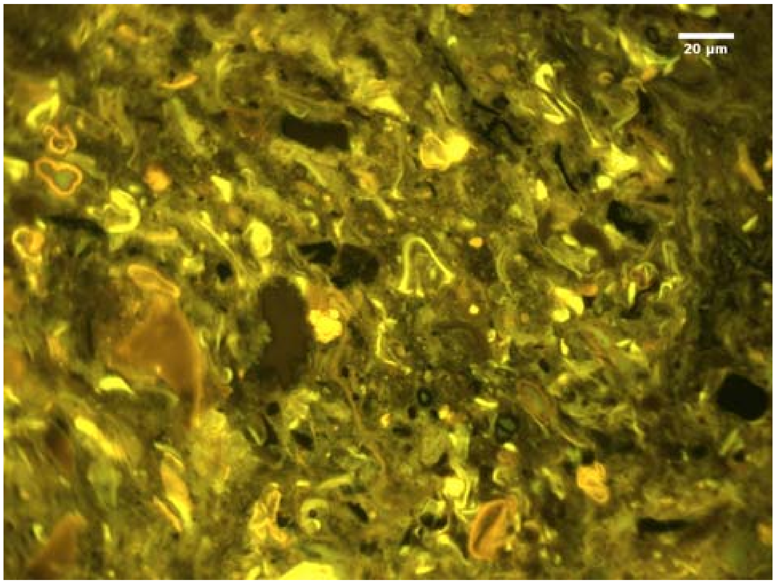
Review of Lignite Resources of Western Tennessee and the Jackson Purchase Area, Western Kentucky

By Paul C. Hackley[1], Peter D. Warwick[1], Roger E. Thomas[2], and Douglas J. Nichols[3]



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Introduction

This review of the lignite deposits of western Tennessee and the Jackson Purchase area in western Kentucky (Fig. 1) is a preliminary report on part of the U.S. Geological Survey's National Coal Resource Assessment of the Gulf Coastal Plain Coal Province. Lignite deposits of western Kentucky and Tennessee are an extension of the Gulf Coastal Plain Coal Province (Cushing and others, 1964), and currently are not economic to mine. These deposits have not been extensively investigated or developed as an energy resource. This review includes a description of the geology of the lignite-bearing units, a discussion of the available coal quality data, and information on organic petrology. Palynological data for lignite samples collected in Kentucky and Tennessee as part of this work are presented in an Appendix.

Jackson Purchase Area, Western Kentucky

The Jackson Purchase area in western Kentucky includes the northernmost part of the Mississippi Embayment of the Gulf Coastal Plain, a trough of Cretaceous through Quaternary sedimentary strata that plunge gently southward along an axis that generally follows the Mississippi River (Fig. 1) (Cushing and others, 1964). The sedimentary strata of the Jackson Purchase area are, in general, flat-lying or gently dipping westward toward the embayment axis. The Jackson Purchase area is situated between the Tennessee River to the east, the Ohio River to the north, and the Mississippi River to the west and the Kentucky-Tennessee State line to the south (Fig. 2). Lignite-bearing counties of the Jackson Purchase area include Ballard, Carlisle, Calloway, Fulton, Graves, Hickman, Marshall and McCracken Counties and the area covers about six percent (2,356 mi^2) of the State. In general, the physiography consists of relatively flat-lying ground, with numerous lakes, ponds, sloughs, and swamps. Local relief generally is less than 100 feet, and the lowest spot in Kentucky, at 260 feet above sea level, is found in the Jackson Purchase area (Kentucky Geological Survey, 2000). Much of the bedrock in western Kentucky was extensively eroded and covered by alluvial deposits from the major rivers within the northern Mississippi Embayment during the Late Tertiary. Alluvial deposits predominantly consist of sand, silt, clay, and gravel materials. Bedrock remnants include Upper Paleozoic limestone exposed in the eastern part of the area and Upper Cretaceous and Lower Tertiary clastic rocks exposed throughout the Purchase area.

The Jackson Purchase area is an important resource of several industrial minerals including silica sand, ceramic clay, and ball clay (Anderson, 2000). Clay is a particularly important constituent of the bedrock stratigraphy of the Purchase area and historically has been mined extensively (Gildersleeve, 1945; Olive and Finch, 1969). Currently, Kentucky is the second largest producer of ball clay in the United States (Anderson, 2000). Ball clays are associated with the Lower Tertiary strata and are used in the United States, Canada, and Mexico for ceramic production (Deems and Vincent, 1997). Kentucky also is one of the

Nation's leading bituminous coal production states with a history of coal mining extending back into the mid-1700s (Energy Information Administration, 1999a). Bituminous coal is produced from two major coal fields elsewhere in the State with an annual output averaging over 160 million short tons (Energy Information Administration, 1999a). Thin, discontinuous lignite beds occur in the Upper Cretaceous and Lower Tertiary strata of the Jackson Purchase area (Olive and McDowell, 1986).

Kentucky Lignite Deposits: Stratigraphic Occurrence

A generalized stratigraphic column showing reported lignite occurrences in the Purchase area is shown in Figure 3. Lignite lenses primarily are found in the Tertiary Wilcox Formation, Claiborne Group, and Jackson Formation and, less frequently, in the Upper Cretaceous McNairy Formation.

The lignite beds in the Upper Cretaceous McNairy Formation (Stephenson, 1914) have been attributed to marine to freshwater deltaic deposition. The McNairy primarily is comprised of light to dark-gray, fine to medium, unconsolidated sand that weathers to yellow or reddish brown (Olive, 1980). Where the McNairy Formation is exposed in the eastern part of the Jackson Purchase area (Fig. 2) it is reported to be 300 to 350 feet thick and disconformable over Paleozoic rocks along the banks of the Kentucky Lake and its tributaries (Olive, 1980). Sands of the McNairy are interbedded with gray, black, or brown clays with minor chert gravels and silts and lignite (Olive, 1980; Olive and McDowell, 1986). These sediments were deposited in a warm temperate to subtropical climate as indicated by pollen studies (Tschudy, 1970). The McNairy is described as predominantly sand in the southern part of the Purchase area and increasingly clay-rich northward to near Paducah (Fig. 2) where it is primarily clay (Olive and McDowell, 1986). In general, lignite deposits are associated with or overlie the clay interbeds and are not laterally extensive. Lignite in the McNairy Formation reportedly is exposed in a bed one and a half feet thick in northeastern Calloway County (Olive, 1980) and is present in the subsurface in the Paducah area, McCracken County (Hower and others, 1990). Lignite lenses in McNairy Formation sands as much as six in thick were observed in the clay pits of various mining companies in the area (Roberts, 1945). In addition to discrete lignite beds, lignitic clays are widely reported from the McNairy (Roberts, 1945; Pryor, 1960; Olive, 1966, 1969, 1980). Petrographic examination of a lignite sample from the McNairy Formation suggests an origin from transported or allochthonous organic material based on abundant inertodetrinite and huminodetrinite content (Hower and others, 1990).

Sediments of the Early Eocene Wilcox Formation consist primarily of clayey sands with interbedded clay and silt (Olive, 1980; Olive and McDowell, 1986) deposited in a freshwater environment (Olive, 1980). The sand is described as light gray and pale brown to yellowish gray and weathers yellowish orange to reddish brown and pinkish gray (Olive, 1980). Whitlatch (1940) referred to Wilcox sands as "sawdust sand" due to the amount of included kaolinite, which produces the sawdust texture. The formation ranges from zero to 200 feet in thickness and disconformably overlies the Paleocene Porters Creek Clay of the underlying Midway Group (Olive, 1980) (Fig. 3). Lignite is found as a discrete lens as much as three feet thick in northeastern Calloway County (Fig. 2) and lignitized plant material and leaf imprints are found in Wilcox sand and clay in many places (Olive, 1980). Whereas the Wilcox Group is an important lignite-bearing unit in the Gulf coastal regions of Texas, Louisiana, and Arkansas (Mukhopadhyay, 1989), deposits of Wilcox lignite are relatively rare in western Kentucky (Hower and others, 1990). The name Holly Springs Formation (Lowe, 1914) previously was used for the lower part of the Wilcox Formation in western Kentucky and it is this portion of the Wilcox that has supported many of the historic ball clay mining operations in western Kentucky (Gildersleeve, 1945).

Overlying the Wilcox in western Kentucky is the Claiborne Group (Fig. 3), a thick sequence composed primarily of sand with interbedded lenses of clayey silt, silty clay, and lignite (Olive, 1980). Most lignite occurrences described in this report are from the Claiborne. The Claiborne Group is reported to be disconformable over the Wilcox and as much as 600 feet thick in the subsurface near the embayment axis at the Kentucky-Tennessee state line (Olive, 1980). The USGS recognizes the Claiborne Group in western Kentucky as consisting of, in ascending order; the Tallahatta Formation, the Sparta Sand, the Cook Mountain Formation, and the Cockfield Formation (Hosman, 1996). The Claiborne dominantly is composed of white, light gray, and pale to medium brown sand, weathering yellowish orange to reddish brown and pinkish gray with common cross-bedding and cut-and-fill structures (Olive, 1980). Lignite primarily occurs in the east-central and western parts of the Claiborne outcrop belt (Fig. 4) where typically it is found in beds less than five feet thick (Olive, 1980). Lignite is reported to be brownish black to black in color, structureless to shaly, and locally composed of woody fragments consisting of tree trunks and stumps (Olive, 1980). Olive and Finch (1969) described a lignite bed approximately two and a half feet thick associated with clays of the Claiborne in Ballard County (Fig. 4). Olive (1971) described as many as three lignite beds in the Claiborne ranging in thickness from a few inches to several feet in the vicinity of Blandville, Ballard County (Fig. 2) and presented proximate/ultimate analytical data for two samples. Based on significant changes in peat thickness, flora, and geochemistry over short distances, it is likely that Claiborne lignites in western Kentucky developed in oxbow lake sedimentary environments (Potter and Dilcher, 1980; Hower and others, 1990). Lignite samples from fresh exposures of Claiborne sediments in Carlisle and Graves Counties have been studied in detail (Hower and others, 1981; 1982; 1990). Lignite usually is found associated with Claiborne clay lenses that typically are narrow, elongated, and curved in shape, surrounded on the bottom and sides by cross-bedded sands, suggesting that they are old meandering stream channels that were ultimately cut off and filled by sediments as oxbow lakes (Potter and Dilcher, 1980). Potter and Dilcher (1980) estimated that the clay and lignite deposits formed over periods ranging from 500 to 1,500 years. The meandering of streams across the embayment axis and temporal formation of oxbow lakes as sites for lignite formation resulted in the current geographic isolation of individual lignite deposits and their discontinuous nature (Potter and Dilcher, 1980). Hower and others (1990) reported that Claiborne lignites are distinct in their general lack of inertinite macerals and in the presence of a diverse, angiosperm-dominated flora.

Overlying the Claiborne Group in western Kentucky is the Jackson Formation, named for exposures near Jackson, Mississippi (Figs. 1 and 3) (Hilgard, 1860). Sediments of the Jackson Formation consist of two primary units; a fine facies composed primarily of silty clay and clayey silt with interbedded sands and a coarse facies composed of sand (Olive, 1980). The Jackson is not divisible from the Claiborne Group as a map unit in western Kentucky owing to similarities in lithologic composition and appearance. A generalized boundary based on palynological (Olive, 1980) data is shown on Figure 4 (Warwick and others, 1997). A petrographic distinction is made between Jackson Formation and Claiborne Group sands in that the Jackson Formation is reported to contain chert, which is absent in the underlying Claiborne (Hower and others, 1990). The contact relation between the Jackson Formation and underlying Claiborne strata is uncertain and is described as gradational (Olive and Finch, 1969), disconformable (Olive, 1980), or conformable (Olive, 1980). The Jackson Formation is estimated to be approximately 400 feet in thickness (Olive, 1972). Lignitized plant material and leaf imprints are found in the silt and clay layers of the fine facies of the Jackson Formation (Olive, 1980). Three lignite samples collected from the Jackson Formation at the Sims clay mine of the Kentucky-Tennessee Clay Company (Fig. 4) were analyzed for proximate/ultimate data and major and trace element concentrations (Tables 1-4). Figure 5 is a photograph from the Sims mine showing the sampled lignite bed. The lignite samples collected from this bed are relatively dense and massive, dull brown to dark gray, and contain thin clay interlayers. Little to no woody material was observed in the lignite bed and no clear rooting was observed in the underclay. Palynological observations of these samples indicate a middle Eocene age (see Appendix). A substantial body of work on the Tertiary paleobotany of western Kentucky and Tennessee has been presented by David Dilcher of Indiana University (now at the Florida Museum of Natural History) and his students and colleagues (e.g., Sun and Dilcher, 1989; Herendeen and Dilcher, 1986, 1987; Mickle and Dilcher, 1987).

Quaternary deposits cover the lignite-bearing Eocene and Cretaceous lithologies of the Jackson Purchase area. These deposits consist of Pliocene and Pleistocene fluvial terraces, Pleistocene glacial deposits and loess and alluvium of Pleistocene and Holocene age underlying the flood plains of modern streams (Olive and Finch, 1969; Olive and McDowell, 1986). Fluvial deposits of Pliocene and Pleistocene age consist of continental gravels that blanket the underlying Eocene sediments and thin from approximately 100 feet in the southeastern part of the Purchase area to about 30 feet along the Ohio River (Olive and Finch, 1969). Loess, consisting of wind-deposited silt, reaches a maximum thickness of about 80 feet bordering the Mississippi River along the western part of the Purchase area and thins to about ten feet in the eastern part of the area (Olive and Finch, 1969). The thickness of over-lying Holocene-Pleistocene alluvium can be as much as 200 feet, particularly in the major river valleys (Olive, 1980).

Kentucky Lignite Mineability

Lignite has not been historically mined in western Kentucky and relatively little data exist characterizing the thickness of overburden and/or contiguity of lignite beds. Lignite and lignitic clays interbedded with commercial clay deposits in the Wilcox Formation historically have been considered overburden and discarded as mine waste (Gildersleeve, 1945). Data provided by the Kentucky-Tennessee Clay Company for the Sims mine in Carlisle County (L. G. Kirk, written communication, 1994) indicate that a Jackson lignite bed (sampled for this work and discussed in text) ranges from zero to eight and a half feet in thickness (Fig. 6) and is covered by 19 to 50 feet of overburden. On average, overburden is approximately 32.8 feet thick. The lignite bed averages six feet in thickness and was encountered in 51 borings spaced over an area less than 0.07 mi^2. The lignite deposit is broadly linear in shape, pinches out toward the east, trends north-south, and thickens in a curvilinear pattern (Fig.6), suggesting deposition in an abandoned channel environment.

Original Resources

No estimates of original lignite resources have been made for western Kentucky. Olive (1971) reported that lignite reserves probably are less than 50,000 short tons in reference to as many as three lignite beds in the Claiborne Formation near Blandville in Ballard County.

Western Tennessee

Lignite has not been developed in western Tennessee as an energy resource though several energy companies conducted extensive exploration programs for lignite resources in the late 1970s (Parks, 1981). The lignite-bearing units of western Tennessee are, as in western Kentucky, part of the Mississippi Embayment sequence of Cretaceous through Quaternary sediments and sedimentary strata (Fig. 1) (Cushing and others, 1964). The Mississippi Embayment units of western Tennessee are, in general, flat-lying or gently dipping westward towards the embayment axis.

Thin, discontinuous lignite beds occur in the Upper Cretaceous and Lower Tertiary Gulf Coastal Plain sediments of western Tennessee (Russell and Parks, 1975). However, despite extensive investigation (Parks, 1981), the lignite deposits of western Tennessee currently are not economically feasible to mine and have not been developed as an energy resource. The lignite-bearing units crop out along a linear belt extending north-northeastward across the State primarily in Fayette, Hardeman, McNairy, Chester, Henderson, Madison, Haywood, Carroll, Weakly, and Henry Counties (Fig. 7). In all cases, lignite beds are described as laterally discontinuous lenses that constitute volumetrically minor components of the geologic units (Russell and Parks, 1975). However, exploration programs and appraisal of hydrologic conditions in anticipation of lignite mining in western Tennessee demonstrated that tremendous (1.0 billion short tons) lignite reserves are present (Luppens, 1978; Parks, 1981).

In the Upper Cretaceous McNairy Formation (Hardeman and others, 1966), lignitic clays occur in association with mined or previously mined ball clay deposits (Nelson, 1912; Russell and Parks, 1975) and primarily are known from Henry County (Fig. 7) (Parks, 1981). Lignite deposits in the overlying Paleocene-Eocene Wilcox Group are thought to be the most abundant in the southern part of western Tennessee in Hardeman County (Parks, 1981). The Eocene Claiborne Group and Jackson Formation also host lignites deposits in western Tennessee (Parks, 1981). Estimates of lignite reserves for western Tennessee indicate that approximately 1 billion short tons of lignite occur in the Claiborne and Wilcox Group units in beds that are two to nine feet thick (Luppens, 1978). A proposal outlining data needed in anticipation of strip-mining of lignite resources in western Tennessee was presented by the U.S. Geological Survey and the Tennessee Division of Geology (Parks, 1981), but further evaluation of lignite resources was not completed and lignite mining has not commenced.

Tennessee Lignite Deposits: Stratigraphic Occurrence

Lignite beds are found in several stratigraphic horizons within the Cretaceous McNairy Formation, the Paleocene Midway Group, the Paleocene-Eocene Wilcox Group, and in the Eocene Claiborne Group and Jackson Formation of western Tennessee. These strata are lateral equivalents of the units described above for western Kentucky but are, in the case of the Wilcox, raised to Group stature in Tennessee as better exposure over a greater area permits more detailed mapping and subdivision of the geologic units. A generalized stratigraphic column for Upper Cretaceous and Tertiary strata in western Tennessee is presented in Figure 8.

The Upper Cretaceous McNairy Formation was named for exposures near Cypress in McNairy County (Fig. 7) (Russell, 1966) and is comprised of non-marine and nearshore marine sands. The unit is described as comprised of three facies: a very fine-grained nearshore basal sand, an overlying coarser sand of fluvial, deltaic, and estuarine origin, and an upper transgressive marine sand (Russell and Parks, 1975). The middle facies contains discontinuous, thin-bedded, lenticular clay bodies consisting of light brown to light gray to white, kaolinite-dominated plastic clays and lignitic clays with fossilized plant fragments (Russell and Parks, 1975). The McNairy Formation ranges from approximately 290 to 500 feet thick in southern Tennessee, dipping gently to the west, and extends entirely across the state, cropping out in a belt approximately 15 miles wide in the south and narrowing to about six miles wide in the north (Nelson, 1911; Russell and Parks, 1975).

The Paleocene Midway Group in western Tennessee (Fig. 8) includes, in ascending stratigraphic order, the Clayton Formation and the Porters Creek Clay (Roberts, 1928; Hosman, 1996). The Clayton Formation crops out in Hardeman and McNairy Counties in southwestern Tennessee, where it disconformably overlies the McNairy Formation and is estimated to average 80 feet in thickness (Russell and Parks, 1975). Lignitic clays locally are found in the Clayton Formation and rare lenses of impure lignite are found associated with clays (Russell and Parks, 1975). The conformably overlying Porters Creek Clay is a distinctive body of offshore marine clay and minor sand ranging from 100 to 150 feet thick. At some localities in the upper part of the Porters Creek, disseminated particles of lignitic material occur in lenses of black silty clay (Russell and Parks, 1975).

The Paleocene-Eocene Wilcox Group (Roberts and Collins, 1926) disconformably overlies the Porters Creek Clay in western Tennessee and includes, in ascending stratigraphic order, the Old Breastworks Formation, the Fort Pillow Sand, and the Flour Island Formation (Parks and Carmichael, 1990a, 1990b; Hosman, 1996). Collectively, these units range from zero to 200 feet thick and crop out in a north-northeast trending belt across western Tennessee, narrowing northward from approximately 13 miles wide in Hardeman County to less than one mile wide in Henry County (Fig. 7). Lignite is present as thin lenses associated with lignitic clays or carbonaceous clay and silt in the Old Breastworks and Flour Island Formations (Parks and Carmichael, 1990a, 1990b). The lignite deposits are described as brownish black to moderate brown and containing variable amounts of clay and silt (Russell and Parks, 1975). Beds range from inches to several feet in thickness but rarely exceed one foot (Russell and Parks, 1975). As in western Kentucky, "sawdust sand" is described as a distinctive feature of Wilcox Group sediments in western Tennessee (Russell and Parks, 1975).

The Claiborne Group in western Tennessee includes, in ascending stratigraphic order, the Memphis Sand, the Cook Mountain Formation, and the Cockfield Formation (Fig. 8). As in western Kentucky, the Claiborne is the dominant lignite-bearing unit of western Tennessee and was the source of the lignite samples collected and analyzed by the USGS as part of this work. Moreover, the important ball clay mining operations of western Tennessee dominantly are developed in Claiborne units or equivalents (Nelson, 1911). Clays of the Claiborne contain an abundant terrestrial fossil flora indicating deposition predominantly in nonmarine environments (Russell and Parks, 1975; Clark, 1977). The basal unit of the Claiborne, the Memphis Sand, disconformably overlies the Flour Island Formation of the Wilcox Group and consists of a thick body of sand with subordinate lenses of clay and silt. The stratigraphic boundary between the uppermost units of the Wilcox and the overlying Memphis Sand is reported to be an erosional surface with local relief of 50 feet or more (Russell and Parks, 1975). The Memphis Sand ranges from zero to about 900 feet in thickness and, where the original thickness is preserved, generally is 400 feet thick or greater (Parks and Carmichael, 1990a). The unit in western Tennessee makes up a substantial part of the Memphis aquifer, an important groundwater resource in the area (Parks and Carmichael, 1990a). Clay and silt lenses are reported to be carbonaceous and lignitic with thin lenses of lignite occurring locally (Parks and Carmichael, 1990a). The Cook Mountain Formation consists primarily of clay, with lesser silt and sand and ranges from 40 to 200 feet in thickness (Parks and Carmichael, 1990a). The unit is conformable over the Memphis Sand and serves as an upper confining layer (Parks and Carmichael, 1990a), but lignite occurrences are not reported. Conformable over the Cook Mountain is the Cockfield Formation, another important aquifer unit in the regional groundwater supply (Parks and Carmichael, 1990b).

The Cockfield Formation primarily is composed of sand with lesser silt, clay, and lignite. Where the original stratigraphy is preserved, the Cockfield ranges from 235 to 270 feet in thickness (Parks and Carmichael, 1990b). In places, the Cockfield has undergone extensive erosion and is highly variable in thickness, ranging from zero to 270 feet (Parks and Carmichael, 1990b). Lignite beds commonly are associated with clays and silts (Parks and Carmichael, 1990b). Three lignite samples were collected from the Cockfield in the Swaim pit of the Spinks Clay Company and analyzed for proximate/ultimate data (Table 1). The location of the collected samples is shown on Figure 7 and palynological data are presented in the Appendix. Figure 9 is a photograph from the Swaim pit showing the sampled lignite bed. The lignite samples collected from this bed are relatively clay-rich and blocky, and contain woody bits and fragments. The lignite bed is elliptical and shows distinct lateral variations. Palynological observations of the lignite samples indicate a middle Eocene age (see Appendix). An additional four samples were collected from the Cockfield Formation in the Roberts pit of the Spinks Clay Company and analyzed for proximate/ultimate data (Table 1) and major and trace element concentrations (Tables 3 and 4). The location of the collected samples is shown on Figure 7 and palynological data are presented in the Appendix. The sampled lignite bed at the Roberts pit contains scattered woody material, becomes increasingly clay-rich upwards, before eventually grading into clay, and is dark yellowish brown (10 YR 4/4) to dusky yellowish brown (10 YR 2/2) in color. The underclay is well-rooted.

The Cockfield Formation is overlain by the Upper Eocene Jackson Formation (Fig. 8), another lignite-bearing unit. Due to similarities in lithology, the Jackson and Cockfield Formations cannot be reliably subdivided and a rough estimate of the thickness of the Jackson Formation is given as zero to 150 feet by Parks and Carmichael (1990b). A similar situation exists in western Kentucky, as outlined above, where the Jackson and Claiborne are distinguished only by petrographic and palynological subtleties and cannot be reliably subdivided in the field.

Coal Quality

Coal quality data for western Tennessee and Kentucky lignite deposits are scarce and previously published material consists of proximate/ultimate and major element analytical data for eleven Claiborne Group lignites and one McNairy Formation lignite in western Kentucky (Hower and others, 1990). Proximate/ultimate analyses of two additional Kentucky Claiborne lignite samples were presented on a geologic quadrangle map (Olive, 1971). This report includes new proximate/ultimate, major- and trace-element analyses for three Jackson Formation lignite samples from western Kentucky (Sims pit) and four samples of Claiborne Group lignite from Tennessee (Roberts pit). An additional three Claiborne Group samples from Tennessee were analyzed only for proximate/ultimate data (Swaim pit). All of the available coal quality data for western Kentucky are presented in Tables 1-4 and the locations of samples are shown on Figure 4 and Figure 7. Coal quality data are discussed in comparison with average and maximum values of Gulf Coast lignites as published in the U.S. Geological Survey Coal Quality Database CD-ROM (USGS COALQUAL) (Bragg and others, 1998). The average and maximum values of Gulf Coast lignites as represented by the analyses contained in the USGS COALQUAL database incorporate all samples obtained from Upper Cretaceous through Tertiary strata in the Gulf Coast Basin and are not representative of a particular formation.

Moisture content of the lignite samples analyzed as part of this work and from Olive (1971) ranges from 39.15 to 51.8 percent on an as-received basis (Table 1), and averages 44.9 percent, higher than the Gulf Coast average of 35.0 percent. Moisture content data from Hower and others (1990) were presented on an as-determined basis for moisture content and indicate 11.16 percent for the McNairy Formation sample and a range of 7.30 to 41.68 percent for Claiborne Group samples (not tabulated here).

Claiborne and Jackson lignite samples from western Kentucky and Tennessee have gross calorific values that range from 5,397 to 6,616 Btu/lb (Table 2) on a moist, mineral-matter-free (m,mmf) basis. The samples collected and analyzed as part of this work and by Olive (1971) have lower gross calorific values than the average of Gulf Coast lignites (7,495 Btu/lb, m,mmf basis) (Fig. 10). However, the data published by Hower and others (1990) indicate relatively higher gross calorific values for Eocene lignite samples from western Kentucky, including some samples of subbituminous rank. These samples may have been allowed to dry substantially prior to analysis and the gross calorific values presented by Hower and others (1990) have been omitted from Table 2 and Figure 10.

Reflectance measurements were performed for seven samples collected as part of this work following American Society for Testing and Materials (ASTM) D 2798-05 methods and procedures (ASTM, 2005a). Maximum reflectance values of ulminite B in immersion oil (R_{max}) range from 0.23 to 0.29 (Table 2), in agreement with the rank classification calculated from the gross calorific value obtained by ASTM D 5865-04 (ASTM, 2005b).

Ash yield ranges from 11.8 to 45.48 percent on a dry basis (Table 2) for the samples analyzed as part of this work and by Olive (1971); ash yield in the sample set presented by Hower and others (1990) is over 50 percent for three samples. Note that samples 7462, 7464, 7465, and 7457 of their data set (Table 2) contain significantly elevated ash; these samples have been excluded from presentation in Figures 10-12. Furthermore, of the lignite samples collected as part of this work, samples PW-94-16, PW-94-18, PW-94-23, and PW-94-30 have a higher ash yield than that permitted in the COALQUAL database (less than or equal to 33 percent on an as-determined basis). These samples have been omitted from presentation in Figures 10-14. In general, ash yield of western Kentucky and Tennessee lignite samples is higher than the average of Gulf Coast lignites (19.8 percent, dry basis); of the 16 samples presented in Figure 11, ten have higher ash yield than the average of Gulf Coast lignite samples. Samples collected in this study have sulfur contents ranging from 0.73 to 2.10 percent on a dry basis (Table 2), and, with the exception of the highest value, all values are below the Gulf Coast average (1.69 percent, dry basis) (Fig. 12). The sulfur content of the previously published data for Claiborne samples ranges from 0.66 to 4.8 percent and is 1.10 percent in the McNairy sample (Olive, 1971; Hower and others, 1990), similar to the Gulf Coast average.

Of the ten samples collected by the U.S. Geological Survey from western Kentucky and Tennessee, seven were analyzed for major and trace element concentrations by inductively coupled plasma emission spectrometry (ICP-AES) and inductively coupled plasma mass spectrometry (ICP-MS) and the analytical results are presented in Tables 3 and 4. In addition, major element analytical data published by Hower and others (1990) are incorporated into Table 3. Of particular interest are concentrations of environmentally sensitive trace elements that have been identified as possible hazardous air pollutants (HAPs) in the United States Clean Air Act Amendments of 1990. The concentrations of the trace elements arsenic, beryllium, cadmium, cobalt, chromium, mercury, manganese, nickel, lead, antimony, selenium, and uranium are compared to average and maximum Gulf Coast lignite values on a whole-coal remnant moisture basis compiled from the USGS COALQUAL database (Bragg and others, 1998) in Figs. 13 and 14. Note that of the seven lignite samples analyzed, only those with ash yield lower than 30 weight percent are strictly comparable with those in the COALQUAL database. Therefore, only five samples are plotted in Figs. 13 and 14.

Organic Petrography

Claiborne and Jackson lignite samples from western Tennessee and Kentucky were prepared following the procedures outlined in Pontolillo and Stanton (1994), and qualitatively examined in incident white and blue light. All of the samples are semi-sapropelic in character; generally liptinite- and mineral-matter-rich, and poor in humic (woody) material, consistent with subaquatic formation in the oxbow lakes of abandoned river and stream channels (Potter and Dilcher, 1980). All samples are mostly devoid of inertinite macerals, with the exception of funginite (Figs. 15A-B), consistent with the petrographic descriptions reported by Hower and others (1990) for Claiborne lignites of the Jackson Purchase area. Trace quantities of the inertinite macerals inertodetrinite and fusinitized corpohuminite are present. Inertinite is qualitatively estimated to comprise <1 vol.% of the organic material for all Jackson and Claiborne samples examined. Huminite mostly consists of detrohuminite (Fig. 15C), an aggregation of perhydrous organic detritus containing fragments of other types of huminite, mineral-matter, liptinite, and scarce inertinite. Some remnant humic plant tissues are present as textinite (Figs. 15D-F). Liptinite macerals include sporinite (Figs. 16A-B), resinite (Fig. 16C), suberinite (Figs. 16D-E), and alginite (Fig. 16F). The occurrence of alginite is consistent with a subaquatic facies for some of the Jackson and Claiborne lignite.

Coalbed Methane

Although the occurrence of biogenetic in-situ coal bed methane in western Tennessee and Kentucky lignites is unknown, deep basin Gulf Coast lignites may contain significant gas resources (Echols, 1995). Warwick and others (2000) reported that desorption of cuttings from the Oak Hill lignite at a depth of about 2,500 feet in Mississippi contained an average of 19 Standard cubic feet (Scf)/ton of gas. However, strata containing lignite beds are not buried this deeply in the subsurface of western Kentucky and Tennessee (Cushing and others, 1964) and presumably would not produce gas. More data are needed to characterize the coal bed methane potential of lignites in the Jackson Purchase area and in western Tennessee.

Conclusions

The Jackson Purchase area of western Kentucky encompasses an area of 2,356 mi^2 and includes eight counties underlain predominantly by alluvial sand, silt, and clay. Lignite beds and lignitic clays occur in the Tertiary Wilcox Formation, Claiborne Group, and Jackson Formation and less frequently in the Upper Cretaceous McNairy Formation. Lignite occurs in these units or their equivalents in western Tennessee in an outcrop belt trending northeastward across the State. Lignite deposits have not been developed in Kentucky and Tennessee because they currently are not economical to mine, although exploration programs indicate that substantial reserves are present. Data regarding lignite coal quality in Kentucky and Tennessee consists of a small data set constituted by the analyses presented and discussed herein.

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The authors thank John SanFilipo for his help in compiling reference material for the Tertiary geology of western Kentucky and Tim Keller for his assistance in the field. Reviews by Susan Tewalt, Linda Bragg, Kris Dennen, Blaine Cecil, and Jim Coleman improved the quality and clarity of this report.

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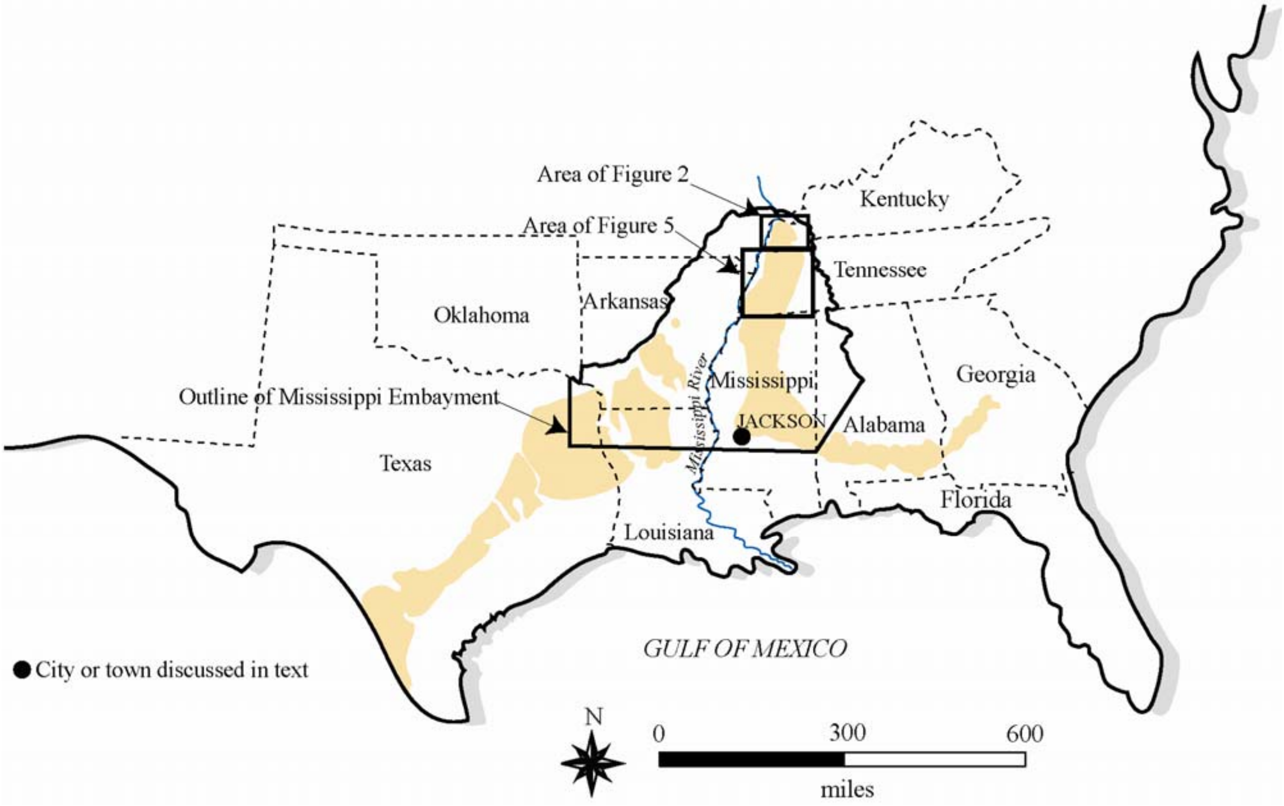


Figure 1. Map showing Coastal Plain deposits of the Mississippi Embayment. Outline of Mississippi Embayment from Cushing and others (1964).

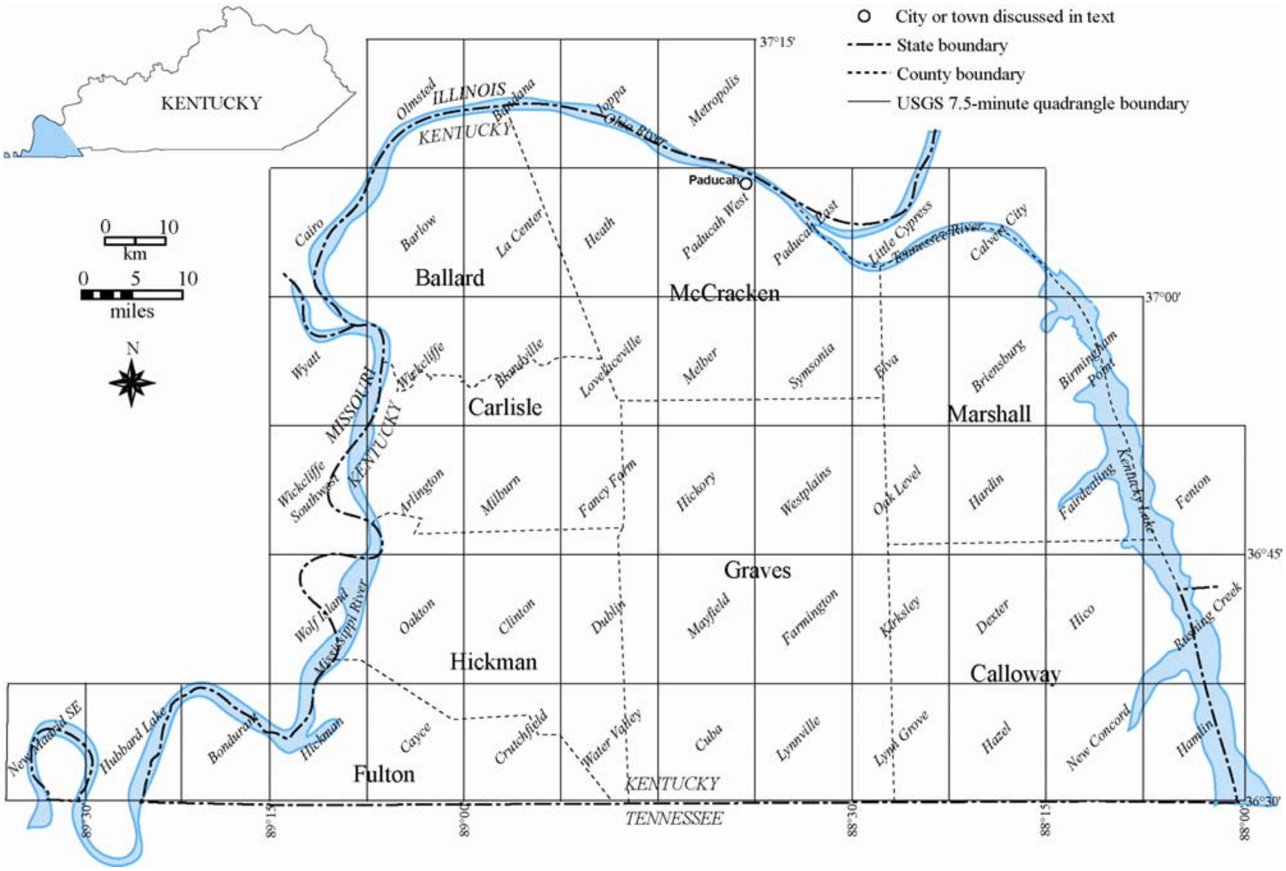
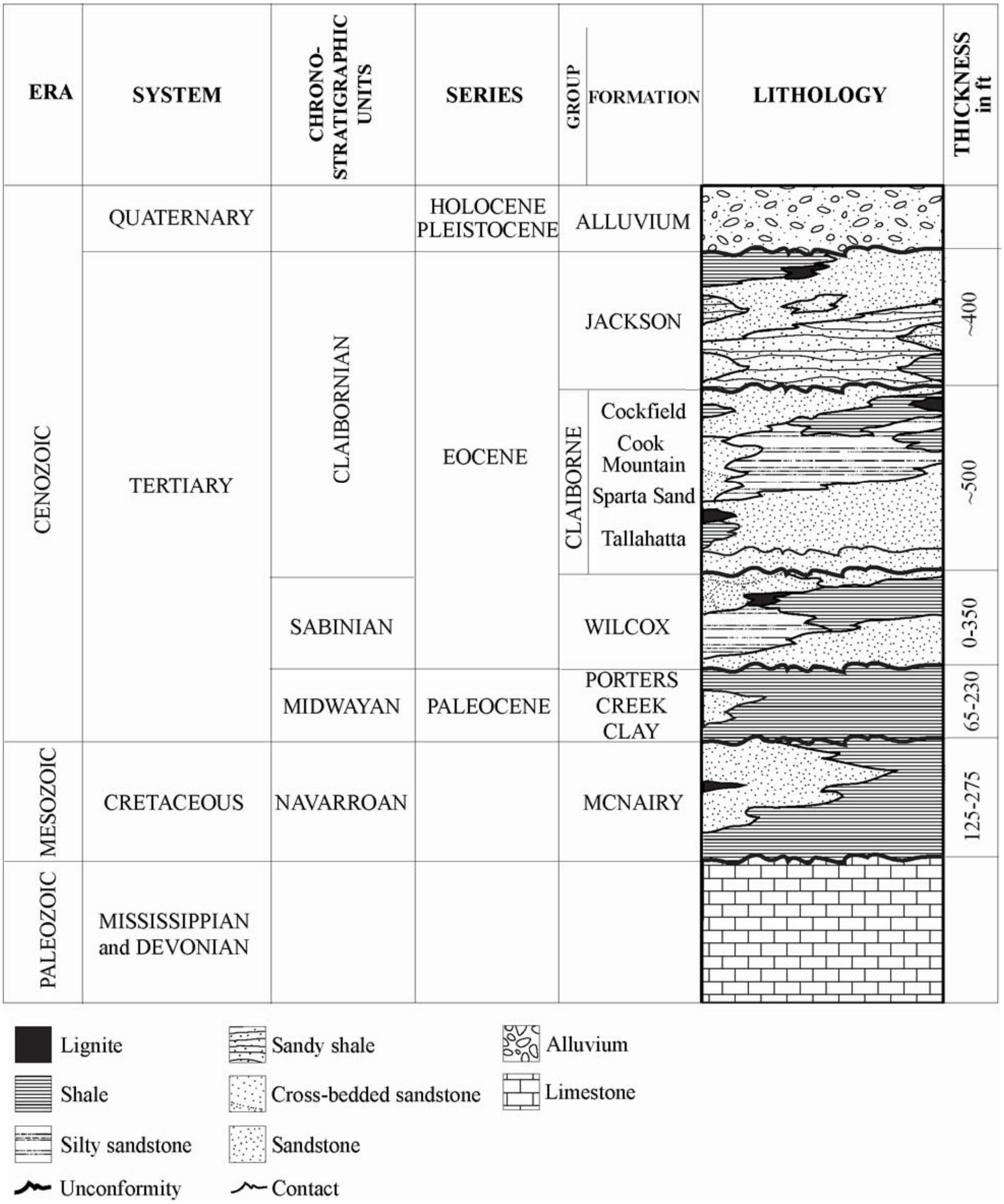


Figure 2. Generalized map of the Jackson Purchase area, western Kentucky, showing county and state boundaries, and USGS 7.5-minute quadrangles. Inset map shows Jackson Purchase area shaded in blue. Modified from Olive (1980) and Warwick and others (1997).



ERA	SYSTEM	CHRONO-STRATIGRAPHIC UNITS	SERIES	GROUP	FORMATION	THICKNESS in ft
CENOZOIC	QUATERNARY		HOLOCENE PLEISTOCENE		ALLUVIUM	
	TERTIARY	CLAIBORNIAN	EOCENE		JACKSON	~400
				CLAIBORNE	Cockfield Cook Mountain Sparta Sand Tallahatta	~500
		SABINIAN			WILCOX	0-350
		MIDWAYAN	PALEOCENE		PORTERS CREEK CLAY	65-230
MESOZOIC	CRETACEOUS	NAVARROAN			MCNAIRY	125-275
PALEOZOIC	MISSISSIPPIAN and DEVONIAN					

Figure 3. Generalized stratigraphic column of the Jackson Purchase area, western Kentucky. Modified from Olive (1972) and Hosman (1996).

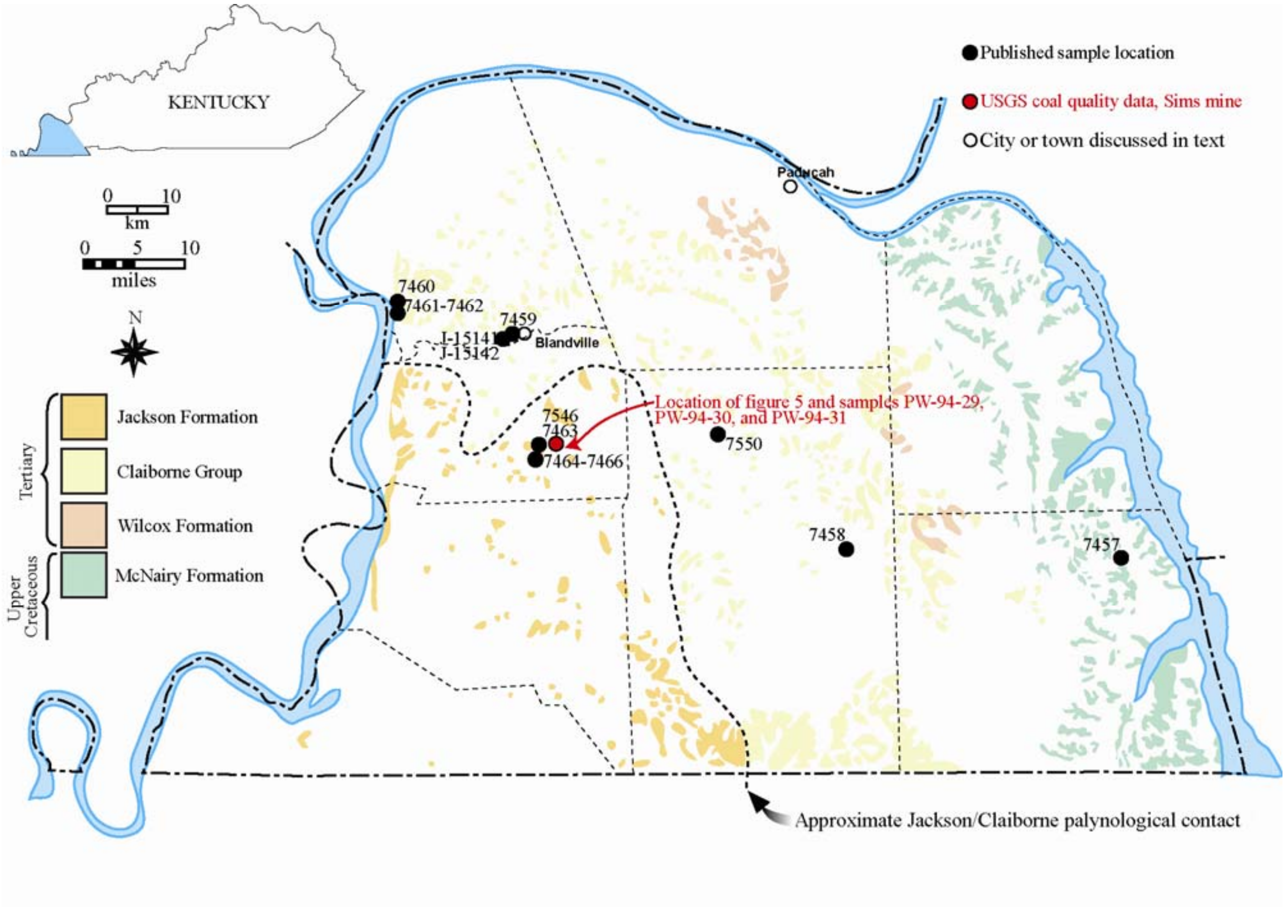


Figure 4. Generalized map of the Jackson Purchase area, western Kentucky, showing sample locations, and outcrop distribution of lignite-bearing McNairy Formation, Wilcox Formation, Claiborne Group, and Jackson Formation units. Inset map shows Jackson Purchase area shaded in blue. Modified from Olive (1980) and Warwick and others (1997). Sample locations are from Olive (1971), Hower and others (1990), and this report.

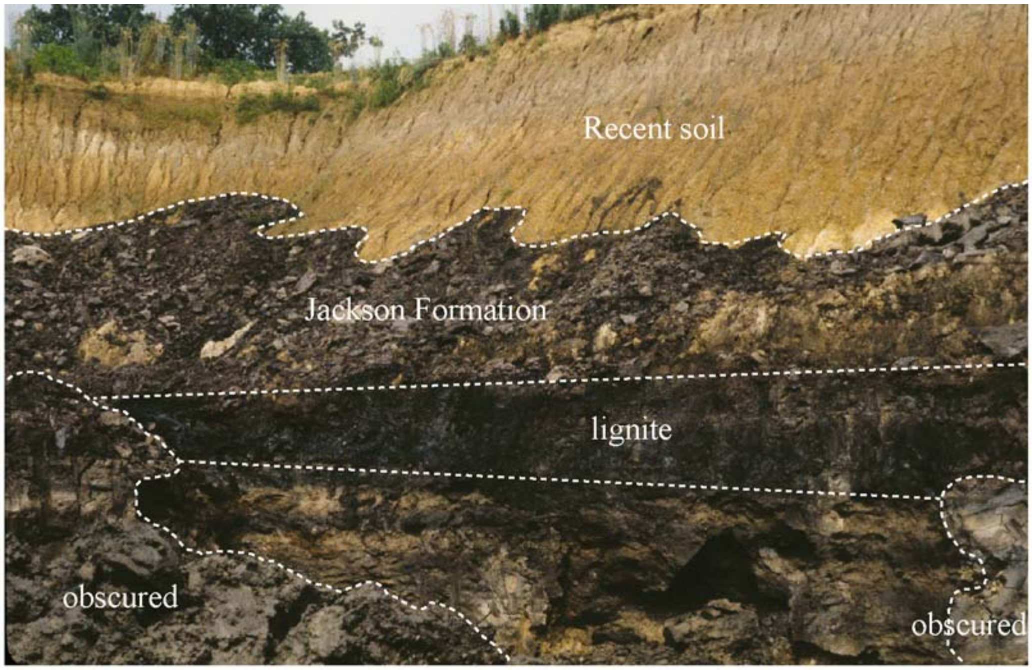


Figure 5. Lignite bed in highwall of Kentucky-Tennessee Clay Company Sims open-pit clay mine, Carlisle County, Kentucky. Refer to figure 4 for location of Sims mine. Lignite bed is 3.32 feet thick where sampled. Samples PW-94-29, PW-94-30, and PW-94-31, discussed in the text, were collected at this locality.

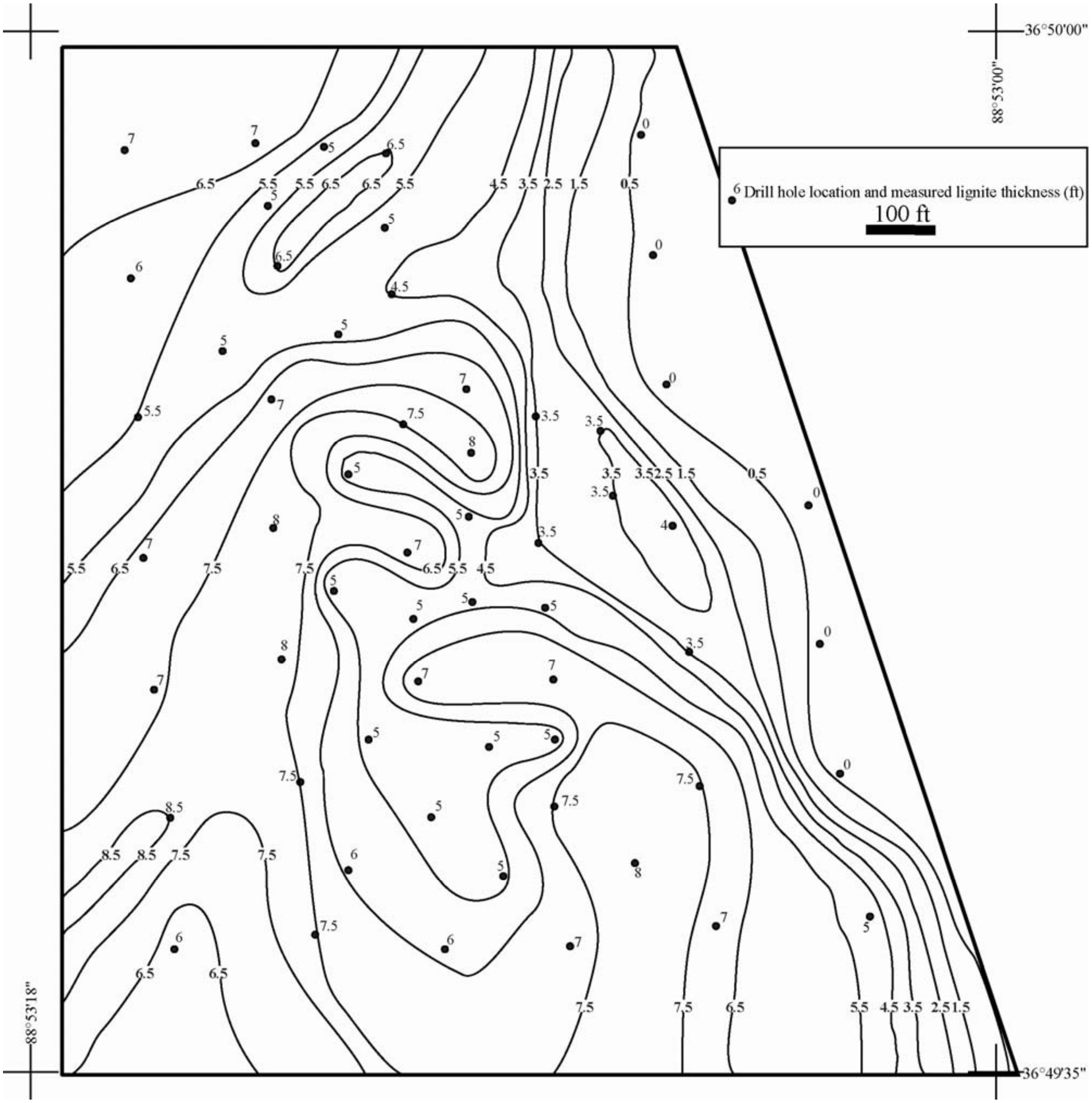


Figure 6. Lignite isopach map of part of the Sims mine, Kentucky-Tennessee Clay Company, Milburn quadrangle, Carlisle County, Kentucky. Data courtesy of L.G. Kirk, Kentucky-Tennessee Clay Company (written communication, 1994). Lignite thickness contoured in one foot intervals. Refer to figure 4 for location of Sims mine.

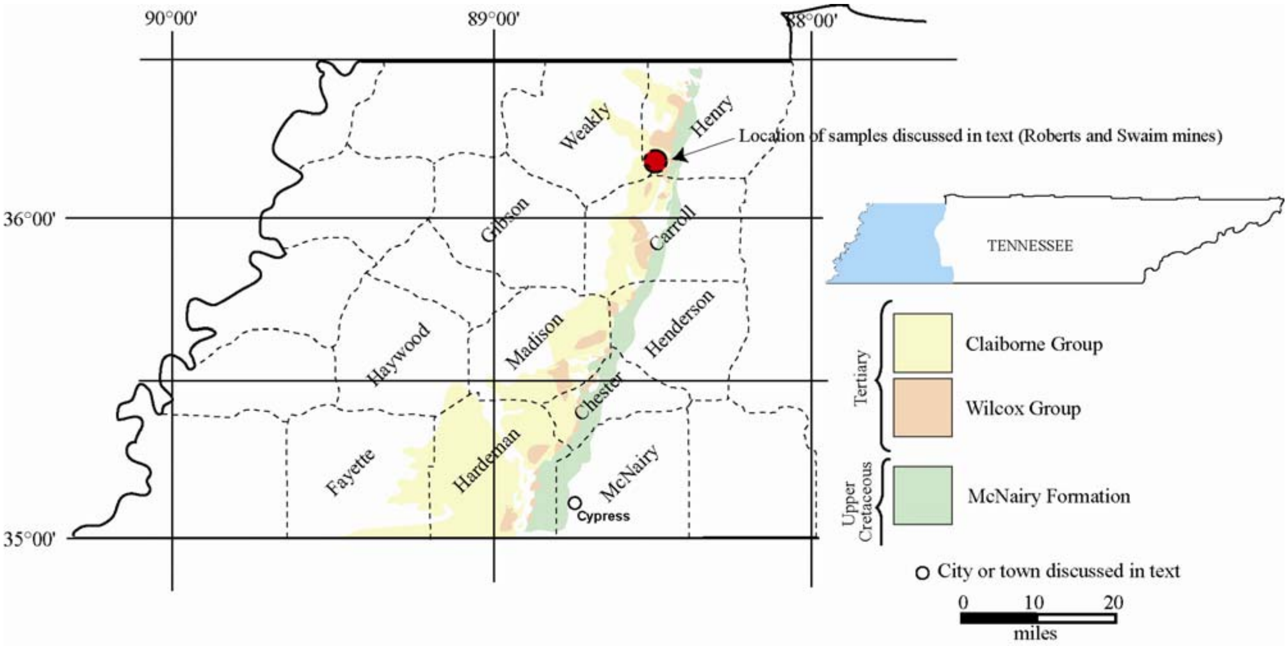


Figure 7. Generalized map of western Tennessee showing sample locations, county boundaries, and outcrop distribution of lignite-bearing McNairy Formation and Wilcox and Claiborne Group lithologies. Inset map shows western Tennessee shaded in blue. Modified from Russell and Parks (1975) and Warwick and others (1997).

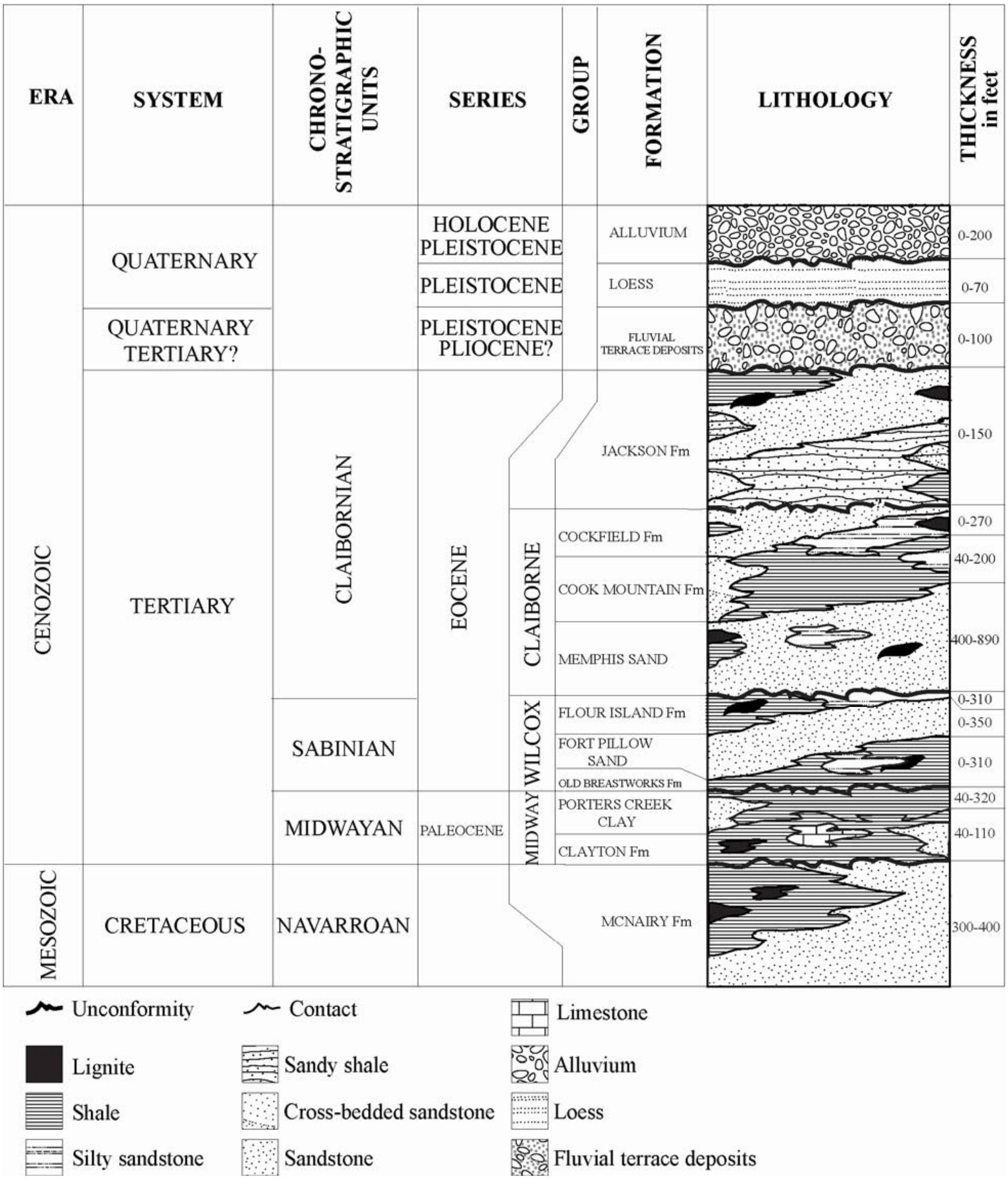


Figure 8. Generalized Upper Cretaceous to Holocene stratigraphic column showing lignite-bearing lithologies of Gulf Coastal Plain geologic units, western Tennessee. Modified from Russell and Parks (1975) and Parks and Carmichael (1990a, 1990b). Fm = Formation.

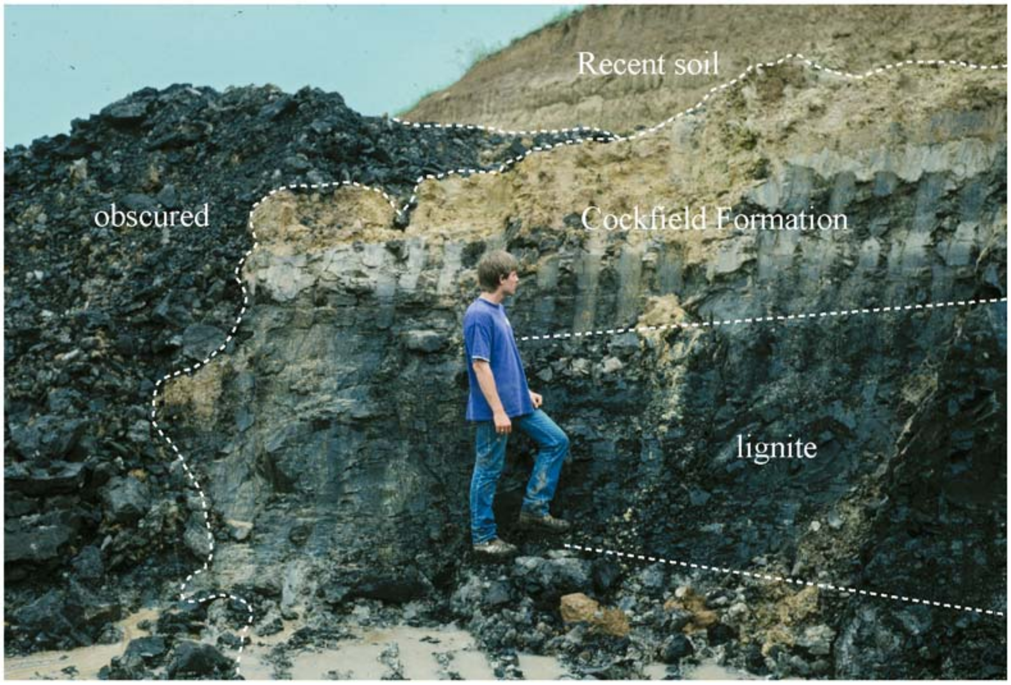


Figure 9. Lignite bed in highwall of Spinks Clay Company Swaim open-pit clay mine, Henry County, Tennessee. Refer to figure 7 for location of Swaim pit. Lignite bed is four and three quarters feet thick. Samples PW-94-16, PW-94-17, and PW-94-18, discussed in the text, were collected at this locality.

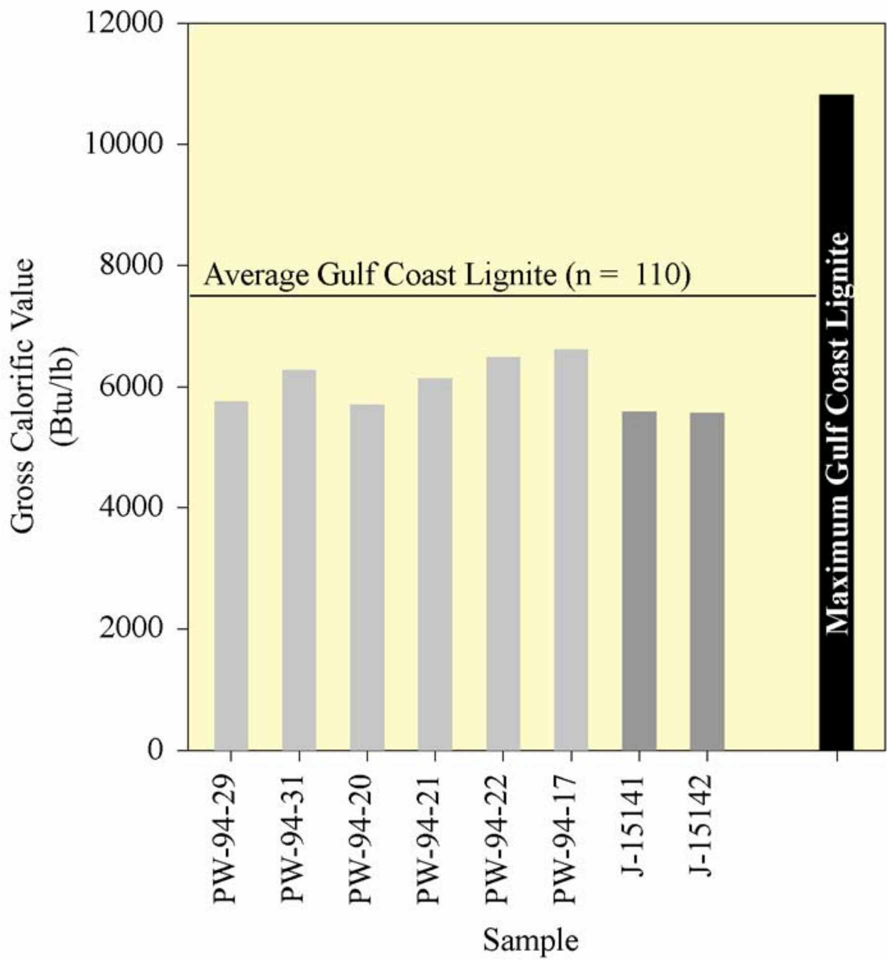


Figure 10. Gross calorific values (moist, mineral-matter-free basis) of western Kentucky and Tennessee lignites. Samples J-15141 and J-15142 are from Olive (1971). Values for the average and maximum Gulf Coast lignite were compiled from Bragg and others (1998). [n = number of samples; Btu/lb = British thermal units per pound].

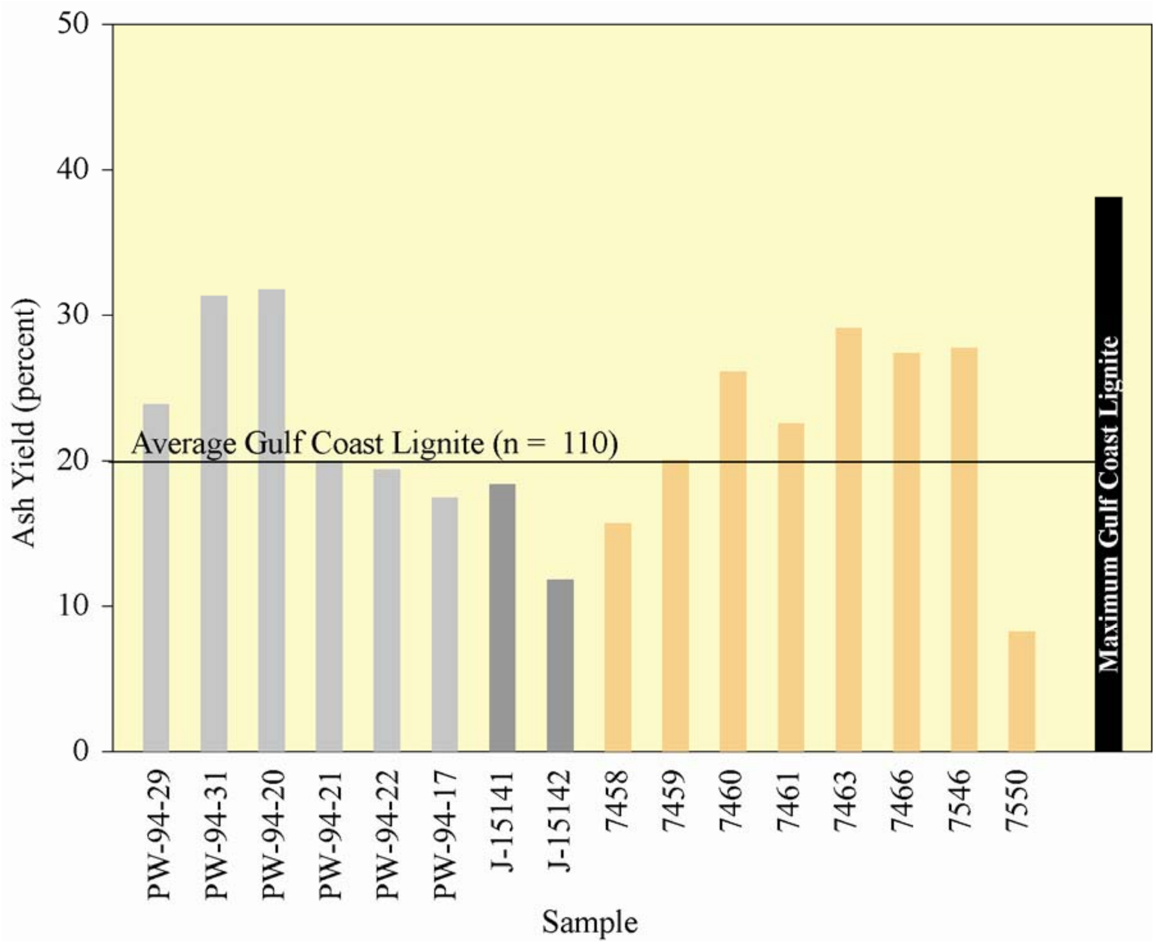


Figure 11. Ash yield (dry basis) of western Kentucky and Tennessee lignites. Samples J-15141 and J-15142 are from Olive (1971) and samples 7458 through 7550 are from Hower and others (1990). Values for the average and maximum Gulf Coast lignite were compiled from Bragg and others (1998). [n = number of samples].

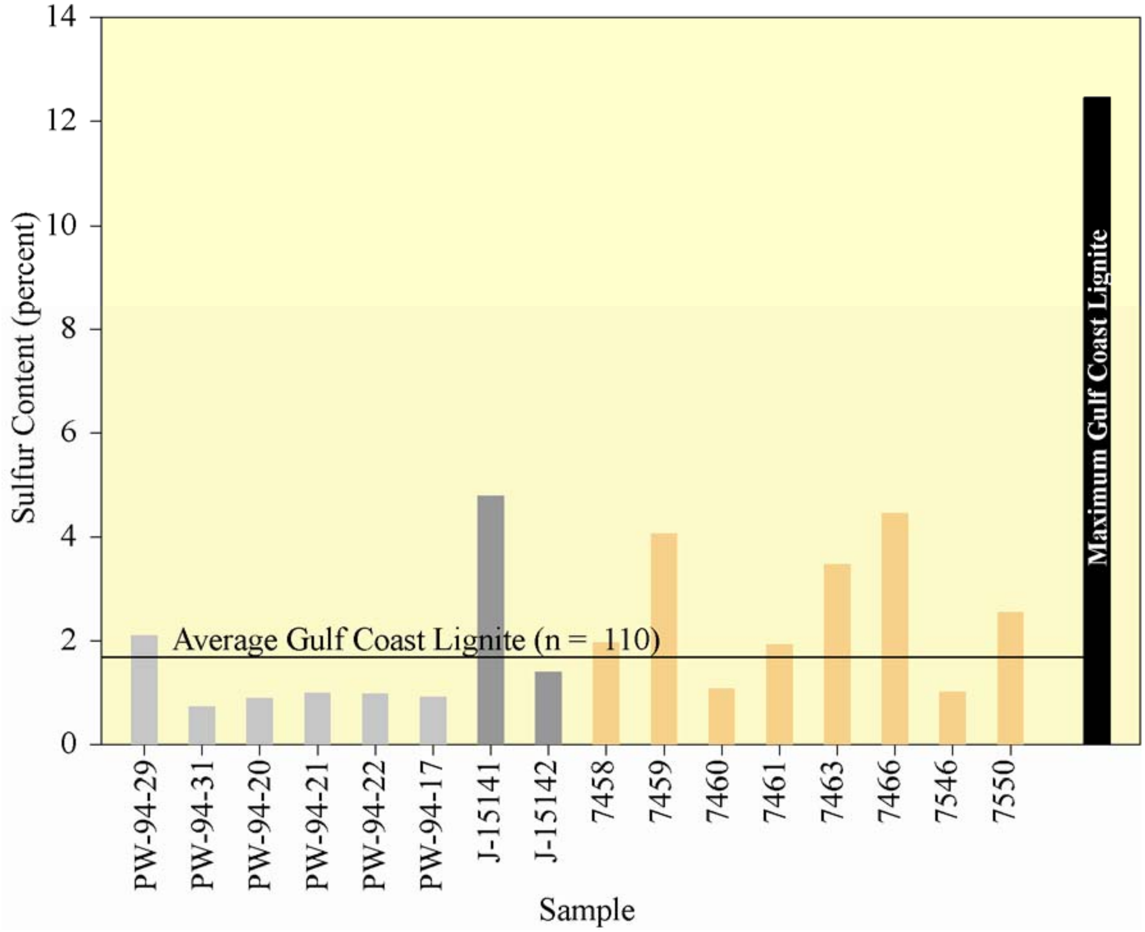


Figure 12. Sulfur content (dry basis) of western Kentucky and Tennessee lignites. Samples J-15141 and J-15142 are from Olive (1971) and samples 7458 through 7550 are from Hower and others (1990). Values for the average and maximum Gulf Coast lignite were compiled from Bragg and others (1998). [n = number of samples].

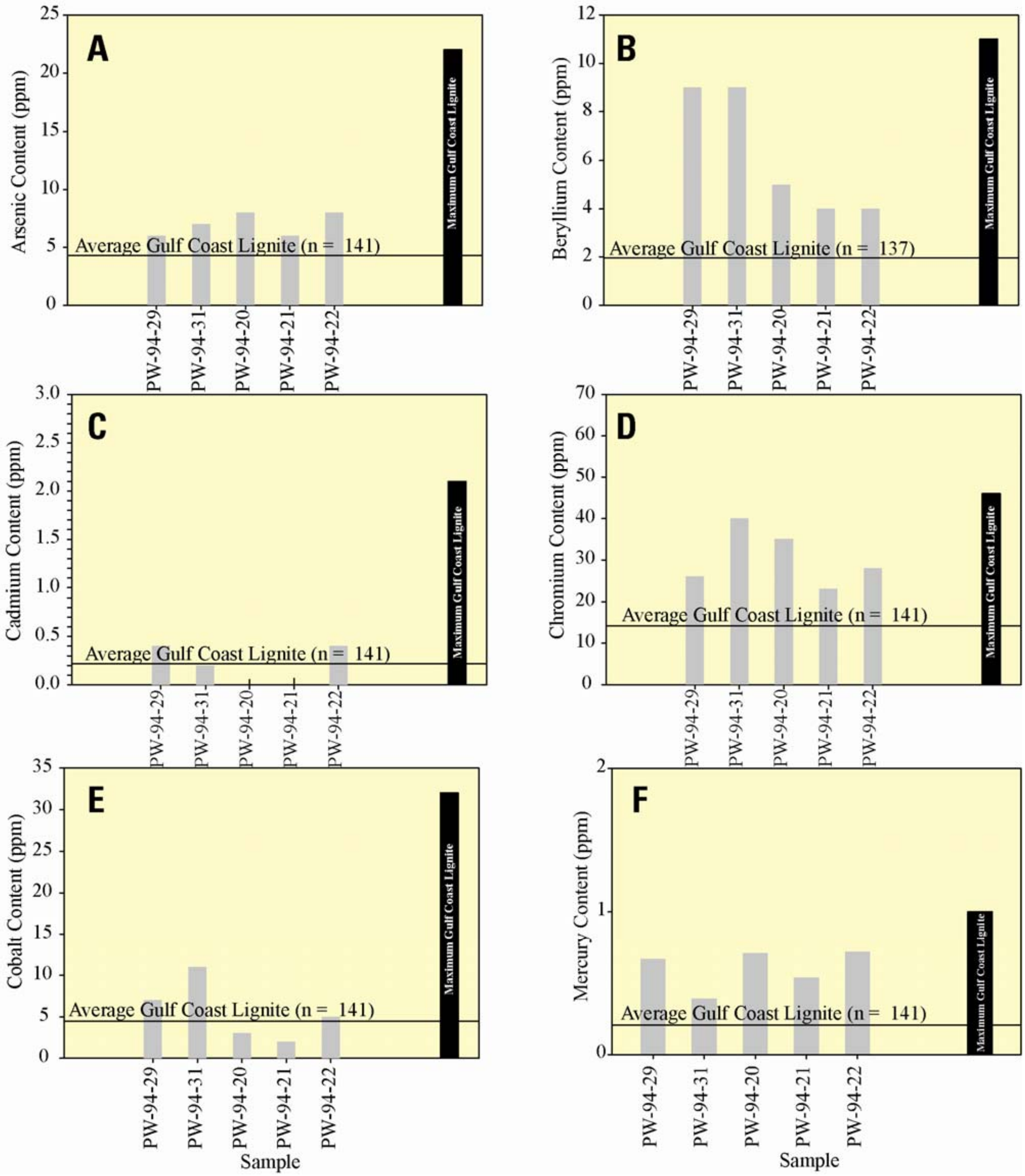


Figure 13. HAPs concentrations in western Kentucky and Tennessee lignite samples. Values on whole-coal, remnant moisture basis (approximately equal to as-determined). Values for the average and maximum Gulf Coast lignite were compiled from Bragg and others (1998). [n = number of samples; ppm = part per million]. A) arsenic, B) beryllium, C) cadmium; concentrations of cadmium in samples PW-94-20 and PW-94-21 were below detection limits (~0.2 ppm), D) chromium, E) cobalt, F) mercury.

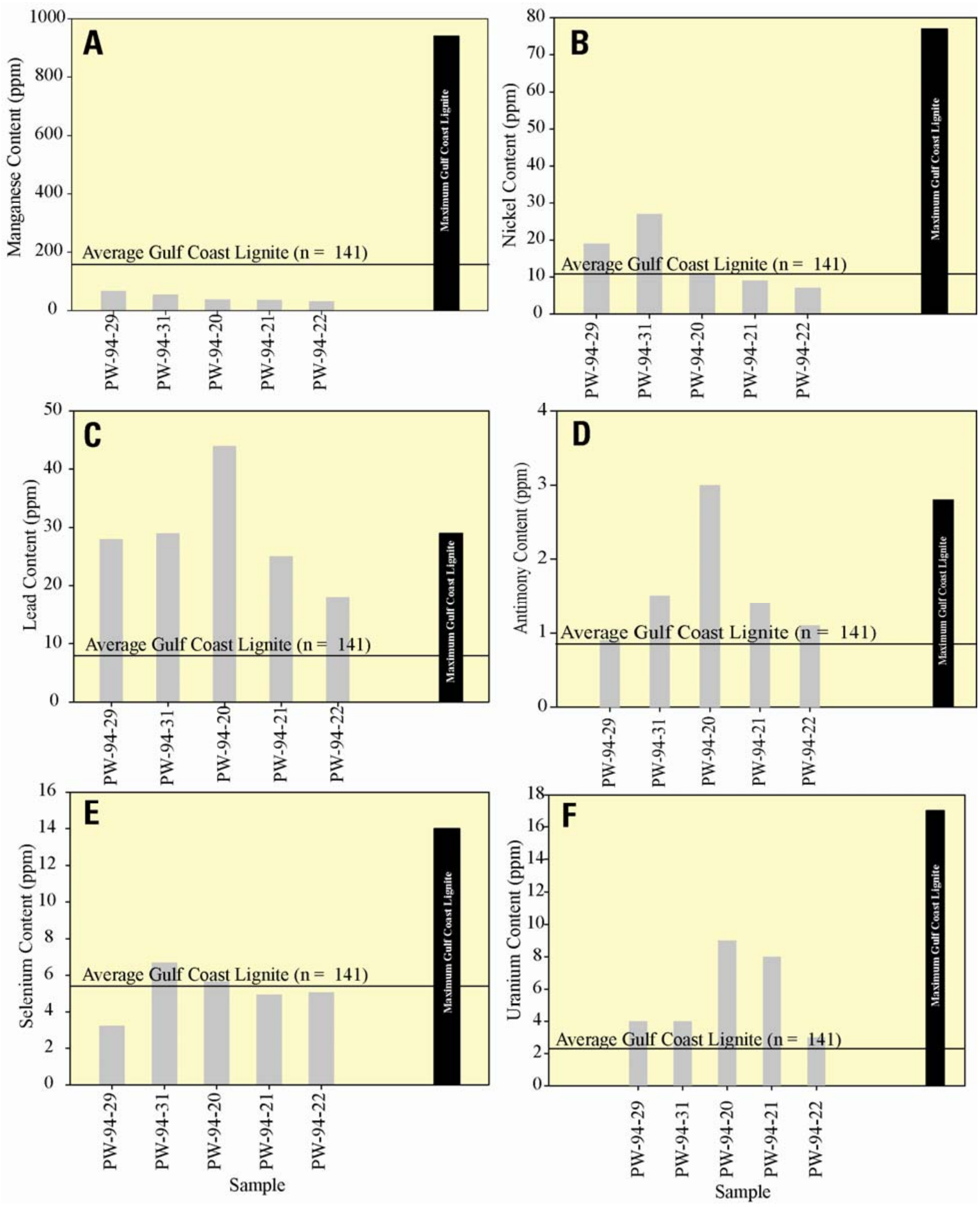


Figure 14. HAPs concentrations in western Kentucky and Tennessee lignite samples. Values on whole-coal, remnant moisture basis (approximately equal to as-determined). Values for the average and maximum Gulf Coast lignite were compiled from Bragg and others (1998). [n = number of samples; ppm = part per million]. A) manganese, B) nickel, C) lead, D) antimony, E) selenium, F) uranium.

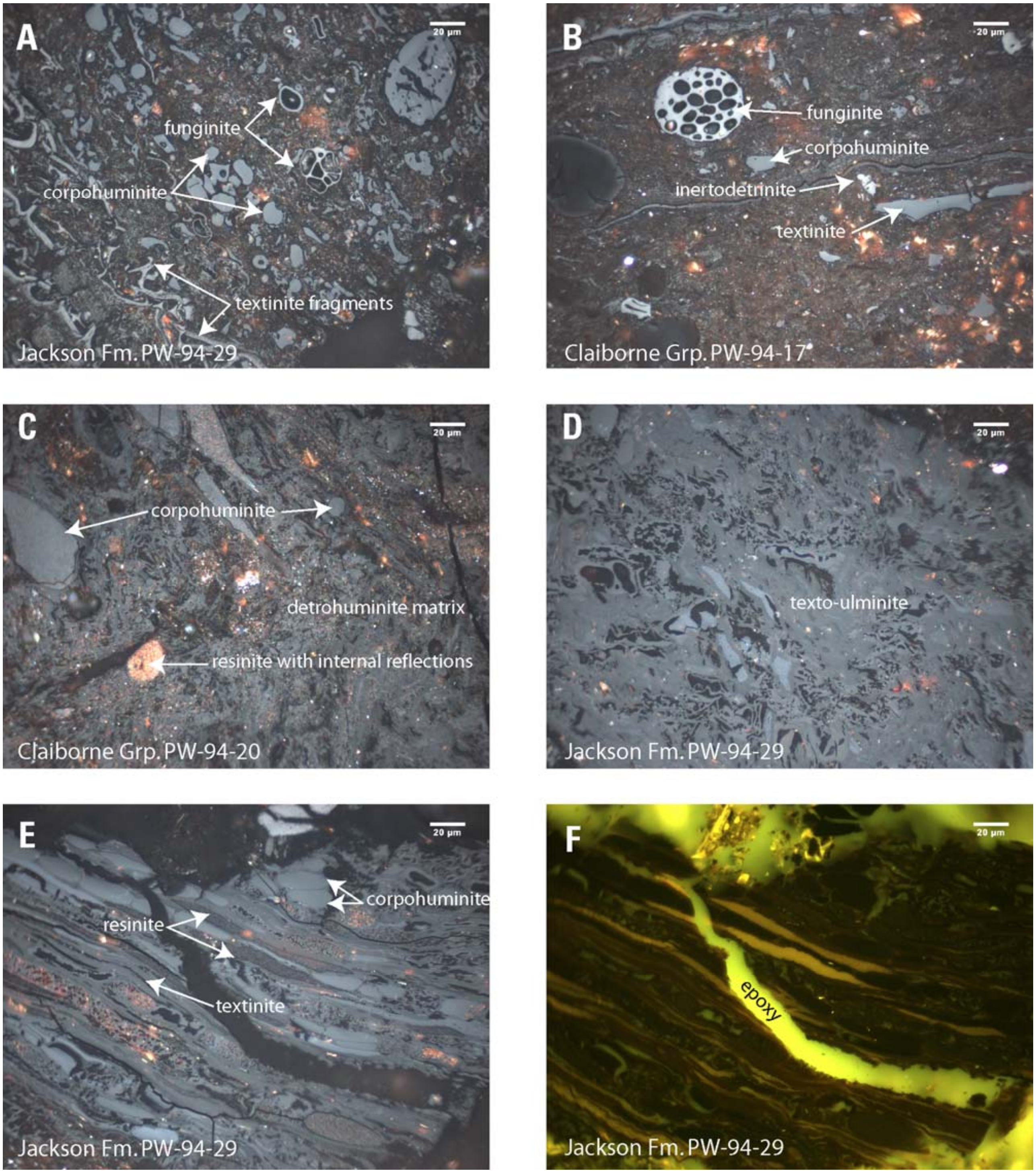


Figure 15. Photomicrographs of western Kentucky and Tennessee lignite samples. All in incident white light under oil immersion except (F) which is in incident blue light. A) Jackson Fm. funginite, B) Claiborne Grp. funginite, C) detrohuminite, D) texto-ulminite, E) textinite A, F) same field of view as (E) under blue light.

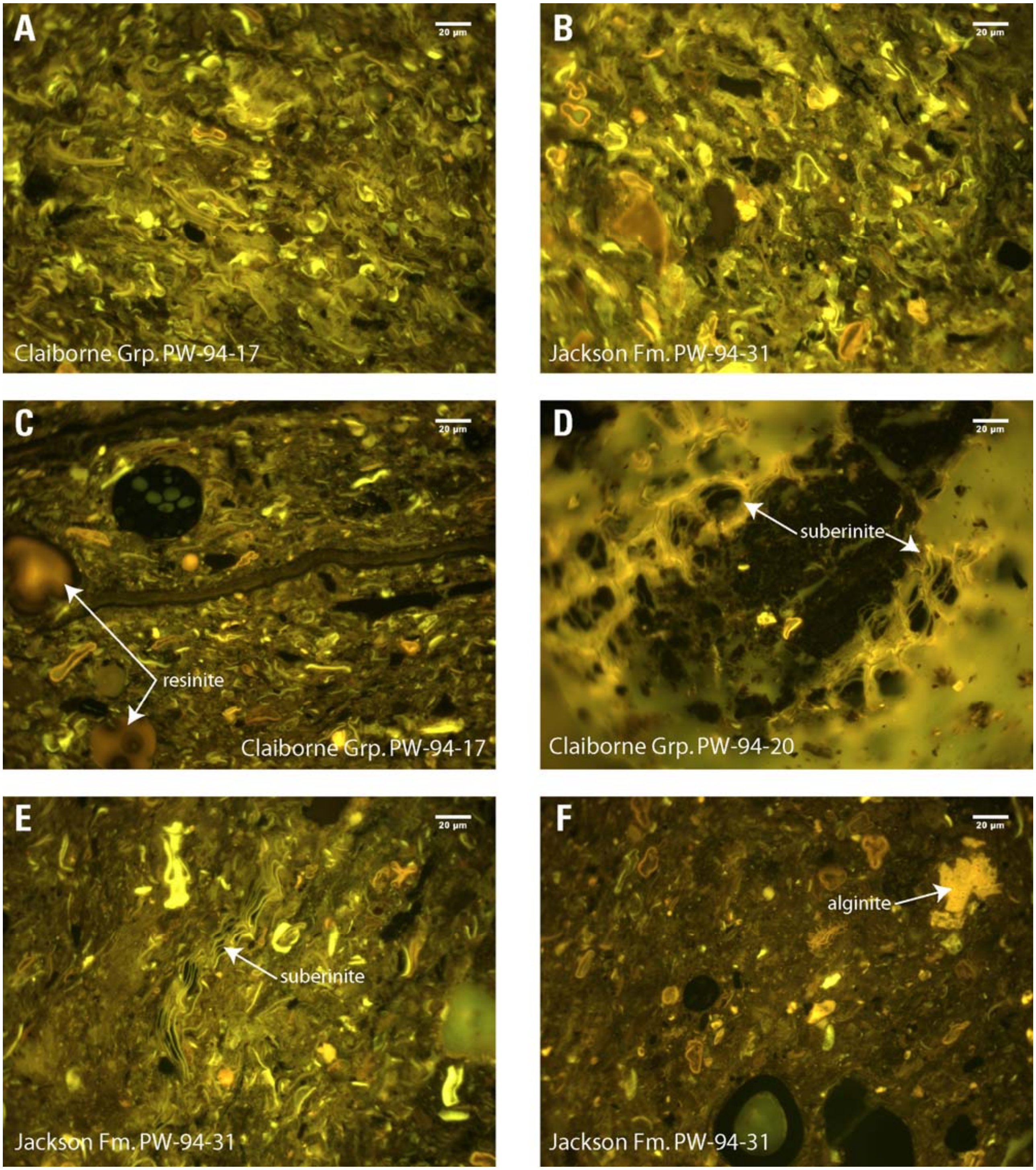


Figure 16. Photomicrographs of western Kentucky and Tennessee lignite samples. All in incident blue light under oil immersion. A) Claiborne Grp. sporinite, B) Jackson Fm. sporinite, C) resinite, D) Claiborne Grp. suberinite, E) Jackson Fm. suberinite, F) Jackson Fm. alginite.

Table 1. Proximate and ultimate analytical data (as-received basis) for western Kentucky and Tennessee lignite samples analyzed as part of this work and from Olive (1971). Abbreviations; Moist = moisture, Ash = ash yield, VM = volatile matter, FC = fixed carbon, H = hydrogen, C = carbon, N = nitrogen, S = sulfur, O = oxygen, n.d.= no data, Btu/lb = British thermal units per pound. Sample locations are shown in figures 4 and 7.

													Forms of Sulfur			
	Sample	**Formation**	**Moist percent**	**Ash percent**	**VM percent**	**FC percent**	**H percent**	**C percent**	**N percent**	**S percent**	**O percent**	**Calorific Value (Btu/lb)**	**Sulfate percent**	**Pyritic percent**	**Organic percent**	**Source of Data**
Sims pit, KY	**PW-94-29**	Jackson	45.42	13.02	26.18	15.38	7.61	28.48	0.31	1.15	49.43	4980	0.22	0.44	0.49	this report
	PW-94-30	Jackson	39.15	27.68	22.43	10.74	6.33	21.95	0.47	0.47	43.34	3790	0.03	0.03	0.41	this report
	PW-94-31	Jackson	42.45	18.10	27.72	11.93	7.27	28.10	0.26	0.42	45.85	5060	0.05	0.01	0.36	this report
Roberts pit, TN	**PW-94-20**	Claiborne	44.09	17.77	23.88	14.26	7.14	26.65	0.25	0.50	47.69	4620	0.00	0.01	0.49	this report
	PW-94-21	Claiborne	46.19	10.76	28.76	14.29	7.97	30.91	0.28	0.53	49.85	5440	0.01	0.01	0.51	this report
	PW-94-22	Claiborne	45.25	10.62	29.85	14.28	8.20	31.51	0.26	0.53	48.88	5760	0.01	0.02	0.50	this report
	PW-94-23	Claiborne	40.78	20.02	27.88	11.32	6.94	27.25	0.26	0.62	44.91	4870	0.01	0.06	0.55	this report
Swaim pit, TN	**PW-94-16**	Claiborne	41.42	20.73	21.95	15.90	6.79	26.27	0.28	0.51	45.42	4610	0.01	0.01	0.49	this report
	PW-94-17	Claiborne	45.17	9.58	31.69	13.56	8.42	32.10	0.24	0.51	49.15	5940	0.01	0.01	0.49	this report
	PW-94-18	Claiborne	40.67	21.88	25.75	11.70	7.10	25.27	0.25	0.54	44.96	4450	0.01	0.03	0.50	this report
	J-15141	Claiborne	48.9	9.2	25.8	16.1	8.0	27.9	0.4	2.5	52.0	5080	n.d.	n.d.	n.d.	Olive, 1971
	J-15142	Claiborne	51.8	5.7	25.6	16.9	8.3	29.6	0.4	0.7	55.3	5240	n.d.	n.d.	n.d.	Olive, 1971

Table 2. Proximate and ultimate analytical data for western Kentucky and Tennessee lignite samples discussed in this report. Abbreviations; S = sulfur, Ash = ash yield, n.d. = no data, Btu/lb = British thermal units per pound. Sample locations are shown in figures 4 and 7. Data are reported on a dry basis (ash yield, sulfur, and sulfur forms), and moist, mineral-matter-free basis (calorific value).

							Forms of Sulfur			
	Sample	**Formation**	**Ash (percent)**	**S (percent)**	**Calorific Value (Btu/lb)**	**R_{max}**	**Sulfate (percent)**	**Pyritic (percent)**	**Organic (percent)**	**Source of Data**
Sims pit, KY	**PW-94-29**	Jackson	23.86	2.10	5,766	0.24	0.41	0.80	0.89	this report
	PW-94-30	Jackson	45.48	0.78	5,397	n.d.	0.04	0.04	0.70	this report
	PW-94-31	Jackson	31.35	0.73	6,278	0.23	0.08	0.02	0.63	this report
Roberts pit, TN	**PW-94-20**	Claiborne	31.78	0.89	5,709	0.26	0.00	0.02	0.87	this report
	PW-94-21	Claiborne	19.99	0.99	6,147	0.29	0.01	0.03	0.95	this report
	PW-94-22	Claiborne	19.40	0.98	6,492	0.25	0.02	0.03	0.93	this report
	PW-94-23	Claiborne	33.80	1.05	6,202	n.d.	0.01	0.10	0.94	this report
Swaim pit, TN	**PW-94-16**	Claiborne	35.39	0.88	5,926	0.29	0.02	0.02	0.84	this report
	PW-94-17	Claiborne	17.47	0.92	6,616	0.28	0.01	0.02	0.89	this report
	PW-94-18	Claiborne	36.88	0.90	5,809	n.d.	0.02	0.06	0.82	this report
	J-15141	Claiborne	18.40	4.80	5,587	n.d.	n.d	n.d	n.d	Olive, 1971
	J-15142	Claiborne	11.80	1.40	5,569	n.d.	n.d	n.d	n.d	Olive, 1971
	7458	Claiborne	15.69	1.97	n.d.	n.d.	0.01	0.06	1.90	Hower and others, 1990
	7459	Claiborne	20.03	4.07	n.d.	n.d.	0.50	1.82	1.75	Hower and others, 1990
	7460	Claiborne	26.13	1.08	n.d.	n.d.	0.05	0.11	0.92	Hower and others, 1990
	7461	Claiborne	22.55	1.93	n.d.	n.d.	0.08	1.35	0.50	Hower and others, 1990
	7462	Claiborne	58.58	0.66	n.d.	n.d.	0.00	0.61	0.05	Hower and others, 1990
	7463	Claiborne	29.10	3.48	n.d.	n.d.	0.29	1.69	1.50	Hower and others, 1990
	7464	Claiborne	40.97	2.95	n.d.	n.d.	0.31	1.64	1.00	Hower and others, 1990
	7465	Claiborne	59.01	0.58	n.d.	n.d.	0.00	0.07	0.51	Hower and others, 1990
	7466	Claiborne	27.38	4.47	n.d.	n.d.	0.12	1.88	2.47	Hower and others, 1990
	7546	Claiborne	27.73	1.01	n.d.	n.d.	0.07	0.15	0.79	Hower and others, 1990
	7550	Claiborne	8.19	2.56	n.d.	n.d.	0.05	0.01	2.50	Hower and others, 1990
	7457	McNairy	52.96	1.10	n.d.	n.d.	0.00	0.60	0.50	Hower and others, 1990

Table 3. Major element analytical data [whole-coal, remnant moisture basis (approximately equal to as-determined)] for western Kentucky and Tennessee lignites analyzed for this work and from Hower and others (1990). Sample locations are shown in figures 4 and 7. [Ash = ash yield, n.d. = no data].

	Sample	Formation	Ash (percent)	SiO_2 (percent)	Al_2O_3 (percent)	CaO (percent)	MgO (percent)	Na_2O (percent)	K_2O (percent)	Fe_2O_3 (percent)	TiO_2 (percent)	P_2O_5 (percent)	Source of data
Sims pit, KY	**PW-94-29**	Jackson	21.50	9.03	6.45	0.49	0.21	0.03	0.11	2.15	0.24	0.02	this report
	PW-94-30	Jackson	43.20	22.90	12.96	0.48	0.39	0.06	0.40	1.21	0.56	0.03	this report
	PW-94-31	Jackson	28.60	16.30	7.15	0.46	0.23	0.04	0.13	0.86	0.72	0.03	this report
Roberts pit, TN	**PW-94-20**	Claiborne	29.20	17.52	5.55	0.47	0.15	0.02	0.05	0.64	1.55	0.05	this report
	PW-94-21	Claiborne	17.50	7.88	5.78	0.49	0.17	0.02	0.06	0.70	0.46	0.02	this report
	PW-94-22	Claiborne	18.40	8.65	5.34	0.48	0.16	0.03	0.10	0.63	0.46	0.02	this report
	PW-94-23	Claiborne	31.80	16.22	10.49	0.51	0.25	0.05	0.26	0.95	0.76	0.05	this report
	7458	Claiborne	15.69	9.25	5.08	0.06	0.02	0.02	0.14	0.33	0.32	0.02	Hower and others, 1990
	7459	Claiborne	20.03	9.15	3.56	0.26	0.02	0.02	0.07	6.48	0.26	0.02	Hower and others, 1990
	7460	Claiborne	26.13	12.61	7.20	1.41	0.67	0.03	0.16	1.69	0.45	0.03	Hower and others, 1990
	7461	Claiborne	22.55	9.83	5.25	1.60	0.70	0.02	0.06	2.88	0.43	0.03	Hower and others, 1990
	7462	Claiborne	58.58	43.43	10.12	1.00	0.57	0.06	0.19	1.85	0.90	0.05	Hower and others, 1990
	7463	Claiborne	29.10	13.83	7.76	0.86	0.20	0.03	0.13	4.41	0.40	0.03	Hower and others, 1990
	7464	Claiborne	40.97	22.55	11.60	0.67	0.23	0.04	0.32	4.52	0.75	0.05	Hower and others, 1990
	7465	Claiborne	59.01	38.03	17.02	0.57	0.35	0.06	0.66	1.04	1.23	0.07	Hower and others, 1990
	7466	Claiborne	27.38	11.60	7.93	0.62	0.18	0.03	0.13	5.59	0.39	0.03	Hower and others, 1990
	7546	Claiborne	27.73	15.14	7.93	1.12	0.33	0.03	0.19	0.79	0.42	0.02	Hower and others, 1990
	7550	Claiborne	8.19	3.01	2.66	0.60	0.12	n.d.	0.06	0.16	0.19	0.01	Hower and others, 1990
	7457	McNairy	52.96	37.37	10.31	0.20	0.05	0.05	0.29	3.72	0.94	0.05	Hower and others, 1990

Table 4. Trace element analytical data [whole-coal, remnant moisture basis (approximately equal to as-determined)] for western Kentucky and Tennessee lignites analyzed as part of this work. All values in parts per million (ppm) except ash yield. Abbreviations; Ash = ash yield, n.a. = not analyzed. < and > = qualified value (for analyses where concentration of element was below detection limit of instrument, value was assumed to be 0.7 of detection limit; for analyses where concentration of element was reported as a greater-than value, value was assumed to be greater-than value - see Bragg and others (1998) for additional explanation). Sample locations are shown in figure 4 and figure 7.

	Sample	Formation	Ash (percent)	Ag	As	Au	B	Ba	Be	Bi	Cd	Cl	Co	Cr	Cs	Cu	Ga	Ge	Hg	Li	Mn
Sims pit, KY	**PW-94-29**	Jackson	21.5	0.3	6	<0.5	13	215	9	0.5	0.4	n.a..	7	26	1.0	26	10	6.9	0.67	12	67
	PW-94-30	Jackson	43.2	0.8	6	<0.9	19	207	6	1.0	0.5	n.a.	5	60	4.8	56	22	2.5	0.30	31	60
	PW-94-31	Jackson	28.6	0.9	7	3.4	11	220	9	0.9	0.2	n.a.	11	40	1.0	43	16	2.2	0.39	14	54
Roberts pit, TN	**PW-94-20**	Claiborne	29.2	1.4	8	2.7	21	251	5	0.9	<0.04	n.a.	3	35	0.4	22	24	26.9	0.71	9	38
	PW-94-21	Claiborne	17.5	0.8	6	2.1	12	245	4	0.9	<0.03	n.a.	2	23	0.6	30	13	6.3	0.54	7	35
	PW-94-22	Claiborne	18.4	0.4	8	1.0	14	239	4	0.4	0.4	n.a.	5	28	1.0	26	9	6.6	0.72	8	31
	PW-94-23	Claiborne	31.8	0.5	9	1.0	16	293	5	0.7	0.3	n.a.	4	64	2.5	48	18	4.1	0.39	29	32

	Sample	Formation	Ash (percent)	Mo	Nb	Ni	Pb	Rb	Sb	Sc	Se	Sn	Sr	Te	Th	Tl	U	V	Y	Zn	Zr
Sims pit, KY	**PW-94-29**	Jackson	21.5	2	8	19	28	7	0.9	8	3.24	2	65	0.1	9	0.9	4	49	30	140	56
	PW-94-30	Jackson	43.2	4	20	17	33	34	1.4	12	3.94	4	86	<0.15	15	0.6	6	108	29	168	104
	PW-94-31	Jackson	28.6	4	17	27	29	8	1.5	10	6.68	4	77	0.2	14	1.0	4	92	43	43	109
Roberts pit, TN	**PW-94-20**	Claiborne	29.2	10	>58.4	11	44	3	2.9	11	5.66	12	137	0.2	24	0.2	9	111	58	11	245
	PW-94-21	Claiborne	17.5	4	26	9	25	4	1.4	8	4.96	8	68	<0.06	23	0.1	8	53	46	4	110
	PW-94-22	Claiborne	18.4	2	14	7	18	6	1.1	7	5.08	3	81	0.1	10	0.2	3	50	29	20	79
	PW-94-23	Claiborne	31.8	3	19	12	32	15	1.7	16	5.29	5	114	<0.11	16	0.4	6	99	35	18	114

Appendix: Palynological Data

By Douglas J. Nichols

Field No.	U.S. Geological Survey No.	Locality	Results
PW-94-16	R4939-B	Swaim clay pit, Weakly Co., TN (36°11.59’N, 88°39.43’W)	Cutinite abundant, palynomorphs sparse; assemblage dominated by lalongate tricolporate pollen, tetracolporate species of saptotaceous affinity common, also present are *Momipites* (*M. tenuipolus* and *M.* sp.), *Caryapollenites prodromus*, and *Symplocos*?. Age middle Eocene.
PW-94-17	R4939-C	Same as above	Same assemblage as R4939-B. Age: middle Eocene.
PW-94-18	R4939-D	Same as above	Same assemblage as R4939-B. Age: middle Eocene.
PW-94-20	R4940-A	Roberts Pit, Weakly Co., TN (36°11.33’N, 88°40.86’W)	Cutinite abundant, palynomorphs sparse: assemblage includes many species of prolate tricolporates and tetracolporates along with *Symplocos*?. Age: middle Eocene
PW-94-21	R4940-C	Same as above	Coarse and fine cuticular debris common; assemblage is dominated by tricolporate pollen, *Momipites* and *Caryapollenites* (“*prodromus* group” of Frederiksen) are present along with the triporate *Symplocos*?. Age: middle Eocene.
PW-94-22	R4940-D	Same as above	Poor preparation with much organic matter but few palynomorphs; essentially the same assemblage as in other samples from this locality. Age: middle Eocene.
PW-94-23	R4940-E	Same as above	Organic matter abundant, palynomorphs sparse, essentially the same assemblage as in other samples from this locality. Age: middle Eocene.

PW-94-29	R4942-A	Sims pit, Carlisle Co., KY (36°49.58′ N, 88°53.42′ W)	Organic matter abundant; assemblage dominated by prolate tricolporate pollen, sapotaceous tetracolporates also common, two species of *Momipites* present. Age: middle Eocene.
PW-94-30	R4942-B	Same as above	Same assemblage as in R4942-A. Age: middle Eocene.
PW-94-31	R4942-C	Same as above	Organic matter abundant, palynomorphs sparse; Essentially the same assemblage as in other samples collected from this locality. Age: middle Eocene.