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Chapter F

A Digital Resource Model of the Middle Pennsylvanian Fire Clay Coal Zone, Pottsville Group, Central Appalachian Basin Coal Region

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2000 RESOURCE ASSESSMENT OF SELECTED COAL BEDS AND ZONES IN THE NORTHERN AND CENTRAL APPALACHIAN BASIN COAL REGIONS

By Northern and Central Appalachian Basin Coal Regions Assessment Team

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CHAPTER F—A DIGITAL RESOURCE MODEL OF THE MIDDLE PENNSYLVANIAN FIRE CLAY COAL ZONE, POTTSVILLE GROUP, CENTRAL APPALACHIAN BASIN COAL REGION

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ABSTRACT

An assessment of the Middle Pennsylvanian Fire Clay coal zone was carried out in partnership with the State geologic surveys of Kentucky, Virginia, and West Virginia. The Fire Clay is an important coal in the central Appalachian region and a top producer in the State of Kentucky. The coal zone is generally composed of multiple benches and contains a volcanic ash or tonstein parting that serves as a regional stratigraphic marker. The Fire Clay coal zone records in the stratigraphic database were uniquely identified so that the coal benches most likely to be mined were the source of thickness data for the resource estimates. The resource model indicates that of the original 6.3 billion short tons of Fire Clay coal, 5.1 billion short tons remain. Most of the remaining resource is in Leslie and Knott Counties, Ky., and Boone County, W. Va., and is thinner and at greater depths than Fire Clay coal deposits previously mined. This resource model for the Fire Clay coal zone must be considered provisional, because the correlation of the zone continues to be evaluated by the West Virginia Geological and Economic Survey.

INTRODUCTION

The Middle Pennsylvanian Fire Clay coal zone is in the central Appalachian Basin coal region (fig. 1) and is distributed in more than 30 counties in the States of Kentucky, Virginia, and West Virginia. The coal zone's extent is approximately 5,500 mi^2 (fig. 2). The Fire Clay coal zone is one of many minable coal beds that formed during Pennsylvanian and Permian time (330-265 Ma) in a subsiding foreland basin that was filled in with sediments that eroded off an ancient landmass located to the east (Hatcher and others, 1989; see Chapter B for additional information). The Fire Clay coal zone is known for its flint clay parting, which has been interpreted as a tonstein of volcanic origin (Bohor and Triplehorn, 1981).

The coal resource assessment model of the Fire Clay coal zone is a cooperative effort between the U.S. Geological Survey (USGS), the Kentucky Geological Survey (KGS), the Virginia Division of Mineral Resources (VDMR), and the West Virginia Geological and Economic Survey (WVGES). At the time of the present assessment, the WVGES had not completed the mapping of the outcrop

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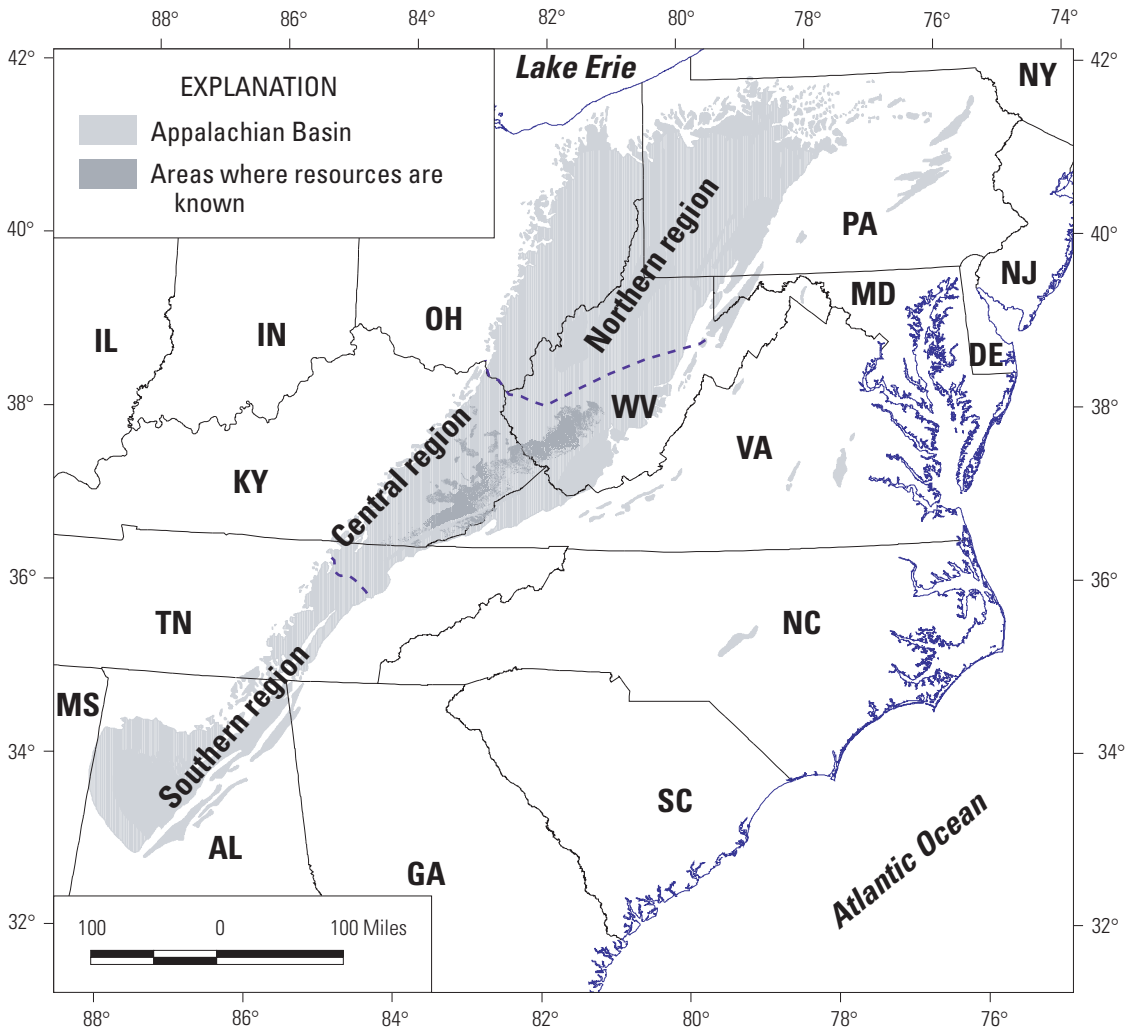

Figure 1. Map showing the location of the northern, central, and southern coal regions of the Appalachian Basin. The Fire Clay coal zone is in the central Appalachian Basin coal region.

extent of the Fire Clay coal zone in West Virginia. Therefore, the boundaries of the resource assessment areas (fig. 2) are a combination of outcrop, distribution of available data, and a computer-generated 1.17-ft (14-inch) coal thickness isoline based on the assessment database. The resource model assessment area boundaries encompass an area of about 2,600 mi^2 and extend from Kanawha and Fayette Counties, W. Va., southwestward to McCreary County, Ky., with limited exposures in Lee and Wise Counties, Va. The outcrop exposures of the Fire Clay coal zone in Tennessee are minimal and thus are not included in this resource model. Figure 2 shows the approximate extent of the Fire Clay coal outcrop (in light gray). This approximate outcrop is complete in Kentucky, matches the resource areas in Virginia, but is incomplete in West Virginia.

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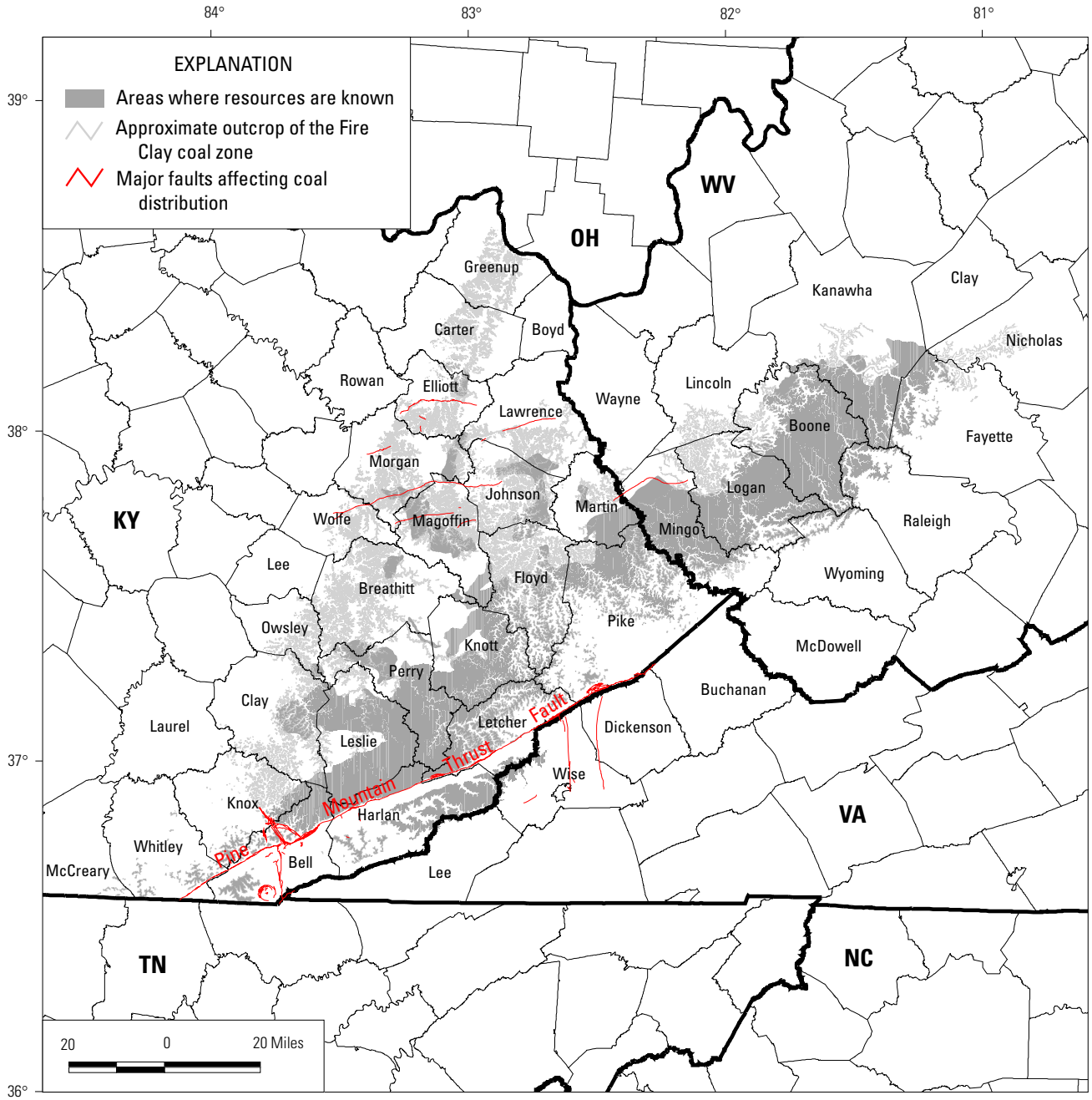


Figure 2. Map showing the approximate extent of the Fire Clay coal zone areas where resources are known. The light gray line, which shows the full outcrop in Kentucky and approximate outcrop in West Virginia, covers an area of about 5,500 mi^2 through more than 30 counties in the three States. Major faults affecting coal distribution are shown. The assessment areas, labeled where coal resources are known and shown in dark gray, incorporate all known outcrop in Virginia and cover a total of 2,600 mi^2 in the three States.

GEOLOGY

GEOLOGY OF THE POTTSVILLE GROUP

Middle Pennsylvanian coal of the Pottsville Group in the central Appalachian Basin coal region is important because of its high quality (low ash yield and sulfur content). The stratigraphic relationships of these coal beds are complex because most beds are laterally discontinuous and split and merge within coal zones. Local and regional faulting have affected coal-bed continuity and distribution. Although reliable correlation of coal beds over extensive distances requires detailed information, the States have used key marine units (mostly upward-coarsening sequences of shale, siltstone, and sandstone with some limestone) as marker beds within the region to remedy earlier miscorrelations (fig. 3). These marine units include the Betsie Shale Member, the Crummies Member, the Kendrick Shale Member and equivalents, and the Magoffin Shale Member and equivalents (fig. 3).

The Fire Clay coal zone of the Pottsville Group (as used in this report; see Chapter B, this report) is a term that groups together the Fire Clay coal bed of West Virginia with its equivalents in Kentucky and Virginia. In West Virginia, the Fire Clay coal bed is located in the Kanawha Formation, about midway between the Dingess Shale Member and the Winifrede Shale Member (marine marker units). In Kentucky, the Fire Clay coal zone includes the Fire Clay coal bed, Fire Clay Rider coal bed, Hazard No. 4 and Jackrock coal beds, located between the Kendrick Shale Member and the Magoffin Member (in the Hyden Formation of Chesnut, 1992). South of the Pine Mountain thrust fault in Kentucky (fig. 2), the coal zone is called the Wallins Creek coal bed and in Virginia, the coal zone is the Phillips coal bed in the Wise Formation. In Tennessee, the coal zone is the Windrock coal bed of the Graves Gap Formation (Rice and others, 1994), although Tennessee is not included in this resource assessment because of minimal exposure. Figure 3 shows the current relationships betwen the group, formation, marine unit, and coal bed names for these Middle Pennsylvanian rocks.

Rocks associated with the Fire Clay coal zone include sandstone, siltstone, shale, and underclay. Sandstone bodies represent both crevasse splay and associated channel deposits that locally contact the Fire Clay coal zone; tidal deposits, open-water bay deposits, and lacustrine sediments are also common in Kentucky (Greb, Hiett, and others, 1999). In Virginia, the Fire Clay coal zone is above a thick (40–80 ft) unnamed sandstone unit and within a thick siltstone sequence (Nolde, 1994). Strata of sandstone and sandy shale (which is often shale with sandstone interbeds) enclose the Fire Clay coal zone in West Virginia (Blake and others, 1994).

The eastern Kentucky coal field is located in a broad, northeast-trending syncline with steeply dipping margins. The Fire Clay coal zone crops out along the western edge of the coal field and wraps around to the southeastern corner of the State (as shown by the approximate outcrop line on figure 2). The eastern Kentucky coal field is divided into two distinct parts by the Pine Mountain thrust fault (fig. 2). Within the southern overthrust sheet, the structure also is a steep-sided, flat-bottomed syncline, with faults that have been interpreted as syndepositional features that influenced sediment distribution, coal thickness, and present-day outcrop patterns of the Fire Clay coal zone (Horne, 1979; Henika, 1994).

GEOLOGY OF THE FIRE CLAY COAL ZONE

The Fire Clay coal zone may occur as a single coal bench or multiple benches containing a regionally extensive flint clay and shale parting, locally known as the "jackrock" parting in Kentucky. The distinctive hard, brown to gray flint-clay parting is interpreted to be a tonstein of volcanic ashfall origin based on the presence of sanidine phenocrysts, beta-quartz paramorphs, euhedral zircons, and minerals such as ilmenite and rutile (Bohor and Triplehorn, 1981; Chesnut, 1985; Lyons and others, 1992, 1994). Age dates ($^{40}Ar/^{39}Ar$) of sanidine samples from the flint-clay parting are 312±1 Ma (Hess and Lippolt, 1986; Rice and others, 1990; Lyons and others, 1992). Because the tonstein is widespread and recognizable, it is a useful datum for stratigraphic correlations of the Fire Clay coal benches, rider, and leader coals; and rock strata above and below the tonstein (Greb, Eble, and Hower, 1999).

The tonstein parting in the Fire Clay coal zone allows recognition of distinct benches of coal. Figure 4 shows the benches and tonstein parting of the Fire Clay coal zone, which are discussed at length in Greb, Hiett and others (1999). The two coal benches can be significantly different in terms of thickness, palynology, and chemical characteristics in Kentucky (Eble and others 1989, 1994, 1995; Eble and Grady, 1990; Greb, Hiett, and others, 1999). These differences suggest that the benches represent two different mires rather than a single mire that was interrupted for a short period of time by clastic influx, drowning, and a volcanic ash fall (Greb, Hiett, and others, 1999). The widespread distribution and regular thickness of the parting suggest that the ash was deposited in shallow water with minimal currents, rather than on a land surface, where erosion would be more likely to occur (Greb, Hiett, and others, 1999). The coal bench below the flint-clay parting was deposited as a planar mire (below the water table) and can be discontinuous with many partings. The upper bench,

SYSTEM	SERIES	PRINCIPAL ROCK-STRATIGRAPHIC UNITS					
		GROUP	KENTUCKY (Modified from Cortland F. Eble, Kentucky Geological Survey, written commun., 1999)	GROUP	VIRGINIA (Modified from James Lovett, Virginia Division of Mineral Resources, written commun., 1998)	GROUP	WEST VIRGINIA (Modified from Bascombe M. Blake, Jr., West Virginia Geological and Economic Survey, written commun., 1998)
PENNSYLVANIAN	MIDDLE	POTTSVILLE	*Peach Orchard coal zone* *Arnett Member* *Hazard/Haddix coal zones* *Magoffin Member* *Fire Clay Rider coal zone* *Fire Clay coal zone (Hazard No. 4 coal bed)* *Whitesburg coal bed* *Kendrick Shale Member* *Amburgy coal bed* *Elkins Fork shale of Morse (1931)* *Upper Elkhorn No. 3 coal zone* *Alma coal zone (Upper Elkhorn Nos. 1 and 2 coal zone)* *Crummies Member* *Pond Creek coal zone (Lower Elkhorn coal bed)* *Little Eagle coal bed* *Betsie Shale Member*	POTTSVILLE	*High Splint coal bed* *Magoffin Member* *Gin Creek coal bed* *Fire Clay coal zone (Phillips coal bed)* *Kendrick Shale Member* *Taggart coal bed* *Taggart Marker coal bed* *Wilson, Upper St. Charles coal beds* *Pond Creek coal zone (Imboden coal bed)* *Betsie Shale Member*	POTTSVILLE	*Coalburg coal bed* *Little Coalburg coal bed* *Arnett Member* *Winifrede coal zone* *Chilton "A" coal bed* *Winifrede Shale Member* *unnamed marine zone* *Fire Clay coal zone* *Cedar Grove (Hernshaw) coal beds* *Dingess Shale Member* *Williamson coal bed* *Campbell Creek limestone of White (1885)* *Peerless coal bed* *No. 2 Gas coal zone* *Powellton coal zone* *Crummies Member* *Eagle "A" coal bed* *Pond Creek coal zone (Eagle coal zone)* *Little Eagle coal bed* *Betsie Shale Member*

Figure 3. Stratigraphic column of part of the Middle Pennsylvanian Pottsville Group showing current nomenclature used in this report and by the States for major coal beds and marine units.

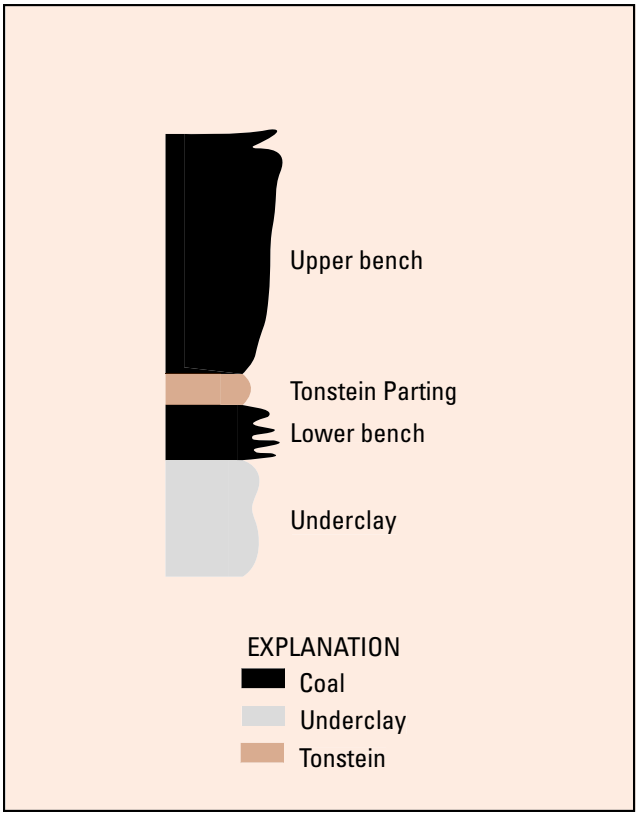


Figure 4. Stratigraphic column depicting the two main benches of the Fire Clay coal zone. The tonstein parting is used as a datum for correlating both the benches of the Fire Clay and other rock units. Data in Kentucky indicate that the lower bench is discontinuous, with numerous partings, and is higher in ash and sulfur than the upper bench. The tonstein parting is often silty or coaly shale overlain by the flint-clay tonstein, but the flint clay can occur directly on underclay (seat rock) where the lower bench is absent. The upper bench is more extensive, with few partings.

which is more continuous, formed, in part, from domed (or ombrogenous) peat located on topographically higher areas that were free of sediment deposition; thus, they have fewer partings (Greb, Hiett, and others, 1999). Discontinuities of the upper bench, however, resulted from postdepositional channeling and splits created by partings. Only a modest amount of geological literature on the Fire Clay coal zone and its tonstein parting is summarized in this report. Appendix 1 lists additional selected references.

Haney and others (1983) compared the regional geometry of the Fire Clay coal zone to major structures mapped in the eastern Kentucky coal field and inferred that coal distribution was controlled by the eastern Kentucky syncline. Weisenfluh and Ferm (1991) described rectangular patterns of Fire Clay coal thickness in mines in Harlan and Leslie Counties, Ky. (fig. 2); they also inferred structural controls on coal thickness distribution, where peat accumulated preferentially along upthrown margins of fault blocks. Sand was intermittently deposited by rivers on the downthrown margins of faults contemporaneously with the peats, resulting in splits and thinner coal. Similar distribution patterns are noted in Perry and Knott Counties, Ky. (Greb, Hiett, and others, 1999).

In Virginia, the Phillips coal bed (fig. 3) occurs either singly or as many as four or five benches in a 25- to 50-ft interval of siltstone (Nolde, 1994). The Lower Phillips coal bed actually is composed of two coal benches (with a third discontinuous bench above) and is separated from the Upper Phillips coal bed (which also has two coal benches) by 10 to 30 ft of shale (Nolde, 1994). The flint clay parting generally is within the lower third of the zone (Nolde, 1994), which would make the Lower Phillips similar to that shown in figure 4. In West Virginia, the Fire Clay coal zone consists of two to three benches of coal within a sandy shale sequence. The coal zone often overlies (within 2-10 ft) an unnamed sandstone unit that ranges from 10 to 40 ft in thickness. Keiser and others (1989) describe the flint-clay parting as light-brownish- to dark-brownish-gray (sometimes nearly black) and varying in thickness from 0 to 6 inches.

MINING HISTORY

The historical development of coal resources in eastern Kentucky and southern West Virginia is related mainly to the rise of transportation in the region (Huddle and others, 1963). Comparatively small quantities of coal were mined prior to the 1880's, mainly along rivers that allowed for shipping. Although railroads had reached the northern and western margins of the eastern Kentucky coal field by 1900, rail lines did not reach the main Fire Clay coal zone resource areas of Knott, Perry, Letcher, and Leslie Counties, Ky. (fig. 2) until the 1910's. Production of coal increased dramatically in the 1920's as branch rail lines continued to grow and underground mines began to mechanize. The development of improved highways, which started in the 1950's and continues to this time, has fostered mining in areas not served by railroads.

The great majority of the Fire Clay coal zone mined to date has been from underground mines, most of which were room-and-pillar drift mines (Huddle and others, 1963). One longwall mine, the James River Coal Company's Middlefork Mine No. 18 in Leslie County, Ky., currently is operating in the equivalent Hazard No. 4 coal bed. Because of the deeply dissected terrain of the region, surface mining has been limited mainly to contour stripping (often in preparation of drift openings) and mountain-top removal.

The Fire Clay coal zone has been mined extensively in Kentucky and the original resources are significantly depleted. Figure 5 shows available Fire Clay coal zone production data by State for Kentucky, Virginia, and West Virginia since 1970 (see Appendix 2 for additional informa-

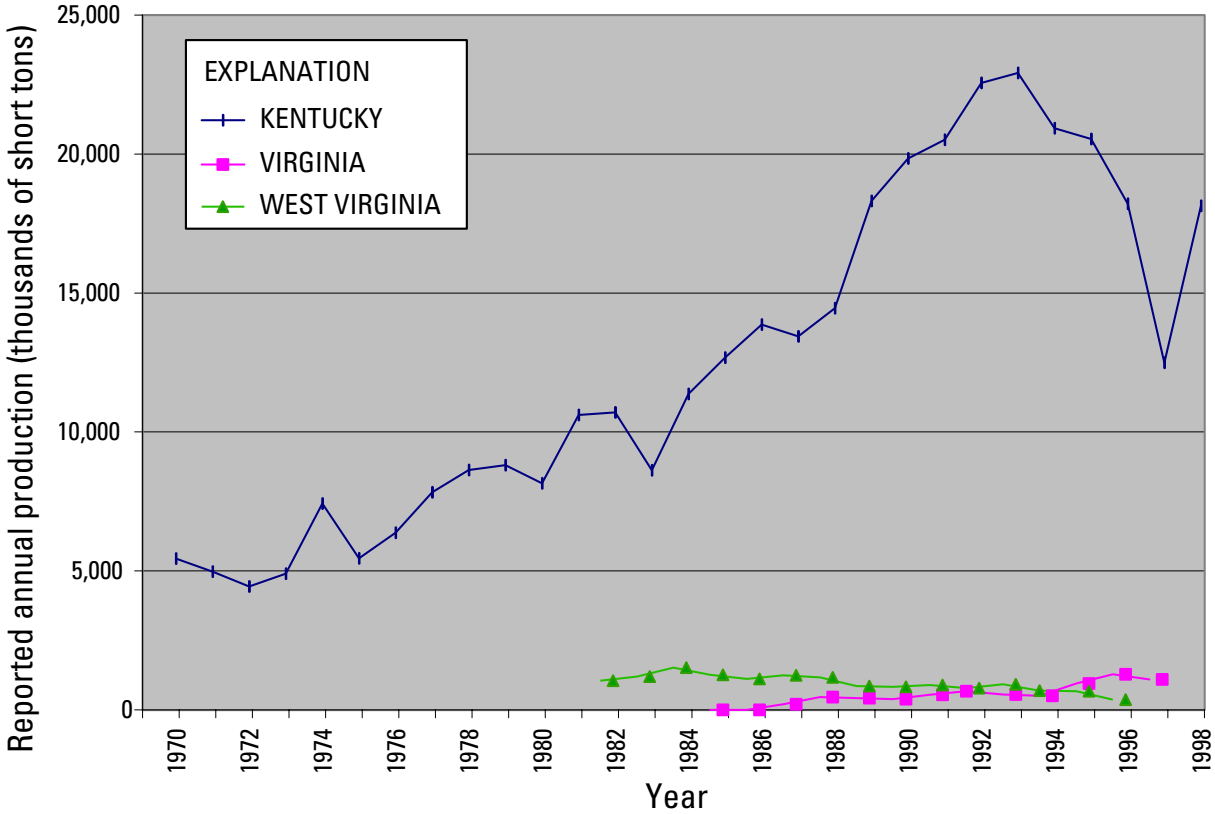


Figure 5. Graph showing recent reported annual production (in thousands of short tons) from the Fire Clay coal zone in Kentucky, Virginia, and West Virginia, assembled from State agencies, from 1970 to 1998. Sources: Sweet (1988, 1989, 1991); Sweet and Nolde (1992, 1993, 1994, 1995, 1996, 1997a, 1997b, 1998, 1999); Gayle H. McColloch (West Virginia Geological and Economic Survey, unpublished search of West Virginia Office of Miner's Health, Safety, and Training—Safety Information System (MHST-SIS) database, 1997); John K. Hiett (Kentucky Department of Mines and Minerals, written commun., 2000); see Appendix 2.

tion). The available data indicate a total production of 511 million short tons since 1929 (Appendix 2). Comprehensive production figures are not available at this time, but mined-out estimates suggest that as much as 1 billion short tons have been mined or lost in mining in Kentucky since the early 1900's.

The annual reported total Fire Clay coal zone production in Kentucky since 1980 ranged from 8 to almost 23 million short tons and averaged about 16 million short tons (figs. 5, 6, Appendixes 2, 3). Most of the minable resources are found in Letcher, Knott, and Leslie Counties, Ky. (fig. 2) and Fire Clay coal zone production dominates the total annual coal production for this geographic area. The production reported for 1998 by the Kentucky Department of Mines and Minerals was 18 million short tons (John K. Hiett, Kentucky Department of Mines and Minerals, written commun., 2000) (fig. 5, Appendixes 2, 3); about 95 percent of this coal was mined by underground methods. The number of mines in Kentucky has decreased from hundreds in the early 1980's to 74 in 1997. Though fewer in number, the average production of these mines has increased significantly. The total Fire Clay production reached a maximum of almost 23 million short tons in 1993 (fig. 5) and has since declined to the current level of 18 million short tons (John K. Hiett, Kentucky Department of Mines and Minerals, written commun., 2000).

The reported production of the Fire Clay coal zone in Virginia has been from both surface and underground mining and has totaled 8.1 million short tons from 1985 through 1998 (fig. 7, Appendix 4). In West Virginia, production data for the Fire Clay coal zone is limited (fig. 8; Gayle H. McColloch, West Virginia Geological and Economic Survey, unpublished search of West Virginia Office of Miner's Health, Safety, and Training—Safety Information System (MHST-SIS) database, 1997). The reported production (some of which may not be Fire Clay coal) for the years 1982 to 1996 in five West Virginia counties totals 15 million short tons (Appendix 5). Mining of the Fire Clay coal zone in Boone County, W. Va. (figs. 2, 11) was conducted prior to 1980 and is not reflected in figure 8 or in Appendix 5.

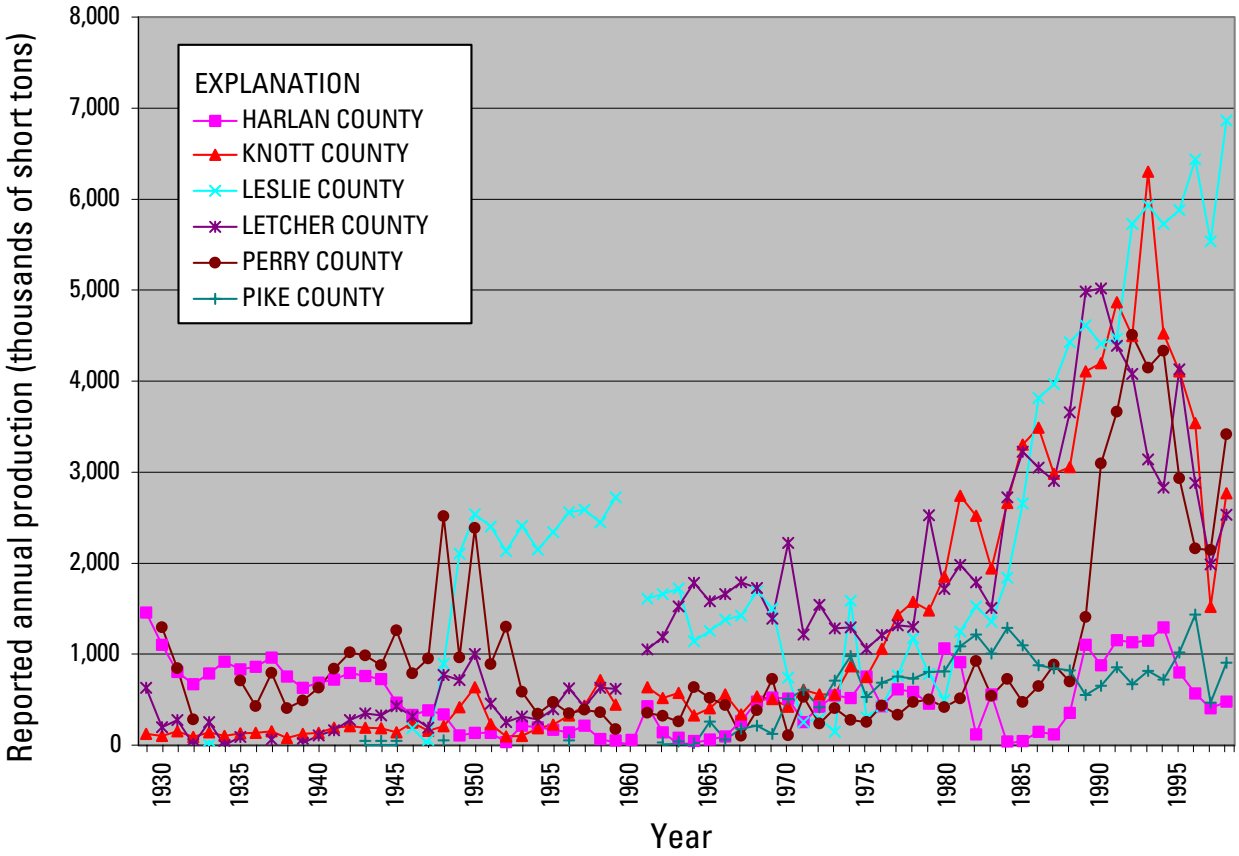


Figure 6. Graph showing recent reported annual production (in thousands of short tons) from the Fire Clay coal zone in Kentucky, by county (where cumulative production was greater than 24 million short tons) from 1929 to 1998. Source: John K. Hiett (Kentucky Department of Mines and Minerals, written commun., 2000); see Appendix 3.

ASSESSMENT METHODOLOGY

DATABASES

Two databases, stratigraphic and geochemical, are the primary tools used to model the Fire Clay coal zone and assess resources. Stratigraphic point locations for this study were obtained from the State geological surveys and used as the regional database. As stated earlier, because data in West Virginia are currently being evaluated, the resource model of the Fire Clay coal zone in this State is likely to change. The data in Virginia were downloaded from the National Coal Resources Data System (NCRDS) and correlations were checked by viewing the data in geological cross sections. Stratigraphic records in Virginia and West Virginia included detailed descriptions of cores and measurements from mines and outcrops. In Kentucky, the data were derived from two KGS databases. The Kentucky Coal Resources Information System (KCRIS) contains descriptions of coal beds from outcrops, roadcuts, and surface and underground mines. Data collected at these localities include total coal thickness, bottom elevation, and, in some cases, total parting thickness. The second Kentucky database contains records of borehole information obtained from coal companies and government agencies; it also includes measurements of rock strata above and below the Fire Clay coal zone.

A total of 2,369 stratigraphic records from the three States compose the publicly available stratigraphic database for the Fire Clay coal zone (fig. 9). Additional confidential stratigraphic data also were used to prepare assessment products. The benches most likely to be mined in the Fire Clay coal zone were tagged in the database (Appendix 6) and were used to calculate resources. The KGS developed guidelines to identify Fire Clay coal zone benches that could be mined, based on the mining practices in Kentucky. The USGS followed these criteria for data selection in Virginia and West Virginia. Benches of the Fire Clay coal zone were identified, or tagged, for use in resource calcula-

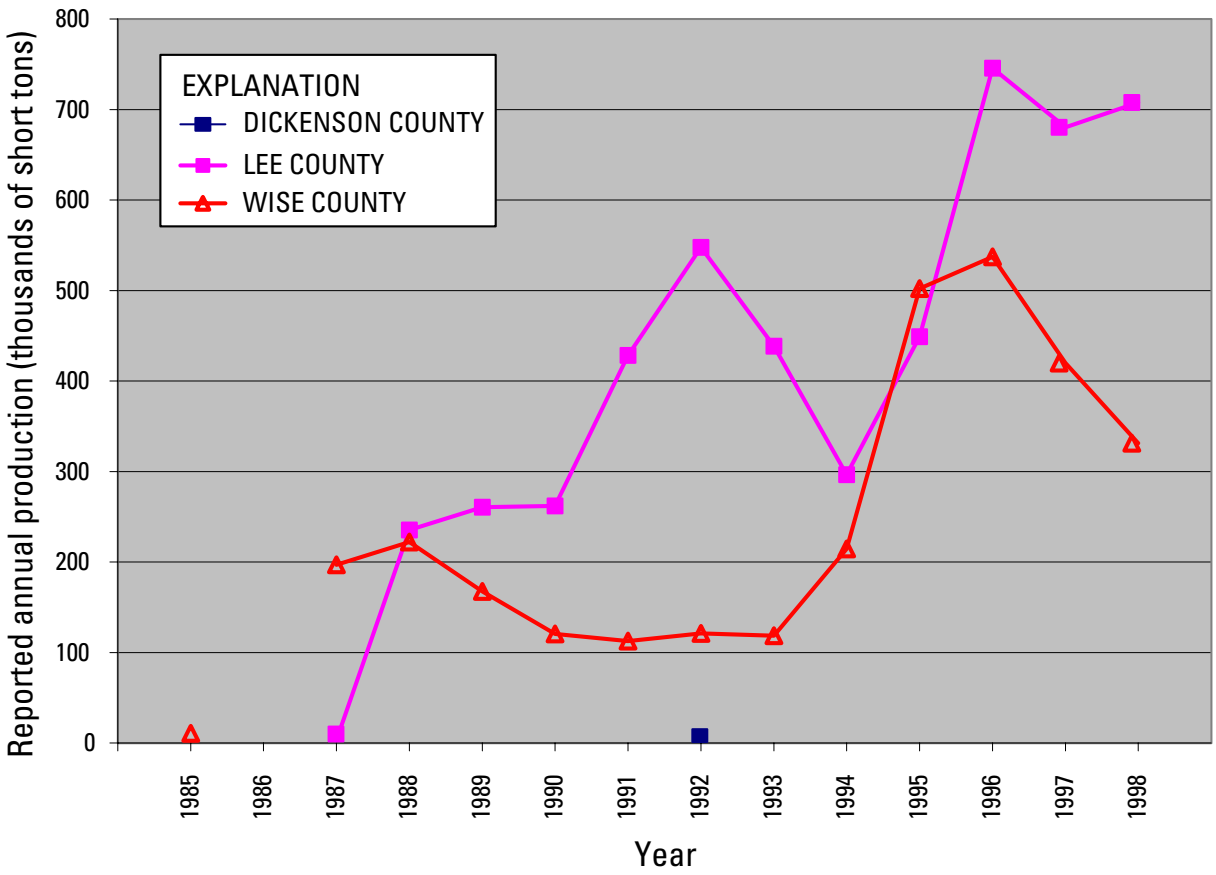


Figure 7. Graph showing recent reported annual production (in thousands of short tons) from the Fire Clay coal zone in Virginia, by county, from 1985 to 1998. Sources: Sweet (1988, 1989, 1991); Sweet and Nolde (1992, 1993, 1994, 1995, 1996, 1997a, 1997b, 1998, 1999); see Appendix 4. For Dickenson County, production was below 1,000 short tons for every year except 1992.

tions on the basis of thickness criteria for the coal and non-coal partings (interburden). For coal that was minable within 200 ft of the surface, the thickness of a single coal interval (defined as having non-coal rock types above and below) had to be at least 1.17 ft. Additional benches were included in the thickness total if the intervening non-coal interval was less than half as thick as the additional coal bench. An exception to this criteria allowed for the inclusion of multiple additional coal intervals if the total non-coal intervals were no more than half as thick as the total additional coal intervals. If no single coal interval met the thickness criteria, the thickest coal within the stratigraphic zone was tagged for use in the database.

The Fire Clay coal zone geochemical database (Appendixes 7, 8, and 9) was derived from the USGS and KCRIS databases (see Appendix 9). The geochemical database consists of analyses, reported on an as-received whole-coal basis, of 59 samples. Fifty-five of the analyses entered into the database are located by latitude and longitude coordinates (fig. 10). The other four samples are considered to be reliable and accurate at least to a county scale. All the geochemical records contain ash yield, sulfur content, and gross calorific value (British thermal units per pound, or Btu/lb), but only 39 of the records were analyzed for as many as 86 different trace elements. Three samples of the Fire Clay coal zone were collected in intervals or benches and were aggregated to obtain representative analyses of the "whole coal bed" chemistry at their locations for the purposes of this study. Additional information on data sources, handling, averaging, and formatting are explained in Appendixes 8 and 9. The geochemical database can be downloaded in ASCII format from Appendix 7.

GEOGRAPHIC INFORMATION SYSTEM (GIS)

Information from the Fire Clay coal zone databases was used in conjunction with vector data (outcrop and mined areas) obtained from maps of the Fire Clay coal to create data layers in a geographic information system (GIS). The outcrop area of the Fire Clay coal zone in Kentucky was compiled from 7.5-minute geologic quadrangle maps and

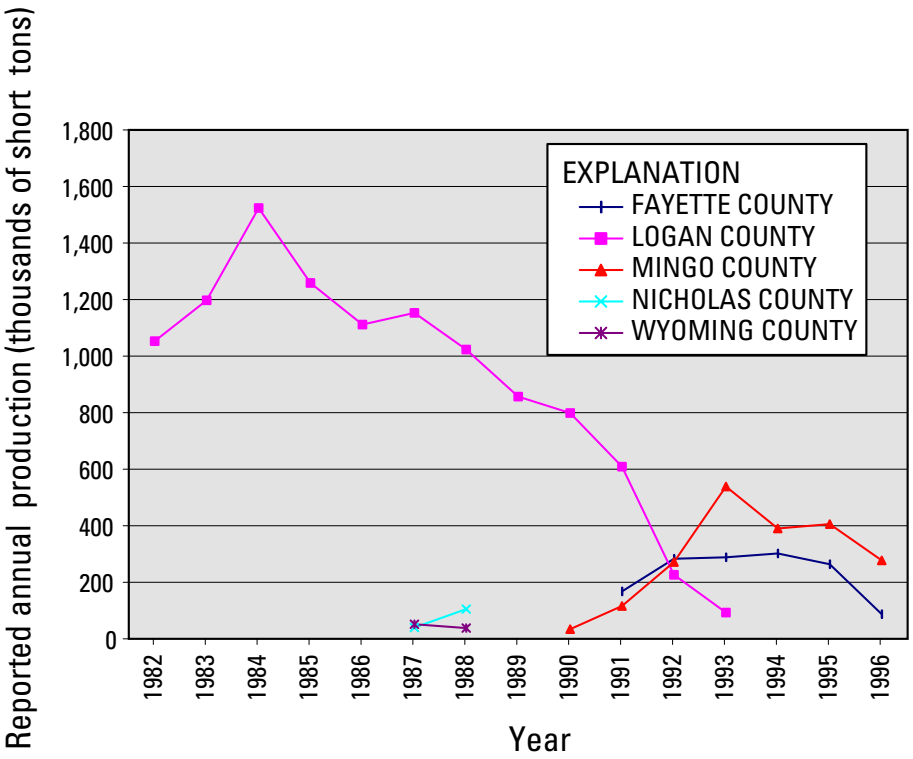


Figure 8. Graph showing recent annual production (in thousands of short tons) from the Fire Clay coal zone in West Virginia, by county, from 1982 to 1996. Source: Gayle H. McColloch (West Virginia Geological and Economic Survey, unpublished search of West Virginia Office of Miner's Health, Safety, and Training—Safety Information System (MHST-SIS) database, 1997); see Appendix 5.

digitized by Kentucky State personnel. For quadrangles where the coal had not been geologically mapped in Kentucky, the outcrop was inferred, where possible, based on underlying or overlying beds. The entire outcrop of the Fire Clay coal zone was thus available and the small outcrop in Virginia was also obtained digitally from the VDMR. The complete outcrop in West Virginia was not available, but crop lines provided by the WVGES (on mylar film sheets at 1:48,000 scale) were digitized by the USGS and joined with those from Kentucky and Virginia in the GIS. A small area of the Fire Clay coal zone is known to extend into northernmost Tennessee (as the equivalent Windrock coal), but these outcrop data were not available and were not incorporated into the digital file. All vector and point information was projected to Albers equal area coordinates.

The outer edges of the resource assessment areas for this study (fig. 11, areas where resources are known) were delineated using a combination of actual outcrop lines, distribution of available data points, and a 1.17-ft (14-inch) thickness line based on criteria of Wood and others (1983). As discussed previously, the distribution of the outcrop is controlled partly by the occurrence of faults, particularly the Pine Mountain thrust fault (fig. 2).

The mined-area coverage was created by combining information from the State geological surveys (fig. 11). The accuracy of mined areas varies based upon the source of information and dates of compilation. Generalized outlines of mined-out areas in Kentucky were collected from the Kentucky Department of Mines and Minerals (KDMM) and transferred to 1:100,000-scale base maps; individual mine boundaries were not documented. The KDMM maps were completed in 1993 and only a few additional mines have been added since that time. The KGS updated the file identifying mined areas of the Fire Clay coal zone after the completion of this assessment. The locations of mined areas in Virginia were provided by the VDMR and are current as of 1994. In West Virginia, mined areas were digitized by the USGS from 1:48,000-scale mylar films made available by the WVGES. The mined-area coverage for the Fire Clay coal zone in West Virginia is considered reasonably complete, but differs from data in Appendix 5 because of the dates of mining.

Part of the structure-contour map for the Fire Clay coal zone (fig. 12) was provided in digital format by the KGS. In Kentucky, the KGS plotted elevation data from their point databases on 1:100,000-scale base maps and manually con-

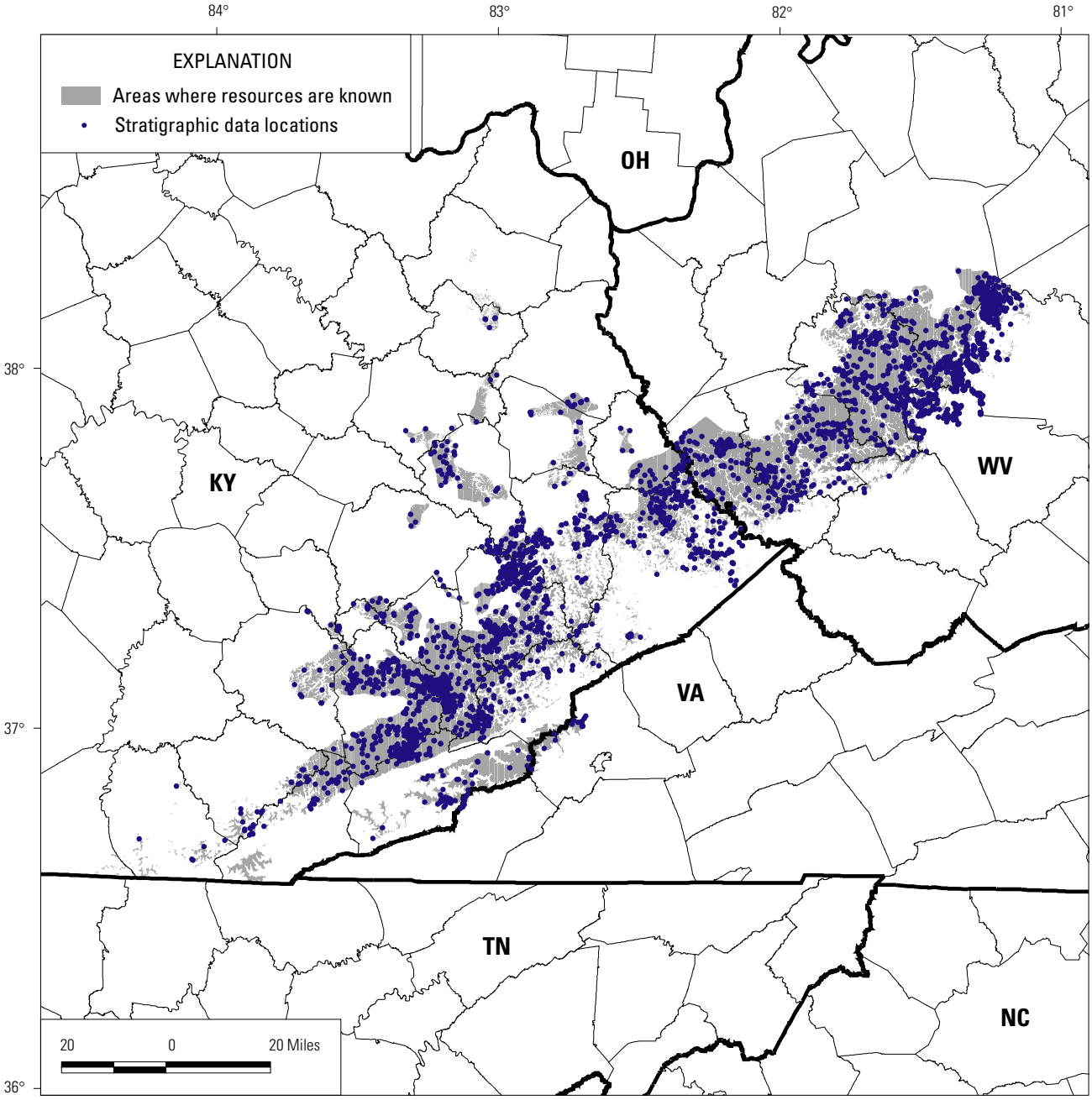


Figure 9. Map showing point locations for public stratigraphic records used to model the coal resource areas of the Fire Clay coal zone. Point identifier or record name, longitude, latitude, coal thickness, and coal elevation for all publicly available records can be downloaded from Appendix 6 in ASCII format. See figure 2 for county names.

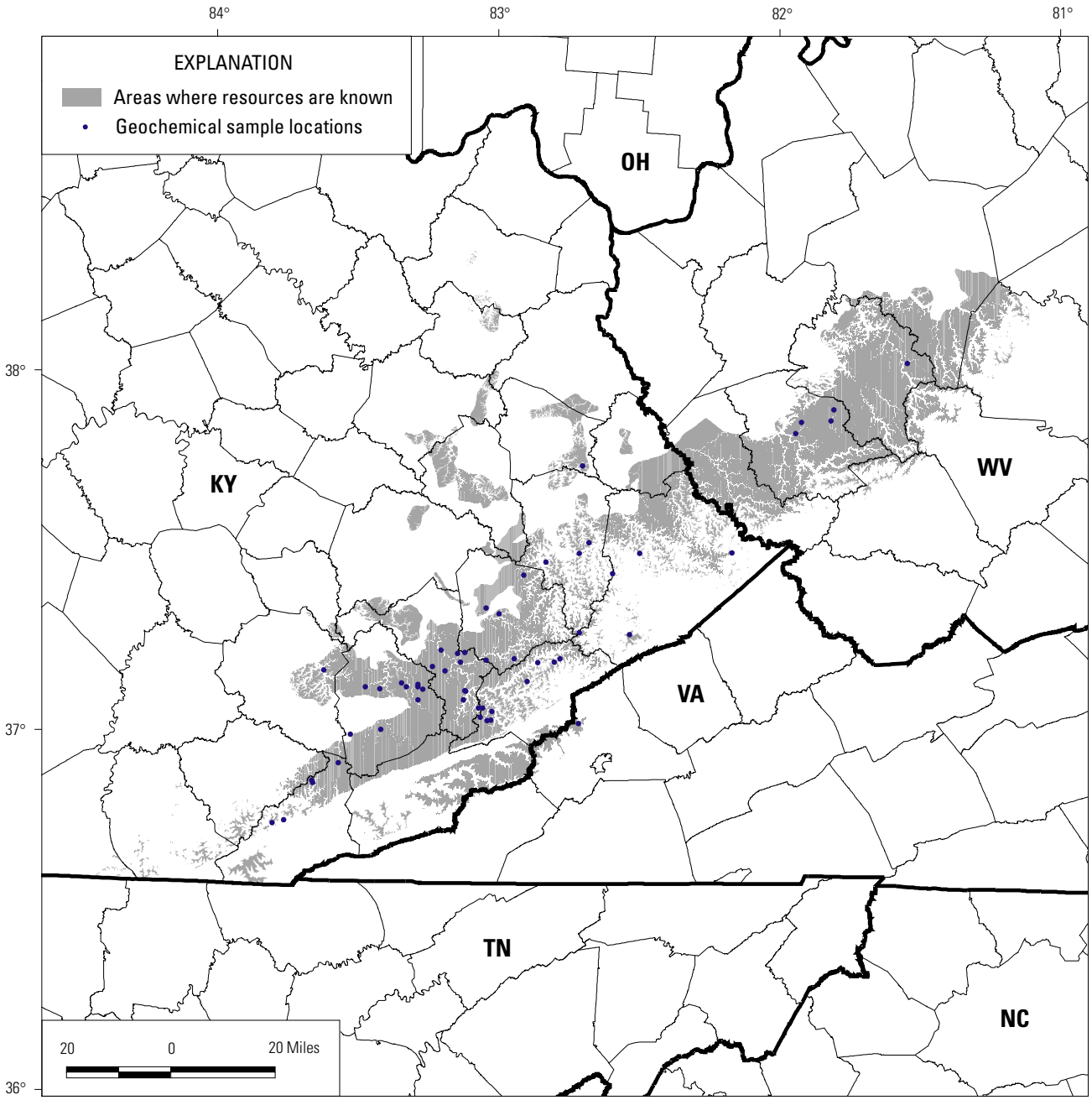


Figure 10. Map showing point locations of geochemical samples of the Fire Clay coal zone for which records are publicly available and located by latitude and longitude. All of the geochemical data can be downloaded in ASCII format from Appendix 7. Appendix 8 contains geochemical metadata, and Appendix 9 contains references for the geochemical data and analyses. See figure 2 for county names.

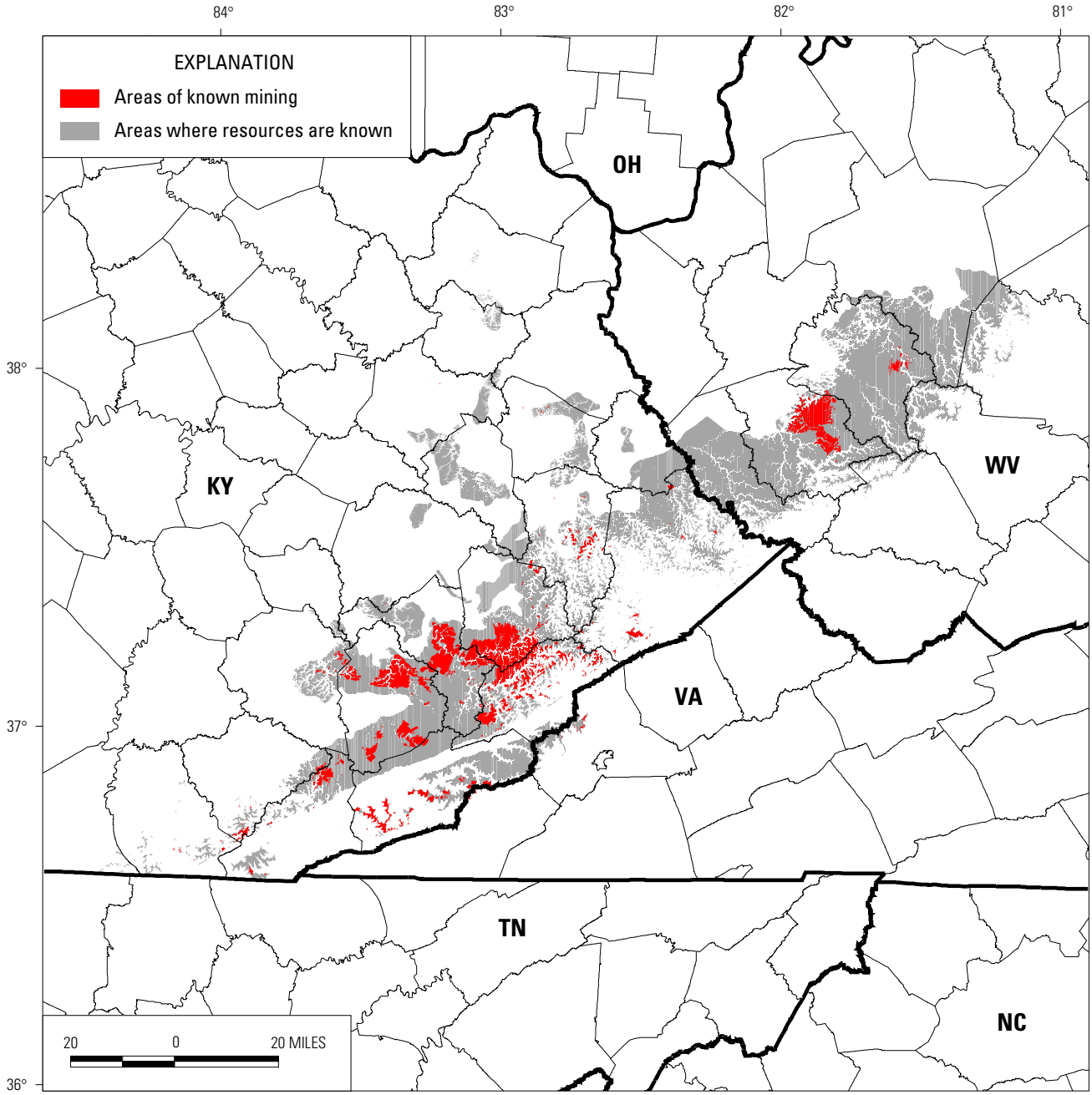


Figure 11. Map showing areal extent of the Fire Clay coal zone where resources are known (gray) and areas of known mining (red). See figure 2 for county names.

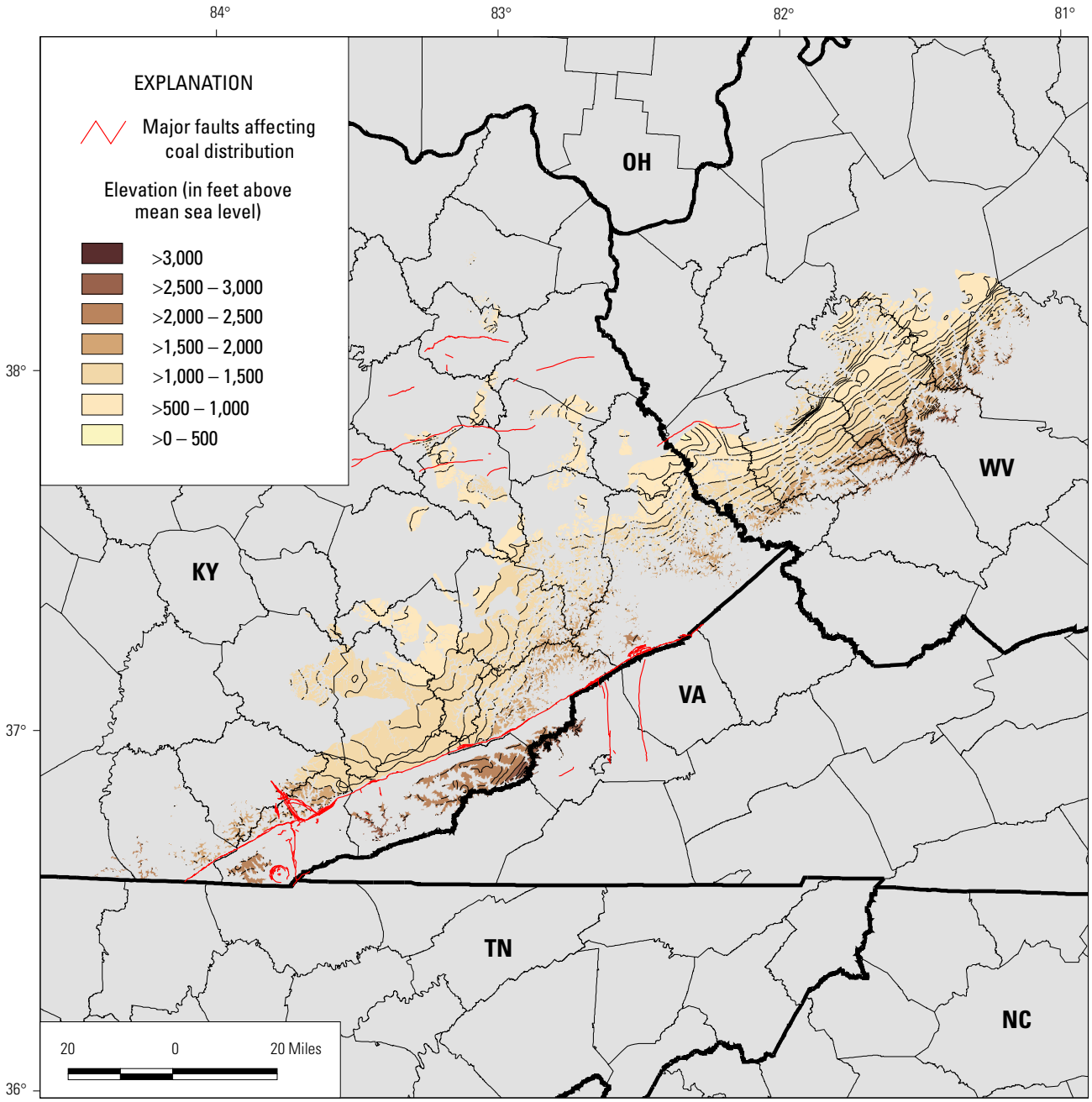


Figure 12. Structure-contour map of the Fire Clay coal zone. The contours are presented on the top of the coal bed at 100-ft intervals. However, for visual acuity, contours were colored in 500-ft intervals. Existing structure-contour maps as well as data from the stratigraphic database were used to create the map.

toured elevation values where data density was deemed sufficient. In areas of insufficient data, elevations were estimated either from the surface elevation of the mapped outcrop line (if proximal to the bed outcrop) or by interpolating the surface from other structurally mapped coal beds using average interburden thicknesses derived from the borehole data. The WVGES provided structure-contour lines on 7.5-minute topographic quadrangles, which were digitized by the USGS. The GIS structure-contour files provided by the KGS and WVGES were converted from elevation lines to points. The Fire Clay coal zone elevation measurements in Virginia were derived from the stratigraphic database. Combining these three sources generated a file that was used to create an elevation grid over all three States using EarthVision[7] software. A GIS file of regional faults also was used to constrain the regional elevation grid in EarthVision. Contours are presented in 100-ft intervals, color-coded to 500-ft intervals on figure 12.

The generalized overburden thickness (fig. 13) was calculated by subtracting the structure-contour grid from a grid constructed of USGS 1:100,000-scale digital elevation models. The contour intervals used for overburden thickness are 0 to 200 ft, >200 to 500 ft, >500 to 1,000 ft, and >1,000 to 2,000 ft and are based on criteria from Wood and others (1983). The thickest overburden is approximately 1,500 ft in Harlan County, Ky. (figs. 2, 13). Because the cell dimensions used in the surface-elevation grid and structure contour grid were large (325 m) and topography is highly dissected, there were occasional errors where the 200-ft overburden-thickness line crossed the cropline (0-ft overburden thickness). The overlap was corrected, where necessary, by preparing a horizontal buffer 100 m from the outcrop to estimate the 0- to 200-ft category.

Figure 14 shows the thickness of the minable benches (using the criteria described above) of the Fire Clay coal zone that was generated from 3,700 thickness records. Identified partings and bone coal over 0.38 inches in thickness were excluded (Wood and others, 1983). The point thickness data provided by the States for the regional database were interpolated into a grid and contacts were generated and contoured in EarthVision. The KGS previously had created a thickness coverage by manually creating contours (excluding some anomalous thickness values) of 1.17-ft categories. The Kentucky part of the regional GIS coverage was replaced by the contours provided by KGS, so contour lines may not match across the State line into Kentucky from either Virginia or West Virginia (fig. 14) because the calculation methods were different. Areas of thin coal (0-1.17-ft thick) usually contain fewer data points than areas of thicker coal; therefore, the certainty of the interpolated thickness is less for thin coal. The thickness map (fig. 14) shows a regional pattern whereby the minable Fire Clay coal zone locally is thick in northwest-southeast-trending belts. Large expanses of coal between the belts are less than 1.17 ft thick. The largest thickness measurement (nearly 10 ft) is in Pike County, Ky. (fig. 2). In most areas of Kentucky where the thickness exceeds 4.67 ft, a rider coal has been included in the minable thickness value for the zone (Thacker, Weisenfluh, Greb, and Esterle, 2000).

RESOURCE MODELING

The original and remaining resources for this assessment were calculated for the Fire Clay coal zone using the GIS coverages discussed previously. In addition, the USGS reliability categories (Wood and others, 1983) for identified resources (defined as within 3 mi of a data point) were derived from all available thickness points. The area of hypothetical resources surrounds the identified category, extending outward to form a rectangle that encompasses all of the assessment areas. To retain all the criteria required for resource calculations (Wood and others, 1983), polygonal coverages for outcrop, coal and overburden thickness, mined areas, reliability categories, and counties were merged into one coverage. Resources were calculated by multiplying the area of each polygon by the average coal thickness within the polygon (the mean of the bounding contour-line values) and by a tonnage factor of 0.445 short tons/ft-m^2 (representing the weight of bituminous coal per unit volume; modified from Wood and others, 1983). Tonnage values were exported to a spreadsheet in order to summarize the original and remaining resources for each county by reliability, coal thickness, and overburden thickness categories. Table 1 shows the original and remaining resource totals by State and county, rounded to millions of short tons and to two significant figures. Appendixes 10 and 11 show the original and remaining resources, by county, in USGS coal thickness, overburden, and reliability categories. Tonnage values in Appendixes 10 and 11 also have been individually rounded to millions of short tons and to

[7]EarthVision is a product of Dynamic Graphics, Inc., 1015 Atlantic Avenue, Alameda, CA 94501

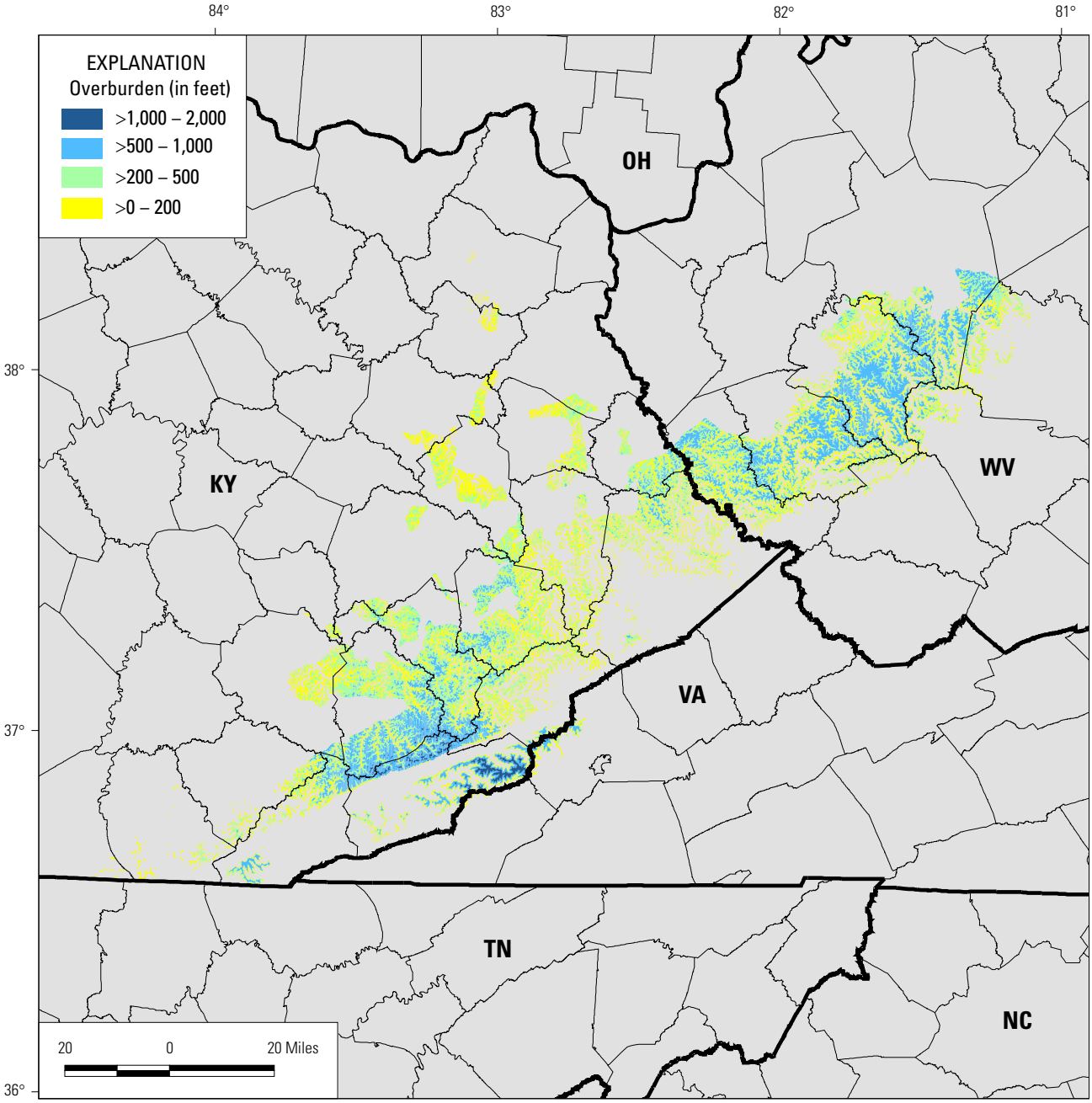
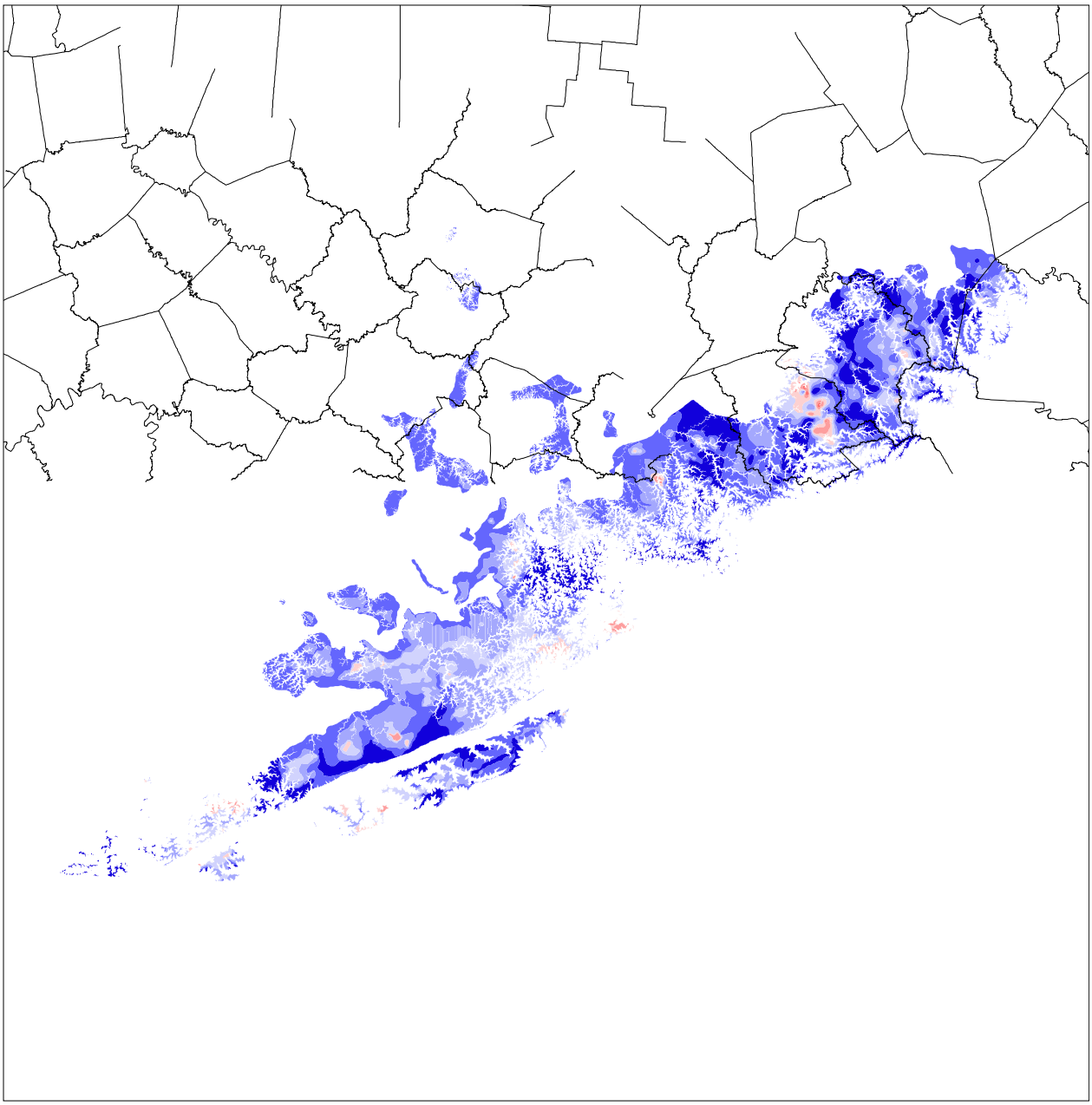


Figure 13. Overburden-thickness map of the Fire Clay coal zone. The map was calculated by subtracting the structure-contour grid on the top of the Fire Clay coal zone from topography. The contour intervals for overburden thickness are variable, based on criteria specified in Wood and others (1983).



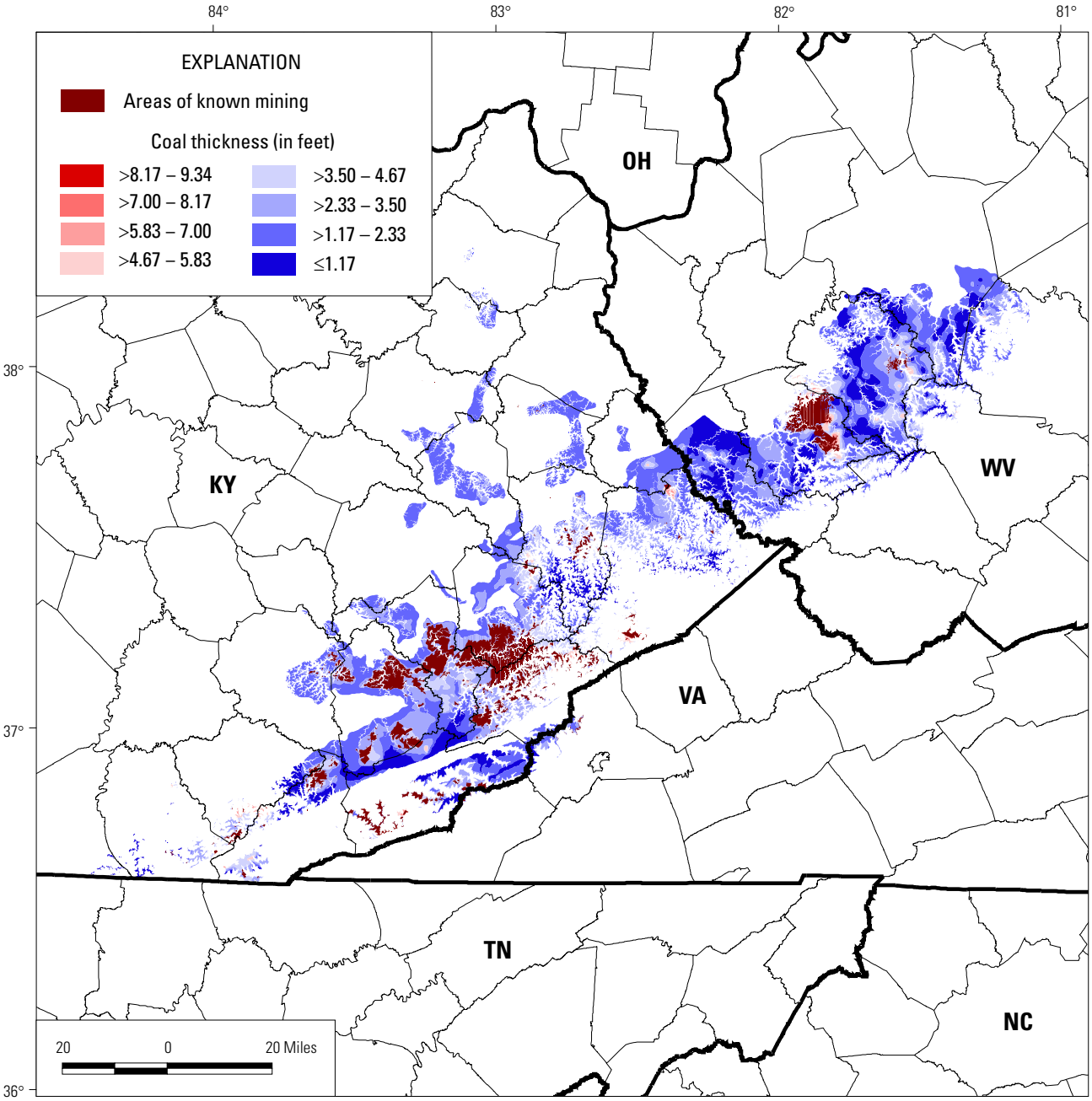


Figure 16. Map showing mined areas overlying thickness contours of the Fire Clay coal zone (fig. 14). Note that the thicker areas already have been mined. See figure 2 for county names.

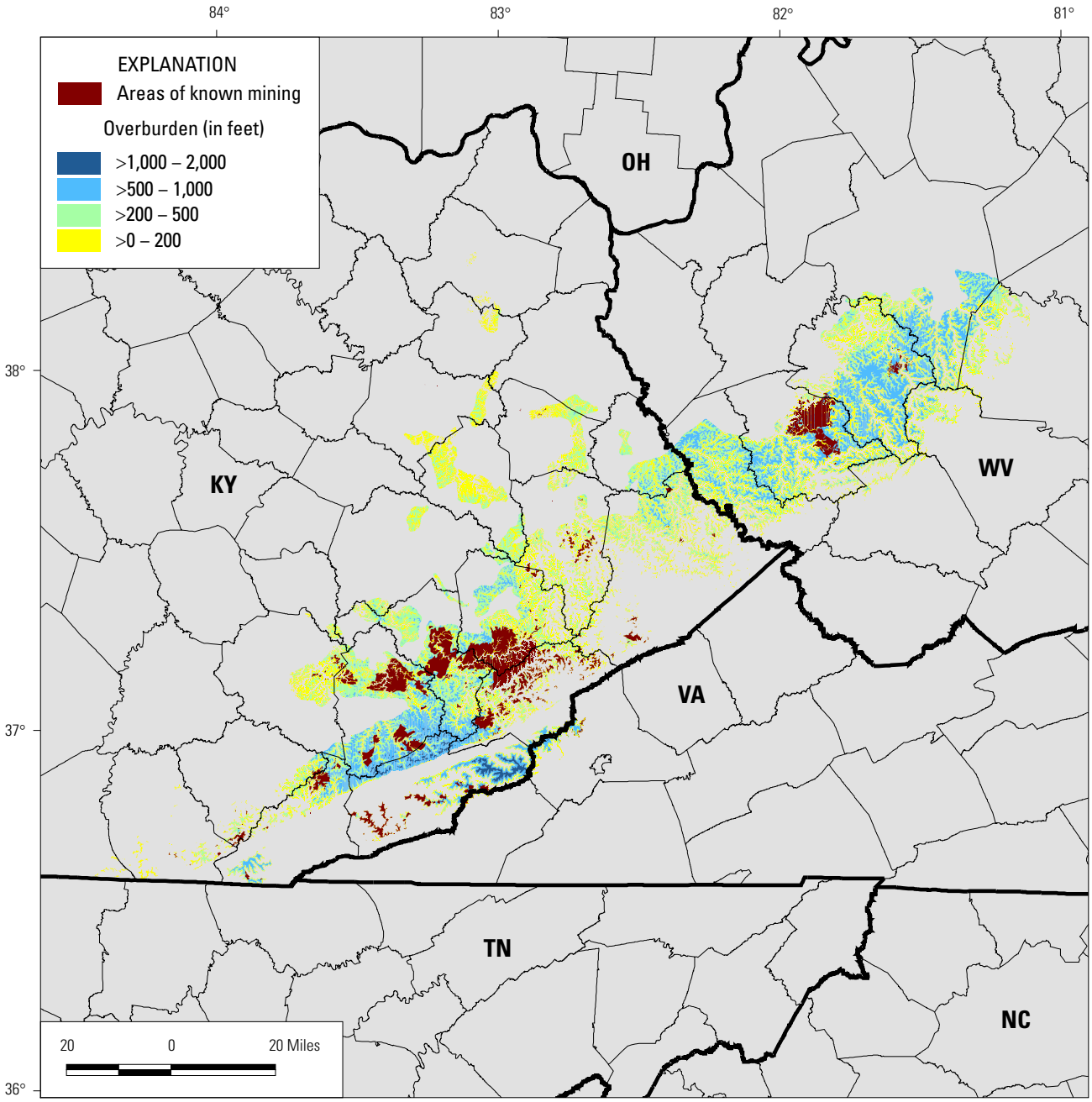


Figure 17. Map showing mined areas overlying overburden thickness of the Fire Clay coal zone (fig. 13). Most remaining coal is below drainage and is not easily accessible. See figure 2 for county names.

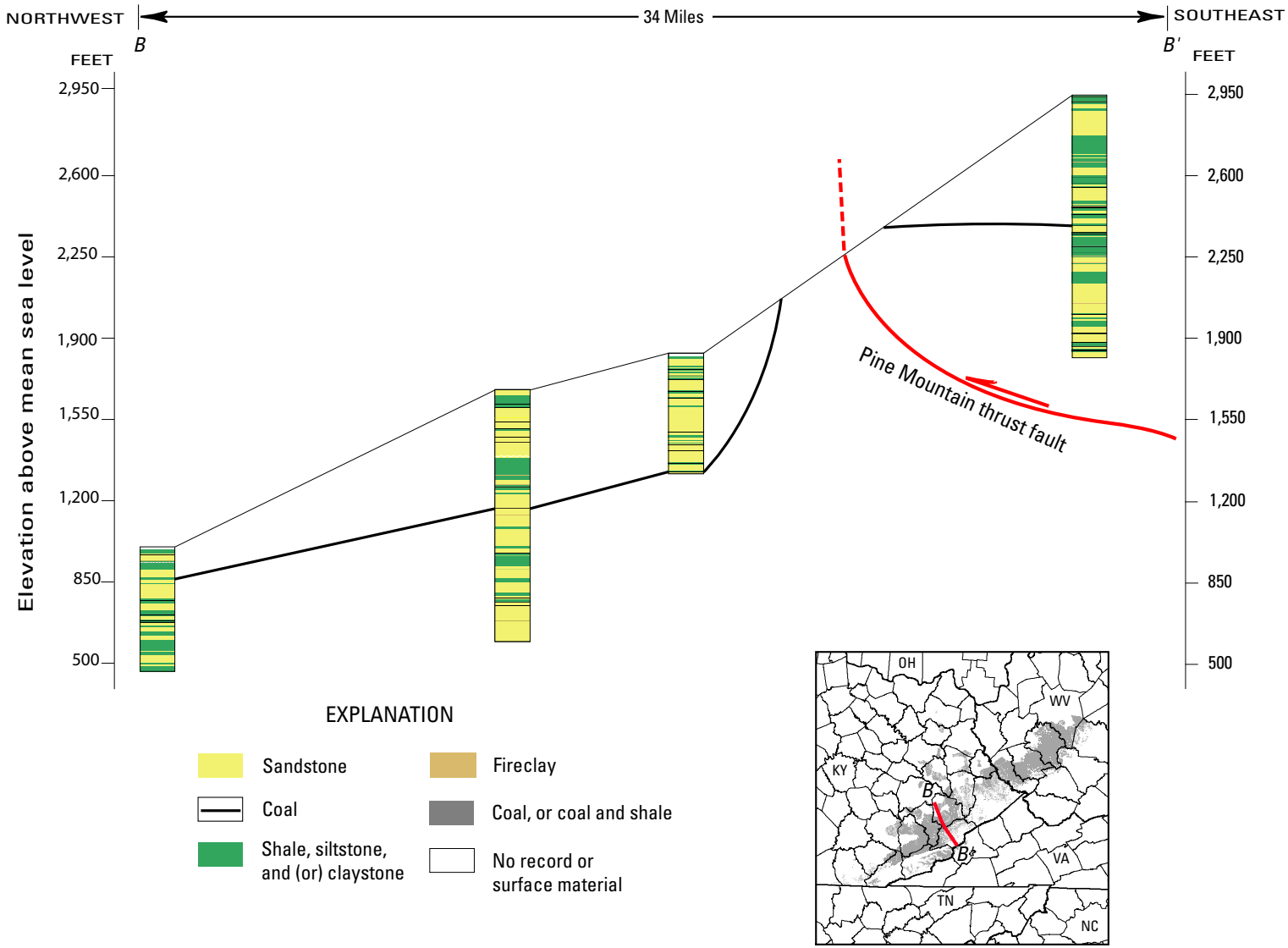


Figure 18. Generalized cross section trending northwest to southeast showing regional structure and the location of the Pine Mountain thrust fault. Columns represent individual cores along line of section *B-B′*. Sandstone and sandy units comprise much of the Pottsville Group strata. Vertical exaggeration X50.

1994; Greb and Weisenfluh, 1996). The sandstone channels generally follow northwest-southeast and northeast-southwest orientations, similar to the coal thickness trends (Greb, Hiett, and others, 1999). Generalized cross section *C-C′* (fig. 19) shows such a channel cut in Leslie County, Ky.

GEOCHEMISTRY

Most of the Fire Clay sample localities in the geochemical database (Appendix 7) are in Kentucky, with one location in Virginia and five locations in West Virginia; therefore, these data represent only part of the Fire Clay coal zone resource (fig. 10). The database metadata file (Appendix 8) contains the steps used to process and eliminate data analyses for this study. The Fire Clay coal zone contains multiple benches; coal quality and thickness are strongly influenced in some areas by the variable nature of the lower bench (below the flint-clay parting). The upper bench is of higher quality (lower ash and sulfur) and contains fewer partings than the thinner lower bench (Eble and others, 1999; Greb, Hiett, and others, 1999). Because the geochemical data in this report represent the entire zone, the quality trends seen at bench scale cannot be discerned. In addition, the amount and distribution of available data impose limits on interpretation.

All 59 of the analyses in the geochemical database for the Fire Clay coal zone are publicly available. Of those, 55 are located by latitude and longitude and are shown in part A of figures 20 to 23, and 25 to 37. County mean data for all 59 analyses are shown in part B of the same figures. Statistical parameters (means, ranges, standard deviations, and number of analyses) are shown in tables 2 to 18.

Data for ash yield, sulfur content, and sulfur-dioxide (SO_2) content are classified into categories of low (≤8 percent percent ash; ≤1 weight percent sulfur; ≤1.2 lbs SO_2 per million Btu), medium (>8 to ≤15 weight percent ash; >1 to <3 weight percent sulfur; > 1.2 to ≤2.5 lbs SO_2 per million Btu), and high (>15 weight percent ash; ≥3 weight percent sulfur; >2.5 lbs SO_2 per million Btu). Ash yield and sulfur content are classified according to Wood and others (1983). Sulfur-dioxide content is classified according to past and present Clean Air Acts. Ash yield, sulfur content, and SO_2 values are presented as both data point maps (part A of figures 20-22), and as county means (part B of figures 20-22). Gross calorific values (fig. 23), and total moisture and trace elements (figs. 25-37), are classified into five data categories, or quintiles, each representing 20-percent of the data values. Because the 20-percent intervals are based on different sets of data (point data from Appendix 7 versus county means from tables 2-18), the ranges of the 20 percent intervals are different for each data set and each chemical parameter. A northwest-southeast trend of improving coal quality for the Fire Clay coal zone in Kentucky was observed by Cortland F. Eble (KGS, written commun., 2000). The limited data in this assessment do not reveal a regional trend in ash yield; the mean ash yield for all Fire Clay coal zone analyses is 10.62±4.53 weight percent. A possible increase in sulfur content to the southwest is indicated in figure 21B. Means of sulfur content, by State, range from 0.80±0.14 weight percent in West Virginia to 1.01±0.48 weight percent in Kentucky.

Federal ambient air quality standards in the Clean Air Act Amendments of 1990 (Public Law 101-549) mandate the amount of SO_2 that can be emitted by electric-generating facilities. Beginning in 2000, the compliance level was set at a maximum of 1.2 lbs SO_2 per million Btu, which equates to 0.6 lbs of sulfur per million Btu. Conversion of sulfur content to lbs of SO_2 per million Btu shows that, overall, the Fire Clay coal zone as mined does not meet 2000 compliance coal standards (fig. 22; table 4), The mean SO_2 value calculated for the Fire Clay coal zone is 1.55±0.77 lbs of SO_2 per million Btu. Although 21 Fire Clay coal zone samples and two county means (fig. 22B; table 4) meet 2000 emission standards, examination of data means (table 4) and county mean maps (fig. 22B) clearly shows that most of the Fire Clay coal zone as mined is noncompliant. Although approximately 90 percent of the coal in Kentucky is washed to remove mineral matter and pyrite, most of the sulfur in the Fire Clay coal zone is organic and cannot removed by coal cleaning; therefore, the coal is usually blended with lower sulfur coals, such as that of the Pond Creek coal zone (Chapter G, this report) in order to make it compliant (Cortland F. Eble, KGS, oral commun., 2000). At present, most electric utility companies meet air quality standards by blending coal; installing flue-gas desulfurization units; retiring older, less efficient units; or purchasing emission allowances from companies that emit less sulfur than the maximum allowed by Phase II of the Clean Air Act Amendments of 1990 (Attanasi, 1998).

The mean calorific value for the Fire Clay coal zone is 12,910±780 Btu/lb (fig. 23; table 5). Floyd and Knott Counties, Ky. (fig. 2) have the lowest mean gross calorific values; based on the very limited available data, gross calorific values seem to increase to the east and south of this area. The apparent rank map of the Fire Clay coal zone (fig. 24; calculated using gross calorific value) shows that nearly all of the coal zone is estimated to be high volatile A bituminous; one small area contains coal of lower rank (high volatile B bituminous). The lower rank assignment is based on only one analysis (of 55 used) and may not be valid. There are no analytical data available where overburden is the thickest (fig. 13) to determine if the rank increases with deeper burial. Because the Fire Clay coal zone is bituminous in rank, the total moisture (fig. 25; table 6) tends to be relatively low, with a mean of 2.58±0.87 weight percent for the entire zone (59 analyses).

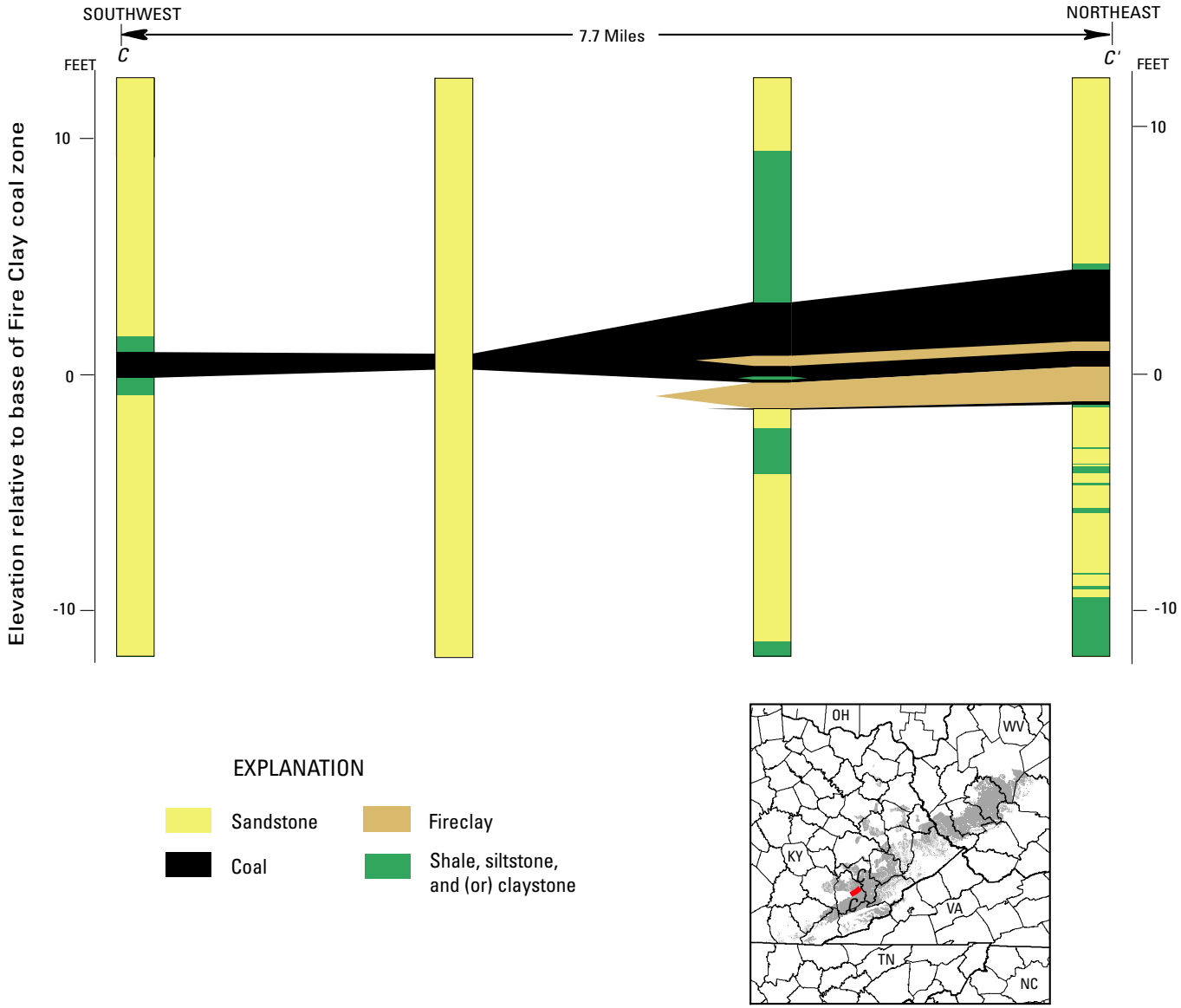


Figure 19. Generalized cross section trending southwest to northeast through the Fire Clay coal zone in Leslie County, Ky. Columns represent individual cores along line of section *C-C′*. The cross section shows the benches and partings of the Fire Clay zone and the zone being cut out by a sandstone channel in the second borehole from the left. Vertical exaggeration X1,200.

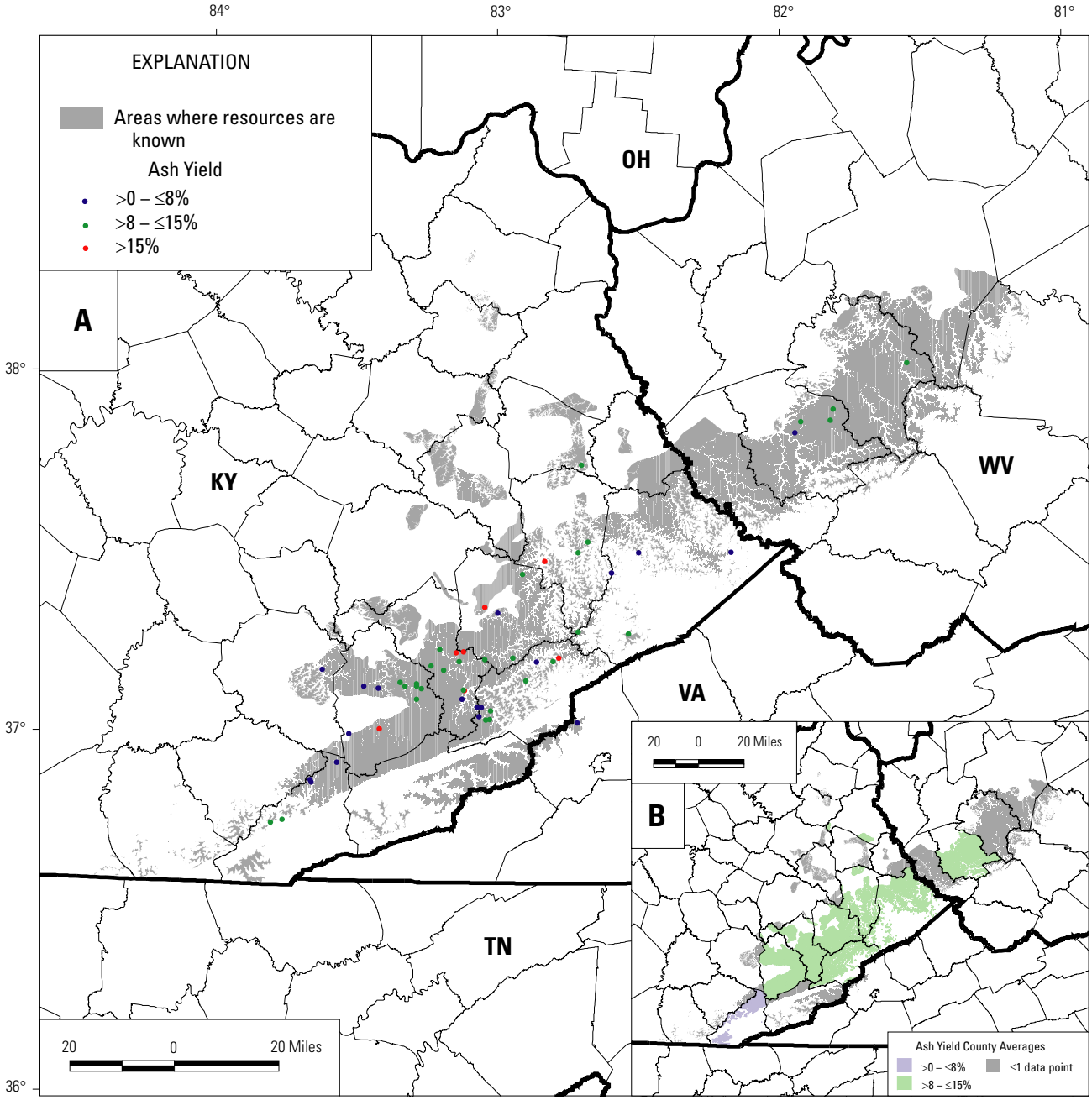


Figure 20. Maps showing ash yield (weight percent, as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows ash yields of the 55 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for ash yields using all 59 records in the geochemical database, including those that are located only to a county level; ash yields range from 3.34 to 24.80 weight percent with a mean value of 10.62±4.53 weight percent (table 2). Ash yields are classified into low (>0 to ≤8 weight percent), medium (>8 to ≤15 weight percent), and high (>15 weight percent) categories as specified by Wood and others (1983). The available data do not suggest a regional trend in ash yield. See figure 2 for county names.

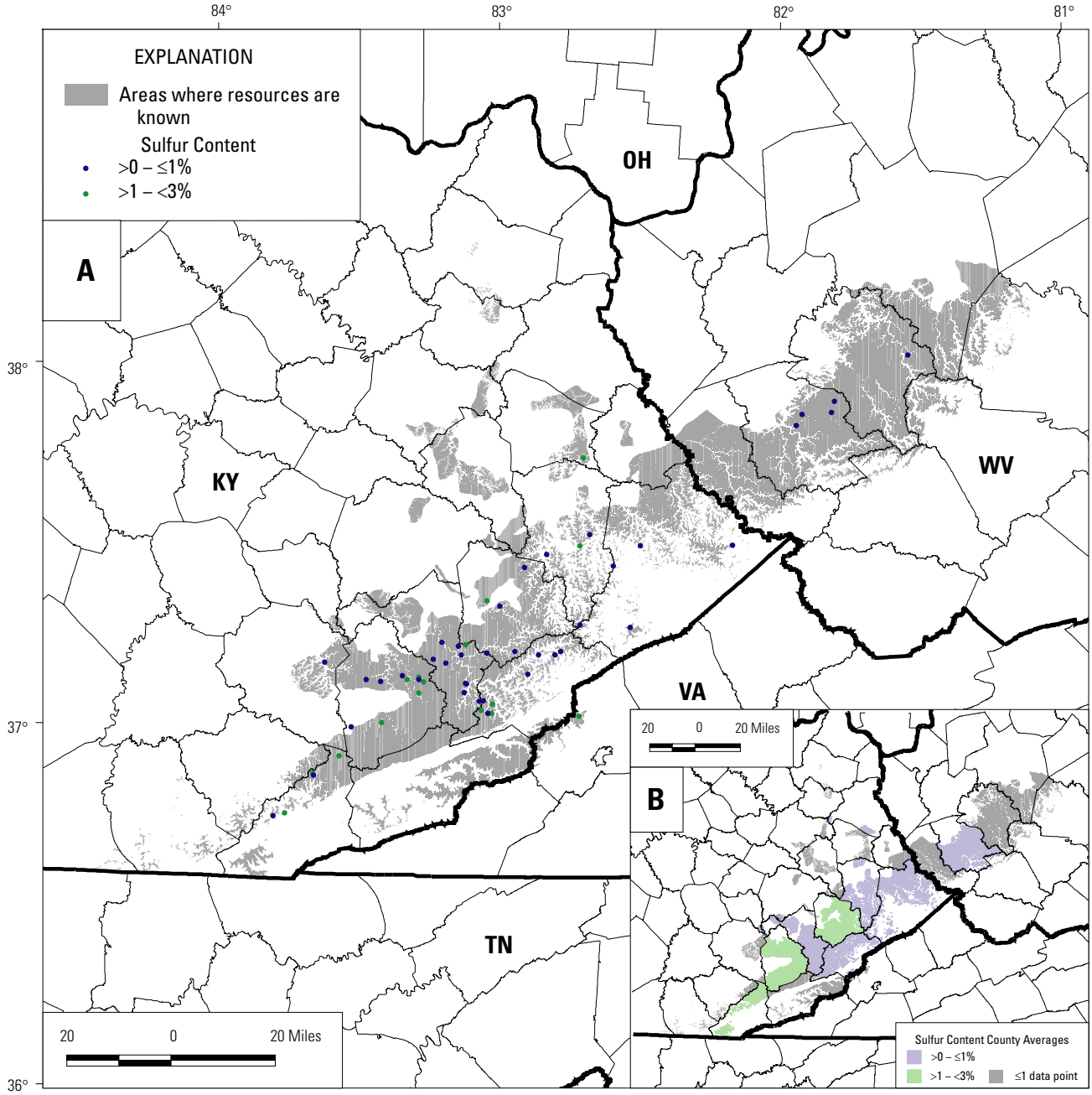


Figure 21. Maps showing sulfur content (weight percent, as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows sulfur contents of the 55 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for sulfur contents using all 59 records in the geochemical database, including those that are located only to a county level; sulfur contents range from 0.50 to 2.65 weight percent with a mean value of 0.99±0.46 weight percent (table 3). Sulfur contents are classified into low (>0 to ≤1 weight percent), medium (>1 to <3 weight percent), and high (≥3 weight percent) categories as specified by Wood and others (1983). The available data suggest that sulfur content possibly increases to the southwest. See figure 2 for county names.

Table 2. Ash yield (weight percent; American Society for Testing and Materials (ASTM) method) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	10.62	3.34	24.80	4.53	59
KY	na	10.8	3.34	24.80	4.69	53
VA	na	nd	6.20	6.20	nd	1
WV	na	9.52	7.72	13.30	2.17	5
KY	Bell	7.35	3.34	10.70	2.68	5
KY	Clay	nd	4.78	4.78	nd	1
KY	Floyd	12.23	5.80	18.70	4.90	5
KY	Johnson	nd	12.15	12.15	nd	1
KY	Knott	14.21	7.70	23.13	5.63	6
KY	Knox	nd	6.24	6.24	nd	1
KY	Lawrence	9.19	6.90	11.48	3.24	2
KY	Leslie	11.54	4.90	24.80	5.59	10
KY	Letcher	9.69	5.80	19.34	3.99	9
KY	Perry	12.10	6.76	20.05	4.31	9
KY	Pike	8.57	5.31	13.64	4.45	3
KY	Wolfe	nd	6.68	6.68	nd	1
VA	Wise	nd	6.20	6.20	nd	1
WV	Boone	nd	8.80	8.80	nd	1
WV	Logan	9.71	7.72	13.30	2.46	4

Table 3. Sulfur content (weight percent; American Society for Testing and Materials (ASTM) method) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	0.99	0.50	2.65	0.46	59
KY	na	1.01	0.50	2.65	0.48	53
VA	na	nd	1.20	1.20	nd	1
WV	na	0.80	0.60	0.90	0.14	5
KY	Bell	1.60	0.92	2.65	0.83	5
KY	Clay	nd	0.68	0.68	nd	1
KY	Floyd	0.86	0.55	1.29	0.30	5
KY	Johnson	nd	1.88	1.88	nd	1
KY	Knott	1.06	0.60	2.58	0.77	6
KY	Knox	nd	0.69	0.69	nd	1
KY	Lawrence	0.98	0.80	1.15	0.25	2
KY	Leslie	1.07	0.76	2.07	0.38	10
KY	Letcher	0.90	0.67	1.29	0.23	9
KY	Perry	0.78	0.50	0.99	0.16	9
KY	Pike	0.76	0.67	0.81	0.08	3
KY	Wolfe	nd	0.85	0.85	nd	1
VA	Wise	nd	1.20	1.20	nd	1
WV	Boone	nd	0.90	0.90	nd	1
WV	Logan	0.78	0.60	0.90	0.15	4

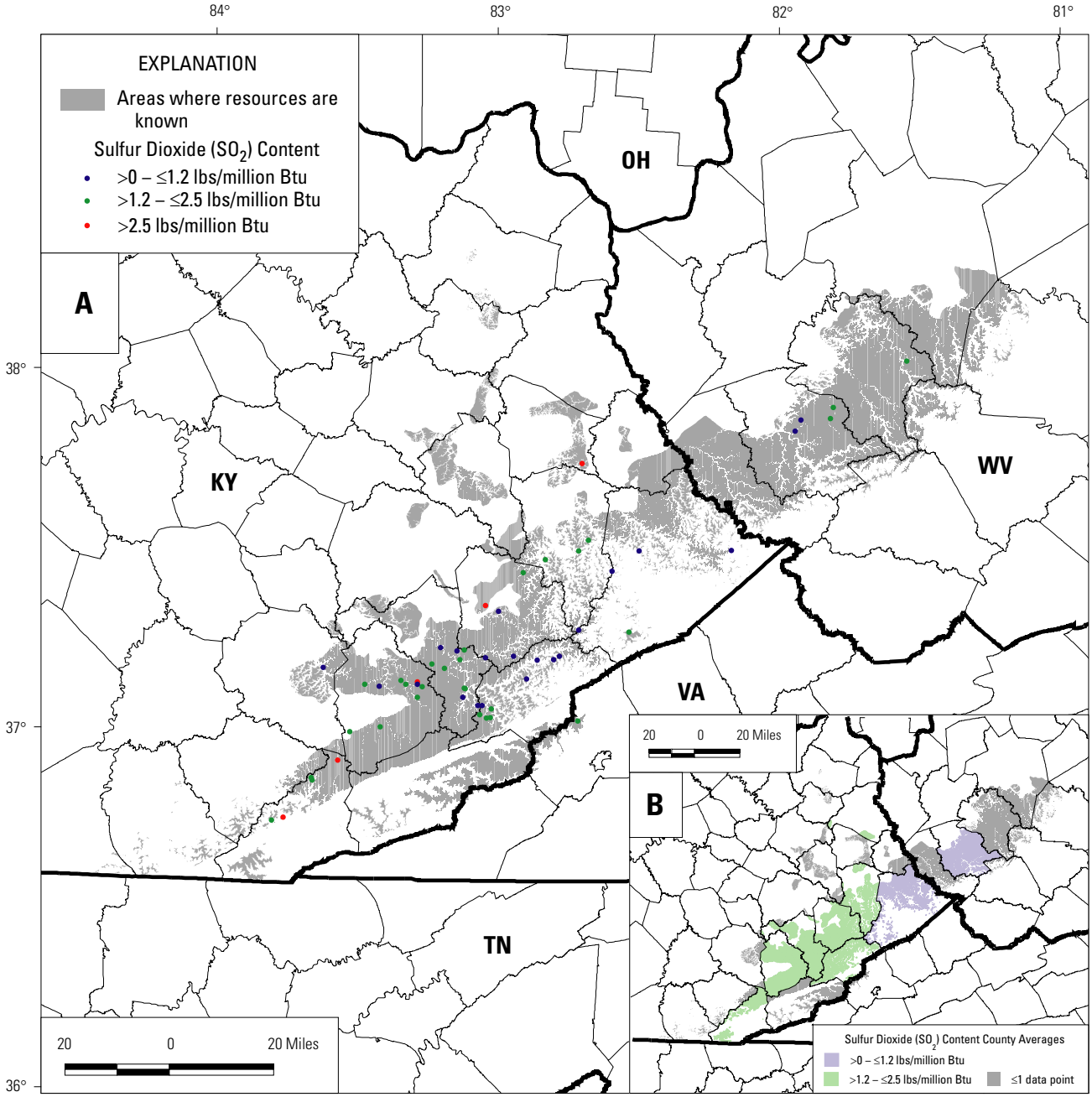


Figure 22. Maps showing sulfur-dioxide (SO_2) content (lbs/million Btu) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows SO_2 contents of the 55 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for SO_2 contents using all 59 records in the geochemical database, including those that are located only to a county level; SO_2 contents range from 0.81 to 4.79 lbs/million Btu with a mean value of 1.55±0.77 lbs/million Btu (table 4). The values are classified into three categories, low (0 to ≤1.2 lbs/million Btu), medium (>1.2 to ≤2.5 lbs/million Btu), and high (>2.5 lbs/million Btu), based on past and present Clean Air Acts. See figure 2 for county names.

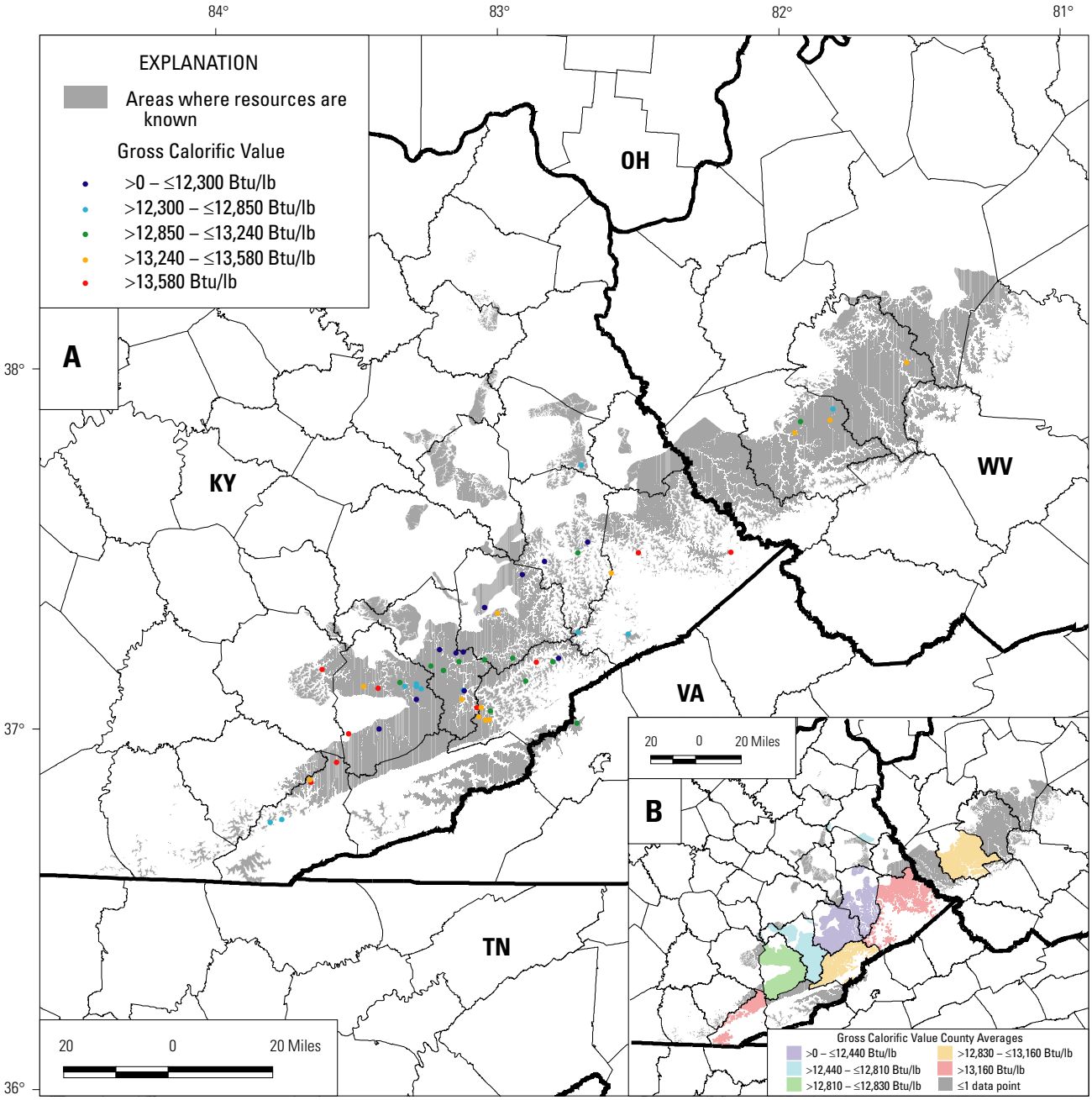


Figure 23. Maps showing gross calorific value (Btu/lb, as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows gross calorific values of the 55 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for gross calorific values using all 59 records in the geochemical database, including those that are located only to a county level; gross calorific values range from 10,770 to 14,210 Btu/lb with a mean value of 12,910±780 Btu/lb (table 5). The values are classified into five categories, each representing 20 percent of the data values. Gross calorific value tends to increase to the east and south. See figure 2 for county names.

Table 4. Sulfur-dioxide (SO_2) content (lbs/million Btu) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	1.55	0.81	4.79	0.77	59
KY	na	1.58	0.81	4.79	0.80	53
VA	na	nd	1.81	1.81	nd	1
WV	na	1.21	0.91	1.42	0.22	5
KY	Bell	2.39	1.37	4.13	1.28	5
KY	Clay	nd	0.98	0.98	nd	1
KY	Floyd	1.39	0.83	2.00	0.49	5
KY	Johnson	nd	3.00	3.00	nd	1
KY	Knott	1.80	0.88	4.79	1.50	6
KY	Knox	nd	1.03	1.03	nd	1
KY	Lawrence	1.54	1.22	1.85	0.45	2
KY	Leslie	1.68	1.13	3.24	0.63	10
KY	Letcher	1.37	1.02	1.92	0.33	9
KY	Perry	1.22	0.81	1.51	0.23	9
KY	Pike	1.14	0.98	1.27	0.15	3
KY	Wolfe	nd	1.38	1.38	nd	1
VA	Wise	nd	1.81	1.81	nd	1
WV	Boone	nd	1.33	1.33	nd	1
WV	Logan	1.18	0.91	1.42	0.24	4

Table 5. Gross calorific value (Btu/lb; American Society for Testing and Materials (ASTM) method) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	12,910	10,770	14,210	780	59
KY	na	12,870	10,770	14,210	810	53
VA	na	nd	13,240	13,240	nd	1
WV	na	13,230	12,680	13,490	330	5
KY	Bell	13,430	12,800	14,210	610	5
KY	Clay	nd	13,930	13,930	nd	1
KY	Floyd	12,440	11,290	13,280	790	5
KY	Johnson	nd	12,530	12,530	nd	1
KY	Knott	12,350	10,770	13,580	1,090	6
KY	Knox	nd	13,430	13,430	nd	1
KY	Lawrence	12,750	12,400	13,090	490	2
KY	Leslie	12,830	10,810	13,970	870	10
KY	Letcher	13,140	11,390	13,740	710	9
KY	Perry	12,810	11,750	13,600	660	9
KY	Pike	13,450	12,710	13,910	650	3
KY	Wolfe	nd	12,340	12,340	nd	1
VA	Wise	nd	13,240	13,240	nd	1
WV	Boone	nd	13,490	13,490	nd	1
WV	Logan	13,160	12,680	13,430	340	4

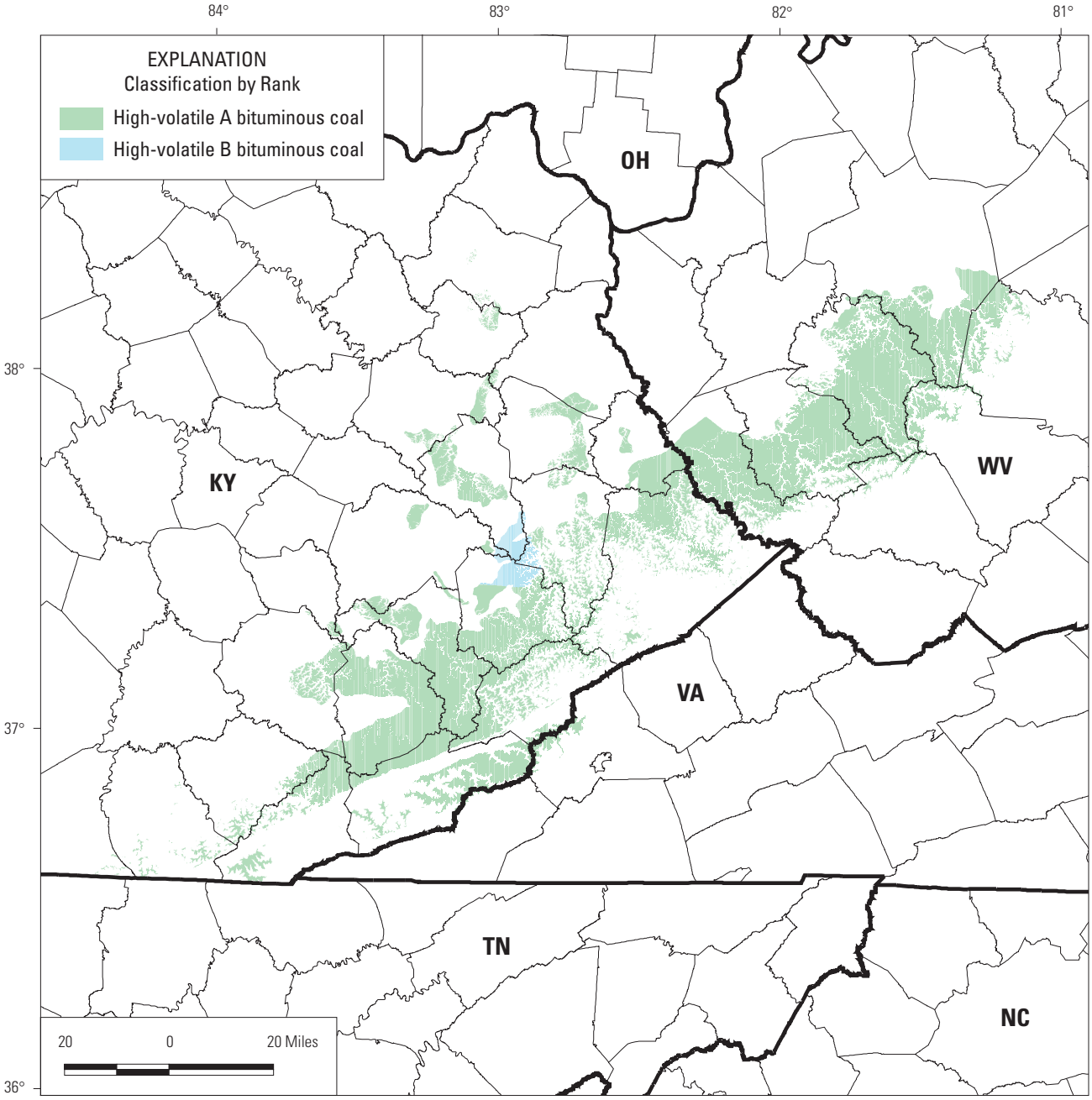


Figure 24. Map showing apparent rank of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia based on 55 analyses. The coal is almost entirely high-volatile A bituminous. The methodology for rank determinations is based on the percentage of fixed carbon in the sample. When dry, mineral-matter-free (dmmf) fixed carbon is >69 percent, rank is determined on dmmf fixed carbon, and when dmmf fixed carbon is <69 percent, rank is determined from moist, mineral-matter-free (mmmf) gross calorific values (American Society for Testing and Materials, 1996). Only gross calorific values were used to determine the rank of the Fire Clay coal zone. The one area shown as high-volatile B bituminous rank reflects a decreasing trend in mmmf-Btu/lb values, but is based on only one analysis and may be invalid. See figure 2 for county names.

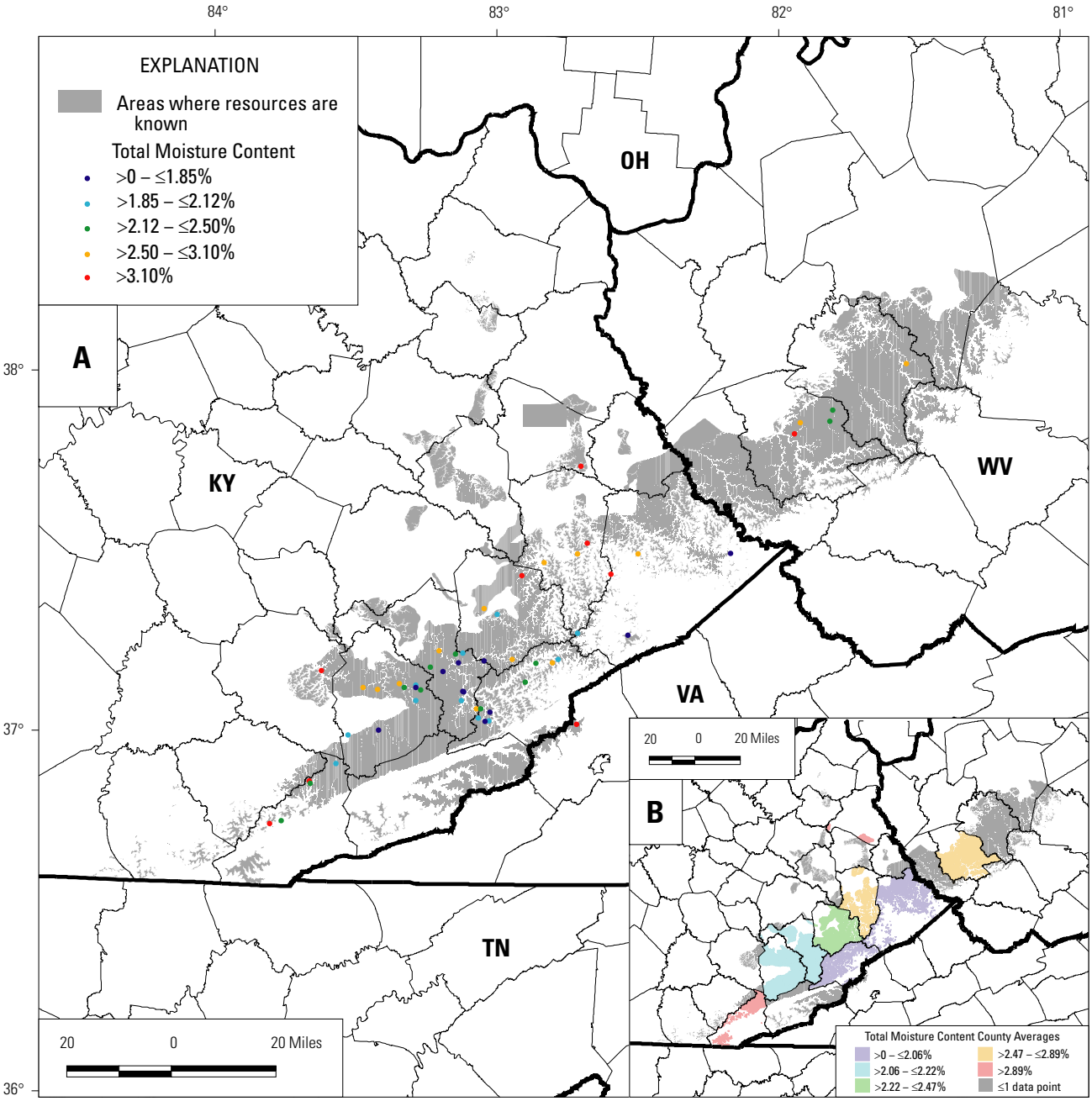


Figure 25. Maps showing total moisture content (weight percent, as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. ASTM (American Society for Testing and Materials) moisture replaced by equilibrium moisture values where available for the Fire Clay coal zone. Map A shows total moisture contents of 55 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for total moisture contents using all 59 records in the geochemical database, including those that are located only to a county level; total moisture contents range from 1.45 to 5.50 weight percent with a mean value of 2.58±0.87 weight percent (table 6). The values are classified into five categories, each representing 20 percent of the data values. The Fire Clay coal zone is a bituminous coal and the moisture content is therefore relatively low. See figure 2 for county names.

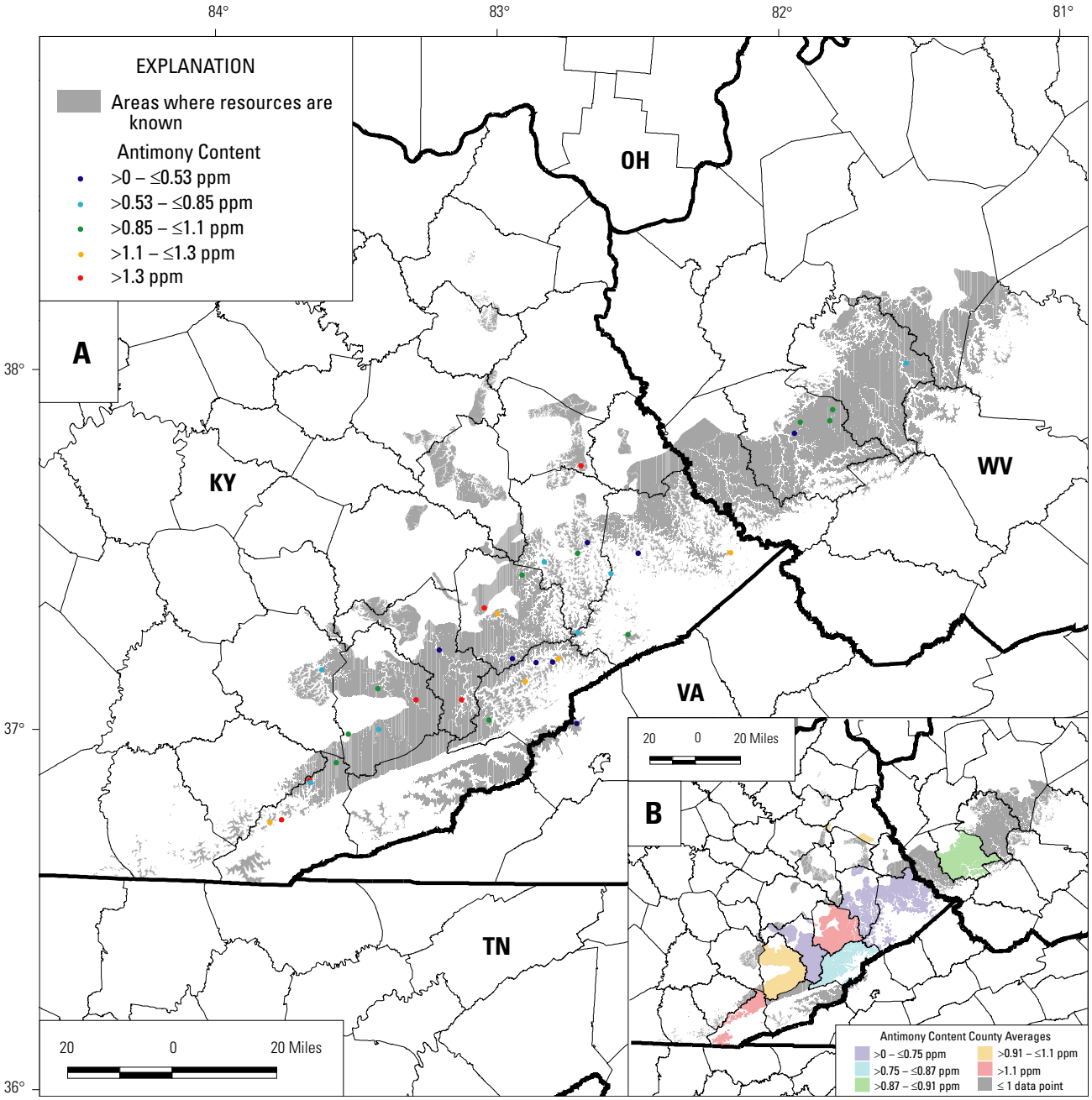


Figure 26. Maps showing antimony content (parts per million (ppm), as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows antimony contents of the 36 geochemical samples for which records are publicly available and are located by latitude and longitude (Appendix 7). Map B shows county averages for antimony contents using all 39 records in the geochemical database, including those that are located only to a county level; antimony contents range from 0.35 to 2.3 ppm with a mean value of 0.98±0.45 ppm (table 7). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

Table 6. Total moisture content (weight percent) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Note: ASTM (American Society for Testing and Materials) moisture replaced by equilibrium moisture values where available. Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	2.58	1.45	5.50	0.87	59
KY	na	2.50	1.45	5.14	0.81	53
VA	na	nd	5.50	5.50	nd	1
WV	na	2.80	2.40	3.30	0.39	5
KY	Bell	2.90	2.08	4.61	1.07	5
KY	Clay	nd	3.44	3.44	nd	1
KY	Floyd	2.89	1.92	3.60	0.67	5
KY	Johnson	nd	3.36	3.36	nd	1
KY	Knott	2.47	1.83	3.80	0.71	6
KY	Knox	nd	3.11	3.11	nd	1
KY	Lawrence	2.96	2.90	3.02	0.08	2
KY	Leslie	2.22	1.80	2.79	0.34	10
KY	Letcher	2.06	1.59	2.78	0.35	9
KY	Perry	2.14	1.57	3.10	0.51	9
KY	Pike	1.95	1.45	2.65	0.63	3
KY	Wolfe	nd	5.14	5.14	nd	1
VA	Wise	nd	5.50	5.50	nd	1
WV	Boone	nd	2.70	2.70	nd	1
WV	Logan	2.83	2.40	3.30	0.44	4

Table 7. Antimony content (parts per million) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	0.98	0.35	2.3	0.45	39
KY	na	1.0	0.35	2.3	0.47	33
VA	na	nd	0.50	0.50	nd	1
WV	na	0.84	0.52	1.1	0.27	5
KY	Bell	1.3	0.70	1.7	0.40	5
KY	Clay	nd	0.83	0.83	nd	1
KY	Floyd	0.75	0.50	1.0	0.20	5
KY	Johnson	nd	2.3	2.3	nd	1
KY	Knott	1.2	0.40	2.2	0.75	4
KY	Knox	nd	1.1	1.1	nd	1
KY	Lawrence	1.0	0.97	1.1	0.092	2
KY	Leslie	1.1	0.82	1.6	0.35	4
KY	Letcher	0.87	0.35	1.3	0.42	5
KY	Perry	0.75	0.50	1.0	0.35	2
KY	Pike	0.74	0.50	1.2	0.40	3
KY	Wolfe	nd	0.80	0.80	nd	1
VA	Wise	nd	0.50	0.50	nd	1
WV	Boone	nd	0.60	0.60	nd	1
WV	Logan	0.91	0.52	1.1	0.27	4

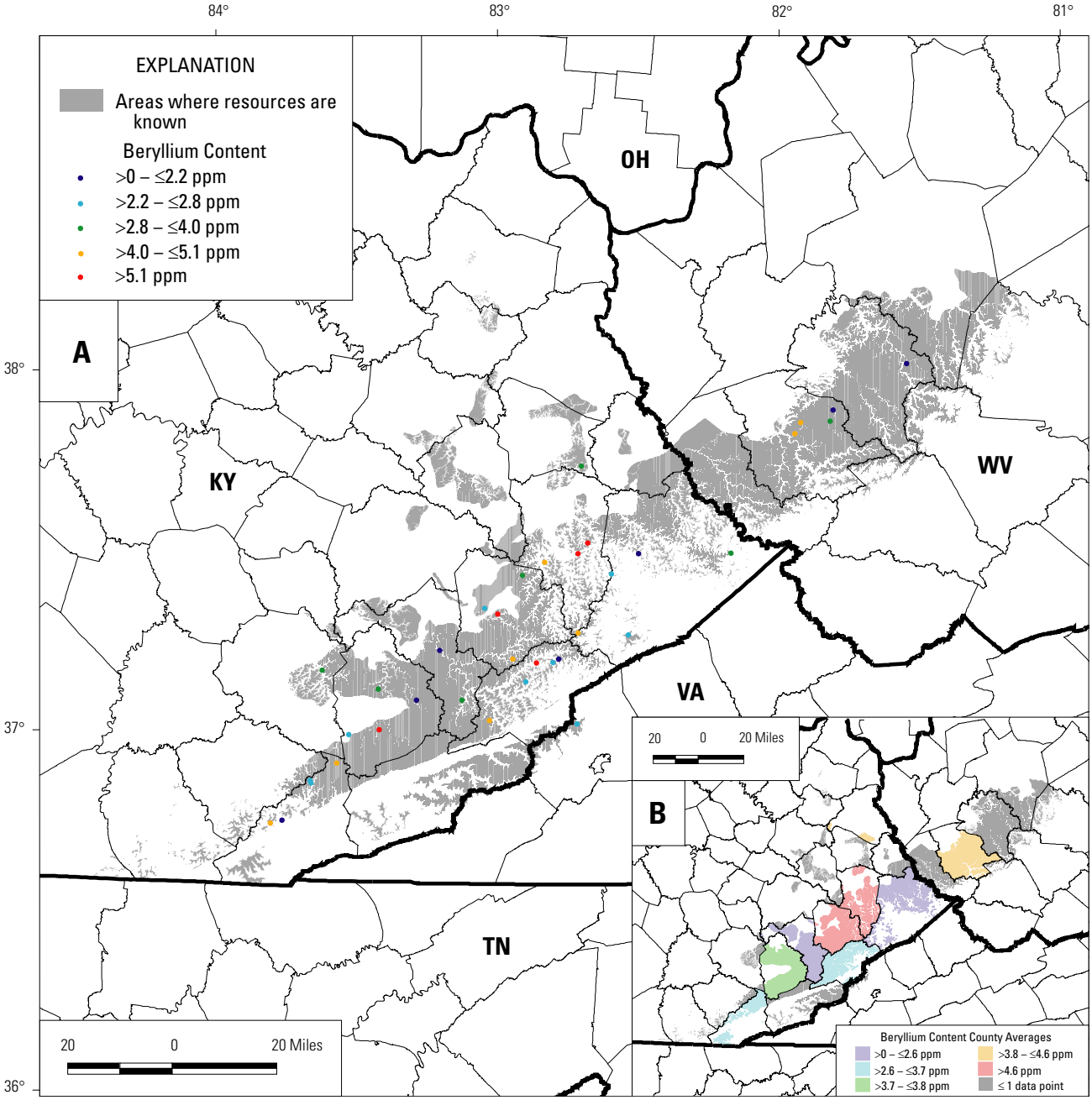


Figure 27. Maps showing beryllium content (parts per million (ppm), as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows beryllium contents for 36 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for beryllium contents using all 39 records in the geochemical database, including those that are located only to a county level; beryllium contents range from 1.0 to 13 ppm with a mean value of 3.9±2.3 ppm (table 8). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

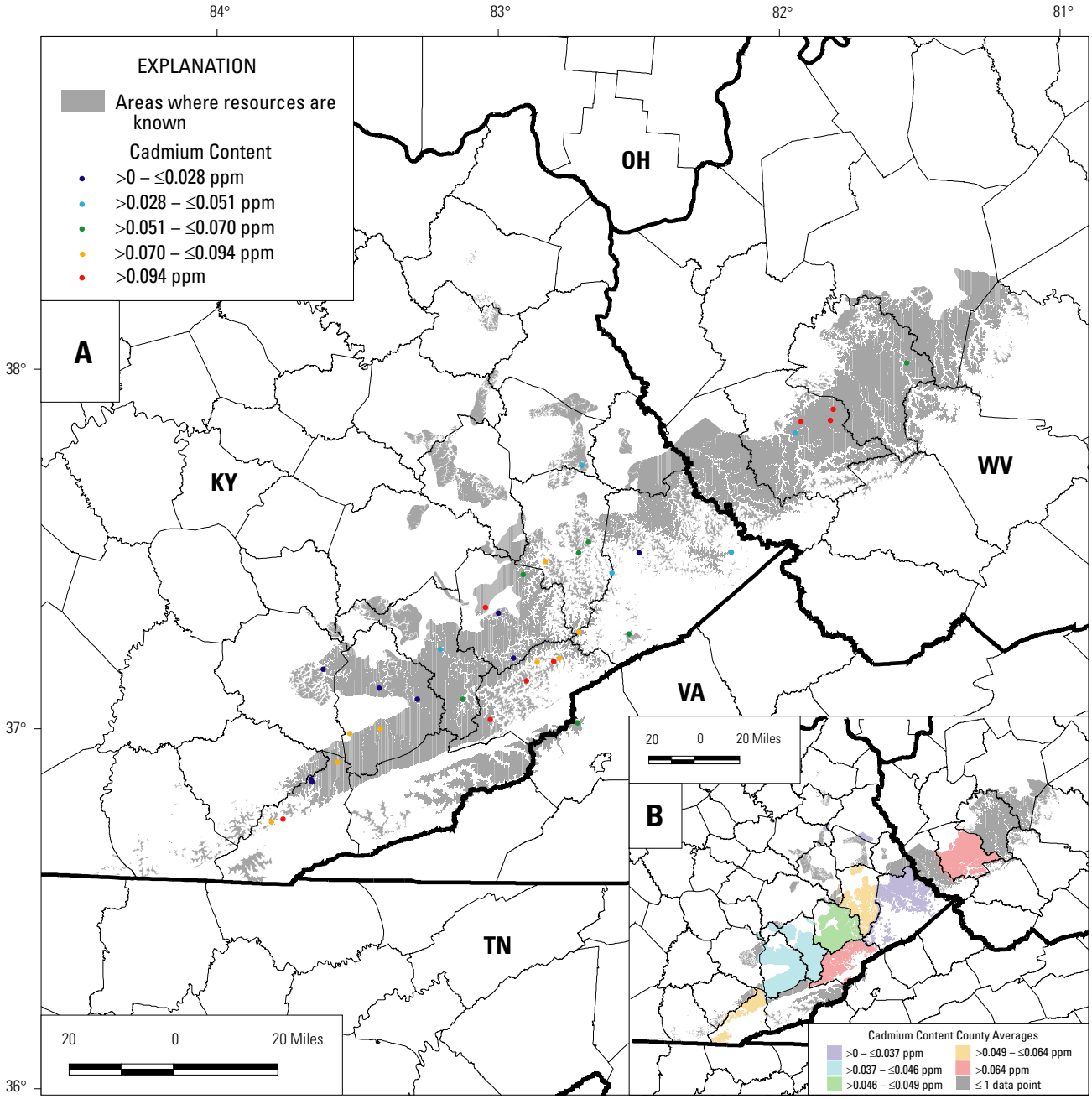


Figure 28. Maps showing cadmium content (parts per million (ppm), as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows cadmium contents of 37 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for cadmium contents using all 39 records in the geochemical database, including those that are located only to a county level; cadmium contents range from 0.0027 ppm in Kentucky to 0.52 ppm in West Virginia with a mean value of 0.081±0.11 ppm (table 9). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

Table 8. Beryllium content (parts per million) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	3.9	1.0	13	2.3	39
KY	na	4.1	1.0	13	2.4	33
VA	na	nd	2.5	2.5	nd	1
WV	na	3.4	1.3	5.1	1.6	5
KY	Bell	3.3	1.0	5.2	1.7	5
KY	Clay	nd	3.4	3.4	nd	1
KY	Floyd	6.1	2.3	13	4.1	5
KY	Johnson	nd	4.0	4.0	nd	1
KY	Knott	4.9	2.8	8.3	2.5	4
KY	Knox	nd	1.9	1.9	nd	1
KY	Lawrence	4.6	3.3	5.8	1.8	2
KY	Leslie	3.8	2.1	7.5	2.5	4
KY	Letcher	3.7	2.0	6.8	1.9	5
KY	Perry	2.6	1.6	3.5	1.3	2
KY	Pike	2.6	1.6	4.0	1.2	3
KY	Wolfe	nd	5.9	5.9	nd	1
VA	Wise	nd	2.5	2.5	nd	1
WV	Boone	nd	1.3	1.3	nd	1
WV	Logan	3.9	2.1	5.1	1.3	4

Table 9. Cadmium content (parts per million) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	0.081	0.0027	0.52	0.11	39
KY	na	0.056	0.0027	0.11	0.032	33
VA	na	nd	0.055	0.055	nd	1
WV	na	0.25	0.046	0.52	0.25	5
KY	Bell	0.063	0.017	0.11	0.039	5
KY	Clay	nd	0.012	0.012	nd	1
KY	Floyd	0.064	0.048	0.083	0.014	5
KY	Johnson	nd	0.047	0.047	nd	1
KY	Knott	0.049	0.011	0.095	0.039	4
KY	Knox	nd	0.038	0.038	nd	1
KY	Lawrence	0.037	0.033	0.041	0.0060	2
KY	Leslie	0.046	0.0027	0.093	0.045	4
KY	Letcher	0.095	0.084	0.11	0.011	5
KY	Perry	0.044	0.036	0.052	0.011	2
KY	Pike	0.036	0.0058	0.055	0.027	3
KY	Wolfe	nd	0.035	0.035	nd	1
VA	Wise	nd	0.055	0.055	nd	1
WV	Boone	nd	0.050	0.050	nd	1
WV	Logan	0.3	0.046	0.52	0.26	4

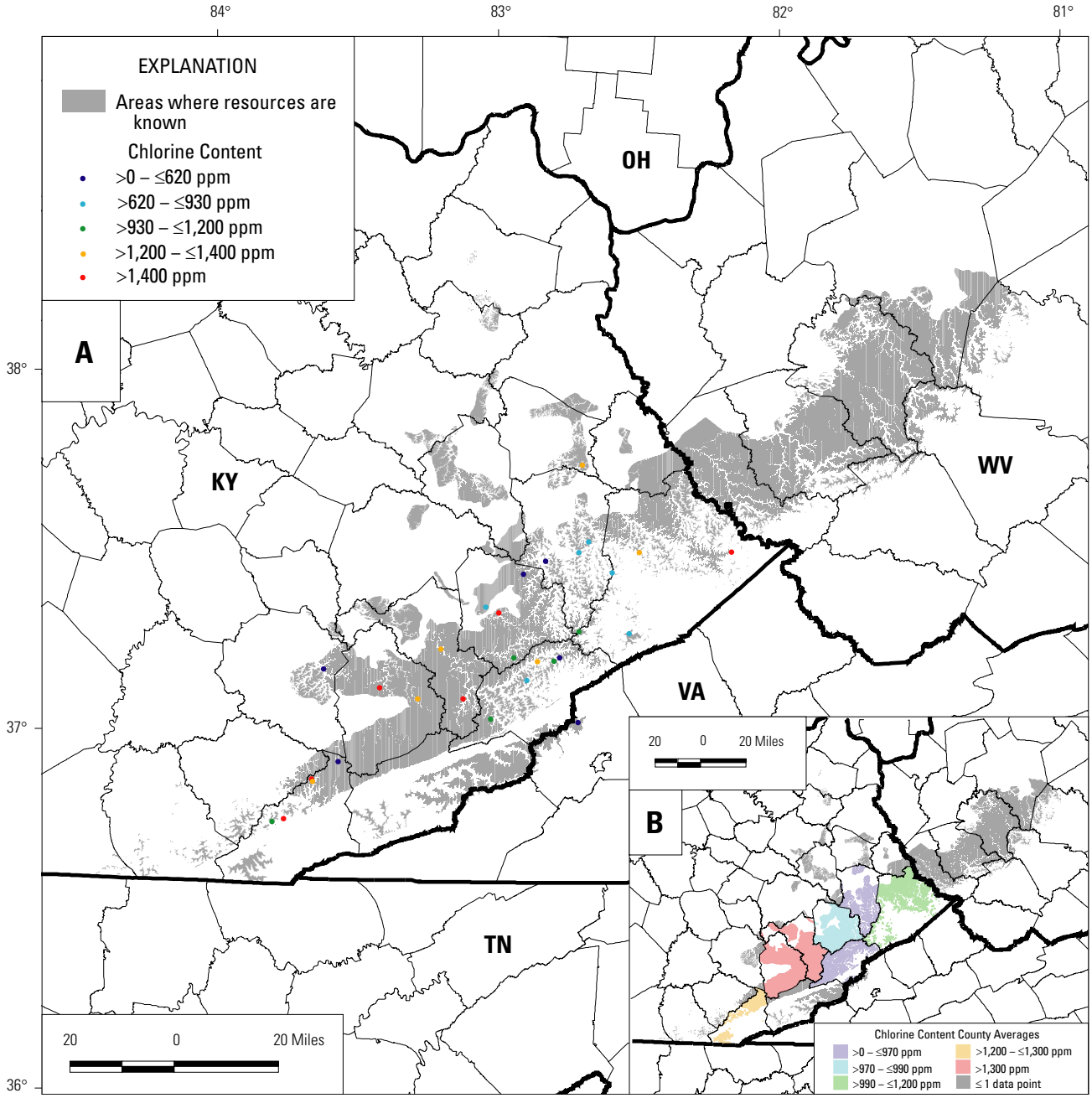


Figure 29. Maps showing chlorine content (parts per million (ppm), as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows chlorine contents of 29 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for chlorine contents using all 32 records in the geochemical database, including those that are located only to a county level; chlorine contents range from 130 to 2,300 ppm with a mean value of 1,100±500 ppm (table 10). The higher chlorine concentrations are in Kentucky. The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

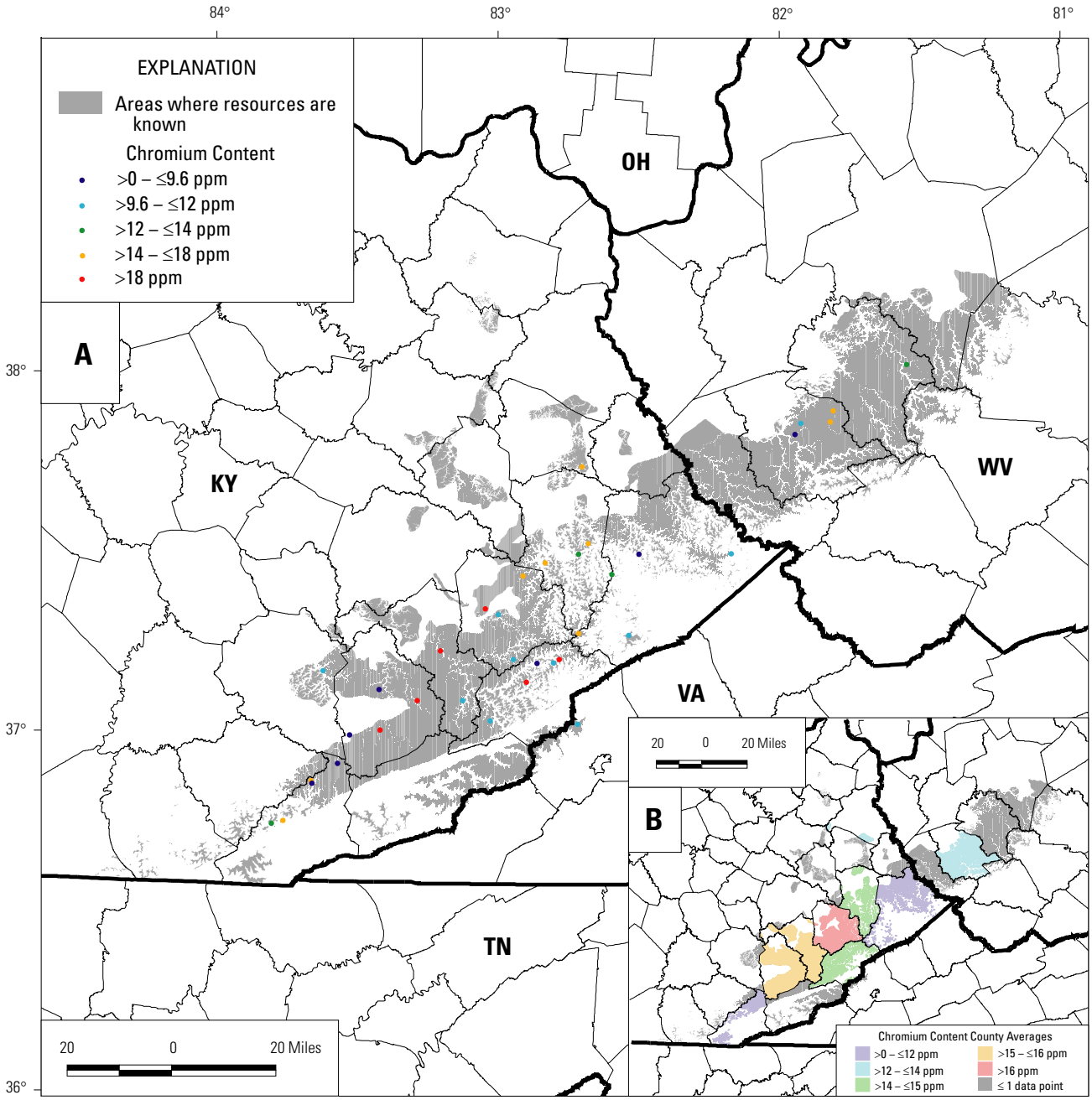


Figure 30. Maps showing chromium content (parts per million (ppm), as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows chromium contents of 36 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for chromium contents using all 39 records in the geochemical database, including those that are located only to a county level; chromium contents range from 6.5 to 33 ppm with a mean value of 14±5.4 ppm (table 11). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

Table 10. Chlorine content (parts per million) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county. There are no analyses for West Virginia.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	1,100	130	2,300	500	32
KY	na	1,100	390	2,300	480	31
VA	na	nd	130	130	nd	1
KY	Bell	1,300	390	1,800	540	5
KY	Clay	nd	550	550	nd	1
KY	Floyd	840	620	1,100	180	5
KY	Johnson	nd	1,400	1,400	nd	1
KY	Knott	990	510	1,700	520	4
KY	Knox	nd	1,800	1,800	nd	1
KY	Lawrence	nd	1,200	1,200	nd	1
KY	Leslie	1,900	1,400	2,300	640	2
KY	Letcher	970	510	1,400	320	5
KY	Perry	1,600	1,400	1,700	210	2
KY	Pike	1,200	680	1,500	430	3
KY	Wolfe	nd	400	400	nd	1
VA	Wise	nd	130	130	nd	1

Table 11. Chromium content (parts per million) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	14	6.5	33	5.4	39
KY	na	14	6.5	33	5.7	33
VA	na	nd	9.8	9.8	nd	1
WV	na	14	9.6	18	3.5	5
KY	Bell	12	6.5	16	3.9	5
KY	Clay	nd	12	12	nd	1
KY	Floyd	15	13	18	2.1	5
KY	Johnson	nd	16	16	nd	1
KY	Knott	19	12	33	9.9	4
KY	Knox	nd	8.9	8.9	nd	1
KY	Lawrence	14	9.8	18	5.8	2
KY	Leslie	16	9.1	23	8.0	4
KY	Letcher	15	9.5	23	5.8	5
KY	Perry	16	11	21	7.1	2
KY	Pike	9.2	6.7	11	2.3	3
KY	Wolfe	nd	12	12	nd	4
VA	Wise	nd	9.8	9.8	nd	1
WV	Boone	nd	13	13	nd	1
WV	Logan	14	9.6	18	4.0	4

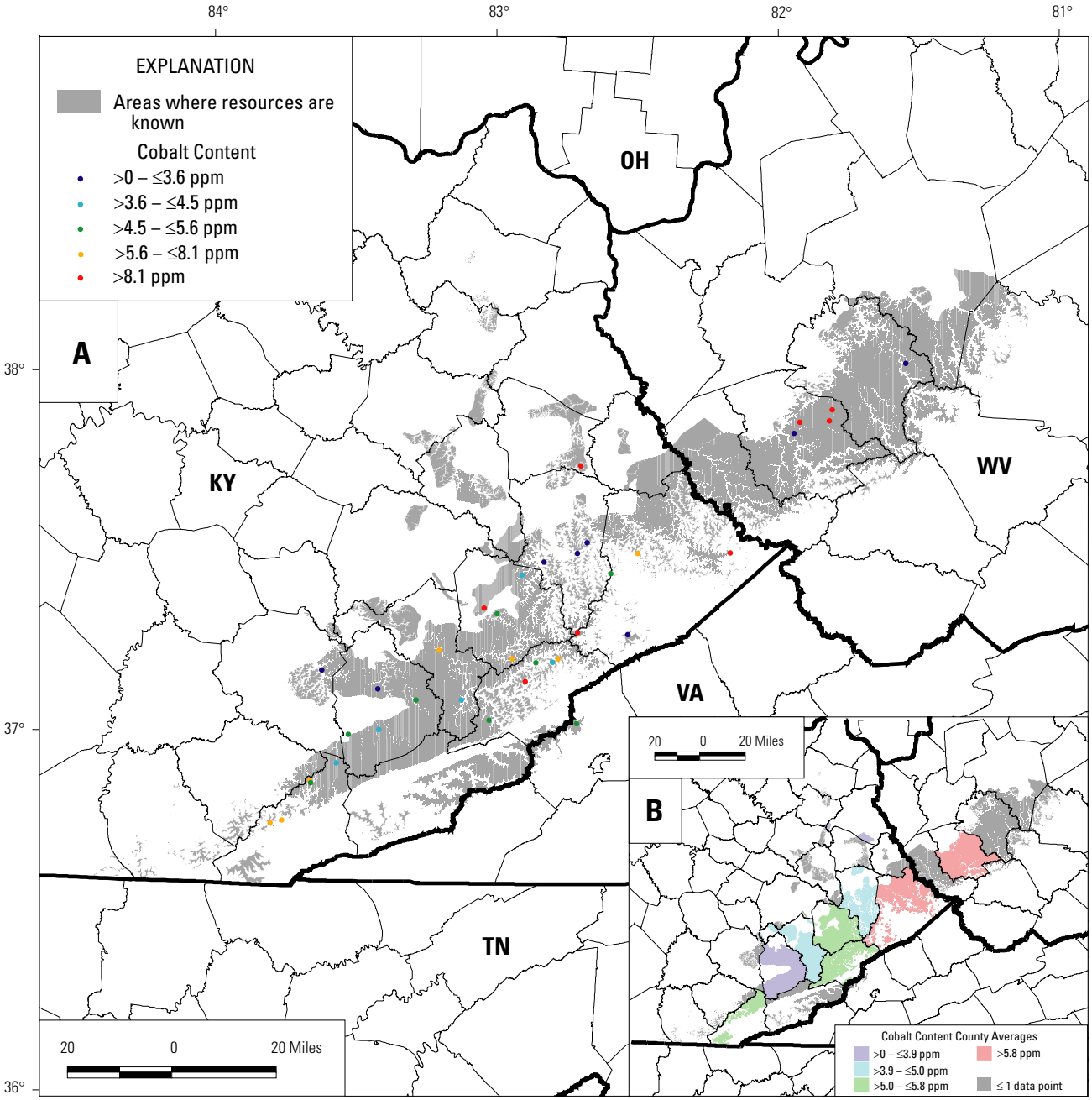


Figure 31. Maps showing cobalt content (parts per million (ppm), as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows cobalt contents of 36 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for cobalt contents using all 39 records in the geochemical database, including those that are located only to a county level; cobalt contents range from 1.5 to 11 ppm with a mean value of 5.5±2.4 ppm (table 12). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

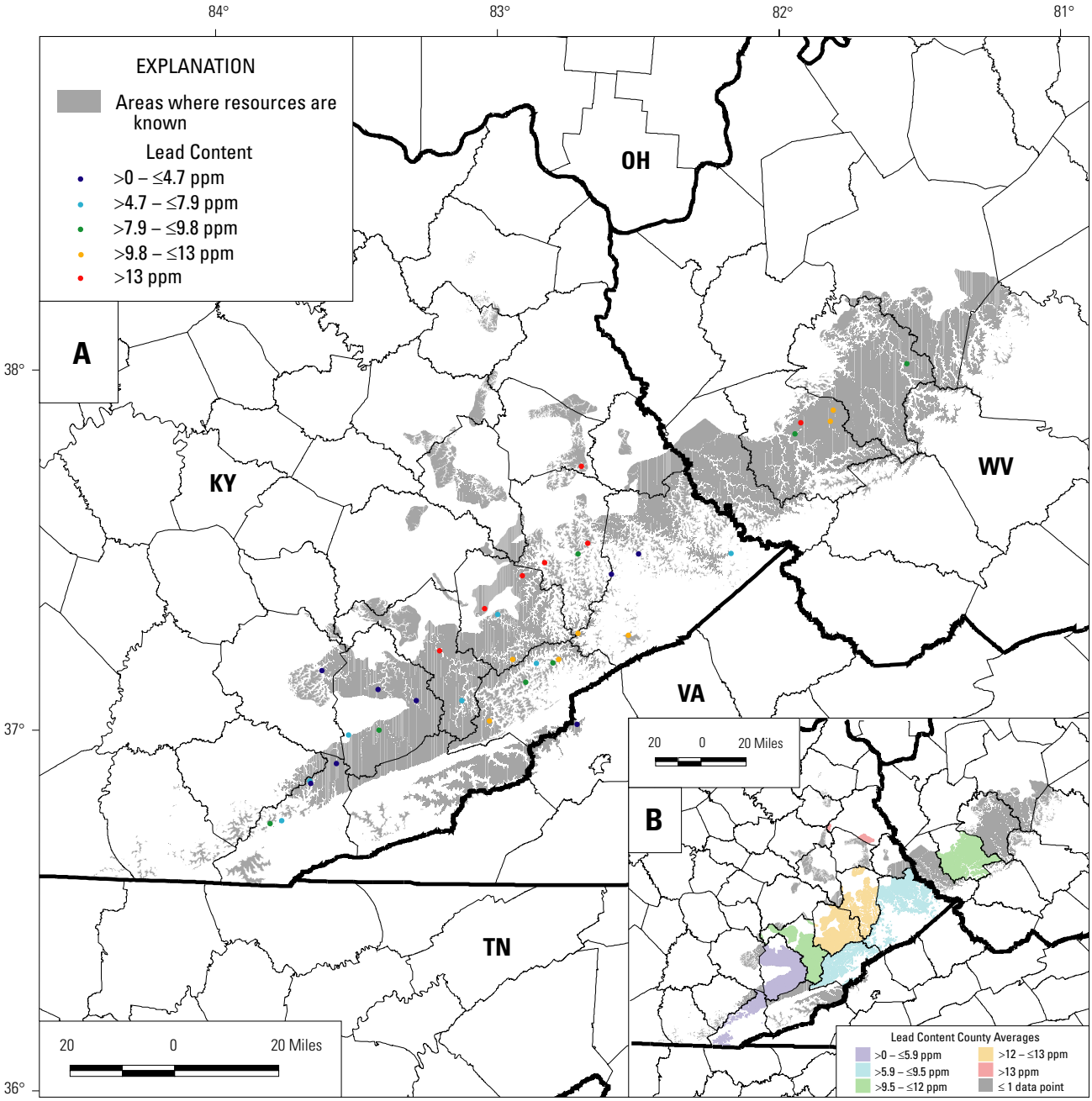


Figure 32. Maps showing lead content (parts per million (ppm), as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows lead contents of 36 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for lead contents using all 39 records in the geochemical database, including those that are located only to a county level; lead contents range from 2.7 to 25 ppm with a mean value of 9.6±4.9 ppm (table 13). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

Table 12. Cobalt content (parts per million) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	5.5	1.5	11	2.4	39
KY	na	5.3	1.5	11	2.2	33
VA	na	nd	4.5	4.5	nd	1
WV	na	6.9	2.7	11	3.6	5
KY	Bell	5.8	4.2	7.9	1.5	5
KY	Clay	nd	1.7	1.7	nd	1
KY	Floyd	4.7	3.3	8.2	2.1	5
KY	Johnson	nd	11	11	nd	1
KY	Knott	5.8	4.0	8.7	2.0	4
KY	Knox	nd	1.5	1.5	nd	1
KY	Lawrence	3.0	2.0	3.9	1.3	2
KY	Leslie	3.9	1.9	5.3	1.4	4
KY	Letcher	5.8	4.1	8.8	1.8	5
KY	Perry	5.0	4.1	5.9	1.3	2
KY	Pike	6.2	3.6	9.1	2.8	3
KY	Wolfe	nd	7.3	7.3	nd	1
VA	Wise	nd	4.5	4.5	nd	1
WV	Boone	nd	3.6	3.6	nd	1
WV	Logan	7.7	2.7	11	3.5	4

Table 13. Lead content (parts per million) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	9.6	2.7	25	4.9	39
KY	na	9.5	2.7	25	5.2	33
VA	na	nd	4.7	4.7	nd	1
WV	na	11	8.5	14	2.2	5
KY	Bell	5.9	2.7	9.7	2.6	5
KY	Clay	nd	4.7	4.7	nd	1
KY	Floyd	13	4.7	20	5.9	5
KY	Johnson	nd	25	25	nd	1
KY	Knott	13	6.2	17	4.7	4
KY	Knox	nd	5.8	5.8	nd	1
KY	Lawrence	14	12	15	2.1	2
KY	Leslie	5.4	2.9	8.8	2.5	4
KY	Letcher	9.5	6.3	12	2.0	5
KY	Perry	11	7.9	15	5.0	2
KY	Pike	6.8	3.9	10	3.1	3
KY	Wolfe	nd	8.8	8.8	nd	1
VA	Wise	nd	4.7	4.7	nd	1
WV	Boone	nd	8.5	8.5	nd	1
WV	Logan	12	9.5	14	1.8	4

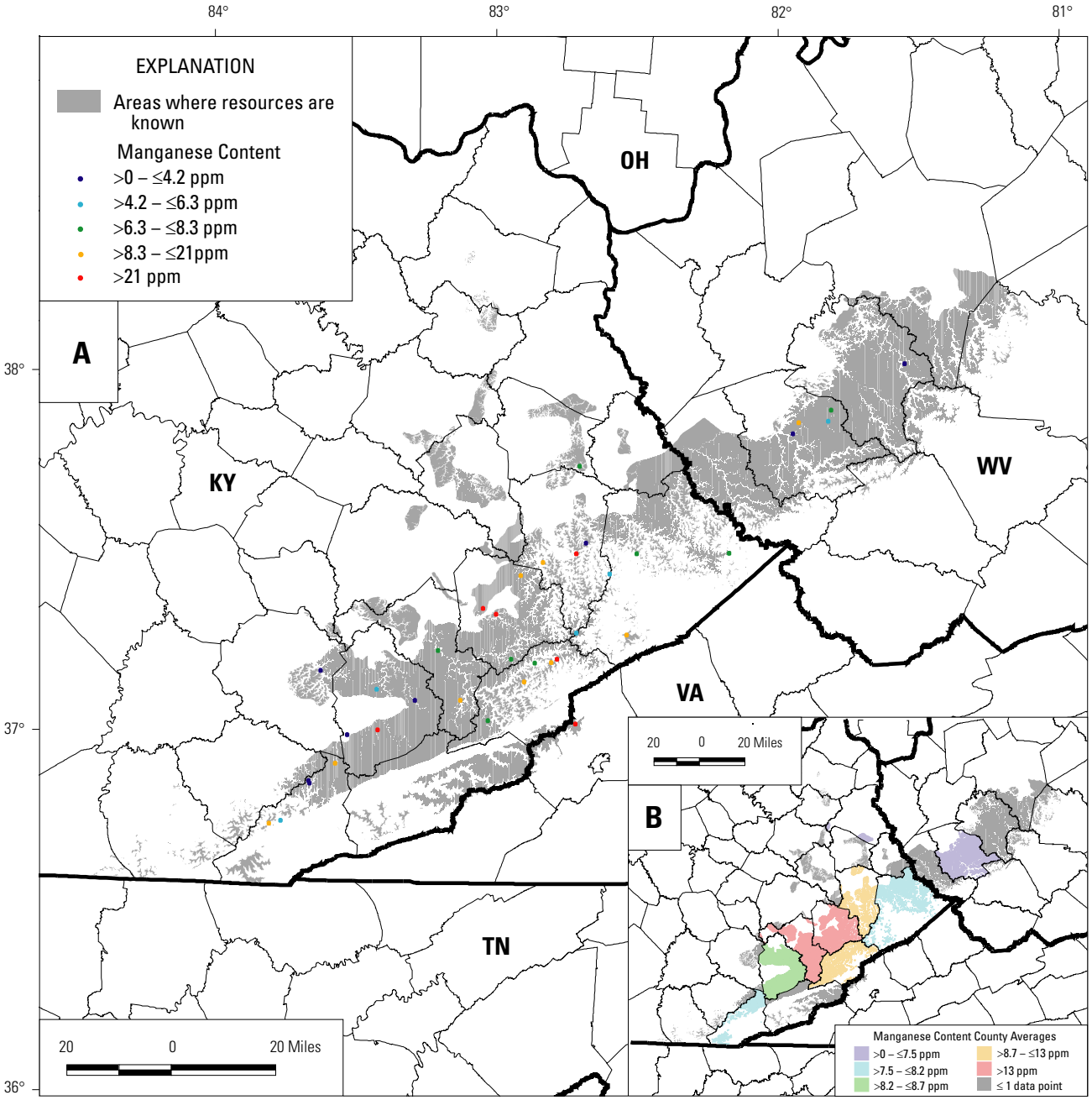


Figure 33. Maps showing manganese content (parts per million (ppm), as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows manganese contents of 36 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for manganese contents using all 39 records in the geochemical database, including those that are located only to a county level; manganese contents range from 1.9 to 43 ppm with a mean value of 11±9.6 ppm (table 14). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

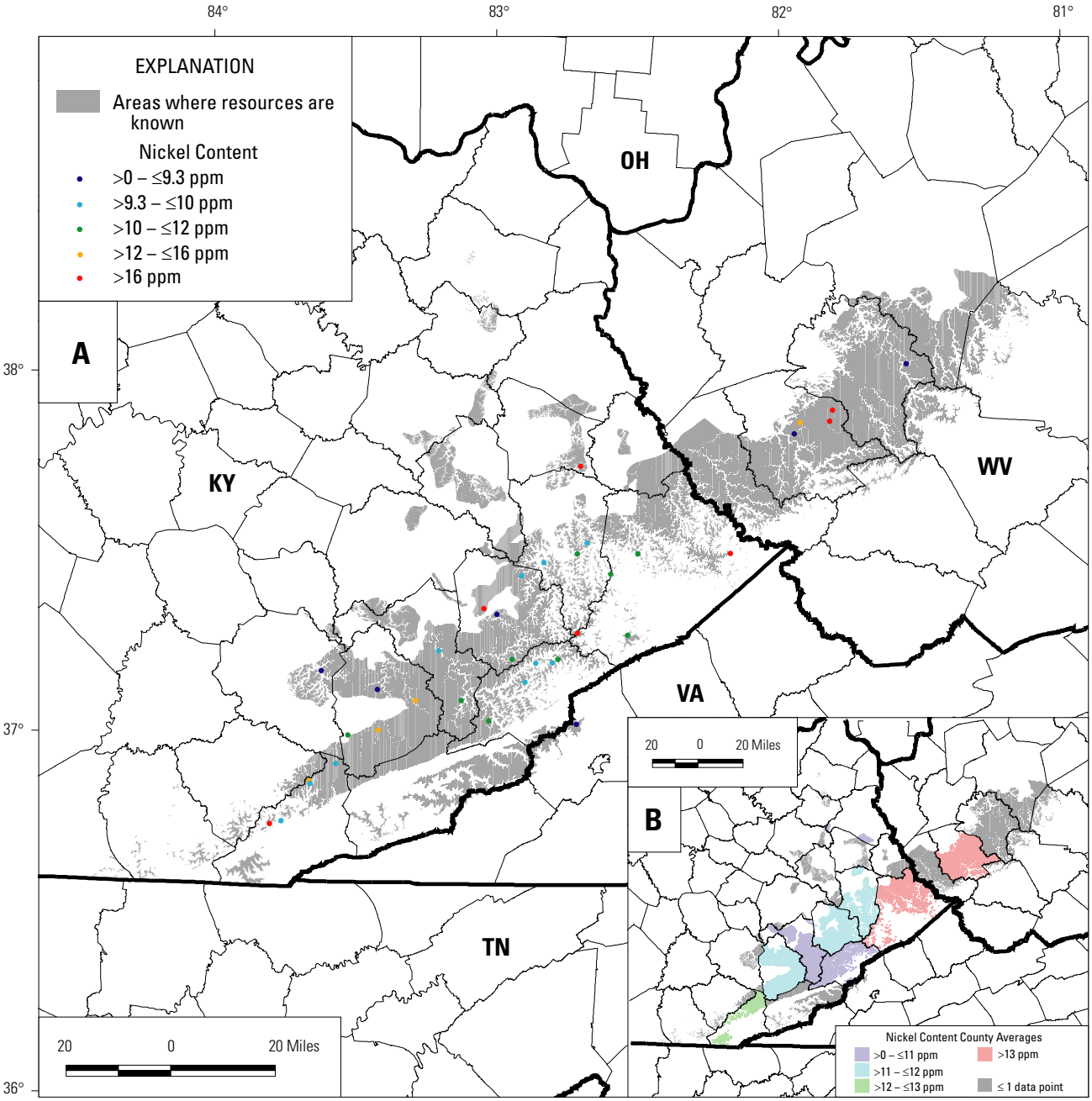


Figure 34. Maps showing nickel content (parts per million (ppm), as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows nickel contents of 36 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for nickel contents using all 39 records in the geochemical database, including those that are located only to a county level; nickel contents range from 3.7 to 24 ppm with a mean value of 12±4.9 ppm (table 15). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

Table 14. Manganese content (parts per million) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	11	1.9	43	9.6	39
KY	na	12	1.9	43	9.7	33
VA	na	nd	29	29	nd	1
WV	na	6.5	2.6	14	4.4	5
KY	Bell	8.1	3.9	18	5.9	5
KY	Clay	nd	3.1	3.1	nd	1
KY	Floyd	13	3.2	43	17	5
KY	Johnson	nd	7.0	7.0	nd	1
KY	Knott	19	6.7	26	8.6	4
KY	Knox	nd	5.1	5.1	nd	1
KY	Lawrence	4.6	4.6	4.6	nd	2
KY	Leslie	8.7	1.9	23	9.7	4
KY	Letcher	13	6.3	28	8.9	5
KY	Perry	15	8.1	21	9.1	2
KY	Pike	8.2	6.4	11	2.5	3
KY	Wolfe	nd	27	27	nd	1
VA	Wise	nd	29	29	nd	1
WV	Boone	nd	2.6	2.6	nd	1
WV	Logan	7.5	4.2	14	4.4	4

Table 15. Nickel content (parts per million) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	12	3.7	24	4.9	39
KY	na	12	3.8	24	4.7	33
VA	na	nd	8.4	8.4	nd	1
WV	na	12	3.7	19	6.9	5
KY	Bell	13	9.1	20	4.5	5
KY	Clay	nd	5.2	5.2	nd	1
KY	Floyd	12	9.5	19	3.9	5
KY	Johnson	nd	24	24	nd	1
KY	Knott	12	5.7	20	6.1	4
KY	Knox	nd	3.8	3.8	nd	1
KY	Lawrence	8.3	4.6	12	5.2	2
KY	Leslie	12	5.7	16	4.7	4
KY	Letcher	11	10	12	0.89	5
KY	Perry	11	10	12	1.4	2
KY	Pike	14	11	20	4.9	3
KY	Wolfe	nd	18	18	nd	1
VA	Wise	nd	8.4	8.4	nd	1
WV	Boone	nd	3.7	3.7	nd	1
WV	Logan	14	6.2	19	5.8	4

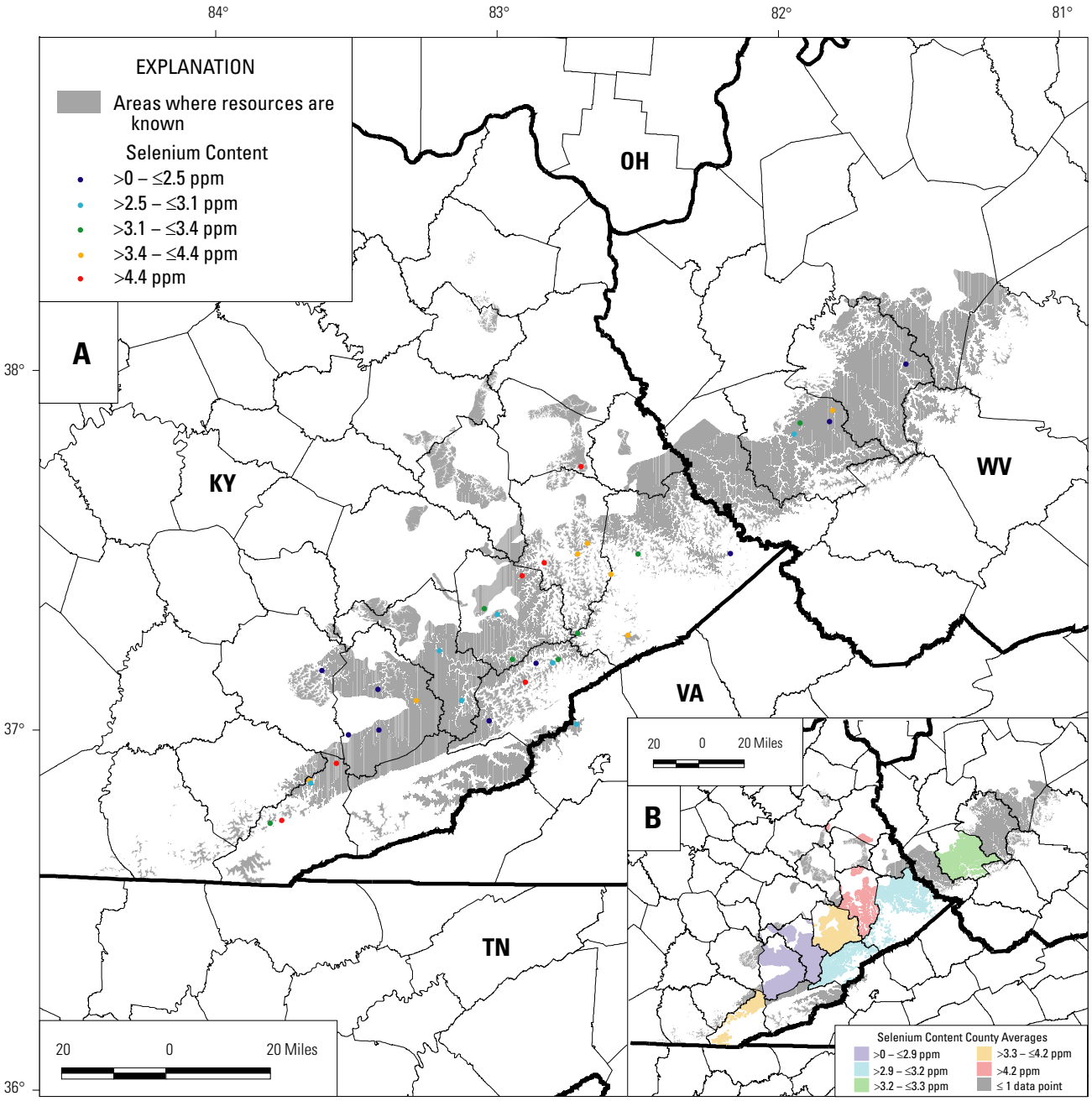


Figure 35. Maps showing selenium content (parts per million (ppm), as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows selenium contents of 36 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for selenium contents using all 39 records in the geochemical database, including those that are located only to a county level; selenium contents range from 1.3 to 7.3 ppm with a mean value of 3.6±1.3 ppm (table 16). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

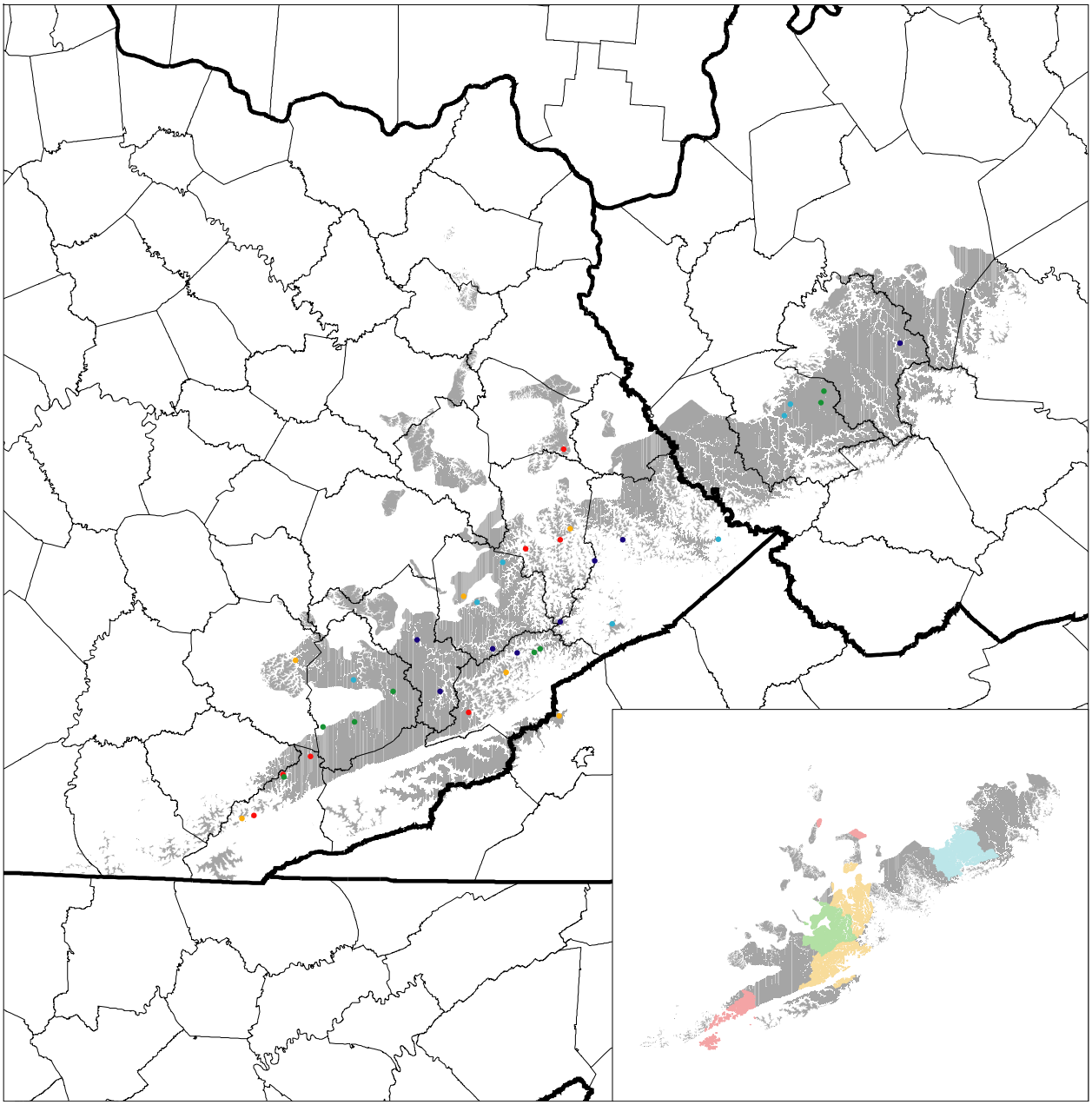


Table 16. Selenium content (parts per million) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	3.6	1.3	7.3	1.3	39
KY	na	3.7	1.3	7.3	1.4	33
VA	na	nd	3.1	3.1	nd	1
WV	na	3.1	2.2	4.1	0.76	5
KY	Bell	4.2	2.8	5.6	1.3	5
KY	Clay	nd	1.8	1.8	nd	1
KY	Floyd	4.5	3.3	5.9	0.97	5
KY	Johnson	nd	7.3	7.3	nd	1
KY	Knott	3.6	2.9	5.0	0.94	4
KY	Knox	nd	2.3	2.3	nd	1
KY	Lawrence	6.2	6.1	6.3	0.14	2
KY	Leslie	2.7	1.9	4.3	1.1	4
KY	Letcher	3.2	1.3	5.9	1.7	5
KY	Perry	2.9	2.7	3.1	0.28	2
KY	Pike	3.1	2.5	3.6	0.56	3
KY	Wolfe	nd	3.8	3.8	nd	1
VA	Wise	nd	3.1	3.1	nd	1
WV	Boone	nd	2.2	2.2	nd	1
WV	Logan	3.3	2.5	4.1	0.68	4

Table 17. Arsenic content (parts per million) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

State	County	M ean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	11	0.70	53	13	39
KY	na	12	0.70	53	14	33
VA	na	nd	10	10	nd	1
WV	na	3.7	1.7	7.6	2.5	5
KY	Bell	29	5.1	53	23	5
KY	Clay	nd	8.0	8.0	nd	1
KY	Floyd	10	1.3	22	9.6	5
KY	Johnson	nd	37	37	nd	1
KY	Knott	6.4	1.3	17	7.2	4
KY	Knox	nd	1.0	1.0	nd	1
KY	Lawrence	14	12	15	2.1	2
KY	Leslie	4.8	3.8	5.6	0.87	4
KY	Letcher	8.2	1.3	20	7.1	5
KY	Perry	1.3	0.70	1.9	0.85	2
KY	Pike	2.8	2.1	3.9	0.95	3
KY	Wolfe	nd	34	34	nd	1
VA	Wise	nd	10	10	nd	1
WV	Boone	nd	1.7	1.7	nd	1
WV	Logan	4.2	2.2	7.6	2.5	4

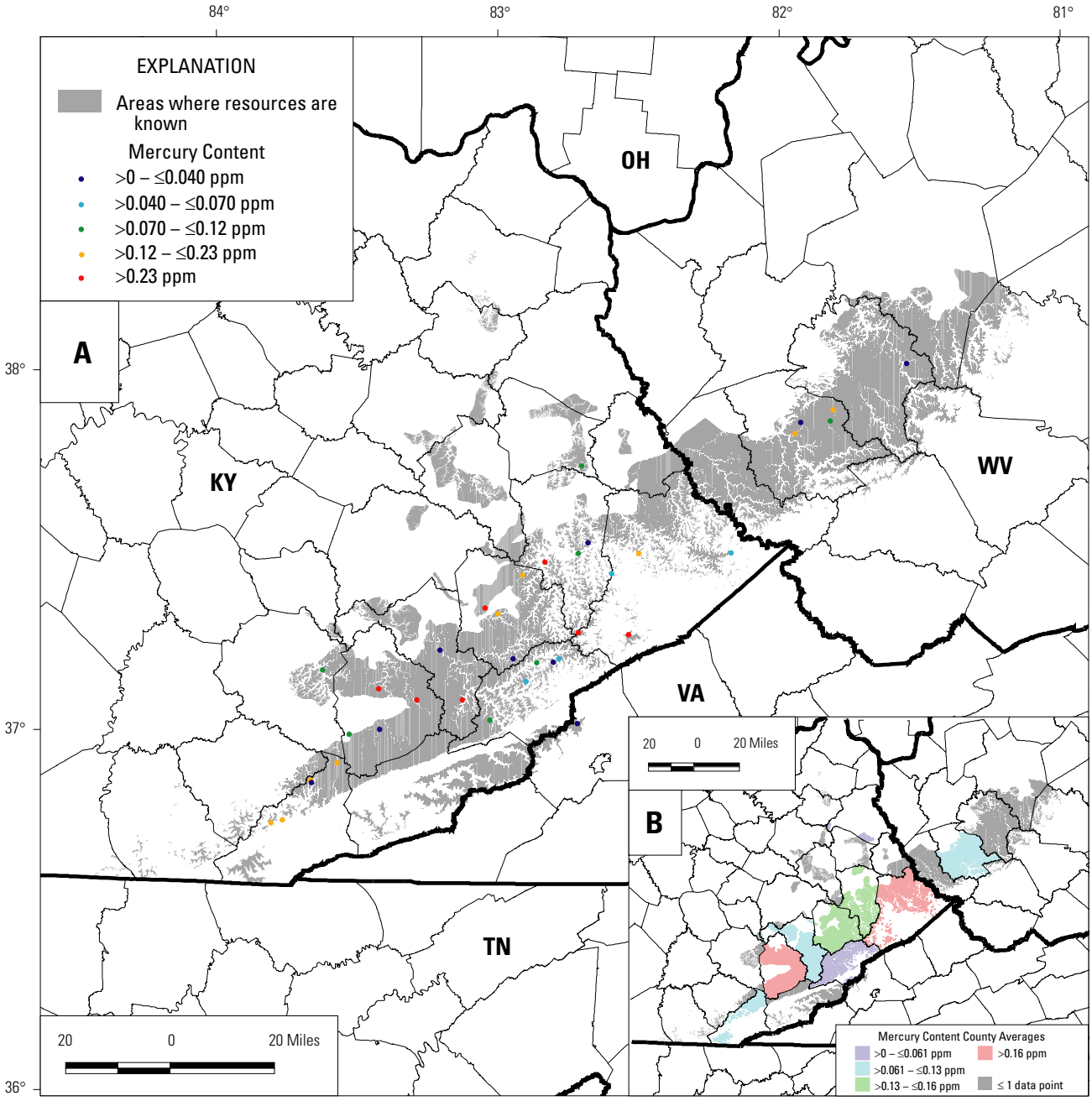


Figure 37. Maps showing mercury content (parts per million (ppm), as-received whole-coal basis) of the Fire Clay coal zone in Kentucky, Virginia, and West Virginia. Map A shows mercury contents of 36 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 7). Map B shows county averages for mercury contents using all 39 records in the geochemical database, including those that are located only to a county level; mercury contents range from 0.0050 to 0.30 ppm with a mean value of 0.12±0.089 ppm (table 18) The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

Table 18. Mercury content (parts per million) means, ranges, and standard deviations for the Fire Clay coal zone on an as-received whole-coal basis, by State and county.

[Abbreviations are as follows: na, not applicable; nd, no data available.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of Samples
ALL	na	0.12	0.0050	0.30	0.089	39
KY	na	0.13	0.0050	0.30	0.092	33
VA	na	nd	0.018	0.018	nd	1
WV	na	0.092	0.030	0.16	0.055	5
KY	Bell	0.13	0.0050	0.20	0.073	5
KY	Clay	nd	0.070	0.070	nd	1
KY	Floyd	0.14	0.034	0.26	0.11	5
KY	Johnson	nd	0.090	0.090	nd	1
KY	Knott	0.16	0.0050	0.26	0.11	4
KY	Knox	nd	0.050	0.050	nd	1
KY	Lawrence	0.055	0.050	0.060	0.0071	2
KY	Leslie	0.17	0.040	0.30	0.12	4
KY	Letcher	0.061	0.033	0.080	0.018	5
KY	Perry	0.13	0.020	0.24	0.16	2
KY	Pike	0.20	0.060	0.30	0.12	3
KY	Wolfe	nd	0.095	0.095	nd	1
VA	Wise	nd	0.018	0.018	nd	1
WV	Boone	nd	0.030	0.030	nd	1
WV	Logan	0.11	0.040	0.16	0.050	4

Twelve elements (antimony, beryllium, cadmium, chlorine, chromium, cobalt, lead, manganese, nickel, selenium, arsenic, and mercury) that may adversely affect the environment are listed by the Clean Air Act Amendments of 1990. For the Fire Clay coal zone, 39 samples were analyzed for these 12 elements (figs. 26-37; tables 7-18). Data availability restricts the interpretation of the distribution of these element concentrations, but chlorine content, which causes corrosion in coal-burning boilers, appears to be greater to the southwest, reaching a maximum in Leslie County, Ky. (table 10; figs. 2, 29B).

ARSENIC AND MERCURY

Two elements are thought to have particularly adverse environmental effects: arsenic (fig. 36; table 17) and mercury (fig. 37; table 18). Concentrations of these elements appear to be low for the Fire Clay coal zone. The mean arsenic concentration (as-received whole-coal basis) for the 39 Fire Clay coal zone samples is 11±13 ppm in comparison to the Appalachian Region coal mean of 35 ppm arsenic (Finkelman and others, 1994) and the U.S. coal mean of 24±5.5 ppm arsenic (Finkelman, 1993). The same 39 samples were analyzed for mercury on an as-received whole-coal basis (fig. 37; table 18). The mean mercury concentration is 0.12±0.089 ppm in comparison to the Appalachian Region mean of 0.21 ppm (Finkelman and others, 1994) and the U.S. mean of 0.17±10 ppm (Finkelman, 1993), but values range widely (0.0050–0.30 ppm, table 18).

RESOURCE ESTIMATES

PREVIOUS RESOURCE STUDIES

Resource estimates for the Fire Clay coal zone in Kentucky were compiled in 1983 (Brant, 1983a,b; Brant, Chesnut, Frankie, and Portig, 1983a,b,c; Brant, Chesnut, Portig, and Smath, 1983) and totaled 5.956 billion short tons. The KGS made a second compilation in 2000 (Thacker, Weisenfluh, Esterle, and others, 2000). The estimated amount of coal greater than 1.17 ft thick decreased from 5.9 billion short tons in the 1983 estimate to 4.1 billion short tons in 2000, a drop of 30 percent. The large difference arises primarily from two factors. Significant amounts of new data were available for the later estimate and resulted in improved definitions of thickness areas. The later work also identified a number of areas where the Fire Clay Rider coal bed was misidentified as Fire Clay; these areas generally contain no Fire Clay coal benches of minable thickness.

Brown and others (1952) reported on the Fire Clay coal zone resources of Virginia (the Phillips bed of the Wise Formation in that report). The total estimated remaining "reserves" in 1952 were 25.05 million short tons, 13.17 million short tons in Lee County and 11.88 million short tons in Wise County, Va. (fig. 2). A more recent estimate of the coal resources of Lee County, Va., by Campbell and others (1991) reported remaining resources of 10.69 million short tons, which is 20 percent less than the earlier estimate by Brown and others (1952).

The Chilton coal bed of Logan and Mingo Counties, W. Va. (fig. 2) was described and its resources were estimated to be 1.7 billion short tons by Hennen and Reger (1914, p. 465). Although the Chilton coal bed of Logan and Mingo Counties has been correlated with the Fire Clay coal zone, all of the coal units assessed in 1914 probably are not equivalent to those included in the Fire Clay coal zone in this study and the figures cannot really be compared.

Huddle and others (1963) published original Fire Clay coal zone "reserves" (defined as minable and potentially minable deposits thicker than 1.17 ft within given reliability limits) that totaled approximately 3.8 billion short tons for eastern Kentucky. The estimate by Huddle and others (1963) is within 10 percent of the current KGS estimate.

ASSESSMENT RESULTS

The results of resource calculations in this study indicate that the original resource of the Fire Clay coal zone was 6.3 billion short tons within the resource assessment areas (fig. 2, table 1, Appendix 10). Of the total, 98 percent is classified as identified resources and the rest as hypothetical. Hypothetical resources are small because the resource assessment areas were created within the spatial distribution of data; no inference to the full extent of the Fire Clay coal zone outcrop was performed in this study. The resource model indicates that about 81 percent of the original Fire Clay coal zone resource remains: 3.2 billion short tons in Kentucky, 49 million short tons in Virginia, and 1.8 billion short tons in West Virginia (table 1, Appendix 11). The original and remaining resource estimates for this study are presented graphically by State, in thickness (fig. 38), overburden (fig. 39), and reliability categories (fig. 40).

Of the total original Fire Clay coal zone resource, about 23 percent was in the >3.5-ft thickness category (Appendix 10). The original resource in Kentucky is estimated to have been 4.2 billion short tons, with 26 percent of the coal >3.5 ft thick (fig. 38). In Virginia, 18 percent of the original resource of 55 million short tons was in this same thickness category (fig. 38), as was 25 percent of West Virginia's original 2.1 billion short tons. Only about 17 percent of the total remaining resource is in the >3.50-ft thickness category, with 17, 18, and 16 percent in Kentucky, Virginia, and West Virginia, respectively. This reveals that a large amount of the thicker coal already has been mined.

Although the Fire Clay coal zone has been mined mostly by underground methods in Kentucky, the distribution of tons within overburden categories is the same for the original and remaining resources (fig. 39). In Virginia, nearly 28 percent of the original resource was in the 0- to 200-ft overburden category, as is 25 percent of the remaining resource (fig. 39). In West Virginia, the greatest percentage (75 percent) of remaining resources is in the 200- to 1,000-ft overburden categories (fig. 39).

CONCLUSIONS

The Fire Clay coal zone has been a major producer in the central Appalachian Basin coal region, particularly in Kentucky. Production rates are declining as thicker, shallower occurrences of the Fire Clay coal zone are depleted. A discussion of the coal resources potentially available for future mining may be found in Chapter J of this report. Fire Clay coal is currently washed and blended with other coal to meet Federal air quality standards. Because much of the remaining 5.1 billion short tons of Fire Clay coal zone resource is below drainage and thinner than coal previously mined, future mining will be more difficult and costly. However, the Fire Clay coal zone should continue to be a major producer for years to come in Kentucky.

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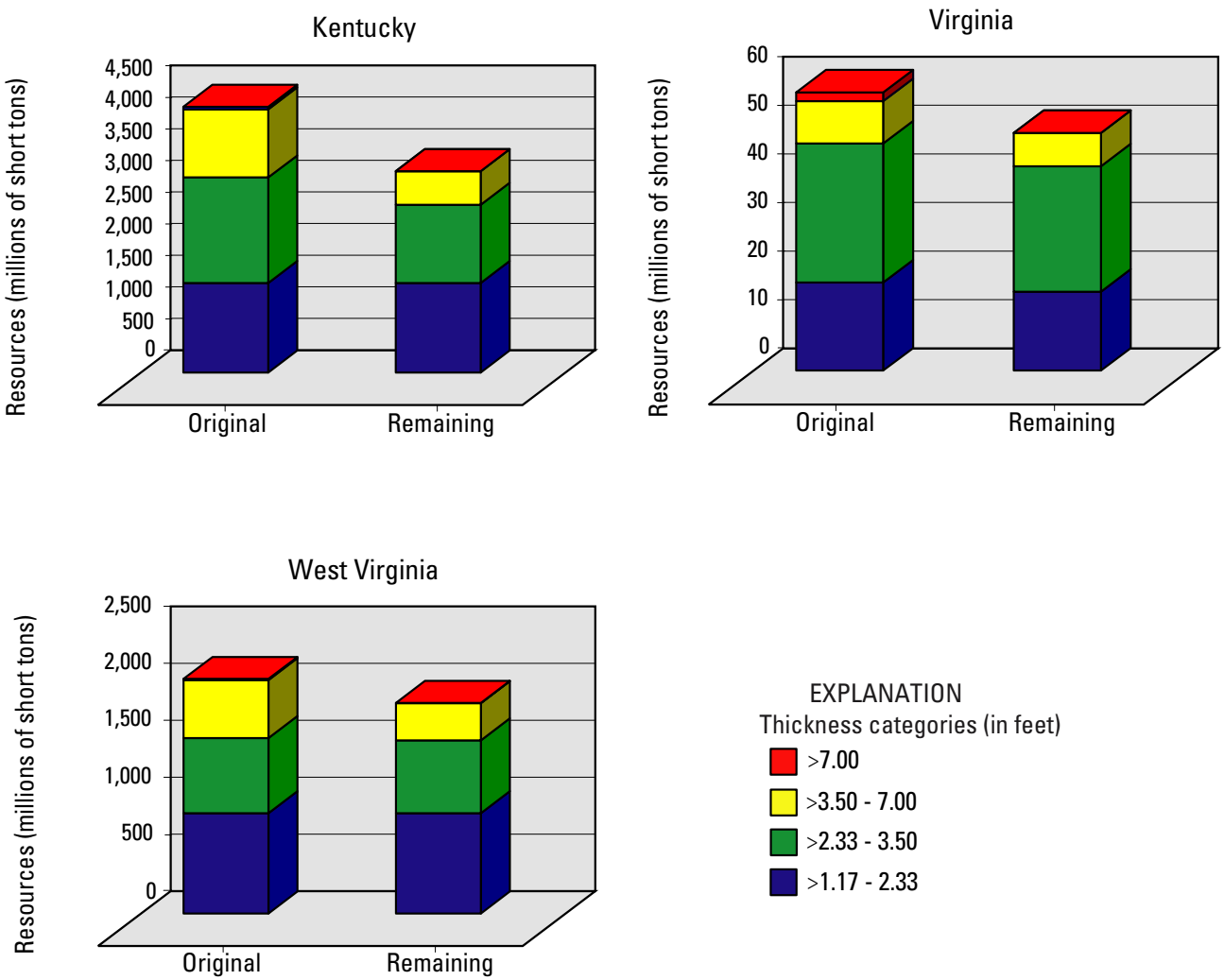

Figure 38. Bar graphs showing original and remaining Fire Clay coal zone resources (millions of short tons), by State and by USGS thickness categories. Note that the thicker coal already has been mined.

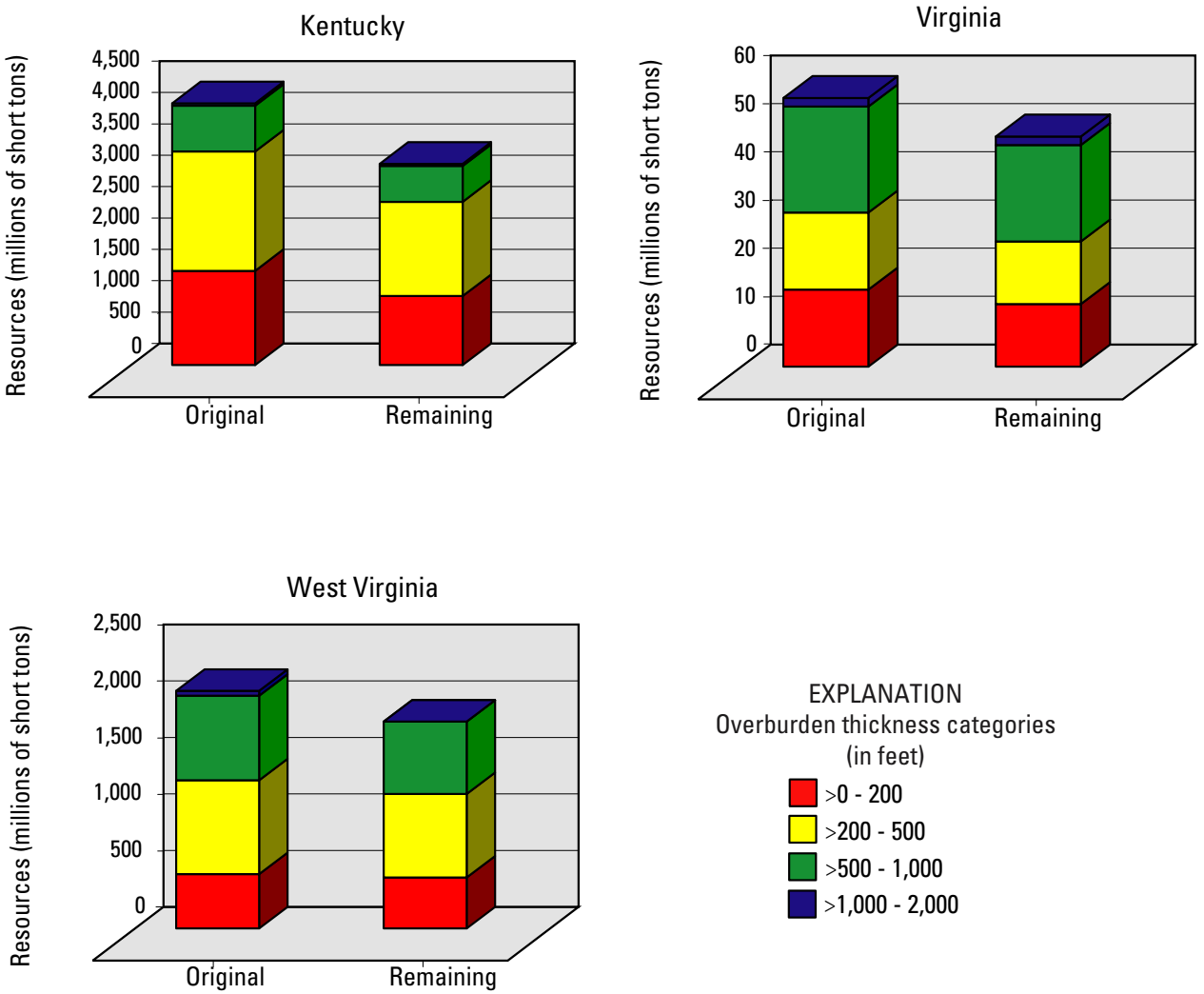

Figure 39. Bar graphs showing original and remaining Fire Clay coal zone resources (millions of short tons), by State and by USGS overburden thickness categories. The thickest overburden category is 1,000 to 2,000 ft, which occurs under the highest hills in all three States.

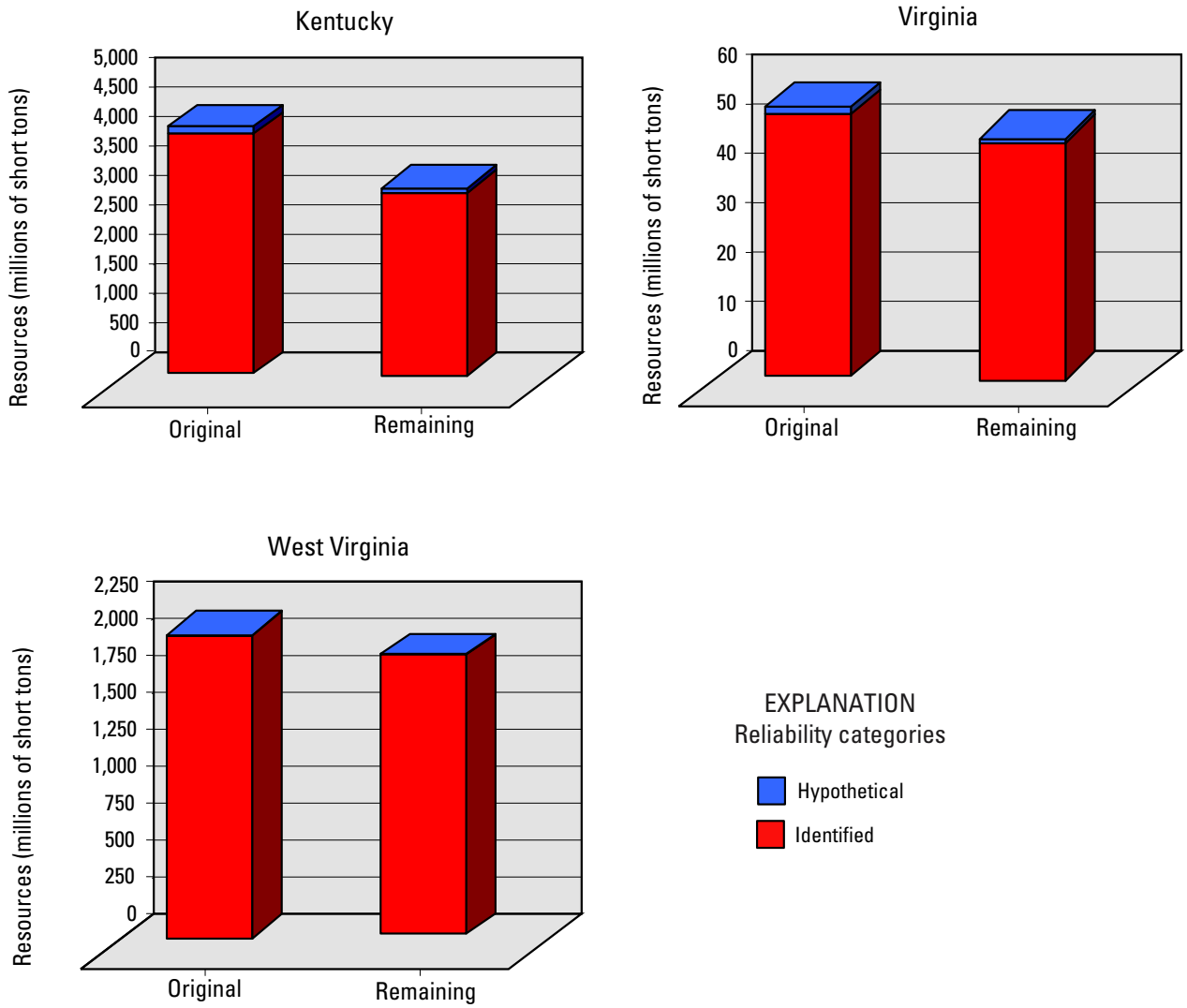

Figure 40. Bar graphs showing original and remaining Fire Clay coal zone resources (millions of short tons), by State and by USGS reliability categories. Identified resources are within 3 miles of a thickness measurement, and hypothetical resources are beyond 3 miles of a thickness measurement.

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APPENDIX 1

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APPENDIX 2

RECENT REPORTED ANNUAL PRODUCTION (IN SHORT TONS) OF THE FIRE CLAY COAL ZONE, BY STATE

[Sources: Sweet (1988, 1989, 1991); Sweet and Nolde (1992, 1993, 1994, 1995, 1996, 1997a,b, 1998, 1999); Gayle H. McColloch (West Virginia Geological and Economic Survey, unpublished search of West Virginia Office of Miner's Health, Safety, and Training—Safety Information System (MHST-SIS) database, 1997), John K. Hiett (Kentucky Department of Mines and Minerals, written commun., 2000). Abbreviations are as follows: nd, no data or the absence of production.]

Year	Kentucky	Virginia	West Virginia	Year	Kentucky	Virginia	West Virginia
1929	2,433,387	nd	nd	1964	4,896,630	nd	nd
1930	2,978,571	nd	nd	1965	4,811,801	nd	nd
1931	2,358,450	nd	nd	1966	4,802,722	nd	nd
1932	1,216,602	nd	nd	1967	4,489,666	nd	nd
1933	1,534,081	nd	nd	1968	5,637,024	nd	nd
1934	1,532,034	nd	nd	1969	5,396,736	nd	nd
1935	2,250,646	nd	nd	1970	5,445,218	nd	nd
1936	1,938,196	nd	nd	1971	4,977,350	nd	nd
1937	2,507,781	nd	nd	1972	4,437,979	nd	nd
1938	1,703,569	nd	nd	1973	4,905,105	nd	nd
1939	1,811,072	nd	nd	1974	7,420,182	nd	nd
1940	2,117,541	nd	nd	1975	5,456,058	nd	nd
1941	2,434,955	nd	nd	1976	6,373,225	nd	nd
1942	2,939,506	nd	nd	1977	7,829,684	nd	nd
1943	3,014,528	nd	nd	1978	8,628,566	nd	nd
1944	2,863,552	nd	nd	1979	8,807,448	nd	nd
1945	2,956,297	nd	nd	1980	8,149,805	nd	nd
1946	2,537,645	nd	nd	1981	10,608,801	nd	nd
1947	2,389,144	nd	nd	1982	10,707,251	nd	1,053,025
1948	5,346,376	nd	nd	1983	8,620,205	nd	1,197,360
1949	4,745,794	nd	nd	1984	11,371,364	nd	1,524,081
1950	8,083,475	nd	nd	1985	12,679,375	420	1,258,826
1951	4,793,046	nd	nd	1986	13,863,711	nd	1,111,396
1952	4,260,717	nd	nd	1987	13,442,005	198,783	1,244,543
1953	4,093,680	nd	nd	1988	14,455,673	457,672	1,166,060
1954	3,551,788	nd	nd	1989	18,314,663	427,917	856,809
1955	4,218,520	nd	nd	1990	19,844,469	382,465	833,321
1956	4,830,958	nd	nd	1991	20,515,380	540,741	892,521
1957	5,088,441	nd	nd	1992	22,560,904	675,986	781,434
1958	4,851,704	nd	nd	1993	22,921,053	557,029	919,639
1959	4,518,358	nd	nd	1994	20,926,252	511,108	692,556
1960	33,649	nd	nd	1995	20,541,376	951,187	669,744
1961	5,270,830	nd	nd	1996	18,209,690	1,282,985	365,117
1962	5,335,369	nd	nd	1997	12,489,949	1,100,119	nd
1963	5,381,486	nd	nd	1998	18,137,953	1,038,852	nd
				Total	510,597,021	8,125,264	14,566,432

APPENDIX 3

RECENT REPORTED ANNUAL PRODUCTION (IN SHORT TONS) OF THE FIRE CLAY COAL ZONE IN KENTUCKY, BY COUNTY

[Source: John K. Hiett (Kentucky Department of Mines and Minerals, written commun., 2000). Abbreviations are as follows: nd, no data available or the absence of production.]

Year	Bell	Breathitt	Carter	Clay	Elliott	Floyd	Harlan	Jackson	Johnson	Knott	Knox	Laurel	Lawrence
1929	70,603	11,815	nd	nd	nd	nd	1,459,743	nd	nd	123,133	139,266	nd	nd
1930	132,315	nd	nd	nd	nd	nd	1,102,306	nd	nd	102,111	149,985	nd	nd
1931	117,342	nd	nd	nd	nd	nd	806,727	nd	nd	150,027	163,122	nd	nd
1932	46,761	nd	nd	nd	nd	nd	668,571	nd	nd	91,987	119,796	nd	nd
1933	75,700	200	nd	nd	nd	nd	790,020	nd	nd	138,138	276,869	nd	nd
1934	65,414	nd	nd	nd	nd	nd	917,852	nd	nd	103,000	445,581	nd	nd
1935	21,446	nd	nd	nd	nd	nd	833,892	nd	nd	131,818	467,452	nd	nd
1936	62,776	nd	nd	nd	nd	nd	858,024	nd	nd	135,327	454,267	nd	nd
1937	87,587	nd	nd	nd	nd	nd	959,812	nd	nd	152,640	451,851	nd	nd
1938	86,812	nd	nd	nd	nd	nd	752,779	nd	nd	80,773	379,476	nd	nd
1939	74,906	nd	nd	nd	nd	nd	629,917	nd	nd	123,802	471,915	nd	nd
1940	90,645	1,963	nd	nd	nd	nd	688,180	nd	nd	132,884	466,914	nd	nd
1941	96,481	nd	nd	nd	nd	nd	721,192	nd	nd	188,931	424,777	nd	nd
1942	95,833	nd	nd	nd	nd	nd	791,059	nd	nd	207,557	552,641	nd	nd
1943	238,092	nd	nd	nd	nd	nd	759,722	nd	nd	191,565	486,617	nd	nd
1944	208,277	nd	nd	nd	nd	13,750	726,055	nd	600	184,039	520,082	nd	nd
1945	202,346	4,834	nd	nd	nd	nd	465,161	nd	nd	138,948	450,444	nd	nd
1946	260,042	nd	nd	nd	nd	nd	330,576	nd	nd	247,338	392,858	nd	nd
1947	59,989	4,000	nd	20,390	nd	nd	384,976	nd	nd	158,880	418,078	37,400	nd
1948	47,100	121,975	nd	31,720	nd	131,921	338,745	nd	nd	207,885	243,104	nd	4,800
1949	116,570	103,371	nd	18,150	nd	nd	107,978	nd	nd	415,704	171,031	nd	nd
1950	173,417	567,376	nd	29,615	nd	nd	135,849	nd	nd	633,989	46,737	nd	nd
1951	208,421	143,189	nd	14,165	nd	nd	135,032	nd	nd	232,216	199,370	nd	nd
1952	134,767	98,622	nd	4,456	nd	nd	32,959	nd	18,881	98,235	78,137	nd	nd
1953	169,948	57,972	nd	57,591	nd	nd	213,139	nd	nd	100,094	94,800	nd	nd
1954	121,228	65,247	nd	89,938	nd	nd	198,503	nd	17,279	184,341	102,367	nd	nd
1955	154,406	66,606	nd	188,479	nd	nd	169,836	nd	33,987	224,208	71,273	nd	nd
1956	145,318	96,700	nd	329,931	nd	nd	140,579	nd	27,250	327,302	149,915	nd	nd
1957	431,734	87,965	nd	296,135	nd	nd	214,936	nd	31,914	434,312	96,697	nd	nd
1958	126,009	72,924	nd	292,084	nd	nd	65,112	nd	21,420	716,306	52,895	nd	nd
1959	47,035	30,980	nd	263,881	nd	nd	29,861	nd	26,777	445,149	39,307	nd	nd
1960	7,700	nd	nd	7,614	nd	nd	8,576	nd	9,484	nd	275	nd	nd
1961	137,238	8,140	nd	544,092	nd	nd	428,034	nd	5,075	636,042	147,704	nd	nd
1962	359,094	1,500	nd	417,452	nd	nd	143,378	nd	10,550	519,287	132,934	nd	nd
1963	115,583	9,300	nd	538,935	nd	nd	12,841	nd	11,623	572,310	187,050	nd	nd
1964	92,732	15,200	nd	617,647	nd	nd	22,272	nd	11,145	324,090	31,241	nd	nd

APPENDIX 3—CONTINUED

Year	Bell	Breathitt	Carter	Clay	Elliott	Floyd	Harlan	Jackson	Johnson	Knott	Knox	Laurel	Lawrence
1965	74,800	100	nd	493,760	nd	nd	60,929	nd	10,078	403,260	10,317	nd	nd
1966	129,547	nd	nd	342,657	nd	nd	97,735	nd	14,362	556,253	64,150	nd	nd
1967	163,557	nd	nd	158,802	nd	3,600	262,156	nd	20,379	339,082	38,254	nd	nd
1968	364,246	200	nd	187,858	nd	13,580	478,110	nd	15,141	532,388	18,995	nd	nd
1969	422,501	nd	nd	163,032	nd	nd	522,442	nd	10,114	507,550	23,225	nd	nd
1970	618,464	2,086	nd	115,875	nd	7,302	512,424	nd	50,380	423,177	117,070	nd	nd
1971	710,728	1,000	nd	129,243	nd	144,212	253,289	nd	28,714	608,480	380,062	nd	nd
1972	222,973	800	nd	nd	nd	156,406	419,538	nd	403,204	556,898	167,959	nd	nd
1973	718,291	nd	18,531	61,868	nd	180,618	547,322	nd	968	556,242	76,088	nd	nd
1974	452,069	3,500	162,516	248,912	nd	568,074	517,145	nd	175,562	866,312	83,860	nd	32,903
1975	107,911	29,860	49,124	307,391	11,905	698,644	752,584	nd	119,791	745,977	39,579	nd	nd
1976	306,792	93,906	79,099	174,272	94,398	712,061	426,334	nd	255,637	1,059,124	12,527	nd	nd
1977	345,914	126,000	95,906	264,430	68,497	818,010	611,677	nd	175,584	1,429,168	159,749	nd	4,141
1978	647,082	111,438	99,994	586,870	30,000	664,460	582,845	30,000	83,191	1,575,982	72,291	nd	7,892
1979	584,659	25,500	155,421	137,855	nd	1,010,408	455,178	nd	36,095	1,476,941	88,979	nd	100,000
1980	239,100	2,116	168,428	158,363	nd	911,197	1,060,909	nd	1,640	1,851,459	241,540	nd	5,000
1981	316,521	15,108	122,651	nd	nd	1,272,916	912,236	nd	nd	2,739,484	133,294	nd	nd
1982	368,693	31,861	134,656	17,459	nd	1,265,139	120,485	nd	66,676	2,521,598	7,700	nd	nd
1983	211,155	30,841	27,341	9,054	6,249	852,989	554,592	nd	45,486	1,938,251	2,297	nd	3,600
1984	290,002	5,404	31,101	nd	17,361	1,084,260	15,031	nd	125,457	2,661,786	54,435	nd	nd
1985	382,392	6,325	25,381	150,000	67,140	823,414	47,604	nd	82,145	3,302,410	89,834	nd	nd
1986	349,540	2,712	19,652	7,680	154,658	1,106,578	147,687	nd	11,962	3,487,317	114,767	nd	nd
1987	240,768	3,030	nd	8,483	62,443	1,063,806	118,400	nd	8,795	2,979,487	266,727	nd	nd
1988	194,702	nd	nd	15,144	137,403	976,486	355,591	nd	5,228	3,054,108	113,171	nd	nd
1989	245,840	nd	nd	5,000	nd	1,153,658	1,100,927	nd	1,167	4,106,516	104,980	nd	nd
1990	318,008	nd	nd	37,715	nd	1,195,665	877,517	nd	nd	4,197,830	8,438	nd	nd
1991	173,358	nd	nd	300	nd	805,761	1,154,659	nd	nd	4,866,590	59,636	nd	nd
1992	310,529	nd	nd	nd	nd	795,359	1,131,437	nd	500,000	4,494,037	79,478	nd	nd
1993	452,145	nd	nd	nd	nd	692,303	1,148,146	nd	nd	6,301,701	51,767	nd	nd
1994	553,386	nd	nd	nd	nd	528,189	1,291,254	nd	nd	4,525,420	256,743	nd	nd
1995	780,147	nd	nd	nd	nd	564,247	798,573	nd	20,793	4,104,852	213,400	nd	nd
1996	254,776	nd	nd	2,117	nd	870,690	567,362	nd	nd	3,537,026	56,100	nd	nd
1997	500	nd	nd	nd	nd	435,083	406,982	nd	nd	1,516,323	nd	nd	nd
1998	482,693	nd	nd	nd	nd	688,396	480,654	nd	nd	2,770,221	nd	nd	nd
Total	16,715,456	2,061,666	1,189,801	7,546,415	650,054	22,209,182	35,833,948	30,000	2,494,534	85,447,618	12,284,240	37,400	158,336

APPENDIX 3—CONTINUED

Year	Lee	Leslie	Letcher	Magoffin	Martin	McCreary	Morgan	Owsley	Perry	Pike	Whitley	Wolfe	Total annual production
1929	nd	nd	628,827	nd	nd	nd	nd	nd	nd	nd	nd	nd	2,433,387
1930	nd	nd	196,876	nd	nd	nd	nd	nd	1,294,978	nd	nd	nd	2,978,571
1931	nd	nd	278,354	nd	nd	nd	nd	nd	842,878	nd	nd	nd	2,358,450
1932	nd	nd	9,547	nd	nd	nd	nd	nd	279,940	nd	nd	nd	1,216,602
1933	nd	600	252,554	nd	nd	nd	nd	nd	nd	nd	nd	nd	1,534,081
1934	nd	nd	187	nd	nd	nd	nd	nd	nd	nd	nd	nd	1,532,034
1935	nd	nd	89,885	nd	nd	nd	nd	nd	706,153	nd	nd	nd	2,250,646
1936	nd	nd	nd	nd	nd	nd	nd	nd	427,802	nd	nd	nd	1,938,196
1937	nd	nd	62,758	nd	nd	nd	nd	nd	793,133	nd	nd	nd	2,507,781
1938	nd	nd	nd	nd	nd	nd	nd	nd	403,729	nd	nd	nd	1,703,569
1939	nd	nd	22,158	nd	nd	nd	nd	nd	488,374	nd	nd	nd	1,811,072
1940	nd	nd	108,008	nd	nd	nd	nd	nd	628,947	nd	nd	nd	2,117,541
1941	nd	nd	165,281	nd	nd	nd	nd	nd	838,293	nd	nd	nd	2,434,955
1942	nd	nd	276,088	nd	nd	nd	nd	nd	1,016,328	nd	nd	nd	2,939,506
1943	nd	nd	351,168	nd	nd	nd	nd	nd	986,639	725	nd	nd	3,014,528
1944	nd	nd	326,314	nd	nd	nd	nd	nd	879,793	75	4,567	nd	2,863,552
1945	nd	nd	428,527	nd	nd	nd	nd	nd	1,260,597	100	5,340	nd	2,956,297
1946	8,640	185,064	314,469	nd	nd	nd	nd	nd	787,658	nd	11,000	nd	2,537,645
1947	nd	9,607	190,817	nd	nd	nd	nd	nd	953,517	nd	151,490	nd	2,389,144
1948	nd	896,922	768,164	10,930	nd	nd	nd	nd	2,516,438	6,231	4,000	16,441	5,346,376
1949	10,074	2,104,400	713,965	nd	nd	nd	nd	nd	959,216	nd	9,805	15,530	4,745,794
1950	nd	2,535,281	1,000,313	73,565	nd	nd	156,599	nd	2,383,644	nd	1,380	345,710	8,083,475
1951	82,250	2,399,632	456,067	nd	nd	nd	nd	2,160	886,380	nd	nd	34,164	4,793,046
1952	100,154	2,129,835	251,233	6,210	nd	nd	nd	135	1,299,368	nd	nd	7,725	4,260,717
1953	83,325	2,407,848	315,060	1,200	nd	nd	nd	1,700	582,783	nd	nd	8,220	4,093,680
1954	nd	2,146,402	280,554	nd	nd	nd	nd	nd	345,444	nd	nd	485	3,551,788
1955	92,000	2,341,164	392,415	321	nd	nd	nd	3,450	473,375	nd	4,000	3,000	4,218,520
1956	71,600	2,559,557	622,458	nd	nd	nd	nd	50	349,616	3,272	nd	7,410	4,830,958
1957	75,000	2,588,330	419,224	1,040	nd	nd	nd	nd	386,772	nd	13,988	10,394	5,088,441
1958	58,175	2,444,530	629,961	1,405	nd	nd	nd	nd	358,023	nd	3,769	9,091	4,851,704
1959	64,700	2,725,358	618,380	840	nd	nd	nd	41,823	172,025	nd	450	11,792	4,518,358
1960	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	33,649
1961	41,585	1,609,954	1,052,301	796	nd	nd	nd	nd	354,636	nd	302,673	2,560	5,270,830
1962	nd	1,658,866	1,187,215	361	nd	75,000	nd	nd	322,286	3,200	500,823	3,423	5,335,369
1963	nd	1,720,688	1,524,416	nd	nd	nd	nd	nd	260,300	16,130	410,194	2,116	5,381,486
1964	nd	1,141,347	1,783,525	nd	nd	nd	4,000	nd	633,422	925	213,782	5,302	4,896,630

APPENDIX 3—CONTINUED

Year	Lee	Leslie	Letcher	Magoffin	Martin	McCreary	Morgan	Owsley	Perry	Pike	Whitley	Wolfe	Total annual production
1965	nd	1,255,367	1,582,700	nd	275	nd	nd	nd	519,274	256,045	144,396	500	4,811,801
1966	nd	1,376,573	1,661,654	nd	nd	nd	nd	nd	438,738	61,053	60,000	nd	4,802,722
1967	20	1,424,997	1,789,031	nd	nd	nd	nd	75	101,082	177,781	10,150	700	4,489,666
1968	nd	1,687,062	1,726,083	nd	nd	nd	nd	100	381,200	213,226	18,735	100	5,637,024
1969	nd	1,504,048	1,391,569	nd	nd	nd	nd	nd	725,081	124,046	3,128	nd	5,396,736
1970	nd	742,916	2,224,381	nd	nd	nd	2,800	nd	109,401	506,377	12,565	nd	5,445,218
1971	nd	255,680	1,217,537	535	35,600	nd	466	nd	531,054	605,441	69,195	6,114	4,977,350
1972	nd	290,767	1,542,772	nd	nd	nd	233	13,170	234,544	414,828	13,887	nd	4,437,979
1973	nd	146,843	1,285,162	nd	nd	nd	111,130	83,204	404,000	709,273	5,565	nd	4,905,105
1974	nd	1,583,879	1,292,232	31,919	nd	nd	87,134	nd	278,081	980,846	55,238	nd	7,420,182
1975	nd	304,970	1,059,192	nd	nd	nd	338,117	nd	252,165	529,200	109,648	nd	5,456,058
1976	6,200	429,154	1,209,200	nd	nd	nd	306,557	35,812	432,611	686,819	52,722	nd	6,373,225
1977	30,000	762,387	1,317,630	33,764	nd	nd	323,050	133,455	330,443	754,004	45,875	nd	7,829,684
1978	nd	1,175,926	1,298,846	71,140	nd	nd	206,012	179,684	472,679	732,234	nd	nd	8,628,566
1979	nd	783,881	2,526,145	nd	nd	nd	57,997	64,000	498,328	806,061	nd	nd	8,807,448
1980	nd	496,864	1,714,692	nd	nd	nd	63,519	7,989	418,100	808,889	nd	nd	8,149,805
1981	nd	1,251,424	1,980,954	3,500	nd	nd	21,212	74,548	513,940	1,083,828	167,185	nd	10,608,801
1982	nd	1,525,725	1,789,361	8,000	nd	nd	nd	70,000	924,884	1,216,493	638,521	nd	10,707,251
1983	nd	1,354,496	1,508,242	61,239	nd	nd	67,920	nd	540,317	1,006,066	400,070	nd	8,620,205
1984	nd	1,838,630	2,723,611	18,493	nd	nd	4,531	30,600	726,995	1,288,927	454,740	nd	11,371,364
1985	nd	2,656,471	3,221,637	14,520	nd	nd	nd	nd	473,345	1,097,960	238,797	nd	12,679,375
1986	nd	3,814,620	3,048,342	nd	nd	nd	nd	15,000	649,081	880,380	53,735	nd	13,863,711
1987	nd	3,966,162	2,904,386	10,417	nd	nd	nd	15,000	882,259	843,140	68,702	nd	13,442,005
1988	nd	4,429,983	3,657,922	nd	nd	nd	nd	nd	696,763	819,172	nd	nd	14,455,673
1989	nd	4,613,205	4,984,081	nd	930	nd	nd	20,626	1,405,773	551,548	nd	20,412	18,314,663
1990	nd	4,412,198	5,018,562	nd	nd	nd	nd	29,657	3,092,841	650,553	5,485	nd	19,844,469
1991	nd	4,467,237	4,387,405	nd	nd	nd	nd	nd	3,662,562	856,102	52,004	29,766	20,515,380
1992	nd	5,729,034	4,076,682	nd	nd	nd	nd	nd	4,508,386	666,760	62,292	206,910	22,560,904
1993	nd	5,931,535	3,137,552	nd	nd	nd	nd	nd	4,147,788	813,536	109,202	135,378	22,921,053
1994	nd	5,727,987	2,832,267	nd	nd	nd	nd	nd	4,332,566	719,671	109,600	49,169	20,926,252
1995	nd	5,878,628	4,128,148	nd	nd	nd	nd	nd	2,931,966	1,015,518	105,104	nd	20,541,376
1996	nd	6,438,076	2,878,915	nd	nd	nd	nd	nd	2,159,263	1,434,376	10,989	nd	18,209,690
1997	nd	5,533,845	1,988,561	nd	nd	nd	nd	nd	2,142,140	466,515	nd	nd	12,489,949
1998	nd	6,864,138	2,533,025	nd	nd	nd	nd	nd	3,412,150	906,676	nd	nd	18,137,953
Total	723,723	124,260,093	97,355,548	350,195	36,805	75,000	1,751,277	822,238	68,202,287	24,714,002	4,714,791	932,412	510,597,021

APPENDIX 4

RECENT REPORTED ANNUAL PRODUCTION (IN SHORT TONS) OF THE FIRE CLAY COAL ZONE IN VIRGINIA, BY COUNTY

[Sources: Sweet (1988, 1989, 1991); Sweet and Nolde (1992, 1993, 1994, 1995, 1996, 1997a,b, 1998, 1999). Abbreviations are as follows: nd, no data or the absence of production.]

Year	Dickenson	Lee	Wise	Total annual production
1985	nd	nd	420	420
1986	nd	nd	nd	nd
1987	nd	2,000	196,783	198,783
1988	nd	235,487	222,185	457,672
1989	nd	260,401	167,516	427,917
1990	nd	261,839	120,626	382,465
1991	nd	428,214	112,527	540,741
1992	7,292	547,758	120,936	675,986
1993	nd	438,538	118,491	557,029
1994	nd	296,582	214,526	511,108
1995	nd	448,933	502,254	951,187
1996	nd	745,775	537,210	1,282,985
1997	nd	680,237	419,882	1,100,119
1998	nd	707,727	331,125	1,038,852
Total	7,292	5,053,491	3,064,481	8,125,264

APPENDIX 5

RECENT REPORTED ANNUAL PRODUCTION (IN SHORT TONS) OF THE FIRE CLAY COAL ZONE IN WEST VIRGINIA, BY COUNTY

[Source: Gayle H. McColloch (West Virginia Geological and Economic Survey, unpublished search of West Virginia Office of Miner's Health, Safety, and Training—Safety Information System (MHST-SIS) database, 1997). Abbreviations are as follows: nd, no data or the absence of production.]

Year	Fayette	Logan	Mingo	Nicholas	Wyoming	Total annual production
1982	nd	1,053,025	nd	nd	nd	1,053,025
1983	nd	1,197,360	nd	nd	nd	1,197,360
1984	nd	1,524,081	nd	nd	nd	1,524,081
1985	nd	1,258,826	nd	nd	nd	1,258,826
1986	nd	1,111,396	nd	nd	nd	1,111,396
1987	nd	1,153,110	nd	39,806	51,627	1,244,543
1988	nd	1,022,925	nd	105,232	37,903	1,166,060
1989	nd	856,809	nd	nd	nd	856,809
1990	nd	798,818	34,503	nd	nd	833,321
1991	167,834	608,745	115,942	nd	nd	892,521
1992	283,540	226,566	271,328	nd	nd	781,434
1993	288,210	93,007	538,422	nd	nd	919,639
1994	302,046	nd	390,510	nd	nd	692,556
1995	263,715	nd	406,029	nd	nd	669,744
1996	87,384	nd	277,733	nd	nd	365,117
Total	1,392,729	10,904,668	2,034,467	145,038	89,530	14,566,432

APPENDIX 6

FIRE CLAY COAL ZONE STRATIGRAPHIC DATABASE

[This ASCII file contains all of the public records used to model the Fire Clay coal zone and includes (1) record identifier, (2) longitude (decimal degrees), (3) latitude (decimal degrees), (4) Fire Clay coal zone potentially minable thickness (ft), excluding partings thicker than 0.38 inch, and (5) elevation of the Fire Clay coal zone (ft above mean sea level). Records that contain a -999 in the elevation or thickness field represent unavailable data or data that were provided in digital vector format.].

CLICK HERE TO GO TO APPENDIX 6

APPENDIX 7

FIRE CLAY COAL ZONE GEOCHEMICAL DATABASE

[This ASCII file contains all of the public records used to model the coal quality for the Fire Clay coal zone and includes NCAID (record identifier), source, State, county, longitude (decimal degrees), latitude (decimal degrees), coal province, coal region, coal field, district, coal formation, coal group, coal bed, sample thickness (ft), system, series/epoch, comments, map, collector, pointid (field identification number), estimated rank, lab code, sample type, analytical type, value represented, total moisture (percent), volatile matter (percent), fixed carbon (percent), ASTM ash (American Society for Testing and Materials; percent), hydrogen (percent), carbon (percent), nitrogen (percent), oxygen (percent), sulfur (percent), SO_2 (lb/million Btu), gross calorific value (Btu/lb), air dried loss (percent), sulfate sulfur (percent), pyritic sulfur (percent), organic sulfur (percent), free swelling index, ash deformation temperature (degrees Fahrenheit), ash softening temperature (degrees Fahrenheit), ash fluid temperature (degrees Fahrenheit), Hardgrove grindability index, USGS ash (U.S. Geological Survey; percent), Si (percent), Al (percent), Ca (percent), Mg (percent), Na (percent), K (percent), Fe (percent), Ti (percent), S (percent), Ag (ppm), As (ppm), B (ppm), Ba (ppm), Be (ppm), Bi (ppm), Br (ppm), Cd (ppm), Ce (ppm), Cl (ppm), Co (ppm), Cr (ppm), Cs (ppm), Cu (ppm), Dy (ppm), Er (ppm), Eu (ppm), F (ppm), Ga (ppm), Gd (ppm), Ge (ppm), Hf (ppm), Hg (ppm), Ho (ppm), La (ppm), Li (ppm), Lu (ppm), Mn (ppm), Mo (ppm), Nb (ppm), Nd, (ppm), Ni (ppm), P (ppm), Pb (ppm), Pr (ppm), Rb (ppm), Sb (ppm), Sc (ppm), Se (ppm), Sm (ppm), Sn (ppm), Sr (ppm), Ta (ppm), Tb (ppm), Th (ppm), Tl (ppm), U (ppm), V (ppm), W (ppm), Y (ppm), Yb (ppm), Zn (ppm), Zr (ppm)].

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APPENDIX 8

METADATA FOR THE FIRE CLAY COAL ZONE GEOCHEMICAL DATABASE

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APPENDIX 9

REFERENCES FOR THE FIRE CLAY COAL ZONE GEOCHEMICAL DATABASE

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APPENDIX 10

ORIGINAL COAL RESOURCES BY OVERBURDEN, RELIABILITY, AND COAL-BED-THICKNESS CATEGORIES, AND BY STATE AND COUNTY, FOR THE FIRE CLAY COAL ZONE

[Resources are rounded to millions of short tons and two significant figures. Reliability categories are as follows: identified, resources calculated for area within 3 mi of a coal-thickness measurement; hypothetical, resources calculated for area farther than 3 mi from a coal-thickness measurement. Asterisk indicates less than 10,000 short tons; St., State.]

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APPENDIX 11

REMAINING COAL RESOURCES BY OVERBURDEN, RELIABILITY, AND COAL-BED-THICKNESS CATEGORIES, AND BY STATE AND COUNTY, FOR THE FIRE CLAY COAL ZONE

[Resources are rounded to millions of short tons and two significant figures. Reliability categories are as follows: identified, resources calculated for area within 3 mi of a coal-thickness measurement; hypothetical, resources calculated for area farther than 3 mi from a coal-thickness measurement. Asterisk indicates less than 10,000 short tons; St., State.]

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