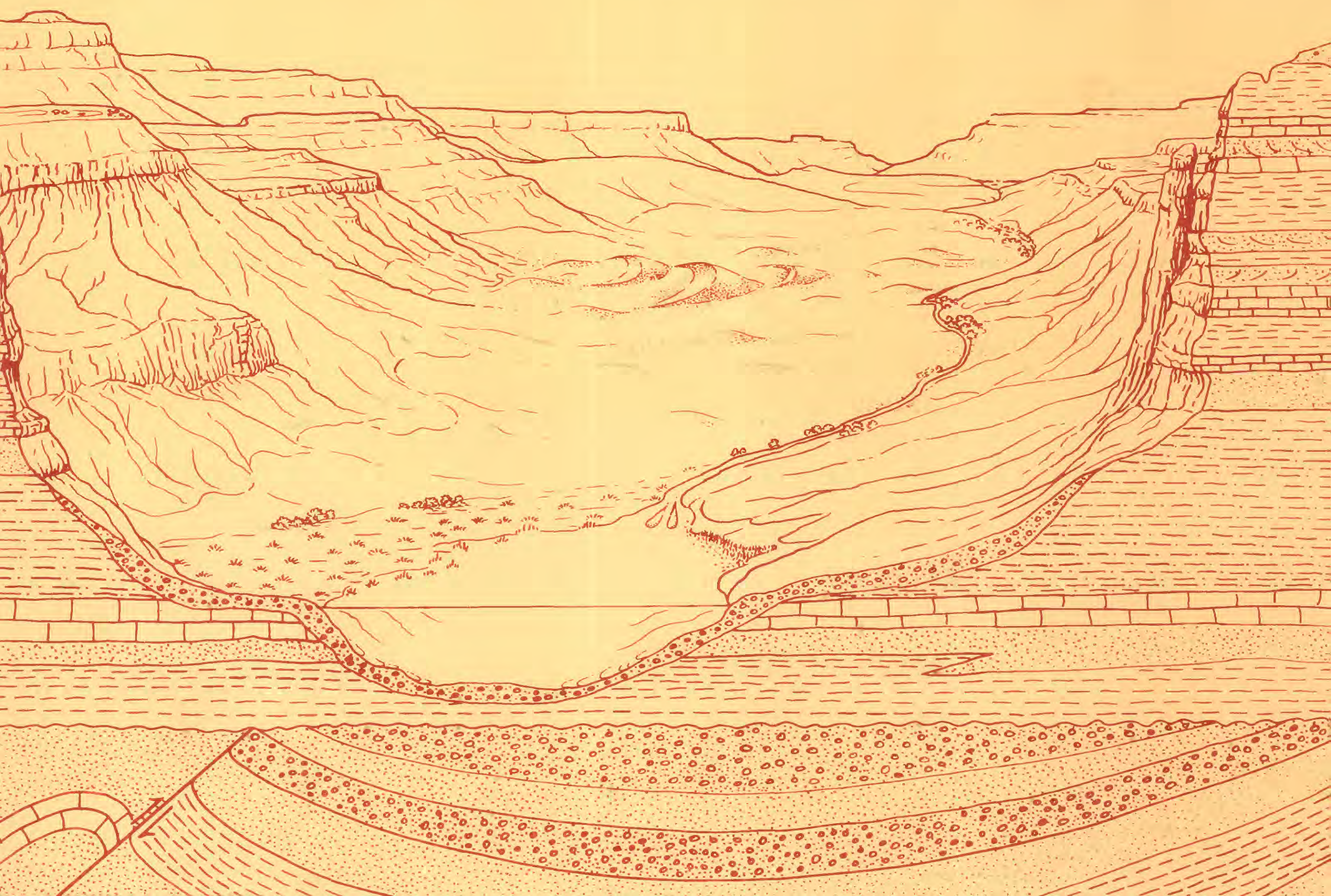
Structural and Stratigraphic Framework of the Giles County Area, a Part of the Appalachian Basin of Virginia and West Virginia

Late Paleozoic Depositional Trends in the Central Appalachian Basin

U.S. GEOLOGICAL SURVEY BULLETIN 1839–E, F



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By ROBERT C. McDOWELL and ARTHUR P. SCHULTZ

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U.S. GEOLOGICAL SURVEY BULLETIN 1839–E, F
EVOLUTION OF SEDIMENTARY BASINS–APPALACHIAN BASIN

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, Jr., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1990

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

Library of Congress Cataloging in Publication Data

(Revised for ch. E, F)
Evolution of sedimentary basins—Appalachian basin.
(U.S. Geological Survey bulletin ; 1839 A–)
Includes bibliographies.
Supt. of Docs. no.: I 19.3:1839A–D
Contents: ch. A. Horses and fensters of the Pulaski thrust sheet, southwestern Virginia / by Arthur P. Schultz — [etc.] — ch. E. Structural and stratigraphic framework of the Giles County area, a part of the Appalachian basin of Virginia and West Virginia / by Robert C. McDowell and Arthur P. Schultz—ch. F. Late Paleozoic depositional trends in the central Appalachian basin / by Kenneth J. Englund and Roger E. Thomas. 1. Geology—Appalachian basin. I. Series.
QE75.B9 no. 1839 A–D 557.3 s [557.4] 88–600224 [QE78.3]

Chapter E

Structural and Stratigraphic Framework of the Giles County Area, a Part of the Appalachian Basin of Virginia and West Virginia

By ROBERT C. McDOWELL and ARTHUR P. SCHULTZ

A description of the bedrock geology of a part of the Appalachian foreland

U.S. GEOLOGICAL SURVEY BULLETIN 1839
EVOLUTION OF SEDIMENTARY BASINS—APPALACHIAN BASIN

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CONVERSION FACTORS FOR SOME SI METRIC AND U.S. UNITS OF MEASURE

To convert from	To	Multiply by
Feet (ft)	Meters (m)	0.3048
Miles (mi)	Kilometers (km)	1.609
Pounds (lb)	Kilograms (kg)	.4536
Degrees Fahrenheit (°F)	Degrees (°C)	Temp °C=(temp °F−32)/1.8

EVOLUTION OF SEDIMENTARY BASINS—APPALACHIAN BASIN

Structural and Stratigraphic Framework of the Giles County Area, a Part of the Appalachian Basin of Virginia and West Virginia

By Robert C. McDowell *and* Arthur P. Schultz

Abstract

The Giles County area is in the western part of the Valley and Ridge province, just south of the Appalachian bend near Roanoke, Va. The area is underlain by rocks of the eastern central Appalachian basin that range in age from Early Cambrian to Late Mississippian and occur in linear folds cut by thrust faults. The rocks, well exposed along the New River, represent a relatively continuous succession of carbonate platform and clastic basinal deposits that is about 15,000 ft thick.

Major structures in the area trend about N. 65° E., typical of the northern part of the southern Appalachians. Thrust faults and axial surfaces of folds dip to the southeast. The major thrust faults are the Pulaski, Saltville, Narrows, and St. Clair, and the surface traces of the latter three terminate just northeast of the study area, in the Roanoke bend. The Narrows fault block contains several major synclines and anticlines, notably the doubly plunging Bane anticline of problematic origin, which is the site of an exploratory test well. Recent studies conclusively show that the area was deformed in a thin-skin style without direct involvement of Precambrian basement rocks.

The largest earthquake known to have occurred in Virginia took place near Pearisburg in 1897. Minor earthquakes have persisted in the Giles County area. Although their origin is not well understood, they appear to originate at great depth in basement rocks.

Mineral resources in the Giles County area include iron, manganese, limestone, and various sources of aggregate. Limestone is the main resource currently being developed. Geologic hazards include landslides, flooding, earthquakes, and karst terrain. None appears to represent a major problem, although the potential for a major earthquake is not yet well known.

Manuscript approved for publication May 18, 1989.

INTRODUCTION

The area of this report includes Giles County in southwestern Virginia and adjacent parts of the surrounding counties in Virginia and West Virginia (figs. 1, 2). The map area is in the eastern central Appalachian basin and is mainly in the western part of the Valley and Ridge structural province, just southwest of a 30° bend in the trend of the Appalachian orogenic belt near Roanoke, Va. (figs. 1, 2). The northwestern part of the area is west of the Allegheny Front in the Allegheny Plateau province. The study area is underlain by sedimentary rocks of Early Cambrian to Late Mississippian age that have been deformed into long, linear fold belts cut by several major thrust faults.

The Giles County area is of special geologic interest because the epicenter of the largest earthquake recorded in Virginia (Modified Mercalli intensity (MMI) of VIII), which occurred in 1897, was near Pearisburg (Campbell, 1898; Hopper and Bollinger, 1971, p. 54–66). Recent work has identified a seismogenic zone within Giles County that may be associated with that event (Bollinger and Wheeler, 1980, 1983; Bollinger, 1981).

In the Giles County area, the New River turns from its northeastward course, along strike, and cuts northwestward across the grain of the Appalachian foreland. Extensive exposures of bedrock along its course across the folded and faulted Valley and Ridge belt make the area particularly useful for interpreting the geology and geologic evolution (see, for example, Butts and others, 1932; Cooper, 1961, 1964, 1968; Bartholomew and others, 1980). In this report, we provide details of the stratigraphy and structural geology of this important area, discuss the development of ideas on its tectonic evolution, and describe the economic aspects (including hazards) of the geology. The area was selected for study because of its relatively high levels of historical and present-day seismicity. Numerous investigations and

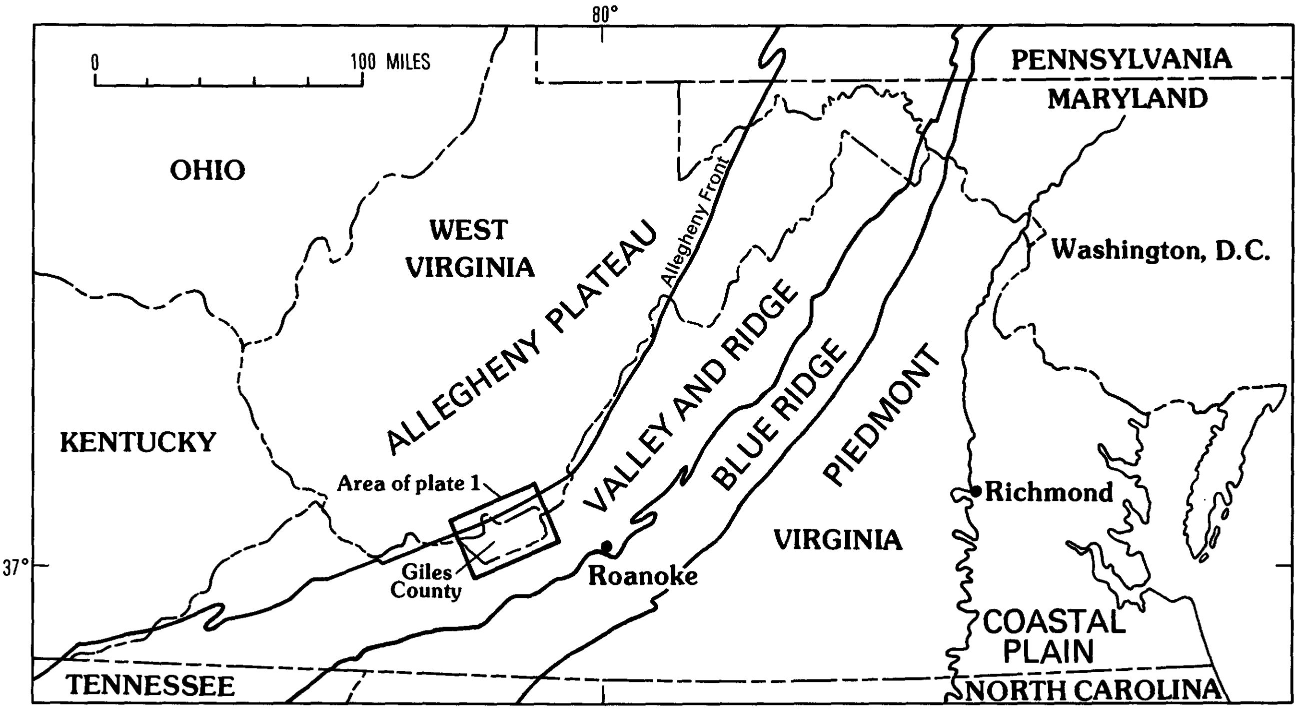


Figure 1. Structural provinces of the Appalachians of Virginia and West Virginia. Location of area of plate 1 is also shown.

extensive geologic mapping within the area by various workers in recent years, as well as those done for this study, make it possible to characterize the geology in considerable detail and provide an exceptional opportunity to analyze the geologic evolution of this part of the Appalachian foreland.

The map of Giles County and vicinity (pl. 1) was prepared by compiling the geologic maps in numerous published and unpublished reports between 1944 and 1986, supplemented by field checking and detailed and reconnaissance mapping by the authors between 1979 and 1987. Figure 3 indicates the source and coverage of most of the previous mapping; other reports used in the compilation include maps of Mercer and Monroe Counties, West Virginia (Reger, 1926), and geologic maps by Cooper (1944a, pl. 3; 1963, pl. 2.1) and Houser (1980, pl. 1). Giles County itself occupies about one-half of the map area, and an unpublished map of the county compiled by W.A. Moon in about 1962, at a scale of 1:31,250, was consulted. Of particular value were unpublished quadrangle maps in the county, at a scale of 1:24,000, produced by members of the Virginia Division of Mineral Resources, including A.P. Schultz, C.B. Stanley, T.M. Gathright II, E.K. Rader, M.J. Bartholomew, S.E. Lewis, and N.H. Evans (fig. 4), and a compilation of these maps at a scale of 1:50,000 by Rader and Gathright (Schultz and others, 1986).

STRATIGRAPHY

Strata in the Giles County area form a relatively continuous succession of carbonate platform and basinal deposits from the Lower Cambrian Rome Formation to the Upper Mississippian Bluestone Formation, a composite thickness of about 15,000 ft. These strata are shown on the generalized columnar section (fig. 5). Stratigraphic nomenclature used in this report is compared in table 1 to that used in Giles County and nearby areas by other workers. The following brief descriptions of the units are based in part on descriptions by Butts (1940), Cooper (1961), and Lesure and others (1982).

Cambrian System

Rome Formation (Lower Cambrian)

The Rome Formation was named by Hayes (1891, p. 143) for exposures at Rome, Ga. The formation contains the oldest red beds of Paleozoic age in the region. In the map area, the Rome is composed predominantly of red laminated clay shale interbedded with lesser amounts of grayish-green clay shale, light- to dark-gray, fine- to medium-grained argillaceous dolomite, and yellowish-gray siltstone. The Rome crops out only on the culmination of the Bane anticline, near Bane, where 250 to 300 ft of the uppermost part of the unit are exposed. Good exposures are in roadcuts along State Road 100, where the beds are intensively fractured and folded. Rome strata are also exposed locally

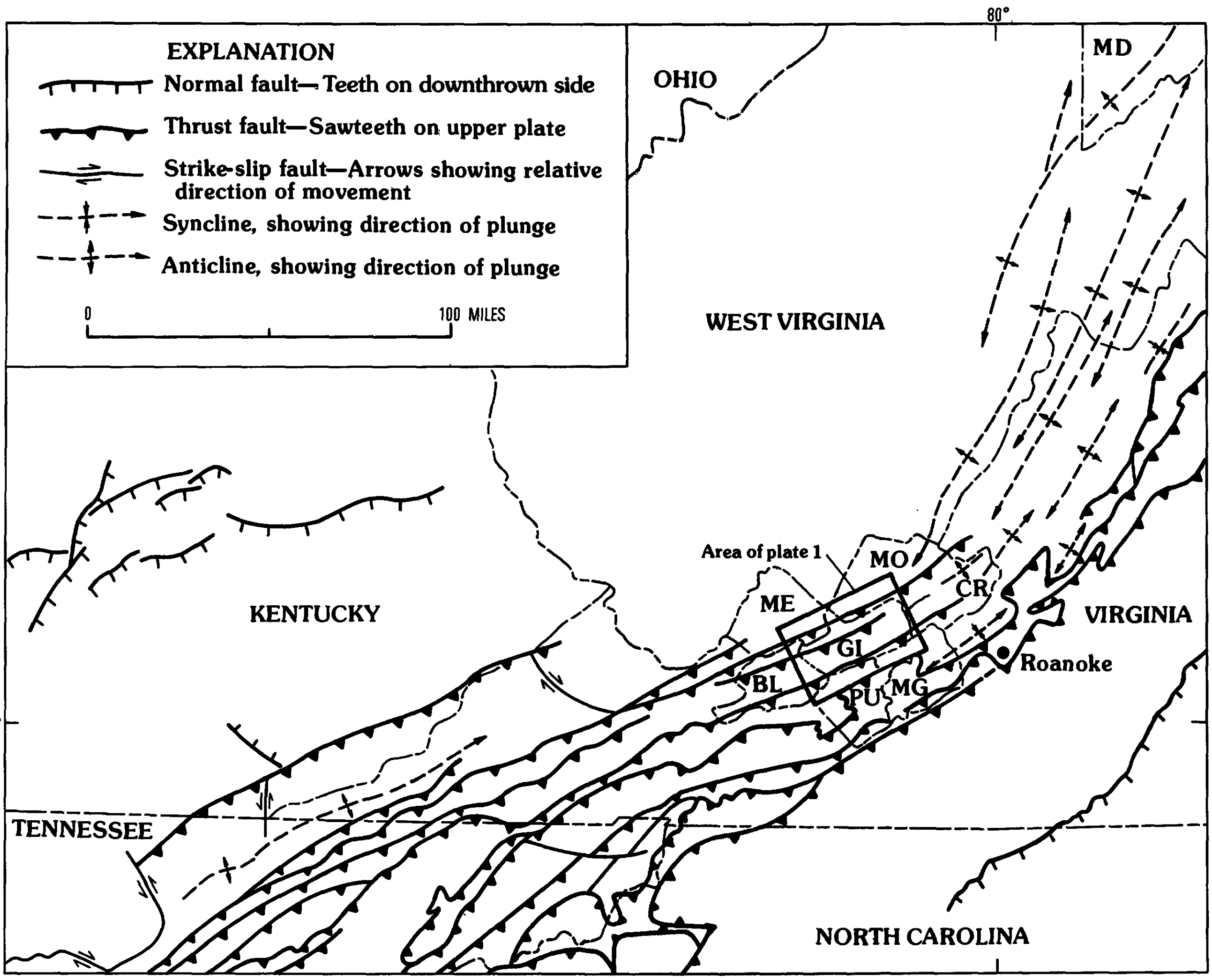


Figure 2. Regional structural setting of the Giles County area of Virginia and West Virginia. Counties, West Virginia: ME, Mercer; MO, Monroe. Counties, Virginia: BL, Bland; CR, Craig; GI, Giles; MG, Montgomery; PU, Pulaski. Location of area of plate 1 is also shown.

in the belt mapped as Nolichucky Shale and Honaker Dolomite southeast of the Pulaski fault.

Abundant mud cracks and ripple marks and sparse marine fossils (mainly trilobites) suggest a shallow marine shelf environment.

Distinctive red Rome shales are found throughout the Valley and Ridge province of Virginia, most commonly on the southeastern side of the province. North of Roanoke, the unit contains a greater percentage of carbonate beds and is generally called the Waynesboro Formation.

Honaker Dolomite (Middle and Upper Cambrian)

The Rome Formation grades upward into gray Honaker dolomites; the contact is placed at the top of the uppermost red shale bed. The Honaker Dolomite, named by Campbell (1897, p. 2) for exposures at the town of Honaker in nearby Russell County, Virginia, is composed of light- to dark-gray, thin- to thick-bedded, fine- to medium-grained dolomite. The lower part of the unit is characterized by irregular stromatolites; oolitic, fine-grained dolomite interbedded with massive, dark-gray, cherty dolomite characterizes the upper part of the unit.

In the Giles County area, the Honaker Dolomite crops out around the Rome Formation in the core of the Bane anticline, and the upper part of the unit is exposed along the hanging walls of the Narrows, Saltville, and Pulaski faults. On the Bane anticline, where the complete formation is present, the Honaker is about 1,000 ft thick (Whitman, 1964). Although the Honaker has previously been assigned by most workers to the Middle Cambrian (Miller and Meissner, 1977), Derby (1965) showed that uppermost Honaker beds contain a Late Cambrian fauna in the Giles County area (Markello and Read, 1982, fig. 2).

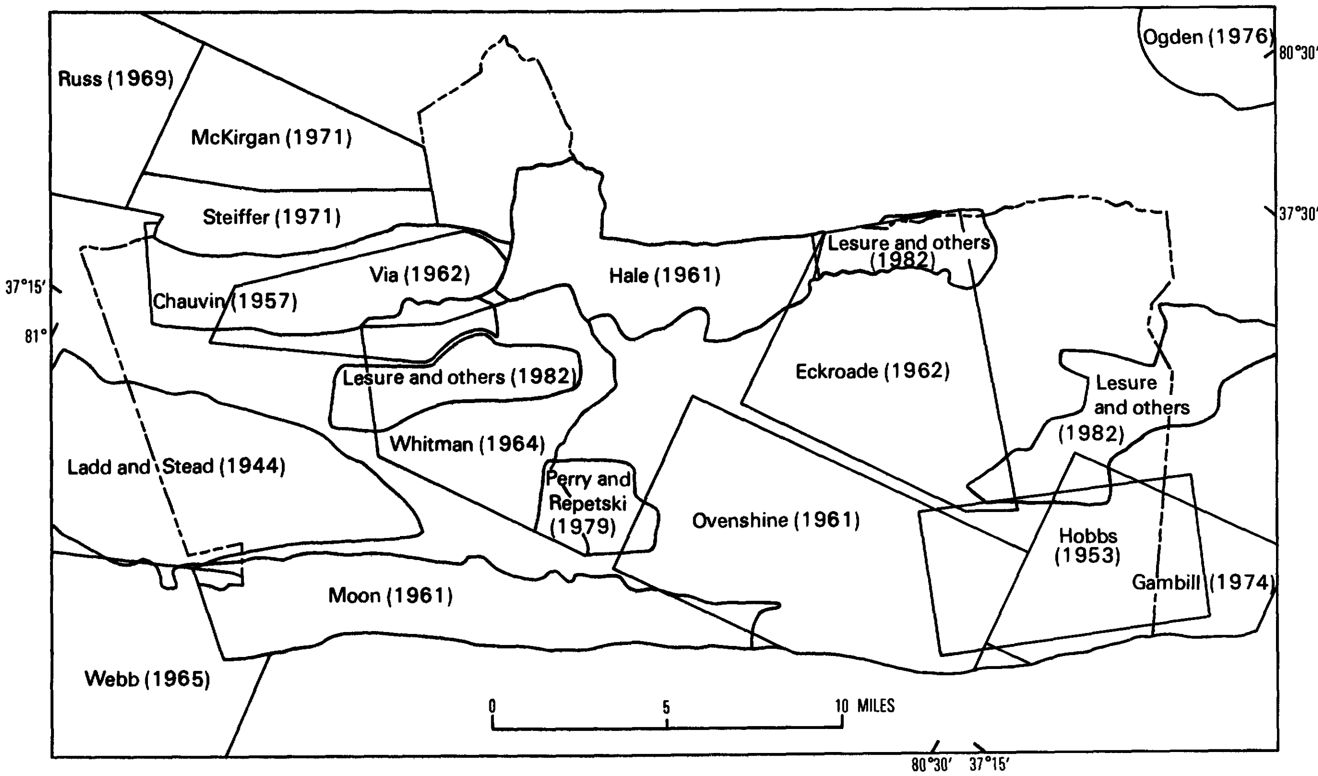


Figure 3. Index to previous mapping in the Giles County area of Virginia and West Virginia.

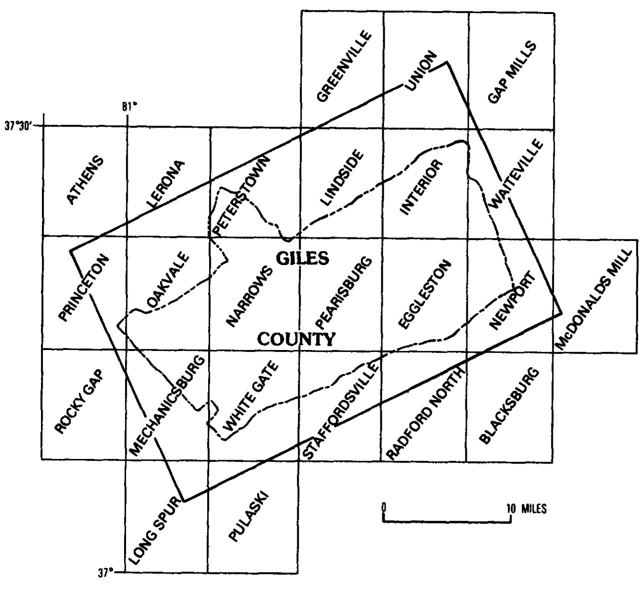


Figure 4. Index to 1:24,000-scale quadrangles in the Giles County area of Virginia and West Virginia.

Nolichucky Shale (Upper Cambrian)

The Honaker Dolomite is conformably overlain by the relatively thin Nolichucky Shale, named by Keith (1896, p. 2) for exposures along the Nolichucky River in northeastern Tennessee. The Nolichucky is composed of olive- to dark-gray, sparsely fossiliferous shale, thin- to medium-bedded gray argillaceous dolomite and olive-gray shale partings, and conglomeratic dolomite that contains flat, gray dolomite pebbles. The formation is about 50 ft thick in the Giles County area (Whitman, 1964).

The Nolichucky Shale is combined with the underlying Honaker Dolomite on the map and, similar to the Honaker, is exposed only around the Bane anticline and locally in the hanging wall along the Saltville and Narrows thrust faults. On the southeastern border of the map area, the combined unit has been mapped as Elbrook Dolomite (Bartholomew and Lowry, 1979), a name generally applied to eastern and northern facies. The Nolichucky Shale in southwestern Virginia was studied in detail recently by Markello and Read (1981, 1982), who concluded that it was deposited in a carbonate-rimmed intrashelf basin. Derby (1965) determined the biostratigraphic zonation of the Nolichucky in the region on the basis of trilobites and demonstrated the onlap-offlap nature of the sequence.

Cambrian and Ordovician Systems

The Knox Group (Upper Cambrian-Lower Ordovician) contains a thick sequence of dolomite, much of it cherty, and a minor amount of sparsely fossiliferous limestone and sandstone. The Knox Group, named by Safford (1869) for outcrops in northeastern Tennessee, is commonly

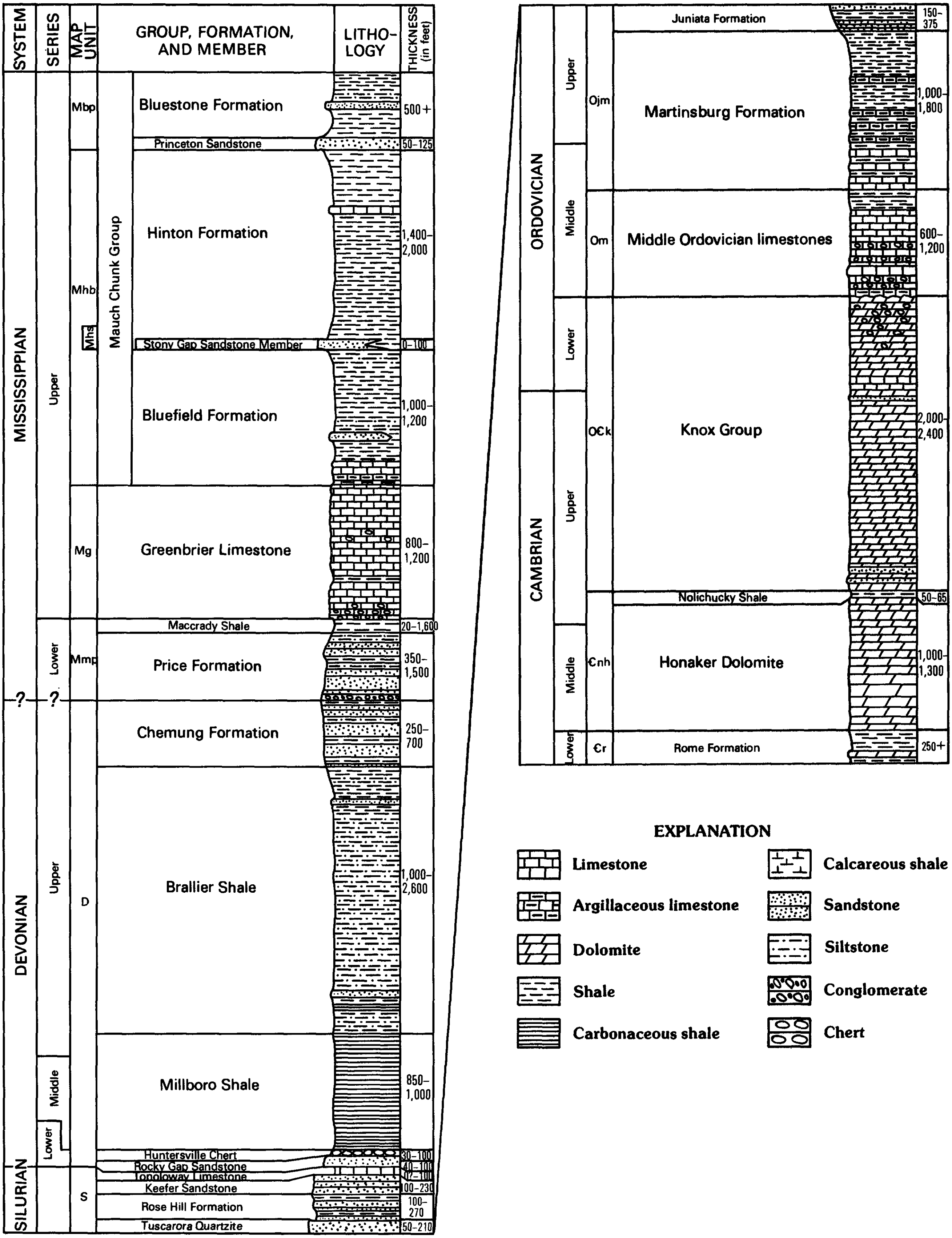


Figure 5. Generalized columnar section for rocks in the Giles County area of Virginia and West Virginia.

Table 1. Stratigraphic nomenclature used in this study and other studies in the Giles County area of Virginia and West Virginia

System	Mercer, Monroe, and Summers Counties, W. Va. (Reger, 1926, fig. 6)	Giles County, Va., and Mercer County, W.Va. (Cooper, 1961, pl. 1)	Botetourt County, Va. (McGuire, 1970)	Southwestern Virginia (Miller and Meisner, 1977)	This report
MISSISSIPPIAN	Mauch Chunk Series: Bluestone Group	Bluestone Formation	(not exposed)	Pennington Group: Bluestone Formation: Upper red member	Mauch Chunk Group: Bluestone Formation.
				Bluestone Formation: Lower member	
	Princeton Conglomerate	Princeton Formation		Princeton Sandstone	Princeton Formation
	Hinton Group	Hinton Formation		Hinton Formation: Little Stone Gap Member	Hinton Formation
				Hinton Formation: Lower red member	
				Hinton Formation: Stony Gap Sandstone Member	Stony Gap Sandstone Member
	Bluefield Group	Bluefield Formation		Bluefield Formation	Bluefield Formation
	Greenbrier Series	"Casper" Limestone		Greenbrier Limestone	Greenbrier Limestone
		"Ste. Genevieve" Limestone			
		Hillsdale Limestone			
		Little Valley Limestone			
	Maccrady Series	Maccrady Formation		Maccrady Shale	Maccrady Shale
	Pocono Series	Price Formation	Price Formation	Price Siltstone	Price Formation
DEVONIAN	Chemung Series	Parrot Formation	Chemung Formation	Chattanooga Shale	Chemung Formation
		"Chemung" Formation			
	Portage	Brallier Formation	Brallier Formation		Brallier Shale
	Genessee-Hamilton-Marcellus Series	Millboro Formation	Millboro Formation		Millboro Shale
		Huntersville Formation	Needmore Formation	Wildcat Valley Sandstone	Huntersville Chert
			Ridgely Sandstone		
			Licking Creek Formation		
	Oriskany Series Helderberg Series	Rocky Gap Sandstone	Healing Springs Sandstone		Rocky Gap Sandstone
			New Creek Limestone		
			Keyser Formation		
SILURIAN	Clinton Series	Tonoloway Limestone	Tonoloway Formation	Tonoloway Limestone	Tonoloway Limestone
		"Keefer" Formation	Keefer Sandstone	Rose Hill Formation	Keefer Sandstone
		Rose Hill Formation	Cacapon Formation	Clinch Sandstone: Upper red sandstone member	Rose Hill Formation
	White Medina Series	Tuscarora Sandstone	Tuscarora Formation	Clinch Sandstone: Lower white sandstone member	Tuscarora Quartzite

Table 1. Stratigraphic nomenclature used in this study and other studies in the Giles County area of Virginia and West Virginia—Continued

System	Mercer, Monroe, and Summers Counties, W. Va. (Reger, 1926, fig. 6)	Giles County, Va., and Mercer County, W.Va. (Cooper, 1961, pl. 1)	Botetourt County, Va. (McGuire, 1970)	Southwestern Virginia (Miller and Meisner, 1977)	This report
	Red Medina Series	Juniata Sandstone	Juniata Formation	Juniata Formation	Juniata Formation
	Martinsburg Series: Lower Maysville Group	Martinsburg Formation	Martinsburg Formation	Reedsville Shale	Martinsburg Formation
	Martinsburg Series: Eden Group				
	Martinsburg Series: Trenton Group			Trenton Limestone	
	Moccasin Series	Eggleston Formation	Eggleston Formation	Eggleston Formation	Middle Ordovician limestone
		Moccasin Formation	Edinburg Formation	Moccasin Formation	
	Stones River (Chickamauga) Series	Witten Limestone		Lower Middle Ordovician limestone formations	
		Gratton Limestone			
ORDOVICIAN		Benbolt Limestone			
		Pearisburg Limestone			
		Lincolnshire Limestone	Lincolnshire Formation		
		Five Oaks Limestone	New Market Limestone		
		Elway Limestone			
		Blackford Formation			
	Beekmantown Series	Knox Group	Beekmantown Formation	Knox Group: Beekmantown Dolomite	Knox Group
			Chepultepec Formation		
			Conococheaque Formation	Knox Group: Copper Ridge Dolomite	
CAMBRIAN	Elbrook? Series		Copper Ridge Formation	Maynardsville Limestone	
		Nolichucky Shale	Elbrook Formation	Nolichucky Shale	Nolichucky Shale
		Honaker Dolomite		Honaker Limestone	Honaker Dolomite
		Rome Shale	Rome Formation	Rome Formation	Rome Shale

divided into two or more formations (table 1). In much of southwestern Virginia, these formations include the Copper Ridge Dolomite of Late Cambrian age and the overlying Beekmantown Dolomite of Early Ordovician age (Miller and Meissner, 1977). In more southeasterly outcrop belts, these formations are separated by the intervening Chepultepec Limestone of earliest Ordovician age (Butts, 1940, p. 95–101), which has been reported in Giles County in outcrop by Frieders (1975) and in well cuttings by Perry and others (1979). Cooper (1961, p. 27–30) found no basis for subdividing the Knox Group in the Giles County area except at the base of *Lecanospira*-bearing limestone, which he considered to be equivalent to the Longview Limestone (lowermost Beekmantown) of Alabama. He suggested that the systemic boundary occurs within the Knox Group below this zone.

The Knox Group is composed mainly of light- to medium-gray, fine- to medium-grained dolomite, commonly stromatolitic or less commonly oolitic, in laminae to massive beds. Several distinctive and locally resistant units of fine- to coarse-grained, light-brown, dolomite-cemented sandstone and light-gray sandy dolomite occur in beds a few inches to several feet thick within the lower half of the Knox Group. The upper half contains scattered beds of light-bluish-gray calcilutite containing stylolites and intraclast zones. Chert is common throughout the Knox, particularly in the upper part, as irregular beds as much as 3 ft thick and as concentrically banded nodules, generally white to light gray but locally black in the lower Knox.

The marine shelf carbonates of the Knox Group are 2,000 to 2,400 ft thick in the Giles County area (Butts and others, 1932; Cooper, 1944a, 1961). The Knox is widely distributed through the area, mainly in a wide belt around the Bane anticline, in the core of the Clover Hollow anticline, and in linear belts in the hanging walls of the Saltville, Narrows, and St. Clair thrust faults. It is well exposed along the New River (for example, at Goodwins Ferry, Pembroke, and Ripplemead and in the Narrows).

Ordovician System

Middle Ordovician limestones

The upper contact of the Knox Group is an irregular erosion surface having as much as 100 ft of relief and overlain by a sequence composed mostly of limestone. This sequence, 600 to 1,200 ft thick, has been subdivided on the basis of fossils, grain size, and compositional variations into as many as 10 formations (Butts, 1940; Cooper, 1944a, 1961) (table 1), each of which is generally 50 to 150 ft thick. These formations have been interpreted by Read (1980) to be carbonate ramp and foreland basin facies associated with downwarp and transgression of exposed Knox shelf carbonates.

The basal unit of this sequence, the Blackford Formation, is composed of interbedded dolomite, argillaceous dolomite, calcareous dolomite, and minor dolomitic limestone and red to gray mudrock. In most places, the basal bed is a breccia or conglomerate composed of angular to subrounded clasts of light-gray to black chert. Locally, these rocks fill depressions (sink holes) on the post-Knox unconformity that, in some places within the region, extend as much as 210 ft below the erosion surface (Mussman and Read, 1986). In the map area, the Blackford is about 2 ft to as much as 130 ft thick and is succeeded by several hundred feet of limestone grading upward to calcareous shale and siltstone. The limestone (from the bottom upward, Elway, Five Oaks, Lincolnshire, Pearisburg, Benbolt, Gratton, and Witten) is predominantly light to medium gray, fine grained to cryptocrystalline, and fossiliferous and commonly contains dark-gray chert lenses and nodules. Lesser amounts of coarse-grained limestone are interbedded in the section. Fossils are mainly brachiopods and bryozoans but include trilobites, echinoderms, corals, and other forms. Limestone in the upper part of this section is argillaceous, darker in color, and irregularly bedded and contains shale interbeds. The Moccasin and Eggleston Formations, at the top of the sequence, are composed of red, argillaceous, fine-grained limestone and red calcareous mudstone (Moccasin) and interbedded gray siltstone and fine-grained limestone (Eggleston). The Eggleston contains several thin "bentonite" (metatuff) beds (Rosenkrans, 1936).

The Middle Ordovician limestones are distributed throughout the Giles County area and, together with the Knox Group and older dolomites and shales, form the bottoms of linear valleys and the rolling lowlands of the Bane anticline area and along the New River. Excellent exposures are in river bluffs near Eggleston and Goodwins Ferry. The Moccasin Formation is well exposed along U.S. Highway 460, north of Newport near Trigg, and in the Narrows of the New River; in good exposures, the characteristic small-scale folding and fracturing of the formation are striking.

Martinsburg Formation

The Eggleston Formation is succeeded over a thin gradational zone by a thick sequence of interbedded limestone, shale, siltstone, and sandstone. This Middle and Upper Ordovician fossiliferous sequence, named Martinsburg Shale by Geiger and Keith (1891, p. 161) for less limy and less fossiliferous beds exposed near Martinsburg, W. Va., is mainly on the middle and lower slopes of mountains and is generally covered by colluvium. In the Giles County area, the lower half of the unit is composed of fossiliferous, fine-grained, gray, thin- to medium-bedded limestone and interbeds of calcareous shale and siltstone. These beds grade upward into a sequence of interbedded shale and calcareous siltstone and sandstone, coarsest at the top. The distinctive large brachiopod *Orthorhyncula linneyi* is near the top of the formation. The Martinsburg, about 1,300 ft thick in the Giles County area, was deposited in shallow marine waters, the sediment supply of which apparently is derived from Taconic orogenic activity to the south and southeast (Walker, 1970). Kreisa (1980) attributed most of the formation to storm deposits. Excellent exposures are located along U.S. Highway 460 in the Narrows.

The Martinsburg Formation is combined with the overlying Juniata Formation on the geologic map (pl. 1).

Juniata Formation

Gray shale and sandstone of the Martinsburg Formation are succeeded gradationally by interbedded red sandstone, siltstone, and shale of the uppermost Ordovician Juniata Formation. The Juniata was named by Darton and Taff (1896) for exposures along the Juniata River in Pennsylvania. Together with the underlying Martinsburg Formation, with which it is combined on the geologic map, it underlies most of the mountain slopes in the Giles County area.

The Juniata Formation was deposited mostly as a delta-plain mudflat (Kreisa, 1980) and is composed mainly of fine-grained, grayish- to dusky-red sandstone that is commonly in planar crossbedded sets as thick as 1 ft. Minor dusky-red clay shale is interbedded in the lower part of the unit and minor grayish-red fissile siltstone and silt shale in the upper part. *Lingula* fragments and reduction spots are locally common. The Juniata in the Giles County area is about 150 to 375 ft thick (Ladd and Stead, 1944; Cooper, 1963). It is well exposed along U.S. Highway 460 in the Narrows, where it is 325 ft thick (Hale, 1961); on Gap Mountain, where the basal contact is covered; and along Stony Creek between Olean and Interior. It generally occupies steep outcrop slopes just below the crest of ridges, where it is commonly covered by cobbles and boulders of the overlying Tuscarora Quartzite.

Silurian System

Tuscarora Quartzite

The Lower Silurian Tuscarora Quartzite, a distinctive ledge-forming orthoquartzite, is exposed along the crest of most of the ridges throughout the Valley and Ridge province of Virginia and West Virginia. The formation was named by Darton and Taff (1896) for Tuscarora Mountain in Pennsylvania. In Virginia, the unit has been called Clinch Sandstone by some workers (for example, Butts, 1940), a name still used in southwesternmost Virginia (Miller and Meissner, 1977). It is composed of very light gray, fine- to coarse-grained quartzite in medium to thick, well-indurated beds. Minor lenses of quartz-pebble conglomerate are present locally; elsewhere, the grains are well sorted. Crossbedding (both trough and planar) is common, generally in thick sets, and sparse worm burrows (*Skolithos* and *Arthrophycus*) are the only fossils. Upper and lower contacts are gradational and are placed at the lowest and highest red beds, respectively.

The Tuscarora Quartzite crops out on ridge crests throughout the Giles County area. Good exposures are found along U.S. Highway 460 at Gap Mountain and the Narrows of the New River and along Stony Creek near Olean. Most of the mountain slopes and many valley bottoms are covered with colluvium in blocks as much as a few tens of feet across; the origin and emplacement of this material have been described by Mills (1981, 1988).

The Tuscarora has been described as littoral marine in origin (Folk, 1960; Hayes, 1974) but more commonly as fluvial (Lowry, 1960; Yeakel, 1962; Dennison, 1970) or as representing some combination of the two environments (Lampiris, 1975). The unit is 50 to 210 ft thick in the Giles County area, about 125 ft thick on Gap Mountain (Spencer, 1970), 50 to 60 ft thick on Little Stony Creek (Eckroade, 1962; Hayes, 1974), about 100 ft thick in the Narrows of the New River (Hale, 1961; Hayes, 1974), and 210 ft thick on Johns Creek Mountain at the northeastern end of Clover Hollow (Hayes, 1974).

Rose Hill Formation

The Tuscarora is succeeded by red hematitic sandstone and shale of the Middle Silurian Rose Hill Formation, named by Swartz (1923) for exposures at Cumberland, Md. In some reports, the Rose Hill is included in the Clinton Group; the Rose Hill in the Giles County area is apparently equivalent to the basal unit of that group, the Cacapon Sandstone (Dennison, 1970). The Rose Hill is composed of dark-grayish-red, medium- to coarse-grained, locally pebbly, hematite-cemented sandstone and lesser amounts of interbedded, fossiliferous, burrowed red siltstone and shale. Sandstone beds locally include clay galls; some beds are greenish gray or mottled. The Rose Hill is probably a lagoonal facies representing marine transgression over the Tuscarora sands (Lampiris, 1975, p. 60). Thick beds of sandstone in the Rose Hill form conspicuous ledges on or just below ridge crests. The formation is 150 to 270 ft thick. Excellent exposures crop out along U.S. Highway 460 on Gap Mountain, where the unit is about 240 ft thick (Lampiris, 1975), and in the Narrows of the New River, where it is 200 to 235 ft thick (Hale, 1961; Lampiris, 1975).

Keefer Sandstone

Red sandstones of the Rose Hill Formation are overlain by very light gray sandstone of the Middle Silurian Keefer Sandstone in a gradational sequence similar in general appearance to the Juniata Formation–Tuscarora Quartzite succession. The Keefer was named by Ulrich (1911) for exposures on Kiefer Mountain in Maryland.

Because of differences in lithology, thickness, and age of the formation in the Giles County area, the name has been used informally by some workers in the area (Dennison, 1970). Butts (1918, 1940) treated the Keefer and the underlying Cacapon (Rose Hill) as members of the Clinton Formation. In the Giles County area, the Keefer is composed predominantly of gray to light-gray, fine- to coarse-grained sandstone and quartzite that are locally crossbedded or ripple marked, burrowed (*Skolithos*), and interlayered with minor reddish-brown sandstone beds. It forms prominent flatirons on dip slopes of ridges and locally crops out as ledges on the crests. Good exposures are seen along U.S. Highway 460 in the Narrows of the New River, where the unit is about 100 ft thick (Hale, 1961), and on Gap Mountain, where it is 220 ft thick (Spencer, 1970). The formation is also well exposed along Stony Creek.

Tonoloway Limestone

A thin, poorly exposed limestone sequence overlies the Keefer Sandstone. This Upper Silurian unit, named Tonoloway Limestone by Ulrich (1911) for outcrops on Tonoloway Ridge in Maryland, is exposed in only a few places in the Giles County area and may be absent in the southeastern part of the area (Ovenshine, 1961, p. 52). Outcrops are in the Dismal Creek drainage in western Giles County, on the southeastern slopes of East River Mountain west of the town of Narrows, and along Stony Creek near Interior. Elsewhere, the presence of this unit is indicated by reddish-brown clayey soil, small sinkholes, or a distinct slope break; it also has been penetrated by shallow drill holes on Flat Top Mountain (Ladd and Stead, 1944). The lower part of the Tonoloway consists of cyclic sequences of fine-grained to cryptocrystalline fossiliferous limestone, dark-gray silty and calcareous shale, and dark-gray massive limestone. The upper part of the formation is composed of thinly laminated, calcareous, dark-gray siltstone and shale, fine-grained cross-laminated sandstone, and minor fossiliferous limestone. The thickness of the Tonoloway locally exceeds 100 ft (Via, 1962) but in most places is less than 50 ft thick.

Devonian System

Rocky Gap Sandstone

Silurian strata in the Giles County area are overlain by a distinctive friable, coarse-grained, crossbedded sandstone that is generally ferruginous or manganiferous. This Lower Devonian unit was named the Rocky Gap Sandstone by Swartz (1929a, p. 82–83) for exposures near Rocky Gap in Bland County, Virginia, about 4 mi west of the Giles County boundary. Many early reports refer to the formation as Becraft Sandstone (Mathews and Pegau, 1934; Butts, 1940; Ladd and Stead, 1944). The Rocky Gap at the type locality now traversed by Interstate Highway 77 was described by Swartz (1929b, p. 68–69) as the "calcareous sandstone" unit of the Giles Formation of Campbell (1894). A nearby section, at Bluefield, Va., was described by Cooper (1944b, p. 126–130). The Rocky Gap locally forms flatirons on the lower slopes of ridges. Good exposures in the Giles County area are found on Gap Mountain along U.S. Highway 460, in the gap through Brushy Mountain between Mechanicsburg and White Gate, in numerous abandoned manganese pits on Flat Top Mountain (Lesure and others, 1982), and elsewhere throughout the area. The Rocky Gap is composed of light-brown, medium- to coarse-grained, crossbedded calcareous sandstone containing vuggy molds of brachiopods and crinoids. Crossbeds are large scale and planar. Iron and manganese streaks, blebs, and stains are common. The calcareous cement is readily removed by weathering, which leaves a friable, indistinctly bedded outcrop. The formation has an average thickness of 65 to 75 ft (Cooper, 1961).

Huntersville Chert

The lower slopes of many ridges in the Giles County area are littered with chert rubble that has weathered from a thin but persistent interval of bedded chert overlying the Rocky Gap Sandstone. This Lower and Middle Devonian unit is the Huntersville Chert, named by Price (1929) for exposures near the town of Huntersville in Pocahontas County, West Virginia. The unit was previously called Onondaga Chert or Onondaga Formation (Mathews and Pegau, 1934; Butts, 1940; Ladd and Stead, 1944). The Huntersville is a massive and irregularly bedded, highly fractured, light- to dark-gray chert; it generally is poorly exposed and is about 50 ft thick in most of the area. A good exposure occurs in a road-metal quarry on the northwestern side of the town of Narrows.

Millboro Shale

The Huntersville Chert is succeeded by a thick sequence of olive-gray to grayish-black, highly fissile clay shale, which was named Millboro Shale by Butts (1940, p. 308) for exposures near Millboro Springs in Bath County, Virginia. The sparsely fossiliferous Middle and Upper Devonian shale occurs throughout the Giles County area in synclinal valleys of the St. Clair and Narrows thrust blocks and in Little Walker and Craig Creek valleys of the Saltville thrust block. Parts of the section are well exposed in roadcuts, borrow pits, and stream banks. Thin sequences of black shale, probably Millboro, occur locally just below the St. Clair thrust on the overturned limb of the Glen Lyn syncline. The upper contact of the formation is gradational over several tens of feet. The thickness of the Millboro is difficult to determine because of repetition of beds by folding and faulting, but Cooper (1961, 1963) reported a thickness of 850 to 1,000 ft.

Brallier Shale

Dark-gray shales of the Millboro Shale grade upward into cyclic, brown, sparsely fossiliferous silty shale and thin beds of siltstone and sandstone. This Upper Devonian sequence was named Brallier Shale by Butts (1918) for exposures near Brallier Station in Bedford County, Pennsylvania. The Brallier crops out mainly in the No Business and Dismal Creek drainages in the southwestern part of the area, on outcrop slopes of Big Walker and Brush Mountains, and along the footwall of the St. Clair thrust fault. The Brallier probably represents distal flysch deposits. Typical lithologies include light-brown, fine-grained sandstone, light-gray to greenish-gray siltstone, and minor light-gray shale. Both the amount of sandstone and the thickness of the beds increase upward through the section; sandstone beds are 3 in thick or less near the base and as much as 1.5 ft thick at the top; very thick, massive, fine-grained sandstone beds also occur locally near the base. The upper contact is gradational and is generally placed (with difficulty) at the base of the lowest, medium-grained, crossbedded, fossiliferous sandstone 6 ft or more thick. The Brallier is about 2,000 ft thick in the Giles County area (Cooper, 1961, 1963).

Chemung Formation

Thin-bedded silty shale, siltstone, and sandstone of the Brallier Shale grade upward into thick-bedded, fine-grained, slightly calcareous, locally fossiliferous (mainly brachiopods) sandstone and interbedded siltstone and shale. Sandstones locally have sole marks and may be turbidites of a proximal flysch facies. In the study area, this Upper Devonian sequence has been called the Chemung Formation on the basis of presumed correlation with the Chemung Group of Hall (1839) near Elmira, N.Y., and it apparently includes at the top the Parrott Formation of Glover (1955) as used by Cooper (1961, p. 59). Because of stratigraphic revisions in the type area, the name "Chemung" probably is no longer appropriate in the Giles County area.

The Chemung crops out in a narrow belt on the northwestern (outcrop) slope of Cloyds and Brush Mountains in Pulaski and Montgomery Counties. Much of it is exposed along State Route 100 on Cloyds Mountain and along the New River in the gap between Cloyds and Brush Mountains, where it is about 700 ft thick (Cooper, 1963, p. 23) (here it is equivalent to Cooper's Parrott Formation and Broadford Sandstone, combined). Overturned Devonian beds beneath the St. Clair thrust include all or part of the Chemung.

Mississippian System

Price Formation

Clastic marine beds of the Chemung Formation are succeeded by the mostly terrigenous, coal-bearing Lower Mississippian Price Formation, named by Campbell (1894, p. 177) for exposures on Price Mountain, a window in the Pulaski thrust sheet in Montgomery County, Virginia, a few miles southeast of the map area (fig. 2). The Price is composed mainly of planar-crossbedded sandstone that generally is feldspathic and micaceous and commonly contains lithic fragments. The base of the formation in most places is marked by one or more ledges of light-gray quartz-pebble conglomerate or conglomeratic quartzite, the Cloyd Conglomerate Member of Butts (1940, p. 343); elsewhere, it is arbitrarily placed within a gradational sequence. Siltstone and shale or mudstone interbeds increase in abundance upward in the section. Thin coal beds, including two seams that have been commercially mined, are near the middle of the unit.

The Price Formation is in a belt encompassing the southeastern (dip) slopes of Cloyds and Brush Mountains; the Cloyd Conglomerate Member crops out along the crests. It is also in a second belt northwest of Peters Mountain and the St. Clair fault, and, in Monroe County, West Virginia, the unit underlies Little Mountain. It is exposed along U.S. Route 460 on Brush Mountain and along State Route 100 on Cloyds Mountain, where it is about 1,000 ft thick (Cooper, 1963, p. 22), and along the New River near Rich Creek, where it is 500 to 600 ft thick (Dally, 1956; Hale, 1961). The Cloyds Conglomerate Member on Cloyds Mountain generally is about 25 ft thick but locally is much thicker.

The Price Formation has been described by Kreisa and Bambach (1973) as a regressive sequence composed of lithofacies representing eight depositional environments, ranging from marine shelf to delta plain and swamp.

Maccrady Shale

The Price Formation grades upward into and interfingers with reddish-brown shale and siltstone of the Lower Mississippian Maccrady Shale. The formation was named by Stose (1913, p. 233–234) for the town of Maccrady, southwest of the map area in Smyth County, Virginia, where the unit contains beds of gypsum, anhydrite, and salt. The Maccrady is the youngest formation in the Valley and Ridge province of Virginia, where it is everywhere succeeded by older beds in thrust-fault contact. It occurs in two linear belts in the Giles County area: on the southeastern dip slopes of Cloyds and Brush Mountains, where as much as 1,600 ft of beds are preserved beneath the Pulaski thrust (Cooper, 1963, p. 22), and northeast of Peters Mountain, where only about 20 to 25 ft form a complete section (Butts, 1940, p. 363; Hale, 1961, p. 38). The formation was probably deposited in a shallow, arid marine basin that was actively subsiding on its southeastern margin.

Because of the great thickness of the Maccrady in the southeastern belt and in the Price Mountain window and because the formation ranges in age in the window to as young as Chesterian, Cooper (1961, 1963) renamed the formation in these areas "Stroubles Formation," but this usage has not been generally accepted.

Greenbrier Limestone

Red shale and siltstone of the Maccrady Formation interfinger with overlying carbonate rocks of the Upper Mississippian Greenbrier Limestone along the northwestern margin of the map area. Although its first use is unclear (Reger, 1926, p. 445–446), the name is derived from the Greenbrier River in nearby Greenbrier and Pocahontas Counties, West Virginia. The unit is generally given formational rank in Virginia and group rank in West Virginia. In Giles County, the interval has been subdivided into 3 or 4 (Butts, 1940; Cooper, 1961) to as many as 11 formations (Reger, 1926); these divisions generally have been defined by faunal elements and have been inconsistently applied. The contact of the Greenbrier with the underlying Maccrady is poorly exposed in Giles County and is generally mapped at the last appearance of red shale float and the first appearance of limestone outcrops or karst topography. The Greenbrier Limestone is on the overturned limb of the Glen Lyn syncline and, to the northeast, in its trough; it is well exposed in railroad cuts along New River and Wolf Creek, north of Narrows, where it is about 1,000 ft thick.

The Greenbrier is composed of medium- to dark-gray, locally oolitic or fossiliferous calcilutite and calcisiltite. Dark-gray to black, irregularly bedded cherts are common. Lesser amounts of argillaceous and dolomitic calcilutite, calcareous shale, and minor siltstone are interbedded with calcilutite and calcisiltite. The formation probably formed on a shallow marine shelf.

Mauch Chunk Group

Upper Mississippian beds above the Greenbrier Limestone in the Giles County area are included in the Mauch Chunk Group, which is primarily a sequence of red and variegated shale and lesser amounts of sandstone and siltstone. The *Mauch Chunk*, first used by Lesley (1876) for exposures at the town of Mauch Chunk (now Jim Thorpe) in eastern Pennsylvania, is about 3,000 ft thick in the Giles County area (Arkle and others, 1979, p. 16). In this area, the group is divisible into *four formations*—the *Bluefield, Hinton*, and *Bluestone Formations* and the *Princeton Sandstone*. Huddle and others (1956, p. 540–543) noted that the "key sandstones" that form the basis for this subdivision—the Princeton Sandstone and the Stony Gap Sandstone Member of the Hinton Formation—are probably lenticular and that their correlation in subsurface studies is uncertain. Recent mapping by the authors (pl. 1) shows that the Stony Gap pinches out in Monroe County, West Virginia.

Bluefield Formation

The Bluefield Formation contains beds transitional between the marine limestone of the underlying Greenbrier Limestone and the terrigenous shale and mudstone typical of the Mauch Chunk Group. The formation, named by Campbell (1896, p. 3) for exposures near Bluefield, W. Va., consists of argillaceous, fossiliferous limestone and calcareous shale interbedded with gray to green clay shale that grades upward into micaceous green to maroon shale and mudstone and sparse interbeds of sandstone and siltstone. The upper Bluefield is generally devoid of fossils and locally contains a few thin coal beds.

The basal contact of the Bluefield Formation is sharp and distinctive in Giles County, although it is locally gradational elsewhere. It is placed at the top of oolitic, fossiliferous limestones, which are overlain by much less resistant calcareous shales of the Bluefield. The upper contact is placed at the base of the Stony Gap Sandstone Member of the Hinton Formation. The distinctive pebbly quartzite pinches out in northeastern Monroe County, West Virginia, and, in that area, the Bluefield and Hinton cannot be differentiated.

The Bluefield Formation is in a narrow belt on the overturned southeastern limb of the Glen Lyn syncline in Giles County and in Mercer and southernmost Monroe Counties, West Virginia. Humphreville (1981) reported a thickness of 1,415 ft for the formation at Glen Lyn, where most of the unit is well exposed along railroad cuts. The uppermost beds of the formation are well exposed nearby in roadcuts along U.S. Highway 460.

Hinton Formation

The Bluefield Formation is overlain by a similar sequence of red, green, and gray arenaceous shale and calcareous siltstone and a few thin beds of fossiliferous limestone and coal. This sequence was named Hinton Formation by Campbell and Mendenhall (1876) for exposures near Hinton in Summers County, West Virginia. It has a hard, resistant, pebbly quartzite at the base, named the Stony Gap Sandstone Member by Reger (1926) for exposures between Bluefield and Princeton in Mercer County, West Virginia. The Hinton is as thick as 2,000 ft in the Giles County area (Cooper, 1971, p. 97), and the Stony Gap Member ranges from 0 to 100 ft thick. Northeast of its pinchout, near Lindside, W. Va., the Hinton cannot be differentiated from the underlying Bluefield Formation. The Stony Gap Member lies along the southeastern limb of the Glen Lyn syncline, and the steeply dipping, resistant beds form Stony Ridge. The axis of the syncline, which here forms the Allegheny structural front, is in lower Hinton shales in most of the Giles County area. The Hinton and Stony Gap are well exposed along U.S. Highway 460 near Oakvale, W. Va.

Princeton Sandstone

A light- to medium-gray resistant sandstone (locally conglomerate) caps or rims higher elevations in northeastern Mercer County, West Virginia. This unit, named Princeton Conglomerate by Campbell and Mendenhall (1876, p. 487, 489) for the town of Princeton in the southwestern corner of the study area, is 40 to 100 ft thick (Campbell, 1896, p. 3; Butts, 1940, p. 403; Cooper, 1961, p. 69; Russ, 1969, p. 29). The Princeton is well exposed in and around Princeton and along nearby Interstate Highway 77. Lithologies range from orthoquartzite to subgraywacke; pebbles include limestone, chert, quartzite, vein quartz, limonite, and shale (Cooper, 1961, p. 69).

Bluestone Formation

The youngest bedrock unit in the Giles County area is the uppermost Mississippian Bluestone Formation, named by Campbell (1896, p. 3) for exposures along the Bluestone River in Tazewell County, Virginia, and Mercer County, West Virginia. It is composed of red to gray shale, lesser sandstone and siltstone, and a few thin coal beds. The total thickness of the Bluestone is about 800 ft (Campbell, 1896, p. 3; Russ, 1969), but only about 500 ft are preserved in the map area. According to Englund (1968; 1979, p. C14), the uppermost beds of the Bluestone Formation, not present in the map area, are Early Pennsylvanian in age.

Both the Princeton Sandstone and the Bluestone Formation are flat-lying or gently dipping beds of the Appalachian Plateau in Mercer County, West Virginia, in the southwestern part of the map area.

STRUCTURAL GEOLOGY AND SEISMICITY

Structural Setting

The Giles County area is mostly in the Valley and Ridge structural province of Virginia and West Virginia; a small part of the area is in the Allegheny Plateau (fig. 1). The area is just southwest of a major bend in the Appalachian orogen at Roanoke, Va. (fig. 2). This bend, the Roanoke recess, marks the boundary between the central and the southern Appalachians. The deformational style of the Valley and Ridge province differs conspicuously across this boundary; Weaver (1970, p. 125) described this change as the "single most striking feature" of the province. Northeast of Roanoke, regional folds are the dominant structures, and thrust faults are few and relatively unimportant; southwest of Roanoke, including the Giles County area, thrust faults dominate, and folds are subordinate in scale and significance. Lowry (1971) analyzed in detail this contrast in deformation style, and Rodgers (1970a, p. 39–43) described the nature of the transition zone and discussed several possible explanations for the contrast.

The Giles County area is thus within the southern Appalachian segment but close to the juncture with the central Appalachians. As a result, structures within the area are dominated by thrust faults, but several prominent folds occur as well (fig. 6). The axis of the northwesternmost fold, the overturned Glen Lyn syncline (pl. 1, cross section) (McDowell, 1982), forms the boundary between the intensely deformed Valley and Ridge province and the much less deformed Allegheny Plateau province (fig. 1). This boundary is known as the Allegheny Front (fig. 1).

All major structures in the Giles County area follow the southern Appalachian trend, about N. 65° E. Thrust faults and axial surfaces of the major folds dip to the southeast and produce a northwest-verging asymmetry of most structures (pl. 1). Surface structures (fig. 6) are well known from mapping, but structures at depth are more problematic and have been interpreted in various ways (fig. 7).

Regional Structures

The Giles County area contains four major thrust faults and several map-scale folds, all of which have been deformed locally by numerous minor structures (fig. 6). The thrusts are, from southeast to northwest, the Pulaski, the Saltville, the Narrows, and the St. Clair. The Pulaski fault, as commonly traced, extends through the Roanoke recess; surface traces of the other three faults terminate in the transition zone, within a few tens of miles northeast of Giles County (fig. 2). The larger folds include, from southeast to northwest, the Spruce Run and Dismal Creek synclines, the Clover Hollow anticline, the Johns Creek syncline, the Bane anticline, and the Pearisburg and Glen Lyn synclines (fig. 6). All are on the Narrows fault block, except for the Glen Lyn syncline, which is in the footwall of the St. Clair fault. These folds and thrust faults are described below in sequence from southeast to northwest.

The Pulaski fault extends for more than 150 mi northeast and southwest of the Giles County area and has been described as "one of the major thrust faults of the Valley and Ridge province of the Appalachians" (Rodgers, 1970b, p. 175). The thrust, which occurs along the southeastern border of the map area, brings Lower, Middle, and Upper Cambrian formations over the Lower Mississippian Price Formation and Maccrady Shale. A few miles southeast of Giles County, the Pulaski thrust sheet contains several large windows. Complex structures within these windows and extensive fault breccia throughout the lower part of the thrust sheet have recently been studied in detail by Schultz (1986a), who developed a model for the pervasive deformation of the sheet. Bartholomew (1979) estimated a minimum lateral displacement of 33 mi for the Pulaski thrust in the Roanoke area.

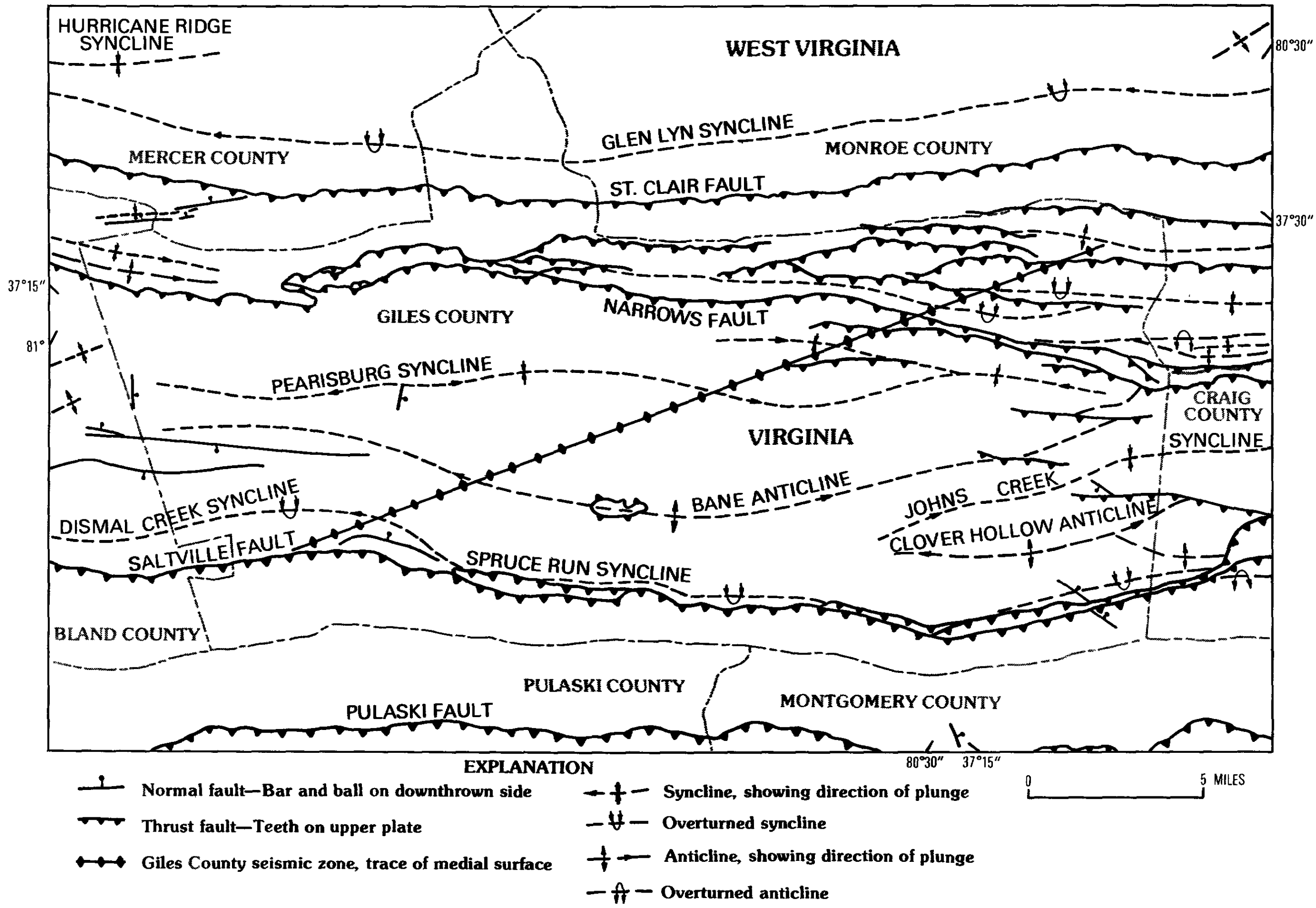
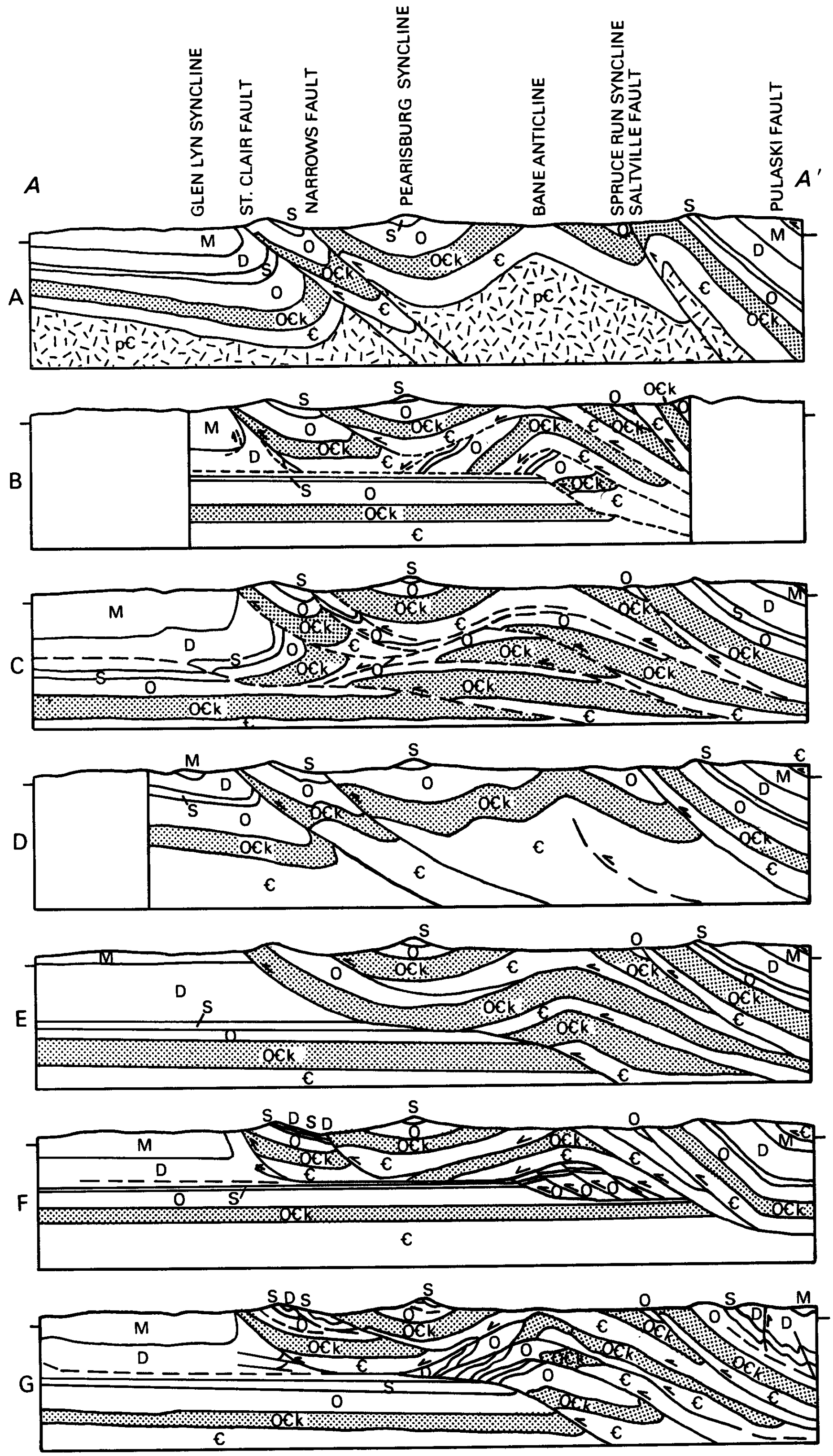


Figure 6. Major structural features in the Giles County area of Virginia and West Virginia.

The leading edge of the Pulaski fault overrides southeast-dipping beds of the Saltville block, which range in age from Middle Cambrian (Honaker Dolomite) to Early Mississippian (Maccrady Shale and Price Formation). These beds, which occur in a simple homocline, form the two mountain ridges and intervening valley along the southeastern margin of the Giles County area. The Saltville fault, which can be traced some 500 mi southwestward to the Coastal Plain of Alabama (Rodgers, 1970a, p. 40), gradually loses displacement to the northeast and apparently terminates in Devonian shales in the core of the Sinking Creek anticline near Newcastle, Va., about 20 mi from Giles County. At Greendale in Washington County, Virginia, some 75 mi southwest of the Giles County area, total stratigraphic displacement is 14,000 ft (Butts, 1940, p. 457). At some places, the fault is a single discrete sliding surface and an inch or less of dolomite gouge; at others, it includes multiple sliding surfaces and pervasive cataclasites (House and Gray, 1982a). The dip of the fault in exposures generally is about 30° but ranges from flat lying near Saltville, Va. (Muangnoicharoen, 1978), to almost vertical at Berton, in Giles County (Stanley, 1983). Most subsurface models show the fault having listric geometry and merging at depth with a master decollement in the Rome Formation (fig. 7, interpretations D–G). A narrow horse of Cambrian-Ordovician carbonate rocks occurs along the trace of the Saltville fault through most of the Giles County area. Models of deformation based on microscopic strain analysis (House and Gray, 1982a) show that the Saltville fault was emplaced under brittle conditions, at temperatures of less than 250 °C (depths of 3–5 mi), and that movement was both seismic (stick slip) and aseismic (cataclastic flow).

Figure 7. Interpretation of structures along line of section *A–A′* (pl. 1). Stratigraphic units: p€, Precambrian; €, Cambrian; O€k, Knox Group; O, Ordovician rocks; S, Silurian rocks; D, Devonian rocks; M, Mississippian rocks. A and D are diagrammatic; others are balanced. Tick mark indicates sea level. Base of sections is -18,000 ft; no vertical exaggeration. All sections are slightly modified, mainly to show the same stratigraphic units. Sources of interpretations: A, Cooper (1961, pl. 8, 36); B, Perry and others (1979, fig. 4); C, Roeder and others (1978, sec. V3); D, Bartholomew and others (1980); E, Woodward and Gray (1985, sec. 16); F, Gresko (1985, fig. 19); G, Kulander and Dean (1986, fig. 6, sec. 10).


A
A'
GLEN LYN SYNCLINE
ST. CLAIR FAULT
NARROWS FAULT
PEARISBURG SYNCLINE
BANE ANTICLINE
SPRUCE RUN SYNCLINE
SALTVILLE FAULT
PULASKI FAULT
A
B
C
D
E
F
G

Overturned beds of Middle Ordovician to Early Devonian age in the footwall of the Saltville fault form the southeastern limbs of the Spruce Run and Dismal Creek synclines (fig. 6). The axial traces of these synclines are overridden near Staffordsville, on U.S. Highway 100, and a gap of 2 to 3 mi forms between them. The Spruce Run syncline extends for about 20 mi northeastward to the southwestern edge of Craig County, Virginia, where it is again overridden by the fault. The Dismal Creek (or Brushy Mountain) syncline extends southwestward a similar distance, and it, too, is overridden again, beyond the map area, in Bland County, Virginia. These two synclines are probably segments of a single structure, represented farther southwest by the Greendale syncline of southwestern Virginia and northeastern Tennessee. In the Giles County area, dips on the southeastern limbs range from vertical to 45° SE. overturned. Dips on the northwestern (common) limbs range from 10° to 45° SE. Structural thinning of as much as 50 percent occurs on the overturned limbs (Stanley, 1983). Cleavage and outcrop-scale folding and faulting occur in Middle and Upper Ordovician limestones and shales of the Spruce Run syncline (Gray, 1981; Simon and Gray, 1982; Stanley, 1983).

The Greendale syncline is one of the most prominent structures of the southern Valley and Ridge province and contains the youngest beds (Upper Mississippian Pennington Formation) southeast of the Allegheny Front. The axial trace of the syncline is exposed for a length of about 45 mi from Saltville, Va., to near the Tennessee border; in Tennessee, where the axial portion is cut out by the Saltville fault, Mississippian beds of the northwestern limb extend for an additional 125 mi (Butts, 1940, p. 458). The Greendale syncline is thus probably the longest continuous fold in the southern Appalachians.

A doubly plunging anticline in eastern Giles County brings uppermost Knox (Lower Ordovician) rocks to the surface in a small but conspicuous axial valley. This small, regional-type fold is less than 10 mi long and is just northwest of the Saltville fault and the overturned Spruce Run syncline (fig. 6). The Clover Hollow anticline is slightly asymmetrical, and its axial surface dips to the southeast. On the basis of strain indices, as well as model studies by House and Gray (1982b), Simon and Gray (1982) concluded that the Clover Hollow anticline is a buckle fold associated with lateral shortening of the Narrows block above a decollement rather than a ramp anticline. Just northeast of the Giles-Craig County line, the axis of the anticline appears to be cut off by an unnamed thrust.

Just northwest of the Clover Hollow anticline is the much larger Johns Creek syncline, which is almost 40 mi long. Only the southwestern part of the syncline, plunging northeast, is in the Giles County area (fig. 6). Devonian beds are preserved in the trough of the syncline.

Central Giles County is dominated structurally by a prominent doubly plunging anticline (fig. 6), commonly called the Bane dome because of its elliptical outcrop shape. Red mudstones of the Rome Formation (Lower Cambrian) are exposed in the core; the Rome is exposed nowhere else northwest of the Pulaski fault in the Giles County area. Recent mapping by Perry and Repetski (1979) shows the presence of a window on the apex of the Bane dome, near Bane, in which uppermost Knox Group dolomite (Lower Ordovician) is exposed below a thrust fault. Rocks of the Rome Formation are highly deformed, displaying numerous mesoscopic upright to recumbent folds, faults, veins, and cleavage. Breccia of the Max Meadows type (Cooper, 1939, p. 59–62) is in isolated localities around the window. The anticline crosses the length of Giles County but apparently does not extend beyond the county boundaries. Near Mountain Lake, the axial trace is displaced by minor faults.

In 1948, a test well—the F.P. Strader No. 1—was drilled for petroleum exploration by the California Company on the apex of the Bane dome to a total depth of 1,443 ft. The well began in the Rome Formation (Lower Cambrian) and bottomed in sandy and oolitic dolomites believed by Cooper (1961, p. 92; 1964, p. 97; 1968, p. 33; 1971, p. 98) to be Shady Dolomite (Lower Cambrian) and later identified by Perry and others (1979) as upper Knox Group (Upper Cambrian and Lower Ordovician). Seismic reflection studies (Edsall, 1974; especially Gresko, 1985) reinforced the view that the Bane dome is the result of thrust duplication of Cambrian through Devonian rocks.

Northwest of the Bane anticline is the Pearisburg (Angels Rest) syncline, which is similar in size and has an axial trace roughly parallel to the Bane anticline (fig. 6). Lower and Middle Devonian rocks are exposed in the trough of the syncline on Pearis and Butt Mountains. A culmination is near Pearisburg, at about the same position along the axis as the culmination of the Bane dome. As is the case for the Bane anticline, the axial trace apparently does not extend beyond the county boundaries (fig. 6).

The northwestern part of Giles County is traversed by the Narrows thrust fault. Southwest of the New River, the fault brings Honaker or Copper Ridge Dolomite (Middle or Upper Cambrian) over Silurian and younger beds for some 40 mi to Tazewell County, Virginia (fig. 2); beyond Tazewell County, the displacement of this block is then transferred by a series of small thrusts and folds to the Copper Creek fault (Grabowski, 1983), which extends across Tennessee almost to the Georgia boundary (Rodgers, 1970a, p. 1). Northeast of the New River, the thrust loses stratigraphic displacement and passes into a zone of imbrication in the Peters Mountain–Big Mountain area. The fault appears to be continuous through this zone into Monroe County, West Virginia (fig. 6). The fault is exposed in a railroad cut along the New River, just north of the town of Narrows. The hanging wall is relatively undeformed, but horse blocks of the footwall are strongly deformed.

The northwesternmost thrust fault in the Giles County area (fig. 6), and in the northern end of the southern Appalachians, is the St. Clair fault. The fault has been traced from its northeastern terminus, the core of an anticline in Alleghany County, Virginia, some 50 mi from the New River, southwestward to the Clinchport and related faults of southwestern Virginia and Tennessee (fig. 2), for a total length of 380 mi (Harris, 1965). The fault is extremely well exposed on U.S. Highway 460 south of Rich Creek, Va., where uppermost Knox Group dolomites (Lower Ordovician) are in bedding-parallel contact with overturned beds of Upper Devonian shale. Although they are probably Millboro Shale, these upper Devonian shales also have been identified as beds of Brallier Shale (Butts, 1940, p. 461) or Chemung Formation (Cooper, 1961, p. 59, pl. 46A; 1971, pl. 9). Other exposures of the fault can be found near Glen Lyn, Va.

Rocks of the footwall of the St. Clair thrust locally have been severely deformed, and footwall formations commonly have been tectonically thinned. Reconnaissance mapping suggests the presence of a series of horses of Ordovician and Silurian rocks along the fault near Zenith, W. Va., in the northeastern corner of the map area.

The overturned Glen Lyn syncline is just northwest of and parallel to the St. Clair fault (fig. 6). Its southeastern limb consists of beds ranging from Late Devonian (Brallier Shale?) to Late Mississippian (Hinton Formation) in age; it is vertical to overturned and dips as low as 30° SE. The northwestern limb is flat to gently dipping; the axial trace of the syncline forms the boundary between the Valley and Ridge and Allegheny Plateau structural provinces, the Allegheny Front (fig. 1). Earlier workers (Reger, 1926; Cooper, 1961, 1971) refer to this structure as the Hurricane Ridge syncline. McDowell (1982) showed that the Hurricane Ridge, named by Campbell (1896), is a separate structure of different form, trend, and tectonic significance.

Tectonic Evolution

Current ideas on the structure and tectonics of the Appalachian foreland have been summarized by Rodgers (1970a) and Hatcher (1981). The Valley and Ridge province is generally characterized as dominated by southeast-dipping thrust faults and asymmetric northwest-verging folds, both of which pass rather abruptly into the much more gently deformed Allegheny Plateau province on the northwest. The boundary between these provinces is known as the Allegheny Front (Rodgers, 1970a, p. 19, 32) (fig. 1), which, in the study area, is along the axial trace of the Glen Lyn syncline (fig. 6).

For many years, a controversy over the involvement of basement rocks in foreland structures occupied much attention (Rodgers, 1949, 1964; Cooper, 1961, 1964, 1968) (fig. 7), and structures in the Giles County area were used to support both sides of this controversy (Cooper, 1964, 1968; Rodgers, 1964; Thomas, 1966; Milici, 1973). Analyses of drilling data (Gwinn, 1964) and seismic profile data (Harris and Milici, 1977) demonstrate a "thin skin" style of deformation in this region, an interpretation now universally accepted (fig. 7, interpretations B–G).

Other problems remain not wholly solved. When and how were these structures formed? These problems are related to the nature of the driving mechanism—gravity or compression. This controversy was discussed briefly by Hatcher (1981, p. 492–493), who pointed out some significant difficulties with the gravity hypothesis. Delineation and analysis of structures in the Giles County area are useful in addressing these problems.

Interpretations of the structural geology of the Giles County area by various authors are shown in sections A through G of figure 7. Cross sections A through E and G are based on surface mapping and a single well, the California Company F.P. Strader No. 1 (total depth 1,443 ft), on the apex of the Bane dome. Cross section F also incorporates results of seismic reflection profiling. These cross sections illustrate several models that have been proposed for the structural evolution of the area. The models differ in three main respects: (1) basement involvement (thick skin) (fig. 7, section A) or detachment (thin skin) styles of deformation, (2) subsurface structure responsible for the Bane anticline, and (3) sequence of thrust fault development.

The Strader well on the Bane anticline, drilled in 1948, was cited by Cooper (1964, p. 97–98) as providing the evidence that persuaded him of basement involvement in the folding and faulting of the Appalachian foreland. He believed that the well penetrated a normal stratigraphic succession and that the basement lay relatively close to the surface (Cooper, 1968, p. 45). His interpretation (fig. 7, section A) was supported by Sears and Robinson (1971) on the basis of gravity data. Using stratigraphic data from the nearby "Hurricane Ridge" (now Glen Lyn) syncline, Thomas (1966) supported Cooper's concept of contemporaneous deformation in this area (Cooper, 1961, p. 100–118; 1964, 1968), in which folds and thrusts were generated by differential subsidence of the basement. This idea was in opposition to the prevailing interpretation that Paleozoic rocks were detached from the basement and moved laterally for great distances (Rich, 1934; Rodgers, 1949, 1953, 1964; Gwinn, 1964). On the basis of this "thin-skin" approach, Milici (1970, 1973) presented interpretations of the Giles County area that account for the structures by means of detachment ("thin skin") thrusts and a repeated section beneath the Bane dome. To resolve this controversy, Byron Cooper and John Rodgers proposed to drill a hole on the Bane dome reaching to the basement, which Cooper believed was within 2,000 ft and Rodgers believed was as deep as 8,000 ft (Cooper, 1971, p. 98). No basement test has yet been drilled, but a reexamination of the Strader well cuttings by Perry and others (1979), using conodont material, reveals that the dolomites below the Rome Formation are from the upper Knox Group rather than the Shady Dolomite. Thus, instead of a normal stratigraphic succession in the Lower Cambrian, the well penetrated a repeated section, a sequence that requires the presence of a subhorizontal thrust (fig. 7, section B), as Milici had predicted earlier. Subsequent seismic reflection profiling confirms this structural model (Gresko, 1985) (fig. 7, section F), and all recent interpretations (fig. 7, sections B–G) are based on it. Most models suggest a duplex structure involving horses (fig. 7, sections B, C, E–G). Basement involvement in Appalachian structures is now regarded as being limited to indirect effects, such as growth structures that were later transported by detachment (Shumaker, 1986; Thomas, 1986; Wheeler, 1986).

The Bane anticline has been related to three types of subsurface structures: (1) basement anticline (fig. 7, section A), (2) blind thrust (fig. 7, section D), and (3) duplex over a basal decollement ramp from Cambrian to Devonian strata (fig. 7, sections B, C, E–G). The basement anticline was proposed as a "thick-skin" solution and is no longer feasible. The duplex models use different tectonostratigraphic units. Sections C and E (fig. 7) involve horses of Cambrian and Ordovician rocks, whereas sections B, F, and G (fig. 7) have horses composed of Cambrian through Devonian rocks. These models generally include bedding-parallel thrusts (decollement) in incompetent shales of the Rome and Martinsburg Formations and the Millboro Shale. In some cases, they require such thrusts in competent Middle Ordovician limestones, an occurrence that seems less likely.

The sequence of thrusting across the Valley and Ridge province also has been problematic. A northwest to southeast development of thrust faults, related to a gravity-sliding mechanism of origin, was suggested by Milici (1975), Harris and Milici (1977, p. 13–14), and Bartholomew and others (1980). This structural model is illustrated by section D (fig. 7). Other workers (Perry, 1978; Hatcher, 1981; Woodward and Gray, 1985) argued that deformation progressed from southeast to northwest (hinterland to foreland) as a result of compression (for example, fig. 7, section E). Mullenax (1981), in a study of mesoscopic features in the Martinsburg Formation in the St. Clair and Narrows blocks, found less internal deformation in the St. Clair block, an observation that he interpreted as inconsistent with gravity-sliding models. Bartholomew and others (1982, p. 125) suggested a thrust sequence in the Giles County–Roanoke area of Pulaski–St. Clair–Narrows–Saltville, a melding of the two viewpoints. The Narrows fault has been interpreted as both a back-limb imbrication of the St. Clair thrust (Perry and others, 1979, p. 651; Roeder and others, 1978; Gresko, 1985, p. 49) (fig. 7, sections B, C, F) and as a splay off the basal detachment zone (Bartholomew and others, 1980; Woodward and Gray, 1985, p. 41) (fig. 7, sections D, E). Of these interpretations, only those of Perry and others (1979) and Gresko (1985) remain within the constraints of surface geology (for example, the presence of Rome Formation on the crest of the Bane anticline and significant footwall synclines beneath the thrusts) (fig. 7, sections B, F).

Seismicity

The Giles County area is within the southern Appalachian seismic zone of Bollinger (1973). The earthquake of May 31, 1897, is the largest shock known to have occurred in Virginia (Campbell, 1898) and one of the largest in the Eastern United States (MMI VIII, $m_b = 5.8$) (Bollinger and Hopper, 1971; Nuttli and others, 1979). The area continues to be relatively active seismically. In addition to numerous microearthquakes, an event of November 20, 1969, near Elgood, W. Va., in the southwestern corner of plate 1, registered a $m_b = 4.3$ (Bollinger and Hopper, 1970). On the basis of current monitoring by a local network and using certain previous events, Bollinger (1981) defined a planar seismic zone in Giles County (fig. 6) that is about 25 mi long, 6 mi wide, and 3 to 15 mi deep and has a nearly vertical dip. This configuration places the zone below detachment thrusts, as figure 7 shows, and mostly within Precambrian basement rocks. Bollinger and Wheeler (1983, 1988) assumed that the seismic zone was the source of the 1897 shock and speculated that the most likely fault mechanism is reactivation of ancient normal faults produced by Iapetan rifting, the Late Precambrian to Early Paleozoic opening of the ocean basin preceding formation of the Atlantic Ocean. An alternative explanation is that the seismic zone, which at N. 43° E. is 20° off the trend of the overlying detachment structures but close to the trend of structures north of the Roanoke reentrant, is related in origin to the central Appalachians. Thus, the seismic zone might represent a basement fault that influenced the formation of those structures and was later overridden by detachment thrusts of the southern Appalachians.

During field investigations for the present study, an extensive search was conducted for neotectonic features at the surface, in either bedrock or surficial deposits, that could be related to seismic activity. No such features were found. Numerous rock falls and slides in the area may have been triggered by seismic shaking. Campbell (1898, p. 235) reported a "landslide of considerable proportions" on the face of Wolf Creek Mountain that was caused by the earthquake of 1897. Schultz (1986b) mapped a giant rockslide complex on Sinking Creek Mountain, just east of the map area, for which he considered seismic shaking a possible initiating mechanism. Mills (1986) reported a downstream increase of about 90 ft in terrace elevation along the New River across the Giles County seismic zone and suggested an origin by fault movement associated with the seismic zone. Such differential uplift cannot be confirmed by structural studies of the bedrock.

MINERAL RESOURCES

The Giles County area contains a modest amount of minor mineral resources (iron, manganese, nonmetallic minerals, and fossil fuels), although the only resources currently being exploited are limestone, dolomite, and siliceous aggregate. The mineral resources of part of Giles County have recently been evaluated by Lesure and others (1982).

Iron

Iron resources are of two types: hematitic sandstone of the Rose Hill Formation (Silurian) and limonite in the Rocky Gap Sandstone (Devonian) and, to a minor extent, in the Tonoloway Limestone and Keefer Sandstone (Silurian). The hematite deposits, generally known as Clinton ores, are the more important of these submarginal resources (Lesure and others, 1982, p. 43).

Hematite is the cementing material between quartz grains in numerous beds of the Rose Hill Formation, which is widely distributed on mountain crests and slopes in the Giles County area. Various investigators have reported that one-fourth to one-third of the Rose Hill is composed of hematitic sandstone (Lesure and others, 1982, p. 46). Cooper (1960, p. 1) indicated that the iron content of the sandstones ranges from 23 to 37 percent; Lesure and others (1982, p. 47) obtained averages for two collections of 14.1 and 20.5 percent and reported results from other studies of 14.0 to 20.7 percent average iron.

Limonite resources, supergene iron deposits commonly referred to as Oriskany ores, have been mined in a few locations in the Giles County area. Lesure and others (1982, p. 54) considered limonite deposits in this area to be small and probably erratic because of the lack of a thick limestone underlying source rocks in the Millboro Shale.

Manganese

Manganese ore deposits are widely distributed in western Virginia and adjacent West Virginia. They are generally restricted to bedrock or residuum at three stratigraphic levels: Shady Dolomite (Lower Cambrian), Knox Group (Upper Cambrian and Lower Ordovician), and Rocky Gap Sandstone (Lower Devonian) (Stose and Miser, 1922, p. 49–50). Only the latter two levels are in the Giles County area.

Most of the manganese deposits associated with the Knox Group are in the Newport district, along Sinking Creek, where the manganese is in weathered residual clays derived from dolomites and dolomite breccias along the Saltville fault (Sears, 1957, p. 3). Other prospects are along Spruce Run and near Pembroke. All of these deposits are shallow and limited in extent and have yielded little ore (Stose and Miser, 1922, p. 119–123).

Manganese deposits related to the Rocky Gap Sandstone are of greater importance and have yielded more ore. The manganese oxides, in nodules and fracture fillings and as cement in sandstone, are associated with Oriskany iron ores of the Rocky Gap, but small amounts are also just below the formation, in the top of the Keefer Sandstone and in clayey residuum over the Tonoloway Limestone. The deposits are at this stratigraphic interval throughout the county (Stose and Miser, 1922, p. 123–142), but the most productive workings have been in the Flat Top Mountain district of southwestern Giles and adjacent Bland Counties (Ladd and Stead, 1944). Reserves in this district were estimated by Ladd and Stead (1944, p. 224) at 5,000 tons of ore, averaging 35 to 40 percent manganese. Lesure and others (1982, p. 64) reported that production from the Stange mine between 1917 and 1959 was more than 45,000 tons of manganese ore.

Nonmetallic Resources

Nonmetallic resources in the Giles County area include limestone and dolomite, quartz sandstone, shale, dimension stone, and phosphate. The economic potential of these resources has been described in detail by Lesure and others (1982, p. 65–72). Chemical-grade limestone is currently being mined from the Five Oaks Limestone (Middle Ordovician) at Kimballton, and limestone and dolomite for crushed rock have been obtained from Cambrian and Ordovician formations at various localities, notably near Ripplemead and Pembroke. Crushed stone is also being quarried from the Huntersville Chert near the Narrows.

No other nonmetallic resources are currently being exploited. Cooper (1944b) described the limestone and dolomite resources of the area in detail. Mathews and Pegau (1934) investigated dimension-stone prospects in "marble" from the Moccasin Formation. Clay and shale for industrial uses were studied by Johnson and others (1965). Prospects for further commercial development of nonmetallic resources are slight.

Fossil Fuels

Fossil fuels include coal, oil, and gas. Coal has been mined on a small scale along the southeastern slopes of Cloyds and Brush Mountains in Montgomery and Pulaski Counties, along the southeastern border of plate 1. Oil and gas have not been obtained in commercial quantities from the area, although gas was produced from the A.W. Hicks No. 6478 well in western Mercer County, West Virginia (Huddle and others, 1956).

Commercial coal is in two minable seams near the middle of the Price Formation (Lower Mississippian), the Merrimac and Langhorne beds (Campbell, 1925, p. 145). The coal beds can be as thick as 6 ft but are generally much thinner (Cooper, 1961, p. 61). Most of the coal is considered to be semianthracite in rank (Campbell and others, 1925, p. 126). Reger (1926, p. 514–518) reported coal in the same stratigraphic position in the Price Formation in Mercer and Monroe Counties, West Virginia, northwest of the St. Clair fault, but the beds are too thin or too impure to be of commercial interest. Because of the steep dip and other structural complications, the coal in Montgomery and Pulaski County is mined only sporadically at present.

Although no oil or natural gas has been discovered in commercial quantities in the Giles County area, thermal maturity studies suggest that rocks of Mississippian age and older are a potential source of natural gas, and structurally prospective areas do exist in the area (Perry, 1982, p. 71–72). Wells drilled northwest of the Glen Lyn syncline have encountered shows of natural gas but no commercial quantities (Perry, 1982, p. 71). The only test well within Giles County, the F.P. Strader No. 1 on the Bane anticline, which penetrated upper Rome Formation and upper Knox Group, was abandoned without encountering either oil or gas (Huddle and others, 1956, p. 531). Stanley and Schultz (1983) investigated coal-bed methane possibilities in Montgomery County, Virginia, and concluded that these resources are of marginal value.

GEOLOGIC HAZARDS

Environmental hazards related to the geologic features of Giles County are not severe and include landslides, karst terrain, floods, and earthquakes.

Slope failures are most likely on steep slopes such as mountainsides and along the New River. Instability is greater where colluvium is present. In the Giles County area, relatively few roads and houses are susceptible to significant risk of slope failure. A major exception is U.S. Highway 460, 1 mi northeast of Narrows, Va., located on a slope composed of brecciated Silurian sandstone along the Narrows fault; the slope has been undercut by the New River and is slowly, but more or less continuously, failing (Cooper, 1961, p. 159; Samford, 1983). Giant ancient landslides similar to those described by Schultz (1986b) and Southworth and Schultz (1986) have recently been recognized on dip slopes throughout the area. Blocks of Silurian sandstones and quartzites as long as 0.6 mi or more have failed and slid or toppled from steep dip slopes at and below ridge crests. These gravity failures occurred during the Pleistocene and early Holocene and currently are not active. The landslides may be mistaken for Alleghenian structures, and care must be taken to differentiate between tectonic and surficial features in these settings.

Karst features, including sinkholes, caves, and sinking or underground drainage, are common in much of the plate 1 area, principally along the floors of valleys underlain by Cambrian-Ordovician carbonate rocks, especially Middle Ordovician limestones. Collapse of such features presents a minor hazard, particularly where the water table has been lowered. Subsurface movement of pollutants is generally more rapid and widespread in karst terrain.

Flooding presents a periodic minor hazard on floodplains along the New River and its larger tributaries.

Earthquakes are a hazard of unknown but potentially dangerous dimensions. On the basis of an analysis of the Giles County seismic zone, Bollinger (1981, p. 281) postulated, for emergency planning, a shock having a magnitude of $m_s = 7$ and MMI IX. Such a shock would result in considerable damage to buildings, including partial collapse, and disruption of water supplies and utilities. (The largest historical earthquake, in 1897, had MMI XIII, and only minor damage resulted). In addition to damage to structures, seismic shaking probably would trigger landslides and rockfalls in areas of steep slope.

A map showing slope categories and karst features of Giles County was compiled by Miller and Hubbard (1986).

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Chapter F

Late Paleozoic Depositional Trends in the Central Appalachian Basin

By KENNETH J. ENGLUND and ROGER E. THOMAS

A description of Carboniferous lithostratigraphy and paleogeography and an interpretation of terrestrial sedimentation and structural trends of the faulted and folded Appalachians

U.S. GEOLOGICAL SURVEY BULLETIN 1839

EVOLUTION OF SEDIMENTARY BASINS—APPALACHIAN BASIN

CONTENTS

PLATE

FIGURES

CONVERSION FACTORS FOR SOME SI METRIC AND U.S. UNITS OF MEASURE

To convert from	To	Multiply by
Feet (ft)	Meters (m)	0.3048
Miles (mi)	Kilometers (km)	1.609
Pounds (lb)	Kilograms (kg)	.4536
Degrees Fahrenheit (°F)	Degrees (°C)	Temp °C=(temp °F−32)/1.8

Late Paleozoic Depositional Trends in the Central Appalachian Basin

By Kenneth J. Englund *and* Roger E. Thomas

Abstract

Trends in the regional extent, stratigraphic distribution, and character of upper Paleozoic terrestrial rocks in the central Appalachian basin were influenced by depositional events associated with basin evolution. Most of these rocks originated as siliciclastic detritus eroded from tectonic highlands that were elevated by plate collision along the southeastern margin of the basin. Terrestrial sediments, indicated by northwestward-prograding delta lobes and fluvial systems, were deposited in a slowly subsiding foreland basin. Concurrently, marine deposition encroached from the northwest in a shallow epicontinental sea that covered an unstable cratonic shelf. The transition from terrestrial to marine environments is evident in time-equivalent sequences of (1) fluvial and deltaic sandstone, (2) coal and related swamp deposits, (3) lagoonal and bay-fill shale, (4) barrier- and offshore-bar sandstone, and (5) marine limestone and shale. Terrestrial progradation extended northwestward during periods of high rainfall and sufficient subsidence to accommodate a high influx of clastic sediments. Conversely, marine incursions extended farthest southeastward during periods of diminishing rainfall and low clastic influx. When equilibrium existed between marine and terrestrial influences (that is, fluctuation from regression to transgression), the stillstand of sea level was accompanied by the development of widespread peat swamps and barrier or offshore bars. As the Appalachian basin evolved, terrestrial deposition gradually shifted northwestward and occupied the entire basin by Early Permian time. In addition, the strandline or wedgeout of terrestrial coal-bearing deposits rotated from N. 30° E. in Early Mississippian time to N. 65° E. in Early Pennsylvanian time. This change in the sedimentation pattern coincided with and possibly established the age of a similar rotation in the strike of deformed strata in the faulted and folded Appalachians, which may have resulted from plate rotation or multiple plate collisions.

Manuscript approved for publication May 18, 1989.

INTRODUCTION

The cross section presented in this report (pl. 1) extends through relatively flat lying Mississippian and Pennsylvanian rocks that underlie the Appalachian Plateaus of eastern Kentucky and southwestern Virginia. This traverse extends for 120 mi from northwest to southeast across most of the central Appalachian basin and is a compilation of data from 250 core holes, oil and gas tests, and surface sections. Geologic quadrangle maps provided additional information on the continuity and correlation of units between data points in eastern Kentucky and in part of southwestern Virginia. Reconnaissance geologic investigations were also sources of information, especially in the unmapped area.

Strata exposed along this traverse are mostly Pennsylvanian in age and represent the principal coal-bearing units in the Appalachian basin. Coal also occurs in older rocks of the faulted and folded Appalachians, southeast of the cross section, where peat accumulation began in the foreland basin in Late Devonian time and continued intermittently in Mississippian time. Peat deposits increased in extent and thickness as terrestrial sediments prograded northwestward across the foreland basin. By Early Pennsylvanian time, terrestrial sedimentation had extended into the area of the Appalachian Plateaus, and, by Middle Pennsylvanian time, it had extended across the cratonic shelf. Coal beds attained their maximum distribution, thickness, and quality in the Pennsylvanian sequence. These beds have been extensively mined during the past 100 years and continue to supply nearly one-half of the coal production in the United States, including as much as 90 percent of the output of high-grade metallurgical coal for domestic and export markets. The final stages of basin filling are recorded by terrestrial coal-bearing deposits of Early Permian age in the Dunkard basin northeast of the cross-section area. The coal beds in the Upper Devonian, Mississippian, and Lower Permian are of minor economic interest.

The purpose of this paper is to synthesize data on the distribution, lithofacies, and depositional environments of upper Paleozoic coal-bearing strata in the central Appalachian basin and to identify trends in basin evolution with a basinwide cross section.

GEOLOGIC SETTING

Coal-bearing strata in the central Appalachian basin are part of a sequence of terrestrial deposits ranging from Late Devonian to Early Permian in age. Although parts of this coal-bearing sequence are located beyond the area of the cross section and are older or younger than strata in the cross section (pl. 1), they are described briefly in order to present a more complete description of the geologic setting and to establish the duration and location of Late Paleozoic terrestrial deposition.

Mississippian and Pennsylvanian strata are preserved principally on the northwestern flank of the Appalachian basin, where they are relatively flat lying and underlie about 190,000 mi^2 of the Appalachian Plateaus (fig. 1). Correlative beds in the faulted and folded Appalachians to the southeast are moderately dipping and are discontinuously distributed in fault slices. A generalized stratigraphic cross section (fig. 2) based on a facies model (Englund and others, 1986b) shows that these late Paleozoic rocks occur in a southeast-thickening wedge in which the formations have an accumulative thickness of about 19,000 ft. There, rocks consist mostly of limestone, sandstone, siltstone, shale, coal, and underclay that are assigned to the following 15 formations: the Hampshire Formation of Late Devonian and Early Mississippian age; the Price Formation, the Maccrady Shale, the Greenbrier Limestone, the Bluefield and Hinton Formations, and the Princeton Sandstone of Mississippian age; the Bluestone Formation of Late Mississippian and Early Pennsylvanian age; the Pocahontas, New River, and Kanawha Formations, the Charleston Sandstone, and the Conemaugh and Monongahela Formations of Pennsylvanian age; and the Dunkard Group of Late Pennsylvanian and Early Permian age (fig. 2). All of these formations contain or are interbedded with coal-bearing strata except for the Greenbrier Limestone.

DEPOSITIONAL UNITS

Descriptions of late Paleozoic rocks of the Appalachian basin are presented in ascending stratigraphic order for the following areas: (1) Upper Devonian and Mississippian rocks in the faulted and folded belt of the central Appalachian basin, (2) Mississippian and Lower and Middle Pennsylvanian rocks of the cross-section area (Appalachian Plateaus) (pl. 1), and (3) Middle and Upper Pennsylvanian and Lower Permian rocks of the Dunkard basin.

Faulted and Folded Appalachians

The oldest significant occurrence of coal and associated terrestrial deposits in the Appalachian basin is in the Hampshire Formation of Late Devonian and Early Mississippian age (Dennison and Wheeler, 1975, p. 71). Available data indicate that the coal is mostly impure and is limited to a few discontinuous beds, as much as 1 ft thick, in the upper part of the formation. The coal occurs in westward-prograding deltaic sequences of sandstone, grayish-red and greenish-gray shale, and siltstone that total more than 3,000 ft thick in the eastern part of the faulted and folded Appalachians. Although these coal occurrences are minor, they do indicate that the environment was favorable for land plants to flourish and for peat to accumulate in association with prograding terrestrial sediments of a slowly subsiding foreland basin. Similar depositional conditions continued throughout late Paleozoic time except for periodic uplifts and marine incursions that restricted the duration and extent of terrestrial deposition.

The upper part of the overlying Lower Mississippian Price Formation also includes a westward-prograding deltaic wedge and associated coal beds (fig. 2) (Englund, 1979). This terrestrial wedge is as much as 375 ft thick in easternmost outcrops, where it contains 15 coal beds, including two widely recognized coal zones—the Merrimac and the Langhorne. Each of those zones attains a maximum thickness of about 18 ft and includes several splits or beds of coal that range from a few inches to about 6 ft in thickness. These terrestrial deposits are distributed along the eastern edge of the basin, predominantly in the present Appalachian faulted and folded belt. A partly equivalent marine facies consisting mostly of prodeltaic sandstone and conglomeratic sandstone occupies the remainder of the formation. The Price Formation totals as much as 1,500 ft in thickness.

The succeeding Maccrady Shale is a lithically distinct red-bed sequence that consists of as much as 1,500 ft of grayish-red shale and siltstone sparsely interbedded with greenish-gray or gray plant-bearing shale, impure coal, and evaporite. The coal occurs in discontinuous beds up to a few inches in thicknesss. As the northwestward progradation of terrestrial clastics ceased in the Price Formation, probably in response to decreasing rainfall, the Maccrady was deposited over the abandoned deltaic systems of the Price in tidal flat and associated near-shore swamp environments.

The Greenbrier Limestone, at the base of the Upper Mississippian Series, represents the most widespread marine incursion during late Paleozoic time (Englund and others, 1986b). It discomformably overlies the Maccrady Shale and consists of as much as 1,500 ft of thick-bedded, very finely to coarsely crystalline limestone that is, in part, oolitic, cherty, or argillaceous. It thins northward and is

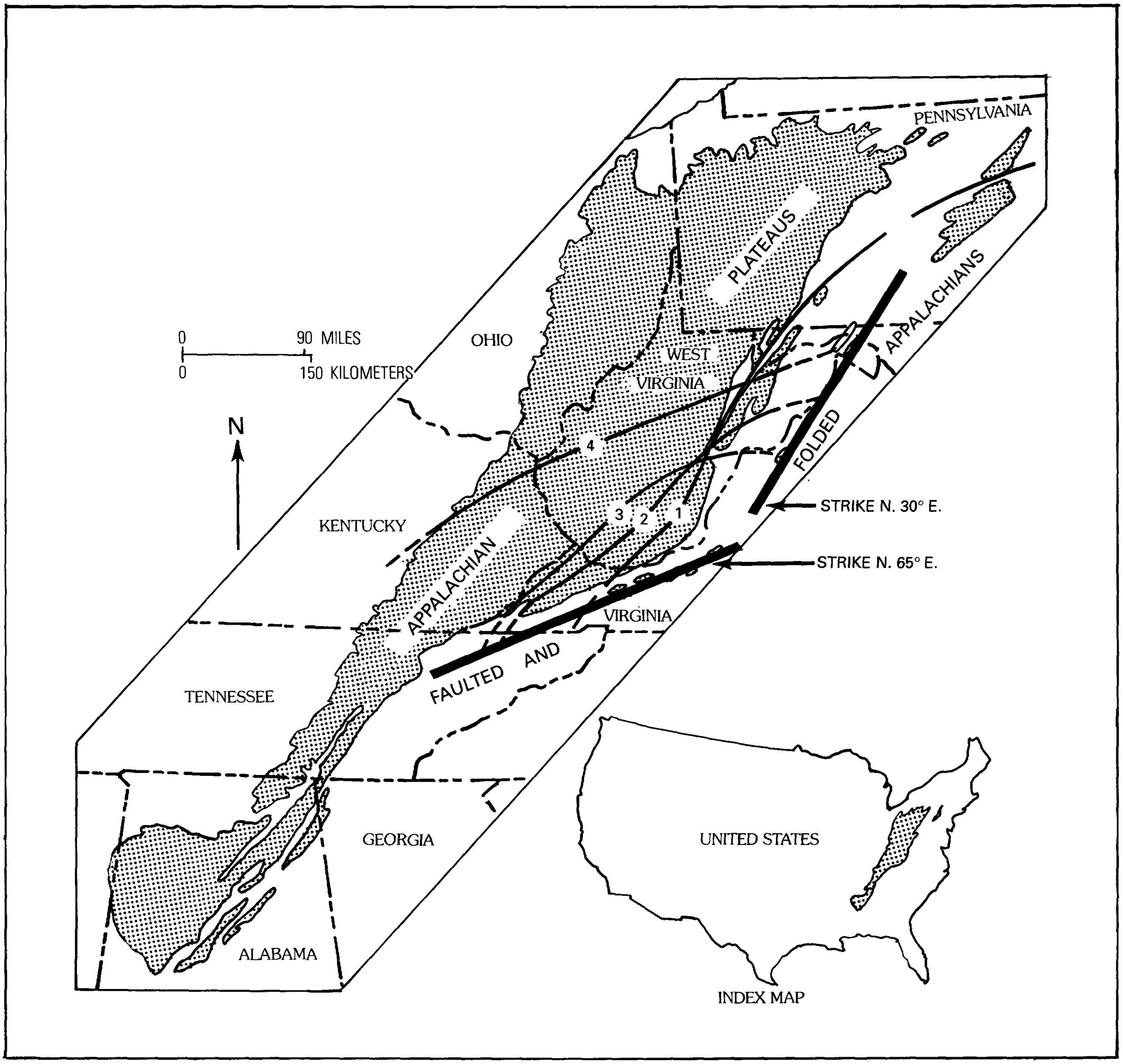

Figure 1. Appalachian basin showing the northwestward extent of terrestrial coal-bearing rocks (shaded) in the Price (1), Bluestone (2), Pocahontas (3), and New River (4) Formations and the strike of major structural trends in the faulted and folded Appalachians.

absent in the northern part of the faulted and folded belt, where it has wedged out in a sequence of grayish-red shale and siltstone.

Although marine deposition was beginning to wane, it prevailed during the deposition of much of the overlying Bluefield Formation, which consists largely of gray, greenish-gray, and grayish-red, partly calcareous shale interbedded with limestone and argillaceous limestone. In easternmost exposures, the formation attains a maximum thickness of about 1,200 ft and includes wedges of sandstone, siltstone, coal, and underclay that were deposited during the initial seaward encroachments of terrestrial sediments in Late Mississippian time. These minor regressions in the Bluefield mark the beginning of a major regressive trend that accelerated in overlying units. Concurrently, the depositional environment for peat accumulation was improving, so that, by Early Pennsylvanian time, widespread peat deposits occupied the southeastern margin of the basin, as the extensive, high-quality Pocahontas coal beds indicate. In the Upper Mississippian formations,

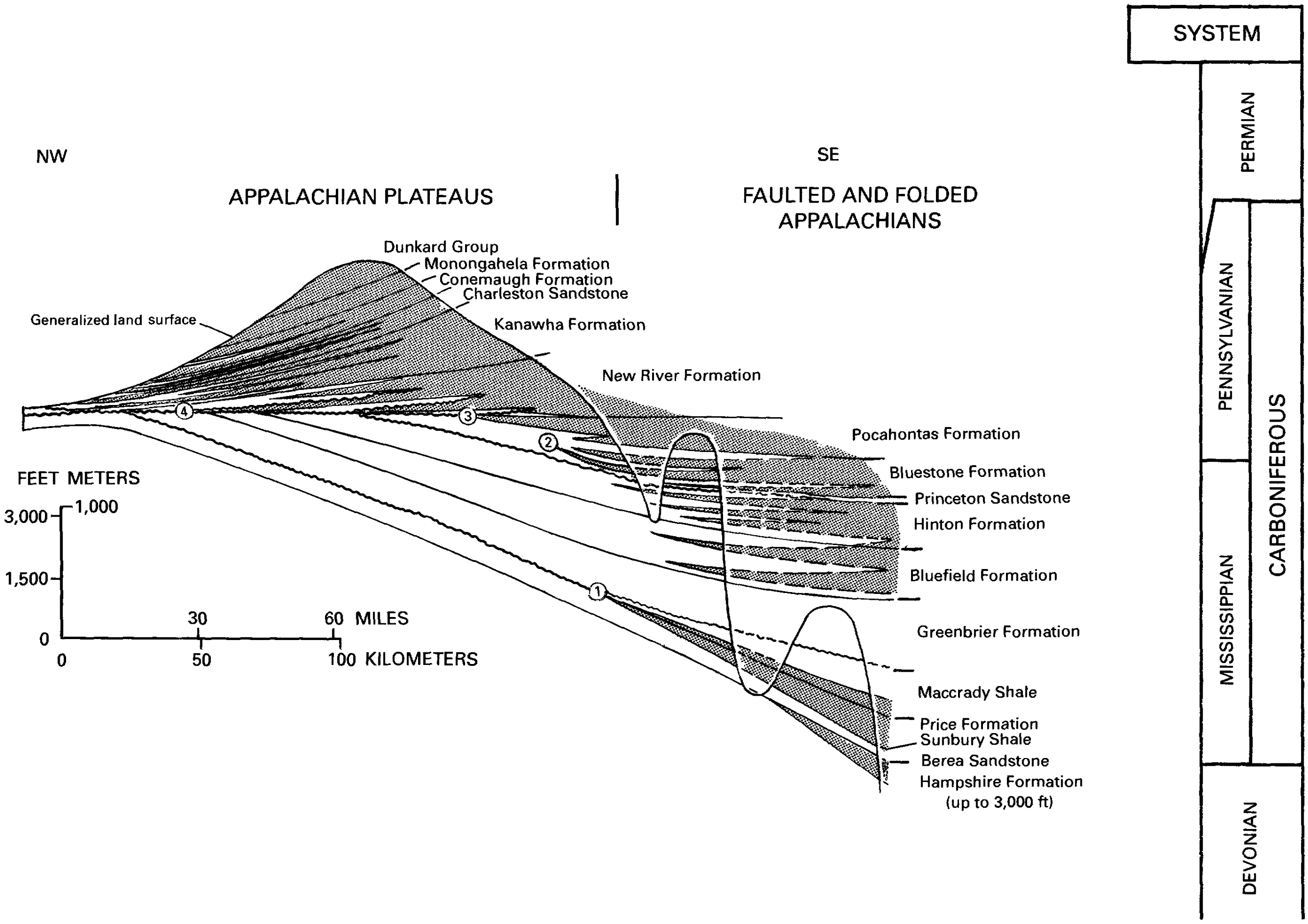

Figure 2. Generalized stratigraphic cross section of the central Appalachian basin (based on Englund and others, 1986b) showing major unconformities (wavy lines) and terrestrial coal-bearing rocks (shaded), dashed where inferred. Extents of terrestrial sequences (1–4) are shown in figure 1.

known coal deposits are generally too thin and structurally unfavorable for conventional mining, but favorable areas for exploration have been recognized (Englund and others, 1986a).

The Bluefield Formation is conformably overlain by the Hinton Formation, which is as much as 1,300 ft thick and is characterized by an abundance of grayish-red, partly calcareous shale and siltstone and includes lesser amounts of medium-gray and greenish-gray shale, sandstone, limestone, coal, carbonaceous shale, and rooted underclay. Exposed coal beds range from a few inches to 31 in thick and occur with shale containing fossil plants. The basal member of the Hinton Formation is a well-sorted quartzarenite that was deposited as a sequence of coalescing offshore bars (Englund and others, 1979). Shallow marine, tidal flat, deltaic, and freshwater swamp environments prevailed during the deposition of succeeding units of the Hinton (Englund and others, 1986b).

Locally, in the faulted and folded Appalachians, the Hinton is unconformably overlain by the Princeton Sandstone, which ranges from a polymictic conglomerate to a coarse conglomeratic subgraywacke as much as 60 ft thick. The matrix of the Princeton is light-gray, fine- to coarse-grained, thick-bedded to massive, calcite-cemented sandstone. Clasts in the formation are diverse in size and composition, are well rounded to angular, and include fragments derived from Devonian and Mississippian rocks (Cooper, 1961, p. 69). The age and variety of lithic fragments, ranging from locally derived limestone, shale, and siltstone to quartz and chert from distant sources, indicate the contemporaneity of Appalachian deformation. The Princeton was deposited on an eroded surface, possibly by storms and offshore currents associated with a marine incursion that continued during the deposition of the basal member of the overlying Bluestone Formation (Englund and others, 1986b).

The Bluestone Formation, which disconformably overlies the Hinton where the Princeton is absent, consists of six members that total as much as 850 ft in thickness. Except for an overall decrease in marine influence, the lithology and depositional environments of the Bluestone Formation are similar to those of the Hinton. The basal Pride Shale Member is mostly dark-gray shale and silty shale that contain marine and brackish-water faunal assemblages, fossil plants, and vertebrates. Where it overlies the Princeton Sandstone, the lower part includes a wedge of greenish-gray and grayish-red shale and one or two thin coal beds. The Pride represents a shallow embayment or lagoon infilling that is overlain by the regressive and probably deltaic Glady Fork Sandstone Member (Englund and others, 1986b). Overlying the Glady Fork and merging with the underlying Pride beyond the extent of the Glady Fork is a major progradation of terrestrial coal-bearing strata assigned to the gray member. In addition to several thin coal beds, the gray member contains carbonaceous shale and freshwater or brackish-water ostracodes and pelecypods. The overlying red member is a tidal flat sequence of mostly grayish-red, partly calcareous shale and siltstone and a few beds of nodular argillaceous limestone (Englund and others, 1981). It also includes freshwater swamp deposits, as several thin beds of coal and underclay indicate. The Bramwell Member, the youngest Mississippian unit in the Bluestone, was deposited during marine transgression across the lower coastal plain underlain by the red member. At the base of the Bramwell, carbonaceous shale containing freshwater and brackish-water faunas grades upward to silty shale and calcareous siltstone that include sparse, thin limestone beds and a highly diverse marine fauna. The overlying upper member of the Bluestone Formation contains an Early Pennsylvanian flora and consists of prodeltaic greenish-gray and grayish-red shale that overlapped the basal deltaic lobes of the Pocahontas Formation.

Mississippian and Pennsylvanian Rocks of the Cross-Section Area

The Mississippian sequence in the cross section (pl. 1) includes formations exposed in the faulted and folded Appalachians plus two additional formations—the Berea Sandstone and the Sunbury Shale (fig. 2). The principal variations noted in the lithology and thickness of these strata in the Appalachian Plateaus are emphasized in the following unit descriptions.

The Berea Sandstone, at the base of the Lower Mississippian Series, crops out in three widely separated areas of the central Appalachian basin: (1) an outcrop belt near the northwestern terminous of the cross section, (2) the northwestern slope of Pine Mountain near the Kentucky-Virginia State line, about 15 mi southwest of the cross section, and (3) near the southeastern terminous of the cross section. In the northwestern outcrop belt, the Berea is a thin- to thick-bedded, very fine grained to fine-grained sandstone as much as 100 ft thick (Morris, 1966). In the Pine Mountain outcrop belt, the Berea is an evenly bedded, very fine grained, quartzose sandstone about 50 ft thick (Alvord and Miller, 1972). At the southeastern edge of the plateaus in Tazewell County, Virginia, the Berea crops out only locally. There it is a thick-bedded to massive, fine- to coarse-grained, conglomeratic sandstone about 5 ft thick (Windolph, 1988). Elsewhere along the southeastern edge of the plateaus, the Berea is absent, and the Sunbury Shale or its correlative, the Big Stone Gap Member of the Chattanooga Shale, rests directly on the Chemung Formation of Devonian age (Englund, 1968; Englund and others, 1979). Descriptions of the Berea from oil and gas tests indicate that the lithology and thickness in the subsurface are similar to those noted in outcrop observations. Berea sediments in the cross-section area were derived from an eastern source and deposited in an epicontinental sea by several westward-flowing rivers (deWitt and McGrew, 1979).

The Sunbury Shale conformably overlies the Berea Sandstone and has a similar distribution and outcrop pattern. It is a black, evenly bedded, highly carbonaceous shale that ranges from about 15 ft thick at the northwestern end of the cross section to 55 ft in the outcrop belt at the southeastern edge of the Appalachian Plateaus. In southwestern Virginia and southern West Virginia, the Sunbury is also known as the Big Stone Gap Member of the Chattanooga Shale and is more extensive than the Berea. A shallow, stagnant sea occupied the central Appalachian basin during Sunbury deposition (Pepper and others, 1954).

The Sunbury Shale along the southeastern edge of the Appalachian Plateaus is conformably overlain by a sequence of conglomeratic sandstone, sandstone, and shale of the Price Formation. Marine invertebrates are common in the sandstone in the lower part of the formation; terrestrial beds, including one or two thin coal beds, are present locally in the uppermost part of the formation. Northwestward across the plateaus, the Sunbury is overlain by the Lower Mississippian Grainger Formation in southwestern Virginia and the Borden Formation in eastern Kentucky. These correlatives of the Price are entirely marine and consist of shale, silty shale, siltstone, and very fine grained sandstone. Marine invertebrates, including brachiopods, crinoids, and bryozoans, are locally abundant in these beds. Thicknesses range from about 600 ft at the southeastern and northwestern edges of the Appalachian Plateaus to a minimum of about 350 ft over the Waverly arch (pl. 1).

The Maccrady Shale consists of 30 to 150 ft of grayish-red shale and siltstone and minor amounts of sandstone and dolomite where it conformably overlies terrestrial coal-bearing beds in the upper part of the Price Formation at the southeastern edge of the Appalachian Plateaus. Northwestward in the subsurface and along Pine Mountain, correlatives of the Maccrady consist mostly of siltstone and sandstone within this thickness range and are known to drillers as the Red Injun sand. At the northwestern end of the cross section (pl. 1), as much as 60 ft of grayish-red and greenish-gray shale and siltstone in the upper part of the Borden Formation may be its correlative.

The Greenbrier Limestone and equivalents extend throughout the subsurface of the Appalachian Plateaus and crop out at the northwestern and southeastern margins and locally at uplifted structures in the intervening area. The Greenbrier disconformably overlies the Maccrady Shale or the Price Formation and, in places, includes a basal conglomerate of well-rounded quartz and chert pebbles. The lithology of the Greenbrier is similar to that of the faulted and folded Appalachians, and its thickness decreases northwestward from 800 to 0 ft, owing partly to the erosion of beds along overlying unconformities. Pre-Pennsylvanian subareal weathering and sinkhole development are also significant features that decrease the thickness of the Greenbrier (Slade Formation at the Kentucky outcrop) on the uplifted southeastern flank of the Cincinnati arch (Englund and Windolph, 1971).

The overlying Upper Mississippian sequence is assigned to the Bluefield, Hinton, and Bluestone Formations and consists predominantly of shale, limestone, and sandstone of marine origin. Intercalated terrestrial wedges containing thin coal beds are confined to the southeastern edge of the Appalachian Plateaus. The Upper Mississippian formations are truncated northwestward at the Lower Pennsylvanian unconformity and are absent where the cross section transects the Waverly arch (Englund, 1972). Remnants of the Bluefield and possibly the Hinton are preserved beneath the unconformity in a shallow trough between the Waverly and Cincinnati arches (Englund and Henry, 1984).

The Bluefield Formation at the base of the Upper Mississippian clastic sequence conformably overlies the Greenbrier Limestone. It consists largely of shale and limestone containing marine fossils. Sandstone is more common in the succeeding Hinton Formation, where it varies from very fine grained and ripple bedded in the basal Stony Gap Sandstone Member to coarse grained, conglomeratic, and massive in the uppermost Tallery Sandstone Member. The thickest and most widely recognized marine unit in the Hinton, the Little Stone Gap Member, is fossiliferous limestone and calcareous shale that total as much as 100 ft thick.

The succeeding Princeton Sandstone wedges out along the disconformity at the top of the Hinton in the eastern part of the Appalachian Plateaus. As a result, it is absent in the cross section, and the Hinton Formation is disconformably overlain by the Pride Shale Member of the Bluestone Formation. The members of the Bluestone are lithically similar to their counterparts in the faulted and folded Appalachians. An exception is the wedgeout of terrestrial coal-bearing beds, including the gray member, in the easternmost part of the plateaus, owing to a westerly increase in marine influences.

Clastic coal-bearing strata assigned to the Lower Pennsylvanian Pocahontas Formation conformably overlie the Bluestone Formation in its eastern exposures. The Pocahontas Formation consists mostly of sandstone and lesser amounts of siltstone, shale, coal, and underclay that prograded northwestward in a series of merging delta lobes and associated near-shore deposits. Periodic abandonment of these major distributary systems permitted the development of extensive swamps and thick peat deposits that were precursors of the principal coal beds, including the Pocahontas Nos. 3, 4, and 6, in the formation. These peat accumulations coincided with stillstands of sea level when a minimal influx of sediments and a stable shoreline allowed waves and currents to form barrier systems consisting of lithically and texturally mature quartz sand (Englund and others, 1986a). From a maximum thickness of about 700 ft at the southeastern edge of the Appalachian Plateaus, the Pocahontas Formation thins northwestward and wedges out in a distance of about 30 mi. Where the formation is thickest, the contact with the overlying New River Formation is conformable at the base of the Pocahontas No. 8 coal bed. The wedging out of the Pocahontas Formation results, in part, from the truncation of upper beds at the Lower Pennsylvanian unconformity at the base of the Pineville Sandstone Member of the New River Formation.

The New River Formation and the partially correlative Lee Formation underlie the Appalachian Plateaus and range in thickness from nearly 2,000 ft on the southeastern side to less than 100 ft on the northwestern side. These formations are coal-bearing sequences of sandstone, siltstone, shale, and underclay that are lithically similar to the Pocahontas Formation except for the presence of thicker and more widespread barrier or offshore bars of quartz-pebble conglomerate and orthoquartzite (Englund and others, 1986b). The latter units onlap the Lower Pennsylvanian unconformity and are progressively younger to the northwest. In general, the Pocahontas coastal depositional model is applicable to the larger scale features of the New River. Beds in the sequence that contain marine fossils are more prevalent to the northwest. Also, in association with the overall shift of facies to the northwest, fluvial deposition encroached from the southeast to dominate the southeastern or terrestrial facies of the New River Formation. The southeastern facies is also characterized by as many as 15 economically important coal beds.

The principal difference between the New River and the Lee Formations regionally is in the placement of the top contact. The uppermost member of the New River is the Nuttall Sandstone Member in West Virginia or its correlative, the McClure Sandstone Member in Virginia. More specifically, the top contact of the New River is placed at the base of the Douglas coal bed or its correlative, the Kennedy coal bed, both of which overlie a thin underclay bed at the top of the sandstone member. Where the uppermost sandstone member is absent or thin and inconspicuous, the top contact of the New River, which is also the top boundary of the Lower Pennsylvanian Series, continues essentially as a chronostratigraphic boundary at the base of the Kennedy or Douglas coal bed. In contrast, the upper contact of the Lee Formation is placed at the top of the uppermost orthoquartzite, which, in places, may be several hundred feet below or above the Kennedy-Douglas coal bed (pl. 1). Regionally, the upper contact of the Lee is diachronous and rises stratigraphically to the northwest (Englund, 1962). The Lee Formation at the northwestern end of the cross section (pl. 1) therefore includes beds of Middle Pennsylvanian age.

Middle Pennsylvanian strata overlying the New River and the Lee Formations in the upper part of the cross section (pl. 1) are identified by several different nomenclatures. In adjoining parts of Virginia and West Virginia where the New River is recognized, these overlying rocks are assigned to the Kanawha Formation. To the southwest in Virginia, where the Lee Formation is identified, they are included in the Norton Formation, the Gladeville Sandstone, and the Wise Formation. In eastern Kentucky, they are included in the Breathitt Formation. The Middle Pennsylvanian sequence is more than 2,000 ft thick and consists mostly of medium- to dark-gray shale and siltstone, fine- to medium-grained sandstone, coal, and underclay. These beds are largely terrestrial and occur in deltaic and fluvial systems that are intercalated with several widespread marine beds. In contrast to the thick beds of conglomeratic quartzose sandstone that are typical of the New River and the Lee, those of the Middle Pennsylvanian are subgraywackes that tend to be thinner, finer grained, feldspathic, and micaceous and have a relatively low quartz content of about 50 to 65 percent.

Dunkard Basin

The Dunkard basin, located about 75 mi northeast of the cross section (pl. 1), contains the youngest terrestrial coal-bearing rocks of the Appalachian basin. The coal occurs in a largely red-bed sequence that is subdivided into the Conemaugh and Monongahela Formations of Late Pennsylvanian age and the Dunkard Group of Late Pennsylvanian and Early Permian age. In the underlying Middle Pennsylvanian Series, the Kanawha Formation and the Charleston Sandstone are also coal bearing and lithically similar to correlative beds shown in the upper part of the cross section (pl. 1).

The Conemaugh Formation, at the base of the Upper Pennsylvanian Series, includes as much as 500 ft of strata from the top of the Upper Freeport coal bed to the base of the Pittsburgh coal bed. The Conemaugh is characterized by an abundance of grayish-red shale or claystone, which is the basis for differentiating the formation from underlying strata where the Upper Freeport coal bed is absent or unidentified. In the southern part of the Dunkard basin, the Conemaugh consists of about 60 percent grayish-red, greenish-gray, and variegated shale and claystone, 30 percent sandstone, and 10 percent gray shale, nonmarine limestone, flint clay, and coal. The percentage of grayish-red beds decreases toward the northwestern part of the basin, where gray beds, which include a few marine limestone units, are prevalent. Sandstone beds are thicker, more massive, and locally conglomeratic to the southeast. The Conemaugh, together with other Upper Pennsylvanian strata, were deposited in association with a delta complex system that prograded westward and northward in the foreland basin onto the craton (Donaldson, 1979). The deltas were fluvial dominated and were fed by suspended load rivers. Extensive lakes developed as the northwestward-prograding streams restricted or sealed the narrow bay that extended northeastward into the Dunkard basin. Coal beds in the Conemaugh are relatively high in sulfur and ash and tend to be thicker and more persistent to the northwest in the facies dominated by gray shale.

The succeeding Monongahela Formation is lithically similar to the Conemaugh and is also characterized by an abundance of grayish-red, greenish-gray, and variegated mudstone and lesser amounts of very fine grained to fine-grained sandstone, gray shale, carbonaceous shale, coal, and nonmarine limestone. The coal beds, with the exception of the economically important Pittsburgh coal at the base of the formation, are also relatively thin, lenticular, and high in ash and sulfur. The Monongahela was deposited as part of the fluvial-dominated northwestward-prograding delta systems that originated in the Conemaugh. Marine beds are absent in the late Paleozoic sequence above the Conemaugh. The thickness of the Monongahela ranges from about 200 to 400 ft.

The overlying Dunkard Group of Late Pennsylvanian and Early Permian age consists of as much as 1,300 ft of largely grayish-red claystone, shale, and siltstone and lesser amounts of interbedded sandstone, limestone, and coal. These strata include the youngest Paleozoic rocks in the basin and are limited in distribution mostly to the Dunkard basin in the adjoining areas of northern West Virginia, southeastern Ohio, and southwestern Pennsylvania. Coal in the Dunkard is high in sulfur and ash, and most of the beds are thin and discontinuous. Of the 20 coal beds in the Dunkard, only the Waynesburg and Washington coal beds have been mined to a significant extent. During deposition, a fluvial-dominated deltaic system prograded from the southeast in association with fluctuating lacustrine, fluvial plain, and coal swamp environments. Climatic variations including seasonal rainfall contributed to the periodic flood of detritus that resulted in the deposition of broad, fluvial-delta plains. During periods of stability, swamps covered large parts of the basin.

DEPOSITIONAL TRENDS

Late Paleozoic rocks in the central Appalachian basin display lateral and vertical trends in the relation of terrestrial to marine deposits and in the distribution and character of coal beds. The first occurrence of coal in the upper part of the westward-prograding Catskill delta complex (Hampshire Formation) records the deposition of peat in association with westward-prograding terrestrial clastic sediments and established a trend that followed during later Paleozoic time. Because the upper coal-bearing part of the Hampshire very likely includes beds of Early Mississippian age (Dally, 1956; Englund and others, 1988), the contemporaneous tectonic uplift and shedding of clastics from the Appalachian positive element to the southeast may have been in response to Late Devonian and Early Mississippian plate collision (Ettensohn, 1985). Marine deposition prevailed in the fringe of the Catskill delta complex and continued on the cratonic shelf to the west throughout Early Mississippian time. This sequence is represented by the Berea Sandstone, Sunbury Shale, and Borden or Price Formations in the cross section (pl. 1).

The surge of terrestrial clastic sediments during the deposition of the upper part of the Price Formation follows the trend of Hampshire distribution in the faulted and folded Appalachians. The Price terrestrial unit includes thicker and more widespread coal beds and extends further to the west, so that its distal end encroaches locally into the margin of the Appalachian Plateaus north of the southeastern end of the cross section (pl. 1). Deltaic deposition was interrupted periodically, and peat accumulated in broad, back-barrier, lagoonal swamps (Englund, 1979). The fact that the coal is mostly low in sulfur (less than 0.5 percent) (Simon and Englund, 1983) may reflect the lack of marine incursions or a decrease in sulfur associated with diagenesis, which is common in many high-rank coal beds. In contrast, this coal is high in ash (greater than 15.0 percent) and contains numerous partings that may have resulted from clastic sedimentation during flood periods. The highly sheared condition of the coal may also have been a factor that increased the ash content by introducing contaminants along shear planes. Waning terrestrial deposition, indicated by a few thin coal beds in the basal part of the overlying Maccrady Shale, was followed by a major marine incursion. The maximum extent of marine incursion was attained during the time when the succeeding Greenbrier Limestone was deposited. During the deposition of the overlying Bluefield Formation, marine conditions began to regress, and terrestrial deposition (including peat) occurred on the southeastern margin of the basin. The northwestward progradation of terrestrial clastic sediments continued throughout Late Mississippian time, mostly in the foreland basin. The distal ends of the Late Mississippian terrestrial facies extended locally into the southeastern part of the Appalachian Plateaus, including the area of the southeastern end of the cross section (pl. 1). Upper Mississippian coal-bearing rocks therefore extend about 15 mi further northwest than similar strata in the Lower Mississippian (fig. 2). Also, the strike of the leading edge or strandline has rotated from about N. 30° E. in Early Mississippian time to N. 40° E. in Late Mississippian time, a reflection of a gradual southwestward increase in the uplift of the source area in the Appalachian uplands.

Mississippian depositional trends indicate that the Appalachian seaway slowly regressed northwestward on the craton in a series of regressive-transgressive events and included several barrier and offshore bars of orthoquartzite. Examples of these marine features are shown by the Carter Caves Sandstone (fig. 3) on the northwestern side of the basin and by the Tallery Sandstone Member of the Hinton Formation (fig. 4) on the southeastern side of the basin. A paleogeographic reconstruction of the Appalachian basin (Craig and others, 1979) indicates the relation of these sandstone bars to peat deposits along the southeastern margin of the basin (fig. 5). When rainfall increased during the deposition of overlying Pennsylvanian sediments (Cecil and others, 1985), the supply of coarse clastics increased, and such deposits became more extensive.

By Early Pennsylvanian time, terrestrial coal-bearing sediments of the Pocahontas Formation dominated the east-central Appalachian basin. The earliest Pennsylvanian sediments consisted of sand, which accumulated in the major distributary channels and lobes. A decrease in grain size and the orientation of the lobes show that clastics prograded northwestward from a southeasterly source, continuing (with minor modification) the trend established in underlying Mississippian strata. At the top of the lower sandstone member of the Pocahontas Formation, sand graded to silt and clay before the accumulation of peat, as recorded by 3 to 6 ft of coal. This peat deposit coincided with a stillstand of the shoreline and a period of minimal influx of clastic sediments (Englund and others, 1986a). Along the stabilized shoreline, the reworking of sediments by wave and current action led to the development of a barrier system consisting of lithically and texturally mature sand. Delta progradation resumed in the middle sandstone member of the Pocahontas. Within this interval, local peat formation associated with delta lobe switching is indicated by the discontinuous Pocahontas Nos. 1, 2, and 2A coal beds. When the distributary systems of the middle sandstone member were abandoned, clastic sedimentation ceased, and an extensive peat deposit, represented by the Pocahontas No. 3 coal bed, accumulated on the delta lobes. The Pocahontas No. 3 coal bed, the thickest and most widely distributed of the Pocahontas coal beds, attained thicknesses of 3 to 9 ft over large areas (fig. 6). Variations in the thickness and quality of the coal indicate that the thickest, low-ash and low-sulfur coal is situated over the abandoned distributary lobes (Englund and others, 1984). This distribution of thick, high-quality coal was influenced by (1) initial and optimum growth of vegetation on the relatively positive high-sand lobes, (2) deposition of thin peat or carbonaceous shale in the greater compactible shale-dominated fringe or interlobe areas, and (3) high

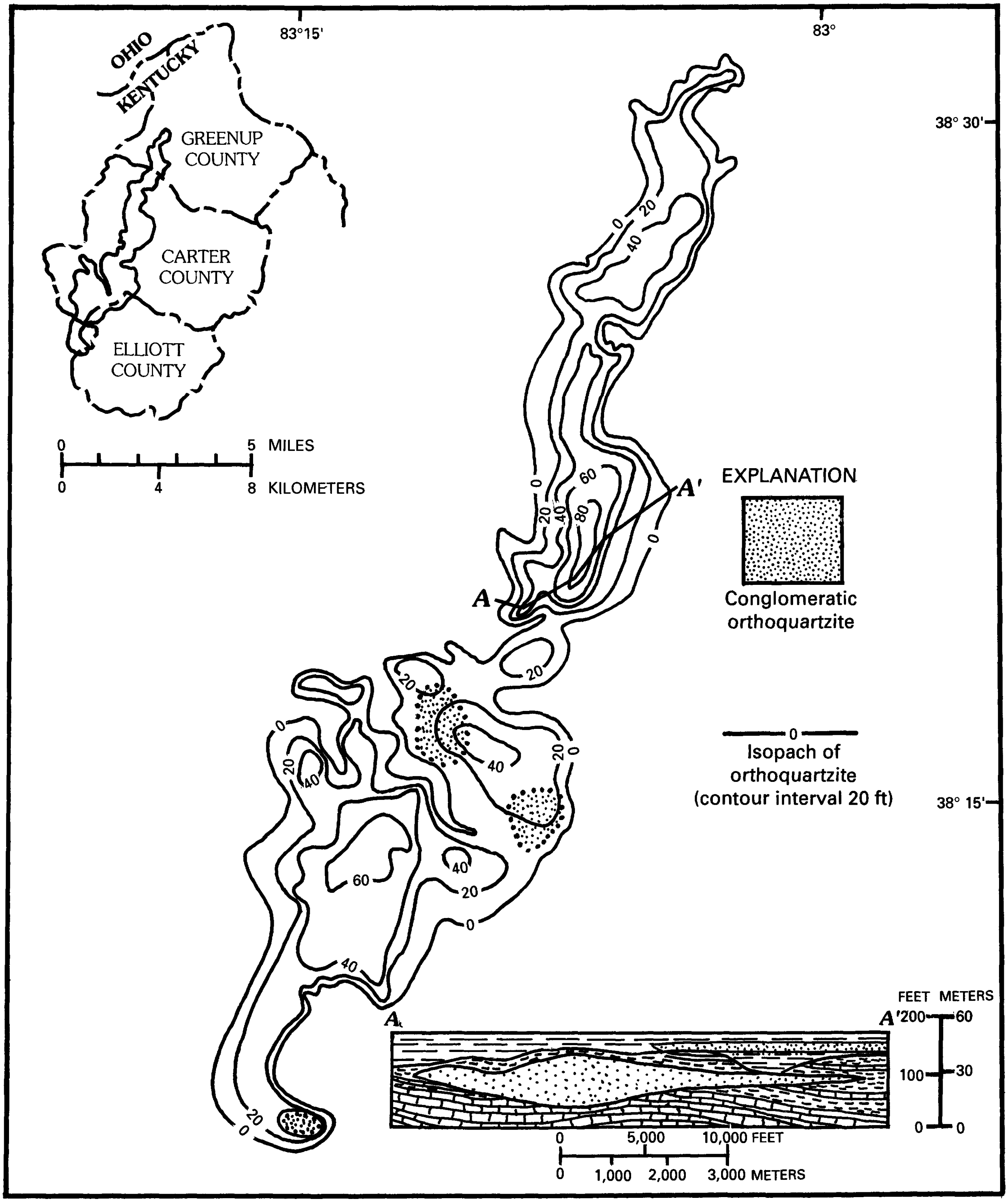

Figure 3. Carter Caves Sandstone in northeastern Kentucky (from Englund and Windolph, 1971). Patterns in cross section are the ones used in plate 1.

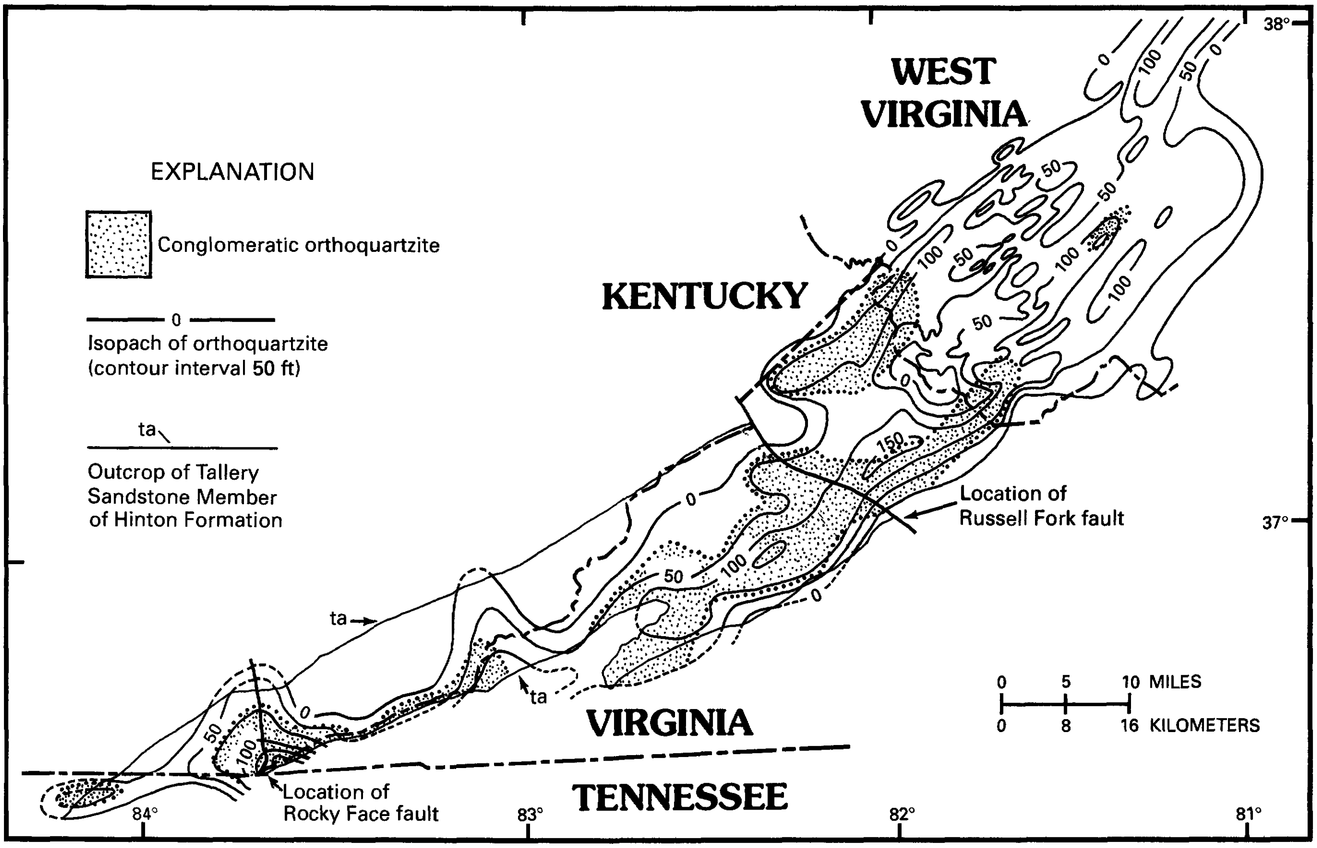

Figure 4. Tallery Sandstone Member of the Hinton Formation on the southeastern side of the central Appalachian basin (restored to original location at the Rocky Face and Russell Fork faults).

rainfall that contributed to the preservation of domed deposits of ombrogenous peat (Englund and others, 1986a). These deltaic lobes (fig. 7) are oriented normal to the strike of the leading edge or strandline of these earliest Pennsylvanian terrestrial strata, which is about N. 45° E.

In the overlying New River Formation, offshore or barrier bars of quartzarenite and quartz-pebble conglomerate are thicker and more widespread. Deposition occurred in a high-energy tidal environment (Cecil and Englund, 1985). These sandstone units continue to be oriented parallel to the southeastern shoreline and wedged out southeastward in a back-barrier sequence containing as many as 36 coal beds. Because of the northwestward shift of the shoreline and associated sediments, fluvial sediments began to encroach on the craton from the southeast.

An example of fluvial sedimentation in the back-barrier sequence is the Richlands channel (Englund and Thomas, 1985), which extended about 30 mi northwestward from Richlands, Va., and truncated as much as 130 ft of underlying coal-bearing strata, as the isopach of underlying beds in figure 8 shows.

As cross section *A–A′* (fig. 9) shows, the channel is 6 mi wide and filled with sandstone and polymictic conglomerate. Clasts in the channel are well rounded and as much as 5 in in diameter and consist mostly of quartz. The Richlands channel and other channels in the New River Formation demonstrate that Pennsylvanian clastics originated from the southeast and were transported N. 25° W. normal to the strandline (fig. 1).

As northwestward regression continued in Middle Pennsylvanian time, terrestrial coal-bearing sediments gradually dominated the Appalachian basin, and marine incursions were limited mostly to the northwestern part of the basin by Late Pennsylvanian time.

During the final stages of basin filling, when the Conemaugh and Monongahela Formations and the Dunkard Group were laid down, rainfall became seasonal (Cecil and others, 1985) but continued to contribute periodic floods of detritus that prograded northwestward and sealed a narrow bay, a remnant of the Appalachian seaway that occupied the central part of the basin. As a result, lakes and swamps developed between the fluvial systems, and red beds, nonmarine limestone, and a few high-ash and high-sulfur peat beds were deposited.

CONCLUSIONS

A significant change in basin sedimentation patterns in late Paleozoic times is indicated by progradation trends

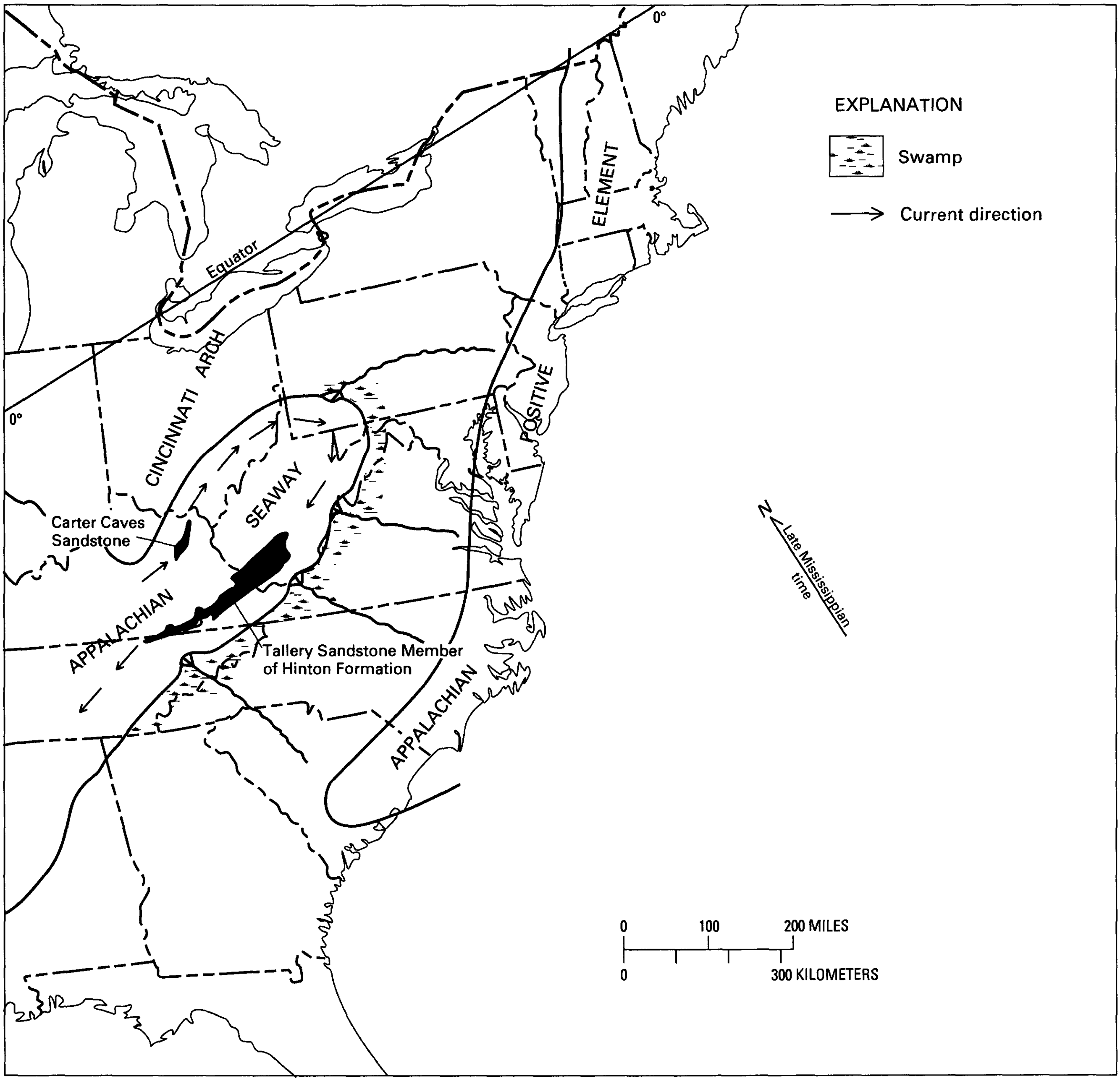

Figure 5. Late Mississippian depositional environment (modified from Craig and others, 1979). Carter Caves Sandstone and Tallery Sandstone Member are plotted to scale.

and by the northwestward extent of terrestrial coal-bearing rocks. The extent or wedgeout of terrestrial units in the Price, Bluestone, Pocahontas, and New River Formations (fig. 2) shows that the northwestward shift of the coal-bearing facies in late Paleozoic time is accompanied by a rotation of the strike of the wedgeout from N. 30° E. in Lower Mississippian strata to N. 65° E in Lower Pennsylvanian strata (fig. 1). The location and magnitude of this change in the sedimentation trend correspond closely to the change in the structural trend in the faulted and folded Appalachians that separates the predominantly folded Appalachians (N. 30° E.) to the northeast from the predominantly faulted Appalachians (N. 65° E.) to the southwest. The close association and parallelism of the sedimentation and structural trends indicate that:

1. Deformation associated with plate collision began in Early Mississippian or Late Devonian time.
2. Folding and deposition in the Appalachians were synchronous, at least in late Paleozoic time (Cooper, 1961).
3. Deformation began northeast of the rotation point and later increased to the southwest, possibly as a result of

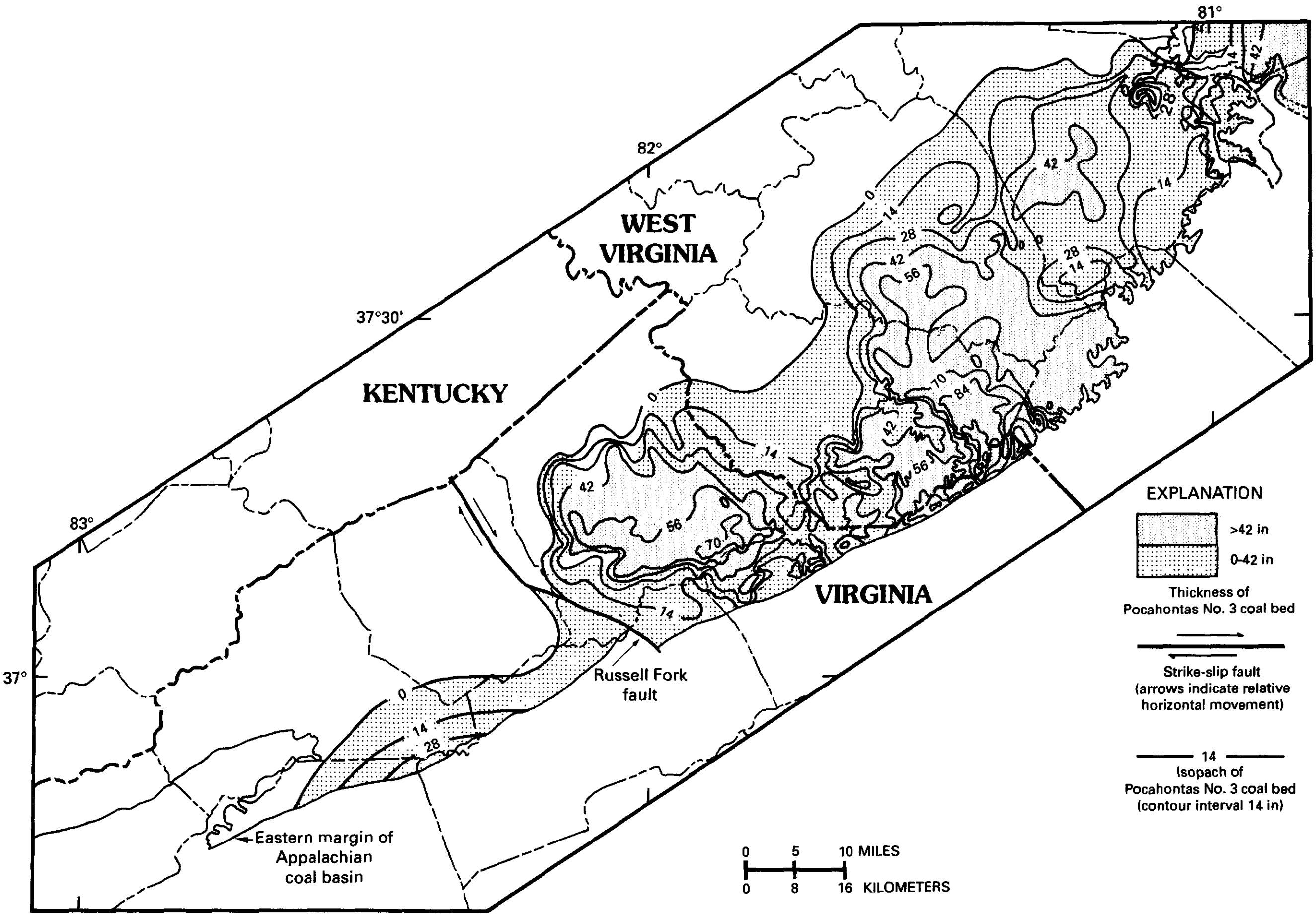

Figure 6. Pocahontas No. 3 coal bed on the southeastern side of the Appalachian basin (from Englund and others, 1986a).

plate rotation or multiple plate collisions such as that of the European plate to the northeast (fig. 10) and the African plate to the southeast (fig. 11).

4. Changes in the structural trend occurred primarily in latest Mississippian and earliest Pennsylvanian time.
5. The southwestward rotation in the structural trend may be responsible for the temporary opening of the Appalachian seaway (fig. 11) to the northeast during Early Pennsylvanian time, which permitted strong southwest-flowing tidal currents to erode earlier Pennsylvanian and Late Mississippian sediments on the cratonic shelf (Lower Pennsylvanian unconformity); the deposition of coarse clastic sediments (pebbly sand) by high-energy tidal currents, similar to the processes observed in the Straits of Malacca (Cecil and others, 1988), followed in later Early Pennsylvanian time.

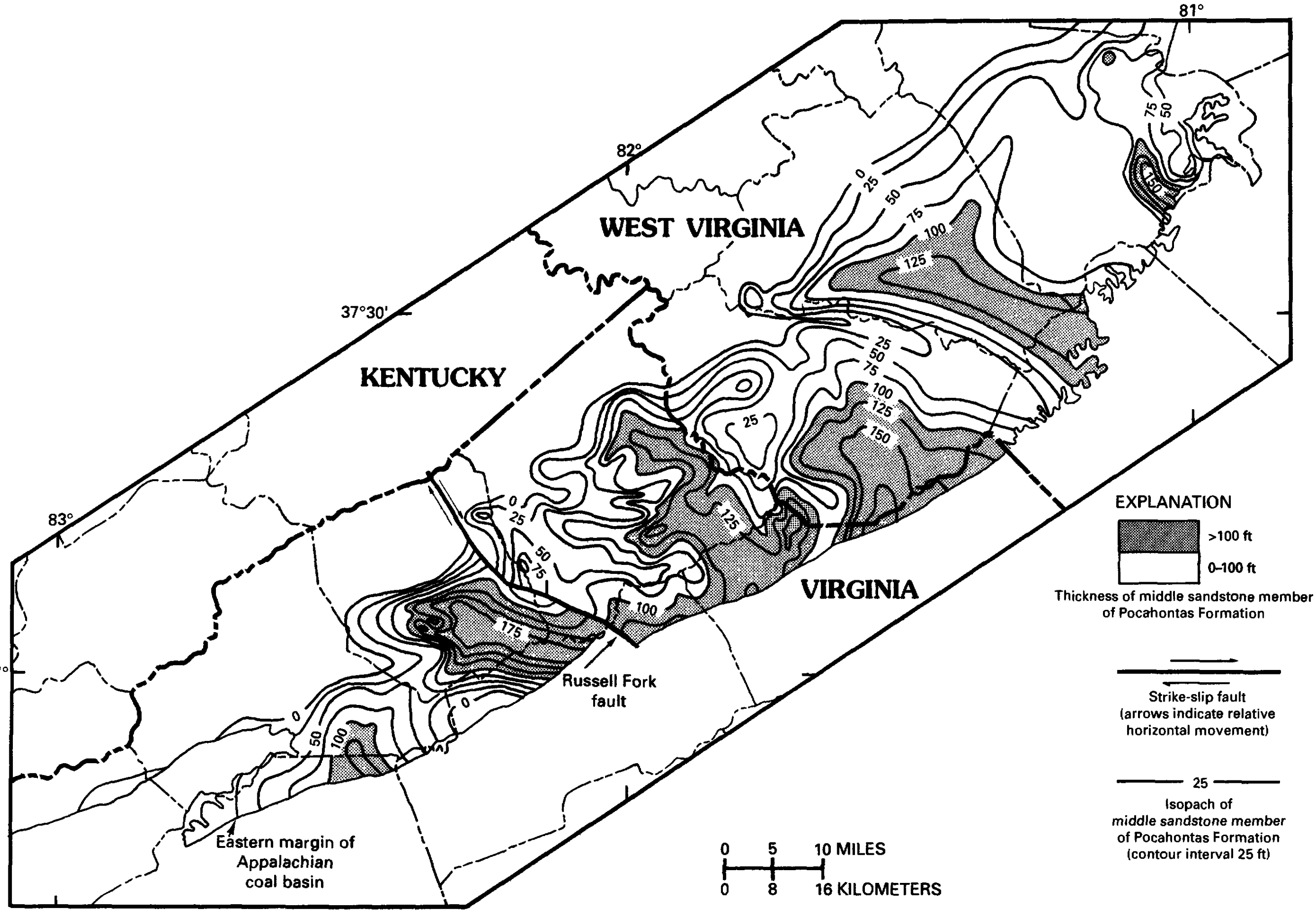

Figure 7. Middle sandstone member of the Pocahontas Formation (from Englund and others, 1986a).

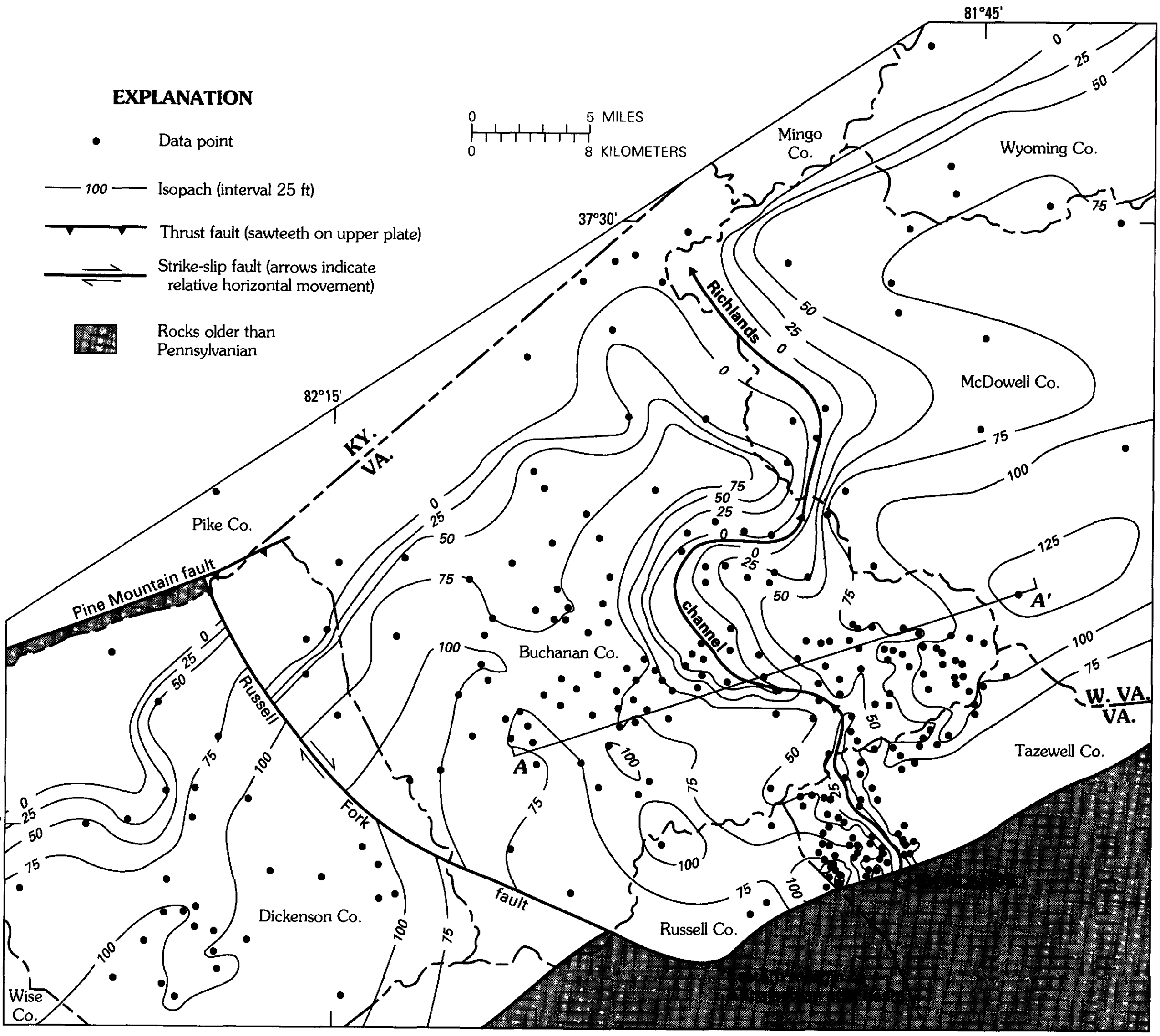

Figure 8. Richlands channel as delineated by an isopach of underlying strata between the Jewell coal bed and the Dismal Sandstone Member of the New River Formation. Cross section *A–A'* is shown in figure 9.

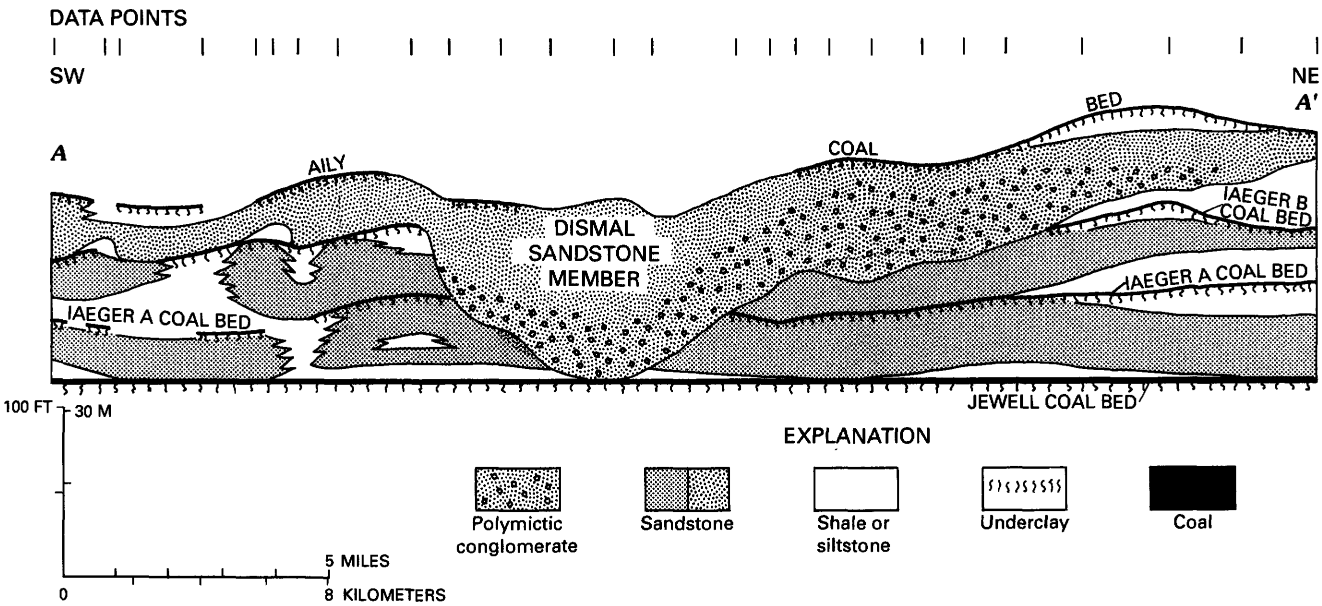

Figure 9. Cross section of the Richlands channel (shown in fig. 8).

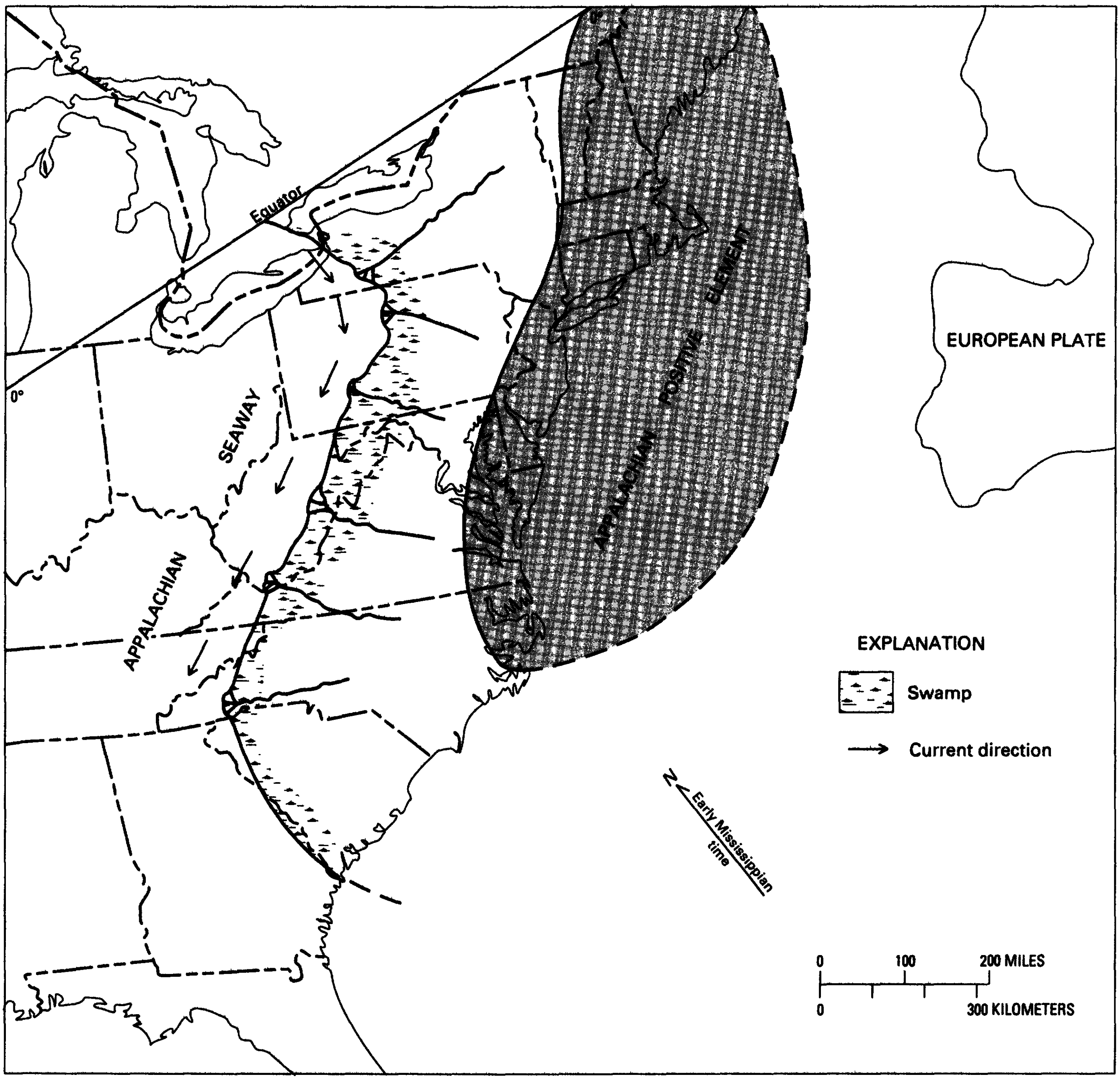

Figure 10. Generalized Early Mississippian paleogeography during maximum terrestrial progradation. Dashed lines indicate the underwater portion of the Appalachian positive element.

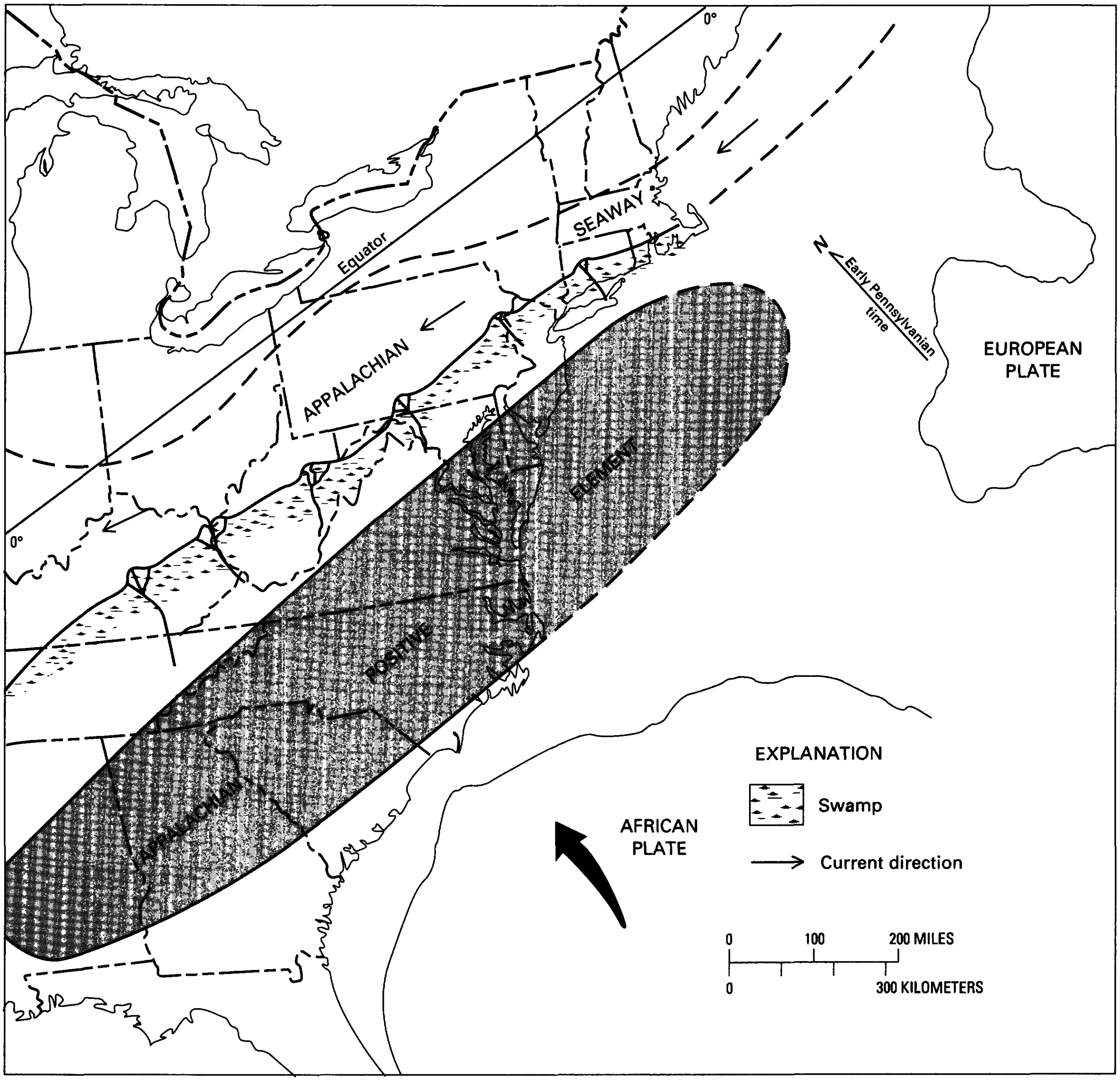

Figure 11. Generalized Early Pennsylvanian paleogeography during maximum terrestrial progradation. Dashed lines indicate the underwater portion of the Appalachian positive element.

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