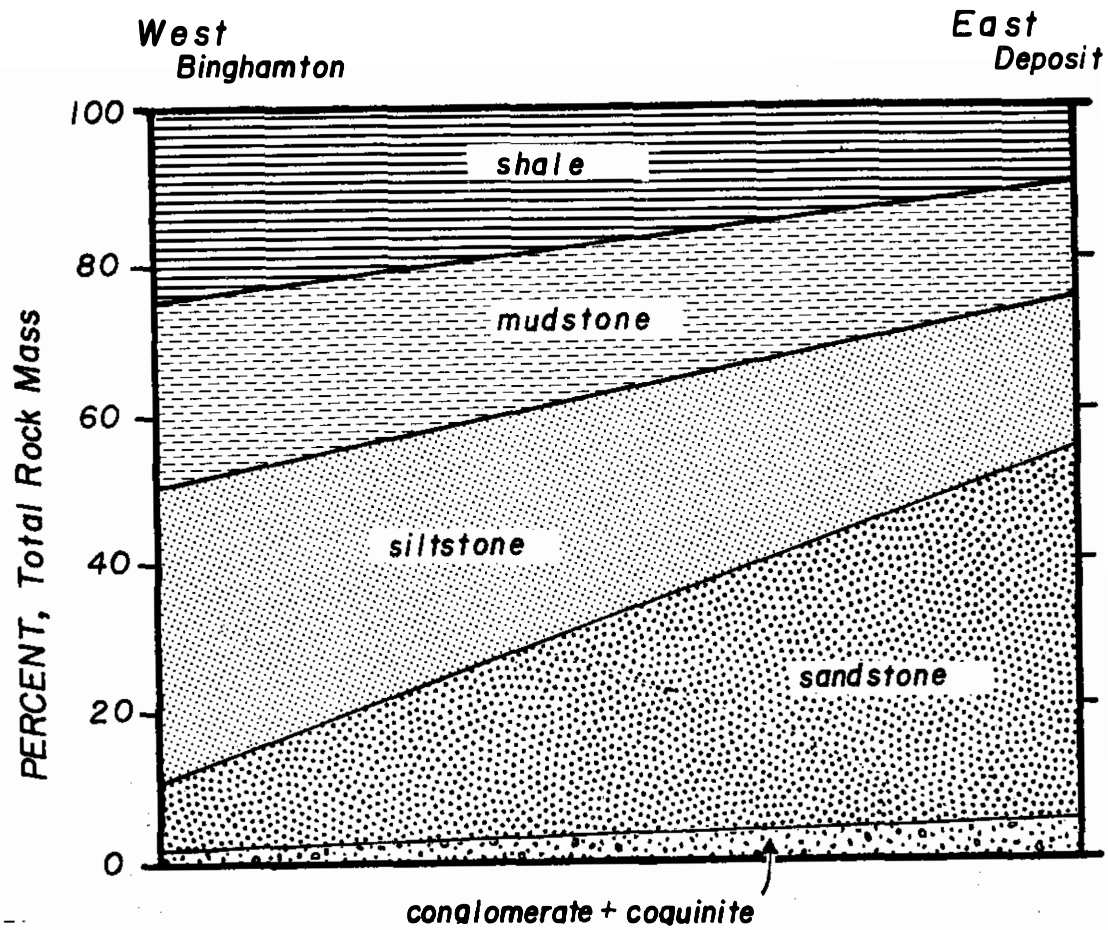


Figure 9. Relative distribution of major lithologies in the study area.

Drainage-basin relief and climate combine to play the dominant role in determining deltaic depositional facies and physiography (Coleman and Wright, 1975). As the Mississippi delta borders a low-relief coastal plain well removed from mountains of active tectonic character, the sediment is predominantly mud and silt with sand representing but a small percentage of total sediment. In contrast, the relative proximity of an active mountain system resulted in a sediment component in the Catskill complex which was dominantly sand (Friedman and Johnson, 1966; Fig. 9). The Catskill alluvial plain, described as being composed of fan, stream, and lacustrine deposits, had a climate which was probably similar to the modern tropical, wet-and-dry savanna of near-equatorial position (Woodrow and others, 1973). The relatively low density of vegetation, especially with respect to grass, resulted in numerous, short-lived floods which provided for the transport of an abundance of coarse sediment to the actively building delta complex. It is the exception rather than the rule for large deltas to have sand as the primary constituent. This is an important factor to consider as sediment grain size plays an important role in the development of environments.

As a modern analogue to the Catskill complex is lacking, it is necessary to reconstruct the Catskill environments from consideration of several delta systems both modern and ancient. Although the modern Mississippi is the best studied of all modern deltas, the writer concluded that information on its ancient lobes (Kolb and Lopik, 1966; Gould, 1970) is much more suitable for comparison. For modern deltas, the Niger, Rhone, and Orinoco River deltas provide excellent comparative information. Leblanc (1975) summarizes references on various aspects of deltaic sedimentation and should be first consulted for specific studies.

Deltaic Environments

Sutton and others (1970) used descriptions of modern deltas to delineate several marine-shelf environments in the Sonyea Group which directly underlies West Falls strata in the Binghamton area. Nonmarine, marsh, estuarine, distributary-mouth bar, delta platform, delta-front sand, prodelta, and open-shelf environments were described. Through the study of Sonyea environments in conjunction with additional specific information on deltaic sedimentation, the writer recognized deltaic environments in the West Falls group. Proceeding from nonmarine to marine, the three major West Falls environments are: the subaerial delta plain, the subaqueous delta plain and the delta platform. These and their sub-environments, diagrammatically summarized in Fig. 10, are considered in detail below.

Subaerial delta plain. The strictly nonmarine environments are grouped into a general environment termed the subaerial delta plain. The modern counterpart of this area is characterized by a large, low-lying floodplain which is dissected by meandering rivers and streams. In the study area, the subaerial delta plain is dominated by channel deposits composed of coarse-grained sandstone which displays a variety of crossbedding, ripple marks, and cut-and-fill features. A much smaller percentage of the strata is composed of floodplain deposits which are characterized by siltstone, silty mudstone, and shale displaying burrows and ripple marks. The presence of mud cracks indicates that portions of this environment were periodically exposed to the atmosphere. In some places thin red beds are associated with these deposits although in general only a very small percentage of the Catskill facies is actually red. Interbedded channel and floodplain deposits are observed to define fining-upwards cyclothems.

Closely associated with a few channels are poorly sorted, coarse-grained and conglomeritic deposits which are interpreted to be levees. These deposits are similar to levee deposits encountered in borings in the Mississippi River delta plain (Kolb and Lopik, 1966) with the well-indurated character and red-orange color of the sediment produced during periods of exposure and desiccation. Abundant organic debris is a common constituent of both Mississippi delta plain and West Falls levee deposits. The extensive exposure in study-area locality 46 provides excellent examples of the channel, floodplain, and levee sub-environments of the subaerial delta plain.

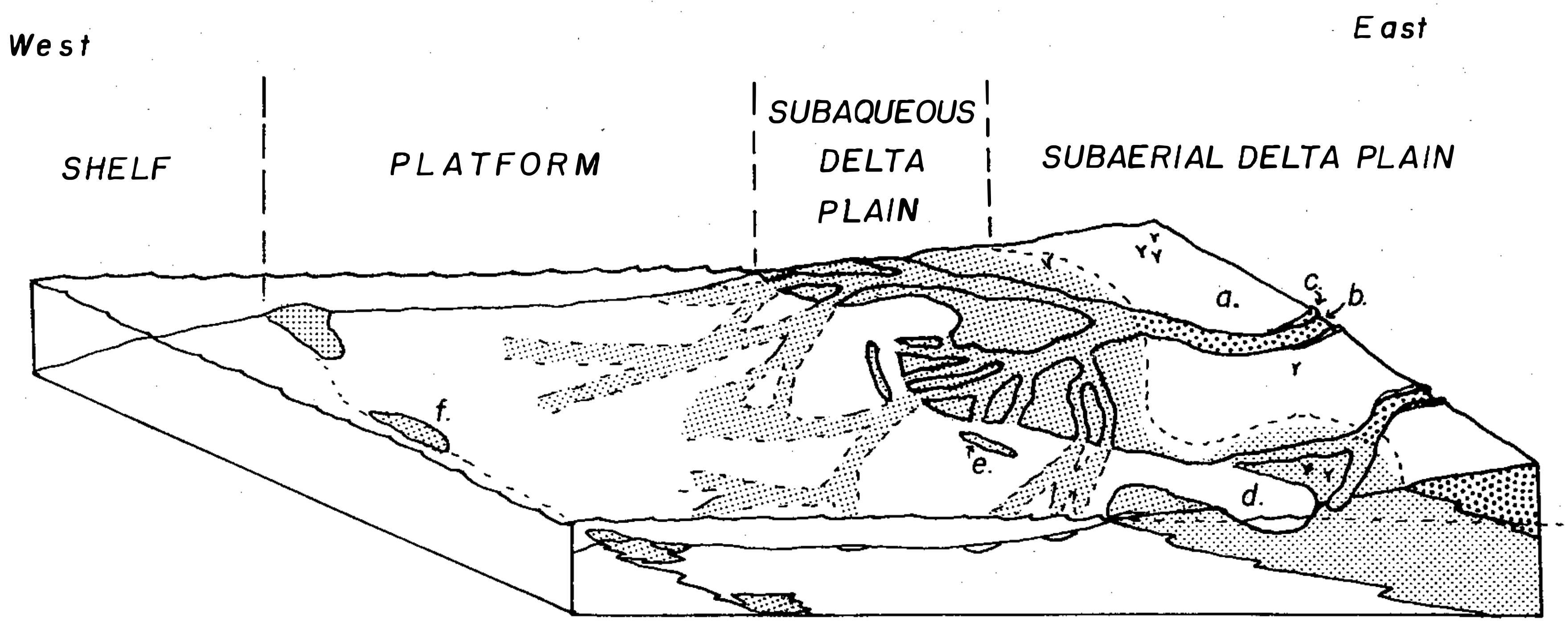


Figure 10. Aerial distribution of West Falls deltaic environments. (a) floodplain, (b) channel, (c) levee, (d) bay, (e) distributary-mouth bar, (f) delta-front sand. Large stipple denotes coarse-grained sand deposits; small stipple denotes fine-grained sand deposits. Sand deposits on the platform are subaqueous continuation of distributaries.

Subaqueous delta plain. Before entering the sea, the rivers of most modern deltas bifurcate into numerous distributaries over a large area which is commonly flooded by tides and river discharges. It is characterized by channels surrounded by marshes and tidal flats which support mangroves, grasses, and other plants. The vegetation tends to stabilize the interdistributary areas. Arms of the sea sometimes reach inland in this portion of the delta in the form of bays. The bays collect silt and clay carried in suspension by the distributaries.

In the study area, large expanses of fine-grained sandstone form a transitional zone between nonmarine and marine environments. This area is termed the subaqueous delta plain. Here, numerous shallow distributaries supplied fine-grained sand to the submerged interdistributary areas. These deposits are now seen as flatbedded and low-angle, cross-bedded sandstones (flagstone). Large channels are rare, indicating that most sediment supplied to this portion of the delta and beyond was carried by the shallow distributaries. These smaller channels frequently plugged with sand and changed course, thus accounting for the large extent of the subaqueous delta-plain deposits. With the exception of oriented plant fragments on a few bedding planes, organic debris is relatively sparse. The lack of stabilizing plant material in this environment would suggest that this would have been an extremely dynamic portion of the delta complex.

Shallow-water marine deposits are also recognized within the subaqueous delta plain. These deposits are interpreted as bays and are characterized by lenses of sandstone interbedded with siltstone, shale, and mudstone. The sandstone lenses formed as a result of channel splaying in the bay vicinity. Marine fossils are rare in the splay sands but are present in significant numbers in the finer-grained bay sediments. This relationship suggests that the splay sands were deposited by streams of relatively fresh water while the remaining bay environment was sufficiently saline to support a marine biota. Locality 1 best displays sub-environments of the subaqueous delta plain.

Delta platform. For modern deltas, the delta platform is described as a broad, terrace-like structure several miles in width which extends from the shoreline to a break in slope at the delta front. This break in slope occurs within water depths between 30 and 60 feet thus defining the platform as a shallow-water marine environment. This area is actively affected by tides and currents which winnow out the finer grained portion of the fluvial-supplied sediment.

As in the Sonyea delta platform, the West Falls platform is dominated by fine sandstone and mudstone. For discussion purposes, the platform is divided into proximal and distal portions. The proximal platform is characterized by numerous lenses of crossbedded sandstone interpreted to be extensions of distributaries into the shallow sea. The water velocity in the distributaries decreased as it moved onto the platform,resulting in repeated bufurcation of the distributaries. In some areas, distributaries broadened and merged with each other to form sheets of sand. Graded beds are common, indicating rapid deposition from turbid water. Accumulations of well-sorted, cross-bedded sandstone are interpreted as distributary mouth bars formed as a result of the reworking and concentration of distributary sand by currents and waves. Current ripples are very common in the proximal platform as are a variety of pillow structures.

Grain size and sandstone bed thickness progressively decrease moving out towards the distal portion of the platform. Sandstone lenses decrease in abundance. Distal platform sedimentary structures include cross lamination, current and wave ripples, and very large pillow structures. Graded beds are still present but are much thinner than those in the proximal platform. Deposits of fossiliferous, crossbedded sandstone occur on the distal platform. These "delta front sands" accumualted by the reworking of sand by currents and waves near the edge of the platform.

As the platform is the largest of the West Falls deltaic environments, this is the environment most frequently seen in outcrop in the Binghamton area. An excellent example of the proximal platform can be seen at locality 42 while the distal platform is best displayed at locality 13.

Dark-mud environment. The four dark-shale members define the only non-deltaic environment observed in the study area. Periodic marine transgression resulted in the accumulation of these relatively fine-grained deposits over the entire range of deltaic environments. The presence of siltstone in the shale members indicates that rivers continued to supply plumes of turbid water to this environment. The presence of only a few fossils in the dark-shale members indicates that this environment was of generally poor quality for fauna.

Cross section of environments. With the environmental interpretation of individual field localities established, the stratigraphic framework of Figure 7 is easily transformed into a cross section of environments in the study area (Fig. 11). This cross section is a summary of data which is the basis for the remaining discussion.

SEDIMENTARY AND ENVIRONMENTAL PATTERNS

Sedimentary Cycles

The distribution of environments in Figure 11 reveals three complete sedimentary cycles associated with the dark-shale framework. The cycles are asymmetrical in configuration with each cycle considered to consist of an interval of regression which is abruptly terminated by a transgressive interval represented by a dark-shale member. (For this discussion, the Moreland Member is not considered as a part of any cycle. In addition, a fourth cycle, post-Corning, was initiated but not completed in the study area due to erosional limitations). During transgression, deltaic sedimentation was essentially halted resulting in the accumulation of the dark muds now represented by the dark-shale members. The net effect of transgression was the displacement of deltaic environments to the east.

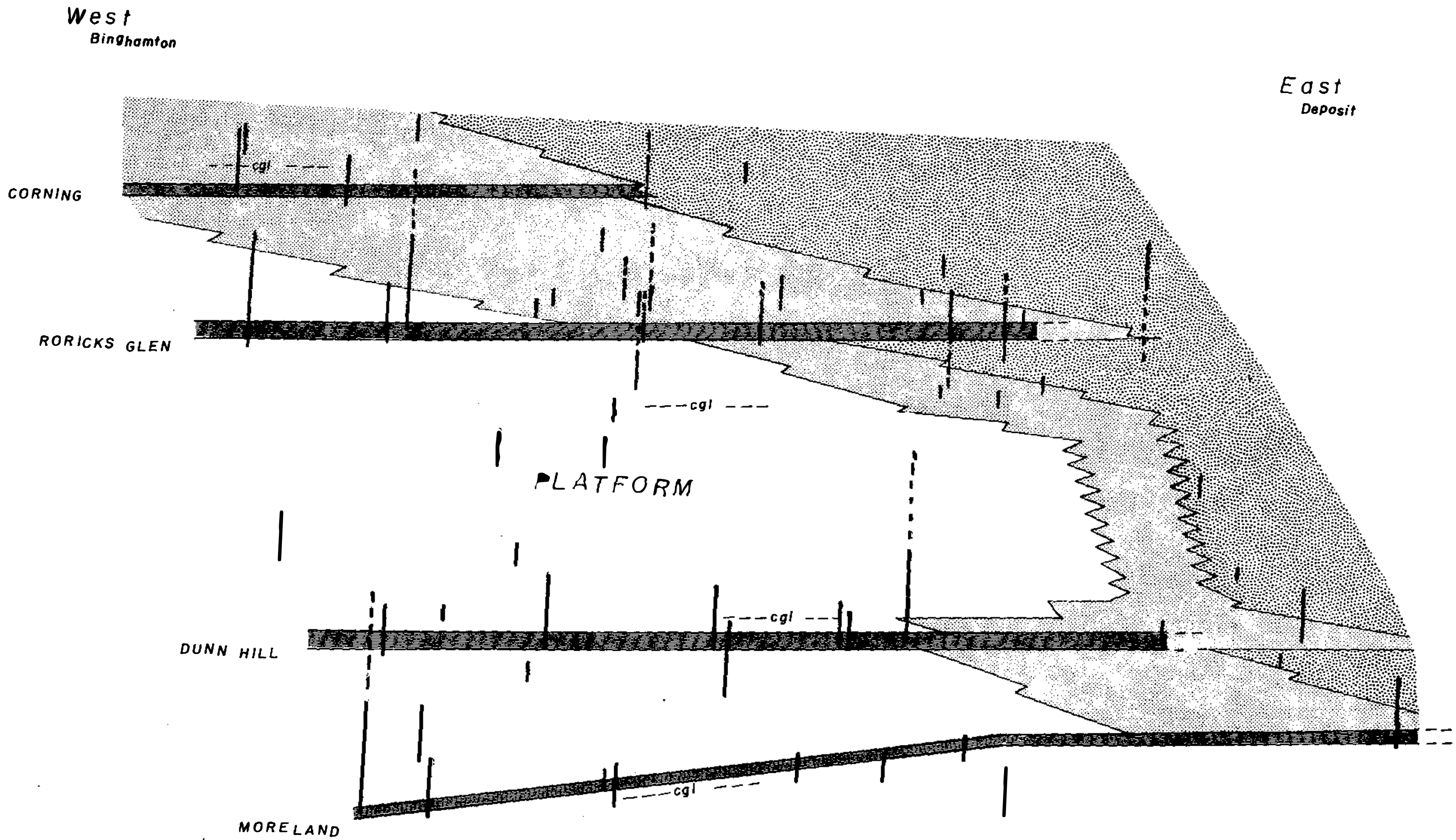


Figure 11. Cross section of West Falls deltaic environments: subaerial delta plain (coarse stipple), subaqueous delta plain (fine stipple), delta platform (blank). Positions of quartz-pebble conglomerates indicated by dashes.

Following transgression, the marine environments redeveloped close to their pre-transgressive positions and continued to prograde westward.

Sonyea time came to an end after a period of rapid regression which extended the width of the delta platform in the Glen Aubrey Formation to approximately 38 miles (Sutton and others, 1970). The prodelta environment which was present in earlier Sonyea time was essentially eliminated due to the rapid westward advance of the delta complex. This final Sonyea regression was brought to a halt by a marine transgression represented by the Moreland Member. As in the Sonyea delta complex, the rate of deltaic progradation in the West Falls delta complex was not uniform. In the Dunn Hill-Roricks Glen interval, progradation virtually reached a standstill in the Binghamton area. Possible explanations for such a standstill include a shift in course of a major river or a gradual subsidence in the nearshore region of the complex at a rate which nearly equalled the supply of sediment. Before completion of the associated cycle, progradation resumed and the deltaic environments rapidly developed westward. Progradation continued at a rapid rate through the last complete cycle. After the deposition of the transgressive Corning Member, regression suddenly resumed resulting in the deposition of the sandstones of the Gardeau Formation which extend several tens of miles west of Binghamton. The obvious erosion of the Corning Member associated with this regressive event is a unique feature with respect to all other shale members in the study area which, with the exception of small amounts of shale-chip conglomerate, conformably grade into overlying rocks.

Significant Features

Figure 11 reveals that the stratigraphic positions of four thin stringers of quartz-pebble conglomerate correlate with periods of rapid deltaic progradation. Nugent (1960) observed three stringers of this type of conglomerate in similar stratigraphic positions to the west of the study area. Woodrow (1968) correlated two of these stringers with conglomerates observed in the Gardeau Formation in Bradford County, Pa. Thus it appears that extensive areas were affected by these rapid pulses of progradation. Uplift of the source area is one possible explanation for the source of energy required for the transport of the pebbles across the platform. An alternative energy source could be provided by intense storms. During storm events, streams and rivers would have altered their courses resulting in the erosion of delta-plain deposits. Previously deposited conglomerates could then be exumed and transported by torrential waters to and across the platform. Downcutting by streams as a result of uplift could have exumed conglomerates in a similar manner; thus, the source area for the quartz pebbles need not be as far east as the Acadian highlands regardless of the source of energy. The high degree of rounding of the pebbles supports the hypothesis that the conglomerates may have been reworked several times before their final deposition. Whatever the mode of deposition, the potential importance of these conglomerates as stratigraphic tools as well as clues to sedimentary mechanisms should be considered in future analysis.

Graded beds observed on the platform are interpreted as proximal turbidites as suggested by Woodrow and others (1973). Catskill climatic conditions allowed for short-lived but intense storms which moved large amounts of relatively coarse-grained sediment across the delta plain and onto the platform. The associated currents winnowed away unconsolidated fine-grained sediment leaving behind shell material as lag deposits. These lag deposits, preserved as coquinites, formed the basal portions of the graded beds deposited as the current velocity diminished. A similar mode of origin for Sonyea coquinites is suggested by Bowen and others (1974) who demonstrated that the coquinites had not been transported very far before their final deposition.

Orientations of current ripples and other sedimentary structures (Fig. 8) imply that two currents were operating on the West Falls delta platform. The westerly current direction is interpreted to be the dominant trend associated with fluvial sedimentation and the transport of sediment across the platform by subsqueous continuation of river currents. A second current direction, approximately S 45° W, is attributed to longshore currents which were operating subparallel to the trend of the shoreline. In addition, interference ripples displaying both directions are common platform-environment sedimentary structures.

At the edge of the delta platform (distal platform environment), crossbedding of delta-front sands show an average orientation of about N 60° W (Fig. 12). This orientation fits a pattern of current-direction change from the platform to the shelf and slope environments where strata thin in a direction of N 60° W. A proportionally larger sediment supply to the region south of New York State could account for this clockwise rotation of the direction of sedimentary-structure orientations.

Factors Controlling Sedimentation Patterns

Transgression. Using the Roricks Glen as a model for dark-shale members, the nature of the West Falls transgressions is now considered. Close examination of the Roricks Glen in the field revealed that the marine portion of this dark-shale member gradually intertongues with rare occurrences of relatively thick floodplain (overbank) deposits. Thick overbank deposition associated with transgression has been shown to exist elsewhere in the Devonian (Johnson and Friedman, 1969). For the Roricks Glen, the thick overbank deposits indicate that drowning of the delta plain occurred which was accompanied by the raising of the base level of the streams and rivers within the delta plain. If the value of 3 feet per mile (Woodrow and others, 1973) is used as an average landslope on the delta plain, shoreline displacement during the Roricks Glen transgression suggests an increase in water depth of approximately 30 feet. As overbank deposition proceeded on the delta plain in response to flooding, the dark muds of the Roricks Glen accumulated on the sediment-starved platform and shelf to the west. By the time the shoreline regained its pre-transgressive position, a minimum of 25 feet of mud (the thickness of the Roricks Glen) had accumulated on the platform. This thickness of mud compensated for the deepening associated with

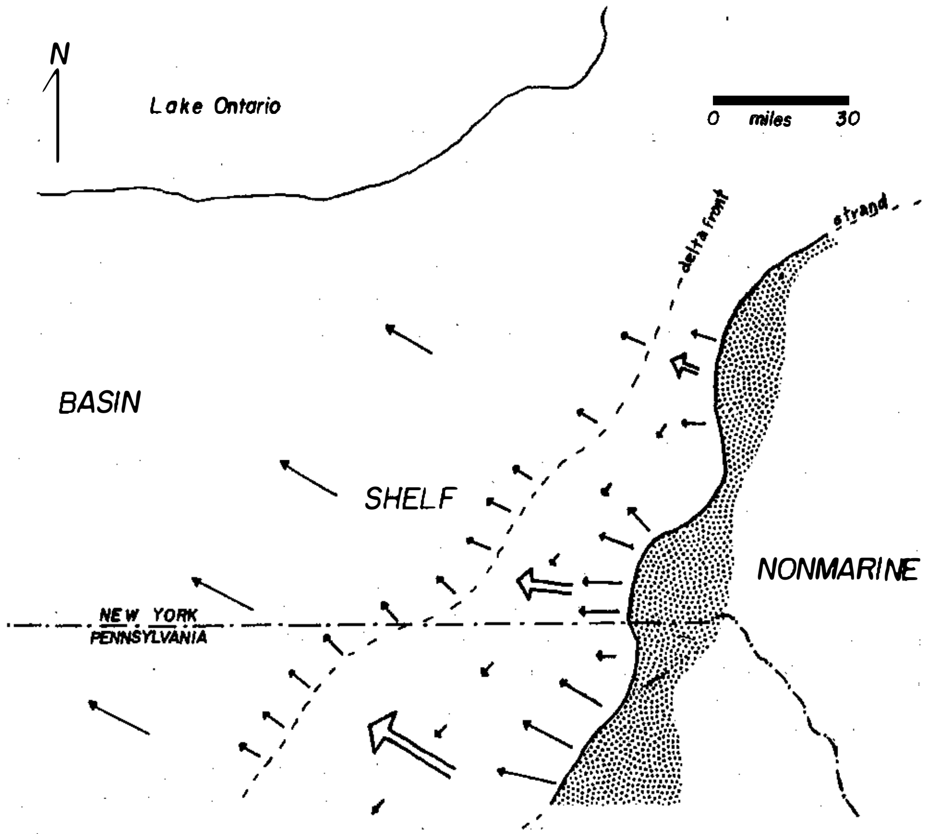


Figure 12. Current directions in the West Falls deltaic and basinal environments. Magnitude of sediment supply indicated by size of open arrows. Stippling denotes the delta plain.

transgression thus allowing the platform to redevelop close to its pre-transgressive position.

Regression. Preservation of the nonmarine correlatives of the Roricks Glen is evidence that a relative lowering of sea level was not responsible for the return of normal deltaic sedimentation on the platform. The effect of a relative sea-level drop would have been the destruction by erosion of overbank deposits in response to the lowering of stream base level. Instead, nonmarine channel and subaqueous delta plain deposits conformably overlie the Roricks Glen. The return of regression is best explained by the completed filling of the flooded delta plain.

Mechanism of cyclic sedimentation. Consideration of both the transgressive and regressive characters of the Roricks Glen model leads to the following conclusions involving the mechanism responsible for the cycles of sedimentation observed in the West Falls Catskill delta complex.

1) Transgression was not caused by an actual rise of sea level.

2) Transgression is best explained by relatively rapid basin-margin subsidence including a large portion if not all of the platform and delta plain. Dark mud accumulated on the platform and shelf as a result of overbank deposition on the delta plain and sediment starvation of environments to the west.

3) Relative lowering of sea level was not responsible for resumed deltaic progradation. Regression resumed after overbank deposition filled in the subsided portion of the delta plain.

Large-scale trends. With the mechanism of transgression and regression established for the model dark-shale member, it is possible to extend this model to the other dark-shale members and briefly consider trends in the evolution of the delta complex on a larger scale. Within the Dunn Hill-Roricks Glen interval, deltaic progradation intensified and resulted in the rapid westward advance of the delta platform onto the shelf. Evidence for this is the presence of the sandstones of the Gardeau Formation far west of the study area. In Gardeau time, a large portion of the shelf appears to have been replaced by platform and subaqueous delta-plain environments which developed in response to an increased supply of sand from the eastern nonmarine environments. It is significant to note a similarly increased sediment supply was determined to have been responsible for the elimination of the prodelta environment at the close of Sonyea time (Sutton and others, 1970). The relatively coarse Gardeau sediments, the correlative Slide Mountain conglomerates to the east of the study area, and evidence for the widespread erosion of the Corning Member suggest that a drastic change in the general pattern of sedimentation occurred in this portion of West Falls time. For the Roricks Glen dark-shale model to remain valid, a relative sea-level drop is necessary to explain the erosion of the Corning. Considering that actual sea-level changes are not evident in pre-Gardeau strata, it appears that uplift of a portion of the basin margin is necessary.

The replacement of the prodelta environment by the delta platform in late Sonyea time may represent the first major effect of the general process of basin filling in New York. Further blending of the delta platform with the marine shelf later in West Falls time could then be interpreted as the next major step in the filling process; the net result is the modification of the various deltaic and basinal environments in response to the shallowing conditions.

To conclude this evaluation of sedimentary mechanisms and trends, the writer suggests that the pattern of subsidence-produced transgressions and uplift later in West Falls time could be extended to define larger cycles of transgression and regression in the Upper Devonian. Such cycles might be represented by the major tongues of black shale and the intervening strata which characterize a large portion of Upper Devonian stratigraphy in New York.

The writer acknowledges Dr. Carlton Brett and Dr. Robert Sutton for reviewing drafts of this manuscript and the thesis from which it was derived.

REFERENCES CITED

Bowen, Z.P., Rhoads, D.C., and McAlester, A.L., 1974, Marine benthic communities in the Upper Devonian of New York: Lethaia, v. 7, p. 93-120.

Coates, D.R., ed., 1963, Geology of south-central New York: N. Y. State Geol. Assoc. Guidebook, 35th Annual Meeting, Binghamton, 116 p.

Coleman, J.M. and Wright, L.D., 1975, Modern river deltas: Variability of processes and sand bodies, in Broussard, M.L., ed., Deltas: Models for exploration: Houston, Texas, Houston Geological Society, p. 99-149.

Dennison, J.M. and de Witt, W., 1972, Redbed zone produced by sea level drop at beginning of Devonian Cohocton Stage delimits Fulton and Augusta lobes of Catskill delta complex, in Stratigraphy, sedimentology and structure of Silurian and Devonian rocks along the Allegheny front: Ann. Field Conf. Pa. Geologists Guidebook no. 37, p. 109-114.

Ehrets, J.R., 1981, The West Falls Group (Upper Devonian) Catskill delta complex: Stratigraphy, environments and aspects of sedimentation: M.S. thesis (unpub.), University of Rochester, New York, 68 p.

Fisher, D.W., Isachsen, Y.W., and Rickard, L.V., 1970, Geologic map of New York: New York State Mus. Sci. Serv., Map and Chart Ser. 15.

Friedman, G.M. and Johnson, K.G., 1966, The Devonian Catskill deltaic complex of New York, type example of a "tectonic delta complex", in Shirley, M.L. and Ragsdale, J.A., eds., Deltas in their geologic framework: Houston, Texas, Houston Geological Society, p. 171-188.

Gould, H.R., 1970, The Mississippi delta complex, in Morgan, J.P., ed., Deltaic sedimentation: modern and ancient: Tulsa, Oklahoma, Soc. Econ. Paleontologists and Mineralogists, Spec. Pub. no. 15, p. 3-30.

Humes, E.C., Jr., 1960, The geology of portions of the Watkins Glen and Ithaca fifteen-minute quadrangles: M.S. thesis (unpub.), University of Rochester, New York, 105 p.

Johnson, K.G. and Friedman, G.M., 1969, The Tully clastic correlatives (Upper Devonian) of New York State: a model for recognition of alluvial, dune (?), tidal, nearshore (bar and lagoon) and offshore sedimentary environments in a tectonic delta complex: Jour. Sed. Petrology, v. 39, p. 451-485.

Kolb, C.R. and Lopik, J.R., 1966, Depositional environments of the Mississippi River deltaic plain - southeastern Louisiana, in Shirley, M.L. and Ragsdale, J.A., eds., Deltas in their geologic framework: Houston, Texas, Houston Geological Society, p. 17-61.

Leblanc, R.J., 1975, Significant studies of modern and ancient deltaic sediments, in Broussard, M.L., ed., Deltas: Models for exploration: Houston, Texas, Houston Geological Society, p. 13-85.

Moore, Derek, 1966, Deltaic sedimentation: Earth Science Reviews, v. 1, p. 87-104.

Morgan, J.P., ed., 1970, Deltaic sedimentation, modern and ancient: Tulsa, Oklahoma, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. no. 15, 312 p.

Nugent, R.C., 1960, Geology of the Elmira, Waverly, and Owego quadrangles: M.S. thesis (unpub.), University of Rochester, New York, 96 p.

Rickard, L.V., 1975, Correlation of the Silurian and Devonian rocks in New York State: New York State Mus. and Sci. Serv. Map and Chart Series no. 24., 16 p.

Sevon, W.D., 1979, Devonian sediment-dispersal systems in Pennsylvania (abs.): Geol. Soc. America Abstracts with Programs, v. 11, p. 53.

Sutton, R.G., 1959, Structural geology of the Dryden and Harford quadrangles, New York: New York State Mus. and Sci. Serv., 15 p.

________, 1963, Stratigraphy in the Apalachin and Binghamton quadrangles, in Coates, D.R., ed., Geology of south-central New York: N. Y. State Geol. Assoc. Guidebook, 35th Annual Meeting, Binghamton, p. 77-78.

________, 1964, Correlation of Upper Devonian strata in south-central New York, in Shepps, V.C., ed., Symposium on Middle and Upper Devonian stratigraphy in Pennsylvania and adjacent states: Pa. Geol. Survey Gen. Geol. Rept. G-39, p. 87-101.

Sutton, R.G., Bowen, Z.P., and McAlester, A.L., 1970, Marine shelf environments of the Upper Devonian Sonyea Group of New York: Geol. Soc. America Bull., v. 81, p. 2975-2992.

Thayer, C.W., 1974, Marine paleoecology in the Upper Devonian of New York: Lethaia, v. 7, p. 121-155.

Wedel, A.A., 1932, Geologic structure of Devonic strata of south-central New York: New York Mus. Bull. 294, 77 p.

Willard, B., 1939, Middle and Upper Devonian, in Willard, B., Swartz, F., and Cleaves, A., eds., The Devonian of Pennsylvania: Pa. Geol. Survey Gen. Geol. Rept. G-19, p. 131-481.

Woodrow, D.L., 1960, The paleoecology and paleontology of a portion of the Upper Devonian in south-central New York: M.S. thesis (unpub.), University of Rochester, New York, 104 p.

________, 1964, Post-Rhinestreet stratigraphy in the Sayre and Towanda quadrangles, Pennsylvania: A progress report, in Shepps, V.C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pa. Geol. Survey Gen. Geol. Rept. G-39, p. 79-85.

________, 1965, Stratigraphy, structure and sedimentary patterns in the Upper Devonian of Bradford County, Pennsylvania: Pa. Geol. Survey Gen. Geol. Rept. G54, 78 p.

Woodrow, D. L., and Nugent, R.C., 1963, Facies and the Rhinestreet Formation in south-central New York, in Coates, D.R., ed., Geology of south-central New York: N.Y. State Geol. Assoc. Guidebook, 35th Annual Meeting, Binghamton, p. 59-86.

Woodrow, D.L., Fletcher, F.W., and Ahrnsbrak, W.F., 1973, Paleogeography and paleoclimate of the depositional sites of the Devonian Catskill and Old Red facies: Geol. Soc. America Bull., v. 84, p. 3051-3064.

Wright, N.A., 1973, Subsurface Tully Limestone, New York and northern Pennsylvania: New York State Mus. and Sci. Serv. Map and Chart Series no. 14.

ROAD LOG FOR WEST FALLS GROUP DELTAIC ENVIRONMENTS

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Glen G. Bartle Drive, main entrance SUNY Binghamton; turn right onto Route 434 east.
2.7	2.7	Bear right, Pennsylvania Avenue exit.
2.8	0.1	Stop sign; turn right onto Pennsylvania Avenue.
3.9	1.1	Gillen Road intersection; pull off on right side of Pennsylvania Avenue (unpaved parking area); walk south to road cut on Pennsylvania Avenue. STOP 1.

STOP 1. DISTAL PLATFORM (Field locality 4).

The relatively thin beds of fine-grained sandstone interbedded with gray shale are characteristic of middle- and distal-platform environments. Sandstone beds of approximately one foot in thickness have basal coquinites 1-2 inches thick; thicker sandstone beds have basal coquinites up to one foot thick. The coquinites are typically composed of disarticulated and articulated brachiopod shells with significant numbers of crinoid columnals. Some sandstone beds are graded coarse-to-fine. The shales are generally not very fossiliferous, but localized areas of bedding planes can produce quite a few well-preserved brachiopods and molluscs. A zone of large pillow structures is distinctly visible near the top of the exposure. The zone is laterally persistant for the length of the exposure. These pillows (denoted as type I) are composed of fine-grained sandstone; the distorted matrix of shale in which they are situated suggests that these structures formed as a result of vertical foundering. Smaller, solitary pillows are present at the base of the exposure near the parking area. These are denoted as type II pillows and are probably formed in a similar manner as type I pillows.

This portion of the platform was well-removed from the effects of rivers and streams. Sand which reached this area was supplied in the form of "sheets" from distributaries, which had merged with each other closer to the shoreline. Grading in the sandstones as well as the presence of basal coquinites indicates a "proximal turbidite" origin.

		Continue south on Pennsylvania Avenue; this road is called Hawleyton Road to the south.
8.9	5.0	Church on right; turn left (east) onto Saddlemeir Road.
9.3	0.4	Turn right onto Brady Hill Road.
11.5	2.2	Pull off on right side of road; walk to outcrop on right side of road. STOP 2.

STOP 2. DARK MUD AND PROXIMAL PLATFORM ENVIRONMENTS (Field locality 7).

The dark-gray and rust-brown mudstones and shales of the Roricks Glen Member are exposed in the basal portion of this exposure. Outcrops of the Roricks Glen on the delta platform are all about 20 feet thick and are composed predominately of mudstone with smaller amounts of shale. Thin-bedded lenses of fine-grained sandstone and siltstone are present in the dark-shale member; fossils are few in number. Flagstones and sandstone lenses near the top of the exposure indicate a return to normal deltaic conditions. The large block of cross-bedded sandstone at the very top of the bank (although slightly dislodged) is of channel origin in what is inferred to be the subaqueous delta plain. Cross-bedded sandstone is present in the form of scattered blocks on the hillside above the roadside exposure. The Roricks Glen will be seen again in a similar environmental association later in the field trip.

		Continue east on Brady Hill Road.
11.8	0.3	Turn left onto Brinkman Road.
13.0	1.2	Turn right onto Conklin Forks Road (unmarked).
16.2	3.2	View of Susquehanna River Valley.
17.3	1.1	Interstate 81 underpass; continue straight. This road becomes Cedarhurst Road which bends to the left and continues up the hill.

17.7	0.4	Brink Road intersection; bear right and continue on Cedarhurst Road.
19.7	2.0	Pull off on right side of road and enter roadside quarry. STOP 3.

STOP 3. SUBAQUEOUS DELTA PLAIN (Field locality 18).

The flagstone deposits in the quarry are typical of the subaqueous delta-plain environment. The large-scale crossbedding in the south wall of the quarry is evidence that this portion of the delta plain is gradational with a distributary-mouth bar within the delta platform. This interpretation is supported by a nearby shale pit which exposes normal delta-platform deposits. Current and wave ripples, low-angle cross-bedding and parting lineations are common sedimentary structures at this locality. Orientations of the structures indicates a southwesterly average current direction. With the exception of oriented plant fragments on a few bedding planes, fossils are rare.

		Continue north on Cedarhurst Road.
20.1	0.4	Turn left onto Zimmer Road (unmarked).
21.8	1.7	Turn left onto Trim Street.
22.3	0.5	Turn right onto Route 11 (northbound).
24.3	2.0	Bear right onto Crescent Drive (signs to Route 81 and Route 17).
24.5	0.2	Turn left onto Francis Street.
24.7	0.2	Turn right onto Court Street (unmarked); continue straight (this road becomes Route 17 east).
36.9	12.2	Exit 80 (Damascus, Lanesboro); bear right onto off ramp.
37.2	0.3	Turn left onto State Line Road; continue 0.1 miles, pull off on right side of road just before Route 17 underpass. Walk uphill on road which parallels Route 17 to road cut on right side of road. STOP 4.

STOP 4. PROXIMAL PLATFORM (Field locality 42).

The numerous lenses of sandstone exposed here are subaqueous extensions of distributaries which flowed westward from the subaqueous delta plain. Near the base of the exposure on this road is a zone of organic-rich sandstone that is interpreted to be the result of a rapid regressive (storm) event which interrupted normal progradation of the deltaic environments. A thin stringer of quartz-pebble conglomerate is associated with this sand deposit. This conglomeritic horizon has been found to exist elsewhere in the study area to the west. In addition to a variety of ripple marks which can be observed on the terraces in the upper portion of the outcrop, a lens of large pillow structures and a variety of crossbedding are among the more obvious sedimentary structures.

		Return to entrance ramp to Route 17 east and proceed on eastbound lane.
39.9	2.7	Exit 81 (East Bosket Road); bear right onto off ramp and pull over on right side of ramp. STOP 5.

STOP 5. PROXIMAL PLATFORM AND SUBAQUEOUS DELTA PLAIN (Field locality 49).

The interbedded flagstones, cross-bedded sandstones, and shales in this exposure illustrate the variety of lithologies which coexist at the margin of the subaqueous delta plain. The beds and lenses of sandstone are small distributary-mouth bars formed as a result of the reworking of sand at the fronts of streams. The relatively dark shale was deposited behind the bars in restricted waters of small bays. Cross-bedded, organic-rich sandstone lenses are the remains of distributaries which migrated laterally in this region. The bar deposits gradually give way to subaqueous delta-plain channel deposits which are composed of more poorly sorted, cross-bedded sandstone. Higher up in the exposure is a 10-foot-thick bed of dark shale and mudstone which is correlative with the Roricks Glen Member. This fine-grained deposit grades upwards into drab-colored overbank deposits of the subaerial delta plain.

		Continue up ramp to top of hill.
40.3	0.4	Turn left onto East Bosket Road (overpass).
40.4	0.1	Turn left onto Old Route 17 (westbound).
42.5	2.1	Hard right turn onto unmarked road; sign to Forest Hill Park.
43.8	1.3	Bear left at "Y" intersection.
44.8	1.0	Top of hill; pull off on right side of road; walk up dirt road to the right up to the quarry. STOP 6.

STOP 6. SUBAQUEOUS AND SUBAERIAL DELTA PLAIN (Field locality 46).

The extensive exposure in this quarry (formally called the Ostrander quarry) displays a variety of flagstone and cross-bedded sandstone of stream origin within the delta plain. Ripple marks and scour marks are very common on the surface of terraces in the quarry. Burrowed and mud-cracked mudstone forms the floor on the second terrace (west face of mountain). These and similar deposits in the quarry are of floodplain origin. Red-orange, conglomeritic debris scattered around the area are levee deposits which can be seen in place as lenses associated with channel sandstone in the quarry walls. A thin red bed is visible about two thirds up the sheer face on the western wall. Just above the red bed (one of only a few in the study area) is a dark-shale bed that is correlative with the Roricks Glen Member. A thin coquinite at the base of the overlying sandstone bed contains shell material left as a lag deposit resulting from winnowing of the very top of the Roricks Glen.

		Return to Old Route 17.
47.1	2.3	Turn right onto Old Route 17.
49.6	2.5	Bridge over Susquehanna River.
49.8	0.2	Flashing red light; turn right onto Route 79 (northbound); Village of Windsor.
53.3	3.5	Sign to Nathanial Cole Park; turn left onto Ouaquaga Road.
53.9	0.6	Turn right onto unmarked dirt road.
55.1	1.2	Yield sign; continue straight (road becomes paved).
55.7	0.6	Stop sign, turn left onto Farm-to-Market Road (unmarked), sign for Nathanial Cole Park.
57.1	1.4	Turn right onto dead-end road.
57.2	0.1	Pull off on right side of road; walk up dirt road to the left to quarry. STOP 7.

STOP 7. DISTAL PLATFORM (Field locality 35).

The conspicuous zone of extremely large pillow structures in the lower section of the quarry is a feature which is characteristic of the distal platform environment. These pillows are referred to as type III and are interpreted to have formed due to repeated foundering of relatively coarse platform sediments which were continually supplied to submarine topographic lows by the reworking effects of waves and currents at the edge of the platform. The mudstone and siltstone matrix of the pillows contains a random distribution of small fossil material consisting mostly of crinoid columnals. The matrix as a whole displays a weak cross lamination in places. The number of lenses and thin beds of sandstones increases upsection indicating the westward progradation of the shoreward environments. Basal coquinites are common in these sandstones. (The top of this section, which is exposed along Farm-to-Market Road at the top of the hill, contains a horizon of dark shale within the Dunn Hill Member).

		Return to Farm-to-Market Road.
57.3	0.1	Turn right onto Farm-to-Market Road.
60.4	3.1	Turn right onto Sanitaria Springs Road.
60.8	0.4	Church on left; turn left onto Old State Road.
65.1	4.3	Intersection with Stratmill Road; continue straight on Old State Road.
68.2	3.1	Pull off on right side of road just after "Fallen Rock Zone" sign. STOP 8.

STOP 8. DISTAL PLATFORM AND DARK MUD ENVIRONMENTS (Field locality 11).

Once again, the presence of extremely large (type III) pillow structures indicates the distal platform environment. Here, the pillows are resting upon and within the Dunn Hill Member. The pillows are compositionally similar to those at STOP 7. Currents on the delta platform were active during the deposition of the Dunn Hill as evidenced by these relatively "coarse-grained" structures as well as lenses of sandstone which display crossbedding. Although not shown here, deposits of fossiliferous, cross-bedded "delta-front sands" can also be fairly well developed only a few feet above a given dark-shale member. Thus, a normal deltaic environments rapidly redeveloped after transgression.

		Continue on Old State Road (downhill).
69.0	0.8	Turn left onto Route 7 (southbound).
69.7	0.7	Bear right onto entrance ramp for Route 17 (Elmira) and Route 81 (Syracuse).
70.3	0.6	Bear left at "Y" on Route 17 West (Elmira).
73.8	3.5	Exit 70 S; bear right onto exit ramp; signs for Route 201 S; Johnson City.
75.1	1.3	Traffic circle; bear right onto Route 201 (sign for SUNY).
75.8	0.7	Follow signs for Route 434 E and SUNY.
76.4	0.6	Turn right; main entrance, SUNY Binghamton. END OF TRIP.