U.S. Department of the Interior
U.S. Geological Survey

Chapter E

Geology and Geochemistry of the Middle Pennsylvanian Lower Kittanning Coal Bed, Allegheny Group, Northern Appalachian Basin Coal Region

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U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1625–C

Prepared in cooperation with the
Maryland Geological Survey
Ohio Division of Geological Survey
Pennsylvania Bureau of Topographic and Geological Survey
West Virginia Geological and Economic Survey

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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ABSTRACT

This report on the Lower Kittanning coal bed is part of the U.S. Geological Survey's (USGS's) National Coal Resource Assessment project (NCRA). The Lower Kittanning coal bed underlies much of the Appalachian Basin coal region in western Pennsylvania and adjacent parts of West Virginia, Ohio, and Maryland. Correlation of the Lower Kittanning with coal beds to the south in southern West Virginia and eastern Kentucky is poorly understood; therefore, southern West Virginia and eastern Kentucky are not included in the assessment.

The Lower Kittanning coal bed is one of the most productive coal beds in the Appalachian Basin. The apparent rank of the coal bed ranges from low-volatile bituminous in the eastern side of the Appalachian Basin to high-volatile C bituminous in the bed's southwestern extent. In general, the Lower Kittanning coal bed is a medium-ash, medium- to high-sulfur coal that can be used for coking purposes as well as for electric power generation. The evolution of the stratigraphic nomenclature of the Allegheny Group and its contained coal beds, as well as the overlying and underlying Pennsylvanian strata in this region, is described in this report. Previous resource studies of the Lower Kittanning coal bed estimate that the original resource was approximately 12.2 billion short tons in Pennsylvania, 4.5 billion short tons in West Virginia (excluding the possibly correlative coal bed in southern West Virginia), and 9.9 billion short tons in Ohio, for a total of about 26.6 billion short tons in the northern Appalachian Basin coal region.

INTRODUCTION

The name "Allegheny" was first used by Rogers (1840) for rocks exposed along the Allegheny River near Pittsburgh, Pa. The coal bed name, "Kittanning," was first used by Rogers (1858) for a coal bed that cropped out along the Allegheny River near the town of Kittanning in Armstrong County, Pa. Work by White (1879) and Chance and Peter (1879) showed that there were three coal beds within the lower to middle part of the Allegheny in western Pennsylvania, which they called the Upper, Middle, and Lower Kittanning coal beds. Correlation of the Lower Kittanning coal bed on a regional basis with coal beds in eastern Kentucky and southern West Virginia, such as the No. 5 Block coal, is uncertain; therefore, those areas are not included in this assessment.

In general, on the eastern side of the Appalachian Basin, the crop line of the coal bed follows the eastern edge of the Dunkard Basin, then encompasses the northern part of the Dunkard Basin across western Pennsylvania into Ohio, and extends from northeastern Ohio southward to eastern Kentucky (figs. 1, 2). In Pennsylvania, the Lower Kittanning underlies almost all of the Main Bituminous, Georges Creek, Castleman, and Lower Youghiogheny coal fields. In

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This chapter, although in a U.S. Geological Survey Professional Paper, is available only on CD-ROM and is not available separately.

This chapter should be cited as:

Milici, R.C., Freeman, P.A., Carlton, R.W., Bragg, L.J., Butler, D.T., and Tewalt, S.J., 2001, Chapter E—Geology and geochemistry of the Middle Pennsylvanian Lower Kittanning coal bed, Allegheny Group, northern Appalachian Basin coal region, *in* Northern and Central Appalachian Basin Coal Regions Assessment Team, 2000 resource assessment of selected coal beds and zones in the northern and central Appalachian Basin coal regions: U.S. Geological Survey Professional Paper 1625–C, CD-ROM, version 1.0

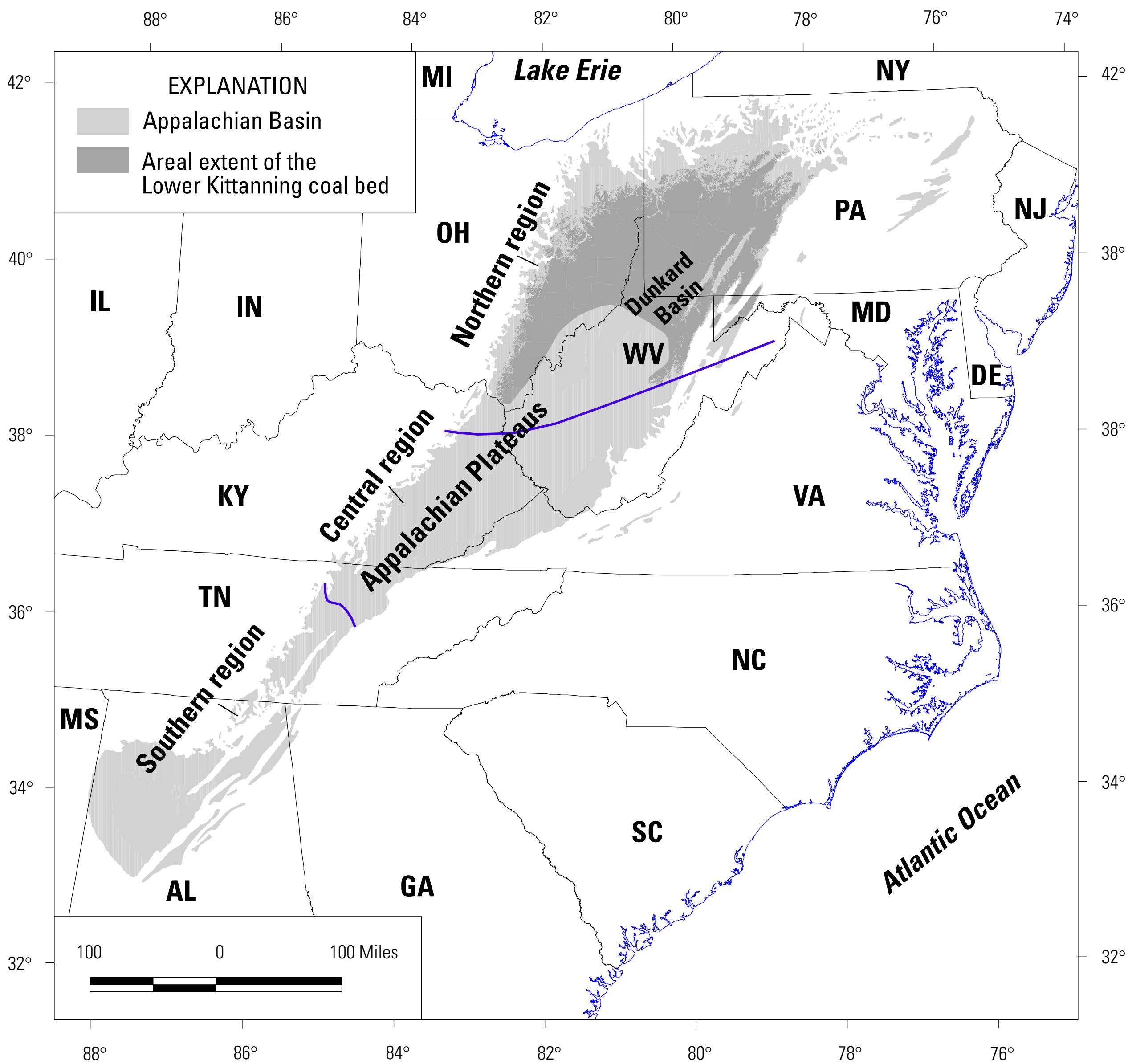

Figure 1. Map showing the location of the northern, central, and southern coal regions of the Appalachian Basin. The Lower Kittanning coal bed is in the northern coal region.

West Virginia, the Lower Kittanning is almost entirely in the northern part of the State. To the south, the coal bed was mapped in the subsurface beneath the Appalachian Basin in Ohio and central West Virginia to where there are little or no data on the stratigraphy and geologic structure of the Allegheny Group (or Formation) and its coal beds. Cross sections *A-A′* and *B-B′*, adapted from columnar sections published by Swartz and others (1922), are shown in figures 3 and 4.

Overall, the data that are available on the location and extent of surface and underground mines are not sufficient to permit a calculation of the coal resources currently remaining in the ground. The U.S. Geological Survey (USGS) in partnership with the State geological surveys of Pennsylvania, West Virginia, Ohio, and Maryland may release these data in the future. The available data on mining are shown in red in figure 5.

This report is a cooperative effort among the Pennsylvania Bureau of Topographic and Geologic Survey (PAGS), the West Virginia Geological and Economic Survey (WVGES), the Ohio Division of Geological Survey (OGS), the Maryland Geological Survey (MGS), and the USGS. In general, the coal crop line was obtained from unpublished manuscripts and published geologic maps. For Ohio, however, OGS prepared the outcrop and mined areas for this project. Stratigraphic and structural data, as well as

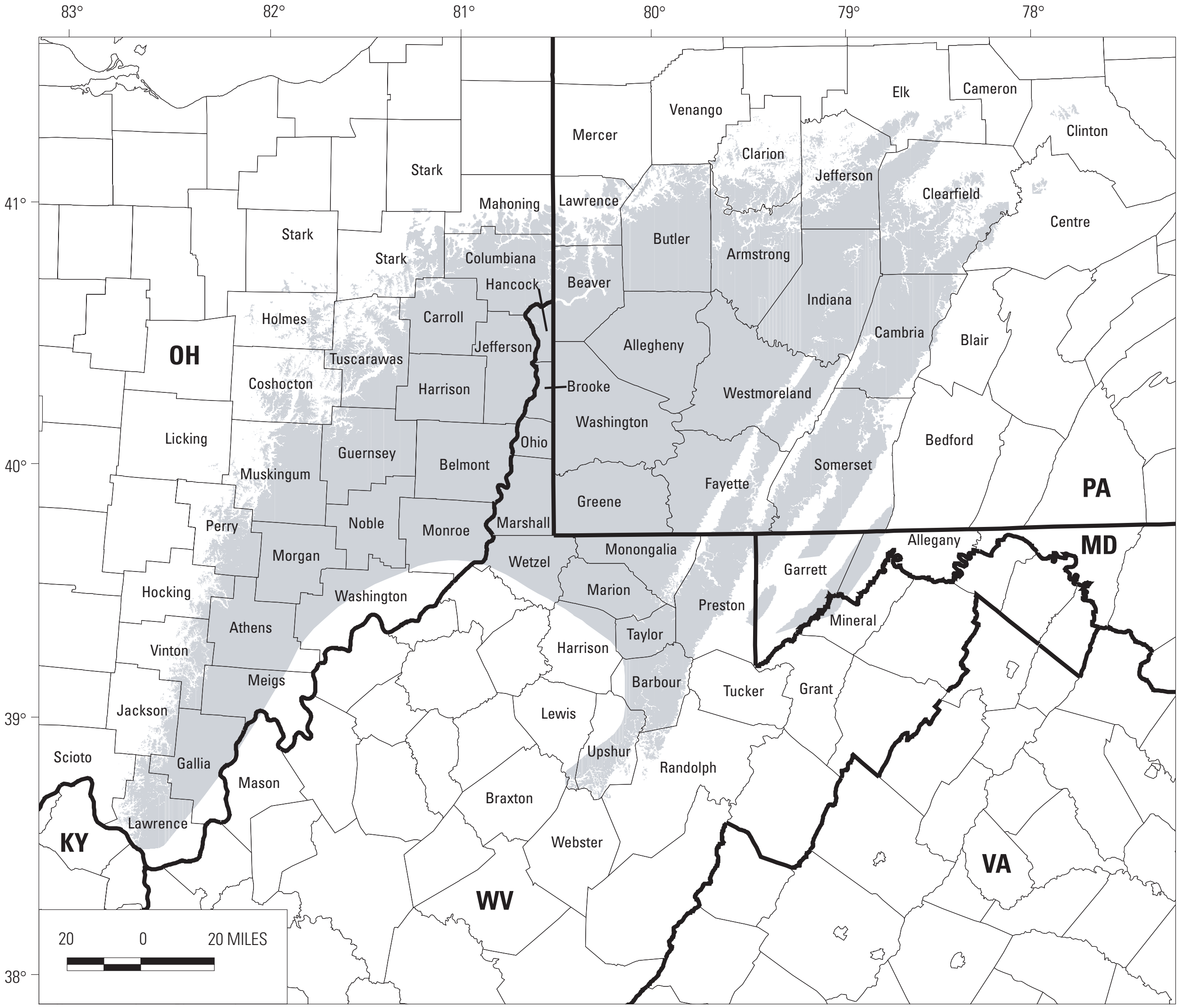

Figure 2. Map showing counties in each State in which the Lower Kittanning coal bed is present. The present assessment of the Lower Kittanning coal bed in West Virginia was not carried to the south and west of its exposures in Lewis, Upshur, and Randolph Counties because correlations with some coal beds (such as the No. 5 Block and No. 6 Block) in Braxton and Webster Counties, as well as other nearby counties, are uncertain.

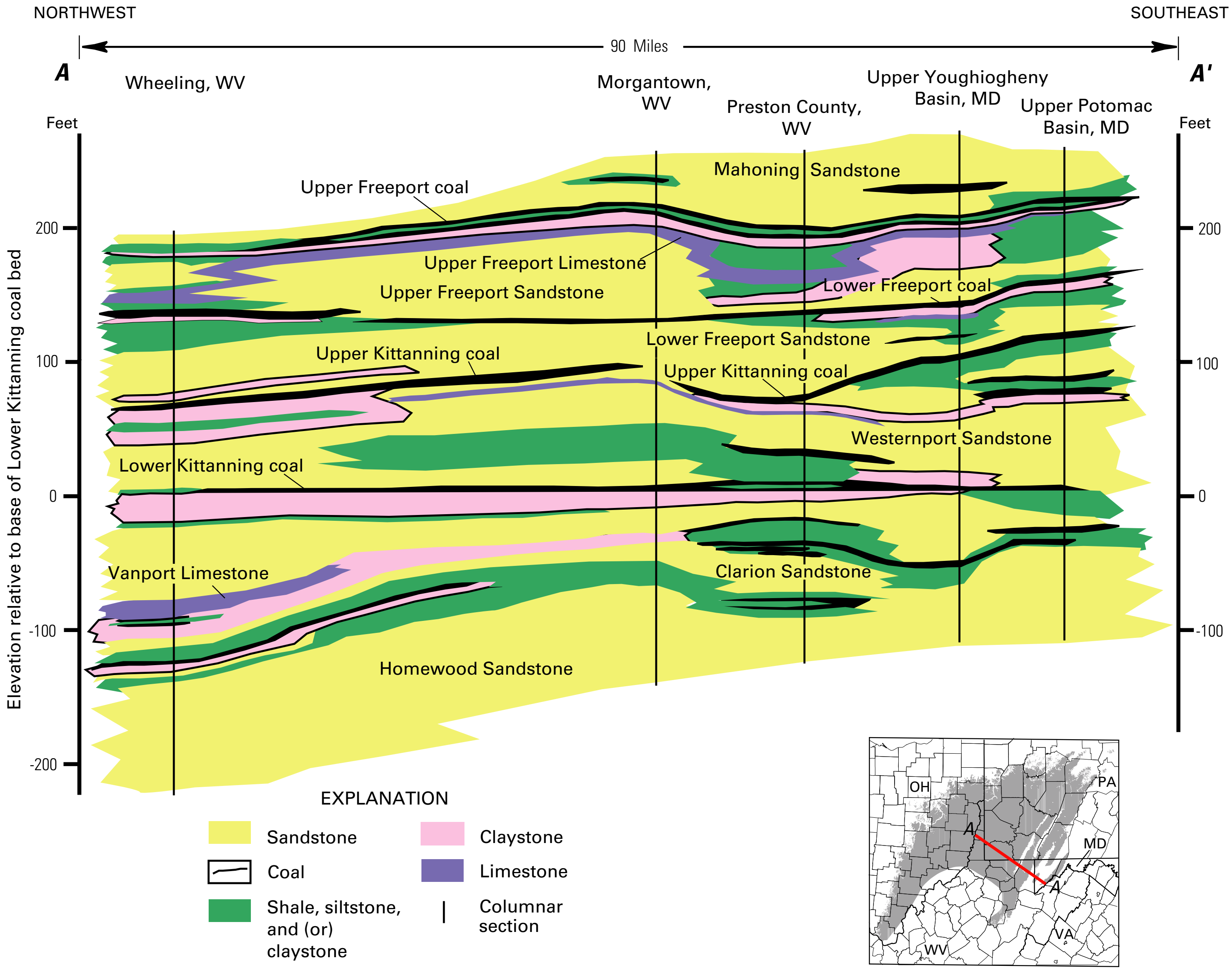

Figure 3. Cross section *A-A′* from Ohio County, W. Va., southeast to Garrett County, Md. (adapted from Swartz and others, 1922). Vertical exaggeration X594.

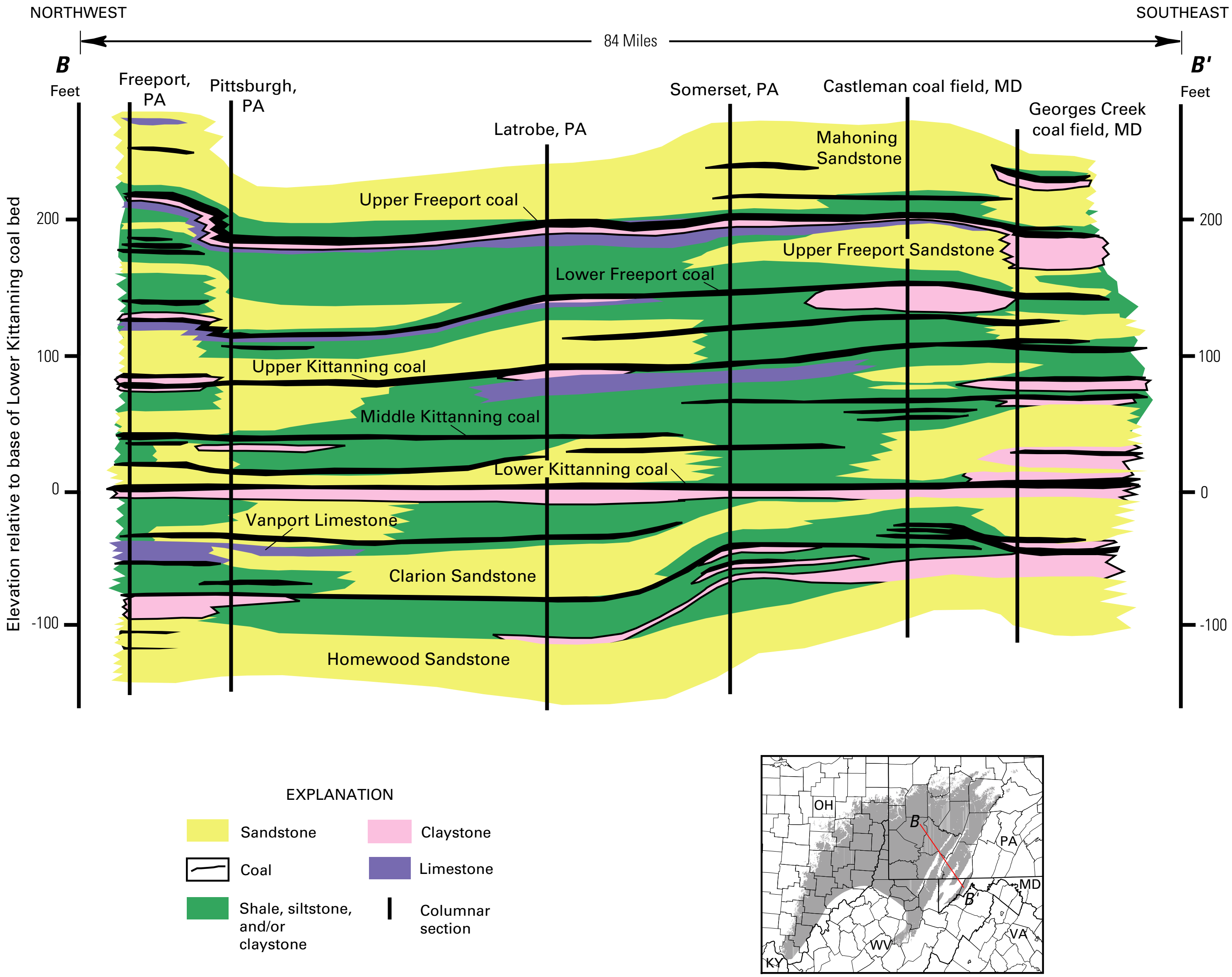

Figure 4. Cross section *B-B′* from Allegheny County, Pa., southeast to Allegany County, Md. (adapted from Swartz and others, 1922). Vertical exaggeration X652.

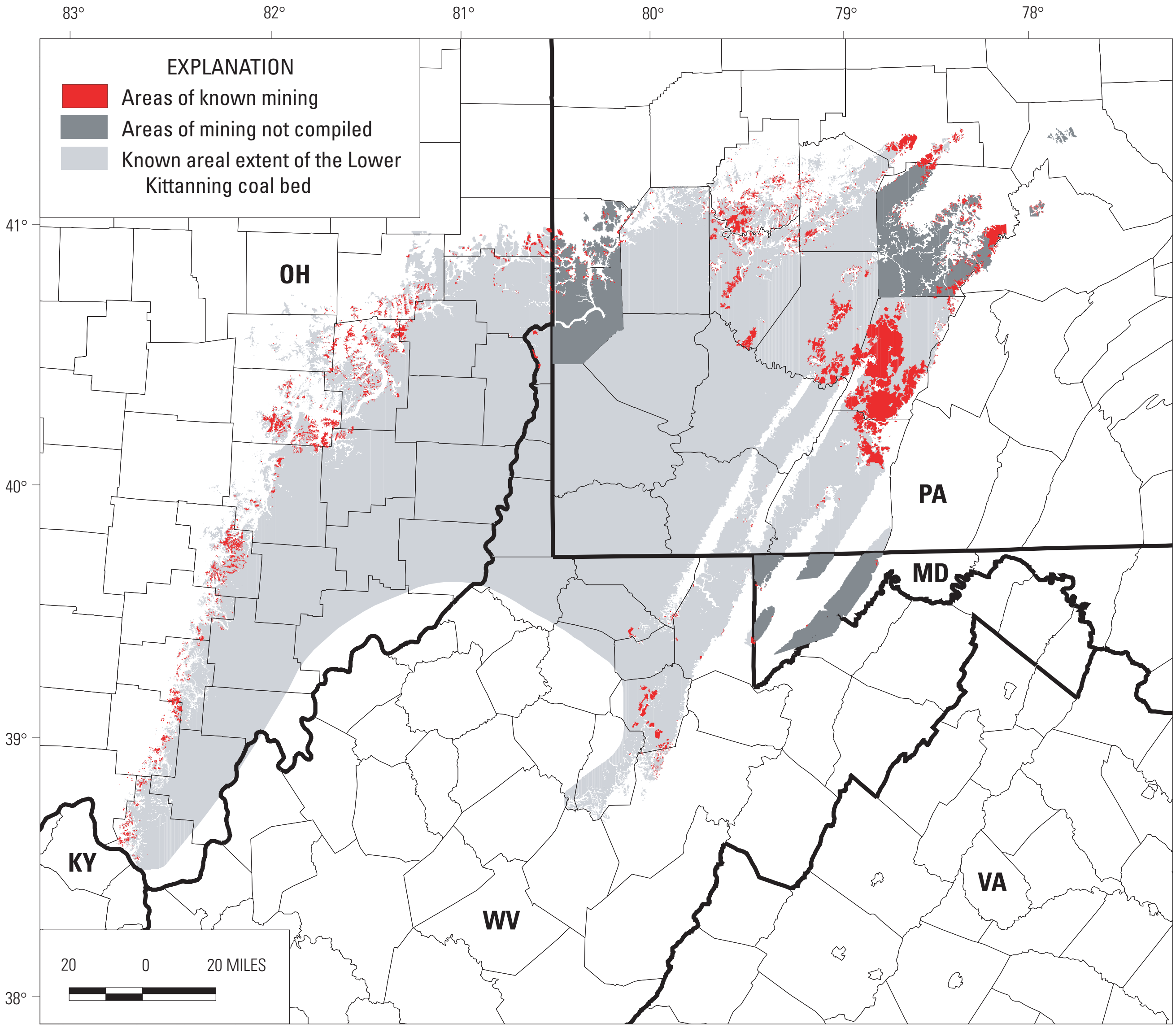

Figure 5. Map showing known areal extent of the Lower Kittanning coal bed (gray), mined areas (red), and areas where compilation of mined areas is incomplete (dark gray). The Lower Kittanning coal bed extends over 18,800 mi^2 throughout western Maryland and Pennsylvania, northern West Virginia, and eastern Ohio. See figure 2 for county names.

coal-bed thickness data, were obtained from the State geological surveys and from the USGS's National Coal Resources Data System (NCRDS).

ACKNOWLEDGMENTS

The authors are indebted to Peter D. Warwick for assistance with software; to Frank Dulong for helping with the stratigraphic databases; to Eric Morrissey for producing graphic files; to David Glick (The Pennsylvania State University) and William Grady (West Virginia Geological and Economic Survey) for supplemental geochemical data; and to Brenda S. Pierce and M. Devereux Carter for reviewing this manuscript and assessment maps during the course of this project.

GEOLOGY

INTRODUCTION

The Lower Kittanning coal bed is within the Middle Pennsylvanian Allegheny Group (as used in this report) (fig. 6) and underlies parts of central and western Pennsylvania, northern and central West Virginia, eastern Ohio, and western Maryland, an area within the northern part of the Appalachian Plateaus physiographic provice (fig. 1). County names in this area are shown in figure 2.

The Carboniferous (Mississippian and Pennsylvanian) deposits of the northern part of the Appalachian Basin accumulated in a northeastward-trending basin (present-day orientation) during the final stages of the Alleghanian orogeny, with the siliciclastic sediment fill derived from cratonic sources to the north, and from orogenic sources to the south and east (Edmunds and others, 1979; fig. 7). In general, Carboniferous sedimentation in the Appalachian Basin was controlled by a combination of tectonics, eustasy, and climate, with tectonics and eustasy providing accommodation space for the sedimentary deposits, and tectonics and climate controlling the amount and type of sediment. Generally, Lower Mississippian carbonate strata were covered by fine- to coarse-grained siliciclastic strata as the African and North American continents collided and produced tectonic uplands along the eastern margin of the North American continent. Where the Mississippian strata grade vertically into overlying Pennsylvanian strata along the eastern margin of the Appalachian Basin coal regions, the rock record contains evidence of a significant regional change in climate (Cecil and others, 1985). Red beds, dolomites, and evaporites that appear to have been deposited in relatively dry climates during the Late Mississippian are overlain by Early Pennsylvanian coal-bearing siliciclastic formations that are indicative of dry-seasonal tropical to everwet tropical climates (Cecil and others, 1985). Edmunds and others (1979, p. B4) described Carboniferous paleoclimates of the Appalachians as follows:

> "Paleomagnetic studies of rocks of Mississippian and Pennsylvanian age (Turner and Tarling, 1975), suggest that Pennsylvania and New York lay slightly south of the equator at that time …. Examination of the Mississippian-Pennsylvanian flora by White (1913) and by Koppen and Wegener (1925) indicated a subtropical setting, although probably not as intensely hot as a low-elevation equatorial setting today would imply. Camp (1956) concluded that Pennsylvania and New York lay near the equator in an area that generally received abundant year-round rainfall."

White (1913, p. 74) considered the Mississippian flora to be rather impoverished and stunted, a fact suggesting that climatic conditions were less than ideal. He further noted that the striking evolution of new plant forms in the Early Pennsylvanian suggests optimum temperature and rainfall conditions. White believed that Middle Pennsylvanian vegetation was somewhat less lush and that a drier period prevailed during late Middle and early Late Pennsylvanian. Latest Pennsylvanian floras reflect a return to a substantially better climate.

In contrast with the cyclical deposition that appears to be dominant in the continental interior, Edmunds and others (1979) emphasized the local control of Pennsylvanian sedimentation. They ascribed the sedimentation of local lithologic units and the vertical and horizontal arrangement of lithosomes to autogenic processes, such as local tectonic subsidence and delta switching. However, they attributed the presence or absence of red beds, marine units, freshwater limestones, average thickness of coal beds, and overall coarseness of the siliciclastic rocks to allogenic processes, such as changes in tectonic subsidence rates, eustatic sea-level changes, and climate. They interpreted the sedimentation of the upper Pottsville and lower Allegheny Groups to have occurred on the lower part of a delta plain in an area in west-central Pennsylvania that was bordered on the north, east, and south by upper-delta-plain depositional environments. Nonmarine lower Allegheny Group strata are interbedded with fossiliferous strata and the marine incursions were controlled either by relatively high tectonic subsidence rates or by eustatic sea-level rise.

In the following sections, which summarize the previous uses of the name "Allegheny," the Allegheny is described as a series (an antiquated term no longer used for lithostratigraphic units), a formation, or a group, depending on the State and decisions made by the authors of each cited report. For the purposes of simplicity in this report, and because of data-entry requirements for the stratigraphic

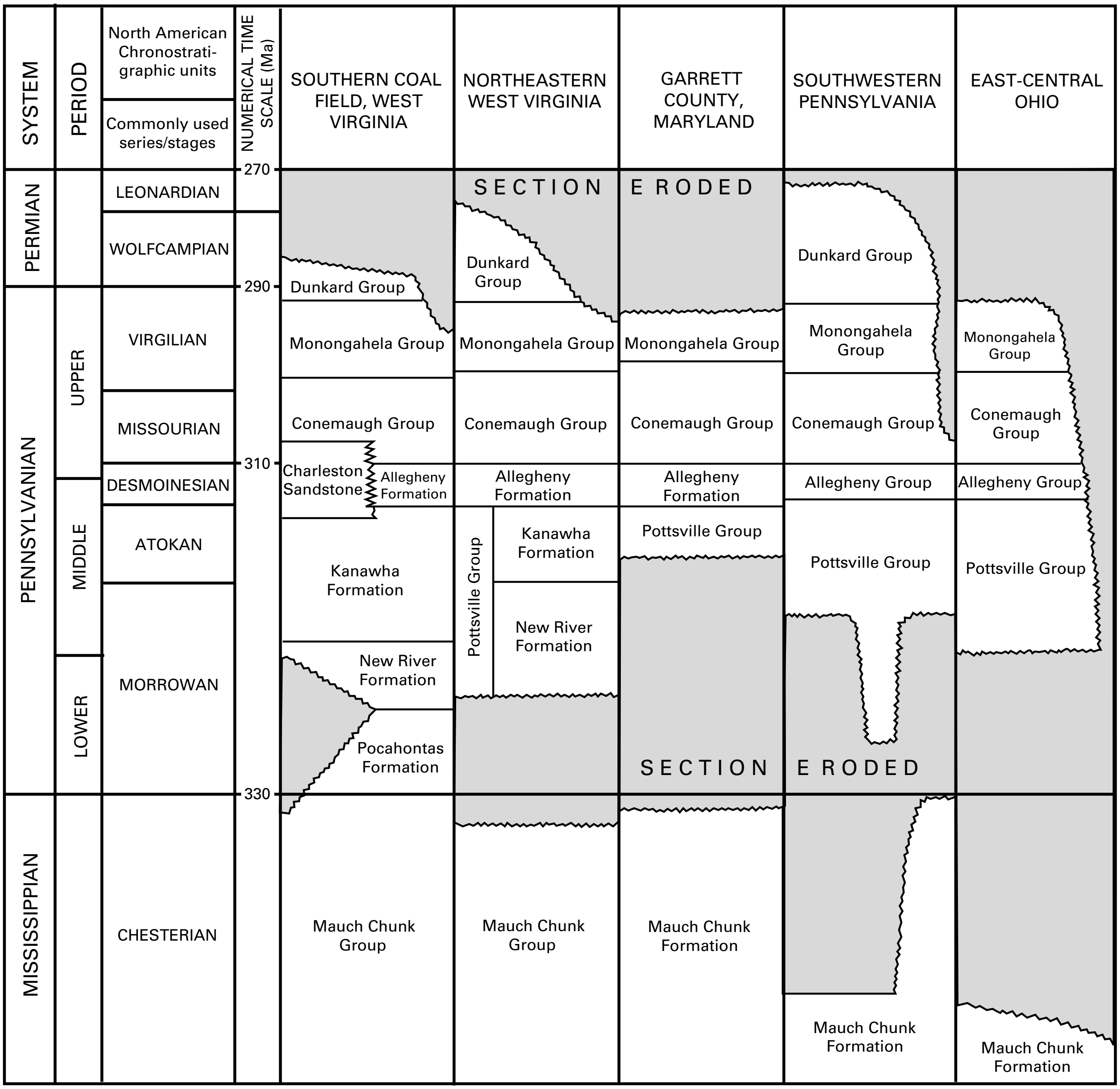

Figure 6. Chart showing historical uses of stratigraphic nomenclature for Pennsylvanian units in Pennsylvania, West Virginia, Ohio, and Maryland (adapted from Patchen and others, 1984).

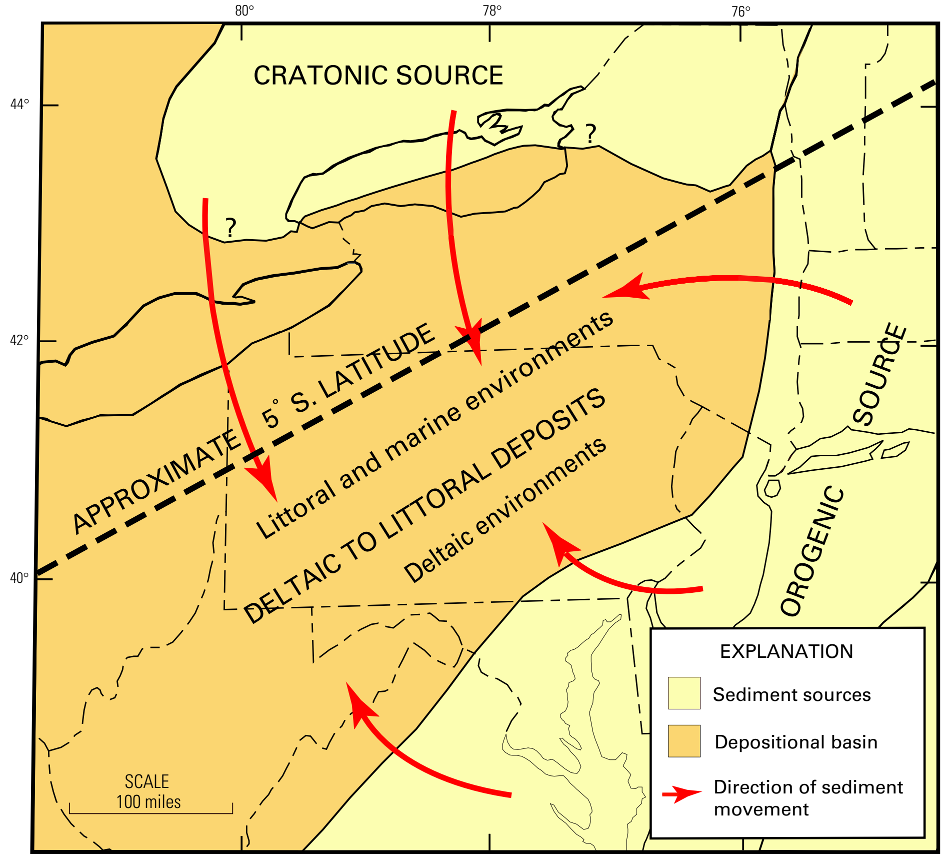

Figure 7. Map showing the generalized paleogeography of the northern Appalachian Basin during the Pennsylvanian (adapted from Edmunds and others, 1979).

database, the term, "Allegheny Group," is used in the discussions of resource assessments for all States. This usage does not constitute a permanent or formal change to the status of the Allegheny or its subunits (fig. 8).

PENNSYLVANIA

The Lower Kittanning coal bed is widespread over much of the bituminous coal field of western Pennsylvania and commonly is surface mined over much of the area (Edmunds, 1995). The Pennsylvania Geological Survey (and its successor organizations) has described the geology of the bituminous coal fields of Pennsylvania in a series of classic publications. The descriptions of the Allegheny Group and Lower Kittanning coal bed in those publications are summarized in the following sections. The evolution of stratigraphic terminology for the principal named units of the Allegheny Formation in Pennsylvania is shown in figure 8 and the informally named beds within the Allegheny Group in the main part of the bituminous coal field of Pennsylvania are shown in figure 9.

ALLEGHENY GROUP (OR SERIES OR FORMATION)

In Pennsylvania, the Allegheny Group, as defined by its excellent exposures along the Allegheny River north of Pittsburgh, previously was called the "Lower Productive Measures" because of its abundant resources of coal. In general, the group consists of sandstone, siltstone, and shale, with relatively small amounts of limestone and coal in a complex arrangement of interbedded channel-fill deposits (fig. 10). The group ranges from about 240 to 320 ft thick. Some of the thickness variation of the Allegheny is the result of erosion at the top of the unit by post-Allegheny channels that subsequently were filled with Conemaugh Group sandstones (Edmunds and Berg, 1973). At present, there is no uniform basinwide stratigraphic terminology to describe the Allegheny rocks.

In general, the Allegheny contains several fossiliferous marine and brackish-water units in its lower half and freshwater limestone in its upper half (fig. 9). The fossiliferous marine Vanport Limestone (fig. 10), which in places is about 40 to 50 ft below the lowermost bed of the Lower Kittanning coal, ranges from about 7 to as much as 40 ft

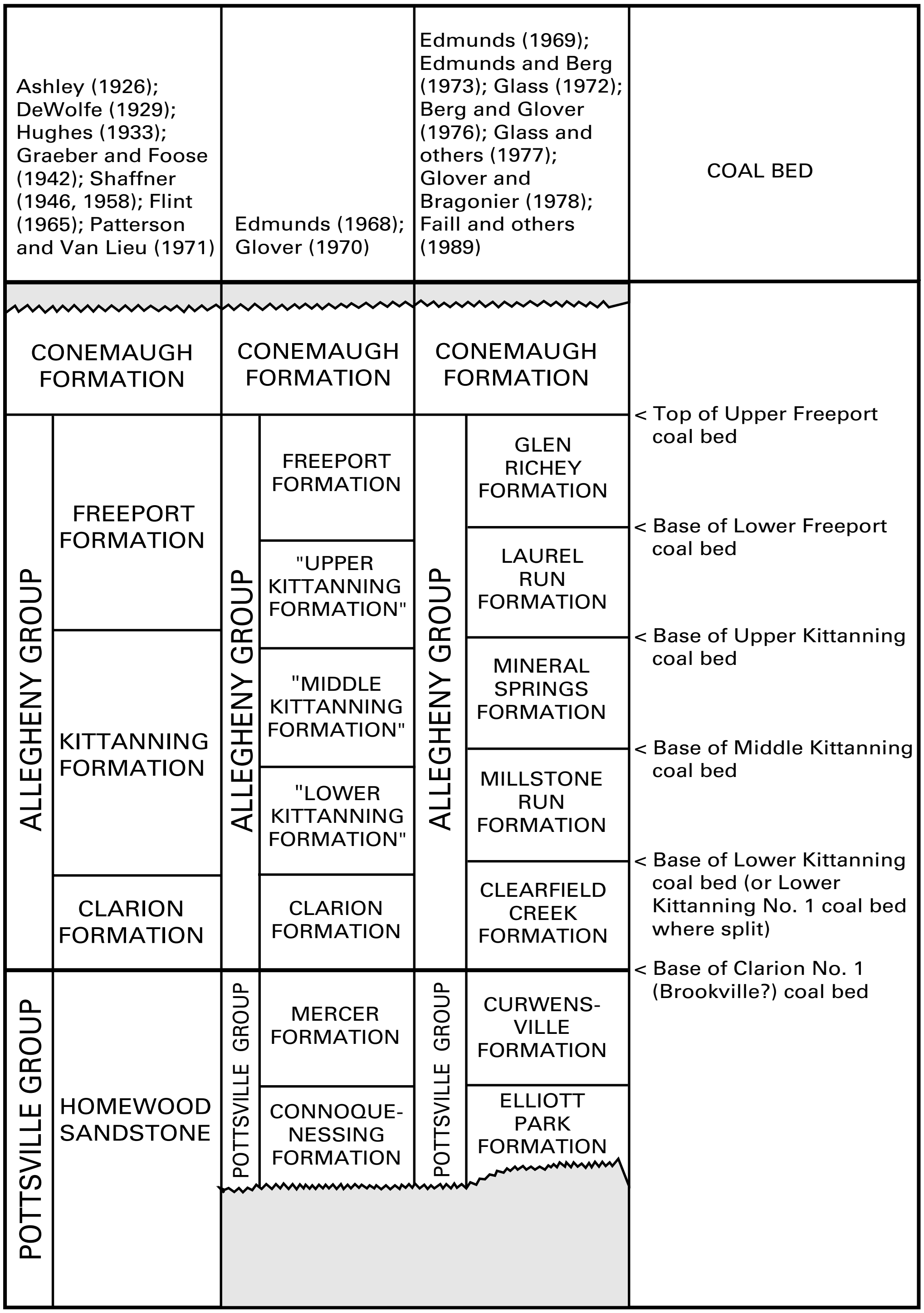

Figure 8. Chart showing generalized stratigraphic nomenclature of the Allegheny and Pottsville Groups in Pennsylvania (adapted from Edmunds, 1969).

Ashley (1926)	Glover and Bragonier (1978)
Freeport Formation	Glen Richey Formation Upper Freeport coal bed (E) Upper Freeport underclay and limestone Butler sandstone Lower Freeport coal bed
	Laurel Run Formation Lower Freeport underclay and limestone Freeport sandstone Upper Kittanning coal bed
Kittanning Formation	Mineral Springs Formation Johnstown limestone Luthersburg coal bed Upper Worthington sandstone Middle Kittanning rider coal bed Middle Kittanning coal bed
	Millstone Run Formation Lower Worthington sandstone Lower Kittanning No. 4 coal bed (B) Lower Kittanning No. 3 coal bed (B) Lower Kittanning No. 1 coal bed (B)
Clarion Formation	Clearfield Creek Formation Kittanning sandstone Vanport limestone Clarion No. 3 (Scrubgrass) coal bed Clarion No. 2 coal bed Clarion No. 1 (Brookville) coal bed (A)

Figure 9. Chart showing named beds within the Allegheny Group in Clearfield and Jefferson Counties, Pa. (Ashley, 1926; Glover and Bragonier, 1978). Subunits of the Clearfield Creek, Millstone Run, Mineral Springs, Laurel Run, and Glen Richey Formations are informal usages of Glover and Bragonier (1978).

thick (DeWolf, 1929; Hughes, 1933). In contrast, the upper part of the Allegheny Group, with its sparsely fossiliferous (gastropods), freshwater limestone deposits, appears to have accumulated generally in nonmarine environments in Pennsylvania as the more marine (littoral) strata (and higher sulfur coal) were displaced westward into Ohio (Edmunds and others, 1979; fig. 7). The Lower Kittanning coal consists of a single bed with multiple benches in much of western Pennsylvania, Ohio, and parts of West Virginia. however, in cnetral Pennsylvania, at the edge of the coal bed's extent, partings within the coal bed increase to where the bed splits into several Lower Kittanning coal beds numbered 1 to 5 from the base upward. In places, one or more of the numbered Lower Kittanning coal beds may be absent, and the stratigraphic section may contain beds numbered in a discontinuous sequence.

In the Punxsutawney 15-minute quadrangle in western Clearfield County and adjacent Jefferson and Indiana Counties (fig. 2), Ashley (1926; fig. 8) mapped the Allegheny Group as extending from the top of the Upper Freeport coal bed (coal bed E) to the base of the seat earth (clay, claystone, underclay) beneath the Brookville coal bed (coal bed A). He divided the group into three formations, the Clarion Formation at the base, the Kittanning Formation, and the Freeport Formation at the top. Ashley (1926) defined the Freeport Formation as those beds that extend from the top of the Upper Freeport coal bed down to the top of the Upper Kittanning coal bed, the Kittanning Formation from the base of the Freeport Formation to the base of the clay under the Lower Kittanning coal bed, and the Clarion Formation from the base of the Kittanning Formation to the base of the group. Ashley (1926) described the Lower Kittanning (or B coal bed) as relatively persistent (not split) and about 3 ft thick in the Punxsutawney 15-minute quadrangle.

DeWolfe (1929) mapped the Allegheny Group in the New Castle 15-minute quadrangle in Lawrence and Beaver Counties (fig. 2) as extending from the top of the Upper Freeport coal bed down to the top of the Pottsville Group (Homewood Sandstone), and thereby included some 25 or 30 ft of shale and claystone below the Brookville coal bed within the lower part of the Allegheny. To add to the confusion in nomenclature, however, DeWolfe (1929) drew the contact between the Pottsville and Allegheny at the base of the Brookville coal and clay interval within his general stratigraphic section, as had been done by earlier workers. In this area, the economic coal beds of the region are within the Allegheny, which ranges from 265 to 325 ft and averages about 290 ft thick. The Lower Kittanning coal bed is about 160 to 165 ft below the Upper Freeport coal bed in this area and averages about 2 ft thick.

In the Freeport 15-minute quadrangle, mostly in Armstrong and Westmoreland Counties (fig. 2), Hughes (1933) measured the Allegheny Group as ranging from about 285 to 320 ft in thickness. In general, the unit consists of shale, siltstone, and sandstone, with several coal and limestone beds. The Lower Kittanning coal bed is persistent in character and thickness (average of 2.75 ft) in the Freeport quadrangle and generally is from 185 to 225 ft below the Upper Freeport coal bed.

Ashley and Clapp (1940) mapped the Lower Kittanning coal bed in the Curwensville 15-minute quadrangle in Indiana, Jefferson, and westernmost Clearfield Counties (fig. 2), using the subdivisions for the Allegheny Group that Ashley had described in 1926, except that they reduced their rank and called them members of the Allegheny Formation, rather than assigning them formation status. In this area, the Lower Kittanning, or B coal bed, is about 2 to 2.5 ft thick, although in a few places its thickness may exceed 4 ft. Throughout this area, the Lower Kittanning coal bed almost everywhere overlies a claystone seat earth that is up to 20 ft thick.

Hickok and Moyer (1940) mapped the Allegheny Group in Fayette County (fig. 2) as consisting of 140 to 230 ft of shale and sandstone with some coal, fireclay, and limestone. They did not, however, subdivide the group into formations. In contrast with most other workers, they selected the base of the group as the top of the Homewood Sandstone (see figure 8), rather than at the base of the Brookville coal bed and underclay. In general, they found the Brookville coal about 20 ft above the top of the Homewood Sandstone. The Lower Kittanning coal bed ranges from about 2 to 5 ft thick

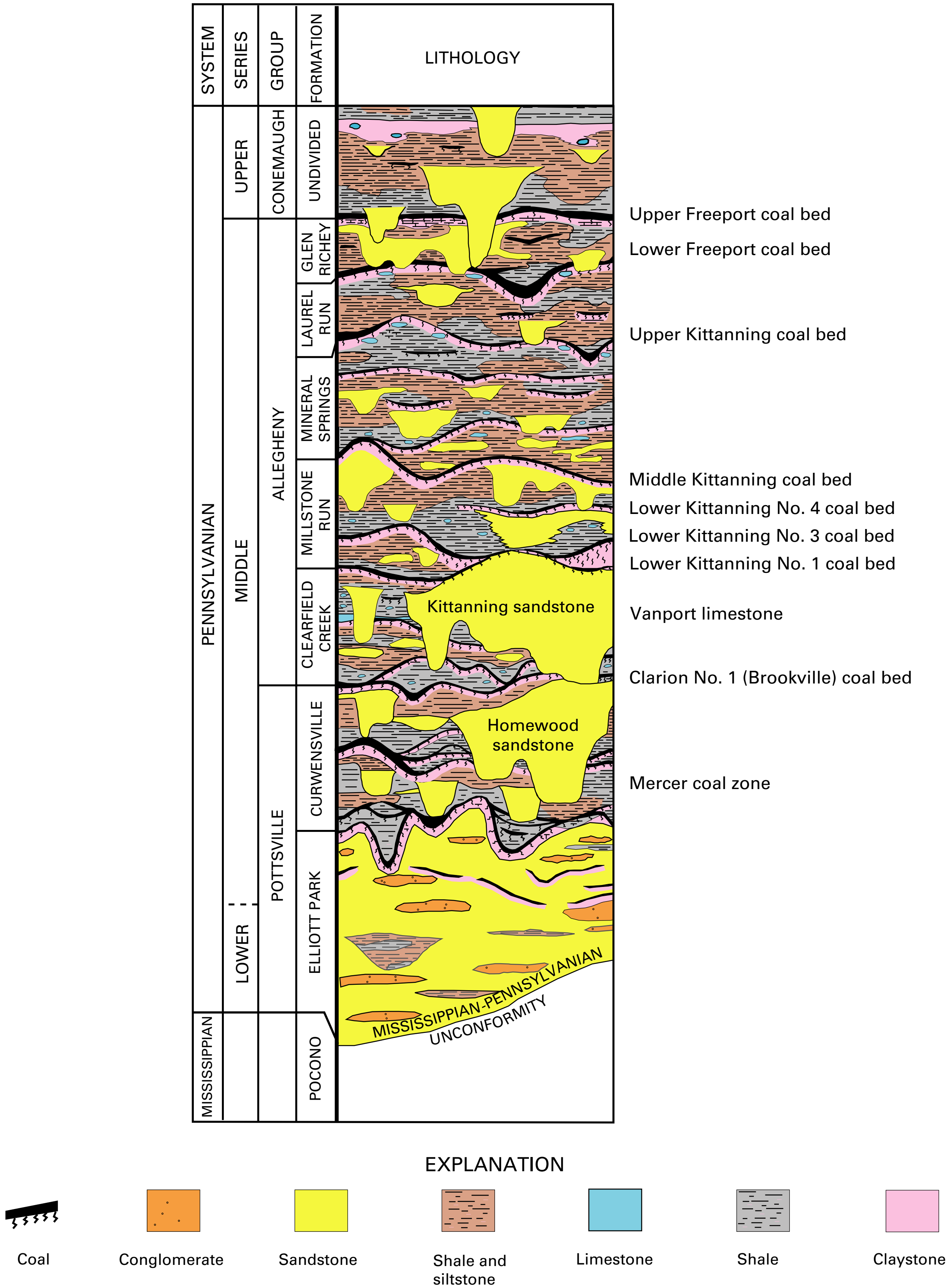

Figure 10. Generalized stratigraphic column of the Allegheny Group in Clearfield and adjacent counties, Pennsylvania (adapted from Glover and Bragonier, 1978).

in this area, with about 1 ft of bony coal at the top in places where the coal bed is thickest. The Lower Kittanning overlies several feet of clay over much of the county, except in a few places where the clay and coal are separated by 1 ft of shale.

Graeber and Foose (1942) mapped and described the geology of the Brookville 15-minute quadrangle in western Jefferson and eastern Clarion Counties (fig. 2). In that area, the Allegheny Group consists of about 325 ft of sandstone, shale, limestone, clay, and coal beds. Like Ashley (1926), they mapped three formations within the Allegheny Group: the Freeport, Kittanning, and Clarion Formations. The Kittanning Formation, in the middle of the group, includes the sandstone, siltstone, shale, claystone, and coal beds from the top of the Upper Kittanning coal bed to the base of the clay under the Lower Kittanning coal bed. Of all of the coal beds within the Kittanning Formation of Ashley (1926), the Lower Kittanning coal bed is the most consistent in thickness and persistent in distribution. In general, its thickness in the Brookville quadrangle ranges from about 2 to 3 ft.

Shaffner (1946) mapped the Smicksburg 15-minute quadrangle, which is mostly in western Jefferson and Indiana Counties (fig. 2), and described the Allegheny Group as consisting of 340 to 370 ft of shale, sandstone, and some limestone strata. He did, however, relate problems with identifying and correlating the Brookville coal bed at the base of the group in western Pennsylvania. He supported Ashley's unpublished suggestion that the base of the Allegheny might have been better placed at the base of the clay bed beneath the Lower Kittanning coal bed rather than at the base of the Brookville, a suggestion that was never adopted. In the Smicksburg quadrangle, the Kittanning Formation of Ashley (1926) extends from the top of the Upper Kittanning coal bed to the base of the clay bed beneath the Lower Kittanning coal bed. The formation consists of about 135 ft of siliciclastic strata that are, in places, interbedded with a few feet of limestone. As in other areas in western Pennsylvania, the Lower Kittanning coal bed (locally called the "thirty-inch vein") is very persistent and uniform. The coal is generally about 2.5 ft thick, and has a range in thickness from about 1 to 4 ft. Where exposed in western Pennsylvania, the coal bed is commonly characterized by lenses and spheroids of pyrite and marcasite.

In the New Florence 15-minute quadrangle, Shaffner (1958) measured what he termed the Allegheny series as about 210 to 260 ft of siliciclastic rock and coal. Shaffner (1958) regarded the Lower Kittanning coal bed to be the most continuous and uniform coal bed in western Pennsylvania and second only to the Pittsburgh in value. The Lower Kittanning commonly exhibits visible pyrite in the form of balls, lenses, and disseminated particles in this quadrangle as well.

In the Donegal quadrangle, Westmoreland, Fayette, and Somerset Counties (fig. 2), Shaffner (1963) described the Allegheny Group as consisting of about 230 ft of sandstone, siltstone, and shale, which he divided into the Clarion, Kittanning, and Freeport Formations. Three main coal beds are in the Kittanning Formation of Shaffner (1963): the Lower, Middle, and Upper Kittanning coal beds. Of these, the Lower Kittanning was the most important economically. The thickness ranges generally from 2.3 to 3.5 ft and it averages about 3.5 ft thick. Of the three Kittanning coal beds, the Lower Kittanning was the one most extensively mined in this quadrangle (Shaffner, 1963).

Patterson (1963) described the geology and coal resources of Beaver County in westernmost Pennsylvania (fig. 2). In Beaver County, the Allegheny Formation, which consists of shale, siltstone, sandstone and coal beds, is about 250 ft thick (Patterson, 1963, pl. 1). In this area, the Lower Kittanning coal bed is discontinuous, has about 2 percent sulfur content and 7 percent ash yield, and ranges from very thin to about 3 ft thick. In general, the Lower Kittanning coal bed is in the middle of a 50-ft-thick section of shale and siltstone that contains concretions and nodules of ironstone and limestone.

In Lawrence County (fig. 2), the Allegheny Formation is about 300 ft thick and consists predominantly of sandstone, siltstone, shale, and coal (Van Lieu and Patterson, 1964). Several beds of freshwater limestone are in the upper part of the formation and the fossiliferous marine Vanport Limestone Member (fig. 10) is about 50 ft above the base of the formation. In general, the Lower Kittanning coal bed is 15 to 30 ft above the Vanport Limestone Member in Lawrence County and is very thin or absent over the eastern half of the county. In western Lawrence County, the Lower Kittanning coal bed ranges from about 1.25 to 3 ft thick and averages about 2 ft.

Flint (1965) described the Allegheny Group in southern Somerset County (fig. 2), from the base of the Brookville coal bed and underclay to the top of the Upper Freeport coal bed, as consisting of about 280 ft of predominantly shale, siltstone, and sandstone with several major coal beds at intervals throughout the section and a few nonmarine limestone beds in the upper part of the section. Based on the major coal beds, Flint (1965) divided the group into the Clarion Formation at the base, the Kittanning Formation, and the Freeport Formation at the top. The Kittanning Formation, from the top of the Upper Kittanning coal bed to the base of the Lower Kittanning coal bed and underclay, occupies a position from about 100 ft to 200 ft below the top of the Upper Freeport coal bed. Flint (1965) combined several of the principal coal beds in Somerset County (fig. 2) into coal groups. The Lower Kittanning coal bed of Flint (1965) consists of two benches; the upper bench is the one most commonly mined. Flint (1965) placed the base of the Kittanning Formation at the base of the upper coal bed and underclay of the lower Kittanning coal group, thereby placing some of the beds included in the lower Kittanning coal group into the Clarion Formation. These beds have been mapped by subsequent workers in nearby areas as benches of the Lower Kittanning coal bed and within the Kittanning Formation, where they belong.

In southern Somerset County, the Lower Kittanning coal bed was thick enough to have been mined on the flanks of the Berlin syncline (Castleman coal field), Lower Youghiogheny and New Lexington synclines (Lower Youghiogheny coal field), and on the flanks of the Accident (Negro Mountain) anticline (Flint, 1965). Most of the coal was mined in the Lower Youghiogheny and Castleman coal fields, where the coal bed was as much as 5.2 ft thick.

Edmunds (1968, p. 24-37) worked in the northern half of the Houtzdale 15-minute quadrangle in east-central Clearfield County (fig. 2) and pre-empted the modern jargon of sequence stratigraphy with his coherent explanation of Pennsylvanian cyclothems as they may be applied to Appalachian Basin Carboniferous strata. For an idealized cycle, one transgressive-regressive deposit would consist of continental sediments at the base (sea level lowstand) that are overlain by transgressive swamp deposits, and then in sequence by open-water sediments (highstand), regressive swamp deposits, and continental sediments (lowstand). Following Ashley (1926), Edmunds (1968) mapped the Allegheny Group from the base of the Clarion-Brookville underclay to the top of the Upper Freeport coal bed. Although Edmunds (1968) retained the Allegheny Group nomenclature of Ashley (1926) and retained the Clarion Formation unchanged, he divided the Kittanning Formation of Ashley (1926) into three informal units, respectively the "lower," "middle," and "upper" Kittanning Formations. Furthermore, he moved the base of the Freeport Formation upward from the top of the Upper Kittanning coal bed to the base of the Lower Freeport underclay. Edmunds (1968) described the Lower Kittanning coal bed in south-central Clearfield County as a coal complex that consists of as many as five splits (beds of coal separated by partings), which he named, from the base upward, the Lower Kittanning Nos. 1 to 5 coal beds. The splits thicken to the west and northwest and, in places, the splits split into splits. In Centre County (fig. 2), the lower four splits of the Lower Kittanning coal bed converge into one thick coal bed that is 5 to 6.5 ft thick. The lower three splits separate to the north, but commonly remain less than 10 ft apart. Of the principal benches, the Lower Kittanning No. 3 coal bed is the most persistent. In places, the No. 3 also splits into two benches, No. 3a and No. 3b. Bench 3a ranges generally from 1 to 2.5 ft thick and commonly was mined with the underlying Lower Kittanning No. 2 coal bed (Edmunds, 1968).

Edmunds (1969) revised the nomenclature of the Allegheny Group in order to eliminate the dual nomenclature for formations and coal beds in Clearfield County (fig. 2) and to better define mappable units. Edmunds (1969) moved the base of the Allegheny Group from the base of the claystone beneath the Clarion No. 1 coal bed to the base of the Clarion No. 1 coal bed. At the base of the group, the Clearfield Creek Formation (fig. 8) extends from the base of the Clarion No. 1 coal bed to the base of the Lower Kittanning No. 1 coal bed. The Clearfield Creek Formation is overlain by the Millstone Run Formation, which extends from the base of the Lower Kittanning coal bed (B coal bed), or Lower Kittanning No. 1 coal bed where split, to the base of the overlying Middle Kittanning coal bed. In some places in Clearfield County, the thickness of the Millstone Run may be as little as 35 ft, which indicates that the overlying Middle Kittanning coal bed was deposited within a broad paleochannel or valley that had eroded into the underlying Millstone Run Formation. The overlying Mineral Springs Formation extends from the base of the Middle Kittanning coal bed to the base of the Upper Kittanning coal bed; the Laurel Run Formation, from the base of the Upper Kittanning coal bed to the base of the Lower Freeport coal bed; and the Glen Richey Formation (at the top) extends from the base of the Lower Freeport coal bed to the top of the Upper Freeport coal bed (fig. 8).

Glover (1970) mapped the southern half of the Clearfield 15-minute quadrangle in north-central Clearfield County and retained the informal nomenclature of Edmunds (1968) for the Allegheny Group. In this area, the group averages about 280 ft thick. The Lower Kittanning coal bed averages 2.5 to 2.9 ft thick where mined, and in some places has partings as much as 2 inches thick. In other places, the coal bed is separated into several benches by partings that are as much as 4.5 ft thick. Glover (1970) recorded small amounts of cannel coal within the Lower Kittanning coal bed in this area.

Patterson and Van Lieu (1971) measured the Allegheny Group as about 280 ft thick in Butler County (fig. 2). They divided the group into the formations that were recognized prior to 1969, namely the Freeport, Kittanning, and Clarion Formations (fig. 8). In general, the Lower Kittanning coal bed at the base of the Kittanning Formation of Ashley (1926) is from a few feet to as much as 40 ft above the Vanport Limestone in this area and ranges from less than 1.9 ft to more than 3.3 ft thick. The coal bed is thin and split into several thinner beds in northern Butler County, absent in the central and northwestern parts of the county, and relatively thick where under deep cover in the southern part of the county.

In Clearfield County, in the southern half of the Penfield 15-minute quadrangle, Edmunds and Berg (1973) mapped the five formations of the Allegheny Group that Edmunds (1969) had redefined previously. Edmunds and Berg (1973) report that the Lower Kittanning coal bed is a single thick bed in Centre and southeastern Clearfield Counties (fig. 2). To the west, the coal bed breaks up into four separate benches, Lower Kittanning Nos. 1, 2, 3, and 4 coal beds, and a rider bed called the Lower Kittanning No. 5 coal bed. A generalized section for the Millstone Run Formation in the Ramey and Houtzdale 7.5-minute quadrangles in Clearfield and Centre Counties is shown in table 1 (modified from

Table 1. Generalized section of the Millstone Run Formation in Clearfield and Centre Counties, Pa. (Glass and others, 1977).

	Thickness (Feet)		
	From		To
Underclay below Middle Kittanning No. 1 coal bed	0	to	6
Siltstone, shale, claystone and clay shale	12	to	22
Lower Kittanning No. 5 coal bed	0	to	1
Clay shale with *Lingula* sp. and *Orbiculoidea missouriensis(?)* grading into sand-silt laminite, and sandstone	15	to	20
(Note: Glass and others (1977) refer to the following rock units as the Lower Kittanning coal complex. In Centre County, all intervening clastic rocks have pinched out and Lower Kittanning coal beds Nos. 1 through 4 have merged into a single, nearly continuous coal bed. Collectively, this complex is 4 to 60 ft thick.)			
Lower Kittanning No. 4 coal bed			
Clay shale with *Lingula* sp., *Anthraconauta* sp., *Orbiculoidea* sp., and others grading into silt shale, and sandstone	0	to	30
Lower Kittanning No. 3b coal bed	0	to	0.5
Underclay, clay shale, and sandstone	0	to	20
Lower Kittanning No. 3a coal bed	0	to	3
Underclay and claystone	0	to	6
Lower Kittanning No. 2 coal bed	0	to	2
Underclay, claystone, and siltstone	0	to	20
Lower Kittanning No. 1 coal bed	0	to	3

Glass and others, 1977). The Millstone Run Formation is generally 60 to 75 ft thick in this area. In general, the Lower Kittanning No. 3 coal bed is the most persistent of the Lower Kittanning coal bed splits. The coal generally is bright and clean, contains a little bone coal, and ranges in thickness from about 1.5 to 3.5 ft thick. Overlying beds of shale, siltstone, and sandstone may be as thick as 50 ft, except where they are removed by the unconformity upon which the Lower Kittanning No. 4 coal bed is deposited (Edmunds and Berg, 1973). A zone containing invertebrate fossils is at the top of the Lower Kittanning No. 3 coal bed and ranges from a few feet thick in the area to as much as 25 ft thick.

Glass (1972, plate 1) estimated that the Allegheny Group consists of about 290 ft of coal-bearing siliciclastic strata in the Philipsburg 7.5-minute quadrangle in western Centre and adjacent parts of Clearfield Counties (fig. 2). He was able to recognize and map the formations within the Allegheny in this eastern area that Edmunds (1969) had previously defined in Clearfield County to the west. In eastern Clearfield County and western Centre County, the Millstone Run Formation ranges generally from 25 to 80 ft thick and averages 55 to 60 ft thick. The Lower Kittanning coal bed commonly consists of 4 to 5 benches, known as the Lower Kittanning Nos. 1, 2, 3a, 3b, and 4 benches. In places, a sixth nonpersistent coal bed is at the top of the formation. The coal benches are separated by claystone and bone partings in beds as much as 3 ft thick. In general, the benches of the Lower Kittanning coal bed separate farther apart to the west in Clearfield County. The Lower Kittanning No. 2 and the overlying Lower Kittanning No. 3 coal beds commonly are mined together. The No. 3 coal bed is about 3 ft thick, and in places in the Philipsburg quadrangle, the combined thickness of the two benches (splits) exceeds 4 ft. The Lower Kittanning No. 4 coal bed, as a rider, is as much as 32 ft above the No. 3 coal bed. The No. 4 coal bed commonly ranges from 0.5 to 0.75 ft thick and is overlain by as much as 33 ft of dark shale that contains invertebrate fossils. The fossiliferous shale grades upward into interlaminated shale, siltstone, and sandstone (Glass, 1972).

Berg and Glover (1976) report that the Allegheny Group in the Sabula and Penfield 7.5-minute quadrangles, in northwestern Clearfield and small parts of adjacent counties, ranges generally from 310 to 330 ft thick and may be as much as 350 ft thick. The Millstone Run Formation (fig. 8) within the Allegheny Group is generally 70 to 80 ft thick in this area and in a few places may be as much as 100 ft thick. In general, the unit is composed of sandstone; siltstone and shale laminites; fossiliferous marine silicilastic sediments; and rooted claystone and coal beds. The Lower Kittanning No. 1 split is poorly developed at the base of the formation in this area. In places, it consists of as much as 0.2 ft of coal, which is overlain by 20 to 27 ft of the clay complex that is beneath the Lower Kittanning No. 3 coal bed. The Lower Kittanning No. 3 coal is the most extensively mined bed in this area and ranges from 1.4 to 3.6 ft thick.

Glass and others (1977) described the Millstone Run Formation in the Ramey and Houtzdale 7.5-minute quadrangles as consisting of 60 to 90 ft of strata that extend from the base of the lowest split of the Lower Kittanning coal complex to the base of the lowest coal of the Middle

Kittanning coal complex. Their section for the Millstone Run Formation and the Lower Kittanning coal bed in western Centre and eastern Clearfield Counties (Glass and others, 1977) is slightly modified as presented in table 1.

Glover and Bragonier (1978) described the Millstone Run Formation in the Hazen, Falls Creek, Reynoldsville, and Dubois 7.5-minute quadrangles in eastern Jefferson and westernmost Clearfield Counties (fig. 2) as "the most lithologically persistent interval in the Allegheny Group...." The thickness of the formation ranges from 60 to 90 ft in this area and generally contains two coal beds, the Lower Kittanning No. 1 and the Lower Kittanning No. 3. The section of siliciclastic rocks between these two coal beds ranges generally from 9 to 40 ft. In some areas, where the coal bed was surface mined, the Lower Kittanning No. 1 increases in thickness to as much as 3.1 ft. The underclay below the Lower Kittanning No. 3 is widespread and in places is as much as 20 ft thick. The Lower Kittanning No. 3 coal bed is persistent and, except for a few places where it is thin or absent, is generally thick enough to have been mined.

The U.S. Bureau of Mines retained the threefold subdivision (Clarion, Kittanning, and Freeport Formations) first proposed by Ashley (1926) for the Allegheny Group in their study of mining and methane content of the Freeport and Kittanning coal beds in Indiana and Cambria Counties (fig. 2; Puglio and Iannacchione, 1979; Iannacchione and Puglio, 1979, table 2). In these counties, the Allegheny Group ranges in thickness from about 250 to 350 ft thick and the strata are folded into relatively low-amplitude, northeast-trending folds. In general, the major stratigraphic units show a regional thinning toward the northwest.

Puglio and Iannacchione (1979) describe the Lower Kittanning coal bed as the most persistent of the Allegheny coal beds in the area, averaging about 3.5 to 4 ft thick, and locally thickening to 6 ft. In Indiana and Cambria Counties, the Lower Kittanning coal bed is a low- to medium-volatile bituminous coal that has been used for making coke, but mostly is used for steam generation. Methane occurs in the deeper mines in synclinal areas; in 1976, three mines in Cambria County, at depths greater than 500 ft, produced an average of 2.6, 2.7, and 3.1 million cubic feet of gas per day of coalbed methane (Iannacchione and Puglio, 1979, table 1). In Indiana County, a core obtained from a coalbed methane test well in the Lower Kittanning coal bed yielded a gas content of 352 ft^3/ton at a depth of 1,057 to 1,060 ft near the axis of the Latrobe anticline. At that time, this content was the highest ever measured from a Pennsylvania coal bed (Puglio and Iannacchione, 1979, table 8).

Faill and others (1989) mapped an area in the Pennsylvania coal fields in the Blandburg, Tipton, and Altoona 7.5-minute quadrangles along the Allegheny topographic front in Cambria and adjacent parts of Centre and southeasternmost Clearfield Counties. The Allegheny Group ranges from 250 to 300 ft thick in this area and the Millstone Run Formation ranges from 62 to 80 ft thick. The Millstone Run Formation contains two of the Lower Kittanning splits: the Lower Kittanning No. 1 coal at the base (as much as 1.6 ft thick), and the Lower Kittanning No. 3 coal (as much as 5.2 ft thick), which is 18 to 31 ft above. The Lower Kittanning No. 3 coal is laterally persistent in this area and is commonly greater than 3 feet thick (Faill and others, 1989).

Table 2. Informal subunits of the Allegheny Formation in northern West Virginia and Maryland (slightly modified from Arkle and others, 1979).

Upper Freeport coal bed
Bolivar clay
Upper Freeport sandstone
Lower Freeport coal bed
Upper Kittanning coal bed
Washingtonville limestone (marine)
Middle Kittanning coal bed
Hamden (Columbiana) limestone (marine)
Lower Kittanning coal bed
Lower Kittanning clay
Vanport (Ferriferous) limestone (marine)
Clarion-Brookville (Lower Mount Savage) coal bed
Clarion-Brookville (Lower Mount Savage) fire clay

WEST VIRGINIA

ALLEGHENY FORMATION (OR SERIES)

In West Virginia, the Allegheny is not subdivided into subordinate mappable units as it is in Pennsylvania and is classified as a formation rather than a group. The Allegheny Formation is defined to include those strata between the top of the Homewood Sandstone (of the Pottsville Group) and the base of the Mahoning Sandstone (of the Conemaugh Group) or top of the Upper Freeport coal bed (Arkle and others, 1979) (table 2). The formation consists of subgraywacke sandstone, siltstone, shale, and mudstone with intercalations of coal, underclay, and a few beds of limestone. In general, the formation ranges from about 125 ft thick in Tucker County, near the Maryland panhandle, to 250 ft thick in Hancock County (fig. 2), the northernmost county in the State. In some places in West Virginia, the lower part of the Allegheny contains marine sandstone and shale; in other places, the lower part consists of thick deposits of Lower Kittanning and Clarion refractory clay that have been mined extensively. The upper part of the formation commonly contains several relatively thin lacustrine limestone beds (Arkle and others, 1979).

In Preston County (fig. 2), Hennen and Reger (1914) included in the Allegheny Series the rocks between the base

Table 3. General section of the Allegheny Series (old terminology), Randolph County, W. Va. (Reger, 1931).

		Thickness (feet)			Total (cumulative) (feet)
1.	Coal, Upper Freeport (Davis), multiple-bedded	3	to	8	8
2.	Shale, Bolivar, sandy, and fire clay, impure	5	to	7	15
3.	Limestone, Upper Freeport, ferriferous, often absent	0	to	5	20
4.	Sandstone, Upper Freeport, gray, massive	20	to	28	48
5.	Coal, Lower Freeport, double-bedded, lenticular	0	to	2	50
6.	Fire clay and shale	2			52
7.	Limestone, Lower Freeport, mostly ferriferous nodules mixed with plastic fire clay	2	to	6	58
8.	Fire clay, Lower Freeport, flinty or plastic	5	to	2	60
9.	Sandstone, Lower Freeport, gray and massive, or shaly	20	to	50	110
10.	Coal, Upper Kittanning, soft, double-bedded	2	to	5	115
11.	Fire clay, Upper Kittanning, often shaly	0	to	5	120
12.	Limestone, Johnstown, gray, shaly, lenticular	0	to	5	125
13.	Fire clay, Hardman, generally impure	0	to	5	130
14.	Sandstone, Upper East Lynn gray, massive	5	to	35	165
15.	Coal, Middle Kittanning, soft, multiple-bedded, often absent or closely associated with Lower Kittanning coal	0	to	5	170
16.	Sandstone, East Lynn, gray, shaly, often represented by thin bed of shale	1.5	to	2	172
17.	Coal, Lower Kittanning, soft, multiple-bedded, mined in conjunction with Middle Kittanning Coal in Roaring Creek region	3	to	8	180
18.	Fire clay, Lower Kittanning, usually represented by sandy shale	2	to	5	185
19.	Shale, sandy	5	to	10	195
20.	Sandstone, Kittanning, gray, massive, often absent	0	to	30	225
21.	Coal, Clarion, double-bedded, often absent	0	to	5	230
22.	Shale, sandy	10	to	20	250
23.	Sandstone, Homewood (Top of Pottsville Series)				

of the Uffington shale, above, and the top of the Homewood sandstone, below. Thus defined, the Allegheny is capped by the Upper Freeport coal bed and consists primarily of siliciclastic strata, including four or five massive beds of sandstone, shale, and several commercial coal beds, fireclay, and limestone. The Allegheny has a maximum thickness of about 260 ft in Preston County (Hennen and Reger, 1914).

The Allegheny Series in Barbour County and adjacent Upshur and Randolph Counties (Reger, 1918), and in southern Lewis County (Reger, 1916) (fig. 2) consists mostly of gray sandstone and gray sandy shale, and is about 250 ft thick.

Reger (1923) described the Allegheny Series in Tucker County (fig. 2) as about 100 to 150 ft thick. There, the Allegheny consists of coarse-grained and, in places, pebbly sandstone, shale, fireclay, limestone, and coal. Reger (1923) considered the Upper Freeport coal bed to be the coal of economic significance in Tucker County. Although the Lower Kittanning coal bed ranges from about 1 to 5 ft thick in the same general area, it is lenticular, contains numerous partings, and has a high ash yield (Reger, 1923).

In Mineral and Grant Counties (fig. 2), the Allegheny Series (Reger, 1924) ranges from about 150 to 200 ft thick. In these counties, the Allegheny consists of sandstone, sandy shale and impure fireclay, coal, several beds of impure ferruginous limestone, and about six major coal beds of which three are commonly of minable thickness (Upper Freeport, Upper Kittanning, and Lower Kittanning). Reger (1924) described the contact of the Allegheny with the underlying Homewood Sandstone of the Pottsville Group as gradational, with the fossil plant flora of the Pottsville changing transitionally to those of the overlying Allegheny. He also pointed out the lithologic differences between the massive quartzose and quartz-pebble conglomeratic sandstone of the Homewood with the relatively impure and finer grained sandstone of the Allegheny. Reger (1931) published a general stratigraphic section for Randolph County (fig. 2; table 3) that shows the principal units of the Allegheny and a total maximum thickness for the formation of about 250 ft.

LOWER KITTANNING COAL BED

Reger (1916) described the Lower Kittanning coal bed in southern Lewis County (fig. 2) as very persistent, 4 to 12 ft thick, but commonly having shale and silty shale (slate) interbeds and partings that would greatly reduce its value.

Of the four minable coal beds in the Allegheny Series in Barbour and Randolph Counties (Reger, 1918) (fig. 2), the Lower Kittanning coal bed had, even by then, been mined extensively. In general, the coal bed is from 15 to 50 ft above the top of the Homewood Sandstone, consists of two benches separated by 0.33 to 0.5 ft of shale (slate) or bony coal, and is about 4 to 7 ft thick.

The Lower Kittanning coal bed in Preston County (figs. 2, 3) consists of at least two beds that are separated by a shale (slate) parting in the middle that ranges in thickness from a few inches to 3 ft even within the same mine. The coal bed, with its upper and lower coal benches and middle shale parting, ranges generally from 4 to 7 ft thick in Preston County, although in places it may be as much as 9.5 ft thick, including a 10-inch-thick parting (Hennen and Reger, 1914).

Reger (1924) described the Lower Kittanning coal bed in Mineral and Grant Counties (fig. 2) as occurring just below the East Lynn Sandstone and 120 to 175 ft below the Upper Freeport coal bed. As in nearby areas, the Lower Kittanning is a "double-bedded seam" with shale (slate) partings near the middle and with a total thickness that ranges generally from 2 to 3 ft.

In the western part of Randolph County (fig. 2), Reger (1931) apparently described the same two benches of coal that he had observed in nearby areas. However, in contrast with the classification used nearby, Reger (1931) identified the lower bench of coal as the Lower Kittanning coal bed and the upper bench as the Middle Kittanning coal bed. In western Randolph County, the Middle Kittanning and Lower Kittanning coal beds are separated by shale and bone coal partings that range from a few inches to several feet thick, and the two coal beds commonly are mined together as one unit, with a total thickness of 7 to 12 ft. From the measured coal bed sections provided by Reger (1931), it appears that it might have been more appropriate to classify the Middle and Lower Kittanning coal beds together in Randolph County as benches of a single named coal bed (Lower Kittanning) as he did in 1918, rather than as two separate coal beds with different names.

In conducting the present assessment of the Lower Kittanning coal bed in West Virginia, areas to the south and west of its exposures in Lewis, Upshur, and Randolph Counties were not considered because correlations with other coal beds (such as the No. 5 Block and No. 6 Block) in Gilmer, Braxton, Nicholas, and Webster Counties and other nearby counties (fig. 2) are uncertain.

OHIO

In Ohio, Pennsylvanian and Permian coal measures form topographic uplands along the western flank of the Appalachian Plateaus physiographic province. There, the coal-bearing strata are on the eastern flank of the Cincinnati structural arch and are in a region that was only slightly deformed by the Alleghanian orogeny. The dominant structure of the Appalachian Plateaus is the general regional dip of the strata to the east and southeast at about 20 to 40 ft per mile, away from the crest of the Cincinnati arch toward the main part of the depositional basin.

Only the northernmost part of the Appalachian Plateaus region in Ohio (as well as adjacent Pennsylvania) was glaciated and covered with till during the Pleistocene (Brant, 1954). To the south, the region is not covered by glacial till and consists of more rugged topography that is dissected by mature, steep-walled valleys.

ALLEGHENY GROUP (OR FORMATION)

In general, the Allegheny Group (or Formation) in Ohio consists of cyclical sequences of sandstone, shale, coal, clay, and limestone that range from about 188 to 290 ft thick and average from about 210 to 225 ft thick (Collins, 1979; Couchot and others, 1980). The group contains 32 named beds (table 4) of which about six coal, limestone, or claystone beds are economically significant. In some places, marine limestone and shale are in the rock units above the Lower Freeport coal bed, although marine beds, such as the Vanport Limestone, are more common in the lower part of the section. The Lower Kittanning coal bed is commonly a brightly banded blocky coal bed that is located in about the middle of the Allegheny Formation in Ohio. The Lower Kittanning is laterally persistent in distribution and thickness (Brant, 1954), as it is in parts of Pennsylvania and West Virginia. In northern Ohio, a bed of 5 to 8 inches of cannel coal is at the top of the Lower Kittanning coal bed. The Lower Kittanning coal bed commonly overlies a light-colored, plastic Lower Kittanning clay, which in some places may be as much as 15 ft thick. The Lower Kittanning clay is the most widespread and productive claystone bed in Ohio (Collins, 1979).

Strata between the Lower Kittanning and Middle Kittanning coal beds are about 30 to 40 ft thick and commonly consist of shale and siltstone, with some clay and limestone, and locally include the Strasburg coal beds (Brant, 1956; table 4). In central to northern Ohio, the marine Hamden Shale occupies the interval between the Lower Kittanning and the Strasburg coal beds. There, the Hamden consists of shale that contains siderite or limestone nodules and marine invertebrate fossils. Brant (1956) reports that the Hamden ranges considerably in composition, and in places it is fissile, carbonaceous, and contains abundant siderite nodules. The Oak Hill clay underlies the Strasburg coal bed in northern Ohio. To the south, the strata between the Lower and Middle Kittanning coal beds are commonly thinner than they are to the north and consist

Table 4. Nomenclature of the Allegheny Group in Ohio (Collins, 1979).

Bed	Material
Upper Freeport No. 7	**Coal,** patchy.
Upper Freeport	Limestone and marly shale.
Bolivar	**Coal,** local, thin.
Bolivar	Clay, flint and plastic.
Upper Freeport	Shale or sandstone.
Dorr Run	Shale, marine, local.
Lower Freeport (Rogers)	**Coal,** patchy.
Lower Freeport	Limestone, local.
Lower Freeport	Shale or sandstone.
Upper Kittanning	**Coal,** seldom present.
Washingtonville (Yellow Kidney ore)	Shale, marine.
Middle Kittanning No. 6	**Coal,** persistent.
Leetonia	Limestone, local.
Red Kidney ore	Shale, siliceous.
Strasburg	**Coal,** local.
Oak Hill	Clay, flint and plastic.
Hamden	Limestone, non-persistent.
Columbiana	Limestone, marine, local.
Lower Kittanning No. 5	**Coal.**
Lawrence	**Coal,** shaly, local.
Kittanning	Shale and sandstone.
Ferriferous	Ore, irregular.
Vanport	Limestone, marine.
Scrubgrass	**Coal,** seldom present.
Clarion No. 4a	**Coal,** patchy.
Canary	Ore, very local.
Clarion	Sandstone, irregular.
Winters	**Coal**, very local.
Zaleski	Flint, impure, marine.
Ogan	**Coal,** local.
Putnam Hill	Limestone, marine.
Brookville No. 4	**Coal,** persistent.

dominantly of massive sandstone. To the south, where the Strasburg coal bed appears to be absent, the Oak Hill clay is overlain by an ironstone-rich shale known variously as “red kidney ore” or “black kidney ore” (Brant, 1956).

The Lower Kittanning coal bed and associated strata are greatly dissected along their outcrop at the edge of the Appalachian Plateaus. Because overburden is generally thin in eastern Ohio, much of the Lower Kittanning coal bed has been surface mined or has the potential to be surface mined. Downdip to the east, the Ohio Division of Geological Survey has identified deep resources in the Lower Kittanning and other coal beds under approximately 700 ft of overburden (Struble and others, 1976; Couchot and others, 1980). Published analyses, however, show that the Lower Kittanning is relatively high in sulfur content in this area and is less desirable for use in coal-fired power plants. Furthermore, the same areas have been penetrated by numerous oil and gas tests, which also may be an impediment to coal mining, if oil and gas resources are present.

MARYLAND

Five coal fields are in elongate synclinal structures in Garrett and Allegany Counties (fig. 2) in western Maryland (some of which continue into Pennsylvania): the Georges Creek, the Upper Potomac, the Castleman, the Lower Youghiogheny, and the Upper Youghiogheny (fig. 11). In their discussion of the coal resources of Maryland, Weaver and others (1976) listed the Lower Kittanning coal bed as a commercially exploitable coal bed, although they ascribed no reserves (resources) to the bed. The general stratigraphy of the Allegheny Formation in northern West Virginia and Maryland is shown in table 2.

Lyons and others (1985) mapped the Pottsville and Allegheny Formations together as one unit in the Castleman coal field. The coal bed marker unit between the Pottsville and Allegheny, the Lower Mount Savage (Brookville) coal bed, is not persistent enough to map as the base of the Allegheny Formation in this area, and Pottsville sandstones

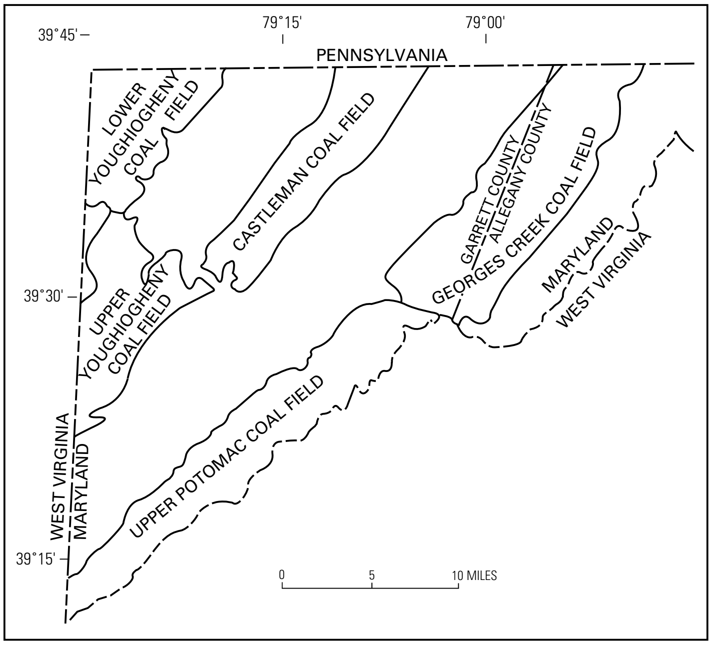

Figure 11. Map showing Maryland coal fields (based on Weaver and others, 1976).

cannot be easily distinguished from Allegheny sandstones. In general, the Allegheny Formation is about 250 to 290 ft thick and consists predominantly of sandstone, siltstone, shale, and coal, with three distinct limestone horizons in the upper part of the formation. Lyons and others (1985) described the Lower Kittanning coal bed as lenticular and generally thin, although in places it may be as much as 4.1 ft thick. They mentioned, however, that the Lower Kittanning had been prospected in this coal field, but apparently was never extensively mined. Lyons and others (1985) also report that the Lower Kittanning contains about 19.5 percent ash yield and 3.5 percent sulfur content in the Castleman coal field.

In the Lower Youghiogheny coal field, Jacobsen and Lyons (1985) mapped the Pottsville and Allegheny Formations together as one unit because the Brookville (Lower Mount Savage) coal bed, which marks the base of the Allegheny Formation, is not as persistent in this area as it is in adjacent West Virginia and Pennsylvania. The top of the Homewood Sandstone (fig. 10), the regionally distributed sandstone formation at the top of the Pottsville Group, may in places be used as the contact between the Pottsville and the Allegheny. In general, however, sandstone in the Homewood could not be separated from basal sandstones of the Allegheny Formation sufficiently well enough to divide the two groups regionally. Nevertheless, Jacobsen and Lyons (1985) estimated that the Allegheny units consist of about 225 ft of sandstone, siltstone, shale, and coal, with only a little limestone in the upper part of the section. The Lower Kittanning coal bed consists of two benches in this coal field, each as much as 3 ft thick. The benches are commonly separated by shale or claystone partings commonly less than 1.1 ft thick. In this coal field, the ash yield of the Lower Kittanning coal bed ranges from about 11 to 15 weight percent and sulfur content ranges from 2 to 3 weight percent. Little data exist for the Lower Kittanning coal bed in the Georges Creek, Upper Potomac, or Upper Youghiogheny coal fields in Maryland. Near Westernport in Allegheny County, the Lower Kittanning consists of one to four beds in strata 70 to 120 ft below the Upper Kittanning coal bed (Toenges and others, 1949). Lower Kittanning coal beds greater than 6 inches thick were identified in 12 core holes in the Georges Creek basin; near Westernport, Toenges and others (1949) inferred about 10.7 million tons of coal from two drill holes and data from a few small drift mines. According to the 2000 Keystone Coal Industry Manual (Hooker, 2000), the Lower Kittanning coal bed is not currently being mined in Maryland.

RESOURCE INVESTIGATIONS

PREVIOUS RESOURCE STUDIES

Coal resource studies have been conducted in the Appalachian Basin for many years and Eavenson (1942) provided a summary of the coal industry's early history in the region. For the purposes of this report, the estimates for original coal resources for the Lower Kittanning coal bed were obtained for Maryland from Weaver and others (1976), for Pennsylvania from Reese and Sisler (1928), for Ohio from Brant (1954; also see Clark, 1917), and for West Virginia from the published county reports (Reger, 1916, 1918, 1923, 1924, 1931). Coal production data by coal bed are generally not available for much of the historical mining in the Appalachian Basin, so it is not possible to estimate remaining resources by subtraction from original tonnages.

Even with present-day digital technology, an adequate resource estimate of Appalachian Basin coal on a bed-by-bed basis is dependent on the amount and quality of the data available to the geologist conducting the estimate. These data include accurately measured coal-bed thicknesses and locations, and accurate correlations of beds across the region. Equally important for the calculation of remaining resources are maps of surface and underground mined areas and the county-level coal-bed production. In order to achieve high-quality assessments of remaining resources, this information must be collected and archived in publicly available databases by government agencies at all levels and with the full cooperation of industry, which is the primary source of exploration data.

Information provided by Weaver and others (1976) indicates that there is little reason to believe that there are significant remaining Lower Kittanning coal resources in Maryland. Toenges and others (1952) determined that no Lower Kittanning coal of “present value” was found in their investigation of the Castleman coal field, Garrett County, Md. The estimate of Brant (1954) indicates that the original resource of the Lower Kittanning coal bed in Ohio is approximately 9.9 billion short tons (table 5). Reese and Sisler (1928) estimated 12.2 billion short tons as the original Lower Kittanning coal bed resource for Pennsylvania. Estimates from the various West Virginia county reports (Reger, 1916, 1918, 1923, 1924, 1931) indicate that the original resource for the Lower Kittanning coal bed in West Virginia is about 4.5 billion short tons. The total original resource for all four states is therefore estimated to be 26.6 billion short tons (table 5). Ashley and others (1944) and Edmunds (1972) concluded that the reserve estimates of Reese and Sisler (1928) were too high. Except for the Pittsburgh coal bed, Ashley and others (1944) reduced Reese and Sisler’s (1928) overall estimate by 40 percent, and Edmunds (1972) considered an additional reduction in Ashley’s (1944) estimate by one-third.

Beginning in the early 1950’s, the U.S. Bureau of Mines, in a series of reports on coking coal for a ten-county area in west-central Pennsylvania (Dowd, Toenges, Turnbull, Cooper, Abernethy, Reynolds, and Crentz, 1950; Dowd, Toenges, Turnbull, Cooper, Abernethy, Reynolds, and Fraser, 1950; Dowd and others, 1951a,b,c; Dowd and others, 1952; Wallace, Dowd, Bowsher, and others, 1953; Wallace, Dowd, Turnbull, and others, 1953; Blaylock and others, 1955; Zeilinger and Deurbrouck, 1968) determined that there were about 4.05 billion short tons of remaining reserves (which was a most conservative calculation of resources) in the Lower Kittanning coal bed. Potentially recoverable coking coal in the bituminous coal fields (table 6) was estimated to be about 1.73 billion short tons. In every one of the counties studied by the U.S. Bureau of Mines (table 6), the remaining measured and indicated reserves (the term, “reserves,” refers to the near-term economic subset of resources) were significantly less than the original resource estimates of Reese and Sisler (1928), which included measured, indicated, and inferred volumes of coal.

Production statistics illustrate the overall decline in production from the Lower Kittanning coal bed from almost 20 million short tons in 1984 to a little more than 8 million short tons in 1995 (fig. 12; Appendix 1). Part of this downturn may be attributed to depletion of the thicker and more accessible deposits of Lower Kittanning coal bed during the past 150 years of mining, and part is related to the relatively high sulfur content of much of the remaining resource that makes it less desirable for use in generating electric power.

DATABASES

In this Lower Kittanning coal bed study, we used digital databases and a geographic information system (GIS) to produce the digital map products used in this study. The geochemical database for the Lower Kittanning coal bed (Appendixes 2 and 3) contains data derived from a variety of sources including the USGS, U.S. Bureau of Mines, The Pennsylvania State University, other Federal and State sources, and variously published analyses (see references in Appendix 4). The records in this database include data from in-ground, mine, tipple, and delivered samples on an as-received whole-coal basis. Approximately one-eighth (273) of the 2,158 analyses entered into the database are located by known latitude and longitude coordinates (fig. 13), while the other records are only considered reliable and accurate to a county scale. Appendix 2 contains the data for 1,155 of the publicly available geochemical records; of those, there are 290 public records that contain analyses for as many as 86 different trace elements. The remaining records contain data for ash yield, sulfur content, and calorific value. Samples of the Lower Kittanning coal bed that were collected in intervals or from benches were aggregated to obtain representative analyses of the “whole coal bed” chemistry at any one location (see Appendix 3 for processing steps). Samples having ash yields greater than 33.33 percent on an as-received whole-coal basis are not defined as coal (Wood and others, 1983) and were removed from the database. Further information about data sources, processing steps, aggregating, and formatting is detailed in

Table 5. Previous estimates of original resources (thousands of short tons) for the Lower Kittanning coal bed.

[Sources: Pennsylvania—Reese and Sisler (1928); West Virginia—Grimsley (1907, Hennen (1913), Hennen and Reger (1914), Reger (1916, 1918, 1923, 1924, 1931); Ohio—Brant (1954). Abbreviations are as follows: nd, no data.]

Pennsylvania		**West Virginia**		**Ohio**	
County	**Thousands of short tons**	**County**	**Thousands of short tons**	**County**	**Thousands of short tons**
Armstrong	1,541,200	Barbour	1,089,153	Athens	322,552
Beaver	526,071	Brooke	nd	Carroll	917,189
Blair	24,300	Grant	nd	Columbiana	1,173,585
Bradford	19,440	Hancock	nd	Coshocton	209,085
Butler	483,423	Lewis	207,581	Gallia	948,029
		Mineral	53,053		
Cambria	2,010,300	Marion	296,340	Guernsey	1,044,519
Cameron	6,480	Monongalia	107,095	Harrison	669,297
Centre	169,164	Ohio	nd	Hocking	48,271
Clarion	460,300	Preston	819,238	Holmes	93,072
Clearfield	1,509,600	Upshur	1,091,997	Jackson	169,635
		Randolph	193,197		
Clinton	34,560	Taylor	639,287	Jefferson	563,114
Elk	14,400	Tucker	nd	Lawrence	812,702
Fayette	302,120			Mahoning	458,348
Indiana	1,798,700	**Subtotal**	4,496,941	Meigs	226,413
Jefferson	696,000		(4.5 billion)	Morgan	100,413
Lawrence	304,627			Muskingum	458,099
Lycoming	44,000			Noble	70,474
Mercer	12,960			Perry	295,884
Somerset	1,500,200			Scioto	4,908
Tioga	54,720			Stark	362,216
Westmoreland	729,000				
				Tuscarawas	749,643
Subtotal	12,241,565			Vinton	203,967
	(12.2 billion)			Wayne	12,574
				Subtotal	9,913,989
					(9.9 billion)

Total 26.6 billion short tons of Lower Kittanning coal

Table 6. Remaining reserves (thousands of short tons) of Lower Kittanning coking coal in Pennsylvania.

[Sources: U.S. Bureau of Mines Reports of Investigations (see first column of table): Dowd, Turnbull, Toenges, Cooper, Abernethy, Reynolds, and Crentz (1950); Dowd, Turnbull, Toenges, Cooper, Abernethy, Reynolds, and Fraser (1950); Dowd and others (1951a,b,c); Wallace, Dowd, Bowsher, and others (1953); Wallace, Dowd, Turnbull, and others (1953); Blaylock and others (1955, 1956).]

USBM	**County**	**Tonnage by significant thickness categories**			**Total tonnage**	**Recoverable tonnage**	**Percent**	
RI No.		**1.17 – 2.33 ft**	**2.33 – 3.50 ft**	**>3.50 ft**	**$\geq$1.17 ft**	**$\geq$2.33 ft**	**Recoverable**	**As of**
5003	Allegheny	8,594	15,060	262	23,916	6,129	40.0	1/1/1953
4801	Armstrong	39,313	407,924	109,551	556,788	219,015	42.3	1/1/1949
4734	Cambria	61,086	253,977	396,205	711,268	339,270	52.2	1/1/1948
5231	Clarion	50,694	254,296	18,314	323,304	153,822	56.4	1/1/1952
5166	Clearfield	152,472	315,281	114,862	582,615	210,947	49.0	1/1/1953
4807	Fayette	42,112	100,537	24,680	167,329	68,544	54.7	1/1/1950
4757	Indiana	206,445	558,329	240,620	1,005,394	419,712	52.5	1/1/1948
4840	Jefferson	40,229	184,781	0	225,010	94,275	51.0	1/1/1950
4998	Somerset	85,842	160,805	173,603	420,250	205,116	61.3	1/1/1952
4803	Westmoreland	6,471	15,430	8,793	30,694	12,159	50.2	1/1/1950
TOTALS		**693,258**	**2,266,420**	**1,086,890**	**4,046,568**	**1,728,989**		

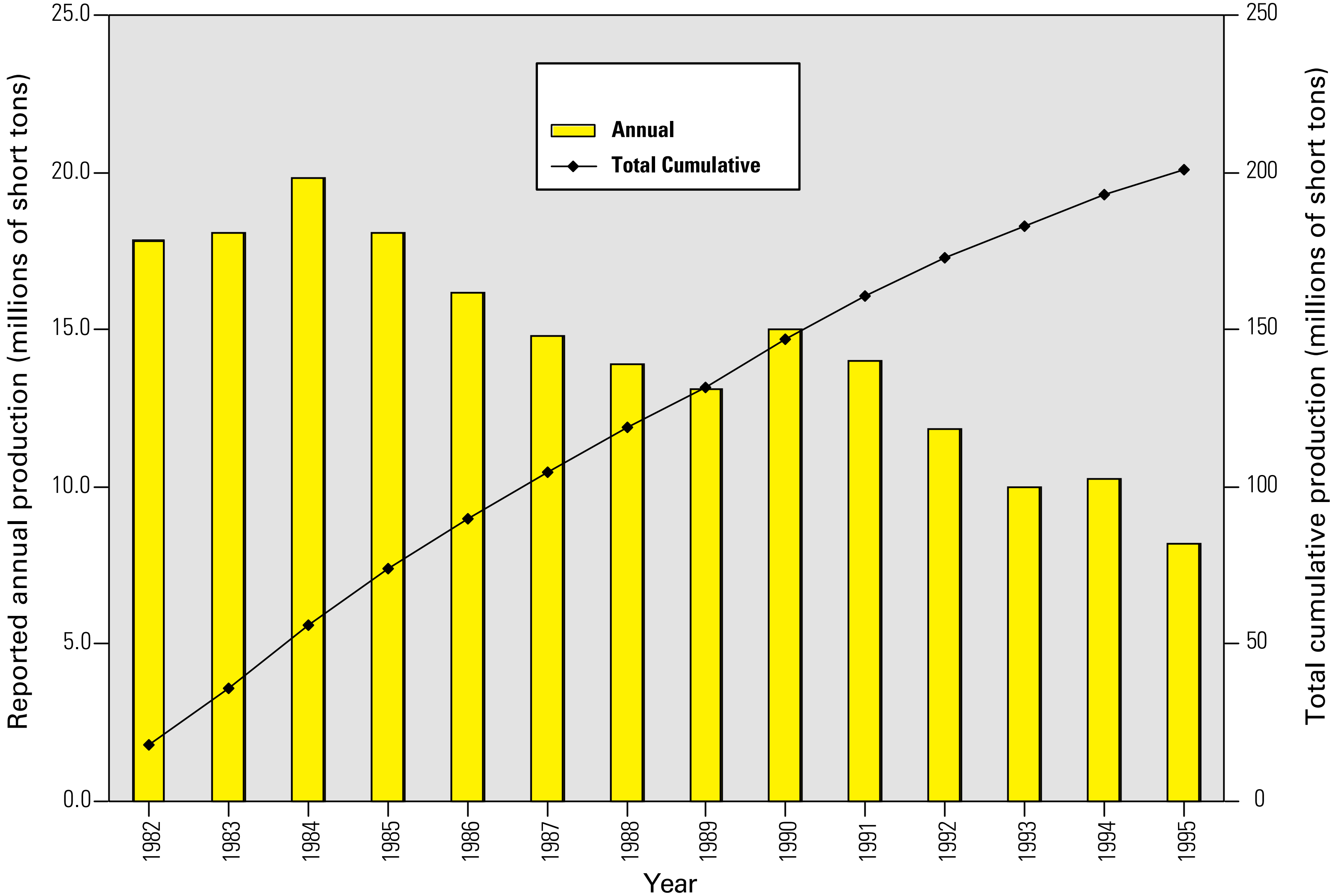

Figure 12. Graph showing annual and cumulative production from the Lower Kittanning coal bed from 1982 to 1995. Also see Appendix 1. Sources of data are as follows: Ohio Division of Labor Statistics (1945–1946, 1947–1964, 1966–1981, 1982–1993), Maryland Bureau of Mines (1969–1995), Commonwealth of Pennsylvania (1975–1995), and 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).

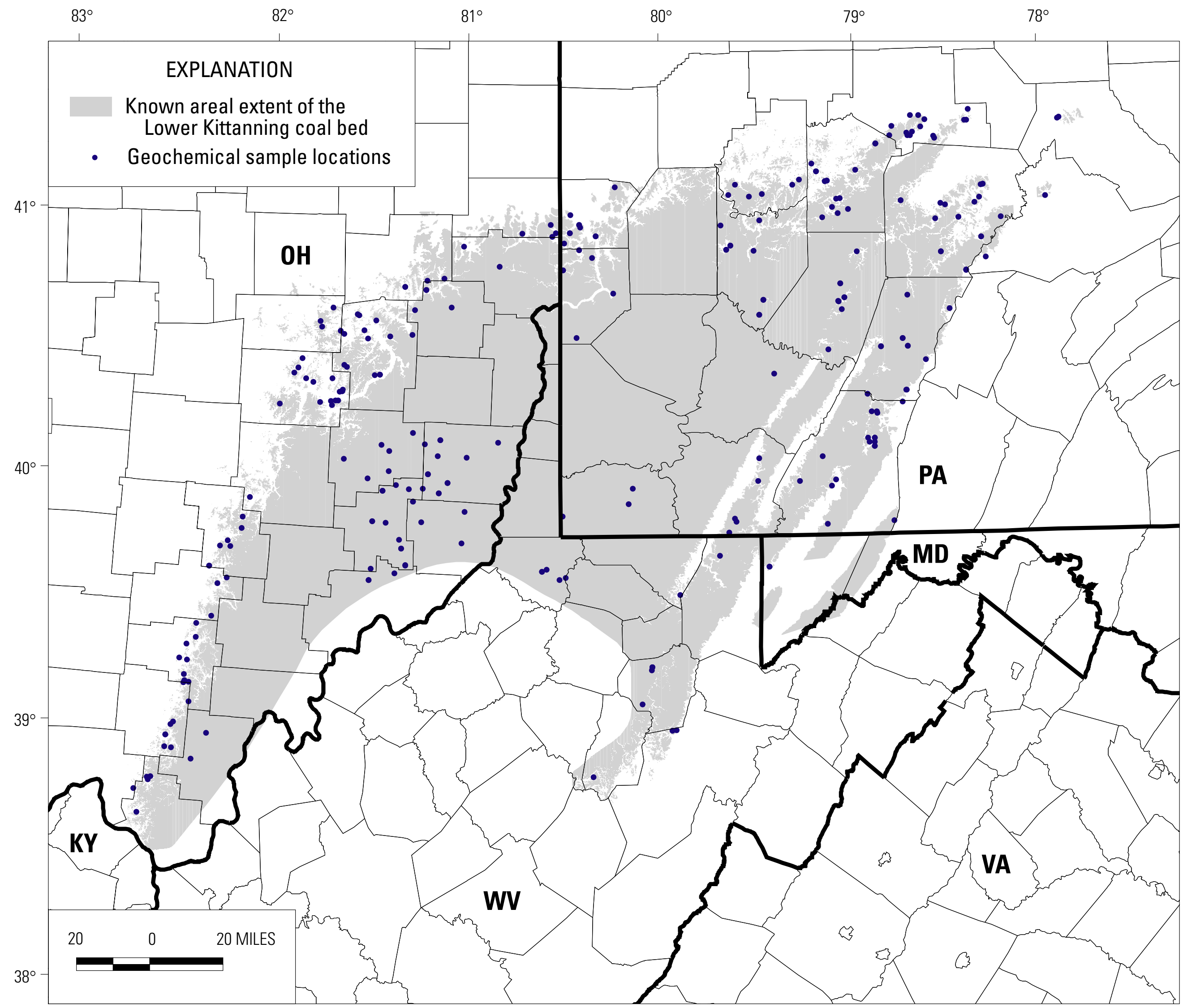

Figure 13. Map showing point locations of geochemical samples for which records are publicly available and located by latitude and longitude. All of the geochemical data can be downloaded in ASCII format from Appendix 2. See figure 2 for county names.

Appendixes 2 and 3 (containing the geochemical database and metadata), which can be downloaded in ASCII format from this report.

RESULTS

GEOCHEMISTRY

The apparent rank of the Lower Kittanning coal bed (fig. 14) decreases from low-volatile bituminous in the eastern part to high-volatile C bituminous in the southwestern part of the coal's areal extent. Figures 15 and 16, along with tables 7 and 8, show the Lower Kittanning coal bed to be a medium-ash, medium- to high-sulfur coal.

The geochemical data may not be representative of the entire Lower Kittanning coal resource because more of the samples are located along the edges of the coal bed's extent than in the middle. Futhermore, samples may be from areas that previously were mined (figs. 5, 13). The number of samples is not evenly distributed among the States: Pennsylvania (1,754), Ohio (368), West Virginia (35), and Maryland (11). Two sets of statistics and geochemical maps are presented for each chemical parameter because both point and county data are contained in the geochemical database. Only the data for the 273 geochemical samples for which records are publicly available and located by latitude and longitude are found in Appendix 2 and are shown on the point-data maps (Map A in figs. 15-31). All data, public and proprietary for 2,158 samples, are incorporated on the county average maps (Map B in figs. 15-31) and in tables 7 through 23. Ash yield and sulfur content are classified into three categories as specified by Wood and others (1983). In addition, the Clean Air Act Amendments of 1990 (Public Law 101-549) regulates the amount of sulfur dioxide (SO_2) produced in the burning of the coal. The amount of SO_2 is calculated as approximately two times the percent of sulfur produced by burning. In the low category, ash yields range from >0 to ≤8 weight percent, sulfur contents range from >0 to ≤1 weight percent, and SO_2 ranges from >0 to ≤1.2 lbs/million Btu. In the medium category, ash yields range from >8 to ≤15 weight percent, sulfur contents range from >1 to <3 weight percent, and SO_2 ranges from >1.2 to ≤2.5 lbs/ million Btu. In the high category, ash contents are >15 weight percent, sulfur contents are ≥3 weight percent, and SO_2 is >2.5 lbs/million Btu. These data are presented as point data in Map A of figures 15 to 17 and as county means in Map B of the same figures.

Gross calorific value, total moisture content, and the geochemistry of selected trace elements are reported in figures 18 through 31. In these figures, point data and county mean data are classified into five data categories, or quintiles, each representing 20 percent of the data. The ranges of the quintiles will be different for each data set and each chemical parameter because they are based on different sets of data (point data as shown in Appendix 2 versus county means calculated in tables 7-23). Most of the maps show no trends on a regional scale.

Overall, figure 15B shows the Lower Kittanning to be a medium-ash coal bed (the mean value for 2,138 samples is 11.98±4.69 weight percent, as-received whole coal basis). When examining ash-yield statistics by State (table 7), mean ash yields range from 10.38±4.20 weight percent (as received whole-coal basis) in Ohio to 17.47±5.98 weight percent (as-received whole-coal basis) in Maryland, which is a fairly large variation. The variation probably is due to sample size: Maryland is represented by 11 samples while Ohio is represented by 340 samples. However, Pennsylvania, which is represented by 1,754 samples, has a mean ash yield of 12.23±4.71 weight percent (as-received whole-coal basis). These mean values imply that the ash yield decreases from east to west; however, the maps of ash yield (fig. 15A, B) do not show distinct trends on a regional scale.

The Lower Kittanning, with an overall mean sulfur content of 2.90±1.55 weight percent (as-received whole-coal basis), is a medium-sulfur coal (table 8). Mean sulfur contents for each State are as follows: 2.75±1.49 for Pennsylvania, 1.73±0.86 for West Virginia, 3.73±1.55 for Ohio, and 3.29±1.58 for Maryland. Figure 16 shows that, in general, the sulfur content of the Lower Kittanning coal bed decreases from west to east.

The Clean Air Act Amendments of 1990 (Public Law 101-549) mandates that the electric power industry comply with legislation regulating the amount of SO_2 that can be released into the atmosphere. The compliance level was reduced from 2.5 lbs SO_2/million Btu to 1.2 lbs SO_2/million Btu, which equates to 0.6 lbs sulfur/million Btu. These compliance levels went into effect at the beginning of 2000. Few of the Lower Kittanning coal samples (fig.17A; table 9) meet pre-2000 emission standards. The data means calculated from sulfur content in table 9 and the county means shown on the map in figure 17B clearly show that, overall, the Lower Kittanning coal bed as mined is noncompliant.

The mean gross calorific value for the Lower Kittanning coal bed is 12,890±940 Btu/lb and ranges from 12,140±760 Btu/lb in Ohio to 13,170±860 Btu/lb in Pennsylvania (fig. 18; table 10). Figure 18 shows that the gross calorific values appear to decrease from east to west. This decrease in gross calorific values reflects changes in rank from low-volatile bituminous through medium-volatile bituminous to high-volatile C from east to west as shown in figure 14.

The total moisture content (fig. 19; table 11) tends to be relatively low with a mean of 3.19±2.05 percent for the entire bed (1,515 analyses) because the Lower Kittanning coal is bituminous in rank. As might be expected, total

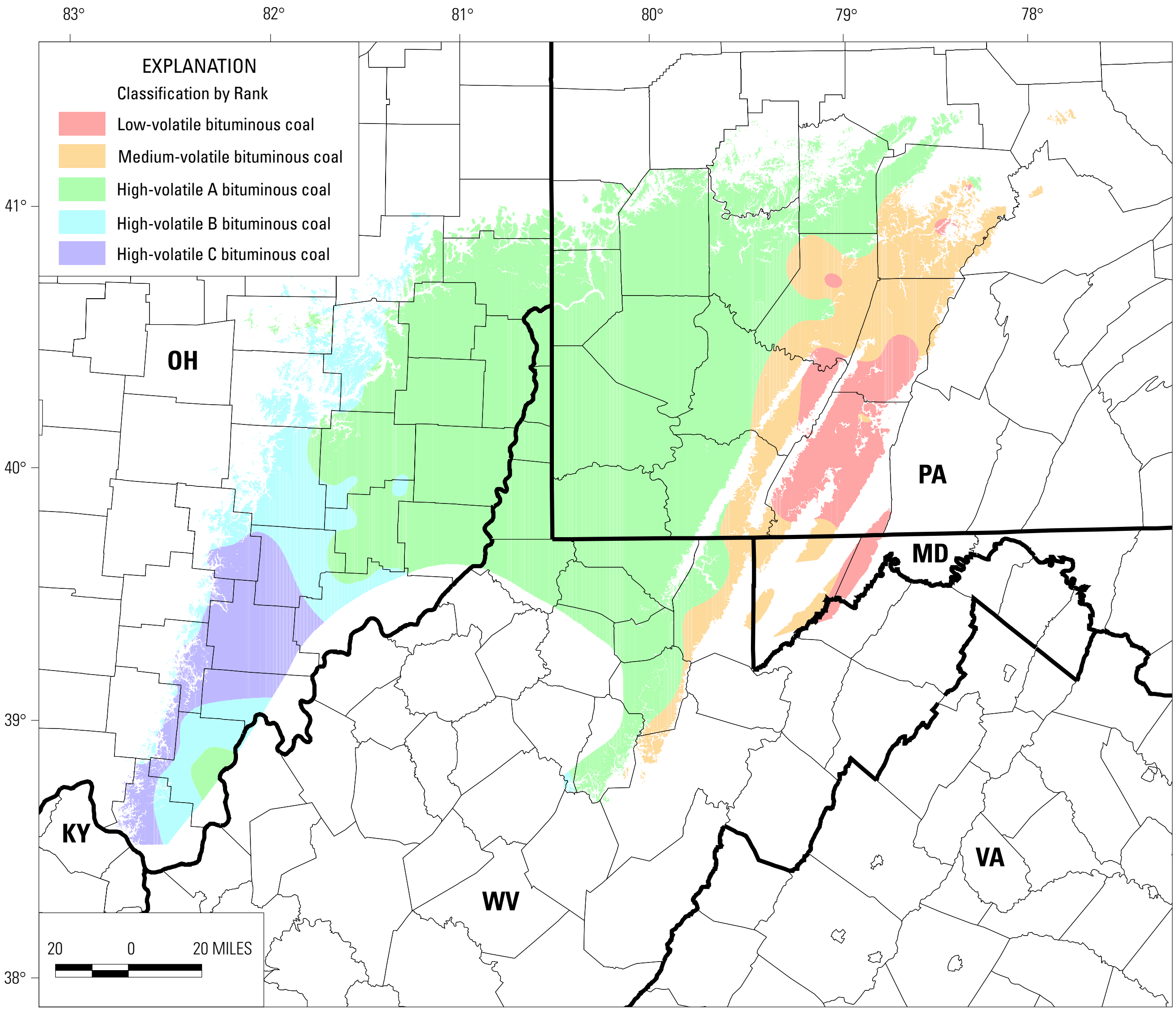

Figure 14. Map showing apparent rank of the Lower Kittanning coal bed based on 271 analyses. The coal tends to decrease in rank from low-volatile bituminous in the east to high-volatile C bituminous in the southwest. Methodology for rank determinations is based on the percentage of fixed carbon in the sample. When dry, mineral-matter-free (dmmf) fixed carbon is greater than 69 percent, rank is determined on dmmf fixed carbon, and when dmmf fixed carbon is less than 69 percent, rank is determined from moist, mineral-matter-free gross calorific values (American Society for Testing and Materials, 1996). See figure 2 for county names.

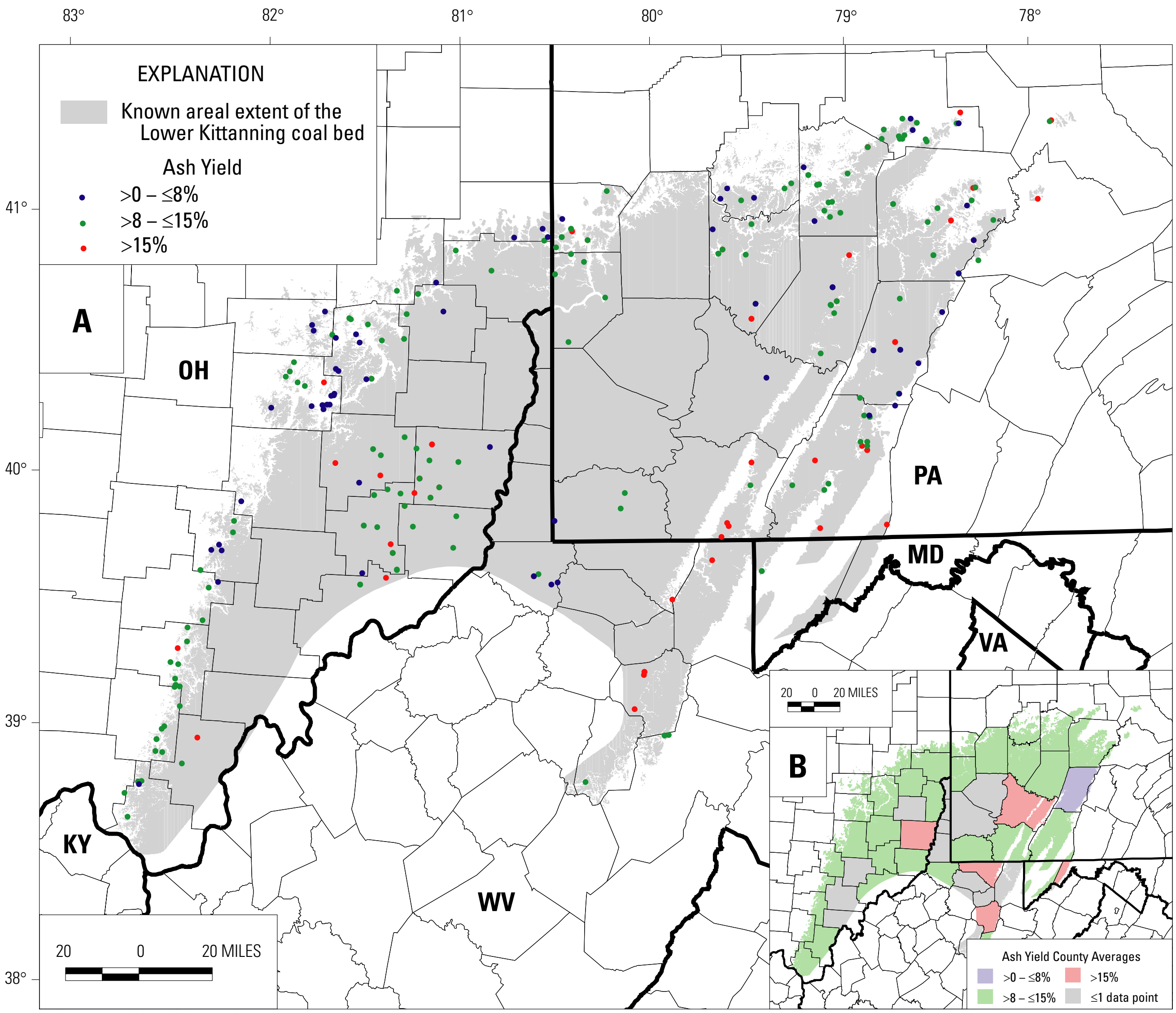

Figure 15. Maps showing ash yield (weight percent, as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows ash yields of the 270 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for ash yields using all 2,138 records in the geochemical database, including those that are located only to a county level; ash yields range from 2.20 to 32.55 weight percent with a mean value of 11.98±4.69 weight percent (table 7). Ash yields are classified into low (>0 to ≤8 weight percent), medium (>8 to ≤15 weight percent), and high (>15 weight percent) as specified by Wood and others (1983). See figure 2 for county names.

Table 7. Ash yield (weight percent; American Society for Testing and Materials method) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	11.98	2.20	32.55	4.69	2,138
PA	na	12.23	2.80	32.55	4.71	1,754
WV	na	12.93	2.46	20.61	3.86	33
OH	na	10.38	2.20	29.10	4.20	340
MD	na	17.47	10.55	26.67	5.98	11
PA	Armstrong	14.06	5.68	26.49	4.46	243
PA	Beaver	12.00	8.16	14.88	2.47	7
PA	Blair	7.64	6.85	8.42	1.10	2
PA	Butler	13.99	5.92	19.11	3.61	56
PA	Cambria	7.75	3.70	18.85	2.23	185
PA	Centre	13.36	7.60	26.81	4.97	20
PA	Clarion	10.73	5.80	19.55	2.78	81
PA	Clearfield	11.40	5.80	28.40	3.65	162
PA	Clinton	10.38	2.80	17.40	5.36	5
PA	Elk	11.36	6.43	30.64	5.78	30
PA	Fayette	12.40	6.51	22.29	5.12	16
PA	Greene	8.87	7.00	10.87	1.94	3
PA	Indiana	13.36	4.24	32.55	4.60	534
PA	Jefferson	13.12	5.55	29.54	4.95	128
PA	Lawrence	11.83	6.34	15.90	2.72	13
PA	Mercer	11.43	8.39	14.98	2.86	4
PA	Somerset	8.97	4.10	22.98	3.56	147
PA	Westmoreland	15.24	7.30	30.53	4.89	118
WV	Barbour	15.87	12.30	18.94	2.25	9
WV	Monongalia	15.85	15.79	15.91	0.09	2
WV	Preston	nd	20.61	20.61	nd	1
WV	Randolph	11.65	9.01	15.06	1.56	15
WV	Upshur	nd	13.00	13.00	nd	1
WV	Wetzel	8.75	2.46	18.24	5.83	5
OH	Belmont	15.44	6.60	27.66	5.82	19
OH	Carroll	11.06	4.50	15.73	3.36	8
OH	Columbiana	8.78	5.00	12.94	2.71	10
OH	Coshocton	9.22	2.20	19.61	3.57	43
OH	Gallia	13.03	9.70	15.80	2.63	5
OH	Guernsey	11.99	7.50	17.30	3.38	13
OH	Hocking	9.54	3.20	13.20	2.94	8
OH	Holmes	8.49	6.00	10.30	1.67	11
OH	Jackson	9.54	2.80	16.76	4.17	16
OH	Jefferson	9.82	6.02	19.01	3.08	22
OH	Lawrence	9.16	4.20	14.68	2.71	27
OH	Mahoning	10.10	3.69	22.69	6.71	17
OH	Monroe	11.83	7.60	19.97	4.09	7
OH	Muskingum	8.44	4.80	15.50	3.31	8
OH	Noble	12.00	6.20	22.20	4.06	15
OH	Perry	10.26	6.30	18.80	2.49	26
OH	Scioto	8.82	6.00	10.60	2.47	3
OH	Stark	9.61	7.05	13.56	2.48	9
OH	Tuscarawas	9.13	3.50	21.99	3.93	45
OH	Vinton	12.82	5.10	29.10	4.84	25
OH	Washington	15.00	11.00	22.00	6.08	3
MD	Allegany	21.86	14.70	26.67	4.35	6
MD	Garrett	12.20	10.55	14.18	1.44	5

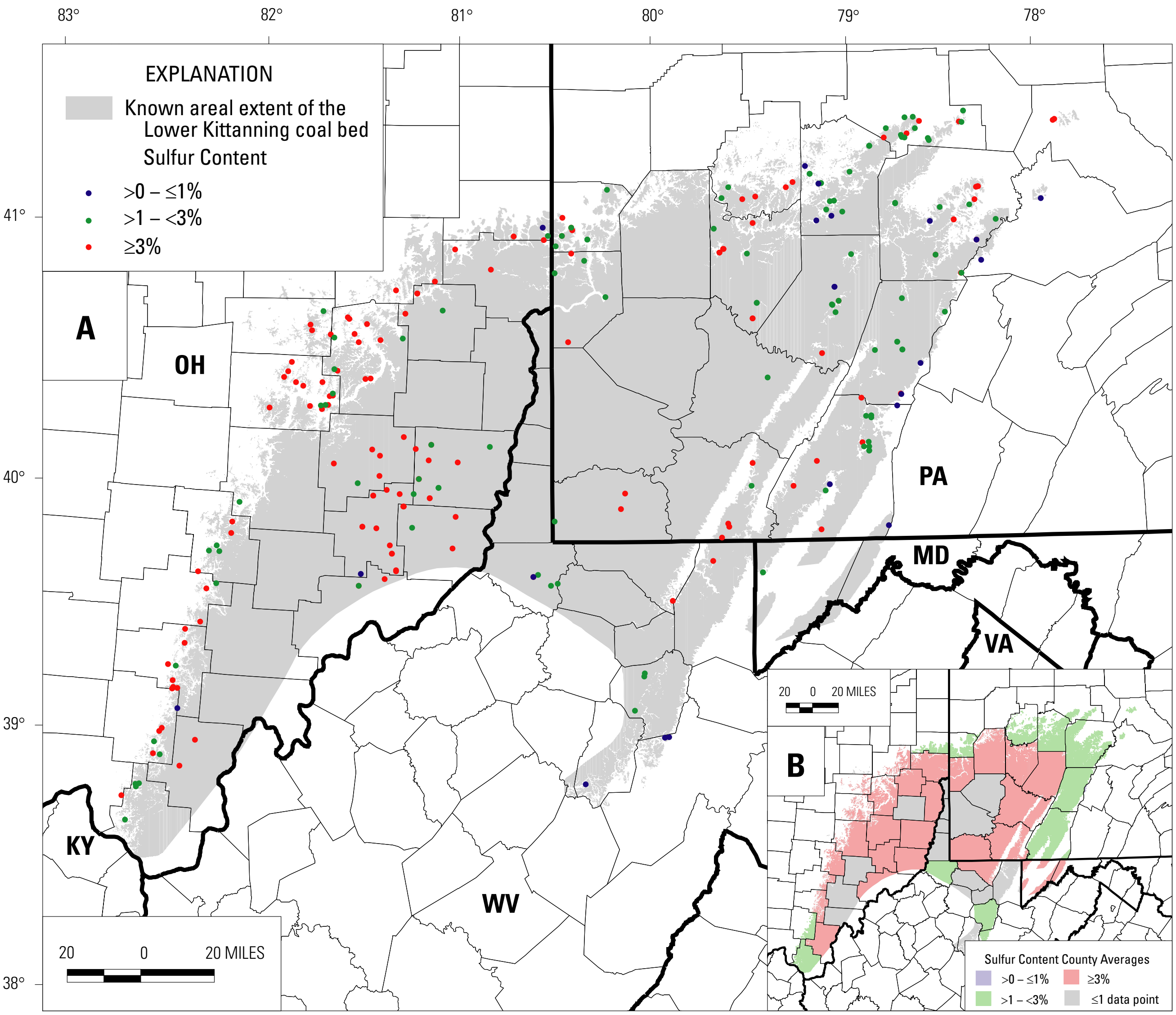

Figure 16. Maps showing sulfur content (weight percent, as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows sulfur contents of the 261 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for sulfur contents using all 2,137 records in the geochemical database, including those that are located only to a county level; sulfur contents range from 0.23 to 9.54 weight percent with a mean value of 2.90±1.55 weight percent (table 8). 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). In general, sulfur content decreases from west to east. See figure 2 for county names.

Table 8. Sulfur content (weight percent; American Society for Testing and Materials method) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	2.90	0.23	9.54	1.55	2,137
PA	na	2.75	0.23	9.54	1.49	1,748
WV	na	1.73	0.60	3.21	0.86	31
OH	na	3.73	0.70	8.00	1.55	348
MD	na	3.29	1.76	5.97	1.58	10
PA	Armstrong	3.40	0.68	8.97	1.56	243
PA	Beaver	3.30	2.19	5.13	0.97	7
PA	Blair	0.70	0.54	0.86	0.22	2
PA	Butler	3.26	0.70	7.45	1.45	56
PA	Cambria	1.81	0.47	5.46	0.91	184
PA	Centre	1.70	0.80	3.61	0.82	20
PA	Clarion	2.85	0.78	9.54	1.56	81
PA	Clearfield	2.25	0.66	6.60	1.05	160
PA	Clinton	2.65	0.66	3.94	1.28	5
PA	Elk	2.34	0.68	4.28	0.93	30
PA	Fayette	3.35	1.75	6.58	1.49	15
PA	Greene	3.90	1.84	5.30	1.82	3
PA	Indiana	3.24	0.54	8.95	1.44	534
PA	Jefferson	2.06	0.23	8.80	1.69	128
PA	Lawrence	2.50	1.04	3.65	0.83	13
PA	Mercer	2.13	1.99	2.27	0.15	4
PA	Somerset	1.61	0.43	5.31	0.87	145
PA	Westmoreland	3.40	0.53	8.33	1.33	118
WV	Barbour	2.16	0.78	2.98	0.85	7
WV	Monongalia	3.20	3.18	3.21	0.02	2
WV	Preston	nd	3.14	3.14	nd	1
WV	Randolph	1.26	0.68	2.18	0.43	15
WV	Upshur	nd	0.60	0.60	nd	1
WV	Wetzel	1.89	0.70	3.02	0.83	5
OH	Belmont	3.24	1.20	5.15	1.16	19
OH	Carroll	4.31	1.60	7.50	2.04	8
OH	Columbiana	4.99	2.50	8.00	1.83	10
OH	Coshocton	4.22	0.99	7.10	1.50	42
OH	Gallia	4.24	2.50	5.54	1.32	5
OH	Guernsey	4.35	1.40	7.40	1.83	13
OH	Hocking	3.39	1.20	6.40	1.66	8
OH	Holmes	4.43	2.50	6.30	1.23	10
OH	Jackson	2.30	0.70	4.40	1.21	15
OH	Jefferson	3.15	2.34	7.30	0.90	34
OH	Lawrence	2.21	0.95	5.70	1.03	27
OH	Mahoning	2.42	0.70	4.57	1.26	16
OH	Monroe	4.20	1.40	6.70	1.92	7
OH	Muskingum	3.58	2.40	4.80	1.06	8
OH	Noble	4.37	0.90	8.00	1.60	15
OH	Perry	4.71	1.90	8.00	1.77	25
OH	Scioto	2.50	1.10	3.90	1.40	3
OH	Stark	4.30	1.90	6.91	1.49	11
OH	Tuscarawas	3.94	1.90	7.20	1.16	45
OH	Vinton	4.27	2.40	6.45	1.01	24
OH	Washington	3.33	2.40	4.00	0.83	3
MD	Allegany	3.21	1.76	5.97	1.65	5
MD	Garrett	3.36	1.99	5.94	1.70	5

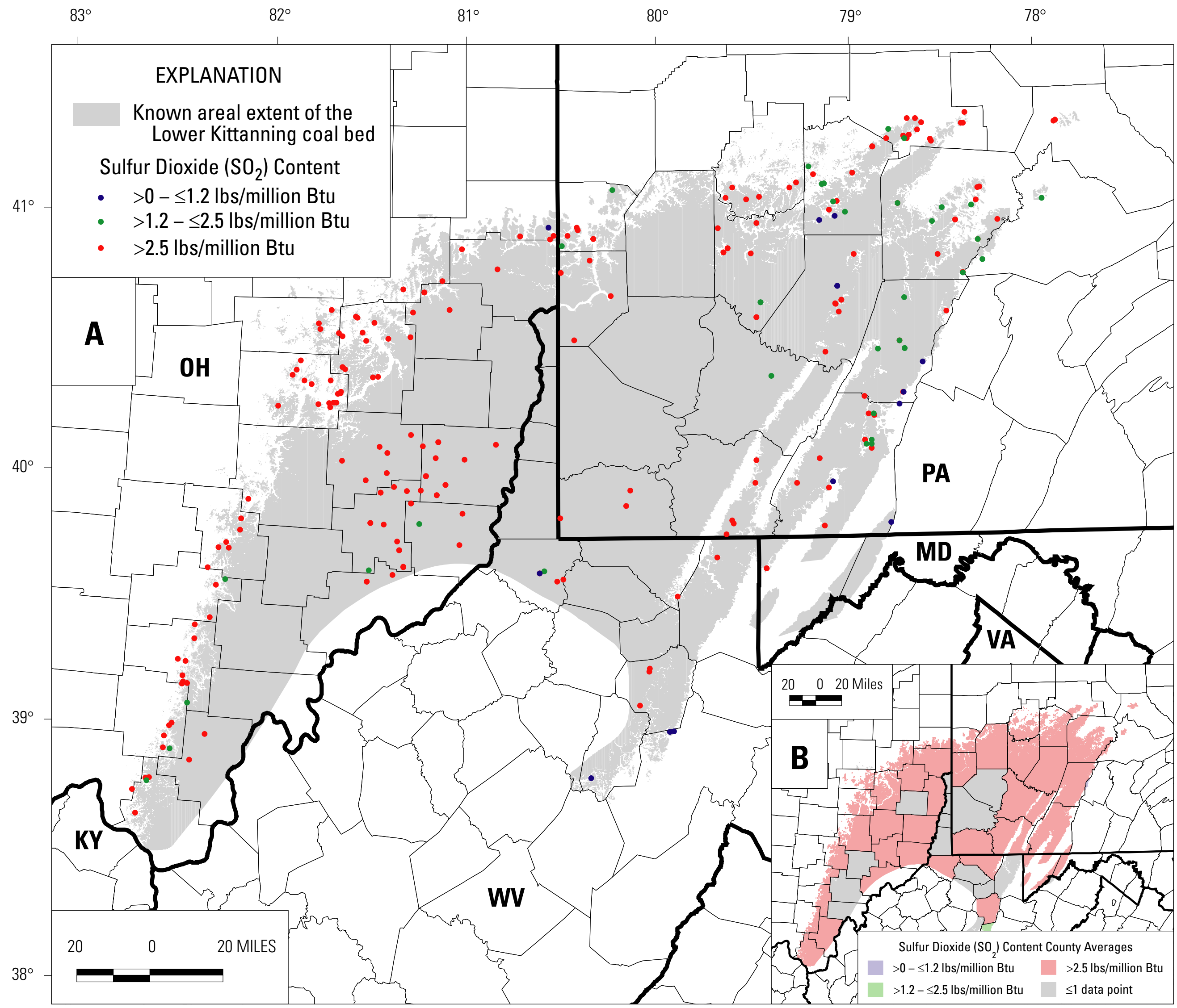

Figure 17. Maps showing sulfur-dioxide (SO_2) content (lbs/million Btu) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows SO_2 contents of the 254 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for SO_2 contents using all 1,325 records in the geochemical database, including those that are located only to a county level; SO_2 contents range from 0.44 to 17.07 lbs/million Btu with a mean value of 4.40±2.67 lbs/million Btu (table 9). SO_2 contents are classified into low (0 to ≤1.2 lbs/million Btu), medium (>1.2 to ≤2.5 lbs/million Btu), and high (>2.5 lbs/million Btu) categories, based on past and present Clean Air Acts. See figure 2 for county names.

Table 9. Sulfur-dioxide (SO_2) content (lbs/million Btu) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	4.40	0.44	17.07	2.67	1,325
PA	na	3.77	0.44	17.07	2.37	942
WV	na	2.72	0.96	5.33	1.42	31
OH	na	6.27	1.02	14.43	2.65	342
MD	na	5.31	2.91	10.74	2.66	10
PA	Armstrong	5.08	1.04	17.07	2.83	160
PA	Beaver	5.08	3.56	7.71	1.47	6
PA	Blair	1.10	0.93	1.26	0.23	2
PA	Butler	4.17	1.02	8.56	2.86	8
PA	Cambria	2.57	0.75	5.30	1.12	130
PA	Centre	2.64	1.29	5.32	1.25	18
PA	Clarion	4.19	1.16	9.02	2.02	63
PA	Clearfield	3.34	1.02	10.81	1.73	134
PA	Clinton	4.08	0.88	5.98	2.01	5
PA	Elk	3.70	1.38	6.51	1.27	25
PA	Fayette	5.30	2.51	11.49	2.68	14
PA	Greene	5.76	2.65	7.95	2.77	3
PA	Indiana	4.63	0.74	12.96	2.44	137
PA	Jefferson	3.07	0.44	15.37	2.94	101
PA	Lawrence	3.66	1.59	5.67	1.31	10
PA	Mercer	3.47	3.11	3.89	0.39	4
PA	Somerset	2.65	0.69	8.28	1.48	105
PA	Westmoreland	5.65	2.26	9.83	2.06	17
WV	Barbour	3.47	1.21	4.92	1.42	7
WV	Monongalia	5.03	5.03	5.03	nd	2
WV	Preston	nd	5.33	5.33	nd	1
WV	Randolph	1.96	1.00	3.65	0.72	15
WV	Upshur	nd	0.99	0.99	nd	1
WV	Wetzel	2.85	0.96	4.96	1.43	5
OH	Belmont	5.41	1.88	8.10	1.92	19
OH	Carroll	7.03	2.52	12.35	3.41	8
OH	Columbiana	7.82	3.75	12.55	3.11	10
OH	Coshocton	7.01	1.65	12.52	2.65	42
OH	Gallia	7.35	4.00	9.88	2.60	5
OH	Guernsey	7.22	2.25	12.98	3.25	13
OH	Hocking	5.80	1.99	11.60	3.09	8
OH	Holmes	7.23	3.92	11.00	2.22	10
OH	Jackson	4.00	1.08	8.11	2.17	15
OH	Jefferson	4.93	3.51	11.74	1.48	34
OH	Lawrence	4.14	1.48	9.86	1.80	21
OH	Mahoning	3.94	1.02	7.09	2.00	16
OH	Monroe	6.70	2.19	10.35	3.00	7
OH	Muskingum	6.05	3.87	9.00	1.90	8
OH	Noble	7.10	1.31	13.14	2.62	15
OH	Perry	8.07	3.31	14.43	3.10	25
OH	Scioto	4.30	1.95	6.92	2.50	3
OH	Stark	7.15	3.43	11.43	2.47	11
OH	Tuscarawas	6.50	3.03	12.82	2.12	45
OH	Vinton	7.47	3.68	11.98	1.97	24
OH	Washington	5.98	3.80	7.95	2.08	3
MD	Allegany	5.55	2.91	10.74	3.09	5
MD	Garrett	5.07	2.91	8.92	2.50	5

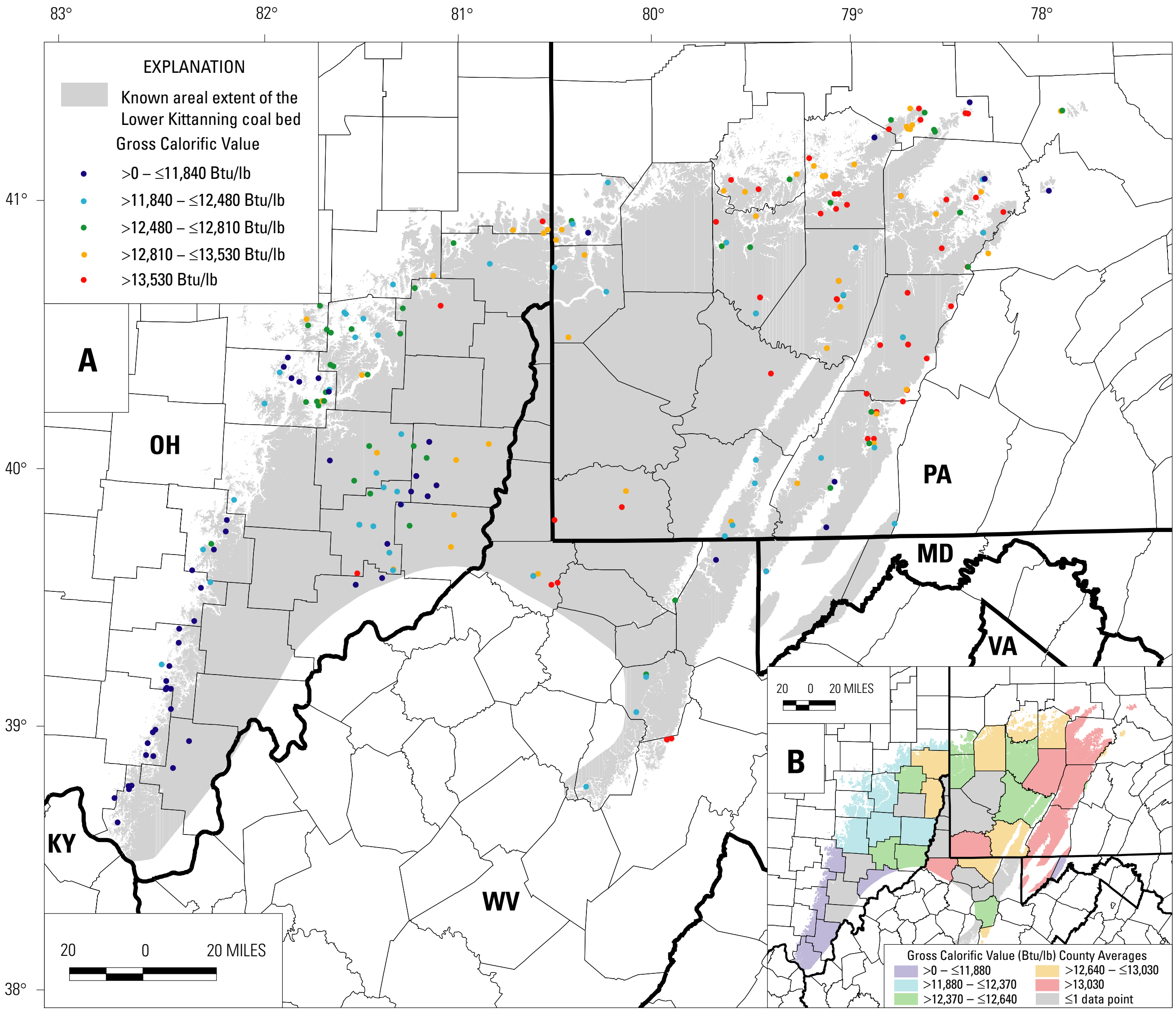

Figure 18. Maps showing gross calorific value (Btu/lb, as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows gross calorific values of the 254 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for gross calorific values using all 1,330 records in the geochemical database, including those that are located only to a county level; gross calorific values range from 9,780 to 15,040 Btu/lb with a mean value of 12,890±940 Btu/lb (table 10). The values are classified into five categories, each representing 20 percent of the data values. Gross calorific value tends to increase to the east. See figure 2 for county names.

Table 10. Gross calorific value (Btu/lb; American Society for Testing and Materials method) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	12,890	9,780	15,040	940	1,330
PA	na	13,170	9,780	15,040	860	940
WV	na	12,910	11,800	14,660	650	30
OH	na	12,140	10,060	13,860	760	340
MD	na	12,500	11,040	13,720	1,000	10
PA	Armstrong	12,640	9,990	14,050	910	160
PA	Beaver	12,610	12,050	13,310	530	6
PA	Blair	12,630	11,670	13,600	1,370	2
PA	Butler	12,880	11,610	13,810	760	8
PA	Cambria	13,980	12,320	14,770	410	130
PA	Centre	12,990	11,140	13,950	720	18
PA	Clarion	12,980	11,860	13,710	380	63
PA	Clearfield	13,310	11,380	14,720	590	136
PA	Clinton	13,290	12,360	15,040	1,050	5
PA	Elk	13,310	11,140	14,050	630	25
PA	Fayette	13,030	11,450	14,300	870	14
PA	Greene	13,630	13,330	13,900	290	3
PA	Indiana	13,090	10,160	14,760	980	137
PA	Jefferson	12,910	10,350	14,410	750	101
PA	Lawrence	12,380	11,840	13,110	500	10
PA	Mercer	12,300	11,560	12,870	560	4
PA	Somerset	13,540	9,780	14,750	750	105
PA	Westmoreland	12,600	10,830	14,140	1,010	17
WV	Barbour	12,540	12,080	12,880	350	6
WV	Monongalia	12,730	12,680	12,780	70	2
WV	Preston	nd	11,800	11,800	nd	1
WV	Randolph	13,000	11,940	13,850	490	15
WV	Upshur	nd	12,150	12,150	nd	1
WV	Wetzel	13,610	12,190	14,660	910	5
OH	Belmont	12,050	10,490	13,530	910	19
OH	Carroll	12,420	11,170	13,860	830	8
OH	Columbiana	12,920	11,530	13,570	610	10
OH	Coshocton	12,170	10,630	13,310	550	42
OH	Gallia	11,740	10,620	12,690	870	5
OH	Guernsey	12,180	11,400	12,850	540	13
OH	Hocking	11,880	11,030	12,650	540	8
OH	Holmes	12,350	11,460	13,060	490	10
OH	Jackson	11,620	10,510	13,530	870	15
OH	Jefferson	12,830	11,260	13,660	550	34
OH	Lawrence	11,820	10,920	13,550	640	21
OH	Mahoning	12,370	10,550	13,740	1,090	16
OH	Monroe	12,500	11,530	13,210	710	7
OH	Muskingum	11,910	10,670	12,570	760	8
OH	Noble	12,400	11,070	13,690	630	15
OH	Perry	11,710	10,670	12,760	450	25
OH	Scioto	11,650	11,270	12,420	660	3
OH	Stark	12,000	11,050	13,100	670	11
OH	Tuscarawas	12,240	10,440	13,400	590	45
OH	Vinton	11,520	10,770	13,050	640	24
OH	Washington	11,430	10,060	12,620	1,290	3
MD	Allegany	11,760	11,040	12,950	790	5
MD	Garrett	13,240	12,420	13,720	530	5

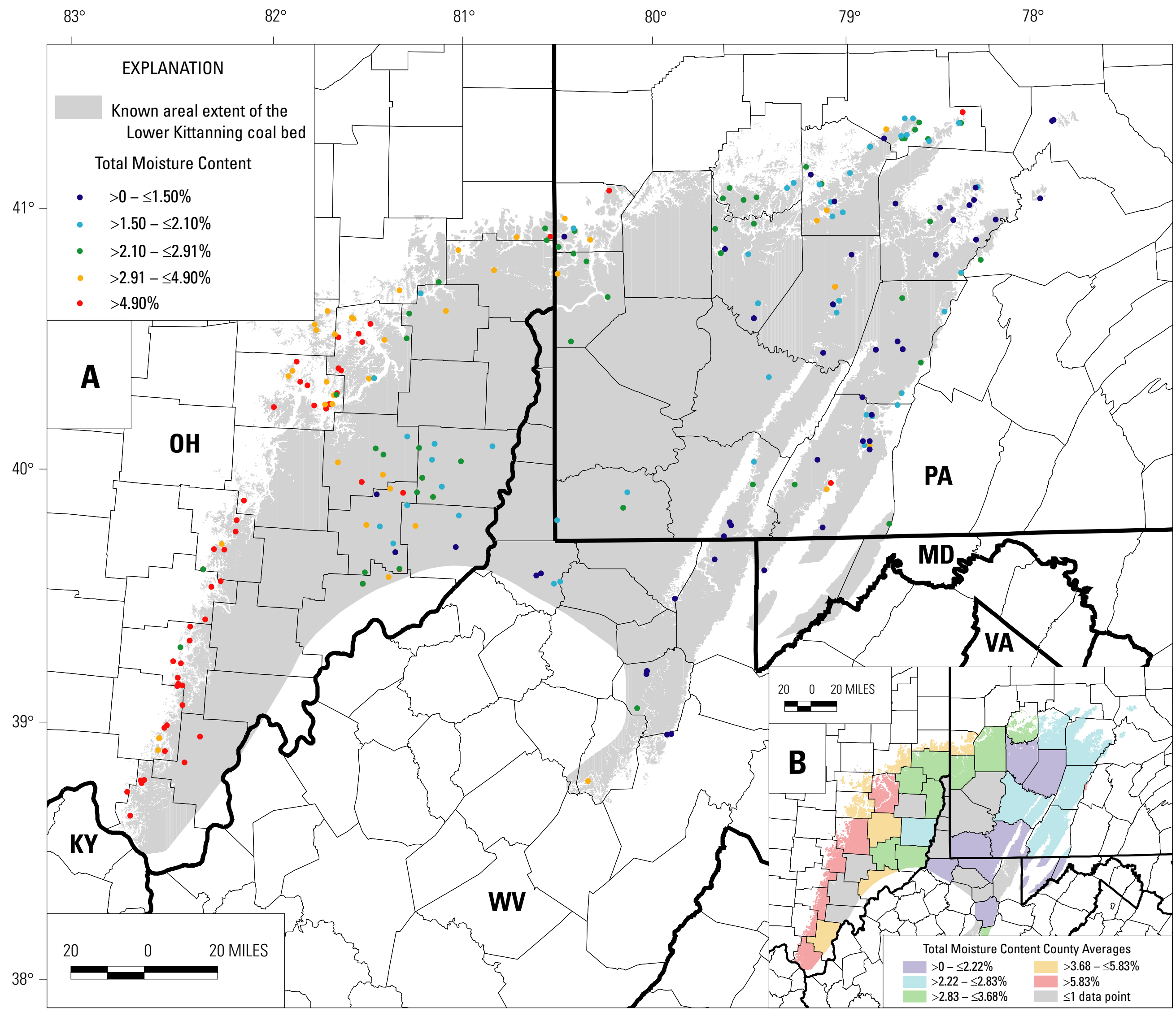

Figure 19. Maps showing total moisture content (weight percent, as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. ASTM (American Society for Testing and Materials) moisture values replaced by equilibrium moisture values where available. Map A shows total moisture contents of the 270 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for total moisture contents using all 1,515 records in the geochemical database, including those that are located only to a county level; total moisture contents range from 0.01 to 10.74 weight percent with a mean value of 3.19±2.05 weight percent (table 11). The values are classified into five categories, each representing 20 percent of the data values. The Lower Kittanning coal bed is a bituminous coal and therefore the moisture content is relatively low. See figure 2 for county names.

Table 11. Total moisture content (weight percent) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

[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.]

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	3.19	0.01	10.74	2.05	1,515
PA	na	2.53	0.01	10.74	1.38	1,115
WV	na	2.36	0.56	6.40	1.51	33
OH	na	5.38	1.40	10.60	2.32	356
MD	na	1.79	0.50	4.46	1.16	11
PA	Armstrong	1.80	0.23	8.40	1.09	175
PA	Beaver	3.21	2.13	4.80	0.95	7
PA	Blair	7.15	4.80	9.50	3.32	2
PA	Butler	2.84	1.21	6.80	1.66	11
PA	Cambria	2.72	0.30	8.99	1.09	176
PA	Centre	2.59	0.60	5.10	1.13	20
PA	Clarion	2.96	0.88	8.20	1.33	68
PA	Clearfield	2.78	0.41	8.70	1.44	146
PA	Clinton	2.69	0.76	5.90	2.18	5
PA	Elk	2.34	0.86	5.46	1.15	30
PA	Fayette	2.16	0.66	3.30	0.84	15
PA	Greene	2.16	1.74	2.88	0.63	3
PA	Indiana	2.22	0.01	10.19	1.57	162
PA	Jefferson	2.52	0.61	10.74	1.37	112
PA	Lawrence	3.94	1.41	8.16	1.82	13
PA	Mercer	5.43	4.70	6.40	0.71	4
PA	Somerset	2.81	0.45	8.69	1.17	147
PA	Westmoreland	2.83	0.58	6.65	1.37	19
WV	Barbour	1.77	0.86	3.50	0.89	9
WV	Monongalia	0.78	0.78	0.78	nd	2
WV	Preston	nd	1.16	1.16	nd	1
WV	Randolph	3.27	1.04	6.40	1.46	15
WV	Upshur	nd	4.80	4.80	nd	1
WV	Wetzel	1.07	0.56	1.51	0.43	5
OH	Belmont	2.64	1.60	5.00	1.05	19
OH	Carroll	3.60	2.00	5.80	1.49	8
OH	Columbiana	3.68	2.50	5.00	0.88	10
OH	Coshocton	5.49	2.10	10.30	1.81	43
OH	Gallia	5.80	2.90	8.70	2.08	5
OH	Guernsey	4.41	2.09	7.00	1.54	13
OH	Hocking	6.29	3.60	9.90	2.07	8
OH	Holmes	5.07	2.27	7.86	1.79	11
OH	Jackson	7.40	2.80	10.60	2.33	16
OH	Jefferson	3.63	2.10	7.40	1.34	34
OH	Lawrence	7.83	3.40	9.60	1.56	27
OH	Mahoning	4.96	2.04	9.50	2.33	17
OH	Monroe	3.14	1.40	9.00	2.65	7
OH	Muskingum	7.69	5.10	10.39	1.79	8
OH	Noble	3.04	1.50	6.40	1.40	15
OH	Perry	6.77	2.42	10.50	1.98	26
OH	Scioto	7.65	7.00	8.66	0.88	3
OH	Stark	5.83	2.70	9.80	2.69	11
OH	Tuscarawas	5.95	1.96	10.60	1.94	46
OH	Vinton	5.89	2.14	10.20	1.95	26
OH	Washington	4.70	2.80	6.70	1.95	3
MD	Allegany	1.47	0.50	2.50	0.76	6
MD	Garrett	2.17	0.99	4.46	1.52	5

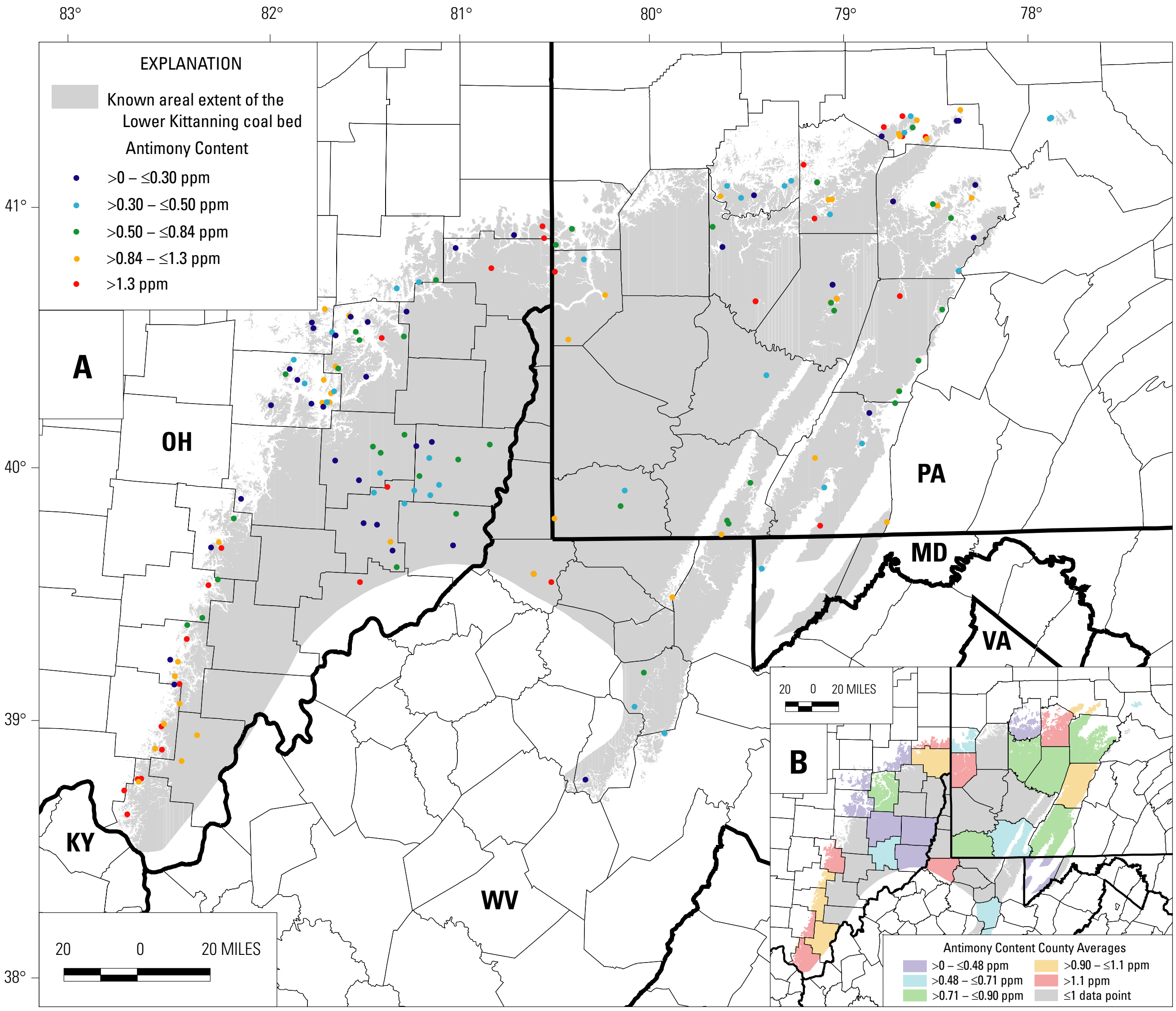

Figure 20. Maps showing antimony content (parts per million (ppm), as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows antimony contents of the 183 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for antimony contents using all 190 records in the geochemical database, including those that are located only to a county level; antimony contents range from 0.098 to 2.9 ppm with a mean value of 0.84±0.62 ppm (table 12). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

Table 12. Antimony content (parts per million) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	0.84	0.098	2.9	0.62	190
PA	na	0.91	0.10	2.9	0.62	87
WV	na	0.99	0.29	2.3	0.68	10
OH	na	0.76	0.098	2.6	0.61	93
MD	na	0.44	0.39	0.50	0.079	2
PA	Armstrong	0.85	0.20	1.5	0.59	5
PA	Beaver	1.4	0.50	2.9	1.0	4
PA	Cambria	1.0	0.79	1.5	0.30	5
PA	Clarion	0.48	0.22	0.89	0.23	6
PA	Clearfield	0.85	0.25	2.2	0.56	15
PA	Clinton	0.67	0.37	1.2	0.49	3
PA	Elk	1.1	0.27	2.4	0.75	17
PA	Fayette	0.69	0.60	0.95	0.17	4
PA	Greene	0.72	0.38	1.0	0.33	3
PA	Indiana	0.80	0.10	1.7	0.54	7
PA	Jefferson	1.3	0.50	2.7	0.74	7
PA	Lawrence	0.64	0.60	0.69	0.064	2
PA	Somerset	0.90	0.30	2.6	0.76	8
PA	Westmoreland	nd	0.50	0.50	nd	1
WV	Barbour	0.59	0.49	0.70	0.14	2
WV	Monongalia	nd	0.97	0.97	nd	1
WV	Randolph	0.50	0.49	0.50	0.0085	2
WV	Upshur	nd	0.29	0.29	nd	1
WV	Wayne	nd	0.98	0.98	nd	1
WV	Wetzel	1.8	1.1	2.3	0.62	3
OH	Belmont	0.46	0.23	0.81	0.18	9
OH	Carroll	nd	0.099	0.099	nd	1
OH	Columbiana	0.92	0.27	1.6	0.93	2
OH	Coshocton	0.41	0.18	0.97	0.21	14
OH	Gallia	0.92	0.87	0.96	0.064	2
OH	Guernsey	0.46	0.16	0.74	0.27	6
OH	Hocking	1.1	0.54	2.1	0.91	3
OH	Holmes	0.47	0.20	0.98	0.35	4
OH	Jackson	1.2	0.48	1.8	0.55	5
OH	Lawrence	2.0	1.2	2.5	0.56	4
OH	Mahoning	1.2	0.099	1.8	0.95	3
OH	Monroe	0.40	0.20	0.60	0.20	3
OH	Muskingum	nd	0.19	0.19	nd	1
OH	Noble	0.71	0.20	1.8	0.63	7
OH	Perry	1.2	0.29	2.6	1.0	4
OH	Scioto	1.0	0.48	1.6	0.77	2
OH	Stark	0.48	0.33	0.79	0.21	4
OH	Tuscarawas	0.73	0.20	1.5	0.45	11
OH	Vinton	0.99	0.098	2.1	0.74	7
OH	Washington	nd	1.7	1.7	nd	1
MD	Garrett	0.44	0.39	0.50	0.079	2

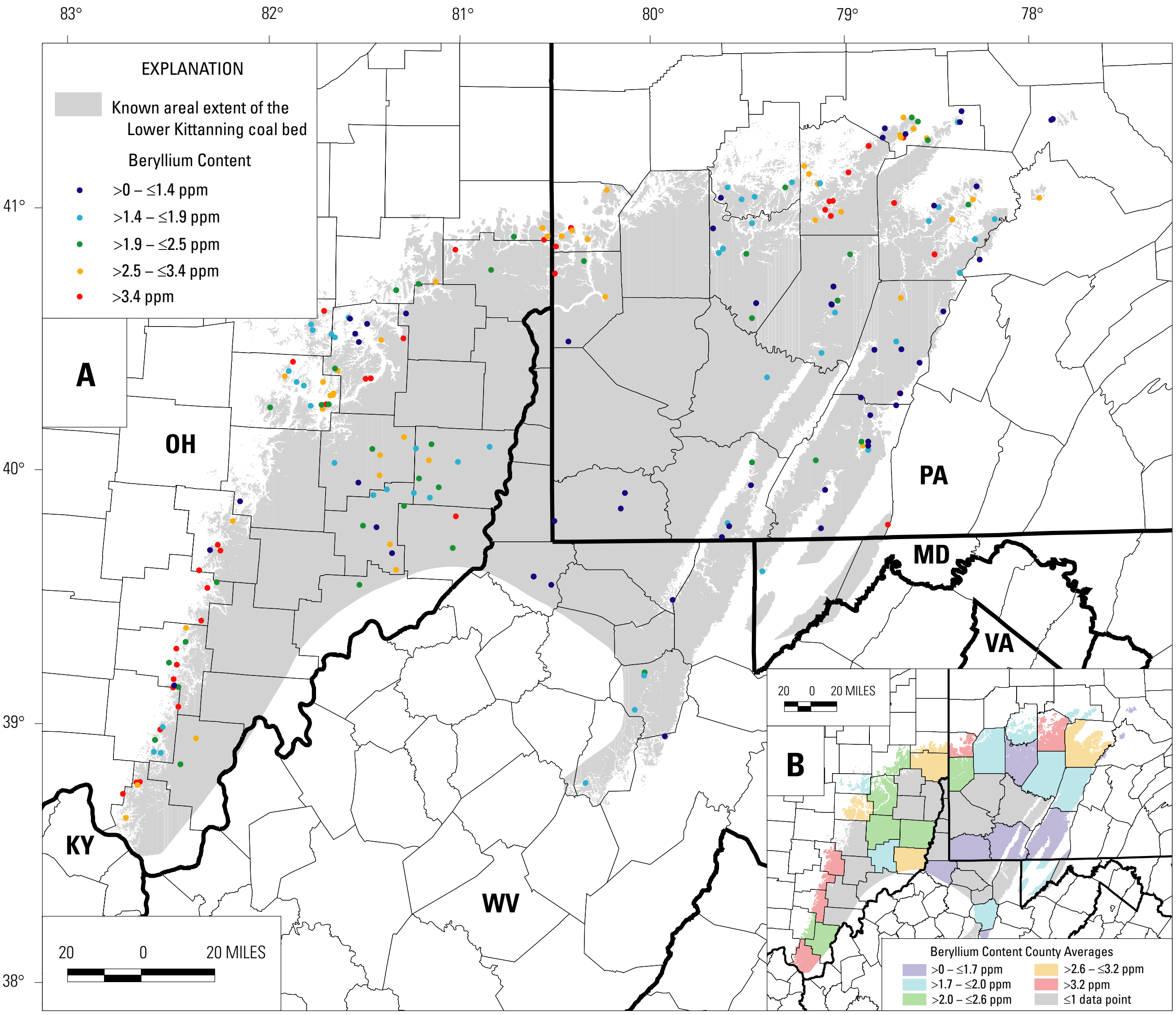

Figure 21. Maps showing beryllium content (parts per million (ppm), as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows beryllium contents of the 242 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for beryllium contents using all 290 records in the geochemical database, including those that are located only to a county level; beryllium contents range from 0.026 to 6.7 ppm with a mean value of 2.4±1.3 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 13. Beryllium content (parts per million) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	2.4	0.026	6.7	1.3	290
PA	na	2.2	0.065	5.5	1.3	160
WV	na	1.3	0.026	2.8	1.0	14
OH	na	2.8	0.037	6.7	1.3	110
MD	na	1.9	1.8	2.1	0.21	2
PA	Armstrong	1.7	0.070	2.6	0.72	12
PA	Beaver	2.4	0.081	4.5	1.8	4
PA	Butler	2.0	1.9	2.1	0.18	2
PA	Cambria	2.0	0.85	4.1	0.94	13
PA	Centre	1.7	0.71	2.8	1.5	2
PA	Clarion	1.9	0.10	2.7	0.70	11
PA	Clearfield	2.7	1.3	5.5	1.2	27
PA	Clinton	1.1	0.78	1.5	0.36	3
PA	Elk	2.0	0.072	3.7	1.2	21
PA	Fayette	1.3	0.11	2.1	0.63	7
PA	Greene	0.091	0.070	0.11	0.020	3
PA	Indiana	1.8	0.75	4.2	1.0	9
PA	Jefferson	3.6	1.9	4.6	0.83	18
PA	Lawrence	3.8	2.6	5.5	1.2	9
PA	Somerset	1.5	0.065	4.6	1.0	18
PA	Westmoreland	nd	1.5	1.5	nd	1
WV	Barbour	2.0	1.5	2.6	0.45	6
WV	Monongalia	nd	0.17	0.17	nd	1
WV	Randolph	0.87	0.11	1.6	1.1	2
WV	Upshur	nd	1.7	1.7	nd	1
WV	Wayne	nd	2.8	2.8	nd	1
WV	Wetzel	0.093	0.026	0.18	0.081	3
OH	Belmont	2.1	1.5	3.3	0.52	9
OH	Carroll	nd	1.2	1.2	nd	1
OH	Columbiana	3.1	2.5	3.6	0.78	2
OH	Coshocton	2.7	1.6	4.0	0.71	16
OH	Gallia	2.6	2.3	2.9	0.47	2
OH	Guernsey	2.2	1.2	2.7	0.58	6
OH	Hocking	3.6	1.9	5.8	1.8	4
OH	Holmes	2.0	1.5	3.5	0.77	6
OH	Jackson	2.6	1.6	4.3	1.1	7
OH	Lawrence	4.5	2.9	6.6	1.6	5
OH	Mahoning	3.2	2.5	3.7	0.48	6
OH	Monroe	2.8	2.0	4.4	1.3	3
OH	Muskingum	nd	1.3	1.3	nd	1
OH	Noble	2.0	1.1	2.9	0.71	7
OH	Perry	3.7	0.037	5.1	1.9	6
OH	Scioto	3.6	1.5	5.7	3.0	2
OH	Stark	2.6	2.1	3.3	0.52	4
OH	Tuscarawas	2.5	0.87	4.3	1.2	14
OH	Vinton	3.6	1.0	6.7	2.0	9
OH	Washington	nd	2.4	2.4	nd	1
MD	Garrett	1.9	1.8	2.1	0.21	2

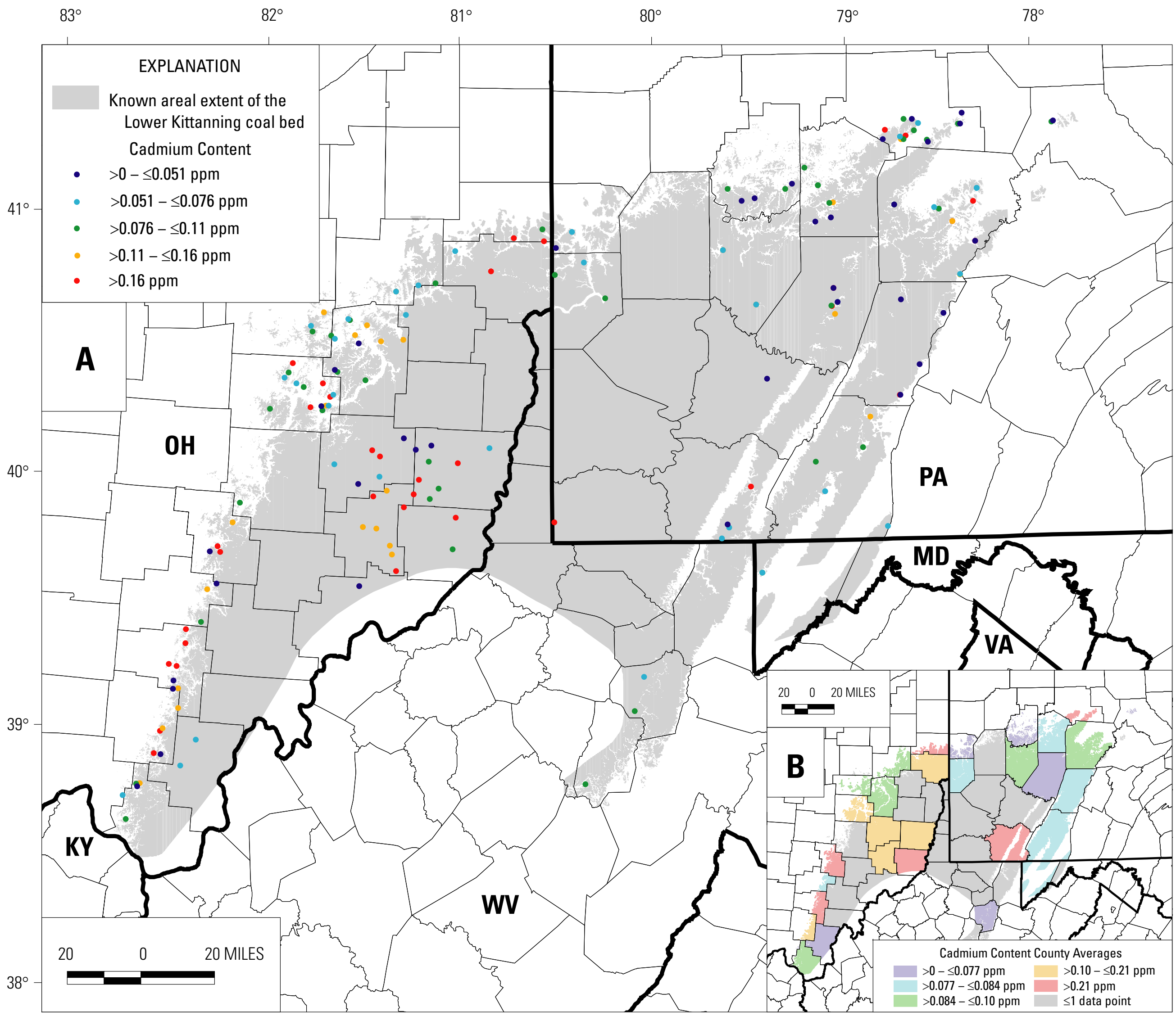

Figure 22. Maps showing cadmium content (parts per million (ppm), as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows cadmium contents of the 171 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for cadmium contents using all 180 records in the geochemical database, including those that are located only to a county level; cadmium contents range from 0.013 to 17 ppm with a mean value of 0.43±2.1 ppm (table 14). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

Table 14. Cadmium content (parts per million) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	0.43	0.013	17	2.1	180
PA	na	0.77	0.017	17	3.1	79
WV	na	0.072	0.021	0.097	0.031	5
OH	na	0.17	0.013	1.5	0.22	93
MD	na	0.081	0.063	0.099	0.026	2
PA	Armstrong	0.091	0.029	0.14	0.049	4
PA	Beaver	0.078	0.054	0.098	0.022	3
PA	Cambria	0.079	0.024	0.25	0.097	5
PA	Clarion	0.051	0.018	0.079	0.027	5
PA	Clearfield	0.10	0.021	0.29	0.076	15
PA	Clinton	0.050	0.023	0.10	0.046	3
PA	Elk	1.9	0.020	15	5.0	16
PA	Fayette	2.3	0.046	9.2	4.6	4
PA	Greene	nd	17	17	nd	1
PA	Indiana	0.073	0.022	0.20	0.057	7
PA	Jefferson	0.083	0.017	0.12	0.040	7
PA	Lawrence	0.057	0.043	0.070	0.019	2
PA	Somerset	0.081	0.054	0.13	0.029	6
PA	Westmoreland	nd	0.049	0.049	nd	1
WV	Barbour	0.077	0.070	0.085	0.010	2
WV	Randolph	nd	0.090	0.090	nd	1
WV	Upshur	nd	0.097	0.097	nd	1
WV	Wayne	nd	0.021	0.021	nd	1
OH	Belmont	0.12	0.021	0.24	0.077	9
OH	Carroll	nd	0.053	0.053	nd	1
OH	Columbiana	0.14	0.076	0.21	0.095	2
OH	Coshocton	0.13	0.047	0.29	0.072	14
OH	Gallia	0.074	0.074	0.075	0.00088	2
OH	Guernsey	0.12	0.045	0.30	0.11	6
OH	Hocking	0.084	0.018	0.14	0.060	3
OH	Holmes	0.098	0.072	0.14	0.032	4
OH	Jackson	0.18	0.031	0.30	0.11	5
OH	Lawrence	0.088	0.049	0.12	0.029	4
OH	Mahoning	0.27	0.096	0.38	0.15	3
OH	Monroe	0.34	0.091	0.70	0.32	3
OH	Muskingum	nd	0.11	0.11	nd	1
OH	Noble	0.21	0.12	0.53	0.16	7
OH	Perry	0.55	0.039	1.1	0.54	4
OH	Scioto	0.042	0.013	0.072	0.042	2
OH	Stark	0.090	0.054	0.16	0.050	4
OH	Tuscarawas	0.089	0.040	0.13	0.033	11
OH	Vinton	0.34	0.027	1.5	0.51	7
OH	Washington	nd	0.038	0.038	nd	1
MD	Garrett	0.081	0.063	0.099	0.026	2

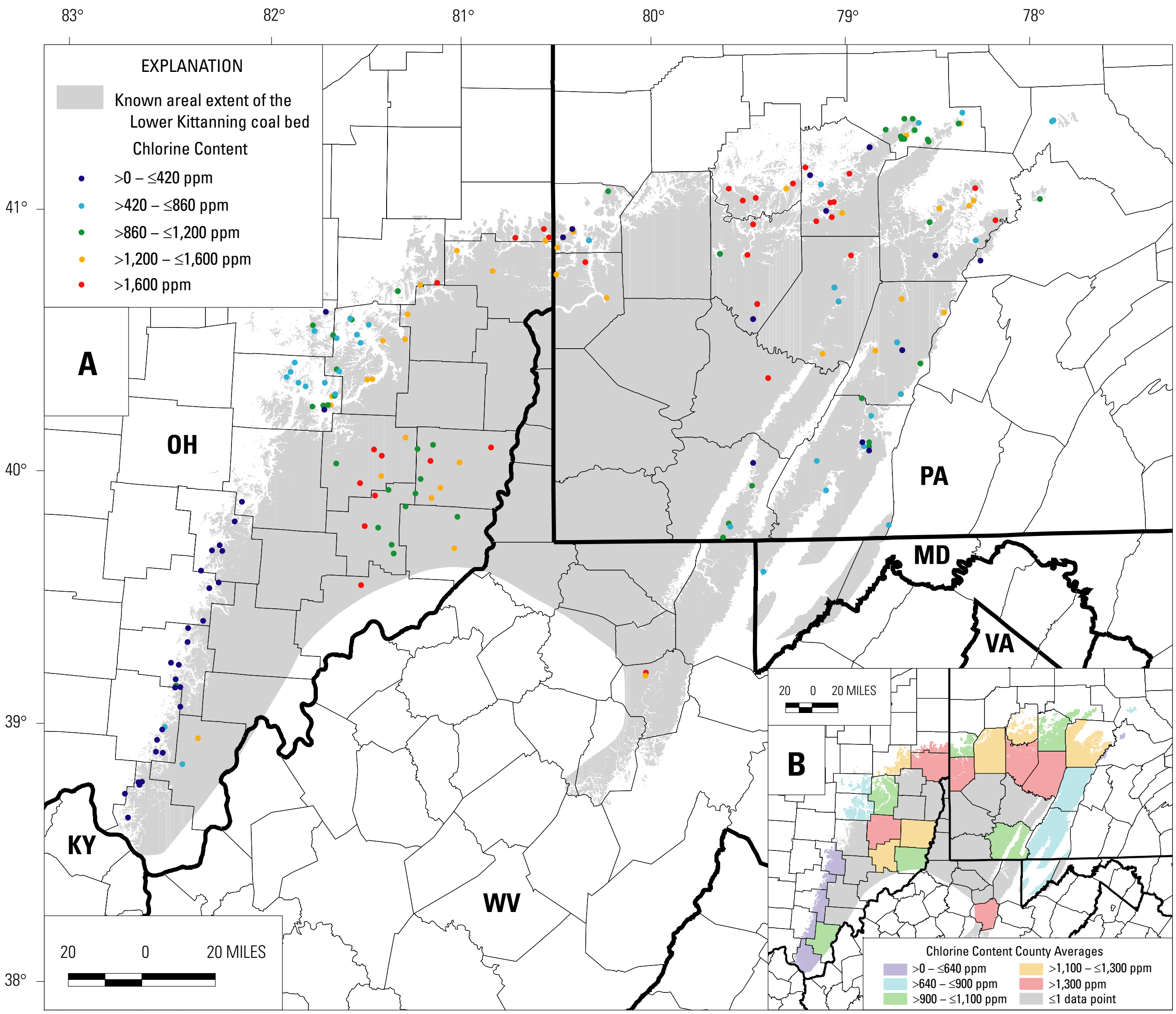

Figure 23. Maps showing chlorine content (parts per million (ppm), as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows chlorine contents of the 201 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for chlorine contents using all 240 records in the geochemical database, including those that are located only to a county level; chlorine contents range from 23 to 2,500 ppm with a mean value of 1,000±620 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 15. Chlorine content (parts per million) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	1,000	23	2,500	620	240
PA	na	1,100	95	2,500	640	130
WV	na	1,800	1,300	2,100	420	3
OH	na	930	23	2,400	590	100
MD	na	740	600	880	200	2
PA	Armstrong	1,400	99	2,000	710	9
PA	Beaver	1,400	1,300	1,700	260	3
PA	Butler	1,200	99	2,300	1,600	2
PA	Cambria	900	99	1,600	530	12
PA	Centre	640	190	1,100	640	2
PA	Clarion	1,200	95	2,000	830	10
PA	Clearfield	1,300	99	2,200	610	20
PA	Clinton	850	610	1,200	280	3
PA	Elk	960	99	1,400	390	19
PA	Fayette	990	390	1,600	400	6
PA	Indiana	1,400	670	2,500	700	6
PA	Jefferson	1,100	97	2,200	830	17
PA	Lawrence	1,100	98	2,100	740	9
PA	Somerset	690	97	1,200	390	14
PA	Westmoreland	nd	2,300	2,300	nd	1
WV	Barbour	1,800	1,300	2,100	420	3
OH	Belmont	1,300	880	2,000	380	9
OH	Carroll	nd	1,500	1,500	nd	1
OH	Columbiana	1,400	1,400	1,500	99	2
OH	Coshocton	880	350	1,500	350	14
OH	Gallia	930	570	1,300	520	2
OH	Guernsey	1,600	1,000	1,900	340	6
OH	Hocking	270	94	420	140	4
OH	Holmes	820	250	1,100	360	5
OH	Jackson	290	97	540	150	6
OH	Lawrence	170	23	380	140	5
OH	Mahoning	1,900	1,500	2,400	400	5
OH	Monroe	1,100	950	1,300	200	3
OH	Muskingum	nd	210	210	nd	1
OH	Noble	1,300	1,100	2,000	390	6
OH	Perry	230	150	370	91	5
OH	Scioto	230	160	310	110	2
OH	Stark	1,300	1,100	1,700	270	4
OH	Tuscarawas	1,100	550	1,600	370	13
OH	Vinton	370	120	900	240	8
OH	Washington	nd	2,100	2,100	nd	1
MD	Garrett	740	600	880	200	2

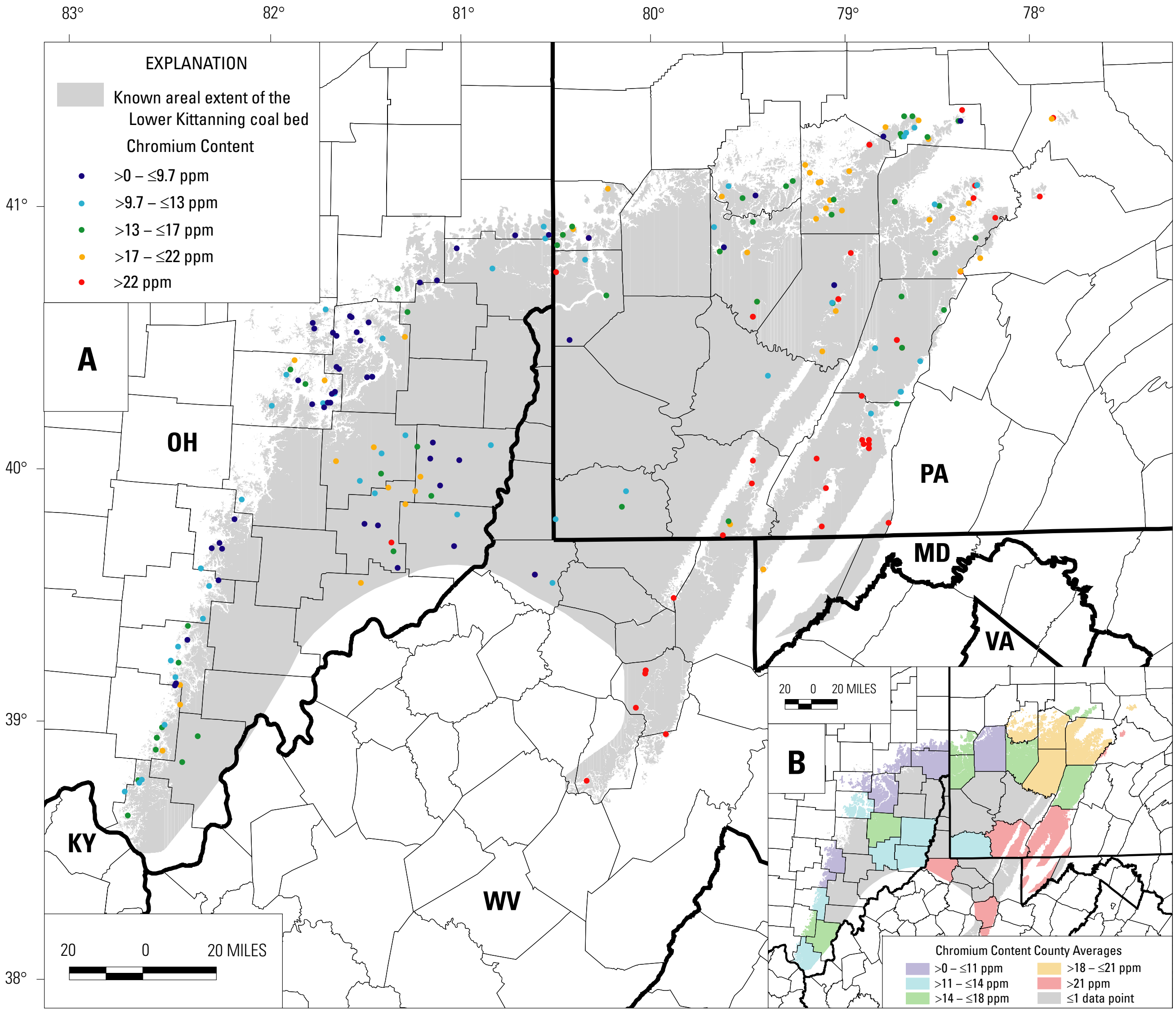

Figure 24. Maps showing chromium content (parts per million (ppm), as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows chromium contents of the 243 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for chromium contents using all 290 records in the geochemical database, including those that are located only to a county level; chromium contents range from 2.6 to 49 ppm with a mean value of 17±8.5 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. Chromium content (parts per million) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	17	2.6	49	8.5	290
PA	na	20	5.1	49	8.3	160
WV	na	28	8.5	46	9.7	14
OH	na	12	2.6	27	4.5	110
MD	na	26	22	30	6.0	2
PA	Armstrong	18	8.9	26	5.6	12
PA	Beaver	15	5.1	25	8.2	4
PA	Butler	10	9.8	10	0.47	2
PA	Cambria	18	10	31	6.6	13
PA	Centre	35	20	49	21	2
PA	Clarion	19	9.0	40	8.7	11
PA	Clearfield	20	10	35	6.6	28
PA	Clinton	21	7.9	34	13	3
PA	Elk	17	8.2	31	5.7	21
PA	Fayette	22	13	31	6.8	7
PA	Greene	14	12	16	1.8	3
PA	Indiana	20	7.5	41	11	9
PA	Jefferson	21	14	37	6.3	18
PA	Lawrence	18	9.2	25	4.7	9
PA	Somerset	28	10	49	11	18
PA	Westmoreland	nd	13	13	nd	1
WV	Barbour	30	23	36	4.8	6
WV	Monongalia	nd	37	37	nd	1
WV	Randolph	31	28	34	4.5	2
WV	Upshur	nd	29	29	nd	1
WV	Wayne	nd	23	23	nd	1
WV	Wetzel	22	8.5	46	21	3
OH	Belmont	12	5.7	20	4.9	9
OH	Carroll	nd	14	14	nd	1
OH	Columbiana	7.3	3.2	11	5.8	2
OH	Coshocton	12	6.9	21	4.2	16
OH	Gallia	16	15	17	1.2	2
OH	Guernsey	15	9.8	19	3.8	6
OH	Hocking	10	5.7	13	3.2	4
OH	Holmes	7.0	2.6	10	2.9	6
OH	Jackson	16	12	19	2.6	7
OH	Lawrence	13	8.9	16	2.7	5
OH	Mahoning	9.4	5.6	13	2.8	6
OH	Monroe	13	8.1	20	6.6	3
OH	Muskingum	nd	11	11	nd	1
OH	Noble	14	7.6	27	7.1	7
OH	Perry	9.2	6.8	13	2.4	6
OH	Scioto	12	11	13	0.89	2
OH	Stark	11	4.9	16	5.0	4
OH	Tuscarawas	10	5.8	21	4.6	14
OH	Vinton	13	7.7	20	4.3	9
OH	Washington	nd	18	18	nd	1
MD	Garrett	26	22	30	6.0	2

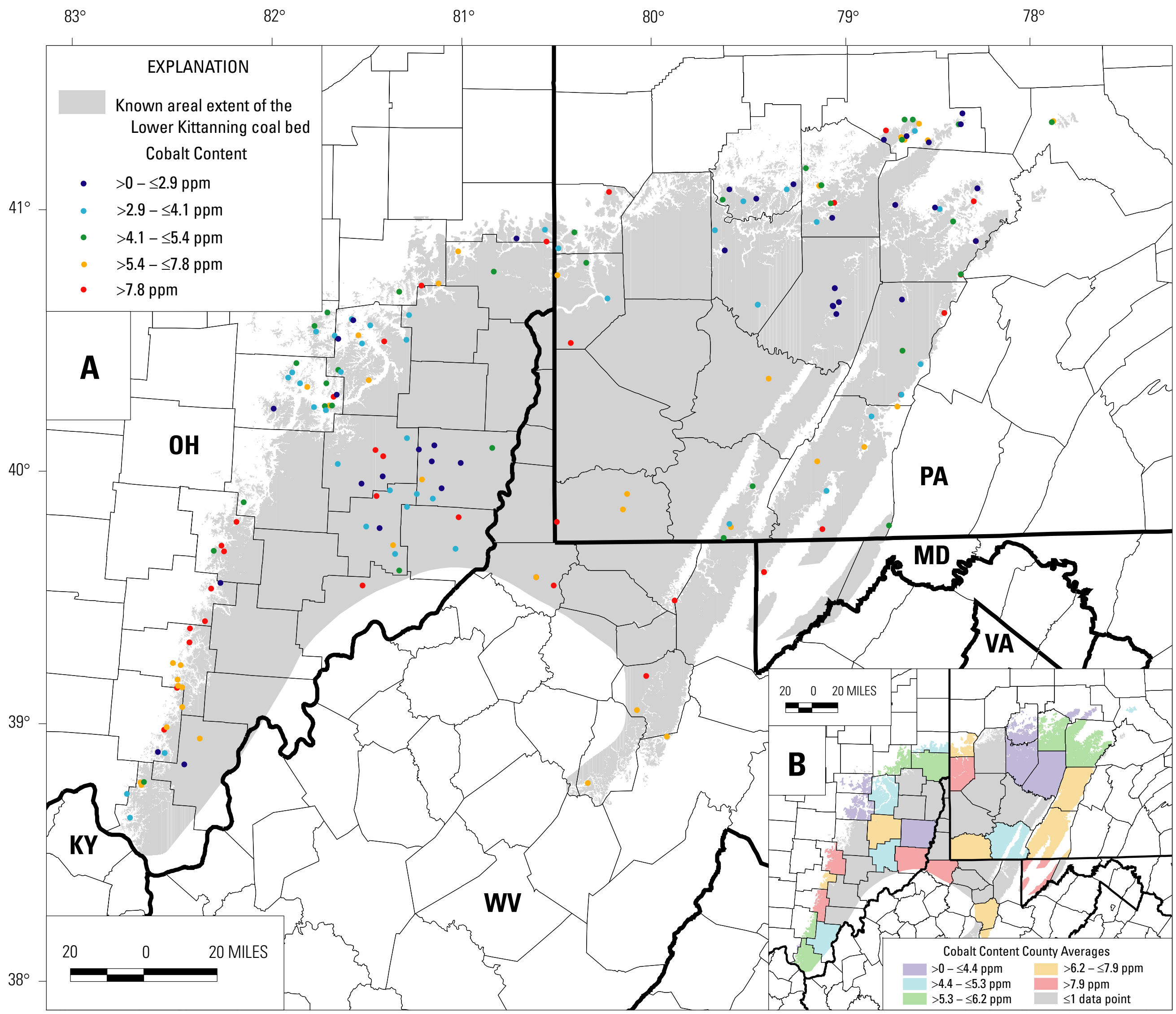

Figure 25. Maps showing cobalt content (parts per million (ppm), as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows cobalt contents of 189 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for cobalt contents using all 210 records in the geochemical database, including those that are located only to a county level; cobalt contents range from 0.98 to 34 ppm with a mean value of 6.1±4.9 ppm (table 17). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

Table 17. Cobalt content (parts per million) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	6.1	0.98	34	4.9	210
PA	na	5.5	1.0	24	3.7	97
WV	na	9.4	2.5	28	6.8	10
OH	na	6.2	0.98	34	5.5	96
MD	na	11	8.2	14	4.2	2
PA	Armstrong	3.5	2.1	4.4	0.9	5
PA	Beaver	10	3.6	24	9.6	4
PA	Cambria	6.5	2.8	19	6.0	7
PA	Clarion	4.4	2.0	9.7	2.3	9
PA	Clearfield	5.9	1.0	14	4.0	17
PA	Clinton	5.3	4.9	5.6	0.34	3
PA	Elk	4.4	1.7	7.9	1.8	17
PA	Fayette	4.9	3.4	5.6	1.0	4
PA	Greene	7.6	6.2	9.1	1.4	3
PA	Indiana	2.8	1.0	7.5	2.1	7
PA	Jefferson	5.5	2.9	10	2.3	9
PA	Lawrence	7.3	3.0	14	6.0	3
PA	Somerset	6.7	3.8	14	3.3	8
PA	Westmoreland	nd	7.8	7.8	nd	1
WV	Barbour	7.9	6.9	8.9	1.4	2
WV	Monongalia	nd	11	11	nd	1
WV	Randolph	6.3	5.1	7.6	1.8	2
WV	Upshur	nd	7.7	7.7	nd	1
WV	Wayne	nd	2.5	2.5	nd	1
WV	Wetzel	15	6.4	28	11	3
OH	Belmont	3.3	2.1	5.7	1.4	9
OH	Carroll	nd	3.1	3.1	nd	1
OH	Columbiana	5.8	4.9	6.6	1.2	2
OH	Coshocton	4.4	2.1	9.4	1.9	14
OH	Gallia	5.0	2.8	7.3	3.2	2
OH	Guernsey	7.9	2.1	24	8.8	6
OH	Hocking	6.8	0.98	11	5.3	4
OH	Holmes	4.3	3.3	5.2	0.78	4
OH	Jackson	5.9	2.9	9.6	2.7	5
OH	Lawrence	5.8	3.6	7.2	1.4	5
OH	Mahoning	5.2	1.7	9.9	4.3	3
OH	Monroe	14	3.2	34	18	3
OH	Muskingum	nd	4.7	4.7	nd	1
OH	Noble	4.6	2.1	8.2	2.4	7
OH	Perry	13	4.4	20	7.1	4
OH	Scioto	3.5	3.3	3.7	0.32	2
OH	Stark	6.2	5.1	8.5	1.5	4
OH	Tuscarawas	4.6	2.8	9.1	2.0	11
OH	Vinton	12	5.8	32	9.1	8
OH	Washington	nd	9.5	9.5	nd	1
MD	Garrett	11	8.2	14	4.2	2

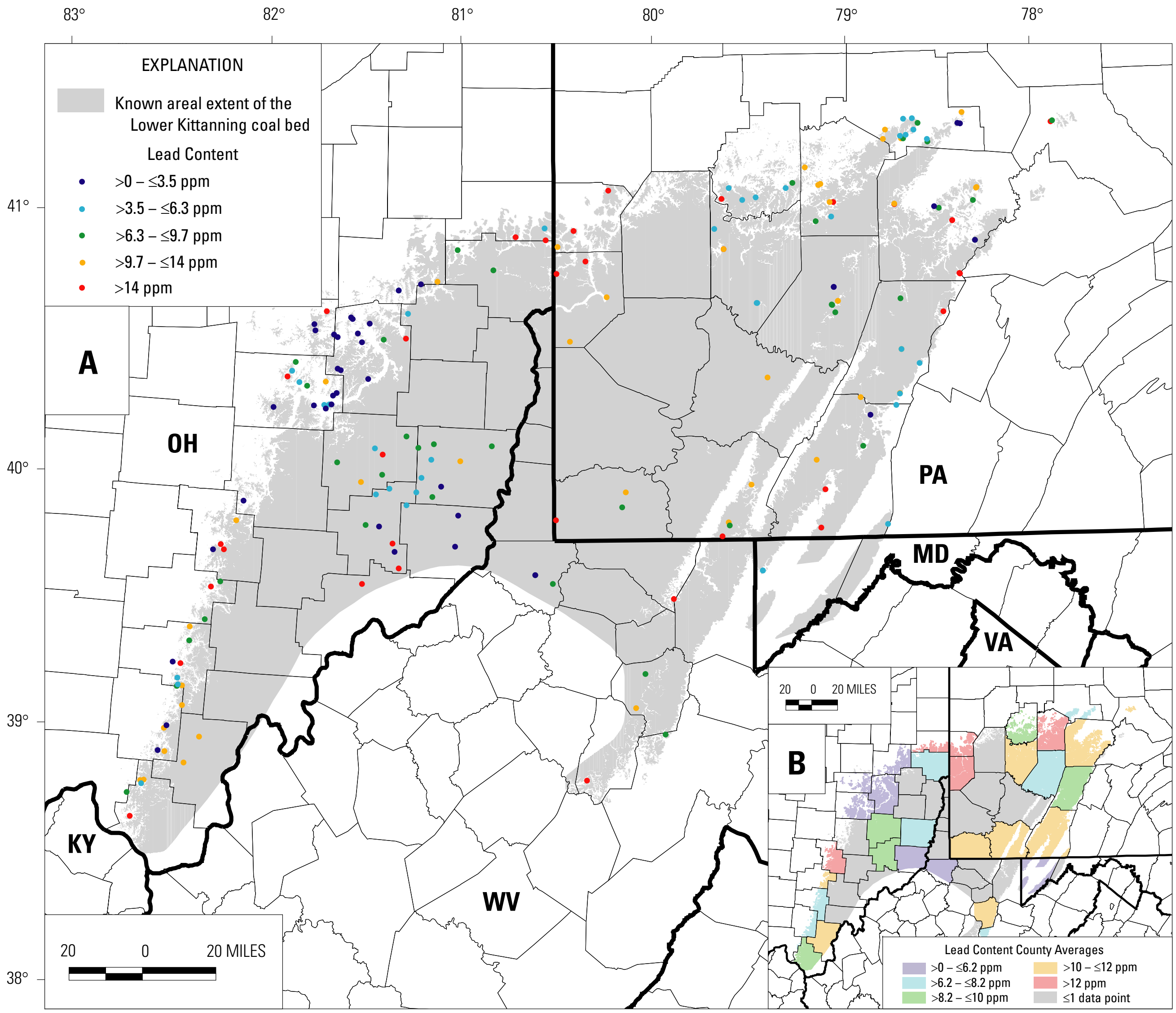

Figure 26. Maps showing lead content (parts per million (ppm), as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows lead contents of 190 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for lead contents using all 210 records in the geochemical database, including those that are located only to a county level; lead contents range from 0.13 to 35 ppm with a mean value of 9.3±6.6 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. Lead content (parts per million) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	9.3	0.13	35	6.6	210
PA	na	11	0.36	35	6.7	98
WV	na	9.1	1.1	17	4.6	10
OH	na	7.9	0.13	31	6.5	96
MD	na	4.3	3.9	4.8	0.62	2
PA	Armstrong	12	4.1	30	11	5
PA	Beaver	15	11	19	3.2	4
PA	Cambria	8.5	2.4	15	4.6	7
PA	Clarion	9.7	5.6	19	4.8	9
PA	Clearfield	12	3.3	32	7.1	17
PA	Clinton	11	3.1	24	11	3
PA	Elk	7.0	0.36	14	3.9	17
PA	Fayette	11	8.2	15	2.9	4
PA	Greene	11	6.9	15	3.9	3
PA	Indiana	8.0	2.4	14	4.2	7
PA	Jefferson	13	5.7	35	8.7	9
PA	Lawrence	19	14	26	6.1	3
PA	Somerset	11	2.6	32	9.4	9
PA	Westmoreland	nd	13	13	nd	1
WV	Barbour	11	9.1	13	2.9	2
WV	Monongalia	nd	15	15	nd	1
WV	Randolph	8.0	7.3	8.8	1.1	2
WV	Upshur	nd	17	17	nd	1
WV	Wayne	nd	5.9	5.9	nd	1
WV	Wetzel	5.1	1.1	7.3	3.5	3
OH	Belmont	7.1	3.5	13	2.6	9
OH	Carroll	nd	4.9	4.9	nd	1
OH	Columbiana	8.2	7.9	8.5	0.41	2
OH	Coshocton	5.5	1.3	17	4.5	14
OH	Gallia	12	11	13	2.0	2
OH	Guernsey	9.5	4.7	18	4.9	6
OH	Hocking	11	8.1	19	5.3	4
OH	Holmes	4.8	0.13	16	7.7	4
OH	Jackson	7.7	1.8	12	4.8	5
OH	Lawrence	10	5.2	17	4.4	5
OH	Mahoning	15	6.2	23	8.5	3
OH	Monroe	2.8	0.99	4.4	1.7	3
OH	Muskingum	nd	2.1	2.1	nd	1
OH	Noble	10	0.55	31	12	7
OH	Perry	13	0.74	24	9.5	4
OH	Scioto	7.0	4.5	9.6	3.6	2
OH	Stark	6.2	2.1	14	5.4	4
OH	Tuscarawas	4.6	0.49	23	6.5	11
OH	Vinton	8.2	2.1	15	4.7	8
OH	Washington	nd	27	27	nd	1
MD	Garrett	4.3	3.9	4.8	0.62	2

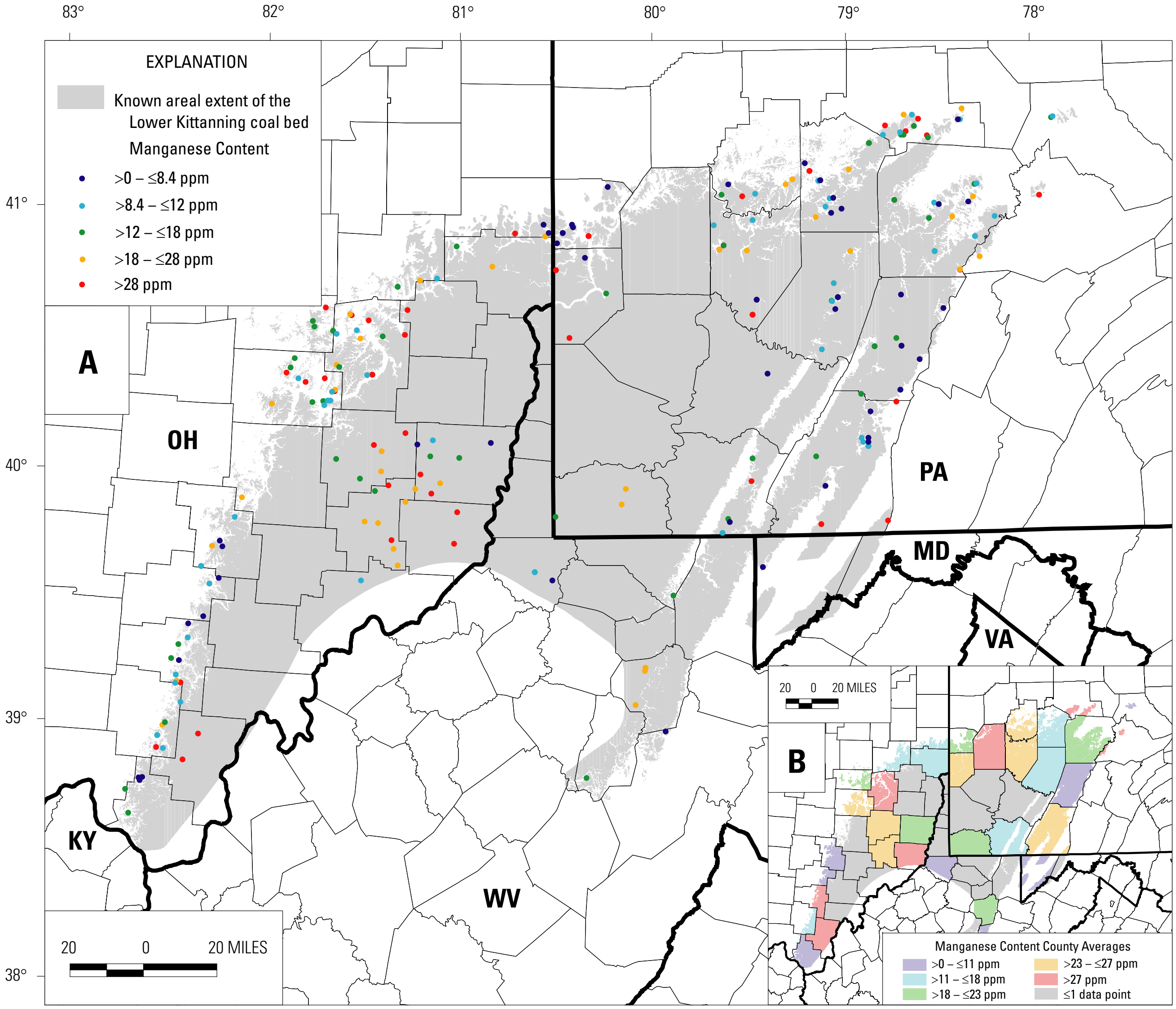

Figure 27. Maps showing manganese content (parts per million (ppm), as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows manganese contents of 243 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for manganese contents using all 290 records in the geochemical database, including those that are located only to a county level; manganese contents range from 1.6 to 190 ppm with a mean value of 22±25 ppm (table 19). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

Table 19. Manganese content (parts per million) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	22	1.6	190	25	290
PA	na	21	1.6	190	27	160
WV	na	16	3.2	27	8.8	14
OH	na	23	2.8	170	24	110
MD	na	6.0	1.6	10	6.3	2
PA	Armstrong	24	3.6	45	14	12
PA	Beaver	24	6.2	37	15	4
PA	Butler	29	23	34	8.1	2
PA	Cambria	9.8	2.1	23	6.7	13
PA	Centre	30	25	35	7.4	2
PA	Clarion	25	5.9	100	26	11
PA	Clearfield	23	6.1	190	34	28
PA	Clinton	8.4	1.6	13	6.1	3
PA	Elk	28	4.1	170	37	21
PA	Fayette	18	5.1	58	19	7
PA	Greene	20	13	27	7.1	3
PA	Indiana	13	5.4	24	6.3	9
PA	Jefferson	17	3.6	74	19	18
PA	Lawrence	21	2.1	100	32	9
PA	Somerset	26	2.2	160	38	18
PA	Westmoreland	nd	3.0	3.0	nd	1
WV	Barbour	24	20	27	3.0	6
WV	Monongalia	nd	13	13	nd	1
WV	Randolph	4.1	3.2	5.0	1.3	2
WV	Upshur	nd	18	18	nd	1
WV	Wayne	nd	3.6	3.6	nd	1
WV	Wetzel	11	5.6	15	4.7	3
OH	Belmont	19	4.5	41	12	9
OH	Carroll	nd	40	40	nd	1
OH	Columbiana	18	14	22	5.8	2
OH	Coshocton	24	9.4	54	15	16
OH	Gallia	34	31	38	5.3	2
OH	Guernsey	27	16	48	12	6
OH	Hocking	9.1	5.3	14	3.9	4
OH	Holmes	20	12	40	11	6
OH	Jackson	17	8.9	29	8.2	7
OH	Lawrence	7.9	3.7	14	3.7	5
OH	Mahoning	14	3.5	49	18	6
OH	Monroe	73	26	150	69	3
OH	Muskingum	nd	25	25	nd	1
OH	Noble	27	18	49	11	7
OH	Perry	11	2.8	21	7.5	6
OH	Scioto	17	17	18	0.78	2
OH	Stark	16	10	26	6.8	4
OH	Tuscarawas	30	9.3	100	25	14
OH	Vinton	29	4.6	170	51	9
OH	Washington	nd	12	12	nd	1
MD	Garrett	6.0	1.6	10	6.3	2

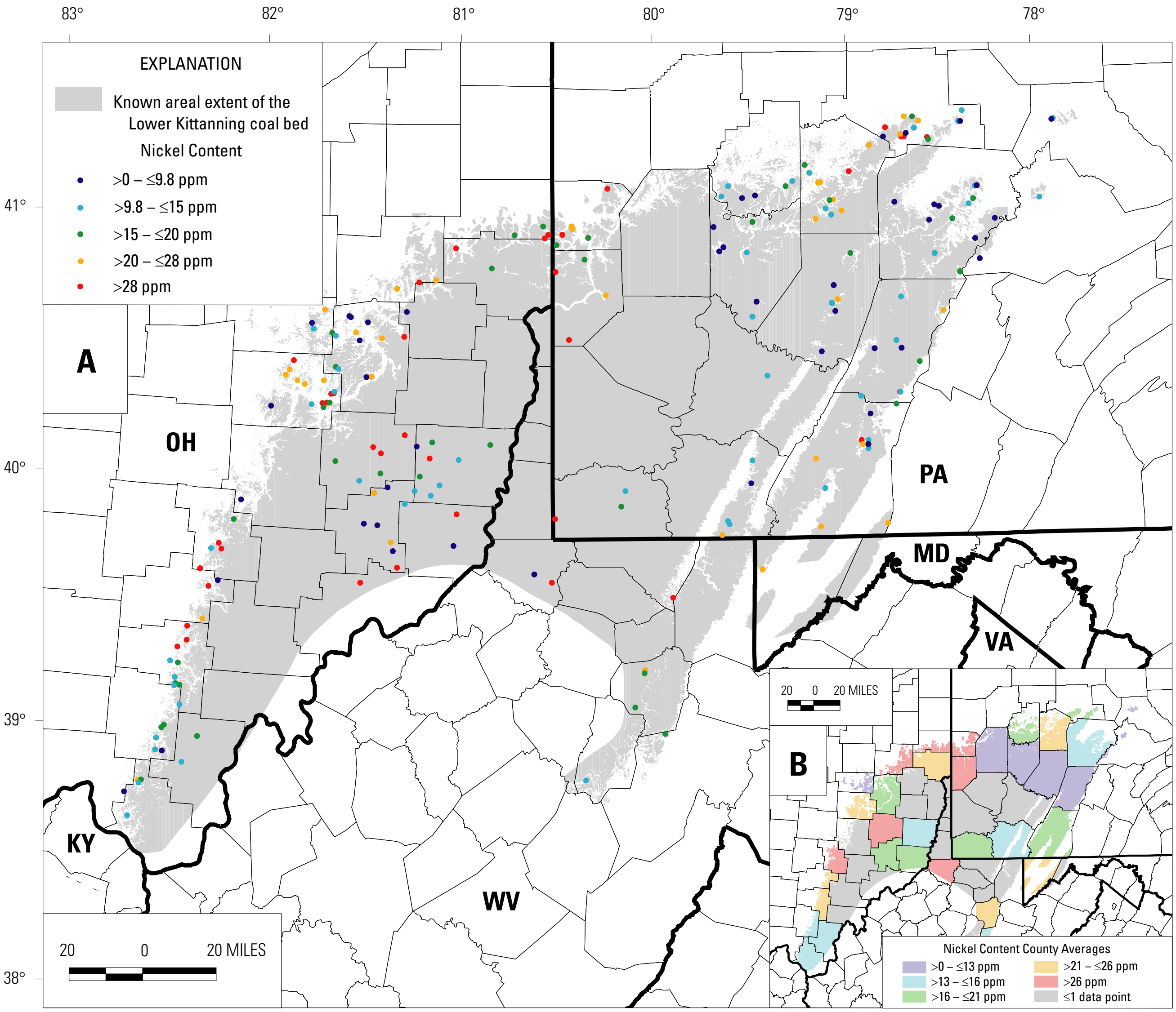

Figure 28. Maps showing nickel content (parts per million (ppm), as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows nickel contents of 243 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for nickel contents using all 290 records in the geochemical database, including those that are located only to a county level; nickel contents range from 3.1 to 69 ppm with a mean value of 20±13 ppm (table 20). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

Table 20. Nickel content (parts per million) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	20	3.1	69	13	290
PA	na	18	3.1	69	12	160
WV	na	23	5.3	51	13	14
OH	na	22	4.4	67	14	110
MD	na	22	21	23	1.6	2
PA	Armstrong	9.9	5.0	16	3.5	12
PA	Beaver	38	18	68	24	4
PA	Butler	9.0	7.4	11	2.2	2
PA	Cambria	13	5.8	30	7.7	13
PA	Centre	10	5.4	15	7.1	2
PA	Clarion	20	7.9	69	17	11
PA	Clearfield	15	4.2	43	9.6	28
PA	Clinton	11	6.4	14	4.1	3
PA	Elk	19	3.1	37	10	21
PA	Fayette	14	9.4	25	5.3	7
PA	Greene	21	15	31	8.9	3
PA	Indiana	12	4.8	23	6.7	9
PA	Jefferson	22	11	40	6.7	18
PA	Lawrence	35	19	58	15	9
PA	Somerset	17	5.1	35	8.1	18
PA	Westmoreland	nd	11	11	nd	1
WV	Barbour	25	17	32	6.6	6
WV	Monongalia	nd	32	32	nd	1
WV	Randolph	14	11	17	4.5	2
WV	Upshur	nd	12	12	nd	1
WV	Wayne	nd	5.3	5.3	nd	1
WV	Wetzel	31	7.9	51	22	3
OH	Belmont	16	9.2	29	5.9	9
OH	Carroll	nd	7.7	7.7	nd	1
OH	Columbiana	25	19	31	8.6	2
OH	Coshocton	24	5.7	43	11	16
OH	Gallia	15	12	18	4.3	2
OH	Guernsey	32	12	57	18	6
OH	Hocking	22	4.4	49	20	4
OH	Holmes	12	5.0	27	8.7	6
OH	Jackson	14	7.7	20	3.8	7
OH	Lawrence	16	9.6	23	5.3	5
OH	Mahoning	28	17	56	15	6
OH	Monroe	20	6.7	44	20	3
OH	Muskingum	nd	8.4	8.4	nd	1
OH	Noble	17	5.5	43	14	7
OH	Perry	37	13	67	19	6
OH	Scioto	10	9.2	11	1.1	2
OH	Stark	28	21	34	5.4	4
OH	Tuscarawas	20	4.8	61	15	14
OH	Vinton	26	12	50	15	9
OH	Washington	nd	38	38	nd	1
MD	Garrett	22	21	23	1.6	2

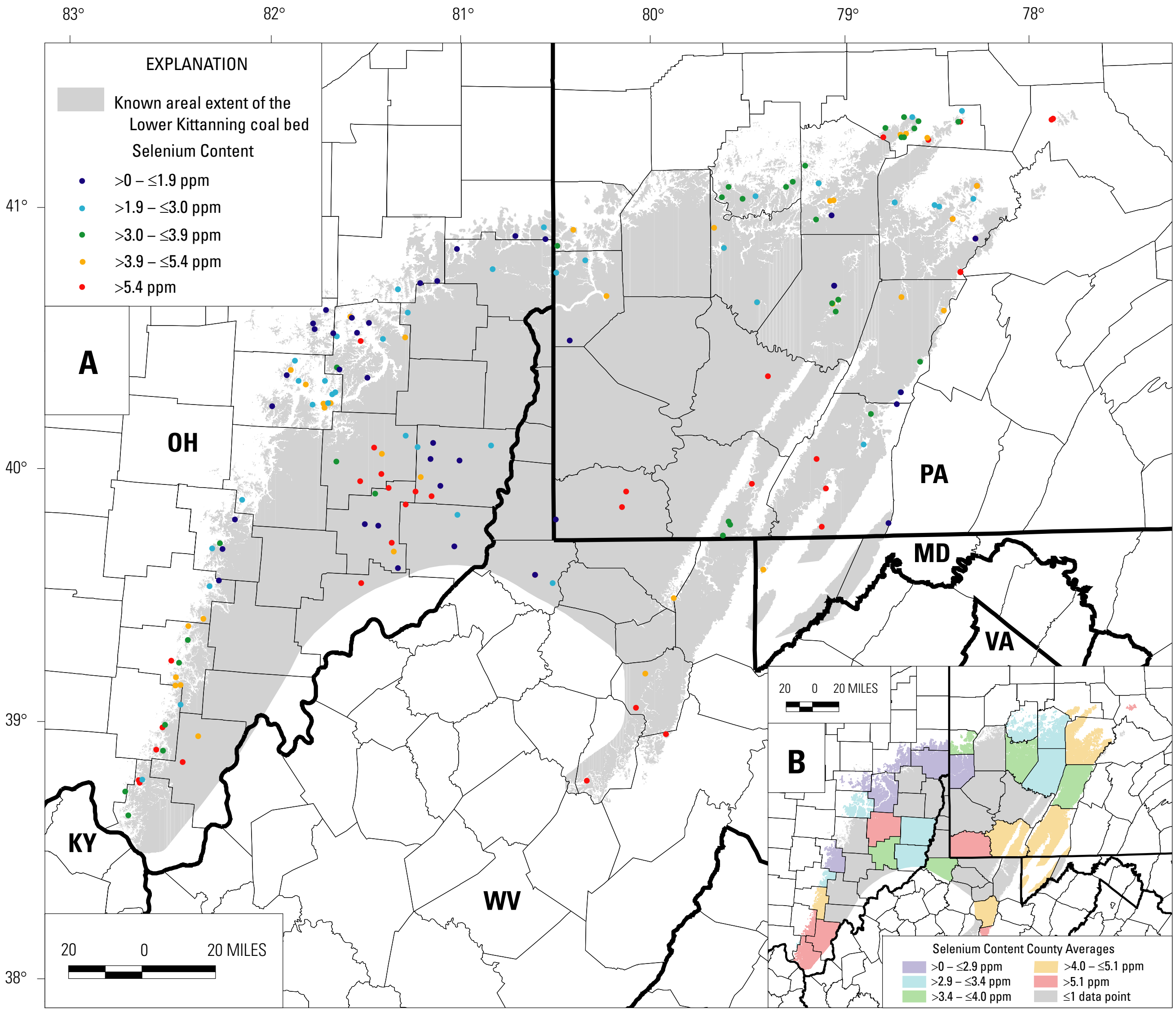

Figure 29. Maps showing selenium content (parts per million (ppm), as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows selenium contents of 183 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for selenium contents using all 190 records in the geochemical database, including those that are located only to a county level; selenium contents range from 0.59 to 12 ppm with a mean value of 3.9±2.2 ppm (table 21). The values are classified into five categories, each representing 20 percent of the data values. See figure 2 for county names.

Table 21. Selenium content (parts per million) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	3.9	0.59	12	2.2	190
PA	na	4.2	0.97	12	2.2	87
WV	na	5.5	0.91	9.6	2.4	10
OH	na	3.4	0.59	12	2.1	93
MD	na	4.6	4.2	5.1	0.65	2
PA	Armstrong	4.0	2.8	5.3	1.1	5
PA	Beaver	2.9	1.7	4.4	1.1	4
PA	Cambria	3.6	1.4	5.3	1.7	5
PA	Clarion	3.2	2.5	3.7	0.43	6
PA	Clearfield	4.6	0.97	9.5	2.7	15
PA	Clinton	5.8	1.4	8.1	3.8	3
PA	Elk	4.1	2.4	6.4	1.1	17
PA	Fayette	4.5	3.4	7.1	1.7	4
PA	Greene	5.9	1.5	9.1	4.0	3
PA	Indiana	3.3	1.3	5.1	1.4	7
PA	Jefferson	3.4	1.8	4.3	0.85	7
PA	Lawrence	3.7	3.3	4.2	0.63	2
PA	Somerset	4.8	1.9	12	3.8	8
PA	Westmoreland	nd	9.1	9.1	nd	1
WV	Barbour	5.1	4.5	5.6	0.77	2
WV	Monongalia	nd	5.3	5.3	nd	1
WV	Randolph	6.5	6.4	6.7	0.20	2
WV	Upshur	nd	9.6	9.6	nd	1
WV	Wayne	nd	5.7	5.7	nd	1
WV	Wetzel	3.8	0.91	7.6	3.5	3
OH	Belmont	3.3	0.90	7.8	2.8	9
OH	Carroll	nd	2.6	2.6	nd	1
OH	Columbiana	1.5	0.59	2.4	1.3	2
OH	Coshocton	3.1	1.5	5.4	1.3	14
OH	Gallia	5.2	4.5	5.9	0.93	2
OH	Guernsey	5.2	2.7	7.6	1.8	6
OH	Hocking	3.0	1.9	4.2	1.2	3
OH	Holmes	1.4	1.4	1.5	0.052	4
OH	Jackson	5.4	2.3	12	3.7	5
OH	Lawrence	5.2	2.8	11	3.9	4
OH	Mahoning	1.8	1.6	2.2	0.31	3
OH	Monroe	3.0	1.0	6.5	3.0	3
OH	Muskingum	nd	2.3	2.3	nd	1
OH	Noble	3.7	1.3	7.7	2.4	7
OH	Perry	2.1	1.2	3.1	0.79	4
OH	Scioto	3.4	3.2	3.7	0.36	2
OH	Stark	1.8	1.1	2.6	0.61	4
OH	Tuscarawas	2.6	1.2	4.9	1.3	11
OH	Vinton	4.8	3.2	6.9	1.2	7
OH	Washington	nd	5.5	5.5	nd	1
MD	Garrett	4.6	4.2	5.1	0.65	2

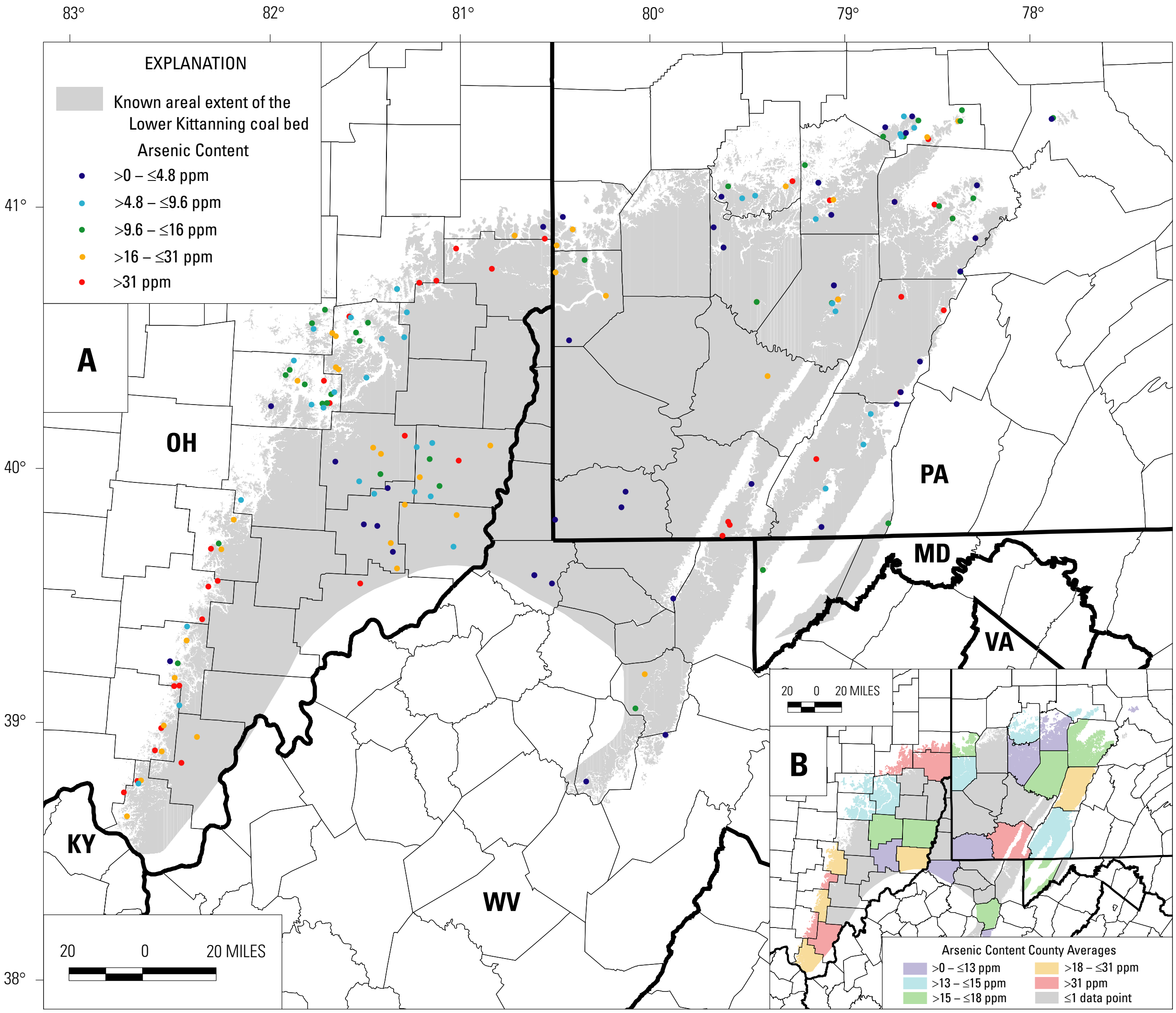

Figure 30. Maps showing arsenic content (parts per million (ppm), as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows arsenic contents of 184 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for arsenic contents using all 190 records in the geochemical database, including those that are located only to a county level; arsenic contents range from 0.13 to 130 ppm with a mean value of 19±20 ppm (table 22). The values are classified into five categories, each representing 20 percent of the data values. Arsenic contents tend to be highest in the south-eastern, north-central, and northwestern parts of the coal bed where ash contents are relatively high. See figure 2 for county names.

Table 22. Arsenic content (parts per million) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	19	0.13	130	20	190
PA	na	16	0.14	90	19	88
WV	na	5.6	0.13	19	7.9	10
OH	na	22	2.9	130	21	93
MD	na	16	15	16	0.66	2
PA	Armstrong	11	0.70	25	9.5	5
PA	Beaver	14	0.81	21	9.3	4
PA	Cambria	31	0.79	90	36	5
PA	Clarion	15	1.0	42	15	6
PA	Clearfield	16	1.6	49	14	15
PA	Clinton	6.6	0.89	15	7.6	3
PA	Elk	14	0.14	79	18	17
PA	Fayette	44	0.68	66	30	4
PA	Greene	0.64	0.35	1.1	0.41	3
PA	Indiana	18	0.30	74	26	7
PA	Jefferson	13	1.0	42	15	7
PA	Lawrence	16	0.96	30	15	3
PA	Somerset	15	0.65	48	16	8
PA	Westmoreland	nd	16	16	nd	1
WV	Barbour	16	13	19	4.0	2
WV	Monongalia	nd	0.83	0.83	nd	1
WV	Randolph	0.95	0.53	1.4	0.59	2
WV	Upshur	nd	1.3	1.3	nd	1
WV	Wayne	nd	18	18	nd	1
WV	Wetzel	0.47	0.13	0.92	0.40	3
OH	Belmont	17	5.6	46	14	9
OH	Carroll	nd	8.2	8.2	nd	1
OH	Columbiana	64	57	72	11	2
OH	Coshocton	15	3.5	50	12	14
OH	Gallia	75	19	130	80	2
OH	Guernsey	18	4.2	33	12	6
OH	Hocking	38	32	46	7.4	3
OH	Holmes	15	9.6	24	6.4	4
OH	Jackson	32	5.1	62	20	5
OH	Lawrence	23	7.8	33	11	4
OH	Mahoning	34	2.9	76	38	3
OH	Monroe	19	6.6	29	11	3
OH	Muskingum	nd	8.2	8.2	nd	1
OH	Noble	9.9	3.5	28	9.5	7
OH	Perry	23	12	34	8.9	4
OH	Scioto	23	11	35	17	2
OH	Stark	36	7.3	92	39	4
OH	Tuscarawas	15	6.4	35	8.1	11
OH	Vinton	23	3.9	47	16	7
OH	Washington	nd	56	56	nd	1
MD	Garrett	16	15	16	0.66	2

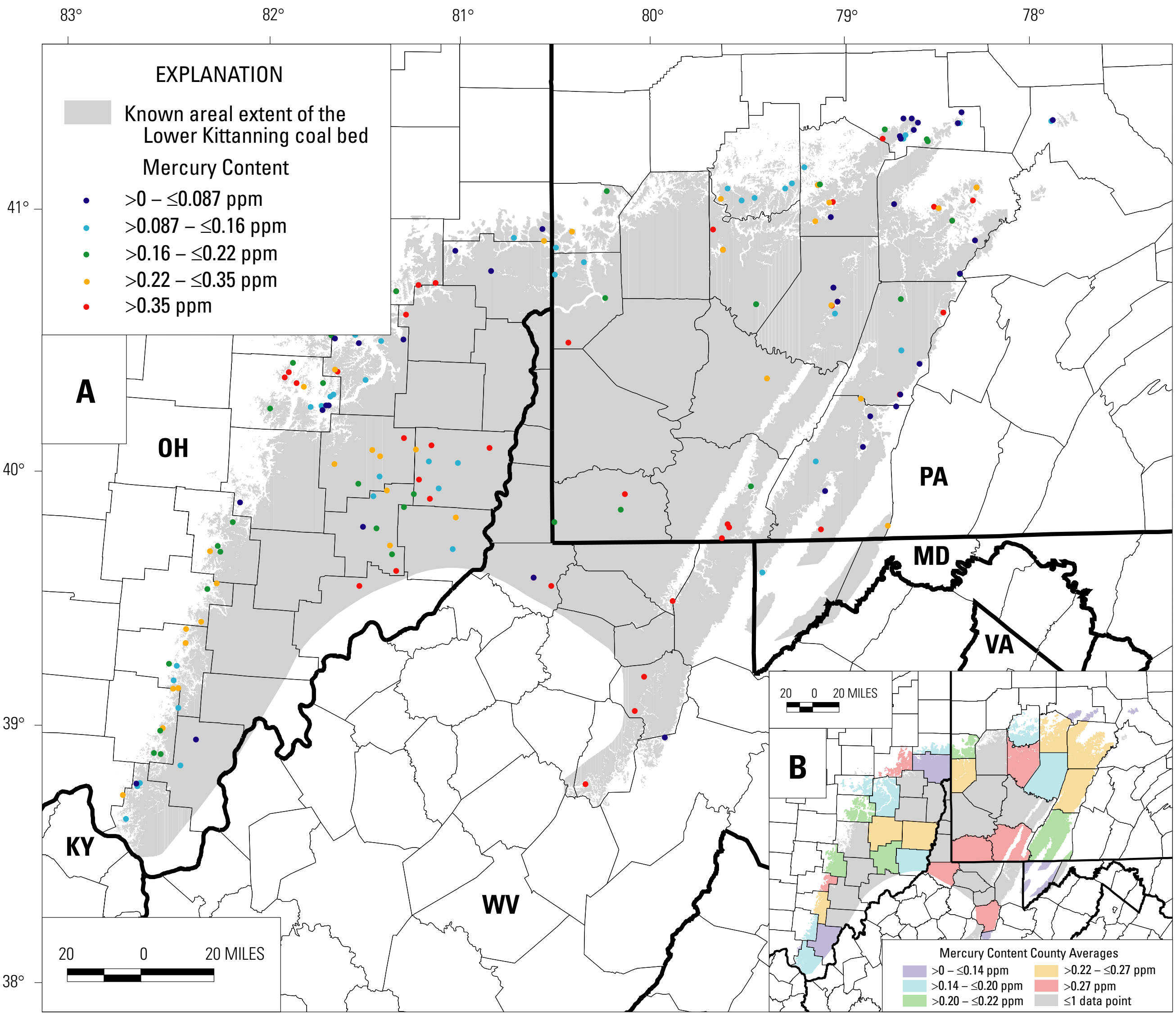

Figure 31. Maps showing mercury content (parts per million (ppm), as-received whole-coal basis) of the Lower Kittanning coal bed in Pennsylvania, West Virginia, Ohio, and Maryland. Map A shows mercury contents of the 189 geochemical samples for which records are publicly available and located by latitude and longitude (Appendix 2). Map B shows county averages for mercury contents using all 200 records in the geochemical database, including those that are located only to a county level; mercury contents range from 0.0024 to 0.98 ppm with a mean value of 0.22±0.18 ppm (table 23). The values are classified into five categories, each representing 20 percent of the data values. In general, mercury content tends to be correlated with sulfur content. See figure 2 for county names.

Table 23. Mercury content (parts per million) means, ranges, and standard deviations for samples of the Lower Kittanning coal bed on an as-received whole-coal basis, by State and county.

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

STATE	COUNTY	Mean	Minimum	Maximum	Standard deviation	No. of samples
ALL	na	0.22	0.0024	0.98	0.18	200
PA	na	0.22	0.0025	0.98	0.20	96
WV	na	0.37	0.0098	0.60	0.24	10
OH	na	0.22	0.0024	0.86	0.15	94
MD	na	0.10	0.10	0.11	0.0046	2
PA	Armstrong	0.41	0.17	0.95	0.33	5
PA	Beaver	0.24	0.098	0.56	0.22	4
PA	Cambria	0.24	0.040	0.55	0.22	7
PA	Clarion	0.20	0.11	0.31	0.084	9
PA	Clearfield	0.23	0.0097	0.68	0.18	15
PA	Clinton	0.075	0.0050	0.14	0.067	3
PA	Elk	0.13	0.0025	0.85	0.20	17
PA	Fayette	0.36	0.17	0.45	0.13	4
PA	Greene	0.31	0.18	0.57	0.22	3
PA	Indiana	0.15	0.0025	0.40	0.15	7
PA	Jefferson	0.27	0.020	0.65	0.18	9
PA	Lawrence	0.21	0.099	0.32	0.11	3
PA	Somerset	0.21	0.0025	0.98	0.31	9
PA	Westmoreland	nd	0.24	0.24	nd	1
WV	Barbour	0.53	0.51	0.56	0.031	2
WV	Monongalia	nd	0.60	0.60	nd	1
WV	Randolph	0.063	0.059	0.067	0.0055	2
WV	Upshur	nd	0.55	0.55	nd	1
WV	Wayne	nd	0.35	0.35	nd	1
WV	Wetzel	0.34	0.0098	0.52	0.29	3
OH	Belmont	0.26	0.099	0.42	0.13	9
OH	Carroll	nd	0.42	0.42	nd	1
OH	Columbiana	0.0024	0.0024	0.0025	0.0000040	2
OH	Coshocton	0.22	0.0068	0.67	0.19	14
OH	Gallia	0.092	0.087	0.096	0.0064	2
OH	Guernsey	0.27	0.098	0.40	0.11	6
OH	Hocking	0.28	0.22	0.33	0.056	3
OH	Holmes	0.20	0.11	0.28	0.070	4
OH	Jackson	0.19	0.11	0.26	0.052	5
OH	Lawrence	0.20	0.053	0.54	0.19	5
OH	Mahoning	0.17	0.074	0.31	0.13	3
OH	Monroe	0.20	0.12	0.27	0.075	3
OH	Muskingum	nd	0.051	0.051	nd	1
OH	Noble	0.22	0.053	0.43	0.12	7
OH	Perry	0.21	0.17	0.30	0.059	4
OH	Scioto	0.14	0.058	0.23	0.12	2
OH	Stark	0.45	0.20	0.86	0.29	4
OH	Tuscarawas	0.15	0.039	0.36	0.10	11
OH	Vinton	0.24	0.13	0.35	0.089	7
OH	Washington	nd	0.45	0.45	nd	1
MD	Garrett	0.10	0.10	0.11	0.0046	2

moisture content of the coal bed is relatively low in samples taken underground, and relatively high in samples taken along the western crop line of the coal bed in Ohio (fig. 19).

Twelve elements (antimony, beryllium, cadmium, chlorine, chromium, cobalt, lead, manganese, nickel, selenium, arsenic, and mercury) are listed by the Clean Air Act Amendments of 1990 (Public Law 101-549) as possibly adversely affecting the environment. For the Lower Kittanning coal bed, 290 representative samples were analyzed for these 12 elements (figs. 20-31; tables 12-23), including arsenic (fig. 30; table 22) and mercury (fig. 31; table 23).

ARSENIC AND MERCURY

The mean arsenic concentration (as-received whole-coal basis) for 190 Lower Kittanning coal bed samples is 19±20 ppm (table 22), which is lower than the mean arsenic concentration of 35 ppm for all Appalachian Basin coals (Finkelman and others, 1994), and is lower than the National mean of 24±5.5 ppm arsenic for all U.S. coal (Finkelman, 1993). In addition, 200 samples were analyzed for mercury (as-received whole-coal basis) (fig. 31). The mean mercury content of the Lower Kittanning coal bed is 0.22±0.18 ppm (table 23). This value is comparable to the mean of 0.21 ppm for all Appalachian Basin coals (Finkelman and others, 1994) and is just slightly higher than the mean of 0.17±10 ppm for all U.S. coal (Finkelman, 1993).

GEOGRAPHIC INFORMATION SYSTEM (GIS)

This Lower Kittanning coal bed study is based on digital files that have been compiled in a GIS. The GIS contains georeferenced information on the areal extent of the coal, mined areas, and geochemistry. Map products for the Lower Kittanning coal bed may be revised in a timely fashion as mine maps or other data become available; as additional resources are discovered, developed, and depleted; and as additional exploration and coal-quality information is acquired. If the USGS databases are kept current, revised digital map products will illustrate the location, thickness, and quality of remaining coal, and will provide the basis for monitoring coal resources and overall resource depletion. The GIS used in this study allows flexibility of output as well as easy access to the basic data supporting the assessment.

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APPENDIX 1

RECENT REPORTED ANNUAL PRODUCTION (IN SHORT TONS) OF THE LOWER KITTANNING COAL BED IN MARYLAND, OHIO, PENNSYLVANIA, WEST VIRGINIA, AS WELL AS TOTAL ANNUAL AND TOTAL CUMULATIVE PRODUCTION (IN MILLIONS OF SHORT TONS) ASSEMBLED FROM STATE AGENCIES

[Sources: Ohio Division of Labor Statistics (1982–1993), Maryland Bureau of Mines (1982–1995), Commonwealth of Pennsylvania (1982–1995), 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 available or the absence of production.]

					Total Production (millions of short tons)	
Year	Pennsylvania	West Virginia	Ohio	Maryland	Annual	Cumulative
1982	11,987,973	2,764,786	2,948,371	153,313	17.9	17.9
1983	11,655,906	4,212,833	2,112,612	93,333	18.1	36.0
1984	13,055,048	4,199,358	2,451,718	119,858	19.8	55.8
1985	11,308,515	4,472,260	2,204,182	65,604	18.1	73.9
1986	10,292,531	3,319,991	2,482,316	67,802	16.2	90.0
1987	8,662,869	3,044,215	3,035,615	37,693	14.8	104.8
1988	7,727,785	3,558,440	2,581,480	27,231	13.9	118.7
1989	6,703,043	3,493,420	2,917,755	8,757	13.1	131.8
1990	8,047,304	4,085,488	2,854,971	3,659	15.0	146.8
1991	7,564,184	3,794,108	2,660,194	nd	14.0	160.8
1992	6,409,742	3,212,008	2,211,488	2,112	11.8	172.7
1993	5,470,385	2,291,250	2,225,976	3,867	10.0	182.6
1994	5,089,994	3,175,660	1,953,225	19,009	10.2	192.9
1995	3,764,934	2,831,644	1,585,059	12,242	8.2	201.1

APPENDIX 2

LOWER KITTANNING COAL BED GEOCHEMICAL DATABASE

[This ASCII file contains all of the public records used to model the coal quality for the Lower Kittanning coal bed and includes NCAID (northern and central Appalachian index number used for bed data records), 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, moisture (percent), 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 (sulfur dioxide; lbs/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, equilibrium moisture (percent), 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), Au (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), In (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), Te (ppm), Th (ppm), Tl (ppm), Tm (ppm), U (ppm), V (ppm), W (ppm), Y (ppm), Yb (ppm), Zn (ppm), Zr (ppm)]

CLICK HERE TO GO TO APPENDIX 2

APPENDIX 3

METADATA FOR THE LOWER KITTANNING GEOCHEMICAL DATABASE

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APPENDIX 4

REFERENCES FOR THE LOWER KITTANNING GEOCHEMICAL DATABASE

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