THE MIDDLE AND UPPER DEVONIAN CLASTIC WEDGE IN NORTHEASTERN PENNSYLVANIA

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INTRODUCTION

Throughout most of the Paleozoic, much of what presently constitutes the eastern half of North America was part of an inland sea which intermittently received clastic sediment from an eastern source area. The Appalachian basin was the central focus of this sedimentation.

The largest integrated wedge of clastic sediment in this basin was deposited by the Catskill delta system during the Middle and Late Devonian. The purpose of this paper is to present an overview of Late Devonian sedimentation, with particular reference to Pennsylvania. The purpose of the field trip is to examine some of the rocks from which interpretations about the Catskill delta system are made. The information presented here derives from the literature as well as my own work. The term "delta system" as used here refers to multiple contiguous deltas operating in the same sedimentary basin at approximately the same time. The Catskill delta system is also a tectonic delta complex in the sense defined by Friedman and Johnson (1966, p. 185-186) for New York State and used by Humphreys and Friedman (1975, p. 369-370) in Pennsylvania: "a deltaic complex built into a marine basin contiguous to an active mountain front and dominated by orogenic sandstone derived from the nearby tectonic highland."

GEOLOGIC SETTING

Source Area

Sedimentary rocks of Paleozoic age occur at the surface or in the subsurface throughout the length of the eastern part of North America. Exposures of rock comprising the total sequence occur in the Appalachian Mountains and extend from central New York to Kentucky. The Cambrian and Ordovician rocks are dominantly carbonates although a moderate quantity of Lower Cambrian clastics occur. The source for these sediments appears to have been to the west. The remainder of the Paleozoic rocks are dominantly clastics and paleocurrent, isopach, and lithofacies data indicate derivation from an eastern source area.

The dramatic change from a western to an eastern source area and the apparent absence of an eastern source has only recently been satisfactorily resolved by the development of plate-tectonic models for the eastern margin of North America (Bird and Dewey, 1970; Schenk, 1971; Dietz, 1972; Hatcher, 1972; Dewey and Kidd, 1974; Rankin, 1975; and Van Houten, 1976). The general plate-tectonic model for the eastern North American continental margin is shown in Figure 1 and a more detailed model for the Devonian is shown in Figure 2.

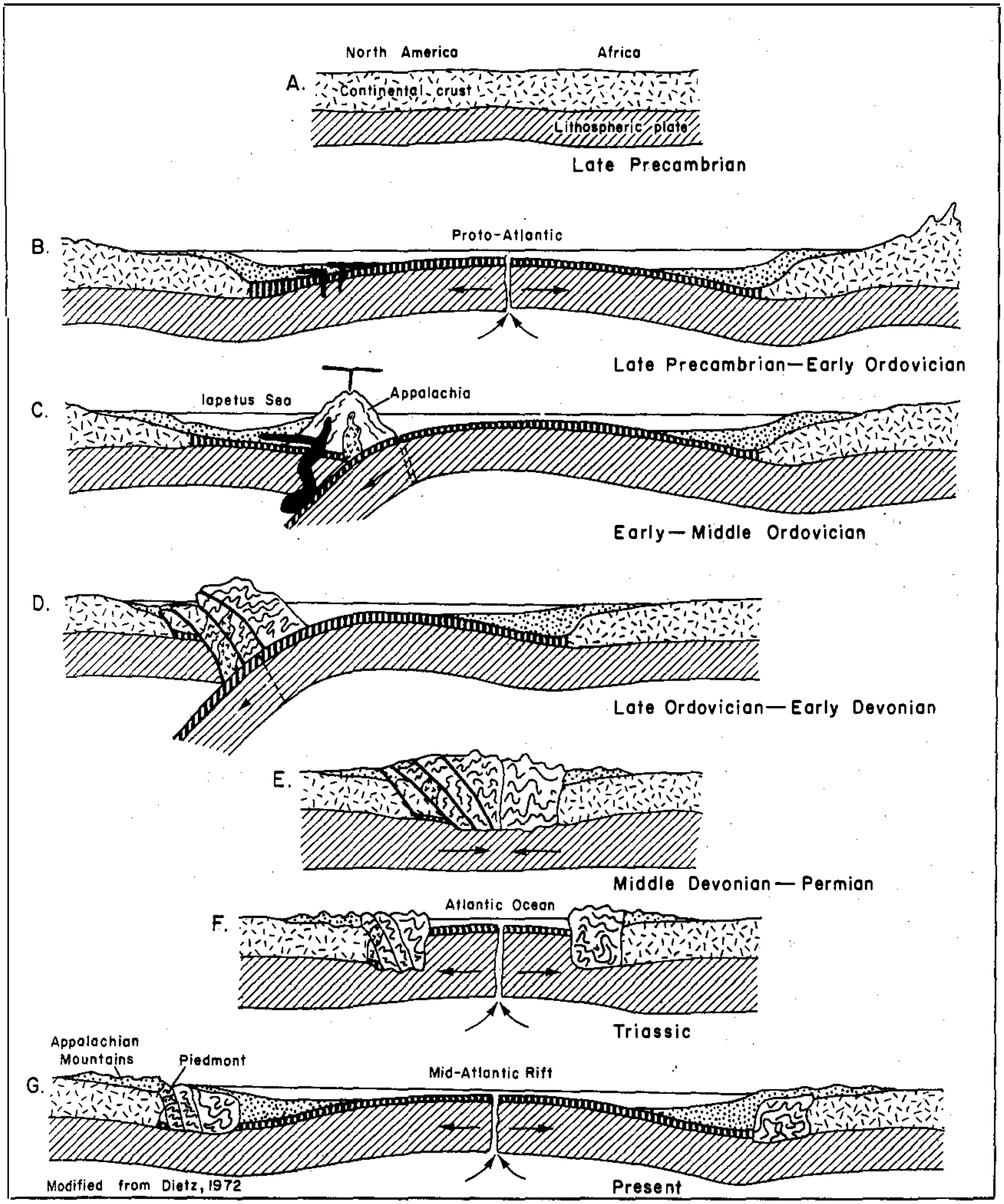

Figure 1. Diagrammatic model of the plate tectonic history of the central Appalachian Basin.

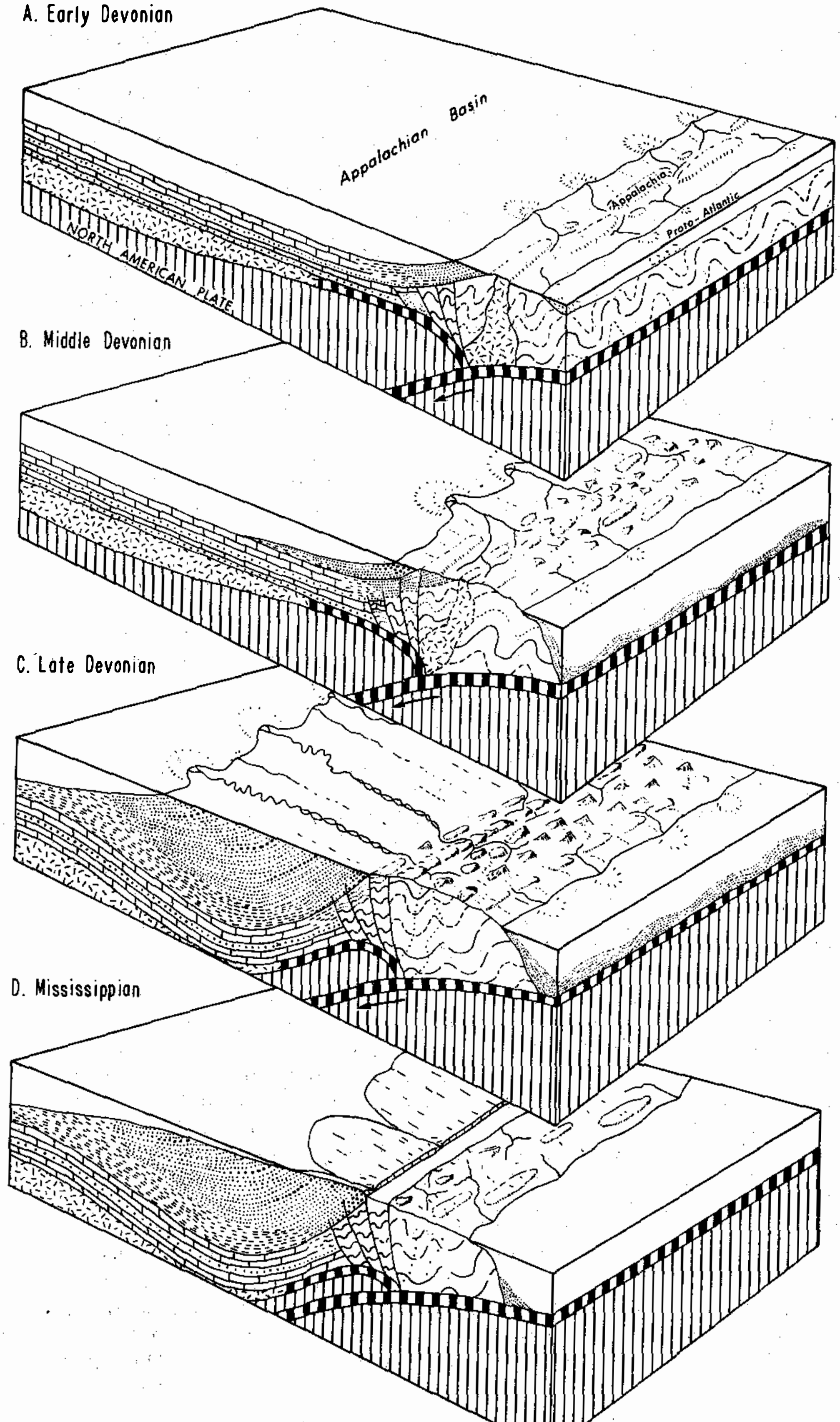

Figure 2. Diagrammatic model of Devonian history of the central Appalachian basin.

During the Late Precambrian through the Early Ordovician the eastern margin of the North American continent was a miogeocline in which some clastics and much carbonate were deposited (Fig. 1B). Sediment entered the basin from the west. Sometime in the Ordovician, North American, South American, and African plate divergence stopped and convergence commenced. Convergence continued following the formation of an island-arc system during the Ordovician (Fig. 1B), and a continental land mass, Appalachia, was developed by Middle Devonian time (Fig. 1E). Appalachia comprised uplifted and metamorphosed Precambrian(?), Cambrian, and Lower Ordovician miogeoclinal sediments as well as volcanics and instrusives. This composition has been confirmed by identification of coarse clasts (Barrell, 1914; Mencher, 1939; Sevon, 1969; Perry and deWitt, 1977; Sevon and others, 1978; Seaman, 1979; and Kirby, 1981) and thin-section petrography (Mencher, 1939; Lucier, 1966; Sulenski, 1969; Kramers and Friedman, 1971; Humphreys and Friedman, 1975; and Sevon, unpublished data) of Catskill rocks. These studies indicate a mixed terrain of low-grade metamorphic and sedimentary rocks and a general absence of feldspar. Quartzites are particularly common as coarse clasts and sericite-chlorite-rich rock fragments are common in thin section.

Estimates of the position of Appalachia during the Devonian and Mississippian range from 40 km (Lucier, 1966) to 204 km (Pelletier, 1958) east of the present outcrop in Pennsylvania and New York. Its actual position is not known, but estimates of 50 to 100 km seem reasonable.

Appalachian Basin

After the development of Appalachia, the eastern part of North America became an elongate inland sea, the Appalachian basin, with a central focus of sediment accumulation in New York and Pennsylvania (Fig. 3; Colton, 1970; Cook and Bally, 1975) and farther east. The large quantities of sediment contributed by Appalachia caused marked subsidence in the eastern part of the basin (Fig. 2C), and presumably even greater thicknesses of Middle and Upper Devonian sediment, now lost to erosion, were deposited east of the present outcrop margin.

Local tectonic activity contemporaneous with sedimentation in the Appalachian basin has been identified primarily in the present Appalachian Plateau part of the former depositional basin, but also occurred farther east. The presence of deep-seated faults along which recurrent movement occurred during Paleozoic sedimentation is discussed by Bradley and Pepper (1938), Woodward (1963), Kelley and others (1970), Harris (1975), Wagner (1976), and Root (unpublished, Pennsylvania Geological Survey, Harrisburg). Growth of folds and their effect on coal deposition in western Pennsylvania is discussed by Kent and Gomez (1971), Williams and Bragonier (1974), and McCulloch and others (1975). Growth of folds during Devonian sedimentation in eastern Pennsylvania and New York has been suggested by Fletcher (1964) and Fletcher and Woodrow (1970), and in north-central Pennsylvania by Woodrow (1968). The Wyoming-Lackawanna Basin in northeastern Pennsylvania was tectonically active during the Mississippian and may have been active during the Late Devonian (Woodrow and Fletcher, 1967; Glaeser, 1974).

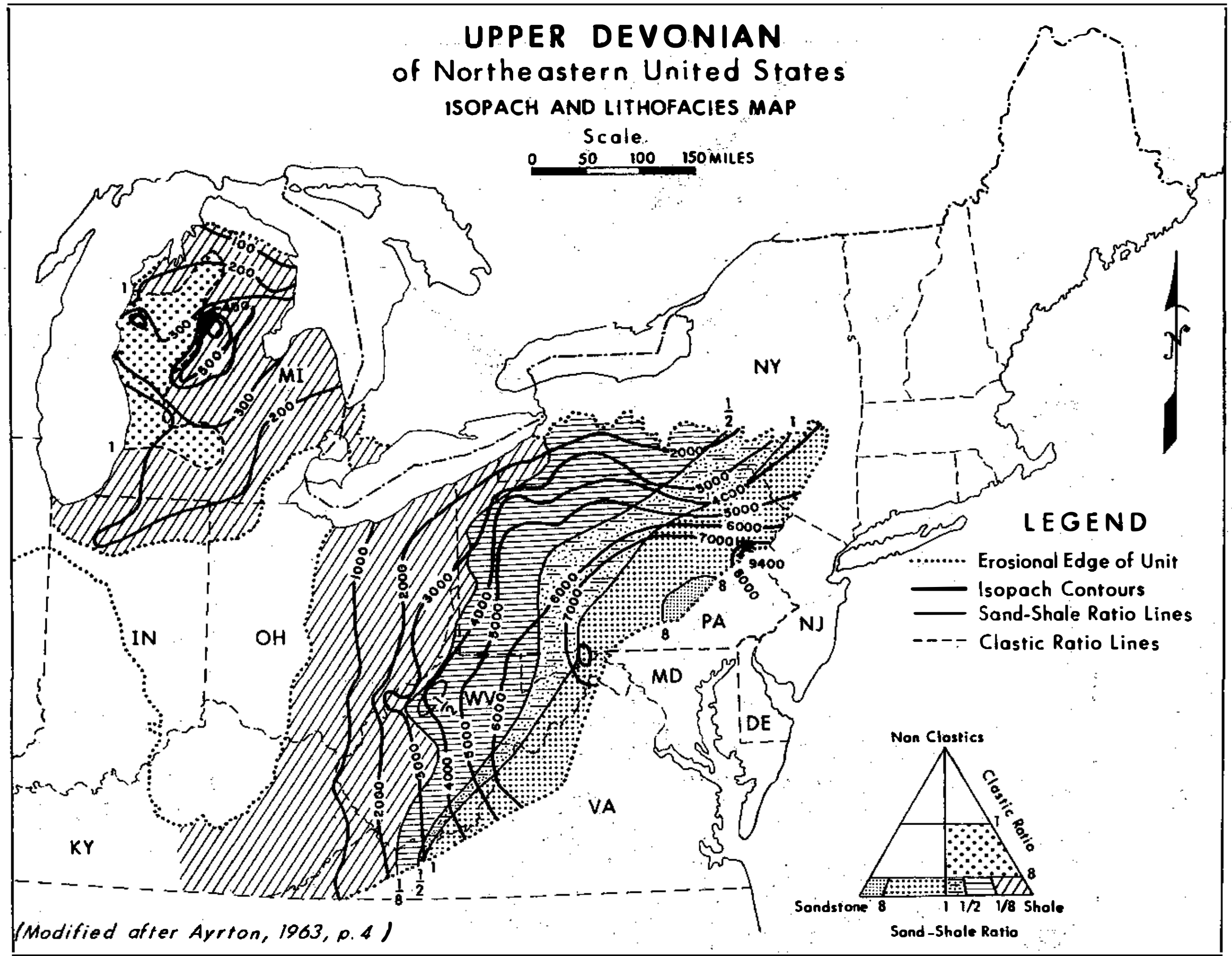

Figure 3. Isopach and lithofacies map for the Upper Devonian of northeastern United States.

Paleogeography and Climate

Available paleoclimatic data combined with some paleomagnetic data allows reconstruction of Devonian world paleogeography (Woodrow and others, 1973; Heckel and Witzke, 1979; Ziegler and others, 1979; and Bambach and others, 1980) and a reconstruction for the Late Devonian is presented in Figure 4. In this reconstruction, the Catskill deltaic system would have developed in an equatorial belt affected by easterly

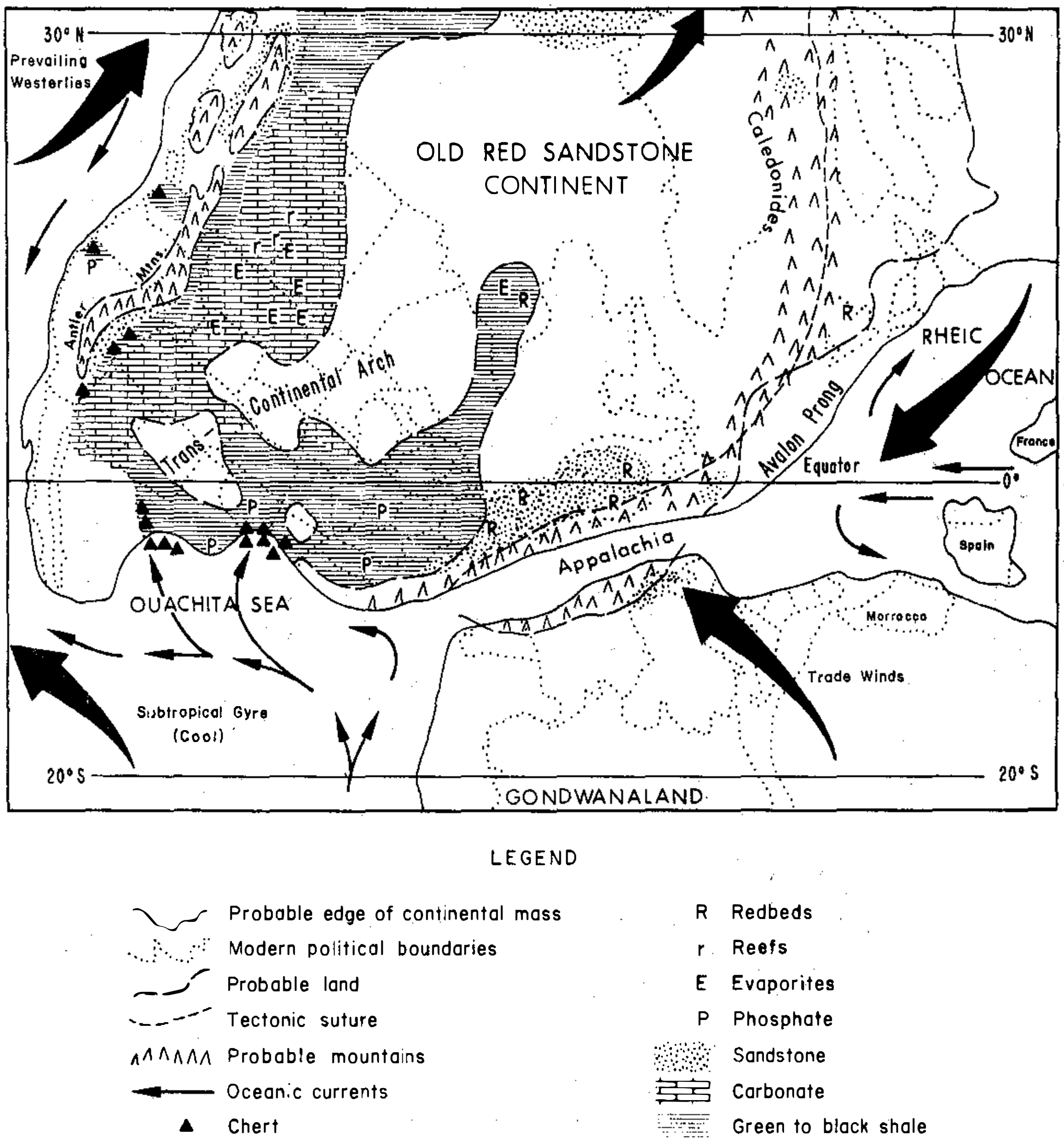

Figure 4. Late Devonian paleogeography and lithofacies for North America. Diagram simplified and modified from Ettensohn and Barron (1980, p. 18).

trade winds. Because of the wind barrier created by Appalachia, the Appalachian basin would have existed in a rain shadow. Seasonal aridity and warm-to-hot temperatures prevailed in the basin and presumably in the western part of Appalachia. Vegetation was sparse to lush on the depositional plain, but its seasonal fluctuations are not known. The extent to which vegetation may have existed in Appalachia is likewise not known.

Modern Analogue

The spatial and tectonic relationship between the New Guinea island arc and the Australian craton (Fig. 5) may be the modern analogue for Appalachia and the North American craton during much of the Paleozoic (Dott and Batten, 1971, p. 295). The equatorial position is not the same in this model as during the Late Devonian, but wind circulation appears comparable and climatic conditions may be similar.

THE CATSKILL DELTAIC SYSTEM

Introduction

Sediments deposited in the Appalachian basin during the Late Devonian are often attributed to the "Catskill delta" with the implication that a single delta of unspecified nature was responsible for all of the sediments. The real situation was well stated by Barrell in 1913 (p. 466):

> "The uniformity in character of the delta from northeast to southwest, its development marginal to the uplands, and somewhat rapid gradation from gravel to sand and clay on leaving the mountains suggests the presence of a number of comparatively short streams which build flat coalescing fans rather than the debouchement of one or two great continental rivers."

Elaboration of this concept of Barrell is the object of the remainder of this paper.

Sediment-Input Systems

Willard (1934) was the first to attempt to define the number and position of the rivers which brought sediment to the Appalachian basin. He named and sited 3 delta lobes in Pennsylvania: Fulton (south central), Snyder (central), and Wyoming (northeast). These lobes defined the hypothetical position of the early Chemung shoreline (the base of Chemung is marked by the first appearance of the brachiopod, *Spirifer disjunctus*). Caster (1938) illustrated the position of 3 arcuate deltas in northwestern Pennsylvania, but says nothing about them. I recently identified the position of the axes of 8 sediment-input systems for the Upper Devonian Appalachian basin (Fig. 6; Sevon and others, 1978; Sevon, 1979a). Locations of axes of sediment-input systems in New York are derived from Burtner (1964) and McCave (1968), and those in Virginia-West Virginia from Dennison (1970) and Dennison and deWitt (1972).

Facies Progradation

At any particular instant of time during development of the Catskill clastic wedge, a variety of specific subaqueous and subaerial environments of deposition coexisted. As progradation and subsidence occurred, one

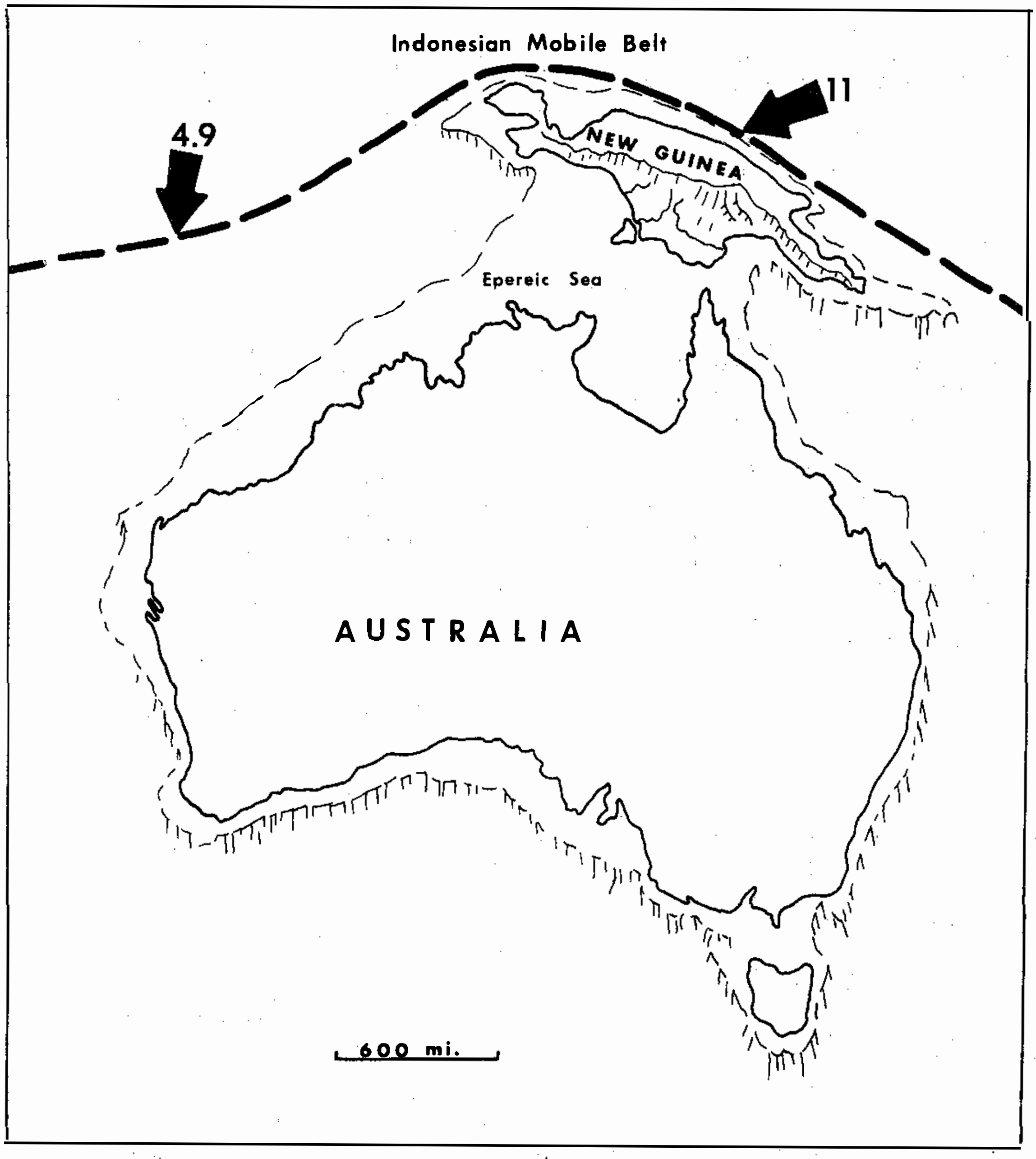

Figure 5. New Guinea and Australia - a modern analogue for Appalachia and the North American craton (Dott and Batten, 1971, p. 295). Direction of tectonic compression indicated by arrows and rates given in cm/year (LePichon, 1968).

depositional environment was succeeded by another and the resulting vertical sequence of sediments exemplified Walther's (1884) law of facies: under the controls of transgression or regression, facies which coexisted laterally will be preserved vertically in stratigraphic sequence. Generally the succession of environments was an orderly progression from farthest offshore to farthest onshore, and the vertical sequence preserved today is, as a whole, one of upward coarsening. These lateral and vertical relationships are shown in Figure 7.

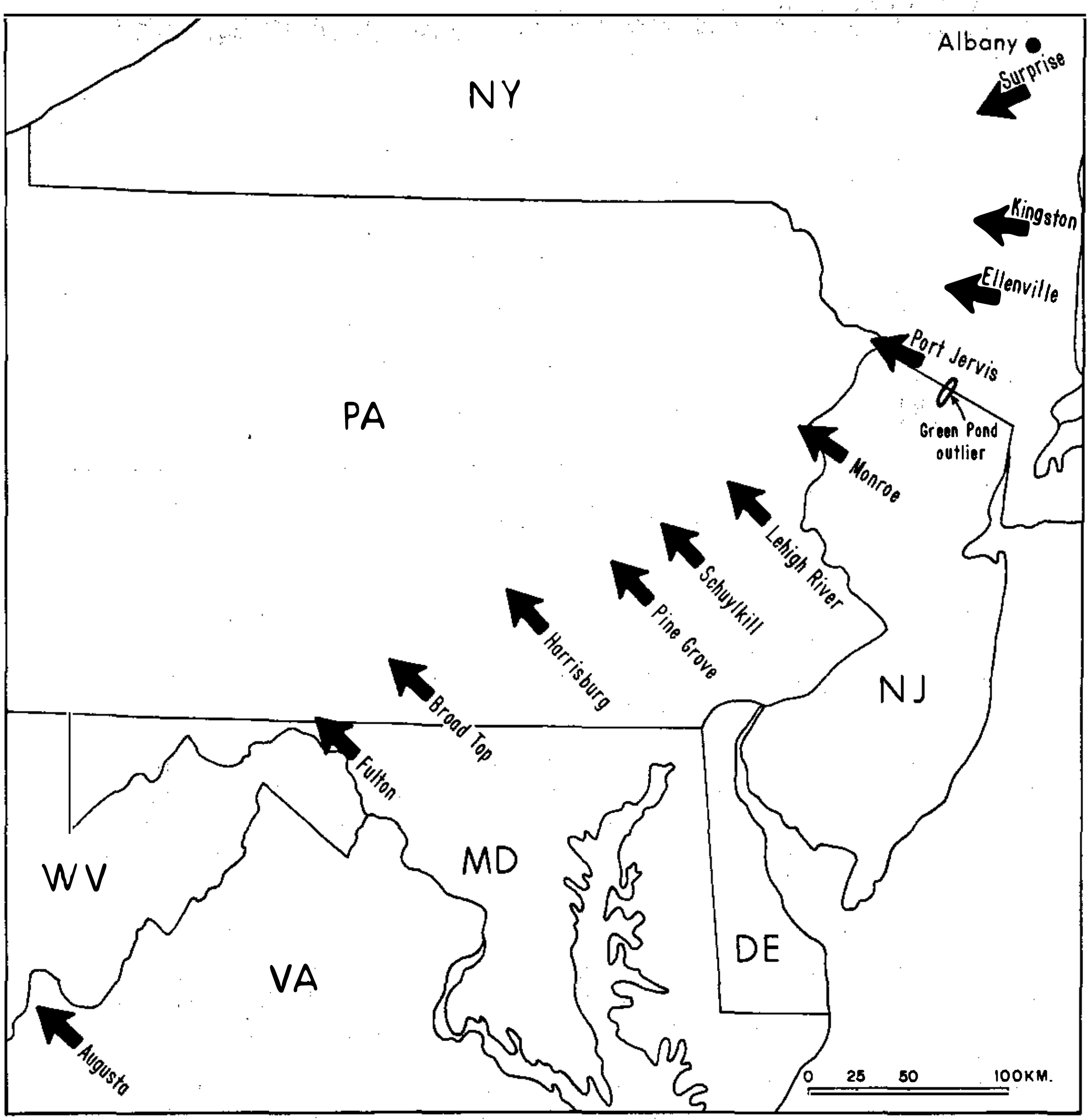

Figure 6. Interpreted axes of sediment-input systems entering the central Appalachian basin during the Devonian.

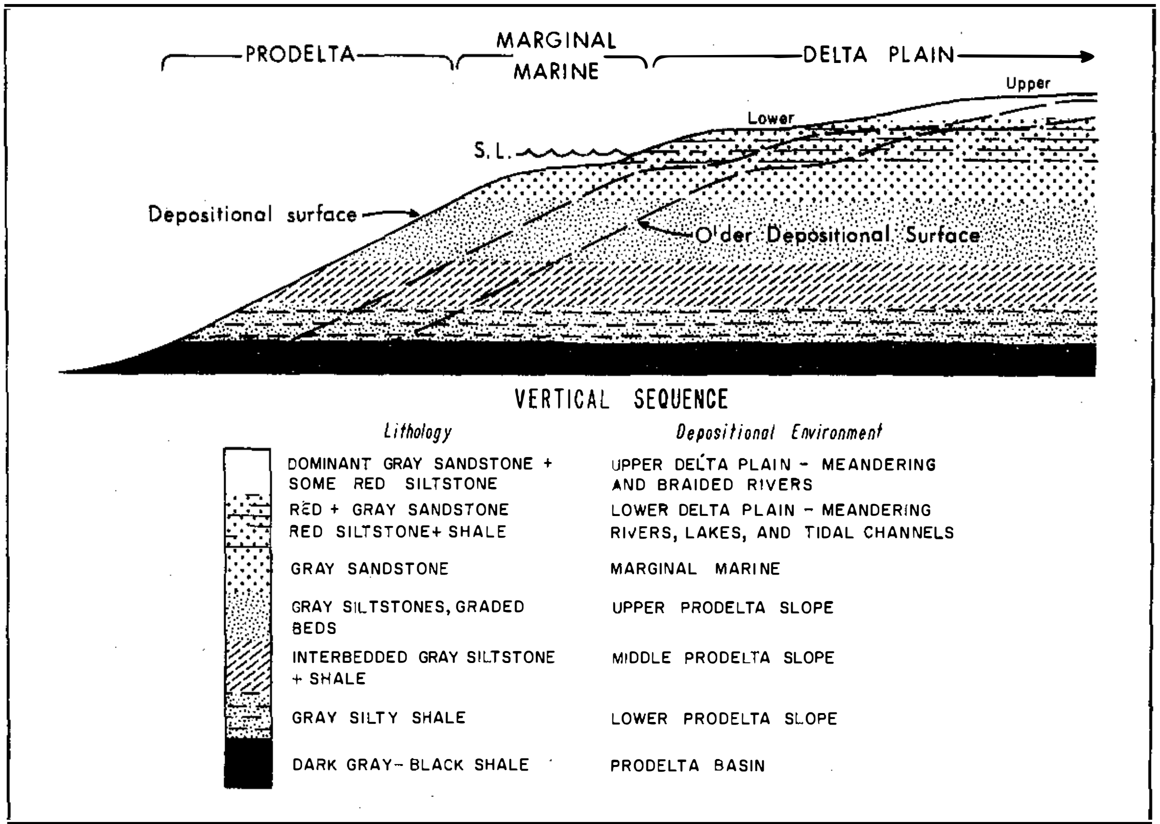

Figure 7. Idealized Middle and Late Devonian Catskill delta progradation model. Modified from Glaeser (1979, p. 347).

Although an orderly progression of rocks representing successive depositional environments occurs uninterrupted in some places, interruptions of orderly progression are common and represented by repetitive sequences. Examples of such sequences are:

1. The Irish Valley "motifs" (repeated facies sequences) in the Irish Valley Member of the Catskill Formation, east-central Pennsylvania (Walker and Harms, 1971; Walker, 1972) which comprise numerous repeated sequences of gray-to-green marine sandstone and/or shale passing upwards into non-marine red mudstone.

2. The Walcksville, Beaverdam Run, and Long Run Members of the Catskill Formation in northeastern Pennsylvania (Epstein and others, 1974; Berg, 1975; Berg and others, 1977) in which the deposits of the Beaverdam Run represent a major marine transgression onto the lower delta plain.

3. Changes in depositional environment and resulting rocks are correlated with major basin-wide sea-level variations by Sutton (1963), Sutton and others (1970), and Dennison and Head (1975). Sutton recognizes regionally correlative black to dark-gray shales which he interprets to

be the deposits representing extensive marine transgression onto the Catskill clastic wedge. Dennison and Head recognize regional lateral migration of terrigenous clastic environments and near-shore carbonate environments in response to sea-level change. Ettensohn and Barron (1981) present a model for the cyclic alternation of black shales and coarser clastics in the Catskill clastic wedge.

4. Glaeser (1974) recognized both regular environmental succession and numerous interruptions in sequence in rocks of the Catskill Formation preserved in the subsurface of northeastern Pennsylvania.

Delta Model

Although the term, delta, has been applied many times to the origin of the progradational deposits of the Catskill delta, a specific model has never been established. In fact, both Allen and Friend (1968) and Walker and Harms (1971) rejected the concept of deltaic deposition. Allen and Friend suggested that Catskill sedimentation occurred in a vast alluvial coastal plain characterized by barrier islands, tidal flats, and lagoons at its western margin, and by meandering and braided streams in its eastern parts. Walker and Harms argued that, at least in south-central Pennsylvania, deposition occurred along a quiet, muddy, prograding coastline which received sediment via longshore currents from a distant source.

In reality, however, the overall progradational character of the Middle and Upper Devonian rocks is consistent with the definition of a delta given by Ferm (1970, p. 247-248):

> "Recent marine deltas form when sediments, carried by rivers into relatively large bodies of open water, accumulate at the river mouth until the surface of the sediment pile reaches sea level. The emergent portion comprises the subaerial expression of the delta.... Delta growth continues as sediment-laden streams pass over the emergent surfaces and deposit sand, silt, and clay over the frontal delta slope. As this process of building new land at the delta margin continues, the delta is said to prograde, and the product of progradation can be thought of as the typical delta sequence."

The formation of the Catskill clastic wedge fits this definition of a delta, but no single delta model can be applied to the whole because the numerous sediment-input systems varied in several ways which affected the manner in which each interfaced with the Appalachian basin:

1. The intensity and timing of orogeny was laterally variable resulting in differential uplift in Appalachia and differential sediment supply to the basin.

2. The length of each of the numerous sediment-input rivers varied through time in relation to itself and the other rivers. This variation

resulted in differences in gradient, grain size of the sediment transported, and, possibly, sediment quantity. These differences in turn caused variations in the character of the depositional environments associated with each stream.

3. The interaction between adjacent sediment-input systems was variable.

The result of the large potential for variation during deposition of the Catskill clastic wedge is that the rocks comprising that wedge are extremely variable in both the vertical and horizontal dimensions. Thus, the interpretations of both Allen and Friend (1968) and Walker and Harms (1971) are correct for specific rocks in specific places, but those interpretations do not necessarily apply to other rocks in other places.

Friedman and Johnson (1966) pointed out that the Catskill deltaic complex in New York State differs considerably from the modern Mississippi River delta (a frequently used model at that time), but is deltaic in nature. Manspeizer (1969) outlined the physical character and dimensions of a single delta complex in south-central New York and north-central Pennsylvania, but, unfortunately, he did not apply a specific model to the rocks nor did he publish the details of the study. The only satisfactory fitting of a delta model to Devonian rocks in Pennsylvania is the work of Kaiser (1972) who established the suitability of the Rhone River delta model for the Middle Devonian Montebello Member of the Mahantango Formation in south central Pennsylvania. Much work remains to be done before even a general model of the whole progradational complex can be generated.

Depositional Environments

Rocks of the Middle and Upper Devonian clastic wedge have long been attributed to sediment deposition in both marine and non-marine environments. However, it has only been in the last 25 years that specific depositional environments have been recognized and described in detail for these rocks. Table 1 presents a summary of the various environments which have been described for the clastic wedge. There is adequate literature available describing the characteristics of these environments and they are not elaborated upon here. Figure 7 illustrates the lateral and vertical position of the broad categories in which more specific environments occur.

Demise of the Catskill Deltaic System

The rocks in Pennsylvania representing latest Devonian and earliest Mississippian time indicate that the following events occurred: (1) sedimentation on the Catskill alluvial plain stopped, (2) erosion occurred in areas nearest to Appalachia and was greatest at the centers of the axes of sediment-input systems, (3) marine waters transgressed onto the alluvial plain (Dennison and Head, 1975), (4) polymictic diamictite, a unique lithology in the Paleozoic rocks of Pennsylvania, was deposited in the areas of greatest erosion (Sevon, 1979b) and (5) the Wyoming-Lackawanna basin actively subsided. The following hypothesis is presented as an explanation.

Subaerial sedimentation at the end of the Devonian was remarkably uniform throughout the Appalachian basin and comprised mainly deposition by meandering streams. During the period when the northwestern South American plate pulled away from the northern Appalachian plate (Dewey and Kidd, 1974), rifting occurred in either Appalachia or the most proximal part of the Catskill alluvial plain. This rifting beheaded the sediment-input rivers and dammed waters draining Appalachia. The cessation of sediment-input caused by the rifting resulted in a sedimentation-subsidence imbalance and marine transgression occurred in the distal part of the alluvial plain. The dammed waters eventually crested the rift dam and began downcutting of the proximal alluvial plain. Erosion may have been amplified in northeastern Pennsylvania because of subsidence in the Wyoming-Lackawanna basin. Transgression apparently encroached far enough onto the alluvial plain to drown some of the newly eroded valleys (Fig. 2D).

At this point one or more flood events of enormous proportions flushed a heterogeneous mixture of debris from Appalachia and resulted in deposition of the polymictic diamictite in the drowned valleys. Regression occurred and fluvial deposition was eventually restored throughout most of the basin.

The diverse lithologies present in the polymictic diamictite provide the final and most intimate information about the composition of Appalachia. Thereafter, throughout the remainder of the Paleozoic, sediment brought into the Appalachian basin from the east was derived by erosion of the most proximal parts of the former alluvial plain.

Paleontology

The Appalachian basin had abundant life during the Middle and Late Devonian. Marine invertebrates flourished wherever environmental niches were available. Fish were apparently abundant in the rivers flowing from Appalachia, and lungfish survived the dry seasons by burrowing into fluvial muds. A variety of air-breathing creatures left abundant tracks and trails in the alluvial muds. Land plants were at least seasonally abundant on the delta plain, but their presence or absence in Appalachia is conjectural.

The fossil remnants and fossil traces of the various forms of life vary from abundant in rocks of marine origin to absent in many rocks of non-marine origin. Good entries into the literature of the marine faunas associated with the clastic wedge are: McGhee and Sutton, 1981; Thayer, 1974; Bowen and others, 1974; Willard and others, 1939; and numerous papers in House and others, 1979. The distribution of trace fossils in the Catskill in New York was recently reviewed by Miller (1979). Berg (1977) discusses bivalve burrow structures and Woodrow (1968) documents aestivation burrows of Devonian lungfish. The world of Devonian plants can be entered through papers by Banks (1966) and Chaloner and Sheerin (1979).

Stratigraphy

The Pennsylvania Geological Survey maps rock-stratigraphic units. These map units represent, for the most part, reasonably homogenous lithologic entities with more or less distinct boundaries. Although genesis

Table 1. Environments of deposition identified in rocks of the Middle and Upper Devonian Catskill clastic wedge.

Environment Source	Geographic Area	Rock Unit
Alluvial fan		
Sulenski, 1969	GPO*	Skunnemunk Fm.
Kirby, 1981	GPO	Skunnemunk Fm.
Braided rivers		
Lucier, 1966	SE NY	Kiskatom-Kaaterskill Fms.
Buttner, 1968	SE NY	Genesee Gp.
Friedman, 1972	SE NY	Catskill Fm.
Glaeser, 1974	NE PA	Sawmill Run
Epstein & others, 1974	NE PA	Berry Run-Clarks Ferry Mbrs.
Humphreys & Friedman, 1975	NC PA	Catskill Fm.
Buttner, 1977	SE NY	Genesee Gp.
Sevon & others, 1978	NE PA	Duncannon Mbr.
Rahmanian, 1979	C PA	Duncannon Mbr.
Kirby, 1981	GPO	Skunnemunk Fm.
Meandering rivers		
Allen, 1965	NE PA	Catskill Fm.
Woodrow & Fletcher, 1967	SE NY-NE PA	Catskill Fm.
McCave, 1968	SE NY	Moscow-Ludlowville Fms.
Johnson & Friedman, 1969	SE NY	Tully Fm.
McCave, 1969	SE NY	Catskill Fm.
Sulenski, 1969	GOP	Bellvale Fm.
Friedman, 1972	SE NY	Catskill Fm.
Glaeser, 1974	NE PA	Duncannon Mbr.
Epstein & others, 1974	NE PA	Duncannon Mbr.
Humphreys & Friedman, 1975	NC PA	Catskill Fm.
Buttner, 1977	SE NY	Catskill Fm.
Rahmanian, 1979	C PA	Sherman Creek Mbr.
Dune		
Johnson & Friedman, 1969	SE NY	Tully Fm.
Delta plain		
Glaeser, 1974	NE PA	Walcksville-Long Run Mbrs.
Epstein & others, 1974	NE PA	Walcksville-Long Run Mbrs.
Kirby, 1981	GPO	Bellvale Fm.
Marsh		
Sutton & others, 1970	SC NY	Sonyea Fm.
Humphreys & Friedman, 1975	NC PA	Catskill Fm.
Interdistributary bay		
McCave, 1968	SE PA	Moscow-Ludlowville Fms.
Tidal deposits		
Woodrow & Fletcher, 1967	SE NY-NE PA	Catskill Fm. (PA)and Laurens and Manorkill Fm. (NY)
McCave, 1968	SE NY	Moscow-Ludlowville Fms.
Johnson & Friedman, 1969	SE NY	Tully Fm.
Friedman, 1972	SE NY	Tully Fm.
Humphreys & Friedman, 1975	NC PA	Catskill Fm.
Rahmanian, 1979	C PA	Irish Valley Mbr.

Table 1. (Continued)

Environment Source	Geographic Area	Rock Unit
Distributary mouth bars		
Sulenski, 1969	GPO	Bellvale Fm.
Sutton & others, 1970	SC NY	Sonyea Gp.
Krajewski & Williams, 1971a	NE PA	Catskill Fm.
Epstein & others, 1974	NE PA	Towamensing Mbr.
Kirby, 1981	GPO	Bellvale Fm.
Tidal channels		
Sutton & others, 1970	SC NY	Sonyea Gp.
Kirby, 1981	GPO	Bellvale Fm.
Estuaries		
Sutton & others, 1970	SC NY	Sonyea Gp.
Beach		
Lucier, 1966	SE NY	Kiskatom-Kaaterskill Fms.
Krajewski & Williams, 1971a	NE PA	Catskill Fm.
Delta front		
Glaeser, 1974	NE PA	Towamensing Mbr.
Delta platform		
Sutton & others, 1970	SC NY	Sonyea Gp.
Nearshore shallow marine		
McCave, 1968	SE NY	Moscow-Ludlowville Fms.
Offshore bar		
Johnson & Friedman, 1969	SE NY	Tully Fm.
Krajewski & Williams, 1971a	NE PA	Catskill Fm.
Distal bar		
Kirby, 1981	GPO	Bellvale Fm.
Lagoon		
Lucier, 1966	SE NY	Kiskaton-Kaaterskill Fms.
Johnson & Friedman, 1969	SE NY	Tully Fm.
Friedman, 1972	SE NY	Hamilton Gp.
Prodelta		
Sulenski, 1969	GPO	Bellvale Fm.
Sutton & others, 1970	SC NY	Sonyea Gp.
Glaeser, 1974	NE PA	Trimmers Rock Fm.
Epstein & others, 1974	NE PA	Trimmers Rock Fm.
Slope shales		
Walker, 1972	SC PA	Irish Valley Mbr.
Open shelf		
McCave, 1968	SE NY	Moscow-Ludlowville Fms.
Sutton & others, 1970	SC NY	Sonyea Gp.

*GPO = Green Pond outlier, see Figure 6.

is not considered a part of the definition of a rock-stratigraphic unit, it controls the composition of rock sequences and the uniformity or diversity of their lithologic components. Thus, the orderly progression of progradational lithologies shown in Figure 7 can be easily subdivided into mappable rock-stratigraphic units in part, but not completely.

Those rocks which originated in the prodelta basin and prodelta environments are generally relatively uniform in lithology and comprise good map units although their boundaries are commonly transitional.

Rocks which originated in the subaerial part of the clastic wedge are characterized by a diversity of lithologies created by (1) multiple depocenters, (2) multiple depositional environments, and (3) variable distance from the source area. This diversity complicates rock-stratigraphic subdivision for these rocks. As a result, the approach in Pennsylvania has been to map assemblages of heterogeneous rocks which generally have arbitrary boundaries. These subdivisions may be well-defined in one area (e.g., Carbon County, PA; Epstein and others, 1974), but lack lateral persistence and require redefinition (e.g., Poplar Gap Member, Berg, 1975). In general, useful subdivisions of the Catskill Formation have been erected wherever detailed mapping (scale 1:24,000) has been done and the lateral relationships of these subdivisions has been established. Figure 8 presents some of the Middle and Upper Devonian stratigraphy currently used in Pennsylvania. Sutton (1963) has utilized regionally persistent black and dark-gray shales as stratigraphic marker horizons in New York State, but their presence and utility in Pennsylvania has not been demonstrated.

Economic Products

A variety of economic products derive from the diverse rocks of the Middle and Upper Devonian clastic wedge in Pennsylvania. Gas and oil have been produced in western Pennsylvania for over 120 years and are closely related to sandstones of the Upper Devonian clastic wedge (Kelley, 1967). Large quantities of flagstone have been produced from lower Catskill Formation sandstones in northeastern Pennsylvania and southeastern New York (Glaeser, 1969; Krajewski and Williams, 1971a & b; Sevon, 1978). Some uranium minerals occur at various stratigraphic levels in northeastern and north central Pennsylvania (Sevon and others, 1978), but the economic potential of these occurrences is currently unknown. Many Middle and Upper Devonian siltstones and sandstones have been utilized as sources for good-quality crushed rock and riprap, and Catskill Formation red shales are frequently quarried for use as random fill and base course for low-use secondary roads.

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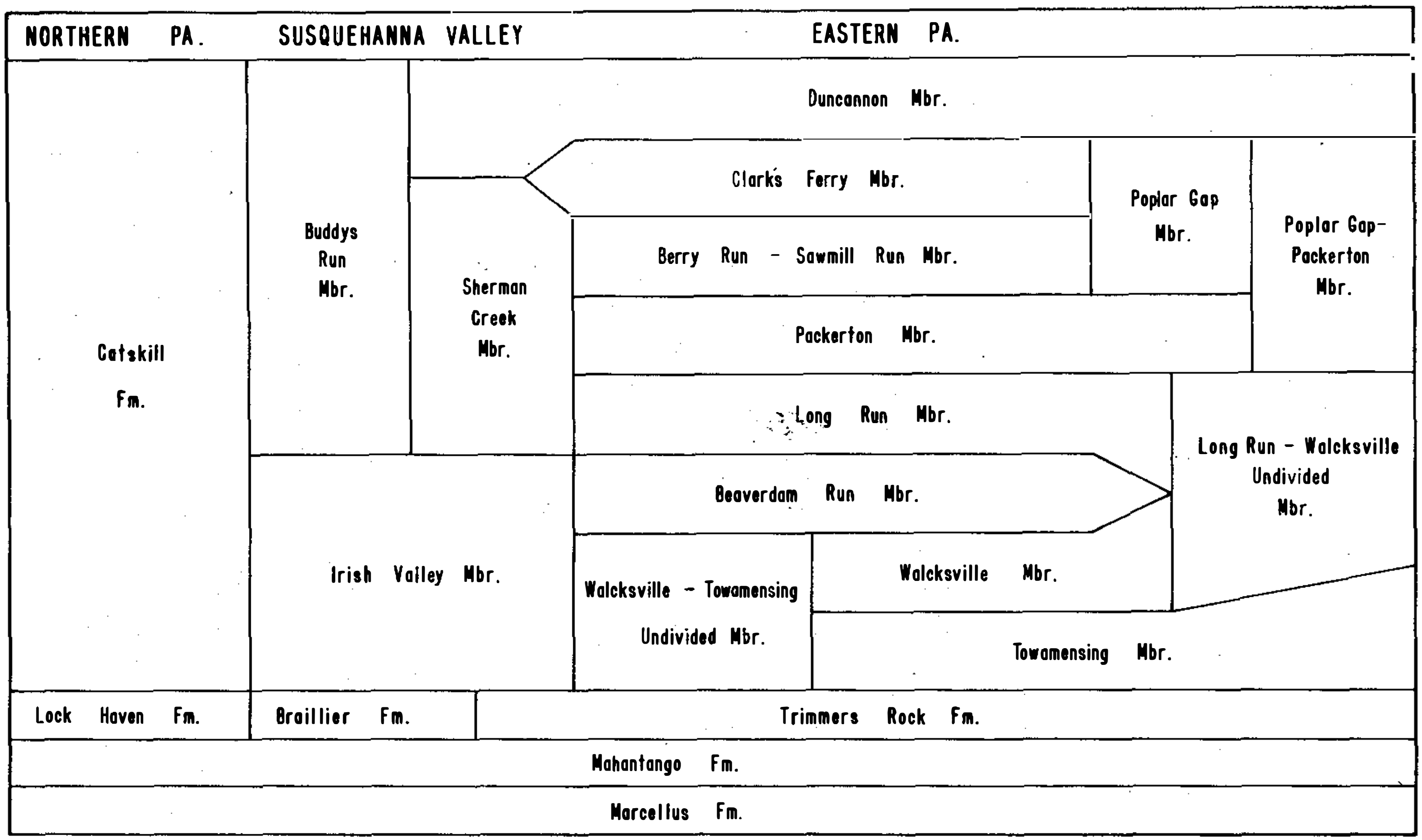

Figure 8. Stratigraphic correlation chart for the Devonian of Pennsylvania (from Berg and others, 1980).

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ROAD LOG AND STOP DESCRIPTIONS FOR CATSKILL CLASTIC WEDGE IN NORTHEASTERN PENNSYLVANIA

Road log starts at junction of Bartle Drive, SUNY Binghamton campus main exit, and New York Route 434

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE AND STOP DESCRIPTION
0.0	0.0	Turn left onto NY Route 434 west.
0.2	0.2	Turn right onto NY Route 201 to Johnson City.
1.0	0.8	Enter traffic circle.
1.2	0.2	Exit traffic circle on NY Route 201 north.
1.6	0.4	Bear left to NY Route 17.
1.9	0.3	Exit right to NY Route 17 east.
5.1	3.2	Bear right onto Interstate 81 south.
14.1	9.0	Exit right at Exit 1, Kirkwood.
14.3	0.2	Turn right at yield sign to NY Route 7.
15.2	0.9	Turn left at stop light onto NY Route 7 south.

16.9	1.7	Turn right following NY Route 7 south.
18.1	1.2	PA-NY state boundary. Now following PA Route 29 south.
19.0	0.9	Brookdale limits.
19.6	0.6	Road intersects on right.
19.9	0.3	STOP 1. Pull off and park at wide berm area.

STOP 1. PRODELTA ENVIRONMENT

Rocks at this stop are exposed in an outcrop along the west side of the road and along the west side of the stream below road level. Stream elevation is 970 feet.

The rocks exposed here comprise dark-gray shales and siltstones of the Lock Haven Formation. The siltstones have sharp bases, overlie shales, and fine upwards into shale. Burrow traces and fossils of marine invertebrates occur. Lateral continuity of beds is good within the extent of the small outcrop.

This is a good problem outcrop. If examined as an isolated entity, how much information can be gained from the outcrop itself? How much does it help to know the relative position of the outcrop in the vertical sequence of Figure 7? How important is context in the study of (1) rock lithology, (2) depositional environment, (3) stratigraphy, and (4) geologic history?

Leave Stop 1 and proceed south on PA Route 29.

22.7	2.8	Lawsville Center limits.
22.9	0.2	Turn left onto Franklin Hill Rd. (State 075).
24.0	1.1	Stone Crop Rd. (Twp. 735) forks to left, keep right on Franklin Hill Rd.
24.5	0.5	Turn left onto gravel lane. Gray house of G. Perkins to left on rise above road. Proceed up hill through gate.
24.7	0.2	STOP 2. Park on flat at quarry entrance.

STOP 2. MARGINAL-MARINE ENVIRONMENT

The flagstone quarry at this site was opened into rocks of the lower part of the Catskill Formation. The flagstone derives from the planar-bedded sandstones exposed in the floor of the quarry at elevation 1660 feet. The sequence of lithologies exposed here (Fig. 9) is interpreted to represent deposition in an offshore bar environment and the following information about the stop is from Krajewski and Williams (1971b, p. 13-15).

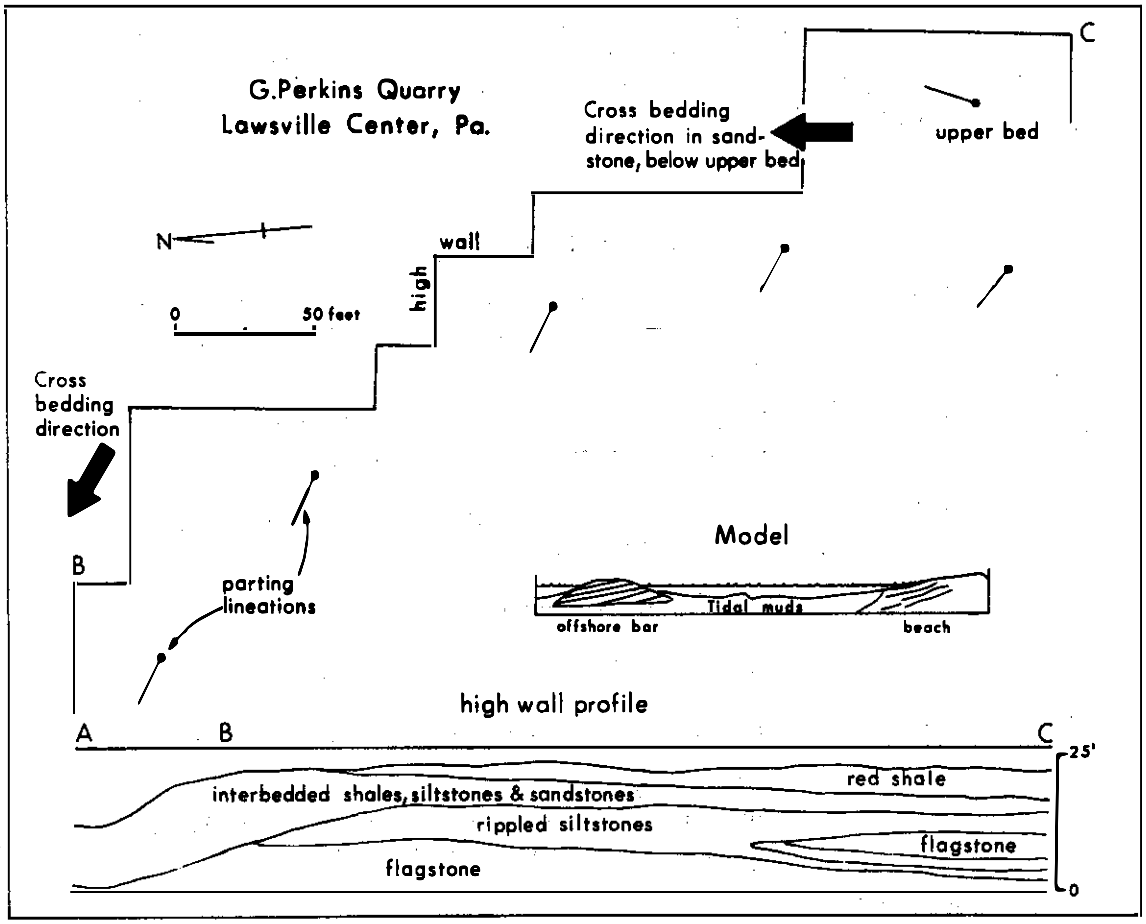

Figure 9. Plan and profile of rocks exposed in flagstone quarry at Stop 2. Rocks are part of lower Catskill Formation. Modified from Krajewski and Williams (1971b, p. 14).

"Characteristics of this type of quarry include:
- a) a convex upper surface;
- b) parallelism of the parting lineation orientation and the down-dip direction of the cross-bedding;
- c) a steep front in the seaward direction;
- d) replacement seaward (northwestward) by darker, fossiliferous, marine shales;
- e) replacement landward (southeastward) by siltstones, small-scale rippled sandstones, and red shales; and,
- f) uniformness and regularity of the joint systems (the high walls of the quarry parallel the joint systems).

"Two offshore bars are visible in the diagram, the larger lower one, and another smaller one in the south end of the quarry. The long direction, or paleogeographic trend, of these bars would be perpendicular to the parting lineation shown in the diagram, or northeast-southwest and east-west for respectively the lower and upper bars. The rock sequence represents a marine transgression onto the tidal flats and shore zone."

Examine this stop with the following questions in mind: (1) How easily can the depositional environment be determined from the physical properties of the rocks? (2) Does the interpretation of this outcrop aid in the interpretation of the rocks at Stop 1? (3) What information can be gained about the source area from this stop?

Return to Franklin Hill Rd.

24.9	0.2	Turn left onto Franklin Hill Rd.
27.1	2.2	Turn left onto paved road to New Milford at cross roads near bottom of hill at Franklin Corners.
31.0	3.9	Turn right at stop sign at Tingley after going under railroad overpass.
31.6	0.6	Turn right onto US Route 11 at stop sign, New Milford limits.
32.2	0.6	Turn left onto PA Route 492 east.
33.2	1.0	(Jackson St.) to Interstate Route 81.
33.7	0.5	Turn right to Interstate Route 81 south.
36.8	3.1	STOP 3. Pull off and park on wide berm at south end of road cut and examine the rocks along the terrace above the road.

STOP 3. FLUVIAL ENVIRONMENT

The rocks at this stop are exposed in the southernmost of three large roadcuts on the west side of Interstate Route 81, all of which expose similar rocks. Elevation here is 1640 feet.

Exposed here are a variety of sandstones, both gray and red, which contain lag gravels, cross beds, planar beds, and ripples (Fig. 10). Interbedded red siltstones are locally burrowed. Lag gravels comprise predominantly calcium-carbonate nodules. Cross-bed forsets are oriented mainly to the southwest while parting lineations are to the northwest. Lateral and vertical relatonships are complex, but the whole can be interpreted in terms of a fining-upward cycle formed by a meandering stream (Allen, 1970).

What features of this outcrop are critical to the interpretation of its depositional environment? How many levels of context are involved in studying this outcrop? What information about the source area can be gained from this outcrop?

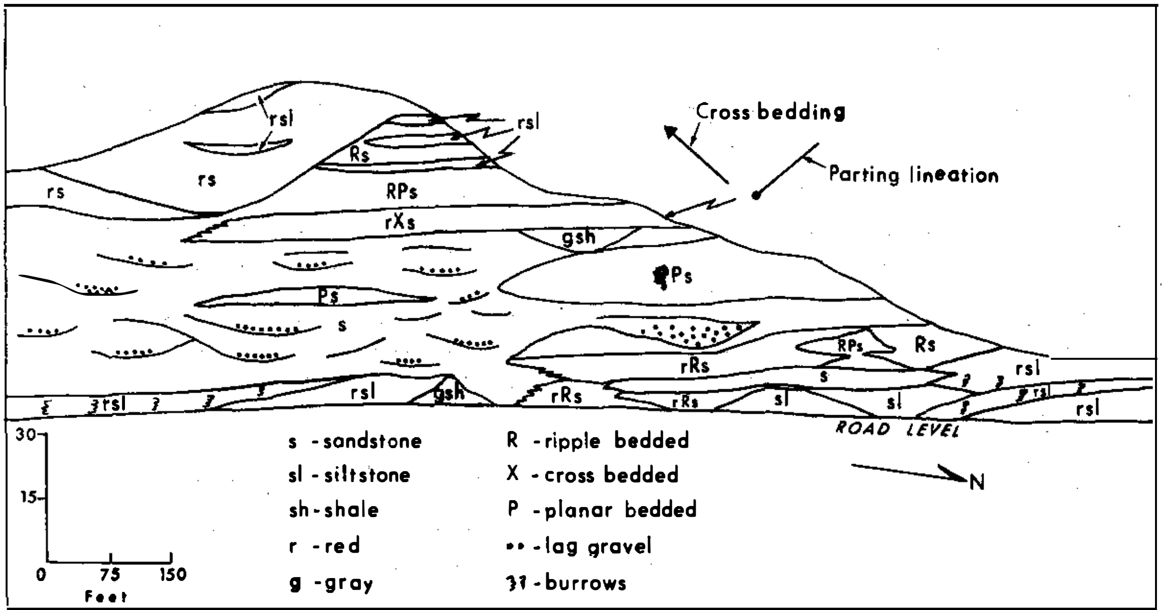

Figure 10. Sketch of rocks exposed in roadcut on west side of Interstate Route 81 south of New Milford (Stop 3). Rocks are part of lower Catskill Formation. Sketch modified from Krajewski and Williams (1971b, p. 67).

Leave Stop 3 and proceed south on Interstate Route 81.

65.4	28.6	Outcrops of Spechty Kopf, Pocono, and Pottsville Formations in road cuts. Entering northwest side of Wyoming-Lackawanna basin.
67.5	2.1	Scarlift reclamation on right.
69.7	2.2	Bear right on Interstate Route 81 south at junction with Interstate Routes 84 and 380.
72.6	2.9	Exit right to Moosic St. and PA Route 307 at Exit 52.
72.7	0.1	Turn right onto PA Route 307 at stop sign.
73.0	0.3	Turn right onto PA Route 307, US Route 11, and Harrison Ave. at stop light.
73.3	0.3	Turn right onto Mulberry St. at stop light.
73.6	0.3	Enter Nay Aug Park.
73.7	0.1	Turn left into parking lot near Brooks Model Coal Mine. Park.

STOP 4. NAY AUG PARK - LUNCH

This stop is principally for the purpose of ingesting food, but some interesting things can be seen.

The Brooks Model Coal Mine area has the entrance to an underground anthracite mine and some old coal cars. The sandstones exposed throughout the park are part of Llewellyn Formation of Pennsylvanian age. This formation contains a number of anthracite coal seams which have been mined, principally by underground methods, in the Wyoming-Lackawanna basin (the northern anthracite field). Exposures along the railroad track along the east side of the park allow evaluation of the depositional environment of the rocks exposed here.

Leave Stop 4 and retrace route proceeding north on Mulberry St.

74.1	0.4	Turn left onto PA Route 307, US Route 11, and Harrison Ave. at stop light.
74.4	0.3	Turn left following PA Route 307 south at stop light.
74.6	0.2	Turn right onto Meadow Ave. at stop light. Follow signs to Interstate Route 81.
74.8	0.2	Turn left at T intersection following signs to Interstate Route 81.
75.0	0.2	Turn left onto Interstate Route 81 north.
77.8	2.8	Bear right to Interstate Routes 84 and 380.
78.7	0.9	Outcrops on both sides of road of basal Pottsville Formation conglomerate. Outcrop to left is upper part of Stop 7.
79.4	0.7	Outcrop to left is Spechty Kopf Formation and site of start of Stop 7. To right across Roaring Branch is dip slope underlain by Spechty Kopf Formation sandstones. Shale exposed below sandstone.
81.5	2.1	Exit left onto Interstate Route 84 east.
82.2	0.7	STOP 5. Park on wide berm to right.

STOP 5. FLUVIAL ENVIRONMENT

The rocks at this stop are exposed in cuts on both sides of Interstate Route 84 east at the point where entrance ramps from Interstate Route 380 east and west join. Park on wide berm on the south side of the road and examine the rocks in the cut on the north side of the road. Cross the interstate with care!

The rocks exposed here are near the uppermost part of the Poplar Gap-Packerton Member of the Catskill Formation (Fig. 8). The sequence (Fig. 11) comprises mainly gray sandstones with some red mudstones. Sandstone and siltstone contacts are sharp. The gray sandstones are cross bedded, contain some lag gravels, and are locally calcareous (calcareous cement weathers brown). Scattered red-shale clasts are common near the bases of some sandstone bed sets. The lag gravels contain some quartz pebbles, but mainly calcium-carbonate nodules, many of which look like oncolites. Root traces occur locally in the sandstones.

The lower red mudstone is burrowed in part and contains abundant calcium-carbonate nodules. Note the thinly laminated character of some of the mudstone enclosing the nodules.

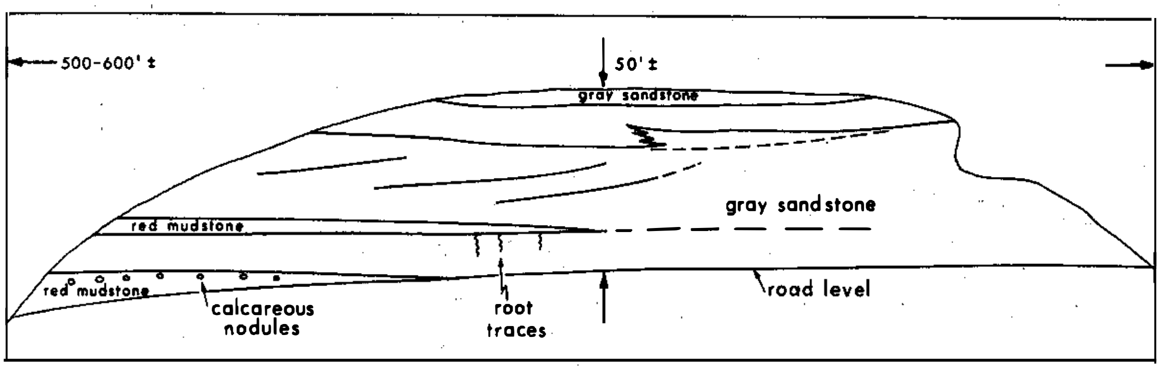

Figure 11. Sketch of rocks exposed in roadcut on north side of Interstate Route 84 just east of junction with Interstate 380 (Stop 5). Rocks are in uppermost part of the Poplar Gap-Packerton Member of the Catskill Formation.

There are many questions to be asked about these rocks. Would information on context be useful in making an environmental interpretation? What information can be gained about the source area? Is source-area information at this outcrop more or less abundant than at Stop 3? What is the significance of the presence of calcium carbonate? How were the calcium carbonate nodules formed in the red mudstones and in the gray sandstones? What is the evidence for a fluvial origin for this sequence? What specific fluvial environment best fits these rocks?

Leave Stop 5 and proceed east on Interstate Route 84.

86.0	3.8	Exit right to Mt. Cobb.
86.2	0.2	Turn left at stop sign.
86.4	0.2	Turn left onto PA Route 348 west at stop sign.
86.7	0.3	STOP 6. Park on wide berm on right.

STOP 6. FLUVIAL ENVIRONMENT

The rocks exposed here are near the lowermost part of the Duncannon Member of the Catskill Formation (Fig. 8). The rocks comprise one complete and two partial fining-upward cycles (Fig. 12). Two cycles have a sharp base with gray sandstone overlying red mudstone. Above the base there is an upward decrease in grain size from sand to clay and change to red color.

The lower sandstone has some calcium-carbonate cement, a few root traces, and bedding changes upward from crossbedding to planar bedding. The overlying red mudstones contain repeated zones with abundant burrows and root traces. The mudstone between these zones is generally thinly laminated. The upper third of the lower major cycle is a smaller cycle which has a grayish red sandstone above a sharp base. Calcium-carbonate nodules are abundant in the mudstone below the sharp base of the upper major cycle. Several large channel cuts occur in the gray sandstone of the upper cycle.

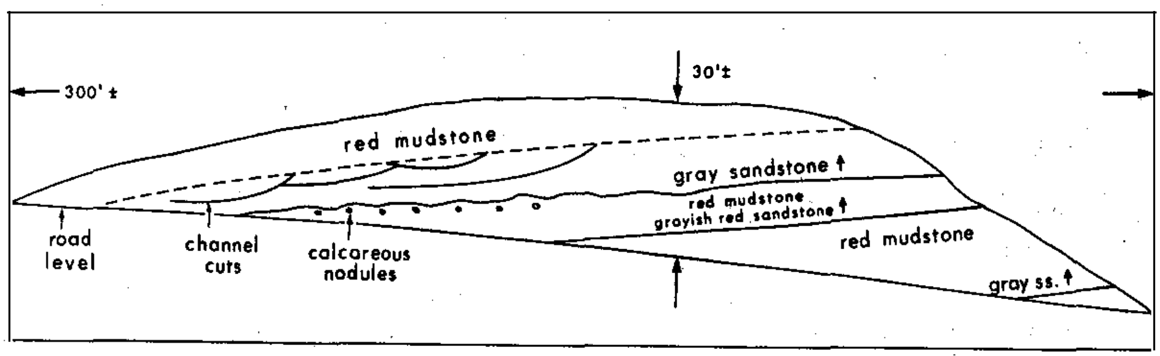

Figure 12. Sketch of rocks exposed in roadcut on north side of PA Route 348 just west of Mt. Cobb (Stop 6). Rocks are in lowermost part of the Duncannon Member of the Catskill Formation.

What is the probable origin of the excellent fining-upward cycles displayed in this exposure? How do these cycles compare with that at Stop 3? What is the significance of the alternating burrowed and non-burrowed zones in the mudstone? How do the calcium-carbonate nodules in the red sandstone compare with those at Stop 5? What differences in depositional environment are suggested by the differences in the rocks exposed here and at Stop 5? Is context of particular value in interpretation of the depositional environment of these rocks? What information about the source area do these rocks provide?

Leave Stop 6 and proceed west on PA Route 348.

89.2	2.5	Bear right to PA Route 435 north.
89.4	0.2	Bear right onto PA Route 435 north at stop sign.
92.2	2.8	STOP 7. Park well off road on berm to right before guard rail starts and just after junction of entrance ramp to Interstate Route 380 west. Bus will proceed 0.8 farther to end of upper outcrop for pickup.

STOP 7. SPECHTY KOPF FORMATION AND LOCAL SUBSIDENCE

This stop occurs at roadcuts on the east side of Interstate Route 380 just south of Dunmore and consists of two parts: a long, high roadcut just north of the entrance ramp (lower outcrop) and a long,low roadcut about 0.7 miles farther north (upper outcrop). The exposures are separated by a covered interval.

The identification of the rocks at this stop is different from that indicated on the 1960 edition of the geologic map of Pennsylvania (Gray and others, 1960), but is in agreement with the 1980 edition of that map (Berg and others, 1980). The changes result from the work of Sevon (1969) and subsequent reconnaissance mapping. The Pocono Formation occurs in the covered interval between the lower and upper exposures.

The lower outcrop (Fig. 13) consists of dark shales and sandstones of the Mississippian-Devonian Spechty Kopf Formation. The shales are here about 300 feet thick and are underlain (in exposures along Roaring Branch) by polymictic diamictite. Interbedded thin siltstone layers exposed in the lower third of the shale in the former Nay Aug quarry across Roaring Branch have bottom-surface flow structures and upper-surface ripples which indicate

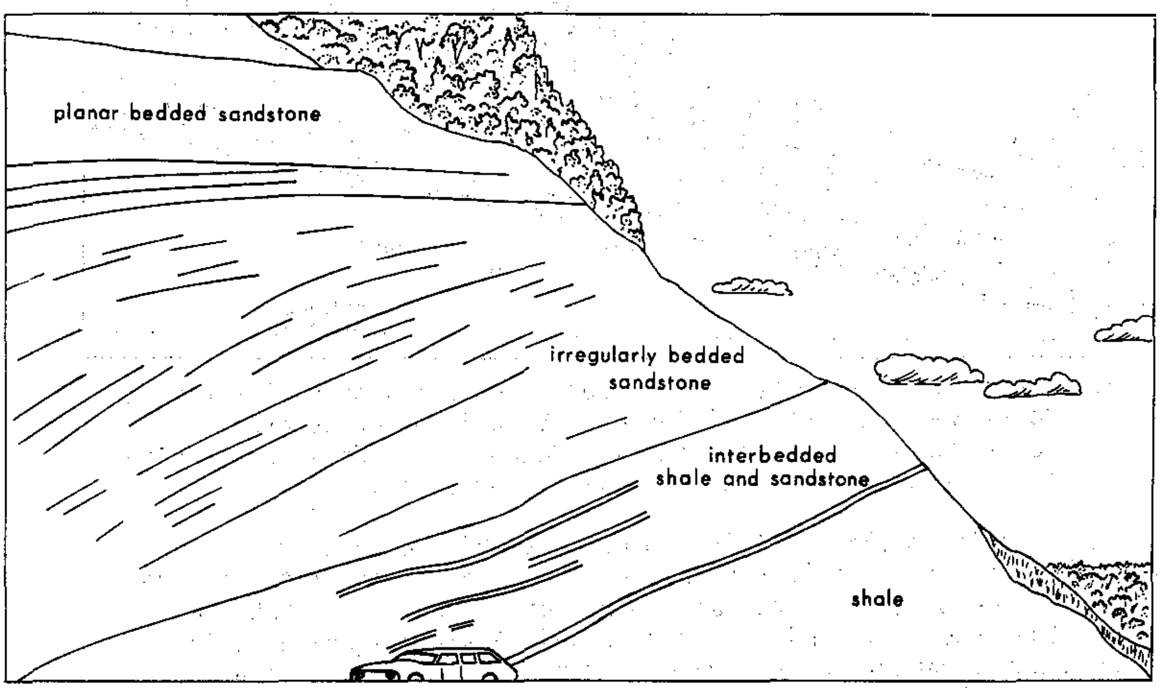

Figure 13. Sketch of rocks exposed in roadcut on east side of Interstate Route 380 just north of entrance ramp from PA Route 435 (Stop 7, lower outcrop). Rocks are part of the Spechty Kopf Formation.

current flow of N12E. Very large and relatively small slump structures occur in the upper third of the shale and are very well exposed here. The contact of the shale and sandstone is gradational through a zone of interbedding. A zone of load casts occurs just below the first sandstone interbed.

The sandstone comprises relatively uniform and moderately well-sorted grain size throughout, is very light gray in color, weathers tan, and is about 160 feet thick. Bedding in the lower part defines wedge-to-irregularly lens-shaped bed sets which dip northwestward at a steeper inclination than the overlying planar beds. The planar bedding is remarkably uniform and persistent. Some beds have ripples, but most are apparently structureless.

What are the environments of deposition of the rocks exposed in this outcrop? The rocks underneath the basal polymictic diamictite are those of the Duncannon Member seen at Stop 6. Does this aid or complicate the interpretation? Also of importance is the fact that 5 miles to the north on the other side of the basin, this sequence is compressed to 110 feet in thickness and is totally absent along all margins of the basin within 20 miles of this locality. The unusual thickness of this sequence and its lateral variation is interpreted to indicate local subsidence at the time of deposition. The regional aspects of these facies (Sevon, 1969; 1979b) are interpreted as part of the demise of the Catskill delta (see earlier text).

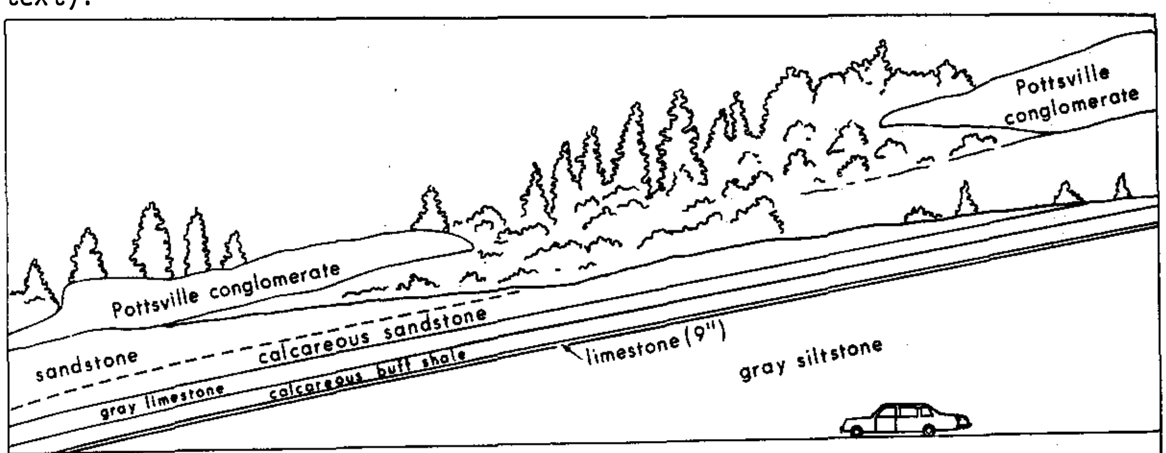

Figure 14. Sketch of rocks exposed in roadcut on east side of Interstate Route 380 just south of Dunmore (Stop 7, upper outcrop). Lower rocks are correlated with Mauch Chunk Formation. White conglomerate is base of Pottsville Formation.

The upper outcrop (Fig. 14) is capped by a white conglomerate of the Pottsville Formation of Pennsylvanian age. The conglomerate is underlain by a sequence of siltstone, sandstones, and limestones which are unlike any other rocks at similar stratigraphic positions anywhere in eastern or central Pennsylvania. The sequence is correlated with the Mississippian Mauch Chunk Formation on the basis of stratigraphic position, but the rocks are very dissimilar from the red siltstones and sandstones which characterize the Mauch Chunk as near as 20 miles to the southwest. However, known facies changes along the southeastern margin of the Wyoming-Lackawanna basin and the abundance of calcium carbonate suggests that such correlation is valid. What environments of deposition may be represented by these lithologies--particularly the thin limestone? Do these rocks, including the Pottsville conglomerate, tell much about the source area?

93.0	0.8	Leave Stop 7 and proceed west on Interstate Route 380.
93.7	0.7	Straight ahead onto Interstate Route 81 north.
98.3	4.6	Pottsville-Spechty Kopf sequence.
139.1	40.8	PA-NY State boundary.
151.9	12.8	Bear left on NY Route 17 west.
155.6	3.7	Turn right onto exit 70 S: Johnson City, NY Route 201 south, and SUNY.
156.3	0.7	Join Riverside Drive.
156.7	0.4	Traffic circle. Exit right immediately.
157.7	1.0	Join NY Route 434 east.
158.0	0.3	Bartle Drive, entrance to SUNY Binghamton. END OF TRIP.