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Chapter B

Coal Resource Assessment Methodology and Geology of the Northern and Central Appalachian Basin Coal Regions

By Leslie F. Ruppert and Charles L. Rice

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1625–C

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

By Northern and Central Appalachian Basin Coal Regions Assessment Team

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CHAPTER B—COAL RESOURCE ASSESSMENT METHODOLOGY AND GEOLOGY OF THE NORTHERN AND CENTRAL APPALACHIAN BASIN COAL REGIONS

By Leslie F. Ruppert[1] and Charles L. Rice[2]

ABSTRACT

The U.S. Geological Survey has assessed six of the top-producing coal beds in the northern and central Appalachian Basin coal regions. The beds include, in ascending stratigraphic order, the Lower Pennsylvanian Pocahontas No. 3 coal bed of the Pottsville Group, the Middle Pennsylvanian Pond Creek and Fire Clay coal zones of the Pottsville Group, the Middle Pennsylvanian Lower Kittanning and Upper Freeport coal beds of the Allegheny Group, and the Upper Pennsylvanian Pittsburgh coal bed of the Monongahela Group. These coals, other coal beds, and associated strata were deposited during Pennsylvanian and Permian time in a southeastern-thickening foreland basin that extends eastward from western Pennsylvania and Maryland and westward to eastern Ohio. The coal in the Appalachian Basin has been mined throughout the last three centuries and has fueled the development and growth of the region and much of the eastern U.S. However, because most of the remaining high-quality, compliant Appalachian Basin coal is mined out or under permit, and current environmental regulations make it more costly to burn higher-sulfur coal, Appalachian Basin production will not be sustainable for more than a few decades.

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INTRODUCTION

The U.S. Geological Survey (USGS) has completed a coal-bed- and coal-zone-specific, five-year-long digital assessment of five major coal-producing regions in the Nation (fig. 1). The five regions are (1) the Appalachian Basin, (2) the Gulf Coast, (3) the Illinois Basin, (4) the Colorado Plateau, and (5) the Northern Rocky Mountains and Great Plains. In 1998, 1,081.9 million short tons of coal, constituting 93 percent of the total U.S. production, were produced from these five regions (table 1; Freme and Hong, [1999]). About 40 percent was produced in the northern and central Appalachian Basin, 10 percent in the Illinois Basin, 5 percent in the Gulf Coast, 9 percent in the Colorado Plateau, and 36 percent in the Northern Rocky Mountains and Great Plains regions (fig. 2). The USGS coal resource assessments have resulted in coal resource assessment maps and descriptions, or models that identify and characterize the coal beds and coal zones that will provide the bulk of the U.S. production for the next several decades. The assessments are designed to provide geoscientists, policy makers, planners, and the general public with concise geologic information on the quantity and quality of the remaining coal. Assessment data can be used to (1) determine the amount of coal that is available for mining and recoverable from mining operations at different costing scenarios, and (2) aid in the identification of areas with potential for coal-bed methane production, mine flooding, surface subsidence, and acid mine drainage.

The Appalachian Basin is divided into three coal-producing regions: (1) the northern region in western Pennsylvania, eastern Ohio, western Maryland, and northern West Virginia, (2) the central region in southern West Virginia, eastern Kentucky, northern Tennessee, and southwestern Virginia, and (3) the southern region in southern

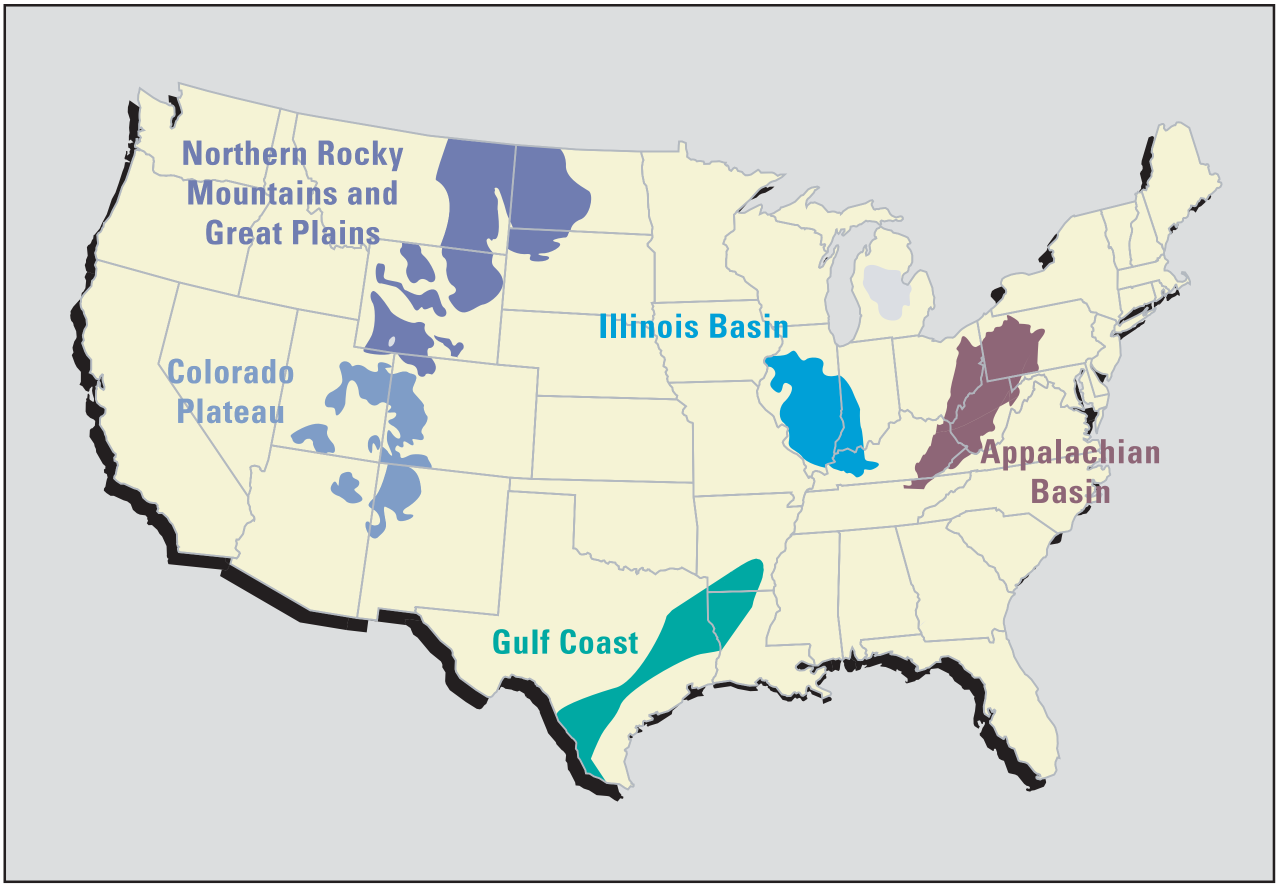

Figure 1. Map showing U.S. coal regions assessed in USGS's 2000 National Coal Resource Assessment project. The five assessed regions produce about 93 percent of the Nation's coal (Energy Information Administration, 1998). The top-producing region is the northern and central Appalachian Basin, followed by the Northern Rocky Mountains and Great Plains, Illinois Basin, Gulf Coast, and Colorado Plateau.

Tennessee, Alabama, and Georgia (fig. 3). Because the southern Appalachian Basin coal region produces only about 6 percent of the region's coal (Energy Information Administration, 1998), coal beds in the southern region were not assessed in this study. Six top-producing Pennsylvanian coal beds were assessed and modeled, three in the northern region and three in the central region, in cooperation with the West Virginia Geological and Economic Survey, Pennsylvania Bureau of Topographic and Geologic Survey, Ohio Division of Geological Survey, Maryland Geological Survey, Kentucky Geological Survey, and Virginia Division of Mineral Resources. The beds, in ascending stratigraphic order, include the Pocahontas No. 3 coal bed, the Pond Creek coal zone and correlatives, the Fire Clay coal zone and correlatives, the Lower Kittanning coal bed, the Upper Freeport coal bed, and the Pittsburgh coal bed (fig. 4). The Lower Kittanning coal bed was assessed for areal extent and geochemistry only.

Each coal bed assessment model (Chapters C, D, F through H) includes descriptions of original and remaining resources, and maps that depict the areal extent, mined areas, structure contours, coal isopach, overburden thickness, ash yield, sulfur content, sulfur dioxide (SO_2) content, calorific value, and selected trace-element contents. Public-domain coal thickness and elevation data used to create the coal-bed models are included as comma-delimited ASCII files in each assessment chapter (Chapters C, D, and F through H). In addition, the data sets used to produce the maps are described in detail in metadata files. The metadata contains information including references for data sources, descriptions, methods, and disclaimers that must be taken into account by users who choose to utilize any or all of the assessment products.

In recent years, the vast majority of coal assessments conducted in the U.S. have been at 1:24,000 quadrangle scale (Englund and Teaford, 1980), county scales (Shaulis, 1985; Skema, 1988; Campbell and others, 1991; Englund and Thomas, 1991), or State scales (Brant and Delong, 1960; Henderson, 1979; McDonald and Wolfe, 1999) scales. Regional, bed-scale assessments are relatively rare; the Illinois Basin Consortium, (composed of the Illinois Geological Survey, Indiana Geological Survey, and

Table 1. Recent coal production, in millions of short tons, from five top-producing coal regions in the U.S. as reported by Freme and Hong [1999].

[Subtotals of separate northern and central Appalachian Basin coal region production are in parentheses. Brackets enclose the combined production subtotal for both the northern and central Appalachian Basin coal regions.]

	1995	**1996**	**1997**	**1998**
Appalachian Basin	430.1	447.2	463.1	455.1
Northern and Central Appalachian	[405.5]	[422.6]	[438.6]	[432.1]
Northern Appalachian	(132.8)	(141.8)	(147.7)	(152.5)
Central Appalachian	(272.7)	(280.8)	(290.9)	(279.6)
Illinois Basin	109.4	111.9	111.6	110.1
Gulf Coast	56.4	58.4	56.8	55.8
Colorado Plateau	89.6	86.9	92.8	96.2
Powder River	333.4	346.2	352.5	387.7
USGS Assessed Regions Total	*1,019*	*1,051*	*1,077*	1,105
U.S. Total Production	***1,033***	***1,064***	***1,090***	***1,119***

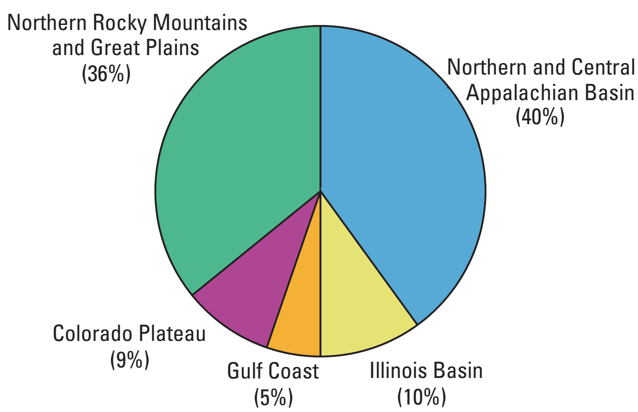

Figure 2. Chart showing 1998 coal production in USGS assessed regions. About 93 percent of all U.S. coal is produced in the five regions. The largest producers in 1998 were the northern and central Appalachian Basin coal regions (40 percent). The Northern Rocky Mountain and Great Plains region produced 36 percent of all U.S. coal, the Illinois Basin 10 percent, Colorado Plateau 9 percent and the Gulf Coast region 5 percent. Production data is from Freme and Hong [1999].

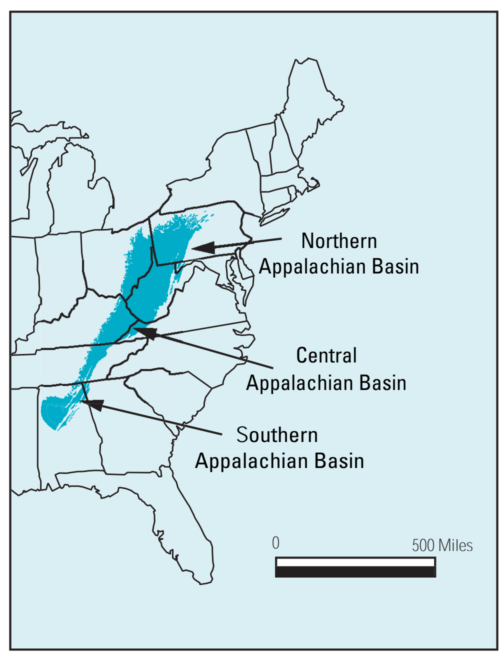

Figure 3. Map showing the three coal-producing regions of the Appalachian Basin. Assessments were conducted on coal beds in the northern and central regions where about 95 percent of Appalachian bituminous coal is produced. The northern region produces approximately 32 percent of Appalachian bituminous coal and the central region about 63 percent (Freme and Hong, [1999]).

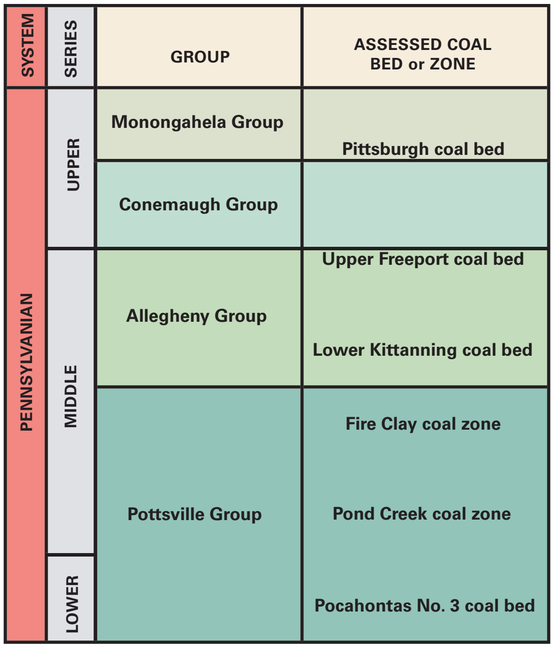

Figure 4. Generalized stratigraphic chart showing relative positions of the six top-producing coal beds or zones assessed in this study. The Lower Kittanning coal bed was assessed for areal extent and geochemistry only. All six coal beds are Pennsylvanian in age.

Kentucky Geological Survey) (Treworgy and others, 1999) and the USGS (Fort Union Coal Assessment Team, 1999) have produced large-scale, digital, coal-bed-specific assessments that extend over multistate areas. Such assessments were challenging to undertake because they require close cooperation between Federal and State geological surveys and permitting agencies, large amounts of geologic and geochemical data, and state-of-the-art computer systems and mapping programs. Once completed, however, these regional assessments will provide reasonable estimates of the remaining quantity and quality of top-producing coal beds in the U.S. The digital aspect of the data allows for easy updates or customized analyses to be conducted in the future.

The resource totals presented in this report are based on coal resources, or the amount of coal within a bed or zone before any mining began (original resources) and the amount remaining after mining (remaining resources). Coal resources are defined as naturally occurring concentrations of coal that may be mined profitably given specific technological and socioeconomic conditions. Coal reserves, which are the known and identified quantities of resources that can be exploited profitably with existing technology under prevailing economic and legal conditions (de Souza, 1990), are a subset of coal resources and are not addressed or quantified in the six assessment models presented here.

The USGS does, however, address the data required to move beyond coal resource estimates to coal reserve estimates in two ways. One of these efforts is ongoing as a USGS/State geological survey cooperative project to estimate the percentage of coal that is available for mining at 1:24,000 scale for either single multiple 7.5-minute quadrangles (Blake and Fedorko, 1988; Loud, 1988; Sergeant and others, 1988, 1989a,b; Carter and Gardner, 1989; Loud and others, 1989, 1991; Davidson and others, 1990; Eggleston and others, 1990; Sites, 1990; Anderson and others, 1991; Sites and others, 1991; Sites and Hostettler, 1991a,b, 1992a,b; Carter and others, 1992; Weisenfluh and others, 1992, 1993; Andrews and others, 1994; Carter, 1996, Chapter H, this CD–ROM; Cetin and others, 1996; McDonald and Wolfe, 1999; Tabet and others, 1999), state- or basin-wide (Thacker and others, 1998; Hoffman and Jones, 1999; Schultz and others, 1999; Greb and others, 2000; Weisenfluh and others, 2000), and basin-wide scales (Treworgy and others, 1999) scales. Available coal is defined as remaining coal resources that are thick and shallow enough to be mined, either by surface or underground methods, that are unencumbered by land use, environmental, societal, regulatory, or technological restrictions as they may apply to a given state or region (Carter and Gardner, 1989).

In addition, as a followup to the coal availability studies, USGS conducted coal recoverability studies on both local and regional scales (Osmonson, 1994; Rohrbacher and others, 1994; Rohrbacher, 1995, 1997; Carter and others, 1995, 1998; Carter and Rohrbacher, 1996, 1998; Scott, 1995, 1997; Scott and Teeters, unpub. data, 1997–1999) and bed scales (Watson and others, 2000). Coal recoverability studies combine future mining and washing recovery models with mine cost models to calculate economically recoverable resources; that is, reserves (Rohrbacher and others, 1993; U.S. Bureau of Mines, 1995). These studies provide resource cost curves that show the quantity and quality of coal that can be prospectively mined and ready for market delivery at incremental cost levels. Results of the USGS coal availability and recoverability studies in the northern and central Appalachian regions are presented in Chapter J (this CD-ROM).

The USGS last published the Nation's coal resources as of January 1974 (Averitt, 1975). This effort, which was designed to characterize all known coal resources within the U.S., was undertaken at a time when energy prices were unstable because of world politics and fears of oil embargoes. The percentage of electricity generated from coal increased from 50 percent in 1970 to 83 percent in 1995 as the Federal government discouraged the use of oil in existing plants and prohibited new construction of gas-fired power plants (Natural Gas Policy Act of 1977) (Attanasi, 1998a). In 2000, energy prices were generally lower than they were in the 1970's and 1980's, the electric power industry is deregulated, Phase II requirements of the Clean Air Act Amendments of 1990 (Public Law 101-549) mandate lower sulfur-dioxide emissions, and the coal mining and transportation industries are each being consolidated (Attanasi, 1998a). These factors have created a huge demand for low-sulfur coal from the Powder River Basin and the central Appalachian Basin region. In 1995, approximately 90 percent of coal from the Powder River Basin and 30 percent of coal from the central Appalachian Basin region that was delivered to power plants met Phase II standards of 0.6 lbs of sulfur per million Btu (fig. 5). Virtually none of the coal from the Illinois Basin and northern Appalachian Basin region met the standards (fig. 5). The coal in the central Appalachian Basin region will continue to be mined, at least in the near future, because electric utility companies can meet air quality standards by coal blending; installation of flue-gas desulfurization units; retiring older, less efficient units; or purchasing emission allowances from companies who emit less sulfur than the maximum allowed by Phase II regulations (Attanasi, 1998a). However, all of these options are more costly than switching to low-sulfur coal (Attanasi, 1998a).

ACKNOWLEDGMENTS

We thank Eric Morrissey for help in preparing the graphics. Robert Milici was invaluable as a reviewer and he willingly shared his expertise in Appalachian Basin coal production and trends with the authors. Comments by Ronald Stanton (USGS) made this a better paper. A special thanks to CONSOL Inc. (Pittsburgh, Pa.) for permission to publish the photograph of the longwall miner, and to the West Virginia Geological and Economic Survey for their photograph of the dragline.

ASSESSMENT METHODOLOGY

The methods for calculating resources in the northern and central Appalachian coal regions generally follow those of Wood and others (1983), Roberts and others (1998), Tewalt (1998), and Roberts and Biewick (1999). Stratigraphic databases were constructed in a commercial drill-hole data management software program (StratiFact[3]) from data records in USGS's National Coal Resources Data System (NCRDS), State geological surveys, and published and unpublished sources. Coal bed correlations were verified with the original records and checked by creating cross sections (Pittsburgh and Pocahontas No. 3 coal beds) or by creating cross sections and maps (Upper Freeport and Lower Kittanning coal beds, as well as the Pond Creek and Fire Clay coal zones). Once correlated and assigned a stratigraphic record identifier, latitude and longitude, coal-bed elevation, and cumulative coal thickness (excluding bone coal and partings greater than 3/8 in) were imported into EarthVision[4], which is a commercial gridding and modeling software package. Grid models of the elevation of the top of the coal bed and the total coal thickness were made for the Pocahontas No. 3, Upper Freeport, and Pittsburgh coal beds. Because the Fire Clay and Pond Creek coals are multiple-bedded coal zones with abundant inorganic parting material, and are not always distinct coal beds, grid models were created for coal benches that were thick enough and close enough to one another to be considered for mining (see Chapters F and G, this CD-ROM). Grids created for the top of the coal beds and coal zones were subtracted from either a combination of 1:250,000- and 1:100,000-scale DEM's (digital elevation models) or 1:100,000-scale DEM's to produce grids of overburden thicknesses.

Coal-bed thickness grids were contoured following the thickness intervals for bituminous coal suggested by Wood and others (1983). The contour maps (showing coal zone total thickness and overburden) were transferred to ArcInfo, a commercially available GIS software package, and joined into one coverage that included (1) reliability circles (following Wood and others, 1983), (2) county boundaries, (3) areal extent and mined-area boundaries, and (4) overburden for the calculation of volumetrics. The resulting tonnages were exported to a spreadsheet to produce resource tables for each coal bed. Detailed methods and the original and remaining coal resource tonnage (by State, county, thickness, overburden, and reliability) are reported in each of the coal-bed resource assessment chapters of this volume (Chapters C, D, and F through H, this CD-ROM).

GEOLOGY OF THE NORTHERN AND CENTRAL APPALACHIAN BASIN COAL REGIONS

The Appalachian Basin extends from New York to Alabama and underlies an area of about 50,000 mi^2 (fig. 6). The basin first developed on late Precambrian (1.1 billion years ago) continental crust that extended along the thinned continental margin of Iapetus (the proto-Atlantic Ocean). During the Alleghany orogeny (265 million years ago), col-

[3]Stratifact is a product of GRG Corporation, StratiFact Software, 4175 Harlan Street, Wheat Ridge, CO 80033. http://www.stratifact.com.

[4]EarthVision is a product of Dynamic Graphics, Inc., 1015 Atlantic Avenue, Alameda, CA 94501. http://www.dgi.com.

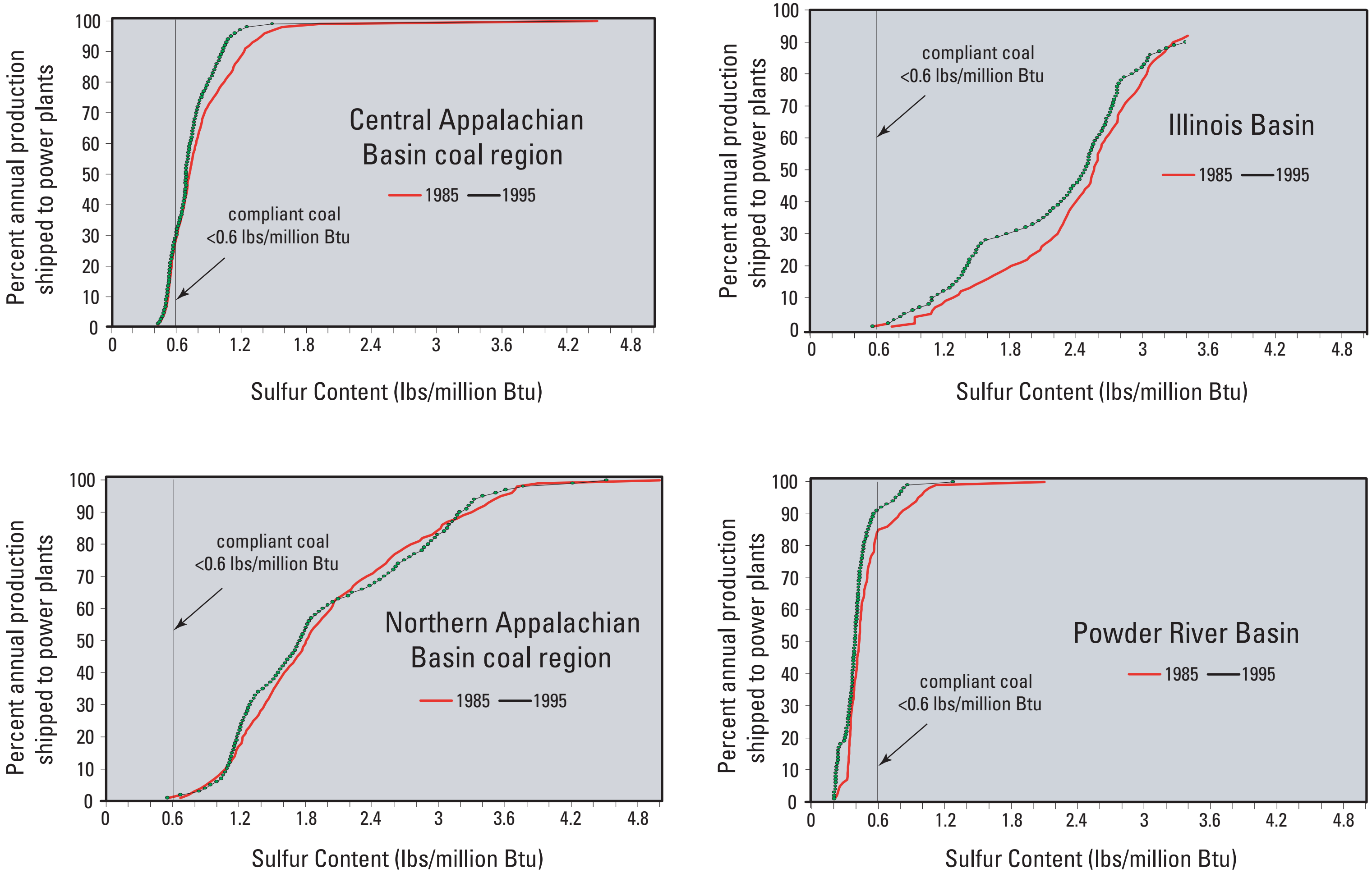

Figure 5. Graphs showing cumulative distribution of U.S. coals shipped to power plants between 1985 and 1995, by pounds of sulfur per million Btu (shown by vertical line in each graph). Phase II of the Clean Air Act Amendments of 1990 (Public Law 101-549) mandates a limit of 0.6 pounds of sulfur per million Btu. About 30 percent of coal from the central Appalachian Basin coal region and 90 percent of coal from the Powder River Basin meet compliance standards. Coals from the northern Appalachian Basin coal region and the Illinois Basin do not meet the standards. Modified from Attanasi (1998a).

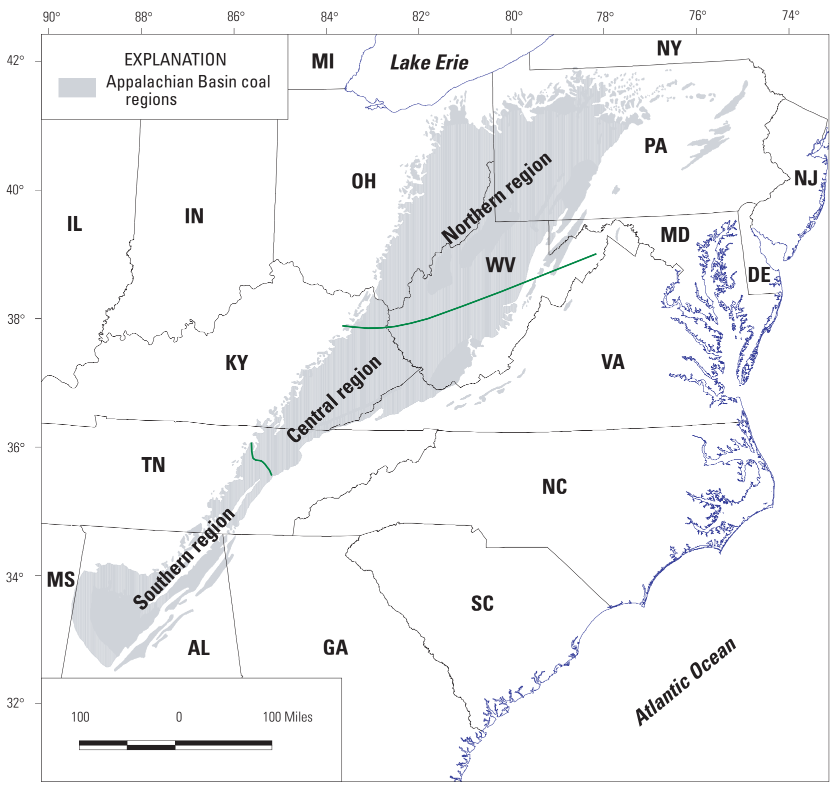

Figure 6. Map showing extent of the Appalachian Basin (in gray). The basin extends over 50,000 mi^2 from New York to Alabama. The basin is divided into three coal-bearing regions (divided by green lines). Assessed coal beds occur in the northern and central regions.

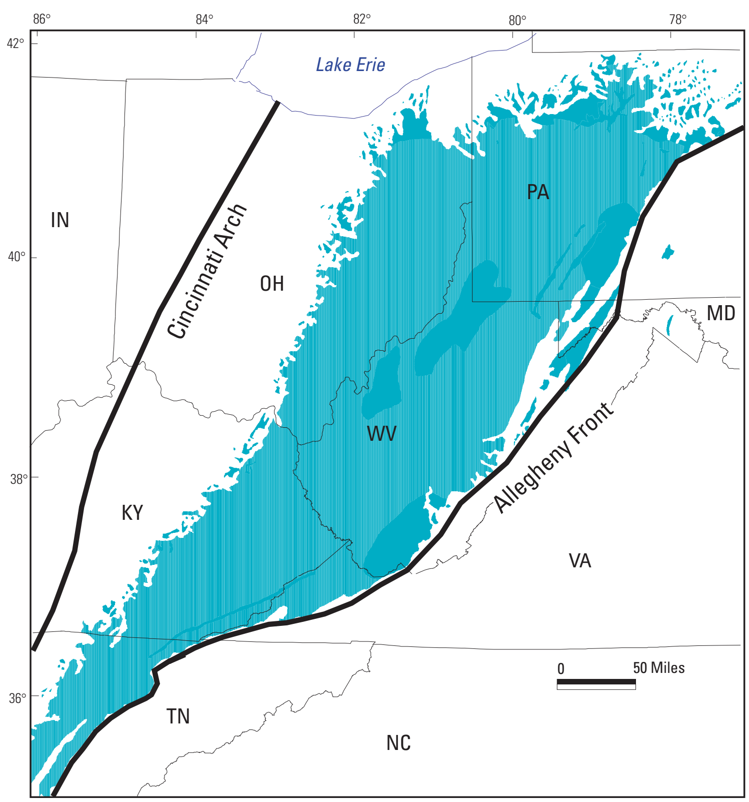

Figure 7. Map showing extent of the Pennsylvanian outcrop belt (green area) in the northern and central Appalachian foreland basin. The basin is a clastic wedge that thickens southeastward. The original eastern edge is eroded, but it is presumed to have been east and parallel to the present day Pennsylvanian outcrop. The western edge of the foreland basin is the Cincinnati Arch.

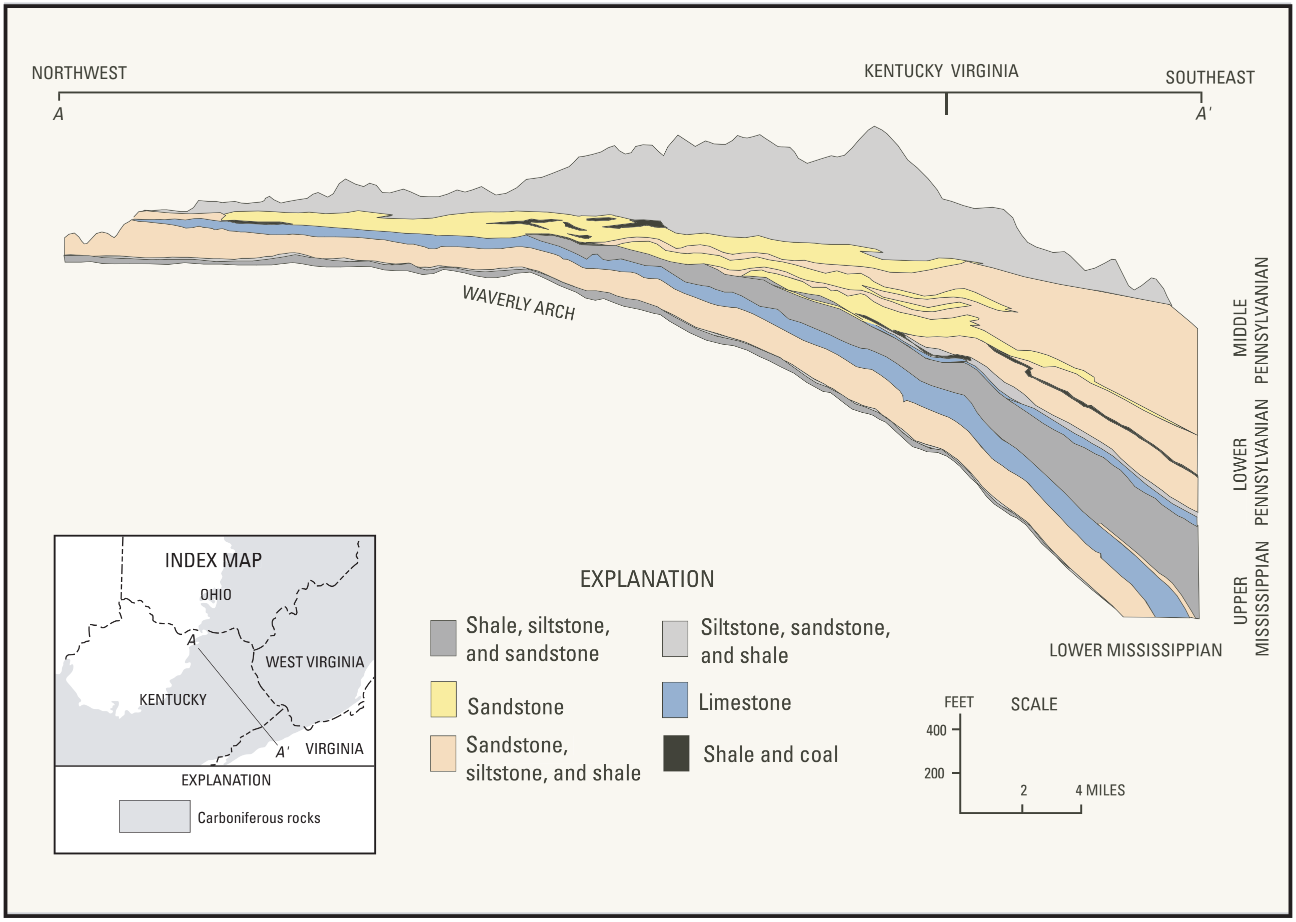

Figure 8. Cross section of Mississippian and Pennsylvanian rocks in the central Appalachian Basin coal region, showing the thickening of sediments from west to east as Pennsylvanian strata onlapped older Mississippian strata. Modified from Englund (1979).

lision of the North American and the African continental plates caused the eastern margin of the North American continent to subside again as an elongated foreland basin (Hatcher and others, 1989). In this basin, Pennsylvanian and Permian rocks formed a clastic wedge that thickened generally southeastward toward the axis of the foreland basin. The axial region was broken by Appalachian thrust sheets that were lifted up and eroded away. However, the basin is inferred to have been east of and parallel to the eastern edge of the present-day Pennsylvanian outcrop belt (fig. 7). The western edge of the foreland basin laps onto the Cincinnati Arch (fig. 7), which, in part, separates the Appalachian foreland basin from the Eastern Interior basin. Pennsylvanian sediments may have been transported from the ancestral Appalachian Mountains across the Cincinnati Arch into the Eastern Interior basin. In the Appalachian Basin, however, the present eastern edge of Pennsylvanian rocks is generally the west- and northwest-facing Allegheny front (fig. 7).

The oldest Pennsylvanian strata are in the deepest part of the Appalachian Basin in southeastern West Virginia and southwestern Virginia in the vicinity of Pocahontas, Va., where sedimentation may have been continuous across the Mississippian-Pennsylvanian boundary (Englund, 1979) Pennsylvanian sediments thin and unconformably onlap progressively older eroded Mississippian strata toward the west and northwest (fig. 8). The youngest Pennsylvanian strata and overlying Permian strata were eroded during the Paleozoic from the central part of the Appalachian Basin and are found today only on the northwestern flank of the basin in Pennsylvania, Ohio, northwestern West Virginia, and northeastern Kentucky.

The depositional character of the Pennsylvanian strata is both deltaic and marginal marine. Sediments were deposited in aqueous environments that include piedmont, valley-flat, channel-fill, marsh, peat-swamp, lake, delta, lagoon, and shallow-sea-floor environments. During the Pennsylvanian, detritus from the ancestral Appalachian Mountains and the Canadian craton to the north extended from the north, east, and southeast in deltaic fans across a broad coastal plain, which at times was flooded by shallow continental seas. The timing of these marine inundations may have been controlled partly by the waxing and waning

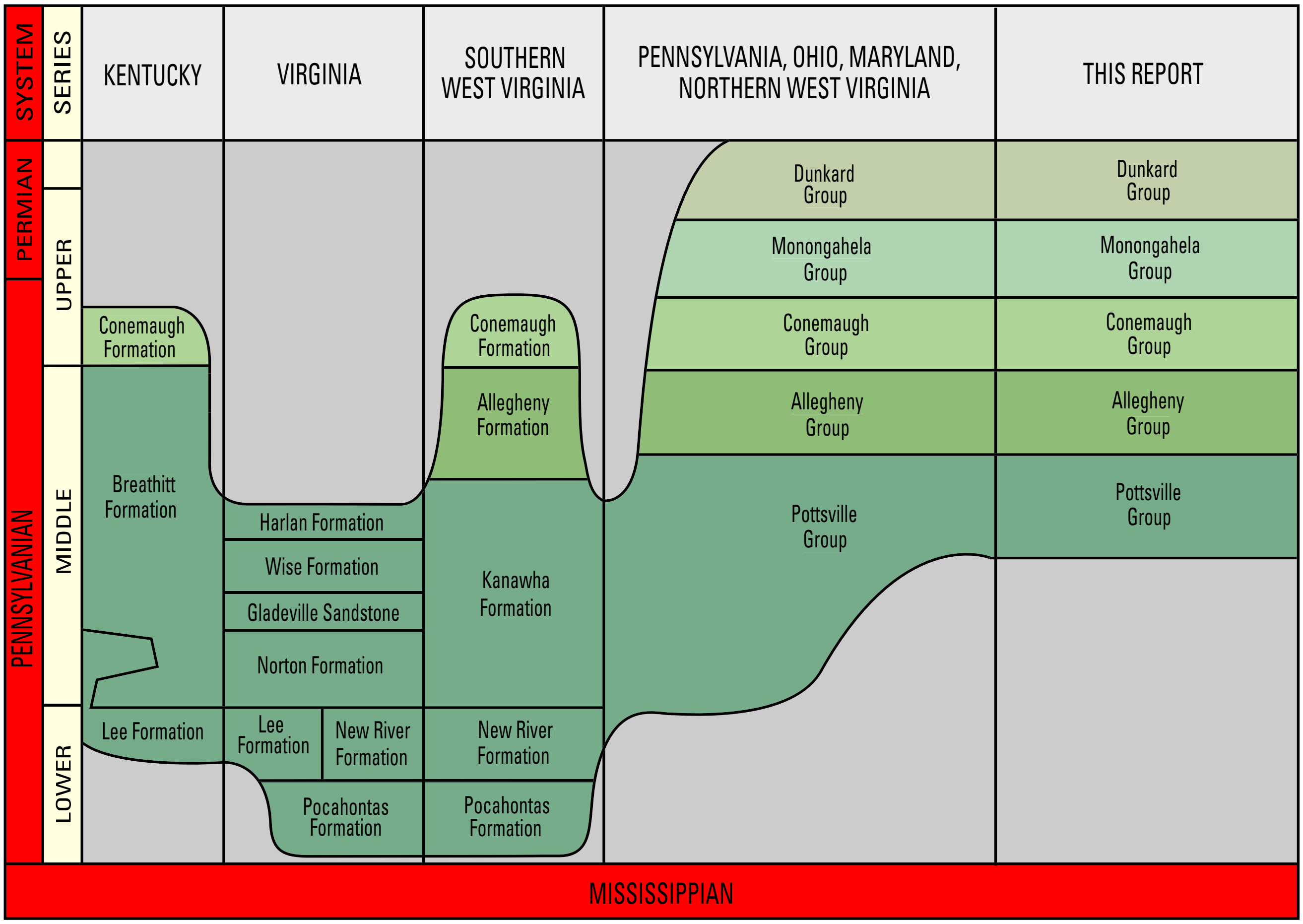

Figure 9. Chart showing stratigraphic nomenclature used in this report for the northern and central Appalachian Basin coal regions. This simplified nomenclature, first established in Pennsylvania, can generally be recognized regionally and was needed because it allowed for storage and manipulation of stratigraphic data. Data from U.S. Geological Survey Professional Papers 1110-A through 1110-L.

of continental glaciers in other parts of the world that affected the general rise and fall of sea level.

The Pennsylvanian and Lower Permian coal-bearing strata today occupy a physiographic region commonly referred to as the Appalachian Plateaus. The Plateaus are, in general, an intricately dissected upland of concordant sharp ridges and V-shaped valleys.

Formal stratigraphic names of Pennsylvanian strata tend to differ from State to State in the northern and central Appalachian Basin coal regions (Rice, Hiett, and Koozmin, 1994). Figure 9 illustrates these differences. This report uses the nomenclature for the major subdivisions first established for these rocks in southwest Pennsylvania, even though they could not be correlated easily across the basin and their use and definitions have been shown to be inappropriate for other areas. Whereas geologic formations (or groups) may be identified by distinctive lithological features, most Pennsylvanian formations (or groups) have been described in terms of bounding coal beds (marker beds) and sandstone units, most of which have proven to be regionally discontinuous. However, in a general sense, the broad definitions of the major stratigraphic subdivisions from the Pennsylvanian can be recognized well enough regionally that they can be used to simplify an otherwise complicated and unwieldy stratigraphic nomenclature which must accommodate a digital coal resource data system. The use of these names does not constitute an official change to stratigraphic nomenclature for either the USGS or the participating State geological surveys. Thus, in this report, the Pennsylvanian strata are divided into four groups (from oldest to youngest): the (1) Pottsville, (2) Allegheny, (3) Conemaugh, and (4) Monongahela Groups (fig. 9). Overlying coal-bearing latest Pennsylvanian and Permian rocks are included in the Dunkard Group.

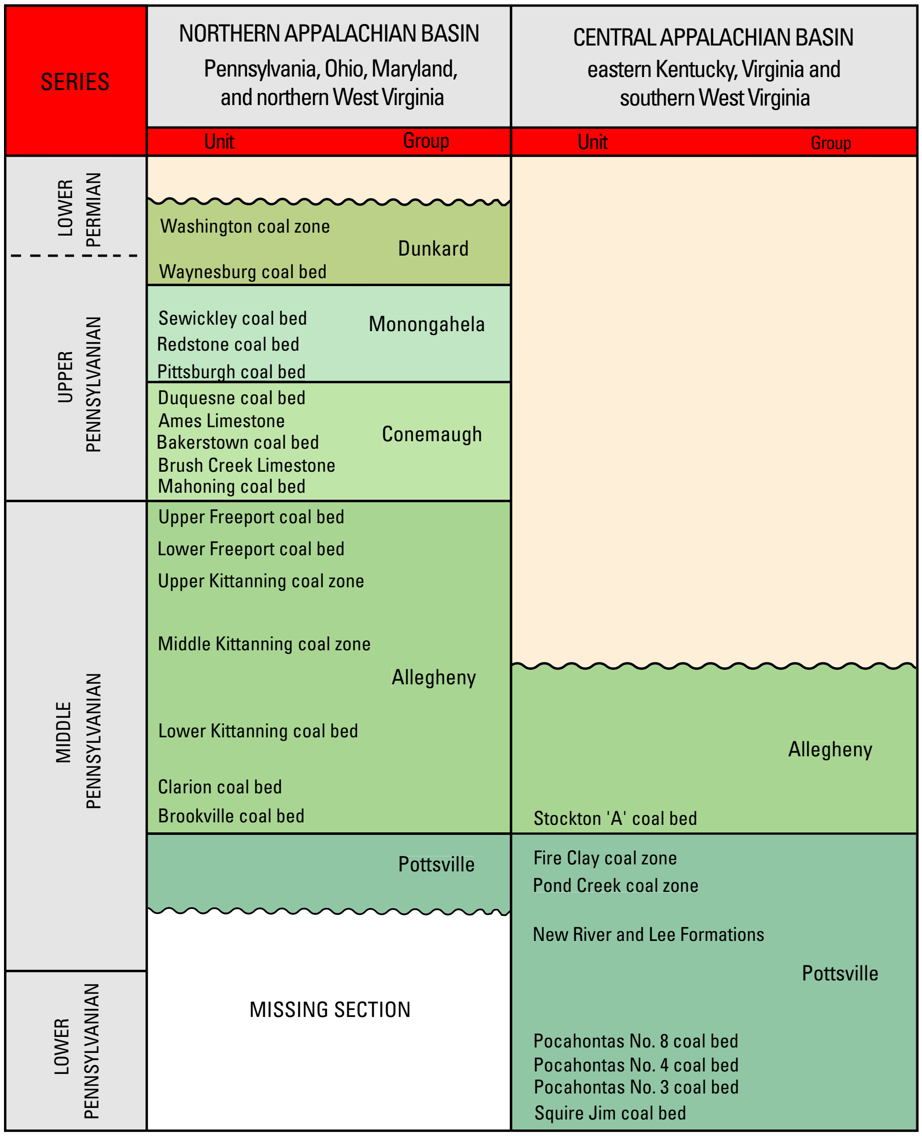

Figure 10. Generalized stratigraphic column of the Pennsylvanian and Lower Permian in the northern and central Appalachian Basin coal regions. Modified from Lyons (1998).

POTTSVILLE GROUP

The oldest Pennsylvanian sediments, the Pottsville Group, extend across the entire Appalachian Basin. The Pottsville Group is named for Pottsville Gap, Schuylkill County, Pa. Contacts between the Pennsylvanian sediments and underlying Mississippian marine limestone and shale (commonly red and green shale) and terrestrial sandstone are clearly erosional in places, but have been interpreted to be transitional or conformable in others (Englund, 1979; Milici and de Witt, 1988; de Witt and Milici, 1989), particularly in the deepest part of the basin where strata of the Pocahontas Formation are at the base of the Pottsville Group. The Pocahontas Formation, which may be as much as 700 ft thick and consists mostly of coal-bearing sequences of carbonaceous shale and siltstone with minor sandstone, does not extend northward beyond Virginia and West Virginia (Englund, 1979). Thick sequences of quartzose conglomeratic sandstone, which overlie the Pocahontas Formation in West Virginia and Virginia, characterize the lower part of the Pottsville Group in other parts of the Appalachian Basin. These strata, which reach a maximum thickness of more than 1,600 ft along the border between Virginia and Kentucky (Rice and others, 1979), are the New River Formation (West Virginia, Virginia), Lee

Formation (Virginia, Kentucky), Sharon Conglomerate (Pennsylvania, Maryland, and Ohio), and the Olean Conglomerate (Pennsylvania) (fig. 10). The strata of the upper part of the Pottsville Group above the conglomeratic sandstone also consists mostly of coal-bearing sequences of carbonaceous shale and siltstone with minor sandstone. In the area along the border between Virginia and Kentucky, total thickness of the Pottsville Group is more than 5,000 ft even though it is truncated at the base by onlap and at the top by erosion. In Ohio, where the Pottsville is thinnest, it averages about 256 ft in thickness (Collins, 1979).

The top of the Pottsville Group is defined in Pennsylvania as the top of the Homewood Sandstone or the top of the fireclay or claystone below the Brookville coal bed (fig. 10). These units are projected into northeastern Kentucky, northern West Virginia, eastern Ohio, and western Maryland with some difficulty because the basal defining units are discontinuous. However, following the correlations of Rice, Kosanke, and Henry (1994), the Brookville coal bed is here correlated with the Newland coal in Ohio, the Princess No. 5 coal in northeastern Kentucky, and the Stockton coal in northern West Virginia. In Maryland, Swartz (1922) correlates the Brookville with the Lower Mount Savage coal bed.

Three of the major coal beds in the Pottsville Group (from oldest to youngest), the Pocahontas No. 3 coal bed, and the Pond Creek and the Fire Clay coal zones, were modeled in this assessment (Chapters F through H, this CD-ROM). The name Pocahontas No. 3 coal bed is used throughout its extent in southwestern Virginia, southern West Virginia, and eastern Kentucky. The Pond Creek coal zone (a term used in this report to encompass all equivalent coal beds of this horizon) is equivalnt to the Lower Elkhorn in Kentucky, the Imboden coal bed in Virginia, and the Eagle coal bed in West Virginia. Local names for the Pond Creek coal zone include the Blue Gem, Bruin, Freeburn, Howard, Pond Fork, Straight Creek, and Vires coal beds, and the Rich Mountain coal zone in Kentucky; and the Campbell Creek, Lower Eagle, and Eagle "A" coal beds in West Virginia. The Fire Clay coal zone is equivalent to the Hazard No. 4 coal bed in Kentucky, the Phillips coal bed in Virginia, and the Fire Clay coal bed in West Virginia. Some of the more common local names for the Fire Clay coal zone include the Dean, Flatwoods, Hazard No. 4, Hyden No. 7, Springfield, Stray, Wallins Creek, and Windrock coal beds in Kentucky; the Chilton coal bed in West Virginia; and the Hignite coal zone and Windrock coal bed in Tennessee.

ALLEGHENY GROUP

The Allegheny Group is named for the Allegheny River in western Pennsylvania. The lithology of the Allegheny Group is similar to that of the underlying Pottsville Group. Unlike the Pottsville, however, it commonly contains thin marine limestone beds in the lower part, particularly in the northern and western parts of its outcrop belt in Ohio and Pennsylvania. The Allegheny Group is defined as extending from the top of the Homewood Sandstone (or the top of the claystone or fireclay beneath the Brookville coal bed) to the top of the Upper Freeport coal bed (fig. 10). Although rather thin (averaging 212 ft in Ohio (Collins, 1979) and as much as 250 ft in West Virginia (Arkle and others, 1979)), the Allegheny Group contains, in addition to its beds of limestone, many valuable beds of coal and clay, justifying its original name of the "Lower Productive Measures" (Wanless, 1939). Two Allegheny Group coal beds, from oldest to youngest, the Lower Kittanning (Chapter E, this CD-ROM) and Upper Freeport (Chapter D, this CD-ROM) coal beds (fig. 10) and their equivalents, were assessed in this study.

CONEMAUGH GROUP

The Conemaugh Group was named for the Conemaugh River in western Pennsylvania and is characterized by sequences of red and green mudstone, claystone, and siltstone. It contains several thin marine limestone beds but only a few thin coal beds, which formerly earned it the name "Lower Barren Measures" (Wanless, 1939). The Conemaugh Group is defined as extending upward from the top of the Upper Freeport coal bed to the base of the Pittsburgh coal bed (fig. 10). The group is about 400 ft thick in Ohio (Collins, 1979) and thickens to 850 to 900 ft in eastern Pennsylvania and West Virginia (Arkle and others, 1979; Edmunds and others, 1979).

MONONGAHELA GROUP

The Monongahela Group was named for exposures along the Monongahela River in western Pennsylvania. It was formally known as the Upper Productive Measures (Wanless, 1939) because it contains several commercial coal beds, including the Pittsburgh coal bed (Chapter C, this CD-ROM). The group is defined as extending from the base of the Pittsburgh coal bed to the base of the Waynesburg coal bed (fig. 10). It is about 250 ft thick in Ohio (Collins, 1979) and as much as 400 ft in West Virginia (Arkle and others, 1979) and consists mostly of red, green, and gray shale and claystone or mudstone, freshwater limestone beds, and locally massive sandstone beds.

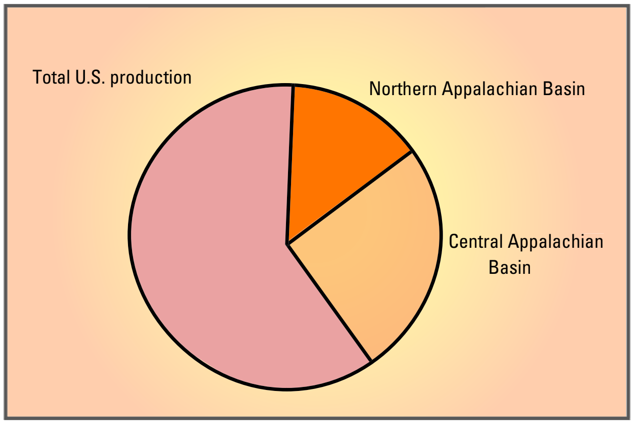

Figure 11. Chart showing 1998 coal production in the northern and central Appalachian Basin coal regions. Total production from these two regions constituted about 40 percent of all U.S. coal production and about 94 percent of the Appalachian bituminous coal production. About 32 percent of Appalachian bituminous coal and 14 percent of all U.S. coal is produced from bituminous coals in the northern Appalachian Basin coal region. Data from Freme and Hong [1999].

DUNKARD GROUP

The Dunkard Group was described from exposures along Dunkard Creek, a tributary to the Monongahela River in southwestern Pennsylvania (White, 1891). The Dunkard Group includes all strata above the base of the Waynesburg coal bed. The base of the Permian generally has been placed in the lower part of the Dunkard Group, 100 to 150 ft above its base. This is supported by the occurrence of the fossil plant, *Callipteris conferta*, in the seat rock of the Washington coal bed and "the generally Permian character of the flora" (Collins, 1979) in the overlying strata.

Strata of the Dunkard are very similar to those of the underlying Monongahela Group, except that the Dunkard contains only thin discontinuous coal beds of little or no commercial value, hence the name "Upper Barren Measures" (Wanless, 1939). The strata consist primarily of red shale and mudstone and thick sequences of lacustrine (fresh- to brackish-water) limestone that are associated with gray shale locally in the northern part of the outcrop area (Arkle, 1974).

MINING IN THE NORTHERN AND CENTRAL APPALACHIAN BASIN COAL REGIONS

About 50 northern and central Appalachian Basin coal beds produced 403.4 million short tons of bituminous coal from 1,421 mines in 1998 (Freme and Hong, [1999]). This production constituted about 40 percent of all U.S. coal production (figs. 11, 12) and about 94 percent of the Appalachian bituminous coal production. About 32 percent of Appalachian bituminous coal and 14 percent of all U.S. coal is produced from bituminous coal in the northern Appalachian Basin coal region (Freme and Hong, [1999]). The Pittsburgh (81 million short tons), Upper Freeport (15 million short tons), and Lower Kittanning (23 million short tons) coal beds together account for 80 percent of the northern Appalachian Basin bituminous coal production (Energy Information Administration, 1998). These three coal beds are expected to account for the bulk of northern Appalachian Basin coal production during the next decade. Coal from the central Appalachian Basin coal region constitutes about 27 percent of all U.S. coal production and about 63 percent of the Appalachian bituminous coal production (Energy Information Administration, 1998). Production from the Fire Clay coal zone (20 million short tons), Pond Creek coal zone (17 million short tons), and Pocahontas No. 3 coal bed (16 million short tons) accounts for about 18 percent of the central Appalachian Basin coal production. About half of the coal from the central Appalachian Basin coal region is produced from the No. 5 Block coal zone in the Allegheny Group, and from the Stockton and Coalburg, Winifrede/Hazard, Williamson/Amburgy, Upper Elkhorn No. 3/Campbell Creek, and the Upper Elkhorn Nos. 1 and 2/Powellton coal zones of the Pottsville Group. These coal zones were not modeled in the current USGS assessment because detailed coal-bed maps and verified coal thickness data were not available, but stratigraphic correlations and production history for each coal zone is discussed in detail in Chapter I (this CD–ROM; also see Chapter I for an explanation of the coal zone names contructed for use in this report).

Coal has been produced in the northern and central coal regions for over 200 years (fig. 13). Historic and recent production records show that about 32 trillion short tons of bituminous coal have been produced; 14.5 trillion in the central part and 18.5 trillion in the northern part (Milici, 1996). Approximately one half of the total cumulative tonnage has been mined in the last 50 years.

Throughout the early 19th century, wood, which was plentiful and cheap, was the primary fuel for household heating and charcoal production. Eavenson (1938) estimated that in 1823, 80 percent of the Nation's annual fuel consumption came from wood, 3 percent from charcoal, 14 percent from anthracite, and less than 2 percent from bituminous coal. However, within 50 years, coal became the primary source of energy throughout the region. A major driver for the change to coal was the development of rail lines, and, to a lesser extent, canals. Between 1839, when the first rail lines and canals were built, and 1880, annual bituminous coal production increased from approximately 147 thousand short tons to about 25 million short tons (Milici, 1996). Cumulative historical production records show the

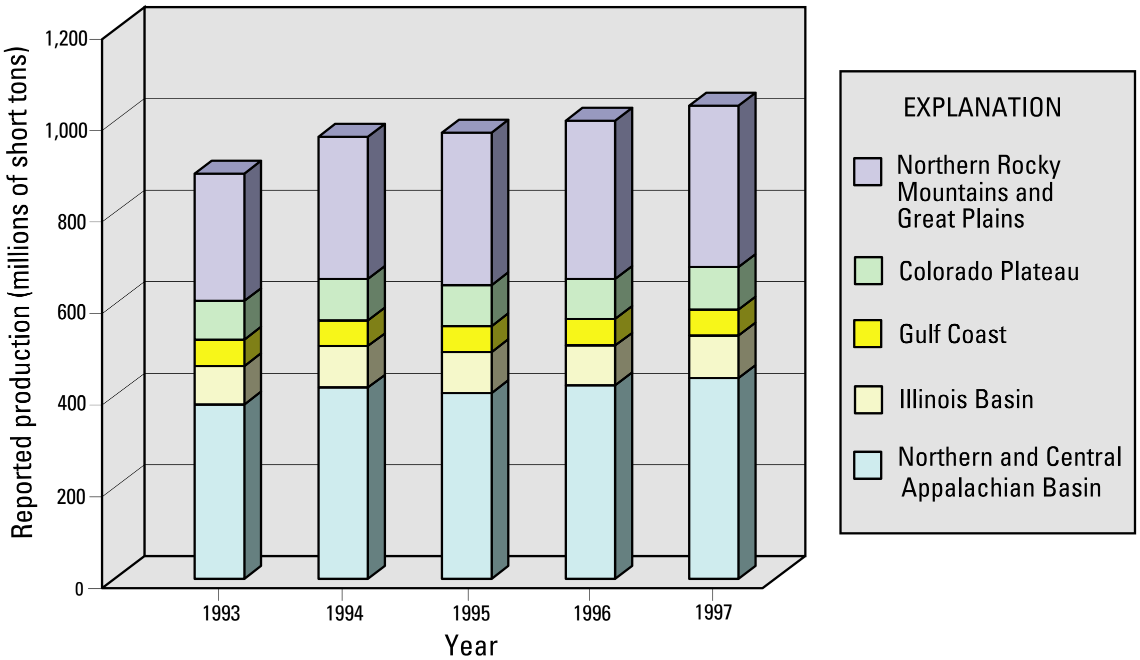

Figure 12. Bar graph showing coal production in USGS assessed regions from 1993 to 1997. Coal production in the northern and central Appalachian Basin coal regions continues to surpass all other coal-producing regions in the U.S., but the Northern Rocky Mountains and Great Plains production is increasing at a more rapid rate than any other region. Data from Energy Information Administration (1998).

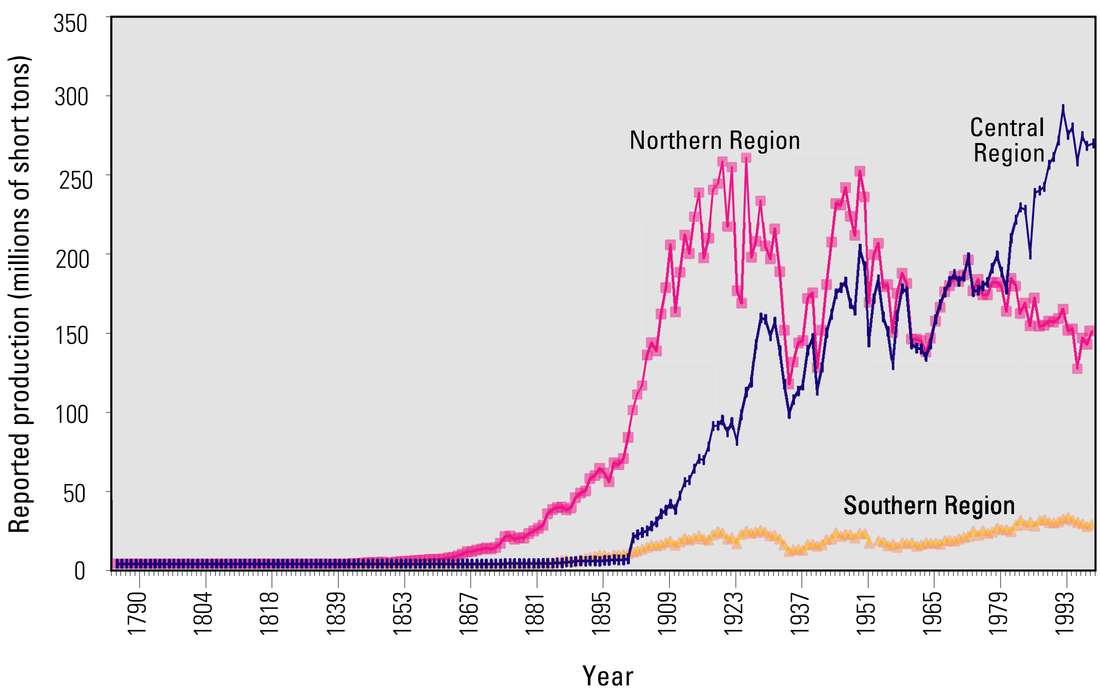

Figure 13. Graph showing annual Appalachian Basin coal production from 1790 through 1995, for the northern, central, and southern coal regions. The production data show three sharp increases in production during World War I, World War II, and in the last 20 years. Central Appalachian Basin production is now at its peak, and northern Appalachian Basin production is declining as the thickest and shallowest coal is mined out. Modified from Milici (1996, 1997a).

Figure 14. Photograph showing longwall mining operation in the Pittsburgh coal bed of the Monongahela Group in northern West Virginia. Photograph by CONSOL Coal Group/Bob Kohler Photography.

impact of the railroads most dramatically. In the first four decades of record keeping (1790–1839), 690 thousand short tons of bituminous coal were mined in the northern and central Appalachian Basin coal regions; in the following four decades, 305 million short tons were mined (Milici, 1996).

The demand for steel in the late 19th century generated an explosive growth in Appalachian Basin coal production, especially in Pennsylvania. In 1899, a total of about 114 million short tons of bituminous coal was mined—65 million short tons in Pennsylvania alone (Milici, 1997b). In that one year, bituminous coal production in the northern and central Appalachian Basin coal regions accounted for more than one third of the total cumulative production from 1840 to 1880 (see Collins, 1976; Crowell, 1995).

Coal production in the northern and central Appalachian Basins coal regions increased throughout the late 19th and early 20th centuries, reaching peaks during World War I, World War II, and from the 1970's through the present (fig. 13). Milici (1997a) demonstrated that the coal production peaks exhibit industrial demand-driven cycles generated by economic expansion. Figure 13 clearly shows that coal production in the northern Appalachian Basin has peaked, primarily because much of the thickest, most accessible, and highest quality coal has been depleted. Coal will continue to be mined in the northern part of the basin for the next several decades because much of the remaining reserves are close to compliance and are thick enough and in large enough blocks to support large, highly productive, longwall mines (fig. 14). For example, Enlow Fork and Bailey mines, Washington and Greene Counties, Pa., are the first and third largest underground mines in the U.S., annually producing over 16 million short tons of Pittsburgh coal (Fiscor, 1999). These mines, and many others, are expected to continue operation throughout the next decade.

Central Appalachian Basin coal production (Milici, 1997a,b; Milici and Campbell, 1997) is at or near its peak in eastern Kentucky and West Virginia and may be several years away from maximum production (Milici, 1996). The coal, which tends to be high in calorific value, low in sulfur, and compliant, is mined by underground, by conventional surface, and increasingly by mountain-top removal methods. Mountain-top removal mining (fig. 15) is a controversial surface mining technique where the tops of mountains are removed to expose multiple coals, depositing the overburden into the heads of adjacent valleys (fig. 16). Many of the permitted mountain-top removal mines are large (as much as 3,100 acres) and located in southern West Virginia. Target coal beds include the No. 5 Block coal zone and the overlying No. 6 coal zone of the Allegheny Group, and the Stockton and Coalburg coal zone of the Pottsville Group (Fedorko and Blake, 1998; Chapter I, this CD–ROM).

The most recent reserve estimates for the northern and central Appalachian Basin coal regions were conducted by Milici (1997b). He estimated that there were 57.3 billion short tons of original reserves. This number compares well to the previous original reserve estimates of Averitt (1975) and the Energy Information Administration (1996) of 59.2 and 50.9 billion short tons, respectively (table 2). Milici estimates that about 33.2 billion short tons of reserves remain in the northern and central Appalachian Basin coal regions, but it is important to note that much of this reserve is deeper, thinner, and of poorer quality than the coal that has been mined. Given current environmental concerns and increased mining costs associated with the remaining resources, demand is likely to continue shifting to low-sulfur, low-cost Western coal and accentuate the coal production declines in the Appalachian Basin.

COALBED METHANE POTENTIAL

Coal beds are both a source and a reservoir for natural gas. Hydrogen, methane, carbon monoxide, heavy hydrocarbons, nitrogen, and oxygen are produced as plants are altered, or coalified, with heat and pressure to form coal. Methane is the most valuable of the coal-bed gases, and it has been commercially extracted from Warrior Basin, central Appalachian Basin coal region, and San Juan Basin coal beds since the mid-1970's (Rice and others, 1993).

Rice (1995) identified three coalbed methane (CBM) plays in the northern and central Appalachian Basin coal regions (fig. 17) containing an estimated 14.062 trillion cubic feet (Tft^3) of technically recoverable CBM gas. Two of the plays, the Northern Appalachian Basin Syncline Play and the Northern Appalachian Anticline Play, are estimated to contain 10.48 Tft^3 and 1.07 Tft^3 of technically recoverable CBM gas, respectively (Rice, 1995). Despite the relatively large volume of CBM reserves in the northern Appalachian Basin coal region plays, the reserves are not economically recoverable at current prices because they are diffused over approximately 12,200 mi^2, and because rates of production and estimated ultimate recoveries are very low (Attanasi, 1998b). In contrast, the Central Appalachian Basin Play is estimated to contain 3.07 Tft^3 technically recoverable CBM gas (Rice, 1995) and much of it is economically recoverable at 1996 market prices (Attanasi, 1998b).

In 1995, 94 percent of the Nation's CBM was produced in coal in the Warrior Basin in Alabama, and the San Juan Basin in Colorado and New Mexico. Production from the northern and central Appalachian Basin coal regions accounted for 31 billion cubic feet (Bft^2) of CBM gas, or 3 percent of the Nation's production (Lyons, 1998). The northern Appalachian Basin region produced about 2 Bft^3 of methane and the central region about 29 Bft^3 (Lyons, 1998). The majority of CBM gas production in the central Appalachian Basin is from Dickenson, Russell, Buchanan, and Wise Counties, Va. In 1998, Virginia coal produced 42.6 Bft^3 of methane from 1,321 wells; in 1997, coal from Wyoming and McDowell Counties, W. Va., produced 567 million cubic feet of methane from 32 wells (R.C. Milici, USGS, oral commun., 1999). Commercial production is concentrated in the Lower Pennsylvanian part of the Pottsville Group (Pocahontas No. 3 and No. 4 coal beds) and the Middle Pennsylvanian part of the Pottsville Group and overlying Allegheny Group (Lower Horsepen, Little Fire Creek, War Creek, Beckley, Lower Seaboard, Sewell, Jawbone, and Iaeger coal beds).

CONCLUSIONS

The northern and central Appalachian Basin coal regions have produced over 32 trillion short tons of bituminous coal in three centuries of mining. Much of the total cumulative production came from the six coal beds that were assessed in the USGS's northern and central Appalachian Basin coal regions—the Upper Pennsylvanian Pittsburgh coal bed; the Middle Pennsylvanian Upper Freeport and Lower Kittanning coal beds; the Middle Pennsylvanian Fire Clay and Pond Creek coal zones; and the Lower Pennsylvanian Pocahontas No. 3 coal bed. Production from these coal beds is expected to continue into the next decade, but at a declining rate because most of the thickest, shallowest, and lowest sulfur coal has been mined. Appalachian Basin coal production in the future will be concentrated in the central Appalachian Basin region because the coal tends to be lower in sulfur content than coal in the northern Appalachian Basin region.

Figure 15. Photograph showing mountain-top removal mining operation in West Virginia. In mountain-top removal surface mines, large amounts of overburden are removed with draglines and dozers to expose multiple benches of low-sulfur coal. The overburden is deposited in heads of adjacent stream valleys. When mining is completed, some of the overburden is returned to the ridge tops to reconstruct original topographic contours. Photograph by West Virginia Geological and Economic Survey.

Figure 16. Photograph showing view of excess-spoil fill, or valley fill, in the Samples Mine, Boone and Kanawha Counties, W. Va. The valley fill is stabilized, terraced, and seeded. Photograph by Susan J. Tewalt.

Table 2. Estimates of coal reserves in the northern and central Appalachian Basin coal regions, in billions of short tons.

State	Original Reserves			Cumulative Production	Remaining Reserves
	Milici (1997)	Averitt (1975)	EIA (1995)	Milici (1997)	Milici (1997)
West Virginia	21.9	20.4	20.1	10.9	11
Eastern Kentucky	9.9	10.3	5	4.9	5
Virginia	4.2	2.8	1.5	2.1	2.1
Pennsylvania	14.6	16.9	12	10.8	3.8
Ohio	5.6	7.4	11.8	3.5	2.2
Maryland	0.4	0.5	> 1.4	0.4	0.1
Tennessee	0.7	0.9	0.5	0.6	> 0.1
TOTAL	**57.3**	**59.2**	**50.9**	**33.2**	**24.2**

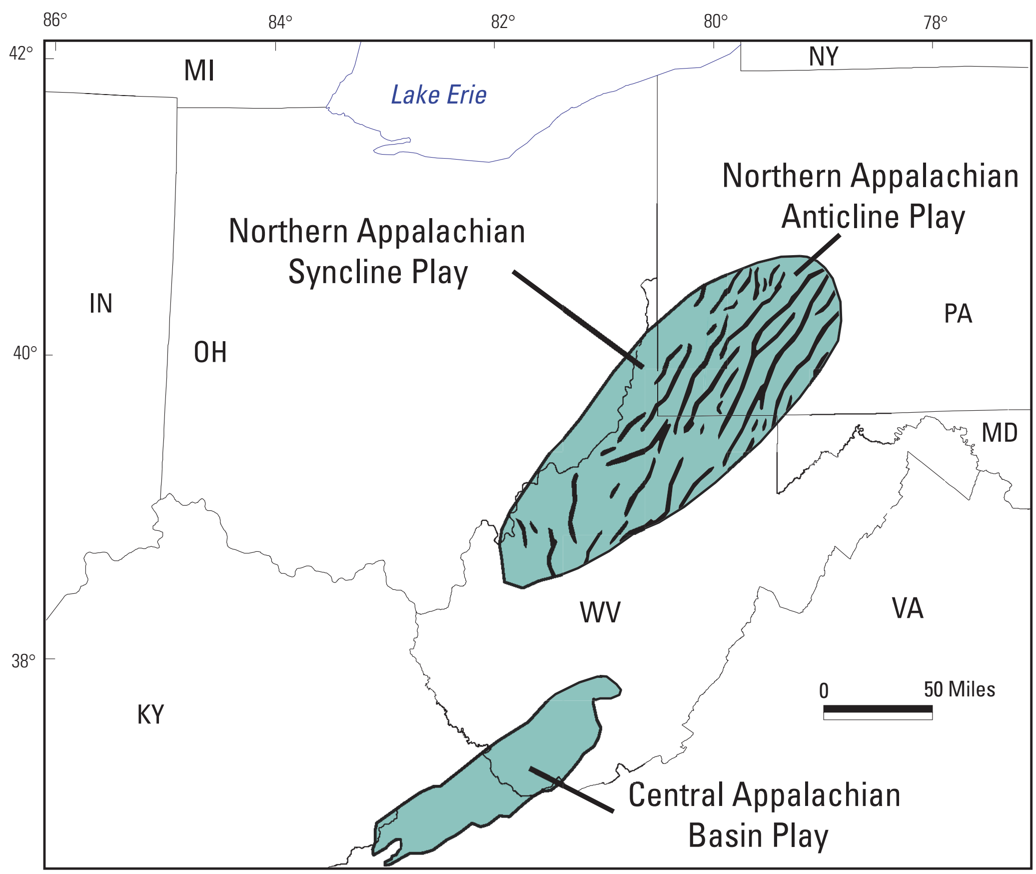

Figure 17. Map showing coalbed methane plays in the northern and central Appalachian Basin coal regions. There are two plays in the northern Appalachian Basin coal region, the Northern Appalachian Anticline Play and the Northern Appalachian Syncline Play. The USGS has estimated that there are 11.55 trillion cubic feet of technically recoverable coalbed methane gas, but it is not economic given current market prices. In contrast, the Central Appalachian Basin Play is smaller, but much of it is economically recoverable at current market prices (Attanasi, 1998b). Modified from Rice (1995).

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