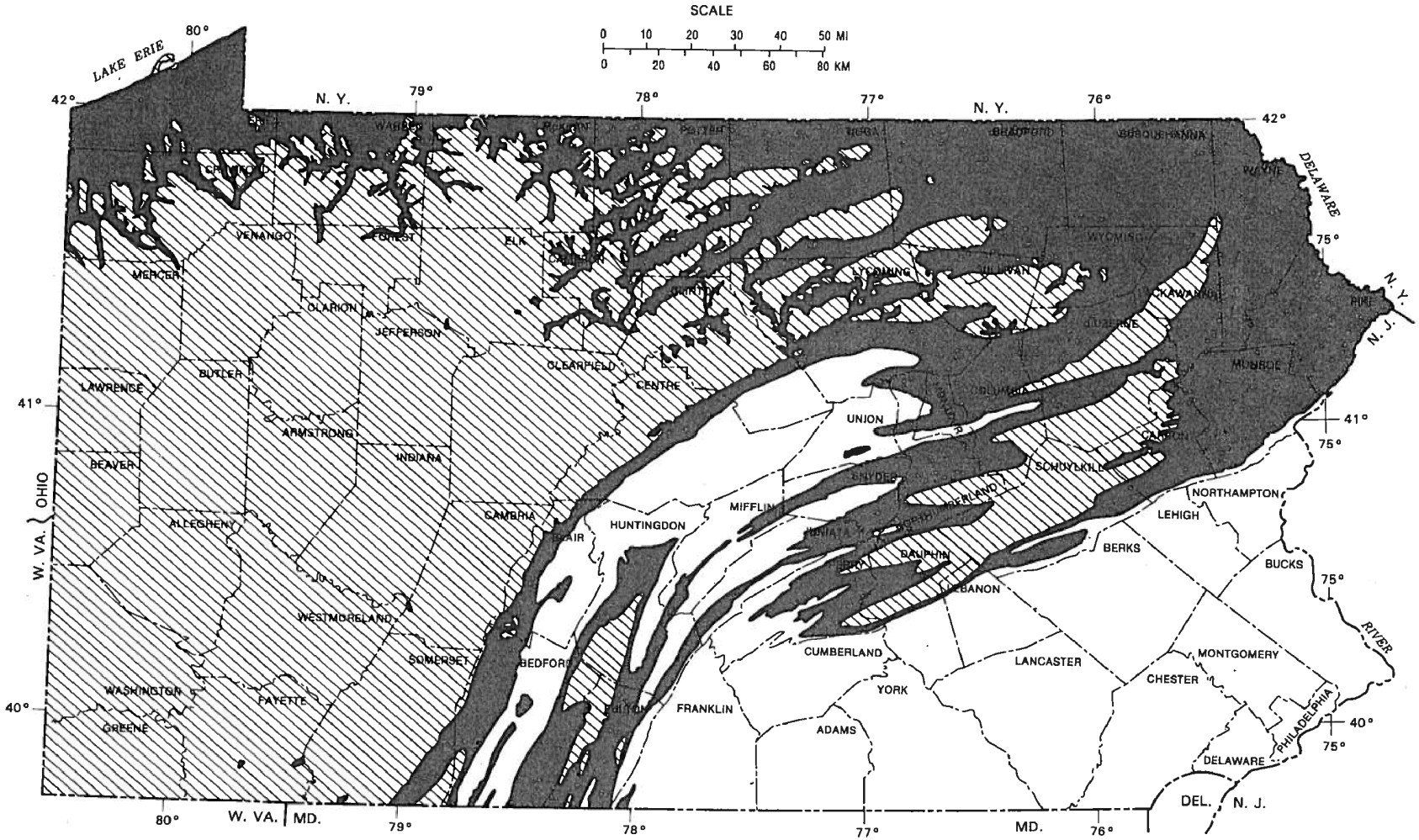

Figure 7–1. Generalized geographic extent of Devonian rocks at the surface (solid color) and in the subsurface (line pattern) in Pennsylvania (from Pennsylvania Geological Survey, 1990).

CHAPTER 7 DEVONIAN

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INTRODUCTION

Sedgwick and Murchison (1839) named the Devonian System on the basis of marine rocks exposed in Devonshire, England. At about the same time, the New York Geological Survey demonstrated that the Devonian section in New York was structurally less complex and stratigraphically more complete than the British section. The New York outcrop belt, recognized as the standard Devonian section in North America, would have been a much better systemic type section than the British section.

The Devonian System in Pennsylvania is thicker and more extensive than even the New York section, but much of it lies in the subsurface in western Pennsylvania (Figure 7-1). It is a westward-thinning wedge of sediments. Its thickness has been measured or estimated at 2,400 feet in Erie County and over 12,000 feet in eastern Pennsylvania (Figure 7-2). Mudrocks are dominant in the Devonian section; however, small amounts of chert and limestone are important constituents in the lower half, and larger quantities of siltstones, sandstones, and conglomerates dominate parts of the upper half. The upper and lower boundaries of the system are mostly conformable, but there are notable exceptions. In northwestern Pennsylvania, near the craton margin, the lower boundary is disconformable, whereas in eastern Pennsylvania, near the major sediment source areas, the upper boundary is disconformable.

The Devonian Period was a time of abundant life and significant changes or developments in biotic history. These include the Early Devonian development of widespread biohermal deposits ("reefs") dominated by stromatoporoids and corals, the rapid adaptive radiation of fishes, the appearance in the Late Devonian of the first land vertebrates, the rise of land plants and the development of primitive forests, and an important mass extinction event within the Upper Devonian (Senecan-Chautauquan boundary). Lower and Middle Devonian rocks in Pennsylvania have the best record of body fossils within the system, but the abundance and diversity of trace fossils in the

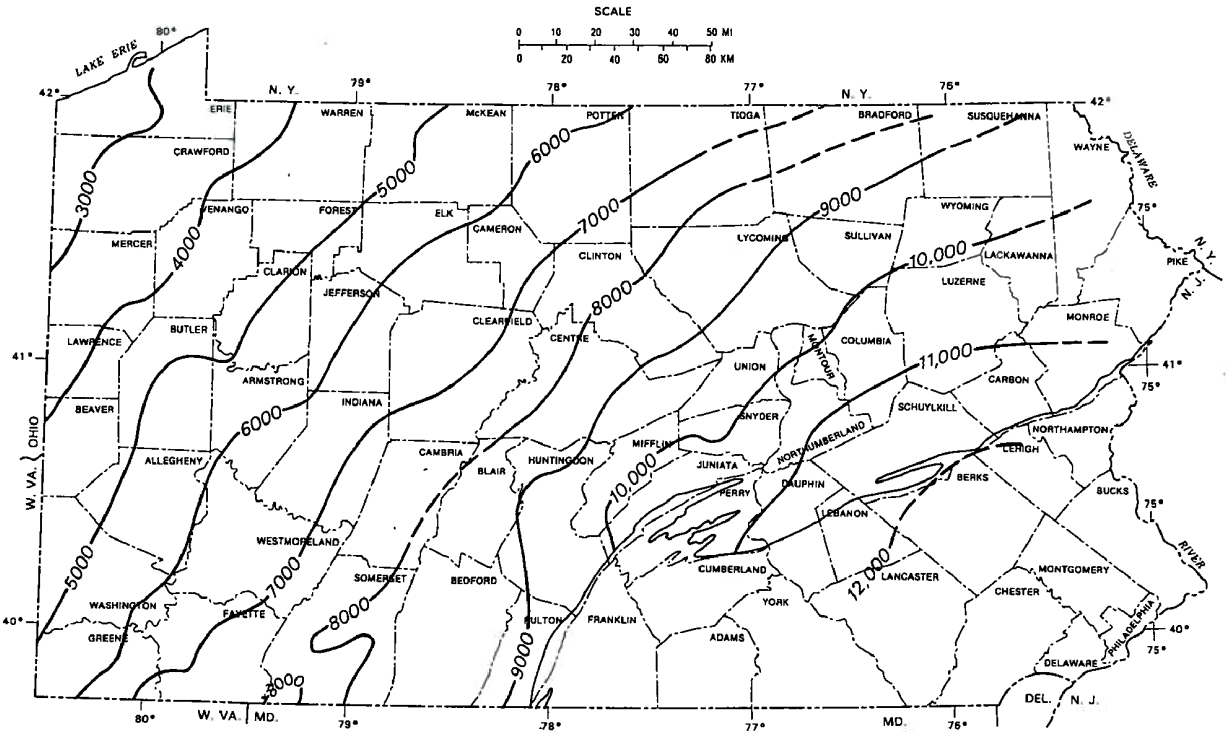


Figure 7–2. Isopach map showing the total thickness of the Devonian section in Pennsylvania, in feet (modified from Oliver and others, 1971, Sheet 7). Contour interval is 1,000 feet. The thin colored line represents the eastern limit of Devonian outcrop.

Upper Devonian indicate that large numbers of marine, freshwater, and terrestrial animals existed at the time of deposition (Hoskins and others, 1983). Land plants thrived in the deltaic plains and eventually formed localized thin layers of coal.

STRATIGRAPHY

Rocks of the Devonian System in Pennsylvania consist primarily of Lower Devonian marine carbonates, cherts, and shales, and Upper Devonian marine to nonmarine, coarse- to fine-grained terrigenous rocks deposited in the prograding Catskill deltaic system. The characteristic rocks of these two divisions interfinger in the Middle Devonian. The descriptions of formations that follow apply primarily to units exposed in central Pennsylvania. For equivalent formations and areas where various formation names are applicable, see Figures 7–3 and 7–4.

Lower Devonian

Rocks of the Lower Devonian consist of strata ranging from bioclastic shelf carbonates to very coarse grained detrital sandstones. Rocks of the Helderbergian Stage are typically limestones and include minor amounts of shale, chert, and detrital quartz (Figure 7–5). Quartz sandstones, siltstones, and shales make up the greatest part of Deerparkian Stage rocks, but limestones and cherts are important constituents, especially in central and eastern Pennsylvania (Figure 7–6). Coarse to fine detrital sediments characterize strata of the lower Onesquethawan Stage.

The basal Devonian unit in Pennsylvania, the Keyser Formation, is discussed in the preceding chapter. The non-Keyser portion of the Helderbergian Stage consists of the New Creek and Corriganville Limestones and the Mandata Shale (Figure 7–3). The limestones are distinguished from the underlying Keyser by their lighter color, lower chert content, and thicker, more massive bedding. Willard and others (1939) felt that the Keyser-New Creek boundary is disconformable throughout central Pennsylvania, but this was not substantiated by later investigations (e.g., de Witt and Colton, 1964; Faill and Wells, 1974). The New Creek Limestone is typically a coarse-grained, massive- to thick-bedded, fragmental biosparite ranging from 3 to 10 feet thick. It

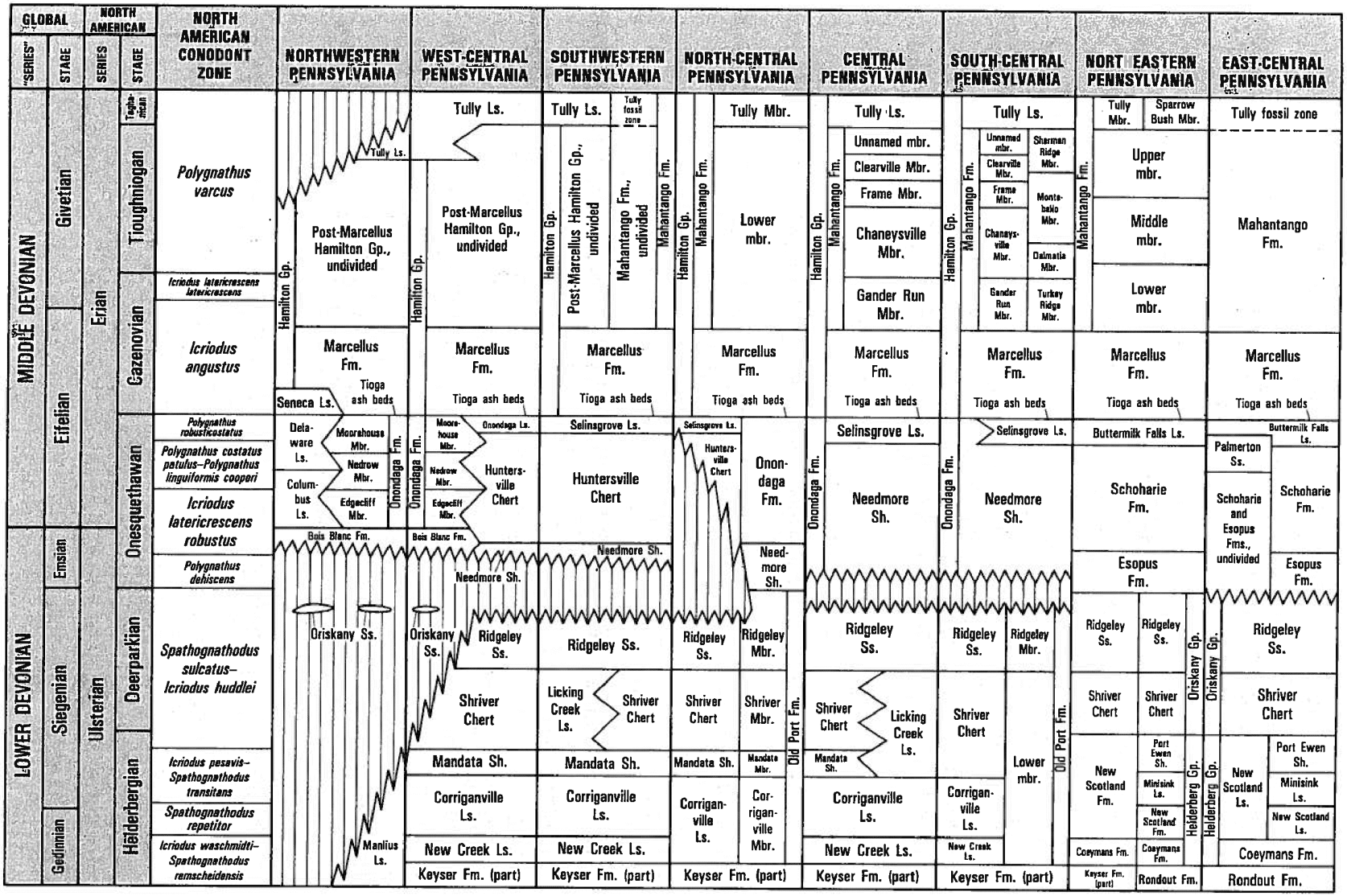


Figure 7–3. Stratigraphic correlation chart of Lower and Middle Devonian rocks in Pennsylvania (modified from Berg, McInerney, and others, 1986, and Rickard, 1975).

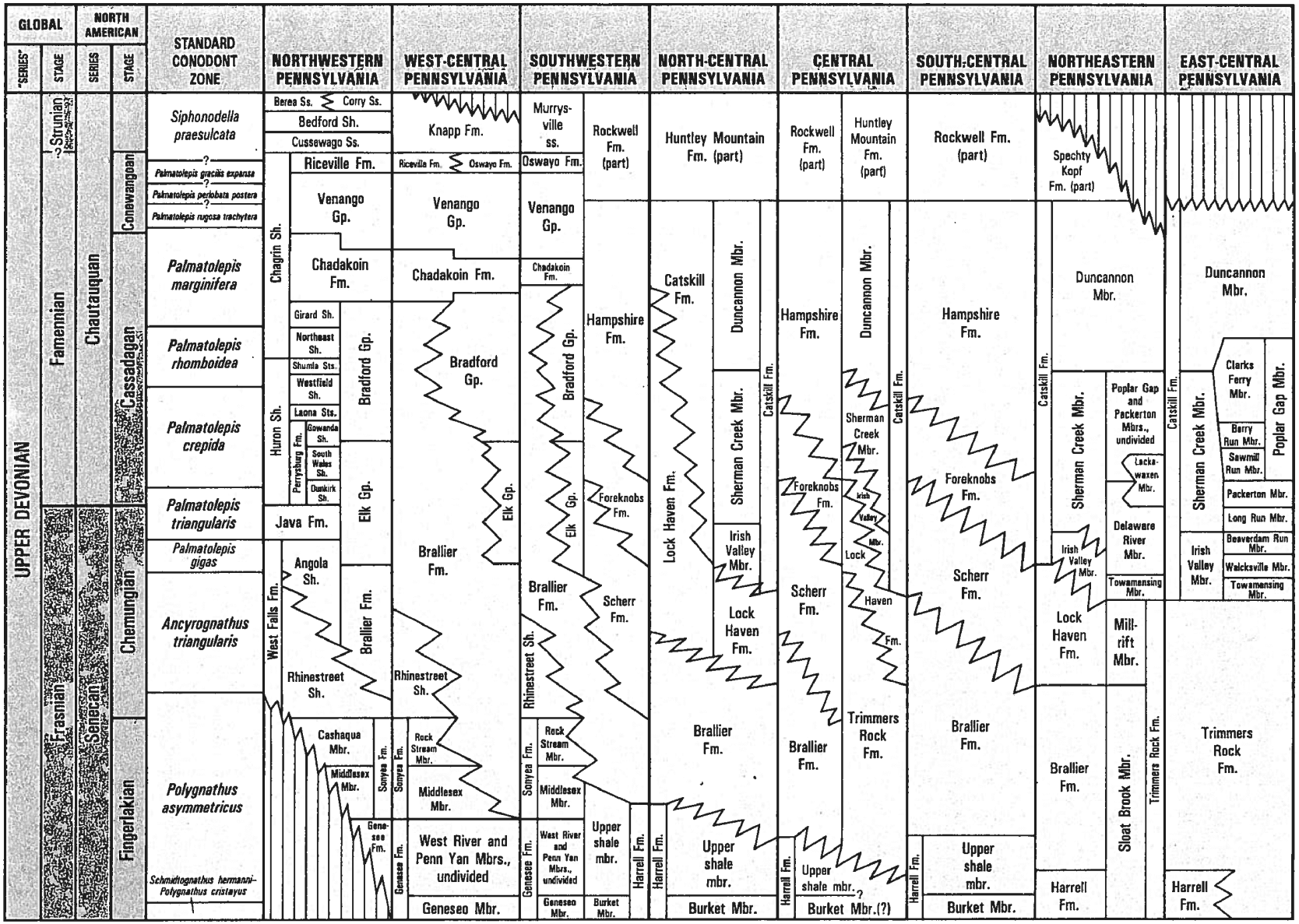


Figure 7–4. Stratigraphic correlation chart of Upper Devonian rocks in Pennsylvania (modified from Berg, McInerney, and others, 1986, and Rickard, 1975).

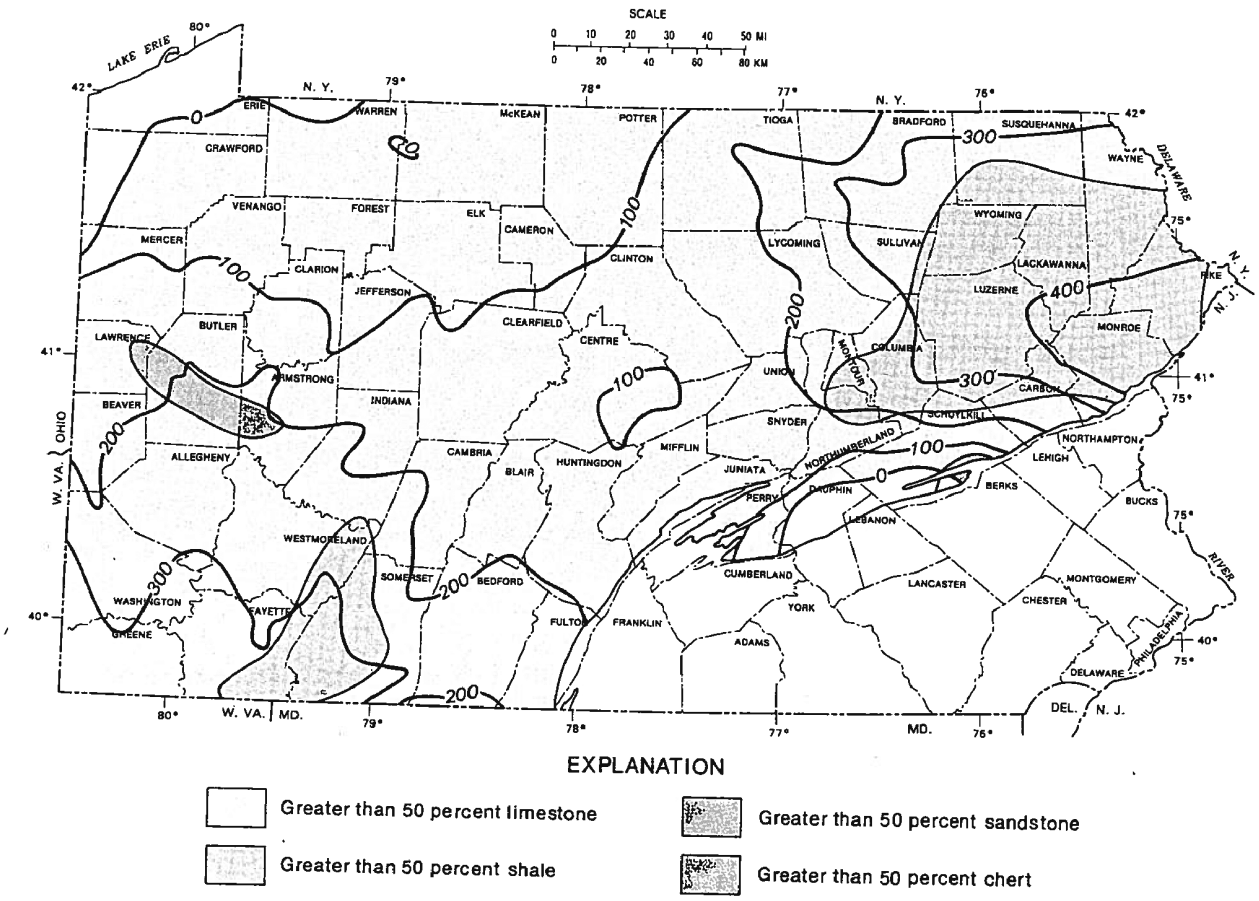


Figure 7–5. Generalized isopach and lithofacies map of the Helderbergian Stage in Pennsylvania (modified from Oliver and others, 1971, Sheet 2). Contour interval is 100 feet. The thin colored line represents the eastern limit of Devonian outcrop.

grades into the Corriganville Limestone, which consists of finely crystalline, thick- to thin-bedded limestones 10 to 30 feet thick. The New Creek is typically the more fossiliferous of the two. These limestone units are difficult to separate, especially in the subsurface (Heyman, 1977) (Figure 7–7). The Mandata Shale is dark gray to black, splintery, thin bedded, fissile to blocky, and siliceous. It contains interbedded chert and limestone layers and small nodules of phosphate. It grades into the Corriganville Limestone and ranges from 20 to 100 feet thick in central Pennsylvania. In northwestern Pennsylvania, the entire sequence of Helderbergian strata consists of carbonates that are referred to by the New York name, Manlius Limestone (Berg, McInerney, and others, 1986). The Manlius, including the Keyser portion, is commonly labeled "Helderberg" by drillers in the area.

The Shriver Chert, Licking Creek Limestone, and Ridgeley Sandstone constitute the strata of the Deerparkian Stage in central Pennsylvania. Light-colored, thin-bedded, cherty and silty mudstones and calcareous and siliceous siltstones characterize the Shriver throughout its outcrop, where it ranges from 80 to 170 feet thick. It grades laterally into the Licking Creek Limestone. The Licking Creek is about 90 feet thick at its type locality in Franklin County, south-central Pennsylvania. Both the Shriver and Licking Creek grade vertically into the Ridgeley Sandstone in an interval of cherty, calcareous siltstone and medium-grained calcareous sandstone or arenaceous limestone. The Ridgeley and its northwestern Pennsylvania equivalent, the Oriskany Sandstone, consist of lithologies ranging from calcareous, fine-grained sandstone to noncalcareous conglomerate, but the dominant lithology is generally white to light-gray, medium-grained, silica-cemented, quartzose sandstone (Figure 7–8).

The Ridgeley ranges in thickness from 8 to 150 feet in outcrop, and in the subsurface decreases from

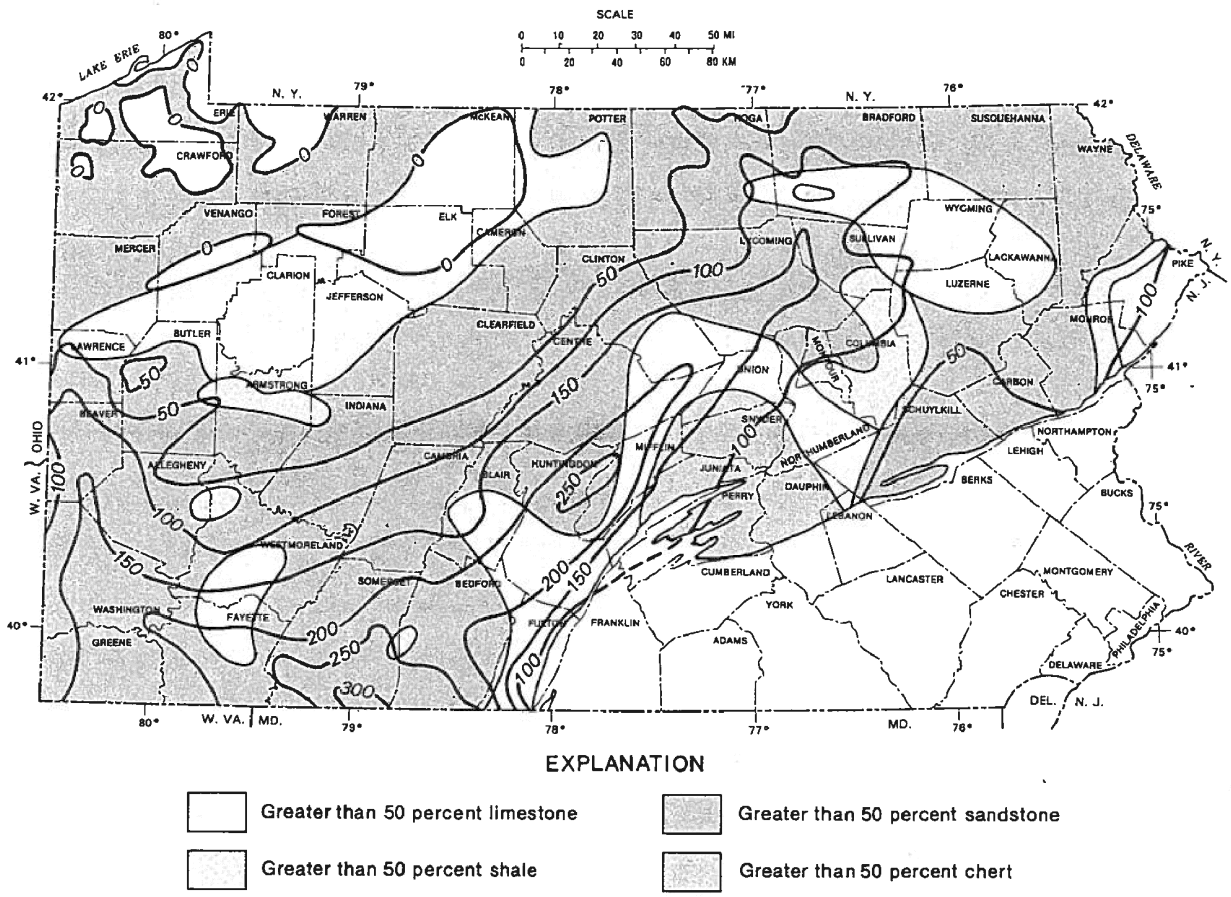


Figure 7–6. Generalized isopach and lithofacies map of the Deerparkian Stage in Pennsylvania (modified from Oliver and others, 1971, Sheet 3). Contour interval is 50 feet. The thin colored line represents the eastern limit of Devonian outcrop.

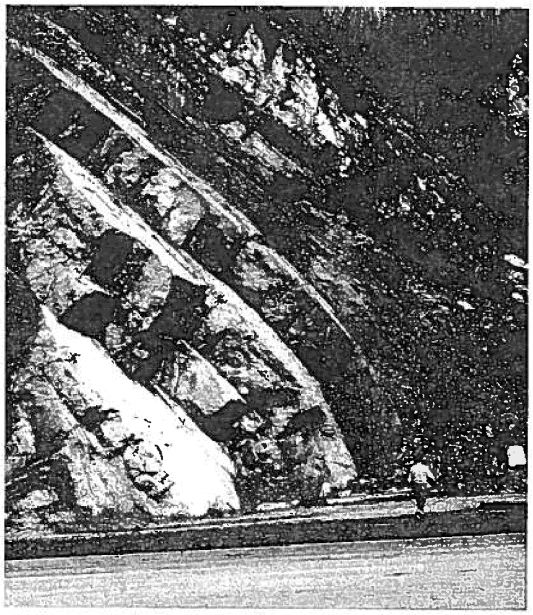


Figure 7–7. Folded and tilted Keyser and Corriganville-New Creek limestones exposed in Everett, Bedford County, are typical of Helderbergian Stage limestones.

over 250 feet in Clearfield County to 0 feet along a pinch-out in northwestern Pennsylvania (Abel and Heyman, 1981). The Oriskany occurs as almost pure quartzose sandstone in patches less than 30 feet thick that generally follow the trends of salt-solution cavities in the Upper Silurian Salina Formation (Kelley and McGlade, 1969).

The Lower Devonian portion of the Onesquethawan Stage (Figures 7–3 and 7–9) is represented by the lower part of the Needmore Shale in central Pennsylvania (discussed under "Middle Devonian" below), the Bois Blanc Formation in the northwest, the lower part of the Schoharie Formation, and the Esopus Formation in the northeast. The Bois Blanc consists of less than 100 feet of sandstone grading upward to silty, shaly, and cherty limestones. It is tran-

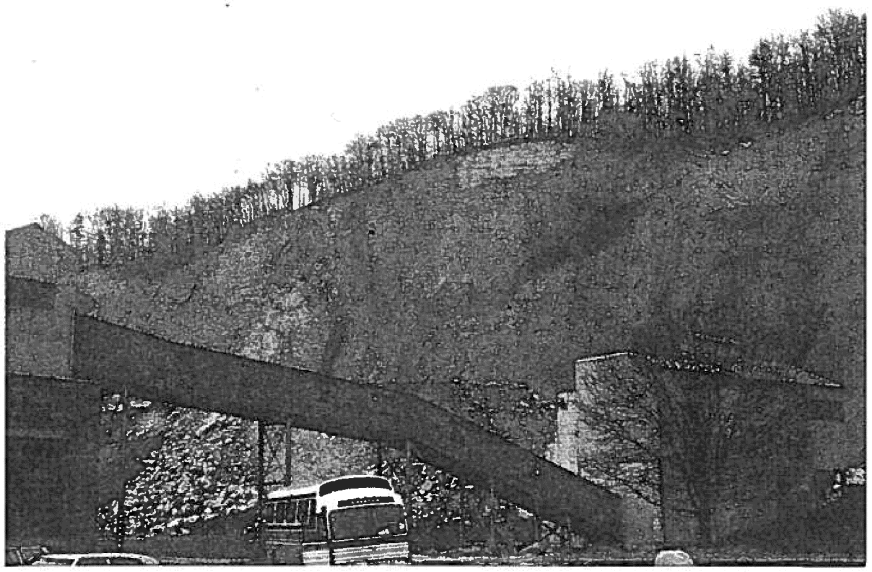


Figure 7–8. Mined outcrop of the Deerparkian Ridgeley Sandstone at a glass-sand plant near Mount Union, Huntingdon County.

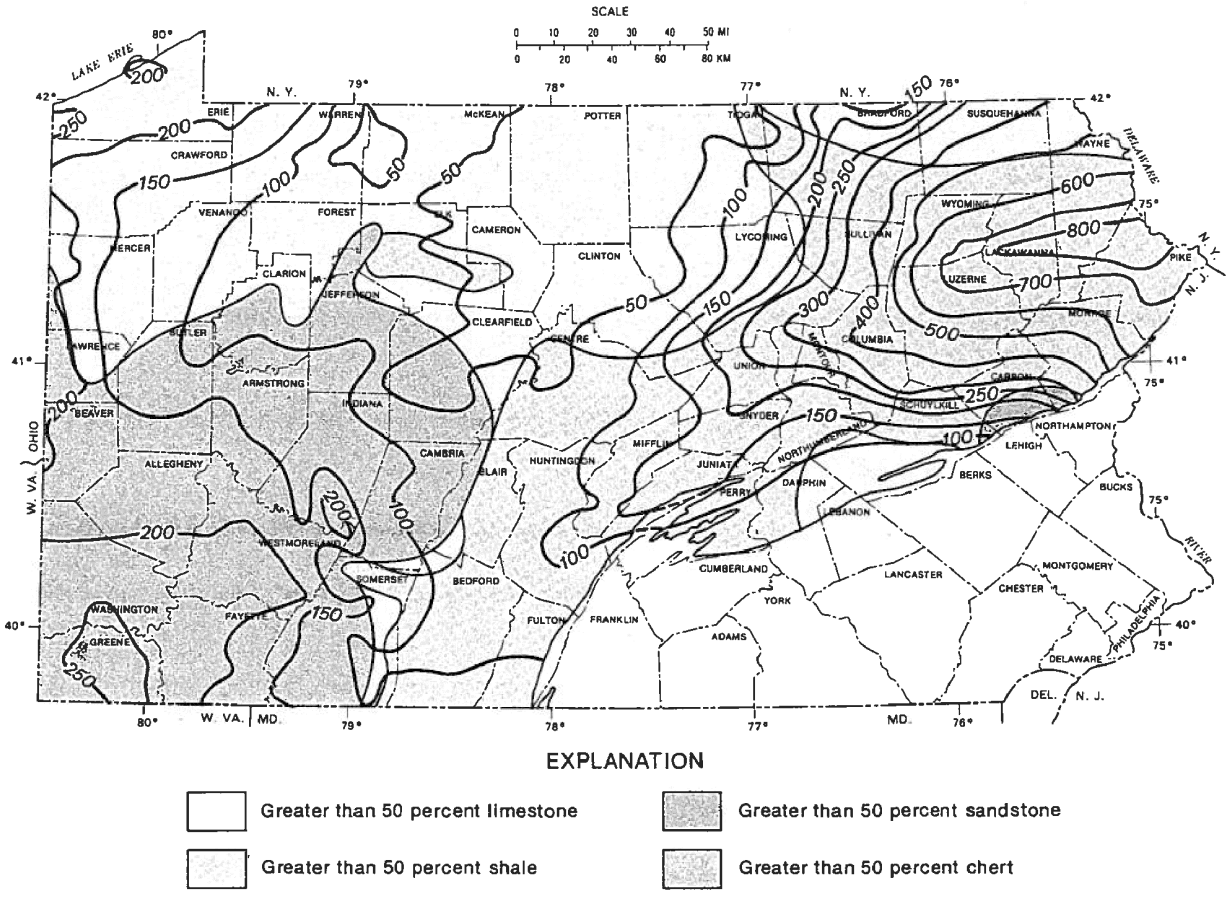


Figure 7–9. Generalized isopach and lithofacies map of the Onesquethawan Stage in Pennsylvania (modified from Oliver and others, 1971, Sheet 4). Contour interval is 100 feet in northeastern Pennsylvania and 50 feet elsewhere. The thin colored line represents the eastern limit of Devonian outcrop.

sitional with the overlying Onondaga Formation, but the basal contact is disconformable (Heyman, 1977). Drillers typically call the Bois Blanc "Oriskany" because of its sandy and silty nature (Harper, 1982). The correlative Esopus Formation consists of dark, light-gray, or brown shales, medium- to dark-gray silty shales, and argillaceous to finely arenaceous siltstones up to 300 feet thick (Epstein and others, 1967). It grades upward into the Schoharie Formation, and the two formations are essentially undifferentiable in the eastern counties.

Middle Devonian

Middle Devonian rocks range from basinal marine shales to nonmarine sandstones. Rocks of the upper Onesquethawan Stage (Figure 7–9) consist of marine cherts, shales, and limestone. The Cazenovian and Tioughniogan Stage rocks (Figure 7–10) are dominated by marine-shelf shales and limestones at the northern and western basin margins, and by coarser nearshore and deltaic detrital rocks in the basin proper. The marine Tully Limestone and its detrital equivalents, where present, make up the rocks of the Taghanican Stage in the uppermost Middle Devonian.

In central Pennsylvania, the formations representing the Onesquethawan Stage are the Needmore Shale and the overlying Selinsgrove Limestone (Inners, 1979). The Needmore, a medium-gray to black, calcareous, commonly fossiliferous shale between 100 and 150 feet thick, grades into the Selinsgrove but lies disconformably on the Ridgeley Sandstone. In west-central Pennsylvania, the upper two thirds of the Needmore grades laterally into the dark-gray, slightly calcareous, locally glauconitic Huntersville Chert. The

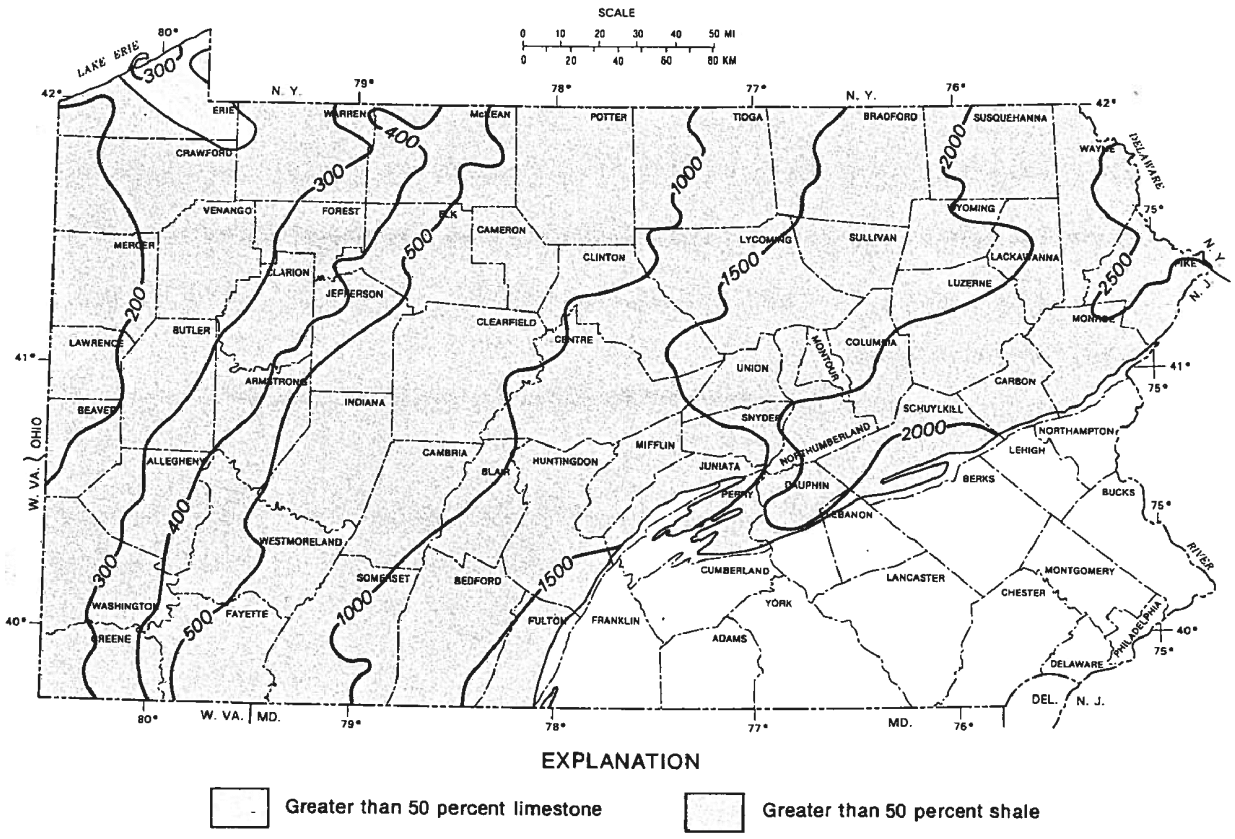


Figure 7–10. Generalized isopach and lithofacies map of the combined Cazenovian, Tioughniogan, and Taghanican Stages (Erian Series) in Pennsylvania (modified from Oliver and others, 1971, Sheet 5). Contour interval is 100 feet in western Pennsylvania and 500 feet elsewhere. The thin colored line represents the eastern limit of Devonian outcrop.

Huntersville is as thick as 250 feet in Fayette and Westmoreland Counties (Jones and Cate, 1957). It grades laterally into the very fine grained to crystalline, light- to dark-brownish-gray, somewhat argillaceous and cherty limestones of the Onondaga Formation in the subsurface of northwestern Pennsylvania (Fettke, 1961). The lower member of the Onondaga Formation, the Edgecliff, may contain a pinnacle-reef facies both in outcrop and in the subsurface (Piotrowski, 1976). To the east, the Onesquethawan section is dominated by argillaceous and calcareous siltstones and white, coarse- to fine-grained sandstones of the Schoharie and Palmerton Formations. The Buttermilk Falls Limestone, a thick (up to 200 feet in Monroe County), argillaceous, and silty formation, occupies the position of the Selinsgrove Limestone in this area (Epstein and others, 1967).

The Tioga ash zone, a series of at least six layers of brown, yellowish-brown, or brownish-gray micaceous shales of volcanic origin (Way and Smith, 1985), marks the approximate boundary between the Onesquethawan and Cazenovian Stages of the Middle Devonian (Figure 7–3). The Tioga, which occurs interbedded with Onesquethawan limestones and limy mudrocks and Cazenovian shales, contains up to 45 percent biotite, but the altered-clay fraction of the shale changes, depending on the surrounding formations (Roen and Hosterman, 1982). Way and Smith (1985) suggested that the Tioga resulted from three separate volcanic events.

A series of four formations, consisting mostly of shales with interbedded or intertonguing limestones, siltstones, and sandstones, constitutes the Hamilton Group (Cazenovian and Tioughniogan Stages) in New York (Rickard, 1975). In the subsurface of western Pennsylvania, these formations are increasingly coarse grained and indivisible to the south and east. In central and eastern Pennsylvania, the Hamilton Group is replaced by the Marcellus and Mahantango Formations (Figure 7–3). The Marcellus consists of 75 to 800 feet of dark-gray to black, highly fissile, homogeneous, carbonaceous shales containing locally abundant pyrite and few fossils. The Mahantango Formation is a complex series of interbedded shales, siltstones, and sandstones ranging from 1,200 to 2,200 feet thick in central and eastern Pennsylvania. The thickest coarse clastic sequences, particularly the Montebello Sandstone Member, occur near Harrisburg, and the average grain size decreases eastward, northward, and westward. Faill and others (1978) described the coarser elements of the Mahantango as a series of 6- to 250-foot-thick, asymmetrical, coarsening-upward sequences that consist of olive-gray silty claystones at the bottom and light-olive-gray siliceous sandstones, conglomeratic sandstones, or conglomerates at the top (Figure 7–11). In western Pennsylvania, the Mahantango Formation grades laterally into the finer grained, undifferentiated upper Hamilton Group just west of the Allegheny Front (Harper and Piotrowski, 1979).

The Tully Limestone, or an equivalent shale or siltstone member of the Mahantango Formation, occupies the top of the Middle Devonian (Figure 7–12). Berg, McInerney, and others (1986) considered the Tully a member of the Mahantango Formation throughout most of its outcrop in the state. The Tully tends to be an olive- to medium-gray, fossiliferous shaly limestone or calcareous shale that may be thicker than 200 feet at some outcrops (Faill and Wells, 1974). In the subsurface, it comprises finely crystalline, brownish-gray, argillaceous limestone with interbedded dark-gray calcareous shales (Fettke, 1961) that are up to 150 feet thick in some areas (Piotrowski and Harper, 1979).

Upper Devonian

The marine and nonmarine rocks of the Upper Devonian (Figures 7–4 and 7–13) were formed from

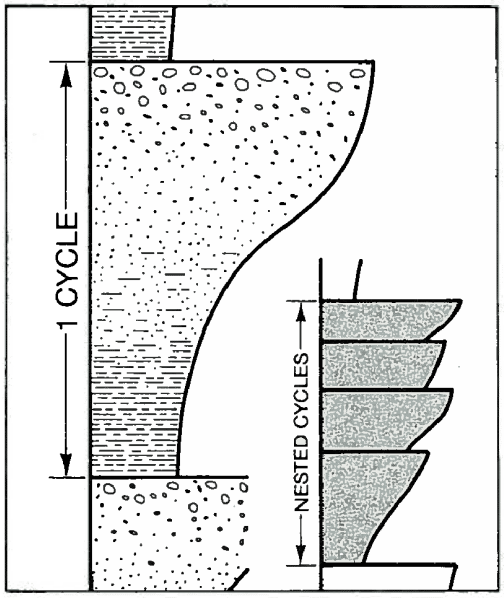
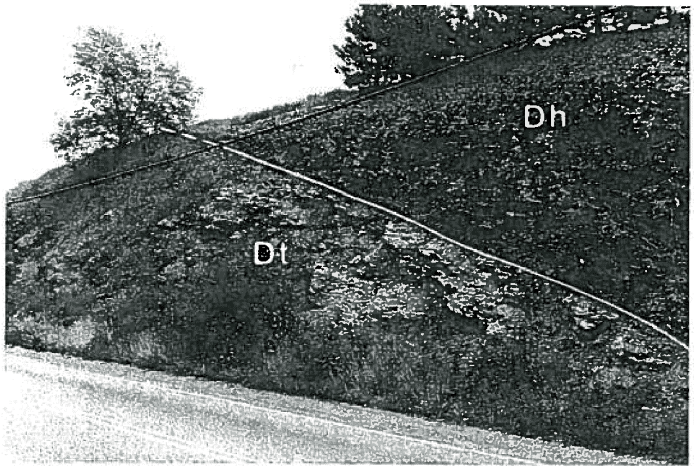


Figure 7–11. An idealized coarsening-upward cycle characteristic of the coarser elements of the Mahantango Formation (from Faill and others, 1978, Figure 1). Nested cycles consist of two or more cycles that have no sand-sized fraction.



A

B

Figure 7–12. Tully Limestone exposures. A. In a roadcut near Newry, Blair County, the Middle-Upper Devonian boundary is prominent where the dark-colored Burket Member of the Harrell Formation (Dh) lies on the light-colored Tully Limestone (Dt). B. Southeast of the Laurel Hill anticline in western Pennsylvania, the Tully Limestone is thin, argillaceous to silty, and commonly nodular.

sediments deposited from east to west across the Appalachian basin (Figure 7–14) during progradation of the Catskill deltaic system. Sevon and Woodrow (1981, p. 11) called this system a series of "multiple contiguous deltas operating in the same sedimentary basin at approximately the same time." The Catskill deltaic system is the type example of a tectonic delta complex, a delta system dominated by orogenic sediments derived from the erosion of an active tectonic complex into a contiguous marine basin (Friedman and Johnson, 1966). This system is the thickest integrated wedge of sediment in the basin and constitutes one of the most complex sequences of rock in North America. The interfingering and coarsening-upward rocks include typical flysch and molasse sequences, providing a classic example of the facies concept that is repeatedly cited in the literature (e.g., Caster, 1934). Because of this complexity, the rocks are categorized here in terms of facies rather than formations.

The rocks of the Upper Devonian can be incorporated into five broadly defined depositional and lithologic facies that form an overall progradational/regressive sequence in the Appalachian basin. They remain relatively consistent throughout the section despite differences in specific provenance, transport systems, and depositional settings (Figure 7–15). The depositional facies intercalate from offshore to onshore (generally speaking, from west to east and from bottom to top). For almost any given time interval in the Late Devonian of Pennsylvania, all five facies can be traced as lateral equivalents. Differences in lithology and depositional setting for these five facies are summarized in Table 7–1.

The dark-colored, organic-rich, basinal shales of Facies I, which are rarely fossiliferous except for styliolinids, lingulid brachiopods, and conodonts, dominate the lower third to half of the Harrell, Genesee, Sonyea, and West Falls Formations and the Huron Shale (Figures 7–4 and 7–16). These rocks are commonly interbedded with the lighter colored, less organic-rich shales and siltstones of Facies II and do not exceed 250 feet in thickness in any one formation (Piotrowski and Harper, 1979). Upper and lower contacts are normally sharply conformable or gradational through a short distance; in northwestern Pennsylvania, however, a major disconformity separates the black shales of the Middle and Upper Devonian (Figures 7–3 and 7–4).

Facies II consists of interbedded subfissile shales, fine- to coarse-grained, very thinly bedded siltstones, and rare thin-bedded, fine-grained sandstones deposited primarily on basin slopes (clinoform of Woodrow and Isley, 1983). Lundegard and others (1980) described the typical formation of Facies II, the Brallier Formation, as a series of turbidites having sharp planar bases and undulatory upper contacts (Figure 7–17).

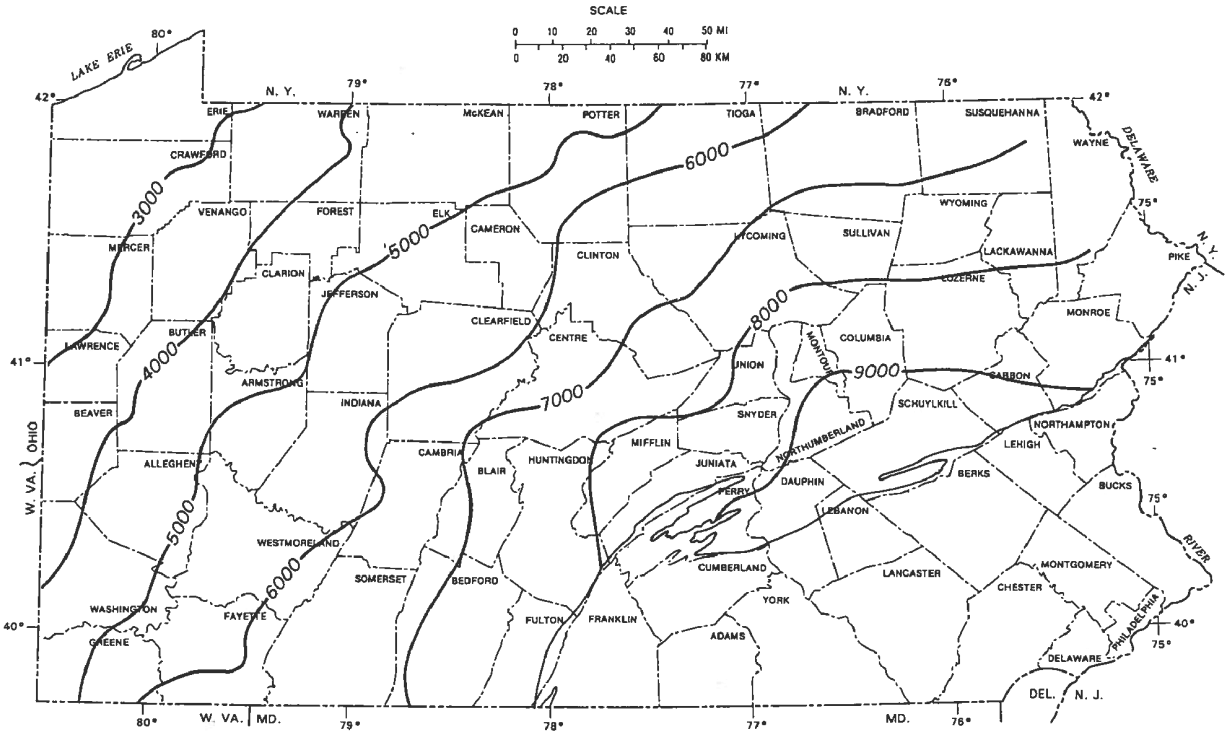


Figure 7–13. Generalized isopach map of the Upper Devonian in Pennsylvania (modified from Oliver and others, 1971, Sheet 6). Contour interval is 1,000 feet. The thin colored line represents the eastern limit of Devonian outcrop.

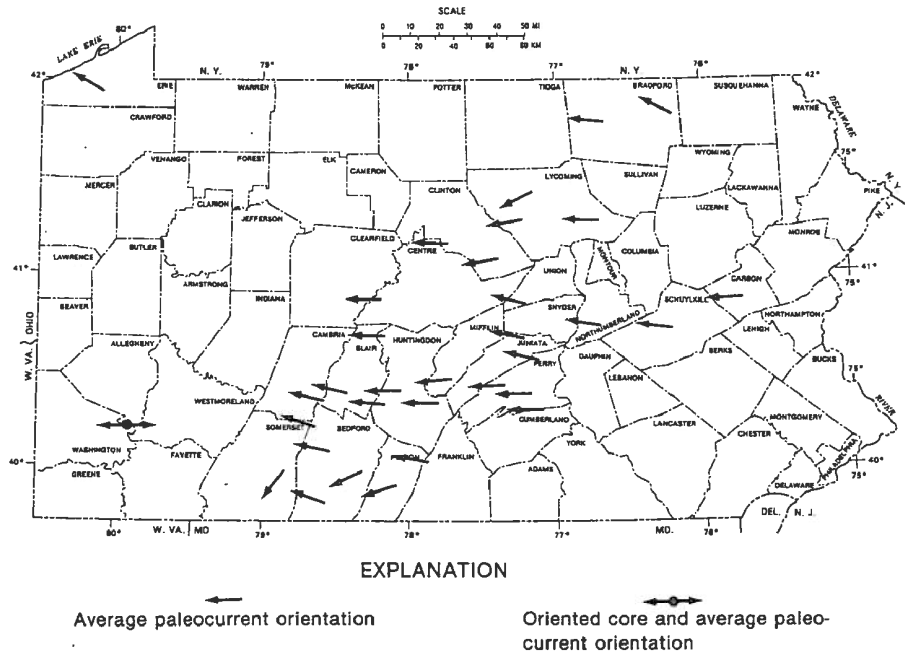


Figure 7–14. Average paleocurrent orientations in Upper Devonian rocks of Pennsylvania (data from Potter and others, 1981, and Lundegard and others, 1980). Paleocurrent orientations indicate that the direction of sediment transport was generally from east and southeast to west and northwest.

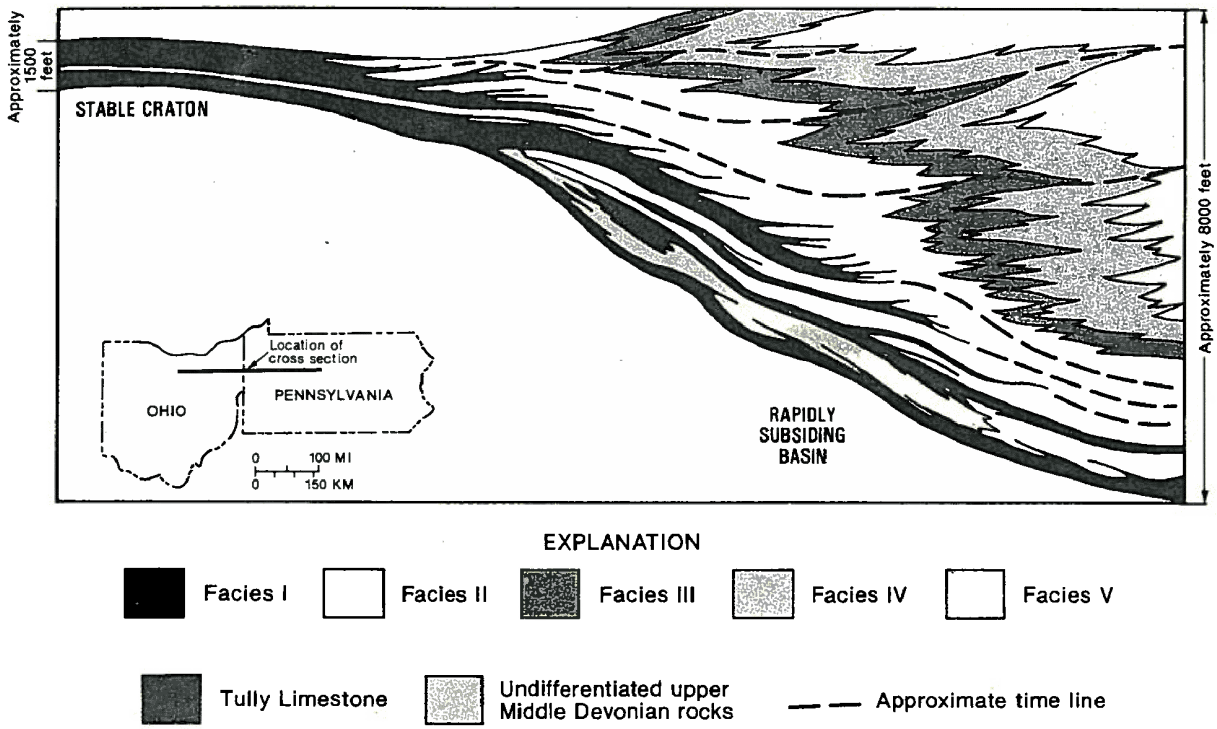


Figure 7–15. Schematic representation of the Upper Devonian facies across the western Appalachian basin (see Table 7–1; slightly modified from Harper and Laughrey, 1987, Figure 10). The relationship of these facies and the formations of the upper Middle Devonian is shown.

They interpreted these sequences as submarine fan deposits, but the rock sequences are better explained as submarine ramp turbidites (*sensu* Heller and Dickinson, 1985). Thicknesses of Facies II rocks range from about 2,500 feet in the Brallier Formation of western and central Pennsylvania to a few tens or hundreds of feet in the Trimmers Rock and other formations (Frakes, 1967).

Facies III rocks are dominant in the Chadakoin, Riceville, and Oswayo Formations and are minor components of many other Upper Devonian formations. Facies III rocks are typically marine clastic rocks that vary extensively in color and texture (Table 7–1) but that are characteristically thin bedded and very fossiliferous. Their thickest occurrence is in the Chadakoin Formation, which exceeds 400 feet in western Pennsylvania.

Facies IV rocks are dominant in the Lock Haven, Scherr, and Foreknobs Formations in central and northeastern Pennsylvania and the Venango, Bradford, and Elk Groups of western Pennsylvania. They are also major components of the Trimmers Rock Formation in eastern Pennsylvania and minor components of the Catskill and Hampshire Formations. These rocks comprise varying amounts of interbedded multicolored mudrocks, shales, and thin- to thick-bedded siltstones, sandstones, and conglomerates (Figures 7–18 and 7–19). Although fossiliferous marine limestones are minor constituents of this facies, they are very important as stratigraphic markers, particularly in the subsurface. Specific lithologic differences between equivalent formations in Facies IV include little more than textural and color variations. For example, the Foreknobs and Scherr Formations contain rocks that are, overall, coarser grained and darker colored than rocks in the equivalent Lock Haven Formation. Thicknesses of the formations made up mostly of this facies range up to several thousand feet.

The complex multiple lithologies of the Catskill and Hampshire Formations (Figure 7–4) mostly belong to Facies V, which typically consists of red, green, or gray, nonmarine detrital rocks. These rocks are commonly interbedded with rocks of Facies IV in the lower portion of the formation. Individual members of the Catskill Formation range from 150 to 3,700 feet thick (the equivalent Hampshire Formation has not been subdivided), and the entire Catskill

Table 7–1. ***Typical Lithologies and Depositional Environments of Upper Devonian Facies in Pennsylvania***

Facies	Lithology	Depositional environment
I	Dark-gray to black, somewhat calcareous, pyritic, sparsely fossiliferous shales.	Anoxic bottom muds of the basin proper (shallow or deep water).
II	Interbedded dark-gray shales and thin-bedded, light- to medium-gray siltstones; sparsely fossiliferous.	Turbidites of the delta-fed submarine ramp (slope).
III	Light- to dark-colored greenish, brownish, purplish, or reddish, highly fossiliferous shales, siltstones, and fine-grained sandstones.	Detrital sediments of the shallow-marine open shelf.
IV	Interbedded silty, micaceous mudrocks and fine- to coarse-grained, thin- to thick-bedded siltstones, sandstones, and conglomerates; moderately to highly fossiliferous. Occasional beds of sparsely to highly fossiliferous limestone.	Delta-derived detrital sediments of mixed fluvial-deltaic and linear-clastic shorelines; interspersed open-marine carbonates deposited during eustatic sea-level rises.
V	Gray to red, thin- to thick-bedded mudstones, claystones, siltstones, sandstones, and conglomerates; sparsely to moderately fossiliferous.	Mixed continental, fluvial-deltaic, and marginal-marine environments.

and Hampshire Formations range from 1,900 to 8,600 feet thick in central and eastern Pennsylvania. The upper and lower contacts of both formations are gradational, based essentially on percentages of red and gray rocks.

The uppermost Devonian rocks in central and eastern Pennsylvania consist of a series of mostly non-red, nonmarine sandstones and mudrocks spanning the Devonian-Mississippian systemic boundary. These rocks make up the Huntley Mountain and Spechty Kopf Formations in the northern counties and the Rockwell Formation in the southern counties. The stratigraphy of these transitional rocks is covered in the next chapter.

DEPOSITIONAL BASIN AND PROVENANCE

The Appalachian basin during the Devonian was part of an extensive inland sea receiving intermittent in-

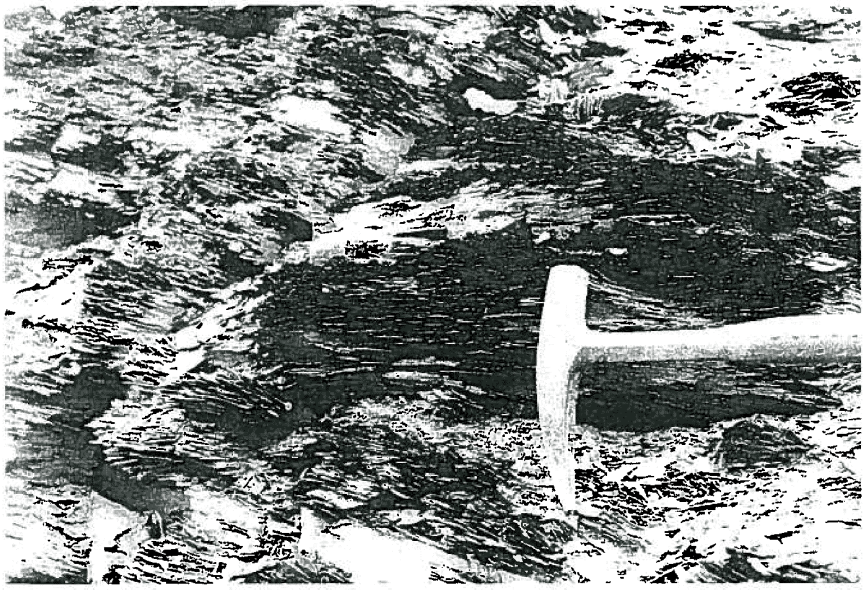


Figure 7–16. Dark-colored, organic-rich shales of Facies I constitute the Burket Member of the Harrell Formation, exposed in a roadcut south of Newry, Blair County. The chippy weathering pattern of the shales is typical of this facies.

flux of terrigenous sediments from the eastern source area, Appalachia. Appalachia consisted originally of Precambrian(?) through Early Ordovician sedimentary, volcanic, and intrusive rocks that were uplifted and metamorphosed during the Taconian orogeny (see Chapter 33). Later tectonic activity during the Acadian orogeny added Middle Ordovician through Early Devonian sedimentary rocks to the eroding uplands. Additional terrigenous material has been reported from northern sources, such as the Canadian Shield and the Adirondacks (e.g., Stow, 1938), but these were probably only of minor influence. Continued sediment influx into the basin during periods of relative tectonic quiescence created an asymmetrical, wedge-shaped deposit due to differences in the subsidence and sedimentation rates at the opposite sides of the basin (Figures 7–2 and 7–15). Large volumes of coarse-grained sediment poured into the eastern trough area, whereas in the west, adjacent to the stable craton, the Devonian sediments were mostly fine-grained particles falling out of suspension.

Available data indicate that during the Devonian, the Appalachian basin lay in the southern hemisphere near the equator, as shown in Figure 7–20.

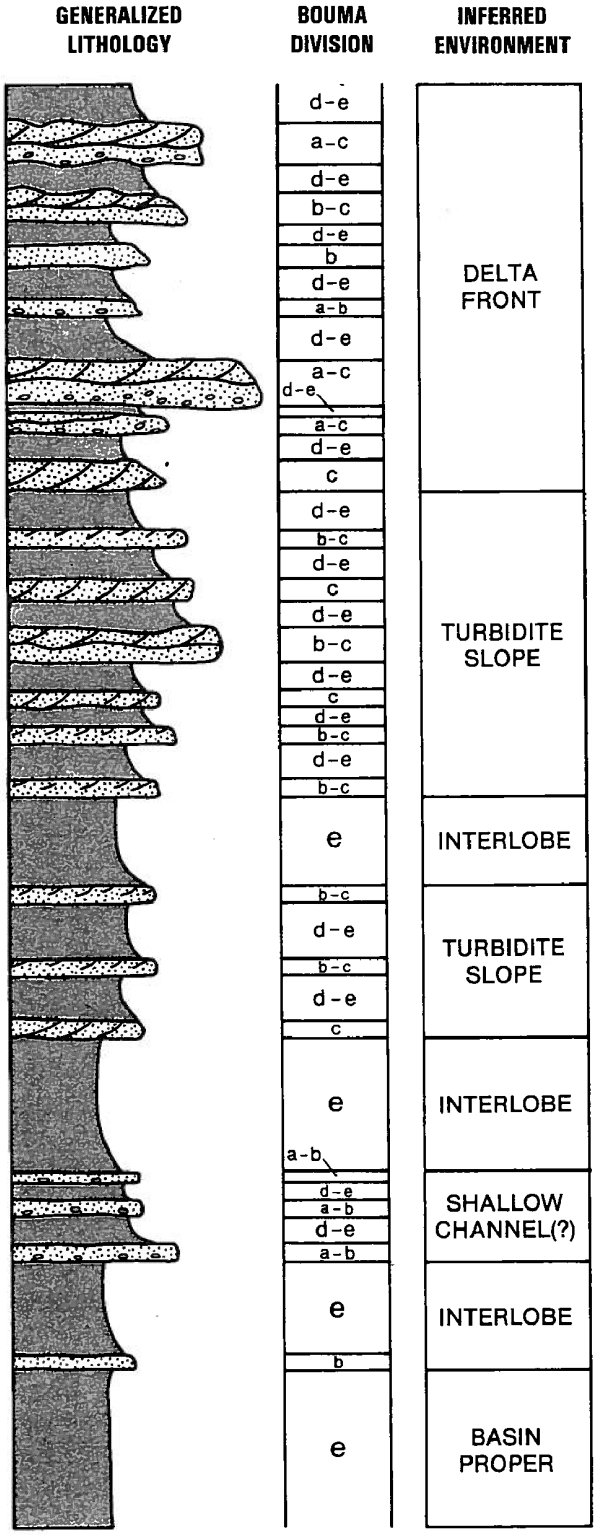


Figure 7–17. Generalized representation of Facies II turbidite sequences of the Brallier Formation in the central Appalachian basin (modified from Lundegard and others, 1980). The total thickness is approximately 1,000 feet. The inset, which has no scale, shows an idealized turbidite sequence and the Bouma divisions used to describe the diagnostic units. Not all divisions are present in all turbidite sequences. For example, Brallier turbidite sequences are rarely complete, consisting mostly of "acde" and "ade" Bouma divisions and subsidiary sequences such as "bcde." See Bouma (1962) for a discussion of turbidite sequences and their interpretation.

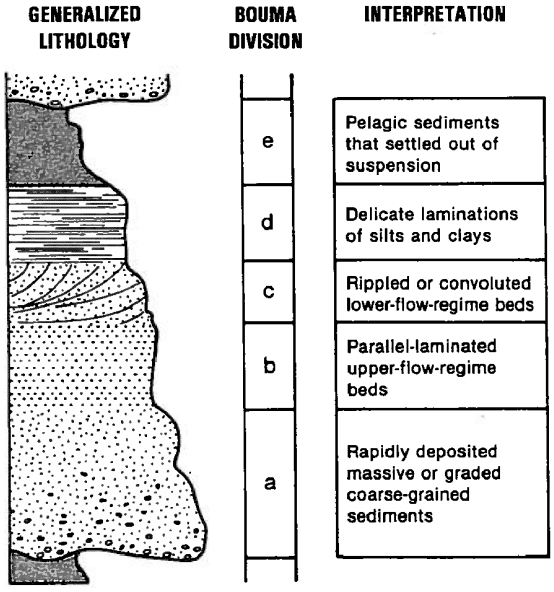


Figure 7–18. Sandstone and siltstone beds of variable thickness, color, and texture, separated by thicker layers of shale characterize Facies IV. Photograph of the Foreknobs Formation exposed near Entriken, Huntingdon County.

Woodrow and others (1973) determined that such a configuration would result in a hot climate with seasonally restricted rainfall. For example, the Late Devonian stratigraphic record, which contains as much as 80 percent of the total thickness of Devonian sediments, may be the result of long-term cyclic storm patterns affecting deposition on Catskill coastal plains and continental shelves.

The position of Appalachia with respect to the central basin is uncertain. Sevon and Woodrow (1981) suggested, however, that a distance of between 30 and 65 miles east of the present eastern outcrop limit is a reasonable estimate.

DEPOSITIONAL ENVIRONMENTS

During the Early Devonian, the Appalachian basin gradually deepened from supratidal mud flats of the Keyser to the stable, shallow-shelf, basin-axis facies of the New Creek and Corriganville Limestones (Head, 1972; Figure 7–3). The New Creek and Corriganville grade laterally into the more nearshore, clastic-rich limestones of the Coeymans and New Scotland Formations to the east (Epstein and

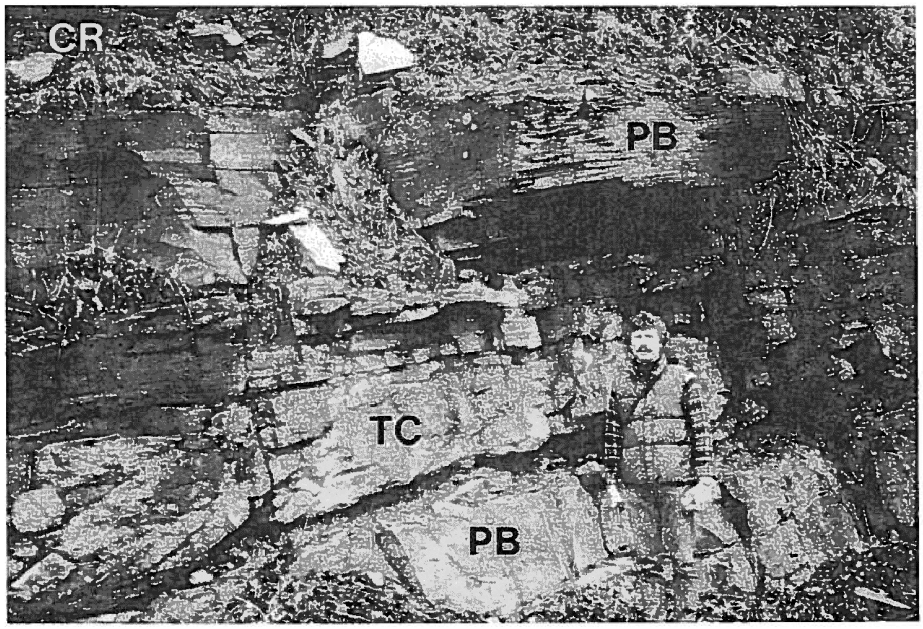


Figure 7–19. Portions of a depositional sequence of Facies IV from southwestern Pennsylvania. Fluvial-deltaic sandstones in the basal Venango Group exposed in a railroad cut in the Youghiogheny River gorge through Laurel Hill near Ohiopyle, Fayette County. From bottom to top, the sandstones exhibit plane beds (PB) of the channel floor, trough crossbeds (TC) and plane beds (PB) of a point-bar sequence, and (at the top left of the photograph) climbing ripple cross-laminations (CR) of the point-bar top.

others, 1967). The Mandata Shale, which overlies the Corriganville, represents the more anoxic bottom muds of the basin floor.

Later in the Early Devonian, the basin became shallower. The Shriver Chert was deposited below wave base as a combination of carbonate muds and shelf-derived silts in the central basin, whereas the Licking Creek Limestone represents deposition on the gently sloping carbonate shelf along the basin margins (Head, 1974). The Ridgeley and Oriskany Sandstones originated in shallow-water environments, such as shelf-bar complexes, beaches, and shorefaces.

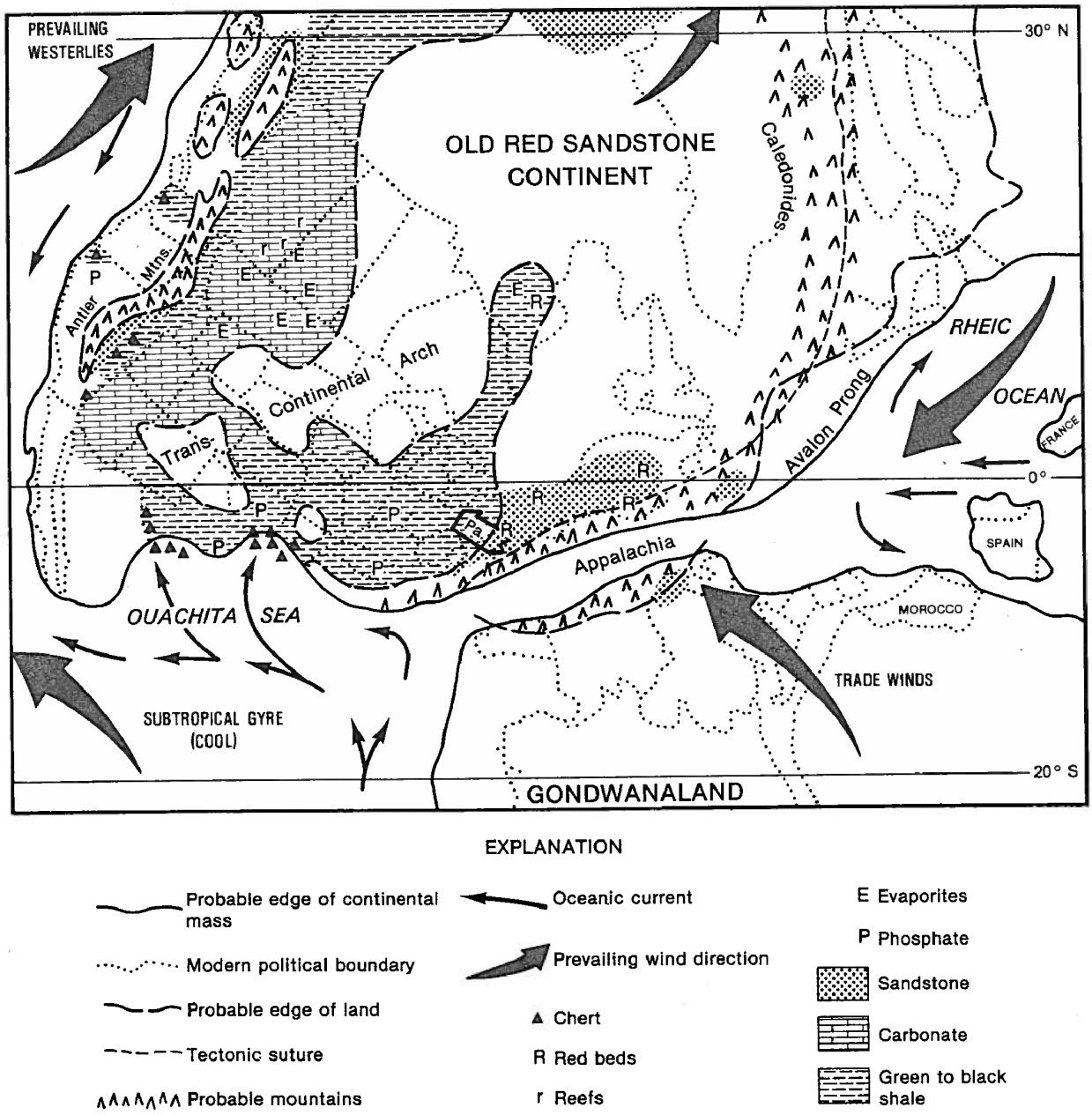


Figure 7–20. Late Devonian paleogeography and lithofacies of North America. Diagram simplified and modified from Ettensohn and Barron (1981, p. 18) by Sevon and Woodrow (1981, Figure 3). This configuration probably also is approximately representative of the Early and Middle Devonian.

Onesquethawan Stage rocks were deposited when the basin was once again deepening. The Bois Blanc Formation grades upward from reworked older formations to stable-shelf limestones and dolomites. The Needmore Shale was deposited along the axis of the basin as mud in stagnant, anoxic water, and the Huntersville Chert accumulated as radiolarian tests and sponge spicules, in part, in the shallower, more aerobic waters on the cratonic side of the basin (Inners, 1979). The Onondaga Formation represents shelf-margin limestones which became argillaceous (Selinsgrove Limestone) and silty (Buttermilk Falls Limestone) farther east. During a short period of volcanism at the end of the Onesquethawan Stage, volcanic ash blanketed the basin, forming the six ash beds of the Tioga ash zone (Way and Smith, 1985).

The Middle Devonian Marcellus Formation is commonly considered to have been deposited in deep anoxic waters (e.g., Potter and others, 1981). It should be emphasized, however, that the Devonian Appalachian sea was probably shallower than 300 feet, so it is unlikely that the shales can be considered "deep" in the same sense that the Atlantic Ocean is deep. It is more likely that the Marcellus Formation, and the Late Devonian black shales, were deposited in a variety of shallow-water anoxic environments, possibly at depths of less than 150 feet. The Mahantango Formation formed as a prograding marine shoreline during early Catskill delta building. The basin returned to more normal marine conditions, but with some terrigenous input, in the Taghanican Stage when the Tully Limestone was deposited. Heckel (1973) suggested a northern source for the carbonate muds and a southeastern source for the terrigenous muds of the Tully and its equivalents.

As the Catskill deltaic system prograded westward across the basin in the Late Devonian, the shape of the shoreline must have been very irregular due to variable rates of sediment supply, positions of different sediment-input systems, tectonic perturbations, and oceanic processes. Willard (1934) was the first to attempt the delineation of Late Devonian shorelines based on the outcrop of the "early Chemung" (the Scherr and lower Lock Haven Formations) in central and northeastern Pennsylvania. His three-lobed delta system was inaccurate, however, and it is unfortunate that this model has been perpetuated in the literature as being typical of the entire Upper Devonian depositional system. More recently, Sevon and Woodrow (1981) showed that sediment dispersal occurred as a result of numerous systems, and Boswell (1988) illustrated the distinct changes in Devonian shoreline configurations through time (Figure 7–21).

The gradual increase in distance from source area to shoreline during progradation was accompanied by a decrease in transport gradient, creating a decrease in grain size and a concomitant increase in depositional complexity across the basin. Sediments ranged from muds, sands, and gravels of Facies V, which were deposited in alluvial fans, braided rivers, and other typical continental environments, to clays and muds of Facies I, which settled out of suspension onto the anoxic basin floor.

SEA-LEVEL VARIATIONS AND TECTONICS

Devonian sea-level variations were due to global eustatic sea-level changes and tectonic pulses. Global and Appalachian basin sea-level variations were correlated by Dennison and Head (1975), Johnson and others (1985), and Boswell (1988). Superimposed on these sea-level variations were tectonic effects of varying magnitudes. The Acadian orogeny was the most important tectonic event of the Devonian. Based on the volume of preserved rocks, the uplifted Acadian highlands poured more than 69,000 cubic miles of sediment into the Catskill deltaic system (Dott and Batten, 1976). Local tectonic pulses affected deposition around the basin, but because of subsequent distortion in the central and eastern areas, this activity is identifiable primarily in the northern and western Appalachian Plateau.

PROBLEMS AND FUTURE RESEARCH

Despite being one of the most studied systems of rocks in Pennsylvania, the Devonian still presents many problems that need to be resolved. Most of these problems are stratigraphic in nature, and many relate to the complex Upper Devonian Series. Some of the more important general problems are listed below.

1. Resolution of the Ridgeley-Oriskany relationship. Many workers feel that the Ridgeley and Oriskany Sandstones are a single unit and have identical source and depositional

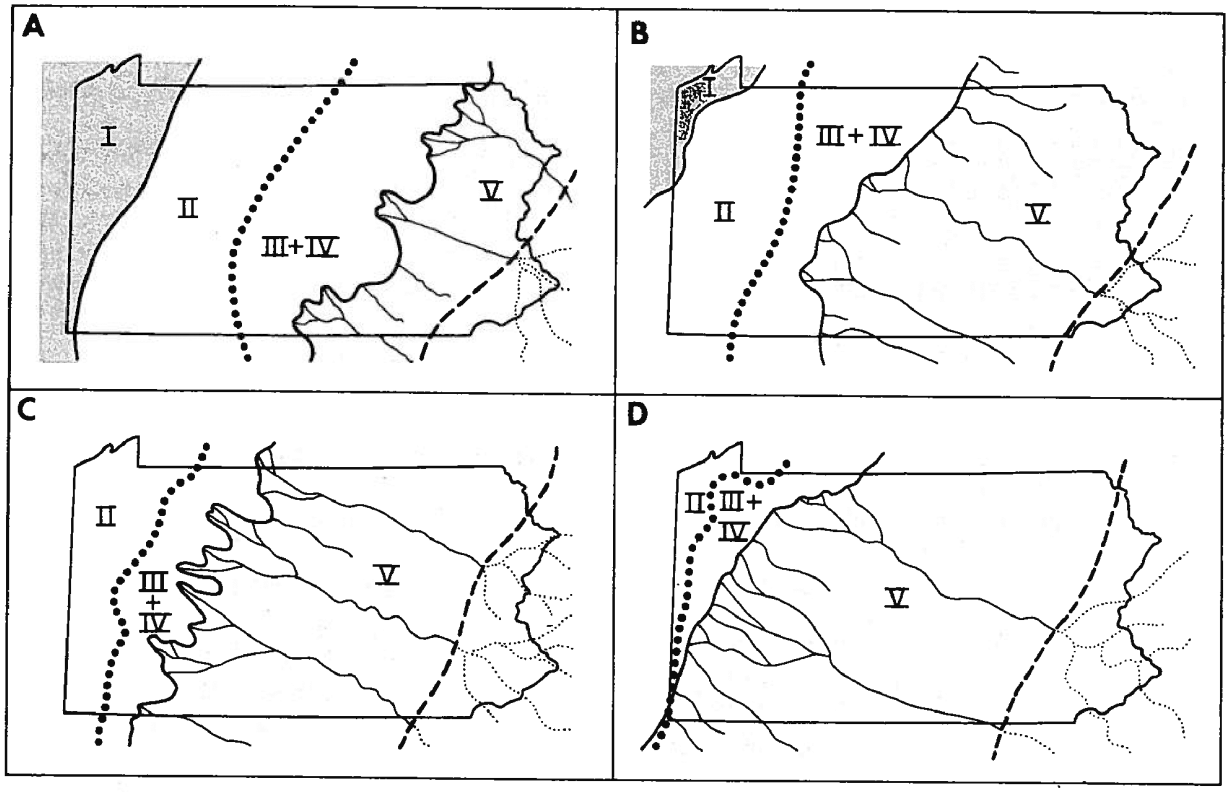


Figure 7–21. Changes in Late Devonian shoreline positions in Pennsylvania (modified from Boswell, 1988). Each diagram represents the hypothetical configuration of the Catskill depositional system during a particular instant of time within a stage: A, Middle Senecan; B, Early Chautauquan; C, Middle Chautauquan; and D, Late Chautauquan. Roman numerals refer to the facies of Figure 7–15. The heavy dotted line represents the shelf edge, and the dashed line represents the edge of the coastal plain.

regimes. Others believe that they are separate formations and that the Oriskany is only partially equivalent to the Ridgeley.

2. Determination of water depth in the Appalachian basin. Black shales (Facies I) have been considered by most authors to be representative of deep-basin deposition. There are, however, numerous indications that these shales were deposited in relatively shallow, stratified water.
3. Lithostratigraphic subdivision of the Catskill and Hampshire Formations. Most of the subdivision of the Catskill is based on the section occurring in northeastern Pennsylvania. The Hampshire Formation has not been subdivided at all.
4. Lithostratigraphic subdivision of the Venango, Bradford, and Elk Groups and the Lock Haven, Foreknobs, and Scherr Formations. At the time of this writing, work was just beginning on the outcrop of the Foreknobs and Scherr. There are limestone marker beds within most of these formations that could be used for ultimate correlation.
5. Biostratigraphic zonation of the Upper Devonian, particularly of the Catskill nonmarine units. Palynology may be best suited for this monumental task.
6. Chronostratigraphic resolution of the Upper Devonian, particularly of the Catskill Formation, based on marine and nonmarine biozones.
7. Redefinition of the distributary systems of the Catskill deltaic complex. Much more needs to be done beyond the work of Sevon and Woodrow (1981) and Boswell (1988).

RECOMMENDED FOR FURTHER READING

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