CHAPTER 6 SILURIAN AND TRANSITION TO DEVONIAN

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INTRODUCTION

Strata of Silurian age (405–430 Ma) constitute only about 10 percent of the relative volume of Paleozoic sedimentary rocks in the central Appalachian basin (Colton, 1970), but they impart a dominant and characteristic physiographic form to the Appalachian Mountain section of the Ridge and Valley province of central Pennsylvania (Figure 6–1). Good exposures of Silurian rocks occur in the eastern part of the state and in the Appalachian Mountain section (Figure 6–2). Silurian rocks in the subsurface are very important petroleum reservoirs in the western part of the state (see Chapter 38B). Knowledge of Silurian lithologies in the subsurface of western Pennsylvania is based on oil- and gas-well cores, drill-cutting samples, and geophysical data.

The demonstrable thickness of Silurian rocks in the state ranges from about 1,200 feet in northwestern Pennsylvania to almost 4,000 feet in eastern Pennsylvania (Figure 6–3). The Silurian System consists of two distinct depositional sequences: (1) a mainly Lower Silurian clastic sequence that extends throughout much of the state as a thin succession of sandstones, conglomerates, and subordinate mudrocks and carbonates; and (2) the Upper Silurian portion of a Silurian-Devonian carbonate sequence that consists of a moderately thick succession of limestones and dolomites and other minor, but significant, lithologies (Colton, 1970).

LOWER LLANDOVERIAN

In Early Silurian time, large volumes of clastic sediment were transported westward into central and northwestern Pennsylvania from eastern highlands raised during the Late Ordovician to Early Silurian Taconic orogeny. Three lithostratigraphic units in three geographic regions are recognized. These are the Shawangunk Formation in eastern Pennsylvania; the Tuscarora Formation in central Pennsylvania; and the Medina Group in northwestern Pennsylvania. The

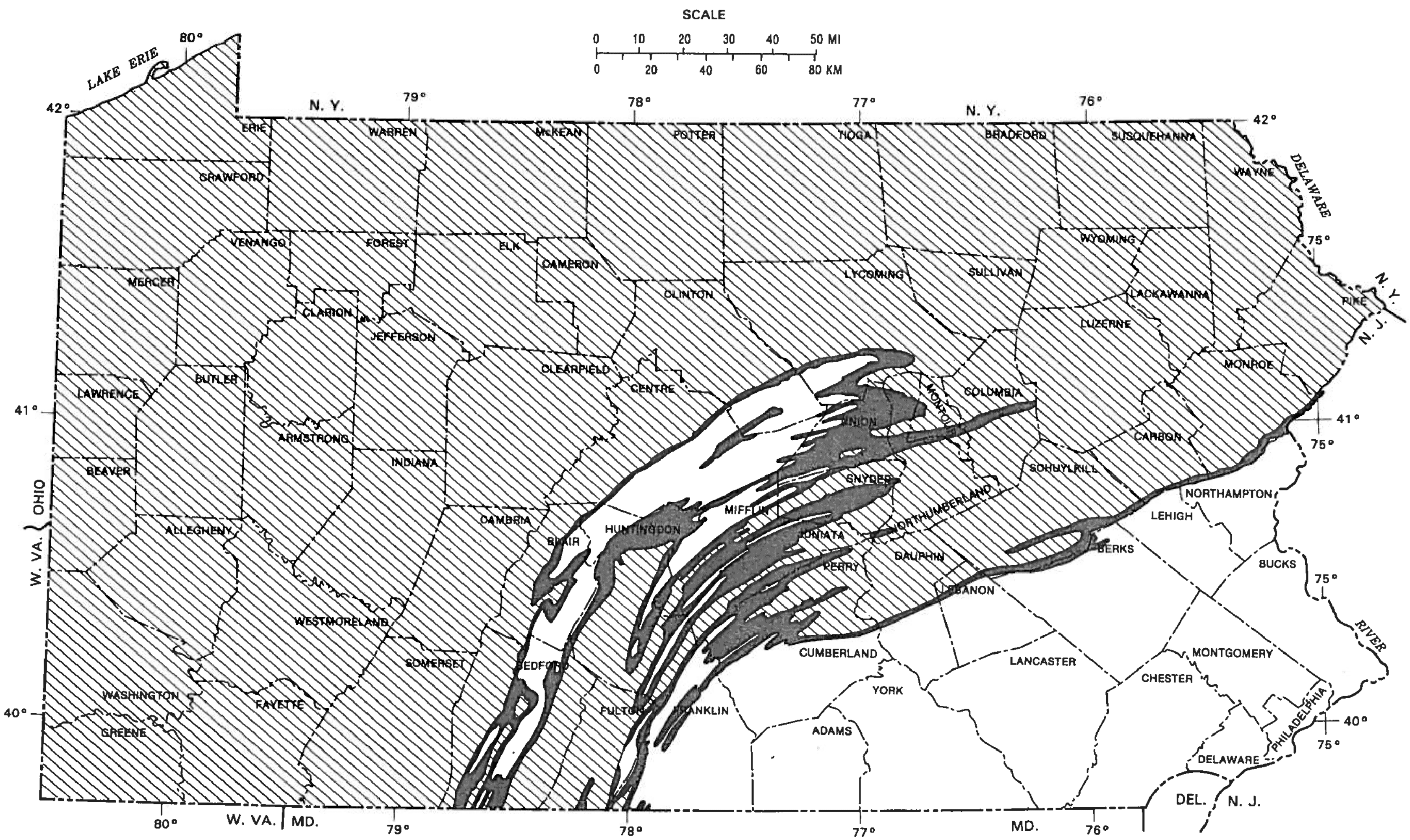

Figure 6–2. Distribution of Silurian rocks at the surface (solid color) and in the subsurface (line pattern) in Pennsylvania (from Pennsylvania Geological Survey, 1990).

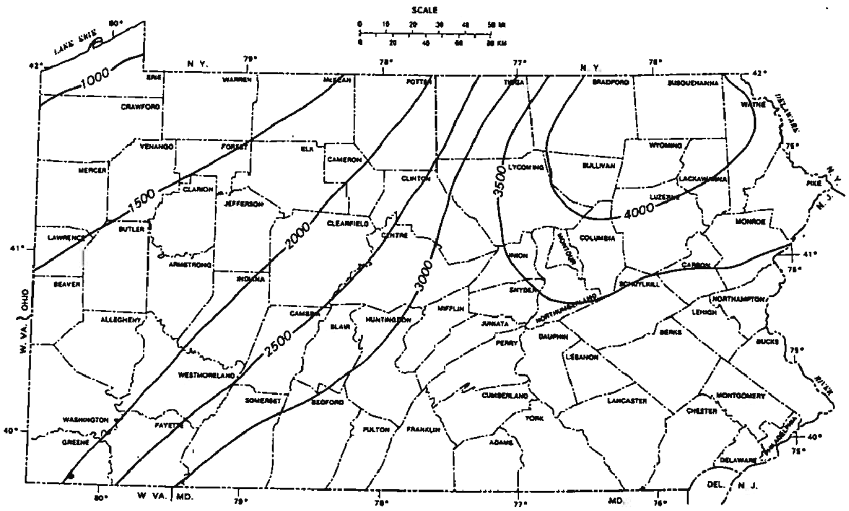

Figure 6–3. Isopach map showing the thickness of Silurian strata across Pennsylvania. Contour interval is 500 feet.

Shawangunk Formation is divided into members and facies (Epstein and Epstein, 1972), the Tuscarora Formation into facies (Cotter, 1982, 1983a), and the Medina Group into formations and informal facies (Piotrowski, 1981; Pees, 1983a; Laughrey, 1984).

Eastern Pennsylvania—Shawangunk Formation

In eastern Pennsylvania, the Shawangunk Formation comprises all of the Llandoverian and much of the Wenlockian Series (Berg, McInerney, and others, 1986). The maximum thickness of the Shawangunk occurs at the Delaware Water Gap, where the formation is 2,100 feet thick. The upper contact with the Bloomsburg Formation is irregular and transitional, whereas the contact with the underlying Martinsburg Formation is an angular unconformity (Epstein and Epstein, 1972). Lithologies in the Shawangunk include coarse conglomerate, quartzose sandstone, and shale. The Shawangunk is sparsely fossiliferous. Fragments of lingulid brachiopods, eurypterid remains, and rare Dipleurozoa (a class of jellyfishlike fossils in the phylum Cnidaria) occur in the Lizard Creek Member. Trace fossils reported from the Shawangunk include the feeding burrow *Arthrophycus alleghaniense* and the vertical burrow *Skolithos*. Epstein and Epstein (1972) interpreted the sedimentary characteristics of the Shawangunk as indicative of deposition in fluvial and paralic environments (Figure 6–4).

Central Pennsylvania—Tuscarora Formation

The Tuscarora Formation is distributed over a large area of central Pennsylvania. Through most of this area, the thickness of the Tuscarora ranges between 492 and 656 feet. It thins to the northwest to a minimum thickness of about 200 feet. The Tuscarora Formation lies conformably on the Upper Ordovician (Ashgillian) Juniata Formation. Conformably above it is the Rose Hill Shale, which is appointed a late Llandoverian age. The Early Silurian àge assignment for the Tuscarora is based on the ages of the juxtaposed formations because there are no datable fossils in the Tuscarora (Berry and Boucot, 1970). Rocks of the Tuscarora Formation consist of quartzose, sublithic, and argillaceous sandstones and shales (Folk, 1960; Cotter, 1982, 1983a; Wescott, 1982). Body fossils are conspicuously absent from the Tuscarora Formation, but a small number of trace fossils, including *Arthrophycus*, *Skolithos*, and *Monocraterion*, occur in varying abundance among different lithofacies (Cotter, 1982, 1983a). Cotter (1982, 1983a) interpreted the eastern part of the Tuscarora Formation as mostly fluvial in origin and the western part as mostly marine (Figure 6–5).

Western Pennsylvania—Medina Group

The Medina Group, which has no outcrops in Pennsylvania, is a sequence of quartzose, sublithic, and subarkosic sandstones, shales, and minor carbonates. It ranges in thickness from 200 feet to less than 140 feet. Workers in northwestern Pennsylvania generally report the Medina as disconformably overlying the red shales of the Ordovician Queenston Formation and conformably underlying the carbonates and shales of the Clinton Group. Body fossils are relatively common in the upper and middle parts of the Medina Group but are notably absent in the lowermost Whirlpool Sandstone (Fisher, 1954). Trace

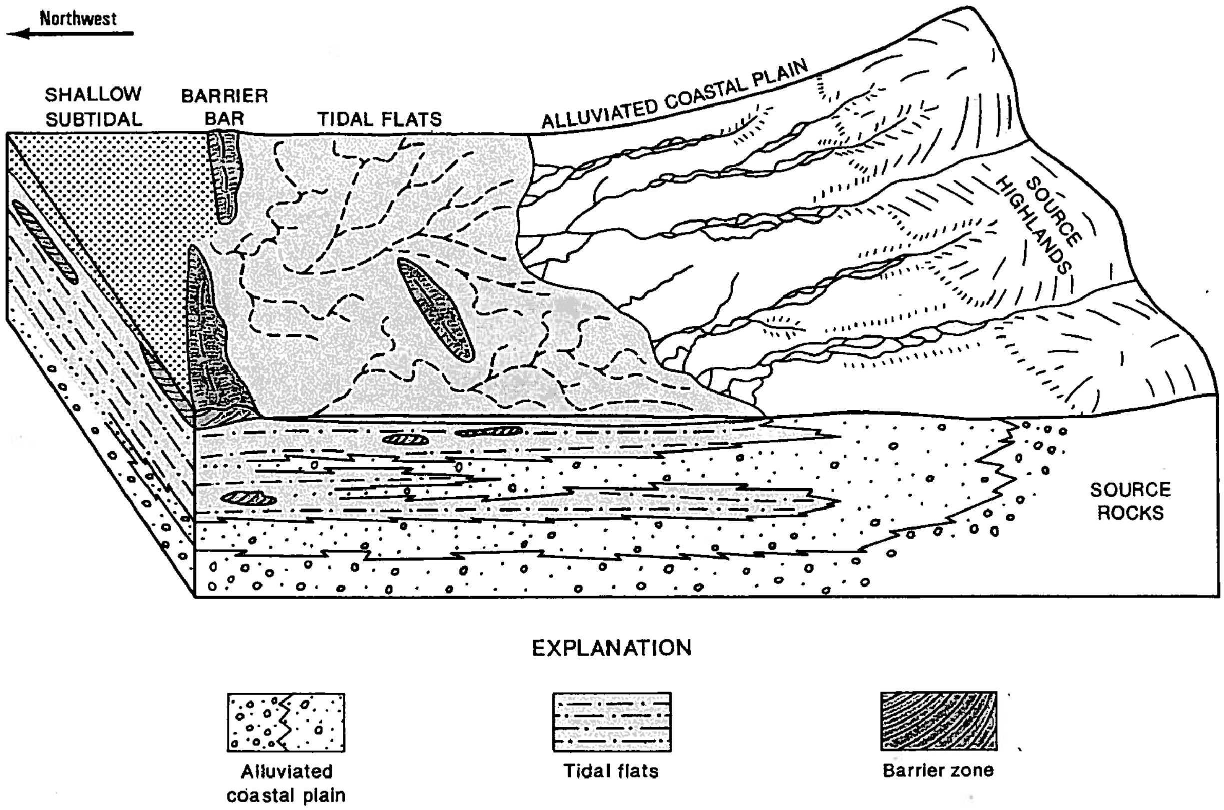

Figure 6–4. Block diagram showing sedimentary environments and major lithofacies in the Shawangunk Formation (from Epstein and Epstein, 1972, Figure 22).

fossils are abundant in the Medina Group and have proved quite useful for interpreting the origin of the rocks (Laughrey, 1984; Pemberton and Frey, 1984; Pemberton, 1987). Numerous workers have attributed the origin of the Medina Group to deposition in a variety of fluvial, deltaic, paralic, and marine sedimentary environments (Figure 6–6) (Kelley, 1966; Kelley and McGlade, 1969; Martini, 1971; Piotrowski, 1981; Laughrey, 1984; Duke and Fawcett, 1987).

Stratigraphic Correlations and Cyclicity

The correlation of lower Llandoverian lithostratigraphic units across western Pennsylvania is shown in Figure 6–7. A consensus developed among earlier workers that the extensive and unbroken continuity of Shawangunk, Tuscarora, and Medina lithologies across Pennsylvania and adjacent states represented a large, but simple, onshore-offshore complex from east to west (Yeakel, 1962; Knight, 1969; Martini, 1971; Smosna and Patchen, 1978; Piotrowski, 1981). This interpretation, most concisely presented by Yeakel (1962) and Smosna and Patchen (1978), implies that the Shawangunk and Tuscarora rocks are alluvial clastics deposited on a coastal plain, and the Medina rocks of western Pennsylvania are deltaic with offshore facies represented farther to the west (Figure 6–8). According to Smosna and Patchen (1978, p. 2,310), however, "Superimposed on this east-west gradation... is a dual origin recognized for the Tuscarora...." This twofold origin is apparent in all of the depositional schematics presented in Figures 6–4, 6–5, and 6–6. Facies analyses of the Shawangunk Formation, Tuscarora Formation, and Medina Group all reveal the imprint of fluvial or paralic and marine environments, although fluvial and transitional facies dominate the Shawangunk rocks of eastern Pennsylvania, and marine facies dominate the Tuscarora and Medina rocks of central and western Pennsylvania.

Cotter's (1983a) investigation of the Tuscarora Formation and work by Duke (1987b) employed contemporary techniques of "sequence stratigraphy," that is, "the attempt to analyze stratigraphic successions in terms of genetically related packages of strata" (Nummedal, 1987, p. iii). This approach promises to provide a dynamic and realistic understanding of Lower Silurian stratigraphy in Pennsylvania. Duke (1987b) has suggested subdivisions of the Medina Group based

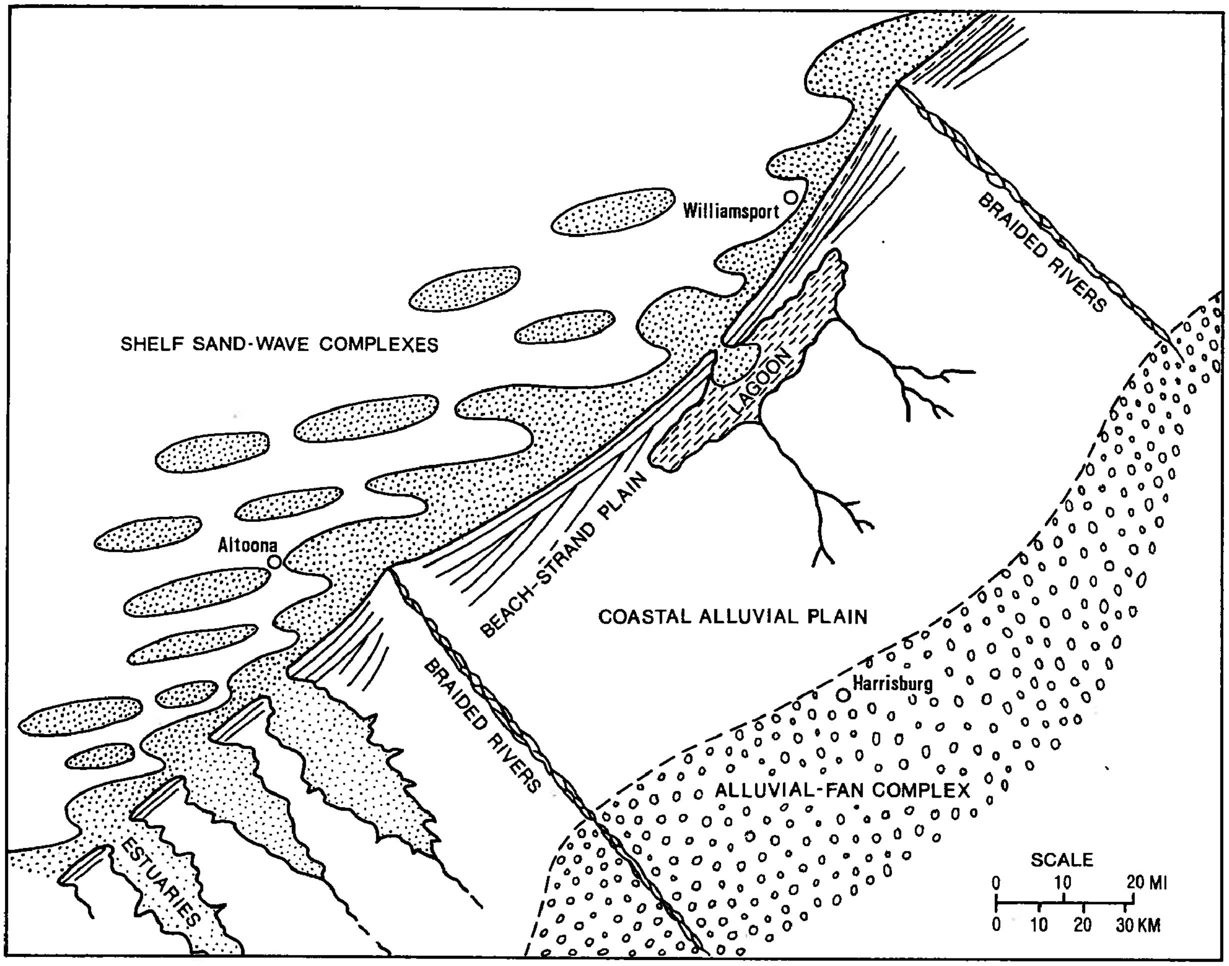

Figure 6–5. Cotter's (1983a, Figure 13, p. 42) interpretation of depositional environments in which the Tuscarora Formation originated during sea-level rise in earliest Llandoverian time. Shoreline and shelf facies migrated southeastward over the coastal alluvial-plain sediments with rising sea level.

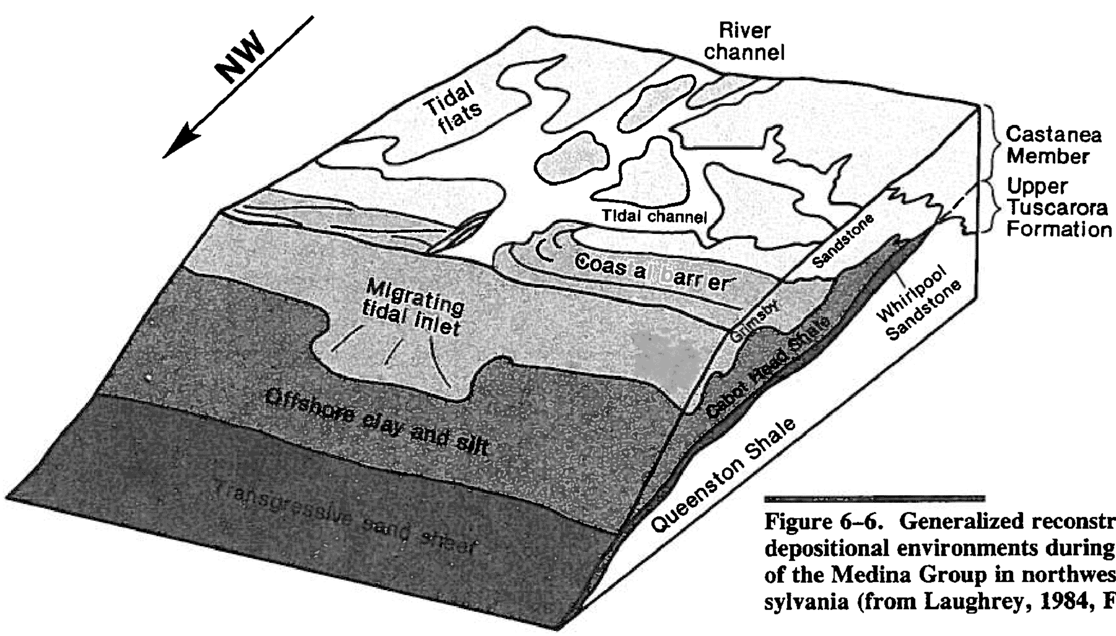

Figure 6–6. Generalized reconstruction of depositional environments during deposition of the Medina Group in northwestern Pennsylvania (from Laughrey, 1984, Figure 21).

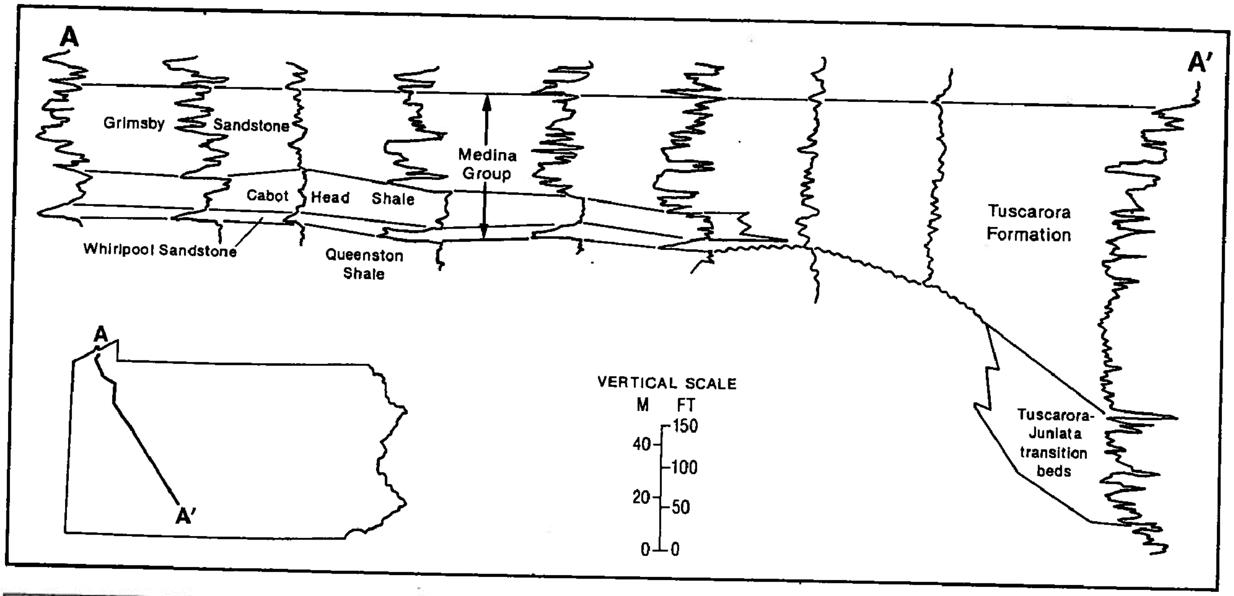

Figure 6–7. Correlation of lower Llandoverian lithostratigraphic units across western Pennsylvania (modified from Heyman, 1977, and Piotrowski, 1981). Correlations are based on subsurface geophysical (gamma-ray) logs.

upon the correlation of erosional unconformities bounding lithologically heterogeneous depositional cycles. The author has attempted to recognize these cycles in whole-diameter cores of the Medina Group from northwestern Pennsylvania and tentatively correlate them with those suggested by Duke (1987a) (Figure 6–9). Duke (1987a, p. 18) proposed that "The unconformity-bounded cyclic depositional sequences recognized in the Medina are essentially identical to depositional cycles recognized...by Cotter (1983a) in the time-equivalent Tuscarora Formation...." Cotter (1983a) ascribed the origin of depositional cycles in the Tuscarora Formation to the interplay of eustatic sea-level fluctuations with tectonic and depositional events. Duke and Fawcett (1987) stated that

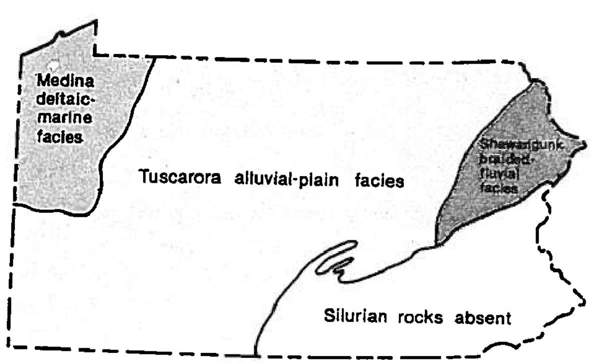

Figure 6–8. Interpretation of the Shawangunk, Tuscarora, and Medina lithologies across Pennsylvania as a simple onshore-offshore complex (modified from Piotrowski, 1981, Figure 3).

depositional cycles in the Medina could be attributed to a number of possible causes, including tectonic processes, regional and/or global climatic variations, global sea-level fluctuations, or oscillatory process-response systems.

UPPER LLANDOVERIAN—LOWER WENLOCKIAN

The lithostratigraphic architecture of the Lower Silurian clastic sequence reveals a relatively uniform record of sedimentation across Pennsylvania and adjacent parts of the central Appalachian basin. A significantly different sedimentary pattern emerged during Middle Silurian time, however. This new pattern, defined by an elongate basin oriented northeast-southwest (Figure 6–10), prevailed into the Devonian Period (Dennison and Head, 1975). The central, or axial, part of the basin remained deeper than the margins through differential subsidence and limited sediment influx (Smosna and Patchen, 1978). Low-energy mud facies were deposited along the basin axis, whereas the southeast and northwest basin margins were regions of higher energy deposition.

Eastern Pennsylvania—Shawangunk Formation

In eastern Pennsylvania, the Middle Silurian is represented by the upper part of the Shawangunk Formation. Coarse-grained fluvial sands continued

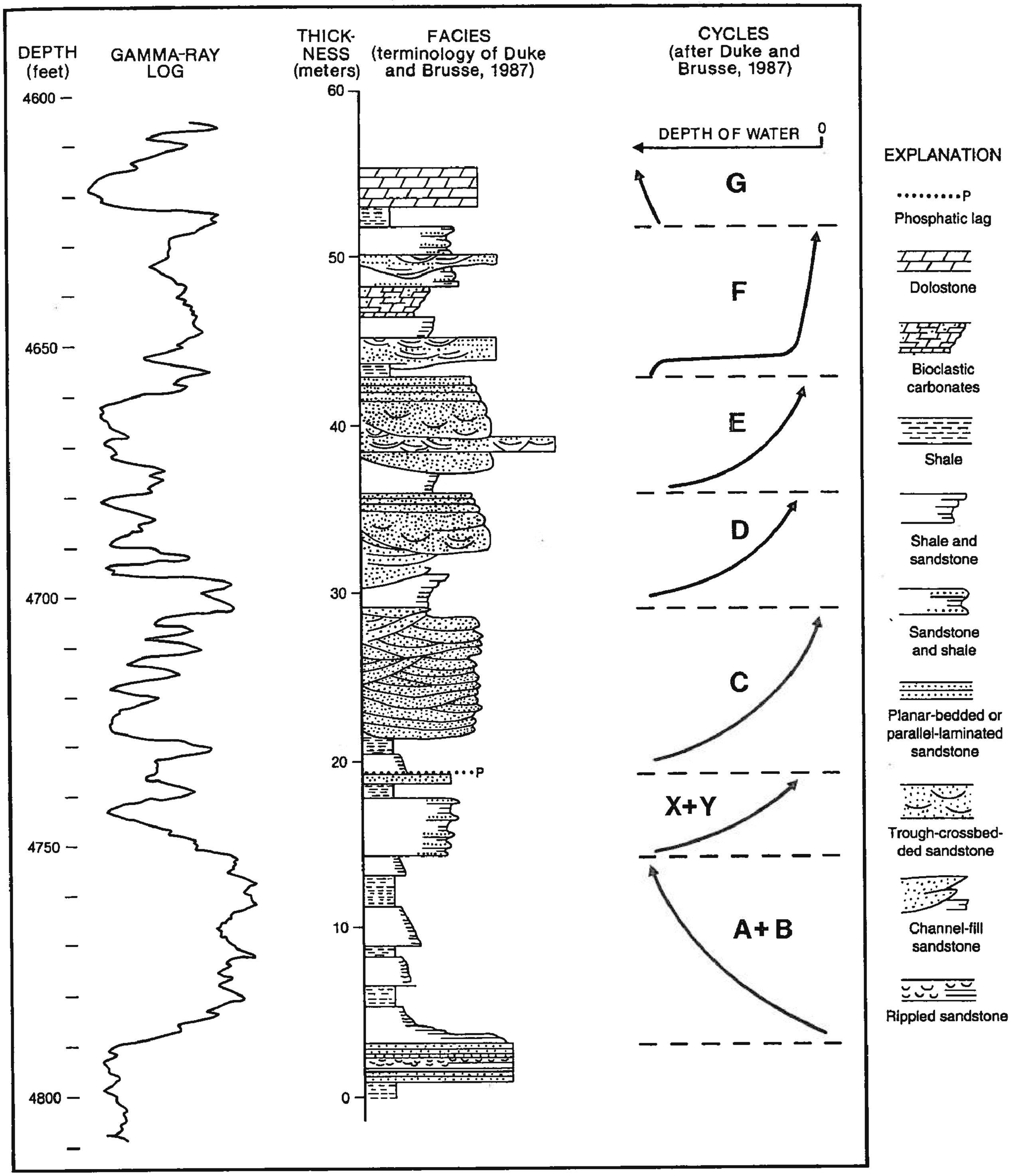

Figure 6–9. Allostratigraphic cycles in the Medina Group recognized in the Creacraft No. 1 well core from Crawford County. The gamma-ray log of the entire cored interval is shown on the left. The facies symbols used in the graphic core description are those of Duke and Brusse (1987). Letters and arrows on the right represent unconformity-bounded cyclic depositional sequences and relative sea-level changes proposed by Duke and Brusse (1987). The recognition of Duke and Brusse's cycles in the core supports their idea of cyclicity in these rocks and suggests that correlation of these Medina cycles with those recognized by Cotter (1983a) in the Tuscarora may be possible.

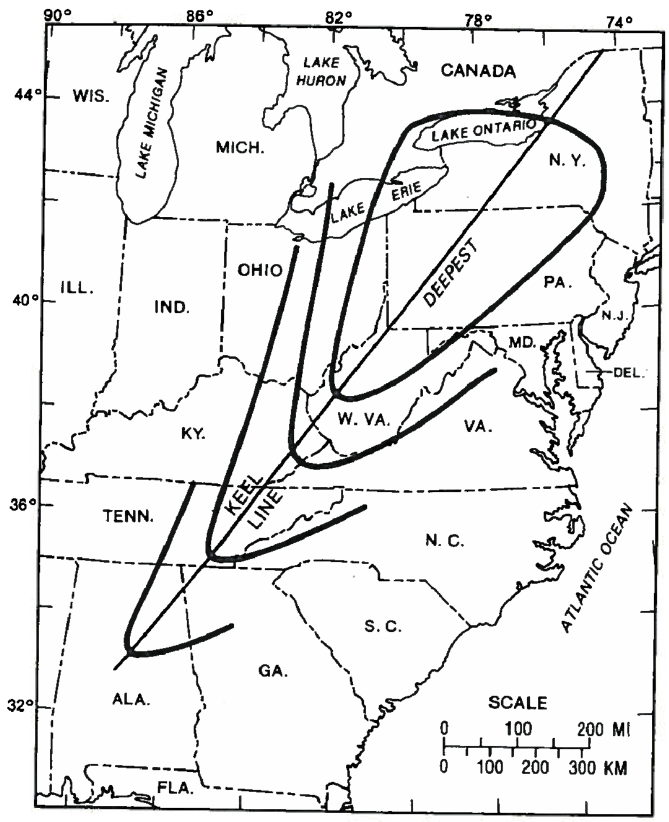

Figure 6–10. Map showing axis of elongate basin and "form lines" that indicate subsidence and sedimentary accumulation patterns during times of low detrital input during the middle and late Paleozoic (from Dennison, 1982, Figure 3). This basin architecture first appeared during Middle Silurian time.

to be deposited by streams bordering the southeastern margin of the newly developed basin (Smosna and Patchen, 1978). These deposits are identified as the Tammany Member, which is the uppermost member of the Shawangunk Formation (Lash and others, 1984). The underlying Lizard Creek Member of the Shawangunk, however, has much in common with basin-margin facies developed to the west (see comments by Lash and others, 1984, p. 83).

Central Pennsylvania—Rose Hill, Keefer, and Mifflintown Formations

The Middle Silurian succession in central Pennsylvania is represented by the Rose Hill, Keefer, and Mifflintown Formations (Figure 6–11). The Rose Hill Formation consists mostly of olive shale and also contains minor purplish shale and thin beds of hematitic sandstone (Cabin Hill and Center Members). The terms "lower shaly member," "middle shaly member," and "upper shaly member" are used informally to designate the intervals of Rose Hill mudrocks below, between, and above the hematitic sandstones. Thin beds of fossiliferous limestone also occur within the Rose Hill near the top of the upper shaly member.

The Keefer Formation conformably overlies the Rose Hill Formation (Figure 6–11). The Keefer contains quartz-cemented fossiliferous quartzose sandstone, hematitic oolitic sandstone, and minor mudrock. Sandstones of the Keefer Formation are very fine to coarse grained, silty, locally conglomeratic, crossbedded, and ripple bedded. Fossils include crinoid stems, brachiopods, and mollusc shells. The trace fossil *Skolithos* is locally abundant.

The Mifflintown Formation is composed of interbedded shallow marine mudrocks and limestones. It conformably overlies the Keefer Formation and underlies the Bloomsburg Formation (Faill and Wells, 1974).

Cotter and Inners (1986) suggested that the Rose Hill, Keefer, and Mifflintown Formations of central Pennsylvania accumulated on a submarine ramp that deepened from the proximal basin margin on the southeast to the basin axis at the approximate position of the modern Allegheny Front (Figure 6–12).

Cotter (1988, p. 242) recognized two "hierarchically superimposed cycles of sea-level fluctuations" in the medial Silurian succession of central Pennsylvania. His lithostratigraphic interpretations (Figures 6–11 and 6–12) suggest that five large-scale cycles of transgression and regression, with a mean recurrence interval of about 2.5 million years, occurred during Middle Silurian time, and that these cycles governed the development of the observed lithostratigraphic framework at the level of formations and members (Cotter, 1988, p. 242–245). Smaller scale cycles (3.3 to 9.8 feet in thickness) of sea-level fluctuations, possibly related to Milankovitch climate cycles, are superimposed on the larger scale transgressive-regressive cycles and are correlative between different contemporaneous facies (Cotter, 1988, p. 244–245).

Western Pennsylvania—Clinton Group

The Clinton Group constitutes Middle Silurian strata in western Pennsylvania. The dominant unit in these strata is the Rochester Shale (Figure 6–11), which consists of a variably fossiliferous, gray mud-

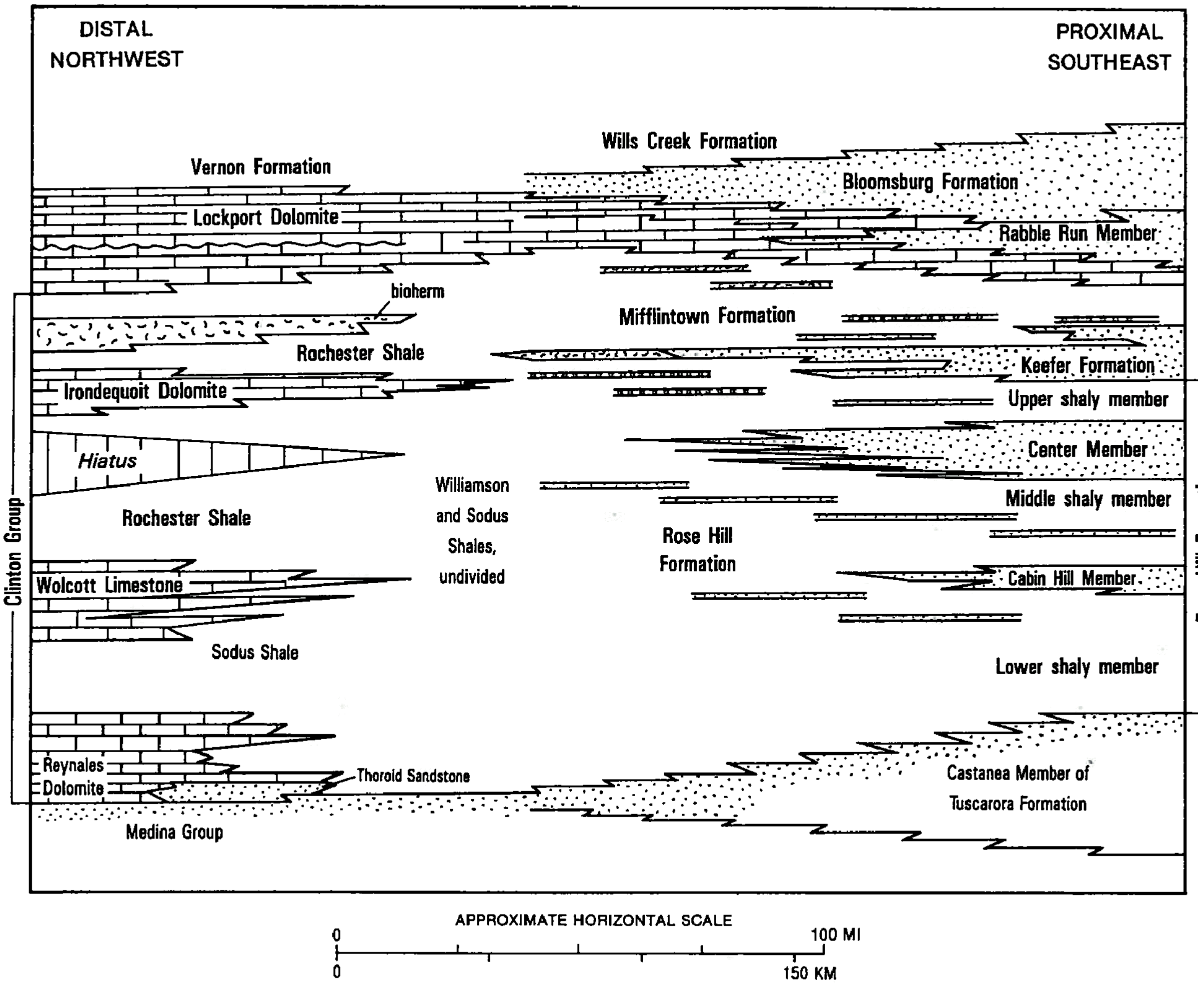

Figure 6–11. Cross section showing Middle Silurian stratigraphic units and lithofacies in central and western Pennsylvania. The cross section is oriented normal to the Appalachian basin axis in central and western Pennsylvania (from unpublished illustration by Edward Cotter, Bucknell University).

stone and numerous interbedded carbonates (Brett, 1983). The carbonate interbeds are interpreted as evidence for episodic, storm-dominated sedimentation on a gentle southeast-sloping ramp (Brett, 1983). Bioherms occur near the top of the Rochester interval toward the basin axis (Cuffey and others, 1985; Figure 6–13). The Rochester is recognized as a member of the Mifflintown Formation in central Pennsylvania (Berg, McInerney, and others, 1986).

The lower part of the Clinton Group consists of interbedded carbonate rocks (Irondequoit, Wolcott, and Reynales Dolomites, Figure 6–11), mudrocks (Williamson, Sodus, and Rochester Shales), and minor sandstone (Thorold Sandstone). These lithologies are equivalent to the Brassfield Limestone, which crops out in southern Ohio. The Brassfield splits westward in the subsurface into several carbonate rock units, which are interbedded with the Rochester Shale (Nelson and Coogan, 1984). The lower units of the Clinton Group lose their identity to the southeast and merge into the distinctive Rose Hill-Keefer sequence (Heyman, 1977; Figure 6–11).

UPPER WENLOCKIAN—LOWER LUDLOVIAN

Eastern Pennsylvania—Bloomsburg Formation

The Bloomsburg Formation of Pennsylvania is composed of grayish-red claystone, siltstone, and clayey, very fine grained to coarse-grained sandstone with small amounts of conglomerate (Hoskins, 1961).

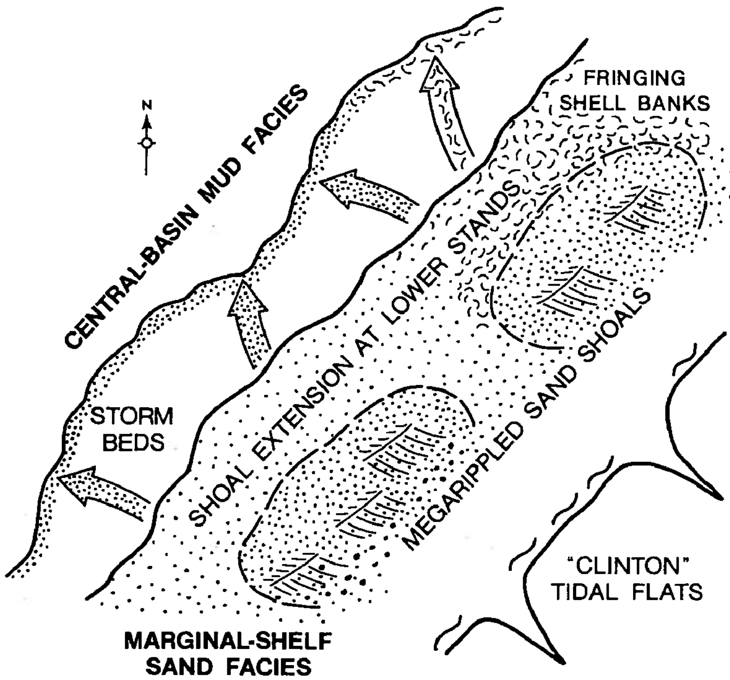

Figure 6–12. Interpretive model of Middle Silurian paleoenvironments in central Pennsylvania on the southeastern side of the Appalachian basin (from Cotter and Inners, 1986, Figure 14).

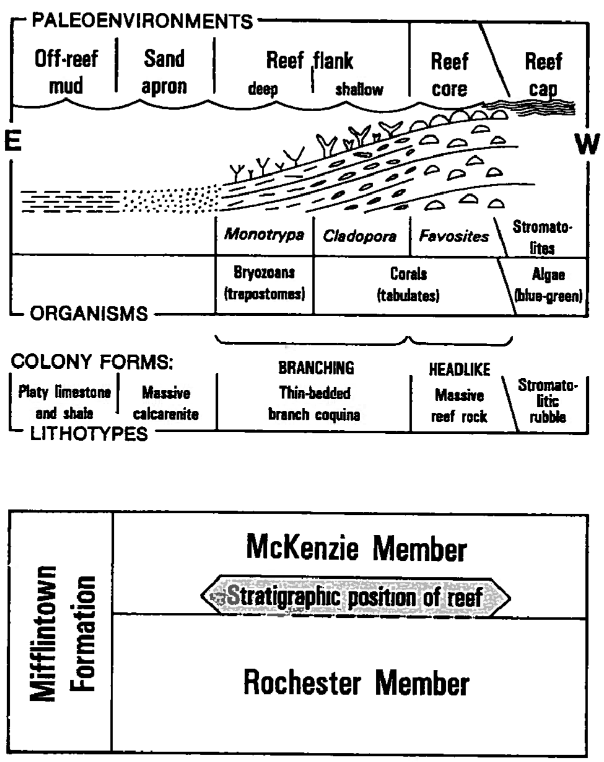

Figure 6–13. Paleoecological interpretation (top) and stratigraphic position (bottom) of a Middle Silurian reef near Lock Haven, Clinton County. Patch reefs such as this one developed on muddy Appalachian sea bottoms (from Cuffey and others, 1985, Figures 2 and 3).

Foraminifera, bryozoans, brachiopods, molluscs, ostracodes, crinoids, and fish scales have been described from the Bloomsburg Formation, but most are rare except for brachiopods and ostracodes.

A generalized stratigraphic section of the Bloomsburg Formation and its correlative units is shown in Figure 6–14. The upper and lower contacts of the Bloomsburg are conformable. The entire Bloomsburg Formation represents a time-transgressive unit. Deposition of the Bloomsburg sediments began in late Wenlockian time and continued well into Ludlovian time. The top of the Bloomsburg Formation is increasingly young toward the east (Hoskins, 1961; Berry and Boucot, 1970).

Traced to the west and southwest from the type area in central Pennsylvania, the red beds of the Bloomsburg Formation thin and are separated into two red-bed units by the marine limestones and shales of the upper member of the Mifflintown Formation (Figure 6–14). The upper red unit continues to carry the name "Bloomsburg" in the west; the lower red unit is included in the Mifflintown Formation and is called the Rabble Run Member. The upper portion of the Bloomsburg Formation contains a persistent sandy unit named the Moyer Ridge Member that is traceable over much of central Pennsylvania.

The Bloomsburg Formation probably represents part of a large volume of deltaic sediments that were deposited over an area from Virginia into New York and possibly into northern Michigan (Hoskins, 1961; Smosna and Patchen, 1978). The sediments are thought to have been deposited in waters sufficiently saline to allow a brackish-water fauna to exist. A few local deposits of nonred quartzose sandstone are interpreted as bar or beach deposits that were reworked sufficiently to remove the clay and coloring matter.

Central Pennsylvania—McKenzie Formation

The McKenzie Formation of central Pennsylvania underlies and laterally interfingers with the

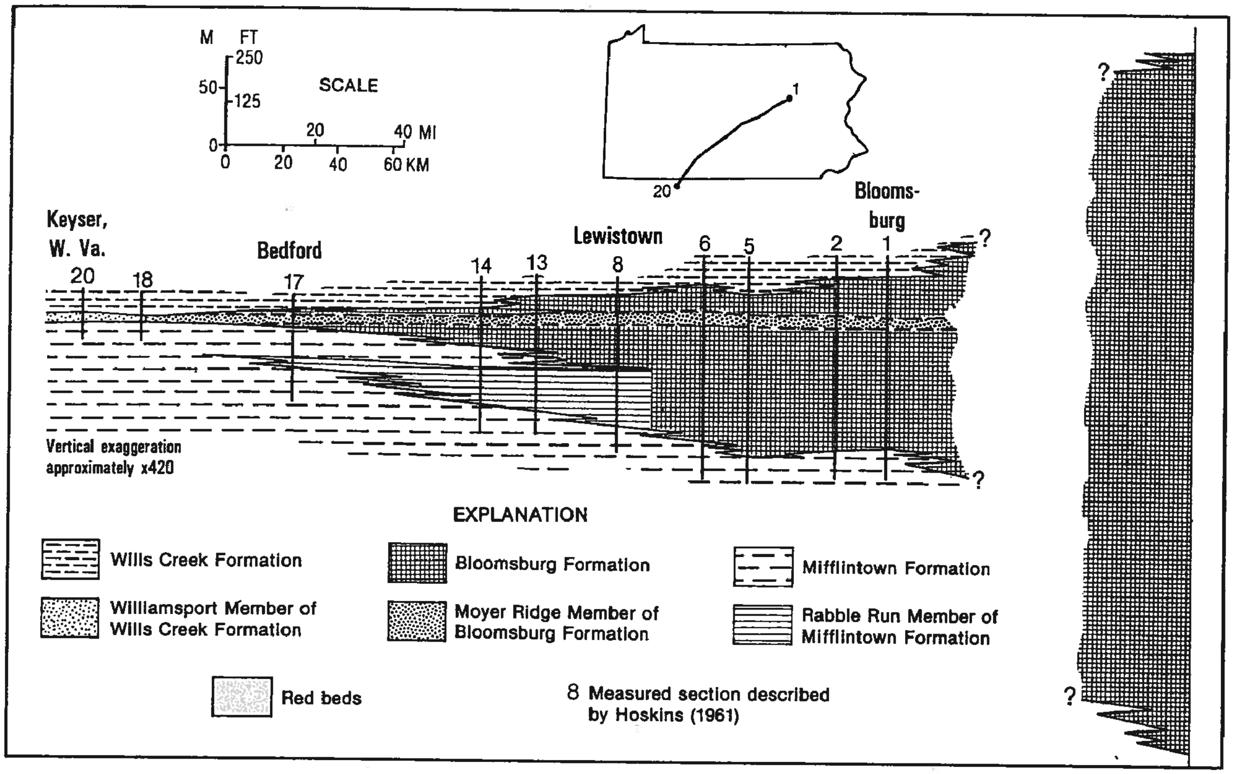

Figure 6–14. Generalized northeast-southwest stratigraphic section of the Bloomsburg Formation and its correlative units, approximately parallel to the Appalachian fold belt (modified from Hoskins, 1961, Figure 6).

Bloomsburg Formation. In much of central Pennsylvania, the McKenzie is designated as the upper member of the Mifflintown Formation; the McKenzie is given formational status in areas where other units of the Mifflintown Formation cannot be distinguished (see Berg, McInerney, and others, 1986).

The McKenzie Formation is composed of dark-olive to gray marine shales containing thin interbedded marine limestone and minor siltstone (Patchen and Smosna, 1975). It ranges in thickness from approximately 200 to 300 feet. The upper and lower boundaries are conformable. Fossils are sparse and include brachiopods, ostracodes, gastropods, and favositid corals (Cotter, 1983b). Coral/stromatoporoid bioherms in the McKenzie have been described by Patchen and Smosna (1975) and Inners (1984). Ripple marks, megaripple bedding, and trace fossils are common (Figure 6–15). The overall depositional envi-

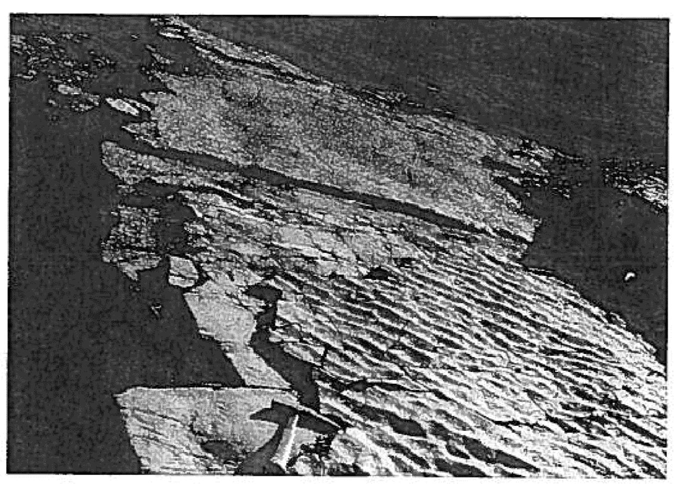

Figure 6–15. Outcrop of limestone of the McKenzie Member of the Mifflintown Formation at Castanea, Clinton County (from Nickelsen and Cotter, 1983, Figure VIII-2A, p. 189). Note the megaripples and ripples on the surface of the limestone and the interbedded shale. The latter is the dominant lithology. Photograph by R. Sacks.

ronment was open marine to intertidal. These environments fluctuated with sea level during late Wenlockian time.

Western Pennsylvania—Lockport Dolomite

The McKenzie Formation grades laterally into the Lockport Dolomite in northwestern Pennsylvania. Although it consists predominantly of dolomite, the Lockport contains some limestone (Rhinehart, 1979; Laughrey, 1987). It has an average thickness of 200 feet in the subsurface of northwestern Pennsylvania. The Lockport is divided into five members at its outcrop in western New York (Zenger, 1965; Crowley, 1973). Such formational subdivisions cannot be resolved by the parastratigraphic format utilized to recognize operational units in the subsurface of northwestern Pennsylvania (Forgotson, 1957; Heyman, 1977). Only the basal DeCew Member can be recognized using the gamma-ray format (Figure 6–16).

Cores and well cuttings of the Lockport Dolomite appear brownish gray and buff to dark gray. The carbonate rocks are finely to moderately crystalline and contain intraclasts, ooids, peloids, and numerous fossils, including stromatoporoids, corals, echinoderms, bryozoans, molluscs, and brachiopods (Figure 6–17). The Lockport Dolomite is a shallowing-upward sequence (sensu James, 1979). Microfacies analysis (Wilson, 1975) suggests that most of the Lockport was deposited subtidally in reef and interreef environments (Zenger, 1965; Crowley, 1973; Rhinehart, 1979; Shukla and Friedman, 1983; Laughrey, 1987). In the upper part of the Lockport, however, some evidence exists for intertidal and supratidal deposition. This includes associations of ooids, stromatolites, and rip-up clasts, evaporite minerals, and sabkha-type dolomite (Shukla and Friedman, 1983; Laughrey, 1987).

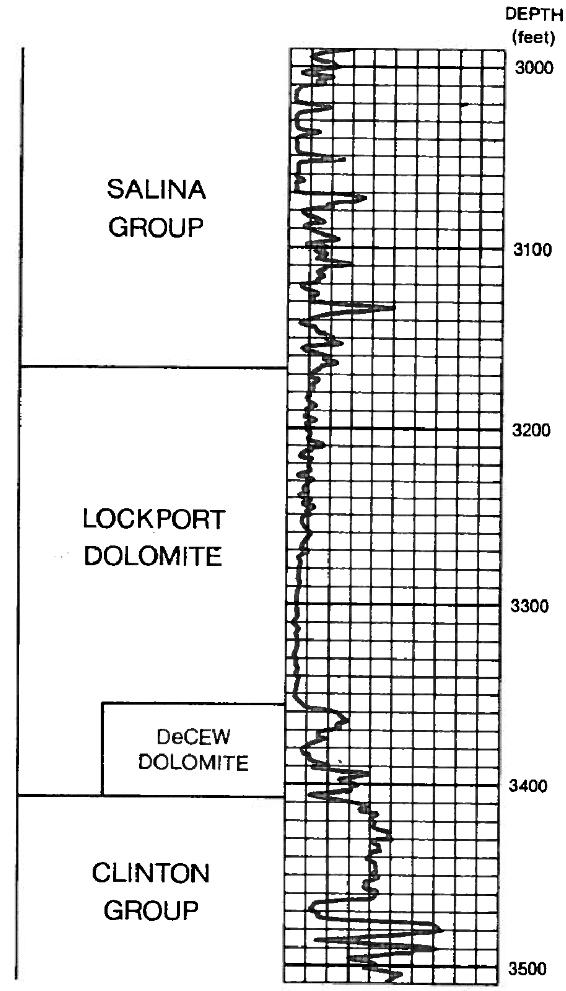

Figure 6–16. Gamma-ray geophysical log showing the stratigraphic position and geophysical character of the Lockport Dolomite and the DeCew Member in the subsurface of northwestern Pennsylvania. The log is from the Mary Mills No. 1 well, Erie County.

UPPER LUDLOVIAN—LOWER PRIDOLIAN

Northeastern Pennsylvania—Poxono Island Formation and Bossardville Limestone

The Poxono Island Formation and Bossardville Limestone lack fossils that can be used for age assignment but are considered Pridolian in age on the basis of stratigraphic position (Berry and Boucot, 1970).

The Poxono Island Formation consists of laminated to finely bedded, mud-cracked, lenticular dolomite, limestone, and calcareous shale. Fossils include brachiopod fragments and ostracodes. The Poxono Island is approximately 140 to 200 feet thick and conformably overlies the Bloomsburg Formation. The Bossardville Limestone consists of very thin bedded to laminated, argillaceous limestones and lesser amounts of calcareous shale. Ostracodes are the dominant fossils. The Bossardville averages 100 feet in thickness. It and the subjacent Poxono Island Formation were deposited in supratidal, intertidal, and subtidal marine environments (Epstein and others, 1974). Epstein and Epstein (1967) stated that there was a deepening of the basin with time, causing a shift from supratidal deposition to subtidal deposition in a restricted lagoon.

Central Pennsylvania—Wills Creek and Tonoloway Formations

The Wills Creek and Tonoloway Formations represent the upper Ludlovian and lower Pridolian global

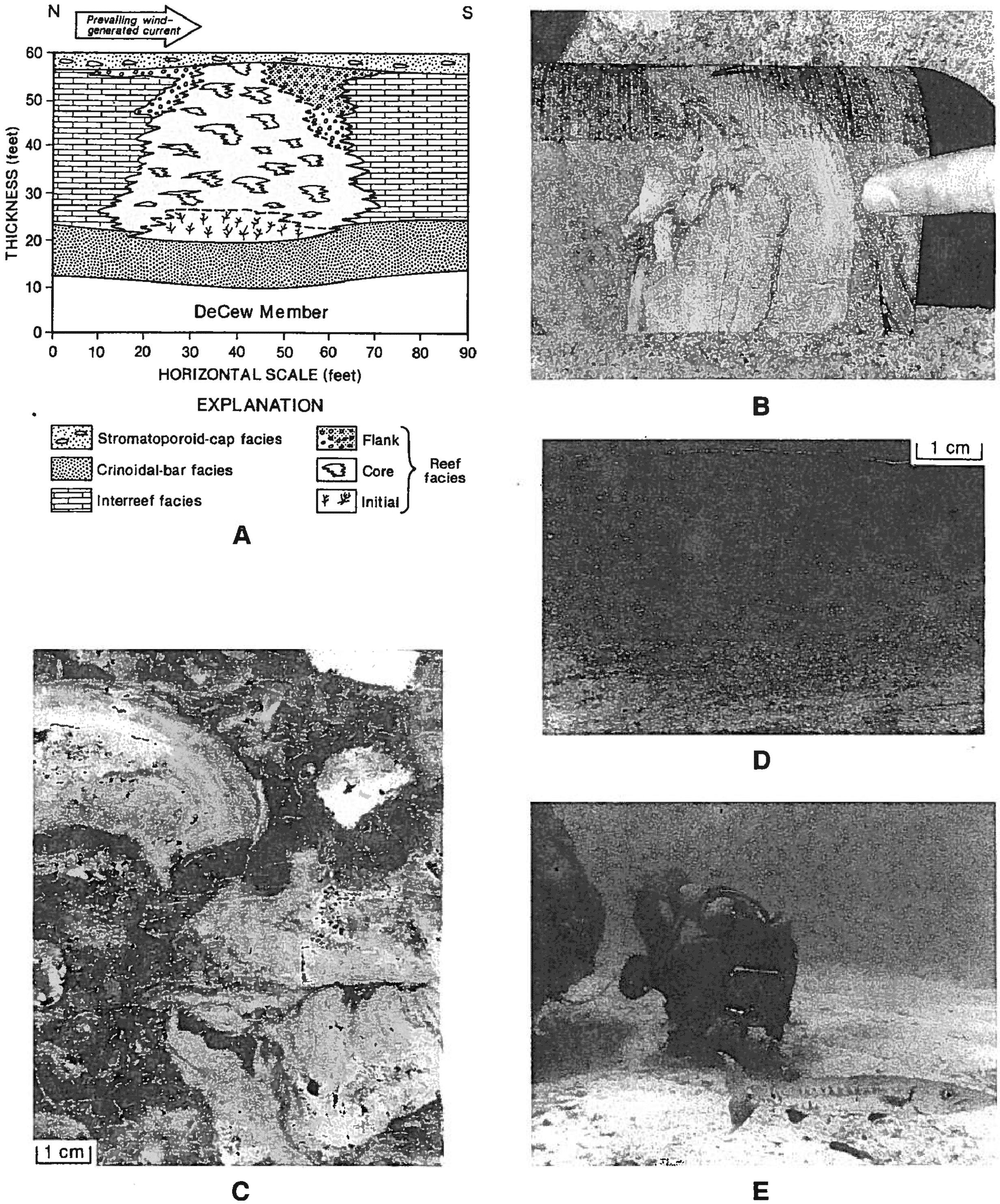

Figure 6–17. Composition and interpretation of reef and interreef lithofacies in the Lockport Dolomite of northwestern Pennsylvania. A. Schematic diagram showing the relative position of a reef-core, reef-flank, and interreef facies in the lower Lockport Dolomite (from Crowley, ©1973, Figure 12, p. 291, reprinted by permission of the American Association of Petroleum Geologists). B. Stromatoporoid in the reef-core facies of the Lockport Dolomite, G. W. Snyder well core, Mercer County. C. Stromatoporoid and coral rubble in a dolomite matrix from the reef-flank facies of the Lockport Dolomite, G. W. Snyder well core, Mercer County. D. Rippled oolitic dolomite in the interreef facies of the Lockport Dolomite, G. W. Snyder well core, Mercer County. E. Modern analog in the Florida Keys for the Lockport biostromal and biohermal lithofacies. The patch reef is just to the left of the diver. The diver and the barracuda hover over reef rubble and carbonate sand.

stages in central Pennsylvania. The Wills Creek Formation consists of variegated claystone, silty claystone, and argillaceous limestone. The thickness of the Wills Creek ranges from 250 to 500 feet. The upper and lower contacts are gradational and conformable.

The Tonoloway Formation conformably overlies the Wills Creek Formation. It consists mainly of laminated to thin-bedded limestone and a few thin beds of calcareous shale. Some thin to medium beds of dense microcrystalline limestone also occur. Faill and Wells (1974) reported the occurrence of pellet textures, ostracode shells, lenses of crystalline calcite, and sedimentary boudinage structures in the Tonoloway.

Both the Wills Creek and Tonoloway Formations consist of numerous shallowing-upward cycles that Lacey (1960), Tourek (1971), and Cotter and Inners (1986) have interpreted as repeated progradational events on very large tidal-sabkha flats (Figures 6–18 and 6–19).

Cyclicity in the Wills Creek-Tonoloway has been ascribed to both autogenic and allogenic mechanisms by different workers. Tourek (1971) proposed that localized basinal control on sedimentation is the principal mechanism governing the cyclicity observed in the sediments, whereas Anderson and Goodwin (1980) suggested eustatic control for the depositional events.

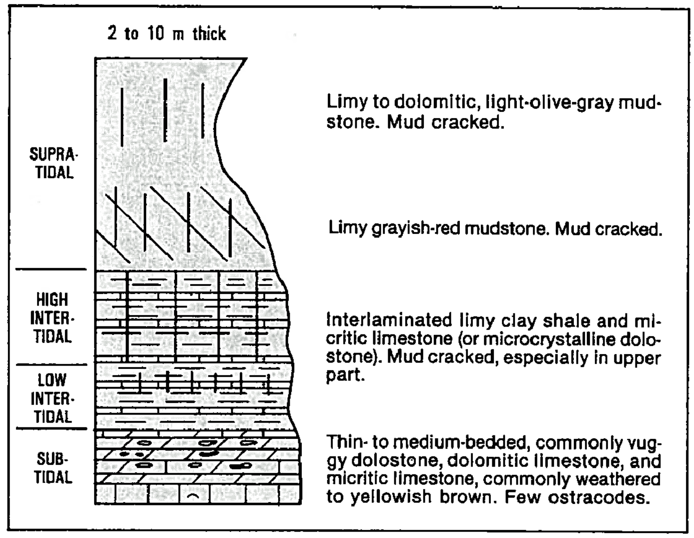

Figure 6–18. Sedimentary cycle in the Wills Creek Formation (from Cotter and Inners, 1986, Figure 16).

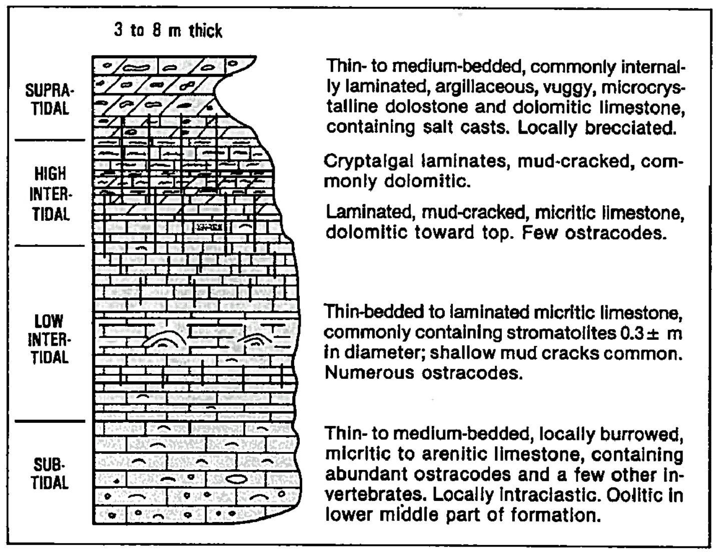

Figure 6–19. Sedimentary cycle in the Tonoloway Formation (from Cotter and Inners, 1986, Figure 16).

Western Pennsylvania—Salina Group

The Salina Group in northwestern Pennsylvania consists of interbedded carbonate and evaporite rocks. It ranges in thickness from over 2,000 feet in the southeastern part of the Appalachian Plateaus area to less than 400 feet at Lake Erie. Correlation of the Salina Group intervals with outcrop equivalents in central Pennsylvania is shown in Figure 6–20. Salt beds of Unit B in Figure 6–20 appear to be continuous from the Michigan basin into the Appalachian basin (Rickard, 1969). This unit contains the first known salt beds of the Salina deposited in Pennsylvania. Rickard (1969, p. 8) stated that the influx of terrigenous sediments of the Bloomsburg delta inhibited the deposition of evaporites in the Unit A rocks (Figure 6–20) of the central Appalachians. The distribution of Unit B indicates that the development of a subbasin in north-central Pennsylvania was controlled by the location of Niagaran reefs, the eastward restriction of the Bloomsburg delta, and a higher platform area in southwestern Pennsylvania (Fergusson and Prather, 1968). The probable paleogeography of the Salina salt basin during mid-Cayugan time is illustrated in Figure 6–21.

	SERIES	CENTRAL AND WESTERN NEW YORK (outcrop and subsurface) AND NORTH-CENTRAL PENNSYLVANIA (subsurface) (Rickard, 1969)			CENTRAL PENNSYLVANIA (outcrop)
UPPER SILURIAN (part)	Cayugan	Cobleskill-Akron Formation			Keyser Formation
		Salina Group	Bertie Formation	Unit H	Keyser Formation
					?
			Camillus Formation	Unit G	Tonoloway Formation
			Syracuse Formation	Unit F*	Tonoloway Formation
				Unit E*	Tonoloway Formation
				Unit D*	Tonoloway Formation
			Vernon Formation	Unit C	Wills Creek Formation
				Unit B*	Wills Creek Formation
				Unit A	Bloomsburg Formation (part)

*Salt beds in Pennsylvania

Figure 6-20. Correlation of evaporite-bearing intervals in the Salina Group with outcrop equivalents in central Pennsylvania (from Cotter and Inners, 1986, Figure 18).

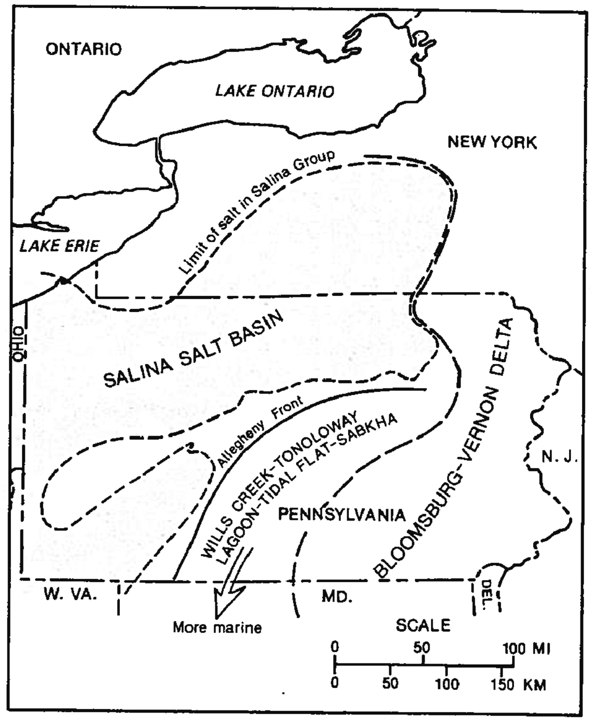

Figure 6-21. General paleogeography of the central Appalachian region in mid-Cayugan time (from Cotter and Inners, 1986, Figure 17).

UPPER PRIDOLIAN—LOWEST DEVONIAN

Eastern Pennsylvania—Keyser and Decker Formations

The Decker Formation is the youngest undisputed Silurian unit in northeastern Pennsylvania (Epstein and others, 1974). Conodonts collected by Denkler (1984) confirm the Pridolian (youngest Silurian) age of the Decker Formation. The interval is 80 to 90 feet thick in northeastern Pennsylvania and consists of arenaceous limestone and some argillaceous siltstone and sandstone. Fossils include ostracodes, brachiopods, bryozoans, stromatolites, and conodonts. The Decker formed as barrier beach and/or biostromal banks (Epstein and others, 1967) and thins to the southwest. The upper and lower contacts are conformable. In some parts of northeastern Pennsylvania, the Decker is overlain by the Andreas Red Beds. The age of the Andreas is uncertain; it may be correlative with the upper part of the Decker Formation or the lowermost Devonian Rondout Formation (Lash and others, 1984; Berg, McInerney, and others, 1986).

The Keyser Formation in eastern Pennsylvania is made up of approximately 125 feet of gray, argillaceous, fossiliferous, nodular limestone and some interbedded calcareous shale (Inners, 1981). Basal and upper contacts are conformable. Inners (1981) interpreted the lower two thirds of the Keyser in eastern Pennsylvania as having formed in a shallow-marine, subtidal shelf environment. Deposition of the upper third of the formation was in shallow lagoons and on intertidal mudflats, similar to that of the subjacent Tonoloway Formation (Inners, 1981). Silurian fossils occur in the lower part of the Keyser, whereas Devonian fossils occur in the upper part, demonstrating that the systemic boundary lies within this formation (Berdan, 1964; Bowen, 1967).

Central Pennsylvania—Keyser Formation

The Keyser Formation of central Pennsylvania represents continuous carbonate sedimentation from Late Silurian into Early Devonian time. Both Silurian and Devonian fossils occur in the Keyser (Bowen,

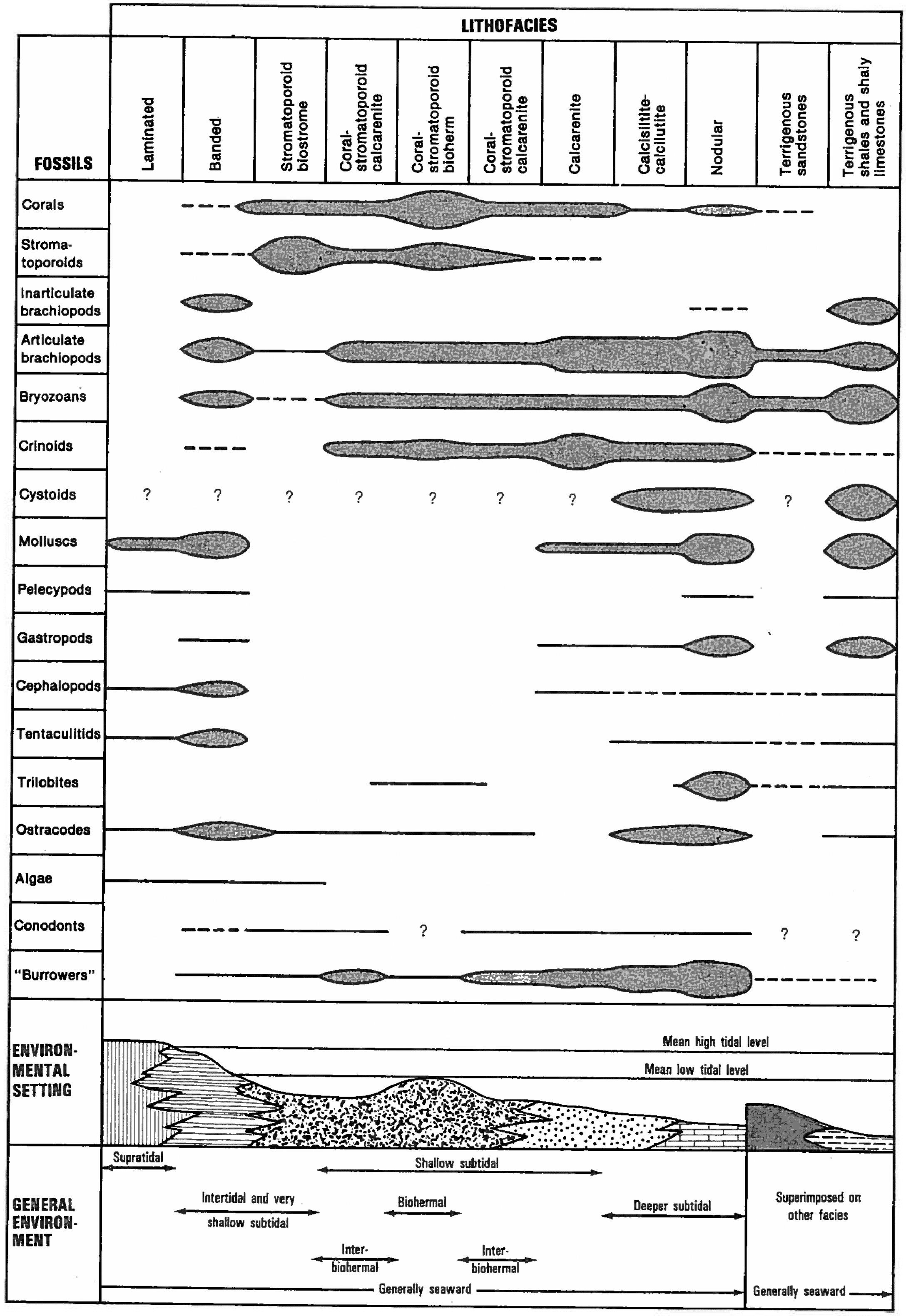

Figure 6–22. Head's (1969, Figure 33) interpretation of environmental relationships between lithofacies, fossils, and the sedimentary depositional setting of the Keyser Formation.

1967). The formation is recognized throughout the central Appalachian basin. The Keyser is a mainly gray, fossiliferous limestone. The upper part of the formation consists of laminated to thin-bedded limestone and dark-gray chert nodules. The rest of the formation is thin to very thick bedded. Stylolites commonly parallel the bedding. Fossils are typically, but not always, disarticulated. Fragments of brachiopods, crinoids, bryozoans, molluscs, and ostracodes are common, but unbroken specimens occur (Hoskins and others, 1983). The reported thickness of the Keyser ranges from 75 to 202 feet. The lower contact of the Keyser with the Tonoloway is sharp and conformable. The upper contacts with Lower Devonian lithologies are less distinctive. In east-central Pennsylvania, the upper Keyser limestones grade upward into cherty limestone and shale, which in turn grade upward into the Devonian Old Port Formation. To the west, the top of the Keyser Formation is marked by a distinct chert bed (Conlin and Hoskins, 1962). Head (1969) described the variations in marine sedimentary environments that existed in the central Appalachians during deposition of the Keyser Formation (Figure 6–22).

Western Pennsylvania—Keyser Formation and Equivalents

In west-central Pennsylvania, the Keyser Formation is recognized in the subsurface of the Appalachian Plateaus province (Heyman, 1977). Farther west and northwest, the lower part of the Keyser is equivalent to the Silurian Bertie Dolomite, Akron and Cobleskill Dolomites, and Bass Islands Dolomite. The uppermost part of the Keyser is equivalent to the Lower Devonian Manlius Formation. In extreme northwestern Pennsylvania, the basal lithologies of the Devonian Onondaga and Oriskany Formations lie directly on the Silurian rocks. This interval, from the base of the Devonian Onondaga Group to the top of the Salina Group, is one of very abrupt lithic changes (Heyman, 1977).

PROBLEMS AND FUTURE RESEARCH

A number of challenging problems and topics for further study await the geologist interested in Silurian sedimentation and stratigraphy in Pennsylvania. A review of these topics is beyond the scope of this article, and those who are curious should read publications listed in "Recommended For Further Reading." A few of the unresolved subjects, however, warrant special mention. The provenance of the framework constituents in the sandstones and conglomerates of the Shawangunk Formation is enigmatic (Epstein and Epstein, 1972). Considerable work is still needed with regard to cyclicity and correlation in the Medina and Tuscarora intervals. The origin of channel deposits in the Grimsby Sandstone and the possible fluvial nature of the lower part of the Whirlpool Sandstone deserve careful attention (Duke and Brusse, 1987; Middleton and others, 1987). Silurian carbonates are mostly dolomitized in the subsurface of western Pennsylvania, whereas mostly limestones occur in the outcrop belt of central Pennsylvania. The differences in the diagenetic history of these rocks would make an excellent research project. Further resolution of the mechanisms controlling cyclicity in the Wills Creek-Tonoloway interval is needed. Finally, detailed correlation and stratigraphy of the interval between the top of the Salina Group and the base of the Onondaga Group would improve our understanding of the subsurface Upper Silurian and Lower Devonian rocks in western Pennsylvania.

RECOMMENDED FOR FURTHER READING

Berdan, J. M. (1964), *The Helderberg Group and the position of the Silurian-Devonian boundary in North America,* U.S. Geological Survey Bulletin 1180-B, 19 p.

Cotter, Edward (1982), *Tuscarora Formation of Pennsylvania,* Society of Economic Paleontologists and Mineralogists, Eastern Section, 1982, Guidebook, 105 p.

________ (1983), *Shelf, paralic, and fluvial environments and eustatic sea-level fluctuations in the origin of the Tuscarora Formation (Lower Silurian) of central Pennsylvania,* Journal of Sedimentary Petrology, v. 53, p. 25–49.

Epstein, J. B., and Epstein, A. G. (1972), *The Shawangunk Formation (Upper Ordovician(?) to Middle Silurian) in eastern Pennsylvania,* U.S. Geological Survey Professional Paper 744, 45 p.

Fergusson, W. B., and Prather, B. A. (1968), *Salt deposits in the Salina Group in Pennsylvania,* Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 58, 41 p.

Hoskins, D. M. (1961), *Stratigraphy and paleontology of the Bloomsburg Formation of Pennsylvania and adjacent states,* Pennsylvania Geological Survey, 4th ser., General Geology Report 36, 125 p.

Laughrey, C. D. (1984), *Petrology and reservoir characteristics of the Lower Silurian Medina Group sandstones, Athens and Geneva fields, Crawford County, Pennsylvania,* Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 85, 126 p.

Smosna, Richard, and Patchen, Douglas (1978), *Silurian evolution of central Appalachian basin,* AAPG Bulletin, v. 62, p. 2308–2328.

Yeakel, L. S., Jr. (1962), *Tuscarora, Juniata, and Bald Eagle paleocurrents and paleogeography in the central Appalachians,* Geological Society of America Bulletin, v. 73, p. 1515–1540.