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Geology, Mining, and Methane Content of the Freeport and Kittanning Coalbeds in Indiana and Surrounding Counties, Pa.

By D. G. Puglio and A. T. Iannacchione

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGY, MINING, AND METHANE CONTENT OF THE FREEPORT AND KITTANNING COALBEDS IN INDIANA AND SURROUNDING COUNTIES, PA.

by

D. G. Puglio [1] and A. T. Iannacchione [2]

ABSTRACT

This Bureau of Mines study covers 25 underground mines that were active in the Upper and Lower Freeport and Lower Kittanning coalbeds in 1976. The coal ranges from low to medium volatile in rank; its primary use is for steam generation. Seven mines emit more than 100,000 cfd of methane gas; those mines are the deepest and largest producers.

The methane gas content of three core samples of the Lower Kittanning coalbed was estimated by the direct method. A sample from a depth of 320 feet contained 0.5 cu cm of gas per gram, at 620 feet there was 0.8 cu cm of gas per gram, and at 1,060 feet there was 11 cu cm of gas per gram. These results suggest that methane control problems will be encountered in the future as deeper coal is mined.

INTRODUCTION

This report is one of a series of investigations conducted by the Bureau of Mines to relate the migration and storage of methane in coalbeds to geologic factors and their effect on underground mining. The investigation of the Freeport and Kittanning coalbeds was undertaken to examine (1) areas where methane control problems will be encountered during future mining, (2) orientation of surface joint and coal cleat systems, (3) regional extent and minability of the coalbeds, and (4) variation in the coal measure stratigraphy of the Freeport and Kittanning Formations.

The study area is contained in the Appalachian Plateau physiographic province and is situated in parts of two sections of that province in west-central Pennsylvania--the Allegheny Mountains section to the east, and the Pittsburgh Plateaus section to the west (fig. 1). The 570-square-mile area includes a large portion of Indiana County and smaller portions of Westmoreland and Armstrong Counties. The area has a long commercial coal mining history, dating to the early 19th century, and an active program of surface and underground mining and property development that rivals any comparable area in

[1] Geologist, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, Pa. (now with Michael Baker, Jr., Inc., Consulting Engineers and Surveyors, Beaver, Pa.).
[2] Geologist, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, Pa.

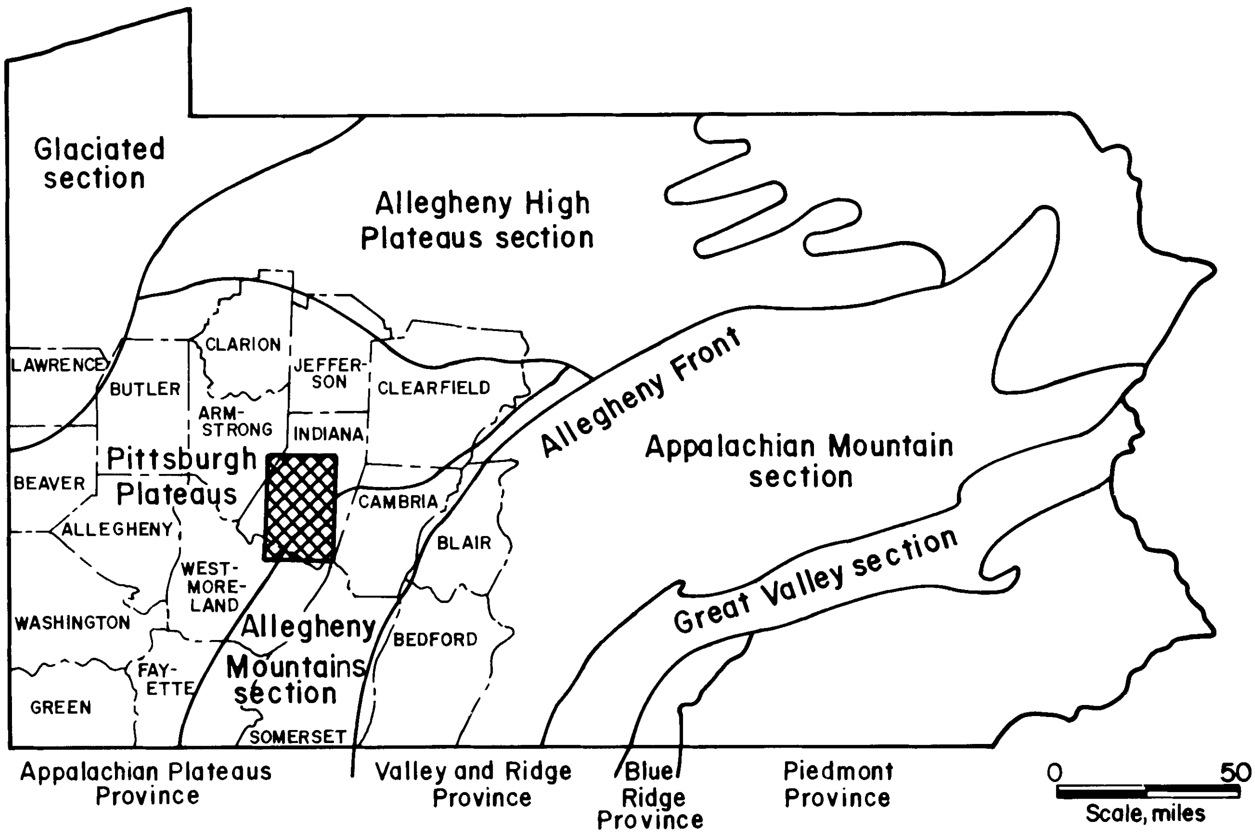

FIGURE 1. - Physiographic location of study area.

the United States. Nine 7' 30" topographic quadrangles further divide the area (fig. 2). Over 800 exploratory core hole logs and gas well logs were employed in the construction of maps and cross sections (fig. 3).

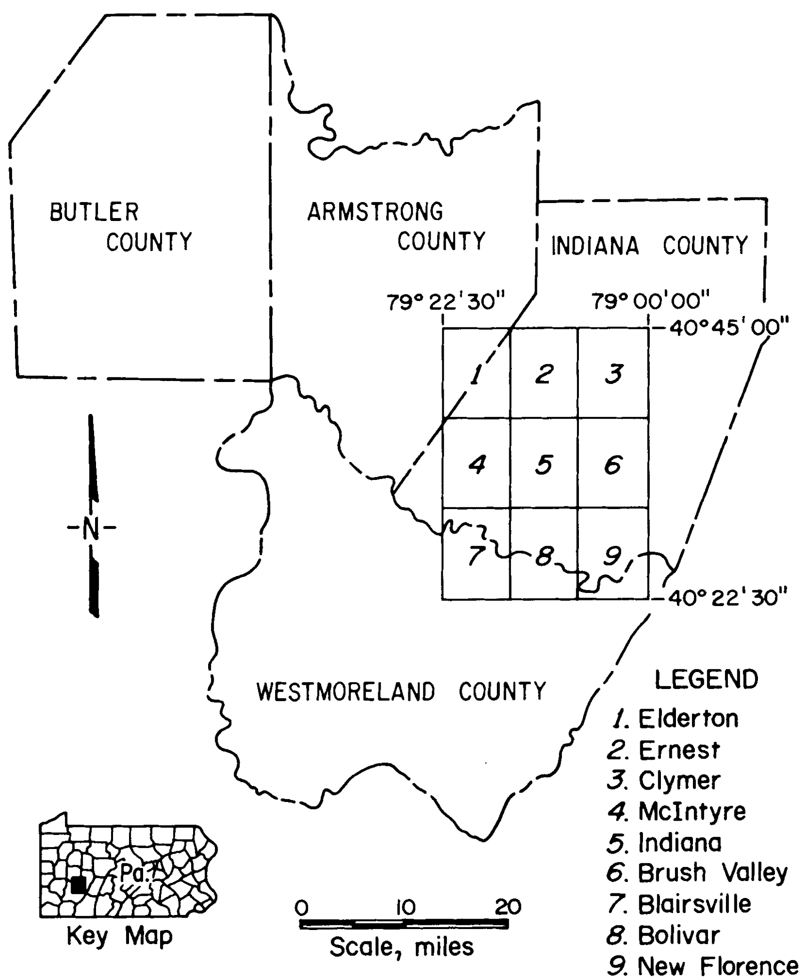

FIGURE 2. - Quadrangles comprising study area.

ACKNOWLEDGEMENTS

The authors thank the following individuals for providing core logs, mine maps, and permission to conduct surface and underground investigations: R. Jubee, D. Shae, and G. Smith of The Rochester and Pittsburgh Coal Co.; R. W. Shank and W. Siplevy of the North American Coal Corp.; G. J. Jones of the Pennsylvania Mines Corp.; G. Kephart (deceased) and K. Mears of the Mears Coal Co.; D. Henigan of the North Cambria Fuel Co.; S. Cortis and T. Alexander of the Pennsylvania Department of Environmental Resources, Bureau of Mine Subsidence; and J. Patton (deceased) of the Equitable Gas Co.

GENERALIZED STRATIGRAPHY

Pennsylvanian System

The rocks exposed at the surface are primarily of Pennsylvanian age, but strata of Mississippian and Devonian age crop out near the Chestnut Ridge anticline, particularly where that structure is breached by the Conemaugh River in the Bolivar quadrangle. Representing an interval between 1,200 and 1,600 feet in thickness, the Pennsylvanian section is divided into four stratigraphic units (fig. 4)(1).[3]

Monongahela Group

Although the Monongahela section is normally 350 to 400 feet thick in its complete development (1), only about 200 feet of it occurs in two synclinal basins in the western quadrangles. The interval from the Pittsburgh coalbed to the Benwood Limestone is preserved in the Latrobe synclinal basin and in the Elders Ridge synclinal basin. The Pittsburgh coalbed has been essentially mined out in these basins.

[3]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

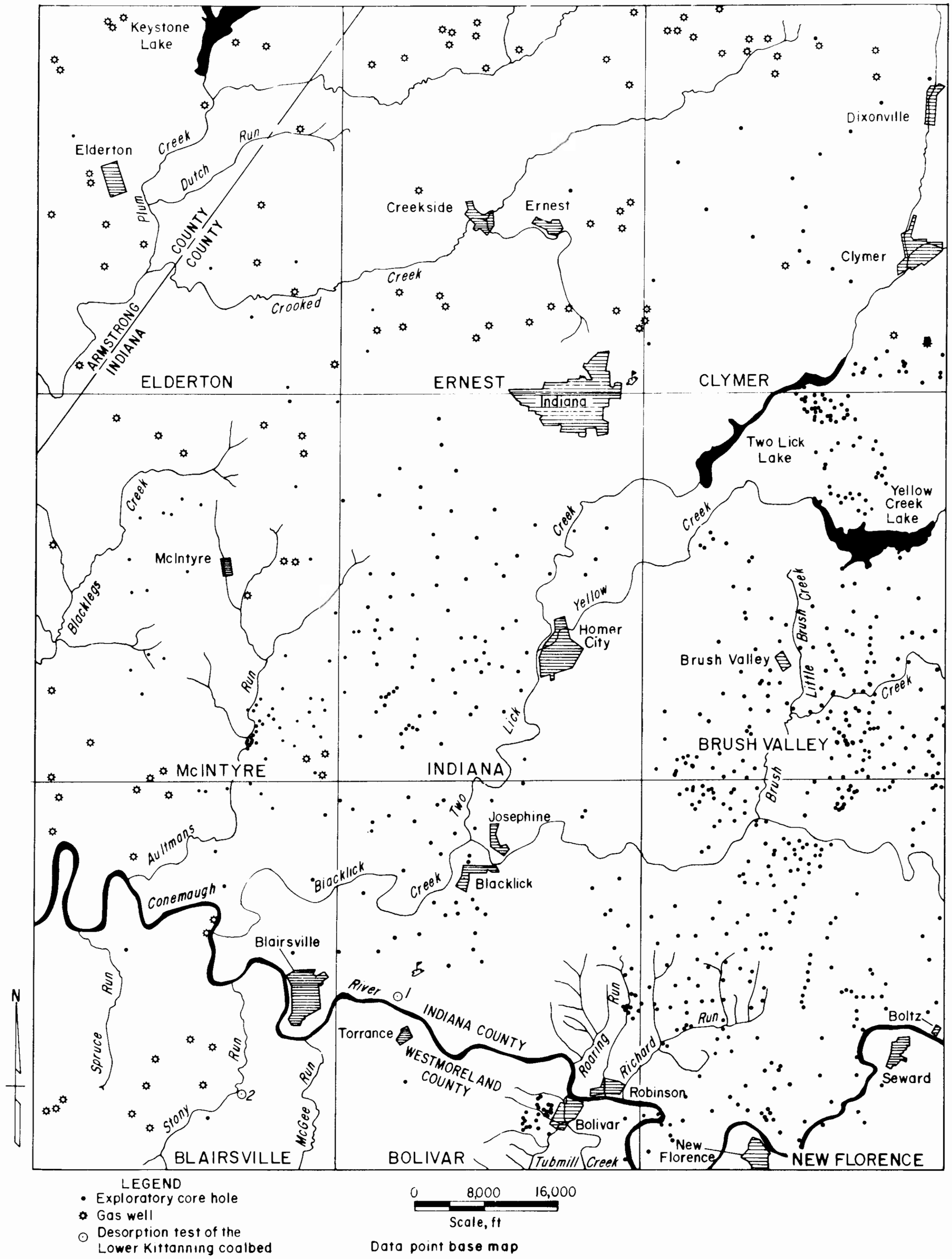

FIGURE 3. - Data-point base map.

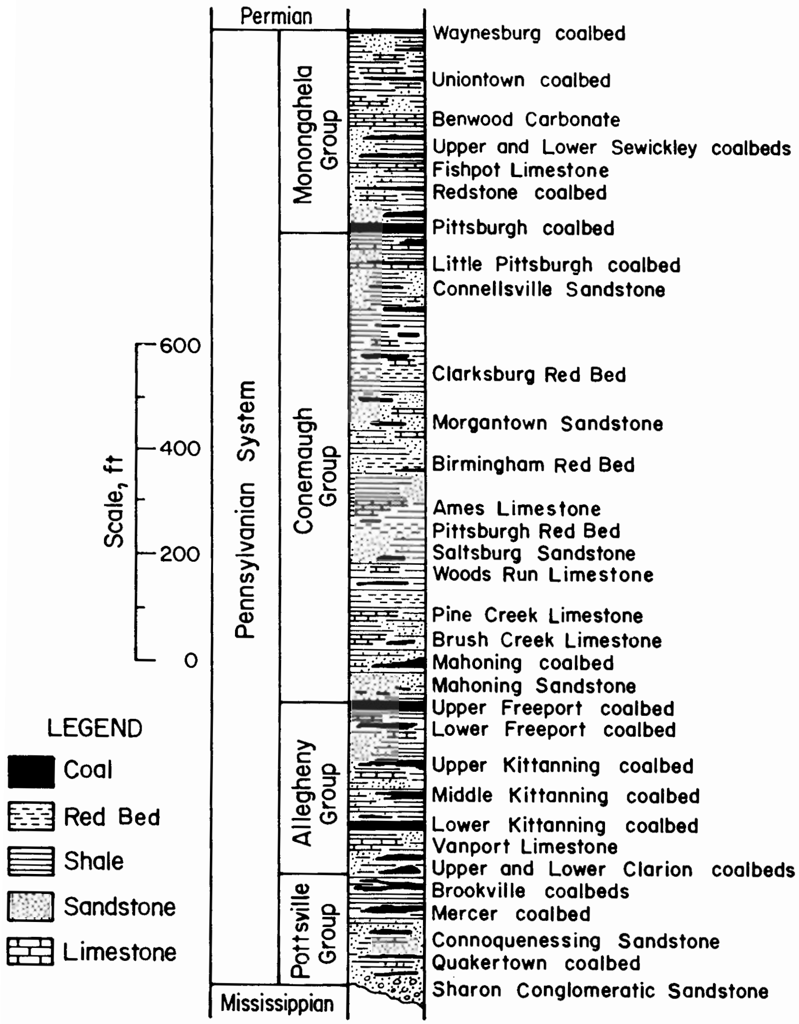

FIGURE 4. - Generalized stratigraphic column of the Pennsylvanian System.

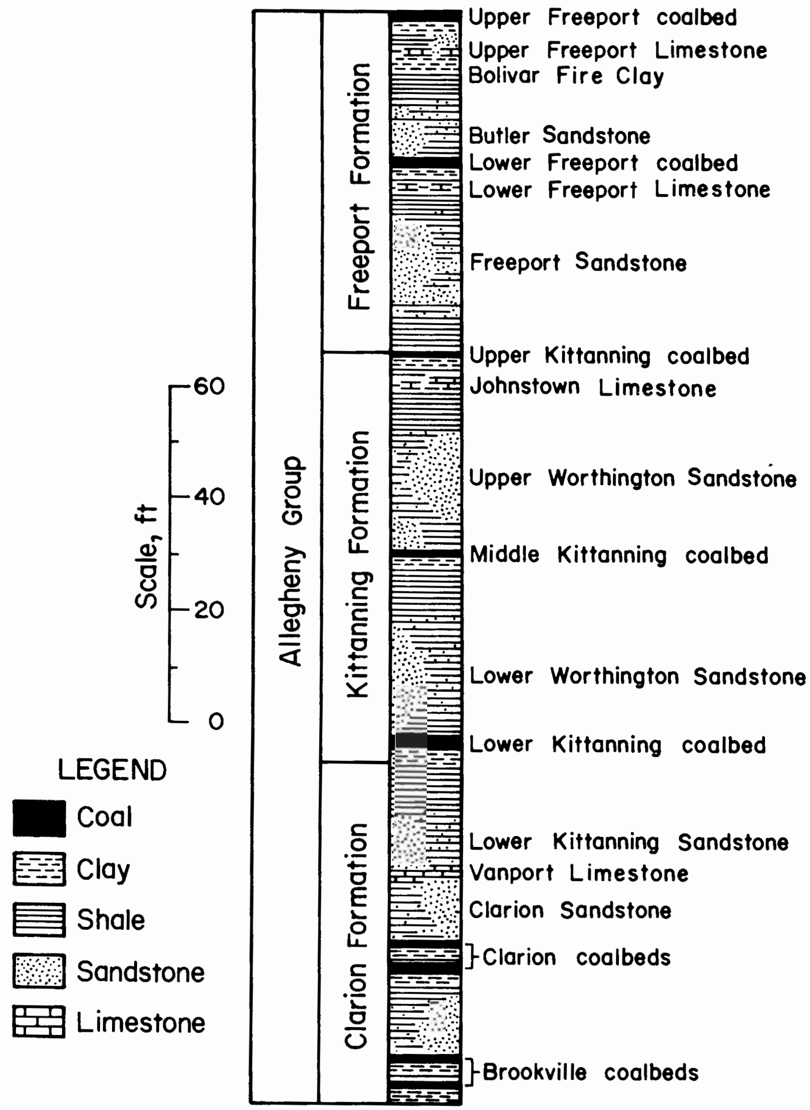

FIGURE 5. - Generalized stratigraphic column of the Allegheny Group.

Conemaugh Group

Most of the section exposed at the surface is of Conemaugh age. The Conemaugh Group, typically from 600 to 900 feet thick (33), occurs between the base of the Pittsburgh coalbed and the top of the Upper Freeport coalbed. The complete Conemaugh section is preserved, generally, only where it is overlain by the incomplete Monongahela section. The coalbeds of Conemaugh age are irregular in thickness and lateral continuity, normally high in ash and sulfur content, and seldom thick enough to mine. None of the Conemaugh coalbeds have been worked on a large scale in the study area. However, two strip mines are presently working the Bakerstown coalbed in the Latrobe synclinal basin to the southwest of the study area in the Latrobe 7' 30" quadrangle.

Allegheny Group

The Allegheny Group occurs between the overlying Conemaugh Group and the underlying Pottsville Group and ranges from 250 to 350 feet in thickness. The upper limit of the Allegheny is marked by the top of the Upper Freeport coalbed, and its lower limit is defined by the base of the Brookville coalbed. The Allegheny is divided into the Freeport, Kittanning, and Clarion Formations (fig. 5). Each division ranges from 85 to 115 feet in thickness, but variations above and below these limits are common. The lithology is generally shale and siltstone, tabular and channel sandstone, coal, claystone, and limestone. The section contains seven, somewhat regionally persistent coalbeds and/or coal groups: Upper and Lower Freeport; Upper, Middle, and Lower Kittanning; Clarion; and Brookville coalbeds. Only the Upper Freeport, Lower Freeport, and Lower Kittanning coalbeds are of economic importance in the study area.

The complete Allegheny section crops out along the flanks of the Chestnut Ridge anticline in the Bolivar, Indiana, Brush Valley, and Clymer quadrangles, and in the Blacklick Creek and Conemaugh River gorges in the New Florence and Bolivar quadrangles. The upper members of the Allegheny section (from the Upper Freeport to the Lower Freeport coalbed horizons) crop out along the flanks of the Jacksonville anticline in the McIntyre quadrangle, and along Plum Creek and its tributaries, Roaring Run and Dutch Run, near the Dutch Run and Roaring Run anticlines in the northern part of the Elderton and Ernest quadrangles.

Pottsville Group

The Pottsville Group is overlain by the Allegheny Group and disconformably underlain by the Mississippian Mauch Chunk Group. The Pottsville section is 150 to 250 feet thick and is divided into two formations--the Mercer and the Connoquenessing. The coalbeds of Pottsville age are seldom thick enough to mine and are of no economic importance in the study area.

STRUCTURAL SETTING

Folding

The strata are folded into relatively open, roughly parallel anticlines and synclines. Trending northeast-southwest, the fold axes are separated by 2 to 5 miles. Flank dips of the structures normally range between 0° and 15° A geologic structure map (fig. 6) drawn on the base of the Lower Kittanning coalbed shows that the axes of five synclines and six anticlines pass through the area.

Structural relief is more pronounced from northwest to southeast. In the Elderton and Ernest quadrangles, the structure is somewhat gentle. The Elders Ridge syncline, plunging to the southwest, becomes a more defined basin from the Ernest quadrangle, where it is somewhat flat and broad, to the northwest corner of the McIntyre quadrangle. The Greensburg syncline and Fayette anticline plunge to the southwest from where they lose their identities near the Conemaugh River in the Blairsville quadrangle to where they enter the area at the southern boundary of the Blairsville quadrangle. The southwest-plunging Latrobe syncline is a deep, troughlike basin where it enters the area at the southern boundary of the Blairsville quadrangle; it gradually rises and flattens out to the northeast and loses its identity just south of the town of Indiana.

The Chestnut Ridge anticline is the most conspicuous flexure; its western limb is steeper both structurally and topographically. The anticline plunges northwest from where it enters the area in the Bolivar quadrangle to about the four-corners area of the Indiana, Brush Valley, Bolivar, and New Florence quadrangles, where it rises to the northeast for about 5 miles in the Brush Valley quadrangle. Just south of where Yellow Creek breaches the anticline, the Chestnut Ridge anticline plunges for another 3 miles to the northeast and begins rising again as it passes out of the area in the southeast corner of the Clymer quadrangle.

Plunging to the northeast and gradually rising to the southwest, the Brush Valley syncline enters the area along the eastern boundary of the Brush Valley quadrangle. It loses its identity as it rises and dies out against the eastern flank of Chestnut Ridge in the northeast corner of the New Florence quadrangle. The southwest-plunging Nolo anticline enters the area at the northeast corner of the New Florence quadrangle, trends northeast-southwest for about 2 miles, and then turns due west for about 2 miles and rises and dies out near Heshbon in the north-central part of the New Florence quadrangle. The Ligonier-Barnesboro syncline plunges to the southwest and gradually rises to the northeast; it is a somewhat broad, flat basin where it passes through the area.

Faulting

Evidence for faulting along the Chestnut Ridge anticline was first reported by Shaffner (33), who cited the occurrence of three separate faults or fault zones. A complex fault zone, inferred from data taken from three gas

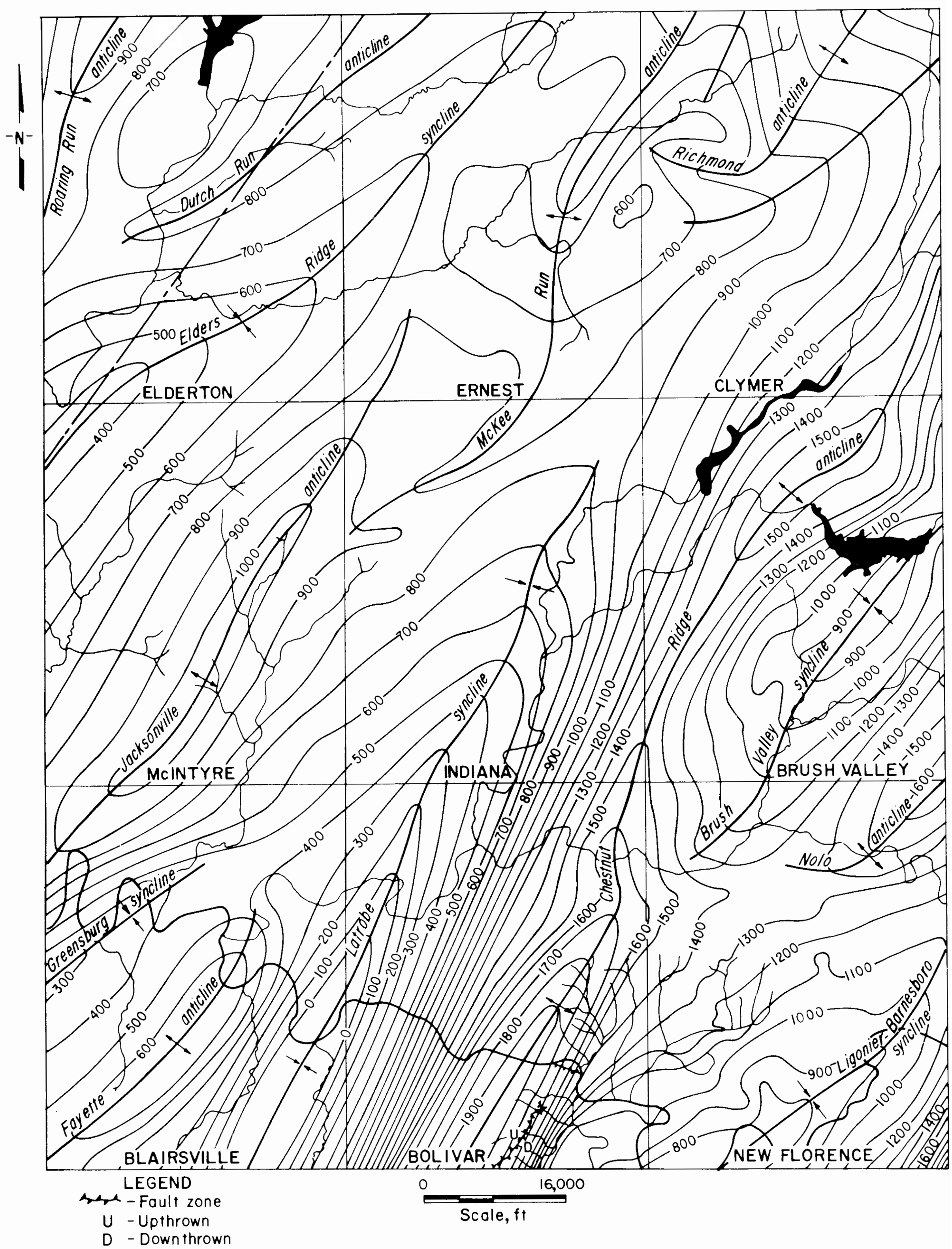

FIGURE 6. - Structure map drawn on the base of the Lower Kittanning coalbed.

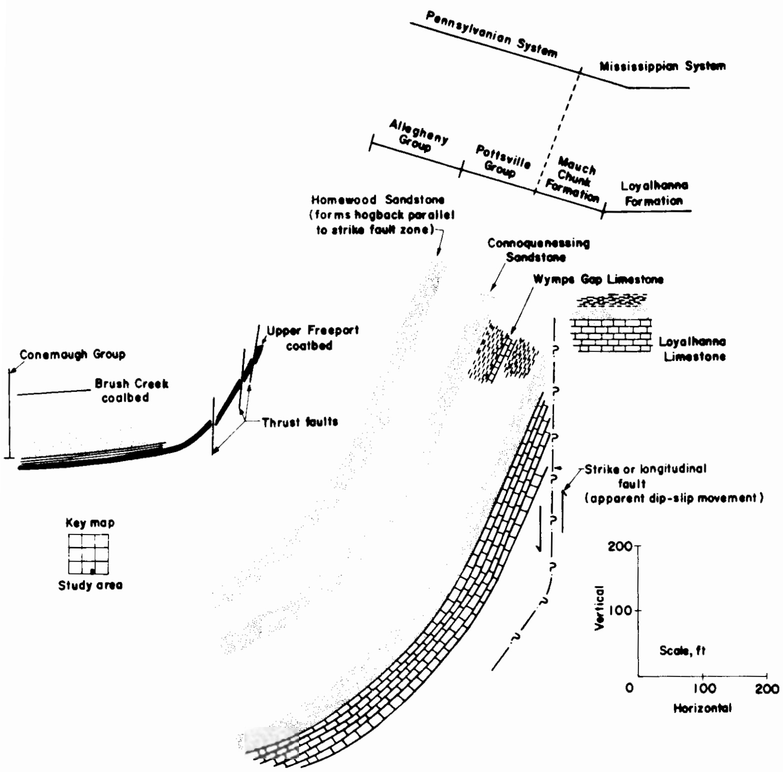

FIGURE 7. - Stratigraphic interval affected by strike fault zone of the east flank of Chestnut Ridge.

wells drilled on the western flank of Chestnut Ridge in the Wilpen quadrangle (immediately south of the Bolivar quadrangle), occurs at depths between 7,000 and 9,000 feet. A tear fault (bottom of figure 6) occurs where the Conemaugh River changes course from north to due west about 1 mile northwest of Bolivar. The third fault zone occurs along the eastern flank of Chestnut Ridge, less than 1 mile southeast of the axis of that structure. From our recent fieldwork, the fault zone has been extended approximately 1-1/2 miles to the northeast from the point where Shaffner originally terminated it. It is traceable for about 3 miles southwest through the Bolivar quadrangle and into the Wilpen quadrangle.

The fault zone strikes roughly parallel to the axis of the Chestnut Ridge anticline, but the actual displacement and direction of movement could not be determined. The section affected by faulting ranges at least from the Middle Mississippian Loyalhanna Limestone to the Upper Freeport coal group, an interval of about 500 feet (fig. 7). On the upthrown side of the fault zone to the northwest, the section is essentially flat lying. On the downthrown side of the fault zone, to the southeast, a drag feature has affected the section between the Loyalhanna Limestone and the Upper Freeport coal group; the units in this interval dip SE 45° and more for about 2,000 feet, where the interval flattens out and approaches horizontal.

About 1/2 mile west of the town of West Bolivar, a strip mine (fig. 8) working the Upper Freeport coal group on the downthrown side of this fault zone has uncovered nearly vertical coalbed dips; such steeply inclined coalbeds have not been observed previously west of the Allegheny Front in Pennsylvania. A section was constructed from exposures in the pit (fig. 9). In a distance of about 2,000 feet, the Upper Freeport coal group horizon passes from a dip of 12° SE to 85° SE at its outcrop. Evidence for three thrust faults was observed on the steep dip slope; their trends and positions are shown on the cross-sectional diagram (fig. 9). Thrusting affected at least the Upper Freeport coal group and the underclay occurring below the lowest coalbed of the group. The displacement of the units by thrust slippage was slight (less than 3 feet). The thrust fault blocks on the dip slope are

FIGURE 8. - Photograph of strip mine with exposure of steep dip slope.

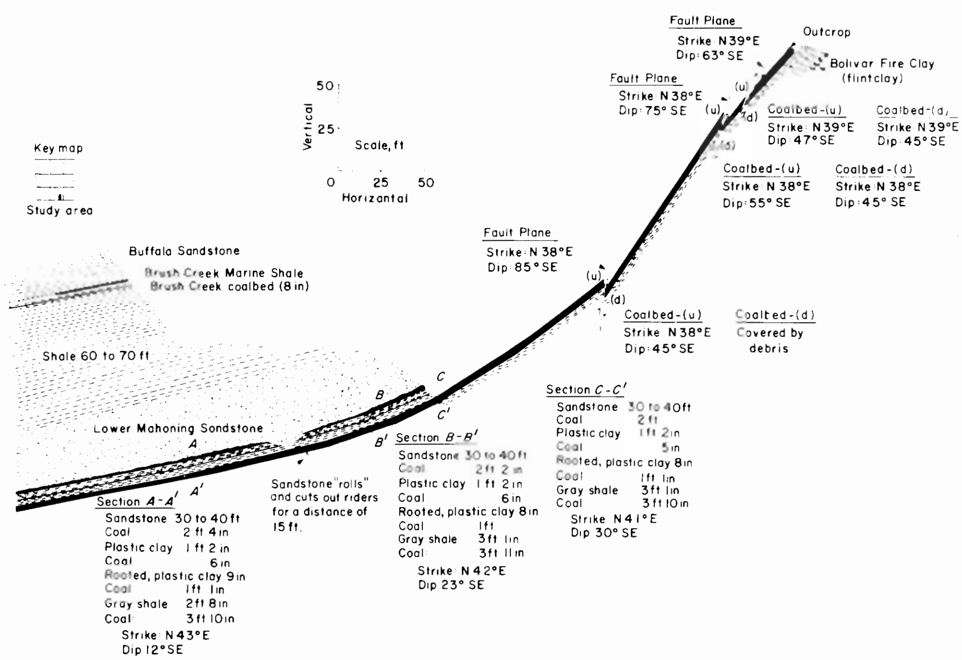

FIGURE 9. - Stratigraphic section constructed from exposures in strip mine with dip slope.

probably the consequence of local adjustment to the drag, which in turn was the consequence of the downwarping by the major strike fault activity.

There was some question as to the identity of the coalbeds being stripped. The stratigraphic position of three units exposed in the strip pit proved that the coalbeds being mined are members of the Upper Freeport coal group. A semi-flint clay horizon, the Bolivar Fire Clay, occurs at about 15 feet below the lower coalbed. The position of the thick sandstone directly above the upper coalbed of the group led to its identification as the basal Conemaugh Mahoning Sandstone. Finally, the position of the thin coalbed and overlying fossiliferous shale, about 110 feet above the coalbeds being stripped, led to its identification as the Brush Creek horizon. Or more specifically, as the Brush Creek coalbed and overlying Brush Creek marine horizon.

McCulloch (22) first reported the occurrence of thrust faults encountered underground in the Lucerne No. 6 mine (fig. 10). Working the Upper Freeport

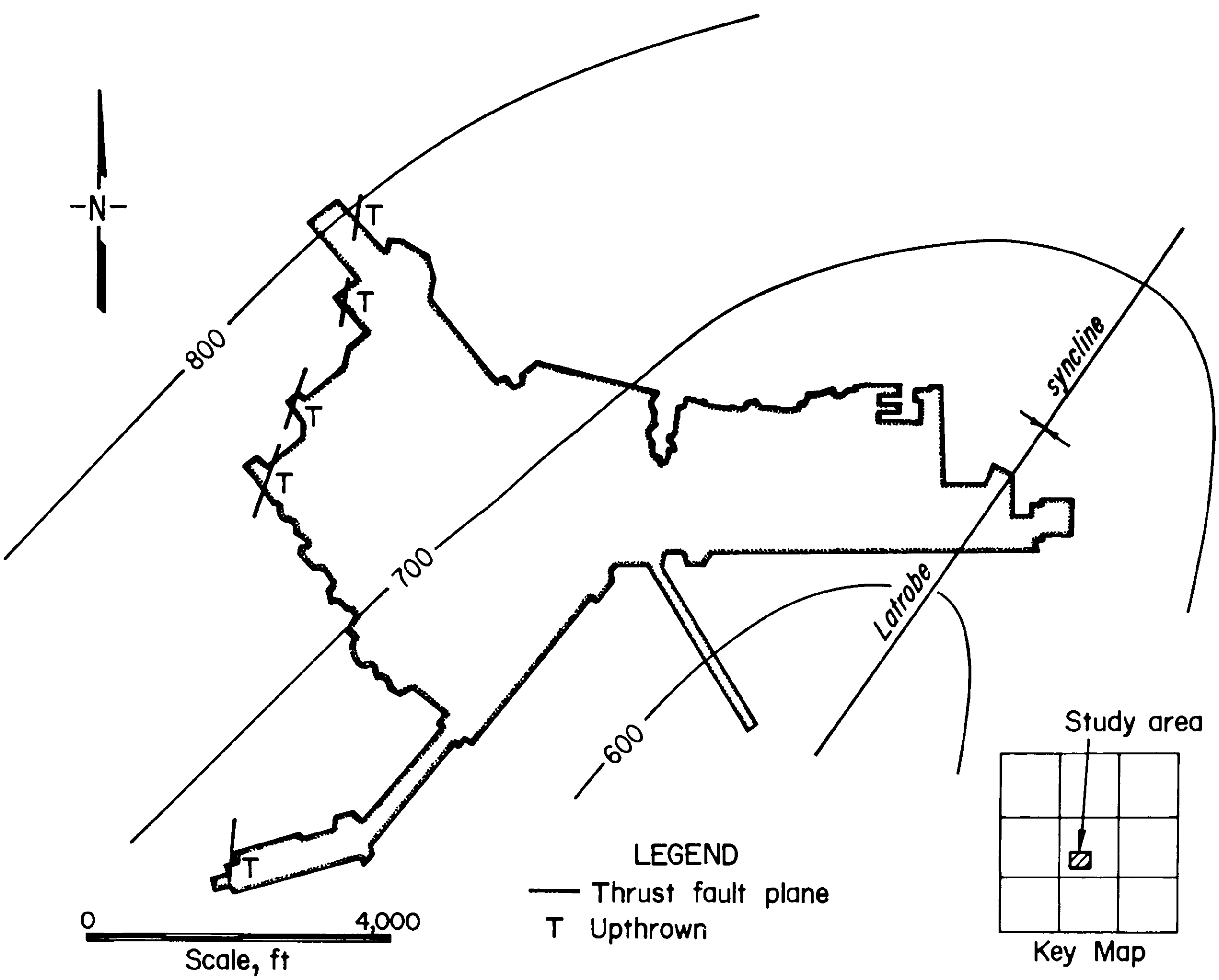

FIGURE 10. - Location of thrust faults in the Lucerne No. 6 mine.

FIGURE 11. - Photograph of thrust fault in the Jane mine.

coalbed in the southwest corner of the Indiana quadrangle, five separate thrust fault zones were observed at various localities in the mine.

Thrust faults similar to those reported by McCulloch were observed in the Lucerne No. 8 and Jane mines. The Lucerne No. 8 mine is working the Upper Freeport coalbed on the western flank of the Jacksonville anticline in the McIntyre quadrangle, about 5 miles northwest of the Lucerne No. 6 mine. The Jane mine is working the Lower Freeport coalbed near the Roaring Run and Dutch Run anticlines in the northwest corner of the Elderton quadrangle, about 10 miles northwest of the Lucerne No. 6 mine. One thrust fault (fig. 11) was observed in each mine. Similar in character to those described by McCulloch (fig. 12), the faults extend from the roof through the coalbed and terminate at the floor, unlike those thrust faults seen in the strip pit near West Bolivar. Each fault plane contained a 1- to 3-inch-thick fault gouge zone or mylonite zone. The faults strike generally parallel to the trend of local structure and cut the coalbed at angles between 20° and 45°. The thrust faults are structurally related and are the consequence of local structural adjustment to the tectonic forces that induced regional folding in the Appalachian Plateau.

Surface Joints and Coal Cleat

Surface joints were measured from outcrop and strip mine exposures over the nine-quadrangle study area. Coal cleat surveys were conducted in 12 mines working within the limits of the study area: One in the Lower Freeport coalbed, two in the Upper Freeport coalbed, and nine in the Lower Kittanning coalbed. The fracture orientation data for each quadrangle (fig. 13) and each mine (figs. 14-16) were plotted on semicircular rose diagrams to evaluate the principal directional trends by the method developed by Diamond (10).

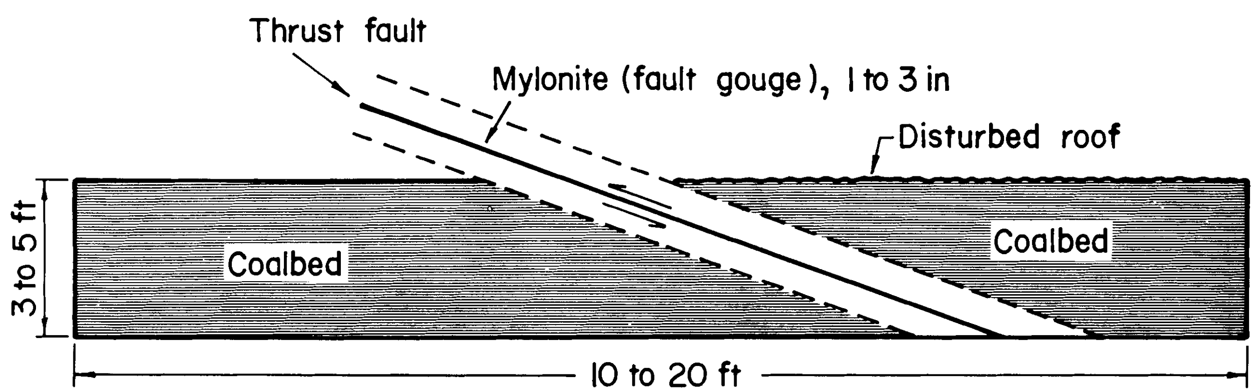

FIGURE 12. - Generalized sketch of typical thrust faults observed underground in the Lucerne Nos. 6 and 8 and Jane mines.

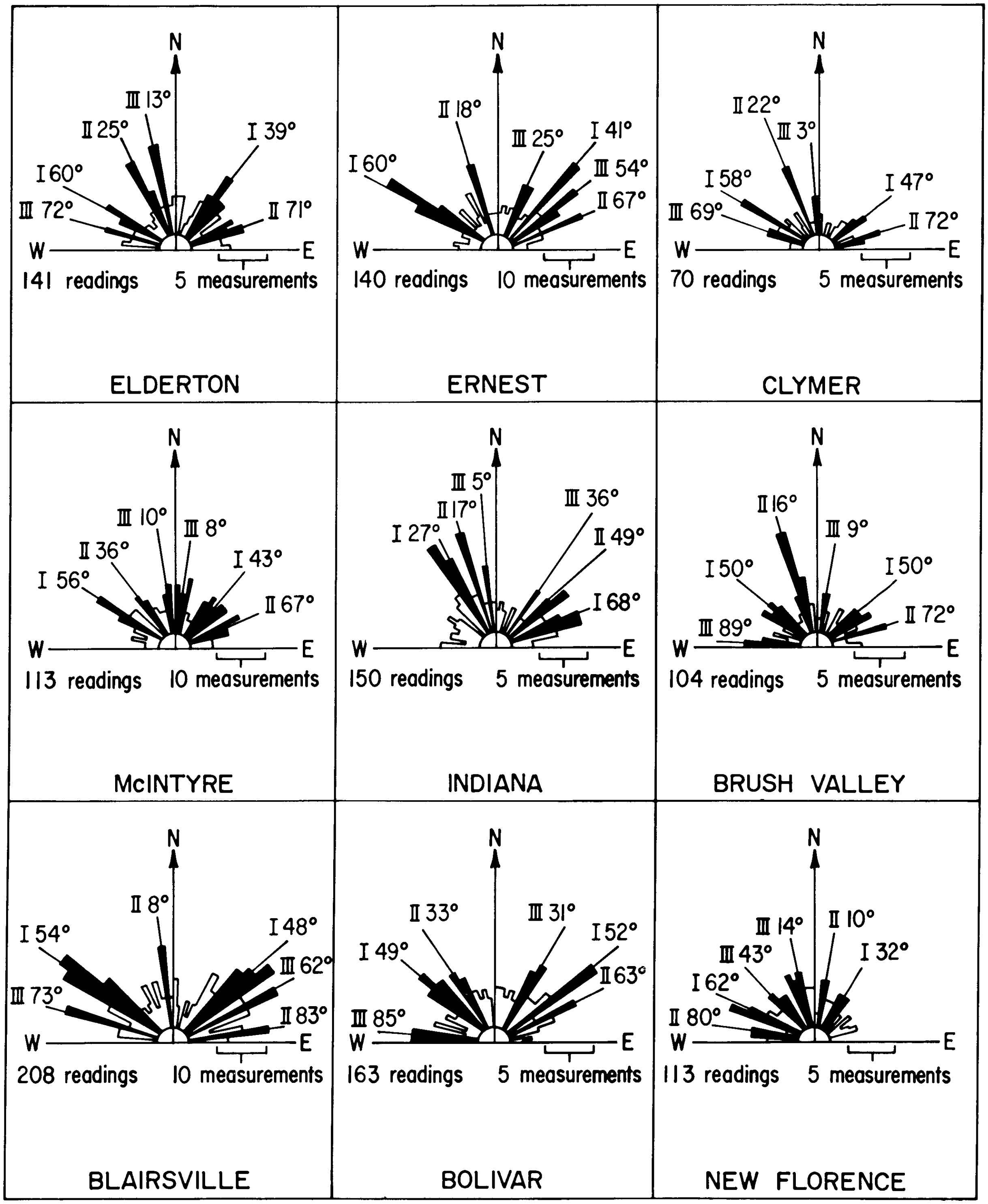

FIGURE 13. - Rose diagrams of surface joints for nine quadrangles.

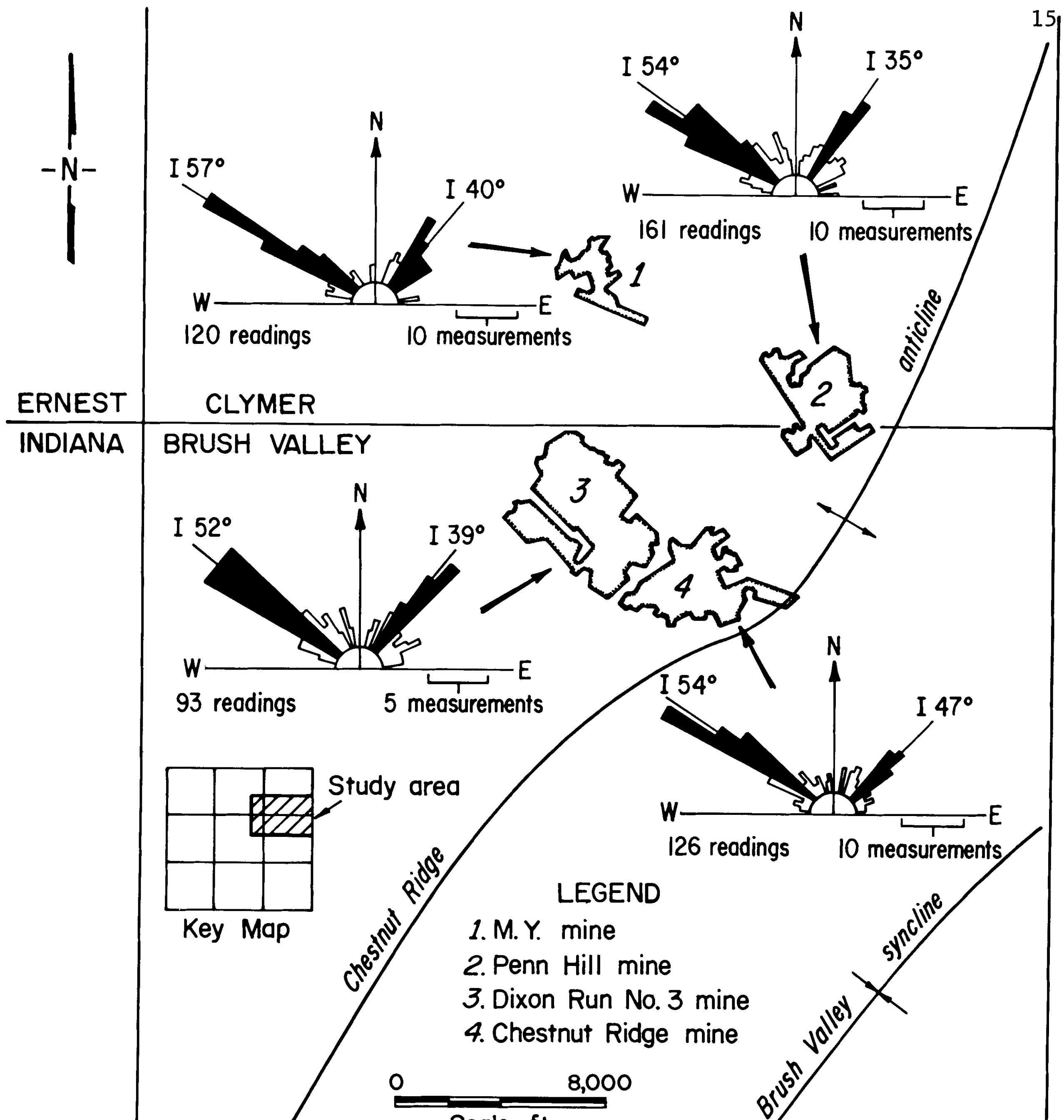

FIGURE 14. - Relationship between local structure and cleat orientation in the M. Y., Penn Hill, Chestnut Ridge, and Dixon Run No. 3 mines.

Surface Joints

An average of 133 joint readings were taken from an average of 13 outcrop stations per quadrangle. Six major directional trends occur in each quadrangle and correspond to three fundamental joint systems (25). The primary, secondary, and tertiary joint systems for each quadrangle are listed in

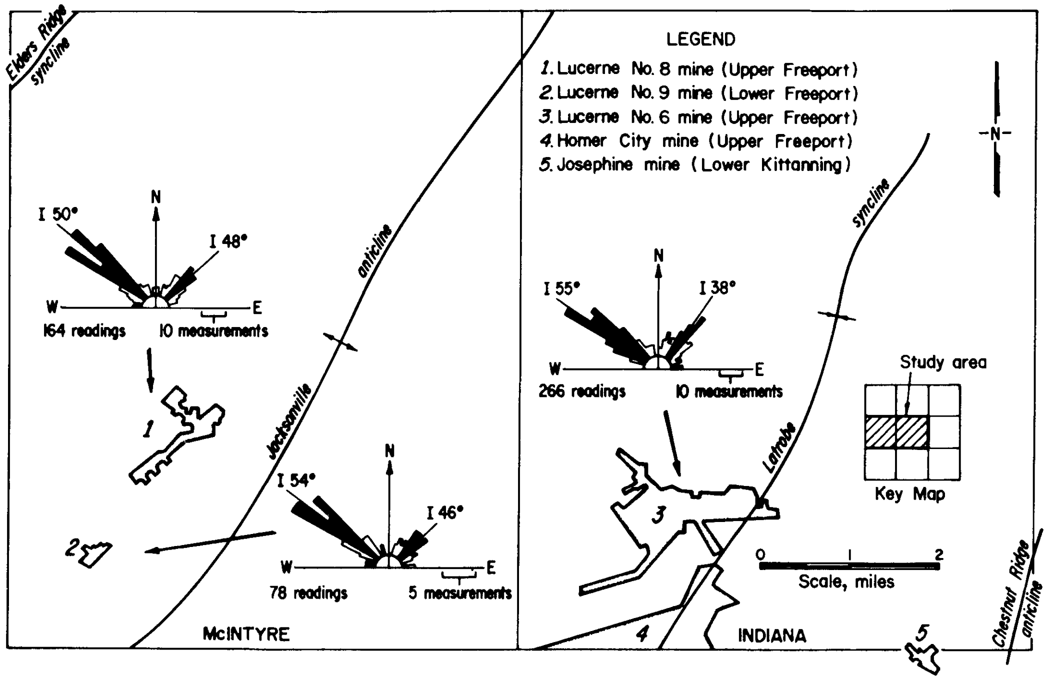

FIGURE 15. - Relationship between local structure and cleat orientation in the Lucerne Nos. 6, 8, and 9 mines.

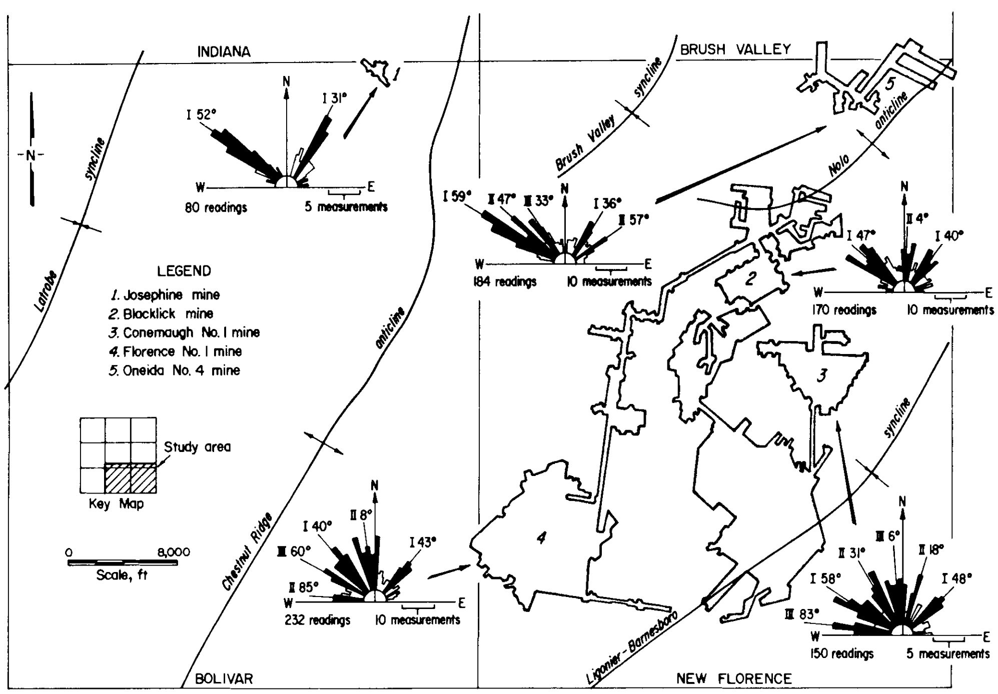

FIGURE 16. - Relationship between local structure and cleat orientation in the Josephine, Oneida No. 4, Florence No. 1, Blacklick, and Conemaugh No. 1 mines.

table 1. Systematic joint trends are generally perpendicular to structural trends and represent extension fractures; nonsystematic joint trends are generally parallel to regional structural trends and represent release fractures (19, 23).

TABLE 1. - Fundamental joint systems for each 7' 30" quadrangle in study area

7' 30" quadrangle	Average trends of fundamental joint system		Angle of separation
	Systematic[1]	Nonsystematic	
Elderton.............	I. N 60° W	N 39° E	99°
	II. N 25° W	N 71° E	96°
	III. N 72° W	N 13° W	59°
Ernest...............	I. N 60° W	N 41° E	101°
	II. N 18° W	N 67° E	85°
	III. N 25° E	N 54° E	29°
Clymer...............	I. N 58° W	N 47° E	105°
	II. N 22° W	N 72° E	94°
	III. N 69° W	N 3° W	66°
McIntyre.............	I. N 56° W	N 43° E	99°
	II. N 36° W	N 67° E	103°
	III. N 10° W	N 8° E	18°
Indiana..............	I. N 27° W	N 68° E	95°
	II. N 17° W	N 49° E	66°
	III. N 5° W	N 36° E	41°
Brush Valley.........	I. N 50° W	N 50° E	100°
	II. N 16° W	N 72° E	88°
	III. N 89° W	N 9° E	98°
Blairsville..........	I. N 54° W	N 48° E	102°
	II. N 8° W	N 83° E	92°
	III. N 73° W	N 62° E	135°
Bolivar..............	I. N 49° W	N 52° E	101°
	II. N 33° W	N 63° E	99°
	III. N 85° W	N 31° E	116°
New Florence.........	I. N 62° W	N 32° E	94°
	II. N 10° E	N 80° W	90°
	III. N 43° W	N 14° W	29°

[1] I. Primary.
II. Secondary.
III. Tertiary.

Coal Cleat

Cleat is the natural fracture system in coalbeds and is analogous to joints (21). The dominant fracture plane(s) is referred to as the face cleat; the secondary fracture plane(s) is referred to as the butt cleat. Normally occurring at right angles to each other, face cleats are analogous to systematic rock joints; butt cleats are analogous to nonsystematic rock joints (21). Face cleats are well developed, cut bedding plane structure, and extend for some distance vertically and horizontally. Butt cleats are less well developed than face cleats, terminate against face cleat planes, and vary more directionally and in frequency of occurrence than face cleats. Spacing of both face and butt cleats in the friable Freeport and Kittanning coalbeds is three to seven per inch.

Cleat orientation controls the directional permeability within coalbeds (4, 21), which in turn influences the rate of methane and water flow into mine workings (4, 20-21). By effectively intercepting these flow paths with either vertical or horizontal borehole patterns, the maximum drainage potential of the unit can be realized. Detailed fracture trend analyses should be conducted before a methane drainage program is initiated. The fundamental cleat systems for each of the mines surveyed are listed in table 2. The in-mine cleat survey technique involved taking 10 to 20 cleat directional readings at stations 500 to 1,000 feet apart.

TABLE 2. - Fundamental cleat systems for each mine surveyed

Mine	Coalbed[1]	Average trends of fundamental cleat systems		Angle of separation
		Face[2]	Butt	
M. Y....................	L.K.....	I. N 57° W	N 40° E	97°
Penn Hill................	L.K.....	I. N 54° W	N 35° E	89°
Chestnut Ridge...........	L.K.....	I. N 54° W	N 47° E	101°
Dixon Run No. 3..........	L.K.....	I. N 52° W	N 39° E	91°
Josephine................	L.K.....	I. N 52° W	N 31° E	83°
Florence No. 1...........	L.K.....	I. N 40° W	N 43° E	83°
		II. N 8° W	N 85° W	77°
		N 60° W		
Blacklick................	L.K.....	I. N 42° W	N 40° E	82°
		N 4° E		
Conemaugh No. 1..........	L.K.....	I. N 58° W	N 48° E	106°
		II. N 26° W	N 18° E	44°
		III. N 6° W	N 83° W	77°
Oneida No. 4.............	L.K.....	I. N 59° W	N 36° E	95°
		II. N 47° W	N 57° E	104°
		N 33° W		
Lucerne No. 6............	U.F.....	I. N 55° W	N 38° E	93°
Lucerne No. 8............	U.F.....	I. N 50° W	N 48° E	98°
Lucerne No. 9............	L.F.....	I. N 54° W	N 46° E	100°

[1] L.K. - Lower Kittanning.
U.F. - Upper Freeport.
L.F. - Lower Freeport.

[2] I. Primary.
II. Secondary.
III. Tertiary.

Face and butt cleat trends in the M. Y., Penn Hill, Chestnut Ridge, and Dixon Run No. 3 mines (fig. 14), working the Lower Kittanning coalbed on the western flank of the Chestnut Ridge anticline, exhibit an excellent structural control. In proximity to the four mines, the axis of the Chestnut Ridge anticline trends N 35° E. Face cleat trends for the four mines average N 54° W, nearly perpendicular to the axis of Chestnut Ridge--the angle of separation being 89°. The average butt cleat trend for the four mines is N 40° E, roughly parallel to the N 35° E-trending Chestnut Ridge anticline.

Face and butt cleat trends in the Lucerne Nos. 6 and 8 mines, working the Upper Freeport coalbed, and the Lucerne No. 9 mine, working the Lower Freeport coalbed, also exhibit an excellent structural control (fig. 15). The Lucerne No. 6 mine is working on the western flank of the Latrobe syncline; the axial trend of that structure in proximity to the mine is N 35° E. Face cleat trends average N 55° W, perpendicular to the trend of the synclinal axis; butt cleat trends average N 38° E, roughly parallel to the axis of the syncline. The axial trend of the Jacksonville anticline in proximity to the Lucerne Nos. 8 and 9 mines is N 35° E. Face cleat trends in the Lucerne No. 8 mine average N 50° W, roughly perpendicular to the axis of that structure--the angle of separation being 85°; butt cleat trends from the mine average N 48° E, roughly parallel to the anticline axis. Face cleat trends in the Lucerne No. 9 mine average N 54° W, nearly perpendicular to the axial trend of the anticline--the angle of separation being 89°; butt cleat trends average N 46° E, roughly parallel to the axial trend of the anticline.

Complex cleating occurs in the Lower Kittanning coalbed in the New Florence quadrangle (fig. 16). Face and butt cleat trends in the Josephine mine, working the Lower Kittanning coalbed on the western flank of the Chestnut Ridge anticline, are rather straightforward and exhibit a structural control much like that seen in the seven mines just described. The presence of three structural anomalies in the New Florence quadrangle has induced the development of primary and secondary fundamental cleat systems in the Lower Kittanning coalbed; a tertiary fundamental cleat system was recorded in the Conemaugh No. 1 mine. The three anomalies that affect the directional trends of face and butt cleats in the Lower Kittanning coalbed are (1) the loss of identity of the Brush Valley syncline and Nolo anticline, (2) the turning due west of the axis of the Nolo anticline, and (3) local changes in the trends of the structures passing through the quadrangle. The deflection of the axis of the Nolo anticline is reflected in cleat trends in the Robinson No. 1 and Conemaugh No. 1 mines, but "normal" trends for face and butt cleats are also recorded in these mines.

Inclined cleat planes were observed in the Oneida No. 4 mine, where primary and secondary fundamental cleat systems were recorded. The inclined fractures dip at an average of 55° to the coalbed and strike between due north to N 65° E. The observed shear planes had a length no greater than 5 inches. The erratic occurrence of the shears did not permit a quantitative trend analysis throughout the mine. Their origin is related to the anomalous behavior of the structural trends in the quadrangle.

MINING

Stratigraphy of Freeport and Kittanning Formations

All deep and strip mining is presently conducted in members of the Freeport and Kittanning Formations of the Allegheny Group (fig. 17). Ferm (14-15) and Williams (41-42) showed that the lithology of the Allegheny section represents deposition in a deltaic environment, where a somewhat low rate of detrital sediment influx permitted the establishment of vast swamp marsh complexes. The complexity of the depositional environment in the delta complex explains the extreme local and regional lithologic gradations that characterize the section. A generalized panel diagram of the Freeport and Kittanning Formation was constructed (fig. 18) to determine regional trends of coalbed development.

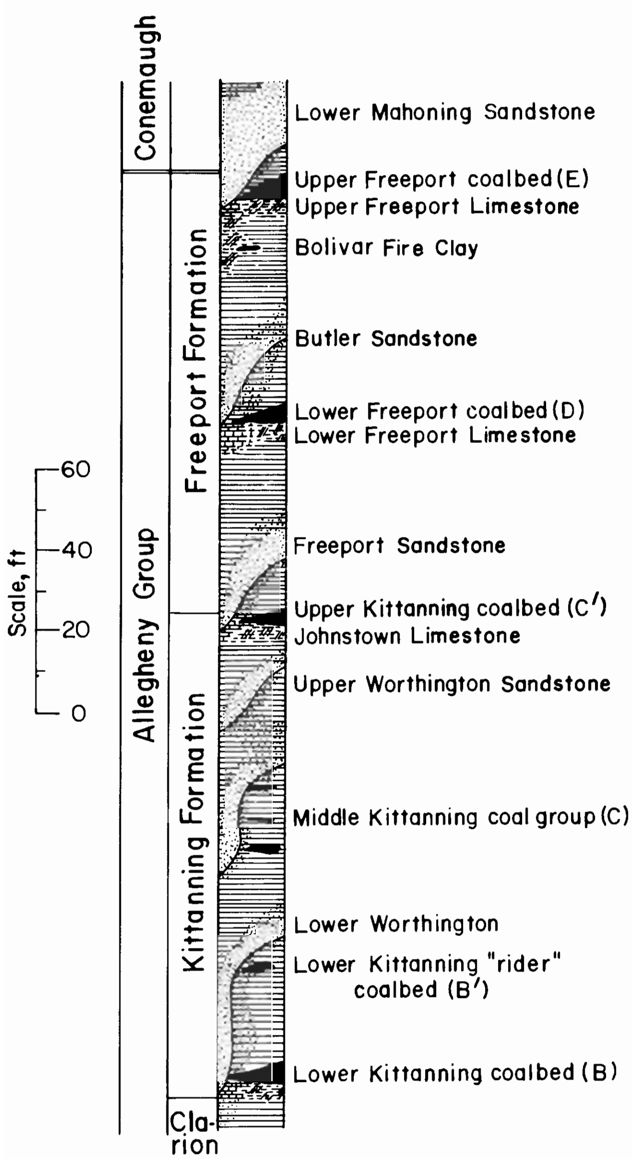

FIGURE 17. - Generalized stratigraphic column of the Freeport and Kittanning Formations.

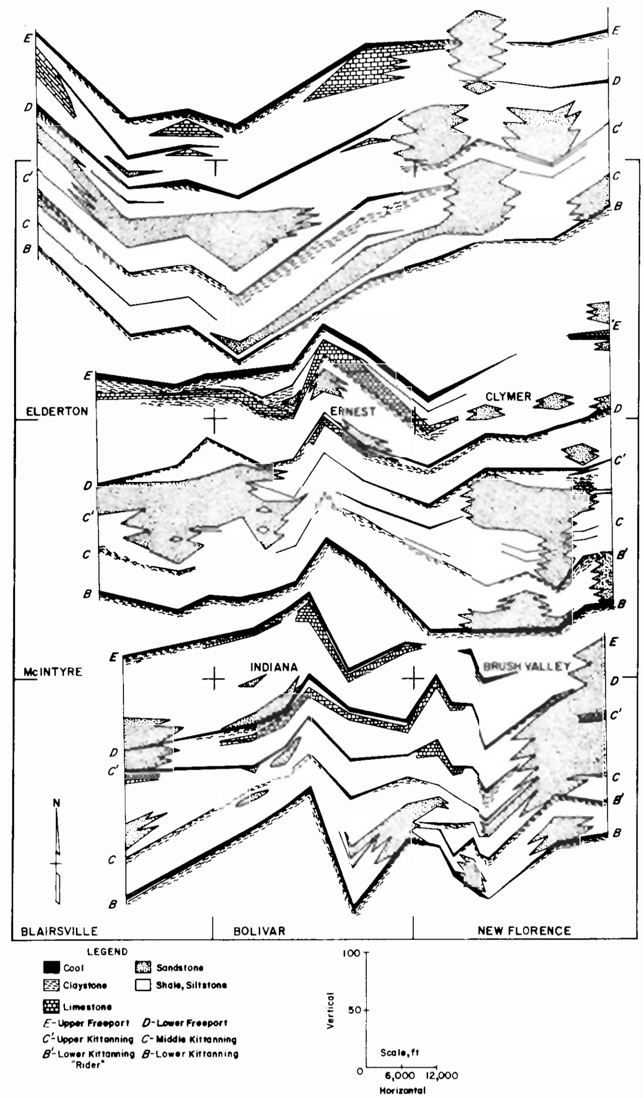

FIGURE 18. - Panel diagram of Freeport and Kittanning Formations over study area.

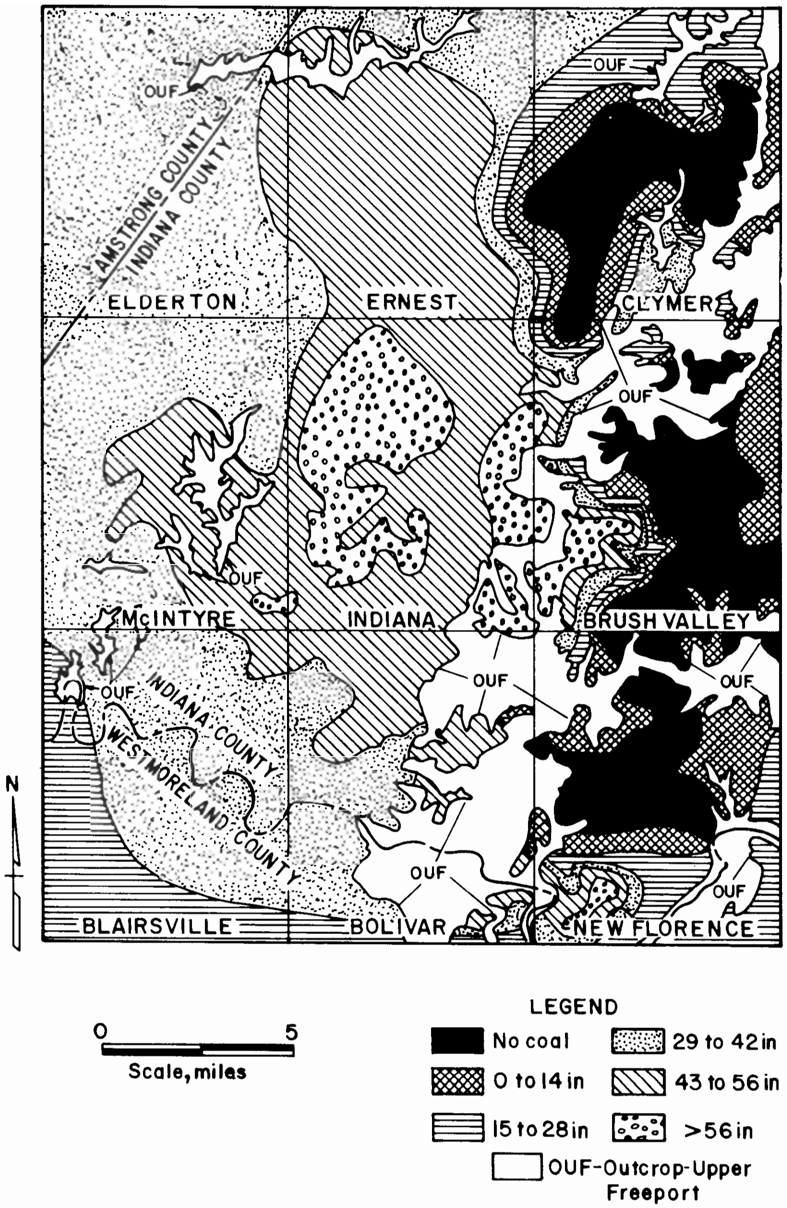

FIGURE 19. - Upper Freeport coalbed isopach.

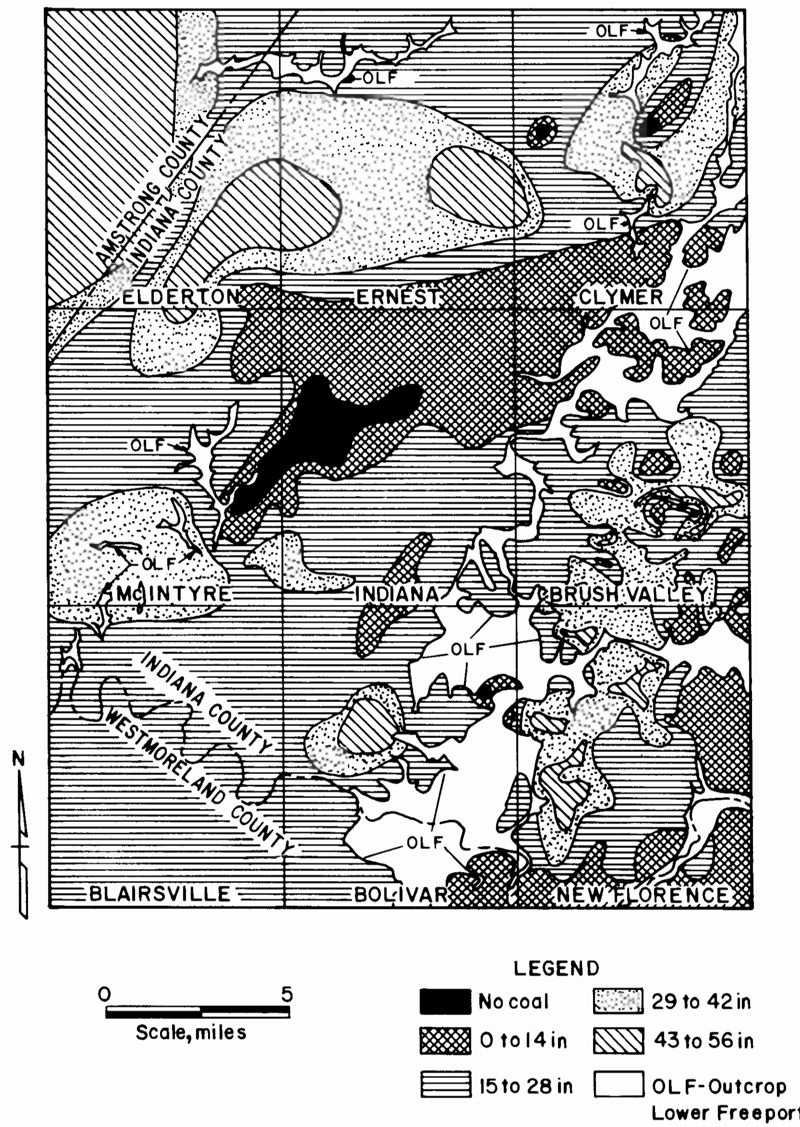

FIGURE 20. - Lower Freeport coalbed isopach.

The interval from the Upper Freeport coalbed to the Lower Kittanning coalbed ranges from 180 to 220 feet and averages about 200 feet. The Upper Freeport coalbed ranges from 0 to more than 56 inches thick (fig. 19) and can be underlain by either a claystone, limestone (Upper Freeport), or shale facies. The Upper and Lower Freeport coalbeds are separated by 40 to 70 feet of shale, siltstone, and/or sandstone. The Lower Freeport coalbed ranges from 0 to more than 56 inches thick (fig. 20) and is normally underlain by a claystone or shale facies. When developed, the Lower Freeport Limestone occurs from 15 to 20 feet below the coalbed and is 5 to 15 feet thick.

Lying 40 to 80 feet below the Lower Freeport coalbed, the Upper Kittanning coalbed normally occurs as one bench of coal but can be split into as many as three benches. Although the total coal thickness of the Upper Kittanning horizon is usually no greater than 28 inches, it is regionally persistent. The Middle Kittanning horizon occurs from 30 to 50 feet below the Upper Kittanning and is usually represented by two or three benches of coal. The Middle Kittanning is the least persistent member of the Freeport and Kittanning coal groups and is usually no more than 28 inches thick. The Lower Kittanning "rider" coalbed is locally developed in the New Florence quadrangle and occurs 10 to 20 feet below the Middle Kittanning horizon and up to 30 feet above the Lower Kittanning. The rider ranges from 14 to 42 inches thick when present. The Lower Kittanning coalbed is probably the most regionally persistent of the Allegheny coalbeds, ranging from 0 to more than 72 inches thick (fig. 21) and normally averaging 36 to 48 inches thick. It can be locally split into two or more benches and is almost always underlain by a claystone.

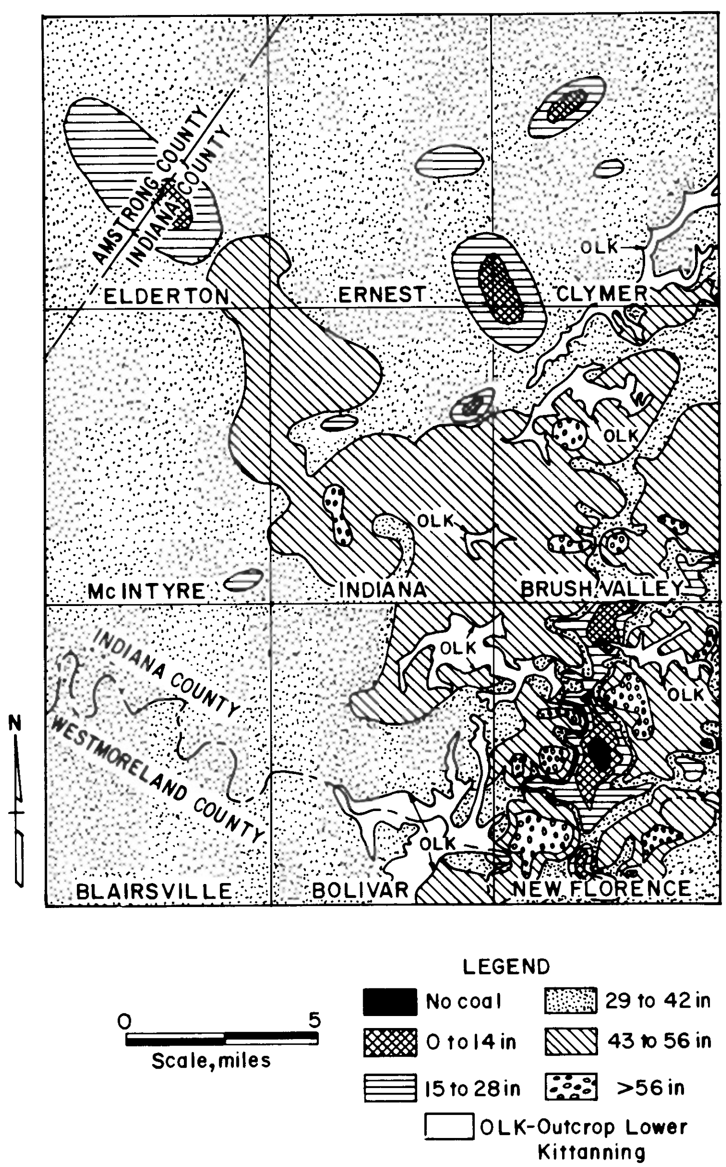

FIGURE 21. - Lower Kittanning coalbed isopach.

The sandstone facies in the section occur as either tabular or lens-shaped bodies. The tabular morphology represents deposition by frequently shifting distributary channels and/or beach or barrier bar deposition. The lens-shaped morphology represents deposition in distributary channels, common in the deltaic environment. Represented regionally by a long, narrow, meandering morphology, the horizon grades laterally to less coarse levee or overbank deposits of shale and/or siltstone. Because rapid abandonment of distributary channels is common, so-called "shale channels" can also be developed in the section. The "shale channels" represent infilling by less coarse sediment after abandonment, in somewhat quiescent, standing water. When channeling activity is penecontemporaneous with peat deposition, the channel can erode the unconsolidated vegetal deposit and disrupt the continuity of the peat body. Nonpenecontemporaneous channeling, after burial and semilithification of the peat deposit, can also erode the section and disrupt coalbed continuity.

Local and regional variations in coalbed thickness have influenced mine planning and development in each of the economically important coalbeds. Variations in coalbed thickness are the consequence of three controls exerted by the deltaic environment: The peat may have been compacted differentially;

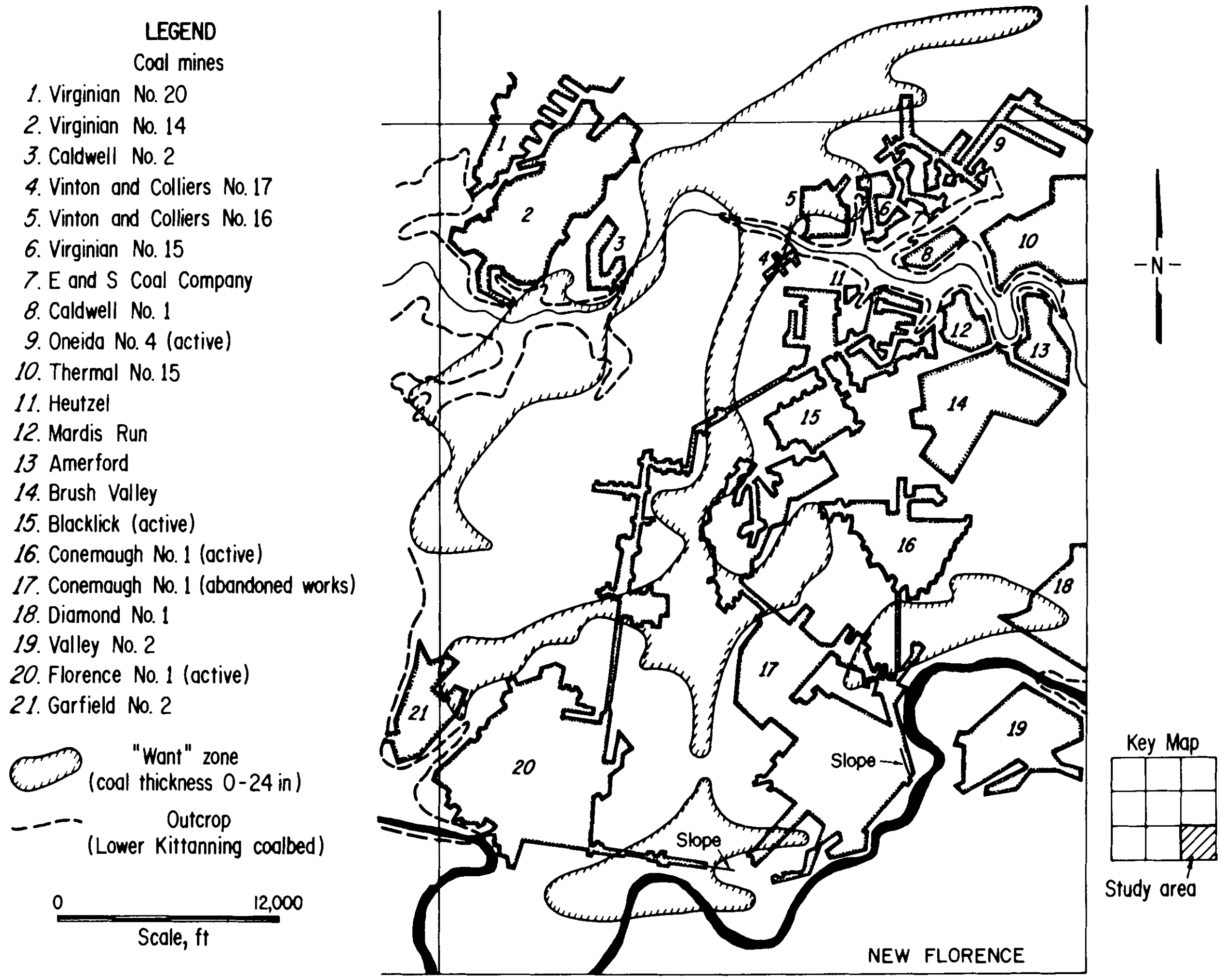

FIGURE 22. - Area affected by distributary channel system in the New Florence quadrangle.

the peat may have been deposited on an undulating, irregular paleotopography; and/or the coal may have been eroded by distributary channeling activity either during or after deposition (27). Each exerts some influence on the final thickness of all coalbeds. The coalbed isopachs (figs. 19-21) show that regional variations in thickness are the norm for the economic coalbeds of the Allegheny Group. Profitable development in those coalbeds has occurred in "pods," where coal thickness is consistently greater than 28 inches over large tracts.

Distributary Channel System in the Lower Kittanning Horizon

A distributary channel system disrupts the continuity of the Lower Kittanning horizon in the New Florence quadrangle (figs. 22-23). The somewhat drastic changes in coal thickness and poor roof conditions associated with the system have affected mine planning and development and coal production. The mains connecting the Blacklick and Florence No. 1 mines were driven through parts of the low-coal or "want" zone, and the mains connecting the old and new works of the Conemaugh No. 1 mine were also driven through a section of the "want" zone (fig. 22). Figure 22 shows how the morphology of the channel system has affected active and abandoned mine development. The occurrence of the distributary channel system has no doubt resulted in the expenditure of large sums of money to drive through the low coal zones, which in turn results in decreased production per man-hour, additional expenses for roof control, and abandonment of active sections.

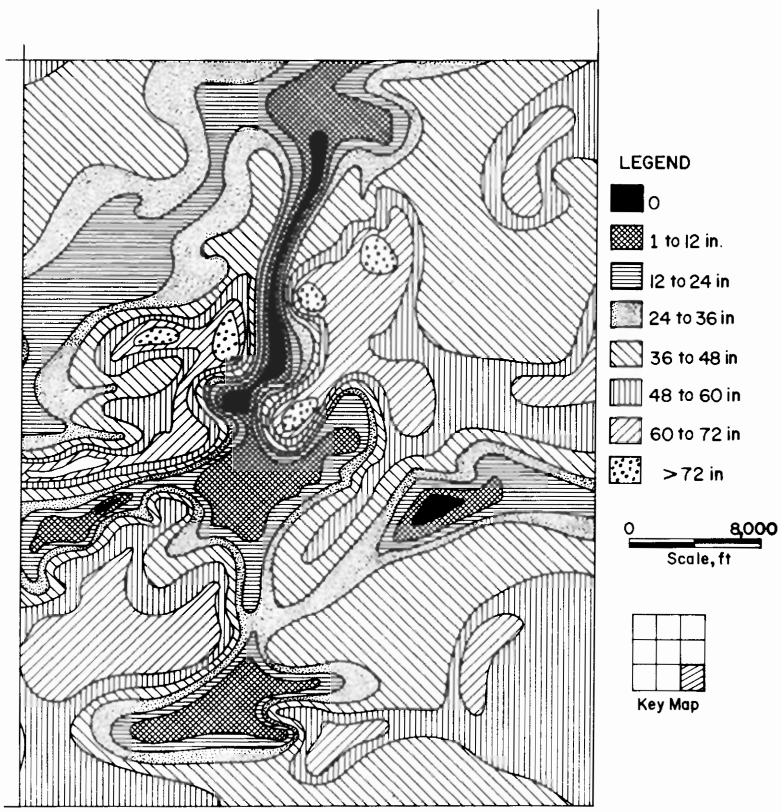

FIGURE 23. - Detailed Lower Kittanning coalbed isopach over New Florence quadrangle.

Three features characterize the channel system:

1. Coal thickness ranges from 0 to 72 inches laterally through the width of the system, which is about 0.25 to 0.5 mile; pods of abnormally thick coal occur along the flanks of the channel. These pods were formed during flooding events that piled up peat along the banks of the channel.

2. The channel system facies is laterally gradational from flank to flank; the lithology passes from "normal" lagoonal or back bay shales to coarser overbank deposits to the

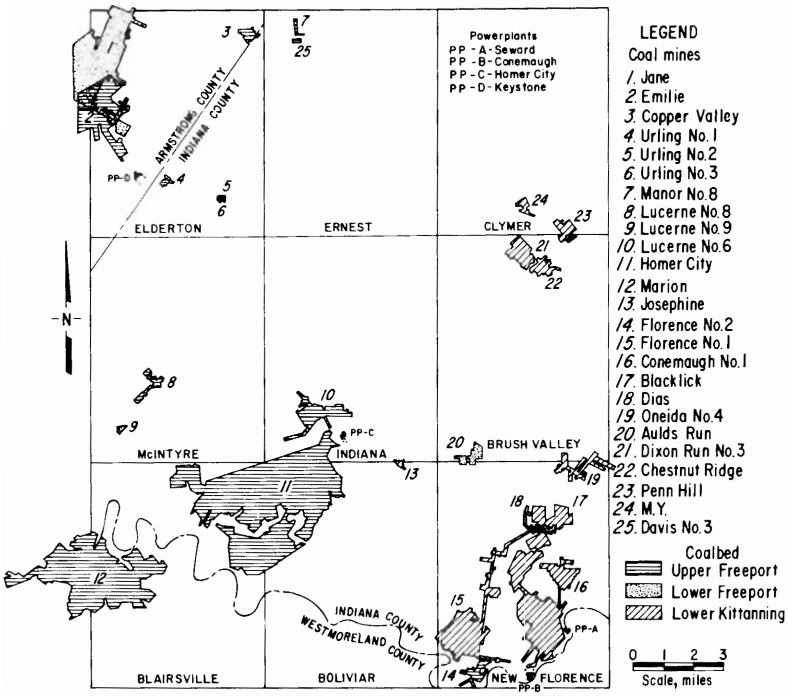

FIGURE 24. - Active underground mines in study area.

coarse infilled sands and silts of the channel.

3. The regional morphology of the system is manifested by a somewhat linear system of at least two converging channels--the most pronounced trending roughly north-south and the other trending roughly east-west, and both converging near the lower center of the quadrangle.

Mining and Production

Twenty-five underground mines (fig. 24) were active in the Upper Freeport, Lower Freeport, and Lower Kittanning coalbeds in 1976. Ten mines were working the Upper Freeport coalbed, six were working the Lower Freeport coalbed, and nine were working the Lower Kittanning coalbed (table 3). Total production from the mines in 1976 was more than 8 million short tons, roughly 3 percent of the total underground production for the United States in 1976, and 20 percent of the total underground production for Pennsylvania in 1976. Twenty-two of the mines employ continuous mining systems with room-and-pillar development for coal extraction. Three mines--Jane, Lucerne No. 6, and Blacklick--employ longwall mining sections along with continuous development for coal extraction. Various retreat mining techniques had been practiced in the now-abandoned sections of the oldest properties in the area.

TABLE 3. - Active mines by coalbed

Coalbed	Mine	Method of development
Upper Freeport (10 mines).....	Lucerne No. 6...........	Shaft, slope.
	Homer City..............	Do.
	Marion..................	Do.
	Emilie..................	Do.
	Lucerne No. 8...........	Do.
	Florence No. 2..........	Do.
	Copper Valley No. 6.....	Drift.
	Manor No. 8.............	Do.
	Urling No. 2............	Shaft, slope.
	Davis No. 3.............	Drift.
Lower Freeport (6 mines)......	Jane....................	Shaft, slope.
	Aulds Run...............	Drift.
	Dias....................	Do.
	Urling No. 1............	Shaft, slope.
	Urling No. 3............	Do.
	Lucerne No. 9...........	Do.
Lower Kittanning (9 mines)....	Florence No. 1..........	Drift, shaft, slope.
	Conemaugh No. 1.........	Shaft, slope.
	Blacklick...............	Drift.
	Oneida No. 4............	Do.
	Penn Hill...............	Do.
	Chestnut Ridge..........	Do.
	Dixon Run No. 3.........	Do.
	M. Y....................	Do.
	Josephine...............	Do.

Most coal production was from the Upper Freeport coalbed, followed by the Lower Kittanning and Lower Freeport coalbeds (table 4). Production from the 10 most productive mines in the area (table 5) accounted for roughly 87 percent (7,107,879 short tons) of the total production from the area in 1976. The Jane and Lucerne No. 6 mines, the two largest producers in the area, were among the top 100 underground bituminous coal mine producers in the United States in 1976. The Jane mine ranked 42d nationally, and the Lucerne No. 6 mine ranked 57th (24).

TABLE 4. - Production by coalbed, 1976

Coalbed	Short tons
Upper Freeport...........	4,009,390
Lower Freeport...........	1,852,042
Lower Kittanning.........	2,302,443
Total................	8,163,875

TABLE 5. - Active mines and production by mine

Rank in area	Mine	Coalbed	Production, short tons
1.	Jane........................	Lower Freeport...........	1,486,585
2.	Lucerne No. 6...............	Upper Freeport...........	1,284,588
3.	Emilie......................	.....do..................	909,052
4.	Homer City..................	.....do..................	758,649
5.	Florence No. 1..............	Lower Kittanning.........	735,874
6.	Conemaugh No. 1.............	.....do..................	477,081
7.	Blacklick...................	.....do..................	462,076
8.	Marion......................	Upper Freeport...........	389,249
9.	Lucerne No. 8...............	.....do..................	315,692
10.	Florence No. 2..............	.....do..................	289,033
11.	Oneida No. 4................	Lower Kittanning.........	252,479
12.	Aulds Run...................	Lower Freeport...........	184,297
13.	Josephine...................	Lower Kittanning.........	137,357
14.	Dias........................	Lower Freeport...........	93,365
15.	Penn Hill...................	Lower Kittanning.........	83,569
16.	Chestnut Ridge..............	.....do..................	78,144
17.	Urling No. 3................	Lower Freeport...........	77,643
18.	Dixon Run No. 3.............	Lower Kittanning.........	60,757
19.	Copper Valley No. 6.........	Upper Freeport...........	45,705
20.	M. Y........................	Lower Kittanning.........	15,112
21.	Manor No. 8.................	Upper Freeport...........	11,985
22.	Lucerne No. 9...............	Lower Freeport...........	10,090
23.	Urling No. 2................	Upper Freeport...........	5,007
24.	Davis No. 3.................	.....do..................	430
25.	Urling No. 1................	Lower Freeport...........	62
	Total.......................	-	8,163,875

Most of the low- to medium-volatile bituminous coal that is surface- and deep-mined in the area is used for the generation of electric power. A small tonnage is used for coke preparation. Four generating stations, operated by the Pennsylvania Electric Co., are located in the area (fig. 24). The Seward and Conemaugh generating stations are located along the north bank of the Conemaugh River in Indiana County. The Homer City generating station is located along Two Lick Creek in the Indiana quadrangle, and the Keystone powerplant is located along Crooked Creek in Armstrong County.

METHANE ASSOCIATED WITH COALBED HORIZONS

Methane is present in the coalbed horizon and most commonly in the coalbed itself. The gas emanates into the mine workings from the working face, from exposed pillars, and sometimes from overlying and underlying units. Although methane is nontoxic, concentrations between 5 to 15 volume-percent in air are explosive. Most bituminous coalbeds have a well-defined cleat system, so the coalbed has a fracture porosity and permeability that may facilitate methane flow or migration into surrounding lithologies or mine workings (4, 8-9). Research by the Bureau of Mines has shown that methane migration is governed by numerous factors: The relative concentration of the gas within the coalbed, the degree of water saturation, the coalbed pressure gradient, and the depth of cover--which influences the coalbed pressure (4, 8-9, 19-21, 28). The source of the methane gas associated with bituminous coalbed horizons is the organic deposit itself, for methane is generated throughout the coalification process (8-9). Methane is physically held within the micropore structure of the coal (4) and is not normally released to the atmosphere unless the coalbed is brought to the surface by tectonic and/or erosional processes.

Methane Emissions

A national survey of mines and associated methane emissions for 1973 (17) showed that Indiana County ranked 10th nationally (table 6) in average methane emissions, averaging about 4.8 MMcfd. In 1975 (16) the average methane emissions had increased to about 5.8 MMcfd for Indiana County, but this can be explained by the fact that three additional mines were included in the more recent survey.

TABLE 6. - Gassiest counties in the United States in 1973 (17)

Rank in Nation	County	State	Daily emissions, MMcf
1.	Monongalia.....	West Virginia.....	40.7
2.	Marion.........	.....do..........	23.1
3.	Buchanan.......	Virginia..........	22.1
4.	Washington.....	Pennsylvania......	12.4
5.	Greene.........	.....do..........	11.7
6.	McDowell.......	West Virginia.....	11.4
7.	Cambria........	Pennsylvania......	9.8
8.	Jefferson......	Alabama..........	9.5
9.	Wyoming........	West Virginia.....	6.0
10.	Indiana........	Pennsylvania......	4.8
11.	Marshall.......	West Virginia.....	4.8

Of the 25 active mines, 7 emit more than 100,000 cfd of methane gas. The Jane mine (table 7), located in Armstrong County, is the only "gassy" mine not located in Indiana County. Four other mines in Indiana County that are not located within the limits of the study area also emit more than 100,000 cfd of methane. Those mines and their average daily emission rates are Lancashire 24B (Lower Kittanning), 400,000 cfd; Greenwich Nos. 1 and 2 (Lower Freeport), 300,000 and 200,000 cfd, respectively; and David (Lower Kittanning), 200,000 cfd.

TABLE 7. - Active mines emitting more than 100,000 cfd of methane (16-18)

Mine	Quadrangle	Depth, feet	Coalbed[1]	Av CH_4 emission per day, MMcf	Av daily production, tons	Av CH_4 cu ft/ton
Homer City.....	Bolivar.....	200-800	U.F.	2.0-2.1	3,000	721
Lucerne No. 6..	Indiana.....	200-800	U.F.	1.5-1.8	5,600	321
Marion.........	Blairsville.	0-800	U.F.	.5- .7	2,500	200
Jane...........	Elderton....	100-500	L.F.	.5- .8	7,000	72
Florence No. 1.	New Florence	0-500	L.K.	.2	2,500	80
Conemaugh No. 1	...do.......	100-500	L.K.	.1	2,200	45
Florence No. 2.	...do.......	0-400	U.F.	.1	1,500	67

[1]U.F. - Upper Freeport.
L.F. - Lower Freeport.
L.K. - Lower Kittanning.

The Homer City, Lucerne No. 6, and Marion mines (table 7) are working the Upper Freeport coalbed in or near the Latrobe synclinal basin at depths of 0 to 800 feet. These mines emit the highest amount of methane per day, are generally the deepest, and are the largest producers in the county.

The Florence Nos. 1 and 2 and Conemaugh No. 1 mines are working the Lower Kittanning and Upper Freeport coalbeds at depths between 0 and 500 feet. Methane emissions from these mines range from 100,000 to 200,000 cfd, which is relatively low, considering that the average daily production of the mines is 1,500 to 2,500 tons. The mines are somewhat shallow and are located in proximity to large areas of outcrop exposure; probably a substantial amount of methane gas has been drained naturally from the outcrop, causing the low methane emissions. None of the other active mines in the area have methane control problems, owing to their proximity to the outcrop, shallow cover, and lower production rates.

Direct-Method Tests

The methane content of three samples of the Lower Kittanning coalbed taken from vertical exploratory core holes in or near the study area was estimated utilizing the direct method (23). The holes located within the study area have been designated as holes 1 and 2 (table 8); these holes are located on the data-point base map (fig. 3). Hole 1 is situated between the Chestnut Ridge anticline and Latrobe syncline, about 1 mile west of the axis of Chestnut Ridge and 1 to 2 miles from the outcrop line of the coalbed, in the Bolivar quadrangle. Hole 2 is situated in the basin of the Latrobe syncline about 0.5 mile west of the axis of the structure, in the Blairsville quadrangle. Hole 3 is located 4 miles west of the study area in the Avonmore quadrangle (directly west of the McIntyre quadrangle), about 0.5 mile east of the axis of the Roaring Run anticline.

TABLE 8. - Direct-method test results for three core samples of the Lower Kittanning coalbed

Hole	Quadrangle and hole location	Depth of coalbed, feet	Coal thickness, inches	Gas content of sample, cu cm/g	Projected gas content, cu ft/ton
1	Bolivar; 1 mile west of the axis of the Chestnut Ridge anticline.	620- 623	36	.8	27
2	Blairsville; 0.5 mile west of the axis of the Latrobe syncline.	1,057-1,060	36	[1]11	[1]352
3	Avonmore; 0.5 mile east of the axis of the Roaring Run anticline (4 miles west of the study area).	323- 327	48	.5	16

[1]This is the highest methane content ever measured in a Pennsylvania coalbed.

As can be seen on the overburden isopach (fig. 25), the interval from the Kittanning coalbed to the Upper Freeport coalbed is more than 1,000 feet deep in parts of the Latrobe synclinal basin. Three of the "gassiest" mines in the area are working the Upper Freeport coalbed in or near this basin at depths between 0 and 800 feet. The Lower Kittanning coalbed is essentially unmined in this basin. The relatively high methane emissions in the active mines working in the basin and the results of the direct-method test on the core of the Lower Kittanning from the basin indicate that methane control problems will be encountered in future workings in the Lower Kittanning coalbed. More direct-method tests should be conducted in the basin so that the methane content of the virgin field can be more accurately estimated. The range of overburden above the Lower Kittanning coalbed for each quadrangle in the study area is shown in table 9. The overburden above the Upper Freeport coalbed can be estimated from this table by subtracting 200 feet from the overburden figures for the Lower Kittanning coalbed.

TABLE 9. - Range of overburden above the Lower Kittanning coalbed for each quadrangle in study area

Quadrangle	Range of overburden, feet	Structures
Elderton	400- 800	Roaring Run anticline. Dutch Run anticline. Elders Ridge syncline.
Ernest	200- 800	McKee Run anticline.
Clymer	0- 800	Richmond anticline. Chestnut Ridge anticline.
McIntyre	200- 800	Elders Ridge syncline. Jacksonville anticline.
Indiana	0- 800	Latrobe syncline. Chestnut Ridge anticline.
Brush Valley	0- 600	Chestnut Ridge anticline. Brush Valley syncline.
Blairsville	200-1,200	Jacksonville anticline. Greensburg syncline. Fayette anticline. Latrobe syncline.
Bolivar	0-1,000	Latrobe syncline. Chestnut Ridge anticline.
New Florence	0- 600	Chestnut Ridge anticline. Brush Valley syncline. Nolo anticline. Ligonier syncline.

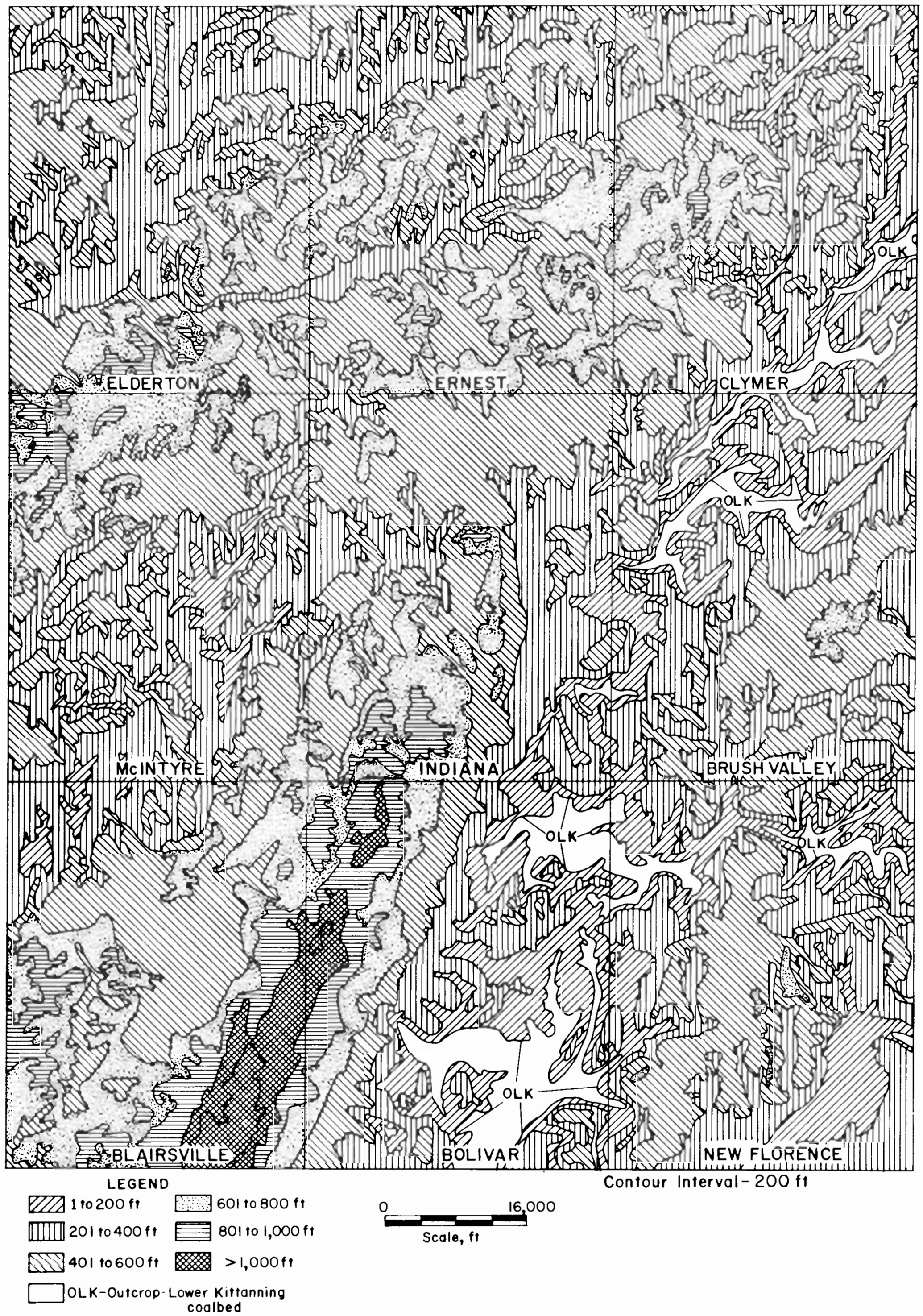

FIGURE 25. - Overburden isopach of the strata above the Lower Kittanning coalbed.

CONCLUSIONS

1. In the study area, the seven mines with the highest methane emissions per day are generally the deepest and largest producers. The mines that have low methane emissions are small drift mines working under shallow cover and have relatively low production rates. Methane emission data from the three mines working the Upper Freeport coalbed near the Latrobe synclinal basin and the results of the direct-method test conducted on a core of the Lower Kittanning coalbed taken from that basin suggest that methane control problems will be encountered in future workings in the Lower Kittanning coalbed in that basin.

2. Of the five coalbed horizons that occur in the Freeport and Kittanning Formations, only the Upper and Lower Freeport and the Lower Kittanning are of economic importance. Underground and surface mining of these coalbeds occurs in areas possessing minable thicknesses that are greater than 28 inches in thickness and that are generally greater than 200 acres in area. The character and quality of the coal contained in the Upper and Middle Kittanning and Lower Kittanning "rider" horizons are not conducive to either small- or large-scale development. Local and regional variation in coal thickness is the norm for the Freeport and Kittanning coalbeds, and is the consequence of depositional controls exerted in the deltaic environment.

3. Complex rock joint systems occur in each quadrangle in the study area and roughly correspond to three fundamental joint systems. The orientation of coal cleat in the friable Freeport and Kittanning coalbeds is structurally controlled. Primary face and butt cleat orientations differ regionally, which is explained by examining regional variations in structural trends. The Lower Kittanning coalbed possesses a complex cleat system locally throughout the New Florence quadrangle, owing to anomalous behavior of structural trends in the quadrangle.

4. Structural and depositional discontinuities have affected mining and development in the economically important coalbeds. To date, 10 separate thrust faults have been reported. When such faults are encountered underground, poor roof conditions can be associated with these features. Depositional discontinuities such as distributary channel systems, regional and local variations of coal thickness, and coalbed splitting or parting affect mine planning, development, and coal production. A northeast-southwest-trending strike fault zone along the eastern flank of Chestnut Ridge affects the section from at least the Lower Mississippian Loyalhanna Limestone to the Upper Allegheny Upper Freeport coalbed, an interval of about 500 feet.

BIBLIOGRAPHY

1. Ashley, G. H. Bituminous Coalfields of Pennsylvania. Pt. I, General Information on Coal. Pa. Geol. Survey Bull M-6, 1928, 241 pp.

2. Birge, G. W., and D. E. Wolfson. Carbonizing Properties of Westmoreland County, Pa., Coals. BuMines RI 5374, 1957, 12 pp.

3. Campbell, M. R. Description of the Latrobe Quadrangle, Pennsylvania. U.S. Geol. Survey Folio 110, 1904, 15 pp.

4. Cervik, J. An Investigation of the Behavior and Control of Methane Gas. Min. Cong. J., v. 53, No. 7, July 1967, pp. 52-57.

5. Crentz, W. L., A. L. Bailey, and J. W. Miller. Preparation Characteristics of Coal Occurring in Westmoreland County, Pa. BuMines RI 4823, 1951, 17 pp.

6. Crentz, W. L., F. Steele, and A. L. Bailey. Preparation Characteristics of Coal Occurring in Armstrong County, Pa. BuMines RI 4788, 1951, 25 pp.

7. _____. Preparation Characteristics of Coal Occurring in Indiana County, Pa. BuMines RI 4763, 1951, 33 pp.

8. Deul, M. Methane Drainage From Coalbeds: A Program of Applied Research. Proc. 60th Meeting, Rocky Mountain Coal Min. Inst., Boulder, Colo., June 30-July 1, 1964, pp. 54-60.

9. _____. The Scientific Basis for Evaluation of the Methane Problem in the New Mines. Proc. W.Va. Coal Min. Inst., Charleston, W.Va., October 1970, pp. 19-20.

10. Diamond, W. P., C. M. McCulloch, and B. M. Bench. Use of Surface Joint and Photolinear Data for Predicting Subsurface Coal Cleat Orientation. BuMines RI 8120, 1976, 13 pp.

11. Dowd, J. J., L. A. Turnbull, A. L. Toenges, R. F. Abernethy, and D. A. Reynolds. Estimate of Known Recoverable Reserves of Coking Coal in Armstrong County, Pa. BuMines RI 4801, 1951, 16 pp.

12. _____. Estimate of Known Recoverable Reserves of Coking Coal in Westmoreland County, Pa. BuMines RI 4803, 1951, 16 pp.

13. Dowd, J. J., L. A. Turnbull, A. L. Toenges, H. M. Cooper, R. F. Abernethy, D. A. Reynolds, and W. L. Crentz. Estimate of Known Recoverable Reserves of Coking Coal in Indiana County, Pa., BuMines RI 4757, 1950, 22 pp.

14. Ferm, J. C. Allegheny Deltaic Deposits. Sec. in Deltaic Sedimentation, ed. by J. P. Morgan. Soc. Econ. Paleon. and Mineralogists, Spec. Paper 15, 1970, pp. 246-255.

15. Ferm, J. C. Characteristics of a Carboniferous Marine Invasion in Western Pennsylvania. J. Sed. Petrol., v. 35, No. 6, 1965, pp. 319-330.

16. Irani, M. C., J. H. Jansky, P. W. Jeran, and G. L. Hassett. Methane Emission From U.S. Coal Mines in 1975, A Survey. A Supplement to Information Circulars 8558 and 8659. BuMines RI 8733, 1977, 55 pp.

17. Irani, M. C., P. W. Jeran, and M. Deul. Methane Emission From U.S. Coal Mines in 1973, A Survey. A Supplement to IC 8558. BuMines IC 8659, 1974, 47 pp.

18. Irani, M. C., E. D. Thimons, T. G. Bobick, M. Deul, and M. G. Zabetakis. Methane Emissions From U.S. Coal Mines, A Survey. BuMines IC 8558, 1972, 58 pp.

19. Kissell, F. N. The Methane Migration and Storage Characteristics of the Pittsburgh, Pocahontas No. 3, and Oklahoma Hartshorne Coalbeds. BuMines RI 7667, 1972, 22 pp.

20. Kissell, F. N., and J. C. Edwards. Two-Phase Flow in Coalbeds. BuMines RI 8066, 1975, 16 pp.

21. McCulloch, C. M., M. Deul, and P. W. Jeran. Cleat in Bituminous Coalbeds. BuMines RI 7910, 1974, 25 pp.

22. McCulloch, C. M., P. W. Jeran, and C. D. Sullivan. Geologic Investigations of Underground Coal Mining Problems. BuMines RI 8022, 1975, 30 pp.

23. McCulloch, C. M., J. R. Levine, F. N. Kissell, and M. Deul. Measuring the Methane Content of Bituminous Coalbeds. BuMines RI 8043, 1975, 22 pp.

24. Mining Informational Services (McGraw-Hill Inc.). Keystone Coal Industry Manual. 1977, 1184 pp.

25. Nickelsen, R. P., and V. D. Hough. Jointing in the Appalachian Plateau Province of Pennsylvania. Geol. Soc. Am. Bull., v. 78, 1967, pp. 607-629.

26. Platt, W. G. The Geology of Indiana County. 2d Geol. Survey of Pennsylvania Rept. HHHH, 1877, 376 pp.

27. Popp, J. T., and C. M. McCulloch. Geologic Factors Affecting Methane in the Beckley Coalbed. BuMines RI 8137, 1976, 35 pp.

28. Price, H. S., R. C. McCulloch, J. C. Edwards, and F. N. Kissell. A Computer Model Study of Methane Migration in Coalbeds. Canadian Min. and Met. Bull., September 1973, pp. 103-112.

29. Puglio, D. G. Geology of the Lower Kittanning Coalbed in Portions of Indiana, Westmoreland, and Cambria Counties, Pennsylvania. Master's Thesis, Univ. Pittsburgh, Pittsburgh, Pa., December 1977, 98 pp.

30. Reese, J. F., and J. D. Sisler. Bituminous Coalfields of Pennsylvania. Pt. III, Coal Resources. Pa. Geol. Survey Bull. M-6, 1928, 153 pp.

31. Richardson, G. B. Description of the Indiana Quadrangle, Pennsylvania. U. S. Geol. Survey Folio 102, 1904, 7 pp.

32. Rogers, H. D. Geology of Pennsylvania. 1st Geol. Survey of Pennsylvania, v. 1, 1858, 586 pp., v. 2, 1858, 1046 pp.

33. Shaffner, M. N. New Florence Quadrangle. Pa. Geol. Survey, Atlas 57, 1958, 165 pp.

34. Sisler, J. D. Bituminous Coalfields of Pennsylvania. Pt. II. Pa. Geol. Survey Bull. M-6, 1969, 511 pp.

35. Smith, F. W., D. E. Wolfson, and B. W. Naugle. Carbonizing Properties of Indiana County, Pa., Coals. BuMines RI 5314, 1957, 18 pp.

36. Stadnichenko, T. Progressive Regional Metamorphism of the Lower Kittanning Coalbed in Western Pennsylvania. Econ. Geol., v. 24, No. 6, September-October 1934, pp. 511-543.

37. Stone, R. W. Description of the Elders Ridge Quadrangle, Pennsylvania. U.S. Geol. Survey Folio 123, 1905, 10 pp.

38. _____. The Elders Ridge Coalfield, Pennsylvania. U.S. Geol. Survey Bull. 225, 1904, pp. 311-324.

39. _____. Mineral Resources of the Elders Ridge Quadrangle, Pennsylvania. U.S. Geol. Survey Bull. 256, 1905, 86 pp.

40. U.S. Bureau of Mines. Bituminous Coalfields of Pennsylvania. Pt. IV. Coal Analyses. Pennsylvania Geol. Survey Bull. M-6, 1928, 268 pp.

41. Williams, E. G. Marine and Fresh Water Fossiliferous Beds in the Pottsville and Allegheny Groups of Western Pennsylvania. J. Paleon., v. 34, No. 5, 1960, pp. 908-992.

42. _____. Stratigraphy of the Allegheny Series in the Clearfield Basin. Ph.D. Thesis, Pennsylvania State Univ., University Park, Pa., pts. I and II, 1957, 454 pp.

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