STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Horace R. Collins, Chief

Geological Note No. 4

COAL RESOURCES OF A PORTION OF THE PAWPAW CREEK WATERSHED, MONROE, NOBLE, AND WASHINGTON COUNTIES

by

Richard A. Struble,
Horace R. Collins,
and
Richard M. DeLong

Columbus
1976

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OHIO DEPARTMENT OF NATURAL RESOURCES
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REVISED CORRELATIONS OF PREVIOUS (1971,1976) DEEP-CORE COAL-RESOURCE STUDIES

The Division of Geological Survey published two reports of deep core-drilling investigations for coal potential in the 1970's. These two publications, Report of Investigations No. 81 and Geological Note No. 4, contain some of the first publicly available information on deep coal resources in the eastern Ohio portion of the Appalachian Basin. These holes were generally widespread and distant from reliable stratigraphic control. As a result, correlations of the coals were tentative until better control was obtained. Subsequent studies in the late 1970's and 1980's have greatly increased the stratigraphic data and the ability to tie surface stratigraphy to the subsurface to the point where revisions of previous correlations can be made. The stratigraphy of Pennsylvanian-age rocks in the Appalachian Basin is well known for difficulties in correlation. Considering the relatively small number of data points available even now, and the distances over which correlations have to be made, all correlations should still be regarded as interpretations. The accompanying table displays the correlation revisions for the two reports mentioned above as a result of the more recent studies.

REFERENCES

Struble, R. A., Collins, H. R., and Kohout, D. L., 1971, Deep-core investigation of low-sulfur coal possibilities in southeastern Ohio: Ohio Geological Survey Report of Investigations No. 81.

Struble, R. A., Collins, H. R., and DeLong, R. M., 1976, Coal resources of a portion of the Paw Paw Creek watershed, Monroe, Noble, and Washington Counties: Ohio Geological Survey Geological Note No. 4.

O.G.S. CORE FILE NUMBER	DEPTH IN CORE (IN FEET)	O.G.S. CHEMICAL ANALYSIS NO.	ORIGINAL CORRELATION	REVISED CORRELATION
2173	1072		Middle Kittanning	Upper Freeport
	1151	698	Lower Kittanning	Lower Freeport
2174	624		Middle Kittanning	Upper Freeport
	675		Lower Kittanning	Lower Freeport
	763	689	Bedford	Lower Kittanning
2175	832	700	Middle Kittanning	Lower Freeport
	891		Lower Kittanning	Middle Kittanning
	918		Brookville	Lower Kittanning
2176	523	704	Middle Kittanning	Upper Freeport
	588	691	Lower Kittanning	Lower Freeport
	647	705	Brookville	Middle Kittanning
	681	692	Bedford	Lower Kittanning
2179	673	701	Middle Kittanning	Lower Freeport
	743	702	Lower Kittanning	Middle Kittanning
	789	703	Brookville	Lower Kittanning
2181	472	707	Middle Kittanning	Upper Freeport
	520	708, 709	Lower Kittanning	Lower Freeport
	610	696	Brookville	Lower Kittanning
	672	697	Bedford	Brookville
2197	761		Middle Kittanning	Lower Freeport
	837		Lower Kittanning	Middle Kittanning
2386	646	770	Middle Kittanning	Upper Freeport
	708		Lower Kittanning	Lower Freeport
	760		Brookville	Middle Kittanning
	814		Bedford	Lower Kittanning
2387	656	771	Middle Kittanning	Upper Freeport
	721	772	Lower Kittanning	Lower Freeport
	768		Brookville	Middle Kittanning
	820	773	Bedford	Lower Kittanning
2388	640	774	Middle Kittanning	Upper Freeport
	697		Lower Kittanning	Lower Freeport

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COAL RESOURCES OF A PORTION OF THE PAWPAW CREEK WATERSHED, MONROE, NOBLE, AND WASHINGTON COUNTIES

by

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Horace R. Collins,
and
Richard M. DeLong

ABSTRACT

A coal-resource evaluation of a portion of the Pawpaw Creek watershed was undertaken to provide data on which to base future land-use decisions for the area. An earlier investigation (Struble *et al.*, 1971) suggested strongly that a large resource of coal existed beneath portions of Monroe, Morgan, Noble, and Washington Counties, Ohio. The Pawpaw Creek area of investigation lies within this potential coal-resource area.

Core borings in the watershed area verified the existence of a potential underground mineable coal resource–Middle Kittanning (No. 6) and Lower Kittanning (No. 5) coals–in the Pawpaw Creek area of investigation. A strippable coal resource–Meigs Creek (No. 9)–is also present in the watershed area.

The strippable coal-resource estimates for the watershed are reported in three thickness categories, two overburden categories, and two reliability categories. The same thickness categories, along with three reliability categories, are used in reporting the underground mineable resource.

Analyses were performed for all coals of mineable thickness and include data on major, minor, and trace elements in the coal ash and major, minor, and trace elements in the whole coal. Standard quality data such as proximate and ultimate analyses, ash and sulfur content, forms of sulfur, and Btu are given also.

SUMMARY

Information on file at the Division of Geological Survey and developed during the course of this study reveals the presence of a significant coal resource in the Pawpaw Creek study area. This resource is distributed among the Meigs Creek (No. 9), Middle Kittanning (No. 6), and Lower Kittanning (No. 5) coal beds.

The Meigs Creek coal is present above drainage throughout the area and, along Pawpaw Creek and its tributaries, can be mined, to the limit of equipment capacity, by the strip method. Coal lying under cover greater than can be removed by strip mining can be reached by auger or drift mining. On the basis of estimates developed during this study, approximately 14,000,000 tons of coal lie within strippable depths (100 feet or less overburden) in the study area. Applying a 90 percent recovery factor, the total estimated amount of coal potentially recoverable by strip mining is 12,600,000 tons. An additional 31,000,000 tons of coal are potentially exploitable by auger and deep mining. Using an average recovery of 50 percent for these methods, it is estimated that the potential recovery would be 15,500,000 tons. The combined estimate of Meigs Creek coal recoverable by use of current mining methods and equipment is about 28,100,000 tons.

The Middle Kittanning coal is estimated to be present in mineable thickness essentially throughout the study area at a depth of approximately 650 feet below the Meigs Creek coal. Mining of this coal would be limited strictly to deep methods. On the basis of the data available it is estimated that there could be on the order of 42,500,000 tons of Middle Kittanning coal of mineable thickness in the study area. Assuming a recovery factor of 50 percent, it is estimated that 21,250,000 tons in this bed are potentially recoverable at the present time.

The Lower Kittanning coal is present in the study area at a depth of about 60 feet below the Middle Kittanning coal. This unit, however, is estimated to be of mineable thickness over one third or less of the study area. This coal, as the Middle Kittanning just above it, would be mineable only by deep methods. It is estimated that approximately 27,000,000 tons of coal are of mineable thickness in this seam; 13,500,000 tons would be potentially recoverable at the 50 percent recovery level.

The Meigs Creek, Middle Kittanning, and Lower Kittanning seams, taken collectively, have an estimated recoverable coal potential of about 62,850,000 tons in the Pawpaw Creek study area.

Approximately another 44,000,000 tons of coal now considered nonmineable could be added to the reserve base if technology is developed for underground gasification of the thin Pittsburgh (No. 8) seam and if a means is developed for recovering the coal lying within the areas of oil and gas fields and adjacent to individual oil and gas wells of the watershed area.

The coals in the study area are within the normal quality range for the same seams elsewhere in Ohio. The Lower Kittanning coal at one site was low in sulfur. This fact, coupled with other data, suggests that the potential of this seam as a source of low-sulfur coal warrants further study.

INTRODUCTION

The nation is experiencing a period of growth where competition for land and open space is increasing. Over the past 30 to 40 years, with greater affluency and improved means of transportation, there has been a shift from crowded city dwellings to more spacious urban community development. The exodus of people from the cities has placed upon local and regional planners pressures to rezone large tracts of land surrounding developing communities or communities with anticipated future growth development. More leisure time for ever larger numbers of people has had a tremendous impact on the growing competition for open space. A need exists for expansion of industrial and housing developments, transportation routes, water supplies, and recreation facilities. Most of the new development will occur on the perimeters of established communities. The increased demand for water supply, flood control, and recreation facilities will result in planning and construction of upland reservoirs in both urban and remote areas.

In the past little consideration was given by planners to the impact of upland reservoirs, industrial and community development projects, or recreational areas on the natural resources of the state. Prime agricultural and timber land has been taken out of production, and mineral resource production which could have aided the well-being of the citizens of Ohio has been lost. It is apparent now that location and evaluation of mineral resources is essential to making future land-use decisions at all levels of government.

The energy crisis, so apparent as a result of the Arab oil embargo, points to the necessity for strict conservation of the nation's fossil fuel resources. It is imperative for the well-being of the nation that no fossil fuel resource be lost because of land-use decisions made without the benefit of reliable geological and mineral resource data.

The Pawpaw Creek watershed of Monroe, Noble, and Washington Counties is located in a portion of Ohio's coal-bearing area. The lack of adequate geological information in this area was the basis of the request that the Division of Geological Survey undertake this study.

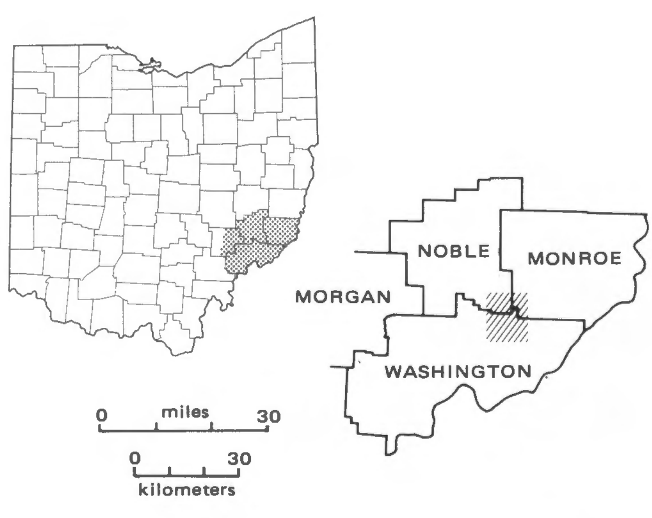

FIGURE 1.–Area of investigation for coal-resource evaluation in a portion of the Pawpaw Creek watershed.

PURPOSE OF THE INVESTIGATION

The purpose of the investigation was to determine, in the study portion of the Pawpaw Creek watershed, the extent, thickness, and chemical quality of all coals mineable by current conventional stripping and underground mining methods. These data would then be used to calculate the mineable coal resources of the watershed and to prepare a report that would be useful in determining land values within the watershed and which would provide a basis on which to make future land-use decisions.

ACKNOWLEDGMENTS

Thanks are offered to landowners in the study area for their cooperation in permitting core borings on their properties and to all Division of Geological Survey staff members who assisted in any way toward the completion of this project. Special thanks are due Mr. Jack H. Medlin, U.S. Geological Survey, and Mr. Forrest E. Walker, U.S. Bureau of Mines, for their roles in providing analytical data on the coals.

LOCATION

The site of investigation (fig. 1) includes that portion of the Pawpaw Creek watershed which lies between latitudes 39°38′ and 39°32′30″ north and between longitudes 81°21′30″ and 81°17′ west. This portion of the watershed includes parts of Bethel Township, Monroe County, Elk Township, Noble County, and Liberty Township, Washington County, Ohio. The village of Germantown lies at the approximate center of the area investigated. The total area investigated comprises approximately 9,000 acres.

SCOPE OF THE INVESTIGATION

Because there was some urgency for evaluation of the coal resources of the Pawpaw Creek watershed, the decision was made to calculate the resource of strippable coal from data already on file with the Division of Geological Survey. New data on strippable coal were generated only where the file data were questioned.

Because no data were available for undertaking the deep-coal resource evaluation, the decision was made to obtain enough core-boring control to be able to report the coal resources in three reliability categories: measured, indicated, and inferred. The following definitions of the reliability categories used in this report are summarized from definitions used by Averitt (1975). Measured and indicated resources as defined by Averitt are equivalent to the proven and probable categories, respectively, of earlier Ohio Division of Geological Survey publications (see Brant and DeLong, 1960, p. 11).

Measured resource - Points of observation and measurement are so closely spaced and thickness and extent of coal beds so closely defined that computed tonnage is judged to be accurate within 20 percent of true tonnage. Points of observation are about ½ mile apart.

Indicated resource - Points of observation and measurement are approximately 1 mile apart, but may be as far apart as 1½ miles for beds of known continuity. For the purpose of this report the indicated-resource area of the watershed is that area beyond an arc of radius ½ mile from a control point and within an arc 2 miles from the same control point.

Inferred resource - Measurements are based primarily on an assumed continuity of coal beds. Coal classed as inferred resource lies beyond an arc of radius 2 miles from a control point.

The spacing of observation points and core borings in the study portion of the Pawpaw Creek watershed area was such as to permit the coal resources for 97 percent of the area to be assigned to the measured and indicated reliability categories. The resource under the remaining 3 percent of the area is designated inferred resource.

METHOD OF APPROACH

This coal-resource investigation was undertaken in two parts. The first part consisted of evaluation of the strippable resource, and the second part considered the potential deep underground mineable resource.

As previously stated, evaluation of the strippable resource was based almost completely on data from the files of the Division of Geological Survey. Elevations and thicknesses of the Meigs Creek (No. 9) coal were obtained from measured stratigraphic sections and available outcrop descriptions and were plotted on 1:24,000 base maps for preparation of structure and coal thickness maps.

Areas below the elevation of the Meigs Creek coal as well as within oil and gas fields and villages and adjacent to individual producing wells were considered nonmineable by virtue of technical or legal constraints and were subtracted from the total area of the watershed for the purpose of calculating the strippable resource.

For the deep coals, only the areas within oil and gas fields and adjacent to individual producing wells were considered to be nonmineable.

Information obtained from three core borings from the watershed indicated the presence of only two coal seams of mineable thickness according to standards (42 inches thick or thicker) commonly employed in Ohio. These seams are the Middle Kittanning (No. 6) and the Lower Kittanning (No. 5) coals of the Allegheny Group, Pennsylvanian System.

The thicknesses of these two seams were measured from the cores and plotted on base maps for interpretation. Additional control points from data on file from previous investigations (Struble *et al.*, 1971) were also used in the thickness interpretation.

When the coal thickness had been plotted, resource reliability arcs were made, at the distances given in the definitions, and the coal resource within each category was calculated.

STRATIGRAPHY

GENERAL STATEMENT

The rocks at the surface in the Pawpaw Creek watershed area are stratigraphically (fig. 2) within the Monongahela Group of the Pennsylvanian System and the Dunkard Group of the Permian System. Rocks of the Dunkard Group have a very limited distribution within the watershed; they are restricted to the tops of the highest hills. The remainder of the surface is in slope or floodplain and is composed of rocks assignable to the Monongahela Group. Units penetrated in the subsurface investigation included the lowermost portion of the Monongahela Group, the Conemaugh and Allegheny Groups, and the uppermost portion of the Pottsville Group. Generalized columnar sections, with the principal coal units identified for each of the three cores, are given in figure 3.

Because the only coals of major importance in the study area occur within the Allegheny and Monongahela Groups, the stratigraphic discussion will be limited to these two groups.

MONONGAHELA GROUP

The Monongahela Group in the area of investigation consists of an alternating sequence of sandstones, shales, mudstones, freshwater limestones, and thin coals and clays. The average thickness of the group in Ohio is 250 feet. The Monongahela Group contains, in terms of current production, the two most economically important coal beds in Ohio: the Pittsburgh and the Meigs Creek coals. Other coals are mined locally, but account for only a small portion of the total coal produced from this group. In the Pawpaw Creek watershed, in the area under investigation, only the Meigs Creek coal has any economic importance at this time.

The Pittsburgh coal is present below drainage in the watershed at a depth of approximately 100 feet below the floodplain areas. In the three cores drilled to evaluate the deeper coals the Pittsburgh ranged in thickness from 19 inches in sec. 24 to 23 inches in sec. 25 of Elk Township, Noble County. On the basis of the three data points, the average thickness of the Pittsburgh coal for the watershed is 21 inches. Because the Pittsburgh coal is below drainage, it would have to be mined by underground methods. At the present time underground mining of a 21-inch seam of coal in Ohio is not considered feasible; therefore this coal was not tabulated as part of the underground mineable resource. However, if technology is ultimately developed to commercially utilize this seam by mining or underground conversion, the resource would approximate 24,944,850 tons. This is determined as follows:

Resource acres	x	*Seam thickness in inches (average)*	x	*Tons coal/acre-inch*	=	*Coal tonnage*
7,919[1]	x	21	x	150	=	24,944,850

[1] Total watershed area of 9,000 acres less 1,081 acres excluded for oil and gas fields and individual wells.

The Meigs Creek coal, on the other hand, is above drainage and is of sufficient thickness to be considered an important strippable resource by today's standards. In that portion of the Pawpaw Creek watershed under investigation the Meigs Creek coal generally occurs in two benches and ranges in thickness from 70 inches in sec. 30, Elk Township, Noble County, to 27 inches in sec. 28, Liberty Township, Washington County. The strippable resource of Meigs Creek coal will be discussed later in the coal resource section of this report.

ALLEGHENY GROUP

The Allegheny Group in the Pawpaw Creek watershed study area consists of an approximately 250-foot repetitive sequence of shales, sandstones, and mudstones and thin coals, clays, and marine limestones. Coals of the Allegheny Group have been economically important in Ohio in the past and still represent a sizeable percent of total coal production for the state. Recent investigations to explore for new resources of low-sulfur coal in Ohio (Struble *et al.*, 1971) indicate that a large (although not necessarily low-sulfur) potential resource of Middle Kittanning coal and Lower Kittanning coal might exist in the Pawpaw Creek study area.

The Middle Kittanning coal was penetrated in each of the three test cores in the present study. The thickness of the seam ranged from 39 inches in sec. 25, Elk Township, Noble County, to 49 inches in sec. 28, Liberty Township, Washington County.

The Lower Kittanning coal was also present in each core

TIME-STRATIGRAPHIC UNITS	ROCK UNITS			
SYSTEM	GROUP	FORMATION	PRINCIPAL BEDS	DRILLERS' OR INFORMAL NAMES
PERMIAN	Dunkard	Greene Fm		
		Washington Fm	Upper Marietta ss	
			Creston-Reds	
			Lower Marietta ss	
			Washington coal	No. 12 coal
			Mannington ss	
?			Waynesburg ss	
PENNSYLVANIAN	Monongahela		Waynesburg coal	No. 11 coal
			Uniontown coal	No. 10 coal
			Benwood ls	
			U. Sewickley ss	Goose Run
		→	Meigs Creek coal	No. 9 coal
			Pittsburgh ss	
			Pittsburgh coal	No. 8 coal
	Conemaugh		Connellsville ss	Mitchell
			Morgantown ss	Wolf Creek
			Gaysport ss	Vincent
			Ames ls	
			Saltsburg ss	Peeker
			Cow Run ss	1st Cow Run
			Cambridge ls	
			Buffalo ss	Buell Run
			Brush Creek ls	
			Mahoning ss	Macksburg 300'
	Allegheny		U. Freeport coal	No. 7 coal
			U. Freeport ss	2nd Cow Run
		→	M. Kittanning coal	No. 6 coal
		→	L. Kittanning coal	No. 5 coal
			Clarion ss	Macksburg 500'
			Putnam Hill ls	
			Brookville coal	No. 4 coal
	Pottsville		Homewood ss	Macksburg 700'
			U. Mercer ss	Germantown
			L. Mercer coal	No. 3 coal
			L. Mercer ss	Schram
			Massillon ss	Salt
			Quakertown coal	No. 2 coal
			Sciotoville ss	Brill
			Sharon coal	No. 1 coal
			Sharon ss, cong	Maxton

FIGURE 2.–Generalized column (Ohio Division of Geological Survey) of Pennsylvanian and Permian rocks for Ohio; mineable coal-bearing units in the Pawpaw Creek watershed are indicated by arrows.

and ranged in thickness from 18 inches in sec. 28, Liberty Township, Washington County, to 64 inches in sec. 25, Elk Township, Noble County.

In keeping with the policy of doing analyses on all coals over 28 inches thick, the Brookville (No. 4) coal was recovered from cores 2386 and 2387 and was submitted for chemical analysis (tables 5, 6, 7, and 8). It should perhaps be further noted that, in a previous study (Struble *et al.*, 1971), Brookville coal of mineable thickness was found only a few miles to the west and to the north and is a resource to be considered in the general area.

No other coal in the Allegheny Group was of sufficient thickness to be included as part of the Pawpaw Creek watershed coal resource.

COAL RESOURCES

Characteristics necessary for the estimation of coal-resource tonnages are (1) areal distribution of the seam, (2) thickness of the seam, and (3) specific gravity of the coal. After tonnages are calculated, the resource is classified into categories according to reliability of the data. The procedures followed for calculating and reporting the coal resources for the Pawpaw Creek watershed are essentially those outlined by Averitt (1975).

The following discussion explains how each of the above characteristics were determined and used in calculating and reporting the coal resources for the area of investigation.

AREAL DISTRIBUTION

The Meigs Creek coal occurs throughout the entire study region except for a small area along the floodplains of Pawpaw Creek and its tributaries; elevations of these floodplains are lower than that of the coal. In conjunction with structural interpretation (fig. 4), elevation data from 16 control points provided the basis for plotting the Meigs Creek coal outcrop on 1:24,000 topographic base maps. The trace of the Meigs Creek crop line on the topographic base made it simple to distinguish the area of less than 100 feet of overburden from the area of greater than 100 feet of overburden.

The Middle Kittanning coal and the Lower Kittanning coal are distributed throughout the entire Pawpaw Creek area; three strategically spaced cores which penetrated both seams confirmed the presence of these seams throughout the basin.

THICKNESS OF SEAM

Following the parameters cited by Averitt (1975), the coal resources of the Pawpaw Creek watershed study area are reported in three categories: (1) 14 inches to 28 inches (thin coal), (2) 28 inches to 42 inches (intermediate coal), and (3) greater than 42 inches (thick coal). All partings greater than 3/8 inch thick were subtracted from the seam thickness in arriving at the thicknesses used in calculating resource tonnages.

In most instances coal tonnages were calculated using the simple average of a thickness category. However, in some cases where data were sparse it was deemed necessary to deviate slightly from this practice. Information from outside the watershed (Struble *et al.*, 1971) was used to estimate average coal thickness where data were less plentiful. Where deviation from a simple average was used, the calculations are in the authors' opinion more accurate reflections of the resource within the context of this study. Following are the average figures used for each thickness category to calculate the tonnage within that category:

Meigs Creek (No. 9) coal (fig. 5)

14 to 28 inches - 21 inches average
28 to 42 inches - 35 inches average
42 to 54 inches - 48 inches average } reported as
greater than 54 inches - 60 inches average } greater than 42 inches

Middle Kittanning (No. 6) coal (fig. 6)

14 to 28 inches - none indicated
28 to 42 inches - 40 inches average
greater than 42 inches - 48 inches average

Lower Kittanning (No. 5) coal (fig. 7)

14 to 28 inches - 21 inches average
28 to 42 inches - 35 inches average
greater than 42 inches - 62 inches average

SPECIFIC GRAVITY

The specific gravity of coal differs according to the rank and the ash content of the coal. Ohio coals are all of bituminous rank. Averitt (1975, p. 21) cites a specific gravity of 1.32 or a weight of 150 tons per acre-inch for bituminous coal in the ground. This conforms with the previous practice of the Ohio Division of Geological Survey and this figure was used in preparing estimates for this study.

RELIABILITY OF DATA

The coal resources of the Pawpaw Creek watershed study area are reported in three categories on the basis of reliability of data. These categories are "measured," "indicated," and "inferred"; see the section on scope of the investigation (p. 2).

Coal resource as used in this report refers to coal that is in the ground and that may be extracted at the present time or extracted (or utilized) in the future as new technology becomes available. For purposes of this report the strippable coal resource, in all categories of reliability, is that coal under less than 100 feet of overburden and essentially recoverable at the present time. Coal which is not mineable at the present time, but which is still a resource, has been identified, and tonnage is calculated separately for that portion of the resource base.

The underground mineable resource, in all categories of reliability, is defined as coal having a thickness of 42 inches or greater. Portions of this underground resource that have been rendered nonmineable at the present time by the presence of oil and gas wells have been calculated and reported separately.

Calculations of strippable and mineable underground resources represent the total coal, in place, that is potentially available for exploitation; these calculations are not estimates of the actual amount of coal that can be

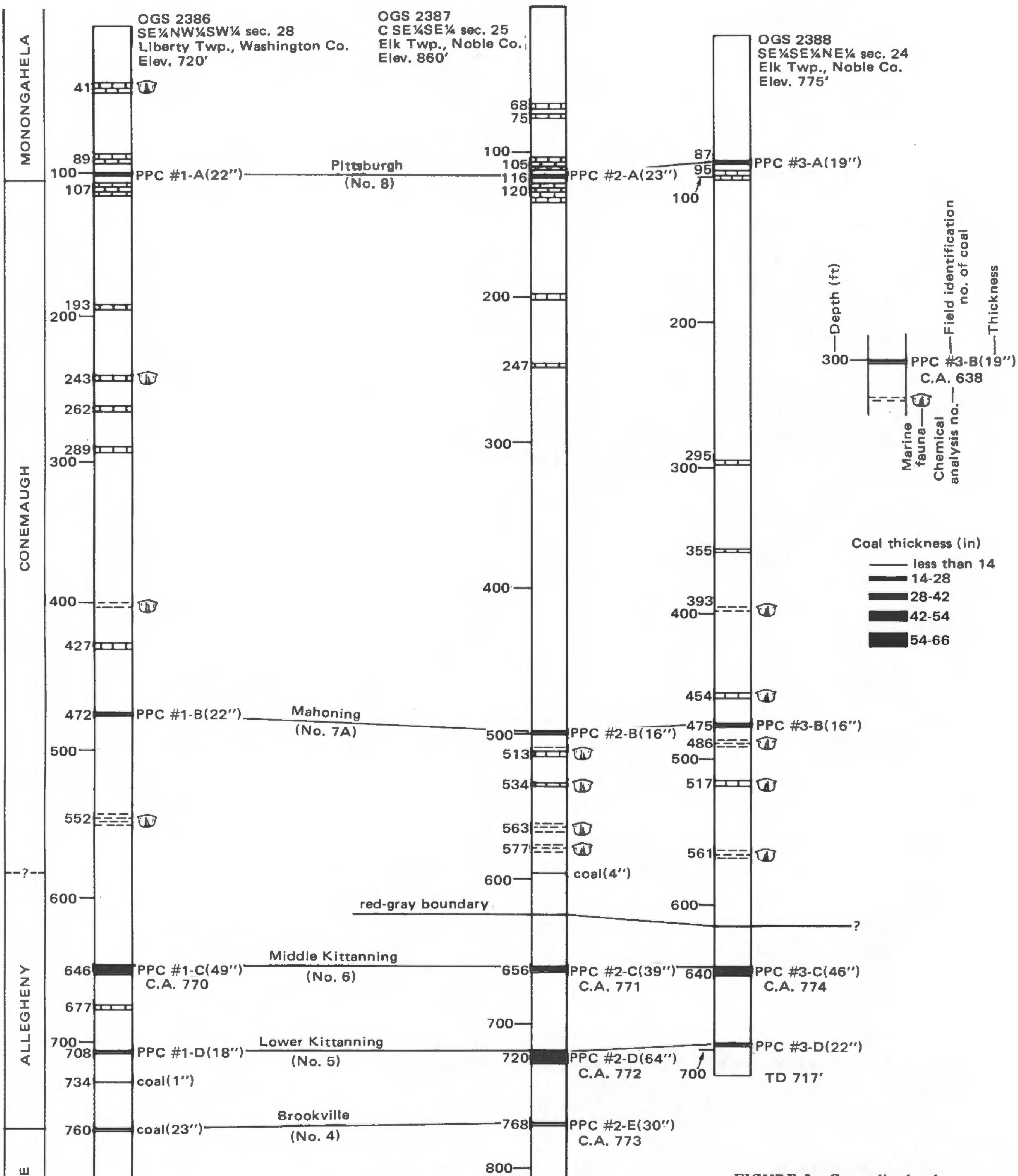

FIGURE 3.–Generalized columnar sections of cores taken for the Pawpaw Creek watershed investigation.

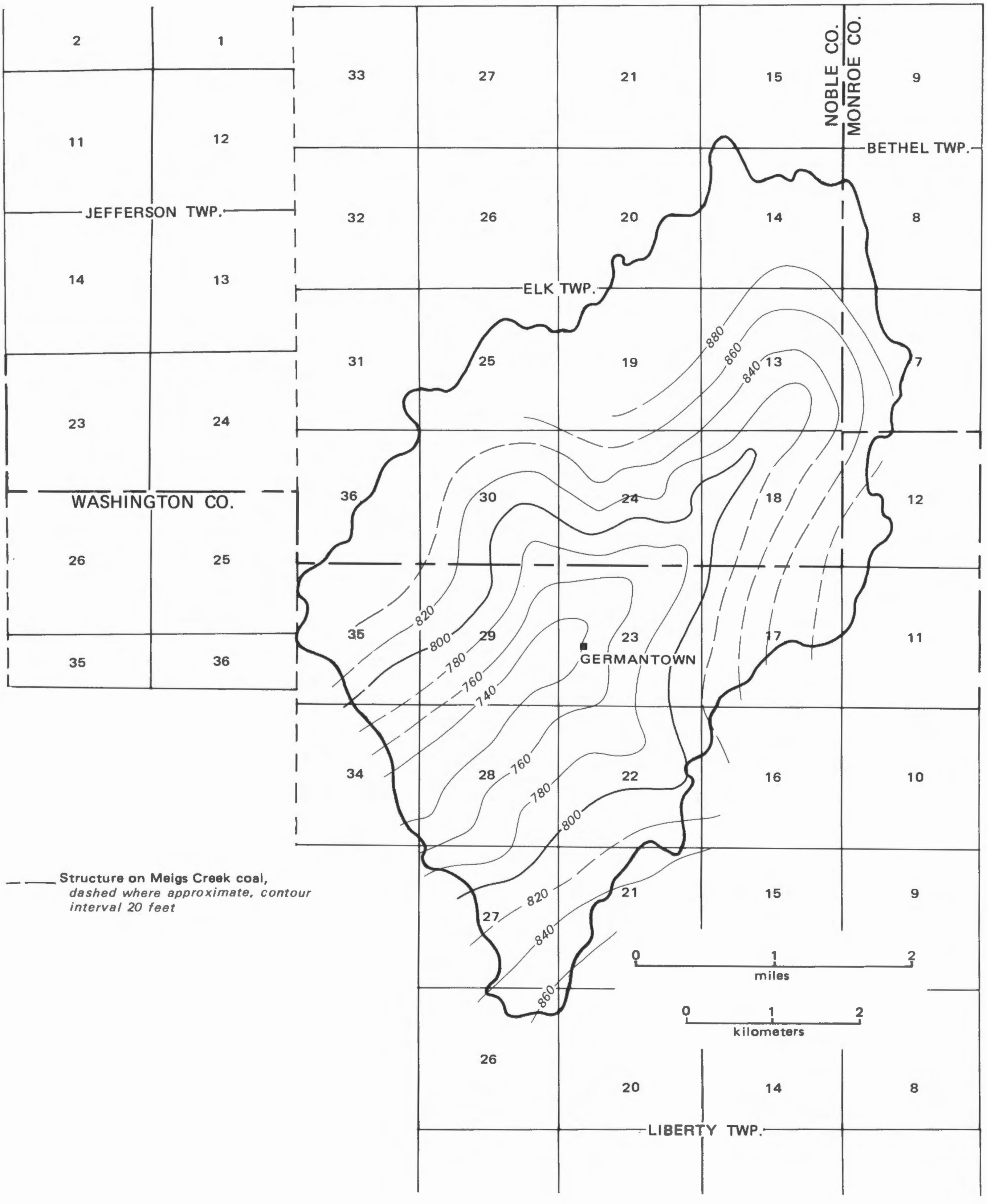

FIGURE 4.–Structure on the Meigs Creek (No. 9) coal in a portion of the Pawpaw Creek watershed.

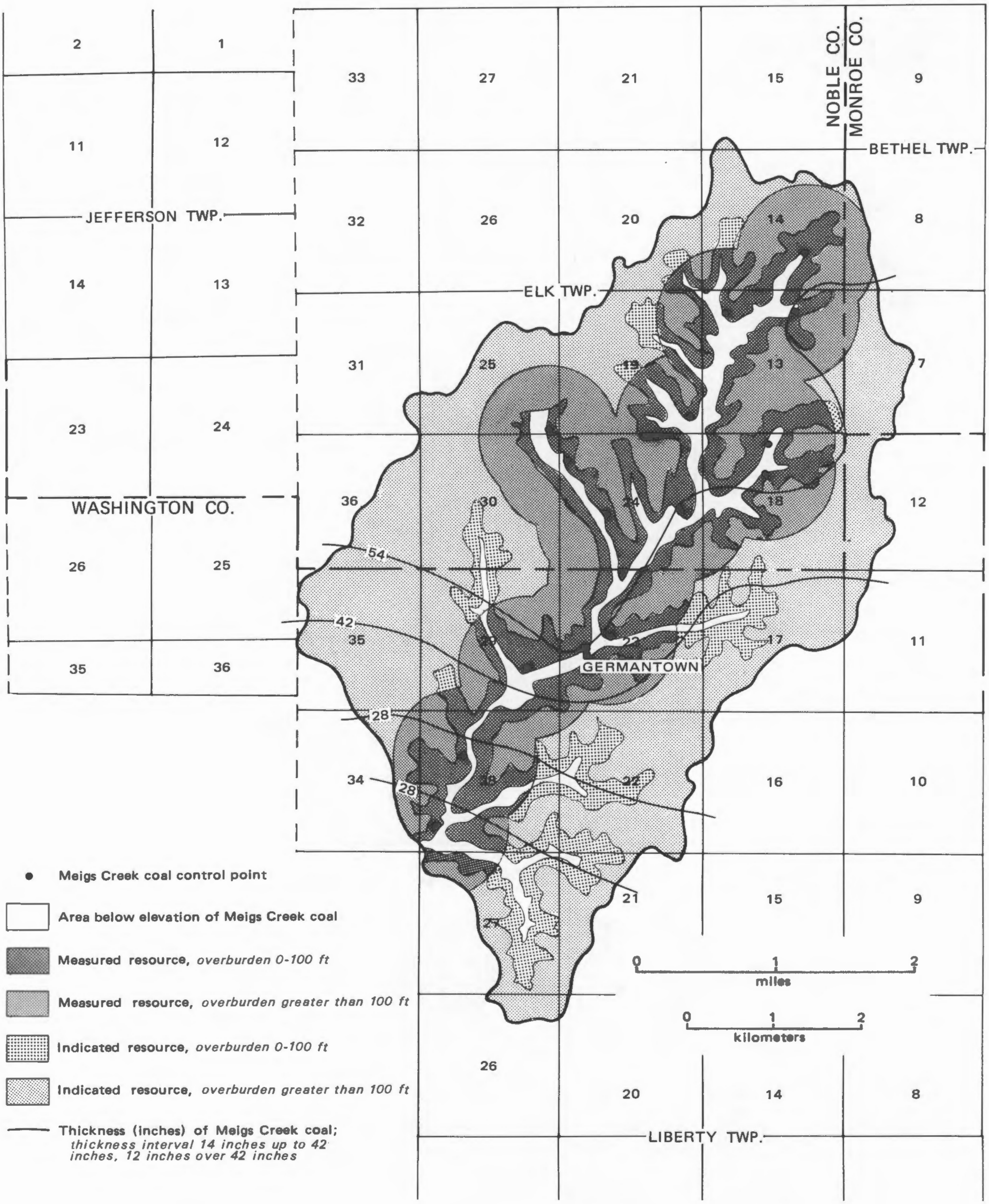

FIGURE 5.–Thickness and resource map for the Meigs Creek (No. 9) coal in a portion of the Pawpaw Creek watershed.

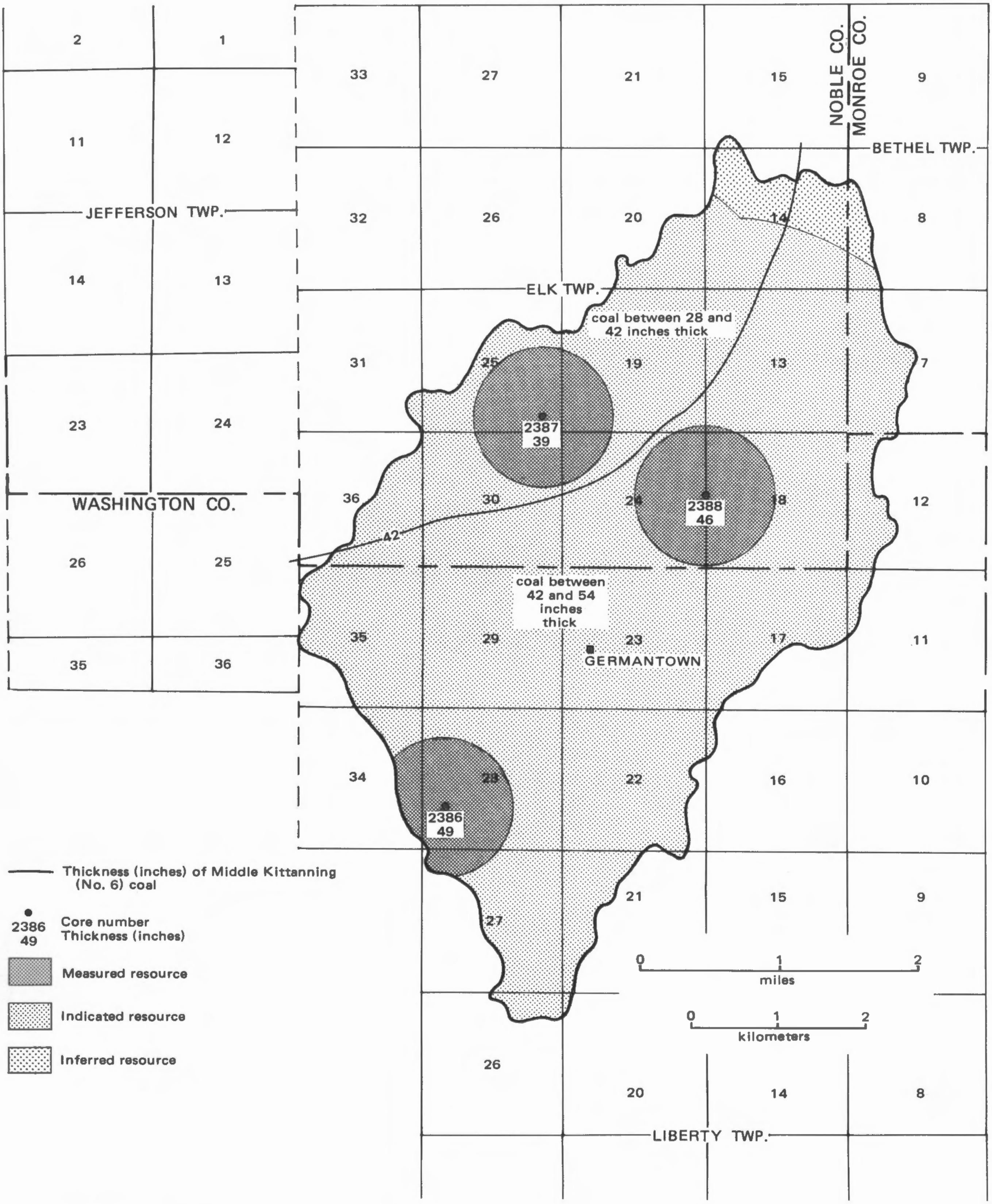

FIGURE 6.–Thickness and resource map for the Middle Kittanning (No. 6) coal in a portion of the Pawpaw Creek watershed.

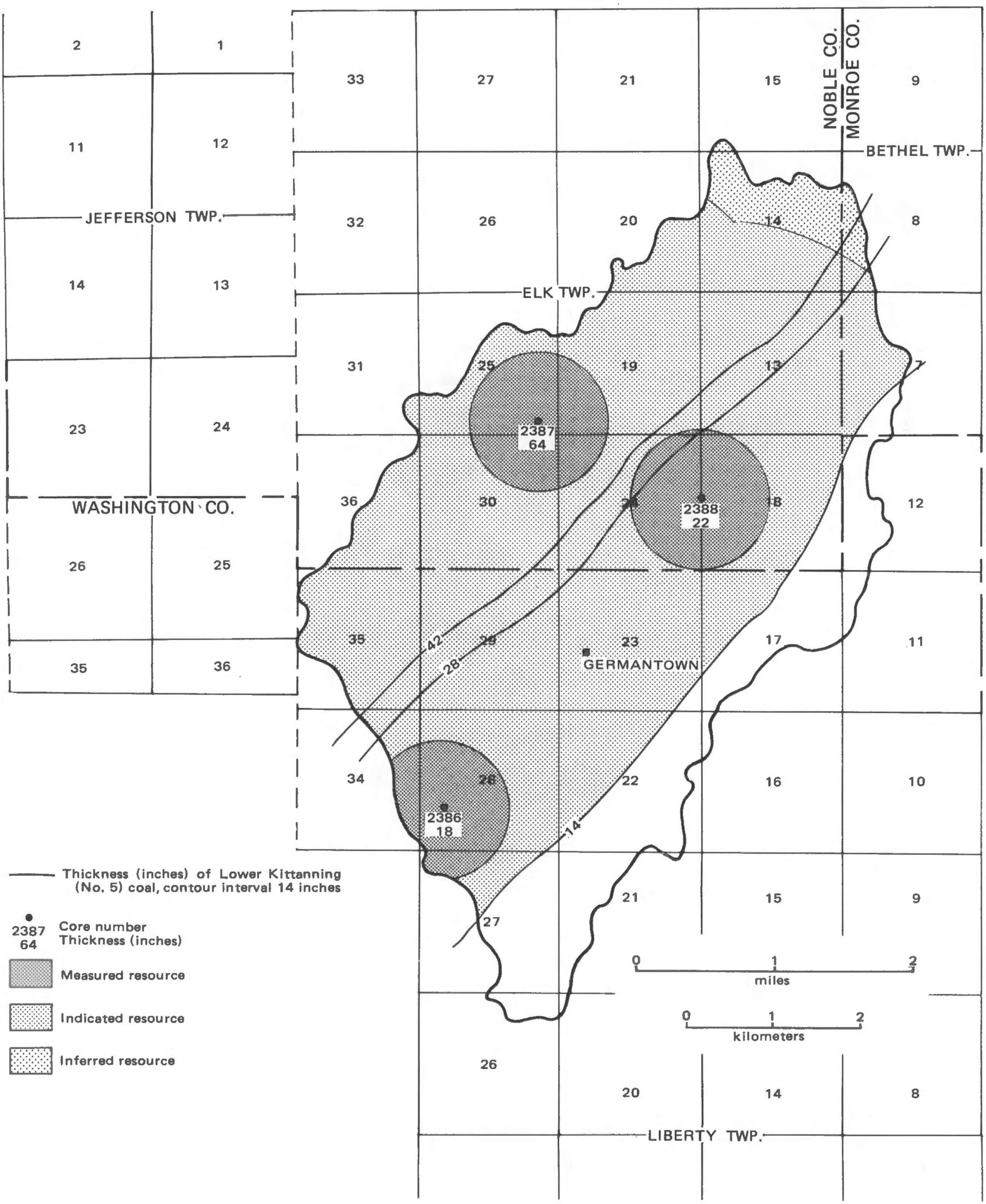

FIGURE 7.–Thickness and resource map for the Lower Kittanning (No. 5) coal in a portion of the Pawpaw Creek watershed.

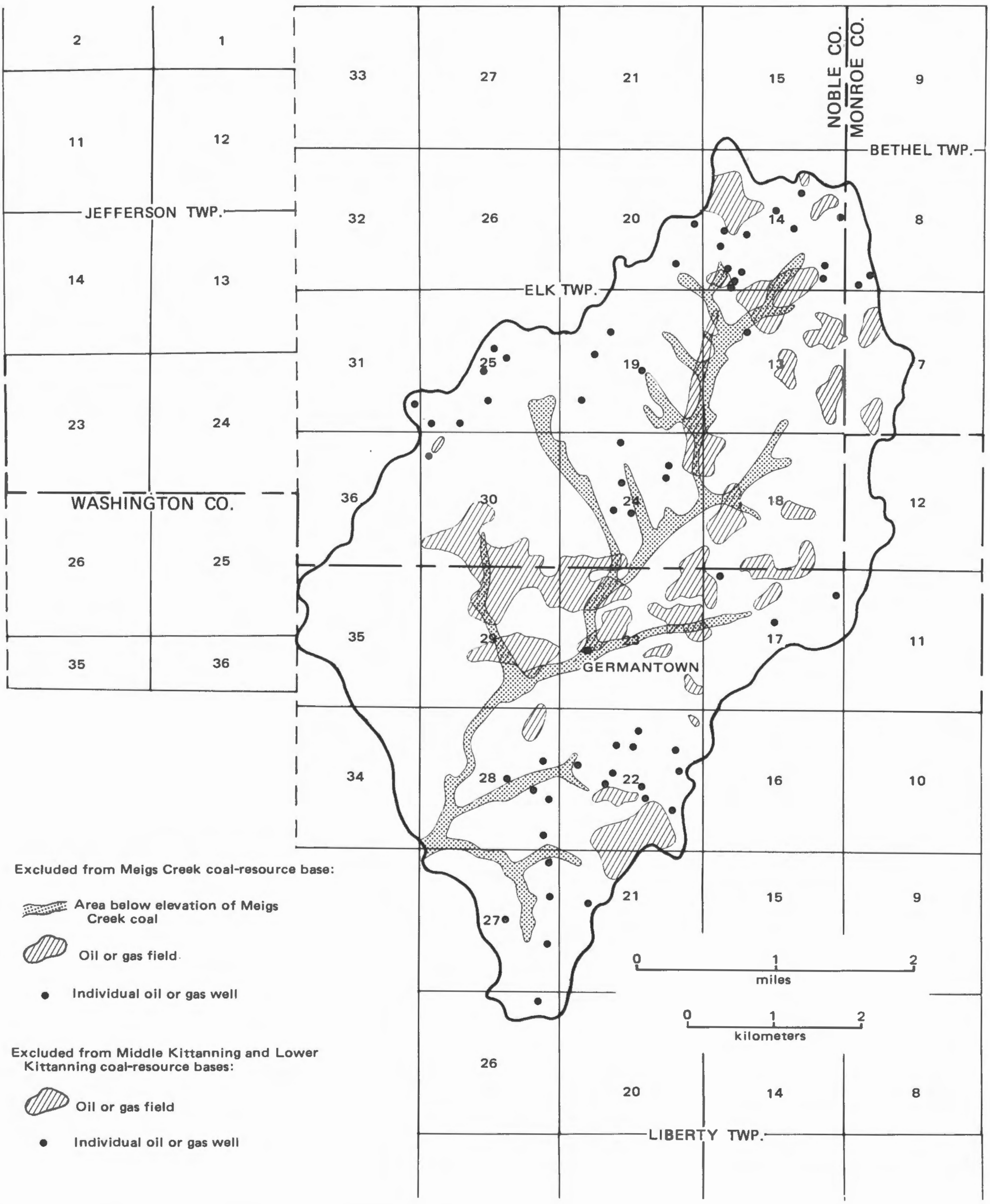

FIGURE 8.–Nonmineable coal areas excluded from the Meigs Creek (No. 9), Middle Kittanning (No. 6), and Lower Kittanning (No. 5) coal-resource bases in a portion of the Pawpaw Creek watershed.

TABLE 1.–*Coal resource of a portion of the Pawpaw Creek watershed: Meigs Creek (No. 9) coal*

Resource category		Thick coal (greater than 42 in)		Intermediate coal (28 to 42 in)		Thin coal (14 to 28 in)		Total coal
		Overburden less than 100 ft	Overburden greater than 100 ft	Overburden less than 100 ft	Overburden greater than 100 ft	Overburden less than 100 ft	Overburden greater than 100 ft	
Measured resource (tons)	Mineable coal	9,307,188	15,577,308	1,282,464	1,424,376	450,450	378,000	28,419,786
	Nonmineable coal[1]	*1,306,530*	*1,473,984*	*21,024*	*115,632*	*3,150*		*2,920,320*
Indicated resource (tons)	Mineable coal	853,758	15,160,590	1,713,456	7,043,040	362,250	699,300	25,832,394
	Nonmineable coal[1]	*743,202*	*2,410,470*	*57,816*	*152,424*	*31,500*	*179,550*	*3,574,962*
Total resource (tons)	Mineable coal	10,160,946	30,737,898	2,995,920	8,467,416	812,700	1,077,300	54,252,180
	Nonmineable coal[1]	*2,049,732*	*3,884,454*	*78,840*	*268,056*	*34,650*	*179,550*	*6,495,282*

[1] Tonnage considered lost to mining because of oil or gas fields or individual wells; not included in tonnage considered potentially recoverable; estimated area 840 acres.

recovered. Estimates of the recoverability of strip coal differ, but 80 to 90 percent would not be unreasonable. Estimates of deep-coal recoverability differ somewhat more, but 50 percent is a widely accepted average.

Tables 1, 2, and 3 list calculated tonnages for each mineable coal seam in the study area. Table 4 lists the tonnage totals of all categories of coal resources for the area. The recoverability factors cited above, plus any special consideration which might apply, would be applicable to these figures.

STRIPPABLE COAL RESOURCE

The Meigs Creek (No. 9) coal is present above drainage at elevations ranging from 750 to 880 feet and is the only strippable coal in the Pawpaw Creek watershed area. Where the seam is under 100 or more feet of overburden, the coal is considered to be part of the underground resource.

TABLE 2.–*Coal resource of a portion of the Pawpaw Creek watershed: Middle Kittanning (No. 6) coal*

Resource category		Thick coal (greater than 42 in)	Potentially recoverable coal[1]		Total coal
			Intermediate coal (28 to 42 in)	Thin coal (14 to 28 in)	
Measured resource (tons)	Mineable coal	5,411,178	3,049,074		8,460,252
	Nonmineable coal[1]	*647,010*			*647,010*
Indicated resource (tons)	Mineable coal	35,933,940	7,685,622		43,619,562
	Nonmineable coal[1]	*6,356,340*	*351,828*		*6,708,168*
Inferred resource (tons)	Mineable coal	1,194,480	388,244		1,582,724
	Nonmineable coal[1]	*56,886*	*181,980*		*238,866*
Total resource (tons)	Mineable coal	42,539,598	11,122,940		53,662,538
	Nonmineable coal[1]	*7,060,236*	*533,808*		*7,594,044*

[1] For purposes of this table potentially recoverable coal is that coal which presently is not economically mineable but which may become useable under different technological or economic conditions. Nonmineable coal is that coal which is not considered extractable because of present technological or legal constraints; estimated area 1,081 acres.

TABLE 3.—*Coal resource of a portion of the Pawpaw Creek watershed: Lower Kittanning (No. 5) coal*

Resource category		Thick coal (greater than 42 in)	Potentially recoverable coal[1]		Total coal
			Intermediate coal (28 to 42 in)	Thin coal (14 to 28 in)	
Measured resource (tons)	Mineable coal	4,671,864	251,424	2,633,400	7,556,688
	Nonmineable coal[1]		*42,048*	*258,300*	*300,348*
Indicated resource (tons)	Mineable coal	20,545,056	2,655,666	6,810,300	30,011,022
	Nonmineable coal[1]	*2,424,168*	*593,928*	*1,209,600*	*4,227,696*
Inferred resource (tons)	Mineable coal	1,783,296	235,710	6,300	2,025,306
	Nonmineable coal[1]	*334,368*			*334,368*
Total resource (tons)	Mineable coal	27,000,216	3,142,800	9,450,000	39,593,016
	Nonmineable coal[1]	*2,758,536*	*635,976*	*1,467,900*	*4,862,412*

[1] See table 2; estimated area of nonmineable coal 884 acres.

The distribution of each of the thickness categories, overburden categories, and reliability categories is shown in figure 5. The areas considered nonmineable at this time are shown in figure 8. The nonmineable area for the Meigs Creek coal comprises 840 acres in which oil and gas wells have been drilled.

The resource estimates, reported in tons for each thickness, overburden, and reliability category, are given in table 1. The figures in *italics* in table 1 represent the resource tonnage considered nonmineable at this time. If in the future it becomes economical to recover this coal, this tonnage would then become a part of the resource base.

UNDERGROUND MINEABLE COAL RESOURCE

The underground mineable resource in the area of investigation is represented by the Middle Kittanning (No. 6)

TABLE 4.—*Grand total of estimated coal resources of a portion of the Pawpaw Creek watershed*

Resource category		Thick coal (greater than 42 in)	Potentially recoverable coal[1]		Total coal
			Intermediate coal (28 to 42 in)	Thin coal (14 to 28 in)	
Measured resource (tons)	Mineable coal	34,967,538	6,007,338	3,461,850	44,436,726
	Nonmineable coal[1]	*3,427,524*	*178,704*	*261,450*	*3,867,678*
Indicated resource (tons)	Mineable coal	72,493,344	19,097,784	7,871,850	99,462,978
	Nonmineable coal[1]	*11,934,180*	*1,155,996*	*1,420,650*	*14,510,826*
Inferred resource (tons)	Mineable coal	2,977,776	623,954	6,300	3,608,030
	Nonmineable coal[1]	*391,254*	*181,980*		*573,234*
Total resource (tons)	Mineable coal	110,438,658	25,729,076	11,340,000	147,507,734
	Nonmineable coal[1]	*15,752,958*	*1,516,680*	*1,682,100*	*18,951,738*

[1] See table 2.

TABLE 5.—*Chemical analyses of coals greater than 28 inches thick, Pawpaw Creek study area*

Sample data					Proximate (%)				Ultimate (%)					Forms of sulfur (%)			Fusibility of ash					
OGS core or strat. sec. no.	Chemical analysis no.[1]	Coal seam	Analyzed thickness (nearest in)	Condition[2]	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Total sulfur	Sulfate	Pyritic	Organic	Initial deformation temperature (°F)	Softening temperature (°F)	Fluid temperature (°F)	Free-swelling index	Heating value (Btu)	Remarks
2386	770	Middle Kittanning (No. 6)	48	a	3.3	38.8	48.5	9.4	5.2	71.3	1.3	8.5	4.3	0.03	3.38	0.92	2090	2140	2190	6	13,100	U.S. Bureau Mines no. K-63901
				b		40.1	50.1	9.8	5.0	73.7	1.3	5.7	4.5	0.03	3.50	0.95					13,550	
				c		44.5	55.5		5.6	81.7	1.5	6.2	5.0	0.03	3.87	1.05					15,020	
2387	771	Middle Kittanning (No. 6)	39	a	3.0	34.4	48.4	14.2	5.0	68.7	1.3	8.3	2.5	0.10	2.06	0.35	2090	2140	2240	4	12,330	U.S. Bureau Mines no. K-65914
				b		35.5	49.9	14.6	4.8	70.7	1.3	6.0	2.6	0.10	2.12	0.36					12,700	
				c		41.6	58.4		5.6	82.9	1.5	7.0	3.0	0.12	2.48	0.42					14,880	
2387	772	Lower Kittanning (No. 5)	64	a	2.8	37.6	53.4	6.2	5.4	75.0	1.5	11.0	0.9	0.01	0.41	0.45	2430	2480	2740	5	13,690	U.S. Bureau Mines no. K-65915
				b		38.7	54.9	6.4	5.3	77.1	1.6	8.7	0.9	0.01	0.42	0.46					14,070	
				c		41.3	58.7		5.6	82.4	1.7	9.3	1.0	0.01	0.45	0.49					15,030	
2387	773	Brookville (No. 4)	30	a	2.2	42.4	46.5	8.9	5.4	71.7	1.4	6.9	5.7	0.13	4.15	1.40	2080	2180	2280	7½	13,260	U.S. Bureau Mines no. K-65916
				b		43.3	47.6	9.1	5.2	73.3	1.4	5.2	5.8	0.13	4.24	1.43					13,550	
				c		47.6	52.4		5.8	80.6	1.5	5.7	6.4	0.15	4.66	1.57					14,910	
2388	774	Middle Kittanning (No. 6)	46	a	3.4	36.9	50.1	9.6	5.2	71.6	1.3	8.7	3.6	0.01	3.11	0.51	2080	2130	2180	5½	12,950	U.S. Bureau Mines no. K-64046
				b		38.2	51.8	10.0	5.0	74.1	1.3	5.8	3.8	0.01	3.22	0.53					13,410	
				c		42.5	57.5		5.6	82.4	1.5	6.3	4.2	0.01	3.58	0.59					14,900	
9285	572-2	Meigs Creek (No. 9), upper bench	44	a	2.2	40.4	43.7	13.7					6.3								12,125	
				b		41.3	44.7	14.0					6.4								12,403	Data on washability characteristics of Meigs Creek (No. 9) samples given in Krumin *et al.* (1952, p. 134-160)
				c		48.0	52.0						7.5								14,419	
9285	572-1	Meigs Creek (No. 9), lower bench	24	a	2.8	36.3	40.6	20.3					5.9								11,160	
				b		37.4	41.7	20.9					6.1								11,480	
				c		47.3	52.7						7.7								14,515	

[1] Analyses 572-1 and 572-2 from Krumin *et al.* (1952) (see Remarks); other analyses by U.S. Bureau of Mines.
[2] a, as received; b, moisture free; c, moisture and ash free.

TABLE 6.–*Major, minor, and trace element composition, whole-coal basis,*[1] *in coals of a portion of the Pawpaw Creek watershed*

Element	OGS chemical analysis no.					Element	OGS chemical analysis no.				
	770	771	772	773	774		770	771	772	773	774
Si (%)	1.0	2.2	NA	1.0	1.6	Zn (ppm)	15.8	106	10	129	10.4
Al (%)	0.73	1.2	NA	0.9	1.0	Ag (ppm) S	0.05L	NA	NA	NA	0.07
Ca (%)	0.165	NA	NA	NA	0.199	B (ppm) S	37	14	20	44	36
Mg (%)	0.050	0.038	0.004	0.045	0.032	Ba (ppm) S	12	67	20	219	230G
Na (%)	0.047	0.072	0.065	0.128	0.056	Be (ppm) S	2.5	1.4	1.3	2.9	2.0
K (%)	0.052	0.183	NA	0.073	0.062	Ce (ppm) S	H	19.2	13.0	N	23
Fe (%)	4.4	1.2	NA	6.5	2.8	Co (ppm) S	6.0	2.9	2.0	7.3	4.1
Mn (ppm)	97	8.6	8.4	20.4	12	Cr (ppm) S	3.5	19.2	13.0	10.2	6.6
Ti (%)	0.031	0.063	NA	0.026	0.064	Ga (ppm) S	3.0	6.7	4.6	14.6	4.5
P (ppm)	50	42	NA	255	93	Ge (ppm) S	3.6	4.8	4.6	22.0	7.6
Cl (%)	NA	NA	NA	NA	NA	La (ppm) S	4.5	6.7	6.5	N	5.5
As (ppm)	80	41.2	11.9	28.1	100	Mo (ppm) S	H	4.8	4.6	2.2	H
Cd (ppm)	0.14	0.23	0.06	0.29	0.08	Nb (ppm) S	1.5L	2.9	2.0	4.4	1.9
Cu (ppm)	25.2	13.4	7.8	17.5	16.1	Nd (ppm) S	7.1L	NA	NA	NA	7.3L
F (ppm)	24	110	44	54	20L	Ni (ppm) S	22.3	9.6	9.8	43.8	11.8
Hg (ppm)	0.24	0.22	0.22	0.44	0.35	Sc (ppm) S	1.7	2.9	2.0	4.4	2.6
Li (ppm)	5.9	10.6	5.1	6.6	7.2	Sn (ppm) S	NA	NA	NA	NA	NA
Pb (ppm)	4.7	9.3	3.6	23.4	9.3	Sr (ppm) S	22	14.4	19.5	43.8	107
Sb (ppm)	0.98	1.8	0.8	0.8	0.80	V (ppm) S	12.5	28.8	19.5	21.9	14.6
Se (ppm)	3.2	2.6	2.9	1.5	0.78	Y (ppm) S	8.3	6.7	6.5	21.9	9.2
Th (ppm)	1.9	NA	NA	NA	4.5	Yb (ppm) S	0.4	0.7	0.7	2.2	0.5
U (ppm)	0.46	NA	NA	NA	0.86	Zr (ppm) S	17.6	14.4	9.8	29.2	37

[1] Si, Al, Ca, Mg, Na, K, Fe, Mn, Ti, P, Cl, Cd, Cu, Li, Pb, and Zn values were calculated from analysis of ash. As, F, Hg, Sb, Se, Th, and U values are direct determinations on air-dried (32°C) coal. Remaining analyses were calculated from spectrographic determinations on ash. G, value greater than value shown; H, value high; L, value less than value shown; N, element not detected; NA, analysis not available; ND, value not determined; S, value determined by semiquantitative spectrographic analysis. Analyses performed by U.S. Geological Survey. See table 5 for coal seam identification.

TABLE 7.–*Major and minor oxide and trace element composition, laboratory-ash basis,*[1] *in coals of a portion of the Pawpaw Creek watershed*

Ash, oxide, or trace element	OGS chemical analysis no.					Ash, oxide, or trace element	OGS chemical analysis no.				
	770	771	772	773	774		770	771	772	773	774
Ash (%)	10.5	9.6	6.5	14.6	10.7	Ba (ppm) S	115	700	300	1,500	2,150G
SiO_2 (%)	20.4	48.0	NA	16.0	32.4	Be (ppm) S	24	15	20	20	19
Al_2O_3 (%)	13.3	23.0	NA	12.0	18.2	Ce (ppm) S	H	200	200	N	214
CaO (%)	2.2	1.5	NA	1.9	2.6	Co (ppm) S	58	30	30	50	38
MgO (%)	0.8	0.66	1.11	0.51	0.5	Cr (ppm) S	33	200	200	70	62
Na_2O (%)	0.6	1.01	1.35	1.19	0.7	Ga (ppm) S	29	70	70	100	42
K_2O (%)	0.6	2.3	NA	0.6	0.7	Ge (ppm) S	35	50	70	150	71
Fe_2O_3 (%)	52.9	18.1	NA	64.0	37.0	La (ppm) S	43	70	100	N	51
MnO (%)	0.6	NA	NA	NA	0.03	Mo (ppm) S	H	50	70	15	H
TiO_2 (%)	0.5	1.1	NA	0.3	1.0	Nb (ppm) S	0.15L	30	30	30	18
P_2O_5 (%)	0.1	0.1	NA	0.4	0.2	Nd (ppm) S	0.68L	NA	NA	NA	0.68L
SO_3 (%)	NA	1.8	NA	2.6	NA	Ni (ppm) S	212	100	150	300	100
Cl (%)	0.02L	0.02L	0.02L	0.02L	0.02L	Sc (ppm) S	16	30	30	30	24
Cd (ppm)	1.3	2.4	0.89	2.0	0.76	Sn (ppm) S	0.15L	ND	ND	ND	0.15L
Cu (ppm)	240	140	120	120	150	Sr (ppm) S	210	150	300	300	1,000
Li (ppm)	56	110	79	45	67	V (ppm) S	119	300	300	150	136
Pb (ppm)	45	97	56	160	87	Y (ppm) S	79	70	100	150	86
Zn (ppm)	150	1,100	160	880	97	Yb (ppm) S	4	7	10	15	5
Ag (ppm) S	0.5L	NA	NA	NA	0.63	Zr (ppm) S	168	150	150	200	346
B (ppm) S	353	150	300	300	339						

[1] Coals were ashed at 525°C. G, value greater than value shown; H, value high; L, value less than value shown; N, element not detected; NA, analysis not available; ND, value not determined; S, value determined by semiquantitative spectrographic analysis. Total Fe reported as Fe_2O_3. Spectrographic results are to be identified with geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, etc., but are reported arbitrarily as midpoints of those brackets, 1.0, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, etc. Precision of the spectrographic data is approximately one bracket at 68 percent confidence or two brackets at 95 percent confidence. Analyses performed by U.S. Geological Survey. See table 5 for coal seam identification.

and the Lower Kittanning (No. 5) coals. The resource is reported in the same categories as the strippable resource except that no overburden categories were used.

The distribution of each thickness and reliability category for the Middle Kittanning and the Lower Kittanning coals is shown in figures 6 and 7. The areas considered nonmineable at this time for the Middle Kittanning and Lower Kittanning coals comprise 1,081 acres of oil and gas fields and areas surrounding individual oil and gas wells (fig. 8).

The resource estimates reported in tons for each thickness and reliability category for the Middle Kittanning coal are given in table 2. Resource estimates for the Lower Kittanning (No. 5) are given in table 3. The figures in *italics* in tables 2 and 3 represent tonnages currently considered nonmineable; these tonnages would become part of the resource base if a means for economical recovery of the coal is developed.

Table 4 shows the total estimated coal-resource tonnage for the Pawpaw Creek study area.

COAL CHEMISTRY

Chemical analyses of the coals recovered from the deep-core portions of this study were performed by the U.S. Geological Survey and the U.S. Bureau of Mines. All coals over 28 inches thick were boxed separately at the drilling site and brought promptly to the Division of Geological Survey offices. The coals were remeasured in detail, and all partings of 3/8 inch or greater thickness were removed. The remaining coal, which constituted the sample thickness, was placed in double plastic bags and shipped to U.S. Geological Survey headquarters at Reston, Virginia. The U.S. Geological Survey split the sample and forwarded one part to the U.S. Bureau of Mines. The U.S. Bureau of Mines provided determinations on moisture, volatile matter, fixed carbon, ash, hydrogen, carbon, nitrogen, oxygen, sulfur, fusibility of ash, free-swelling index, and heating value (Btu). Major, minor, and trace element analyses on coal ash and whole coal were provided by the U.S. Geological Survey. The analytical data for the Meigs Creek coal were determined by the Ohio State University Engineering Experiment Station during a previous cooperative study with the Ohio Division of Geological Survey. No trace element data are available for the Meigs Creek coal.

The coals in the Pawpaw Creek study area for the most part fall within the normal quality range for the same seams elsewhere in Ohio (table 5). There is one occurrence, from core number 2387, of low-sulfur Lower Kittanning coal. Coal with a sulfur level in the range of 0 to 1 percent is generally considered to have low sulfur content, although some industries use 1.5 percent as an upper limit for low-sulfur coal. By any standard, however, the 0.9 percent sulfur level recorded for the Lower Kittanning in this study is low and could prove to be significant.

TABLE 8.–*Content of seven trace elements*[1] *in coals of a portion of the Pawpaw Creek watershed*

Trace element	OGS chemical analysis no.				
	770	771	772	773	774
F (ppm)	24	110	44	54	20L
Hg (ppm)	0.24	0.22	0.22	0.44	0.35
As (ppm)	80	41.2	11.9	28.1	100
Sb (ppm)	3.2	1.8	0.8	0.8	3.4
Se (ppm)	0.6	2.6	2.9	1.5L	0.7
U (ppm)	0.046	NA	NA	NA	0.86
Th (ppm)	1.6	NA	NA	NA	4.2

[1] Analyses on air-dried (32°C) coal. L, value less than value shown; NA, analysis not available. Analyses performed by U.S. Geological Survey. See table 5 for coal seam identification.

The uppermost 46 inches of the Lower Kittanning coal in a hole (OGS 2181) drilled about 4 miles southwest of core number 2387 of the present study was also relatively low in sulfur, only 1.59 percent, on an as-received basis. This coal, which was recovered during a previous study directed toward location of low-sulfur coal, had a total thickness of 87 inches and for analysis was divided arbitrarily into two benches. The lower portion of the seam had high sulfur content, but, because the division for analytical purposes was arbitrary, it is possible that a greater thickness than the upper 46 inches is relatively low in sulfur content. This possibility warrants further investigation because the occurrence of a thick body of low-sulfur or relatively low-sulfur coal in this portion of Ohio could be of major economic significance.

Tables 6 and 7 present data on major, minor, and trace elements in the whole coal and in the coal ash. Table 8 gives the content of seven trace elements as determined on air-dried coal. This is the first time that such detailed analytical data have been available to the Division of Geological Survey; these determinations mark a significant step forward in our knowledge of Ohio coals. Such data are vital to evaluating and planning for matters relating to methods of use, mining, environmental controls, and use of coal for liquefaction or gasification. Ohio is the nation's largest user of coal, and use of Ohio's native coal resources is critical to the continued economic well-being of the state. Information of the type developed for this report will help Ohio to use available resources most efficiently.

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