STATE OF OHIO
John J. Gilligan, Governor
DEPARTMENT OF NATURAL RESOURCES
William B. Nye, Director
DIVISION OF GEOLOGICAL SURVEY
Horace R. Collins, Chief

Report of Investigations No. 81

DEEP-CORE INVESTIGATION OF LOW-SULFUR COAL POSSIBILITIES IN SOUTHEASTERN OHIO

by

Richard A. Struble,
Horace R. Collins,
and
Douglas L. Kohout

Columbus
1971

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INTRODUCTION

A rapidly expanding population and economy has created a variety of complex pressures upon the environment. One well-recognized pressure is pollution. For years society has refused to accept or has misunderstood the fact that the environment is not totally self-cleansing or that it is not capable of absorbing infinite quantities of untreated wastes. During the past decade, however, a widespread awareness of the threat of pollution to the quality of our way of life has been developing. This awareness is causing and will continue to cause pressure to be initiated at all levels of government (1) to monitor, regulate, and abate environmental pollution, (2) to determine those levels of potential pollutants that can be safely tolerated without endangering the environment, and (3) to develop technology and methods to reverse the adverse effects of pollutants so that the environment can be restored to a desirable state.

Because of the immensity of the problem pollution cannot be solved by controls alone. Pollution will remain until each person recognizes that he individually through his life style contributes to the problem. Man must therefore adopt living habits which will be within the pollution tolerance of the environment.

This study is just one contribution to the solution of the multifaceted problems facing man in his effort to bring the total environment into balance with the needs of modern society. Through a united and cooperative effort by every individual, by industry, and by government at all levels, this goal can be achieved. This report describes the results of an investigation carried out by the Ohio Division of Geological Survey in an attempt to find new and significant reserves of low-sulfur coal in the deep heretofore-unexplored portion of the Ohio coal basin. The report indicates also the Division's awareness of a growing air pollution problem and the need for intelligent discussions based upon reliable data in planning future air pollution control measures.

PURPOSE OF INVESTIGATION

One of the more complex and serious aspects of the total pollution problem is that of air pollution. It has been strongly suggested that the large volume of sulfur dioxide released through the burning of high-sulfur fossil fuels for electrical generation is a major contributor to atmospheric pollution. In Ohio as elsewhere in the nation there is a need to control the level of sulfur dioxide in the atmosphere while satisfying the very high electrical energy needs of society. Because Ohio is a leading producer of coal which is consumed by the electrical utilities industry it seemed particularly apt that a major effort be made by the Division of Geological Survey to assist in research on the air pollution control problem. It is hoped that the information gained during this study will provide a basis on which to make intelligent decisions and to plan future air pollution control methods.

Four avenues of approach are open to investigators studying ways to reduce atmospheric sulfur dioxide levels that result from burning of high-sulfur coals: (1) the discovery and development of new reserves of low-sulfur coals, (2) the development of new techniques for removing sulfur dioxide from the stack gasses of fossil-fuel-burning plants, (3) the development of new and better techniques for lowering the level of sulfur or for removing it from the coal, and (4) substitution of low-sulfur or non-sulfurous fuel sources such as natural gas or fissionable material. The Division of Geological Survey is involved in study of the first three of these approaches. The feasibility and relative ease with which any of these avenues could provide solutions is in approximate order of listing, with the fourth procedure being the least feasible and most difficult to accomplish. There are many technical barriers to the adoption of any of these procedures, but the burning of low-sulfur coal is a positive step which would appear to offer the greatest potential in terms of immediacy. This step has had widespread public appeal and, accordingly, restrictions on the sulfur content of coal have been instituted in many metropolitan areas. Implementation of this approach, however, introduces additional problems: low-sulfur coal is already in short supply and the vast quantities needed to maintain current electrical power requirements must be found and produced, priorities must be established with other industries (*e.g.*, steel, the production of which requires low-sulfur coal) using low-sulfur coal, and existing power plants, designed for high-ash–high-sulfur coal, must be modified for the efficient handling of low-sulfur coal.

Ohio has been a leading commercial producer of coal since the early 1800's. Exact production figures vary somewhat but coal totalling on the order of 2,500,000,000 tons has been mined in the State. Virtually all of the known low-sulfur coal reserves were mined out in the late 1800's and early 1900's. Chemical and geological data accumulated from outcrops, mines, and cores strongly indicated that the probability of finding substantial additional low-sulfur coal reserves in the known mining districts was extremely small. Mining in Ohio, however, has been confined largely to easily accessible beds; the deeper less-accessible portions of the coal basin have been virtually ignored by the mining industry. Deep shafts in Ohio are rare and there has been little mining or exploration below a depth of 400 feet.

From the available data it was apparent that if significant reserves of low-sulfur coal were to be located in Ohio a search would have to be made in the relatively unexplored deep portion of the coal basin. An examination of the immediate needs and research capability of the Geological Survey and the probability of making a useful contribution in a relatively short period of time led to the present study.

ACKNOWLEDGMENTS

A proposal for funding consideration for the study was submitted to the National Air Pollution Control Administration. A favorable review by NAPCA made support possible as a Demonstration Project Grant under the Clean Air Act, as amended (P.L. 90-148). The investigation was sponsored jointly by the United States Department of Health, Education, and Welfare, the National Air Pollution Control Administration (grants 68A-3812D and 69B-3812D), and the Ohio Department of Natural Resources, Division of Geological Survey.

The authors would like to acknowledge the assistance of Richard M. DeLong and Joel D. Vormelker of the Ohio Division of Geological Survey during portions of the preliminary and intermediate phases of the project.

SCOPE OF INVESTIGATION

Coal in Ohio is confined to the rocks of the Permian and Pennsylvanian Systems. Coal production has therefore been restricted to the 32 counties of eastern and southeastern Ohio underlain by these rock systems (fig. 1). These counties occupy approximately the northwestern one-quarter of the northern Appalachian coal basin of Kentucky, West Virginia, Pennsylvania, and Ohio. Production in Ohio has come primarily from the counties in the western and northern portions of the State's coal-bearing region, where minable coals have been readily accessible. Those counties bordering the Ohio River south of Belmont County have had little deep production.

The counties comprising this deepest portion of the Ohio coal basin include all or part of Athens, Gallia, Lawrence, Meigs, Monroe, Morgan, Noble, and Washington (fig. 1). This area was chosen for study because it offered the greatest possibility of finding new low-sulfur coal reserves. Jackson and Vinton Counties were included in the preliminary investigation because of the once-famous Sharon (No. 1) and Quakertown (No. 2) coal fields. Coal produced from these fields was a low-sulfur fuel of very high quality and the possibility of extending these old mining areas could not be overlooked.

To achieve the maximum areal coverage and to provide the greatest amount of information to stimulate additional exploration by private companies, cores were taken at widely spaced locations throughout the study area. All holes were scheduled to penetrate at least the Allegheny Group because this sequence, in the authors' opinion, was the most promising source of minable coals. Within the limits of funding, selected cores were scheduled to penetrate the entire coal-bearing sequence and to bottom in the uppermost Mississippian. If the Maxville Limestone was encountered at the top of the Mississippian sequence, drilling was continued through that unit.

It is hoped that the data presented here will serve as a guide to both industry and government in the location of potential new coal reserves and in the ultimate development of these resources.

STUDY PROCEDURES

The study was divided into three phases: preliminary, intermediate, and final. The primary goal of the preliminary phase was to select drilling sites which

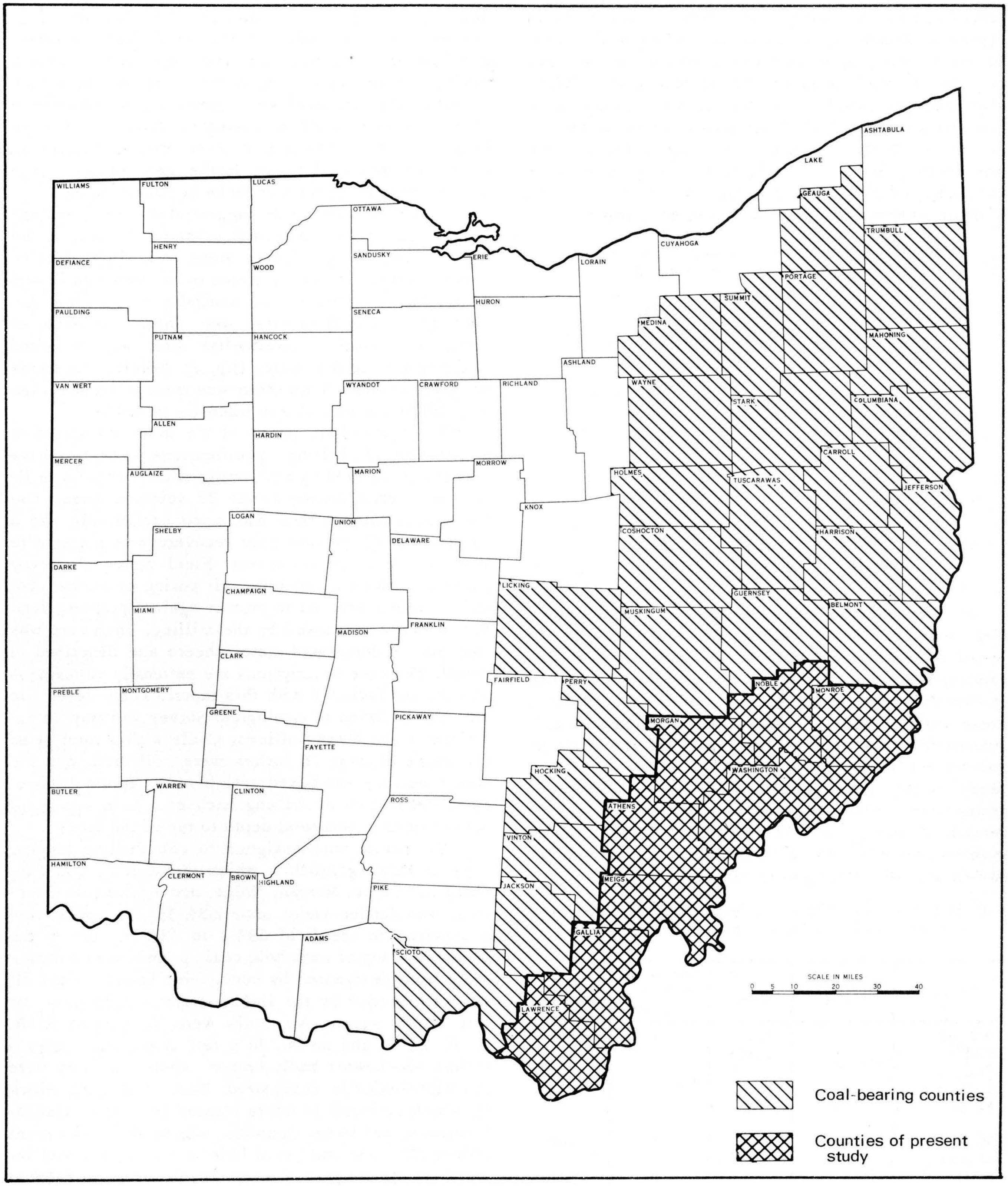

FIGURE 1.–Location map.

offered the greatest possibility of finding minable reserves of coal (preferably low-sulfur). To arrive at this objective, sample suites from oil and gas wells in the 10-county study area were examined for the presence of coals as well as other stratigraphic units. Thirty-eight existing sample descriptions from previous studies were used also. Only those wells in close proximity to others having adequate sample descriptions were omitted from the study. Eighty-one sample suites were examined and described. The distribution and footages of these samples are shown by counties in table 1.

TABLE 1.—*Well samples examined and described during preliminary phase of investigation*

County	Number of wells	Total footage
Athens	15	20,153
Gallia	6	7,852
Jackson	6	2,866
Lawrence	5	3,229
Meigs	15	24,984
Monroe	8	15,310
Morgan	8	10,320
Noble	5	7,150
Vinton	12	6,942
Washington	1	1,291
Total	81	100,097

It is recognized that variations in sample collection methods used by drillers, irregularities in the length of the sampled interval, and difficulties in correlating the amount of coal in a sample with the actual thickness of the coal all detract from the quality of these data. However, in the absence of more reliable information and with the awareness of the need for careful evaluation, these data were judged useful to a study of this type. Data from 72 cores, primarily in fringe areas, were evaluated also and used in the selection of coring sites. The distribution, by county, of core records and previously examined well records are shown with their footages in table 2.

TABLE 2.—*Cores and previously described well samples evaluated during preliminary phase of investigation*

County	Number of cores	Total footage	Number of well descriptions	Total footage
Athens	19	8,299	5	6,550
Gallia	3	2,493	--	--
Jackson	1	95	--	--
Lawrence	25	6,325	--	--
Meigs	6	2,307	--	--
Monroe	--	--	1	1,980
Morgan	9	3,752	--	--
Noble	--	--	2	2,570
Vinton	7	811	--	--
Washington	2	1,280	30	42,430
Total	72	25,362	38	53,530

During the preliminary phase all available well sample and core descriptions were plotted on strip logs and compared to establish the occurrence, tentative correlations, and possible areal distribution of the coals. Limited data from private sources were consulted in the site evaluation; however, no information so received was used in making the final report. Core location sites, approximate total drilling footage at each site, and coal target depths were selected from the analysis of the total of these accumulated data.

The preliminary study suggested that the possibility of discovering additional reserves of coal in the Jackson and Vinton County areas was slight relative to possibilities in the total area to be investigated and within limits of the monies available for drilling. Accordingly, no drilling sites were chosen in either of these two counties. Twenty-five sites were selected in the remaining 8 counties (fig. 2). Detailed locations are given in table 3. An effort was made to locate holes on publicly owned property wherever possible.

The intermediate phase of the study consisted of preparation of drilling specifications, administrative aspects of the bidding and letting of contracts for drilling, and actual coring at the 25 selected sites. The wire-line coring method was used exclusively and a minimum of 95 percent core recovery was required to meet contract specifications. Field crews of Survey personnel closely monitored all coring to insure contract conformance and to protect against property damage or pollution caused by the drilling. Each core was laid out on corrugated metal sheets and described in detail. The core descriptions are extremely voluminous and are not included with this report. They are on file with the Division of Geological Survey and may be examined in the Survey offices. Coals with a total seam thickness of over 28 inches were collected, and the remaining core was boxed and labeled for future studies. Upon completion of drilling each core hole was pressure cemented from total depth to top of the hole.

The coring was assigned to two drilling blocks. Work in Drilling Block I, which included 11 holes located in Monroe, Morgan, Noble, and Washington Counties, was funded under grant 68A-3812D. Cores were designated in the field 68A-1 to 68A-11, and in the descriptive log of each hole coals greater than 6 inches thick were designated by successive letters of the alphabet preceded by the field location number, *i. e.*, at site 68A-1 successive coals were designated A1-A, A1-B, A1-C, and so on. In a few cases coals over 6 inches which were badly broken, shaly, or bony were not alphabetically designated. Work in Drilling Block II, which included 14 holes located in Athens, Gallia, Lawrence, and Meigs Counties, was funded under grant 69B-3812D. One additional hole in this series was located in Washington County. Cores were designated 69B-1 through 69B-14, and coal designations followed the same notation as in Block I. Each core description was subsequently assigned an official core file number.

Table 3 relates the field designations and Division of Geological Survey core file numbers.

Coals over 28 inches in seam thickness were sealed in Saran wrap and aluminum foil and stored under water pending further preparation for chemical analysis. Each coal core was subsequently assigned a chemical analysis number (C.A.), unwrapped in the laboratory, measured and described in detail, and cut on a Skil-Saw equipped with a corundum blade. Following the method recommended by the U.S. Bureau of Mines (Holmes, 1911), partings or mineral bands over ⅜ inch thick were excluded from the sample. An oriented sample consisting of one-third of each sample was rewrapped and stored under water as a reserve sample for subsequent

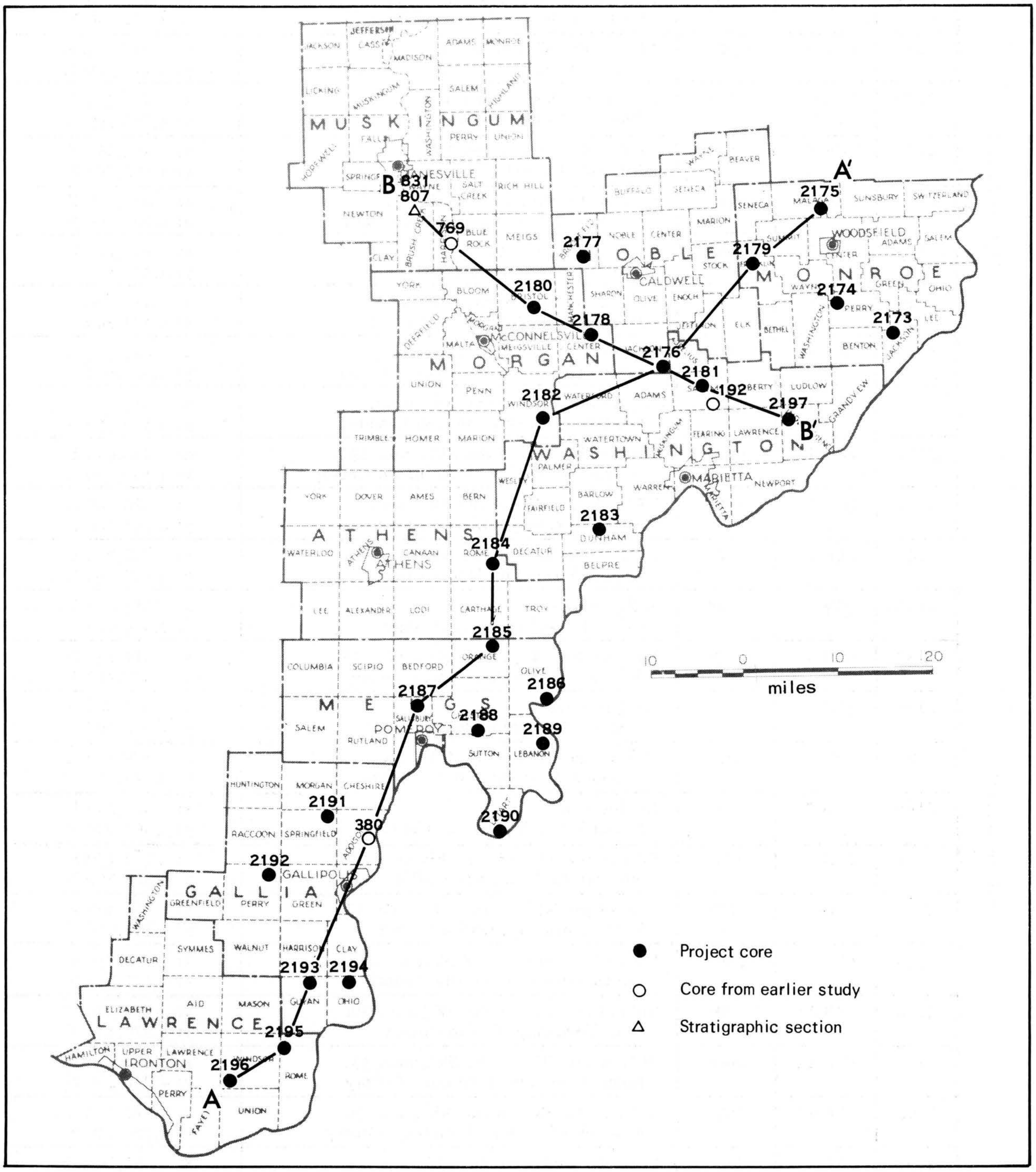

FIGURE 2.—Core locations and lines of cross section.

TABLE 3.—*Locations of cores*

	File no.	Field no.	Elev. (topo.)	Section, township, county	Universal Transverse Mercator coordinates, zone 17
Drilling Block I	2173	68A-1	800+	NW¼ of the NE¼ of the NE¼ sec. 32, Jackson Township, Monroe County	x: 498,540 E y: 4,835,800 N
	2174	68A-2	750+	SE¼ of the SW¼ of the SW¼ sec. 30, Perry Township, Monroe County	x: 489,550 E y: 4,931,750 N
	2175	68A-3	1030+	NE¼ of the SW¼ of the NE¼ sec. 3, Malaga Township, Monroe County	x: 488,350 E y: 4,407,300 N
	2179	68A-4	950+	SW¼ of the NW¼ of the NE¼ sec. 16, Franklin Township, Monroe County	x: 475,250 E y: 4,399,600 N
	2176	68A-5	750+	SW¼ of the NE¼ of the NW¼ sec. 35, Jackson Township, Noble County	x: 456,560 E y: 4,382,780 N
	2177	68A-6	820+	SE¼ of the SW¼ of the SE¼ sec. 28, Brookfield Township, Noble County	x: 444,710 E y: 4,402,100 N
	2178	68A-7	680+	Center SW¼ sec. 15, Center Township, Morgan County	x: 445,110 E y: 4,386,150 N
	2180	68A-8	670+	SE¼ of the SE¼ of the NW¼ sec. 27, Bristol Township, Morgan County	x: 435,470 E y: 4,393,800 N
	2181	68A-9	640+	W½ lot 3, Duck Creek Allotment, Salem Township, Washington County	x: 467,200 E y: 4,380,800 N
	2182	68A-10	640+	N½ lot 40, Big Bottom Allotment, Windsor Township, Morgan County	x: 436,550 E y: 4,376,350 N
	2183	68A-11	620	SW¼ of the SW¼ of the SE¼ sec. 18, Dunham Township, Washington County	x: 444,040 E y: 4,354,780 N
Drilling Block II	2184	69B-1	580+	NW¼ of the NE¼ of the SW¼ sec. 3, Rome Township, Athens County	x: 426,780 E y: 4,351,300 N
	2185	69B-2	620+	SW¼ of the NW¼ of the NW¼ sec. 18, Orange Township, Meigs County	x: 422,250 E y: 4,337,200 N
	2186	69B-3	570+	NE¼ lot 124, Olive Township, Meigs County	x: 433,670 E y: 4,326,810 N
	2187	69B-4	670+	NW¼ of the NW¼ of the NW¼ sec. 18, Salisbury Township, Meigs County	x: 411,170 E y: 4,328,270 N
	2188	69B-5	600+	NE¼ fraction 30, Chester Township, Meigs County	x: 420,600 E y: 4,322,300 N
	2189	69B-6	580+	SW¼ of the NE¼ of the NW¼ sec. 23, Lebanon Township, Meigs County	x: 429,500 E y: 4,315,560 N
	2190	69B-7	630+	N½ lot 234, Letart Township, Meigs County	x: 424,230 E y: 4,305,000 N
	2191	69B-8	580+	SE¼ of the SW¼ of the SE¼ sec. 12, Springfield Township, Gallia County	x: 392,170 E y: 4,308,550 N
	2192	69B-9	580+	SE¼ of the NE¼ of the NE¼ sec. 13, Perry Township, Gallia County	x: 383,370 E y: 4,297,450 N
	2193	69B-10	680+	NE¼ of the SE¼ of the SW¼ sec. 18, Guyan Township, Gallia County	x: 387,730 E y: 4,279,710 N
	2194	69B-11	600+	SE¼ of the SE¼ of the SW¼ sec. 30, Ohio Township, Gallia County	x: 394,510 E y: 4,279,150 N
	2195	69B-12	600+	SE¼ of the SE¼ of the SW¼ sec. 35, Rome Township, Lawrence County	x: 381,850 E y: 4,268,260 N
	2196	69B-13	560+	NE¼ of the SW¼ of the NE¼ sec. 30, Windsor Township, Lawrence County	x: 372,050 E y: 4,265,250 N
	2197	69B-14	720+	SE¼ of the SE¼ of the NE¼ sec. 23, Independence Township, Washington County	x: 483,200 E y: 4,372,010 N

petrographic studies. Two-thirds of the sample was submitted for chemical analysis.

The final phase of the study included stratigraphic evaluation of the new data and preparation of the final report. Multicolor lithologic strip logs were prepared for all cores and tentative correlations were made between adjacent locations. Thicknesses for each coal that was assigned a tentative correlation were plotted on small-scale maps of the study area. Details of the final data evaluation constitute the remainder of this report.

STRATIGRAPHY

General statement

The coal-bearing sequence of Ohio was long ago subdivided into five large units based on the relative content of minable coal. The original names applied to these divisions referred to this relative coaliness. The geographic names on the right were subsequently applied to each of these divisions in keeping with geologic nomenclatural practice:

Upper Barren Measures	Permian	Dunkard Group
Upper Productive Measures	Pennsyl-vanian	Monongahela Group
Lower Barren Measures		Conemaugh Group
Lower Productive Measures		Allegheny Group
Seral Conglomerate		Pottsville Group
	Mississippian	

Distribution of these groups is shown in figure 3. Rocks penetrated in this study ranged from slightly above the Washington coal in the Dunkard Group of Permian age to slightly below the Maxville Limestone at the top of the Mississippian. The total coal-bearing sequence involved is approximately 1,550 feet thick and consists of a repetitive series of sandstones, shales, clays, siltstones, mudstones, marine and freshwater limestones, coals, and other minor rock types.

A few relatively thin minable coals are found in the Permian age Dunkard Group and in both the Conemaugh and Pottsville Groups of Pennsylvanian age. However, the principal coals mined in Ohio are in the Monongahela and Allegheny Groups. The most important individual coal beds are the Meigs Creek (No. 9) and Pittsburgh (No. 8) in the Monongahela Group and the Upper Freeport (No. 7), Lower Freeport (No. 6A), Middle Kittanning (No. 6), and Lower Kittanning (No. 5) in the Allegheny Group. The stratigraphic positions of the major coal and marine beds in the Pennsylvanian and Permian coal-bearing sequence are shown in figure 4.

It was believed formerly that the major groups and many of the individual beds which comprised them were laterally persistent and could be correlated with considerable accuracy over substantial geographic areas. More recent work has questioned this concept and it can, in fact, be shown that most individual beds cannot be correlated precisely over long distances. This has given rise in more recent years to the "delta concept," which provides substantial insights into the origin and depositional environments of Pennsylvanian rocks and has been most useful in explaining the nature of the stratigraphic framework. As yet, however, it lacks in providing an adequate nomenclature for discussing the many economically important beds.

The broad stratigraphic framework which has been previously developed for the northern Appalachian Basin, and for the Ohio portion in particular, has proved useful for comparison and discussion of coal beds at widely scattered points. Although some imprecision may result from the stratigraphic treatment used here, it was judged most suitable for the particular problem. Correlations presented here are based on homotaxy and should be considered tentative.

Further studies based on a larger number of data points should serve to clarify the deltaic framework of the Pennsylvanian rocks in eastern Ohio. The scope of the current study and deadlines imposed by funding precluded an exhaustive stratigraphic investigation at this time. Studies along these lines, using data acquired in the present project plus additional information which is becoming available, are planned.

The longest single core was 1,525 feet (2189, Lebanon Township, Meigs County) and the longest aggregate interval was 1,696 feet (2173, Jackson Township, and 2174, Perry Township, Monroe County). Cross sections along both the structural dip and strike are shown diagrammatically on plates 1 and 2 (pocket). Skeletal columnar sections for individual cores, showing both coals and marine units, are presented on plates 3 and 4 (pocket).

Correlations were made from core to core by carefully comparing details of adjacent logs and arriving at a "best fit" of all stratigraphic elements present. Wherever possible the elevation of the Pittsburgh coal was determined at each site from surface exposures. One cross section (pl. 2) was carried to the outcrop to establish the tentative correlations. In addition, generalized sections of the cores were compared on a three-dimensional model.

Good general correlation is shown by the major Pennsylvanian units, *i.e.*, Monongahela, Conemaugh, Allegheny, and Pottsville Groups, although a precise boundary between groups cannot be designated in each case. This difficulty in Pennsylvanian correlation has long been recognized and does not detract seriously from the gross correlations.

Monongahela Group

The Monongahela Group consists of an alternating sequence of sandstones, shales, clays, mudstones, coals, and freshwater limestones. The average thickness of the group in Ohio is approximately 250 feet.

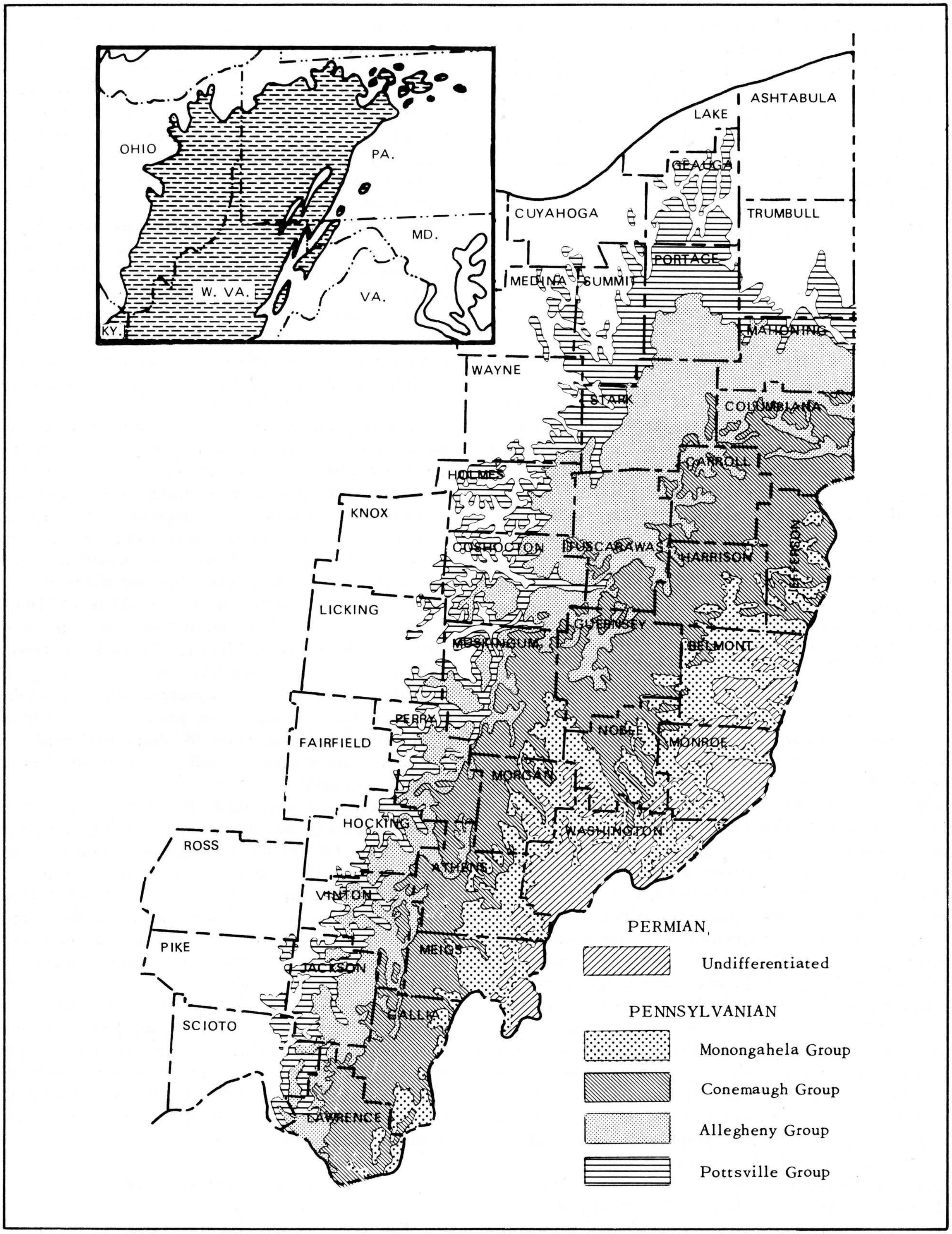

FIGURE 3.—Generalized geologic map of the coal-bearing rocks of Ohio (modified from Geologic Map of the United States, U.S. Geological Survey, 1932, reprinted 1960); *inset,* northern Appalachian coal basin.

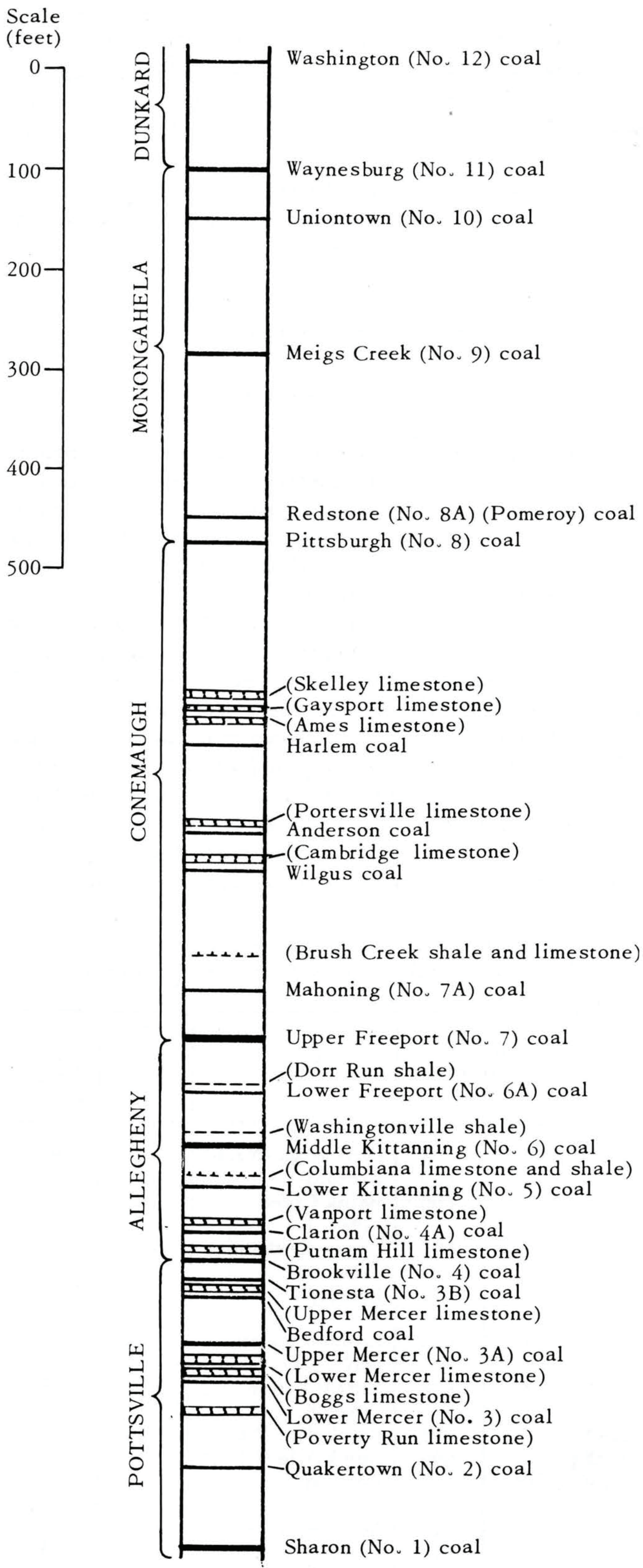

FIGURE 4.—Simplified diagrammatic columnar section of the Pennsylvanian and Lower Permian systems in Ohio (marine units in parentheses; modified from Brant and DeLong, 1960).

The Monongahela contains, in terms of current production, the two most economically important coal beds in the State: the Pittsburgh and the Meigs Creek. Sixty percent of the total coal production in Ohio in 1969 came from these two beds.

Most cores started, by intent, below the Pittsburgh coal; this unit was recognized in most of the few cores which did start higher in the section. It was identified in cores 2173, 2174, 2175, and 2179. The Redstone (Pomeroy) coal was present in cores 2188 and 2189; the Meigs Creek coal was identified in core 2175. A sequence equal to the thickness of the entire Monongahela section was penetrated only in cores 2173 (Monroe County), and 2186, 2189, and 2190 (Meigs County).

Conemaugh Group

The Conemaugh Group is 400 to 450 feet thick and is characterized by thin marine zones, red mudstones, freshwater limestone, thick sandstones and a lack of thick coals. Good gross correlations can be made for this sequence but an examination of the number of marine units recognized from core to core suggests that there is considerably less lateral persistence of these beds than has been generally believed. Classically, these marine beds are interpreted as having wide areal extent and have been extensively used as key beds in establishing regional correlations. It seems, however, that a reinterpretation of the Conemaugh sequence, particularly the marine beds, is in order. Conemaugh marine units are found progressively lower in the section from west to east (pl. 2) but it is not yet clear to what extent this may reflect thickening of the section rather than the introduction of new units. No effort was made to correlate individual marine beds in this sequence. The Upper Freeport coal, which marks the base of the Conemaugh, was rather uniformly absent; however, in a few cores (2177, 2178, 2179) a coal is found in the relative stratigraphic position of this unit.

A marked color change occurs in the argillaceous rocks, generally in the interval between the positions of the Mahoning and the Upper Freeport coals. The position of the change is indicated on plates 1-4 as the red-gray boundary. Red argillaceous rocks (mudstones and shales) are abundant in both the Pennsylvanian and Permian sections above the red-gray boundary. Red shales or mudstones are notably absent below the boundary in the remainder of the Pennsylvanian section, although in many areas red shale again becomes abundant in the upper Mississippian. Shales and clays below the red-gray boundary are normally some shade of gray. This rather marked color change in the argillaceous rocks of the Pennsylvanian was noted long ago by White (1903, p. 226), who suggested the use of this color change (with modification) as the dividing line between the Conemaugh and the Allegheny. The authors are uncertain as to the merits of this suggestion but did find the feature useful for making a rapid gross correlation between a number of widely scattered points. The red-gray boundary was useful as an additional point in establishing a "best fit" between adjacent core holes. Collins and Smith (in press) also found this color change to be useful in establishing correlations in the subsurface section of Washington County, Ohio.

Allegheny Group

The Allegheny Group consists of a 225 to 520 foot repetitive series of sandstones, shales, coals, clays, and thin marine and freshwater limestones. On the outcrop it is the most economically important sequence of rocks in the Pennsylvanian System and it was anticipated that it also held the greatest potential for significant new deep coal reserves. As expected, the thickest coals were found in this group. Except for the Meigs Creek and Pittsburgh of the Monongahela Group and the Bedford of the Pottsville Group, all seams of minable thickness (*i.e.*, 42 inches or greater) were found in the Allegheny Group, in the relative stratigraphic positions of the Middle Kittanning, Lower Kittanning, and Brookville coals. With a few minor exceptions, the majority of the coals falling in the 28- to 42-inch thickness category were also found in the Allegheny.

No persistent marine units were found in the positions of the Washingtonville shale, Columbiana limestone and shale (of Sturgeon and DeLong, 1964), Vanport limestone, or Putnam Hill limestone. However, one or more of these units is present in several of the cores. The marine fauna present in shales overlying the Lower Kittanning coal in closely grouped cores (fig. 2, 2176, 2178, 2182) suggests a marine embayment entering from the west. Marine beds over the Brookville coal in a similar grouping (fig. 2, 2176, 2177, 2178, 2180) invite the same interpretation. There is, however, insufficient evidence available at the present time to establish the distribution and stratigraphic relationships of these and other similar units.

Pottsville Group

The Pottsville Group in the study area ranges from 145 to 350 feet in thickness (cores 2180 and 2176) as a result of the topographic relief of the unconformable post-Mississippian–pre-Pottsville surface. The Pottsville group in Ohio is characterized by sandstones which are conglomeritic in many places, shales, and thin coals, clays, and marine beds. Rocks of this group display less lateral persistence than do those of the middle and upper Pennsylvanian. This lack of general lateral continuity was obvious between adjacent cores in the project area. Marine or brackish-water fossils were recorded in a few cores in the relative positions of the Upper and Lower Mercer limestones but, in contrast to the outcrop, such units were very limited in occurrence (pls. 1-4).

An upper Pottsville coal tentatively correlated with the Bedford was found at or near minable thickness in two cores (2174, 2181). Because of the highly variable thickness of the group and generally poor agreement between adjacent sites no attempt was made to assign even tentative correlations to the coals or marine units below the Bedford. Most coals in this portion of the group were of substantially less than minable thickness. However, in two cores (2193, 2195) coals in the 28- to 42-inch category were found.

CHEMICAL ANALYSES

General statement

Chemical analyses for this study were performed under contract by the Engineering Experiment Station of The Ohio State University. Coals less than 28 inches thick were not analyzed. Analyses of coals from 28 to 42 inches thick included proximate, B.T.U., total sulfur, forms of sulfur, and ash fusion.

The analyses performed on each of these thickness groupings were based primarily on mining probability. In the present investigation a seam thickness of 42 inches was considered to be the lower thickness limit for minable coal. It is well known that coals less than 42 inches thick are minable; in fact thin high-quality coals are extensively mined in some states. In Ohio, however, 42 inches has been a practical lower limit for deep mining most coals. The current energy crisis and increasing demands for coal may bring the lower

TABLE 4.—*Coals 28" to 42" thick: proximate, B.T.U., total sulfur, and forms of sulfur analyses performed*

Core file no.	Sample no.	Chemical analysis file no.	Seam	Seam thickness (in)	Reserve thickness (in)
2173	A1-E	688	Pittsburgh (No. 8)	38	38
2174	A2-D	689	Bedford	41	37
2175	A3-B	690	Meigs Creek (No. 9)	34½	25⅞
2176	A5-C	691	Lower Kittanning (No. 5)	30	30
2176	A5-E	692	Bedford	32½	32½
2177	A6-C	693	Lower Freeport (No. 6A)	32½	30½
2178	A7-C	694	Middle Kittanning (No. 6)	31½	31½
2180	A8-F	695	Brookville (No. 4)	40½	33
2181	A9-E	696	Brookville (No. 4)	38	38
2189	B6-H	712	Bedford	34	34
2190	B7-F	713	Not designated	38	33¾
2191	B8-A	714	Lower Freeport (No. 6A)	29	25⅜
2193	B10-E	715	Not designated	38½	32¾
2195	B12-G	716	Not designated	34½	24¼
2197	B14-D	717	Brookville (No. 4)	35	35

practical mining limit down to about 36 inches, particularly if low-sulfur coal is involved. It does not seem probable, however, in the light of current economic conditions, that coals less than 28 inches in thickness could be deep mined in Ohio.

Those coals falling in the 28- to 42-inch and the 42-inch or over categories are listed in tables 4 and 5. The results of the chemical analyses are given in tables 6 to 9 and figures 5 to 8.

TABLE 5.—*Coals 42" or more thick: proximate, ultimate, B.T.U., total sulfur, forms of sulfur, and ash fusion analyses performed*

Core file no.	Sample no.	Chemical analysis file no.	Seam	Seam thickness (in)	Reserve thickness (in)
2173	A1-H	698	Lower Kittanning (No. 5)	48⅜	47⅛
2175	A3-C	699	Pittsburgh (No. 8)	50½	49½
2175	A3-F	700	Middle Kittanning (No. 6)	47	47
2179	A4-C	701	Middle Kittanning (No. 6)	52½	52½
2179	A4-D	702	Lower Kittanning (No. 5)	41½	36
2179	A4-E	703	Brookville (No. 4)	43⅛	36⅛
2176	A5-B	704	Middle Kittanning (No. 6)	47	47
2176	A5-D	705	Brookville (No. 4)	52	41
2177	A6-D	706	Middle Kittanning (No. 6)	45	43¼
2181	A9-B	707	Middle Kittanning (No. 6)	44	42
2181	A9-C	708	Lower Kittanning (No. 5) (upper bench)	48	46
		709	Lower Kittanning (No. 5) (lower bench)	45	40⅝
2181	A9-F	697	Bedford	42	34½
2188	B5-A	710	Redstone (No. 8A) (Pomeroy)	43	40⅛
2189	B6-A	711	Redstone (No. 8A) (Pomeroy)	42	42

Forms of sulfur

General statement.—Sulfur occurs in coals in both inorganic and organic forms. Inorganic sulfur may be pyritic or sulfate sulfur. The latter occurs primarily as gypsum; other sulfate minerals known to occur in coal are largely oxidation products of pyrite. Percentages of all forms of sulfur are reported in the following paragraphs on a moisture-free basis.

Pyritic sulfur.—The iron sulfide pyrite (FeS_2) is the commonest inorganic form of sulfur. Marcasite may occur as discrete finely disseminated microscopic particles measuring a few microns in diameter, as thick visible lenses or veins, or as small or large nodules (or balls) ranging from a few inches to several feet in diameter. Lenses range from extremely small but visible blebs to several inches of pyrite having substantial lateral continuity. Vein fillings are generally only thin films of pyrite occurring as facings on the vertical joints (cleats).

Large particles of pyrite can be more or less successfully removed by various coal-cleaning (washing) techniques. However, such removal becomes increasingly difficult with decreasing particle size; pyrite in the size range of only a few microns is presently for intents and purposes economically and technically impossible to remove.

The majority of the sulfur present in the coals of Ohio is pyritic sulfur. In the present study pyritic sulfur ranged from a low of 1.08 percent (C.A. 708) in the Lower Kittanning coal to a high of 6.69 percent (C.A. 696) in the Brookville coal (tables 6-9). Some of the pyrite present in the coals studied was in the macroscopic size range (see descriptions of seams, figs. 5-8). This pyrite content could most probably be lowered somewhat by present-day cleaning techniques. However, pyrite smaller in size than current cleaning technology will remove must be compensated for in some other fashion.

An evaluation of the washability of the coals recovered in this study was beyond the technical and financial scope of the project. Representative fractions of each coal were saved, however, for subsequent petrographic evaluation which will shed additional light on the pyrite particle sizes and their distribution. It is hoped then to relate these data to washability.

Organic sulfur.—Organic sulfur, which is the sulfur that was present in the plants from which the coal was originally formed, is the second most common form of sulfur present in Ohio coals. All of the samples analyzed contained organic sulfur in amounts ranging from a low of 0.21 percent (C.A. 697) in the Bedford coal to a high of 1.90 percent (C.A. 690) in the Meigs Creek coal (tables 6-9). There is no way known to remove organic sulfur from coal prior to burning. Even if it were theoretically possible to remove all pyritic and sulfate sulfur from coal there would still be organic sulfur present in most cases. As in the case of finely disseminated pyrite, some other means of compensating for this sulfur must be found.

Sulfate sulfur.—The third and least common form of sulfur present in Ohio coal is sulfate sulfur. It is relatively unimportant in terms of total sulfur and in the samples studied ranged from 0.01 percent in several coals to 0.23 percent in the Middle Kittanning coal (C.A. 706) (tables 6-9). This form of sulfur occurs primarily as very thin secondary joint fillings of gypsum ($CaSO_4 \cdot 2H_2O$).

Total sulfur

Range of sulfur content.—Total sulfur in the samples analyzed ranged from a low of 1.62 percent (C.A. 708) in the Lower Kittanning coal to a high of 7.65 percent (C.A. 696) in the Brookville coal (tables 6-9). Table 10 summarizes the range in total sulfur percentages by coal bed.

TABLE 6.—*Chemical analyses of coals greater than 28 inches thick, Monroe County*

Sample and boring data					Proximate (%)				Ultimate (%)					Forms of sulfur (%)			Ash fusion temperature (°C)				Gross heating value	
O. G. S. no.	Chemical analysis no.	Analyzed thickness (in)	Condition*	Coal seam	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Total sulfur	Sulfate	Pyritic	Organic	Initial deformation temperature	Softening temperature	Hemispherical temperature	Fluid temperature	B. T. U.	Calories
2175	690	25 7/8	a	Meigs Creek (No. 9)	1.48	37.88	42.85	17.79					5.40	0.01	3.52	1.87					11,760	6533
			b			38.45	43.49	18.06					5.48	0.01	3.57	1.90					11,940	6633
			c			46.92	53.08														14,570	8094
2173	688	38	a	Pittsburgh (No. 8)	1.05	42.01	46.19	10.75					6.61	0.01	4.74	1.86					13,000	7222
			b			42.46	46.68	10.86					6.68	0.01	4.79	1.88					13,140	7300
			c			47.63	52.37														14,740	8189
2175	699	49½	a	Pittsburgh (No. 8)	1.71	41.22	47.25	9.82	4.91	71.32	1.19	7.95	4.81	0.03	2.94	1.84	2060	2200	2290	2400	13,020	7233
			b			41.94	48.07	9.99	5.00	72.56	1.21	6.35	4.89	0.03	2.99	1.87					13,250	7361
			c			46.59	53.41		5.56	80.61	1.34	7.06	5.43								14,720	8178
2175	700	47	a	Middle Kittanning (No. 6)	1.56	39.01	48.51	10.92	4.95	72.02	1.38	7.19	3.54	0.02	2.92	0.60	2070	2180	2280	2340	13,150	7306
			b			39.63	49.28	11.09	5.03	73.16	1.40	5.72	3.60	0.02	2.97	0.61					13,360	7422
			c			44.57	55.43		5.66	82.29	1.57	6.43	4.05								15,030	8305
2179	701	52½	a	Middle Kittanning (No. 6)	1.92	38.25	49.77	10.06	4.94	72.69	1.38	7.70	3.23	0.07	2.64	0.52	2040	2140	2260	2320	13,160	7311
			b			39.00	50.74	10.26	5.04	74.11	1.41	5.89	3.29	0.07	2.69	0.53					13,420	7456
			c			43.46	56.54		5.62	82.58	1.57	6.56	3.67								14,950	8306
2179	702	36	a	Lower Kittanning (No. 5)	1.45	38.14	45.53	14.88	4.66	67.46	1.09	6.13	5.78	0.06	4.52	1.20	2190	2280	2320	2390	12,390	6883
			b			38.70	46.20	15.10	4.73	68.45	1.11	4.74	5.87	0.06	4.59	1.22					12,570	6983
			c			45.58	54.42		5.57	80.62	1.31	5.59	6.91								14,810	8228
2173	698	47⅛	a	Lower Kittanning (No. 5)	1.23	38.93	50.60	9.24	5.08	74.31	1.34	6.90	3.13	0.01	2.33	0.79	2200	2280	2370	2440	13,460	7478
			b			39.41	51.23	9.36	5.14	75.24	1.36	5.73	3.17	0.01	2.36	0.80					13,620	7567
			c			43.48	56.52		5.67	83.01	1.50	6.32	3.50								15,030	8350
2179	703	36⅛	a	Brookville (No. 4)	1.45	40.20	46.22	12.13	4.94	70.71	1.09	7.18	3.95	0.06	2.76	1.13	2080	2150	2280	2340	12,970	7206
			b			40.79	46.90	12.31	5.01	71.75	1.11	5.81	4.01	0.06	2.80	1.15					13,160	7311
			c			46.52	53.48		5.71	81.82	1.27	6.63	4.57								15,000	8333
2174	689	37	a	Bedford	0.87	37.11	41.31	20.71					6.76	0.03	5.58	1.15					11,570	6428
			b			37.44	41.67	20.89					6.82	0.03	5.63	1.16					11,670	6483
			c			47.33	52.67														14,760	8200

* All samples fresh; a, air dried; b, moisture free; c, moisture and ash free

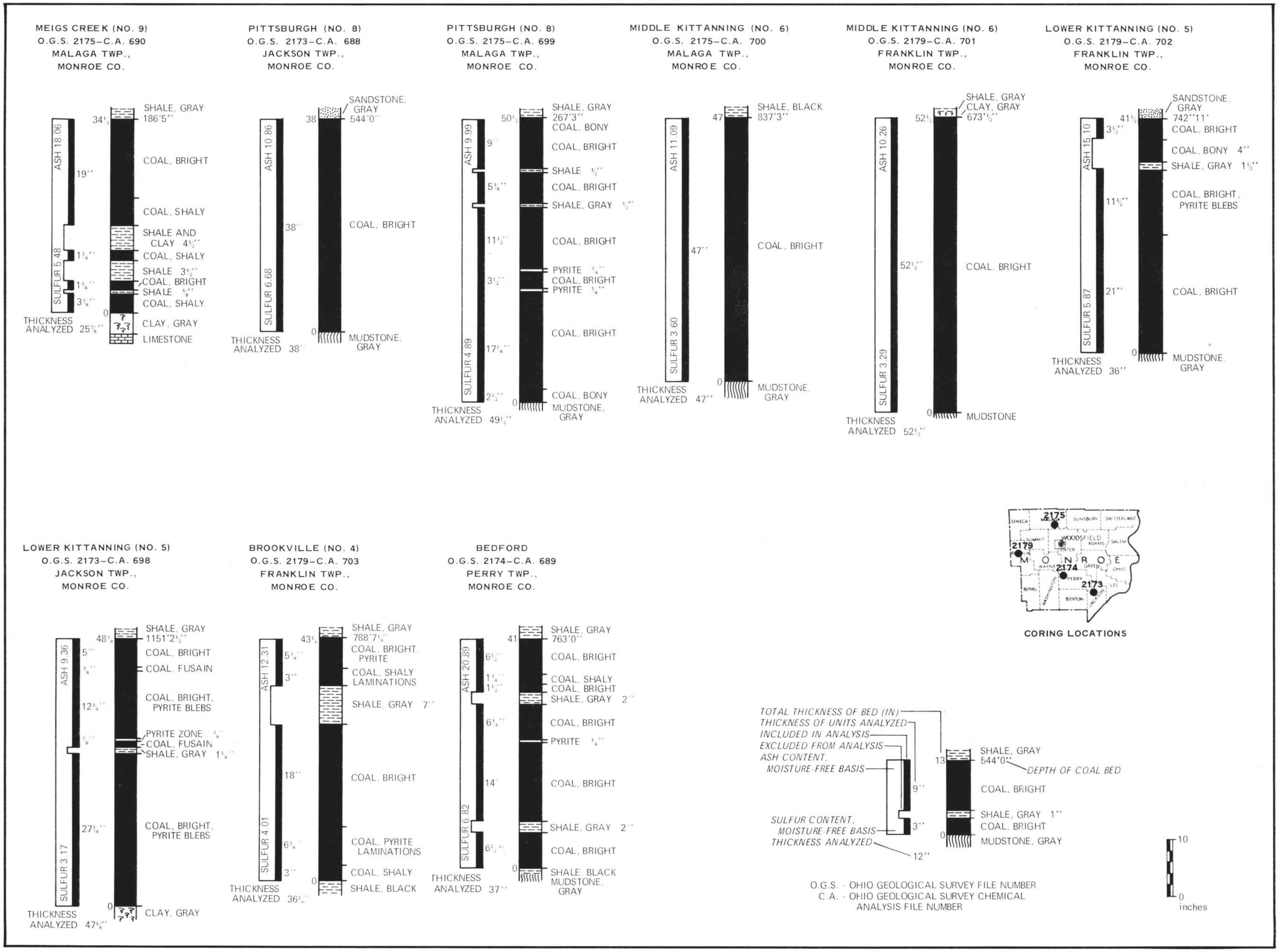

FIGURE 5.—Graphic sections of coals greater than 28" thick, Monroe County; see table 6 for complete chemical analyses.

TABLE 7.—*Chemical analyses of coals greater than 28 inches thick, Noble and Morgan Counties*

Sample and boring data					Proximate (%)				Ultimate (%)					Forms of sulfur (%)			Ash fusion temperature (°C)				Gross heating value	
O. G. S. no.	Chemical analysis no.	Analyzed thickness (in)	Condition*	Coal seam	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Total sulfur	Sulfate	Pyritic	Organic	Initial deformation temperature	Softening temperature	Hemispherical temperature	Fluid temperature	B. T. U.	Calories
2177	693	30½	a	Lower Freeport (No. 6A)	1.78	39.80	45.61	12.81					5.26	0.02	4.32	0.92					12,500	6944
			b			40.52	46.44	13.04					5.36	0.02	4.40	0.94					12,720	7067
			c			46.60	53.40														14,630	8128
2176	704	47	a	Middle Kittanning (No. 6)	1.93	40.68	46.94	10.45	5.00	71.91	1.32	8.25	3.07	0.03	2.67	0.37	2080	2120	2190	2310	13,070	7261
			b			41.48	47.86	10.66	5.10	73.33	1.35	6.43	3.13	0.03	2.72	0.38					13,320	7400
			c			46.43	53.57		5.71	82.08	1.51	7.20	3.50								14,910	8283
2177	706	43¼	a	Middle Kittanning (No. 6)	2.80	40.47	46.35	10.38	4.84	69.02	1.26	10.13	4.37	0.22	2.84	1.31	2160	2270	2340	2410	12,670	7039
			b			41.64	47.68	10.68	4.98	71.01	1.30	7.53	4.50	0.23	2.92	1.35					13,040	7244
			c			46.62	53.38		5.58	79.50	1.46	8.42	5.04								14,600	8111
2178	694	31½	a	Middle Kittanning (No. 6)	1.48	44.28	44.74	9.50					5.23	0.01	4.42	0.80					13,130	7294
			b			44.95	45.41	9.64					5.31	0.01	4.49	0.81					13,330	7406
			c			49.75	50.25														14,750	8194
2176	691	30	a	Lower Kittanning (No. 5)	1.33	41.44	45.91	11.32					6.07	0.02	5.37	0.68					12,850	7139
			b			42.00	46.53	11.47					6.15	0.02	5.44	0.69					13,030	7239
			c			47.44	52.56														14,710	8172
2176	705	41	a	Brookville (No. 4)	1.87	41.41	45.95	10.77	4.91	70.12	1.28	7.52	5.40	0.16	3.74	1.50	2040	2080	2170	2250	12,930	7183
			b			42.20	46.82	10.98	5.00	71.46	1.30	5.76	5.50	0.16	3.81	1.53					13,180	7322
			c			47.41	52.59		5.62	80.27	1.46	6.47	6.18								14,800	8222
2180	695	33	a	Brookville (No. 4)	2.34	38.09	50.91	8.66					2.32	0.01	1.77	0.54					13,130	7294
			b			39.00	52.13	8.87					2.38	0.01	1.81	0.56					13,440	7467
			c			42.80	57.20														14,750	8194
2176	692	32½	a	Bedford	1.39	37.19	50.49	10.93					3.48	0.01	3.03	0.44					12,960	7200
			b			37.72	51.20	11.08					3.53	0.01	3.07	0.45					13,140	7300
			c			42.42	57.58														14,780	8211

* All samples fresh; a, air dried; b, moisture free; c, moisture and ash free

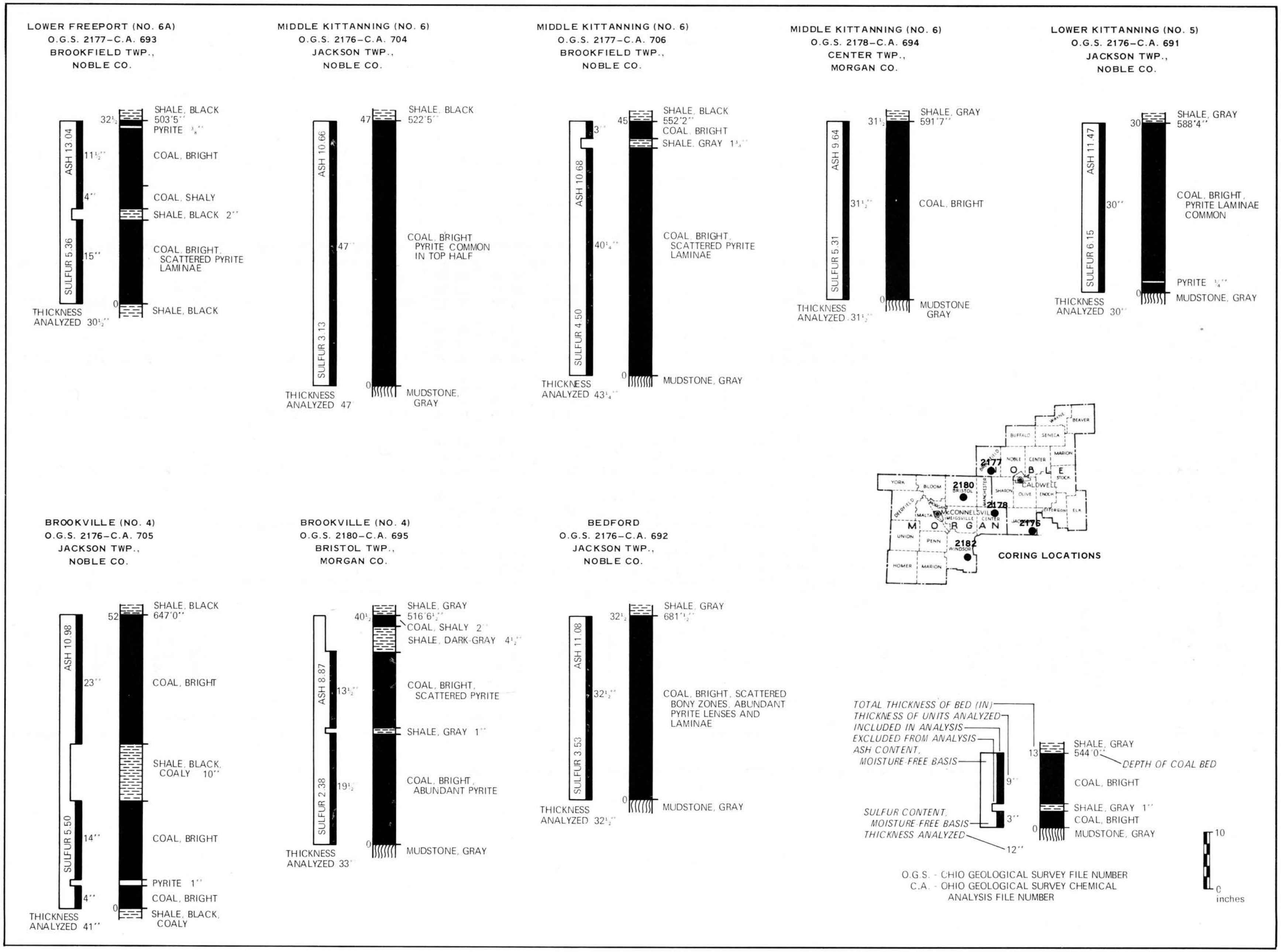

FIGURE 6.—Graphic sections of coals greater than 28" thick, Noble and Morgan Counties; see table 7 for complete chemical analyses.

TABLE 8.—*Chemical analyses of coals greater than 28 inches thick, Washington County*

Sample and boring data					Proximate (%)				Ultimate (%)					Forms of sulfur (%)			Ash fusion temperature (°C)				Gross heating value	
O. G. S. no.	Chemical analysis no.	Analyzed thickness (in)	Condition*	Coal seam	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Total sulfur	Sulfate	Pyritic	Organic	Initial deformation temperature	Softening temperature	Hemispherical temperature	Fluid temperature	B. T. U.	Calories
2181	707	42	a	Middle Kittanning (No. 6)	1.97	37.76	48.06	12.21	4.76	69.81	1.25	8.53	3.44	0.06	2.72	0.66	2120	2280	2330	2380	12,800	7117
			b			38.52	49.02	12.46	4.86	71.21	1.28	6.68	3.51	0.06	2.77	0.68					13,070	7261
			c			44.00	56.00		5.55	81.35	1.46	7.63	4.01								14,930	8294
2181	708	46	a	Lower Kittanning (No. 5)	1.96	38.42	50.91	8.71	5.06	74.24	1.52	8.88	1.59	0.02	1.06	0.51	2560	2610	2630	2640	13,340	7411
			b			39.19	51.93	8.88	5.16	75.72	1.55	7.07	1.62	0.02	1.08	0.52					13,600	7556
			c			43.01	56.99		5.66	83.10	1.70	7.76	1.78								14,930	8294
2181	709	40 5/8	a	Lower Kittanning (No. 5)	2.01	37.79	47.35	12.85	4.69	68.12	1.30	7.83	5.21	0.09	4.18	0.94	2040	2120	2180	2240	12,610	7006
			b			38.57	48.32	13.11	4.79	69.52	1.33	5.93	5.32	0.09	4.27	0.96					12,870	7150
			c			44.39	55.61		5.51	80.01	1.53	6.83	6.12								14,820	8233
2181	696	38	a	Brookville (No. 4)	1.23	41.04	46.21	11.52					7.56	0.03	6.61	0.92					12,980	7211
			b			41.55	46.79	11.66					7.65	0.03	6.69	0.93					13,140	7300
			c			47.03	52.97														14,870	8261
2197	717	35	a	Brookville (No. 4)	1.28	40.39	42.90	15.43					7.21	0.12	6.57	0.52					12,180	6767
			b			40.91	43.46	15.63					7.30	0.12	6.65	0.53					12,340	6856
			c			48.49	51.51														14,620	8122
2181	697	34½	a	Bedford	1.34	38.16	48.97	11.53					4.18	0.01	3.97	0.20					12,900	7167
			b			38.68	49.63	11.69					4.24	0.01	4.02	0.21					13,080	7267
			c			43.80	56.20														14,810	8228

* All samples fresh; a, air dried; b, moisture free; c, moisture and ash free

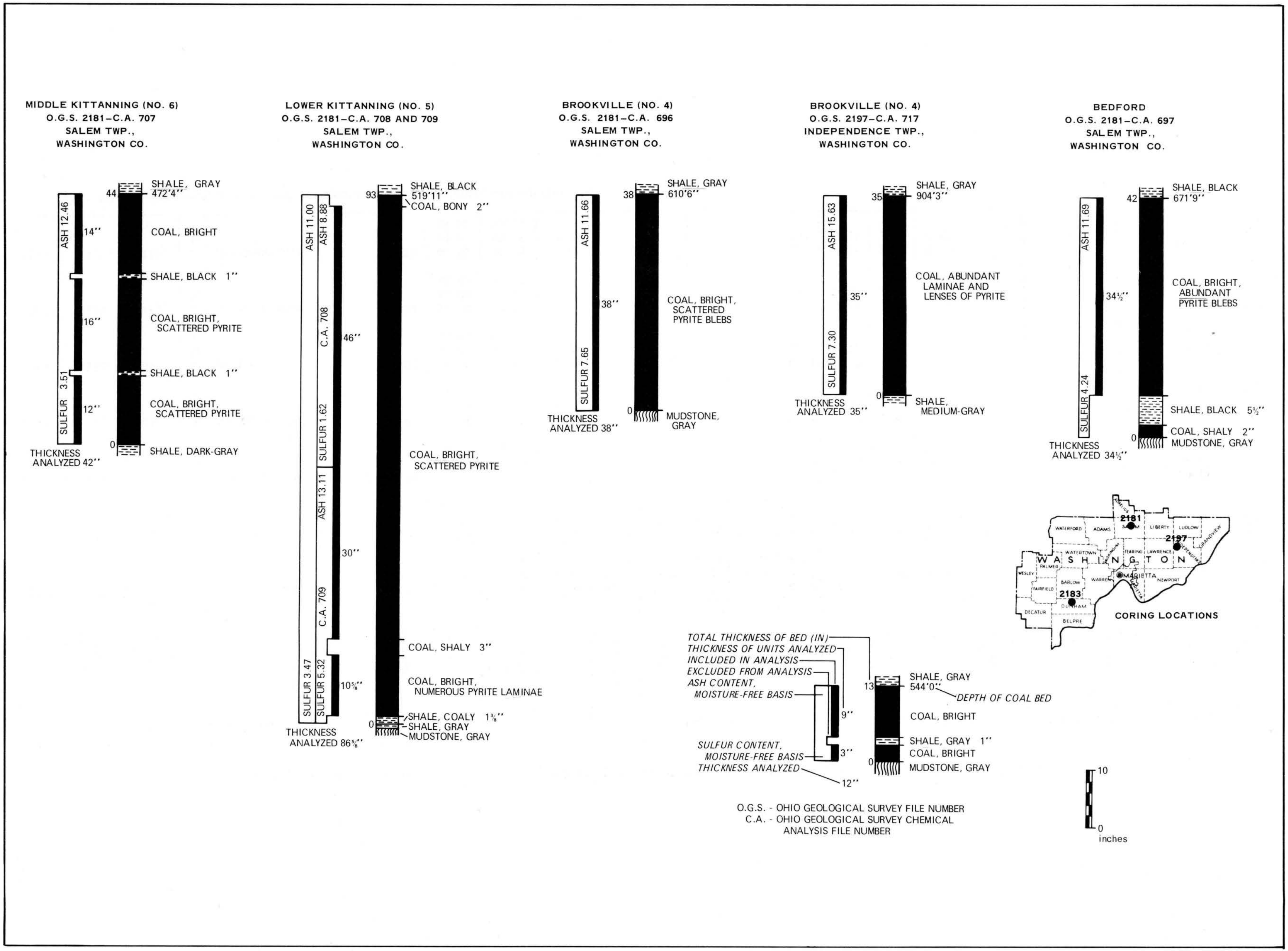

FIGURE 7.—Graphic sections of coals greater than 28" thick, Washington County; see table 8 for complete chemical analyses.

TABLE 9.—*Chemical analyses of coals greater than 28 inches thick, Meigs, Gallia, and Lawrence Counties*

Sample and boring data					Proximate (%)				Ultimate (%)					Forms of sulfur (%)			Ash fusion temperature (°C)				Gross heating value	
O. G. S. no.	Chemical analysis no.	Analyzed thickness (in)	Condition*	Coal seam	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Total sulfur	Sulfate	Pyritic	Organic	Initial deformation temperature	Softening temperature	Hemispherical temperature	Fluid temperature	B. T. U.	Calories
2188	710	40 1/8	a	Redstone (No. 8A)	4.43	43.02	43.66	8.89	4.80	68.50	1.13	13.29	3.39	0.13	2.32	0.94	2080	2170	2320	2380	12,290	6828
			b			45.02	45.68	9.30	5.02	71.68	1.18	9.27	3.55	0.14	2.43	0.98					12,869	7149
			c			49.64	50.36		5.53	79.02	1.30	10.24	3.91								14,180	7878
2189	711	42	a	Redstone (No. 8A)	4.02	42.73	44.29	8.96	4.66	69.48	1.13	12.58	3.19	0.11	2.35	0.73	2140	2300	2390	2490	12,280	6822
			b			44.52	46.14	9.34	4.88	72.70	1.18	8.58	3.32	0.11	2.45	0.76					12,790	7106
			c			49.11	50.89		5.38	80.19	1.30	9.47	3.66								14,110	7839
2191	714	25 3/8	a	Lower Freeport (No. 6A)	5.19	38.68	46.99	9.14					3.72	0.12	3.05	0.55					11,890	6606
			b			40.80	49.56	9.64					3.92	0.13	3.21	0.58					12,540	6967
			c			45.15	54.85														13,880	7711
2190	713	33 3/4	a	Not designated	3.01	37.41	47.41	12.17					2.13	0.04	1.31	0.78					12,000	6667
			b			38.57	48.88	12.55					2.20	0.04	1.35	0.81					12,370	6872
			c			44.11	55.89														14,150	7861
2189	712	34	a	Bedford	2.61	37.66	48.67	11.06					4.20	0.12	3.33	0.75					12,300	6833
			b			38.67	49.97	11.36					4.31	0.12	3.42	0.77					12,630	7017
			c			43.63	56.37														14,250	7917
2193	715	32 3/4	a	Not designated	5.51	37.88	49.33	7.28					2.50	0.06	1.98	0.46					12,160	6756
			b			40.09	52.21	7.70					2.65	0.06	2.10	0.49					12,870	7150
			c			43.43	56.57														13,940	7744
2195	716	21 1/4	a	Not designated	3.70	40.65	46.09	9.56					3.34	0.11	2.68	0.55					12,320	6844
			b			42.21	47.86	9.93					3.47	0.11	2.79	0.57					12,790	7106
			c			46.86	53.14														14,200	7889

* All samples fresh; a, air dried; b, moisture free; c, moisture and ash free

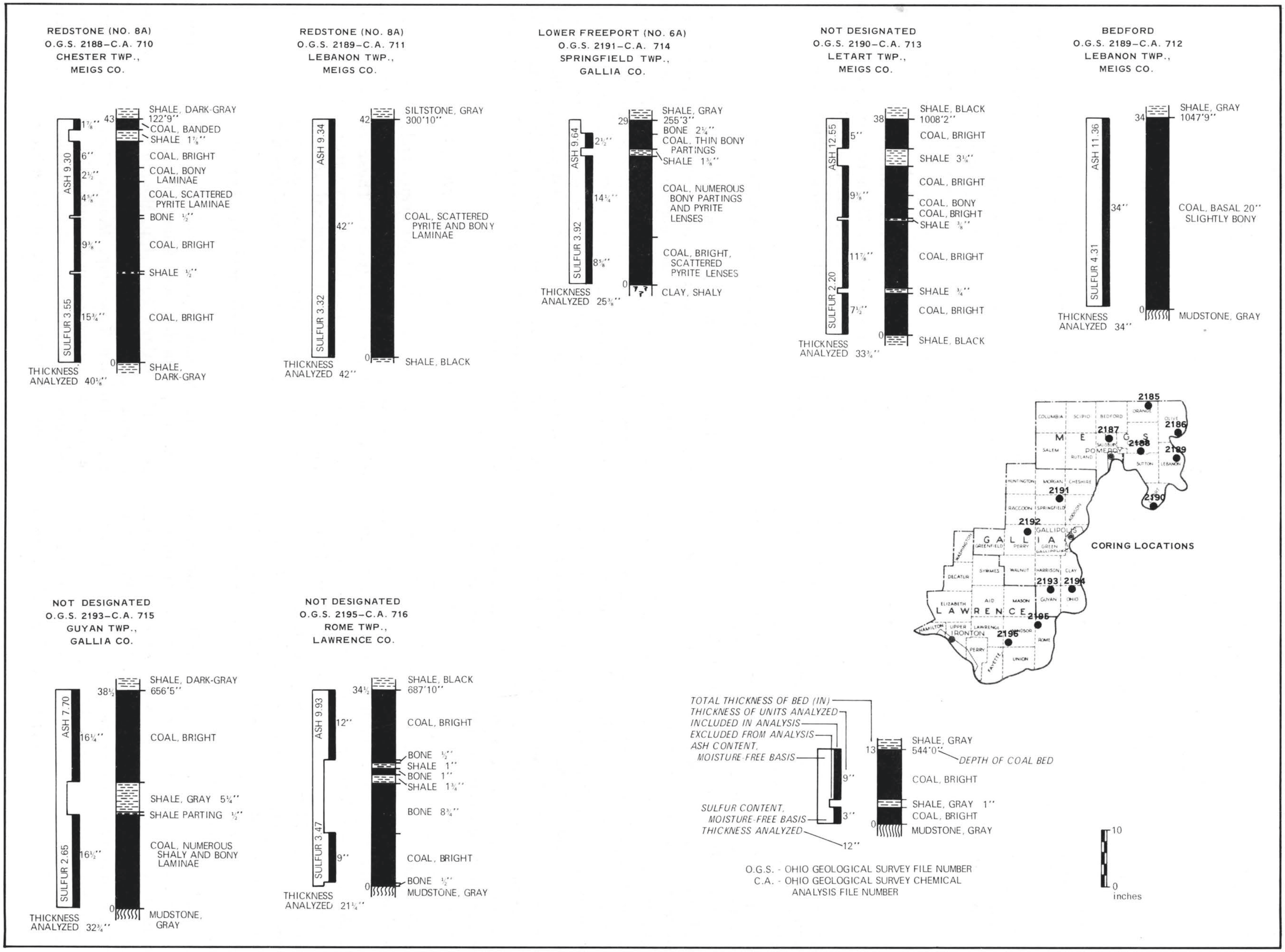

FIGURE 8.—Graphic sections of coals greater than 28" thick, Meigs, Gallia, and Lawrence Counties; see table 9 for complete chemical analyses.

TABLE 10.—*Summary of sulfur percentages by coal bed*

Coal seam	Number of analyses	Highest sulfur percentage*	Lowest sulfur percentage*	Average sulfur percentage*
Meigs Creek (No. 9)	1	5.48	5.48	5.48
Redstone (No. 8A)	2	3.55	3.32	3.44
Pittsburgh (No. 8)	2	6.68	4.89	5.79
Lower Freeport (No. 6A)	2	5.36	3.92	4.64
Middle Kittanning (No. 6)	6	5.31	3.13	3.89
Lower Kittanning (No. 5)	5	6.15	1.62	4.43
Brookville (No. 4)	5	7.65	2.38	5.37
Bedford	4	6.82	3.53	4.73

*All sulfur percentages on moisture-free basis

Low sulfur.—The term "low sulfur" is somewhat ambiguous, having different limits depending on the technological needs of the industry using the coal. However, present-day usage commonly considers coal with 1.5 percent or less total sulfur as low sulfur. Using 1.5 as the upper limit, it can be seen from table 10 that no low-sulfur coal was found in this study. It is possible that areas of low-sulfur coal remain undetected between the widely spaced core sites.

The top 46 inches of the Lower Kittanning coal in Salem Township, Washington County (core 2181, C.A. 708), however, has a sulfur level (1.62 percent) very close to the upper limit for low-sulfur coal. In all probability this portion of the coal could be washed down to a low-sulfur coal. In this single sample the upper portion of the coal is thick enough to be mined selectively. However, the areal extent of this coal remains to be demonstrated and, unless the low-sulfur portion of the seam remains on the order of 42 inches thick, selective mining to yield a better quality coal would become difficult and would not be economically feasible.

Medium-low sulfur.—Coal in the range of 1.5 to 2.5 percent sulfur may be considered medium-low-sulfur coal. Medium-low-sulfur coal was recorded in only a few samples (tables 7-9) and only one of these (Lower Kittanning, core 2181) is of minable thickness. Undoubtedly some improvement could be obtained by washing coals that contain only slightly above the upper limit of medium-low sulfur to lower their total sulfur to the medium-low range.

Normal sulfur.—Most Ohio coals fall in the range of 3 to 5 percent total sulfur, which may be considered the normal range. The majority of the samples analyzed for this report fall in this range (tables 6-9). A few samples contained over 6 percent sulfur, with 7.65 percent (Brookville, core 2181) the highest level noted.

Some reduction in total sulfur could probably be achieved in all of these coals by washing. The amount of reduction should be comparable to that obtainable by current practice on coals with similar sulfur levels and with similar geologic histories.

ADDITIONAL INFORMATION ON ESTABLISHED COAL AREAS

General statement

As stated previously, the present study was designed to develop information on the deep (generally below 400 feet) coals of the basin. The stratigraphically higher and shallower coals have received considerable attention by both industry and the Division of Geological Survey. Core locations were selected with this goal in mind and at most sites coring started below the stratigraphic position of the higher and better-known coals. However, where these coals were encountered at thicknesses of 28 inches or greater, samples were collected for chemical analyses in the interest of completeness. The following three coals are in this category.

Meigs Creek (No. 9) coal

The Meigs Creek coal, which is the second most important seam in Ohio in terms of current production, was found with sufficient thickness to sample in only one locality (core 2175, Malaga Township, Monroe County). Chemical and thickness data for this seam is given in table 6 and figure 5. Considerable previous work has been done on the areal distribution, thickness, chemistry, washability, and petrography of this coal and the interested reader is referred to Smith, Brant, and Amos (1952), Krumin (1952, 1957), and Cady and Smith (1955).

Redstone (No. 8A) (Pomeroy) coal

Cores 2188 and 2189 in Chester and Lebanon Townships, Meigs County, went through minable thicknesses of the Redstone coal (pl. 4). These two occurrences are within the mapped deep reserve area of the Pomeroy Field (DeLong, 1955). Chemical analyses for the two samples of Redstone coal are given in table 9 and graphic sections are shown on figure 8.

Pittsburgh (No. 8) coal

The Pittsburgh coal, which ranks first in current tonnage production, was found in minable thickness in core 2175, Malaga Township, Monroe County, and coal of near-minable thickness was encountered in core 2173, Jackson Township, Monroe County. The Pittsburgh coal in this region is part of the well-documented Belmont Field (DeLong, 1955), which has long been the most important coal field of the State.

POTENTIAL NEW RESERVE AREAS

General statement

Possible interpretations of the areas underlain by coal with seam thickness in the categories 14 to 28, 28 to 42, 42 to 54, 54 to 66, 66 to 78, 78 to 90, and 90 inches or more are shown in figures 9 through 15. It should be noted that these figures represent only one possible interpretation; much additional drilling will be required to substantiate the possibilities suggested. It should be noted also that figures 9 through 15 are intended to be a guide to further exploration; the possibility that substantial pockets of coal were missed because of the low drilling density cannot be overlooked. This is particularly important in those areas where coals slightly below mining thickness may be extensions from thicker pockets.

Data gathered during this study strongly suggest the presence of significant reserves of both the Middle

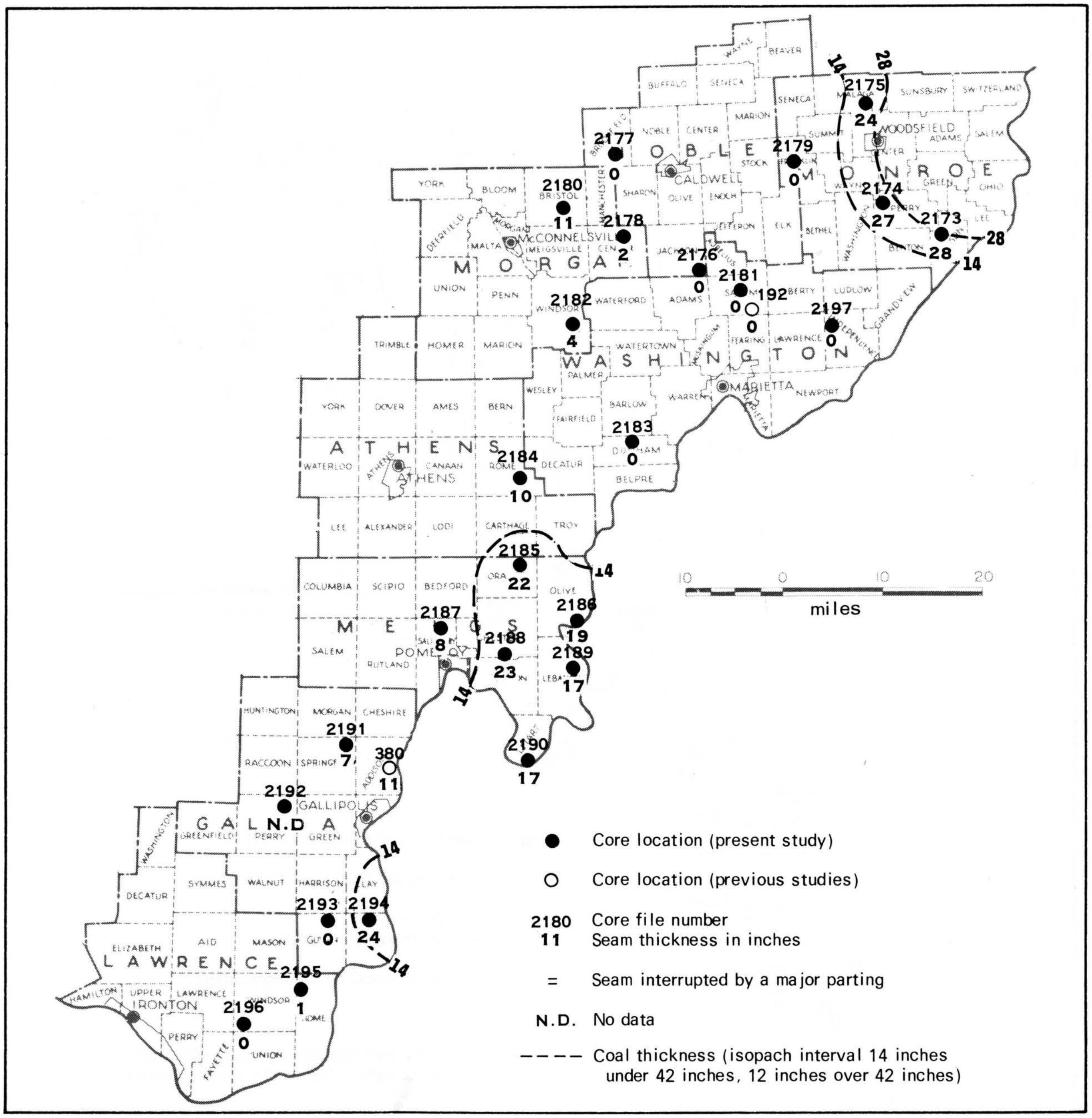

FIGURE 9.—Thickness and interpreted distribution of Mahoning (No. 7A) coal.

and Lower Kittanning (figs. 12 and 13) coals in Monroe, Noble, and Washington Counties. Thicknesses recorded for the Bedford (fig. 15) in the same counties suggest somewhat less strongly that minable reserves of this coal may also be present in the area. Occurrences of the Brookville (fig. 14) of minable thickness were observed in both Noble and Monroe Counties. Forty-one inches of Brookville was observed at one location in Morgan County.

Coal-seam thicknesses in the 28- to 42-inch category were also recorded for each of the seams listed above as well as for the Mahoning and Lower Freeport, and for two undesignated coals lying about 25 feet and 194 feet, respectively, below the Bedford.

A composite map (fig. 16) showing areas having the greatest prospect potential was made by overlaying the interpreted distribution maps for the Middle Kittanning, Lower Kittanning, Brookville, and Bedford coals. The overlapping of the inferred areas of minable beds suggests a small area which could have all four coals.

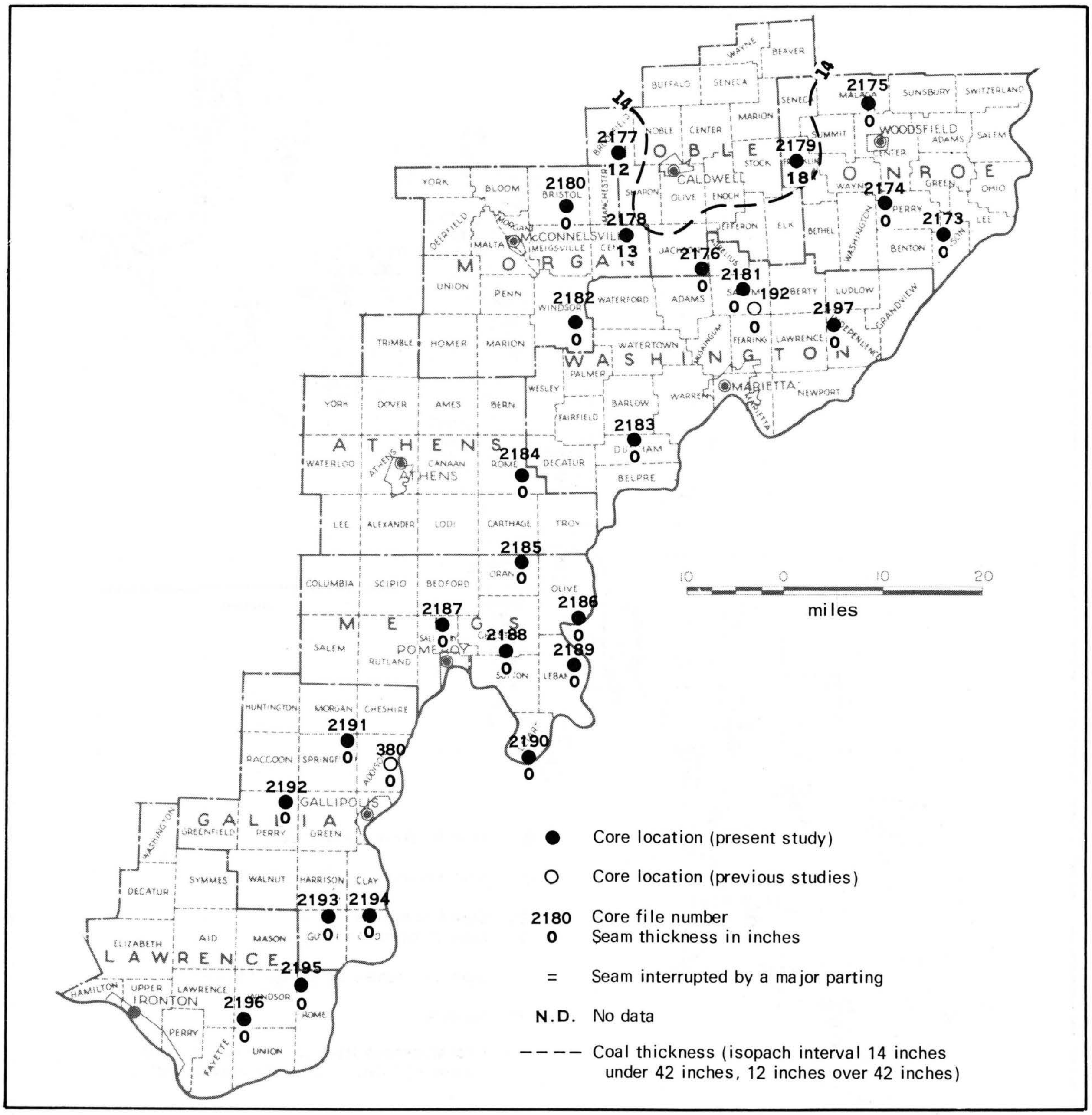

FIGURE 10.—Thickness and interpreted distribution of Upper Freeport (No. 7) coal.

Although no single core revealed all four seams of minable thickness, these coals may all have reserve potential in the area centering on Noble and parts of adjacent counties. Seven of the nine cores which penetrated coals of minable thickness are found in the area outlined on figure 16. Two cores with minable Redstone (Pomeroy) coal are located in Meigs County and were not included on figure 16 since the distribution of that coal has been previously mapped (DeLong, 1955).

Taking into account the limitations of the data and the interpretations as mentioned above, the following discussion by individual bed is presented:

Mahoning (No. 7A) coal

Nowhere in the study area did coal in the stratigraphic position of the Mahoning approach minable thickness (fig. 9). Although data are sparse it is believed that this coal has little reserve potential in the study area.

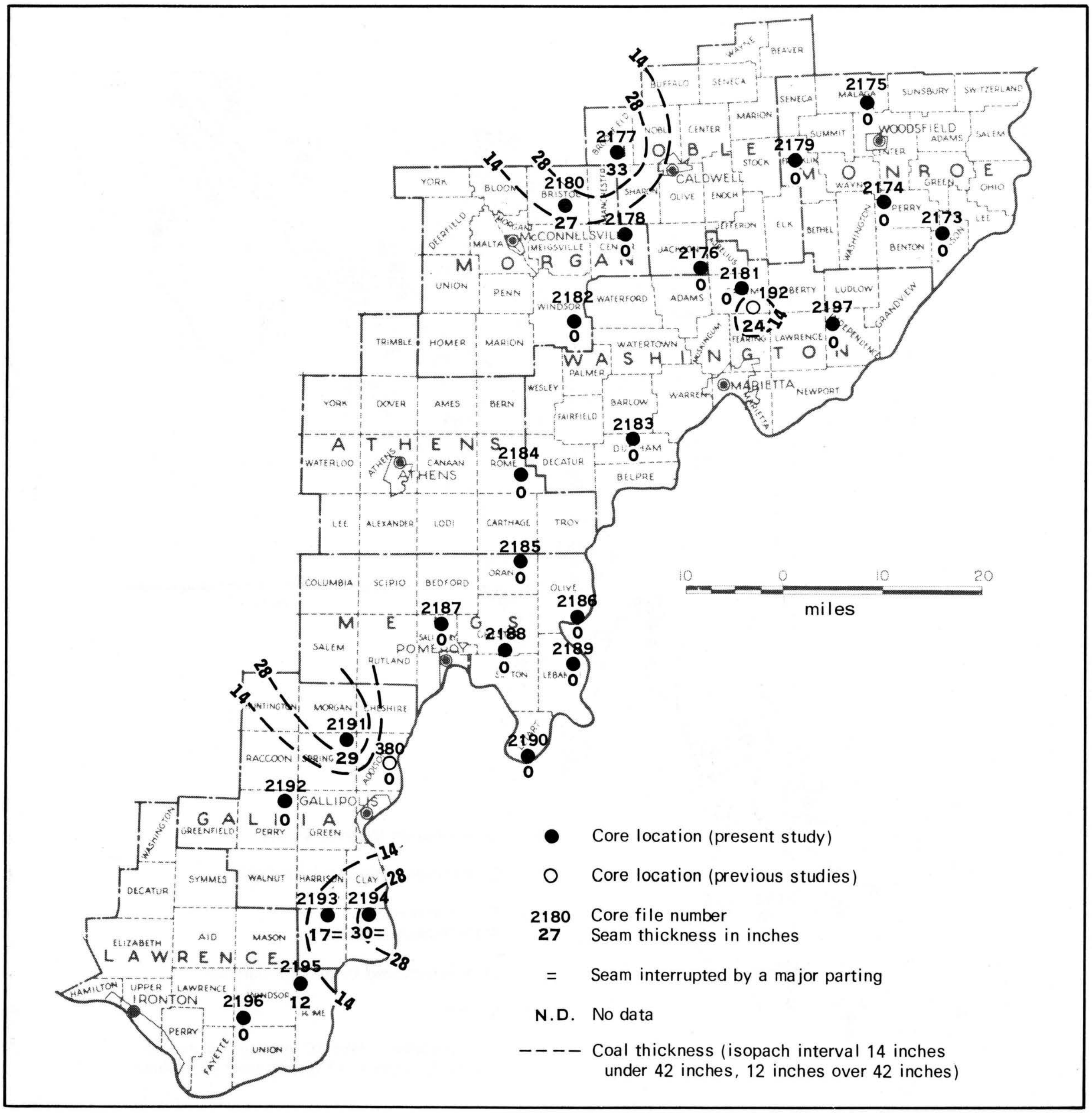

FIGURE 11.—Thickness and interpreted distribution of Lower Freeport (No. 6A) coal.

Upper Freeport (No. 7) coal

The Upper Freeport coal was rather conspicuous by its absence in nearly all of the cores drilled (fig. 10). The suggested area of over 14-inch coal centered on Noble County seems to be an extension from the once important Cambridge Field a few miles to the northwest. Much low- to medium-low-sulfur coal was formerly produced from the Cambridge Field and additional exploration in the area between the main field and the 14-inch isopach suggested on figure 10 may be in order.

Lower Freeport (No. 6A) coal

No Lower Freeport coal of minable thickness was recorded in the study area (fig. 11). The two occurrences of over 28-inch coal in Gallia and Noble Counties apparently represent localized areas of accumulation; additional drilling will be required to determine if thicker coal can be found adjacent to these sites.

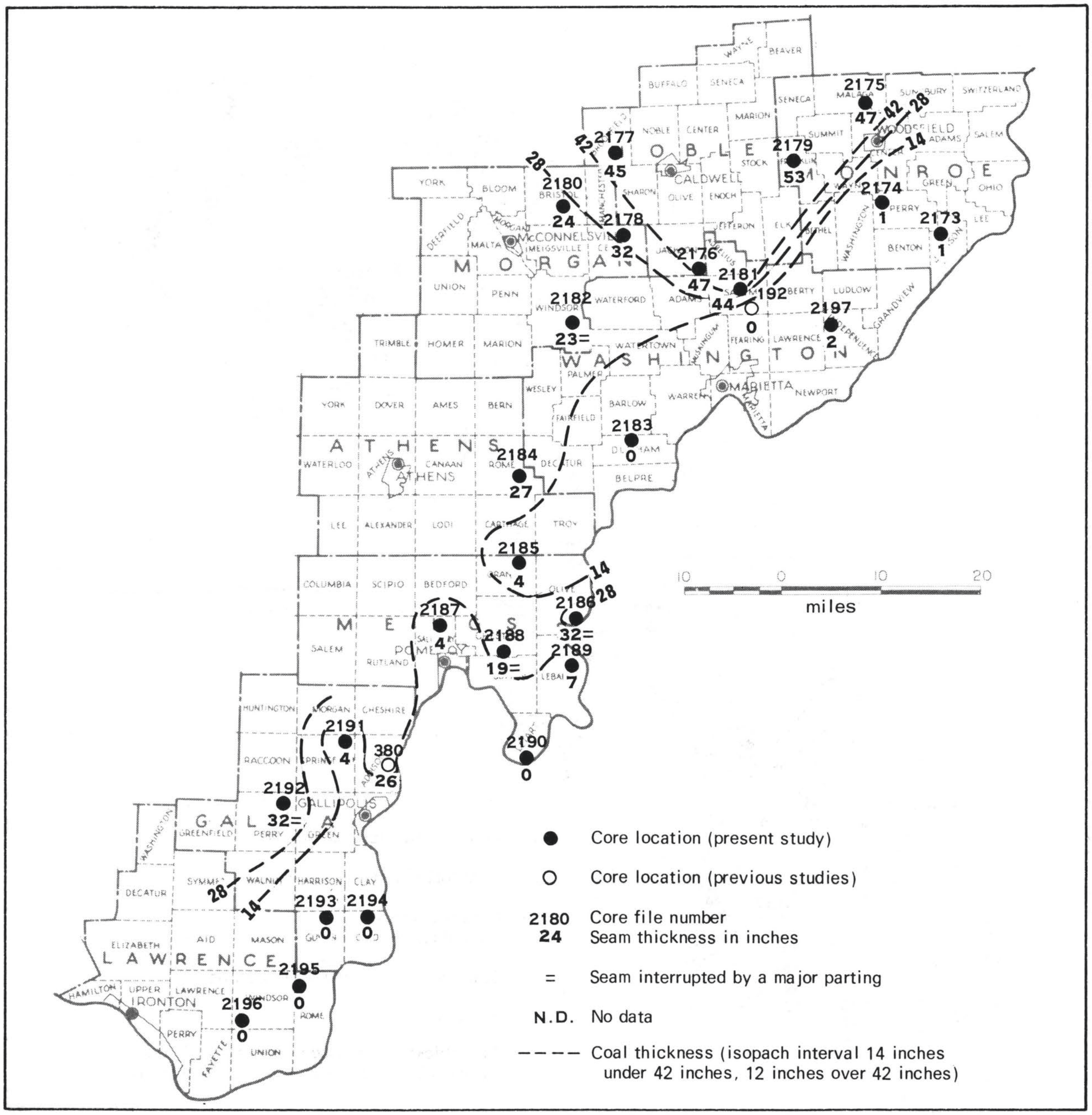

FIGURE 12.—Thickness and interpreted distribution of Middle Kittanning (No. 6) coal.

Middle Kittanning (No. 6) coal

Of all the coals investigated the Middle Kittanning (fig. 12) holds the greatest potential for new and significant reserves. There is a strong possibility that substantial portions of western Monroe, north-central Washington, and all of Noble Counties are underlain by minable Middle Kittanning coal. By projection it would seem reasonable that a large portion of western Belmont and southern and eastern Guernsey Counties could also be underlain by this coal. If this interpretation proves correct, a very substantial tonnage can be added to the coal resources of the State.

Minable Middle Kittanning coal is known to occur on the crop and in a few cases some distance down dip into the deeper portion of the basin in Athens, Gallia, Lawrence, and Morgan Counties. Because of the existence of a fairly substantial body of information on the coal in these areas, cores were located only along the eastern edges of these counties.

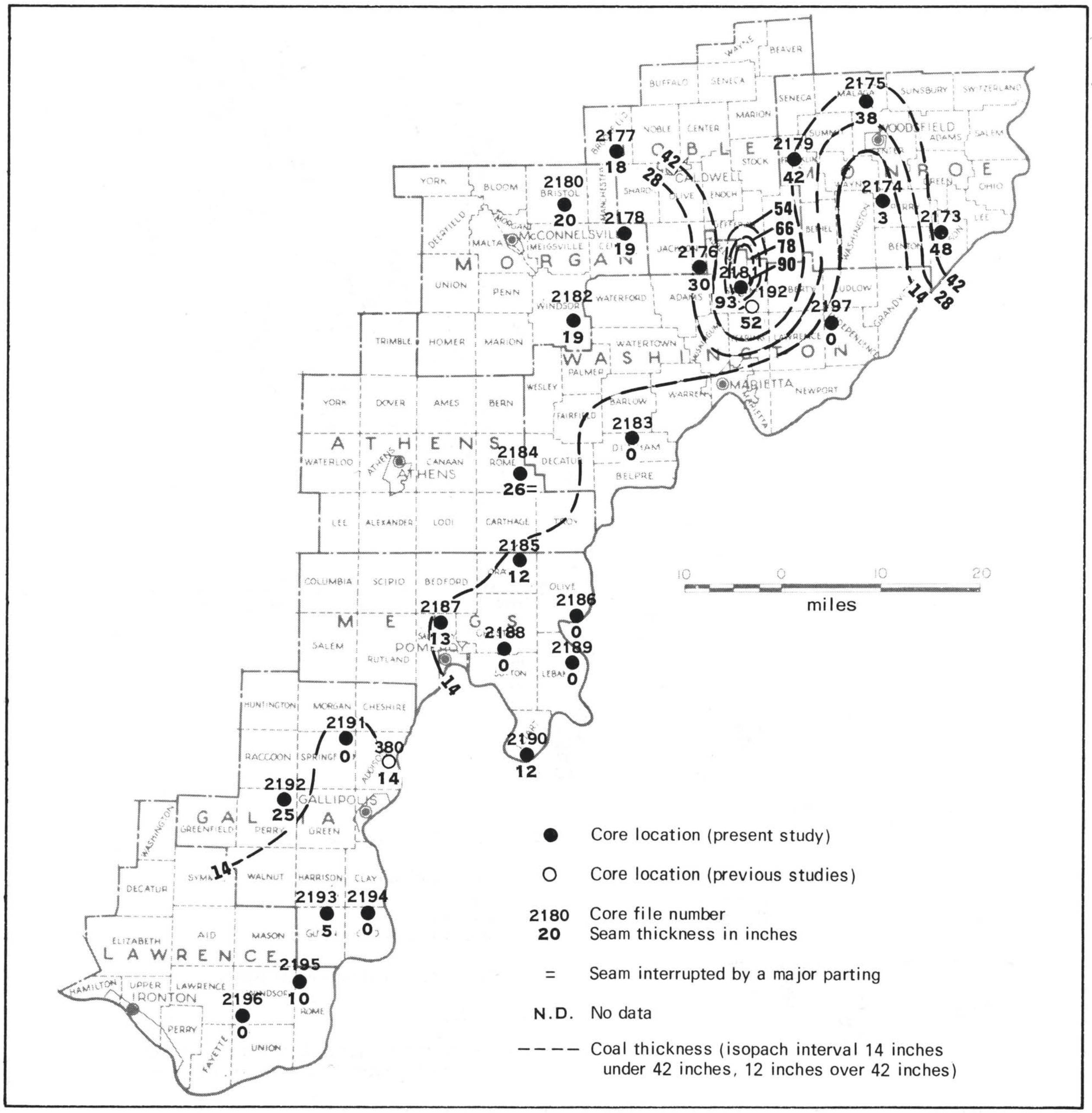

FIGURE 13.—Thickness and interpreted distribution of Lower Kittanning (No. 5) coal.

The 27 inches of this coal in Rome Township, Athens County (core 2184), may be an eastward extension of the Canaanville Field, located in Canaan Township just to the west. Middle Kittanning coal of minable thickness is present in reserve quantities in the Canaanville Field; exploration in the area of Canaan, Carthage, Lodi, and Rome Townships would seem to offer a good possibility for finding additional reserves.

Lower Kittanning (No. 5) coal

Ninety-three inches of coal correlated with the Lower Kittanning was found in Salem Township, Washington County (core 2181, fig. 13). This was the thickest coal encountered during the study. Bownocker and Dean (1930, p. 72) reported that two test wells drilled in the same vicinity had penetrated 5 feet 8 inches and 4 feet 5½ inches of coal which they correlated with the Middle Kittanning. The record of only the latter of these tests is extant (core 192) and, based upon the log of this hole, the present authors disagreed with Bownocker and Dean and assigned a tentative correlation of Lower Kittanning to the thick (52-inch) coal

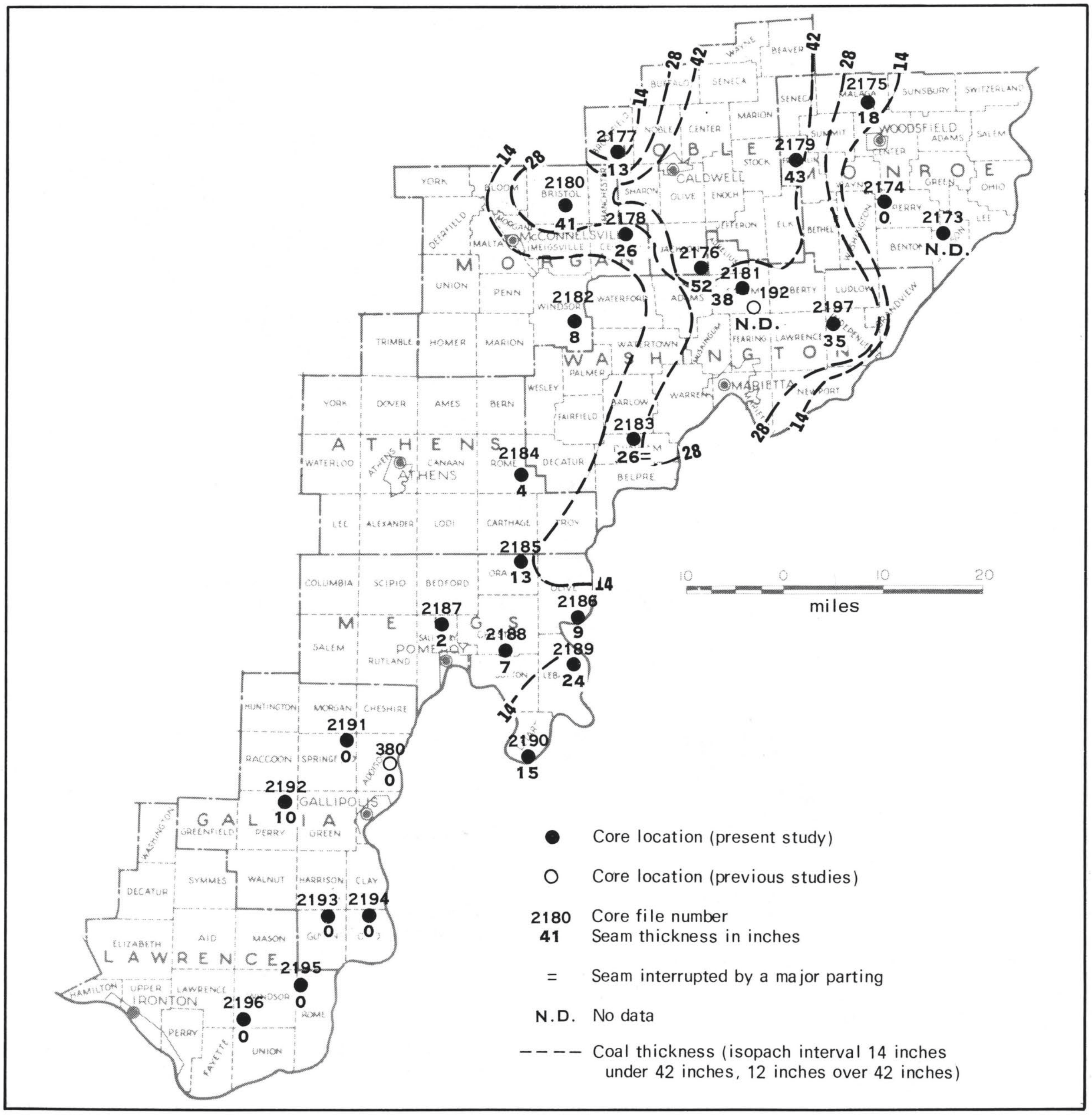

FIGURE 14.—Thickness and interpreted distribution of Brookville (No. 4) coal.

recorded in their log.

The potential area of minable coal (fig. 13) appears to be centered along a line extending from western Monroe to north-central Washington County. Coal of minable or near-minable thickness in eastern and northern Monroe County (cores 2173 and 2175) seems to offer a strong suggestion that important quantities of coal could be present in these areas. Further drilling will be needed to resolve this possibility.

Clarion (No. 4A) coal

Coal of minable or near-minable thickness was not encountered in the position of the Clarion coal except possibly in core 2190, Letart Township, Meigs County (pl. 4). In this core the two benches of coal lying just above the unit correlated as the Brookville may represent the Clarion. A large body of thick coal which has been correlated with the Clarion is known to occur

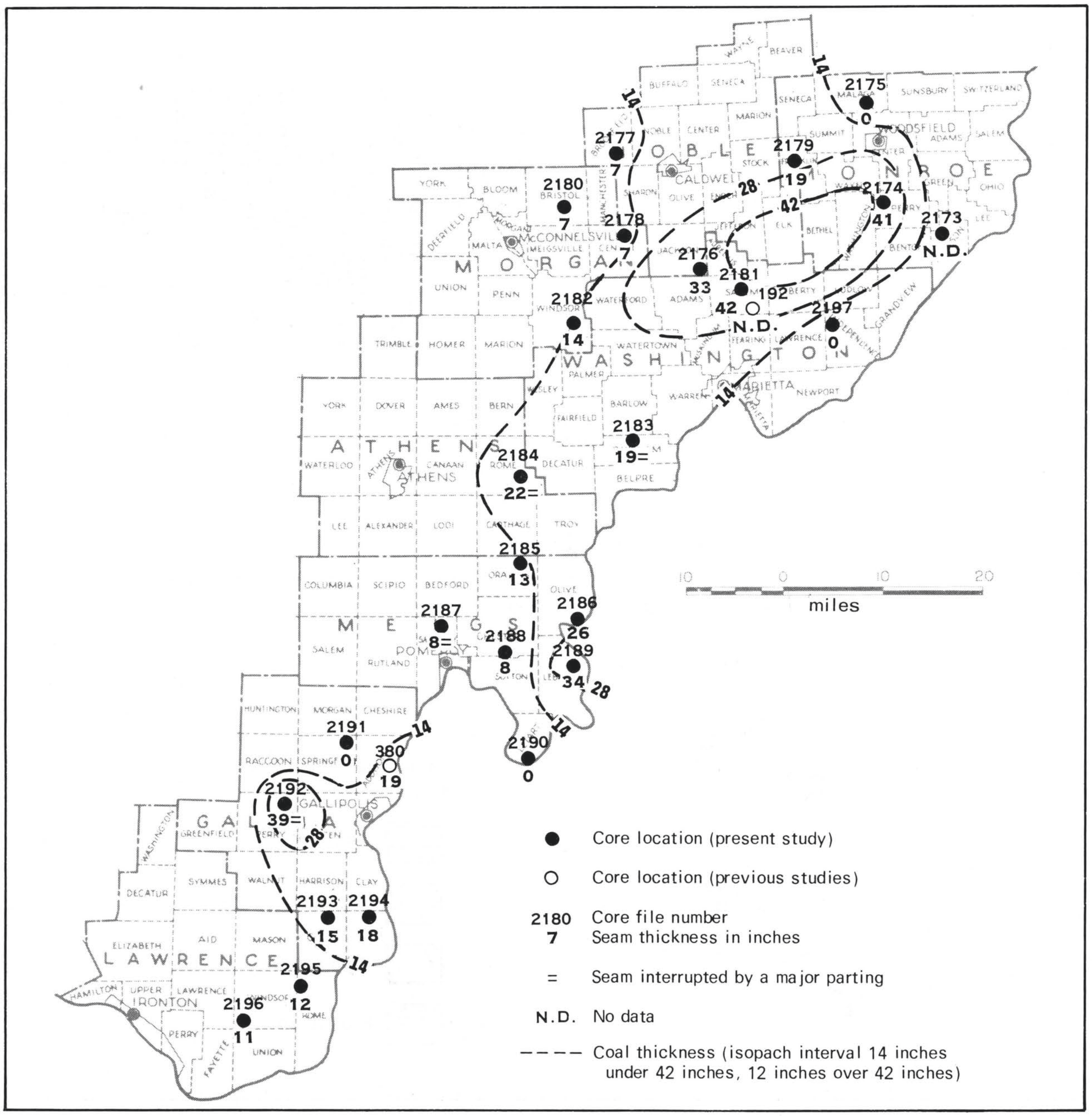

FIGURE 15.—Thickness and interpreted distribution of Bedford coal.

roughly west of a line drawn between core 2191 in Springfield Township, Gallia County, and core 2187 in Salisbury Township, Meigs County. In keeping with the original plan to develop the maximum amount of new data, no cores were located in this area. However, the possibility that this field extends eastward to include the occurrence in Letart Township cannot be overlooked and southeasternmost Meigs County should merit consideration as a prospect area.

Brookville (No. 4) coal

Coal in the position of the Brookville was found in most cores. It was present in minable or near-minable thickness in an area encompassing eastern Morgan, southern Noble, north-central Washington, and western Monroe Counties (fig. 14), suggesting that a substantial body of minable coal may be present in an area centered on Noble County.

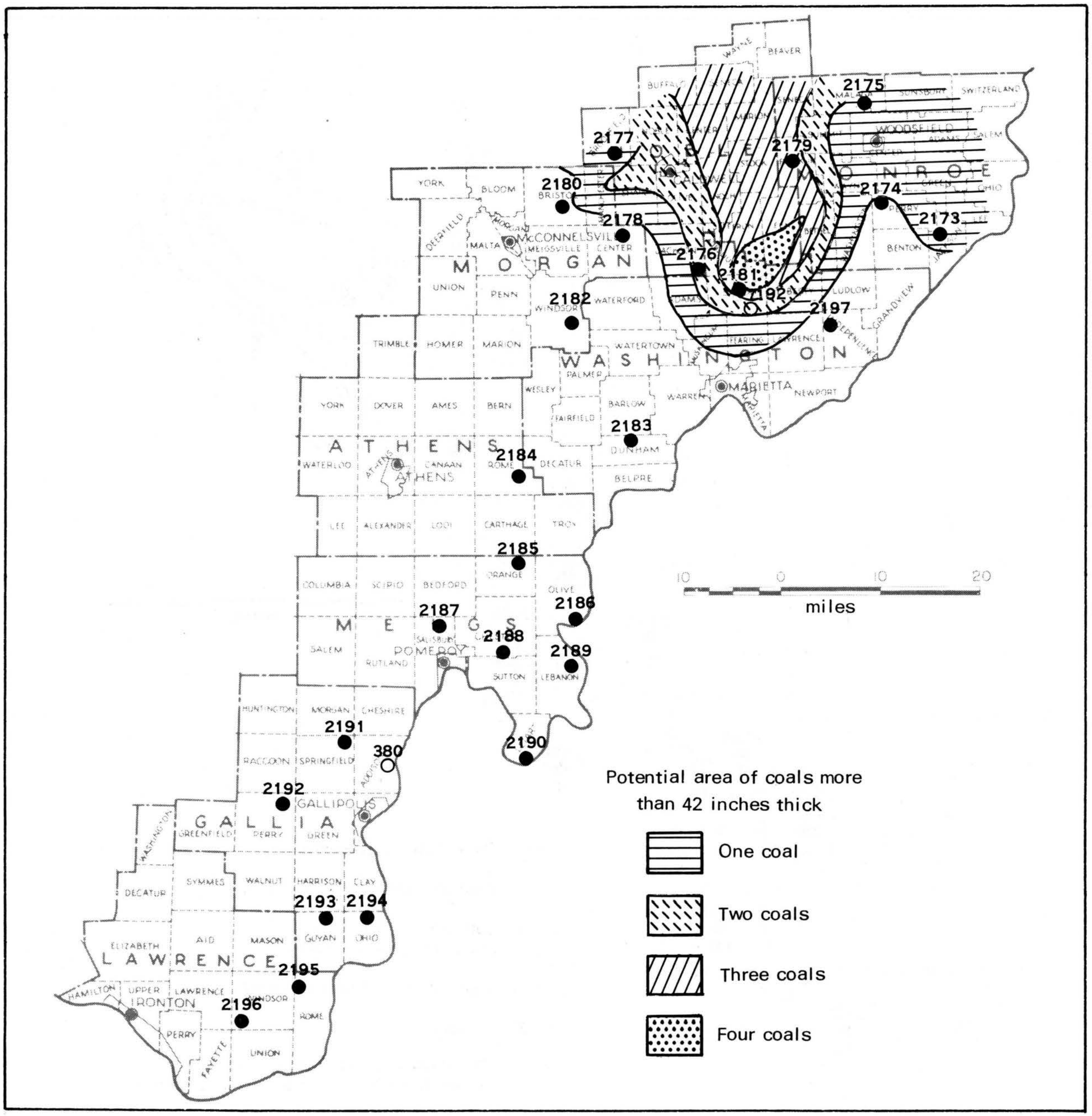

FIGURE 16.—Map of prospect potential.

Bedford coal

Coal in the position of the Bedford is present at or near minable thickness in western Monroe, eastern Noble, and northern Washington Counties (fig. 15) and this area offers relatively high potential for the discovery of significant new reserves. Other areas suggesting some potential are eastern Meigs and western Gallia Counties in the vicinities of cores 2189 and 2192, respectively.

Undesignated Pottsville coals

Two coal beds greater than 28 inches thick were observed below the Bedford coal in Gallia and Lawrence Counties. At a depth of 688 feet in core 2195, Rome Township, Lawrence County, a 34½-inch coal was encountered 194 feet below the Bedford (pl. 4). A second coal 38½ inches thick was found in Guyan Township, Gallia County, 25 feet below the Bedford at a depth of 657 feet in core 2193 (pl. 4).

These thicknesses, although not minable, may indicate potential minable reserves in the southwestern Gallia-northeastern Lawrence Counties area.

CONCLUSIONS

Although no new low-sulfur coal reserves can be postulated from the findings of this study, a significant amount of important information has been obtained.

First, and perhaps most important, data developed during the study strongly indicate that substantial new and previously unreported reserves of deep coal, albeit not low-sulfur, are probably present under large portions of Monroe, Noble, Meigs, and Washington Counties (figs. 9 through 15). It is highly probable also that portions of Belmont and Guernsey Counties are similarly underlain. However, much additional drilling will be required to substantiate this interpretation and to develop the area if this projection is found to be essentially correct.

The authors believe that, considering the staggering and continually growing demands for energy and the fact that the release of SO_2 can ultimately be controlled by means other than that of burning low-sulfur coal, the most important contribution of this study is the location of potential new deep-mine coal resources.

Second, the investigation has contributed more basic data to the fund of information and to the ultimate understanding of the subsurface geology of the Pennsylvanian system in Ohio than any study to date. Information developed and samples collected during the program are of the greatest scientific value and will provide the basis for future research into the economic, paleontologic, petrographic, and stratigraphic aspects of these rocks. Some such studies are now being undertaken using these data as a nucleus and others are planned for the near future.

Last, although no low-sulfur coal was found, its occurrence in pockets smaller than could be detected by the drilling density used cannot be ignored. Low-sulfur coal areas in formerly active mining regions were of a size and areal extent that could escape detection with the drilling spacing used in the present coring program. An effort was made by the Division of Geological Survey to investigate this possibility in the high probability areas (fig. 16); however, funds were not available for this check.

Considering the number of holes drilled for this project without finding low-sulfur coal and given depositional conditions essentially similar to those responsible for the formation of other Ohio coals, the probability of finding significant quantities of low-sulfur coal in the deep portion of the Ohio basin does not seem to be good. It would seem to the authors that, at least from the Ohio point of view, major emphasis should be placed on developing and perfecting methods of lowering SO_2 emission from fossil-fuel-burning plants rather than on additional search for low-sulfur coal.

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A
A′
PLATE 1
NORTH-SOUTH CROSS SECTION
DATUM: MIDDLE KITTANNING (NO. 6) COAL
LINE OF SECTION SHOWN IN FIGURE 2
CORE 380 IS A NON-PROJECT CORE ON FILE WITH THE OHIO DIVISION OF GEOLOGICAL SURVEY
MONONGAHELA
CONEMAUGH
ALLEGHENY
POTTSVILLE
MISSISSIPPIAN
DEPTH (FT)
TENTATIVE CORRELATION
FIELD IDENTIFICATION NO. OF COAL
THICKNESS
CHEMICAL ANALYSIS NO.
LOWER FREEPORT
B8-A(29") C.A. 714
MARINE FAUNA IN SILTSTONE
MARINE FAUNA IN SHALE
MARINE FAUNA IN LIMESTONE
COAL THICKNESS (IN)
<14
14-28
28-42
42-54
54-66
66-78
79-90
>90
none present
miles
feet
O.G.S. 2196 NE¼SW¼NE¼ SEC. 30 WINDSOR TWP., LAWRENCE CO. ELEV. 560+ TOPO.
O.G.S. 2195 SE¼SE¼SW¼ SEC. 35 ROME TWP., LAWRENCE CO. ELEV. 600+ TOPO.
O.G.S. 2193 NE¼SE¼SW¼ SEC. 18 GUYAN TWP., GALLIA CO. ELEV. 680+ TOPO.
O.G.S. 380 SW¼NE¼ SEC. 15 ADDISON TWP., GALLIA CO. ELEV. 550+ TOPO.
O.G.S. 2187 NW¼NW¼NW¼ SEC. 18 SALISBURY TWP., MEIGS CO. ELEV. 670+ TOPO.
O.G.S. 2185 SW¼NW¼SW¼ SEC. 18 ORANGE TWP., MEIGS CO. ELEV. 620+ TOPO.
O.G.S. 2184 NW¼NE¼SW¼ SEC. 3 ROME TWP., ATHENS CO. ELEV. 580+ TOPO.
O.G.S. 2182 N½ LOT 40 BIG BOTTOM ALLOTMENT WINDSOR TWP., MORGAN CO. ELEV. 640+ TOPO.
O.G.S. 2176 SW¼NE¼NW¼ SEC. 35 JACKSON TWP., NOBLE CO. ELEV. 750+ TOPO.
O.G.S. 2179 SW¼NW¼NE¼ SEC. 16 FRANKLIN TWP., MONROE CO. ELEV. 950+ TOPO.
O.G.S. 2175 NE¼SW¼NE¼ SEC. 3 MALAGA TWP., MONROE CO. ELEV. 1030+ TOPO.
MAHONING (NO. 7A)
LOWER FREEPORT (NO. 6A)
RED-GRAY BOUNDARY
MIDDLE KITTANNING (NO. 6)
LOWER KITTANNING (NO. 5)
BROOKVILLE (NO. 4)
BEDFORD
MAXVILLE
PITTSBURGH (NO. 8)
UPPER FREEPORT (NO. 7)
UNIONTOWN (NO. 10)
MEIGS CREEK (NO. 9)
T.D. 701'
T.D. 950'
T.D. 927'
T.D. 961'
T.D. 977'
T.D. 973'
T.D. 925'
T.D. 955'
T.D. 884'7"
T.D. 852'
T.D. 1199'

PLATE 2
NORTHWEST-SOUTHEAST CROSS SECTION

DATUM: MIDDLE KITTANNING (NO. 6) COAL
LINE OF SECTION SHOWN IN FIGURE 2
CORE 769 AND STRATIGRAPHIC SECTIONS 807 AND 831 ARE NON-PROJECT RECORDS ON FILE WITH THE OHIO DIVISION OF GEOLOGICAL SURVEY

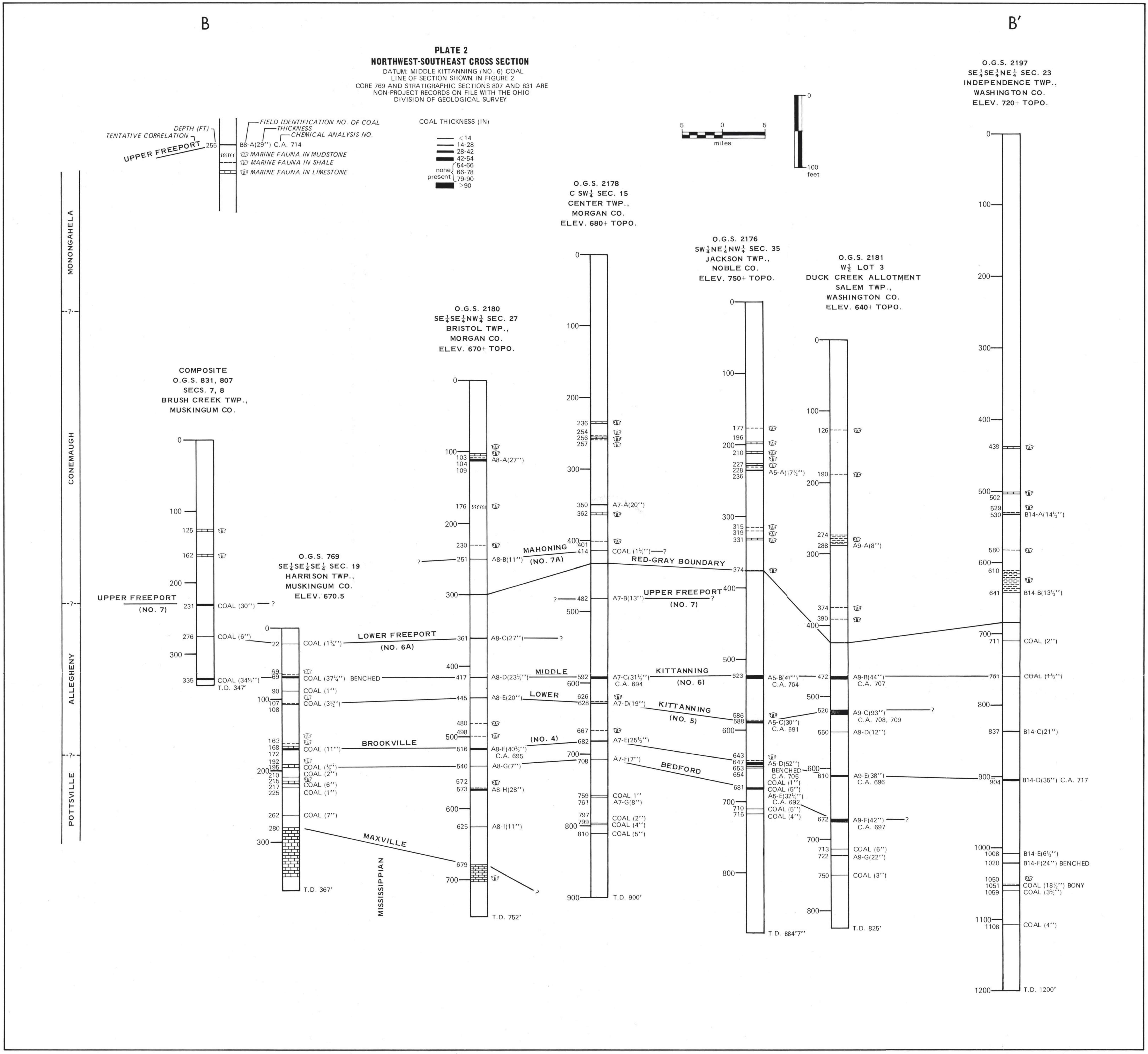

PLATE 3
COLUMNAR SECTIONS OF CORES IN MORGAN, NOBLE, MONROE, AND WASHINGTON COUNTIES
DATUM: MIDDLE KITTANNING (NO. 6) COAL


PLATE 4
COLUMNAR SECTIONS OF CORES IN ATHENS, MEIGS, GALLIA, AND LAWRENCE COUNTIES
DATUM: MIDDLE KITTANNING (NO. 6) COAL
ATHENS COUNTY
MEIGS COUNTY
GALLIA COUNTY
LAWRENCE COUNTY
MONONGAHELA
CONEMAUGH
ALLEGHENY
POTTSVILLE
O.G.S. 2184 NW¼NE¼SW¼ SEC. 3 ROME TWP., ATHENS CO. ELEV. 580± TOPO.
O.G.S. 2187 NW¼NW¼NW¼ SEC. 18 SALISBURY TWP., MEIGS CO. ELEV. 670± TOPO.
O.G.S. 2188 NE¼ FRACTION 30 CHESTER TWP., MEIGS CO. ELEV. 600± TOPO.
O.G.S. 2185 SW¼NW¼NW¼ SEC. 18 ORANGE TWP., MEIGS CO. ELEV. 620± TOPO.
O.G.S. 2190 N½ LOT 234 LETART TWP., MEIGS CO. ELEV. 580± TOPO.
O.G.S. 2189 SW¼NE¼NW¼ SEC. 23 LEBANON TWP., MEIGS CO. ELEV. 580± TOPO.
O.G.S. 2186 NE¼ LOT 124 OLIVE TWP., MEIGS CO. ELEV. 570± TOPO.
O.G.S. 2192 SE¼NE¼NE¼ SEC. 13 PERRY TWP., GALLIA CO. ELEV. 580± TOPO.
O.G.S. 2193 NE¼SE¼SW¼ SEC. 18 GUYAN TWP., GALLIA CO. ELEV. 680± TOPO.
O.G.S. 2191 SE¼SW¼SE¼ SEC. 12 SPRINGFIELD TWP., GALLIA CO. ELEV. 580± TOPO.
O.G.S. 2194 SE¼SE¼SW¼ SEC. 30 OHIO TWP., GALLIA CO. ELEV. 600± TOPO.
O.G.S. 2196 NE¼SW¼NE¼ SEC. 30 WINDSOR TWP., LAWRENCE CO. ELEV. 560± TOPO.
O.G.S. 2195 SE¼SE¼SE¼ SEC. 35 ROME TWP., LAWRENCE CO. ELEV. 600± TOPO.
REDSTONE (NO. 8A) (POMEROY)
MAHONING (NO. 7A)
RED-GRAY BOUNDARY
LOWER FREEPORT (NO. 6A)
MIDDLE KITTANNING (NO. 6)
LOWER KITTANNING (NO. 5)
BROOKVILLE (NO. 4)
BEDFORD
DEPTH (FT)
TENTATIVE CORRELATION
FIELD IDENTIFICATION NO. OF COAL
THICKNESS
CHEMICAL ANALYSIS NO.
MARINE FAUNA IN SANDSTONE
MARINE FAUNA IN SHALE
MARINE FAUNA IN LIMESTONE
COAL THICKNESS (IN)
CORING LOCATIONS