The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Virginia

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110-C

Prepared in cooperation with the Virginia Division of Mineral Resources

Historical review and summary of areal, stratigraphic, structural, and economic geology of Mississippian and Pennsylvanian rocks in southwestern Virginia

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1979

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THE MISSISSIPPIAN AND PENNSYLVANIAN (CARBONIFEROUS) SYSTEMS IN THE UNITED STATES—VIRGINIA

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ABSTRACT

Carboniferous rocks in Virginia range from Early Mississippian to Middle Pennsylvanian in age and consist mostly of interbedded sandstone, siltstone, shale, limestone, claystone, and coal. These sedimentary deposits are assigned to 15 formations, which underlie areas that total approximately 7,000 km² in the Appalachian Plateaus and the Valley and Ridge physiographic provinces in the southwestern part of the State.

The sedimentation patterns and fossil content of the rock sequence have recorded fluctuations between marine and continental depositional environments in the east-central part of the Appalachian basin. In Mississippian time, marine events predominated during the deposition of a southeastward-thickening sequence of mostly limestone, shale, and siltstone, which, to the east, includes lobes of barrier-bar and terrestrial coal-bearing sediments. A repetition of marine and terrestrial environments prevailed until Early Pennsylvanian time, when a major seaward progradation of deltaic coal-bearing sediments took place. Deposition was continuous across the systemic boundary in the trough area or eastern part of the Appalachian basin, whereas on the western limb of the basin, including westernmost Virginia, Upper Mississippian and Lower Pennsylvanian rocks were eroded sufficiently to form a hiatus between the Mississippian and Pennsylvanian Systems. The deposition of terrestrial coal-bearing sediments continued throughout Early and Middle Pennsylvanian time with only an occasional marine transgression. Carboniferous rocks were folded and faulted by thrusting from the southeast during late or post-Paleozoic deformation. Consequently, strata in the Appalachian Plateaus were gently folded and, in the Cumberland overthrust sheet, thrust about 6.4 km to the northwest. At the southeastern edge of the plateaus and in the Valley and Ridge province, Carboniferous strata were highly folded and faulted.

Coal, natural gas, and limestone are the principal mineral resources of economic interest in the Carboniferous rocks of Virginia. Coal of high-volatile A to low-volatile bituminous rank is the principal developed mineral resource.

INTRODUCTION

The Mississippian and Pennsylvanian Systems in Virginia are represented by approximately 5,100 m of sedimentary rocks consisting of intercalated sandstone, siltstone, shale, claystone, limestone, and coal. The distribution of the rocks representing these systems is limited to the western part of the State, principally to the Appalachian Plateaus, and, to a lesser extent, to isolated areas of the adjoining Valley and Ridge province (fig. 1). Within the Appalachian Plateaus, strata are relatively flat and, except for sharply upturned beds near the southeastern edge, show only slight to moderate structural deformation. In contrast, correlative rocks of the Valley and Ridge province are found in several discontinuous and highly deformed fault slices that strike northeast across the west-central part of the State. Rocks of Mississippian age are the most widely distributed and include: (1) subsurface beds beneath Pennsylvanian rocks of the Appalachian Plateaus, (2) upturned beds at the southeastern edge of the plateaus, and (3) sporadic occurrences in the faulted and folded belt of the Valley and Ridge province. These rocks are largely of marine origin, but locally they grade into, and include, nearshore and terrestial deposits. Pennsylvanian rocks consist mostly of terrestial coal-bearing deposits that underlie the Appalachian Plateaus in the east-central part of the broad Appalachian coal basin and a few outliers in the faulted and folded belt. The latter areas are too small to show at the map scale.

The stratigraphic nomenclature used in this paper has not been reviewed by the Geologic Names Committee of the U.S. Geological Survey. The nomenclature used here conforms with the current usage of the Virginia Division of Mineral Resources.

EARLY INVESTIGATIONS

Early investigations of the Mississippian and Pennsylvanian rocks of Virginia were made by Lesley (1873), Stevenson (1881), Rogers (in MacFarlane, 1879), Boyd (1887), and McCreath and d'Invilliers (1888). These studies furnished pre-

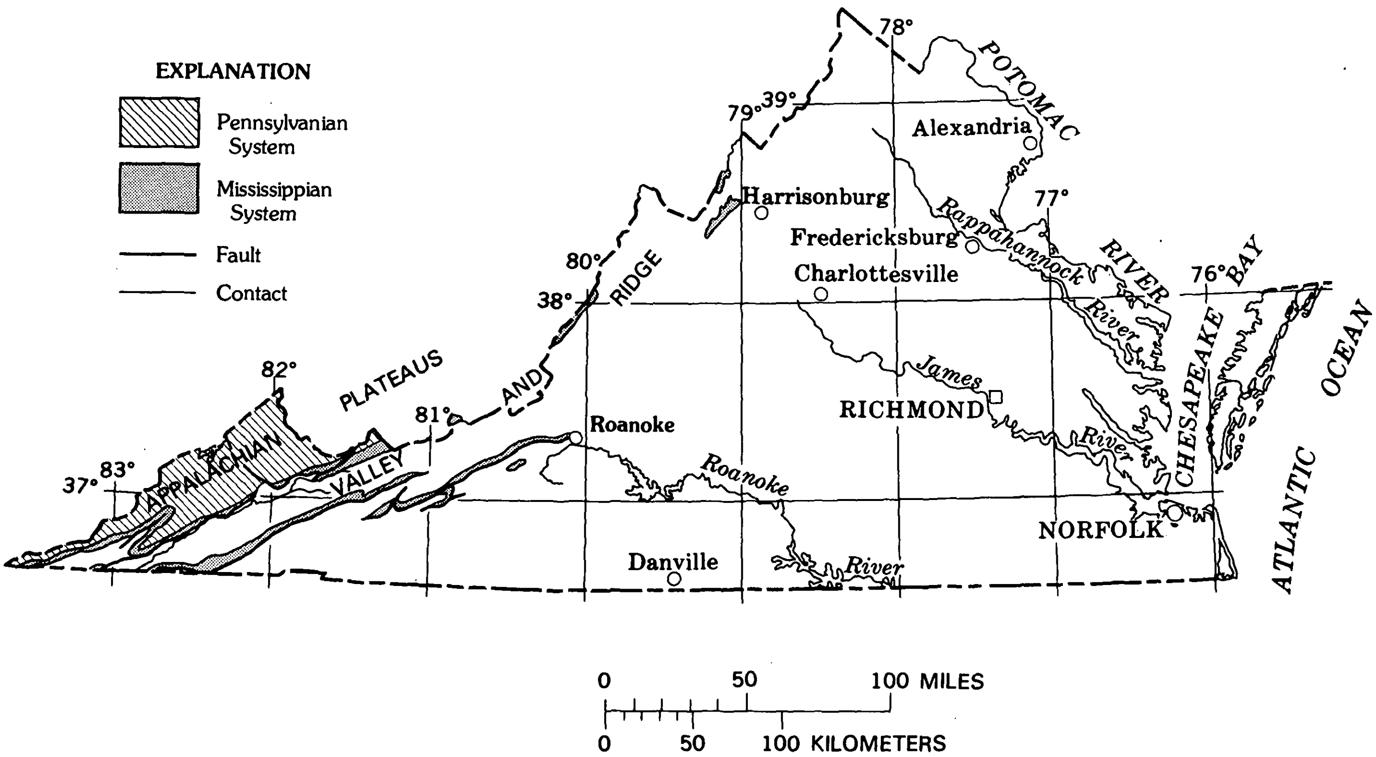


FIGURE 1.—Outcrop of the Mississippian and Pennsylvanian Systems in Virginia.

liminary assessments of the economic potential of various mineral occurrences and also provided the incentive for later comprehensive efforts to subdivide and map Carboniferous rocks (Campbell, 1893, 1894a, 1896, 1897; Ashley and Glenn, 1906; Butts, 1914; and Hinds, 1916). The nomenclature used by these workers differed from area to area, but by the early 1920's a relatively standardized set of subdivisions had been established in county and regional reports (Hinds, 1918; Harnsberger, 1919; Giles, 1921, 1925; Wentworth, 1922; Eby, 1923; and Campbell and others, 1925). Subsequent reports covered a broad range of stratigraphic studies, economic assessments, and geologic mapping that delineated occurrences of coal or natural gas in Carboniferous rocks (Butts, 1940, 1941; Averitt, 1941; Cooper, 1944; Wanless, 1946; Wilpolt and Marden, 1949; Brown and others, 1952; Huddle and others, 1956; Harris and Miller, 1958; Englund and Smith, 1960; Englund, 1964a, b; LeVan, 1962; Read and Mamay, 1964; and Miller, 1965). Recent reports emphasize both geologic mapping and regional stratigraphic studies (Englund and Delaney, 1966; Englund, 1968a, 1974; R. L. Miller, 1969; M. S. Miller, 1974; Miller and Roen, 1971).

PRESENT INVESTIGATIONS

Current studies of rocks of Mississippian and Pennsylvanian age in Virginia are concerned principally with regional stratigraphy, resource assessments, and geologic mapping. To meet the need for a standard reference section for rocks of Pennsylvanian age, the establishment of a Pennsylvanian System stratotype was initiated in 1972 by the U.S. Geological Survey in consultation with interested geologists from State surveys, industry, and universities. For this study, a composite stratotype consisting of stratigraphically overlapping outcrop sections has been assembled with the support of paleontologic investigations, geologic mapping, and core drilling (Englund and others, 1977). These sections are located along a line between Tazewell County, Va., and the Dunkard basin in west-central West Virginia.

The Virginia Division of Mineral Resources is cooperating with the U.S. Geological Survey in the collection of coal samples for analyses including ultimate and proximate, heat-content, free-swelling index, ash-fusibility, and major-, minor-, and trace-element determinations (Medlin and Coleman, 1976). This study is contributing to a nationwide program to assess the environmental and economic aspect of increased coal consumption including conversion processes, recoverable mineral by-products, and optimum utilization.

Mississippian and Pennsylvanian rocks are also being mapped in several 7½ minute quadrangles in Virginia for updating the assessment of the quantity and quality of coal resources (Miller and Meissner, 1978; Meissner and Miller, unpub. data; Englund and Warlow, unpub. data). In this study, coal beds are being mapped and sampled for information on the areal extent, thickness, chemical composition, rank, ash and sulfur contents, and lateral changes in the coal deposits. Additional research concerning thickness and lithic variations in the roof and floor rocks, depositional controls and systems, and postdepositional structural features is being conducted to determine the effect of these geologic factors on the exploration and development of coal resources.

GEOLOGIC SETTING

CONTACT RELATIONS WITH UNDERLYING ROCKS

In Virginia, Mississippian strata conformably overlie rocks of Late Devonian age. At Cumberland Gap, underlying strata consist of about 60 m of black shale assigned to the Chattanooga Shale of Late Devonian age. Northeastward, this shale increases in thickness to about 244 m at Big Stone Gap, where it includes a middle member of gray siltstone (Miller, 1965). The upper or Big Stone Gap Member of the Chattanooga Shale is a black shale or siltstone that is partly Mississippian in age (Harris and Miller, 1958). Continuing northeastward along the outcrop belt at the southeastern edge of the Appalachian Plateaus, strata of Late Devonian age increase in thickness to about 610 m in northern Tazewell County, where they consist of the Brallier Shale, a medium- to dark-gray shale with lesser amounts of interbedded siltstone and sandstone, and the Chemung Formation, a medium-light-gray very fine to fine-grained sandstone with minor amounts of greenish-gray shale. Only a few thin beds of black shale, typical of the Chattanooga Shale, are in these Upper Devonian rocks. In the northeasternmost exposures of this outcrop belt, basal Mississippian strata consist of as much as 15 m of black shale that correlates with the Big Stone Gap Member (Englund, 1968a). The discontinuous belt of Carboniferous rocks in the adjoining Valley and Ridge province also includes the Big Stone Gap Member at the base of the Mississippian System. The underlying Upper Devonian strata are assigned to the Braillier Shale and the Chemung Formation (Bartlett and Webb, 1971).

The age of Upper Devonian formations is based on conodonts (Roen, Miller, and Huddle, 1964) and brachiopods (Butts, 1940, p. 319–331; Cooper, 1944, p. 142; and Bartlett and Webb, 1971, p. 34–35).

CONTACT RELATIONS WITH OVERLYING ROCKS

The youngest Carboniferous rocks in Virginia are the Harlan Formation of Middle Pennsylvanian age. Only remnants of the formation are preserved on mountaintops in the southwesternmost part of the State where the upper contact is an erosional surface. Carboniferous rocks are not known elsewhere in Virginia where younger formation of Triassic, Cretaceous, and Tertiary age are present. In nearby areas of Kentucky and West Virginia, rocks equivalent to the Harlan Formation are conformably overlain by younger Pennsylvanian strata.

STRUCTURAL EVENTS DURING THE DEPOSITION OF CARBONIFEROUS ROCKS

The deposition of strata of Carboniferous age in the Appalachian basin took place during a period of slow subsidence as recorded by the shallow-water character of most of the sedimentary sequence. Subsidence was greatest along the eastern margin of the basin where the thickest sequence of strata accumulated. Deposition continued with only minor interruption throughout the Mississippian Period and into the early part of the Pennsylvanian Period. During deposition of the Mississippian strata, slight warping has been reported in nearby areas of West Virginia (Cooper, 1961, p. 95–99; Thomas, 1966) and along the Waverly arch in Kentucky (Englund, 1972). However, such relationships are not readily evident in Virginia.

Shortly after the deposition of the Pocahontas Formation in Early Pennsylvanian time, this southeastward-thickening wedge of Mississippian and Pennsylvanian rocks was uplifted, mostly where the western margin of deposition overlapped the eastern flank of the Cincinnati arch. Subsequent erosion truncated Lower Pennsylvanian strata including part of the New River Formation, the Pocahontas Formation, and Upper Mississippian strata, including several members in the upper part of the Bluestone Formation. Westward beyond the State, rocks of Late Mississippian age were completely eroded in places.

After the period of widespread erosion between the Mississippian and Pennsylvanian Systems, which was progressively greater toward the Cincinnati arch and along the crest of the Waverly arch, the deposition of Lower Pennsylvanian strata resumed. Again, the rate of deposition of coal-bearing strata in the Lower and Middle Pennsylvanian Series approximated the rate of subsidence, which was greatest along the eastern margin of the basin.

STRUCTURAL EVENTS FOLLOWING DEPOSITION

At the end of Carboniferous sedimentation, a southeastward-thickening wedge of sediments extended from the Cincinnati arch southeast across southwestern Virginia and into the trough of the Appalachian geosyncline. The youngest sediments of Middle Pennsylvanian age were virtually flat lying after their deposition. Perhaps an additional 300 m or more of Pennsylvanian sediments accumulated in Virginia and have since been eroded. During the Appalachian orogeny, possibly as early as Late Pennsylvanian or Early Permian time, mountain-building stresses were projected northwest with sufficient intensity to affect Carboniferous rocks throughout southwestern Virginia. Consequently, the present attitude of Carboniferous rocks reflects both the regional downwarping of the Appalachian geosyncline and structural deformation associated with postdepositional faulting.

Structurally, the areas underlain by Carboniferous rocks are divided by faulting into three distinct segments: (1) relatively flat lying rocks of the Appalachian Plateaus northeast of the Cumberland overthrust sheet, (2) gently folded and faulted rocks of the Cumberland overthrust sheet, and (3) intensely folded and faulted rocks of the Valley and Ridge province. In the area of relatively flat lying rocks of the Appalachian Plateaus, Carboniferous rocks dip mostly 1° to 2°. Locally, along gentle northeast-trending flexures, the dip increases to as much as 5°. At the southeastern edge of the area, beds are near vertical or slightly overturned.

Rocks of the Cumberland overthrust sheet have moved about 6.4 km northwestward (Englund, 1971) and are warped into two broad folds—the Middlesboro syncline and the Powell Valley anticline. In Virginia, this thrust sheet is bounded on the northeast by the Russell Fork fault and in the subsurface by the Pine Mountain overthrust fault. Strata in the trough of the Middlesboro syncline are gently warped but may dip as much as 5° on the fringes of the trough area. The syncline is outlined by resistant Lower Pennsylvanian conglomeratic sandstone, which dips from a few degrees to nearly vertical along Cumberland Mountain and from 20° to 30° along Pine Mountain on the southeast and northwest limbs, respectively. The Powell Valley anticline parallels the Middlesboro syncline and plunges northeastward beneath Carboniferous rocks, which dip from a few degrees to vertical or slightly overturned (fig. 2).

In the areas of intensely folded and faulted rocks, Carboniferous rocks are almost entirely Mississippian in age, are found in fault slices as much as 5 km wide and 170 km long, and generally dip from 0° to 50°.

STRATIGRAPHY

Carboniferous rocks in Virginia range in age from Early Mississippian to Middle Pennsylvanian and are of marine and terrestrial sedimentary origin. Of this sequence, the lower 2,500 m are assigned to eight formations of Mississippian age and the upper 2,600 m, to seven formations of Pennsylvanian age (fig. 3).

MISSISSIPPIAN SYSTEM

BIG STONE GAP MEMBER OF THE CHATTANOOGA SHALE

The Big Stone Gap Member (Stose, 1923) of Late Devonian and Early Mississippian age includes basal Carboniferous strata in most of southwestern Virginia. In the type area, Big Stone Gap, Va., it consists of black evenly bedded shale and siltstone as much as 80 m thick. Northeastward, the member thins to 3 m or less in the Bramwell area, and southwest of Big Stone Gap, it merges with the underlying part of the Chattanooga Shale, which is entirely Devonian in age at Cumberland Gap. In the type section, the member contains both Early Mississippian and Late Devonian conodont faunas. The lowest definitely Mississippian conodont fauna is found about 28 m above the base and is characterized by *Siphonodella*, which is present throughout the upper part of the member. The following species have been identified (Roen and others, 1964):

Elictognathus lacerata (Branson and Mehl)
Polygnathus communis (Branson and Mehl)
  inornatus (E. R. Branson)
Pseudopolygnathus sp.
Siphonodella duplicata (Branson and Mehl)
  quadruplicata (Branson and Mehl)
Spathognathodus aciedentatus (E. R. Branson)

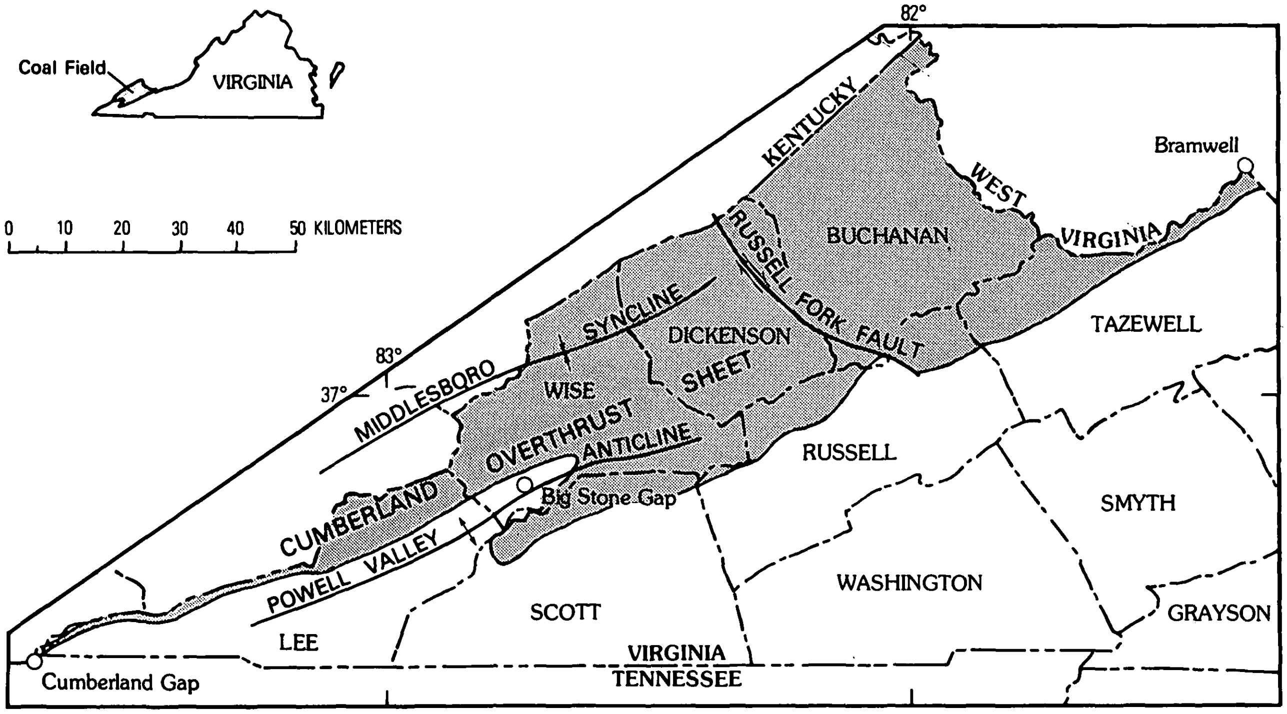


FIGURE 2.—Index map of the southwestern Virginia coal field (shaded).

PRICE FORMATION

The Price Formation (Campbell, 1894b) of Early Mississippian age is also known as the Grainger Formation in southwesternmost Virginia, where it includes the basal Mississippian strata. Elsewhere in Virginia, the formation conformably overlies the Big Stone Gap Member of the Chattanooga Shale. The Price consists largely of light-gray very fine to medium-grained sandstone and light-gray to greenish-gray shale, silty shale, and siltstone. Grayish-red beds also are present locally. Eastward in the Valley and Ridge province, the formation coarsens and includes feldspathic sandstone and well-rounded quartz pebbles and granules. Several glauconite beds have been recognized (Bartlett and Webb, 1971, p. 36), and coal beds have been locally noted in the formation (Campbell and others, 1925).

As much as 6 m of cherty dolomite, a wedge of the Fort Payne Chert, is at the top of the Price Formation at Cumberland Gap (Englund, 1964b). In the northeastern outcrops of Mississippian rocks, strata equivalent to the Price consist of coarse-grained conglomeratic sandstone assigned to the Pocono Formation, which overlies the Hampshire Formation of Devonian age. The thickness of the Price Formation increases northeastward from 90 m at Cumberland Gap to more than 500 m in the faulted and folded belt.

Marine fossils are abundant locally in the Price Formation and include the following forms (Bartlett and Webb, 1971, p. 36):

Brachiopods:
- *Camarotoechia* sp.
- *Chonetes* sp.
  - *shumardanus* De Koninck
- *Dictyoclostus burlingtonensis* (Hall)
- *Punctospirifer* sp.
- *Reticularia pseudolineata* (Hall)
- *Schellwienella*? sp.
- *Schuchertella desiderata* Hall and Clark
- *Spirifer* cf. *S. stratiformis* Meek
  - *winchelli*? Herrick
- *Teteracamera*? sp.
- *Torynifer* cf. *T. pseudolineata* (Hall)

Bryozoans:
- *Cystodictya* sp.
- *Fenestrellina regalis*? (Ulrich)
  - *tenax* (Ulrich)
- *Polypora impressa*? (Ulrich)
- *Rhombopora* sp.

Pelecypods:
- *Allorisma*? sp.
- *Aviculopecten*? sp.
- *Solemya*? sp.

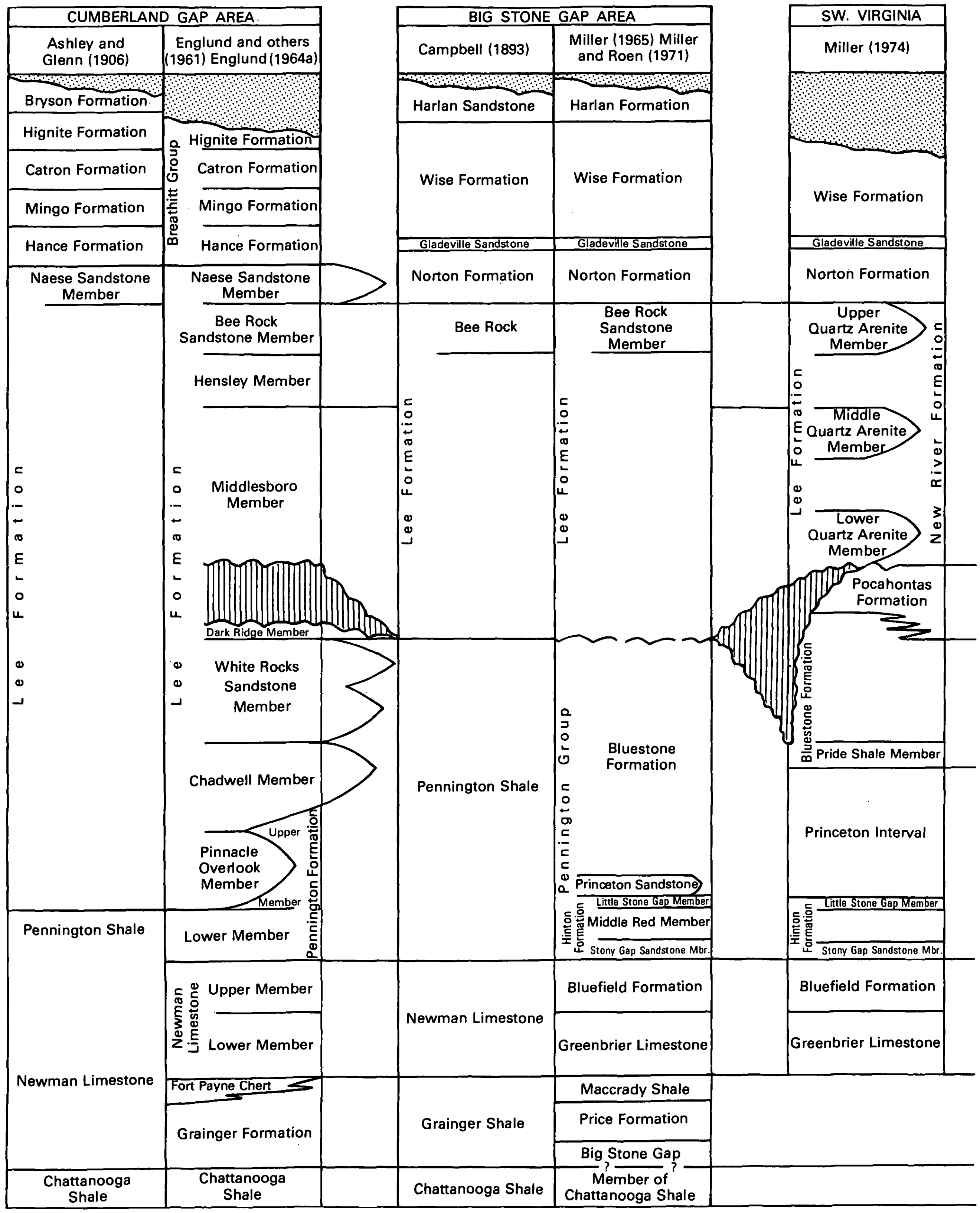


FIGURE 3.—Stratigraphic nomenclature used in southwestern Virginia; vertical lines indicate strata missing.

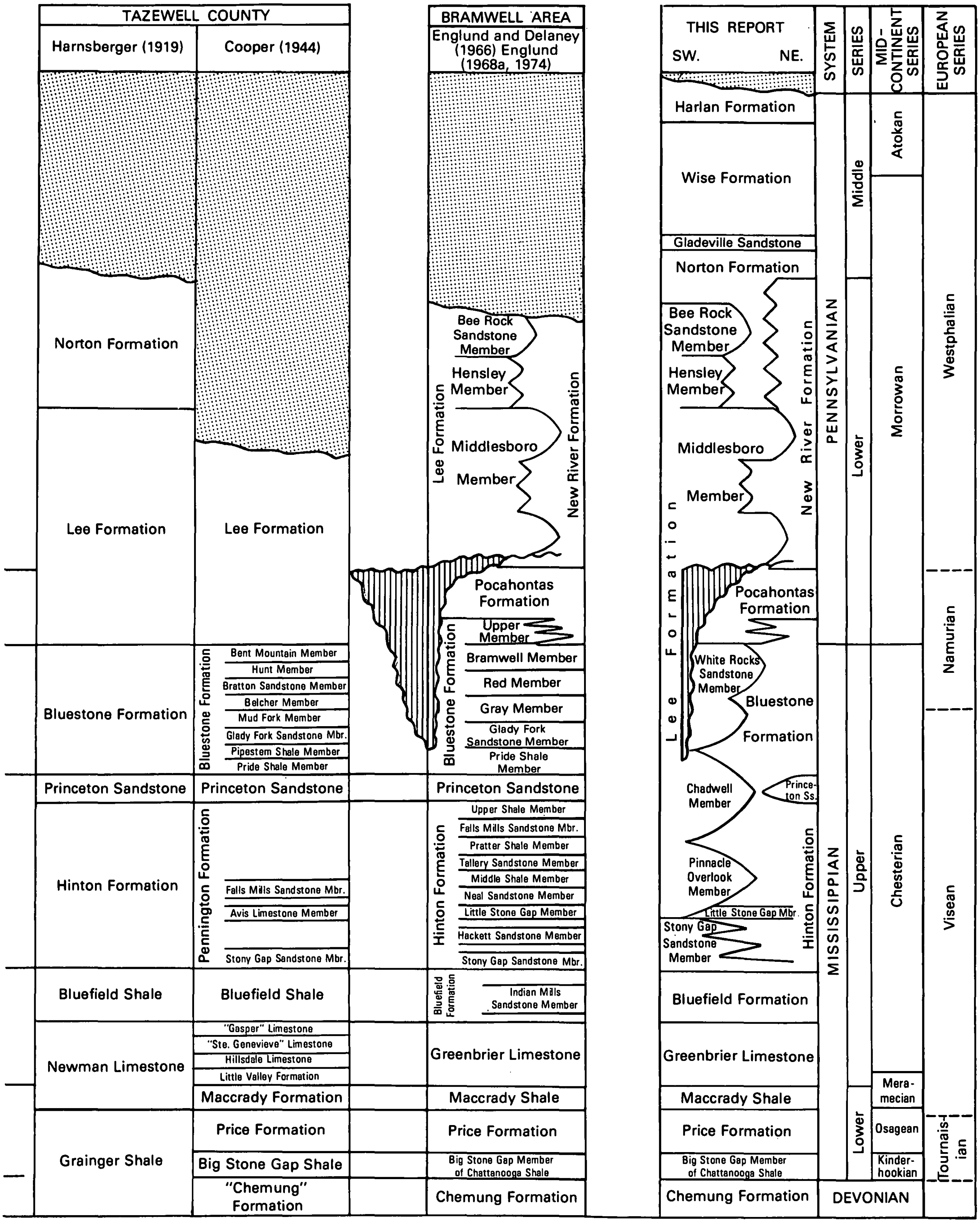


FIGURE 3.—Continued.

Gastropods:
- *Euphemites galericulatus* (Winchell)
- *Oxydiscus* sp.

Correlative beds in nearby areas of Tennessee contain the following faunas of Early Mississippian age, most likely Osagean (Englund, 1968b, p. 9):

Corals:
- *Cyathaxonia* sp. indet.
- *Amplexizaphrentis* sp. undet.
- *Trochophyllum verneuili* Milne Edwards and Haime
- "Zaphrentoid" corals
- *Cladochonus amplexus* (Rowley)

Bryozoans:
- *Fenestella* sp. indet.
- *Saffordotaxis* cf. *S. incrassatus* (Ulrich)
- *Cystodictya* sp. undet.

Brachiopods:
- *Schuchertella* sp.
- *Chonetes* aff. *C. glenparkensis* Weller
  - sp.
- Small spinoise productoid
- *Strophalosia*? sp.
- *Productina sampsoni* (Weller)?
- *Labriproductus*? sp.
- Rhynchonellid indet.
- *Punctospirifer subellipticus* (McChesney)
- *Strophopleura* sp.
- *Spirifer* aff. *S. shephardi* Weller
  - aff. *S. vernonensis* Weller
- *Spirifer* or *Branchythris* sp. indet.
- *Crurithyris* cf. *C. parva* (Weller)

Pelecypods:
- *Cypricardinia* sp.

Gastropods:
- *Platyceras* sp.

Echinoderms:
- Crinoid stems and plates
- Batocrinoid anal tube
- Echinoid plate

Trilobites:
- *Phillibole* cf. *P. conkini* Hessler
- *Proetides*? sp. indet.

Ostracodes:
- *Bairdia* sp.
- *Graphiadactyllis lineata* (Bassler)
- *Graphidactyllis*? sp.

MACCRADY SHALE

The Maccrady Shale (Stose, 1913) of Early Mississippian age is a distinctive grayish-red to bright-red shale including minor amounts of sandstone, silistone, or very finely crystalline dolomitic limestone. It attains a maximum thickness of about 45 m in the Bramwell area, thins southwestward, and is absent at Cumberland Gap. Thinning has resulted from truncation at the disconformable base of the overlying Greenbrier Limestone. Fossils, consisting of small assemblages of bryozoans and brachiopods of Osagean age, are sparse in the Maccrady Shale (Butts, 1940, p. 353; Cooper, 1944, p. 153).

GREENBRIER LIMESTONE

In southwestern Virginia, the Greenbrier Limestone (W. B. Rogers, in Macfarlane, 1879) of Late Mississippian age has been identified as part of the Newman Limestone (Campbell, 1893, p. 38) or has been divided into the Warsaw Formation and the St. Louis, Ste. Genevieve, and Gasper Limestones by Butts (1940, p. 355–381) or the Little Valley Formation and the Hillsdale, "Ste. Genevieve," and "Gasper" Limestones by Cooper (1944, p. 154–169). The Greenbrier consists mostly of thick-bedded very finely to coarsely crystalline limestone that is light olive gray and, less commonly, medium gray and brownish gray. It also includes oolitic, cherty, and yellowish-gray weathering argillaceous limestone beds and a few interbeds of greenish-gray or grayish-red shale. It extends throughout most of the area underlain by Carboniferous rocks and ranges from a minimum thickness of about 80 m at Cumberland Gap to about 335 m in the Bramwell area. A maximum thickness of about 900 m is found in the faulted and folded belt. Marine faunas of Late Mississippian age are present in nearly all beds of the Greenbrier Limestone. The following fossils were collected from basal beds assigned to the Little Valley Formation by Cooper (1944, p. 156–157):

Protozoan:
- *Endothyra* sp.

Coral:
- *Triplophyllum compressum* (Edwards and Haime)

Blastoid:
- *Pentremites conoideus* Hall

Bryozoans:
- *Fenestralia sancti-ludovici* (Prout)
- *Fenestrellina serratula* (Ulrich)
  - *tenax* (Ulrich)
- *Fistulipora* sp.
- *Stenopora* sp.
- *Worthenopora spinosa* (Ulrich)

Brachiopods:
Camarotoechia cf. *C. grosvenori* (Hall)
mutata (Hall)
Cliothyridina sp.
Echinoconchus biseriatus (Hall)
Orthotetes kaskaskiensis (McChesney)
Productus cf. *P. altonensis* Norwood and Pratten
indianiensis Hall
tenuicostus Hall
Reticularia salemensis Weller
Spirifer bifurcatus Hall
Streptorhynchus ruginosum (Hall)
Pelecypod:
Aviculopecten amplus Meek and Worthen

The lower middle part of the Greenbrier, assigned to the Hillsdale Formation, has yielded the following forms (Cooper, 1944, p. 159):

Algae:
"Giranvella" sp.
Corals:
Lithostrotionella "canadensis" (Castlenau)
prolifera (Hall)
Syringopora virginica Butts
Bryozoans:
Dichotrypa sp.
Fenestrellina tenax (Ulrich)
Hemitrypa proutana Ulrich
Polypora bisertiata Ulrich
Stenopora sp.
Brachiopods:
Brachythyris altonensis Weller
Cliothyridina sublamellosa (Hall)
Dielasma sp.
Orthotetes kaskaskiensis (McChesney)
Productus ovatus Hall
gallatinensis Beede
tenuicostus Hall
Spirifer delicatus Rowley
cf. *S. pellaensis* Weller
Gastropod:
Bellerophon cf. *B. sublaevis* Hall

The following fossils were collected from the upper middle part ("Ste. Genevieve" equivalent) of the Greenbrier Limestone (Cooper, 1944, p. 163–164):

Corals:
Menophyllum princetonensis (Ulrich)
Syringopora sp.
Triplophyllum spinulosum (Edwards and Haime)
Blastoids:
Pentremites princetonensis Ulrich
buttsi Ulrich
pulchellus Ulrich
Crinoid:
Platycrinites huntsvillae Safford
Bryozoans:
Batostomella interstincta Ulrich
Fistulipora peculiaris Rominger
Lioclemella sp.
Brachiopods:
Athyris densa Hall
Cliothyridina cf. *C. parvirostris* (Meek and Worthen)
hirsuta (Hall)
sublamellosa (Hall)
Dielasma sp.
Echinoconchus genevievensis Weller
Girtyella indianensis (Girty)
Productus ovatus Hall
inflatus McChesney
parvus Meek and Worthen
Spiriferina sp.
Spirifer pellaensis Weller

Fossils in the upper part, ("Gasper" equivalent) of the Greenbrier include (Cooper, 1944, p. 168):

Corals:
Campophyllum gasperense Butts
Triplophyllum spinulosum (Edwards and Haime)
Blastoids:
Pentremites "godoni" Ulrich
pyriformis Say
sp.
cervinus Hall
patei Ulrich
Crinoids:
Agassizocrinus sp.
cf. *A. conicus* Wachsmuth and Springer
Platycrinites sp. (stem plates not spinose)
Pterotocrinus serratus Weller
spatulatus Wetherby
Talarocrinus inflatus Ulrich
ovatus Worthen
Bryozoans:
Archimedes proutanus Ulrich
sp.
Cystodictya sp.
Brachiopods:
Chonetes cf. *C. chesterensis* Weller
Cliothyridina sublamellosa (Hall)

Composita trinuclea (Hall)
Diaphragmus elegans (Norwood and Pratten)
Echinoconchus sp.
Eumetria verneuilana (Hall)
Orthotetes cf. *O. kaskaskiensis* (McChesney)
Spirifer leidyi Norwood and Pratten
Spiriferina cf. *S. spinosa* (Norwood and Pratten)

BLUEFIELD FORMATION

The Bluefield Formation (Campbell, 1896) of Late Mississippian age is also identified in southwestern Virginia as the upper member of the Newman Limestone. It conformably overlies the Greenbrier Limestone and consists mostly of medium- to medium-dark-gray, greenish-gray, and grayish-red partly calcareous shale. Interbedded limestone and argillaceous limestone is fine crystalline to medium crystalline and light olive gray to medium gray. Locally, the formation includes beds of siltstone or fine-grained sandstone as much as 24 m thick. Also, a few thin coal beds associated with underclay and carbonaceous shale are present in places. The Bluefield Formation increases in thickness eastward from about 90 m at Cumberland Gap to 365 m in the Bramwell area. It is found throughout the area of Carboniferous rocks in southwestern Virginia, except for a few localities where only lower Mississippian rocks are preserved.

The Bluefield is abundantly fossiliferous, particularly the limestone and calcareous shale beds in the lower part of the formation. The forms listed below indicate that the Bluefield is correlative with the Glen Dean Limestone and possibly the Golconda Limestone of the midcontinent region (Cooper, 1944, p. 171–172):

Blastoids:
Pentremites brevis Ulrich
maccalliei Schuchert
Crinoid:
Pterotocrinus spatulatus Wetherby
Bryozoans:
Archimedes communis Ulrich
sp.
Fenestrellina cf. *F. tenax* (Ulrich)
Fistulipora sp.
Polypora sp.
Septopora subquadrans Ulrich
Stenopora sp.
Brachiopods:
Camarophoria explanata (McChesney)
Cliothyridina sublamellosa (Hall)
Diaphragmus elegans (Norwood and Pratten)
Eumetria verneuilana (Hall)
Orthotetes cf. *O. kaskaskiensis* (McChesney)
Productus cf. *P. inflatus* McChesney
Reticularia setigera (Hall)
Spirifer cf. *S. increbescens* Hall
cf. *S. transversa* (McChesney)
Pelecypods:
Aviculopecten sp.
Edmonia sp.
Myalina sp.
Sphenotus sp.

HINTON FORMATION

The Hinton Formation (Campbell and Mendenhall, 1896) of Late Mississippian age is characterized by abundant grayish-red partly calcareous shale and siltstone, but it also includes several intercalated sandstone beds, minor amounts of medium-gray and greenish-gray shale, fossiliferous limestone and calcareous shale, and a few thin beds of coal or carbonaceous shale underlain by rooted underclay. It conformably overlies and locally intertongues with the Bluefield Formation. Southwestward from Big Stone Gap, correlative strata have been included in the Pennington Formation or Group.

The Stony Gap Sandstone Member at the base of the Hinton is commonly quartzose, highly resistant, ripple bedded and as much as 30 m thick. It consists of white to very light-gray, very fine to medium-grained sandstone, which locally splits into two or more beds with greenish-gray or grayish-red shale intervening. Well-rounded pebbles and cobbles also are found in the member at a few localities. In places, the member grades to micaceous ripple-bedded sandstone that contains a relatively small amount of quartz.

The thickest and most widespread of several marine beds in the Hinton Formation is the Little Stone Gap Member (Miller, 1964) or Avis Limestone of Reger (1926). It is found as much as 185 m above the Stony Gap Standstone Member in the Bramwell area but converges southwestward to within 25 m of the top of the Stony Gap Sanstone Member near Cumberland Gap. The Little Stone Gap Member consists of medium-gray limestone, argillaceous limestone, and calcareous shale that totals as much as 23 m in thickness. Marine fossils, including brachiopods, pelecypods, bryozoans, and gastropods of Chesterian age are common in the member.

The Tallery Sandstone Member is the most prominent and widely distributed of several sandstone units in the upper part of the Hinton Formation. It is white to light gray, very fine to medium grained, thick bedded to massive, and, in most places, quartzose. It commonly contains well-rounded quartz pebbles and, for this reason, has been misidentified as the stratigraphically higher Princeton Sandstone (fig. 4).

The Tallery Sandstone Member ranges from 0 to 50 m in thickness and is split locally into two or more beds separated by medium-gray or greenish-gray shale.

The total thickness of the Hinton Formation ranges from a minimum of 50 m at Cumberland Gap to as much as 395 m in the Bramwell area.

PRINCETON SANDSTONE

The lithically distinctive Princeton Sandstone (Campbell and Mendenhall, 1896) of Late Mississippian age conformably overlies the Hinton Formation. It has been described as a polymictic conglomerate or as a coarse conglomeratic subgraywacke (Cooper, 1961, p. 69) and consists mainly of light-gray, fine- to coarse-grained, thick-bedded to massive calcite-cemented sandstone. Clasts in the formation are highly diverse in composition, size, and abundance and are composed of well-rounded to angular fragments of quartz, shale, siltstone, limestone, chert, and ironstone. The Princeton Sandstone attains a maximum thickness of about 18 m in the Bramwell area. Southwestward it becomes thinner, less conglomeratic, and grades to a very fine grained ripple-bedded sandstone before wedging out at the base of the Pride Shale Member of the overlying Bluestone Formation in west-central Tazewell County, Va. Fossils in the Princeton are largely limited to reworked specimens in limestone clasts.

MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS

BLUESTONE FORMATION

The youngest Mississippian strata in Virginia are included in the Bluestone Formation (Campbell, 1896), which consists of six widely recognized members. The Bluestone attains a maximum thickness of about 250 m in Tazewell County, Va..

The Pride Shale Member (Reger, 1926), at the base of the formation, is a dark-gray evenly bedded shale that grades locally to silty shale or to interlaminated siltstone and shale. Basal beds of the member may include partly calcareous greenish-gray and grayish-red shale. Pyrite and ironstone nodules and lenses as much as 1.3 cm thick are common in the dark-gray shale. A characteristic feature of the member is a grooved or fluted vertical surface in relatively fresh or slightly weathered exposures. From a maximum thickness of about 80 m in the Bramwell area, the Pride Shale thins southwestward and is not differentiated southwest of Big Stone Gap. Marine and brackish-water fossils are found locally in the member.

The Glady Fork Sandstone Member (Reger, 1926) varies in composition from silty ripple-bedded sandstone to coarse conglomeratic subgraywacke. The sandstone is light gray, fine to coarse grained, and thin bedded to massive. Well-rounded to angular clasts in the member are composed of quartz, shale, siltstone, limestone, chert, and ironstone. The Glady Fork sandstone is found only in Tazewell County where it ranges from 0 to 18 m in thickness.

The gray member of the Bluestone Formation is a wedge of interbedded medium-gray shale, light-gray sandstone, siltstone, argillaceous limestone, and a few thin beds of coal and associated underclay. It is restricted to Tazewell County, where it attains a maximum thickness of 60 m, and, where the Gladys Fork Sandstone wedges out, the gray member merges southwestward with the Pride Shale Member. Fresh- or brackish-water ostracodes and pelecypods are found in several beds of carbonaceous shale. A flora, dominated by *Stigmaria stellata* is found in several beds of the member (Gillespie and Pfefferkorn, 1977).

The red member of the Bluestone Formation is largely grayish-red, partly calcareous shale, siltstone, and sandstone. Lesser amounts of greenish-gray to medium-gray shale, siltstone, sandstone, argillaceous limestone, rooted underclay, coal, and carbonaceous shale are also present. The member is as much as 100 m thick in the Bramwell area, thins southwestward, and wedges out in the Big Stone Gap area. Ostracodes and *Lingula* are common in carbonaceous shale beds.

The Bramwell Member (Englund, 1968a), the uppermost unit of Mississippian age in the Bluestone Formation, is predominantly medium-gray to medium-dark-gray shale that coarsens upward and locally grades from very fine to fine-grained ripple-bedded sandstone. A persistent basal bed of black carbonaceous shale contains abundant ostracodes, pelecypods, and *Lingula;* overlying beds of the

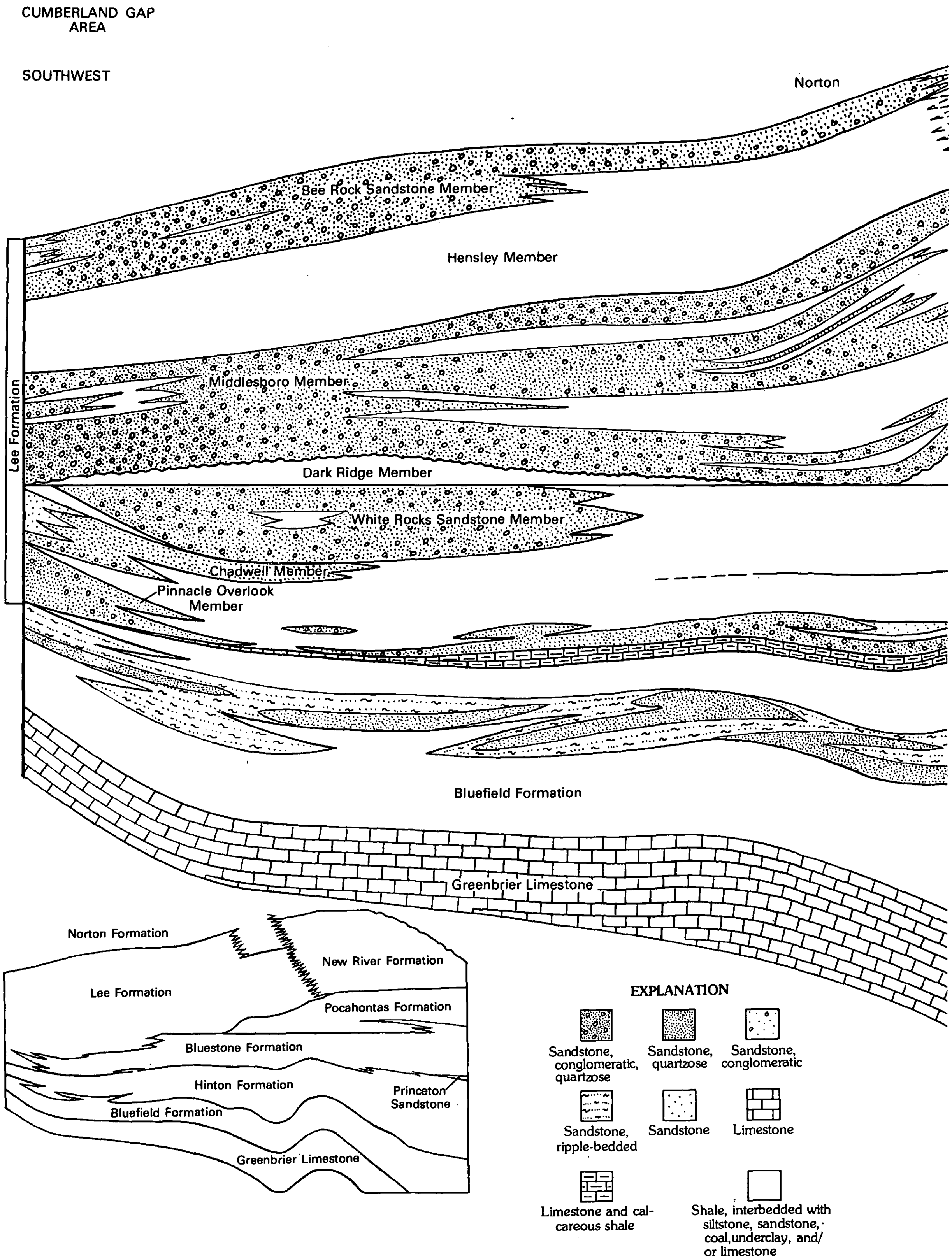


FIGURE 4.—Stratigraphic cross section showing the relation of formations to the Mississippian-Pennylvanian systemic boundary between the Cumberland Gap and Bramwell areas of the southwestern Virginia coal field. Line of section shown in figure 2.

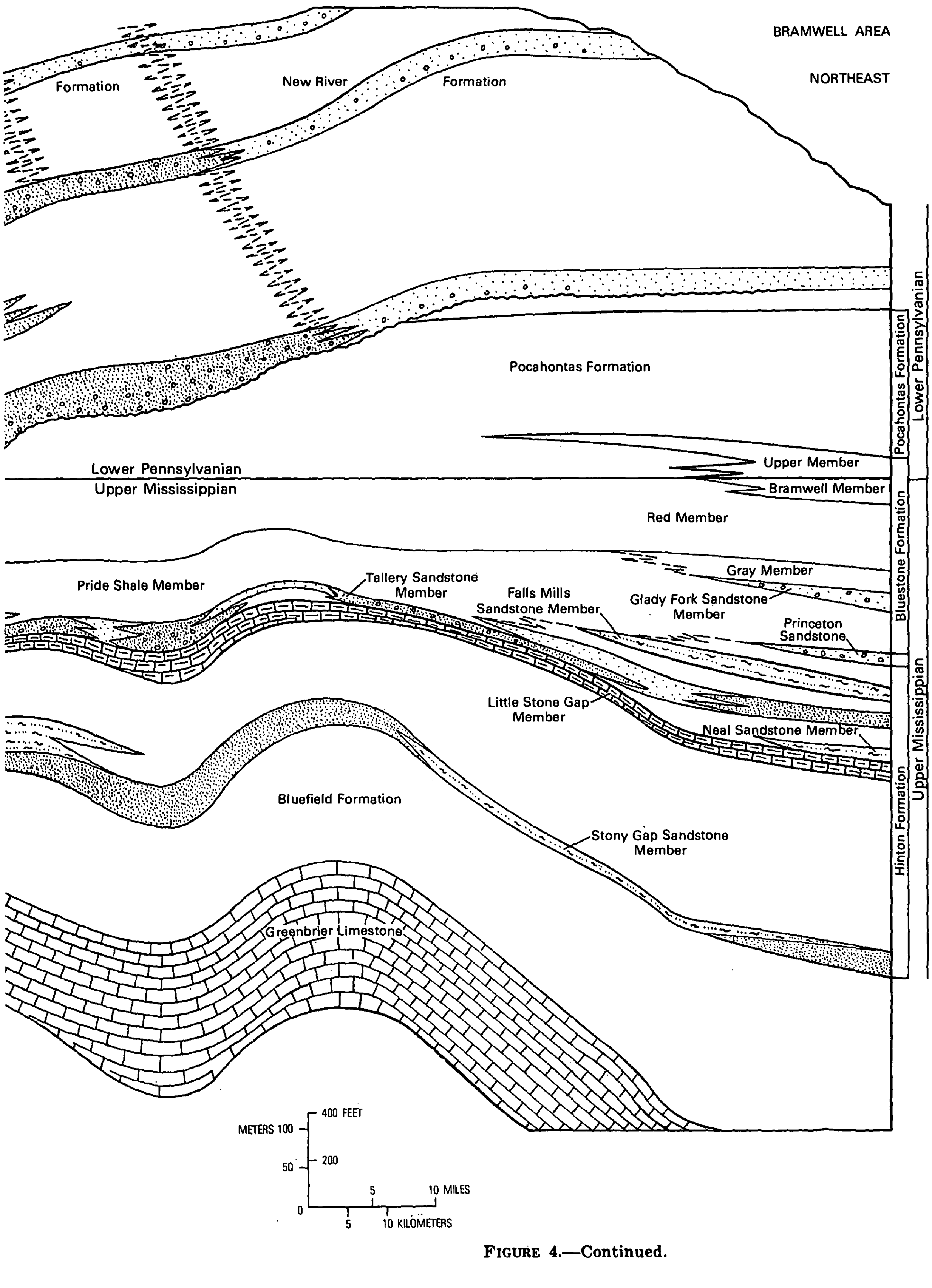


FIGURE 4.—Continued.

member contain articulate brachipods and pelecypods. Ellipsoidal argillaceous limestone concretions, 15–50 cm in diameter, are found locally. In Virginia, the member is limited to Tazewell County, where it ranges from 16 to 36 m in thickness. The following assemblages of Late Mississippian age were collected from a marine faunule in the Bramwell Member (Englund, 1974, p. 34).

USGS 22500–PC
- *Fenestella* sp.
- *Polypora?* sp.
- *Lingula* sp.
- *Orbiculoidea* sp. indet.
- *Orthotetes* cf. *O. kaskaskiensis* (McChesney)
- *Diaphragmus* cf. *D. cestriensis* (McChesney)
- *Ovatia* sp.
- *Anthracospirifer leidyi* (Norwood and Pratten)
- *Eumetria* cf. *E. vera* (Hall)
- *Polidevcia* sp.
- *Paleyoldia* sp. indet.
- *Aviculopecten* sp. (approaching Limipecten)
- *Posidonia?* sp. indet.
- *Solenomya* sp.
- *Sphenotus* sp. indet.
- *Wilkingia?* sp.
- *Edmondia* sp.
- *Composita subquadrata* (Hall)
- *Knightites (Retispira)* sp.

USGS 22754–PC
- *Lingula* sp.
- *Orbiculoidea?* sp. indet.
- *Orthotetes* aff. *O. kaskaskiensis* (McChesney)
- *Diaphragmus* cf. *D. cestriensis*
- *Ovatia* cf *O. elongata* Muir-Wood and Cooper
- *Anthracospirifer leidyi* (Norwood and Pratten)
- *Composita subquadrata* (Hall)
  sp.
- *Eumetria* cf. *E. vera* Hall
- *Beecheria* cf. *B. whitfieldi* (Girty)
- *Schizodus* sp.
- *Cypricardella?* sp.
- *Sphenotus* sp. indet.
- Bellerophontid gastropod, indet.
- Trilobite pygidium (fragment)

The upper member of the Bluestone Formation consists principally of slightly calcareous shale and siltstone that show the typical grayish-red and greenish-gray colors of the Bluestone Formation. A persistent bed of light-greenish-gray sparsely rooted claystone and scattered ironstone spherules is at the top of the member. The member intertongues and grades laterally with the lower sandstone member of the Pocahontas Formation of Early Pennslyvanian age. For this reason and because of the presence of *Neuropteris pocahontas*, a Lower Pennsylvanian fossil, the upper member is classified as Pennsylvanian in age. The member ranges from 0 to 24 m in thickness and merges westward with the red member of the Bluestone Formation.

LEE FORMATION

The Lee Formation (Campbell, 1893) of Late Mississippian and Early Pennsylvanian age has been divided in the type area, Lee County, Va., into seven mapped members, which are, in ascending order: Pinnacle Overlook, Chadwell, White Rocks Sandstone, Dark Ridge, Middlesboro, Hensley, and Bee Rock Sandstone Members (Englund, 1964a). The Late Mississippian members—Pinnacle Overlook, Chadwell, and White Rocks Sandstone Members—are quartzose sandstone and conglomeratic sandstone lobes that total as much as 135 m in thickness, and intertongue with the Bluestone or Pennington Formation. Basal Pennsylvanian beds consist of dark-gray shale, fine-grained sandstone, coal, and underclay which constitute the Dark Ridge Member, a correlative of the Pocahontas Formation. The Middlesboro Member disconformably overlies the Dark Ridge Member, Pocahontas Formation, or the Bluestone Formation. It is the most prominent and extensive member of the Lee Formation, especially in the Cumberland Gap and Big Stone Gap areas, where it consists of four locally coalescing quartzose and conglomeratic sandstone tongues that total as much as 150 m in thickness. Northeastward, the proportion of nonresistant strata in the member increases, a relationship that is accompanied by a divergence and splitting of the quartzose conglomeratic tongues (fig. 4). The lower and upper tongues of the member were designated lower and middle quartz arenite members of the Lee Formation by Miller (1974, p. 63).

The Hensley Member of the Lee Formation is a sequence of nonresistant sandstone, siltstone, shale, coal, and underclay as much as 122 m thick. Where the Bee Rock Sandstone Member tongues out, strata equivalent to the Hensley Member are included in the Norton Formation (fig. 4).

The Bee Rock Sandstone Member, the uppermost unit of the Lee Formation in Virginia, consists of two lobes of quartzose conglomeratic sandstone that are as much as 90 m thick. It grades at its northeastern fringe to nonresistant feldspathic sandstone of the Norton Formation.

The seven members of the Lee Formation aggregate 485 m in thickness. Plant fossils are found throughout the Lee Formation, and the floras are similar to those listed for the New River and Pocahontas Formations. Fresh- and brackish-water invertebrate faunas are also present.

PENNSYLVANIAN SYSTEM

POCAHONTAS FORMATION

The Pocahontas Formation (Campbell, 1896) is a northwestward-thinning wedge of coal-bearing clastic rocks that underlies an area of about 9,000 km^2 at the southeastern edge of the Appalachian coal field. It conformably overlies the Bluestone Formation, and, in contrast to the variegated and calcareous beds of that formation, the Pocahontas consists of interbedded light- to dark-gray sandstone, siltstone, shale, coal, and underclay. Of these, sandstone is most abundant and constitutes about 70 percent of the formation; siltstone, shale, and underclay total 28 percent; and coal, the remaining 2 percent. Outcrops in Virginia are limited to a narrow discontinuous belt of upturned beds at the southeastern edge of the coal field (fig. 2). From a maximum thickness of about 299 m in the outcrop area, the formation thins northwestward for about 48 km to where it wedges out in the subsurface at an average depth of about 450 m below the principal valley floors.

Fresh- or brackish-water pelecypods and *Lingula* are present in several beds; plant fossils, including stems, leaves, and roots, are found throughout the formation. The flora is characterized by an abundance of *Neuropteris pocahontas*, and other reported forms are as follows (Pfefferkorn and Gillespie, 1977):

Lyginopteris sp.
Mesocalamites sp.
Mariopteris pottsvillea White
Calamites sp.
Palmatopteris furcata (Brongniart) H. Potonie
Asterophyllites charaeformis Sternberg
Neuropteris smithsii Lesquereux

NEW RIVER FORMATION

The Pocahontas Formation is conformably overlain by the New River Formation of Early Pennsylvanian age in most outcrop areas. This conformable contact, placed at the base of the Pocahontas No. 8 coal bed, extends northwestward for several kilometers to where the upper beds of the Pocahontas Formation are truncated by the unconformity at the base of the Pineville Sandstone Member of the New River Formation or the correlative Middlesboro Member of the Lee Formation. Northwest of the area underlain by the Pocahontas Formation, upper beds of the Bluestone Formation were also eroded away, and there the disconformity at the base of the New River coincides with the widespread Mississippian-Pennsylvanian unconformity (Englund, 1969). In addition, a hiatus is substantiated by the absence of floral zone 4 of Read and Mamay (1964).

The New River Formation (Fontaine, 1874) is widely recognized in West Virginia, but in Virginia it is limited to parts of Buchanan and Tazewell Counties where the laterally equivalent Lee Formation has tongued out. The New River ranges from about 425 to 520 m in thickness and is a coal-bearing sequence of sandstone, siltstone, shale, and underclay. Lithically, it is similar to the Pocahontas Formation except for the presence of thicker and more widespread beds of quartz-pebble conglomerate or congomeratic sandstone. To the southwest and west, these coarse clastic rocks grade to quartzose conglomeratic sandstone of the Lee Formation (Englund and Delaney, 1966). Sandstone in the New River Formation is typically light gray, fine to coarse grained, thin to thick bedded, and locally massive. In addition to quartz, which ranges from 45 to 65 percent, the sandstone contains a notable amount of white-weathering feldspar, mica, and carbonaceous grains. Fossil plants are abundant in the formation, including the following forms, which were identified in conjunction with the Pennsylvaian System stratotype study in nearby areas of West Virginia (Pfefferkorn and Gillespie, 1977):

Calamites sp.
Asterophyllites charaeformis Sternberg
Lyginopteris sp.
Mariopteris pottsvillea White
Alethopteris decurrens Artis
Sphenophyllum cumeifolium (Sternberg) Zeiller

Fresh- or brackish-water faunules are found in several beds of the New River Formation. A marine assemblage collected from a calcareous shale overlying the Pocahontas No. 8 coal bed in Buchanan and Tazewell Counties (Henry and Gordon, 1977) includes:

Rugose coral, gen. and sp. indet.
Small pelecypods indet.
Pelmatozoan columnals
Paleyoldia? sp.
Lingula carbonaria McChesney
Schizodus? sp. indet.

Orbiculoidea sp. indet. (fragment)
Bellerophontacean, gen. and sp. indet.
Small marginiferid productoid?
Straparollus (*Euomphalus*?) sp. indet.
Composita sp. indet.
Pleurotomaracean gen. and sp. indet.
Nuculopsis cf. *N. girtyi* Schenck
Palaeosolen sp.
Phestia sp.
Fish scales

NORTON FORMATION

The Norton Formation (Campbell, 1893) of Early and Middle Pennsylvanian age is composed mostly of medium- to dark-gray shale and siltstone and lesser amounts of fine- to medium-grained sandstone, coal, and underclay. In contrast to the quartzose conglomeratic sandstone typical of the Lee Formation, that of the Norton tends to be finer grained, feldspathic, and micaceous, and has a relatively low quartz content of 50 to 60 percent. In most areas, the Norton Formation conformably overlies the Lee Formation; however, where the Lee is absent along the Virginia-West Virginia State line, correlative beds are assigned to the Kanawha Formation, which overlies the New River Formation. The thickness of the Norton increases northeastward from a minimum of 165 m to as much as 600 m. Fossil plants, including stems, leaves, and roots, are found throughout the formation. Several carbonaceous shale beds contain fresh- or brackish-water pelecypods and *Lingula.*

GLADEVILLE SANDSTONE

The Gladeville Sandstone (Campbell, 1893) is a widely recognized resistant unit that conformably overlies the Norton Formation. In the type area, Miller (1969) described the formation as a massive, strongly crossbedded medium-grained quartzose sandstone about 15.5 m thick. Regionally, the Gladeville grades to fine-grained feldspathic micaceous sandstone that is nonresistant and possibly absent in places.

WISE FORMATION

The Wise Formation (Campbell, 1893) of Middle Pennsylvanian age is an important coal-bearing sequence in the southwestern Virginia coal field. It conformably overlies the Gladeville Sandstone and, in addition to coal, consists of sandstone, siltstone, shale, underclay, and limestone. The sandstone is light gray, fine to medium grained, thin bedded to massive, micaceous, feldspathic, and contains about 50–60 percent quartz. Several sandstone members, including the Robbins Chapel, Keokee, Clover Fork, and Reynolds Sandstone Members are as much as 30 m thick (Miller, 1969, p. 25–30). The shale and siltstone are mostly medium to dark gray, but beds of black carbonaceous shale and calcareous shale are also present. Two widespread marine units in the formation—Kendrick Shale of Jillson (1919) and the Magoffin Beds of Morse (1931)—consist of limestone, calcareous shale, or siltstone that contains abundant brachiopods and pelecypods. Fossil plants are abundant in many shale and siltstone beds. The Wise Formation averages about 580 m in thickness.

HARLAN FORMATION

The Harlan Formation (Campbell, 1893) of Middle Pennsylvanian age conformably overlies the Wise Formation and includes the youngest Carboniferous rocks in Virginia. Sandstone is the dominant lithology; it ranges from fine to coarse grained, light to medium light gray, and feldspathic to quartzose. At the base of the formation the sandstone is massive, cliff forming, and occupies channels that truncate underlying beds. Siltstone, shale, and several coals and associated underclay are present in overlying beds. The Harlan Formation attains a maximum thickness of about 200 m in the highest mountaintops along the Virginia-Kentucky State line. Plant fossils are found throughout the formulation.

MISSISSIPPIAN-PENNSYLVANIAN BOUNDARY

The boundary between the Mississippian and Pennsylvanian Systems in Virginia has been placed, by definition and on the basis of paleontologic data, at the contact between the Bluestone and Pocahontas Formations. This long-standing practice has continued in recent studies in the southeasternmost outcrops where the Pocahontas attains its maximum thickness of about 213 m. However, a modification of this relationship, the systemic boundary ex- to the northwest of the lower sandstone member of the basal tongue of the Pocahontas Formation in the upper part of the Bluestone Formation. Because of this relationship, the systematic boundary extends from the base of that sandstone member into the upper part of the Bluestone Formation at approximately the contact between the Bramwell Member and the upper member (fig. 4). About 48 km northwest of the outcrop area, the unconformity at the base of the Pineville Sandstone Member of the

New River Formation, or the Middlesboro Member of the Lee Formation, truncates the Pocahontas Formation and the upper part of the Bluestone Formation. Thus, the depositional continuity of beds across the systemic boundary is replaced to the northwest by a widely recognized hiatus. Maximum truncation of Mississippian beds takes place near the Virginia-Kentucky State line, where the Middlesboro Member disconformably overlies the Pride Shale Member of the Bluestone Formation.

FACIES CHANGES

The facies in the Carboniferous rocks of Virginia are representative of various continental and marine depositional environments. For example, the Lower Mississippian Price Formation and its correlatives consist of greenish-gray shale and siltstone containing marine fossils in the Cumberland Gap area and westward. In the easternmost outcrops of the faulted and folded belt, this part of the stratigraphic section is a coarse clastic terrestrial coal-bearing sequence. Similarly, a largely marine facies of fine clastic rocks in the Bluestone Formation of the Bramwell area is represented to the southwest by nearshore deposits of coarse orthoquartzite that dominate the Lee Formation in the Cumberland Gap area. The latter rock type in overlying beds of the Lee also intertongues and grades laterally with coal-bearing paludal and fluvial facies of the Norton and New River Formations, which are characterized by feldspathic subgraywacke sandstones. An idealized facies relationship between marine and continental rocks is also shown by marine shale in the Bluestone Formation and clean-washed bar sandstone, alluvial distributary sandstone, and coal-bearing paludal deposits in the Pocahontas Formation, which are found in lateral sequence southeastward across the southwestern Virginia coal field (Englund, 1974).

DEPOSITIONAL ENVIRONMENTS

Patterns of sedimentation in the Carboniferous rocks of Virginia record the fluctuations of marine and continental environments in a shallow, slowly subsiding basin. Southwestern Virginia was inundated by a shallow marine sea during the initial deposition of Early Mississippian sediments in the Big Stone Gap Member of the Chattanooga Shale. A detailed study of the lithically similar Chattanooga Shale in Tennessee by Conant and Swanson (1961, p. 60–62) concluded on the basis of paleontologic and sedimentologic data that deposition was in a shallow-water marine environment. The overlying Price Formation recorded the first seaward progradation of terrestrial sediments during Mississippian time in Virginia. Beds of coal and carbonaceous shale intercalated with fluvial sandstone indicate that deposition took place in broad coastal swamps that were periodically crossed by fluvial distributaries, while marine deposition continued to the west in the correlative Grainger Shale of the Cumberland Gap area.

Extensive marine transgression is again evident in the overlying Maccrady Shale, which may represent nearshore tidal deposits that were uplifted and eroded slightly prior to the onlap of subtidal to supratidal clastic and nonclastic Greenbrier sediments. Marine organisms flourished during deposition of the Greenbrier, and the fragmental condition of the fossils indicates a nearshore or tidal environment of deposition. A seaward encroachment of nearshore mud and sand and brief periods of marine transgression are recorded in the overlying Bluefield Formation. At times, brackish- or fresh-water swamps supported vegetation growth and peat accumulation. The Stoney Gap Sandstone Member at the base of the Hinton Formation records a convergence of offshore bars, as indicated by sandstone distribution patterns, by the clean, well-washed, and well-sorted character of the sand, and by the occurrence of marine limestone beds a few meters above and below the member. A repetition of terrestrial and marine environments continued throughout the deposition of the Hinton Formation, as shown by the local occurrences of coal, lagoonal shale, bar sandstone, and limestone.

The deposition of the Princeton Sandstone suggests a high-energy prograding shoreline where well-rounded quartz and chert pebbles were transported by longshore and tidal currents together with locally derived limestone clasts. Miller (1974, p. 109) proposed a quiet-water lagoonal environment, directly behind beach-barrier bars for the origin of the overlying Pride Shale Member, which contains both brackish-water and marine faunas. The Glady Fork Sandstone Member represents the intertidal redistribution of sand and gravel by current and wave action which preceded the seaward progradation of terrestrial sediments of the gray member of the Bluestone. The red member of the Bluestone contains thin nodular limestone of a supratidal environment as well as tidal-creek channels. The drowning of the coastal plain on which the red member was deposited took place during the deposition of marine sediments of the Bramwell Member of the Bluestone.

Deposition of the Pocahontas Formation began with a coarse clastic wedge building seaward over marine sediments and intertonguing with the prodeltaic mud of the upper member of the Bluestone Formation. Thickness and lithic variations in this clastic wedge demonstrate that sand deposition was concentrated in several merging delta lobes and was interspersed with quartz-pebble gravel along some of the main distributaries. The orientation of these delta lobes indicates a general northwest progradation of sediments originating from the southeast. During deposition of the upper part of the basal sand wedge, a decrease in the influx of sand was accompanied by southeastward encroachment by mud over areas of relatively thin sand, mostly in the interlobe areas. The main distributaries continued to disperse sand at a reduced rate but in sufficient quantities to permit intertonguing on a small scale with mud during the final phase of sand deposition. Deposition of the silt and mud was followed by accumulation of peat, as recorded by coal as much as 1.2 m thick over the sand lobes. The concentration of peat on abandoned lobes may have been due to the greater compactibility of mud in the interlobe areas, resulting in lagoons with water too deep for optimum growth of vegetation.

Marine regression to the northwest resumed during deposition of the middle and upper parts of the Pocahontas Formation, which consist of several delta lobes stacked above those of the lower unit. The superposition of lobes over lower ones indicates that the sediments were transported generally along the same drainage lines that existed previously. During the deposition of these beds, the shoreline stabilized sufficiently for the formation of a barrier bar of clean well-washed sand. The location of the thickest part of the bar just beyond a large centrally located lobe suggests that distributaries of this lobe were the principal source of sand. At the distal edges of the lobe, the sand was subject to reworking and winnowing by waves and longshore currents, possibly from the northeast, as indicated by a gradual southwestward thinning of the bar away from distributaries of the principal lobe. Continued regression during the deposition of the Pocahontas was accompanied by a northwestward growth of alluvial distributaries over and beyond the barrier bar. Swamp deposits are more extensive upward in the sequence and consist of silt, mud, and peat that accumulated over abandoned sublobes and, to a lesser extent, in interlobe areas. The widespread occurrence of peat may have been related to shoreline stability as well as to a minimum influx of sediments. Incursion of clastic materials decreased abruptly, and widespread swamp conditions prevailed during deposition of the Pocahontas No. 3 coal bed.

After the deposition of the Pocahontas Formation, much of the area was inundated by a transgressing sea, and marine muds were deposited locally above the Pocahontas No. 8 coal bed. Shortly thereafter, the northwestern edge of the formation was uplifted and extensively eroded. Truncation of the Pocahontas Formation and beds in the upper part of the underlying Bluestone Formation was followed by the deposition of the overlying New River and Lee Formations in environments dominated by coastal and near-coastal deltaic processes. Sedimentation was similar in many respects to that of the Pocahontas Formation, except for the formation of more widespread and thicker barrier bars of clean well-washed sand.

The Norton Formation, which intertongues with the Lee Formation in Virginia, represents back-barrier, lagoonal, and lower delta-plain environments where coal beds are relatively thin and discontinuous. Landward from the deposits, the coal beds are thicker and more widespread, and intervening sandstones occupy channels characteristic of the upper delta plain. A similar relationship is recorded upward in the Norton and overlying formations, except for the Wise and Harlan Formations which also contain fluvial sandstones that occupy deeply incised channels of an alluvial plain. Therefore, the environmental sequence extends laterally as well as upward from the Lee Formation, from back-barrier, through lower and upper delta-plain, to an alluvial-plain environment.

IGNEOUS ROCKS

Igneous activity during the deposition of Carboniferous rocks in Virginia is suggested by the occurrence of sanidine in a bentonite bed associated with a coal bed of uncertain correlation in the Wise Formation (Nelson, 1959). Sanidine also occurs in a flint clay bed in the Fire Clay coal of Kentucky (Seiders, 1965), a correlative of the Wallins Creen coal bed of the Wise Formation. These occurrences, which may represent the same bed, have been attributed to a volcanic origin.

ECONOMIC RESOURCES

COAL

Bituminous coal is the principal developed mineral resource in rocks of Carboniferous age in Virginia. Commercial mining, which began in the late 1880's in the southwestern Virginia coal field has depleted extensive areas of the most accessible high-quality coal. Most production has come from underground mines, including both large mines that have facilities for rail shipment and many small mines that use truck haulage. Large-scale surface mining began in the 1940's and now accounts for 30 percent of total production, mostly from narrow contour strips on mountain slopes which locally are accompanied by auger mining. A record amount of 36 million metric tons of coal was mined from underground and surface operations in 1976 (Virginia Dept. of Labor and Industry, 1977).

Small-scale mining of semianthracite, which began in the early 1900's in the Valley coal fields of the faulted and folded belt, attained a maximum annual production of about 247,000 metric tons in 1926 (Brown and others, 1952, p. 39). Commercial mining of this coal was inactive in 1976.

Coal in the southwestern Virginia coal field consists of common banded varieties that range in rank from high-volatile A to low-volatile bituminous. Mined coal beds commonly have a high free-swelling index (Nos. 5–9), a low to medium sulfur content (0.5 to 2.0 percent), a high heat value (13,500 to 14,900 Btu), and a low ash content (2 to 9 percent). Because of its excellent coking properties, the coal is in demand by both the domestic and foreign markets. A comparison of the trace-element content of Virginia coal beds with those of other areas shows essentially the same or much lower concentration (Medlin and Coleman, 1976). Available analyses of semianthracite from the Valley coal field indicate that the coal is mostly low in sulfur content (0.3 to 1.2 percent), moderately high in ash (12.8 to 28.4), and moderately high in heat value (10,530 to 12,890 Btu) (U.S. Bureau of Mines, 1944).

Coal is found in nine formations of Carboniferous age in Virginia and in at least 120 beds, of which 55 are of economic importance. The Pocahontas, New River, Norton, and Wise Formations contain most of the coal resources and mining development. The distribution of individual coal beds ranges from those a few square kilometers in area to widespread beds that extend throughout much of the southwestern Virginia coal field. Coal bed thicknesses range from less than 1 cm to as much as 5 m, but more commonly from 1 to 1.5 m in mining areas.

Coal beds of Carboniferous age contain a total remaining identified resource of 8,662 million metric tons (Averitt, 1975, p. 15). Of this total, about 47 percent is in thin beds (35–70 cm thick), about 35 percent in intermediate beds (70–105 cm thick), and about 18 percent in thick beds (more than 105 cm thick) (Brown and others, 1952). Recent investigations have indicated the presence of an additional 4,535 million metric tons of undiscovered resources.

NATURAL GAS AND PETROLEUM

Natural gas has been produced commercially from Carboniferous rocks in Virginia since 1938. Initial production was from sandy zones in the Little Valley Limestone, equivalent to part of the Greenbrier Limestone, of the Early Grove gas field in the Ridge and Valley area of Scott County (Averitt, 1941). The first commercial gas well in the Appalachian Plateau of Virginia was completed in 1948 in sandstone of Late Mississippian age (LeVan, 1962). Gas production is currently from the Price Formation, Greenbrier Limestone, and the Hinton Formation. Nearly 7,000,000 Mcf of gas was produced from 180 wells in 1976 from Mississippian and Devonian rocks (Lytle and others, 1977). Rocks of Carboniferous age lack petroleum production, but shows of oil have been reported at several horizons in these strata.

LIMESTONE

The Greenbrier Limestone has been the principal source of crushed stone in rocks of Carboniferous age. It has been quarried at several localities for roadstone and concrete aggregate.

ACKNOWLEDGMENTS

The writer is grateful for the fieldwork collaboration and contributions of his research associates, particularly R. L. Miller, C. R. Meissner, Jr., J. F. Windolph, Jr., and R. C. Warlow. Reviews by G. H. Wood, Jr., T. W. Henry, and P. C. Lyons provided many critical and helpful suggestions. The cooperation of the Virginia Division of Mineral Resources is sincerely appreciated

REFERENCES CITED

Ashley, G. H., and Glenn, L. C., 1906, Geology and mineral resources of part of the Cumberland Gap coal field, Kentucky: U.S. Geol. Survey Prof. Paper 49, 239 p.

Averitt, Paul, 1941, The Early Grove gas field, Scott and Washington Counties, Va.: Virginia Geol. Survey Bull. 56, 50 p.

———1975, Coal resources of the United States, January 1, 1974: U.S. Geol. Survey Bull. 1412, 131 p.

Bartlett, C. S., Jr., and Webb, H. W., 1971, Geology of the Bristol and Wallace quadrangles, Virginia: Virginia Div. Mineral Resources Rept. Inv. 25, 93 p.

Boyd, C. R., 1887, The economic geology of the Bristol and Big Stone Gap section of Tennessee and Virginia, pursuing the general course of the South Atlantic and Ohio Railroad: Am. Inst. Mining Engineers Trans., v. 15, p. 114–121.

Brown, Andrew, Berryhill, H. L., Jr., Taylor, D. A., and Trumbull, J. V. A., 1952, Coal resources of Virginia: U.S. Geol. Survey Circ. 171, 57 p.

Butts, Charles, 1914, The coal resources and general geology of the Pound quadrangle of Virginia and Kentucky: U.S. Geol. Survey Bull. 541–F, p. 165–221.

———1940, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, 568 p.

———1941, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 2, 271 p.

Campbell, M. R., 1893, Geology of the Big Stone Gap coal field of Virginia and Kentucky: U.S. Geol. Survey Bull. 111, 106 p.

———1894a, Description of the Estillville quadrangle [Kentucky-Virginia-Tennessee]: U.S. Geol. Survey Geol. Atlas, Folio 12, 7 p.

———1894b, Paleozoic overlaps in Montgomery and Pulaski counties, Virginia: Geol. Soc. America Bull., v. 5, p. 171–190.

———1896, Description of the Pocahontas quadrangle [Virginia-West Virginia]: U.S. Geol. Survey Geol. Atlas, Folio 26, 7 p.

———1897, Description of the Tazewell quadrangle [Virginia-West Virginia]: U.S. Geol. Survey Geol. Atlas, Folio 44, 7 p.

Campbell, M. R., and Mendenhall, W. C., 1896, Geologic section along the New and Kanawha Rivers in West Virginia: U.S. Geol. Survey Ann. Rept. 17, pt. 2, p. 473–511.

Campbell, M. R., and others, 1925, The Valley coal fields of Virginia: Virginia Geol. Survey Bull. 25, 300 p.

Conant, L. C., and Swanson, V. E., 1961, Chattanooga shale and related rocks of central Tennessee and nearby areas: U.S. Geol. Survey Prof. Paper 357, 91 p.

Cooper, B. N., 1944, Geology and mineral resources of the Burkes Garden quadrangle, Virginia: Virginia Geol. Survey Bull. 60, 229 p.

———1961, Grand Appalachian field excursion Field Trip 1 *of* Geol. Soc. America, Ann Mtg., Cincinnati, Ohio, Nov. 1961: Virginia Polytechnic Inst. Eng. Ext. Ser., Geol. Guidebook 1, 187 p.

Eby, J. B., 1923, The geology and mineral resources of Wise County and the coal-bearing portion of Scott County, Virginia: Virginia Geol. Survey Bull. 24, 617 p.

Englund, K. J., 1964a, Stratigraphy of the Lee Formation in the Cumberland Mountains of southeastern Kentucky: U.S. Geol. Survey Prof. Paper 501–B, p. B30–B38.

———1964b, Geology of the Middlesboro South quadrangle, Tennessee-Kentucky-Virginia: U.S. Geol. Survey, Geol. Quad. Map GQ–301.

———1968a, Geologic map of the Bramwell quadrangle, West Virginia-Virginia: U.S. Geol. Survey Geol. Quad. Map GQ–745.

———1968b, Geology and coal resources of the Elk Valley area, Tennessee and Kentucky: U.S. Geol. Survey Prof. Paper 572, 59 p.

———1969, Relation of the Pocahontas Formation to the Mississippian-Pennsylvanian systemic boundary in southwestern Virginia and southern West Virginia [abs.]: Geol. Soc. America Abs. with Programs, [v.1], pt. 4, p. 21.

———1971, Displacement of the Pocahontas Formation by the Russell Fork fault, southwest Virginia: U.S. Geol. Survey Prof. Paper 750–B, p. B13–B16.

———1972, Central Appalachian tectonics as indicated by structural features in Carboniferous rocks [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 56, no. 10, p. 2108.

———1974, Sandstone distribution patterns in the Pocahontas Formation of southwest Virginia and southern West Virginia: Geol. Soc. America Spec. Paper 148, p. 31–45.

Englund, K. J., Arndt, H. H., Gillespie, W. H., Henry, T. W., and Pfefferkorn, H. W., 1977, A field guide to proposed Pennsylvanian System stratotype, West Virginia: American Assoc. Petroleum Geologists/Society Econ. Paleontologists and Mineralogists, Ann. Convention, Washington, D.C., June 1977, 80 p.

Englund, K. J., and DeLaney, A. O., 1966, Intertonguing relations of the Lee Formation in southwestern Virginia: U.S. Geol. Survey Prof. Paper 550–D, D47–D52.

Englund, K. J., and Smith, H. L., 1960 Intertonguing and lateral gradation between the Pennington and Lee formations in the Tri-State area of Kentucky, Tennessee, and Virginia [abs.]: Geol. Soc. America Bull., v. 71, no. 12, p. 2015.

Englund, K. J., Smith, H. L., Harris, L. D., and Stephens, J. G., 1961, Geology of the Ewing quadrangle, Kentucky and Virginia: U.S. Geol. Survey Geol. Quad. Map GQ–172.

Fontaine, W. M., 1874, The "Great Conglomerate" on New River, West Virginia: Am. Jour. Sci., 3d, v. 7, p. 459–465, 573–579.

Giles, A. W., 1921, The geology and coal resources of Dickenson County, Virginia: Virginia Geol. Survey Bull. 21, 224 p.

———1925, The geology and coal resources of the coal-bearing portion of Lee County, Virginia: Virginia Geol. Survey Bull. 26, p. 1–177.

Gillespie, W. H., and Pfefferkorn, H. W., 1977, Plant fossils and biostratigraphy at the Mississippian-Pennsylvanian boundary in the Pennsylvanian System stratotype area, West Virginia-Virginia [abs.]: Bot. Soc. America Misc. Ser. 154, p. 41.

Harnsberger, T. K., 1919, The geology and coal resources of the coal-bearing portion of Tazewell County, Virginia: Virginia Geol. Survey Bull. 19, 195 p.

Harris, L. D., and Miller, R. L., 1958, Geology of the Duffield quadrangle, Virginia: U.S. Geol. Survey Geol. Quad. Map GQ–111.

Henry, T. W., and Gordon, Mackenzie, Jr., 1977, Late Missippian and Pennsylvanian faunas in area of proposed Pennsylvanian System stratotype *in* Englund and others. A field guide to proposed Pennsylvanian System stratotype section, West Virginia: American Assoc. Petroleum Geologists/Society of Econ. Paleontogists and Mineralogists, Ann. Convention, Washington, D.C., June, 1977, p. 26–31.

Hinds, Henry, 1916, The coal resources of the Clintwood and Bucu quadrangles, Virginia: Virginia Geol. Survey Bull. 12, 206 p.

———1918, The geology and coal resources of Buchanan County, Virginia: Virginia Geol. Survey Bull. 18, 250 p.

Huddle, J. W., Jacobson, E. T., and Williamson, A. D., 1956, Oil and gas wells drilled in southwestern Virginia before 1950: U.S. Geol. Survey Bull. 1027–L, p. 501–573.

Jillson, W. R., 1919, The Kendrick shale; a new calcareous fossil horizon in the coal measures of eastern Kentucky: Kentucky Dept. Geology and Forestry, ser. 5, v. 1, no. 2, p. 96–104.

Lesley, J. P., 1873, The geological structure of Tazewell, Russell, and Wise counties, in Virginia: Am. Philos. Soc. Proc., v. 12, p. 489–513.

LeVan, D. C., 1962, Wells drilled for oil and gas in Virginia prior to 1962: Virginia Div. Mineral Resources, Mineral Resources Rept. 4, 47 p.

Lytle, W. S., Edwards, Jonathan, Jr., Debrosse, T. A., Bender, E. P., Hermann, J. B., Kelly, W. W., Jr., Patchen, D. G., and Brock, S. M., Jr., 1977, Oil and gas developments in Maryland, Ohio, Pennsylvania, Virginia, and West Virginia: Am. Assoc. Petroleum Geologists Bull., v. 61, no. 8, p. 1269–1304.

Macfarlane, James, 1879, The geologists traveling hand-book. An American geological railway guide. . . : New York, D. Appleton and Co., 216 p.

McCreath, A. S., and d'Invilliers, E. V., 1888, Resources of the upper Cumberland Valley of southeastern Kentucky and southwestern Virginia: Louisville, Ky., 152 p.

Medlin, J. H., and Coleman, S. L., 1976, Geochemistry of lower Pennsylvanian coal beds, *in* Englund, K. J., Cecil, C. B., Stricker, G. D., and Warlow, R. C., Guidebook to Carboniferous stratigraphy of southwestern Virginia and southern West Virginia: Geol. Soc. America, Northeast-Southeast Sec. Mtg., Arlington, Va., March 1976, Field Trip Guidebook 3, p. 14–17.

Miller, M. S., 1974, Stratigraphy and coal beds of upper Mississippian and lower Pennsylvanian rocks in southwestern Virginia: Virginia Div. Mineral Resources, Bull. 84, 211 p.

Miller, R. L., 1964, The Little Stone Gap Member of the Hinton Formation (Mississippian) in southwest Virginia: U.S. Geol. Survey Prof. Paper 501–B, p. B39–B42.

———1965, Geological map of the Big Stone Gap quadrangle, Virginia: U.S. Geol. Survey Geol. Quad. Map GQ–424.

———1969, Pennsylvanian formations of southwest Virginia: U.S. Geol. Survey Bull. 1280, 62 p.

Miller, R. L., and Meissner, C. R., Jr., 1978, Geologic map of the Big A Mountain quadrangle, Russell and Buchanan Counties, Virginia: U.S. Geol. Survey Geol. Quad. Map GQ–1350.

Miller, R. L., and Roen, J. B., 1971, Geologic map of the Keokee quadrangle, Virginia: U.S. Geol. Survey Geol. Quad. Map GQ–851.

Morse, W. C., 1931, Pennsylvanian invertebrate fauna: Kentucky Geol. Survey, ser. 6, v. 36, p. 293–348.

Nelson, B. W., 1959, New bentonite zone from the Pennsylvanian of southwestern Virginia [abs.]: Geol. Soc. America Bull., v. 70, no. 12, pt. 2, p. 1651.

Pfefferkorn, H. W., and Gillespie, W. H., 1977, Plant fossils in the proposed Pennsylvanian System stratotype *in* Englund, K. J., and others, A field guide to proposed Pennsylvanian System stratotype section, West Virginia: Am. Assoc. Petroleum Geologists/Soc. Econ. Paleontologists and Mineralogists Ann. Mtg., Washington, D.C., June 1977, [Guidebook], p. 21–26.

Read, C. B., and Mamay, S. H., 1964, Upper Paleozoic floral zones and floral provinces of the United States: U.S. Geol. Survey Prof. Paper 454–K, p. K1–K35.

Reger, D. B., 1926, Mercer, Monroe, and Summers counties: West Virginia Geol. Survey [County Rept.], 963 p.

Roen, J. B., Miller, R. L., and Huddle, J. W., 1964, The Chattanooga Shale (Devonian and Mississippian) in the vicity of Big Stone Gap, Virginia: U.S. Geol. Survey Prof. Paper 501–B, p. B43–B48.

Seiders, V. M., 1965, Volcanic origin of flint clay in the Fire Clay coal bed, Breathitt Formation, eastern Kentucky, *in* Geological Survey research 1965: U.S. Geol. Survey Prof. Paper 525–D, p. D52–D54.

Stevenson, J. J., 1881, A geological reconnaissance of parts of Lee, Wise, Scott, and Washington counties, Virginia: Am. Philos. Soc. Proc., v. 19, p. 219–262.

Stose, G. W., 1913, Geology of the salt and gypsum deposits of southwestern Virginia: U.S. Geol. Survey Bull. 530–E, p. 232–255.

———1923, Pre-Pennsylvanian rocks, *in* Geology and mineral resources of Wise County and the coal-bearing portion of Scott County, Virginia: Virginia Geol. Survey Bull. 24, p. 22–62.

Thomas, W. A., 1966, Late Mississippian folding of a syncline in the western Appalachians, West Virginia and Virginia: Geol. Soc. America Bull., v. 77, no. 5, p. 473–494.

U.S. Bureau of Mines, 1944, Analyses of Virginia coals: U.S. Bur. Mines Tech. Paper 656, 159 p.

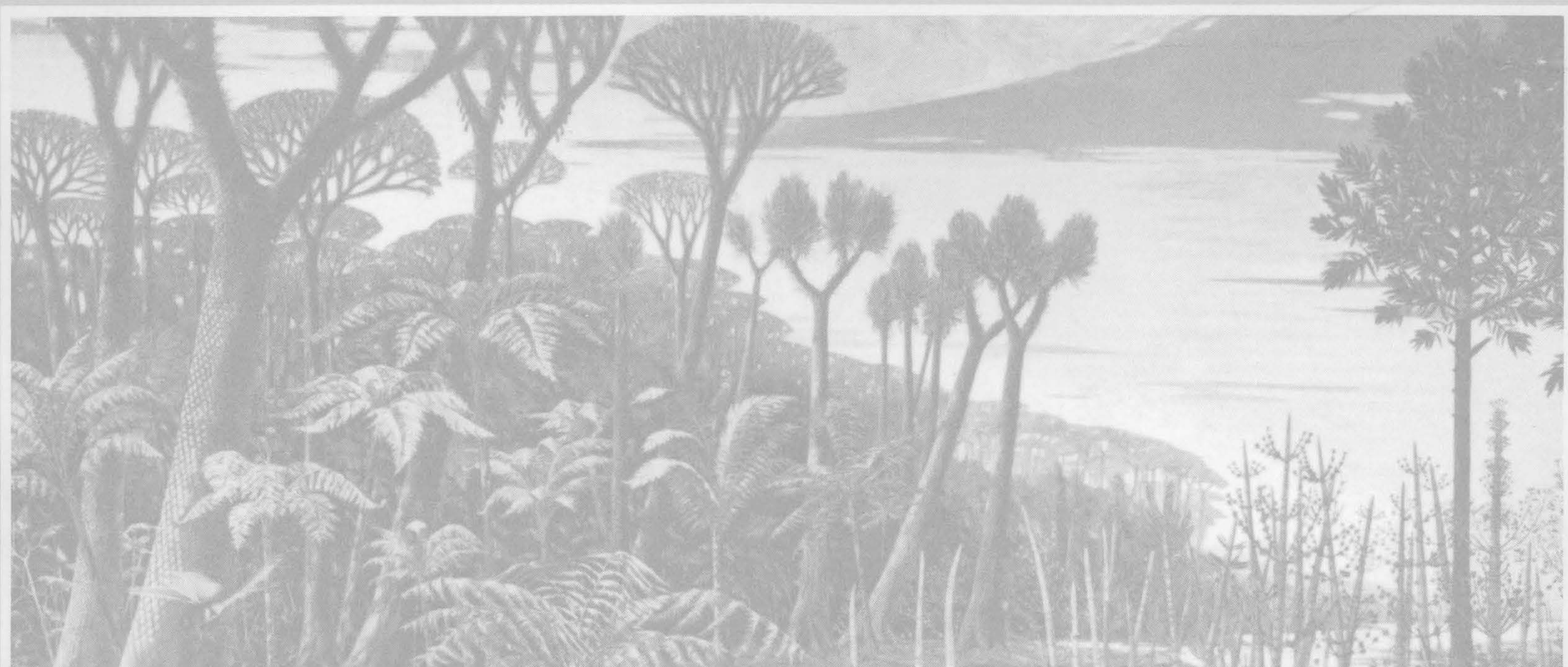
Virginia Dept. of Labor and Industry, 1977, Annual Report for 1976: Richmond, 99 p.

Wanless, H. R., 1946, Pennsylvanian geology of a part of the Southern Appalachian coal field: Geol. Soc. America Mem. 13, 162 p.

Wentworth, C. K., 1922, The geology and coal resources of Russell Couny, Virginia: Virginia Geol. Survey Bull. 22, 179 p.

Wilpolt, R. H., and Marden, D. W., 1949, Upper Mississippian rocks of southwesern Virginia, southern West Virginia, and eastern Kentucky: U.S. Geol. Survey Oil and Gas Inv. (Prelim.) Chart 38, 3 sheets, text.

The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States



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ON THE COVER

Swamp-forest landscape at time of coal formation: lepidodendrons (left), sigillarias (in the center), calamites, and cordaites (right), in addition to tree ferns and other ferns. Near the base of the largest *Lepidodendron* (left) is a large dragonfly (70-cm wingspread). (Reproduced from frontispiece in Kukuk, Paul (1938), "Geologie des Niederrheinisch-Westfälischen Steinkohlengebietes" by permission of Springer-Verlag, New York, Inc.)

The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—

A. Massachusetts, Rhode Island, and Maine, by James W. Skehan, S.J., Daniel P. Murray, J. Christopher Hepburn, Marland P. Billings, Paul C. Lyons, and Robert G. Doyle

B. Pennsylvania and New York, by William E. Edmunds, Thomas M. Berg, William D. Sevon, Robert C. Piotrowski, Louis Heyman, and Lawrence V. Rickard

C. Virginia, by Kenneth J. Englund

D. West Virginia and Maryland, by Thomas Arkle, Jr., Dennis R. Beissell, Richard E. Larese, Edward B. Nuhfer, Douglas G. Patchen, Richard A. Smosna, William H. Gillespie, Richard Lund, Warren Norton, and Herman W. Pfefferkorn

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H. Georgia, by William A. Thomas and Howard R. Cramer

I. Alabama and Mississippi
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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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Library of Congress catalog-card No. 79-52491

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock Number 024-001-03174-4

FOREWORD

The year 1979 is not only the Centennial of the U.S. Geological Survey—it is also the year for the quadrennial meeting of the International Congress on Carboniferous Stratigraphy and Geology, which meets in the United States for its ninth session. This session is the first time that the major international congress, first organized in 1927, has met outside Europe. For this reason it is particularly appropriate that the Carboniferous Congress closely consider the Mississippian and Pennsylvanian Systems; American usage of these terms does not conform with the more traditional European usage of the term "Carboniferous."

In the spring of 1976, shortly after accepting the invitation to meet in the United States, the Permanent Committee for the Congress requested that a summary of American Carboniferous geology be prepared. The Geological Survey had already prepared Professional Paper 853, "Paleotectonic Investigations of the Pennsylvanian System in the United States," and was preparing Professional Paper 1010, "Paleotectonic Investigations of the Mississippian System in the United States." These major works emphasize geologic structures and draw heavily on subsurface data. The Permanent Committee also hoped for a report that would emphasize surface outcrops and provide more information on historical development, economic products, and other matters not considered in detail in Professional Papers 853 and 1010.

Because the U.S. Geological Survey did not possess all the information necessary to prepare such a work, the Chief Geologist turned to the Association of American State Geologists. An enthusiastic agreement was reached that those States in which Mississippian or Pennsylvanian rocks are exposed would provide the requested summaries; each State Geologist would be responsible for the preparation of the chapter on his State. In some States, the State Geologist himself became the sole author or wrote in conjunction with his colleagues; in others, the work was done by those in academic or commercial fields. A few State Geologists invited individuals within the U.S. Geological Survey to prepare the summaries for their States.

Although the authors followed guidelines closely, a diversity in outlook and approach may be found among these papers, for each has its own unique geographic view. In general, the papers conform to U.S. Geological Survey format. Most geologists have given measurements in metric units, following current practice; several authors, however, have used both metric and inch-pound measurements in indicating thickness of strata, isopach intervals, and similar data.

This series of contributions differs from typical U.S. Geological Survey stratigraphic studies in that these manuscripts have not been examined by the Geologic Names Committee of the Survey. This committee is charged with insuring consistent usage of formational and other stratigraphic names in U.S. Geological Survey publications. Because the names in these papers on the Carboniferous are those used by the State agencies, it would have been inappropriate for the Geologic Names Committee to take any action.

The Geological Survey has had a long tradition of warm cooperation with the State geological agencies. Cooperative projects are well known and mutually appreciated. The Carboniferous Congress has provided yet another opportunity for State and Federal scientific cooperation. This series of reports has incorporated much new geologic information and for many years will aid man's wise utilization of the resources of the Earth.

H. William Menard
Director, U.S. Geological Survey

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