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Reducing Hazards in Underground Coal Mines Through the Recognition and Delineation of Coalbed Discontinuities Caused by Ancient Channel Processes

By Carla A. Kertis

UNITED STATES DEPARTMENT OF THE INTERIOR

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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	m	meter
ft	foot	mi	mile
g/cm^3	gram per cubic centimeter	pct	percent
km	kilometer	km^2	square kilometer
lb/ft^3	pound per cubic foot	mi^2	square mile

REDUCING HAZARDS IN UNDERGROUND COAL MINES THROUGH THE RECOGNITION AND DELINEATION OF COALBED DISCONTINUITIES CAUSED BY ANCIENT CHANNEL PROCESSES

By Carla A. Kertis [1]

ABSTRACT

Because coalbed discontinuities often pose serious economic and safety problems in underground coal mines, criteria were documented for the recognition and prediction of discontinuities in advance of mining. Pennsylvanian strata in Indiana and Armstrong Counties, PA, were deposited as part of fluvio-deltaic complexes with channel-phase sandstones as the predominant type of coalbed discontinuity. Coalbed isopach maps constructed for this study delineated numerous want areas (areas of no coal) with elongate to linear geometries. A comparison of coalbed isopach and corresponding sandstone isolith maps of the study area revealed many examples of a thick-sandstone, thin-subjacent-coalbed relationship. Nearly 60 pct of the want areas in the study area were found to lie subjacent to thick (> 20 ft [6 m]) sandstone accumulations. In addition to erosion of the coalbed, channels may contribute to coalbed splitting, coalbed thinning over paleotopographic highs, abnormal coalbed thicknesses, and deterioration of coal quality. If these features are considered, then approximately 80 pct of all interruptions in the economic coalbeds in this area result from channel activity. By using the criteria developed in this study and described in this Bureau of Mines report, the occurrence of coalbed discontinuities may be predicted and anticipated in advance of mining.

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INTRODUCTION

Exploratory drilling, mine development, and methane drainage are severely hampered by coalbed discontinuities. Since discontinuities result in absence or thinning of the coalbed, the coal reserves and production potential of a mine property may be overestimated if an undetected discontinuity lies within its boundaries. Discontinuities encountered during mine development inhibit the extension of mine entries and may cause the abandonment of some sections (11).[2] A coalbed gas reservoir may be compartmentalized by discontinuities, thereby precluding effective methane drainage (15, 26). In certain geologic settings, a coalbed discontinuity may behave as a gas reservoir and emit methane into mine workings that intercept it (31). Water, or water and gas, may accumulate in mine entries in the proximity of discontinuities. In addition, roof stability and coal quality commonly deteriorate in the proximity of a coalbed discontinuity (14).

Coalbed discontinuities are varied in geometry and genesis. The term "coalbed discontinuity" refers to any physical feature or process that results in the interruption of coalbed continuity. Therefore, coalbed discontinuities may result from nondeposition or erosional processes, from sedimentation processes, or from structural activity. Some features that lie parallel to bedding planes within the coalbed may be considered discontinuities. Partings, or binders, in coalbeds consist mainly of minerals and must be separated during preparation of the mined coal to preserve high coal quality and are therefore one type of discontinuity.

Various features that cut across bedding planes, such as faults, slumps, and clastic dikes, are more commonly recognized as coalbed discontinuties. Faulting may offset the coalbed to such a degree that successful mine development is inhibited (15). Channel-bank slumping, although genetically different from faulting, produces similar offsets in the coalbed (35). Both faulting and slumping discontinuities are variable in the amount of vertical displacement they cause and lateral extent (5).

Clastic dikes are irregularly shaped bodies that cut across coalbeds. These structures are filled with brecciated clastic material and are believed to result from differential compaction (5, 32) or collapse into tensional cracks (7). Clastic dike discontinuities are generally less than 5 ft (1.5 m) wide and extend up to several thousand feet laterally. Because clastic dikes serve as barriers to migration of methane gas, large unexpected gas emissions may be experienced as a mining machine cuts through the dike and encounters virgin coal on the other side. Additionally, clastic dikes often give rise to serious roof control problems (7).

Local topographic variations in the peat swamp may result in thinning or absence of the coalbed over high areas. Structural highs that developed contemporaneously with peat deposition may also produce discontinuous coalbeds (12).

However, in comparison to the discontinuities mentioned above, the most deleterious coalbed discontinuities are more commonly the result of scouring by ancient fluvio-deltaic channels. The coal-bearing strata in Indiana and Armstrong Counties, PA, were deposited as part of fluvio-deltaic complexes that prograded across the study area to the northwest and south (2-4, 6, 8-10). Channels cut erratic courses over the alluvial and delta plain and commonly scoured out peat accumulations and underlying deposits as well. The fluvio-deltaic channels, which subsequently filled with sand and, locally, finer grained sediments, are the predominant type of coalbed discontinuity found in the study area.

The study area, located in western Pennsylvania, has a long history of commercial coal production and remains active with both surface and underground

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

mine development (27). The recoverable coal resources in Indiana and Armstrong Counties are estimated to be over 3.3 billion short tons (3 billion metric tons) (22). Mining is expected to continue to be a leading industry in this area and may intensify in the future to exploit the abundant coal reserves. Therefore, the ability to recognize coalbed discontinuities and predict their occurrence would be especially beneficial to the mining industry in this area.

The project described in this report was undertaken to delineate coalbed discontinuities associated with channel deposits and to document criteria for their recognition and prediction. To accomplish this, isopach maps of several of the economic coalbeds in the area--the Upper Freeport, the Lower Freeport, and the Lower Kittanning--were constructed, and want areas were delineated. Comparison of these maps with sandstone isolith maps of the area showed a relationship between thick sandstone and thin or no subjacent coal in many cases. In light of this relationship, if the major channel-phase sandstones of an area can be delineated, then areas likely to be plagued by channel discontinuities can also be discerned and predicted. Once these discontinuities have been located, main entry systems, longwall panels, shafts, and slopes can be positioned to avoid the hazards associated with coalbed discontinuities.

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STUDY AREA AND DATA BASE

The area chosen for this project lies in the Appalachian Plateau physiographic province of western Pennsylvania and straddles the Allegheny Mountain and Pittsburgh Plateau sections (fig. 1). Eight 7-1/2′ quadrangles from Indiana and Armstrong Counties and a small part of Westmoreland County constituted the study area, which encompassed approximately 450 mi^2 (1,170 km^2). The quadrangles studied were Whitesburg, Avonmore, Elderton, McIntyre, Ernest, Indiana, Clymer, and Brush Valley (fig. 2).

Data from coal-exploration drill holes and wireline log data from gas wells were used in this study. A total of 636 data points, including 403 core descriptions and 233 electric logs (fig. 3), was collected from coal companies, the Pennsylvania Geological Survey, and the Petroleum Information Corp. Midland, TX. All of the geophysical-log (gas well) data points represent gamma-ray logs. In addition to the gamma-ray logs, bulk-density logs were run in 20 of the holes.

Coals, sandstones, and limestones are defined by sharp deflections to the left on gamma-ray logs (fig. 4). Unfortunately, this similarity in log response makes coalbeds virtually indistinguishable from thin sandstone or limestone beds on gamma-ray logs. Bulk-density logs, when available, confirm the presence of coals.

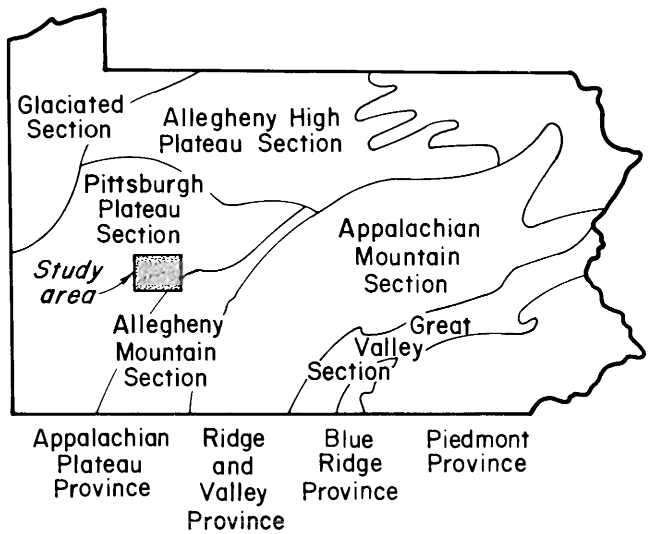


FIGURE 1. - Physiographic setting of study area.

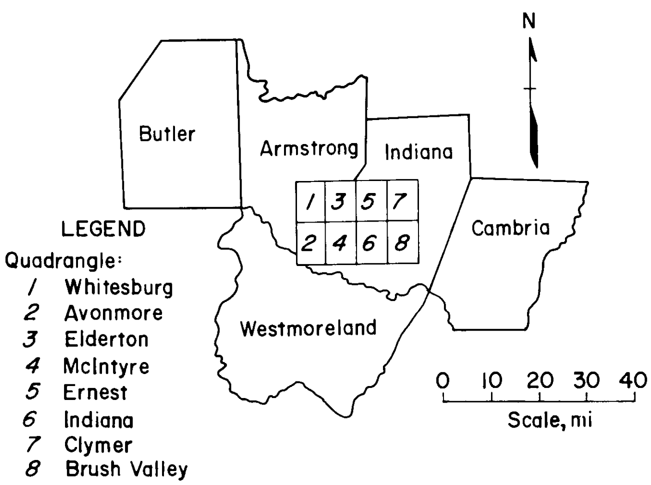


FIGURE 2. - Seven-and-one-half-minute quadrangles comprising study area.

A bulk density of less than 2.0 g/cm^3 (124 lb/ft^3) was interpreted as coal. In this study, the geophysical logs were used to determine the presence or absence of coal, not to estimate coal thickness. However, sandstone thicknesses were estimated from the geophysical logs.

STRATIGRAPHY

The geologic interval examined in this study was restricted to the coal-bearing strata of the Pennsylvanian System (fig. 5). In Indiana and Armstrong Counties, the Pennsylvanian rocks are predominantly detrital, with shale and sandstone the most common lithologies (28).

The Pottsville Group comprises the basal Pennsylvanian strata in the study area and consists of thick-bedded sandstones and a variable sequence of clays, coals, and shales (33). These thick sandstones give a characteristic response on gamma-ray logs and provide a marker bed for approximating the base of the coal measures of the Allegheny Group.

The major emphasis of this study was placed on coalbeds of the Allegheny Group, which conformably overlies the Pottsville Group and ranges from 250 to 350 ft (75 to 110 m) in thickness. Siltstones and shales, the most common lithologies, are interbedded with coalbeds, limestones, and lenticular sandstones. Seven coalbeds and/or groups of coalbeds occur in the Allegheny Group: the Brookville Coalbed, at the base; the Clarion Coalbed; the Lower, Middle, and Upper Kittanning Coalbeds; and the Lower and Upper Freeport Coalbeds, at the top (28, 30). Of these, only the Upper Freeport, the Lower Freeport, and the Lower Kittanning Coalbeds are mined on a large scale in Indiana and Armstrong Counties. The Upper Kittanning Coalbed occurs in minable thicknesses at some locations, but production from these areas is limited (1). Because of their regional extent and economic viability, the Upper and Lower Freeport and the Lower Kittanning Coalbeds were the focal point of this study.

The Conemaugh Group immediately overlies the Allegheny Group and consists of a series of sandstones and shales punctuated by several calcareous marine horizons (28, 30). Because coalbeds in the Conemaugh Group are thin and laterally discontinuous, they have not been intensively worked in the study area and were not included in this study.

The uppermost Pennsylvanian strata exposed in the study area belong to the Monongahela Group, a sequence of shale, sandstone, limestone, and coal (30). The Monongahela is restricted to 14 mi^2 (35 km^2) of exposure in the southwestern portion of the study area along the axis of the Elders Ridge syncline (29). The base

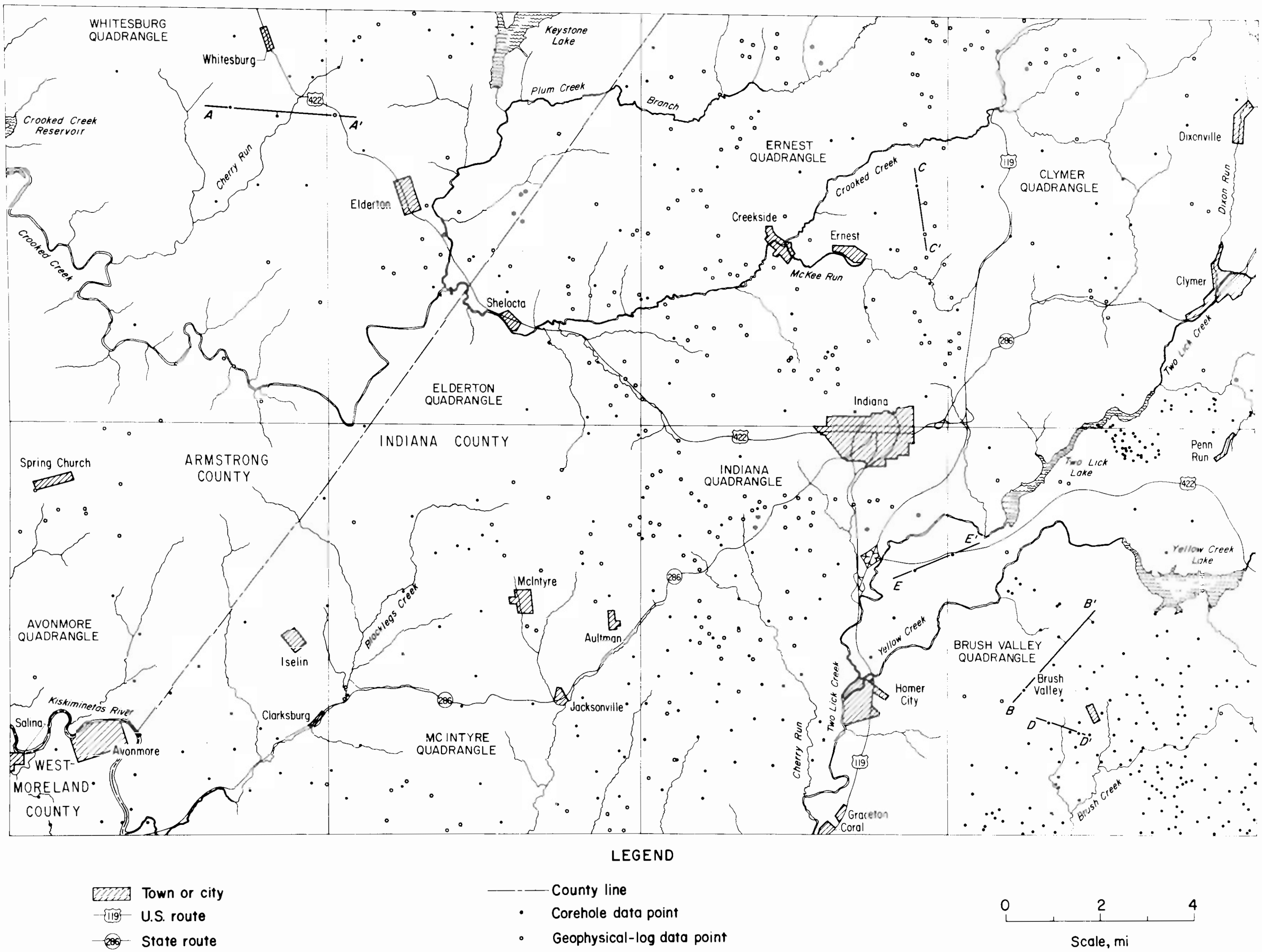


FIGURE 3. - Base map of study area. (Lines *A-A′*, *B-B′*, etc., indicate locations of cross sections shown in figures 13-14 and 16-18.)

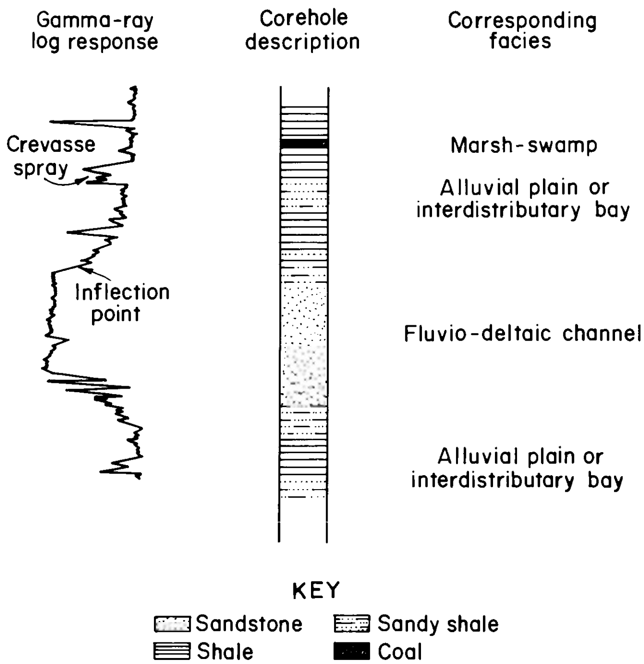


FIGURE 4. - Typical gamma-ray log response for various lithologies and corresponding facies.

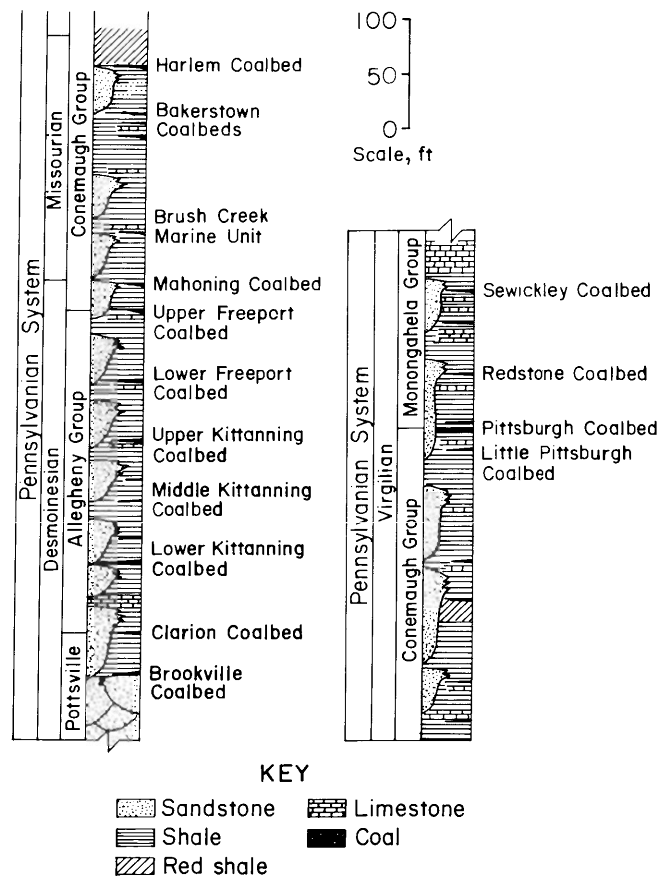


FIGURE 5. - Generalized stratigraphic column of units in study area.

of the Monongahela is marked by the Pittsburgh Coalbed, which was economically important in this area in the past (30), but now is essentially mined out (27). For these reasons, the Pittsburgh Coalbed is not included in this study.

STRUCTURAL SETTING

Deformation of the strata in Indiana and Armstrong Counties occurred during the late Paleozoic Allegheny orogeny. Compressional forces from the southeast produced relatively tight folds east of the Allegheny Front and successively more gentle folds across the Appalachian Plateau physiographic province to the west (24, 30). In most of the folded Plateau region, limbs of major anticlines are broken by east-dipping thrust faults in Lower Devonian strata (13). The structure of Pennsylvanian rocks in the study area is characterized by gently folded strata that form relatively open, subparallel anticlines and synclines. The fold axes generally trend northeast-southwest and are about 2 to 5 mi (3 to 8 km) apart (27). A structural contour map of the area, drawn on the top of the Upper Freeport Coalbed, is shown in figure 6.

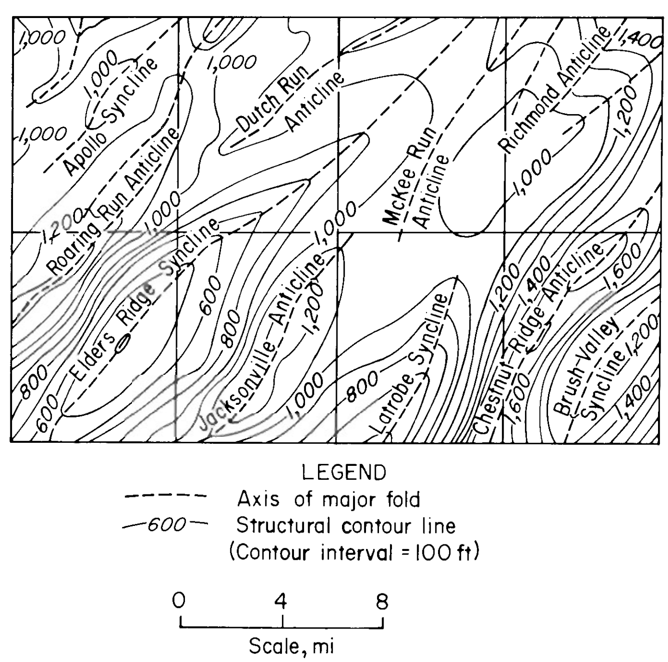


FIGURE 6. - Structural contour map of study area drawn on top of Upper Freeport Coalbed.

Major faults are absent within the study area. However, minor faults (with displacement less than 10 ft [3 m]) are relatively common. Thrust faults have been observed in the Lucerne No. 6 Mine in the Indiana quadrangle (21) and in the Lucerne No. 8 and Jane Mines in the McIntyre and Elderton quadrangles (27). These faults are largely intraformational and extend from the roof through the coalbed and the floor. Striking parallel to the trend of local structures, these faults are a consequence of local structural adjustment to the tectonic forces of the Allegheny orogeny or result from differential compaction or slumping (27).

PROBLEMS ASSOCIATED WITH FLUVIO-DELTAIC CHANNEL DISCONTINUITIES

Channel sandstones pose a host of problems in underground coal mines. Areas where the coalbed has been removed or thinned by scouring are an impediment to mining both because of the loss of economic coalbed thickness and because more roof rock must be removed to maintain proper entry height.

The presence of channel sandstone discontinuities in some cases adversely affects coal quality. In the Hartshorne Coalbed in eastern Oklahoma, a decrease in the free-swelling index (FSI) with approach to a distributary-channel sandstone has been documented (14). The sulfur content of a coalbed near a channel may also increase to well above the average level for the coalbed (14, 19). Infiltration of ground water and sulfur-bearing solutions from the sandstone has been suggested as a possible means for the deterioration of coal quality adjacent to channel sandstone discontinuities (19). The opposite is true in the Illinois basin, where the sulfur content of the coal is lowest immediately adjacent to the channels (23). This anomaly is attributed to the unique depositional setting of strata in that basin. The ash content of a coalbed may also increase in the proximity of a channel-phase sandstone as a result of increased clastic deposition in the peat swamp during episodes of flooding. The resultant overbank deposits may become thick enough to form partings or splits in the coalbed. This has been documented in Illinois, where splitting of the Herrin No. 6 Coalbed becomes more pronounced with approach to the Anvil Rock Sandstone (25).

Severe roof stability problems have been encountered as mining approaches channel-phase sandstones. Several features that have been recognized as reasons for roof control problems are (1) slickensided surfaces between adjacent cross-bed sets, (2) slickensided contacts between sandstone and shale as a result of differential compaction, and (3) prominent joints (14). Spalling of rock along slickensides or joint planes can produce spectacular roof falls, especially in the zone adjacent to a channel where the strata coarsen from shale to sandstone. Areas of roof instability as a result of differential compaction near a sandstone channel have been noted in mines in Cambria County, PA (20), and west-central Illinois (19). If the channel-fill sandstone is massive and does not break easily, longwall chocks may be pinned beneath a cantilever beam produced by flexure of the sandstone.

A rise in the floor elevation of the coalbed is commonly known as a roll. Rolls are often coupled with areas where the coal has been scoured out by a channel. Rolls may occur on either flank of a channel-phase sandstone and are the result of peat accumulation over natural levees adjacent to the channel (19) or differential compaction (14). Because they create irregular roof and floor topography through locally variable dips and may impound water, rolls are a hindrance to safe and economical coal production. Additionally, they sometimes inhibit the movement of mining machinery.

Like many other sandstones, channel-phase sandstones may serve as aquifers and reservoir rocks. Therefore, water and/or gas may accumulate in a channel sandstone and subsequently be released into adjacent mine workings. Water commonly accumulates along the irregular bottom of the sandstone, where it is trapped by underlying layers of impervious shale. Severe water accumulation problems may occur where the channel sandstone is intersected by underground workings. If the water is saline, as in west-central Illinois, mining equipment may be corroded (25). Roof bolting, which is especially necessary in the unstable area adjacent to the channel-fill sandstone, may aggravate water problems because the aquifer may be tapped, resulting in increased seepage (19). Ground water from the sandstone may react with pyrite in the coalbed and adjacent strata to produce acid drainage. Environmental laws require that this water meet minimum standards of pH and mineral content before being discharged into surface streams (17). The handling and treatment of acid mine water add to the operating costs of the mine.

Similarly, methane-gas-emission problems multiply in the proximity of channel-phase sandstones. In eastern Oklahoma, where natural gas is produced from Hartshorne distributary-channel sandstones that are in direct contact with the Hartshorne Coalbed, investigators concluded that gas-emission problems could be anticipated in any mine workings that advance toward these sandstones (14). In a mine in northern West Virginia, abnormally high methane emissions adjacent to a channel-phase sandstone were documented (31). The presence of channel discontinuities increases the likelihood of a methane ignition not only because of increased emissions, but also because the sudden thinning or absence of the coalbed may cause mining machinery to generate sparks as the cutting bits strike the roof rock.

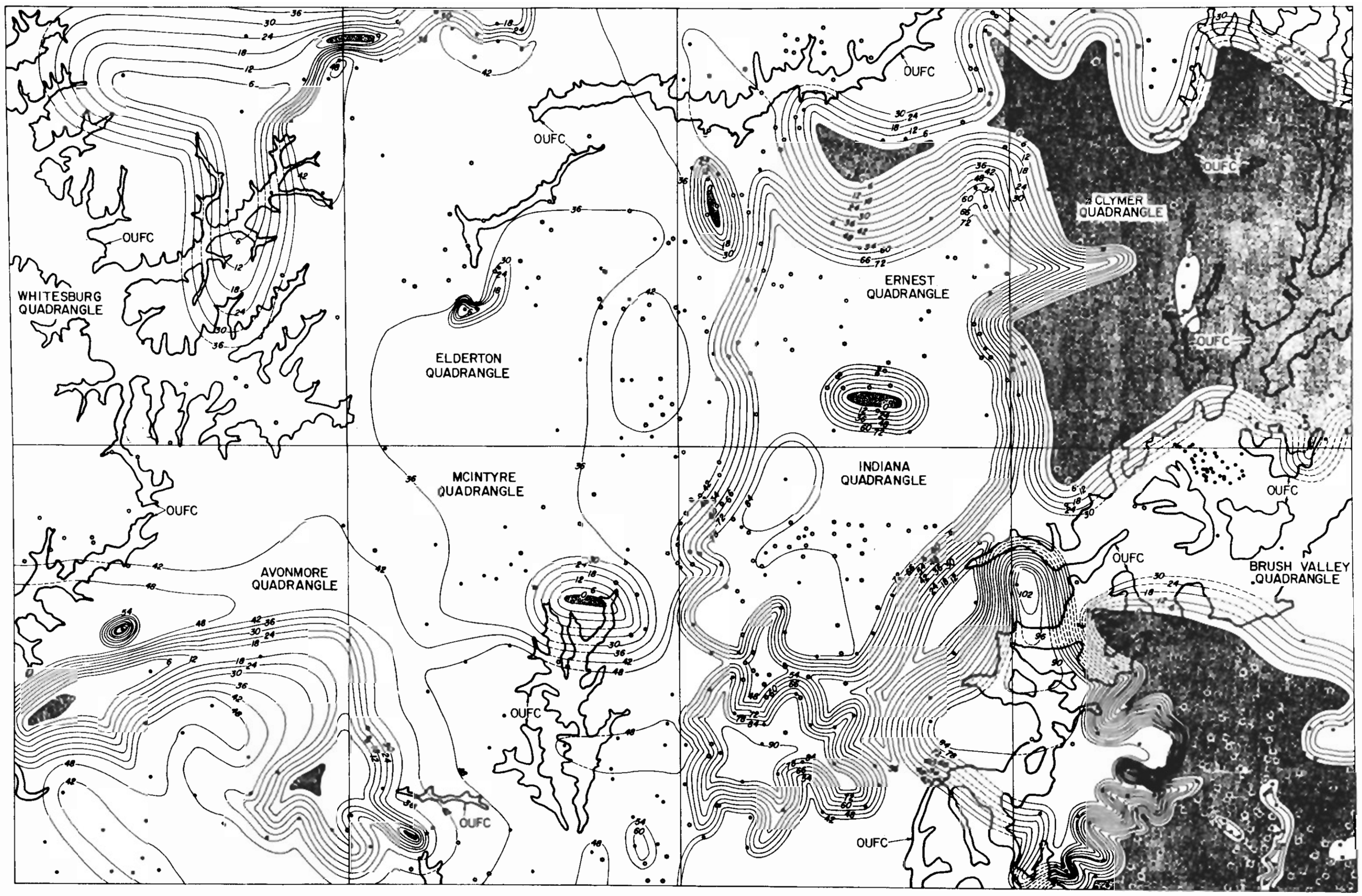
In some cases, the coalbed may thicken substantially immediately proximate to the channel. Some coalbeds have been known to double or triple in thickness (19). This thickening may be the consequence of (1) increased peat deposition contiguous to the channel, stimulated by the more rapid subsidence of the denser sandstone (relative to the density of peat); (2) slumping of the coalbed over itself; or (3) an increasing number of partings as the channel is approached. However, any possible economic advantage gained through thickening of the coalbed is lost if the coalbed has been eroded by channel activity. Additionally, all of the previously described problems associated with channel-phase sandstones are likely to be more prominent in the area immediately adjacent to the channel deposit.

PATTERNS OF COAL DISTRIBUTION

To delineate areas of discontinuous coal, isopach maps of the Upper Freeport, Lower Freeport, and Lower Kittanning Coalbeds were constructed (figs. 7-9). A contour interval of 6 in (15 cm) was used so that any subtle changes in coalbed thickness that might impend with approach to a coalbed discontinuity could be discerned. (The contour maps constructed for this study were not computer-generated. Even spacing of contour lines was used to arbitrarily eliminate the effects of irregularities in channel shape.) Areas of thin, split, or no coal were closely scrutinized for clues leading to interpretations of the genesis of these discontinuities.

UPPER FREEPORT COALBED

The Indiana quadrangle and the southern half of the Ernest quadrangle are underlain by thick accumulations of Upper Freeport coal (60 to 92 in [150 to 230 cm]). Two anomalously thick tracts of coal are present in the western Brush Valley quadrangle and in the western Avonmore quadrangle (fig. 7). Numerous small, pod-shaped want areas (< 2 mi^2 [< 5 km^2] in size) occur throughout the study area. Extensive areas of no coal are found in the Clymer and Brush Valley quadrangles (fig. 7). Although no study has specifically addressed the absence of the Upper Freeport Coalbed in these



LEGEND

- **OUFC** Outcrop of Upper Freeport Coalbed
- • Corehole data point
- • Geophysical-log data point (Only presence or absence of the coalbed has been determined from geophysical logs. Absence of the coalbed is indicated by "O".)
- Coal-thickness contour line (Contour interval = 6 in. Broken lines indicate inferred contours.)
- Upper Freeport Coalbed absent

0 2 4

Scale, mi

FIGURE 7. - Isopach map of Upper Freeport Coalbed.

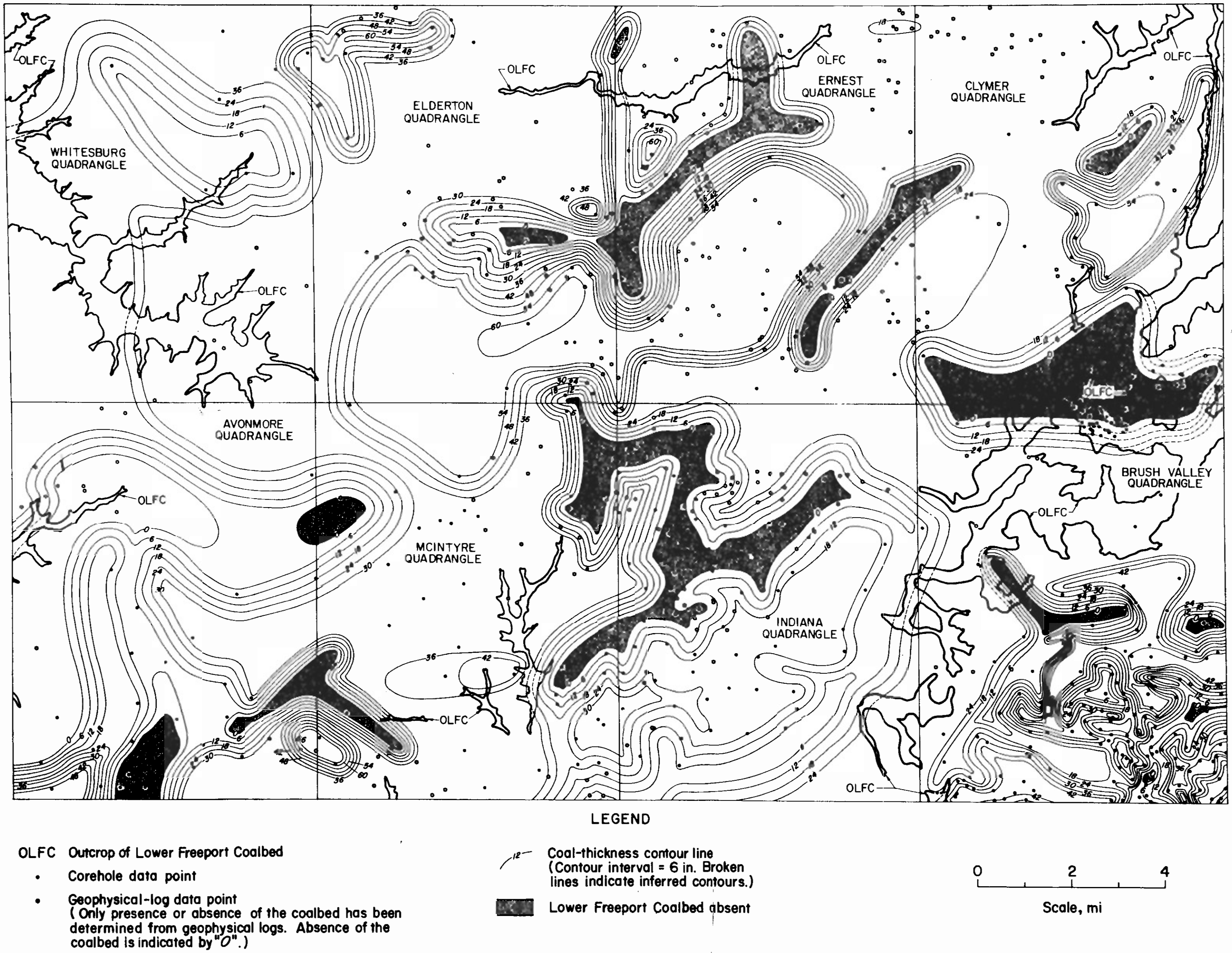
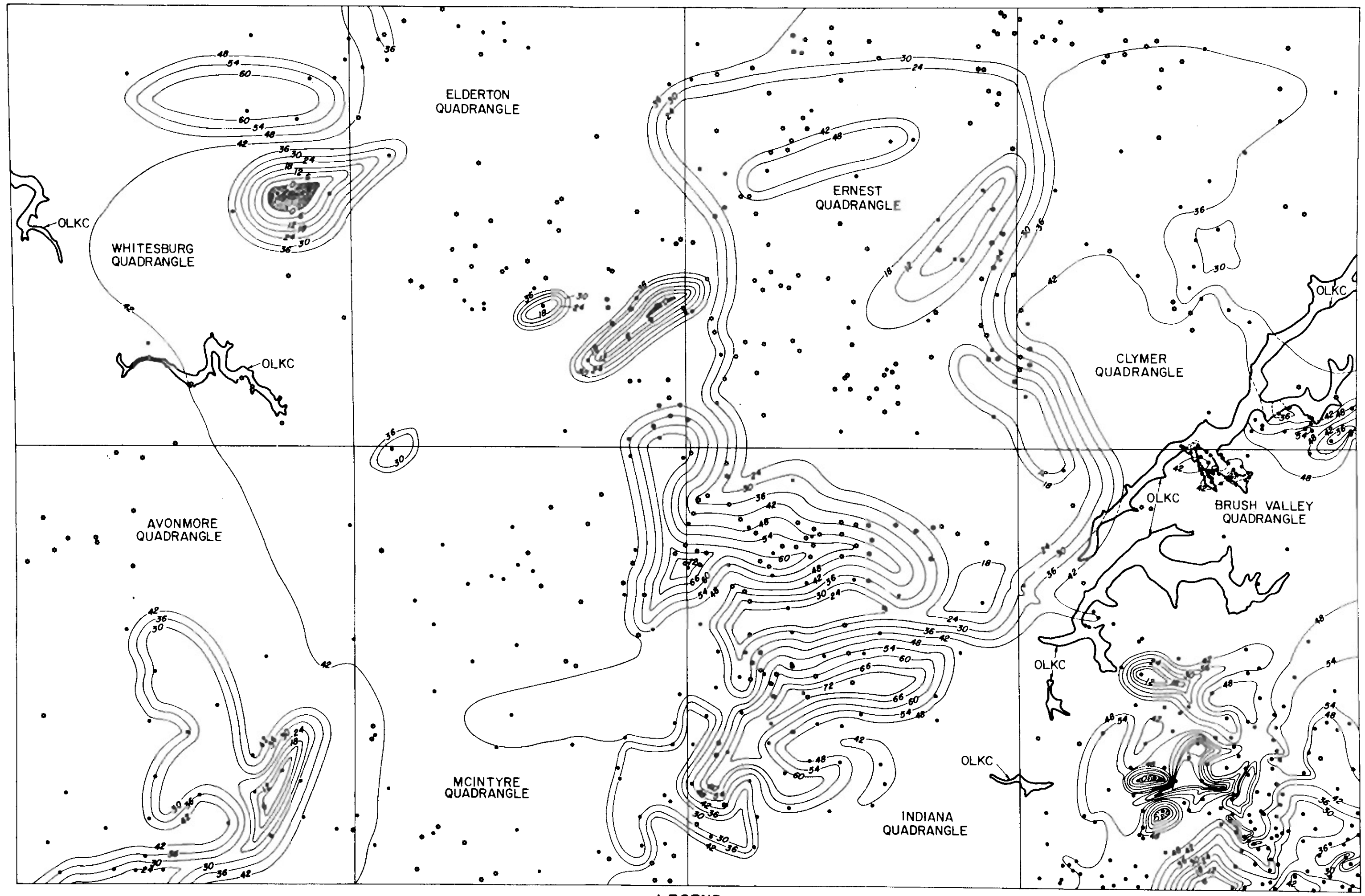


FIGURE 8. - Isopach map of Lower Freeport Coalbed.



LEGEND

OLKC Outcrop of Lower Kittanning Coalbed

• Corehole data point

• Geophysical-log data point (Only presence or absence of the coalbed has been determined from geophysical logs. Absence of the coalbed is indicated by "O".)

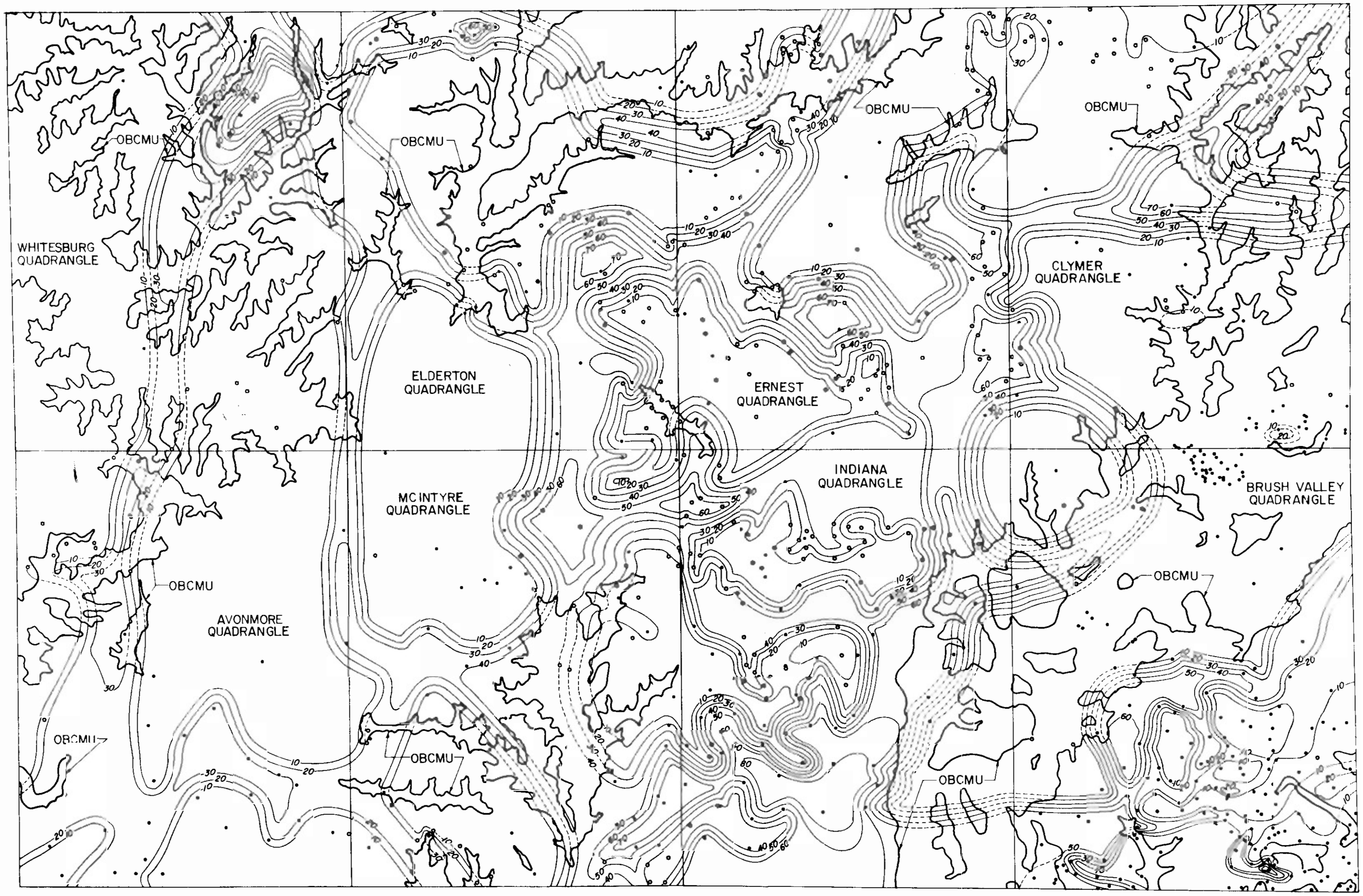
Coal-thickness contour line (Contour interval = 6 in. Broken lines indicate inferred contours.)

Lower Kittanning Coalbed absent

0 2 4

Scale, mi

FIGURE 9. - Isopach map of Lower Kittanning Coalbed.



LEGEND

OBCMU Outcrop of Brush Creek marine unit

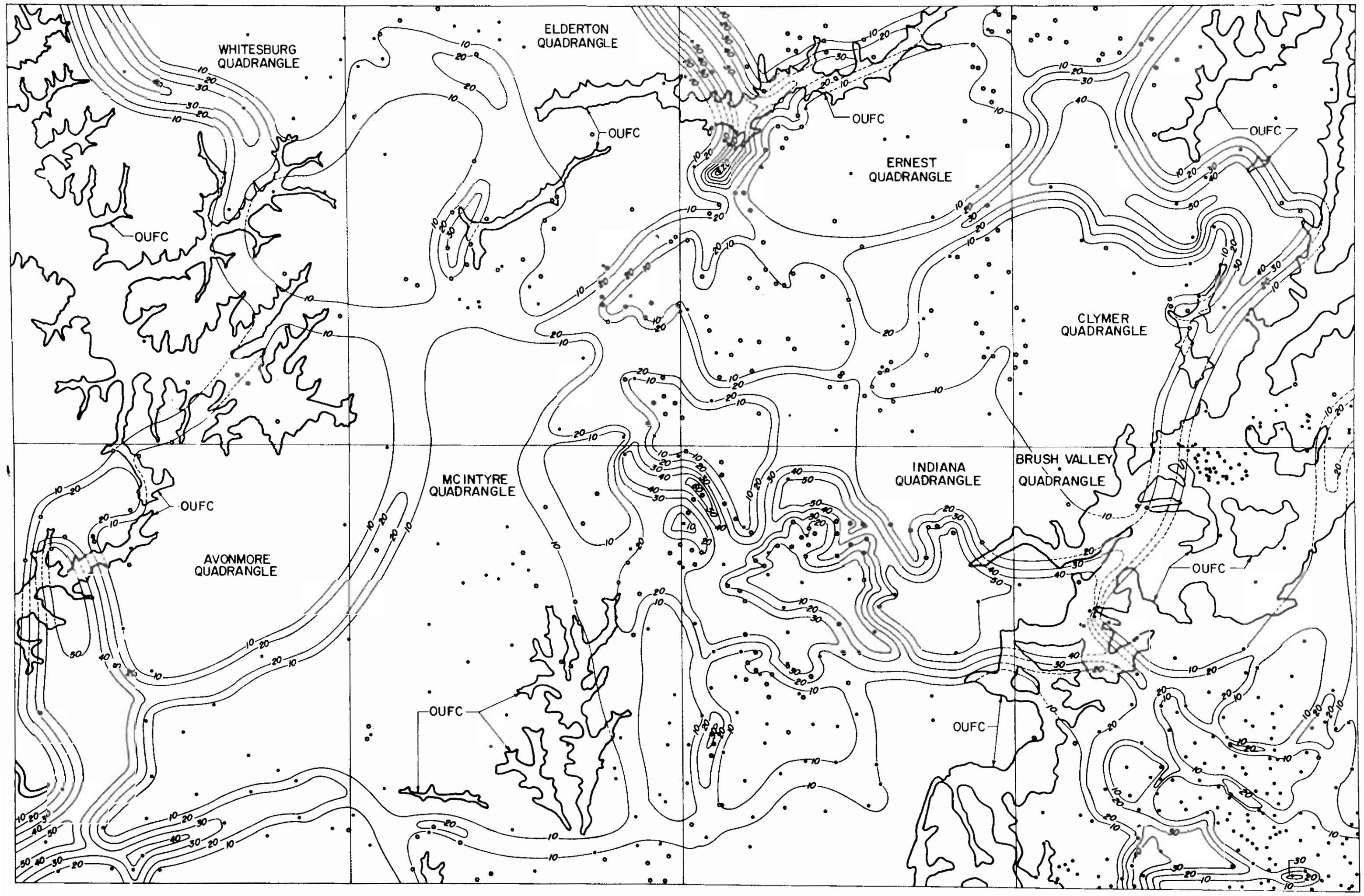
- • Corehole data point
- ∘ Geophysical-log data point

Sandstone-thickness contour line (Contour interval = 10 ft. Broken lines indicate inferred contours.)

0 2 4

Scale, mi

FIGURE 10. - Sandstone isolith map of Brush Creek marine unit to Upper Freeport Coalbed interval.



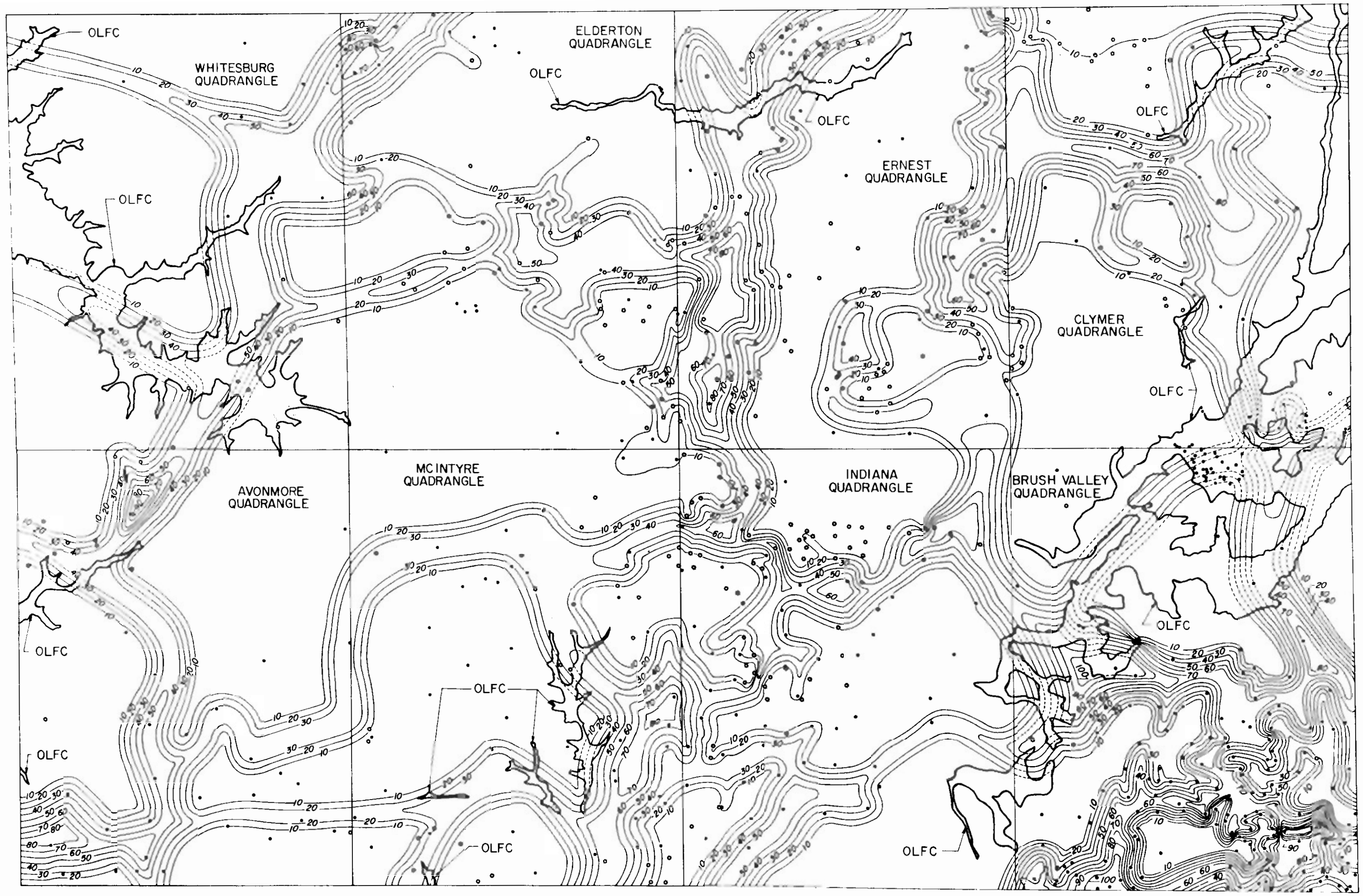
LEGEND

OUFC Outcrop of Upper Freeport Coalbed
• Corehole data point
∘ Geophysical-log data point

Sandstone-thickness contour line (Contour interval = 10 ft. Broken lines indicate inferred contours.)

Scale, mi: 0 2 4

FIGURE 11. - Sandstone isolith map of Upper Freeport Coalbed to Lower Freeport Coalbed interval.



LEGEND

OLFC Outcrop of Lower Freeport Coalbed
• Corehole data point
∘ Geophysical-log data point

Sandstone-thickness contour line (Contour interval = 10 ft. Broken lines indicate inferred contours.)

Scale, mi: 0 2 4

FIGURE 12. - Sandstone isolith map of Lower Freeport Coalbed to Lower Kittanning Coalbed interval.

quadrangles, inferences in the literature indicate nondeposition of the coal over growing structural highs, such as the Chestnut Ridge, Nolo, and Laurel Hill anticlines (18, 34).

LOWER FREEPORT COALBED

Lying an average of 80 ft (24 m) below the Upper Freeport Coalbed, the Lower Freeport Coalbed is the most laterally discontinuous of the three coalbeds analyzed in this study. Want areas in the Lower Freeport Coalbed typically possess a shoestring geometry (fig. 8). Unlike the Upper Freeport and Lower Kittanning Coalbeds, the Lower Freeport is relatively thin and is only locally greater than 60 in (150 cm) thick.

LOWER KITTANNING COALBED

The Lower Kittanning Coalbed occurs an average of 200 ft (60 m) below the Upper Freeport Coalbed. Of the three coalbeds examined in this study, the Lower Kittanning is the most laterally persistent; fewer discontinuities have been identified in this coalbed than in the overlying Upper and Lower Freeport Coalbeds. The thickest accumulations of the Lower Kittanning Coalbed (> 72 in [> 180 cm]) occur in the Indiana and Brush Valley quadrangles (fig. 9).

SANDSTONE DISTRIBUTION

Sandstone isolith maps with a contour interval of 10 ft (3 m) were drawn for three intervals, one immediately suprajacent to each of the three economic coalbeds (figs. 10-12). These intervals were (1) the Brush Creek marine horizon to the Upper Freeport Coalbed, (2) the Upper Freeport Coalbed to the Lower Freeport Coalbed, and (3) the Lower Freeport Coalbed to the Lower Kittanning Coalbed. These divisions were chosen because they are easily recognized by their delimiting marker beds. These intervals are not of equal thickness, nor do they individually maintain uniform thicknesses across the study area. However, the thickness of each interval tends to increase where thick sandstone is present.

As revealed by the sandstone isolith maps and numerous cross sections, sandstone bodies in all three intervals display a shoestring geometry (1-2 mi [2-4 km] wide, tens of miles long). These units were interpreted as channel-phase sandstones that interfinger laterally with alluvial plain and interdistributary bay deposits. Several major channels (> 40 ft [> 12 m] thick) and numerous minor ancillary channels constitute the sandstone strata in each interval. A few crevasse splay deposits, recognized by their coarsening upward character and lobate geometry, were delineated. Examples can be seen in the Brush Creek to Upper Freeport interval in the eastern McIntyre quadrangle (center of figure 10) and in the Lower Freeport to Lower Kittanning interval in the central Elderton and central Indiana quadrangles (figure 12, north-central and east-central portions). Many of the channel sandstones with numerous bifurcations can be traced the length of the study area. In many cases, these sandstone channels trend north-south to northeast-southwest and lie subparallel to local structures.

RELATIONSHIP BETWEEN COAL AND SANDSTONE THICKNESSES

Through comparison of the coalbed isopach and corresponding sandstone isolith maps, a relationship between coal and sandstone thicknesses was clearly perceived. The coalbed isopachs indicated 41 want areas in the study area. Of these, 24 (59 pct) are located subjacent to thick (> 20 ft [> 6 m]) sandstone accumulations. Generally, these want areas display elongate to linear geometries and appear to be related to channel-phase sandstone systems. These discontinuities are most probably the result of (1) erosional scouring by channels that breached their levees and issued across marsh-swamp environments during episodes of flooding or (2) scouring of buried semiconsolidated peat deposits by younger channels. After eroding coeval and older, underlying deposits, the channels filled with sand or, occasionally, finer grained sediments.

Numerous examples of the thick-sandstone, thin-subjacent-coalbed association were found throughout the study area. In the northeastern portion of the Whitesburg quadrangle, a 1-in (3-cm) thickness of Upper Freeport coal is overlain by more than 90 ft (27 m) of sandstone. (Compare figures 7 and 10.) Figure 13 is a cross section showing this relationship. Apparently, the coalbed was incised by a large channel that was subsequently filled with sediment. Within 5,000 ft (1,500 m) laterally from the sandstone-filled channel, the Upper Freeport Coalbed regains its normal thickness of approximately 3 ft (1 m) for this portion of the study area. Similar associations of thick sandstone and thin Upper Freeport coal sequences occur in the western Avonmore, east-central McIntyre, south-central Ernest, and east-central Indiana quadrangles.

The Lower Freeport Coalbed has been scoured out by channels in several locations in the study area. Manifestations of this phenomenon are exhibited in the northern Indiana and central Brush Valley quadrangles, and along the border between the McIntyre and Avonmore quadrangles. (Compare figures 8 and 11.)

The Lower Kittanning Coalbed, although the most persistent coalbed in the study area, is not immune to the erosive effects of channels. Notable examples of channel scouring of the Lower Kittanning Coalbed are evident in the west-central Indiana, east-central Whitesburg, and central Brush Valley quadrangles. (Compare figures 9 and 12.) The cross section in figure 14 illustrates that erosion by a channel has removed a portion of the Lower Kittanning Coalbed in the central Brush Valley quadrangle. This cross section shows that the Lower Freeport Coalbed also has been removed by channel scouring in the same area. The sandstone isolith maps suggest vertical stacking of channel-phase sandstones at this location. (Compare figures 11 and 12.)

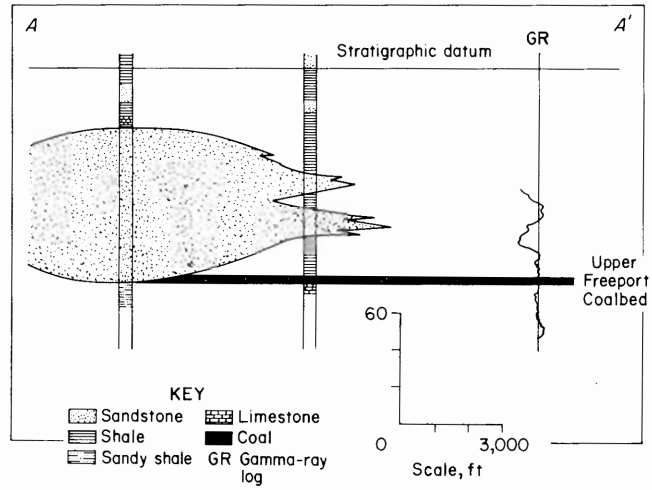


FIGURE 13. - Cross section depicting scouring of Upper Freeport Coalbed by a channel. (For location, see line *A-A′* in figure 3.)

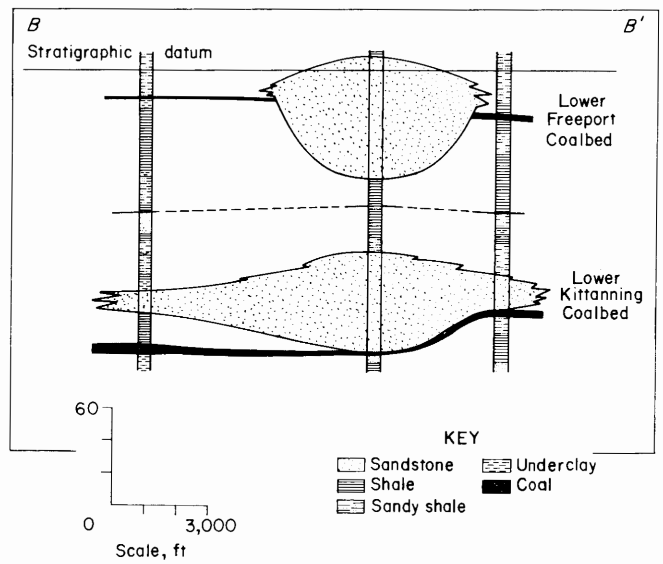


FIGURE 14. - Cross section depicting scouring of Lower Freeport and Lower Kittanning Coalbeds by channels. (For location, see line *B-B′* in figure 3.)

Ancient fluvio-deltaic channels cannot always be detected by delineating shoestring sandstone deposits. In certain geologic settings, a fluvio-deltaic channel may fill with clay rather than sand (5). Therefore, it is reasonable to assume that some coalbed discontinuities that do not lie in areas of thick sandstone accumulations may be attributed to clay-filled, abandoned channels. Several channels filled with clay and shale have been recognized in mines working the Lower Freeport Coalbed in the northern Whitesburg and Elderton quadrangles (Gary D. Ball, Rochester & Pittsburgh Coal Co., personal communication). Unfortunately, such clay-filled channels are practically indistinguishable from the surrounding alluvial plain or interdistributary bay deposits on geophysical logs and in corehole descriptions. Consequently, recognition and prediction of these channels require extensive field work, mine reconnaissance, or thorough well control.

EFFECTS OF CHANNELS ON PEAT DEPOSITS

Fluvio-deltaic channels exert a profound effect on peat accumulations by the removal of peat. Although some peat may be displaced laterally by differential compaction of a sand-filled channel, most absences of peat are a result of current action within the channel. However, processes associated with active channels and features related to sandstone-filled channel bodies also decidedly influence adjoining peat deposits. Splits in the coalbed, thinning of the coalbed over levee deposits, and, in some cases, decreased coal quality are consequences of contemporaneous channel activity. On the other hand, topographic highs created by inequitable compaction of sand-filled channels relative to adjoining muds inhibit the accumulation of peat and result in thinning or absence of coalbeds. In addition, some instances of deterioration of coal quality result when sulfur-bearing solutions percolate through permeable sandstone-filled channels.

SPLITS

Splits in a coalbed are generated when detrital material is introduced into a peat swamp by overbank flooding or by crevasse splays (fig. 15). Coalbed partings generated by crevasse splays tend to be areally restricted, coarsening upward sequences that occur on one side of the channel (fig. 15). Crevasse splays are generally singular events; therefore, they produce one fairly thick split in a coalbed. Overbank flooding creates thinner, finer grained, laterally persistent coalbed partings. Because flooding events occur repeatedly and affect widespread areas, numerous coalbed partings resulting from overbank flooding may be found on both sides of the channel (fig. 15).

The Lower Freeport Coalbed is split into three benches immediately adjacent to a channel deposit in the east-central portion of the Ernest quadrangle, as shown in the cross section in figure 16. The coalbed is split only on one side of the channel, indicating that crevasse splays produced the partings. Other corehole data showed that the Upper Freeport Coalbed is also split, in the southwestern McIntyre and north-central Whitesburg quadrangles and that the Lower Kittanning Coalbed forms two benches in the central Brush Valley quadrangle (<u>16</u>).

THINNING OF COALBEDS OVER TOPOGRAPHIC HIGHS

Topographic highs produced by the formation of natural levees adjacent to

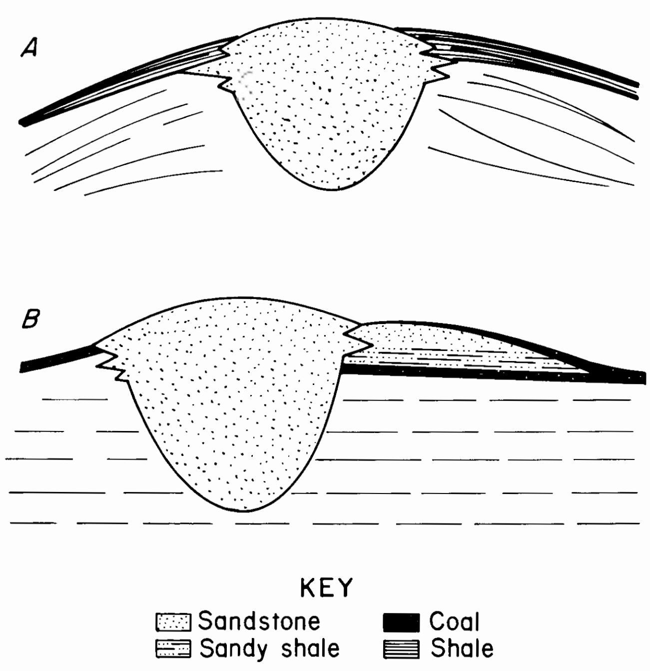


FIGURE 15. - Two ways splitting is induced in a coalbed. *A*, Overbank flooding; *B*, crevasse splay.

channels inhibit the accumulation of peat. These high areas tend to be drier and more oxidizing than lower areas, thereby precluding preservation of peat. The change in elevation of the coalbed as it rides up over the levee deposits is commonly referred to as a roll. The Lower Kittanning Coalbed thins adjacent to a channel in the southern Brush Valley quadrangle, as exhibited in the cross section in figure 17. The coalbed thins to 4 in (10 cm) over accumulations of sandy shale (natural levee) that were deposited adjacent to the channel during overbank flooding events. Other examples of coalbed thinning over topographically high levee deposits are found in the Lower Freeport Coalbed in the southwestern McIntyre and eastern Elderton quadrangles. (Compare figures 8 and 11.)

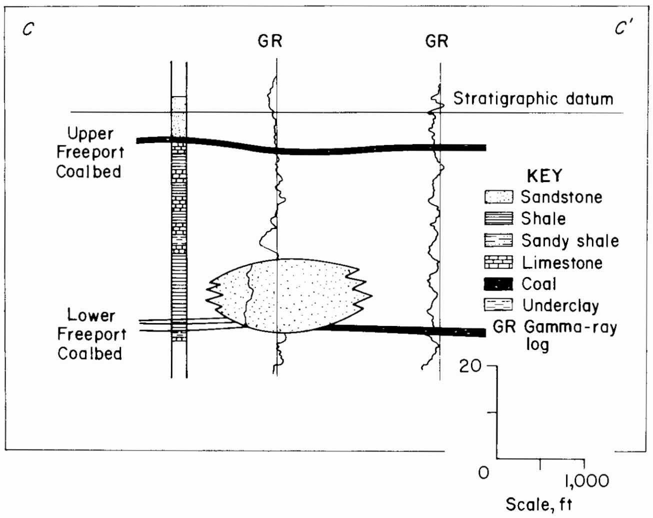


FIGURE 16. - Cross section of splits in Lower Freeport Coalbed. (For location, see line *C-C′* in figure 3.)

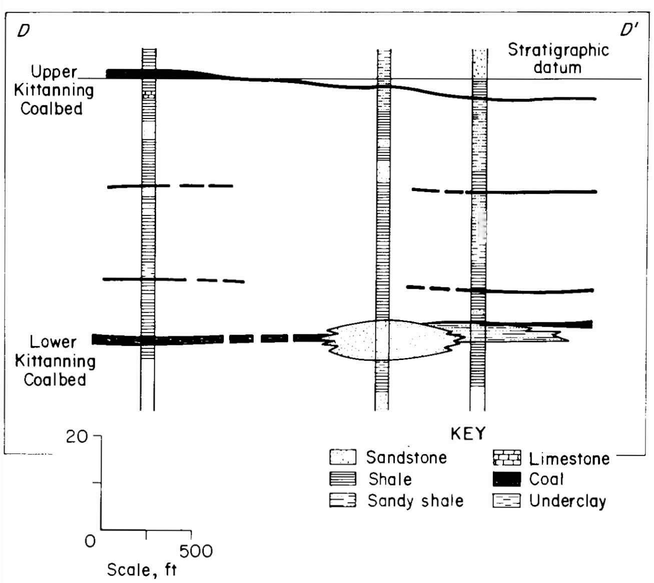


FIGURE 17. - Cross section illustrating thinning of Lower Kittanning Coalbed over a natural levee. (For location, see line *D-D′* in figure 3.)

Channel-sandstone bodies experience insignificant compaction after deposition and therefore form topographic highs as adjoining muds dewater and compact. Peat swamps developed after sand deposition and mud compaction are unable to successfully inhabit these high areas, and the result is absence or thinning of coalbeds. Although no examples of this phenomenon have been recognized in the study area, others have documented thinning of the Upper Hartshorne Coalbed over Upper Hartshorne distributary-channel sandstones in Oklahoma (14).

ABNORMALLY THICK PEAT ACCUMULATIONS

Differential compaction of a channel filling with sand relative to contiguous deposits may generate abnormally thick peat accumulations. As the sand accumulates, sediments under the channel body compact differentially. This is reflected at the surface as differential subsidence. Deposition in contemporaneous peat swamps immediately adjacent to the channel keeps pace with this "subsidence," thus producing thick accretions of peat. Pods of unusually thick coal may also be the consequence of flooding events that piled up peat along the banks of the channel (27) or sedimentary slumping.

Two tracts of anomalously thick Upper Freeport coal are present in the western Avonmore and western Brush Valley quadrangles (fig. 7). Both of these thick-coal areas adjoin channel-phase sandstones. Figure 18 depicts the increased thickness of the coalbed in the Brush Valley quadrangle. The advantages of mining these thick coal deposits are quickly offset by the previously mentioned economic and safety problems attendant to channel discontinuities. This case proves to be no exception, as within 1,000 ft (305 m) in lateral distance to the west of this thick accumulation, the coal has been almost entirely removed by current action within the channel.

COAL QUALITY

In some cases, the quality of coal is adversely affected by the presence of channels. Overbank flooding in an active channel may increase the mineral content of the coalbed by introducing clastic material into the peat swamp. An inactive, sand-filled channel may serve as a conduit for the infiltration of sulfur-enriched solutions, thereby increasing the sulfur content of the coalbed.

Deterioration of coal quality with approach to a sand-filled channel does not occur in every case. However, a few examples of this negative influence of channels were found in the study area. (The lack of extensive coal-quality data precluded the construction of iso-sulfur maps of the entire study area. Limited data permitted only local evaluations.)

In the central Brush Valley quadrangle, a sandstone-filled channel immediately overlies the Lower Kittanning Coalbed. In its active phase, this channel scoured out portions of the peat precursor of the coalbed. Where the Lower Kittanning Coalbed is overlain by the channel sandstone, the sulfur content of the coalbed generally varies from 3 to greater than 6 pct (fig. 19). Where the sandstone channel is absent, the sulfur content of the coalbed averages 2.50 pct or less. The iso-sulfur contour lines lie subparallel to the trend of the channel-phase sandstone, implying that there is some influence by the channel.

Ash content of the coalbeds does not display the strong correspondence to channel deposits as does sulfur content.

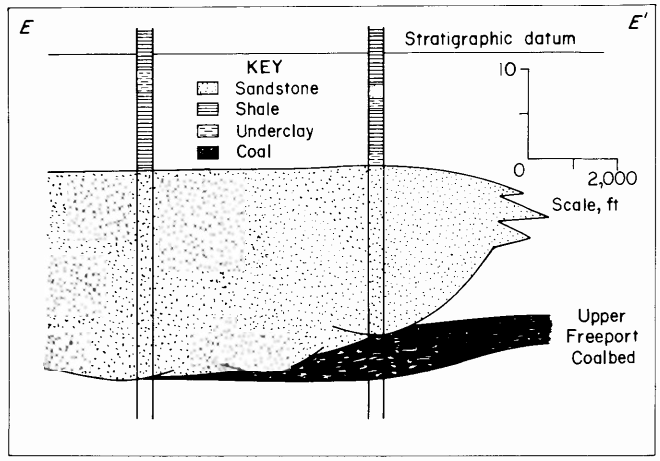


FIGURE 18. - Cross section showing anomalous thickness of Upper Freeport Coalbed adjacent to a channel deposit. (For location, see line E-E' in figure 3.)

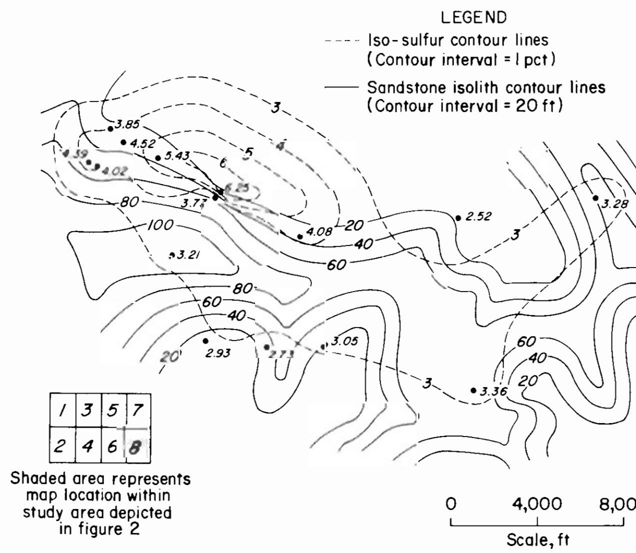


FIGURE 19. - Map of increased sulfur content in Lower Kittanning Coalbed with approach to a sandstone-filled channel.

In some coreholes adjacent to channels, a higher coalbed ash content was indicated. However, no distinct correlation could be discerned.

EFFECTS OF STRUCTURAL CONTROLS ON CHANNELS

As mentioned previously, structural folds growing contemporaneously with peat deposition may have produced extensive want areas in the Upper Freeport Coalbed over the Chestnut Ridge and Nolo anticlines. Subtle effects of structural controls are also expressed by channel-phase sandstones. Several areas of stacked sandstone zones that tend to coincide with structurally low areas have been recognized in Conemaugh Group strata (18). In this study, comparison of the three sandstone isolith maps and the structural contour map of the study area revealed some relationships between the positions of many of the sandstone-filled channels and structural (paleotopographic) lows.

Comparison of the sandstone isolith maps (figs. 10-12) reveals that some sandstone channels are vertically juxtaposed in successive horizons. Several areas of sandstone stacking coincide with and lie subparallel to the synclines (structural and topographic lows) in the area. In some cases, sandstone channels in all three intervals are vertically stacked in the synclines (along the axis of the Elders Ridge syncline, on the western flank of the Brush Valley syncline, and along the northern portion of the axis of the Latrobe syncline). The superposition of sandstone-filled channels and their correspondence to local structural trends imply that folds were growing during the time of sedimentation and that they exerted some control on the location of channel courses.

PREDICTION OF COALBED DISCONTINUITIES IN ADVANCE OF MINING

The serious hazards that accompany coalbed discontinuities may severely hamper mine development. All mine personnel involved in planning and development should be aware of the existence of coalbed discontinuities and the problems they create in underground coal mines.

The results of this study showed that in the portion of the northern Appalachian basin in which the data were collected, coalbed discontinuities are most commonly the result of scouring by ancient fluvio-deltaic channels. In many cases, these channels are not randomly oriented, but tend to lie subparallel to local flexures; in some cases, they are preferentially located along synclinal axes. With these points in mind, several steps should be taken when a prospective mine property is evaluated with respect to coalbed discontinuities. These steps are as follows:

1. Build a data base for the area. By including information from gas-well geophysical logs, the data base will be greatly enhanced at a fraction of the cost of drilling exploratory coreholes.
2. Construct a structure map of the area, paying particular attention to the traces of anticlinal and synclinal axes.
3. Delineate ancient channels through the construction of sandstone isolith maps. (In western Pennsylvania, the channels may tend to be vertically stacked and often will coincide with structurally low areas.)
4. After the channel deposits have been delineated, mine development should be planned for areas where channels are absent. If it is impossible to avoid zones where there is a high probability of encountering channels, mine layouts should be designed to intersect the channel trend at an angle which most alleviates the hazardous conditions that may be induced by the presence of the channel. In this portion of the Appalachian basin, channels tend to follow strike. Therefore, by orienting headings at a suitable angle with respect to strike, the number of mine entries hampered by the adverse conditions created by fluvio-deltaic channel discontinuities could be limited.

Using the criteria developed in this study for the recognition of coalbed discontinuities, areas likely to be affected by the problems associated with discontinuities can be predicted well in advance of mine development. Channel deposits can be traced for several miles, and, because of their vertically stacked arrangement in this portion of the Appalachian basin, problem areas can also be predicted deeper in the section. By anticipating the occurrence of coalbed discontinuities, and planning mine development accordingly, the safety and economic hazards discontinuities create in underground coal mines may be minimized or avoided.

SUMMARY AND CONCLUSIONS

Sandstone-filled channels are the predominant coalbed discontinuity in the studied portion of Indiana and Armstrong Counties. Of the 41 want areas in the study area, 24 (59 pct) lie subjacent to thick sandstone accumulations. However, if areas of split coal adjacent to channels and areas of thin coal over natural levee deposits are also included, then approximately 80 pct of all interruptions in the economic coalbeds in this area result from channel activity.

Serious safety hazards and economic risks are created in underground coal mines by sandstone-filled channels. An obvious economic disadvantage results when the coalbed has been removed by channel scouring. Other economic disadvantages engendered by channels are splitting of the coalbed and deterioration of coal quality in the proximity of the channel. Significant safety hazards correlated with channel-sandstone discontinuities include roof-rock instability, water accumulation problems, and dangers associated with methane emissions.

The use of inexpensive gas-well geophysical logs can assist in the delineation of sandstone-filled channels. Prospective mine properties may be evaluated with respect to coalbed discontinuities without the drilling of numerous costly exploratory boreholes. Because fluvio-deltaic channels in the northern Appalachian basin possess shoestring geometries, their trends and occurrence may be predicted well in advance of mine development with an adequate data base. Recognition of the various features associated with channels--coalbed thinning over levee deposits, splitting of the coalbed, diminished coal quality, and rolls in the coalbed--will aid in the prediction of coalbed discontinuities caused by channel scouring before the actual want areas are encountered. Once the location of a channel deposit is ascertained, the direction of mine headings can be planned to avoid the unfavorable mining conditions that accompany channel discontinuities.

If sufficient data are available, the methods described in this report can be applied to other coal-bearing areas and basins to predict the occurrence of channel discontinuities.

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