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

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

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

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ABSTRACT

Carboniferous strata are distributed widely across Tennessee. In general, Mississppian deposits in eastern Tennessee are thick and are dominated by terrigenous clastic deposits in the Appalachian geosyncline; Mississippian deposits to the west are thin and are composed of limestone that was deposited on a carbonate platform. The geosyncline was filled, and the carbonate platform was ultmately overlapped by Upper Mississippian and Pennsylvanian terrigenous clastic deposits.

Geosyncline sequences are present in several isolated areas on Valley and Ridge thrust blocks, whereas carbonate platform deposits extend from the western Valley and Ridge, beneath the Cumberland Plateau, to the western Highland Rim. Stratigraphic nomenclature reflects regional changes in stratigraphic sequences from the geosyncline to the carbonate platform. The Carboniferous strata were deposited in marine, littoral, and delta-plain environments.

Tennessee produces petroleum from Mississippian strata, primarily in the northern part of the Cumberland Plateau. Pennsylvanian strata contain abundant coal beds, and five of these, the Sewanee, Coal Creek, Jellico, Big Mary, and Pewee, contain most of the reserves.

INTRODUCTION

Carboniferous strata underlie a great area of central and eastern Tennessee, extending westward from limited exposures on fault blocks in the Valley and Ridge across the Cumberland Plateau to the broad plateau of the Highland Rim (fig. 1). The lower part of the Mississippian section is preserved on the Highland Rim, which forms a crude ellipse around Ordovician and Silurian strata of the Central Basin (Nashville structural dome) of Tennessee. The most completely preserved section of Carboniferous strata in the State is beneath the Cumberland Plateau, where the stratigraphy of the older beds is known both from their extensive exposure along the linear Sequatchie Valley and from the many oil tests drilled in the region.

The lower part of the Carboniferous sequence in Tennessee is composed largely of carbonate rocks that were deposited on a relatively shallow stable platform to the west, and of terrigenous clastic and carbonate rocks that were deposited in a subsiding geosyncline to the east (fig. 2). The upper part of the sequence consists almost entirely of coal-bearing terrigenous clastic deposits, representing either coastal barrier island-lagoon depositional environments or the depositional environments diagnostic of deltaic sedimentation (fig. 3). The carbonate sequence is separated from the coal-bearing beds by a transitional unit, the Pennington Formation, a heterogeneous unit composed of many lithologies. In general, the lower carbonate rocks and the transitional Pennington Formation are Mississippian, whereas overlying terrigenous clastic rocks are Pennsylvanian.

Structurally, the Cumberland Plateau lies in a broad elongated downwarp between the Nashville dome and the thrusts of the Valley and Ridge. The synclinorium plunges gently northeastward from a broad, low, west-trending cross structure, a branch of the Nashville dome, that extends along the southern boundary of Tennessee west of Chattanooga. The southeastern regional dip from the Nashville dome, combined with the gentle northeastern regional plunge induced by the Chattanooga arch, accounts for the distribution of the coal-bearing strata of the plateau; only lowermost Pennsylvanian beds remain in the southern plateau, whereas younger beds are preserved in the Wartburg basin and on the Pine Mountain block to the northeast.

Historically, the Tennessee coal field has been divided into northern (Glenn, 1925) and southern Nelson, 1925) coal fields. The boundary generally follows the routes of the old Tennessee Central Railway and

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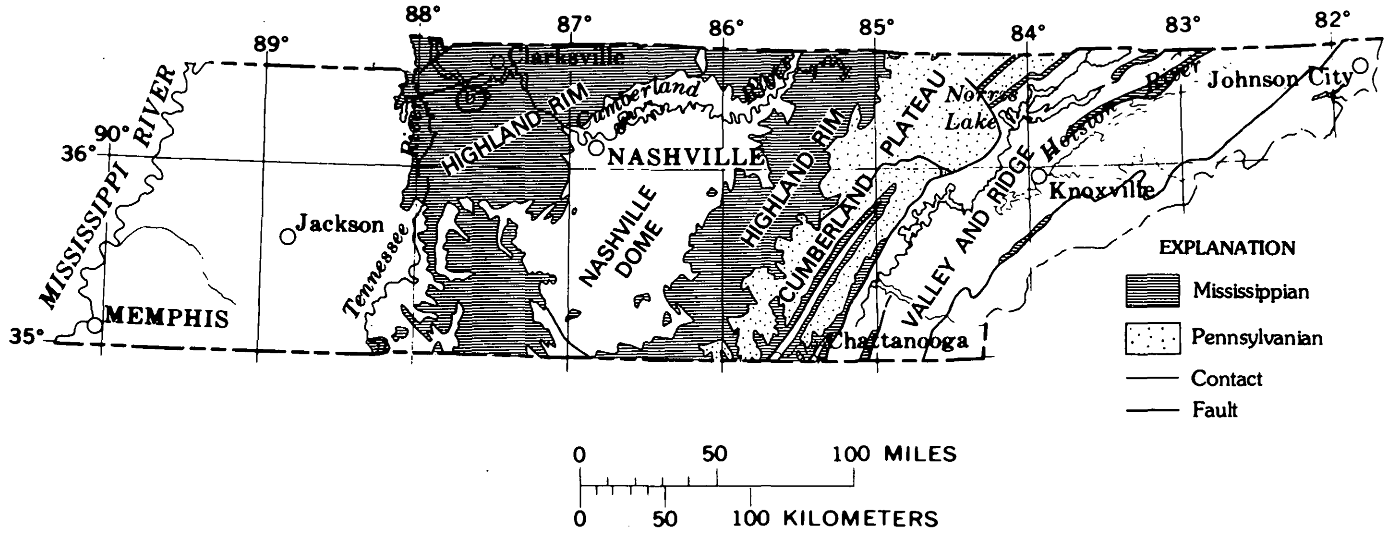
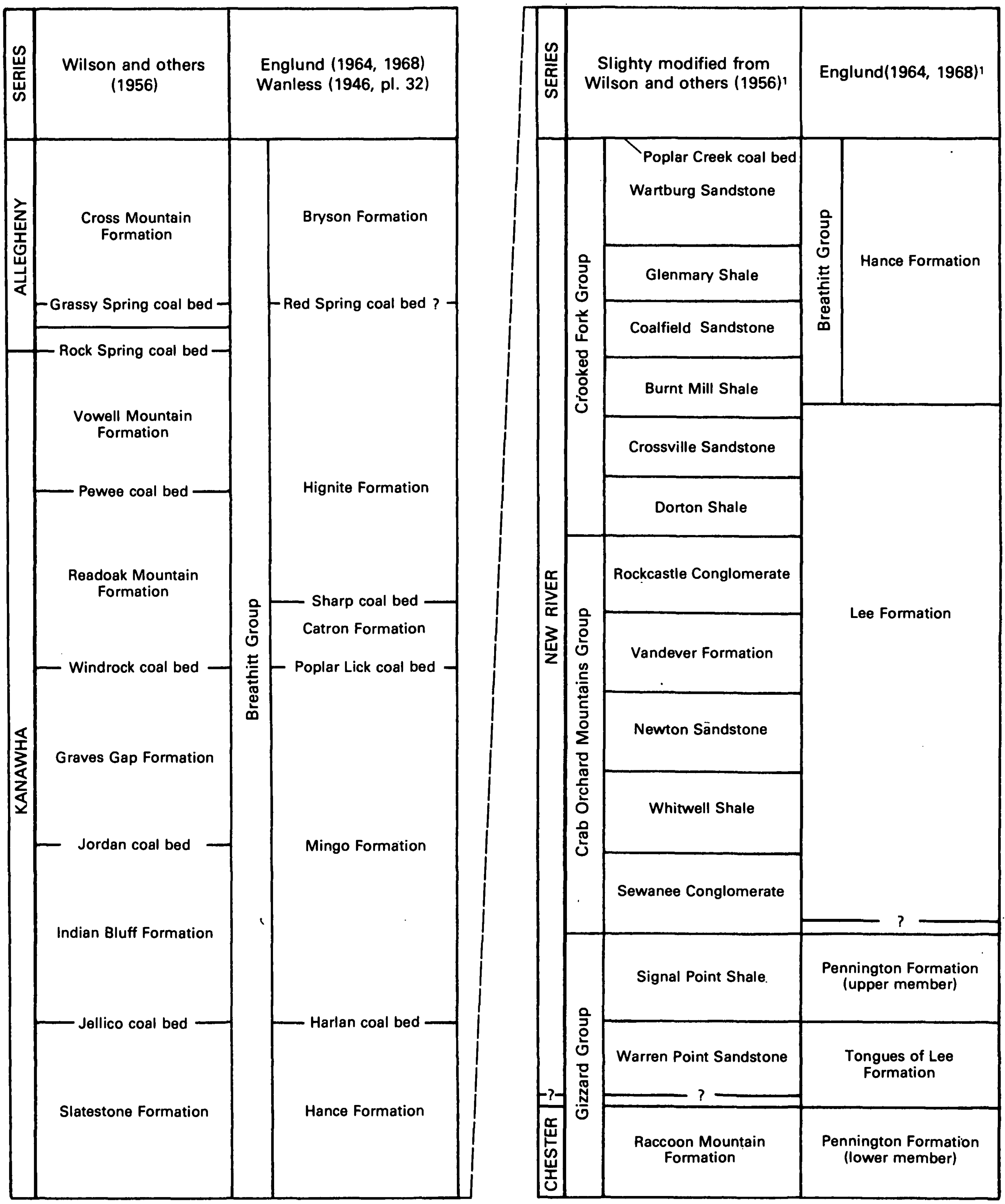


FIGURE 1.—Distribution of Carboniferous strata in Tennessee (from King and Beikman, 1974).

SERIES	WESTERN HIGHLAND RIM	CUMBERLAND PLATEAU AND EASTERN HIGHLAND RIM	PINE MOUNTAIN BLOCK (Englund, 1964, 1968)	NEWMAN RIDGE (Mixon and Harris, 1971)	BELT EAST OF CLINCH MOUNTAIN (Sanders, 1952, unpub. data; Hasson, 1973)	CHILHOWEE MOUNTAIN (Newman and Nelson, 1965)
CHESTERIAN		Gizzard Group (lower part) Pennington Formation Bangor Limestone Hartselle Sandstone	Pennington Foramtion Newman Limestone	Pennington Formation Newman Limestone	Pennington Formation Newman Limestone: Cove Creek Formation Fido Sandstone Fisher Creek Limestone Gilliam Creek Limestone	
MERAMECIAN	Ste. Genevieve Limestone St. Louis Limestone Warsaw Limestone	Monteagle Limestone St. Louis Limestone Warsaw Limestone	Newman Limestone	Newman Limestone	Clifton Creek Limestone Snowflake Formation Laurel Branch Limestone Pressmens Home Formation Maccrady Formation	Greasy Cove Formation
OSAGEAN	Fort Payne Formation	Fort Payne Formation	Fort Payne Chert / Grainger Formation	Grainger Formation	Grainger Formation	Grainger Formation
KINDERHOOKIAN	Maury Shale	Maury Shale	Maurý Shale	? Chattanooga Shale (upper part)	? Chattanooga Shale (upper part)	? Chattanooga Shale (upper part)

FIGURE 2.—Nomenclature of Mississippian strata in Tennessee.



¹Queried double lines show opinions concerning the Mississippian–Pennsylvanian boundary.

FIGURE 3.—Nomenclature of Pennsylvanian strata in eastern Tennessee and adjacent parts of Kentucky. Only coal beds that separate formations are shown.

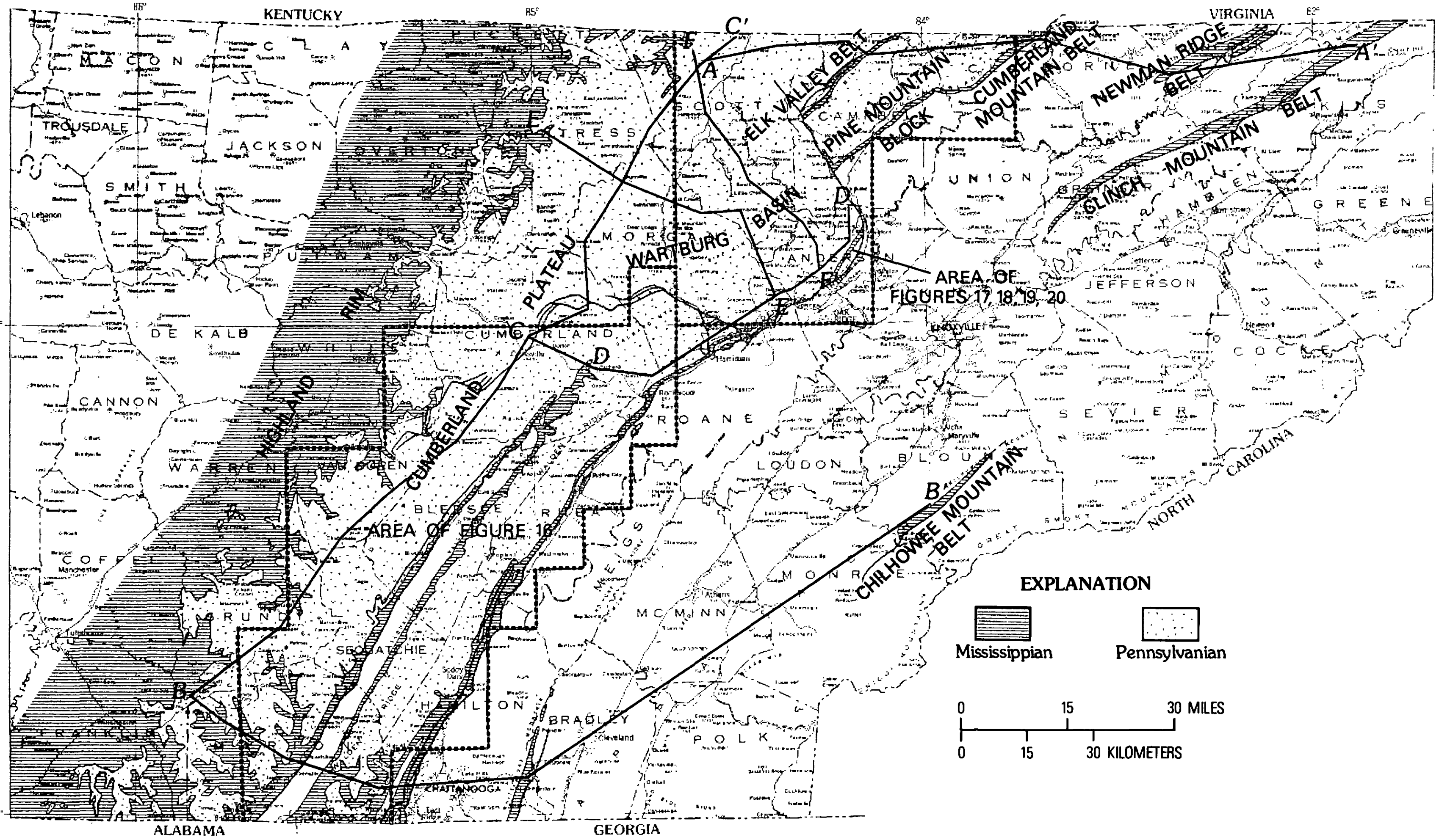


FIGURE 4.—Location of stratigraphic cross sections in eastern Tennessee.

the more recently constructed Interstate 40 between Harriman and Monterey. The southern Cumberland Plateau and the western part of the northern plateau consist of broad, moderately dissected uplands underlain by widespread thick orthoquartzites and interbedded shale units. In contrast, the higher mountains in the northeastern part of the Cumberland Plateau in Tennessee are underlain by units composed mostly of shale and siltstone and thinner sandstone beds; these sandstone beds are not nearly so widespread as the orthoquartzites and are generally subgraywackes. Carboniferous strata are exposed on the western half of the Pine Mountain thrust block; this part of the block is in the plateau.

Four major outcroppings of Carboniferous strata occur on the thrust blocks of the Valley and Ridge of Tennessee: on Whiteoak Mountain to the south, near Chilhowee Mountain along the toe of the Blue Ridge, and to the north near Clinch Mountain and on Newman Ridge. The outcrop along the Blue Ridge contains only the lower part of the Mississippian section; a little Pennsylvanian is preserved at the top of the section along Whiteoak Mountain; and the Pennington Formation caps the Mississippian sections in the Clinch Mountain strike belt and on Newman Ridge. Regional stratigraphic cross sections along lines shown in figure 4 are presented herein to illustrate Devonian to Pennsylvanian thickness and facies variations in eastern Tennessee.

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 Tennessee Department of Conservation, Division of Geology.

ACKNOWLEDGMENTS

The regional stratigraphic framework was compiled largely by Milici. Briggs summarized research on delta-plain depositional environments performed at the University of Tennessee under DOE (U.S. Department of Energy) Research Contract No. E-(40-1)-4946. Knox assisted in preparing the regional stratigraphic cross sections and contributed the sections on the Coal Creek and Jellico coal beds. Sitterly contributed the sections on the Pewee and Big Mary coal beds, and Statler described the petroleum resources of Carboniferous strata in Tennessee. A. R. Leamon assisted in preparing the coal maps. E. T. Luther reviewed the manuscript.

STRATIGRAPHY

The final major cycle of Paleozoic sedimentation in Tennessee began with the Middle to Late Devonian submergence of an erosional surface that cut across beds ranging in age from Middle Ordovician to Early Devonian. Then, mud, silt, and sand of the Chattanooga Shale were deposited on this surface.

The Chattanooga Shale lies upon about 25 formations in central and eastern Tennessee (fig. 5). Basal beds of the Chattanooga range generally from Middle to Late Devonian in age. With minor exceptions, the Devonian-Mississippian boundary—the base of the Carboniferous system—is either within or at the top of the Chattanooga Shale. On the basis of studies of conodonts, plant fossils, and bones, Conant and Swanson (1961, p. 21) described the Chattanooga as being entirely Devonian in central Tennessee. However, conodonts studied by Roen and others (1964) and fossils described by Glover (1959) show that the upper part of the Chattanooga is Mississippian in the Valley and Ridge near Big Stone Gap in southwestern Virginia and near Chilhowee Mountain in eastern Tennessee.

CHATTANOOGA SHALE

The Chattanooga Shale (Hayes, 1891), which is a potential source of uranium and hydrocarbons,

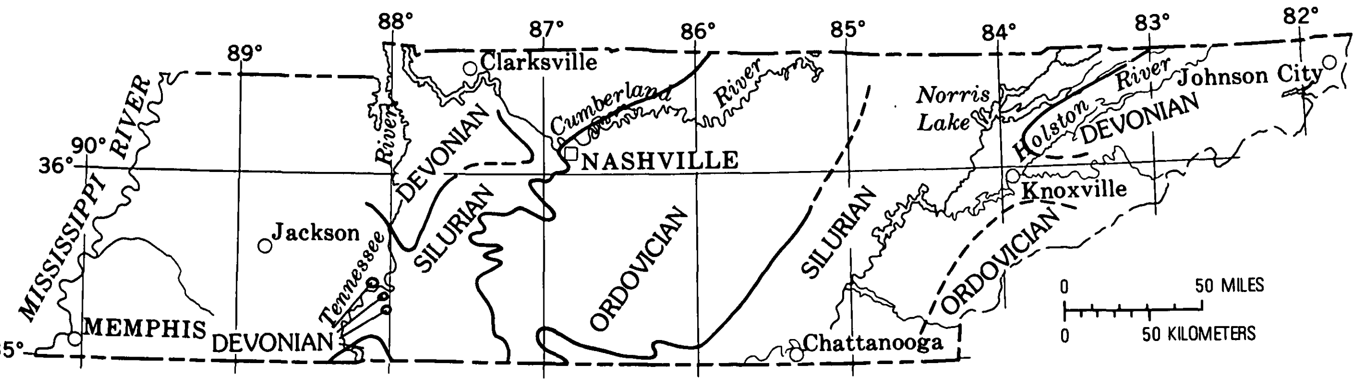


FIGURE 5.—Ages of pre-Chattanooga strata in eastern Tennessee.

varies greatly in thickness in Tennessee. In places in central Tennessee, the formation is absent altogether (Conant and Swanson, 1961, pl. 1; Wiethe and Sitterly, 1978). Elsewhere in central Tennessee it ranges from 3 to 10 m (10 to 33 ft) in thickness. The formation thickens greatly to the east and may be as much as 610 m (2,000 ft) thick in the Greendale syncline along Clinch Mountain (fig. 6).

Chilhowee Mountain belt.—The Chattanooga Shale is about 7.6 m (25 ft) thick along the northwest flank of Chilhowee Mountain (Neuman and Nelson, 1965, p. D40–D41). There the formation consists of dark gray carbonaceous shale and has several centimeters of fine-grained sandstone at its base. In the Chilhowee Mountain strike belt, the Chattanooga overlies the Bays Formation (Middle Ordovician) unconformably, in some places resting on quartzites and in other places on bentonitic volcanic ash within the Bays (Glover, 1959, p. 145).

Fossils collected by Neuman and Nelson (1965) and by Glover (1959) indicate that the Chattanooga along Chilhowee Mountain is of Late Devonion or Early Mississippian age.

Clinch Mountain belt.—The Paleozoic stratigraphy of the Greendale syncline along Clinch Mountain was studied in detail by Sanders (1952). The nomenclature of Devonian and Mississippian formations that was proposed by Sanders (1952) for that region has not been formally published but has been modified and adopted by the Tennessee Division of Geology for mapping purposes and is used in this report.

The Chattanooga Shale crops out along the southeastern flank of Clinch Mountain. The formation thickens markedly from about 122 m (400 ft) at the southern end of the outcrop belt in Grainger County to about 610 m (2,000 ft) in Hawkins County, and from this area thins northeastward into Virginia.

In the Greendale syncline strike belt, the Chattanooga rests on older Devonian beds that are commonly mapped with the Clinch Sandstone because they are so thin. Sanders (1952) recognized about 1.8 m (6 ft) of coarse-grained fossiliferous sandstone, which he correlated with the Ridgely Sandstone (Lower Devonian) of the central Appalachians. On Clinch Mountain, the Ridgely (or Oriskany) is in places overlain by about 0.3 m (1 ft) of yellowish-gray chert, which Sanders (1952) correlated with the Huntersville Chert of West Virginia.

Dennison and Boucot (1974) correlated the pre-Chattanooga Lower Devonian sequence at Little War Gap on Clinch Mountain with the Wildcat Valley Sandstone of Miller, Harris, and Roen (1964) and divided it into a lower Oriskany Member (2.9 m, 9.4 ft thick) and an upper Huntersville Member (2.4 m, 7.9 ft thick), which is composed of fine-grained glauconitic and phosphatic sandstone.

Sanders (1952) subdivided the Chattanooga Shale of the Greendale syncline into three units (classified as members by the Tennessee Division of Geology), the Little War Gap Shale Member at the base, the Klepper School Member in the middle, and the Salt Lick Gap Shale Member at the top. Hasson

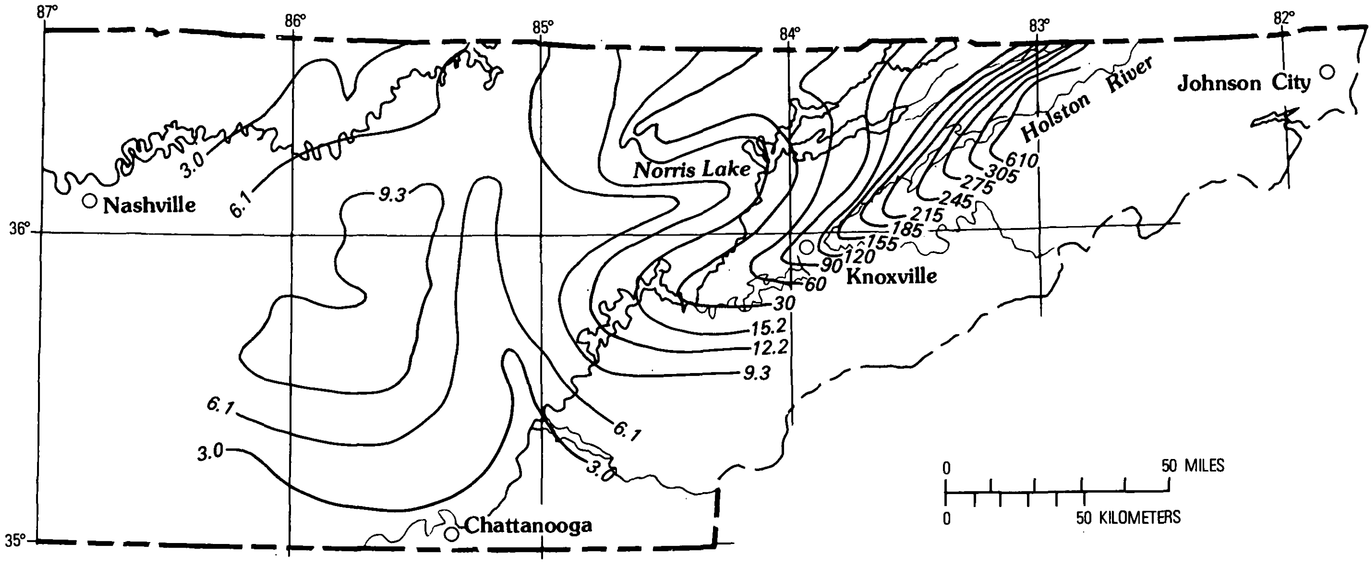


FIGURE 6.—Isopach map of the Chattanooga Shale in eastern Tennessee (in part from Conant and Swanson, 1961, pl. 15). Isopachs in meters.

(1972, 1973) and Dennison and Boucot (1974) placed the top of the Chattanooga Shale at a somewhat higher stratigraphic level than did Sanders (1952).

A detailed section of the Little War Gap Shale Member was measured along Tennessee Highway 70 near Little War Gap in Clinch Mountain by Dennison and Boucot (1974, p. 98–99). In this section, the member is 287 m (940 ft) thick and generally consists of fissile black shale and subsidiary amounts of gray shale.

The Klepper School Member consists generally of finely laminated dark-gray micaceous siltstone, dark-gray laminated silty shale, and interlaminated light-gray and dark carbonaceous siltstone and shale. Southwest of its type section on Tennessee Highway 70, the Klepper School contains beds of very fine grained light-gray sandstone that range in thickness from 15 to 61 cm (0.5–2 ft). Sanders (1952) estimated the unit to be about 244 m (800 ft) thick at its type section, thinning to 152 m (500 ft) or less to the southwest. Dennison and Boucot (1974) measured 327.4 m (1,074 ft) for the Klepper School Member at its type section.

Sanders (1952) mapped about 7.6 m (25 ft) of fissile black shale above the Klepper School Member as the Salt Lick Gap Shale Member, but exposures are too poor to designate and measure a type section. Correlation of the upper part of the Chattanooga Shale, including the Salt Lick Gap Shale Member, in the Greendale syncline in Tennessee with strata near Big Stone Gap in southwestern Virginia is in question. Hasson (1972) placed as much as 65.8 m (216 ft) of the basal beds of Sanders' (1952) Grainger Formation in the Chattanooga Shale and correlated this unit with the Big Stone Gap Member of the Chattanooga Shale (Roen and others, 1964). If Hasson (1972) is correct, then the Big Stone Gap, including the Salt Lick Gap Shale at its base, should be extended into Tennessee as the upper member of the Chattanooga Shale.

Newman Ridge and Pine Mountain block.—The Chattanooga Shale thins progressively to the northwest, and on Newman Ridge along the southeast side of Powell Mountain, it consists of about 122 m (400 ft) of grayish-black carbonaceous shale (fig. 7). The shale is commonly pyritic and contains small amounts of interbedded greenish-gray shale (Harris and Mixon, 1970; Mixon and Harris, 1971; Harris and others, 1962). On Newman Ridge, the Chattanooga overlies the Upper Silurian Hancock Dolomite (Sneedville Limestone of Hardeman and others, 1966).

On the Pine Mountain block near Cumberland Gap, the Chattanooga is 61–91 m (200–300 ft) thick and consists mostly of grayish-black carbonaceous and pyritic shale that lies unconformably on the Hancock Dolomite (Englund, 1964; Harris, 1965). Englund (1964) considered the 15.2 m (50 ft) of greenish-gray shale that in places is at the base of the Chattanooga to be part of that formation.

Central Tennessee.—Because of its potential as a low-grade uranium resource, the Chattanooga in central Tennessee and in nearby areas was extensively studied by the U.S. Geological Survey (Hass, 1956; Glover, 1959; Conant and Swanson, 1961). The Chattanooga lies on formations ranging in age from Middle Ordovician to Devonian in central Tennessee; the older beds are truncated over the crest of the Nashville dome (Wilson, 1949, pl. 2; Conant and Swanson, 1961, pl. 3). In central Tennessee, the Chattanooga is divided into three members, a basal Hardin Sandstone Member, a middle Dowelltown Member, and an upper Gassaway Member.

The Hardin Sandstone Member is generally present in several counties in central Tennessee, where it is as much as 4.9 m (16 ft) thick (Conant and Swanson, 1961, fig. 6). The member consists of massive fine-grained gray sandstone containing minor amounts of phosphate and bones. The Hardin Sandstone Member was regarded by Conant and Swanson (1961, p. 28) as a local overthickening of a widespread but very thin basal Chattanooga sandsone or conglomerate. They preferred to restrict the use of the name Hardin to the area where the unit is thick, is of Devonian age, and is fine grained and massively bedded. The Hardin Sandstone Member is Upper Devonian, but elsewhere the age of the thin basal sandstone or conglomerate varies as the age of the overlying shale varies and is, in different places, Late Devonian or possibly Mississippian (Conant and Swanson, 1961, p. 25).

The Dowelltown Member overlies either the Hardin Sandstone Member or the much older beds beneath the Chattanooga and consists of a lower black shale unit and an upper unit composed of interbedded light-gray claystone and dark-gray shale beds. The member is present around the northern and central parts of the Highland Rim, where it is commonly 4.6–6.1 m (15–20 ft) thick, but it is not very thick near the southern border of Tennessee.

The contact between the Dowelltown Member and overlying Gassaway Member was interpreted by Conant and Swanson (1961, p. 29) to be a diastem or slight unconformity within the Chattanooga. The

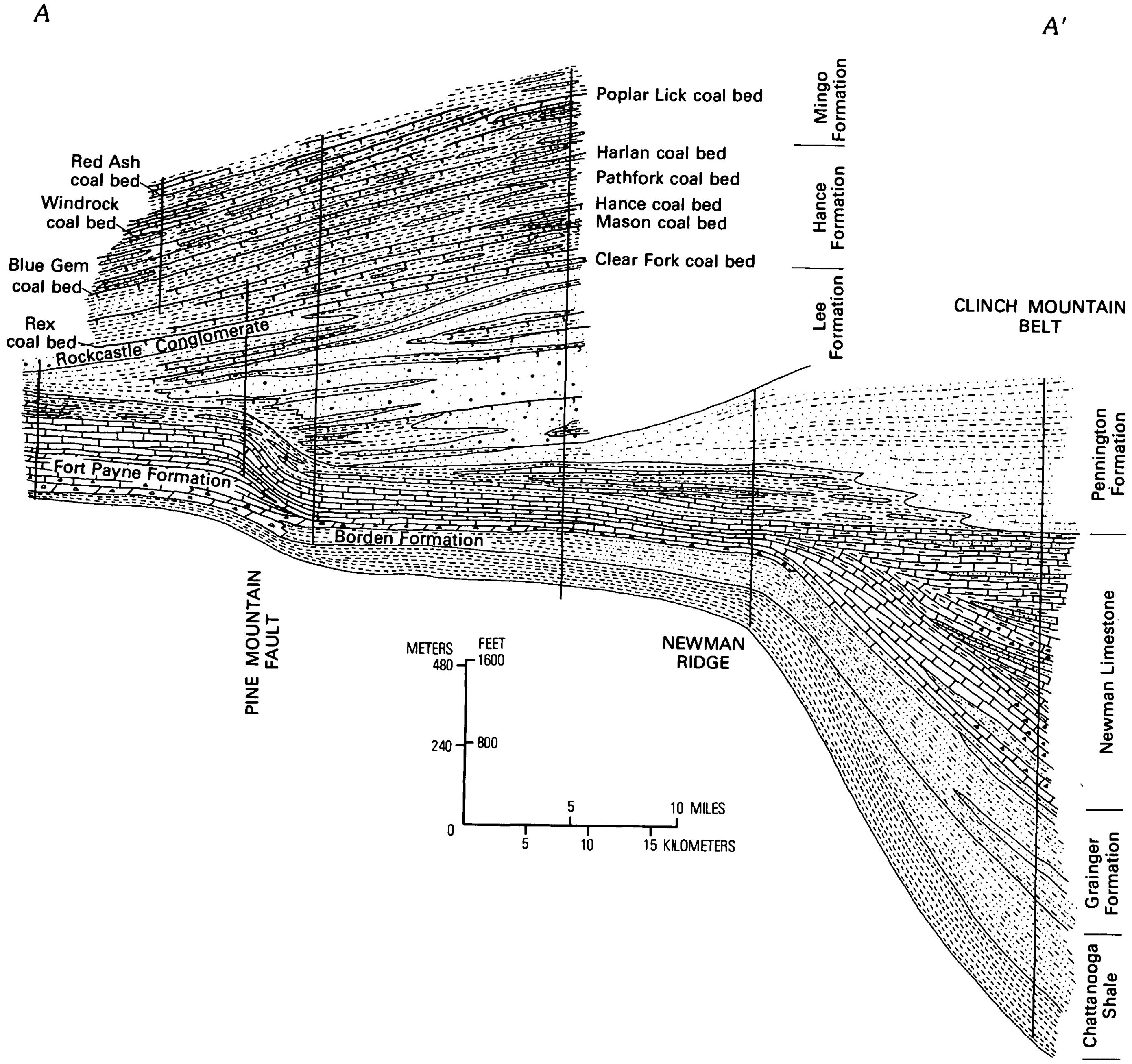


FIGURE 7.—Stragraphic cross section along line A–A'.

Gassaway Member is the most widespread of the three members of the Chattanooga Shale. Typically the unit consists of massive black bituminous shale. In Tennessee, the member is generally 4.6–6.1 m (15–20 ft) thick but thins to the south, and along the southern Tennessee border, it is less than 3 m (10 ft) thick.

GRAINGER FORMATION

The Grainger Formation (Keith, 1895) overlies the Chattanooga Shale in the Chilhowee Mountain, Clinch Mountain, and Newman Ridge strike belts and in exposures on the Pine Mountain block. The formation grades to the west and south into the Fort Payne Formation and to the north and northwest into the Borden Formation (figs. 7, 8). The Grainger reaches a maximum thickness of 320 m (1,050 ft); the thicker sections are near Chilhowee Mountain, and thinner ones are on the Pine Mountain block (fig. 9).

Chilhowee Mountain belt.—Neuman and Nelson (1965, p. D43) measured 320 m (1,050 ft) of

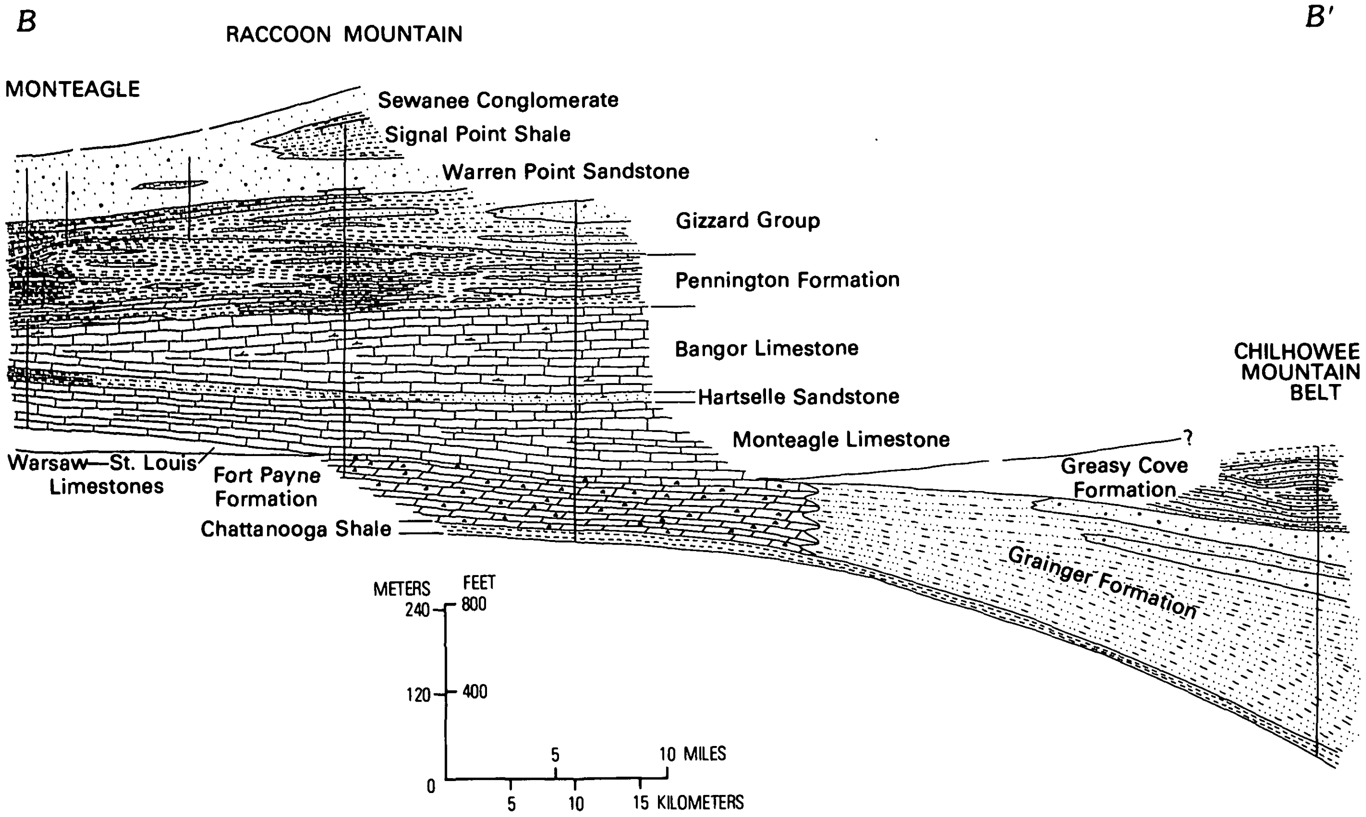


FIGURE 8.—Stratigraphic cross section along line B–B

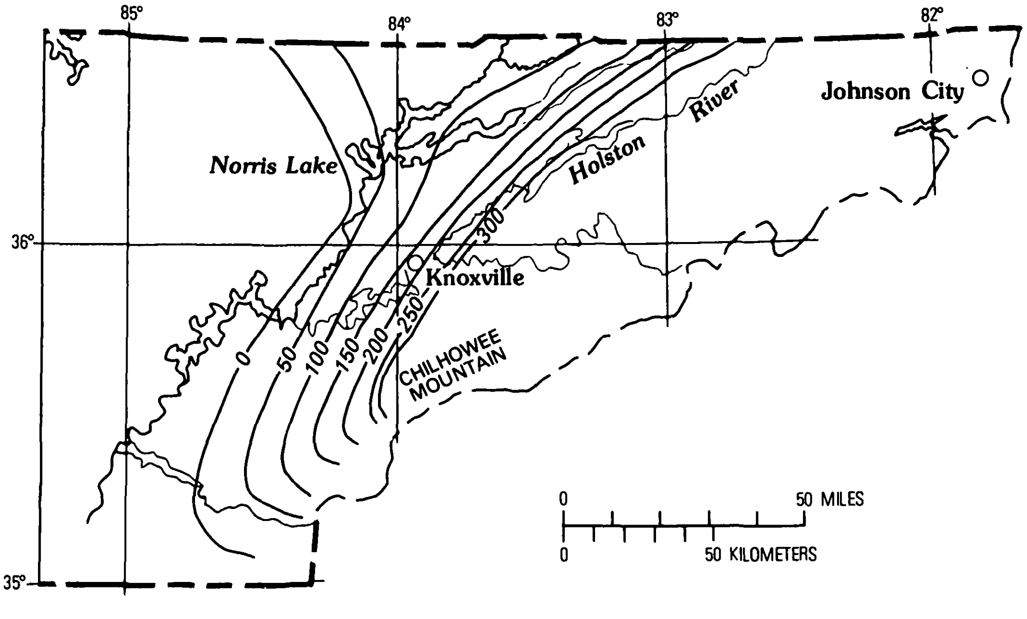


FIGURE 9.—Generalized isopach map of the Grainger Formation in eastern Tennessee. Isopach interval 50 meters.

Grainger near Chilhowee Mountain. The lower and middle parts of the formation consist of gray shale and sandy shale that is overlain by massive gray sandstone and siltstone. The upper part of the formation consists of coarser grained and conglomeratic sandstones containing quartz pebbles as much as 2.5 cm (1 in.) long. The formation contains a few beds of fossiliferous sandy limestone; the fossils suggest that the Grainger in this area is of Warsaw age.

Clinch Mountain belt.—The type area of the Grainger is in the Greendale syncline, along a low ridge called Pine Mountain which is east of Clinch Mountain. The Grainger was studied there by Sanders (1952) and by Hasson (1972, 1973). Sanders (1952) divided the Grainger into four lithologic members, a basal member, a lower sandstone member, a middle siltstone-shale member, and an upper sandstone member. The basal member, which is 61–91 m (200–300 ft) thick, consists of dark-gray argillaceous shale and olive-gray siltstone, thin beds of fine-grained sandstone, and a little limestone. The lower sandstone member ranges from 15.2 to 61 m (50 to 200 ft) in thickness along the Greendale syncline in Tennessee. The unit consists of very fine grained light-gray sandstone and some pebble conglomerate. The middle member of the Grainger consists of 122 to 152 m (400 to 500 ft) of gray shale and olive-gray siltstone; two glauconite zones are in the upper part. Except for the glauconite beds, the middle and basal members are lithologically similar. The upper sandstone member of the Grainger consists of as much as 45.7 m (150 ft) of very fine grained to coarse-grained feldspathic, medium-gray sandstone and some interbedded olive-gray silty shale. Cross bedding is common, and the upper part of the member contains pebble conglomerate of vein quartz, quartzite, feldspar, and slate.

Hasson (1972, 1973) restricted the Grainger Formation in the Greendale syncline to the upper three members of Sanders (1952) and correlated the basal member with most of the Big Stone Gap Member of the Chattanooga Shale in southwestern Virginia. Hasson (1973) provided two measured sections of the Grainger (restricted), one at the type section in Grainger County, and another in Hawkins County, which he designated as the standard reference section for the formation. Depending upon the assignment of the basal member of the Sanders (1952), the Grainger is either 168 or 234 m (552 or 768 ft) thick at the standard reference section. Hasson (1972, 1973) concluded that the Grainger was of Kinderhook-Osage age, on the basis of brachiopods, bryozoans, and crinoid columnals that he studied.

Newman Ridge.—In the Newman Ridge strike belt—the next belt northwest of the Greendale syncline—the Grainger Formation is considerably thinner than in the Greendale syncline. Near the south end of Newman Ridge, the Grainger, as mapped by Harris and Mixon (1970) and Harris and others (1962), consists of 107–122 m (350–400 ft) of greenish-gray shale and siltstone, some grayish-red shale is near the middle of the formation, and about 6.1 m (20 ft) of thin-bedded greenish-gray chert is at the top.

Pine Mountain block.—The Grainger thins and changes markedly to the northwest between its exposures on both sides of the Middlesboro syncline on the Pine Mountain block. Near Middlesboro, Ky., the formation consists of 91–99 m (300–325 ft) of greenish-gray and grayish-red shale containing abundant siderite nodules; about 6.1 m (20 ft) of Fort Payne Chert is at the top (Englund, 1964). On the northwest side of the Pine Mountain block, the Grainger consists of a maximum of 69 m (225 ft) of greenish-gray and grayish-red shale containing siderite nodules. The formation thins and intertongues with the Fort Payne to the southwest between Jellico and Pioneer, to where only about one-third meter (a foot) of shale (Maury Formation) is at the base of the Fort Payne (Englund, 1968, fig. 6). Fossils described by Englund (1968, p. 9) show that the Grainger is of early Osage age.

Paul Potter (oral commun., 1976) pointed out that the unit mapped as Grainger by Englund (1968) at Jellico is lithologically similar to the Borden Formation of eastern Kentucky. Like Potter, the present writers believe that the term Grainger should be used in eastern Tennessee where the formaton is thick, sandy, and silty and predominantly gray, whereas the term Borden is more appropriate for correlative thinner greenish-gray and grayish-red shale of the Jellico-Pioneer area. The change in facies from Grainger to Borden lithologies seems to be related to the tectonic setting in which the strata were deposited; the Borden was deposited on the stable shelf, and the Grainger on the shelf edge and in the basin.

FORT PAYNE FORMATION

The Grainger (or Borden) grades laterally into the Fort Payne Formation; where the two coexist, the Fort Payne overlies the Grainger (Smith, 1890). The Fort Payne Formation is widespread in Tennessee; it extends from the western part of the Valley and Ridge, passes beneath the Cumberland Plateau, where it crops out along the eastern side of Sequatchie Valley and in Elk Valley, to the Highland Rim. The boundary between the Fort Payne and Grainger or Borden is shown approximately by the zero isopach in figure 9. The formation ranges from about 30 to 91 m (100 to 300 ft) in thickness.

The base of the Fort Payne is marked almost everywhere by the thin (generally about a meter (3 ft) or less) Maury Formation (Stafford and Killebrew, 1900). The Maury is characteristically a greenish-gray to grayish-green shale, mudstone, siltstone, or claystone. Phosphate nodules are common and in some places, the formation is abundantly glauconitic. The Maury is too thin to map separately and is commonly included with the Fort Payne.

The Fort Payne Formation contains several lithologies and facies in Tennessee. The stratigraphy of the formation has not been studied in detail on a regional basis, and much of the description in this report was obtained from published geologic quadrangle maps. Wilson (in press) mapped about 76.2 m (250 ft) of cherty limestone and dolomite in the Whiteoak Mountain syncline. Englund (1968) described the Fort Payne as consisting of 30 to 53 m (100 to 175 ft) of finely crystalline bedded cherty dolomite containing greenish-gray shale partings in the area of its transition to the Borden Formation.

In northern Sequatchie Valley, the Fort Payne consists of about 61 m (200 ft) of siliceous and cherty limestone and dolomite. To the south, the formation is thinner and more deeply weathered so that outcrops consist of beds of crinoidal chert.

The Fort Payne of the Highland Rim is a heterogeneous mixture of carbonate and terrigenous clastic material and a rock described by the Tennessee Division of Geology on many geologic quadrangle maps as silicastone. Silicastone is defined by the Tennessee Division of Geology in its quadrangle mapping as "sedimentary rocks composed of fragmental (silt-size) and/or precipitated silica."

Calcareous shale and siltstone and cherty argillaceous limestone are the dominant lithologies of the eastern Highland Rim. However, Chowns and Elkins (1974, p. 887) noted that dolomite, which had not been reported by previous workers (see for example, Wilson and Barnes, 1968), was present in the Fort Payne in the area that they studied. The formation ranges from about 21.3 to 39.6 m (70 to 130 ft) in thickness in the southeastern Highland Rim and is 76.2 m (250 ft) or more thick to the northeast, near Kentucky. In places, the lower part of the formation consists of several meters of greenish-gray to light-olive-gray shale that encapsulates beds, bioherms, and lenses of crinoidal limestone as much as 9 m (30 ft) thick (fig. 10). Chert is abundant throughout the formation in carbonate rocks and calcareous siltstones as bands, beds, lenses, nodules, or irregularly shaped masses. Two silicastone-bearing areas of Fort Payne are in central Tennessee, one at the Kentucky line and a larger area that appears to extend from the central part of the eastern Highland Rim to the southwestern part of the western Highland Rim (fig. 10).

Geodes of quartz are common in the Fort Payne. Those studied by Chowns and Elkins (1974) appear to be pseudomorphs after anhydrite and are associated with tidal-flat and lagoonal sedimentary sequences. Chowns and Elkins (1974) identified siliceous sponge spicules and spiculite in the Fort Payne and Warsaw; these fossils may have been the source of the abundant silica in the formation.

In the southwestern Highland Rim, the Fort Payne can be divided into an upper cherty facies and a lower siltstone facies. The cherty facies consists of irregular rough plates and granules of brown, gray, or black chert in a matrix of calcareous brown to gray siltstone, and interbedded chert and siltstone. The lower siltstone facies consists of gray calcareous massively bedded siltstone containing siliceous and calcareous geodes and irregular beds of chert. Locally, the lower siltstone facies contains crinoidal and glauconitic limestone beds, and in places it is petroliferous. In this area, the Fort Payne ranges in thickness from 61 to 91 m (200 to 300 ft).

The lower siltstone facies gives way to the northeast so that the cherty facies overlies silicastone-bearing strata (fig. 10). The silicastone is generally gray to brownish gray and contains various amounts of calcite and dolomite. Chert and quartz geodes are common. Olive-gray to brownish- or greenish-gray shale is present beside and below the silicastone in this area, and crinoidal limestone is locally abundant within the shale.

In the northwestern part of the Highland Rim, the upper cherty facies is absent, and the Fort Payne is represented mostly by brownish-black, brownish-gray, and grayish-black calcareous siltstone. The siltstone in places is shaly, is cherty, or contains quartz geodes. In places, the upper part of the Fort Payne contains crossbedded calcarenite 15.2 m (50 ft) or more below the Fort Payne-Warsaw contact, the calcarenite is similar to that of the Warsaw Limestone.

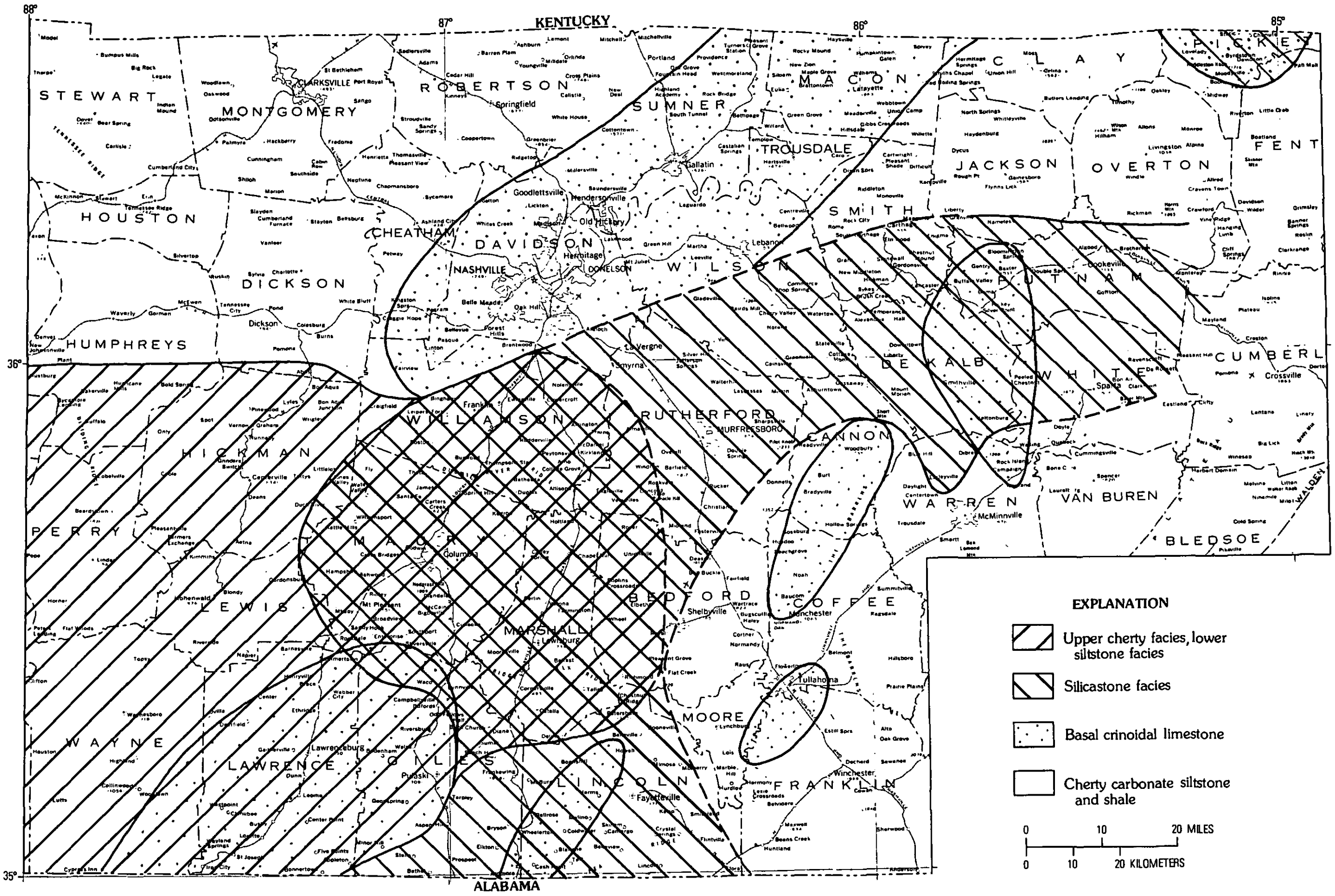


FIGURE 10.—Facies of the Fort Payne Formation in central Tennessee.

In the north-central Highland Rim, the formation consists of brownish-black to gray cherty calcareous or dolomitic siltstone and shale that is interbedded with gray cherty and silty dolomitic limestone. Lenticular masses and bioherms of crinoidal limestone as much as 7.6 m (25 ft) thick are present in the lower part of the Fort Payne in the western and northern Highland Rim (fig. 10).

In the western valleys of the Tennessee and Cumberland Rivers along the Kentucky line, the Fort Payne is represented by brown to black dense chert interbedded with siliceous shaly limestone and calcareous to dolomitic siltstone. Some of the chert is in rough irregular plates and granules in a siliceous or calcareous matrix. Small siliceous geodes are common. The New Providence Shale is a facies within the Fort Payne in places in this area and is represented by about 6.1 to 21.3 m (20 to 70 ft) of medium-gray to grayish-green calcareous and glauconitic shale and a few thin beds of silty nodular crinoidal limestone.

The Fort Payne Formation, as mapped by the Tennessee Division of Geology, includes all beds between the Maury Formation and Warsaw Limestone and is of Kinderhook or Kinderhook-Osage age (Conkin and Conkin, 1975).

NEWMAN LIMESTONE AND EQUIVALENTS

The Newman Limestone (Campbell, 1893, p. 38) consists of those beds between the top of the Fort Payne Formation and the base of the Pennington Formation (fig. 2). The unit is mapped as a formation on Newman Ridge and on the Pine Mountain block (Mixon and Harris, 1971; Englund, 1964, 1968). The Tennessee Division of Geology recognizes formations within the Newman in the Clinch Mountain strike belt east of Newman Ridge and uses a slight modification of the nomenclature proposed by Sanders (1952, and unpub. data in the files of the Tennessee Division of Geology). Strata equivalent to the lower part of the Newman were recognized by Neuman and Nelson (1965) in the Chilhowee Mountain belt. In the Cumberland Plateau and Highland Rim, Newman equivalents are divided into another set of formations that are mostly limestone but contain subordinate amounts of sandstone and shale.

CHILHOWEE MOUNTAIN BELT

Neuman and Nelson (1965) named the post-Grainger Mississippian beds near Chilhowee Mountain the Greasy Cove Formation. The unit consists of about 305 m (1,000 ft) of gray argillaceous limestone interbedded with red and gray fine-grained sandstone, siltstone, and shale (fig. 8). The top of the formation has been cut off by faulting, and younger beds are unknown in this area. Brachiopods in limestone beds suggest that the Greasy Cove is of Warsaw age.

CLINCH MOUNTAIN BELT

The Newman Limestone is estimated to be between 637 and 914 m (2,090 and 3,000 ft) thick in the strike belt east of Clinch Mountain (fig. 7), where it was subdivided by Sanders (1952), from base upward, into the: Maccrady Formation, Pressmens Home Formation, Laurel Branch Limestone, Snow Flake Formation, Clifton Creek Limestone, Gilliam Creek Limestone, Fisher Creek Formation, Fido Sandstone, and Cove Creek Formation.

The Maccrady Formation (Stose, 1913) consists of about 18.3–21.3 m (60–70 ft) of gray to grayish-red claystone, shale, calcareous siltstone, and sandstone. In places, grayish-red siltstone is gypsiferous, reflecting the equivalence of the Maccrady in Tennessee to the gypsum-bearing beds of the same age in southwestern Virginia.

The Pressmens Home Formation (J. E. Sanders, unpub. data in the files of the Tennessee Division of Geology) consists of about 45.7 m (150 ft) of calcareous siltstone, sandstone, limestone, and dolomite. In places, the limestone is cherty, and the unit locally contains 3 to 4.6 m (10 to 15 ft) of oolitic limestone near its top at the type section in the Pressmens Home quadrangle.

The Laurel Branch Limestone (Sanders, 1952) is composed of very fine grained dark-gray to black limestone that contains chert nodules and lenses and silicified corals, brachiopods, and bryozoans. The unit is about 24.4 m (80 ft) thick.

Sanders (1952) named the Snow Flake Formation for a siltstone unit 36.6 to 39.6 m (120 to 130 ft) thick between the Laurel Branch and Clifton Creek limestones. The unit is composed of silty shale and siltstone lithologically similar to the Grainger Formation. The base of the Snow Flake is marked by 0.3 m (1 ft) of calcareous sandstone. The sandstone is overlain by about 30 m (100 ft) of weathered silty shale and calcareous siltstone, and then by 2.4 m (8 ft) of fissile black limestone and 2.4 m (8 ft) of fissile black shale, and at the top by about 3 m (10 ft) of silty crystalline fossiliferous limestone.

The Clifton Creek Limestone (Sanders, 1952) is composed of about 39.6 m (130 ft) of dark-gray to black finely crystalline limestone containing small scattered nodules of black chart. Dark-gray oolitic limestone that is 0.3 m (1 ft) thick is about 7.6 m (25 ft) below the top.

The Gilliam Creek Limestone (Sanders, 1952) is about 122 m (400 ft) thick and consists typically of cherty gray to brownish-gray limestone, some argillaceous to silty, and some containing "porphyritic" crystals of calcite in a matrix of aphanitic rock. In general, the unit consists in its lower part of 40 m (130 ft) of medium crystalline limestone containing 0.6 m (2 ft) of oolitic limestone 12.2 m (40 ft) above the base. Next above is 18.3 m (60 ft), more or less, of silty aphanitic and cherty limestone, above which is 3.7 m (12 ft) of very coarsely crystalline calcarenite. The upper part of the formation is composed of interbedded cherty and silty limestone.

The Fisher Creek Formation (Sanders, 1952) consists of three members. The lower member is composed of about 152 m (500 ft) of coarse silty laminated gray limestone, gray crossbedded calcarenite, greenish-gray to yellowish-gray shaly and calcareous siltstone, and fine-grained gray limestone. The middle sandstone member of the Fisher Creek Formation consists of 15.2 m (50 ft) of medium-grained calcareous gray sandstone in beds 15–30 cm (0.5–1 ft) thick; in places, the sandstone grades laterally into calcarenite. The upper member of the Fisher Creek Formation consists of about 305 m (1,000 ft) of interlaminated gray limestone, coarser silty limestone, greenish-gray calcareous siltstone, and fine-grained gray limestone. Massive calcarenite beds are present in subordinate amounts.

The Fido Sandstone of Butts (1927) consists 6.1–15.2 m (20 to 50 ft) of very fine to medium-grained gray calcareous sandstone or grayish-red sandy calcarenite in the Clinch Mountain belt. The formation is commonly crossbedded and in places contains fossil fragments.

The Cove Creek Formation of Butts (1927) consists of three members in the Clinch Mountain belt in Tennessee, a lower limestone member, a middle sandstone member, and an upper limestone member. The lower member consists of 68.6–107 m (225–350 ft) of massive argillaceous limestone containing laminations, ribbons, and discontinuous lenses of quartz sand. The middle member is composed of about 15.2 m (50 ft) of fine- to medium-grained gray calcareous sandstone and sandy calcarenite. The upper member consists of gray argillaceous or shaly limestone interlaminated with siltstone. The member is about 30 m (100 ft) thick, and the total thickness of the Cove Creek Formation of Butts (1927) ranges from 122 to 152 m (400 to 500 ft) in Tennessee.

The names Cove Creek Limestone and Fido Sandstone were abandoned by the U.S. Geological Survey on the basis of a report by Wilpolt and Marden (1949). They replaced the name Cove Creek Limestone by the name Bluefield Formation, which has precedence, and the Fido was determined to be equivalent to the lower part of the Bluefield and the upper part of the Greenbrier Limestone (Keroher and others, 1966). For this reason, the Cove Creek and Fido should not be perpetuated in the stratigraphic nomenclature for Mississippian strata in Tennessee, and a set of local names should be proposed.

The great thickness and lithologic aspects of the Newman Limestone in the Greendale syncline suggest that it is largely a slope deposit marginal to the carbonate platform. However, detailed petrologic studies have not yet been made.

NEWMAN RIDGE AND PINE MOUNTAIN BLOCK

The Newman Limestone consists of a lower limestone member and an upper limestone and shale member on Newman Ridge and on the Pine Mountain block (Mixon and Harris, 1971; Harris and Mixon, 1970; Harris and others, 1962, Harris, 1965; Engund, 1964, 1968). The formation thins from 241 m (790 ft) on Newman Ridge to a maximum of 223 m (730 ft) along Cumberland Mountain to no more than 210 m (690 ft) in Elk Valley.

The formation is more calcareous to the northwest, primarily because of an increase in thickness of the lower limestone member. This member is composed of about 70 m (230 ft) of chert-bearing light-olive-gray calcilutite interbedded with bioclastic and oolitic limestones on Newman Ridge and of 79 m (260 ft) of similar lithologies along Cumberland Mountain; in Elk Valley, the lower member is 122–131 m (400–430 ft) thick and its lowest 6.1 m (20 ft) consists of finely crystalline olive-gray or dolomitic argillaceous limestone that contains lenses of coarse sand and jasper-bearing conglomerate. This basal unit is overlain by oolitic and bioclastic gray limestone that contains thin beds of greenish-gray or grayish-red shale.

The upper member is about 171 m (560 ft) thick on Newman Ridge and consists of greenish-gray shale and siltstone interbedded with olive-gray calcilutite, argillaceous calcilutite, and medium-grained oolite. In the Cumberland Mountain belt, the upper members consists of 99 m (325 ft) or more of medium-gray calcareous shale interbedded with medium-gray to olive-gray calcilutite and oolitic, bioclastic limestone. In Elk Valley, the correlative unit is composed principally of gray, greenish-gray, and grayish-red shale interbedded with fine- to coarse-grained limestone or argillaceous limestone and is 67.1–100.6 m (220–330 ft) thick.

The Mississippian section on I–75 south of Jellico was studied in detail by members of a Sedimentation Seminar at the University of Cincinnati, and a detailed report of the seminar is being published by the Tennessee Division of Geology (in press). Significantly, the seminar group was able to identify in the Newman at Jellico the formations typical of the Mississippian section in the Cumberland Plateau to the west and south, including a bit of the Warsaw, the St. Louis, Monteagle, Hartselle, and Bangor.

The Newman (or Bangor)-Pennington contact is picked differently by different workers. In the Elk Valley region, Englund (1968, p. 13) mapped the top of the Newman at the base of 6.1 m (20 ft) of massive sandstone, placing the considerable thickness of interbedded shale and limestone beds below in the upper member of the Newman. In Tennessee, other workers map the base of the Pennington lower in the section, selecting as a matter of convenience the base of yellowish-gray weathering silty dolomite beds a little above the solid limestone of the Bangor. The reader should be aware, therefore, that the upper member of the Newman Limestone, as mapped in Newman Ridge and on the Pine Mountain block, may include correlatives to beds mapped elsewhere within the lower part of the Pennington Formation.

CARBONATE PLATFORM DEPOSITS OF THE CUMBERLAND PLATEAU AND HIGHLAND RIM

Beneath the Cumberland Plateau and Highland Rim, the Fort Payne Formation is overlain by a carbonate sequence containing minor amounts of sandstone and shale. On the eastern side of the Nashville dome, the sequence is divided into the Warsaw, St. Louis, and Monteagle Limestones, the Hartselle Sandstone, and the Bangor Limestone (figs. 11 and 12). West of the dome, where the upper

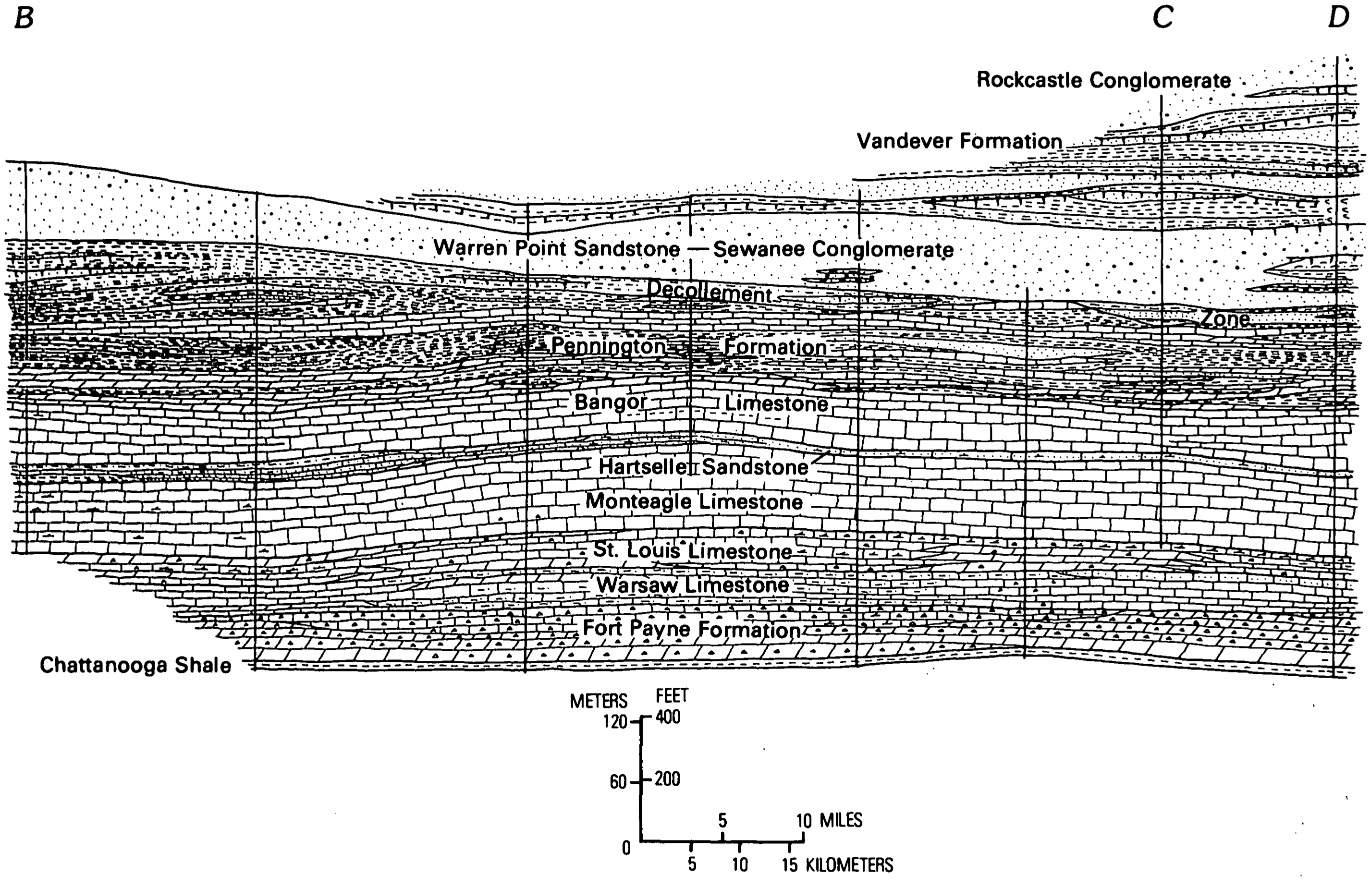


FIGURE 11.—Stratigraphic cross section along line B–C–D.

part of the section is removed by erosion, the Ste. Genevieve Limestone occupies the position of the Monteagle.

WARSAW LIMESTONE

The Warsaw Limestone (Hall, 1857) is 15–55 m (50 to 180 ft) thick on the eastern Highland Rim. It is distinguished from the Fort Payne and the St. Louis by the character of its chert; chert in the Warsaw is mostly porous or spongy, whereas chert in the adjacent formations is dense and hard.

In the southern part of the Cumberland Plateau and eastern Highland Rim, the Warsaw is composed of slightly cherty brown to gray, medium- to coarse-grained bioclastic limestone. In some places the formation is sandy, silty, or dolomitic.

Terrigenous clastic content increases generally to the north, so that the Warsaw in the east-central Highland Rim consists of dark-gray to brownish-gray sandy and silty limestone, which is bioclastic in part. In places, calcareous shale, siltstone, and argillaceous limestone are the dominant lithologies, and these are commonly interbedded with bioclastic calcarenite. Silicastone containing quartz geodes is common in the lower part of the formation in some places.

On the northeastern part of the Highland Rim along the Kentucky line, the Warsaw is composed mostly of calcareous crossbedded very fine to medium-grained sandstone that grades laterally within short distances into crossbedded silty or sandy bioclastic limestone.

On much of the western Highland Rim, the Mississippian limestones are weathered to a rubble of chert and clay. Where preserved in that area, the Warsaw is represented by 12–61 m (40–200 ft) of gray, yellowish-brown, brownish-gray, or olive-gray fine- to coarse-grained limestone. The limestone is commonly crossbedded and bioclastic and in places is glauconitic. Some is silty or dolomitic. Local oolitic limestone beds at the top of the Warsaw are regarded as possible equivalents to the Salem Limestone of nearby States. Chert is common in the formation as nodules, lenses, and large irregular masses. Dolomitic limestone, silty dolomite, and sandy siltstone are also common in the formation,

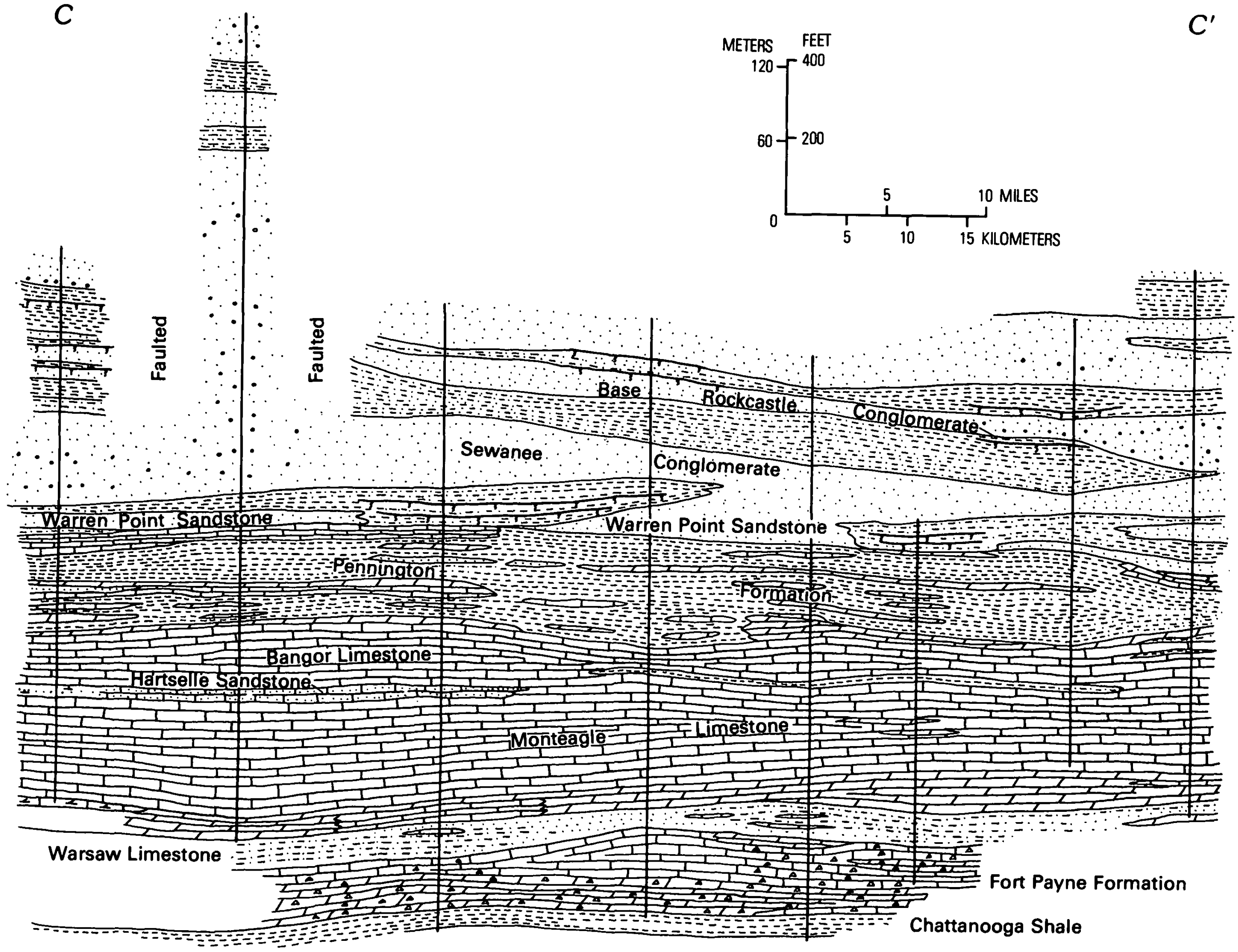


FIGURE 12.—Stratigraphic cross section along line C–C′.

and these generally are brownish gray to yellowish brown, are cherty, and contain small siliceous geodes.

ST. LOUIS LIMESTONE

The St. Louis Limestone (Engelmann, 1847) generally ranges from 12 to 55 m (40 to 180 ft) in thickness on the eastern Highland Rim. In the southeastern Highland Rim, the St. Louis is composed mostly of yellowish-gray, yellowish-brown, and gray very fine to medium-grained dolomitic limestone and dolomite containing balls and dolls of dense pale-blue to bluish-gray chert. Gray bioclastic limestone is common in some places and locally contains fragments of algae, crinoids, and brachiopods.

Northeastward along its outcrop the St. Louis consists of medium- to medium-dark-gray, brownish-gray, or light-olive-gray limestone, containing beds of brownish-gray to yellowish-brown, fine-grained dolomite and walnut- to baseball-sized spherical chert cannonballs. Quartz geodes are common in some places. Some beds contain calcite bird's eyes, and some are petroliferous. In places, the formation contains thin beds of greenish-gray shale. Foraminifera were observed in several places in the formation along the Kentucky line and on the western Highland Rim.

The St. Louis Limestone ranges from 45.7 to 108.2 m (150 to 355 ft) in thickness on the western Highland Rim but more commonly is about 61 m (200 ft) thick. There the formation consists of fine- to coarse-grained yellowish-gray, yellowish-brown, and gray limestone and silty or dolomitic limestone. Some is crossbedded and bioclastic, but more commonly beds are thick to massive. Thin oolitic zones are present locally within the unit. In places, the upper part of the St. Louis consists of fine- to medium-grained gray limestone that contains abundant rounded cannonballs of chert. These beds overlie poorly sorted calcarenites that are locally petroliferous. Elsewhere cherty calcareous siltstones or silty dolomite beds as much as 6.1 m (20 ft) thick mark the base of the formation.

The formation is characterized by more or less abundant *Lithostrotion proliferum* and *Lithostrotionella castelnaui*, and these fossils together with the cannonball cherts are the key to identification of the unit.

MONTEAGLE AND STE. GENEVIEVE LIMESTONES

The Monteagle Limestone (P. R. Vail, 1959, in Stearns, 1963, p. 4–8) consists of 45.7–115.8 m (150–380 ft), commonly about 76 m (250 ft), of light- to medium-gray and light-olive-gray bioclastic and oolitic limestone and some beds of light-gray to light-olive-gray, bird's-eye-bearing micrite. Greenish-gray to olive-gray shale and yellowish-gray dolomitic interbeds are common in some sections, but are only a small part of the formation. Medium- to dark-gray and bluish-gray chert is present locally in some beds but is generally not abundant. A yellowish-gray to yellowish-orange, porous bryozoan-bearing chert (Lost River Chert of Elrod, 1899) serves as a marker bed near the base of the formation. The porous chert is produced by weathering of siliceous limestone beds in a zone 1 m (3 ft) or less thick and is common as blocks or pieces in the soil overlying the zone. In some places, scattered sand grains are in limestone beds near the base of the formation.

The Ste. Genevieve Limestone (Shumard, 1860) on the northwestern Highland Rim is stratigraphically equivalent to the lower part of the Monteagle Limestone on the eastern Highland Rim and plateau. The Ste. Genevieve consists of about 61 m (200 ft) of rock lithologically similar to that of the Monteagle. The Lost River Chert of Elrod (1899) persists to the western Rim and serves there too as marker beds 3–6.1 m (10–20 ft) above the base of the formation. Only in the structurally deformed Wells Creek basin area of the northwestern Highland Rim have Mississippian beds younger than the Ste. Genevieve been preserved. In this area, a graben contains about 61 m (200 ft) of beds younger than the Ste. Genevieve; these beds have been tentatively correlated with the Renault, Bethel, and Paint Creek Formations of western Kentucky.

Depositional environments of carbonate sands near Monteagle, Tenn., ranged from shoals to the interior platform (Bergenback and others, 1972). Shoal deposits of crossbedded oolitic carbonate sands are separated by subaerial crusts, represented by micrites containing fenestral fabrics and laminae; the crusts formed during brief periods of emergence. Brecciated nodular beds of micrite and dololutite are interpreted to represent caliche paleosols. Oolitic sands of tidal and marine sand deposits grade into poorly sorted, burrowed, pelletal, and bioclastic sands that accumulated in interior platform environments.

HARTSELLE FORMATION

The Hartselle Formation (Smith, 1894), a persistent clastic unit in the predominantly carbonate sequence, is as much as 27.4 m (90 ft) thick. In general, the Hartselle consists of olive-gray to greenish-gray shale, silty shale, and rippled to crossbedded, grayish-orange, yellowish-brown, and gray sandy limestone and calcareous sandstone. In places where the clastic unit is absent, the stratigraphic interval is marked by yellowish-gray dolomite. Zones of oolitic and bioclastic limestone are near the base of the formation in some places. Where sandstone is the dominant lithology, the Hartselle forms a prominent topographic bench along the western Cumberland Escarpment between the surfaces of the Highland Rim and Cumberland Plateau. The Hartselle is generally thin or absent in southern Tennessee; where present, it is represented mostly by shale. The formation thickens and becomes more sandy along its outcrop to the north, but in the subsurface to the northeast it thins and grades into a shaly facies.

BANGOR LIMESTONE

The Bangor Limestone (Smith, 1890) consists of 24.4 to perhaps 152.4 m (80 to 500 ft) of medium-gray to medium-dark-gray, or brownish-gray limestone. The Bangor is commonly petroliferous and is generally darker and more argillaceous than the Monteagle. The formation generally contains oolitic and bioclastic beds. A few thin beds are dolomitic and pale yellowish brown; thin beds of greenish-gray to olive-gray shale are common. The formation generally contains lenses and nodules of medium-gray to medium-dark-gray chert. The Bangor is thickest in the southeastern part of the Cumberland Plateau, thinning generally to the west across the plateau and to the north into Kentucky.

PENNINGTON FORMATION

The Pennington Formation (Campbell, 1893) is a heterogeneous unit composed of dolomite; limestone; red, green, or gray shale; fine-grained sandstone; and conglomeratic sandstone. In general, the formation ranges in thickness from 30 to 152.4 m (100 to 500 ft). On the eastern side of the plateau, the Pennington is thicker and contains a greater proportion of terrigenous clastic deposits; to the west, it is thinner and more calcareous.

The Pennington may be divided into five stratigraphic units that have some lateral continuity (Vail, 1959). Silty, yellowish-gray and light-olive-gray to brownish-gray fine-grained dolomite beds in a zone ranging from 1 to 10 m (3.3–33 ft) in thickness commonly mark the base of the formation. In some places, the dolomite contains quartz-filled geodes, and less commonly it contains vugs filled with celestite or strontianite. Frazier (1975) concluded that celestite-bearing geodes in Fentress County are replacements of gypsum nodules that formed a little way beneath the surface of a sabkha-like environment. The basal dolomite zone is in many places overlain by limestone, succeeded by beds of red and green shale, fine-grained sandstone or quartz-pebble conglomerate, an upper limestone unit, and locally by some shale and sandstone at top. Limestone beds generally resemble those of the Bangor and are gray, oolitic to bioclastic, and, in places, shaly.

In Tennessee, the Pennington contains beds that were deposited in littoral (but nondeltaic) depositional environments. Bergenback, Horne, and Inden (1972) recognized that the Pennington near Monteagle contains units deposited in tidal flat, tidal channel, levee, and intertidal environments. Milici (1974) described fine-grained sandstones within the Pennington as representing offshore sandbars formed from fine sand and clay winnowed by waves and longshore currents from beach sands. A regional stratigraphic cross section (fig. 13) shows that quartz-pebble conglomerates on the northeast can be traced southwestward into fine-grained sandstone typical of the Pennington. According to Englund and Smith (1960) and Englund (1968), these conglomerates are tongues of Lee in the Pennington in northeastern Tennessee and adjacent parts of Virginia and Kentucky. As shown in the cross section (fig. 13), these tongues are in places overlain by red and green Pennington shale and appear to pass laterally below beds of limestone.

In southern Tennessee, similar beds of quartz-pebble conglomerate interbedded with olive-gray to dark-gray carbonaceous shale and siltstone and thin coal are called Gizzard and are considered to be of Mississippian or Pennsylvanian age (Milici, 1974). Englund (1968) classified strata similar to those in the Gizzard as Pennington and placed the top of the Pennington (base of Lee) at a higher stratigraphic level. The Pennington-Gizzard problem and its relation to the nature of the Mississippian-Pennsylvanian boundary was discussed by Milici (1974).

THE COAL MEASURES

The coal-bearing strata of Tennessee are mostly of Early and Middle Pennsylvanian age (fig. 3) and are divided generally into a lower sequence of thick orthoquartzite interbedded with shale and some coal, and an upper sequence dominated by shale but containing subsidiary amounts of sandstone and much more coal than the lower sequence. This basic division is apparent in the stratigraphic cross section of the northern Cumberland Plateau (figs. 7, 13–15). Wilson and Stearns (1960) recognized this dichotomy, referring to the orthoquartzites as blanket sandstones and to the upper sandstones as digitate. Ferm (1974) showed that on a regional basis, the progradational sequence from Pennington red and green shale, limestone and fine-grained argillaceous sandstone through the orthoquartzite to the section dominated by shale and many coal beds represented a transition from marine deposits to littoral deposits and then to delta-plain facies.

Units deposited in shoreline environments are evident in the Gizzard and Crab Orchard Mountains Groups and persist perhaps into the lower part of the Crooked Fork Group. Quartzose barrier sandstones (deposited in beaches, tidal deltas, tidal channels, washovers, and bars) are abundant in the Gizzard and Crab Orchard Mountains Groups (Ferm and others, 1972; Milici, 1974; this report, fig. 3). Sandstone formations vary widely in thickness, generally ranging from 10 to 100 m (33 to 328 ft), although composite sandstone bodies 91–122 m (300–400 ft) thick are known in a few places. Quartz-pebble conglomerate and conglomeratic sandstone characterize each of the blanket sandstones in some places. However, the Sewanee and Rockcastle Conglomerates almost everywhere contain at least a few quartz pebbles. Thick dark-gray shale associated with the orthoquartzite sandstone bodies is thought to have been deposited in back-barrier lagoons. In places, this shale is calcareous and contains marine fossils. Elsewhere, it grades through burrowed and flasered beds, interpreted to be tidal flats, into sandstone. Coal beds are associated with

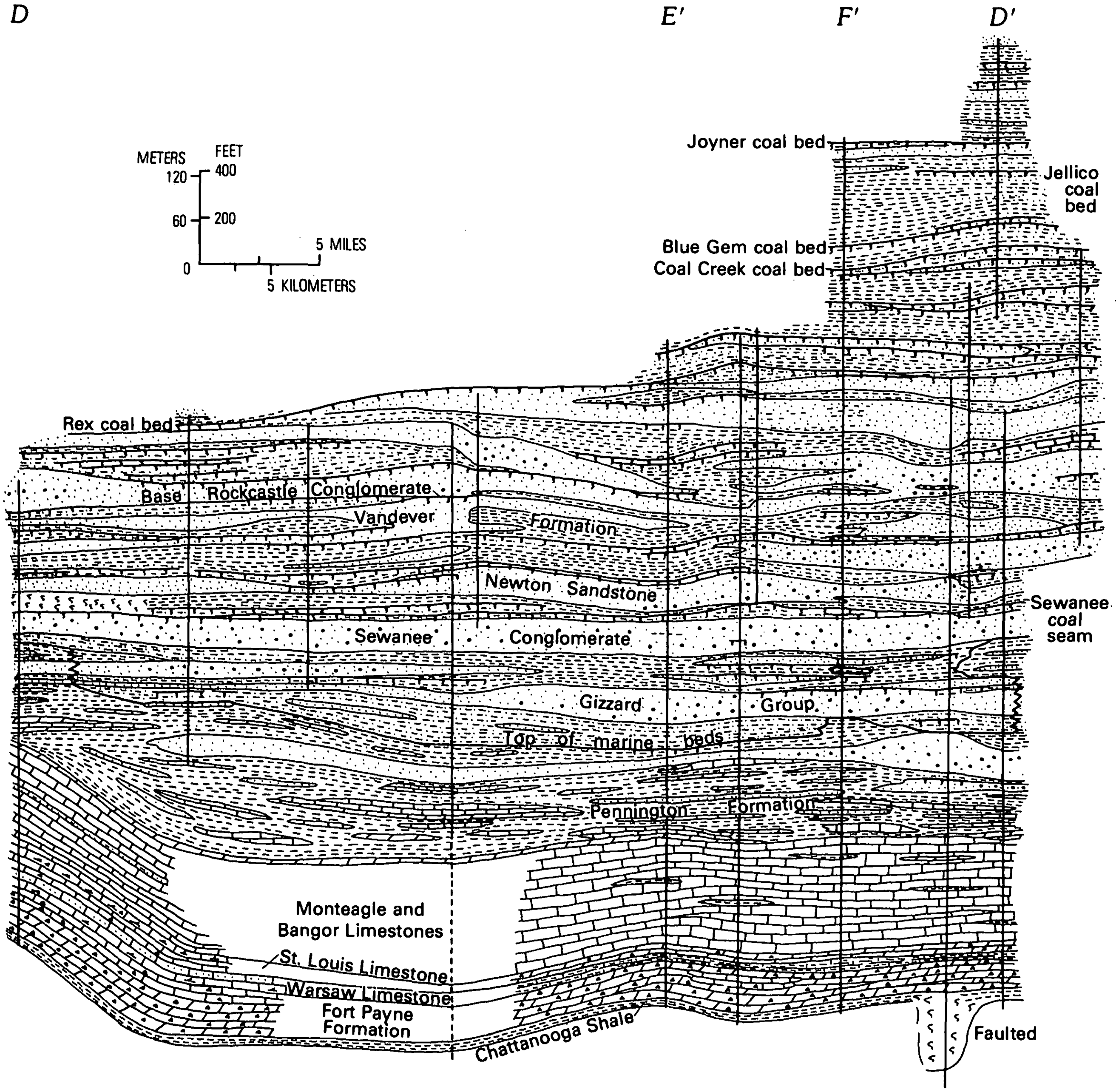


FIGURE 13.—Stratigraphic cross section along line D–E′–F′–D′

these back-barrier-fill sequences, and in places, marsh deposits are characterized by thick zones containing fossil roots and by anastomosing channel fills of sandstone, shale, and siltstone.

GIZZARD GROUP

The Gizzard Group (Safford, 1869) is composed of three formations, the Raccoon Mountain Formation, Warren Point Sandstone, and Signal Point Shale. In southern Tennessee, the boundary between the Raccoon Mountain and Pennington Formations is picked at the top of the highest red or green shale or limestone, and in a few places, at the top of recognizable Pennington Sandstone. This convention generally separates coal-bearing beds above from the main mass of marine strata below.

The convention used for selecting the top of the Pennington in southern Tennessee does not work well around the periphery of the Wartburg basin, where the stratigraphic reconstruction (fig. 13) illustrates a complex facies between the Pennington and the Gizzard, wherein quartz-pebble conglomer-

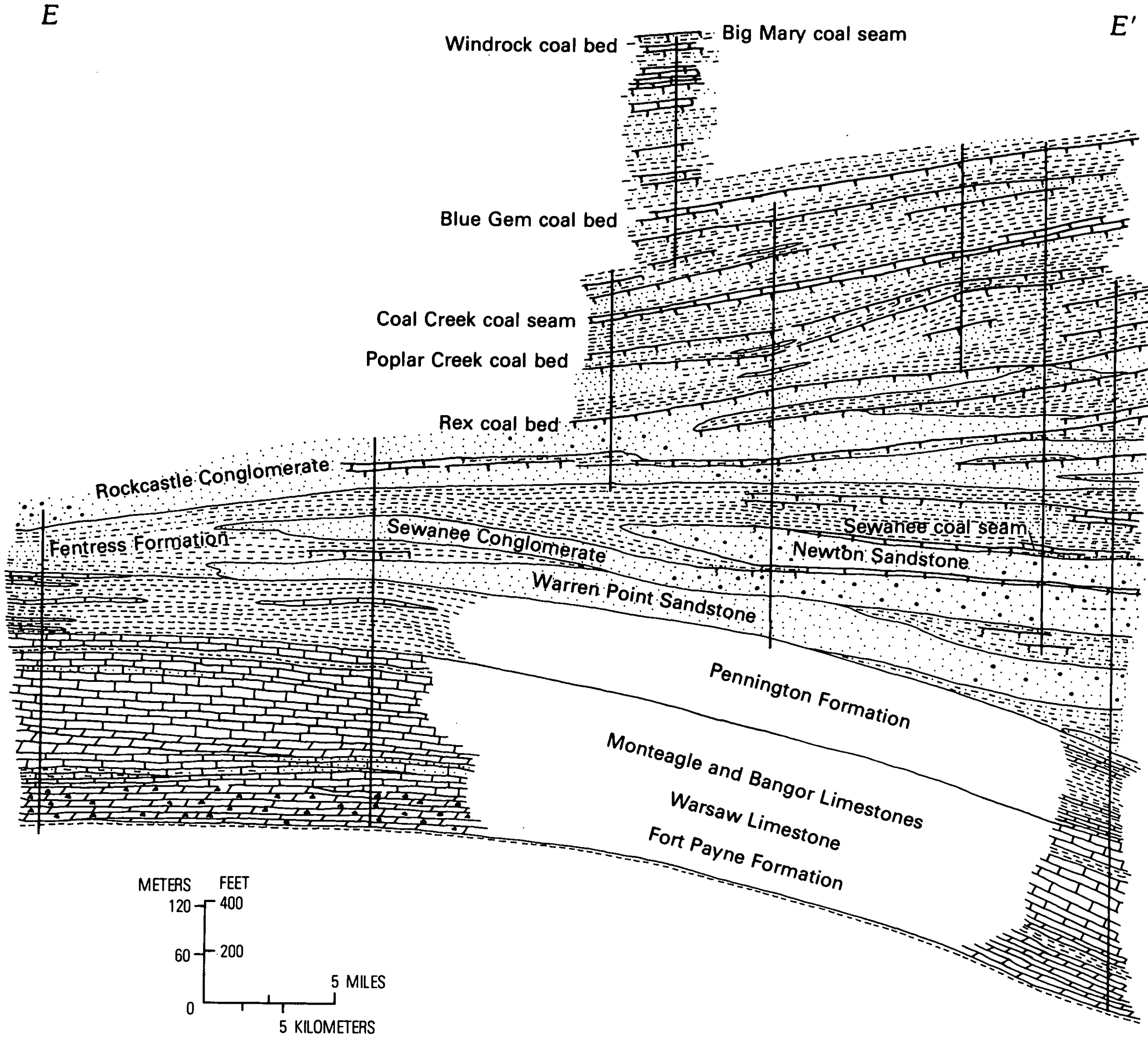


FIGURE 14.—Stratigraphic cross section along line E–E'.

ate, coal, carbonate deposits, and red beds intertongue both laterally and vertically. Similar facies variations were reported by Horne and others (1974) along the Mississippian-Pennsylvanian boundary in northeastern Kentucky and by Englund and Smith (1960) and Englund (1968) in northern Tennessee and adjacent States.

Raccoon Mountain Formation.—The Raccoon Mountain Formation (Wilson and others, 1956) consists of a few tens of meters to about 91 m (300 ft) of gray shale, siltstone, sandstone, and coal. In some places in southern Tennessee, the Raccoon Mountain Formation is thick, it contains as many as seven coal beds in the Sale Creek and Raccoon Mountain coal basins (Milici, 1974). These coal beds are mostly thin and discontinuous, although some are of good grade and were extensively mined at one time.

Warren Point Sandstone.—The Gizzard Group is divided by separating out the Warren Point Sandstone (Nelson, 1925), which is a persistent mappable unit in southern Tennessee. Where thick, the formation consists of 30–91 m (100–300 ft) of fine to coarse sandstone that in places contains abundant quartz pebbles. In places, thin shale and coal beds interrupt the sequence of massive sandstone. Where the Warren Point thins to several meters and is indistinguishable from the sand in the Raccoon Mountain, the Gizzard is divided into informal map units. Regionally, the Warren Point consists of a series of laterally discontinuous lenticular sand bodies, which

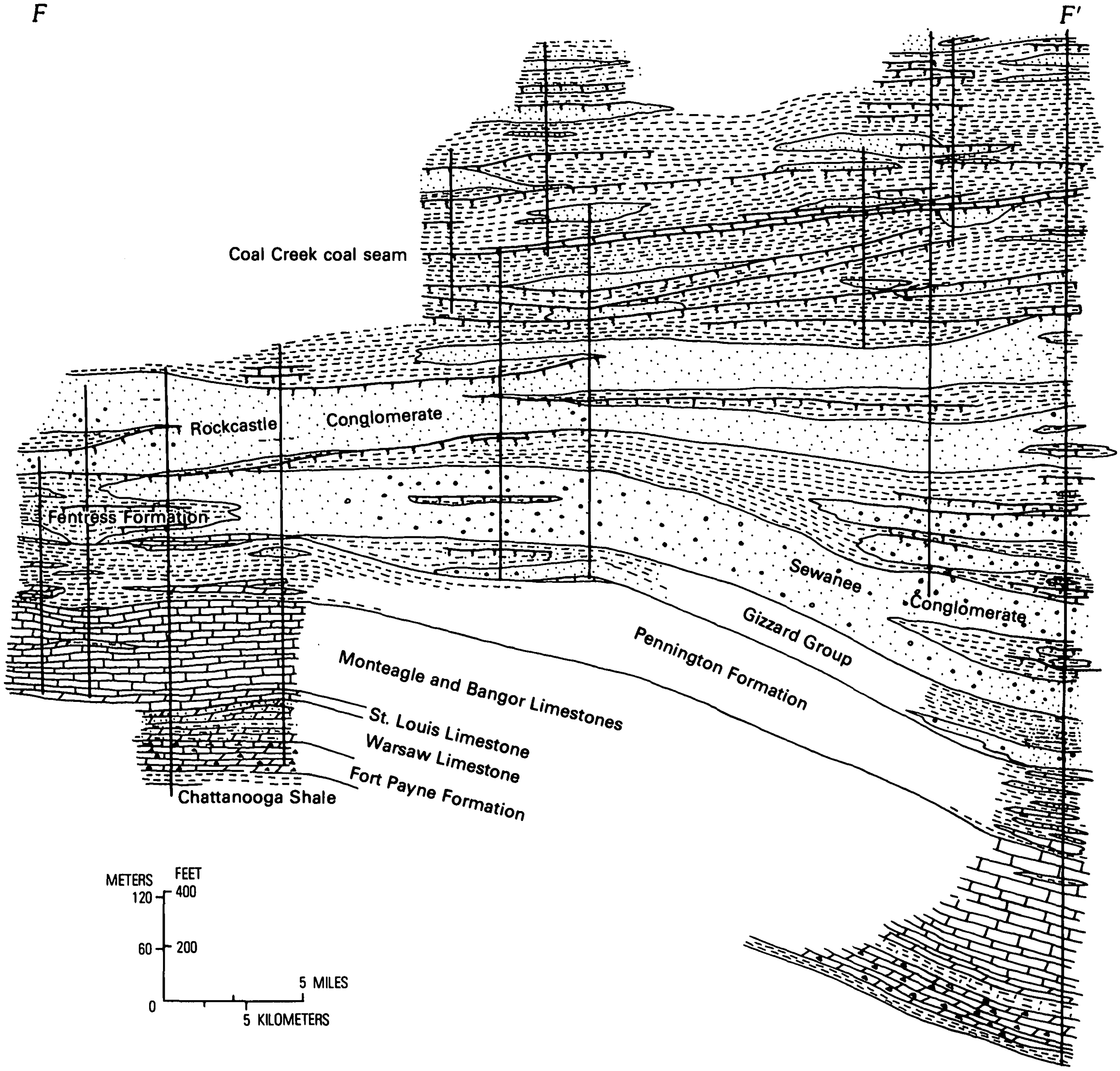


FIGURE 15.—Stratigraphic cross section along line F–F′

are correlated by position in sequence to the type area. In this way, Gizzard sandstone bodies in the subsurface of northern Tennessee are correlated with Warren Point Sandstone in southern Tennessee (figs. 11–14).

Signal Point Shale.—The Signal Point Shale (Wilson and others, 1956) consists generally of 20–55 m (66–180 ft) of gray shale, siltstone, thin sandstone, and a few thin coal beds. Where mappable, this fine-grained clastic unit separates the massive sandstone and conglomeratic sandstone of the Warren Point Sandstone from the Sewanee Conglomerate. In many places, the Signal Point is missing, and coarse quartz-pebble conglomerate and conglomeratic sandstone of the Sewanee lie upon the Warren Point. In a few places, the entire Gizzard is missing, and the Sewanee rests directly on the Pennington Formation. Where the Sewanee and Warren Point are lithologically similar, they are mapped together as a thick composite sand body. Coal beds within the Signal Point are mostly thin, discontinuous, and only locally important.

CRAB ORCHARD MOUNTAINS GROUP

The Crab Orchard Mountains Group (Wilson and others, 1956) includes the Sewanee Conglomerate, Whitwell Shale, Newton Sandstone, Vandever Formation, and Rockcastle Conglomerate. The group is represented by these five formations in the southern Cumberland Plateau and in the Crab Orchard Mountains. On the northwestern part of the plateau, the lower stratigraphic units grade laterally into the Fentress Formation, and only the Rockcastle persists as a mappable unit (Wilson, 1956).

Sewanee Conglomerate.—The Sewanee Conglomerate (Safford, 1893) is the most persistent stratigraphic unit in the Tennessee coal measures. The formation ranges generally from 24.4 to 27.4 m (80 to 90 ft) in thickness, but in some areas it is as much as 61 m (200 ft) thick. It is composed of fine- to coarse-grained sandstone and contains pebbles, which are locally abundant. In several places, the formation thins to several meters, and the quartz pebbles are absent. The Sewanee Conglomerate is exposed on much of the southern plateau, is easily recognizable in the subsurface of the Wartburg basin (fig. 13), but thins to the northwest where it grades into the Fentress Formation (figs. 14, 15).

Whitwell Shale.—The Whitwell Shale (Butts and Nelson, 1925) consists of about 10 m (33 ft) to as much as 61 m (200 ft) of gray shale, silty shale, sandstone, and coal. The formation contains most of the commercial coal in the southern plateau (fig. 16). The most widely prospected seam is the Sewanee, which is generally within the lower half or third of the formation. The Richland coal bed, which is at or near the base of the Whitwell, is also of commercial quality. As many as four seams are within the Whitwell in some areas, but there individual coal beds are too thin to be commercially expoitable.

In the past, most of the mining of the Sewanee and Richland coal beds was in the southern part of the plateau, near Whitwell and Tracy City, and this is still the area of greatest activity. The quadrangles northeast of the Whitwell-Tracy City district and the area west of Rockwood contain sizable coal reserves. Most of the Sewanee and Richland coal is marketed either as steam coal or, after being washed, as metallurgical coal. Although Whitwell coal is currently being prospected by deep core drilling, some areas in the southern plateau are relatively untested.

Newton Sandstone.—The Newton Sandstone (Nelson, 1925) consists generally of about 10 m (33 ft) to as much as 45.7 m (150 ft) of fine- to medium-grained sandstone. In some places, the formation is coarse grained, contains quartz pebbles, and is conglomeratic. The formation is generally persistent in the southern plateau, between the shale and siltstone of the Whitwell and Vandever. In a few places, the Whitwell Shale is absent, and the Newton rests directly upon the Sewanee. The Newton Sandstone is below drainage in the Wartburg basin, where it consists of sandstone, some of which contains quartz pebbles (figs. 13–15). Like other formations of the Crab Orchard Mountains Group, the Newton grades northwestward into shale and siltstone of the Fentress Formation.

Vandever Formation.—The Vandever Formation (Nelson, 1925) ranges generally from 61 to 137 m (200 to 450 ft) in thickness and consists mostly of shale and sandstone and some siltstone and coal beds. The formation is divided into three members in the southern plateau. The upper and lower members, which consist of shale, minor siltstone, thin sandstone, and coal beds, are separated by a middle sandstone member. Where the sandstone member is thick and conglomeratic, it is mapped as the Needleseye Conglomerate Member of the Vandever Formation (Luther and Swingle, 1963). The Vandever Formation contains two main coal beds, the Lantana seam in the lower member and the Morgan Springs near the top of the upper member. Both of these seams are generally suitable for steam coal.

In the subsurface of the Wartburg basin, the Vandever consists of anastomosing sandstone, conglomeratic sandstone, and shale containing beds of coal (fig. 13). The top of the Vandever is difficult to select in this region because of irregular facies variations in the formation.

Fentress Formation.—The Fentress Formation (Glenn, 1925) consists of the interlaminated and flasered shale and fine sandstone and thin beds of sandstone and coal between the top of the Pennington and the base of the Rockcastle Conglomerate along the northwestern side of the Cumberland Plateau. The Fentress Formation is as much as 76.2 m (250 ft) thick. Like the facies in the Gizzard, those in the Fentress are extremely variable, and both formations are overlain by blanket orthoquartzites.

Rockcastle Conglomerate.—The Rockcastle Conglomerate (Campbell, 1898) is a widespread blanket orthoquartzite throughout much of the central and northwestern parts of the Cumberland Plateau. In general, the formation ranges from 30 to 91 m (100

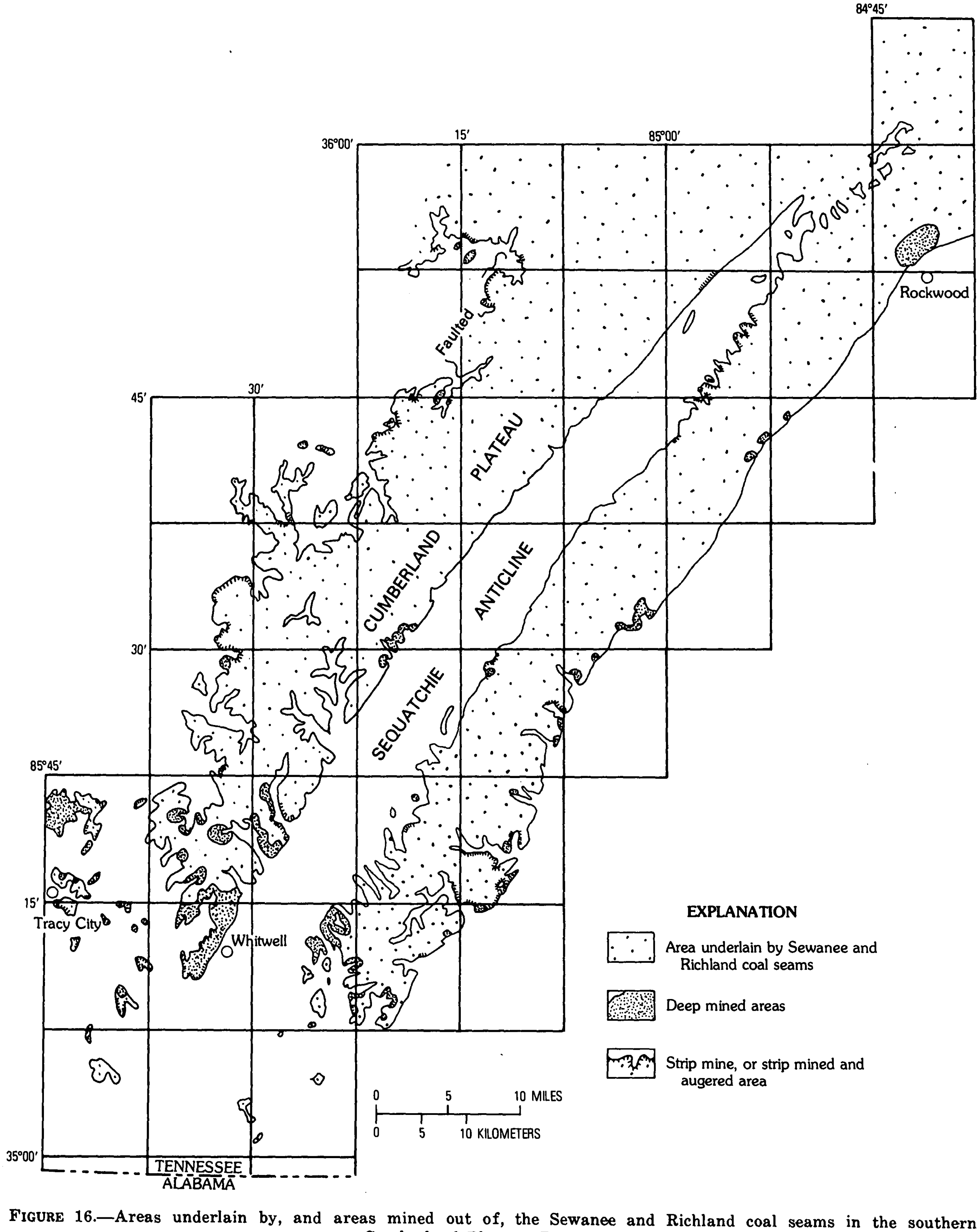


FIGURE 16.—Areas underlain by, and areas mined out of, the Sewanee and Richland coal seams in the southern Cumberland Plateau, Tennessee.

to 300 ft) in thickness and consists of fine- to coarse-grained, locally conglomeratic sandstone. The formation generally contains a widespread shale and coal bed (Nemo) near the middle. To the east, shale interbeds are more common and thicker and, like the Vandever, the formation consists of anastomosing shale and sandstone and thin coal beds (figs. 13–15). The Rockcastle can thus be divided regionally into a barrier phase consisting generally of orthoquartzite to the west, and a back barrier phase of orthoquartzite, shale, and coal to the east.

CROOKED FORK GROUP

The Crooked Fork Group consists of a succession of six shale and sandstone formations (fig. 3): the Dorton Shale (Wilson and others, 1956), the Crossville Sandstone (Wanless, 1946), the Burnt Mill Shale (Wilson and others, 1956), the Coalfield Sandstone (Wilson and others, 1956), the Glenmary Shale (Wilson and others, 1956), and the Wartburg Sandstone (Keith, 1896). The Crooked Fork Group crops out around the periphery of the Wartburg basin and in belts on either side of the Crab Orchard Mountains (Hardeman and others, 1966). The group ordinarily ranges from 91 to 122 m (300 to 400 ft) in thickness and is the uppermost to contain thick sandstone. However, the sandstone of the Crooked Fork is not nearly as thick or laterally persistent as that in the groups below.

The formations within the Crooked Fork range generally from 20 to 30 m (66 to 100 ft) in thickness, although locally several were mapped as 45.7 m (150 ft) thick. The shale is generally medium to dark gray and in places is interbedded with siltstone or thin sandstone. Sandstone is commonly fine to medium grained but in places may be coarser. Quartz pebbles are uncommon within the sandstone but are present in the Crossville and Wartburg sandstones in an area north of the New River. Although the depositional environments of the Crooked Fork Group have not been studied in detail, it is apparent that these beds are transitional between the littoral beach-barrier sequence below and the delta-plain sequence above.

The only coal bed of significance in the group is the Rex, which is at or near the base of the Dorton Shale. In places, the Rex is thick enough to be commercially exploitable and after washing may be suitable as a metallurgical grade coal. The Poplar Creek coal bed at the top of the group is of local commercial significance.

DELTA-PLAIN SEQUENCE

In Tennessee the beds above the Wartburg Sandstone are divided into six formations, all named by Wilson, Jewell, and Luther (1956): the Slatestone Formation, Indian Bluff Formation, Graves Gap Formation, Redoak Mountain Formation, Vowell Mountain Formation, and Cross Mountain Formation (fig. 3). Wilson, Jewell, and Luther (1956) originally described the thick units as groups, but when it became apparent that they could not be easily divided into mappable units, they were reduced in rank to formations (Hardeman and others, 1966).

Slatestone Formation.—The Slatestone Formation consists of 91 to 219 m (300 to 720 ft) of gray shale and subsidiary amounts of siltstone and silty sandstone. The formation includes the strata between the top of the Poplar Creek coal bed and the top of the Jellico coal bed. The formation consists of gray clayey to sandy shale that in places is separated into members by four mappable fine- to medium-grained sandstones, named by Wilson, Jewell, and Luther (1956) the Stephens, Petros, Sand Gap, and Newcomb sandstones. The sandstones are lenticular and commonly are 10 m (30 ft) or more thick but rarely are more than 30 m (100 ft) thick. Important coals within the formation are the Coal Creek, Petros, Blue Gem, and Jellico coals. The Coal Creek and the Jellico are the most extensively mined and have the largest reserves in the formation.

Coal Creek coal bed.—The Coal Creek coal bed underlies much of the northern Tennessee coal field (fig. 17). It is a high-quality steam coal (table 1). Thicknesses may be as much as 1.65 m (5.42 ft), but they vary greatly within short distances. A rider seam commonly is about 6.1 m (20 ft) above the coal. Recoverable reserves of the Coal Creek coal are in Anderson, Campbell, and Claiborne Counties. Additional reserves are in Morgan and Scott Counties in a coal seam that is variously correlated either with the Poplar Creek or with the Coal Creek. Because evidence is not available to resolve the correlation problem, the two areas are separated by a dashed line in figure 17. For convenience, however, the coal tonnage is included with the Coal Creek even though the correlation is uncertain. Total recoverable reserves of the Coal Creek coal are approximately 190 million short tons.

Extensive underground mining of the Coal Creek seam began in 1870 and continued into the 1950's in Anderson County near Oliver Springs, Briceville, Lake City, and Eagan (fig. 17). Today, the only

TABLE 1.—*Representative analyses and rank of selected Tennessee coal beds*

[Data from Luther, 1959, and Johnson and Luther, 1972]

Seam	Proximate percent				Ultimate percent					Heat value (btu)	Ash softening tempera-ture/°F	Rank average [1]
	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen			
Sewanee	3.04	29.21	58.17	9.62	0.93	4.96	75.29	1.48	8.16	13,099	2,532	hvAb[2]
Coal Creek	3.47	36.44	55.49	4.67	1.34	5.42	76.26	1.86	9.64	13,760	2,030	hvBb
Jellico	3.06	36.79	53.53	6.68	2.20	5.54	77.06	1.89	8.6	13,509	2,304	hvBb
Big Mary	3.08	36.0	49.67	11.27	3.12	5.1	70.83	1.49	8.51	12,667	2,304	hvCb
Pewee	3.60	36.81	54.23	5.7	.68	5.55	78.73	1.65	10.18	13,571	2,421	hvBb

[1] Ranked according to Standard Specifications for Classification of Coals by Rank of the American Society for Testing and Materials, 1967.
[2] Abbreviations.
hvAb=high-volatile A bituminous.
hvBb=high-volatile B bituminous.
hvCb=high-volatile C bituminous.

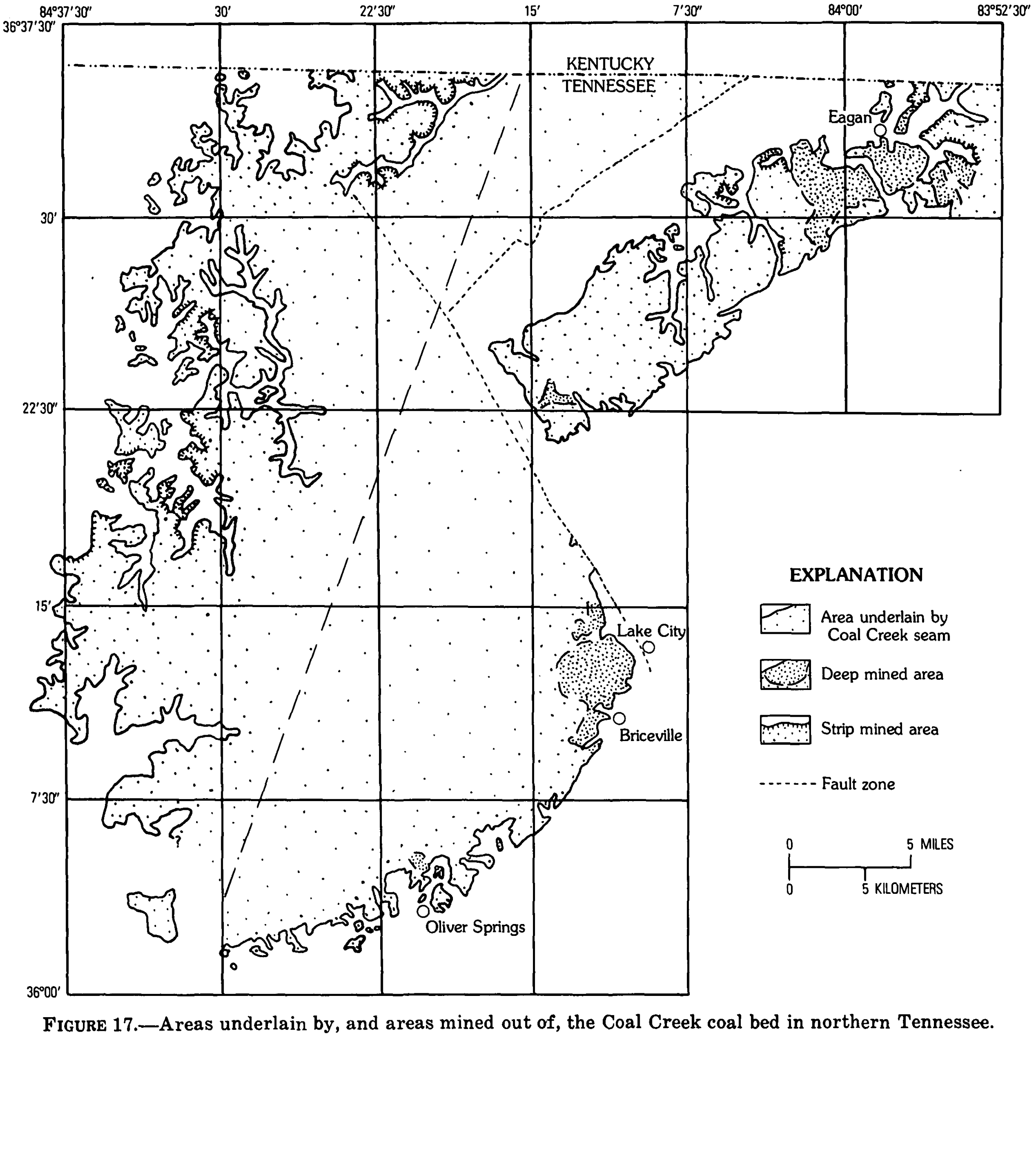


FIGURE 17.—Areas underlain by, and areas mined out of, the Coal Creek coal bed in northern Tennessee.

major underground mine on the Coal Creek coal is the Consolidation Coal Co. mine on Tackett Creek in Claiborne County. Less than 20 percent of the total Coal Creek surface trace has been surface mined.

Jellico coal bed.—Approximately 122 m (400 ft) above the Coal Creek coal is the Jellico coal (fig. 18). The Jellico coal is a medium-grade seam (table 1). Recoverable reserves are in Anderson, Campbell, Claiborne, Morgan, and Scott Counties. These reserves total approximately 54 million short tons.

Present deep mining of the Jellico coal is limited to a few relatively small mines. However, large old deep mines are near Petros, Jellico, and Log Mountain west of Bryson. Many of the surface mines on the Jellico seam are near the large old underground mines at Petros and Jellico. In addition to these, several strip mines are on the Jellico coal in Scott County. Less than 10 percent of the total surface trace of the Jellico coal is stripped.

Indian Bluff Formation.—The Indian Bluff Formation consists of 61 to 143 m (200 to 470 ft) of clayey to sandy gray shale and minor amounts of siltstone and sandstone. The formation includes the strata between the top of the the Jellico coal and the top of the Pioneer Sandstone Member, or Jordan coal bed where the Pioneer is absent. The Indian Bluff Formation is in places divided into members by the Seeber Flats (Wilson and others, 1956),

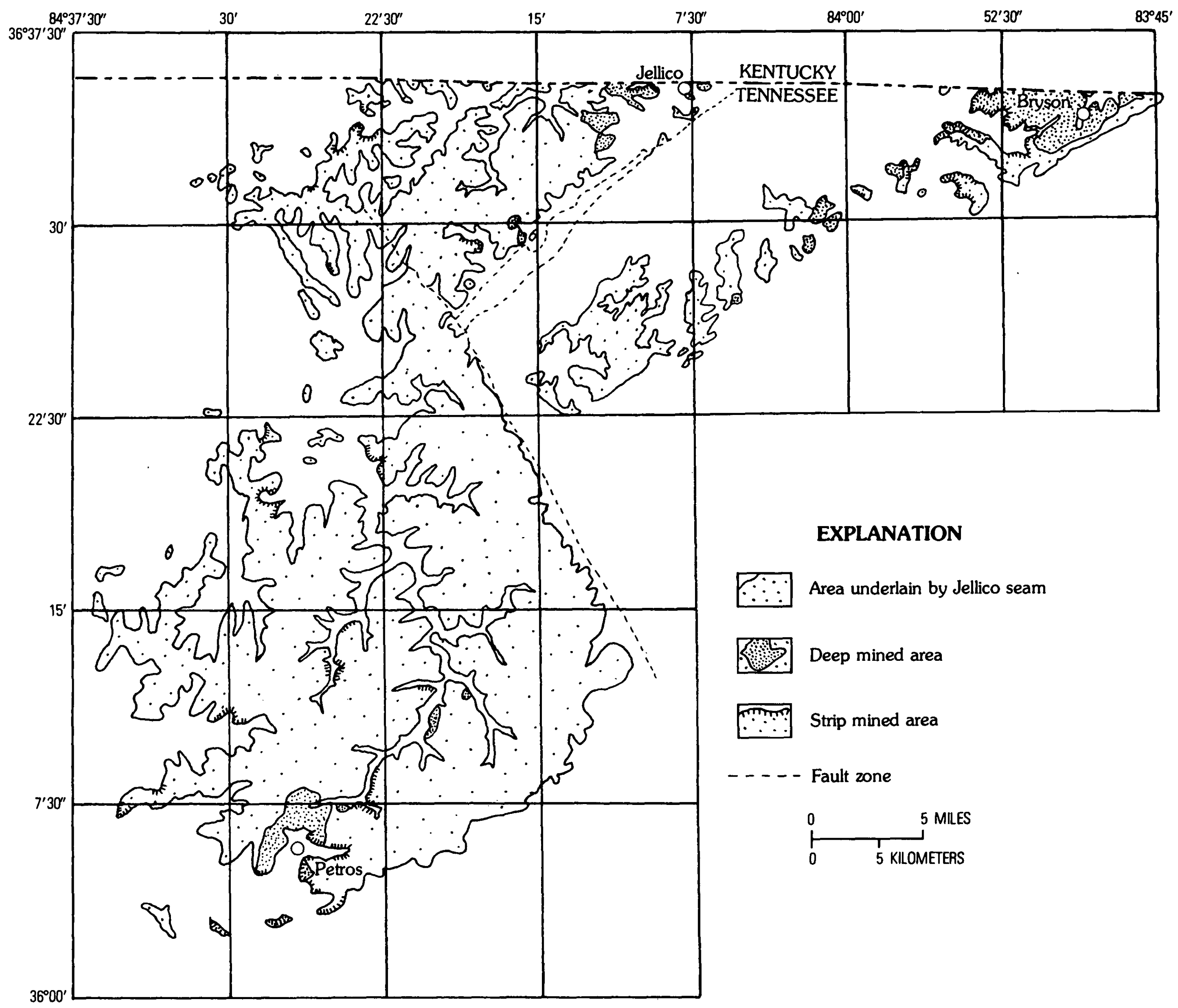


FIGURE 18.—Areas underlain by, and areas mined out of, the Jellico coal bed in northern Tennessee.

Stockstill (Wilson and others, 1956), and Pioneer Sandstones (Glenn, 1925). The sandstones are fine to medium grained and lenticular. Thicknesses of these sandstones are as much as about 24 m (80 ft), and of the three, the Pioneer Sandstone is the thickest and most widespread. The only coal bed of any economic significance within the Indian Bluff Formation is the Joyner seam.

Graves Gap Formation.—The Graves Gap Formation extends from the top of Pioneer Sandstone to the top of the Windrock coal bed. The formation consists of 55 to 122 m (180 to 400 ft) of clayey to sandy gray shale and minor amounts of siltstone and sandstone. In places, sandstone beds, named the Armes Gap Sandstone and Roach Creek Sandstone by Wilson, Jewell, and Luther (1956), are thick enough to divide the formation into members. The sandstones are generally fine to medium grained and lenticular. These sandstone members may be as thick as 21–24 m (70 to 80 ft). The Graves Gap Formation contains four economically important coal beds, the Jordan, Lower Pioneer, Upper Pioneer, and Windrock.

The Redoak Mountain Formation.—The Redoak Mountain Formation includes the strata between the top of the Windrock coal and the top of the Pewee coal. The formation consists of 91 to 140 m (300 to 460 ft) of gray clayey to sandy shale and minor amounts of sandstone and siltstone. In places, the formation is divided into members by lenticular sandstones named the Caryville, Fodderstack, and Silvey Gap Sandstones by Wilson, Jewell, and Luther (1956). The Silvey Gap and Caryville are as thick as 20 m (65 ft), but the Fodderstack is thinner and locally attains a thickness of 10 m (30 ft). Important coal beds in the Redoak Mountain Formation are the Big Mary, Beech Grove, Sharp, Red Ash, Walnut Mountain, and Pewee. Of these, the Big Mary (fig. 19) and the Pewee (fig. 20) are the most widely mined and contain the greatest reserves.

Big Mary coal bed.—Recoverable reserves of the Big Mary coal bed were 101,274,000 short tons in 1959 (Luther, 1959). The Big Mary seam ranges in thickness from 0.30 to 2.59 m (1 to 8.5 ft), including shale partings and beds that range generally from 0.05 to 1.2 m (0.17 to 4 ft). In a few places, the Big Mary is split by shale beds as much as 3 m (10 ft) thick, so that each split is too thin to mine. The Big Mary has been extensively strip mined, augered, and deep mined in Tennessee (fig. 19). Approximately 20 percent of the Big Mary cropline has been strip mined. The most extensively deep-mined areas are near Petros, Devonia, Rosedale, Turley, and Fork Ridge. The Big Mary seam is a low-grade steam coal because of its relatively high sulfur and ash contents (table 1). The Tennessee Valley Authority purchases most of the coal mined from the Big Mary seam.

Pewee coal bed.—The Pewee coal bed is at the top of the Redoak Mountain Formation approximately 116–122 m (380–400 ft) above the Big Mary coal bed. Recoverable reserves of the Pewee seam were 32,934,000 short tons in 1959 (Luther 1959). Since then, an undetermined amount has been mined. The Pewee seam ranges in thickness from approximately 0.3 to 2.1 m (1 to 7 ft) including partings that range from 5 to 76 cm (0.17 to 2.5 ft). At most places the coal is solid, or partings aggregate less than 15 cm (0.5 ft) in thickness. The Pewee has been extensively strip mined, augered, and deep mined in Tennessee (fig. 20). Approximately 35 percent of the Pewee cropline has been strip mined. The most extensively deep-mined areas are in the mountains surrounding Pewee and in the areas northwest of Petros, west of Fork Ridge, and north of Windrock. The Pewee is a high-grade steam coal (table 1).

Vowell Mountain Formation.—The Vowell Mountain Formation includes the strata between the top of the Pewee coal and the top of the Frozen Head Sandstone. The formation ranges from 70 to 128 m (230 to 420 ft) in thickness and consists of gray clayey to sandy shale and minor siltstone and some sandstone. A sandstone member in the middle of the formation was called the Pilot Mountain Sandstone by Wilson, Jewell, and Luther (1956). Glenn (1925) named the Frozen Head Sandstone at the top. Like other sandstones in the delta-plain sequence, these sandstones are fine to medium grained, are lenticular, and may be as much as 18–20 m (60–65 ft) thick. The coal beds in the Vowell Mountain Formation are the Split, Petree, Lower and Upper Pine Bald, and Rock Spring coals. Only the Lower Pine Bald coal and the Rock Spring coal have been mined, and the Rock Spring is the highest seam in Tennessee that has been mined underground on a large scale (Luther, 1959, p. 136). Barlow (1969) studied the plant fossils of the northern coal field and concluded that the Rock Springs coal bed was the base of the Allegheny Series in Tennessee.

Cross Mountain Formation.—The Cross Mountain Formation includes strata between the top of the Frozen Head Sandstone and the top of Cross Mountain and is 169 m (554 ft) thick at its type section. These are the youngest Pennsylvanian beds preserved in Tennessee. The formation is composed of sandstone and shale members lithologically similar

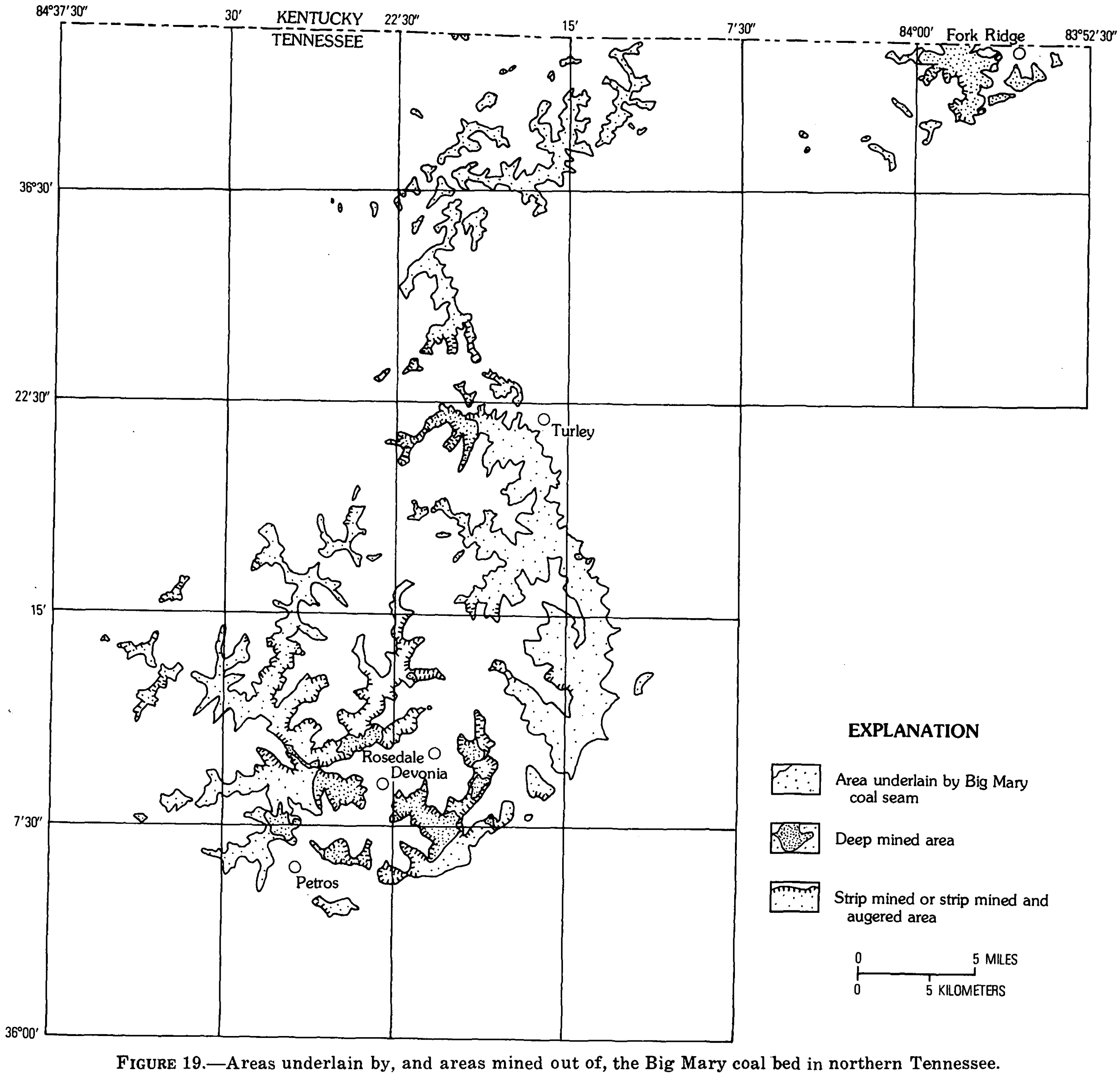


FIGURE 19.—Areas underlain by, and areas mined out of, the Big Mary coal bed in northern Tennessee.

to the strata below. Named sandstone members are the Low Gap and Tub Spring Sandstones. They are both lenticular and vary greatly in thickness; the Low Gap reaches a maximum of 21.3 m (70 ft), and the Tub Spring is as much as 15.2 m (50 ft) thick. The Cross Mountain contains six named coal seams in Tennessee, but only the Upper and Lower Grassy Spring coals, the Cold Gap coal, and the Lower Wild Cat coal have been mined (Johnson and Luther, 1972, p. 5).

INDICATORS OF DEPOSITIONAL ENVIRONMENTS IN THE UPPER-DELTA-PLAIN SEQUENCE

The sequence reviewed in this section includes the upper three (Redoak Mountain, Vowell Mountain, and Cross Mountain) of six formations generally assigned to the Middle Pennsylvanian in Tennessee. The interval, which is about 305 m (1,000 ft) thick, was selected for study because it was only recently strip mined, and the highwall exposures are largely

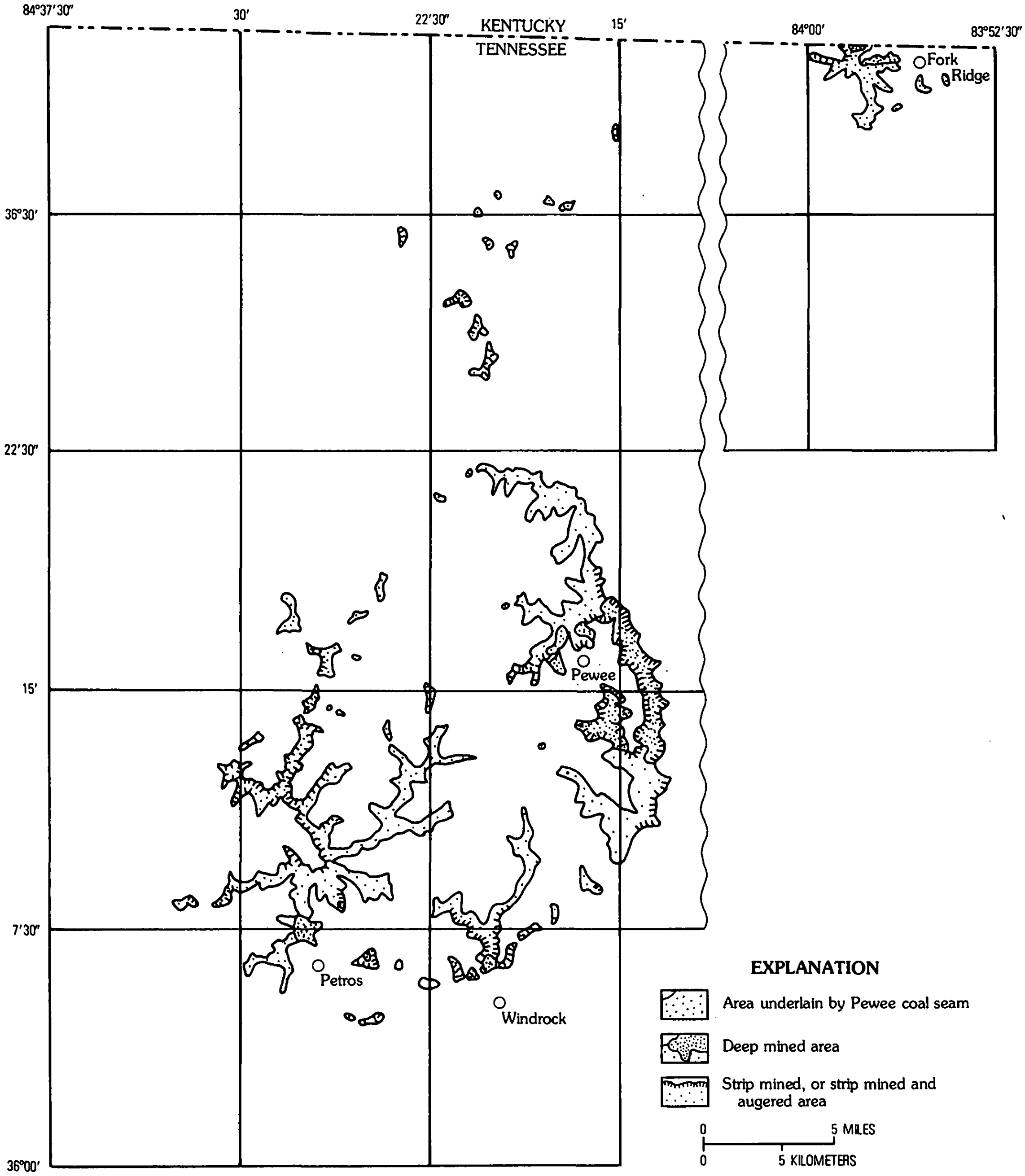


FIGURE 20.—Areas underlain by, and areas mined out of, the Pewee coal bed in northern Tennessee.

unreclaimed. The interval contains a dozen or more minable coal seams within the Wartburg basin, but only two or three (principally the Big Mary and Pewee coals) are laterally continuous and minable almost basinwide.

Figure 21 is a columnar section of the 305-m- (1,000-ft-) thick sequence, the width of which is designed to show both the primary lithology, and selected drawings of 50-m- (164-ft-) long sections of strip-mine highwalls. The lateral sections depict facies relationships seen in highwall exposures near the Scott-Anderson County line. The columnar section consists of several sequences that coarsen upward, each of which begins with dark-gray shale and fauna indicative of a marine or brackish-water incursion. Overlying channel, levee, and splay deposits reflect the progradation and reestablishment of the delta. The extent and duration of each episode is indicated by the thickness and extent of the facies. The establishment of a coal swamp signaled the end of each progradational phase, at which time the river system that maintained the complex was

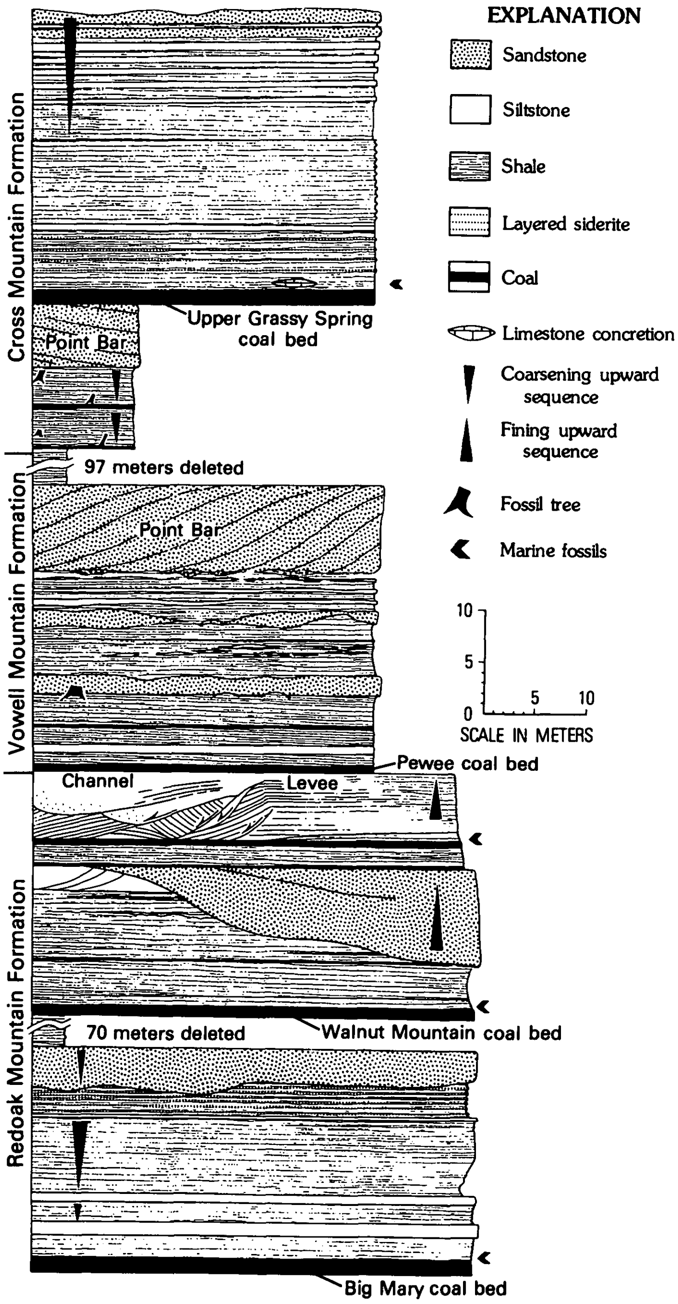


FIGURE 21.—Columnar section of upper Middle Pennsylvanian coal-bearing sequence, with drawings of strip-mine highwalls.

abandoned; then, when subsidence exceeded sedimentation, the delta plain was inundated.

The stage of delta development represented by the columnar section was principally that of the lower delta plain and was characterized by broad interdistributary bays and sluggish channels having low, barely emergent levees and numerous but localized crevasse splays. Although the sequence is generally one of progradation leading to the ultimate establishment of an upper-delta-plain/terrestrial environment, this progradation was intermittent and was punctuated by many reversals or lateral shifts in environment. The environments represented range from shallow-water marine to those of the upper delta plain including freshwater swamps and coalesced point-bar deposits.

The broad areal extent of the Big Mary coal bed within the Wartburg basin and the marine zone that typically overlies it testify to the abandonment and inundation of a widespread delta complex. At least seven marine incursions took place within the interval studied. The one that covered the Big Mary coal was relatively slow to retreat, as is evidenced by a sequence that is 17 m (55 ft) thick of medium- to dark-gray clay shale beds that contains a diverse marine fauna, rhythmically repetitious thin layers of siderite, and several tabular clayey siltstone beds interpreted to be delta-front sheet deposits. The marine zone is discontinuous and is locally absent eastward across the basin. This absence suggests that the sea invaded from the west (Thomas Roberts, oral commun., 1977). A second prominent marine zone covers the Upper Grassy Spring coal bed, but, because the Grassy Spring coals are confined to only the higher mountain tops, strip mines are few and far apart, and the associated marine zone is poorly described. Distributary-mouth bar sequences were observed in highwalls above both the Big Mary (White, 1975) and Upper Grassy Spring (top of section—fig. 21) coals.

When the delta complex grew substantially, channels formed and meandered broadly, forming extensive point-bar deposits such as those in the highwalls above the Pewee coal bed (fig. 21). Abundant fossil remains of large trees are preserved in growth position on levees and in interdistributary areas at several horizons but are best preserved in the interval overlying the Pewee coal bed. The presence of many large trees is interpreted to signify the establishment of a freshwater swamp similar in some ways to modern cypress swamps.

SIDERITE

Siderite is present throughout the entire study interval, in both marine and nonmarine beds. The nature of siderite occurrences varies within the sequence, however, and is considered useful in interpreting depositional environments. In sequences known to be marine by virtue of fossils and facies associations, siderite is present in thin (about 5 cm, 2 in.) persistent layers that alternate with the dark-gray silty shales. Above the marine deposits, these layers grade into segmented disk-shaped nodular masses as the sequence in which they are enclosed coarsens and becomes less marine. Occurrences of siderite in this layered form are typical both of the gray shale sequence overlying the Big Mary coal bed and of other marine intervals within the sequence studied.

The marine formation of siderite was not accepted by Berner (1971). He described siderite as a relatively common constituent of ancient nonmarine sediments, where it is normally found in association with coal beds and freshwater clay. He stated further that siderite is not stable in marine sediments and has never been observed forming in modern marine sediments.

Large lens-shaped concretions of siderite or limestone (micrite) as much as 2.4 m (8 ft) in diameter and 1 m (3.3 ft) in width are found within the marine to brackish intervals, especially above the Big Mary coal, but the concretions are not everywhere associated with layered siderites. That these concretions, called "flying saucers" by the miners, are clearly diagenetic is indicated by the fact that thin laminae of the enclosing shale pass undisturbed into the carbonate masses. Subsequent compaction caused draping of layers immediately above and beneath the concretions.

Where trees are preserved in growth position in carbonaceous shale of terrestrial origin, siderite is present in large irregularly shaped masses, some of boulder proportions. Unlike the conformable disk-shaped masses in the marine intervals, the irregularly shaped masses cut across the bedding as did the roots of ancient trees around which they nucleated. Less commonly, siderite masses filled in and preserved the trees themselves. Siderite masses of the irregularly shaped variety are most abundant where fossil trees are large and numerous; hence, they are believed to be useful in recognizing freshwater-swamp and upper-delta-plain environments.

Both nonmarine and marine siderite deposits are believed to have lithified quickly, whether they precipitated chemically as a primary sediment or formed diagenetically. As channels moved and the shales and their interbedded siderite layers were scoured, the lithified siderite formed large clasts in channel lag deposits.

FOSSIL TREES

Studies of the fossil trees preserved in growth position in the area around the Wartburg basin have provided a new understanding of depositional environments and rates of sedimentation. The transition from a lower-delta plain to an upper-delta plain environment is marked by a gradual change in flora. Following widespread marine incursions, such as the one that terminated the Big Mary coal swamp, the delta complex from lower to upper delta plain was slowly reestablished.

The lower delta plain is characterized by thin and areally restricted levees, splays, and bar deposits devoid of plants preserved in life position. Coincident with the growth in size and extent of the levees and splays is the appearance of the tree, *Calamites*. Because of the early appearance of *Calamites* in the reestablishment and progradation of the delta, *Calamites* is thought to have been more salinity tolerant than the larger *Lepidodendron* and *Sigillaria* found preserved in growth positions higher in the sequence and hence higher on the delta plain. Probably *Calamites* first became established on low, barely subaerial levees where pore waters were fresh to brackish but where salinity varied widely seasonally if not diurnally. Because *Calamites* had a wide range of salinity tolerance, it persisted on the delta plain in freshwater environments.

Upward in the section and in association with larger and coarser levee, splay, and point-bar deposits, the larger *Lepidodendron* and *Sigillaria* appear and become abundant. These larger trees probably had a low salinity tolerance and grew only in freshwater environments. The trees became established first on levees on the lower delta plain where pore waters were fresh; they spread onto the upper delta plain and into the freshwater interdistributary areas, became more abundant, and formed swamps. The presence of *Calamites* among *Lepidodendron* and *Sigillaria* indicates that the environments in which *Calamites* flourished included freshwater environments. *Sigillaria* and *Lepidodendron* are particularly abundant in the interval immediately overlying the Pewee coal.

In strip-mine highwalls, the sequence observed consists of interbedded, interdistributary silty gray shale and undulating distal levee or flood deposits. Fossil trees 1 m (3.3 ft) or more in diameter have roots in the gray shale, indicating that the trees grew in a shallow-water, highly carbonaceous swamp environment. The undulating fine sandstone and siltstone layers represent flood deposits, which periodically covered the swamps and buried the trees to depths of 0.5 m (1.6 ft) or more. Burial to such depths kills most modern trees, but these ancient trees were capable of generating new roots at the new sediment-water interface (fig. 22).

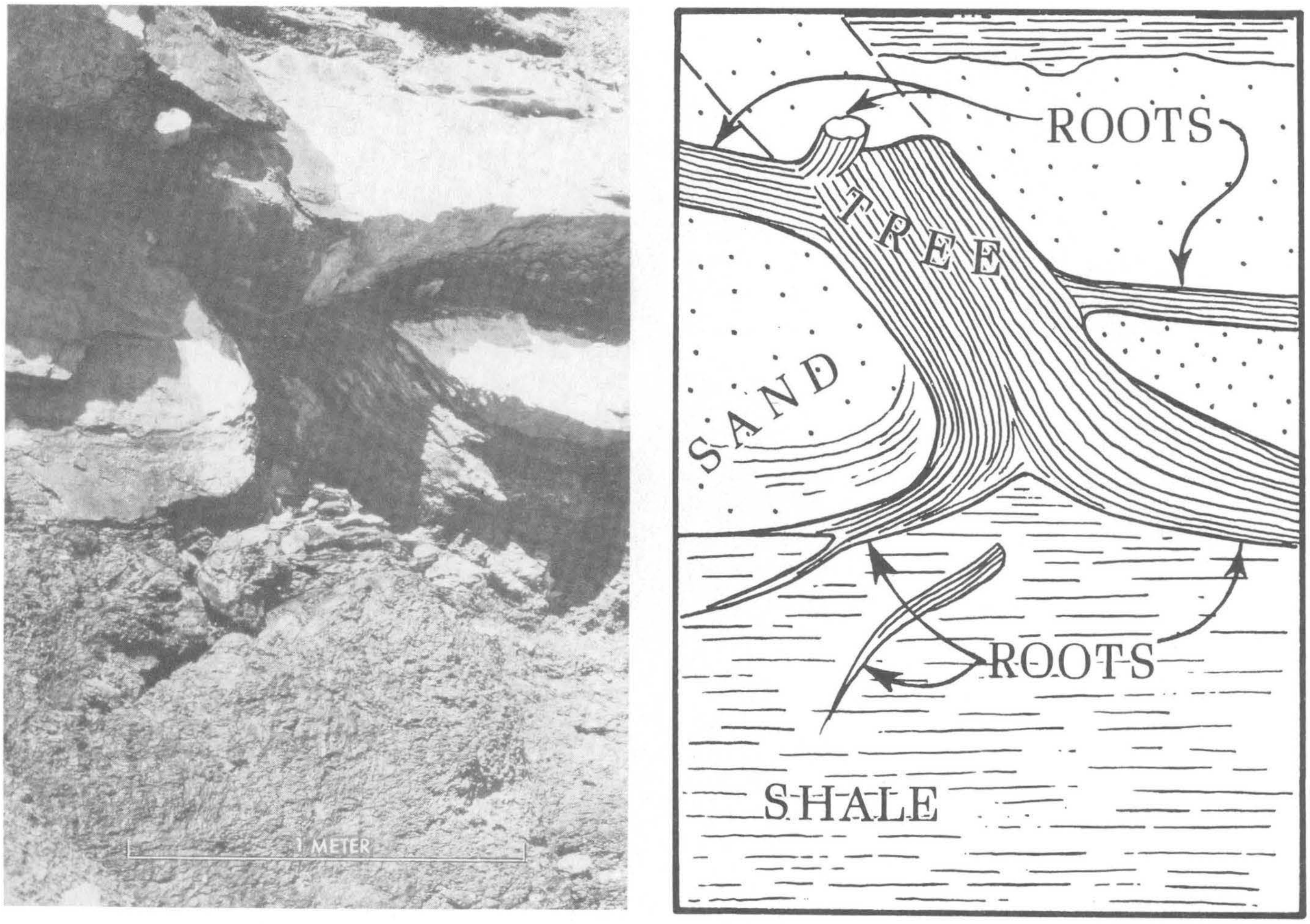


FIGURE 22.—Tree, showing generation of new roots at a higher sediment-water interface that formed when the base was buried by a flood deposit.

In several deposits, the base of a fossil tree is surrounded by a planar-convex body of sandstone as shown in figure 23. The sand collected in a depression produced by compaction of the swamp-floor mud by the increasing weight of the growing trees. During floods, the depressions around the bases of trees were filled with the coarser sediment carried by the moving water. Within the planar-convex bodies, numerous carbonaceous partings contain roots and conform to the curvature of the lower convex boundary of the sand body, indicating that tree growth, compaction, sand deposition, and the generation of new roots at each successive sediment-water interface were all parts of a gradual continuing process.

Figure 24 shows a tree that was buried to a depth of 4.6 m (15 ft). Because the tree is in growth position and shows no root regeneration, it probably was buried very quickly, certainly before it could decay. Probably the tree (and others like it) grew in a back swamp, the level of which was substantially below the water level of the adjacent levee-confined river. When crevasses formed in the natural levee, sediment-laden waters rushed into the back swamp, their velocity was quickly checked, and deposits were immediately laid down around the trees. Thus, a tree, rooted in mud, could be buried by 4.6 m (15 ft) of sediment without being knocked over by the transporting current. Minkin (1977) described several trees that were bent over, all at the same level and in the same direction during burial by such a flow. Moving sediment and water apparently continued to push against the upper parts of the trees after the lower parts of the trees had been buried and stabilized.

HEAVY METALS AND SULFUR

Franks (1976) and Thompson (1977) conducted studies of the heavy-metal content and associations of several depositional facies in the hope that these

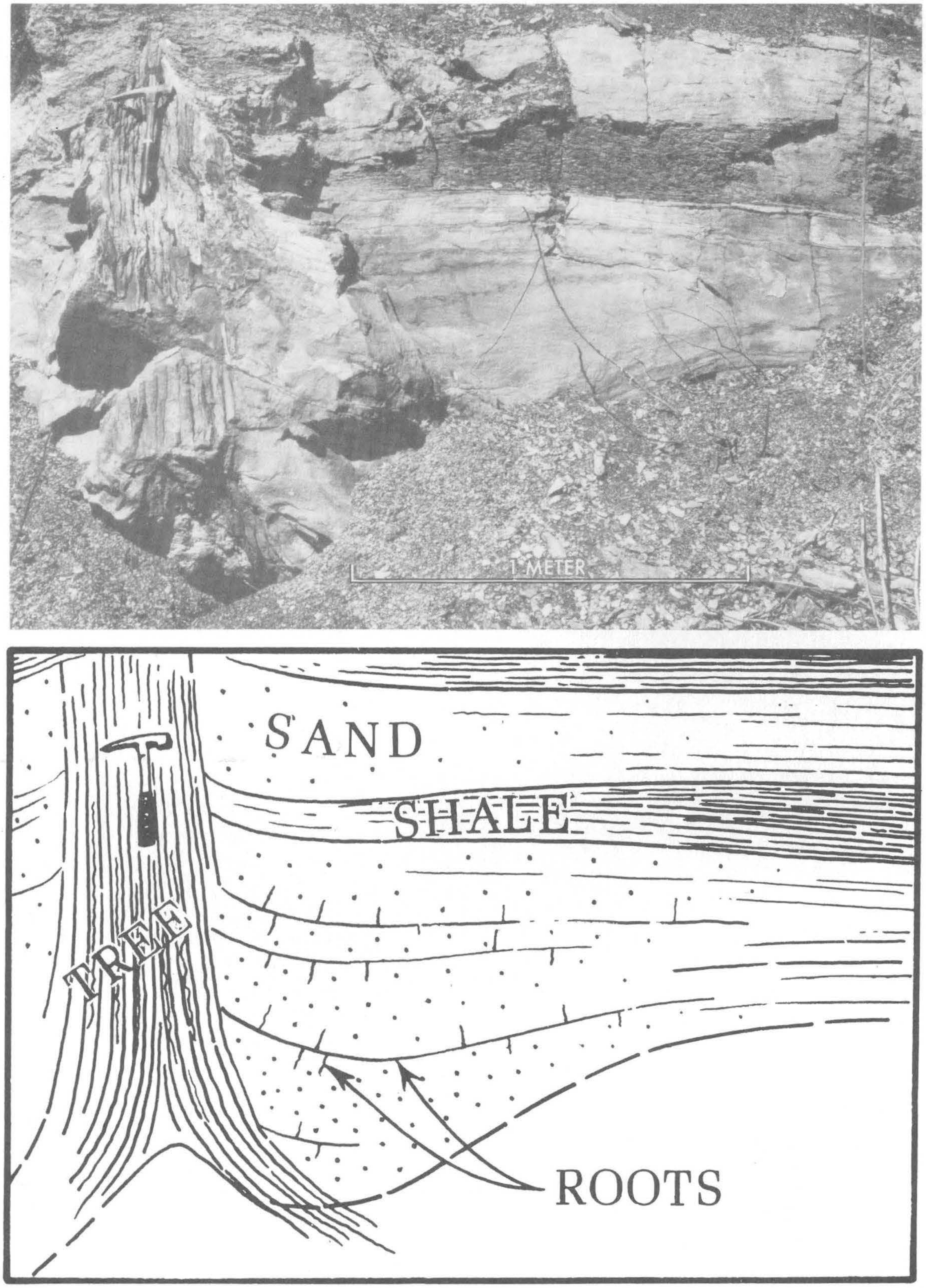


FIGURE 23.—Planar-convex sand bodies at the base of a fossil tree.

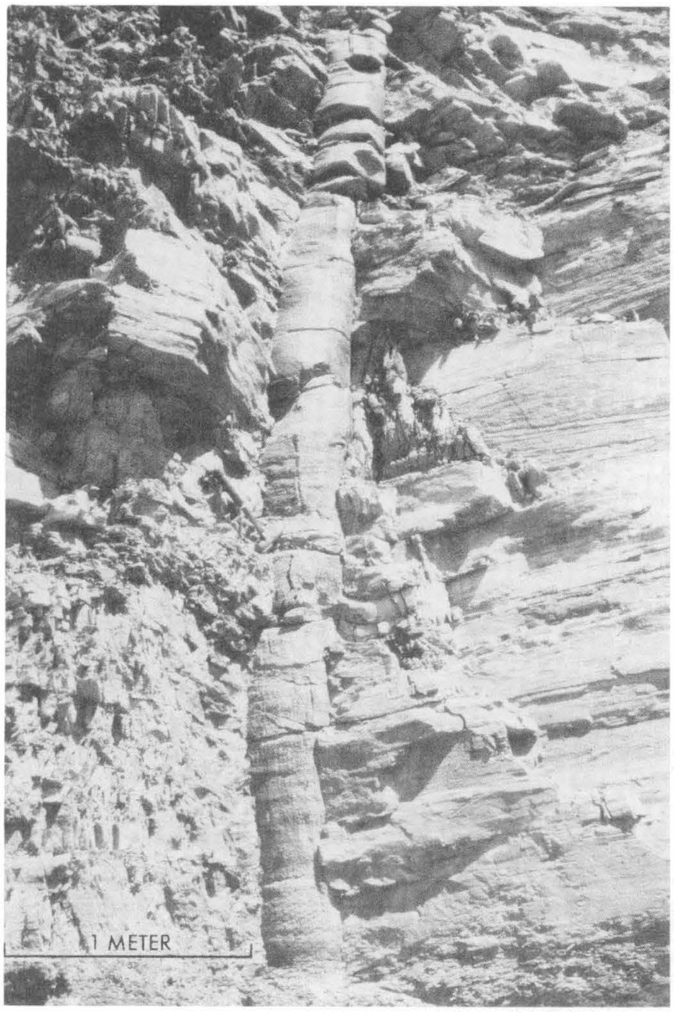


FIGURE 24.—*Lepidodendron* buried in growth position by shaly deposits to a depth of 4.6 m (15 ft).

would provide criteria for distinguishing marine from nonmarine sediments or marsh deposits from swamp deposits. The two studies focused on the Big Mary and Pewee coals and the sedimentary rocks, exposed above them in strip-mine highwalls. The Big Mary was selected because it is overlain by a marine sequence and the Pewee because it is overlain by freshwater swamp deposits. The elements investigated were As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Rb.

The studies were inconclusive about the value of these elements as environmental indicators. However, the studies did show that the concentration of heavy metals is primarily a function of grain size. Concentrations are high in the shale, particularly in the shale immediately overlying coal beds, but are relatively low in the coarser deposits. The coal beds themselves have low concentrations of the heavy metals.

The coal in the Middle Pennsylvanian sequence is typically high in sulfur and ash. In places, the Big Mary coal contains 2.8 percent sulfur and 9.5 percent ash, and the Pewee coal contains 1.1 percent sulfur and 10.9 percent ash (Garman and Jones, 1975). The ash content reflects proximity to a source of detrital sediment during peat accumulation, whereas sulfur content relates in some degree to the position on the delta-plain complex where the coal formed. The high sulfur content of the Big Mary supports the inference that it was formed on the lower delta plain in association with brackish or marine water. The moderate sulfur content of the Pewee coal supports the interpretation that it was deposited higher on the delta plain in association with fresh water in a depositional environment similar to that of the Eocene Wilcox lignite of Texas (Kaiser, 1974). The high sulfur and heavy-metal concentrations in these and other Middle Pennsylvanian coals indicate that the Tennessee area, like the area in West Virginia described by Horne and others [1] (1977), was slow to subside.

MISSISSIPPIAN OIL AND GAS FIELDS IN THE NORTHERN CUMBERLAND PLATEAU

Most of Tennessee's oil production has come from carbonate reservoirs of Mississippian age in Scott and Morgan Counties. Since 1969, more than 90 percent of the State's oil production has come from Fort Payne reservoirs found in these two counties. Although oil and gas production in this area dates from the early 1900's, the discovery of the Oneida West Fort Payne pool in 1969 initiated an active shallow play which is still continuing. Although the primary objective is limestone of the Fort Payne Formation, smaller oil and gas pools are in the Monteagle, Bangor, and Warsaw limestones and the Hartselle sandstone. To date, no significant discoveries have been made in the Pennsylvanian rocks, although several small oil wells and shut-in gas wells have been completed in Lower Pennsylvanian sandstone in Scott County.

Figure 25 shows the locations of the more important Fort Payne and Monteagle pools in Scott, northern Morgan, and eastern Fentress Counties. Table 2 lists selected pools, discovery dates, number

[1] Horne, J. C., Ferm, J. C., Caruccio, F. T., Cohen, A. D., Baganz, B. P., Cantrell, C. L., Corvinus, D. A., Geidel, G., Howell, D. J., Mathew, D., Melton, R. A., Pedlow, G. W., Sewel, J. M., and Staub, J. R., 1977, Depositional models in coal exploration and mine planning, unpublished manuscript on file with (1) Tennessee Div. Geology, Knoxville, Tenn., and (2) Carolina Coal Group, Dept. Geology, Univ. South Carolina, Columbia, S.C.

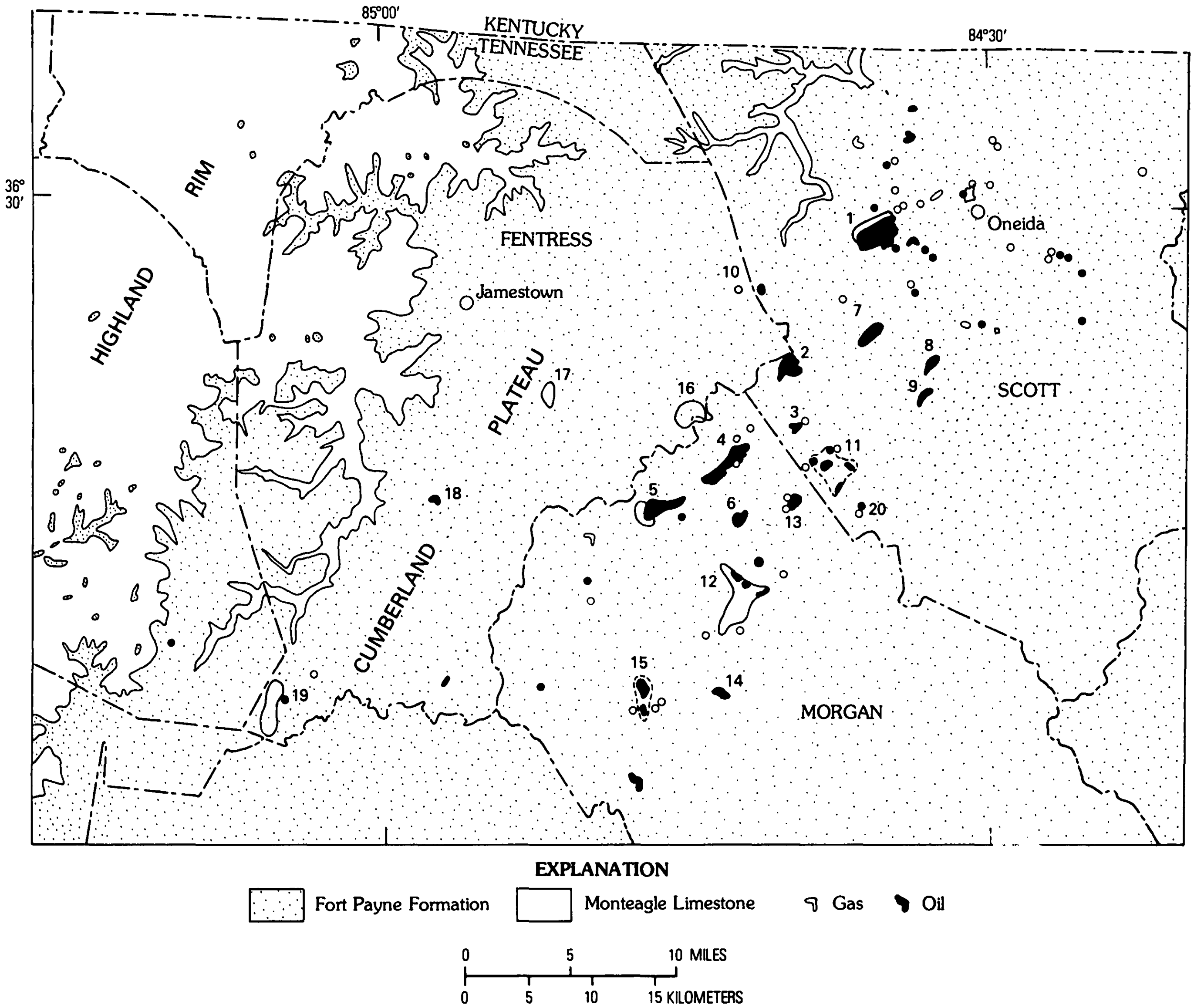


FIGURE 25.—Mississippian oil and gas pools in the northern Cumberland Plateau. Dashed line encloses a group of oil pools. Fort Payne production: 1. Oneida West, 2. Honey Creek So., 3. Gum Branch, 4. Indian Creek, 5. Burrville, 6. Boone Camp (abandoned), 7. Lick Branch unit, 8. Low Gap, 9, Reuben Hollow, 10. Hurricane Ridge. Monteagle production: 11. Glenmary, 12. Sunbright, 13. Union Hill, 14. Little Clear Creek, 15. Douglas Branch, 16. Shirley, 17. Big Branch, 18. Grimsley North, 19. Hurricane Creek, 20. Coal Hill.

of producing wells, and cumulative oil production. Fort Payne reservoirs have produced nearly 4 million bbl of oil in Scott and Morgan Counties, 3.8 million bbl since 1969. Data on gas-pool production are omitted from table 4 because production to date has been quite limited. Owing to lack of pipeline facilities, many of the gas wells in the trend are currently shut-in.

As presently known, the area of productive Fort Payne is about 32 km (20 mi) long, is 13–19 km (8–12 mi) wide, and trends northeast from Burrville in Morgan County to Oneida in Scott County. No major structural features are present in the area, which is west of the Pine Mountain fault block and north of the Cumberland Plateau overthrust. Regional dip is about 7.6 m/km (40 ft/mi) to the southeast. Mapping of the subsurface reveals only minor structural warping. Available data indicate that most Mississippian reservoirs are primarily stratigraphic traps having little or no relationship to observed structure.

Fort Payne reservoirs consist of one or more zones of vugular porosity found within local lenses or mounds of fossiliferous and fragmental limestone

TABLE 2.—*List of selected Mississippian oil and gas pools, Tennessee*

Number in figure 25	Field name, County	Year of discovery	Number of producing wells	Cumulative production to December 1977 (bbl)
	Fort Payne Pools			
6	Boone Camp, Morgan	1924	13	150,000 est.
1	Oneida West, Scott	1969	40	1,215,687
(Off fig. 25)	Broken Leg, Overton	1970	10	43,699
2	Honey Creek So., Scott	1972	15	239,586
3	Gum Branch, Scott	1973	6	71,509
4	Indian Creek, Morgan	1973	35	1,312,102
5	Burrville, Morgan	1974	39	321,700
7	Lick Branch Unit, Scott	1976	26	463,968
8	Low Gap, Scott	1976	18	100,863
9	Reuben Hollow, Scott	1977	10	37,456
	Monteagle Pools			
11	Glenmary, Scott	1916	20	206,500 est.
14	Little Clear Creek, Morgan	1928	4	79,050
20	Coal Hill, Scott	1950	1	38,567
15	Douglas Branch, Morgan	1972	12	47,288

[1] Abandoned.

that overlie the typical massive chert and siliceous carbonate rocks of the lower Fort Payne. These lenses are generally tabular or elongate, locally are as thick as 24 m (80 ft), and range in areal extent from 80–120 ha (200–300 acres) to 7–10 km^2 (3–4 mi^2). Studies of samples indicate that these lenses contain little or no chert and are in sharp contact with the underlying cherty carbonate. They are overlain by dark-gray, impermeable, dolomitic siltstones (upper part of the Fort Payne and lower part of the Warsaw) which serve as seals for the reservoirs. Structural mapping indicates that a surface of considerable relief is on the top of the cherty carbonates even within the limits of a single pool. Previous studies (Statler, 1971, 1975) suggest that the thickness and configuration of the cherty carbonate in the lower part of the Fort Payne may have an important bearing on the location and geometry of the productive limestone lenses.

Younger Mississippian oil and gas fields have been found in a wider area extending into western Fentress County, and several small fields have been found along the eastern edge of the Cumberland Plateau in Anderson and eastern Morgan Counties. The most important of these fields are in the Monteagle Limestone, which locally has good porosity and permeability in the massive oolitic and bioclastic limestone facies. Most of the Monteagle discoveries are gas reservoirs; they are apparently mainly stratigraphic traps, although structural warping may contribute fracture porosity locally. The fact that several gas-gathering systems are currently being constructed in the area should greatly stimulate interest in and drilling for these shallower gas reservoirs.

Outside of the area shown in figure 25, the Cumberland Plateau is only sparsely drilled. Although widely scattered wildcats in the southern and eastern parts of the plateau have not yet found commercial quantities of oil or gas, large areas remain virtually untested. Mississippian lithologies and drilling depths are comparable to those of the producing area in the northern plateau.

REFERENCES CITED

Barlow, J. A., 1969, Stratigraphy and paleobotany of the youngest Pennsylvanian strata in the Caryville, Tennessee area: Knoxville, Univ. Tennessee, Ph.D. dissert., 341 p.

Bergenback, R. E., Horne, J. C., and Inden, R. F., 1972, Stops 3 and 4—Depositional environments of Mississippian carbonate rocks at Monteagle, Tennessee, *in* Ferm, J. C., Milici, R. C., and Eason, J. E., Carboniferous depositional environments in the Cumberland Plateau of southern Tennessee and northern Alabama: Tennesse Div. Geology Rept. Inv. 33, p. 14–18.

Berner, R. A., 1971, Principles of chemical sedimentology: New York, McGraw-Hill, 240 p.

Butts, Charles, 1927, Oil and gas possibilities at Early Grove, Scott County, Virginia: Virginia Geol. Survey Bull. 27, 18 p.

Butts, Charles, and Nelson, W. A., 1925, Geology and mineral resources of the Crossville quadrangle, Tennessee: Tennessee Div. Geology Bull. 33–D, 41 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.

——— 1898, Description of the Richmond quadrangle [Kentucky]: U.S. Geol. Survey Geol. Atlas, Folio 46, 4 p., 4 maps.

Chowns, T. M., and Elkins, J. E., 1974, The origin of quartz geodes and cauliflower cherts through the silicification of anhydrite nodules: Jour. Sed. Petrology, v. 44, no. 3, p. 885–903.

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.

Conkin, J. E., and Conkin, B. M., 1975, Lower Mississippian sequence at Standing Rock, Stewart County, Tennessee [abs.]: Geol. Soc. America Abs. with Programs, v. 7, no. 4, p. 478.

Dennison, J. M., and Boucot, A. J., 1974, Little War Gap at Clinch Mountain provides standard reference section for Silurian Clinch Sandstone and most nearly complete Devonian section in eastern Tennessee: Southeastern Geology, v. 16, no. 2, p. 79–101.

Elrod, M. N., 1899, The geologic relations of some St. Louis group caves and sinkholes: Indiana Acad. Sci. Proc., 1898, p. 258–267.

Engelmann, George, 1847, Remarks on the St. Louis Limestone: Am. Jour. Sci., 2d ser., v. 3, p. 119–120.

Englund, K. J., 1964, Geology of the Middlesboro South quadrangle, Tennessee-Kentucky-Virginia: U.S. Geol. Survey Geol. Quad. Map GQ–301, scale 1:24,000.

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

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, pt. 2, p. 2015.

Ferm, J. C., 1974, Carboniferous environmental models in Eastern United States and their significance, *in* Briggs, Garrett, ed., Carboniferous of the southeastern United States: Geol. Soc. America Spec. Paper 148, p. 79–95.

Ferm, J. C., Milici, R. C., and Eason, J. E., 1972, Carboniferous depositional environments in the Cumberland Plateau of southern Tennessee and northern Alabama: Tennessee Div. Geology Rept. Inv. 33, 32 p.

Franks, C. D., 1976, Heavy metal content of coal and associated rocks in the Indian Fork watershed, Anderson County, Tennessee: Knoxville, Univ. Tennessee, unpub. Master's thesis.

Frazier, W. J., 1975, Celestite in the Mississippian Pennington Formation, central Tennessee: Southeastern Geology, v. 16, no. 4, p. 241–248.

Garman, R. K., and Jones, M. L., 1975, Mineral resources summary of the Fork Mountain quadrangle, Tennessee: Nashville, Tennessee Div. Geology, 30 p. (Accompanies Geol. Map GM 129–NW.)

Glenn, L. C., 1925, The northern Tennessee coal field: Tennessee Div. Geology Bull. 33–B, 478 p.

Glover, Lynn, 1959, Stratigraphy and uranium content of the Chattanooga Shale in northeastern Alabama, northwestern Georgia, and eastern Tennessee: U.S. Geol. Survey Bull. 1087–E, p. 133–168.

Hall, James, 1857, Observations upon the Carboniferous limestones of the Mississippi Valley [abs.]: Am. Assoc. Adv. Sci. Proc., v. 10, pt. 2, p. 54–56.

Hardeman, W. D., and others, 1966, Geologic map of Tennessee: Knoxville, Tennessee Div. Geology, 4 sheets, scale 1:250,000.

Harris, L. D., 1965, Geologic map of the Tazewell quadrangle, Claiborne County, Tennessee: U.S. Geol. Survey Geol. Quad. Map GQ–465, scale 1:24,000.

Harris, L. D., and Mixon, R. B., 1970, Geologic map of the Howard Quarter quadrangle, northeastern Tennessee: U.S. Geol. Survey Geol. Quad. Map GQ–842, scale 1:24,000.

Harris, L. D., Stephens, J. G., and Miller, R. L., 1962, Geology of the Coleman Gap quadrangle, Tennessee and Virginia: U.S. Geol. Survey Geol. Quad. Map GQ–188, scale 1:24,000.

Hass, W. H., 1956, Age and correlation of the Chattanooga Shale and the Maury Formation: U.S. Geol. Survey Prof. Paper 286, 47 p.

Hasson, K. O., 1972, Lithostratigraphy of the Grainger Formation (Mississippian) in northeast Tennessee: Knoxville, Univ. Tennessee, Ph.D. dissert.

——— 1973, Type and standard reference of the Grainger Formation (Mississippian), northeast Tennessee: Tennessee Acad. Sci. Jour., v. 48, no. 1, p. 17–22.

Hayes, C. W., 1891, The overthrust faults of the southern Appalachians: Geol. Soc. America Bull., v. 2, p. 141–152.

Horne, J. C., Ferm, J. C., and Swinchatt, J. P., 1974, Depositional model for the Mississippian-Pennsylvanian boundary in northeastern Kentucky, *in* Briggs, Garrett, ed., Carboniferous of the southeastern United States: Geol. Soc. America Spec. Paper 148, p. 97–114.

Johnson, R. C., and Luther, E. T., 1972, Strippable coal in the northern Cumberland Plateau area of Tennessee: Tennessee Div. Geology Rept. Inv. 34, 41 p.

Kaiser, W. R., 1974, Texas lignite; near-surface and deep-basin resources: Texas Univ. Bur. Econ. Geology Rept. Inv. 79, 70 p.

Keith, Arthur, 1895, Description of the Knoxville quadrangle [Tennessee and North Carolina]: U.S. Geol. Survey Geol. Atlas, Folio 16, 6 p., 4 maps.

———1896, Description of the Briceville quadrangle [Tennessee]: U.S. Geol. Survey Geol. Atlas, Folio 33, 5 p., 4 maps.

Keroher, G. C., and others, 1966, Lexicon of geologic names of the United States for 1936–1960: U.S. Geol. Survey Bull. 1200, 3 v.

King, P. B., and Beikman, H. M., compilers, 1974, Geologic map of the United States (exclusive of Alaska and Hawaii): Reston, Va., U.S. Geol. Survey, 3 sheets, scale 1:2,500,000.

Luther, E. T., 1959, The coal reserves of Tennessee: Tennessee Div. Geology Bull. 63, 294 p.

Luther, E. T., and Swingle, G. D., 1963, Geologic map of the Fairmount quadrangle, Tennessee: Tennessee Div. Geology Geol. Map GM 105–NE, scale 1:24,000.

Milici, R. C., 1974, Stratigraphy and depositional environments of Upper Mississippian and Lower Pennsylvanian rocks in the southern Cumberland Plateau of Tennessee, *in* Briggs, Garrett, ed., Carboniferous of the southeastern United States: Geol. Soc. America Spec. Paper 148, p. 115–133.

Miller, R. L., Harris, L. D., and Roen, J. B., 1964, The Wildcat Valley Sandstone (Devonian) of southwest Virginia: U.S. Geol. Survey Prof. Paper 501–B, p. B49–B52.

Minkin, S. C., 1977, Pennsylvanian deltaic sediments of the northern Cumberland Plateau, Tennessee: Knoxville, Unv. Tennessee, unpub. Master's thesis, 141 p.

Mixon, R. B., and Harris, L. D., 1971, Geologic map of the Swan Island quadrangle, northeastern Tennessee: U.S. Geol. Survey Geol. Quad. Map GQ–878, scale 1:24,000.

Nelson, W. A., 1925, The southern Tennessee coal field: Tennessee Div. Geology Bull. 33–A, 239 p.

Neuman, R. B., and Nelson, W. H., 1965, Geology of the western Great Smoky Mountains, Tennessee: U.S. Geol. Survey Prof. Paper 349–D, 81 p.

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

Safford, J. M., 1869, Geology of Tennessee: Nashville, Tenn., 550 p.

———1893, The topography, geology and water supply of Sewanee: Tennessee State Board Health Bull., v. 8, no. 6, p. 89–98.

Safford, J. M., and Killebrew, J. B., 1900, The elements of the geology of Tennessee: Nashville, Tenn., Foster and Webb, 264 p.

Sanders, J. E., 1952, Geology of the Pressmen's Home area, Hawkins and Grainger Counties, Tennessee: New Haven, Conn., Yale Univ., Ph.D. dissert., 253 p.

Shumard, B. F., 1860, Observations on the geology of the County of Ste. Genevieve [Mo.]: St. Louis Acad. Sci. Trans., v. 1, p. 404–415.

Smith, E. A., 1890, Geological structure and description of the valley regions adjacent to the Cahaba coal field, pt. 2 *of* Squire, Joseph, Report on the Cahaba coal field: Montgomery, Geol. Survey Alabama, p. 133–180.

———1894, Geological map of Alabama: Montgomery, Geol. Survey Alabama, 2 sheets (explanatory chart and geologic map), scale 1:633,600.

Statler, A. T., 1971, Fort Payne production in the Oneida West area, Scott County, Tennessee, *in* Proceedings of Symposium on Future Petroleum Potential of NPC Region 9 (Illinois basin, Cincinnati arch, and northern part of Mississippi embayment), Champaign, Illinois, March 11 and 12, 1971: Illinois State Geol. Survey, Illinois Petroleum 95, p. 94–110.

———1975, Recent oil and gas activities in Tennessee: Am. Inst. Mining, Metall. and Petroleum Engineers, Soc. Petroleum Engineers, Preprint SPE 5449.

Stearns, R. G., 1963, Monteagle Limestone, Hartselle Formation, and Bangor Limestone—a new Mississippian nomenclature for use in middle Tennessee, with a history of its development: Tennessee Div. Geology Inf. Circ. 11, 18 p.

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

Tennessee Division of Geology, in press, Mississippian section on Interstate 75 south of Jellico, Campbell County, Tennessee—[Report of Sedimentation Seminar, University of Cincinnati, Cincinnati, Ohio]: Tennessee Div. Geology Rept. Inv.

Thompson, C. M., 1977 Characterization of the heavy metal content of coal-bearing stratigraphy from the New River basin, Tennessee; heavy metals released by static leaching of the Big Mary coal sequence: Knoxville, Univ. Tennessee, unpub. Master's thesis, 53 p.

Vail, P. R., 1959, Stratigraphy and lithofacies of Upper Mississippian rocks in the Cumberland Plateau: Evanston, Ill., Northwestern Univ., unpub. Ph.D. dissert, 143 p.

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

White, J. F., 1975, Depositional environments of Pennsylvanian Redoak Mountain Formation, northern Cumberland Plateau, Tennessee: Knoxville, Univ. Tennessee, unpub. Master's thesis, 118 p.

Wiethe, J. D., and Sitterly, P. D., 1978, Recently discovered Upper Ordovician-Lower Mississippian stratigraphic section in which the Chattanooga Shale is absent: Tennessee Acad. Sci. Jour., v. 53, no. 1, p. 12–13.

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

Wilson, C. W., Jr., 1949, Pre-Chattanooga stratigraphy in central Tennessee: Tennessee Div. Geology Bull. 56, 407 p.

———1956, Pennsylvanian geology of the Clarkrange, Obey City, Campbell Junction, and Isoline quadrangles: Tennessee Div. Geology Geol. Quad. Maps, Folio 1, 13 p.

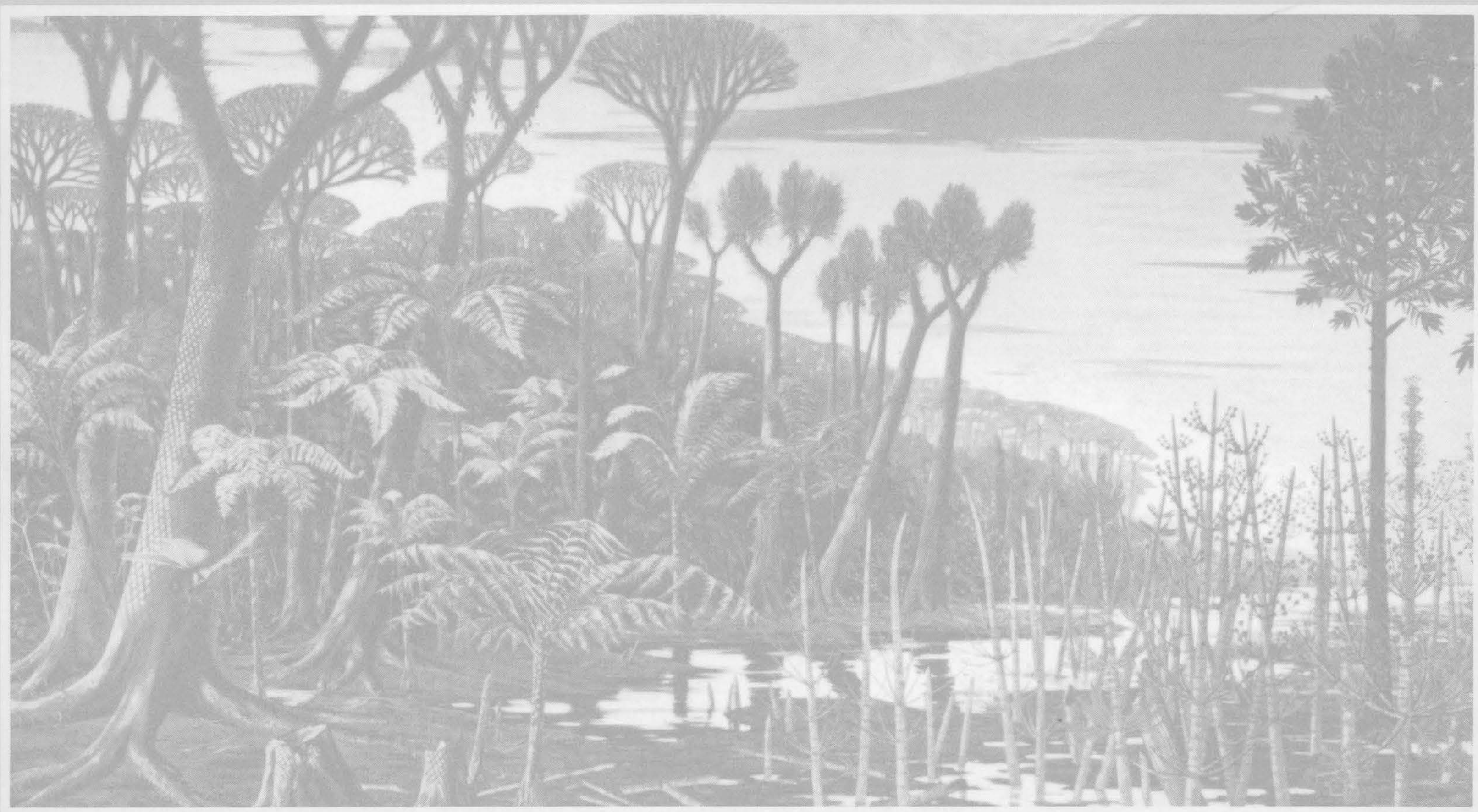
Wilson, C. W., Jr., and Barnes, R. H., 1968, Geologic map of the Woodbury quadrangle, Tennessee: Tennessee Div. Geology Geol. Map GM 319–SE, scale 1:24,000.

Wilson, C. W., Jr., Jewell, J. W., and Luther, E. T., 1956, Pennsylvanian geology of the Cumberland Plateau: Nashville, Tennessee Div. Geology [unnumbered folio], 21 p.

Wilson, C. W., Jr., and Stearns, R. G., 1960, Pennsylvanian marine cyclothems in Tennessee: Geol. Soc. America Bull., v. 71, no. 10, p. 1451–1466.

Wilson, R. L., in press, Geologic map of the Ooltewah quadrangle, Tennessee: Tennessee Div. Geology Geol. Map GM 112–SE, scale 1:24,000.

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—

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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

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

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