Geologic Structure and Mine Roof Falls in Selected Coal Beds Within Appalachia

David Hylbert

Research Report No. 8
APPALACHIAN DEVELOPMENT CENTER
Morehead State University
Morehead, Kentucky

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David Hylbert
Professor, Department of Geoscience
Morehead State University
Morehead, Kentucky

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Morehead, Kentucky

March 1984

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

Coal mining has always been a dangerous occupation. Anyone who has lived close to a mining area has heard stories about miners trapped or killed as a result of a mine roof fall. It has been assumed by many people that such tragedy is inevitably linked to coal mining.

The major premise of this report is that precautionary measures can be taken to prevent some percentage of mine roof fall accidents by examining the geologic structure above a potential or existing mine site. The approach used and the results of this report should be of particular interest to mining company engineers, geologists, mine workers unions, and mining regulatory agencies.

Douglas Dotterweich
Editor

ABSTRACT

This study investigated stratigraphic and structural causes of roof falls in room-and-pillar drift coal mines in nine mines in eastern Kentucky and the Dunkard Basin of West Virginia and Pennsylvania.

Results of earlier stratigraphic and structural studies were applied to several new mines. It was found that similiar rock sequences contributed to unstable roof conditions. Structure contour and isopach maps were found useful in projecting these trends together with fence diagrams.

Using Landsat imagery, a direct relationship was found between lineament direction and the trends of rock jointing, roof fall zones, "snap top" zones and sandstone channels in the examples cited. It was found that, by analyzing lineament intersections, from 50 percent to 65 percent coincided with roof falls.

INTRODUCTION

Study Background

This report summarizes the results of research conducted pursuant to Contract number J0188002 between the U.S. Bureau of Mines and Morehead State University, Morehead, Kentucky.

The major objectives of the study were to consider roof falls in selected underground coal mines in the eastern Kentucky area from a geologic standpoint. Specifically, the study dealt with an evaluation of causes of roof falls in these mines by considering roof-rock characteristics. In addition, efforts were made to test and demonstrate the efficiency of geologic hazard projection techniques developed under a previous contract (H0133018).

Contract number J0188002 was submitted to the Bureau as an unsolicited proposal and was funded for a two-year period from December 12, 1977 through December 12, 1979. However, a six-month modification to the original contract provided for an evaluation of the eastern Kentucky mining area using Landsat imagery and a comparison of this area with selected mines in the Dunkard Basin of northern West Virginia and southwestern Pennsylvania (Figure 1). A second three-month contract modification extended the contract to September 12, 1980.

This report is written using United States Bureau of Mines format. The units of measure are duel English-metric, except for metric usage in classification schemes and video enhancing scales.

Location of Study Areas and Mine Selection

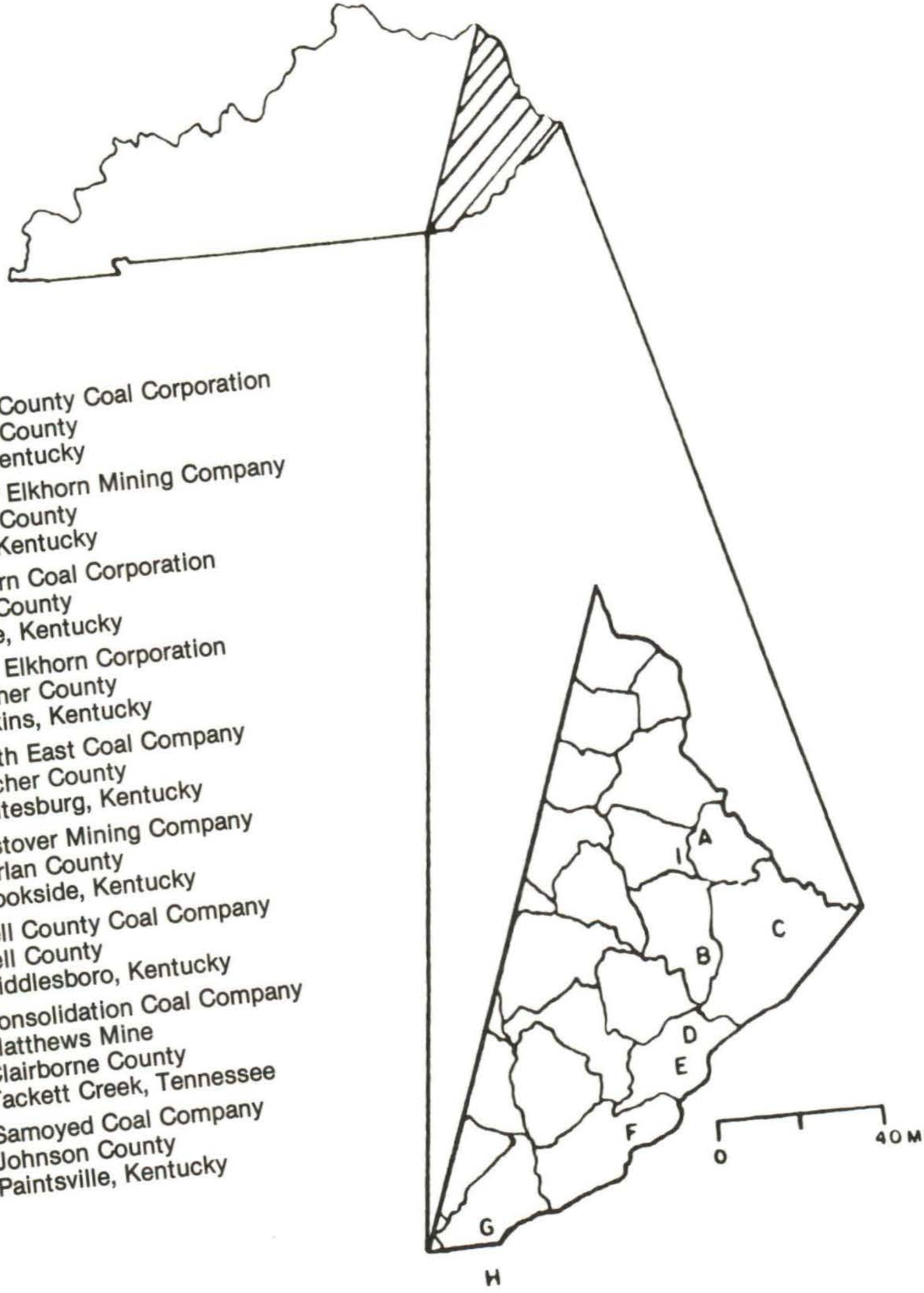
The major objective early in the study was to identify at least six mines in eastern Kentucky that are operating in the Harlan and Darby coal beds or their equivalents for study. Based on discussions with mine management personnel, the Kentucky State Department of Mines and Minerals and district offices of the Mining Enforcement and Safety Administration, several possible mines were identified. Theses mines were then visited as potential study sites. Figure 2 shows the locations of mines that agreed to cooperate in the research and Figure 3 shows these companies and respective coal beds. It will be noted from Figure 3 that the Martin County Coal Company operates in the Coalburg and Stockton Coal beds, the Samoyed in the Stockton, and Eastern Coal Corporation in the Lower Elkhorn (Pond Creek). However, because of geographic coverage and comparison purposes these mines were also included in the study.

Regional Structure

As a basis for a consideration of possible structural influences in the eastern Kentucky area Figure 4 was compiled. Most of the principle regional structural elements are shown together with sources of data. It will be noted that the previously mapped extent of the structures is located outside of the study area. However, these structures were considered because of their possible effects beyond their mapped extent. Also, several of the structures were analyzed using Landsat imagery in order to test the effectiveness of analysis methods developed in this study and the projection of known structures beyond their mapped extent. Table 1 summarizes the more important structures in the area.

Figure 1. Study Areas in Eastern Kentucky and Northern West Virginia

Figure 2. Names and Locations of Cooperating Coal Companies



A Martin County Coal Corporation
Martin County
Inez, Kentucky

B Turner Elkhorn Mining Company
Floyd County
Drift, Kentucky

C Eastern Coal Corporation
Pike County
Stone, Kentucky

D Beth Elkhorn Corporation
Letcher County
Jenkins, Kentucky

E South East Coal Company
Letcher County
Whitesburg, Kentucky

F Eastover Mining Company
Harlan County
Brookside, Kentucky

G Bell County Coal Company
Bell County
Middlesboro, Kentucky

H Consolidation Coal Company
Matthews Mine
Clairborne County
Tackett Creek, Tennessee

I Samoyed Coal Company
Johnson County
Paintsville, Kentucky

Figure 3. Cooperating Coal Companies and Coal Bed Correlations

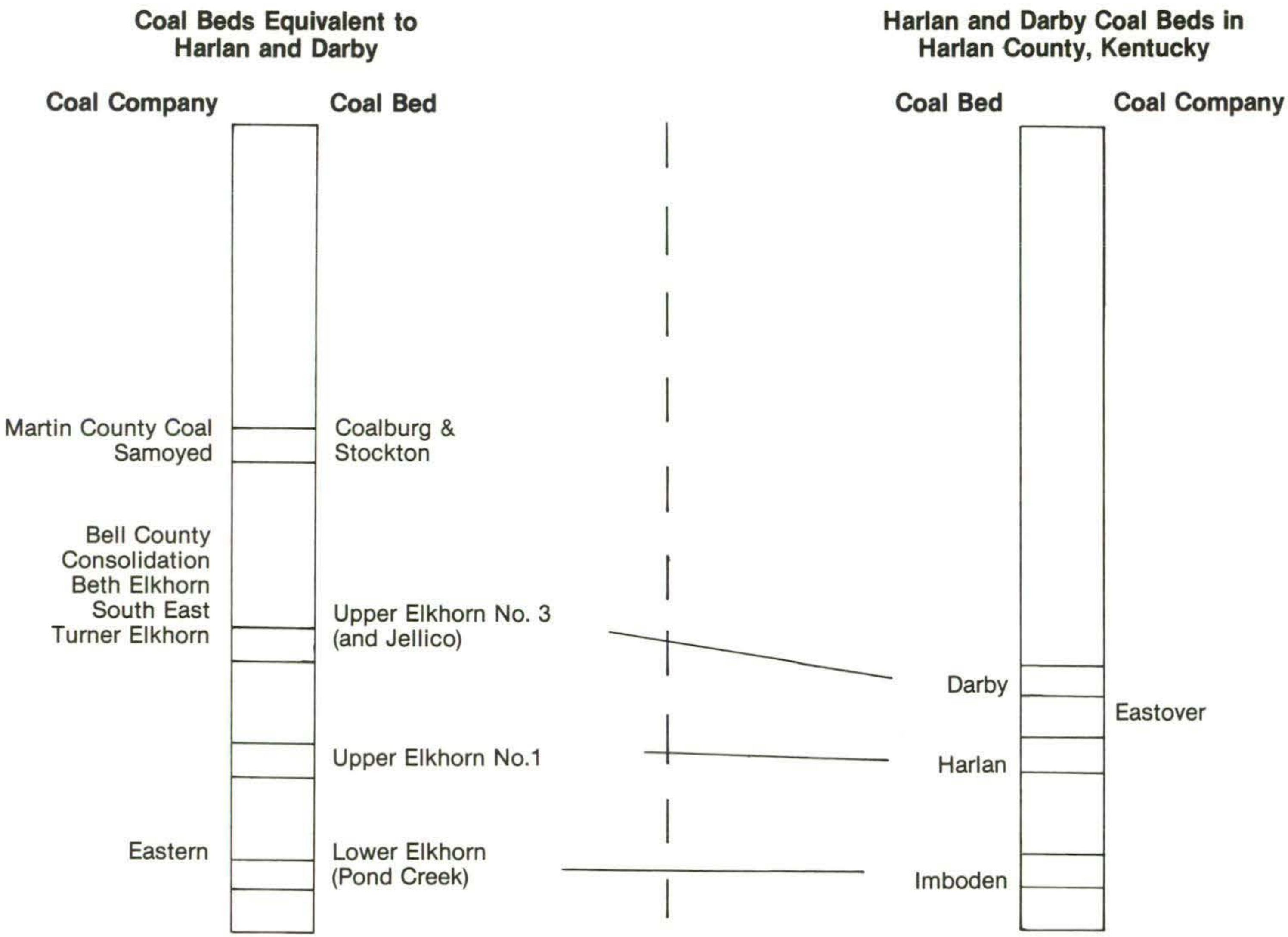
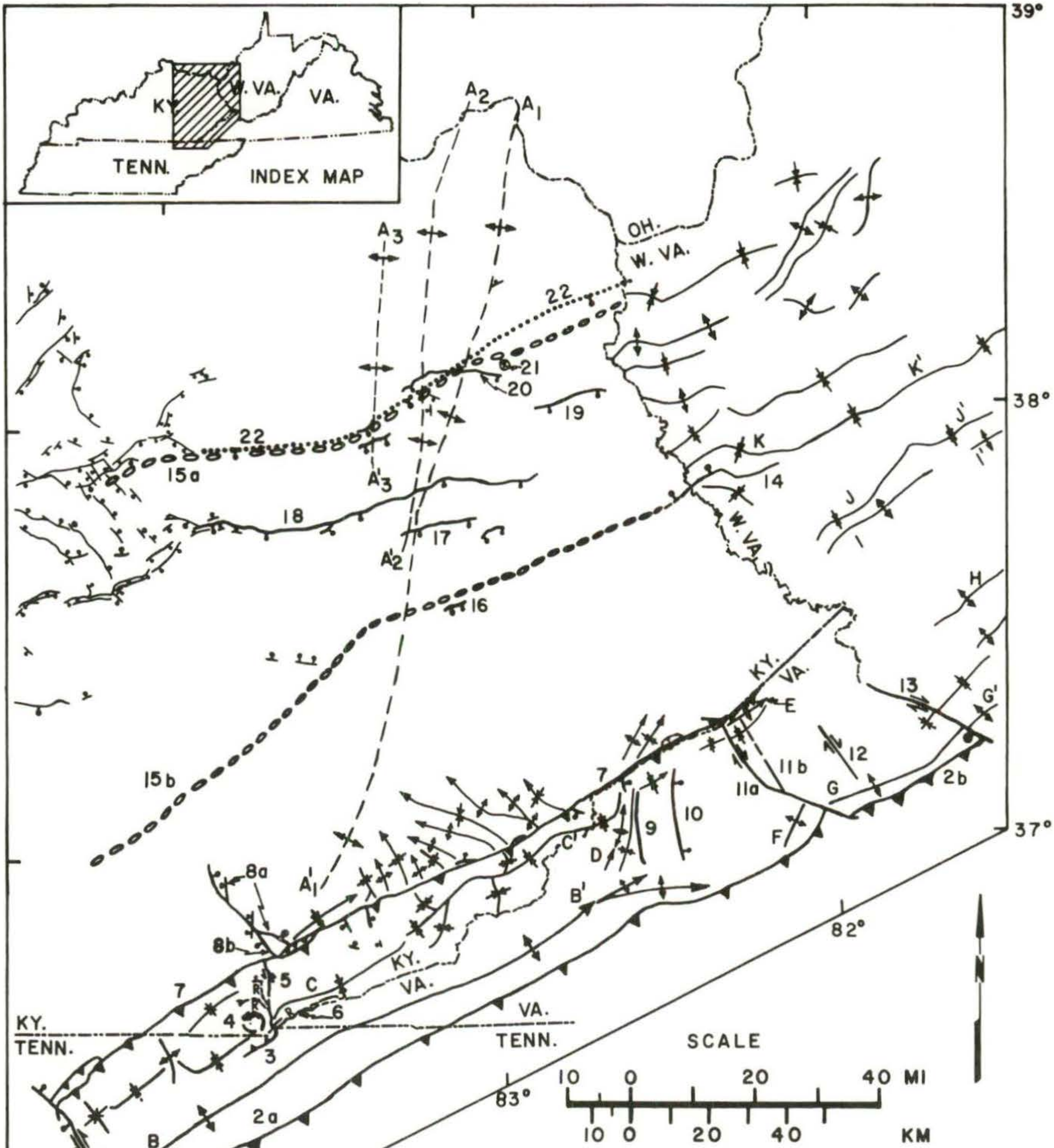


Table 1. Fault Classification, Structural Trend, and Original Workers*

Fault	Classification	General Trend	Worker(s)
Pine Mountain fault	Thrust fault	N 65°E to N 70°E	Safford (1869)
Russell Fork fault	Right-lateral strike-slip ("tear fault")	N 40°W to N 70°W	Wentworth (1921a); Rich (1934)
Coeburn fault	Normal fault	N 5°W	Johnston & others (1975)
Bishop-Bradshaw Creek fault (Canebreak fault)	Right-lateral strike-slip	N 60°W	Elder & others (1974); Johnston & others (1975)
Irvine-Paint Creek fault zone	Normal fault	N 87°E	Gardner (1915)
Warfield fault	Normal fault	N 56°E	White (1908); Hennen & Reger (1915); Huddle & Englund (1962)
Johnson Creek fault	Normal fault	N 79°E	Browning & Russell (1919)
"Indian Creek" Lineament	Possible fault	N 5°W	Eby (1923); Johnston & others (1975)
"Spring Fork" fault	Normal fault	N 68°E	Previously unnamed
Little Pawpaw fault	Unclassified	N 28°W	Wentworth (1921b)
Keen Mountain fault	Right-lateral strike-slip	N 37°W	Elder & others (1974)

* Refer to Figure 4 for geographic location and spatial relationship of structures.

Figure 4. Generalized Map of the Major Structural Elements of Eastern Kentucky and Adjacent States



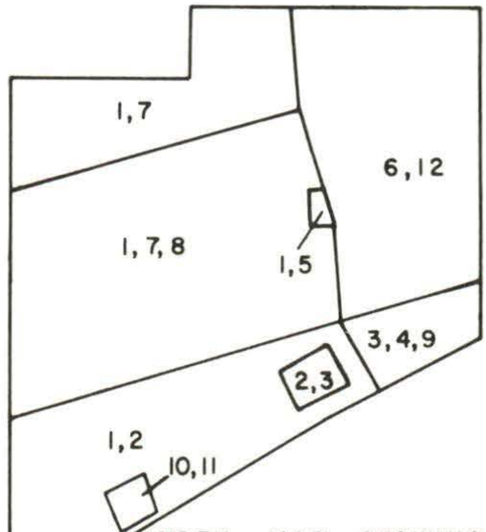
Compiled by Thomas F. McLoughlin

August 1979

Cartography by Michael E. Stamper
and
Thomas F. McLoughlin

Figure 4. Key to Geologic Features

1. Jacksboro fault
2a. Hunter Valley-Wallen Valley and Clinchport thrust fault zones
2b. Middle Creek thrust fault zone
3. Doublings fault zone
4. Middlesboro "disturbance structure"
5. Rocky Face fault
6. Cudjos Cave fault
7. Pine Mountain thrust fault
8a. White Mountain fault zone
8b. Dorton Branch fault zone
9. "Indian Creek" lineament (Possible fault)
10. Coeburn fault
11a. Russell Fork fault
11b. Little Pawpaw fault (unclassified)
12. Keen Mountain fault
13. Bishop-Bradshaw (Canebrake) fault
14. Warfield fault
15a. Rome trough - northern boundry
15b. Rome trough - southern boundry
16. "Spring Fork" fault
17. Johnson Creek fault
18. Irvine-Paint Creek fault zone
19. Blain Creek fault
20. Little Sandy fault
21. Periodotite body (Hunt and others, 1971)
22. Kentucky River fault zone
A_1-A_1' Waverly arch (after Watkins, 1963)
A_2-A_2' Waverly arch (Cambrian-Ordovician axis) (after Woodward, 1961)
A_3-A_3' Waverly arch (Mississippian axis) (Modified from Ettensohn, 1975)
B-B' Powell Valley anticline
C-C' Middlesboro syncline
D Buck Knob anticline and Dorchester syncline
E Pine Mountain anticline
F Sourwood Mountain anticline
G-G' Dry Fork anticline
H Pineville anticline
I-I' Wake Forest anticline
J-J' Handley syncline
K-K' Warfield anticline



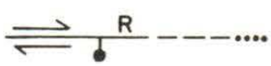
INDEX MAP SHOWING SOURCES OF DATA

SOURCES OF DATA

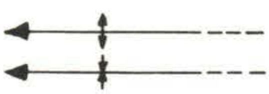
1. Potts (1979)
2. Froelich (1973)
3. Johnston and others (1975)
4. Elder and others (1974)
5. Huddle and Englund (1962)
6. Cardwell and others (1968)
7. Dever and others (1977)
8. Ammerman and Keller (1979)
9. Padgett and Ehrlich (1978)
10. Englund and others (1964)
11. Englund (1964)
12. Hennen (1915)

GEOLOGIC SYMBOLS

Thrust fault; saw teeth on upper plate.



Fault; bar and ball on downthrown side; arrows show relative horizontal movement; R indicates reverse fault, R is on upthrown side; dashed where located approximately or unclassfied; dotted where concealed.



Anticline (top) and syncline, showing trace of axial plane and plunge of axis; dashed where located approximately.

STRATIGRAPHIC RELATIONSHIPS AND ROOF FALLS

General Environments of Deposition

The area of study in eastern Kentucky is composed of rocks that are sedimentary in origin. The Carboniferous coal-bearing strata is composed essentially of sandstones, shales, coals and underclays. The majority of the rocks represent sediment deposition in marginal marine or nonmarine environments. Most geologists consider deposition to have taken place on a series of deltas or delta lobes with a general northwest transport direction from a source area to the east and southeast (8, 13, 18). Deposition took place in the Appalachian Basin, which has been divided into the Pocahontas Basin to the south and west and the Dunkard Basin to the northwest (Figure 5).

Within this fluvio-deltaic system, a complex arrangement of subenvironments has been recognized. Figure 6 shows a possible model from the Brahmaputra River showing overbank flooding onto levee deposits and Figure 7 shows how deltaic streams may shift course and build subdeltas into deeper water bays.

With continual lateral shifting of streams, coupled with vertical building of the deltaic sequence through time, a complex arrangement of sediments results that is generally discontinuous laterally and vertically.

Representative Sedimentation Units

During the course of previous field and in-mine investigations in Harlan County, Kentucky several stratigraphic relationships became apparent (22). First, vertical intervals between coals are cyclic. Figure 8 shows that two basic cycles are present. Fining-upward cycles, beginning with cross-bedded sandstone, often containing "lag gravels" in the base, become thinner bedded and finer-grained upward. These are believed to represent stream channel deposits (See also C in Figure 10.) The second type of cycle is the coarsening-upward cycle. In this instance, fine-grained sandstones, siltstones or shales near the base of the section become coarser grained and thicker bedded upward. This cycle probably indicates bays or swamps being filled laterally or by flooding from channels (See also E in Figure 11.)

Figures 9, 10 and 11 are representative sedimentary cycles together with an environmental interpretation, recognized in the Harlan County, Kentucky study (22). Very similar sedimentary cycles are recognizable in mines reported in this paper, and reference will be made to these figures as appropriate.

Siltstone/Shale Immediate Roof

Relatively thick siltstone/shale immediate roof was encountered at several mines in the study area. This roof type is characterized by laminated siltstone and/or shale, generally in a coarsening-upward sequence, and often is capped by a rider coal bed. Figure 12 shows a typical example at the Southeast Coal Company's Polly No. 4 mine. Observations indicate that stability of this type of roof is controlled by the following factors:

1. Disruption of bedding by structural features. Jointing, faults and "slips" formed during soft-sediment compaction all contribute to instability as shown in Figures 13 and 14.

2. Lateral facies changes. Thick immediate roof often changes laterally to sandstone abruptly. "Slips" along this shale-sandstone contact, as well as soft-sediment contortion of the shales, are responsible for falls.

Figure 5. Map of Kentucky and Surrounding States Showing Axial Trends of the Dunkard, Pocahontas and Warrior Basins

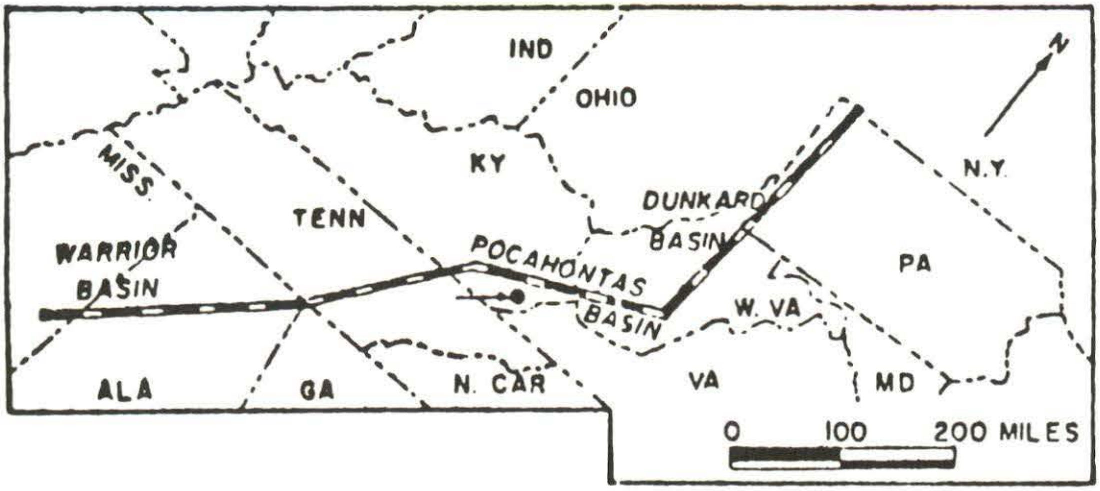


Figure 6. Crevasse Splays Deposited During Flood in the Floodbasin of the Brahmaputra River

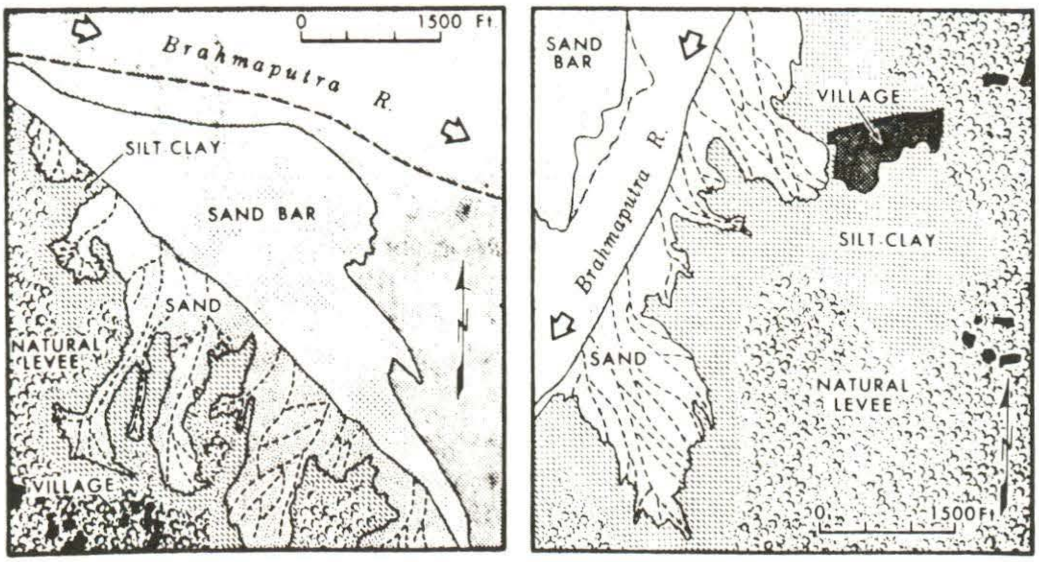


Figure 7. Interdistributary Bay Model as Proposed by Elliott

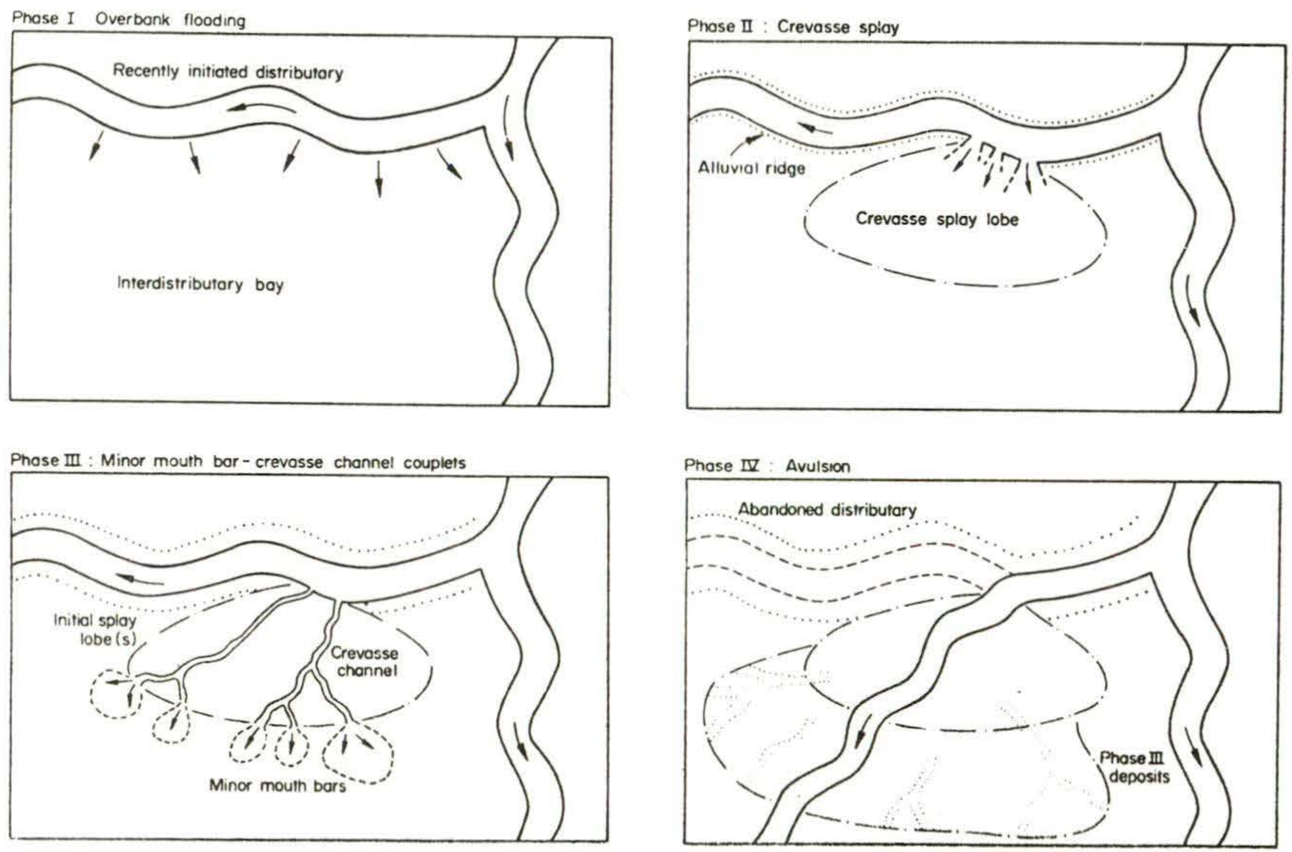
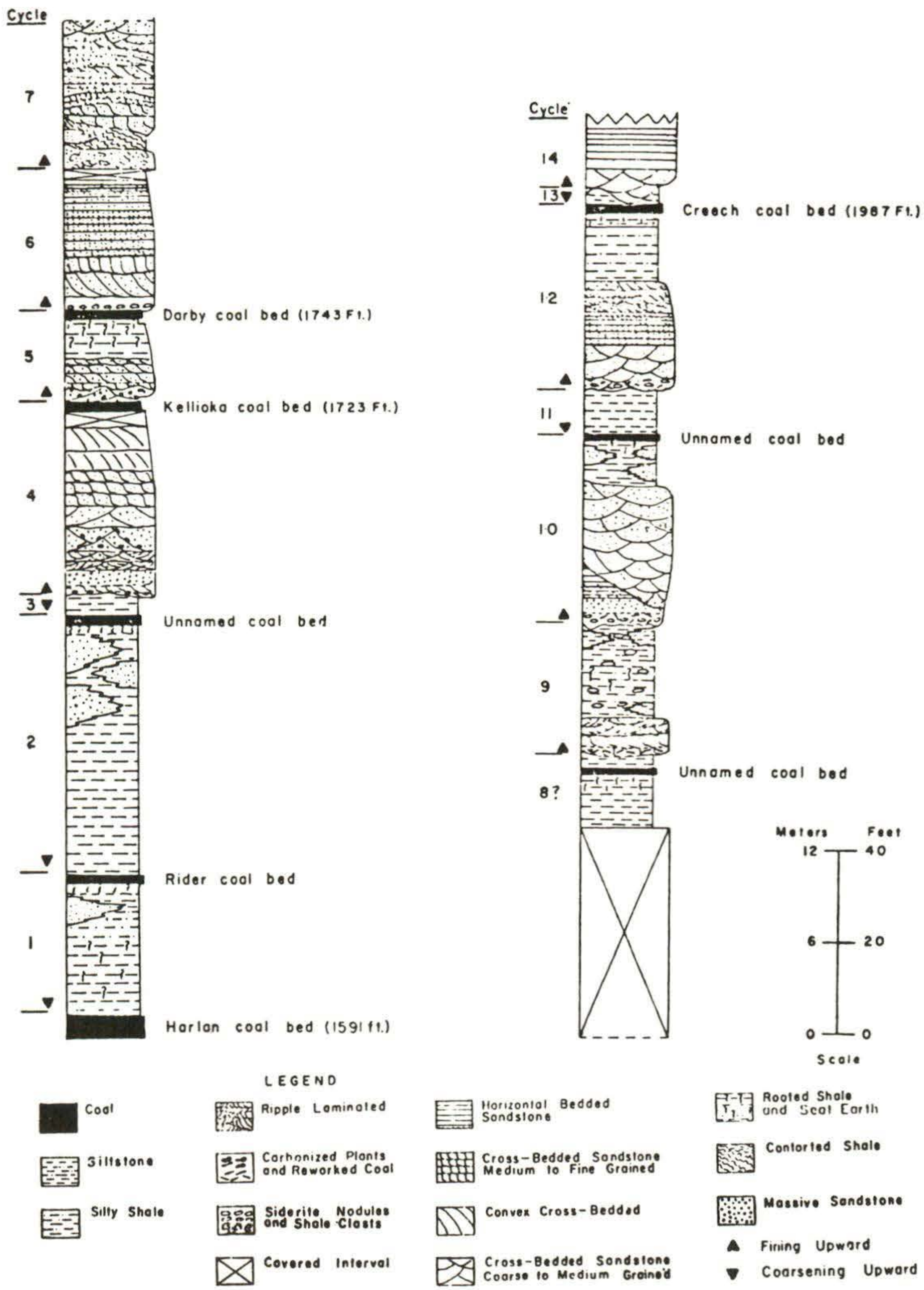


Figure 8. Brookside Stratigraphic Section*



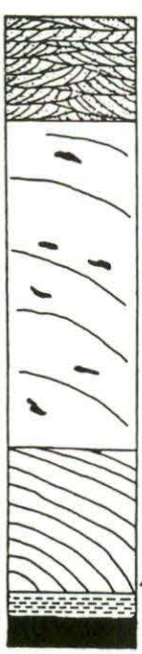
*Numbers refer to coarsening upward and fining upward cycles.

Figure 9. Representative Sedimentation Units Harlan County, Kentucky Sections A and B*

A

Unit	OBSERVED FACTS	INTERPRETATION
4	Light-to medium gray sandstone, fine-to medium grained, becomes shaly upward.	Probably vertical accretion deposits or splays.
3	Light-to medium gray sandstone, fine-to medium grained.	Probably vertical accretion deposits or splays.
2	Light-to dark gray shale/silt-stone.	Vertical accretion deposit from overbank floods.
1	Bituminous coal.	Coal-forming backswamp/marsh deposit.

(Not to Scale)



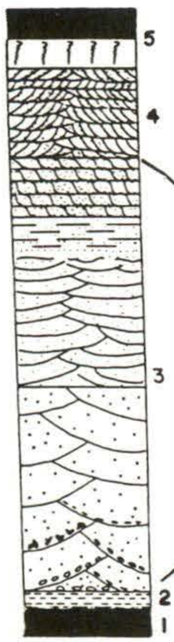
B

Unit	OBSERVED FACTS	INTERPRETATION
4	Light gray fine sandstone. Ripple laminated. Small-scale cut and fill.	Probably vertical accretion deposit. Levee, swale-fill or backswamp.
3	Light-to medium gray, fine-to medium grained sandstone, massive, but weathers in convex cross-beds. Contains Carbonized plant material. Becomes thicker bedded upward.	Probably formed by migration of river mouth bars to form lake-interdistributary bay fill.
2	Light to dary gray shale/silt-stone.	Vertical accretion deposit from overbank floods.
1	Bituminous coal.	Coal-forming backswamp/marsh deposit.

(Not to Scale)

*See Figure 8 for legend.

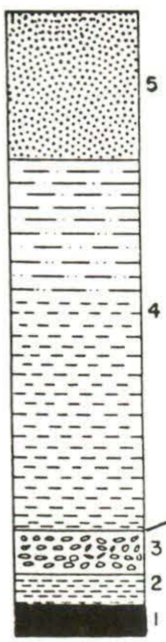
Figure 10. Representative Sedimentation Units Harlan County, Kentucky Sections C and D*



C

OBSERVED FACTS	INTERPRETATION
Seat earth and bituminous coal.	Coal-forming backswamp/marsh deposit.
Siltstone and fine grained sandstone. Ripple laminated. Parallel and wavy lamination. Rooted.	Probably vertical accretion deposit. Levee, swale-fill or backswamp.
Light gray, fine-to medium grained sandstone. Small-to medium scale cross-beds.	Probably lateral accretion deposits formed during lower stage of stream flow on point bars. Deposition from bedload and/or suspension.
Light gray, coarse-to medium grained sandstone, lag at base and scattered upward. Trough cross-bedding (Large to medium scale). Horizontal bedding locally.	Channel deposit probably formed in deepest part of meandering channel by lateral accretion.
Light to dark gray shale/siltstone. Laminated with ironstone bands and nodules upward.	Vertical accretion deposit from overbank floods. Thick units may include coarsening-upward crevasse splay or lake-interdistributary bay fill upward.
Bituminous coal.	Coal-forming backswamp/marsh deposit.

(Not to Scale)



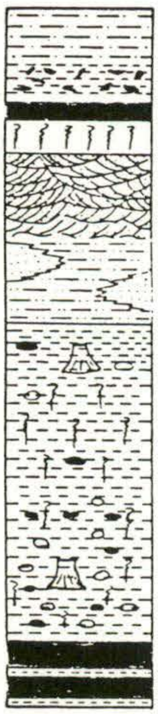
D

OBSERVED FACTS	INTERPRETATION
Light gray, massive-to thick bedded sandstone. Cross-bedded laterally, medium-to coarse grained.	Probably channel deposit formed by lateral accretion.
Light-to medium gray shale grading upward into silty shale.	Probably formed as sedimentation in abandoned channel. Symmetrical channel shape is preserved. (100 feet wide and about 10 feet deep as indicated by units 3 and 4).
"lag gravel" conglomerate.	Channel deposit probably indicating high velocity.
Light-to dark gray shale/siltstone	Vertical accretion deposit from overbank floods.
Bituminous coal.	Coal-forming backswamp/marsh deposit.

(Not to Scale)

*See Figure 8 for legend.

Figure 11. Representative Sedimentation Units
Harlan County, Kentucky
Section E*



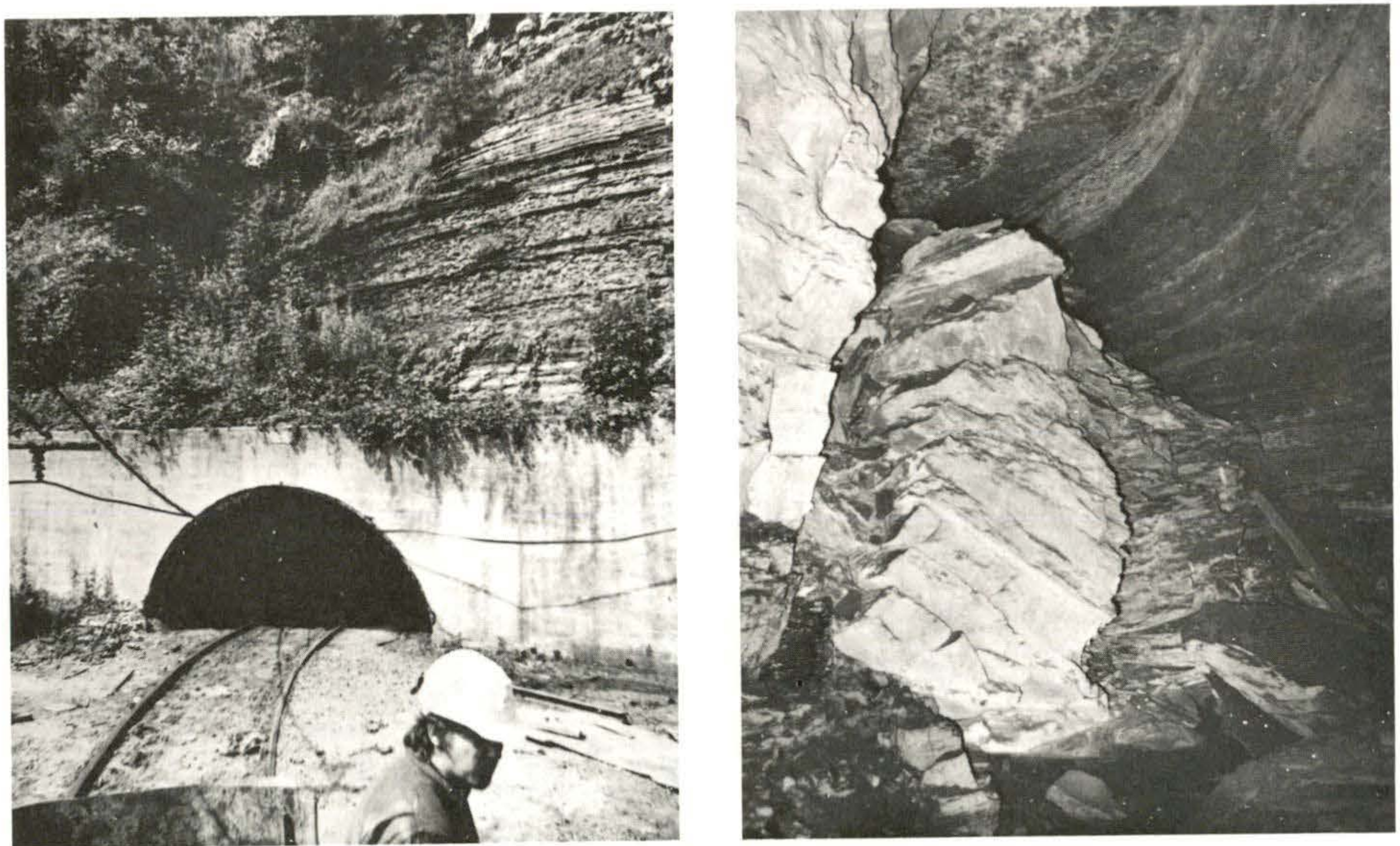
E

Unit	OBSERVED FACTS	INTERPRETATION
5	Seat earth and bituminous coal.	Coal-forming backswamp/marsh deposit.
4	Light gray fine sandstone. Ripple laminated. Small-scale cut and fill.	Probably vertical accretion deposit. Levee, swale-fill or backswamp.
3	Light-to dark gray silty shale, laminated. Wavy bedded with fine sandstone locally.	Vertical accretion deposit from overbank floods or crevasse splays.
2	Medium-to dark gray shale, rooted with standing stumps (kettle-bottoms). Contains ironstone and siliceous nodules.	Probably backswamp and/or marsh deposit. Possibly inundated to form lake and/or bay.
1	Bituminous coal.	Coal-forming backswamp/marsh deposit.

(Not to Scale).

*See Figure 8 for legend.

Figure 12. Entrance and Underground Views of Siltstone/Shale Roof at Southeast Coal Company's Polly Number 4 Mine



A. Entrance to portal of Southeast Coal Company's Polly No. 4 mine. Shows laminated siltstone and shale with rider coal bed beneath sandstone ledges about 15 feet above portal..

B. View inside mine with fall extending upward to position of rider coal bed.

3. Depth of overburden. While actual overburden thickness varies considerably in roof falls involving thick shale immediate roof, most of these falls occur with overburden thicknesses of from about 80 feet to 200 feet (24-61 m). However, observations indicate that in some cases relatively thin overburden is stable, whereas shale roof falls may occur under as much as 700 feet (213 m) of overburden. Evidence strongly suggests that other contributing factors govern these falls. Most shallow overburden is encountered when valleys are crossed. In these instances, jointing is more frequent and ground water often contributes to instability as it moves downward along joint planes. Also, it appears that lateral in-situ stresses are often present in the vicinity of valleys; especially deep, steepwalled ones. High in-situ stresses are indicated by shears or "cutters" in the roof, floor or between the roof and rib. Kettlebottoms, which are lithified remains of standing trees buried rapidly by sediments, are sometimes found in thick siltstone/shale roof. The basal parts of these circular plant fossils sometimes fall and consititute a roof hazard.

4. Presence of rider coal bed. Many falls involving thick shale roof extend upward to a rider coal bed, often underlain by underclay. In this instance, the coal bed/underclay likely represent an especially incompetent layer coupled with the fact that ground water is likely to concentrate along this stratigraphic horizon.

Thin-Bedded Sandstone

Reference to representative sedimentation unit A in Figure 9, shows that thin-bedded sandstone may occure when deltaic streams in flood break through the natural levees and spread sediment out over the floodplain in a fan-shaped deposit. These sediments grade from channel sandstones on one side to floodplain muds and silts outward. These are referred to as crevassesplay deposits and shown in Figure 6, and Figure 7.

These thin-bedded sandstone deposits are locally referred to as "stackrock" because of the stacked arrangement of individual beds (Figure 15). Most roof falls involving "stackrock" appear to fail under conditions similar to thick shale immediate roof, except that the "stackrock" tends to react as a more brittle material under stress. Slickensided joints or "slips" indicating soft-sediment of deformation are not as common as in shales. Also, the presence of carbonized plant debris and mica on the bedding plans likely contribute to instability. Many falls involving "stackrock" tend to fall as a unit. An examination of these fall areas indicated that, in some cases, roof bolt length may determine the height of the fall. In these cases, the roof fall "unit" is often bounded by fractures (Figure 15). Also, thin-bedded sandstone seems to be especially unstable when the bedding dips into the entry as shown in Figure 16. This relationship is also true of other rock types and bedding thicknesses.

Sandstone Channels

Example I

An excellent example of a sandstone channel is shown in Figure 17. The Channel was exposed in cross-section in the Number 9 Section of Mine Number 1, Consolidation Coal Company.

The channel shown is one of a series that are oriented generally about N30^{o}E. A secondary trend of about N60^{o}W is also present. The channels are discontinuous along their trend and vary from 400 feet (122m) to about 3,500 feet (1067 m) in length and from 100 feet (31 m) to 300 feet (92 m) in width according to company information.

Figure 13. Soft Sediment Deformation, Bell County Coal Company

Figure 14. Large Sandstone Roll in the Hignite Mine, Bell County Coal Company

Figure 15. Thin-Bedded Sandstone ("Stackrock") in Eastern Coal Corporation's Pike County Mine

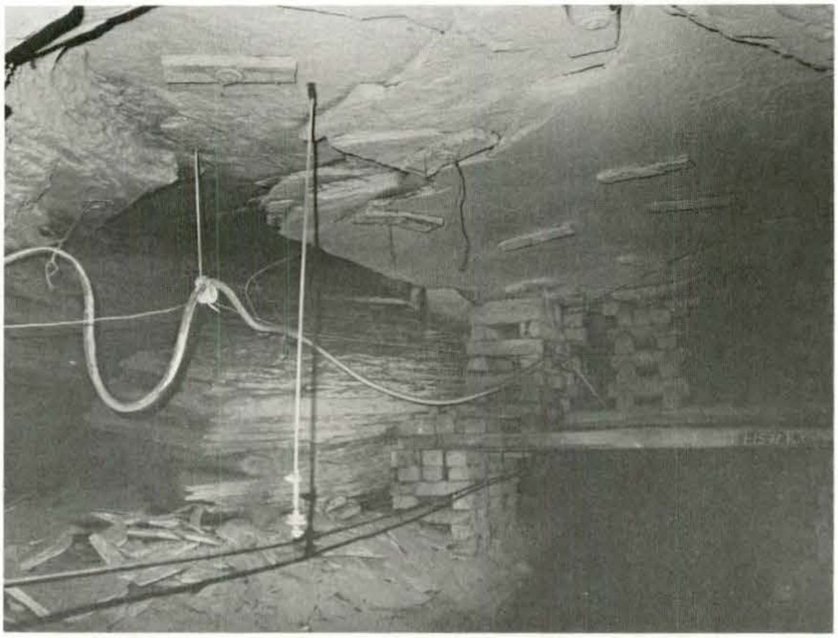


Figure 16. Eastward-Dipping Thin-Bedded Sandstone in Southeast Coal Company's Polly Number 4 Mine

The normal vertical roof profile is shown in Section A (Figure 17). The Jellico coal bed is overlain by about 10 feet to 15 feet (3 m-5 m) of laminated siltstone and shale containing ironstone bands and nodules. This unit typically becomes coarser-grained upward with as much as 10 feet (3 m) of interbedded shale and thin beds of sandstone (Unit 3 of Section A). A thin rider coal bed and underclay may be present at the top of this unit, but was not observed at this locality.

Marginal to the channel (Section B), unit 3 typically is cut by curving "slips" and is contorted indicating soft-sediment compaction and/or slumping. Joints and "slips" parallel the trend of the channel.

The Jellico coal bed at locations A and D is as much as eight feet (2.4 m) thick, but rolls under the axis of the channel (location C). This tendency of the coal to thicken (at D), then thin as the floor dips under the channel appears to be a good indication of the presence of the channel.

Example II

While several factors appear to contribute to roof falls in this example, the presence of a sandstone channel likely contributes significantly.

Figure 18 shows a part of F section of Beth-Elkhorn's Number 22 mine. (See also Figure 46.) The sandstone roll body, mapped by Dr. Raymond Nagell of Bethlehem Steel Corporation, is somewhat unusual in that it is bounded by faults that dip under the roll. The displacement varies from six inches (15 cm) to 48 inches (1.2 m). The Elkhorn Number 3 coal bed is for the most part, unfaulted. However, it is displaced three feet (.9 m) at one place. The fault plane is "slickensided" and fragments of shale and sandstone form a breccia.

While the area of the sandstone roll body was inaccessible at the time of this investigation due to water, the area immediately to the northwest was visited. Figure 18 indicates that cutters or shears had developed generally parallel to the headings and several large falls had occured. The columnar section shown to the left is from a roof-fall approximately 20 feet (6.1 m) high. The fall occurred in dark laminated shale up to the second rider coal bed. The sandstone exposed at the top of the fall is white with re-worked carbonized plant debris.

Although the northwest advancement of the panel was terminated at about the position shown, it is possible that roof conditions might have improved based on rock type. At the working face the immediate roof consisted of ripple laminated siltstone and fine sandstone instead of shale.

Probable factors that contributed to roof falls at this area include:

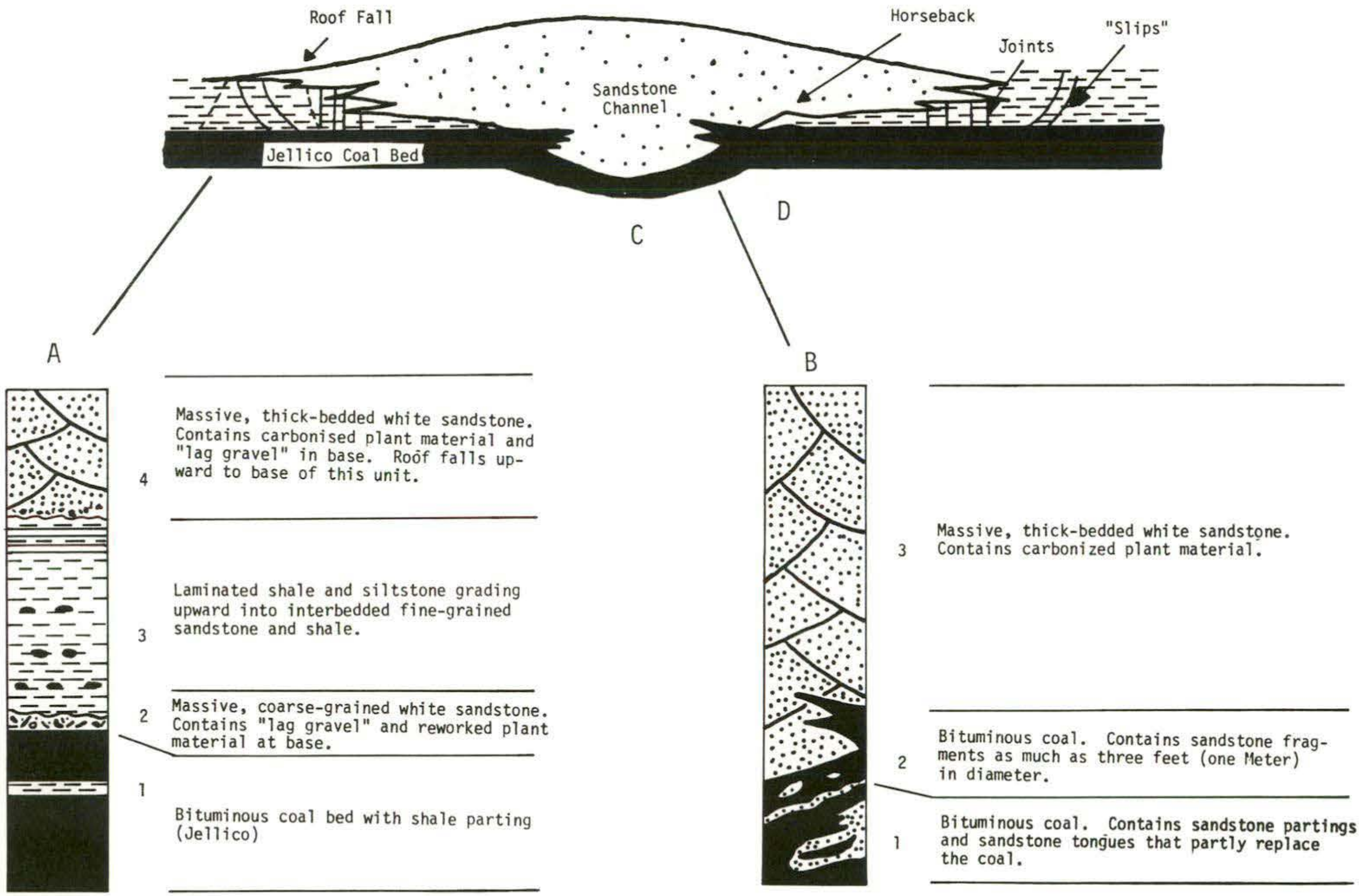
1. The abrupt change from sandstone (roll body) to thick laminated shale and possible weakening of roof rocks by differential compaction during or shortly after consolidation.

2. The presence of rider coal beds in the roof.

3. The presence of jointing. Intersecting lineaments suggest possible zones of weakness at this location (Figures 44 and 46).

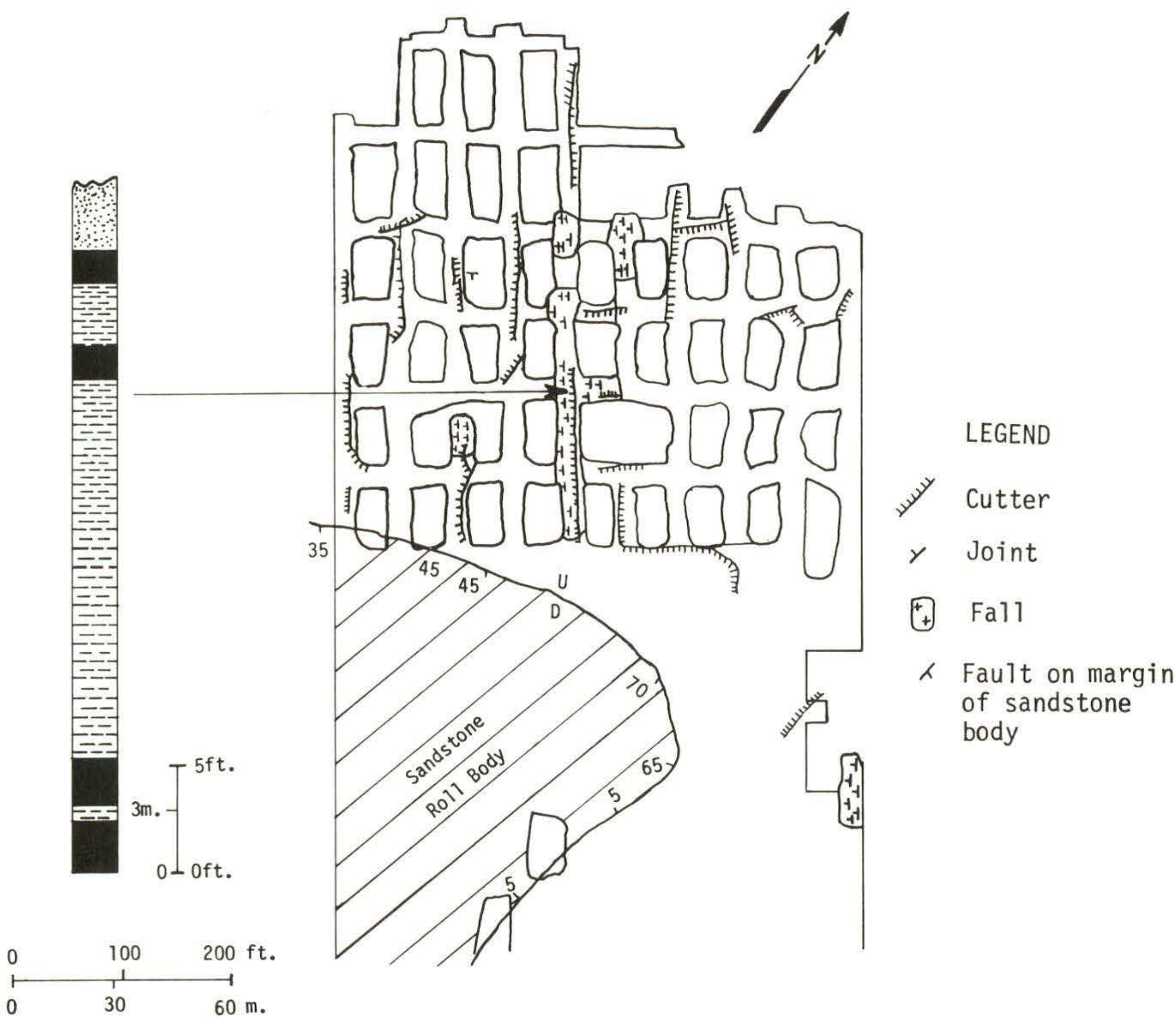
4. Shallow overburden is present in this area. Overburden thickness is about 260 to 300 feet (79 m-92 m) in this area. In addition, a surface stream crosses on the surface directly above (Big John Hollow). Water entering the mine from the roof at the roof fall also contributes to instability.

Figure 17. Cross Sectional View of Sandstone Channel, Consolidation Coal Company*



*Approximate vertical scale of sections is 1 in. = 10 ft. Horizontal scale of profile is 1 in. = 20ft.

Figure 18. Mine Map of F-Section, Beth-Elkhorn Mine 22 Showing Sandstone Roll Body and Roof Falls



Projection of Sandstone Channels

Projection Using Structure Contour and Isopach Maps

As part of the final report on contract H0133018, sandstone channels were projected in Eastover Mining Company's Darby Number 4 mine at Highsplint, Kentucky (22). The projections in that mine were based largely on detailed in-mine mapping, with supplemental data (floor elevations) supplied by the company. First, the projections were based on structure contours of the mine floor. This method assumes that in many cases the floor dips beneath major sandstone rolls as in Figure 17. This assumption is not always valid, especially with minor channels in the roof, but generally channel trends can be established. Secondly, coal thickness (isopach) maps were used, based on the fact that coal thickness is often less directly beneath sandstone channels. Also, immediate roof thickness (isopach) maps were of considerable value in that study.

Structure contour maps drawn on the base of the Elkhorn Number 3 coal bed and coal thickness maps were used in the present study in an attempt to project channel trends in the Beth-Elkhorn Number 22 mine. Because the mine is large with many parts inaccessible, methods were based largely on information and data supplied by the company. This information included the position of known channels, floor elevators and coal thickness. Figure 19 shows known channels with structure contours superposed and Figure 20 shows channels with coal thickness (isopach) superposed. Control points for both maps were taken about every third break (80 feet to 100 feet (24 m-31 m)), so control was excellent. The following statements may be made concerning the maps:

1. Sandstone channels are concentrated in the northwest part of the mine and presented many problems with roof control and want zones or low coal. Both structure contour and coal isopach maps follow these trends.

2. The sandstone roll trends are generally perpendicular to the strike of the structure contours and, for the most part, occupy structural lows (Figure 19).

3. The isopach map shows that the coal thins considerably beneath sandstone channels and trends follow channels. To the southeast, projected axial trends of the channels are shown as dashed lines on Figure 20.

4. Based on sufficient drill core data and/or projections between active parts of mine, possible channels may be anticipated in advance of mining. These projections would be more accurate in a large expanding mine where trends could be established.

Projection Using Fence Diagrams

Figure 21 is a fence diagram of a portion of Eastern Coal Corporation's Number 4 mine. A stratigraphic section measured at the portal is shown in Figure 22 (indicated also on Figure 21). The stratigraphic sequence at the portal above the Pond Creek coal bed includes about four feet (1.2 m) of silty shale overlain by as much as 30 feet (9m) of cross-bedded sandstone with "lag gravel" near the base. Overlying the sandstone two rider coal beds occur with associated shales and underclays.

The fence diagram shown in Figure 21 is based on driller's logs of nine core holes. The coal at the base is the Pond Creek and the uppermost coal is the Alma.

Also, almost all of the mine area covered by the diagram was visited, and additional information was obtained from company personnel as to roof rock conditions. This information provided control for areas between drill hole locations.

From the fence diagram several important stratigraphic relationships are evident as follows:

1. Roof rocks in the eastern section of the mine are dominated by channel sandstone. However, while the coal is relatively thinner in this area, no want zones or

Figure 19. Map of Beth-Elkhorn Mine 22 Showing Structure Contour Lines Superposed Over Known Sandstone Channels

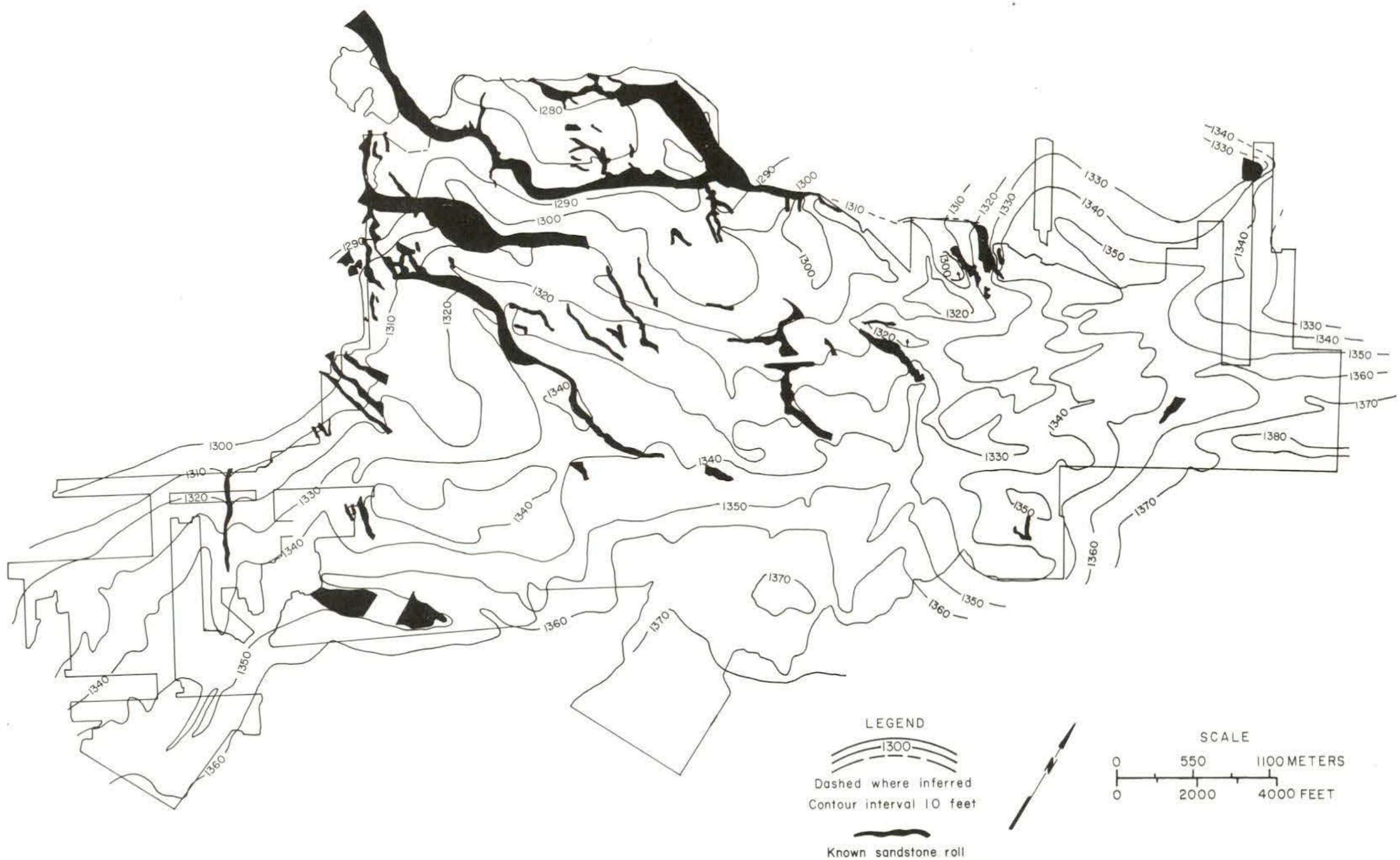


Figure 20. Map of Beth-Elkhorn Mine 22 Showing Coal Thickness Lines Superposed and Projected Axes of Sandstone Channels

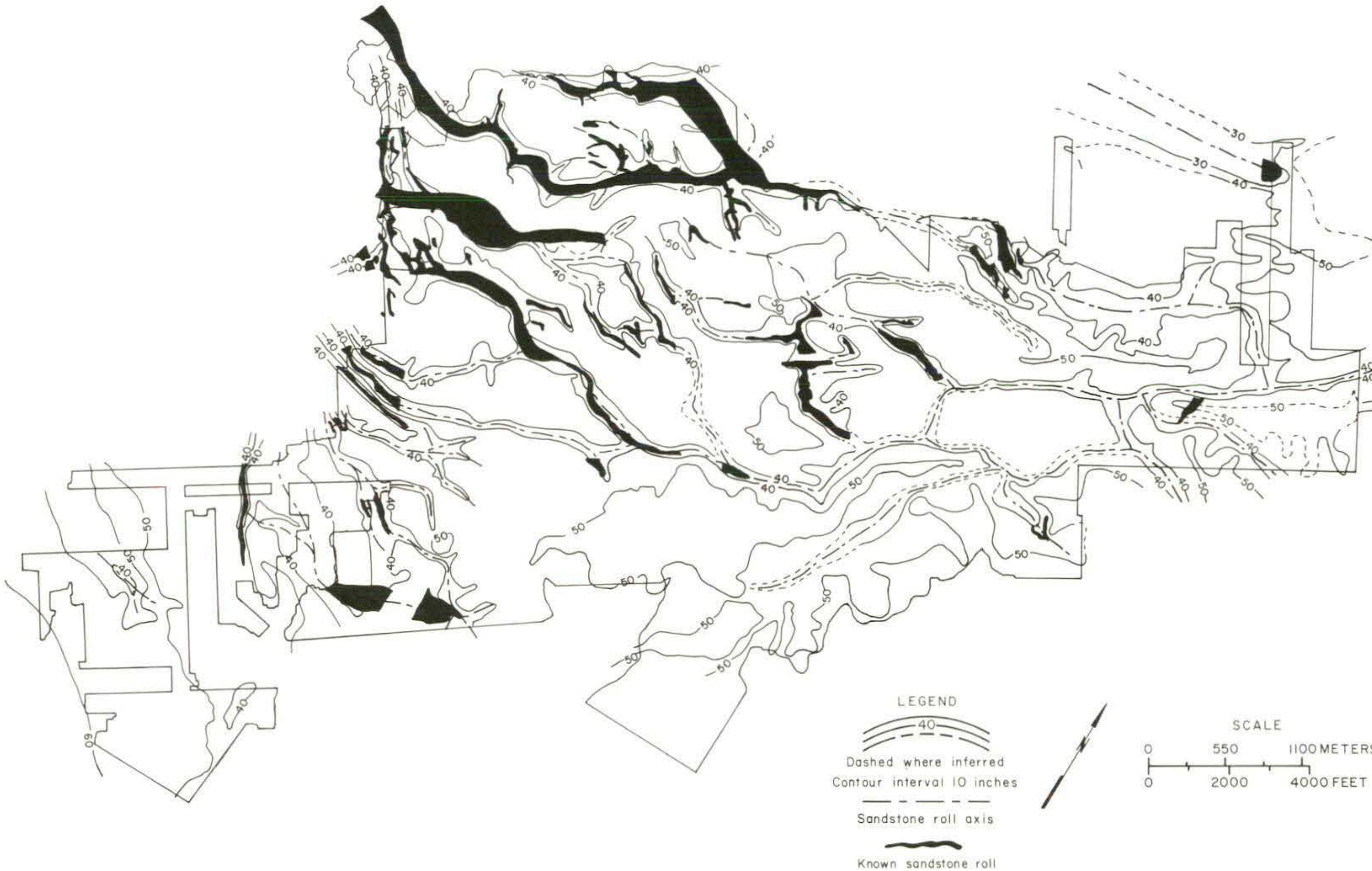


Figure 21. Fence Diagram of a Portion of Eastern Coal Corporation's Pike County Mine

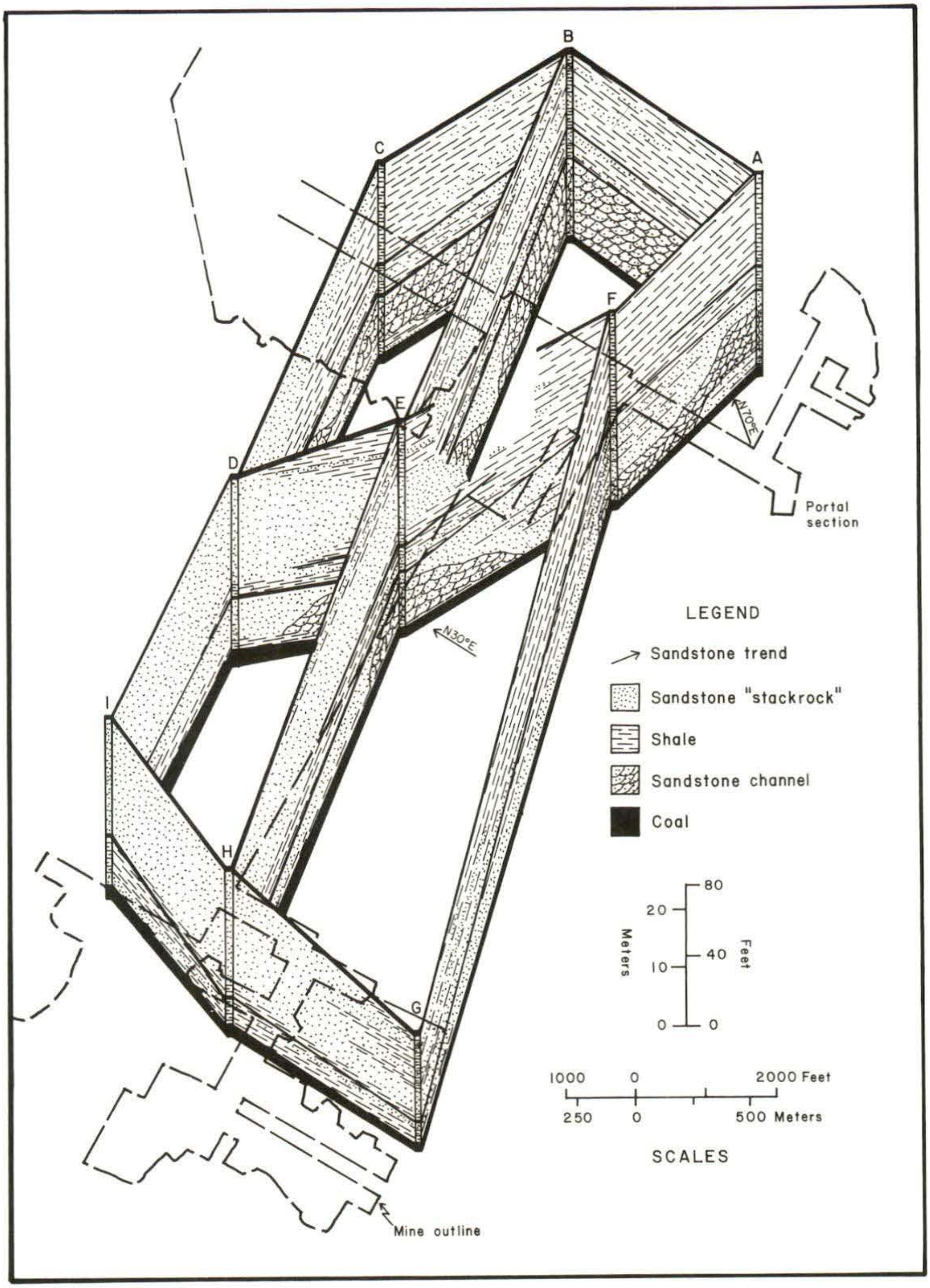
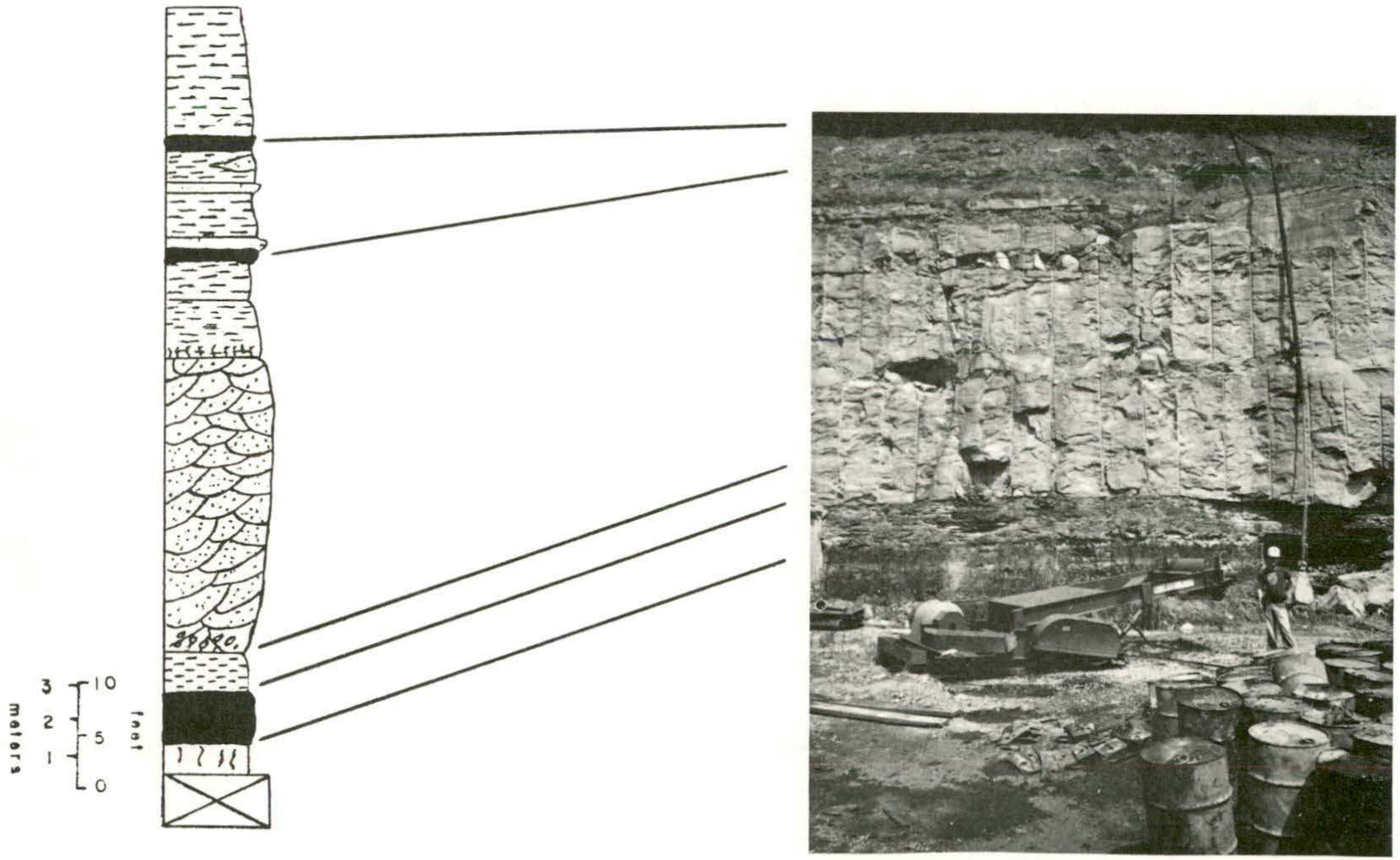


Figure 22. Photograph and Measured Stratigraphic Section at Portal of Eastern Coal Corporation's Pike County Mine



washouts were observed. Based on core drill information, mine inspection and directional trends of sandstone rolls, the sandstone trends about N60°E to N70°E in this part of the mine. A smaller channel in the vicinity of core E (Figure 21) trends N30°E. This N70°E trending channel sandstone is also shown in Figure 37 as the southernmost channel near the center of the figure. Note on Figure 37 that three larger channels in the same mine to the north and west have cut completely through the coal and produced major washouts.

2. Lateral to the sandstone channels in Figure 21, the roof rock is composed dominantly of thin-bedded, fine grained sandstone, referred to as "stackrock." The area of the mine in the vicinity of cores D and I show "stackrock" and Figure 15 is a photograph of falls in "stackrock" about midway between cores E and H.

3. Intertonguing with or marginal to areas of "stackrock" are roof rocks composed of laminated shale and siltstone with ironstone bands. These roof rocks are usually overlain by "stackrock" forming coarsening-upward vertical sequences.

4. The Pond Creek coal bed is relatively thicker in areas of the mine directly overlain by laminated shale and "stackrock" compared to areas directly overlain by channel sandstone. For example, in the vicinity of core B the coal is about four feet (1.2 m) thick compared to as much as seven feet (2.1 m) in the vicinity of core I.

5. Roof stability in the mine appears to be dependent to a large degree on roof rock type. Most of the larger falls have occurred in laminated shale/siltstone and in "stackrock" especially under valleys with less than 200 feet (61 m) of overburden. Smaller falls have occurred marginal to sandstone rolls, but in areas of the mine overlain by massive sandstone the roof is generally good.

6. In this mine the presence of rider coals appears to have a direct bearing on roof falls. At the portal, two rider coals are 40 feet and 50 feet (12 m-15 m) respectively above the Pond Creek coal bed. According to core drill information, the uppermost rider and the Pond Creek generally becomes less toward the north and west (Figure 21). Several of the larger falls in "stackrock" and laminated shale/siltstone extend upward as much as 20 feet (6 m) to this rider coal in the northern and western parts of the mine shown in Figure 21.

7. Fence diagrams, such as the one shown in Figure 21, appear to provide an excellent overall view of the mine roof. This is especially true in the example cited, because the relatively level floor under the eastern part of the mine precludes the use of structure contour maps in projecting the channels. However, since the spacing of drill holes is great, supplemental information from in-mine investigations is necessary.

Summary of Stratigraphic Features

Table 2 is a summary of the occurrences of major roof hazards that may be attributed to geologic roof hazards. These are considered to be primary sedimentary features that are directly related to the depositional aspects of the rocks and do not include secondary structural features (joints, faults and folds). It should be emphasized that lateral changes in roof rock commonly occur in a single mine or between close adjacent mines.

Table 2. Summary of Geologic Conditions in Selected Mines in Eastern Kentucky*

	Mine Area									
	1	2	3BC	3HS	4	5	6	7	8	9
Geologic Hazards										
Paleochannels	X	X	X	X	X	X̲		X	X	X̲
Soft Sediment Deformation & Slips	X̲			X	X		X̲	X		
Thick Immediate Roof	X	X		X	X	X	X			
Rider Coal Bed	X		X		X	X̲	X	X	X	X̲
"Stack Rock"	X	X̲	X		X	X		X		
Kettlebottoms		X̲	X	X̲					X̲	

* Consolidation Coal Company is located in Tennessee

X-Common
X̲-Rare or Uncommon

1. Consolidation Coal Company
2. Bell County Coal Company
3. Eastover Mining Company
   3BC-Bailey Creek
   3HS-Highsplint (Darby)
4. Beth-Elkhorn
5. Southeast Coal Company
6. Turner Elkhorn Coal Company
7. Eastern Coal Company
8. Martin County Coal Company
9. Samoyed Coal Company

STRUCTURAL RELATIONSHIPS AND ROOF FALLS

Study of Lineaments by Satellite Imagery

The use of Landsat imagery in the detection of zones of structural weakness that may cause unstable roof conditions has been reported by several investigators (2, 11, 31, 32, 39). The imagery has been successfully used to delineate "lineaments", which are topographic and/or tonal alignments that may reflect structural anomolies such as faults or joint systems.

Imagery analysis is appealing because it permits a relatively rapid evaluation of a mining area on both a local and regional scale. Also, inaccessible (or forested) areas may be analyzed and imagery lineaments correlated with known structural features in the area so that subsequent field work is greatly reduced. Additionally, geographic coverage of Landsat imagery is essentially complete and available to the general public.

The procedure discussed was developed as a consequence of research directed toward coal mine roof falls during the present contract. Satellite imagery analysis has been used to develop methods of roof stability evaluation in advance of mining.

Development of Procedure

Satellite imagery was obtained from the USGS-EROS Data Center, Sioux Falls, South Dakota 57198. The imagery obtained consisted of 1:1,000,000 scale positive transparencies and prints of black and white infrared band 7 imagery, which is recommended for geologic studies (39). Winter scenes were selected to avoid excessive vegetation and to obtain scenes with a low-sun elevation which enhances topographic alignments. Black and white prints at a scale of 1:250,000 were also obtained for reference purposes and for possible direct plotting of lineaments.

A review of current literature indicated that the detection of linear features on Landsat imagery has been accomplished by at least four methods:

1. Inspection of the imagery film transparencies on a light table with hand magnifiers.

2. Stereoscopic viewing of pairs of transparencies and/or positive prints using scanning stereoscopes to gain a three-dimensional effect and for better topographic expression.

3. Electronic analysis of film transparencies with video-enhancing devices and taking pictures of the resulting scenes displayed on the television monitor screen.

4. Projection of the entire scene and/or enlarged portions of the original scene onto blank screens at various distances and viewing the projected scene with a Ronchi (diffraction) grating (2, 26, 29, 31).

In the analysis of satellite imagery, then, the major objectives are twofold. First, a method should be employed to enhance, or bring into definition, linear features on the imagery. Preferably, the imagery scale should be large enough so that magnifiers are not necessary. Secondly, lineaments must be transferred to a suitable base map with reasonable accuracy for proper evaluation.

Attempts at imagery analysis using current techniques proved to be difficult and time-consuming, especially the transferral of lineaments to base maps. However, the method of imagery analysis developed during the present study combines some of the currently used techniques into a single operational step and provides a more rapid, accurate and economical means of enhancing imagery and transferring data to base maps.

Satellite Imagery Procedures

Because the two methods outlined here involve differing degrees of enhancement and data transfer they are described separately.

Method A-Ronchi Grating Enhancement. Ronchi grating is a type of light diffraction grating consisting of parrallel lines ruled on a four inch (.1 m) piece of plastic film or optical glass (Figure 23). Gratings are available from the Edmond Scientific Company with lines spaced from 50 to 300 lines per inch (2.54 cm). However, 200 lines per inch (2.54 cm) has been recommended (22). Light passing through narrow slits of the Ronchi grating enhances linear features by diffraction reinforcing their lengths (10,35).

The following procedure describes the Ronchi Grating Enhancement method:

1. Areas of interest were outlined on the original 1:1,000,000 scale positive transparency. The area was cut out and mounted in a 35 mm slide holder.

2. The base map covering the same study area was mounted on a wall. Topographic maps on a scale of 1:24,000 (7.5 minute) were found suitable for local work and 1:250,000 scale maps provided a more regional view. It is important to note that when using positive imagery transparencies the map should be hung upside down so that north is down. If the maps are hung with north up, the view direction of the imagery will cause the topography projected on the map to be inverted (Figure 24). The maps may be oriented with north up when using negative imagery transparencies.

3. Using a slide projector, the imagery slides were projected onto the topographic map (room darkened) and the projector and/or map moved until the image coincided with the map. Tabel 3 summarizes the combinations of projector lenses used and the general projector distances from the screen. It was found that there was surprisingly close geometric match or registration of topography and drainage lines. Registration of imagery to topographic base maps is attributed to the fact that Landsat images, unlike aerial photographs, have very little geometric distortion because of the narrow scan angle of the satellite scanner. This allows registration with topographic maps constructed with a Lamber conic conformal projection (34).

4. Once the unenhanced imagery and maps were alinged, the projected image could be enhanced using the Ronchi grating mounted in front of the projector lens. The grating was rotated slowly and damping rotational motion performed until the enhanced direction was clearly distinguished and pinpointed (Figure 25).

5. With a direction of strong imagery enhancement (linear trends) "locked in," the analyst was free to approach the map and evaluate linear trends. Actual plotting of lineaments was made on transparent overlays on the base map to scale. In addition, a "homemade" indexing device on the Ronchi grating holder permitted the direct determination of bearings and angular relationships between lineaments as the grating was rotated and plotting proceeded (Figures 23 and 26).

6. Direct correlations of surface and in-mine features with lineaments were also conveniently made using the method. Using a 1:24,000 topographic base map, the mine outline was superimposed on a transparent overlay. Additional features, such as roof-fall areas, rock jointing and known faults could be added to test correlations and possible projections of these features with lineaments. Because the imagery was projected on topographic contours, overburden thickness above the mine elevation could be determined directly. When making such correlations, the analyst used a flashlight to effectively "erase" the projected image temporarily. At this stage, a certain amount of ground truth could be performed as linear features were detected. Topographic, cultural, hydrologic and dominant structural features reflected in the topography were directly comparable.

Figure 23. Photograph of the Ronchi Grating and "Indexing Device"

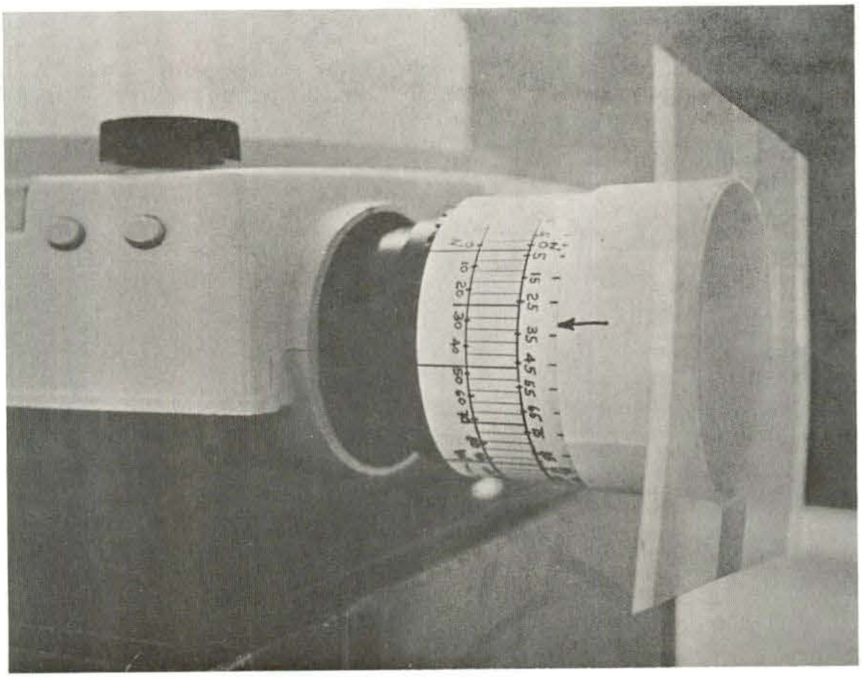


Figure 24. Projection of Satellite Imagery onto a Topographic Base Map

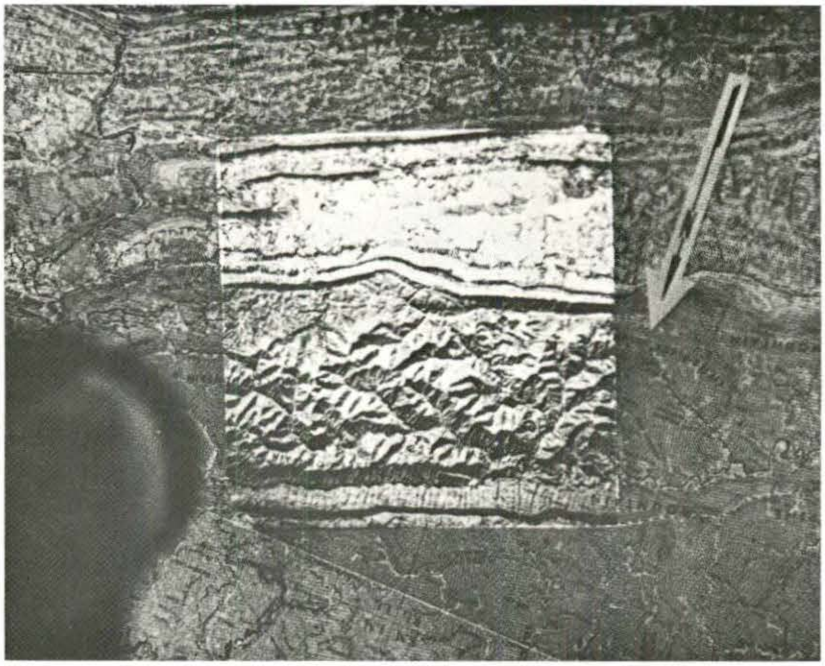


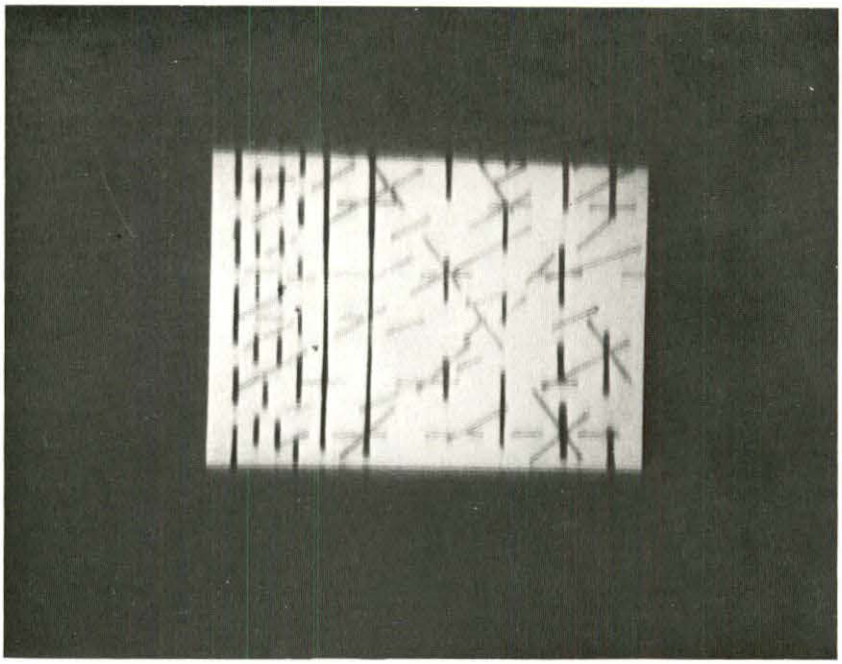
Table 3. Imagery Projection Distances and Lenses Used*

Imagery Type	Imagery Scale 35mm slide	Scale of Base Map	Lens focal length** (In.)	(m)	Distance to screen (Ft.)	(m)
Unenhanced	1:1,000,000	1:250,000	4	0.11	1.76	(0.54)
Unenhanced	1:1,000,000	1:24,000	4	0.11	14.5-15.0	(4.4-4.6)
Video-Enhanced	1:350,000	1:24,000	5	0.13	6.5	(1.98)

* Projector Specifications: Kodak Ektagraphic slide projector Auto focus Model AF-2

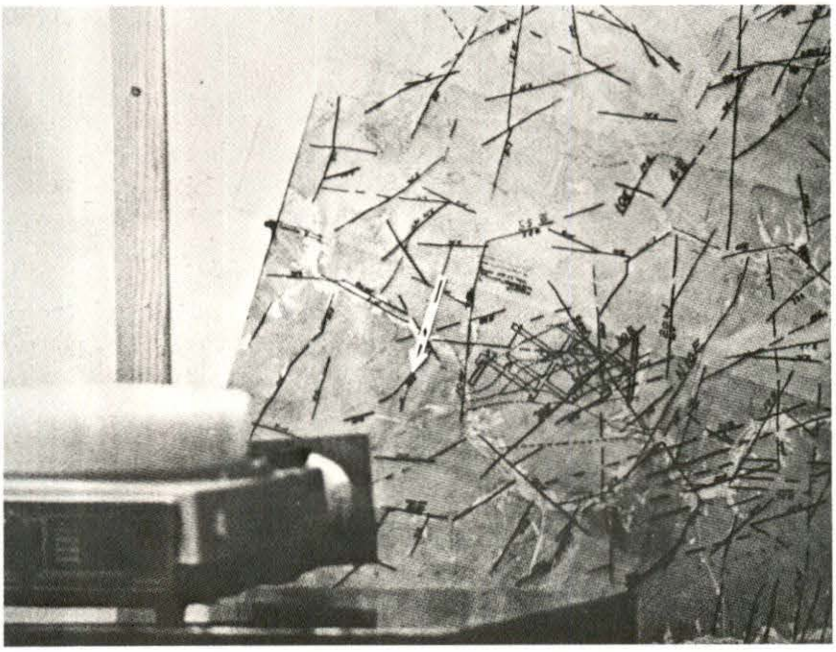
** Lens Specification: Kodak Projection Extanar Zoom Lens 4 to 6 inch focal length, and Kodak Projection Ektanar Lens—5 inch focal length

Figure 25. Ronchi Grating Enhancement of Simulated Lineament Patterns



Ronchi grating lines are oriented parallel to the east-west axis of the photograph. The fringes of light diffracted along the north and south edges of the projected image are the result of lengthwise image overlap. Shown also is the relative dense black tone of enhanced linears compared to linear features (light gray lines) oriented at angles other than perpendicular to the grating lines.

Figure 26. General View Showing the Arrangement for Imagery Enhancement and Lineament Plotting



The Ronchi grating is in position over the projector lens. The lineaments are on a plastic overlay using topographic 1:24,000-scale base maps. Also shown are a subsurface coal mine outline and reconstructed paleodrainage (sandstone channel axes projections) indicated by short dashed lines.

Method B-Video Enhancement Method. The second method involved the implementation of a video-enhancing system. The video-enhancing system is essentially a film densitometer which electronically detects and correlates tonal (gray level or photographic film density) present in satellite imagery film transparencies. Variations in the film density seen by the television camera (or scanner) are "edge enhanced" or "color enhanced" and displayed on monitor screens. Thirty-five mm color slides of the television monitor screen were taken and then projected onto the topographic base maps as in the Ronchi grating method. Comparatively speaking, the video-enhancing system is more effective in detecting tonal linear features than the Ronchi grating and also delineates ridge and valley alignments with results reasonably comparable to the Ronchi grating method (Figures 27 and 28).

Difficulties Encountered

The two basic difficulties experienced with the enhancement methods used in this study in the analysis of the satellite imagery are as follows:

1. Sun azimuth and elevation. As previously mentioned, the imagery used in this study were winter scenes with sun elevations of 23° to 29° and sun azimuths of about 140°. These sun positions tended to illuminate southeast-facing slopes and darken northwest-facing slopes (Figure 29). However, the inherent geometry of low sun angle and sun azimuth tended to introduce a bias emphasizing topography that approached a right-angle relationship with the illumination direction of the sun (NE-SW trends) while topography oriented from N30°W to N50°W (generally parallel to the solar illumination) are more evenly illuminated, and edge contrasts tended to be subdued. It was found that topographic alignments in this NW-SE directional range were somewhat more discernible when imagery was enhanced with Ronchi grating at a scale of 1:250,000 but may be over looked in analysis at scales of 1:24,000.

2. Scan lines. The approximate east-west (generally N80°W to 90°W) trending scan lines inherent to Landsat imagery were visible as faint but distinct lines. These were readily enhanced both by the Ronchi grating and video-enhancing system and produced false lineaments, masked true lineaments or, in some cases, reinforced true lineaments.

Evaluation of Lineament Data in Eastern Kentucky

With the development of the satellite imagery technique discussed previously, it seemed advisable to test the usefulness of satellite imagery by evaluating known structures in the eastern Kentucky area. The lineament interpretation in the next two sections of the study was done by Mr. Thomas McLoughlin as well as the generalized structure map in Figure 4 of this report.

Beginning with several of the known structures shown on Figure 4, imagery analysis was used to verify and to project structural elements beyond their mapped extent (Figure 30). The lineaments plotted represent linear features detected by Ronchi grating and video-enhancement of imagery using 1:24,000-scale topographic maps. Ground truth field studies were then conducted to check the position and direction of lineaments (Figures 30 and 31). Field studies involved mapping structural data (jointing, coal cleat and faulting) using a Brunton compass. This information was then plotted as each field locality as shown on Figure 31.

Figure 30 shows lineament data together with field data. While only the more persistent lineament trends are shown, it is apparent that lineament trends are reflected in structural trends measured in the field. Further, since many of the lineaments represent zones of jointing, it follows that these zones represent extensions of faults beyond the mapped extent of the faulting. This conclusion is supported by the fact that lineaments were found to closely parallel or correlate with mostly systematic jointing and coal face cleat trends.

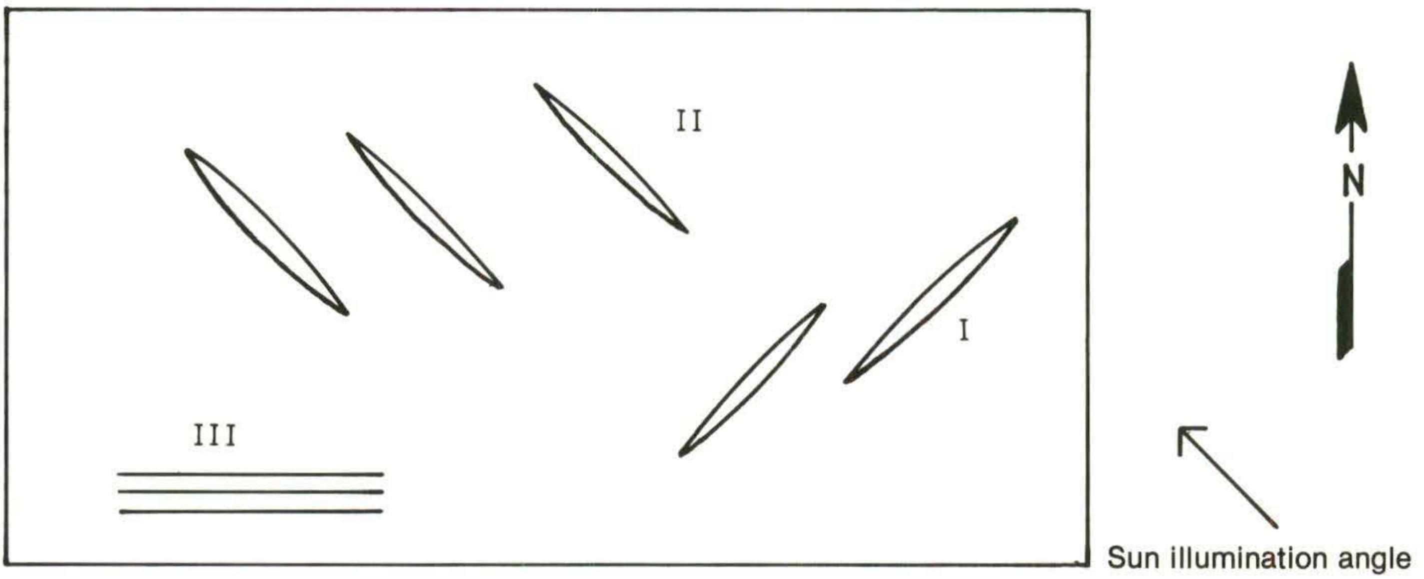
Figure 27. Photograph of Monitor Screen Showing Contrast Edge Enhancement of Imagery Film*

*Geographic reference points shown by "E" and "H."

Figure 28. View of Video Enhancer Showing Camera in Position to Photograph Monitor Screen*

*Note geographic reference points plotted on the screen.

Figure 29. Diagram Showing Effects of Solar Position Versus Topographic Trends and Scan Lines



I. Northeast-southwest linear features enhanced as they are normal to sun illumination direction.

II. Northwest-southeast linear features not as well enhanced because they are parallel to sun illumination direction.

III. East-west linear features present, but "hidden" because they parallel scan lines.

Figure 30. Regional Lineament Pattern Map Superposed Over Ground Truth and Generalized Regional Drainage

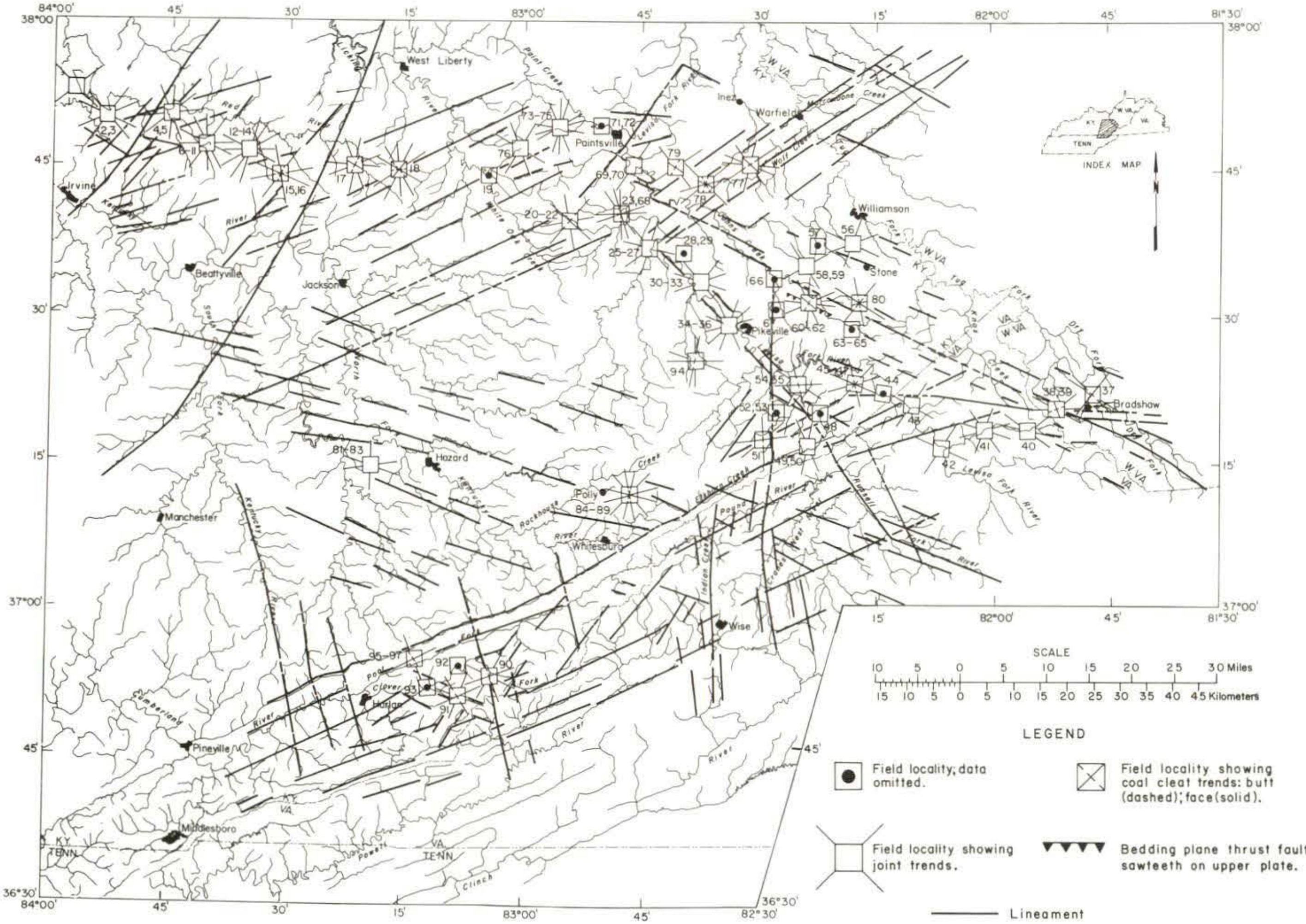
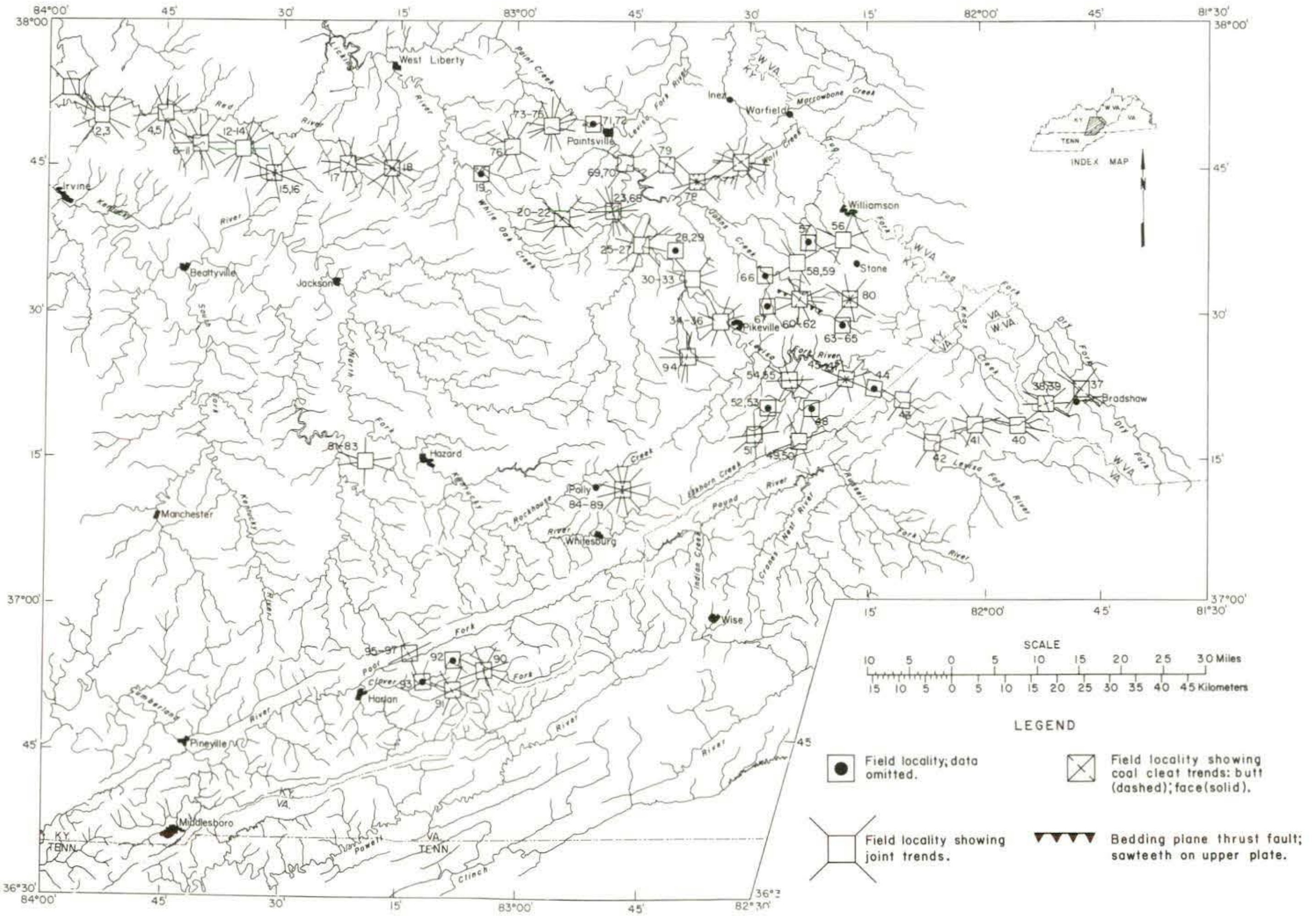


Figure 31. Index Map Showing the Locations of Ground Truth Control Points Superposed Over the Generalized Regional Drainage



Evaluation of Mining Areas

During the course of satellite imagery investigations under the present contract, two contrasting methods of treatment were used. The first method was used in initial investigations of the Harlan and Pike County areas discussed in this and the previous section of the report. In these analyses, lineaments were classified into Type A (valley), Type B (ridge) and Type C (tonal). The investigation of the West Virginia area by the author, assisted by Mr. Mike Stamper, is discussed in the next section. A somewhat different methodology was used when it was found that the concept of "zone lines" could be used to connect areas of "snap top." It was only after the West Virginia area was analyzed that attempts to analyze mines in the eastern Kentucky area using "zone lines" to connect roof fall areas was attempted. For this reason, the Beth-Elkhorn Number 22 mine is discussed after the West Virginia study area as an example of this later development in imagery analysis.

Evaluation of Eastover Mining Company Area. A portion of Harlan County, Kentucky was selected for direct comparison of satellite imagery and included those areas previously studied under contract H0133018. The primary research objective was the analysis and possible prediction of roof stability based on the correlation of structural and stratigraphic trends observed in underground coal mines and surface outcrop exposures. A summary of conclusions and recommendations made in that report are as follows and are summarized in Figure 32:

1. Based on statistical analysis, the mean directions of a four-set joint mean pattern closely parallels mean coal cleat patterns and agrees with a structural origin as predicted by a strain-ellipsoid model.

2. The Holocene drainage net developed in the Middlesboro basin appears to be structurally (joint) controlled.

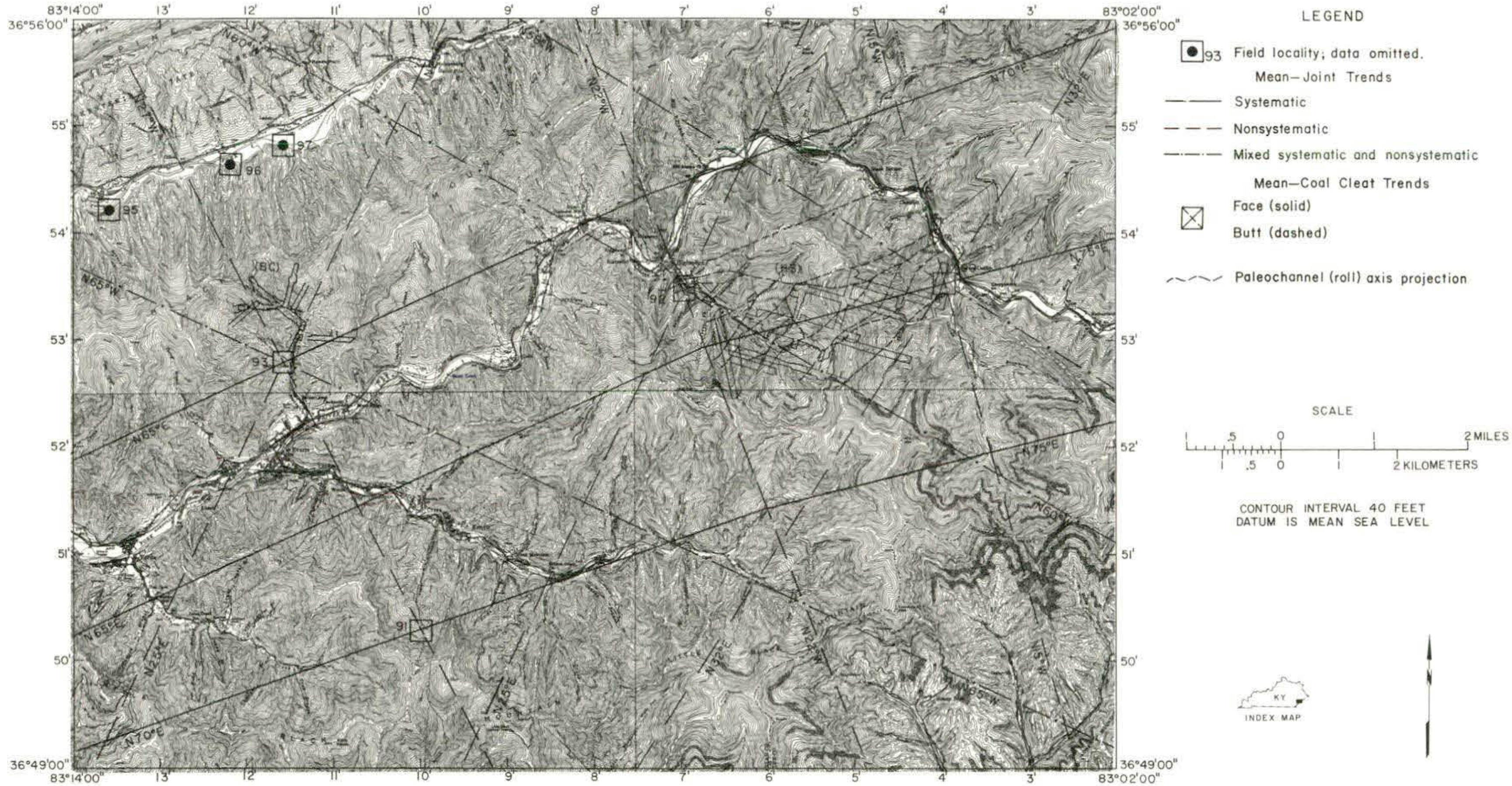
3. A direct relationship between joint frequency and directions with sandstone roll (paleochannel) trends was found. Regionally, the mean-paleochannel trends for the Harlan-Darby coal horizon intervals is unimodal, with a sediment transport direction from the northeast to the southwest. Locally, in the area of Highsplint, Kentucky, the paleochannel trends occur in a braided pattern. The sandstone channel axes dominantly trend northeast-southwest.

In general, there were three basic varieties of simple lineament-types recognized using the video-enhancing system and Ronchi grating enhancement techniques: drainage valley alignments, ridge alignments, and tonal alignments. These are referred to as lineament types A, B and C, respectively. The lineaments presented in Figures 33, 34 and 35 were compiled on the basis of comparisons of the linear features with lineament trends enhanced at a scale of 1:250,000 (Figure 30) and mean-joint trends (Figure 32). Comparatively speaking, the video-enhancing is more effective in detecting Type C linear features reasonably comparable to the Ronchi grating analysis with respect to directional trends and lineament placement. However, Type A lineaments enhanced by the video-enhancing system are generally shorter. Fewer of these crossed topographic highs than those enhanced with Ronchi grating.

Based on the direct comparison of the data in Figures 33, 34 and 35, the following tentative lineament classification was followed:

1. Type A lineaments. Drainage valley lineaments parallel the axis of the Middlesboro syncline and the mean directions of the four-joint-set patterns determined previously from field observations. The lineaments displayed a relatively narrow range in variance from the mean joint directions. The northeasterly trending lineaments parallel directions of systemic rock jointing and coal face cleat. Northwesterly trending lineament sets follow "mixed" systematic and nonsystematic joint directions and coal butt cleat.

Figure 32. Paleodrainage Net Superposed Over the Mean-Joint and Coal Cleat Patterns Mapped in Harlan County, Kentucky*



*(modified from Hylbert, 1977, Figures 40, 43, and 75).

Figure 33. Area of Eastover Mining Company's Highsplint and Bailey Creek Mines Showing Type A (Topographic Valley) Lineaments

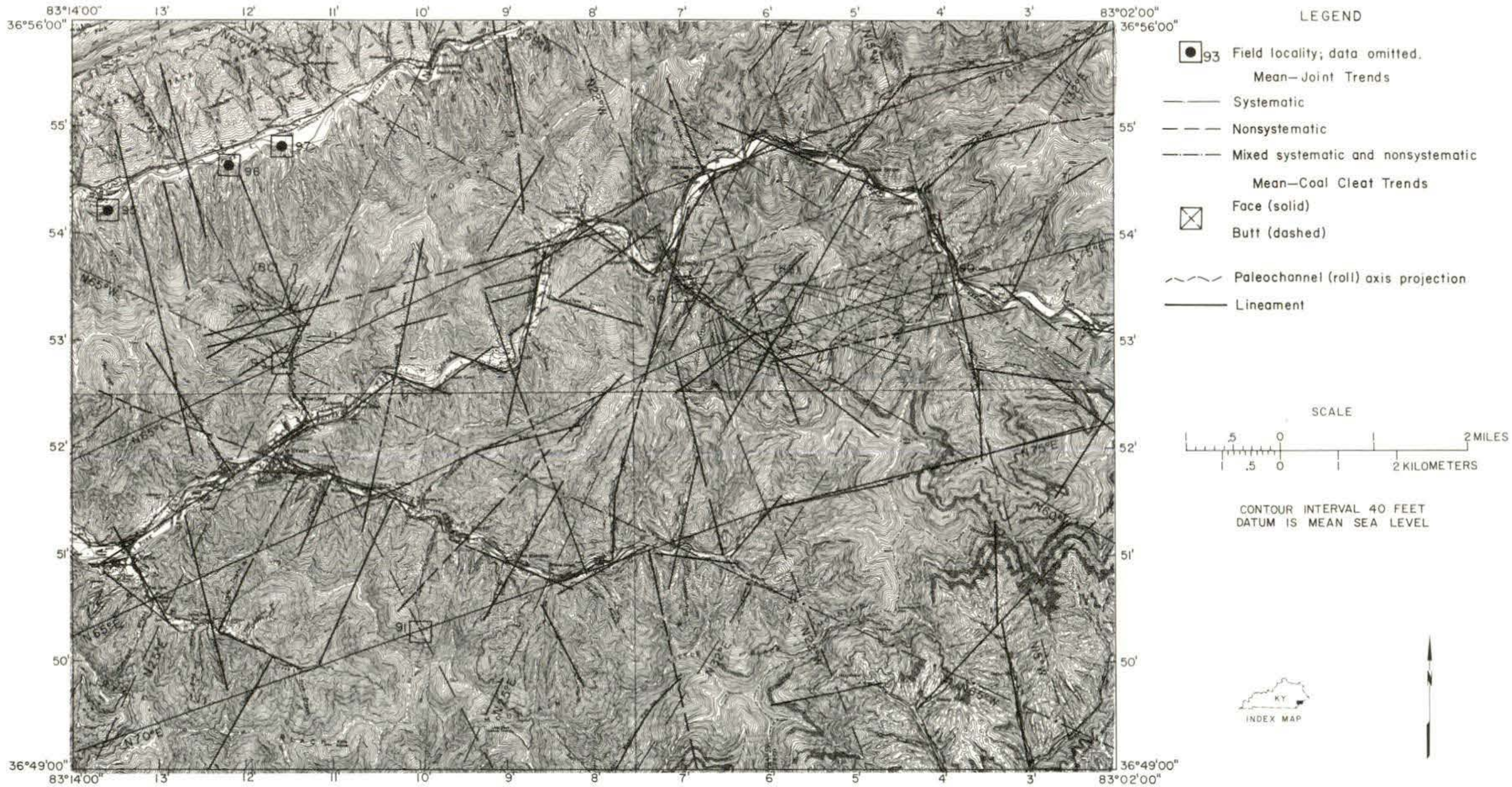


Figure 34. Area of Eastover Mining Company's Highsplint and Bailey Creek Mines Showing Type B (Topographic Ridge) Lineaments

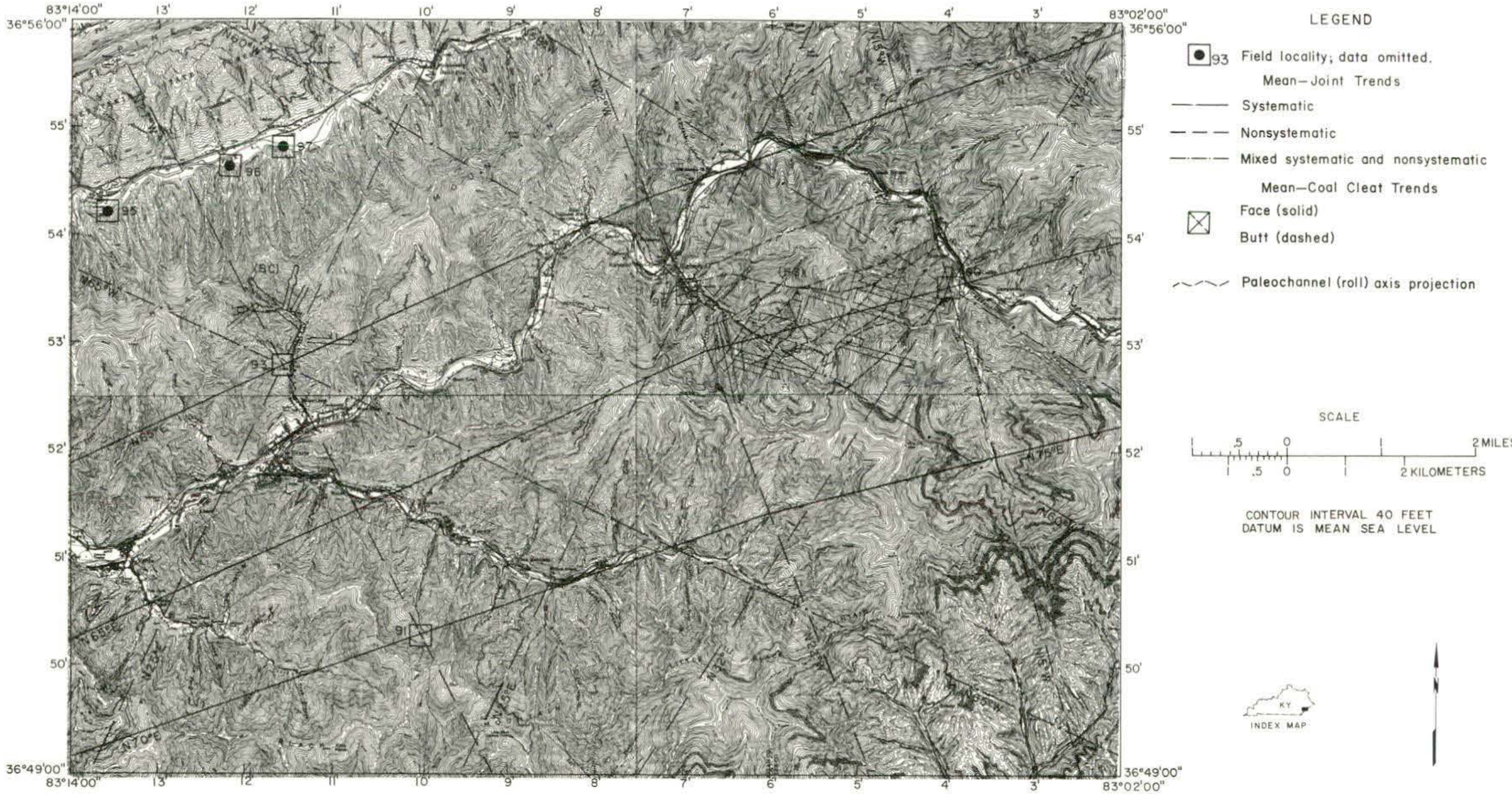
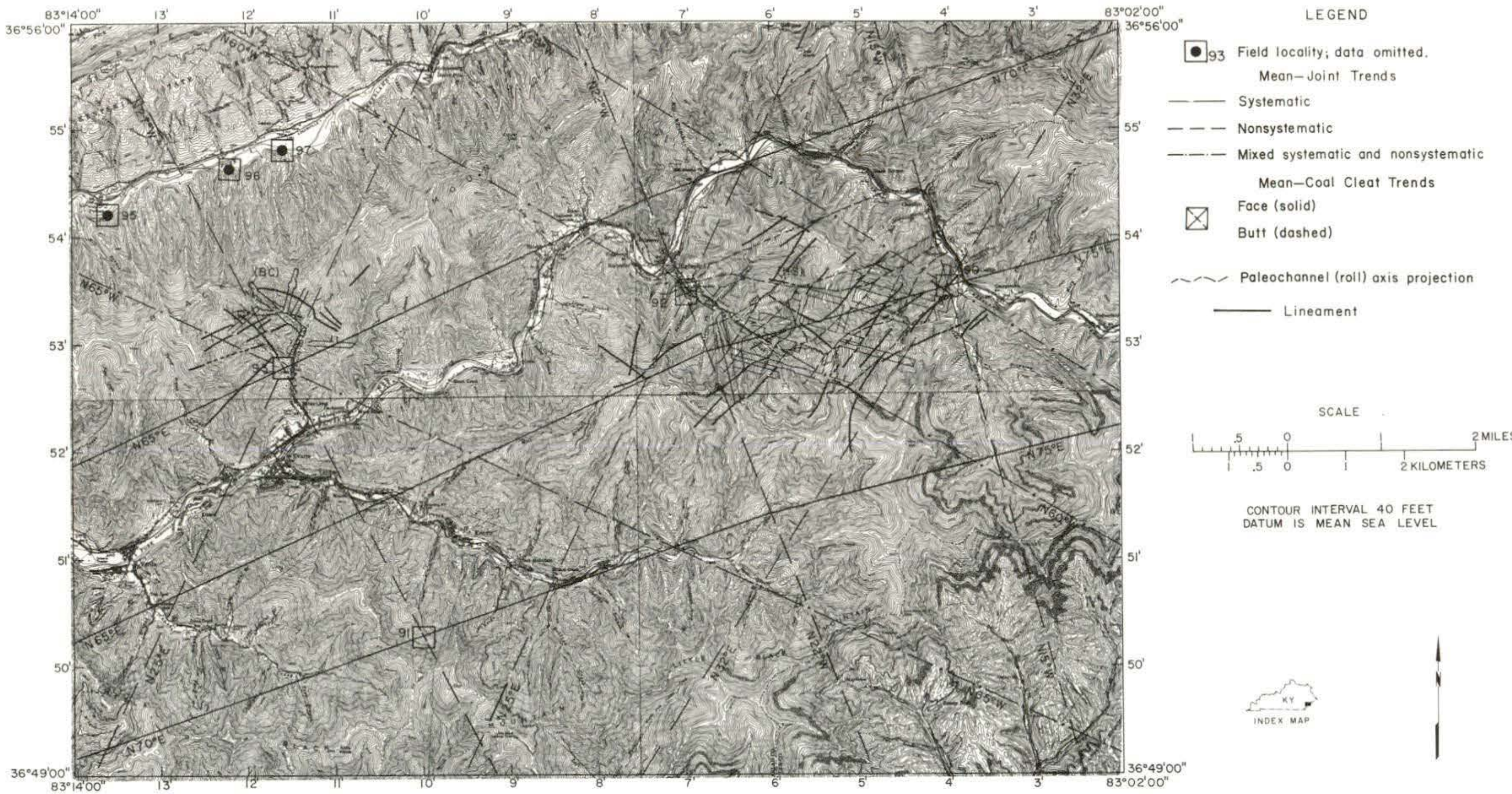


Figure 35. Area of Eastover Mining Company's Highsplint and Bailey Creek Mines Showing Type C (Tonal) Lineaments



2. Type B lineaments. Directions of linear or slightly curvilinear topographic ridge alignments, which are at least 0.5 mile (0.8 km) in length, parallel paleochannel trends. These lineaments for the study area trend approximately N65°E and N30°W. The northeasterly trends which were more strongly expressed by Ronchi grating enhancement parallel the Middlesboro synclinal axis and the general regional paleocurrent "mean azimuth" determined by Hylbert (15). These lineaments parallel or coincide with sandstone channel bodies.

3. Type C lineaments. Tonal lineaments parallel lineament types A and B. But locally tonal lineaments more closely coincided with paleochannel bodies and joint trends mapped underground than other lineament types.

In general, Type A lineaments, which parallel major drainage divides appear to represent zones of jointing and/or major lateral facies changes from shales and siltstone to sandstone which cap most of the ridges in the region. Lineaments which appear to be continuous at a scale of 1:250,000 are comprised of segments of various lengths. This observation is in agreement with that of Moore (26) who concluded that lineaments are composed of short, discontinuous segments.

Eastern Coal Corporation, Pike County, Kentucky. Using the general lineament classification developed for Harlan County, Kentucky, the area in Pike County was enhanced using Ronchi grating only. Comparisons were made with mapped sandstone channels and reconnaissance-type joint measurements both in surface exposures and underground coal mine (Figure 36). This area was selected because of its proximity to the projected trends of a known major structural feature (i.e. Bishop-Bradshaw Creek fault), and because of the existence of the extensive Eastern Coal Corporation underground coal mine in which major paleochannels have been mapped.

Following only a general imagery analysis of the region, correlations between paleochannel, joint, and lineament trends presented in Figure 37 were found to be similar to those in Harlan County, Kentucky. The two major ridge lineament directions, N65°W and N50°E parallel Pennsylvanian-age sandstone channels mapped in the subsurface. The N65°W trend is the trend of the "Johns Creek" lineament and the N50°E is parallel to the Warfield fault trend.

These observations strongly suggest structural control of depositional patterns during the Pennsylvanian period closely comparable to that reported by Padgett and Ehrlich (28) in southern West Virginia:

> Our data would indicate a sequence of events involving vertical movement along the fault zone occurring during sedimentation (hence the abrupt stratigraphic thickening as one crosses the fault)... The orientation of the trellis paleodrainages and the orientation of the major jointing (N60°E) for the area coincide...The trellis channel lengths of the Pocahontas Number Four parallel this jointing suggesting the tectonism that produced the deformation (gentle folds and faults in the area) controlled the ancient drainage patterns.

Although evidence collected to date is still incomplete, the above comparisons tend to suggest that the Bishop-Bradshaw Creek fault may have also influenced the structural and depositional patterns along its length into southeasternmost Kentucky. More detailed studies will be necessary to substantiate these observations.

Figure 36. Paleochannels and Reconnaissance Joint and Coal Cleat Patterns Mapped in the Area of the Eastern Coal Corporation, Pike County, Kentucky

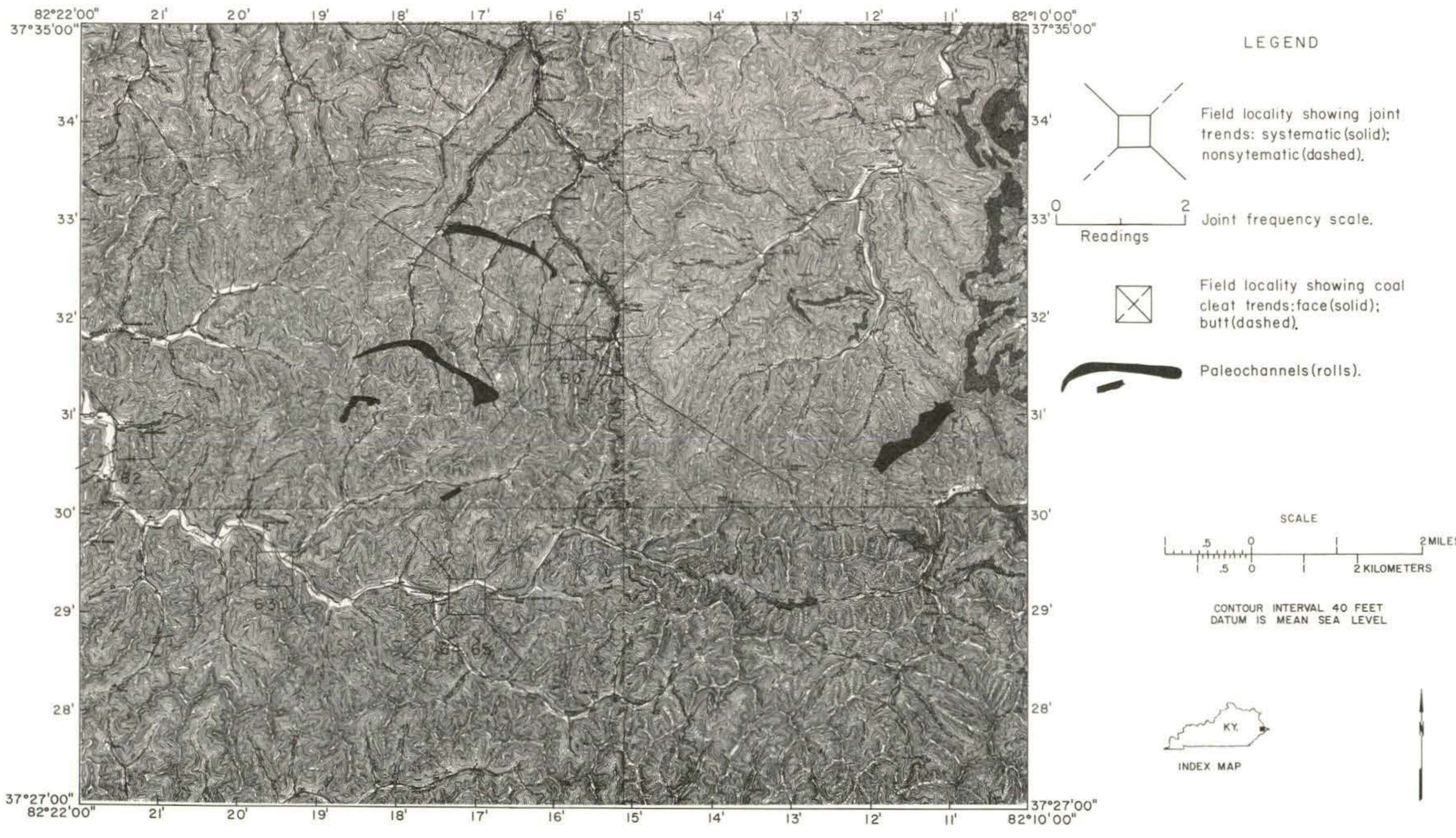
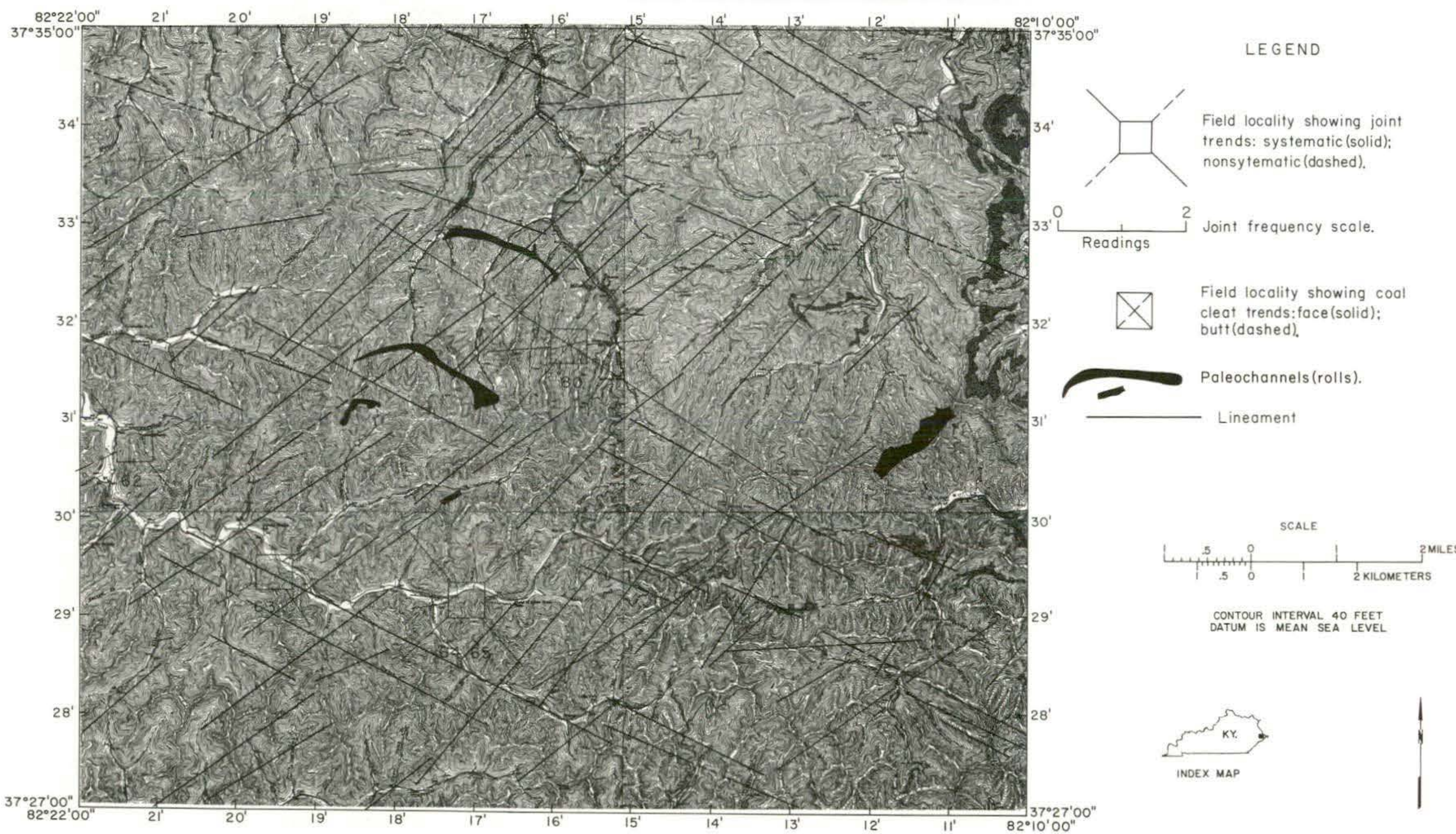


Figure 37. Area of Eastern Coal Corporation, Pike County, Kentucky, Showing Lineaments Superposed Over Ground Truth Data



Satellite Imagery Analysis-West Virginia

Purpose and Scope. The primary objective of this section was to consider an area in the Dunkard Basin of West Virginia and Pennsylvania in terms of satellite imagery analysis.

After consultations with Mr. Noel Moebs, Technical Project Officer for the contract, it was decided to focus attention on the area shown in Figure 38. The area includes the southeastern portion of Green County, Pennsylvania and parts of Monongalia and Marion Counties, West Virginia.

Extensive underground mining of the Pittsburgh coal bed has been done in the area by several companies. Overbey, et al (27) listed 12 factors that may contribute to unstable roof and concluded that at least two or three factors may operate in a single area.

In order to investigate satellite imagery analysis, the Bureau supplied 1:24,000-scale topographic maps of the area which had zones of unstable roof plotted (Figure 38). These zones are herein referred to as "snap top." Information concerning the character of "snap top" was outlined by Moebs (25), Dahl and Parsons (6) and Ferguson(16).

Some features of "snap top" described by these authors are:

1. The term "snap top" is applied to roof that fails with a snapping sound along steeply-dipping shear planes (cutters) that develop shortly after mining exposure. These shears are believed to develop due to high in situ stresses.

2. Areas of "snap top" are more commonly associated with rooms driven in a north-south direction.

3. "Snap top" most commonly occurs in mines situated beneath narrow, steep-walled valleys with relatively high relief. It is also more common in north-south trending valleys.

4. Areas of "snap top" are more commonly associated with areas of shallow overburden. Most "snap top" occurs at a depth of 600 feet (183 m) or less.

5. Ferguson (16) attributed "snap top" to differential stresses generated during valley erosion and the effects of unloading or valley stress release.

Geologic Setting. The study area is located within the Appalachian Plateau province. The area is hilly with a topographic relief generally of 400 to 500 feet (122m to 152m). Tributary streams are steep-walled with narrow valley bottoms and entrenched meanders of the major streams indicate rapid downcutting.

The Pittsburgh coal bed is late Pennsylvanian in age and is believed to have been deposited in the Dunkard basin area associated with deltaic sequences of clays, shales, siltstones and sandstone. Limy facies above the coal are common indicating a marine influence.

The sequence of sedimentary rocks in the area have been gently folded into anticlines and synclines. Figure 39 shows that these structures trend northeast-southwest, with dips generally less than five degrees.

The face cleat of the Pittsburgh coal bed in the area strikes about N70^{o}W and the butt cleat strikes about N20^{o}E. Rock jointing in the associated rocks is present as several systems discussed in the report and by Bench, et al (2).

Procedure. For this area, 1:1,000,000-scale satellite images were analyzed using the video-enhancing system. Thirty-five millimeter slides were taken of the video screen of both unenhanced and edge-enhanced scenes. These slides were then projected to scale on the 1:24,000-scale topographic maps on which areas of severe "snap top" had been plotted. The methodology followed was:

1. Unenhanced lineaments were plotted first on plastic overlays followed by edge-enhanced lineaments. At this stage the "snap top" zones were covered to help eliminate bias.

Figure 38. Location Map of the Study Area Covered by 1:24,000—Scale Topographic Maps

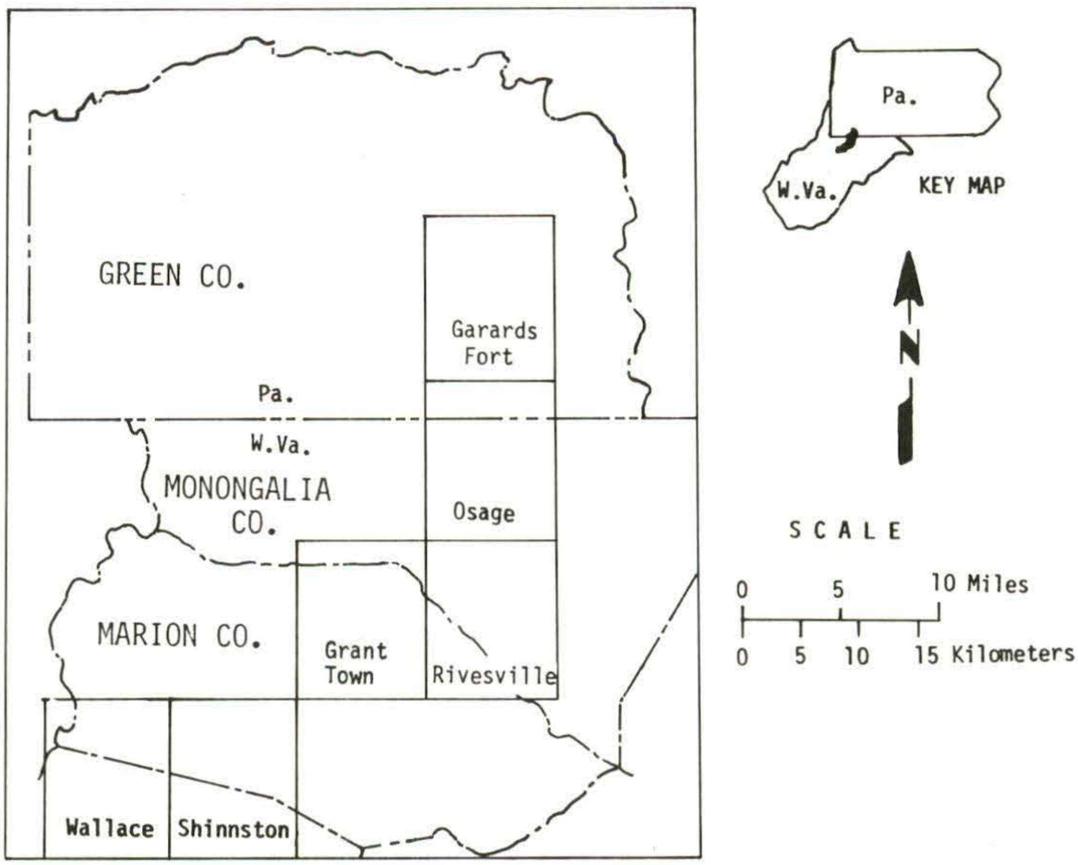
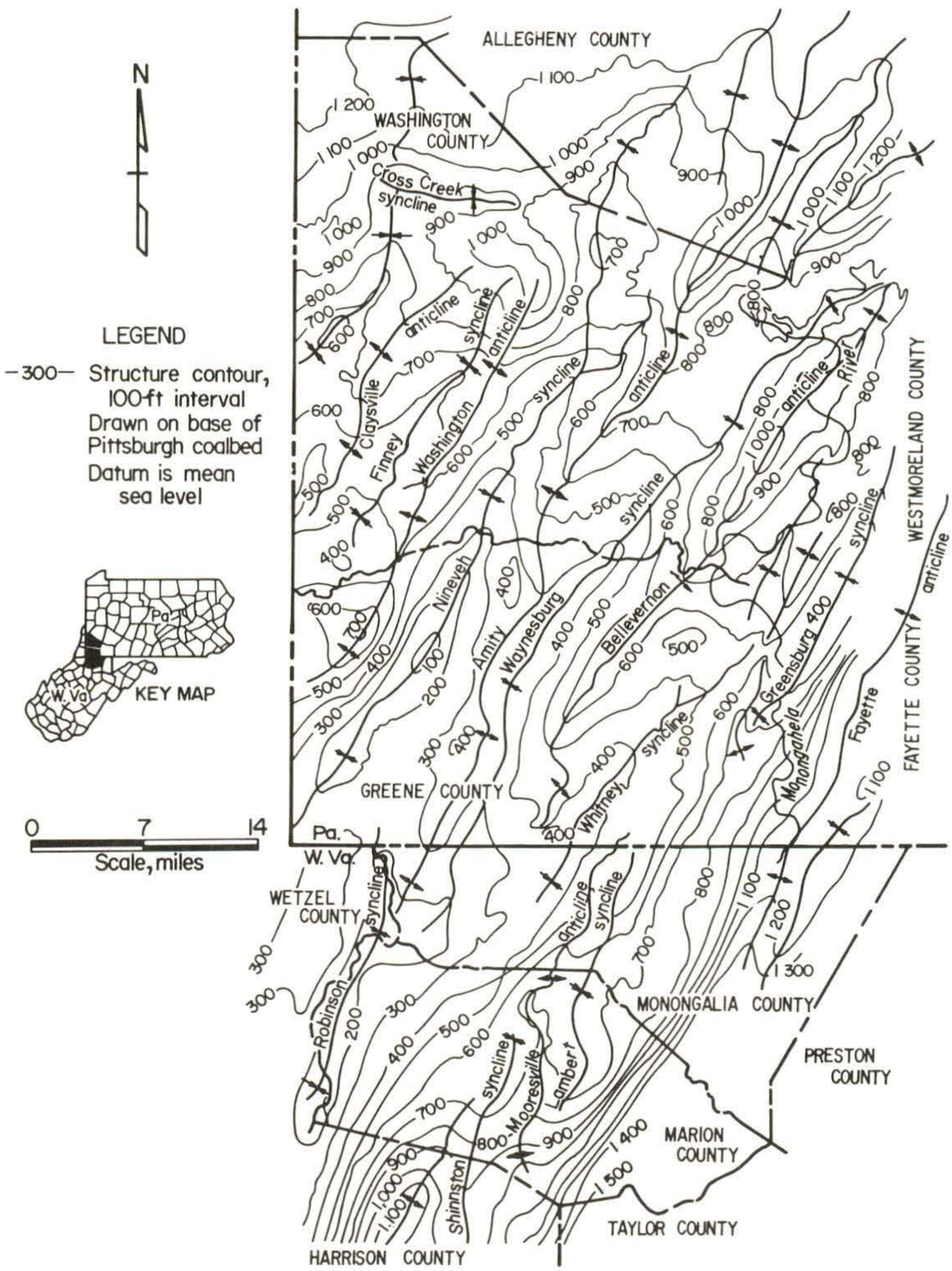


Figure 39. Map of Study Area Superposed Over Structure Map Drawn on the Base of the Pittsburgh Coal Bed* ©



*modified from Bench, et al (2) after Roen and Farrel (33).

2. A Ronchi grating mounted on the projector lens was used to determine topographic alignments. These directions were plotted on the plastic overlay as a "rose diagram" together with estimated "strength" of the alignment direction--ie. strong, moderate or weak. A comparison of these directions with those determined by Bench, et al (2) for the same area showed reasonably good agreement.

3. One of the characteristic features noted on the areas of "snap top" with lineaments superimposed was that many lineaments were parallel to or truncated areas of "snap top" (Figure 40). On this basis, an attempt was made to connect "snap top" areas by drawing lines between and/or parallel to them. It became evident that these lines were reasonably parallel to the Ronchi grating and lineament directions and formed "snap top" zones (Figures 40 and 41).

4. At this stage, the total area was divided into four areas for more detailed analysis (Figure 40). In each of the four areas, lineaments were retained only if they were closely parallel to and /or crossed one or more areas of "snap top." This decision was based on the assumption that, if the lineaments had structural significance, those most closely associated with known "snap top" would be most useful in projecting areas of possible "snap top" in advance of mining. Figure 42 shows area four in more detail.

5. In each of the four areas, lineament intersections were plotted and numbered. Table 4 shows the results for each area and totals. With an average of 61.9 percent of the intersections coinciding with "snap top," it is reasonable to assume that the lineaments are closely related to "snap top." Also, while not shown in Table 4, it was found that of a total of 213 lineament intersections, 104 (48.8%) intersections occurred in valleys, 99 (46.5%) occurred on valley sides and only 10 (4.7%) occurred on ridges.

6. Next, the valley trend of "snap top" was measured (Figure 42). Tables 7, 8, 11 and 14 show "snap top" directions at lineament intersections. A comparison with Tables 5, 6, 9, 10, 12 and 13 shows that "snap top" directions follow Ronchi grating and "snap top" zone directions .

7. In order to delineate possible "snap top" valleys in each of the four areas, all valleys parallel to "snap top" zone directions were measured using either the Ronchi grating or mechanical drafting arm. These valley alignments are shown on Table 15. Valleys that coincided with more frequent "snap top" directions within the area were considered possible "snap top" valleys (Table 15 and Figure 42).

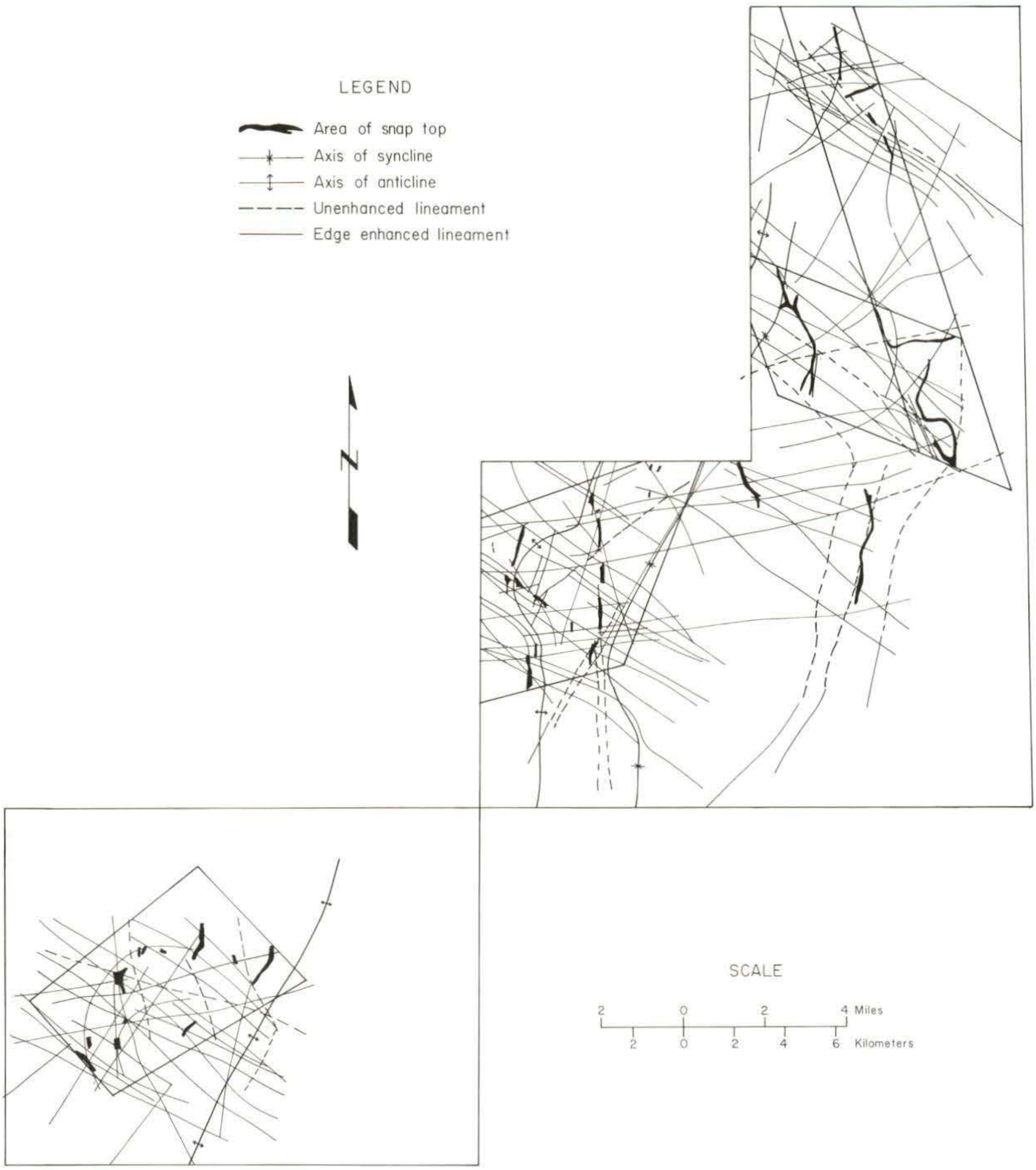
At this stage, possible "snap top" valleys should be considered indivdiually in terms of geologic conditions that might affect the roof.

Conclusions. 1. The reasonably close correlations between Ronchi grating, "snap top" zone lineament, and valley trend directions strongly suggests that rock jointing and in-situ stresses are important contributing factors in these roof failures.

2. "Snap top" zone lines provide a method of grouping areas of "snap top." For example, Figure 42 shows that the seemingly random orientation of "snap top" falls within two zones. One trends northeast-southwest parallel to the Wolf Summit anticline (and coal butt cleat) and the other trending about N70^{O}W (parallel to the coal face cleat). The single exception is an area of "snap top" near the center of the figure.

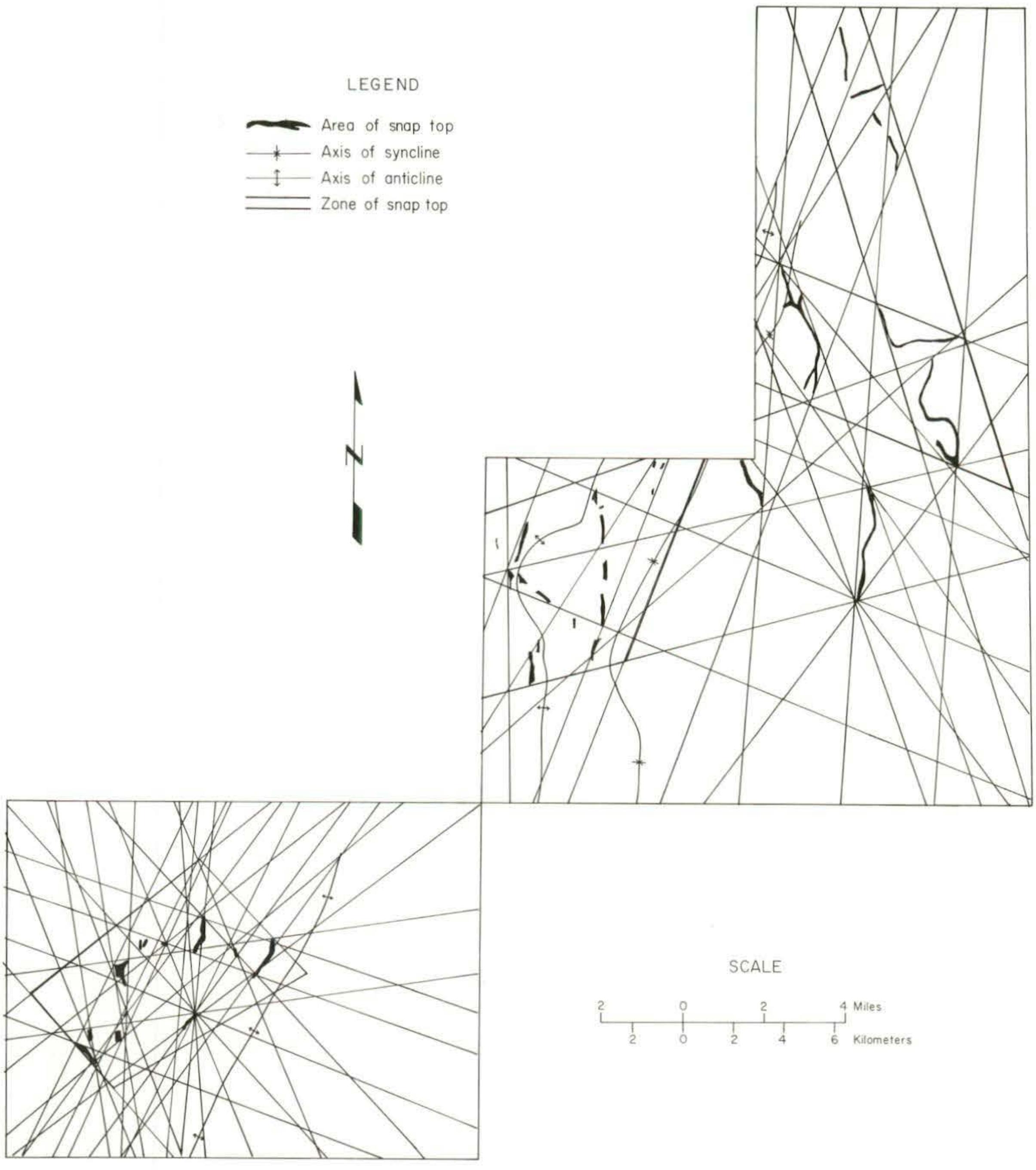
3. By using a combination of Ronchi grating, lineament intersection, and known "snap top" valley directions, it is possible to isolate valleys favorable for "snap top" within a given area. By considering percentages of valley directions (Tables 7, 8, 11 and 14) it is possible to speculate as to the most probable valley directions for "snap top" on an area-by-area basis. Consultations were held with officials of the Consolidation Coal Company, Morgantown, West Virginia, to see if any of the valleys designated as favorable for "snap top" had actually experienced roof failure. It appears that one large valley in area three had experienced severe roof problems as predicted. However, the possible "snap top" valleys in area four (Figure 42) had not experienced roof problems as predicted.

Figure 40. West Virginia-Pennsylvania Study Area Showing Lineaments and "Snap-Top"*



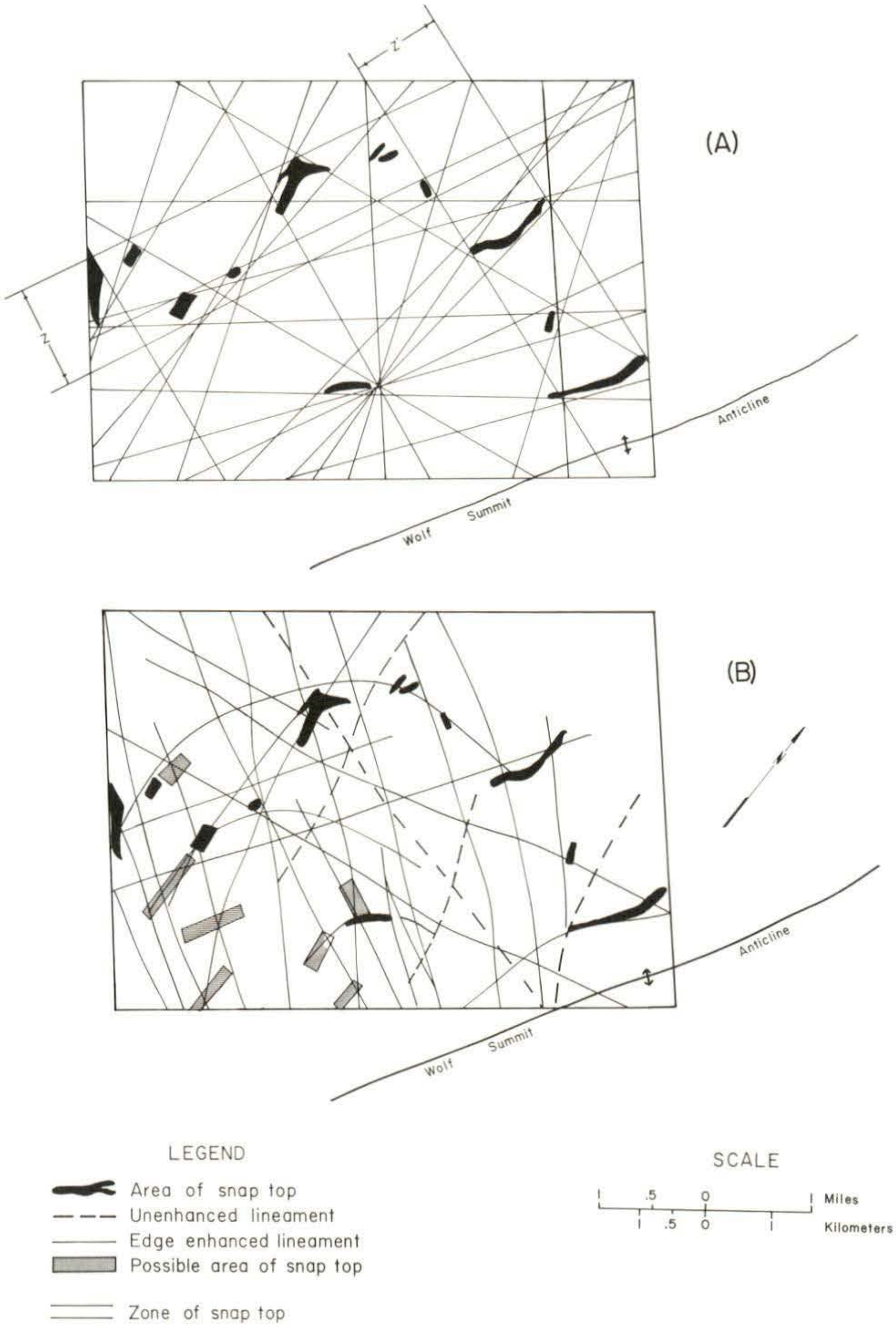
*Also shown are boundaries of four areas chosen for detailed analysis.

Figure 41. West Virginia-Pennsylvania Study Area Showing Zones of "Snap-Top"*



*A comparison with Figure 40 shows that zone lines are essentially parallel with lineament trends.

Figure 42. Detailed View of Area Four Showing Known Areas of "Snap-Top" Together with Possible Areas of "Snap-Top"*



*Detailed view of area 4 shown in Figure 40. Zone lines shown in (A) above are generally parallel to lineaments in (B) below. z' and z' in (A) show zone lines bounding "snap top" parallel to and perpendicular to Wolf Summit anticline respectively.

Table 4. Lineament Intersections and "Snap Top"

Area	Total Lineament Intersections	Total Intersections Coinciding With "Snap Top"	Percent Intersections Coinciding With "Snap Top"
I	32	21	65.9
II	57	35	61.4
III	73	45	61.6
IV	51	31	60.8
Totals (Areas I-IV)	**213**	**132**	**61.9**

Table 5. Ronchi Grating Trends, Osage, W. Va.-Penn. Quadrangle (Areas I and II)

Systems

N 10°E (M)-N 65°W (M) (75° separation)

N 24°E (M)-N 65°W (M) (87° separation)

N 40°E (S)-N 35°W (M) (85° separation)

N 53°E (S)-N 24°W (W) (77° separation)

N 76°E (W)-N 12°W (M) (88° separation)

Table 6. Zone Trends, Osage, W. Va.-Penn. Quadrangle (Areas I and II)

East Trends	West Trends
N 05°E	N 65°W-N 67°W
N 20°E	N 40°W
N 37°E	N 19°W
N 73°E-N 76°E	N 16°W

Table 7. "Snap Top" Valley Directions at Lineament Intersections (Area I)

Valley Directions	Number	Percent
N 10°E-N 12°E	7	33.3
N 88°E	3	14.3
N 15°W	1	4.8
N 20°W-N 25°W	8	38.1
N 50°W	2	9.5
Totals	**21**	**100.0**

Table 8. "Snap Top" Valley Directions at Lineament Intersections (Area II)

Valley Directions	Number	Percent
North-N 12°E	15	42.9
N 25°E	3	8.6
N 88°E	3	8.6
N 10°W-N 15°W	2	5.7
N 25°W-N 30°W	10	28.6
N 50°W	2	5.7
Totals	**35**	**100.1**

Table 9. Ronchi Grating Trends, Grant Town, W. Va., Quadrangle (Area III)

Systems
N 15°E (M)-N 74°W (W) (89° separation)
N 37°E (S)-N 52°W (M) (89° separation)
N 56°E (S)-N 35°W (W) (91° separation)
N 74°E (W)-N 08°W (M) (89° separation)
N 86°E (W)-N 08°W (M) (94° separation)

Table 10. Zone Trends, Grant Town, W. Va., Quadrangle (Area III)

East Trends	West Trends
North-South-N 05°E	N 67°W
N 20°E	N 36°W-N 40°W
N 37°E	N 16°W-N 19°W
N 50°E	
N 70°E-N 76°E	

Table 11. "Snap Top" Valley Directions at Lineament Intersections (Area III)

Valley Directions	Number	Percent
N 10°E-N 13°E	5	11.1
N 27°E	4	8.9
N 35°E-N 40°E	4	8.9
N 65°E	1	2.2
N 72°E-N 75°E	6	13.3
N 82°E	3	6.7
N 05°W-N 15°W	15	33.3
N 50°W-N 52°W	7	15.5
Totals	**45**	**99.9**

Table 12. Ronchi Grating Trends, Shinnston and Wallace, W. Va., Quadrangles (Area IV)

Systems
N 09°E (M)-N 70°W (W) (79° separation)
N 22°E (M)-N 65°W (W) (87° separation)
N 36°E (S)-N 43°W (W) (79° separation)
N 58°E (S)-N 28°W (W) (86° separation)
N 84°E (W)-N 08°W (W) (92° separation)

Table 13. Zone Trends, Shinnston and Wallace, W. Va., Quadrangles (Area IV)

East Trends	West Trends
N 03°E-N 05°E	N 70°W-N 72°W
N 25°E	N 43°W
N 36°E	N 22°W-N 24°W
N 48°E-N 50°E	N 05°W-N 09°W
N 80°E-N 81°E	

Table 14. "Snap Top" Valley Directions at Lineament Intersections (Area IV)

Valley Directions	Number	Percent
N 05°E-N 08°E	4	12.9
N 20°E-N 25°E	5	16.1
N 40°E	1	3.2
N 45°E-N 50°E	6	19.4
N 70°E	1	3.2
N 05°W-N 08°W	8	25.8
N 20°W	1	3.2
N 65°W	1	3.2
N 68°W-N 70°W	4	12.9
Totals	**31**	**99.9**

Table 15. Valley Trend Analysis

Area	Valley Trends Measured		Valley Trends Coinciding With "Snap Top"		Possible "Snap Top" Valleys	
	Total	Percent	Total	Percent	Total	Percent
I	54	100	15	27.8	2	3.7
II	60	100	13	21.7	2	3.3
III	61	100	14	23.0	6	9.8
IV	94	100	20	21.3	7	7.4
Totals (Areas I-IV)	**269**	**100**	**62**	**23.0**	**17**	**6.3**

4. The process of isolating valleys favorable for "snap top" as outlined here only takes into account valley trends, some structural information inferred from lineaments, and overburden thickness where available. Many other important considerations such as roof rock characteristics, the presence of rider coal seams, local discontinuities in the roof rock, or the presence of water would have to be considered for a complete analysis of each valley on an individual basis.

Beth-Elkhorn Number 22 Mine

The Beth-Elkhorn Number 22 mine provided an excellent study site for satellite imagery analysis. The mine is large and reasonably good mine maps in several scales were available. Several mine maps were especially helpful because bad roof and/or low coal areas had been noted. Also, company personnel were very helpful in providing information and tours of the mine. As mentioned previously, this mine is used as an example of the development of a somewhat different technique of imagery analyses using "zone lines" to connect roof fall areas.

Imagery Analysis Procedures. Analysis procedures of the mine followed the format discussed earlier. First, imagery was projected to scale on 1:24,000-scale topographic maps with the mine map superposed. Lineaments were plotted on plastic overlays and Ronchi grating directions plotted as a rose diagram in one corner of the scene. Figure 43 shows lineaments plotted in the mine area on a topographic map base and the following may be noted:

1. In general, unenhanced lineaments are tonal, and do not closely follow ridges and valleys.

2. Edge enhanced lineaments, while sometimes not closely following ridges and valleys, tend to follow topographic features or connect adjacent ridges and/or valleys more frequently than unenhanced lineaments.

3. Density contour lineaments, indicated by "breaks" in edge enhanced lineaments, were produced by video enhancement in the density contour mode after reducing the width of edge enhancements to a narrow line. These lineament "breaks" apparently represent valleys and/or gaps in ridges and are produced when the edge enhanced lineament crosses a valley at an angle or parallels a ridge. The density contour lineaments shown on Figure 43 were drawn by connecting several adjacent "breaks" in the enhanced lineaments. After analyzing several mine areas, it became evident that the use of density contours is greatly dependent on topographic relief. If the relief is too great or drainage lines widely spaced, not enough "breaks" are visible to connect. Conversely, if the relief is too low or drainage too closely spaced, the edge enhanced lineaments produce a maze that is very difficult to interpret. However, the Beth-Elkhorn Number 22 mine area was suitable for the use of density contours.

In some cases, density contours parallel edge enhanced lineaments. It is noteworthy, however, that in this area they parallel probable structural directions not shown by either edge enhanced lineaments or unenhanced lineaments.

4. Also shown in Figure 43 are roof fall areas. It is evident that many of the lineaments parallel, cross or coincide with roof falls in the mine. It should be noted that not all "roof fall zones" in the mine represent actual roof falls. Many of these areas were inaccessable and were designated on mine maps as "bad roof." It is likely, then, that these areas would be either roof fall areas or unstable roof that required additional support measures.

Using a similar procedure as that used with the West Virginia study area, attempts were made to construct zones of roof falls by connecting roof fall areas. Ronchi grating directions were used as a guide. It was found that zones could be delineated and that in most cases the zone lines paralleled lineament directions as shown in Figure 44.

Figure 43. Beth-Elkhorn Mine 22 Showing Lineaments Superposed Over Roof Falls

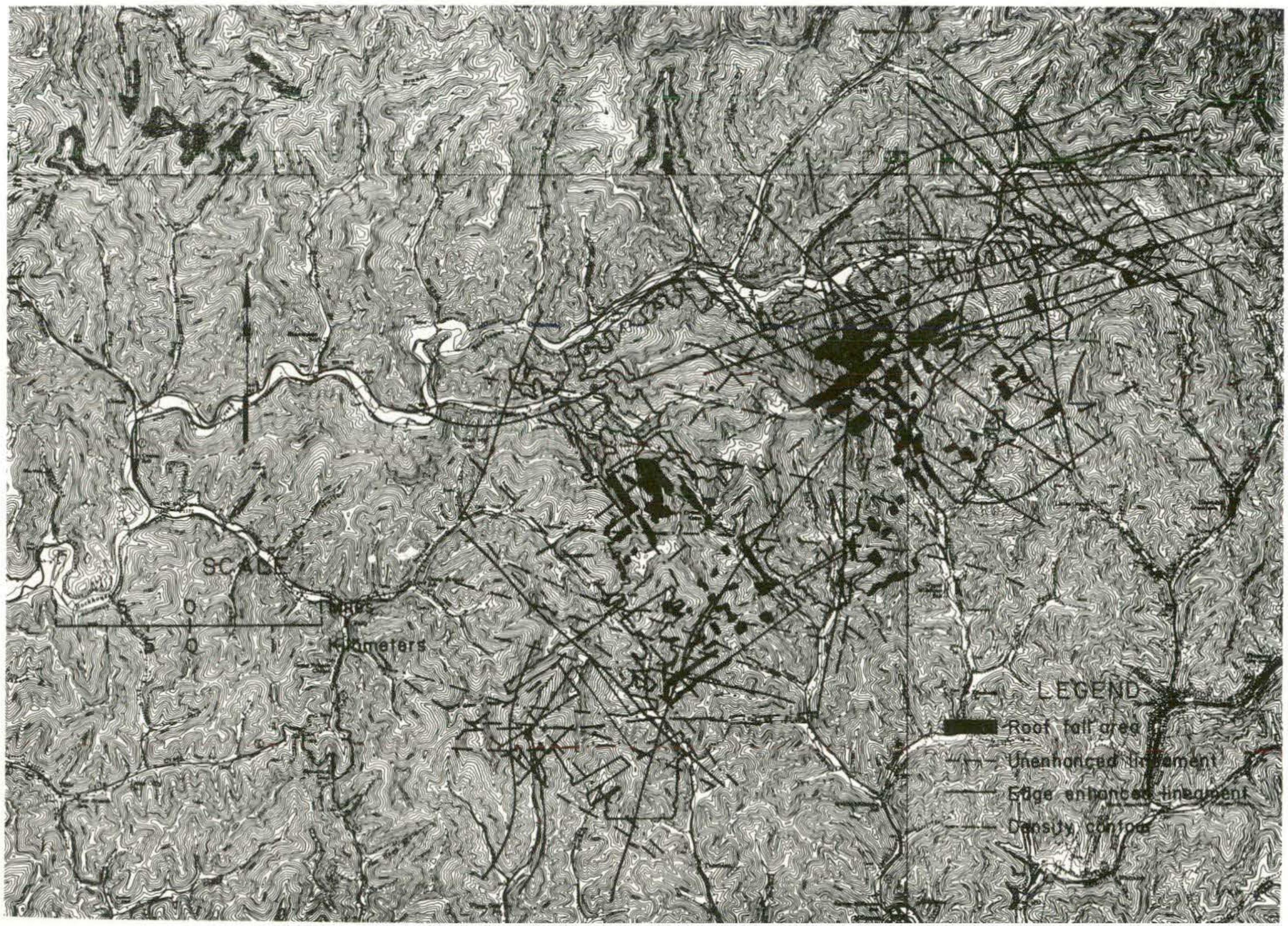
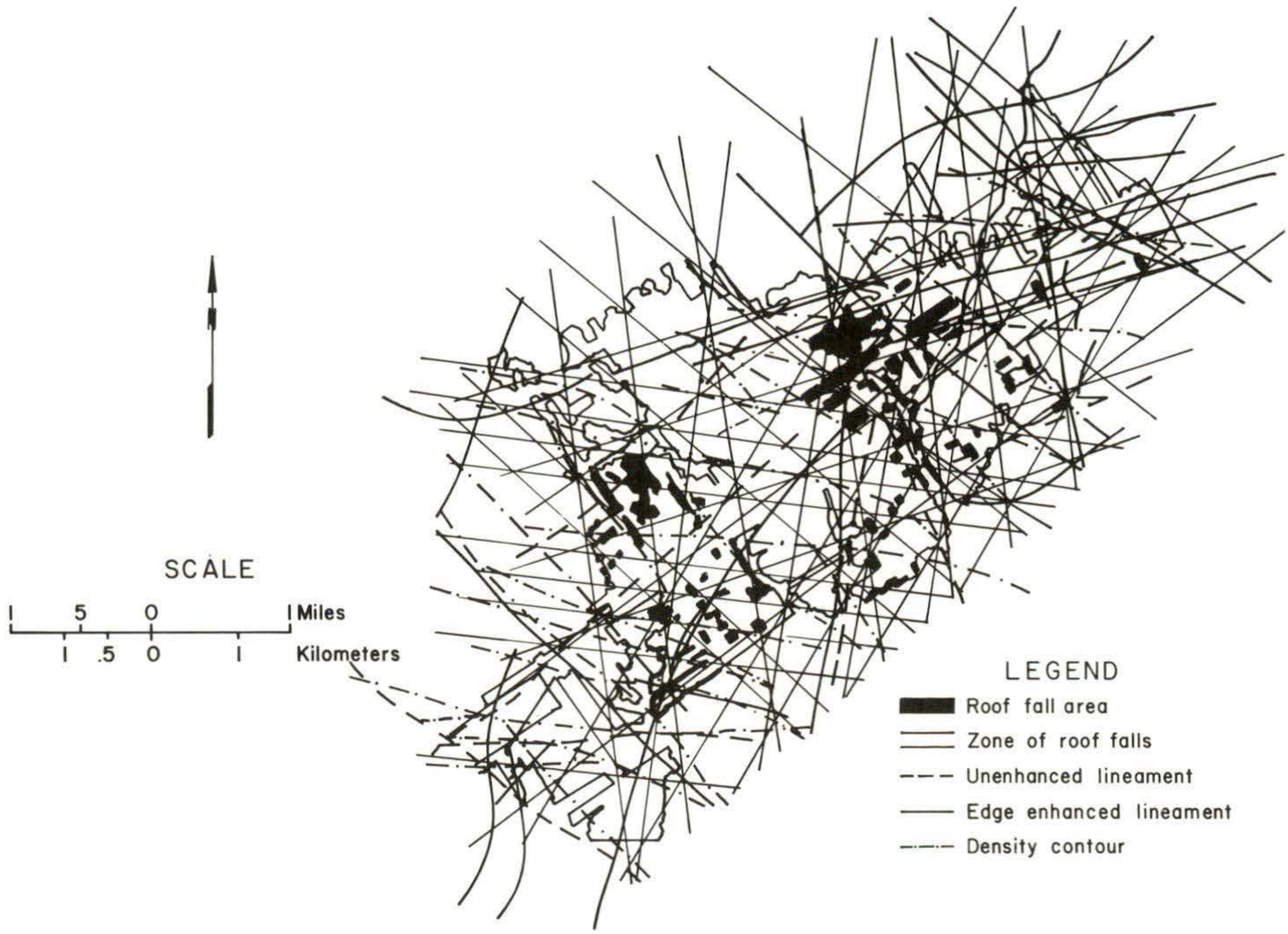


Figure 44. Beth-Elkhorn Mine 22 Showing Lineaments and Zone Lines Superposed Over Roof Fall Areas*



*Zone lines do not delineate specific zones, but show parallel trends with lineaments. Figure 45 shows zone lines without lineaments for comparison.

The next step in the process was to compare in-mine and surface structural data gathered in the field. The surface data was gathered at outcrops of the Elkhorn 3 coal horizon and at outcrops of the Fireclay coal bed (400 feet (122 m) higher) and the Francis or Hazard No. 8 coal (900 feet (274 m) higher). These localities represent a total of about 140 readings taken with a Brunton compass, and correspond very closely with both lineament and roof fall zone directions. Of particular importance is the strong indication that structural directions, represented by joints and perhaps faults, extend vertically to a depth of at least 800 feet to 1000 feet (244-305 m). This indicates that, since the company plans to mine the Fireclay coal bed, structural information derived by analysis of the Number 22 mine (Elkhorn Number 3 coal bed) may be useful in mining the Fireclay coal bed above (Figure 45).

Lastly, in superposing sandstone channels over the roof fall zone lines, it is evident that a close relationship exists between sandstone channel trends and Ronchi grating directions, lineament directions and roof fall zone lines (Figure 46).

Analysis of Lineament Intersections. In order to analyze lineament intersections in the mine, all intersections were circled and numbered consecutively on the lineament overlay. Each intersection was then considered as to type(s) of lineament(s) involved in the intersection, overburden thickness at the intersection and whether the intersection coincided with valleys, valley sides or ridges. The coincidence of intersections with roof falls and paleochannels was also noted. Some interpretation was necessary when intersections were close to, but did not coincide exactly with roof falls or channels. An arbitrary radius of 100 feet (31 m) was chosen. If the intersection was plotted 100 feet (31 m) or less from the roof fall or channel, it was considered "close to" the roof fall or channel.

Within the framework of these considerations, the following statements may be made concerning lineament intersections:

1. The results are summarized from a total of 79 intersections. However, some intersections occurred where only two lineaments crossed, whereas other intersections involved three or four lineaments crossing at a single point. Because of this fact, totals as to lineament type will not equal 79. Lineament types that coincide with or occur near (within 100 feet (31 m)) a roof fall or unstable area are as follows:

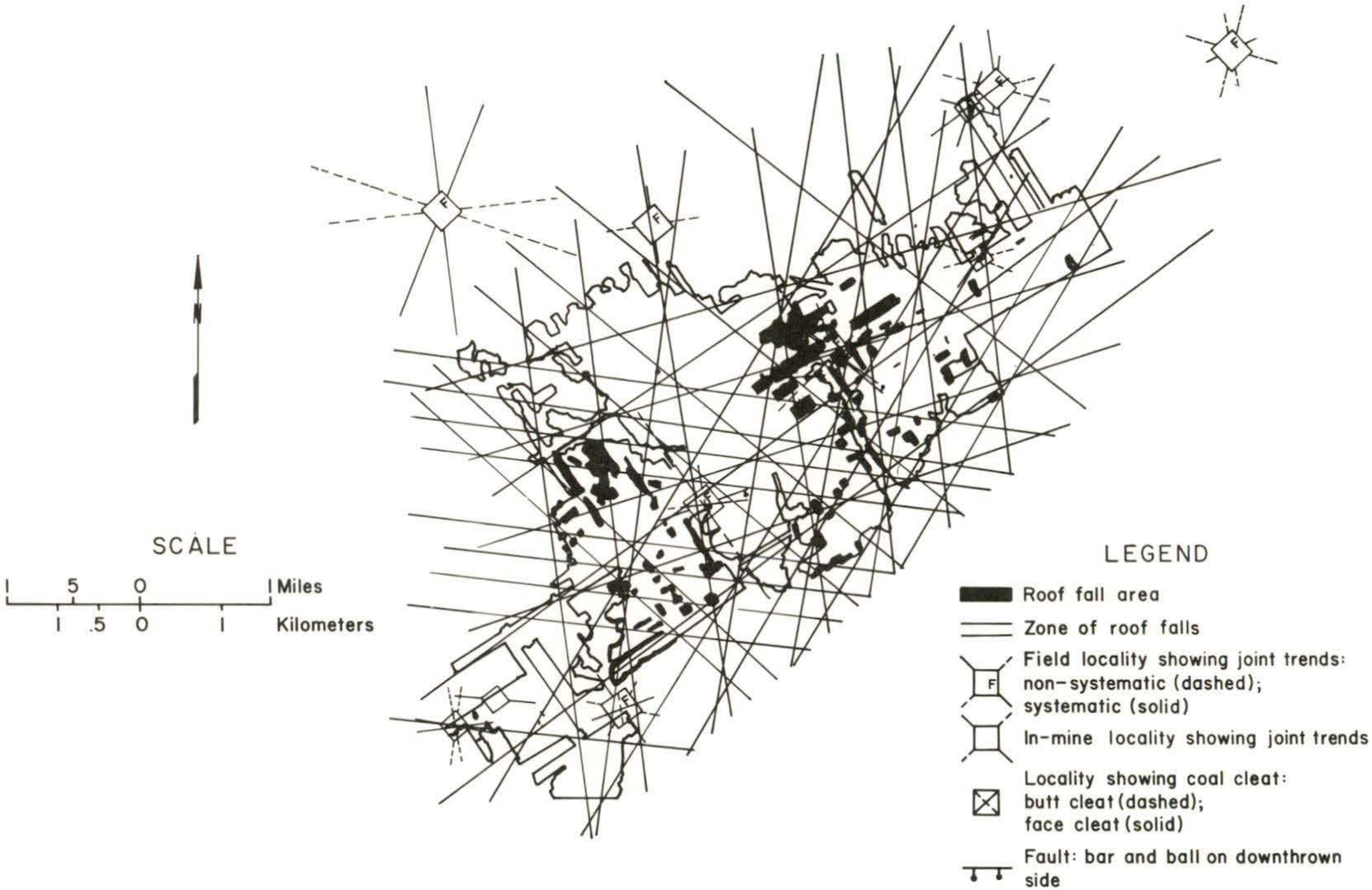
	Number	Percent
Unenhanced	14	15.4
Density contour	30	33.0
Edge enhanced	47	51.6
Totals	91	100.0

As is evident, edge enhanced lineaments account for the largest percentage of intersections. This percentage is even higher in most of the other mines analyzed where denisty contours were not useful. Also, if only intersections occurring at roof falls are considered the results are similar. Unenhanced lineaments account for 10 (16.4 percent, density contour for 22 (36.1 percent), and edge enhanced for 29 (47.5 percent) of the intersections.

2. Of greatest importance in lineament intersection analysis is the coincidence of intersections (without regard to type) with roof falls as follows:

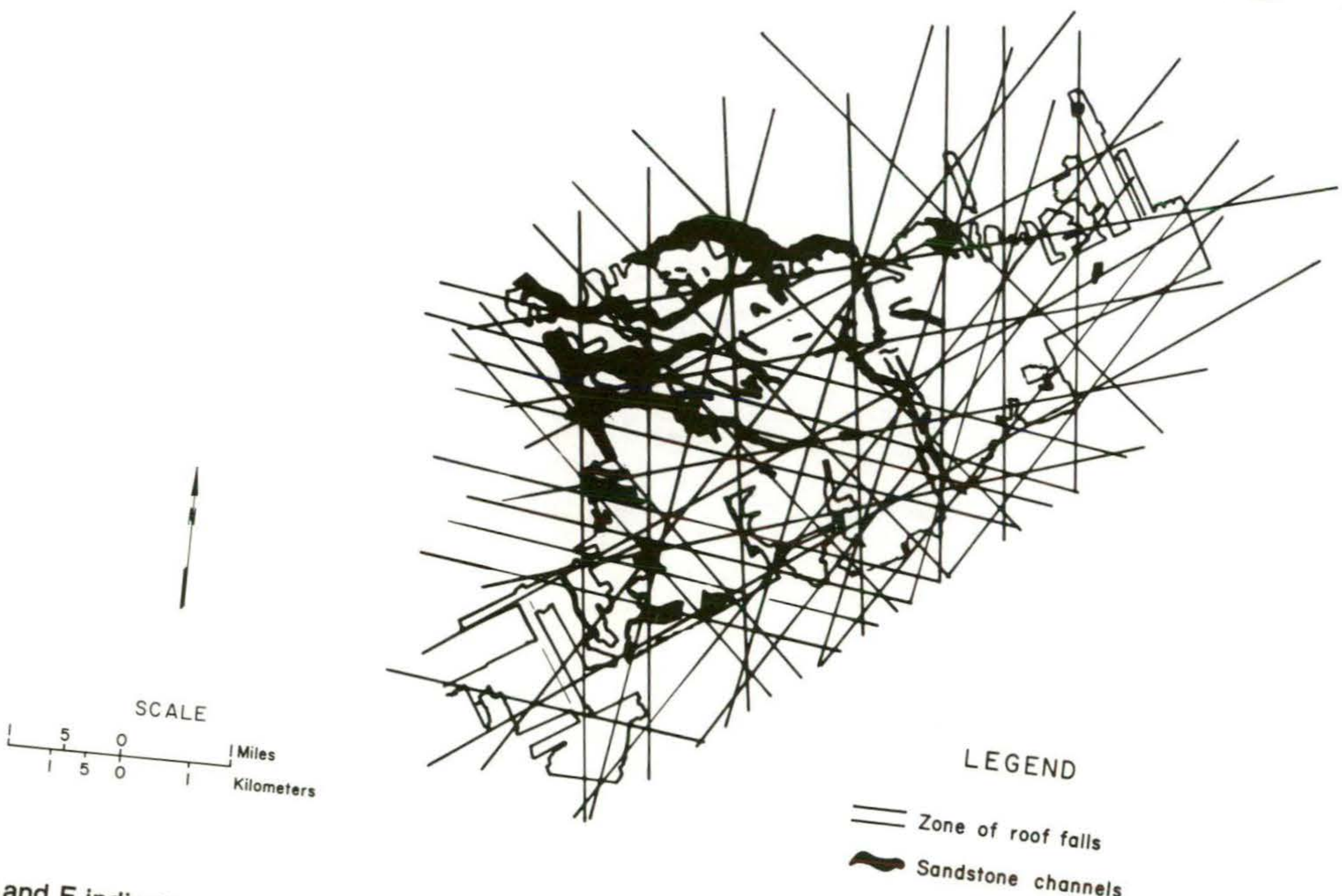
	Number	Percent
Coincidence with Roof Falls	27	34.2
Intersection Near Roof Falls	12	15.2
Not Associated with Known Falls	40	50.6
Totals	79	100.0

Figure 45. Beth-Elkhorn Mine 22 Showing Zone Lines Superposed Over Roof Falls*



*Note close correlation with surface and in-mine structural trends (joints and faults).

Figure 46. Beth-Elkhorn Mine 22 Showing Zone Lines Superposed Over Sandstone Channel Trends*



*D and F indicate D and F Sections in the mine.

By combining intersection coincidence and intersections near roof falls, about 50 percent of all intersections may be associated.

3. A comparison was also made between lineament intersections and paleochannels or sandstone axis projections that coincided with roof falls. The results are as follows:

	Number	Percent
Intersections Coincide	13	33.3
Intersections Close or Possible	12	30.8
Intersections do not Coincide	14	35.9
Totals	39	100.0

By combining coincidences and close or possible coincidences a total of 25 or 64.1 percent is obtained.

4. Consideration was given to the topographic relationship of lineament intersections at the 39 roof falls. Intersections at valley sides accounted for 21 (53.8 percent), intersections under valleys for 10 (25.6 percent) and ridge intersections for 8 (20.5 percent). A casual inspection of the distribution of unstable roof shown on Figure 45 indicates that many of these areas either underly or are marginal to valleys. By combining valley and valley side intersections 31 or 79.4 percent occurrance supports this relationship.

A consideration of overburden thickness at intersections showed that overburden thickness above the Elkhorn 3 coal bed at ridge intersections ranged from 200 feet to 700 feet (61 m-213 m). Under valleys overburden ranges from about 80 feet to 300 feet (24 m-92 m) and from 100 feet to 700 feet (31 m-213 m) for valley side intersections.

Conclusions. The foregoing lineament analysis of the Beth-Elkhorn mine has been viewed from two standpoints. First, it is evident that lineaments give an excellent indication of trend or direction when compared to structural, roof fall, and paleochannel trends. The second aspect has been to relate lineament intersections to roof falls. It was assumed that lineament intersections should indicate (if lineaments reflect structural zones of weakness) areas in the mine where these zones intersect and cause especially unstable conditions.

Analyses to date concerning both of these standpoints lead to the following conculsions:

1. The close correlation of lineament trends with structural features and paleochannel trends is encouraging, especially with the discovery that these trends match closely with zones of roof falls. Matching zones of roof falls, however, was successful only at the Beth-Elkhorn No. 22 mine where extensive mining together with sufficient data on roof conditions provided enough data to delineate zones of roof fall. The same procedure was attempted at the Southeast Coal Company's Mathews mine and Martin County Coal Corporation. At these mines some roof fall zones could be delineated, but none were as evident as the Beth-Elkhorn No. 22 mine. Also, some interesting results in drawing zone lines came from the Bell County Coal Company. In the area of the Hignite mine, several old mine maps were available from three coal beds immediately below the Hignite coal bed. In analyzing these maps, attempts were made to draw zone lines using apparent mine heading terminations as possible unstable roof indicators and Ronchi grating directions for zone line directions.

2. It is evident that by drawing "roof fall zone lines" areas of roof falls are bracketed by these lines (Figures 43 and 45). Attempts at using these bracketed zones to project unstable roof conditions has only been partly successful, probably because of local conditions of roof rock, stress distribution, or mining operations.

3. Where lineament trends can be established, it would appear that heading directions laid out to avoid paralleling these directions would provide maximum pillar support in roof and pillar mines. However, improved roof caving might be achieved in longwall and/or shortwall operations if the face were advanced parallel to these trends.

4. One of the perplexing problems of lineament analysis to date concerns roof falls at lineament intersections. Of the seven mines analyzed, the percentage of roof falls coinciding with or occurring near (within 100 feet (31 m)) of lineament intersections ranged from 50 percent to 65 percent. While these percentages may provide some indication of potential roof fall areas in advance of mining, observations to date have indicated several possible sources of error in lineament analyses as follows:

Figure 47 is a diagram showing three coal beds. Because lineament placement is observed on the surface (top of the block) the ideal situation would be shown at A. In this case rock jointing extends downward to the lowermost coal bed vertically. If two vertical lineaments intersected, roof fall areas might be predicted wih accuracy.

Cases B and C in Figure 47 have been observed in the field. In these cases either single joints, zones of jointing or faults are shallow features and do not extend to the lower coal beds.

Case D in Figure 47 shows a relatively wide zone of jointing on the surface, but not all joints extend to the lower coal bed. In this case the roof fall area in the lower coal bed might be predicted, but the location would be in error. This case has not been directly observed in the field, but lineaments on imagery (especially edge enhanced) commonly show this "banded" characteristic.

Case E in Figure 47 represents a dipping fracture set. In this case the location of the fracture set would be in error, the magnitude of which would be dependent on the degree of dip of the fracture set and depth below the surface.

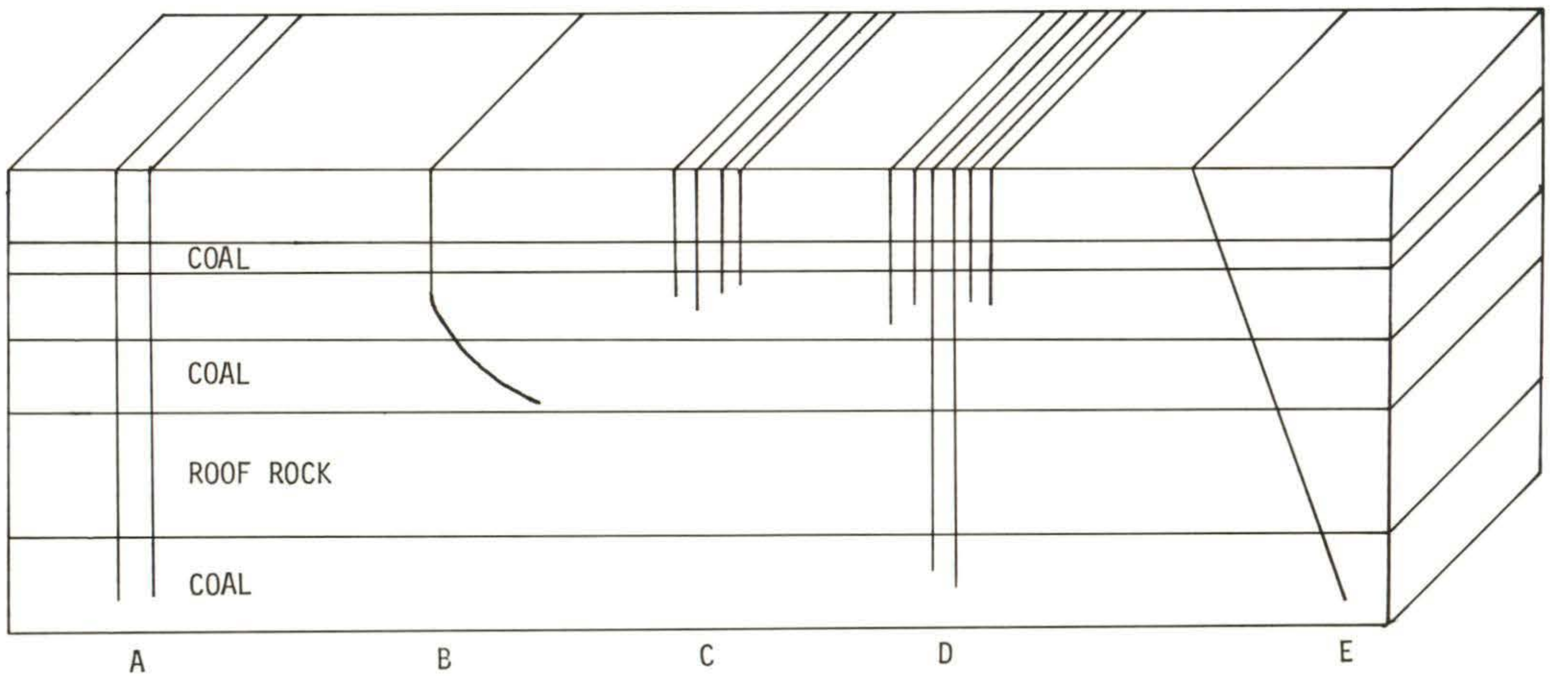
Some evidence to date suggests that "major" lineaments that parallel headings may indicate roof fall conditions, even where no lineament intersection exists (or is evident). This was observed in the Beth-Elkhorn No. 22 mine at two locations. In both cases, rock jointing and roof fall orientation coincided exactly with lineament direction and placement, even though lineament intersections were not evident at the roof falls.

An observer's tendency to identify lineaments appears to be somewhat subjective. Especially with enhanced images, it is often difficult to decide how many lineaments to include. This is not as great a problem if only lineament trends or directions are plotted. However, extreme variations often occurred if different observers attempted to plot single lineaments. In this study, the procedure generally followed was to use two observers to plot lineaments and to plot only those that were "agreeable" to both.

The Landsat imagery used in this study were useful in resolving surface features with a minimum width of about 300 feet (92 m) to 400 feet (122 m). As a result, only "zones" could be plotted and many narrow linear features likely were overlooked. It is believed that with improved imagery products, the usefulness of the technique of lineament analysis will be greatly enhanced. Also, the supplemental use of U-2, side-looking radar imagery and low level aerial photography may provide excellent results.

5. It is concluded from this study that lineament analysis provides an excellent "first approximation" in predicting the directional trends of structural features, and in some cases sedimentary features, that may contribute to roof failure. However, it is believed that strong consideration must be given to local roof rock characteristics for a more accurate determination.

Figure 47. Block Diagram Showing Possible Surface Lineament Expression Versus Subsurface Structural Expression



SUMMARY AND CONCLUSIONS

Research and Findings

This investigation was conducted with the aim of expanding geologic studies done at the Eastover Mining Company, Harlan County, Kentucky under USBM Conract H0133018. The major goals of the present contract were to investigate stratigraphic and structural conditions associated with unstable roof at selected mines in eastern Kentucky to determine if similar conditions existed on a more regional scale. Significant findings resulting from these studies include the following:

1. A comparison of representative sedimentation units determined for Harlan County, Kentucky with roof strata in eastern Kentucky indicated that similar units were present in the mines studied. This suggests similar environments of deposition for the coal beds and related rocks.

2. Roof falls in the mines studied have been caused chiefly by stratigraphic discontinuities, separation along bedding planes of poorly bonded strata, lateral change in roof-rock character (facies changes) and linear sandstone channels. Locally, roof falls appear to be caused by high in situ stresses.

3. A classification scheme was devised under contract H0133018 that relates roof stability with both lithologic and structural features. This study indicated that the classification scheme has considerably more value when applied to mines with heterogeneous or laterally changeable roof rocks.

4. On the basis of trend analysis procedures, it was found that sandstone bodies could be delineated and projected in advance of mining. These procedures included the construction of structure contour maps, isopach maps and fence diagrams. Further, it was found that these procedures could be used if sufficient data was available from mine mpas supplemented by reconnaissance surveys and drill core data.

5. The use of remote sensing techniques using Landsat imagery in the determination and projection of structural features was successful in correlations between mines. Landsat imagery provides a rapid and more accurate means of determining structural trends than the computer programs developed under contract H0133018. Analysis of lineaments correlated with roof falls, "roof fall zone lines" and structural trends showed close agreement in trend, but only a 50-65% incidence with roof falls. It is believed that the technique needs refinement and that studies involving imagery with better resolution coupled with other remote sensing imagery products will provide better control.

6. Analysis of "snap top" in the West Virginia study area by remote sensing showed that the close correlation of "snap top" zones, Ronchi grating directions, and valley trend direction strongly suggests that rock jointing and in situ stresses are important contributing factors of these roof failures.

Advice to Operators

On the basis of research findings to date, the following procedures may be used to evaluate roof conditions and to project possible unstable roof in advance of mining. It is important to emphasize that accuracy in roof projections is dependent on the amount of data available.

1. The first consideration in roof rock evaluation would be a detailed stratigraphic section of the roof strata. If outcrop exposures and/or drill core and oil and gas well logs are available, information as to lateral or vertical changes in rock type are important. Geologic information is often available from geologic maps and state

and federal research publications. Relevant information may also be derived from mine maps of nearby mines operating in the same coal bed in terms of obstructions to mining such as sandstone "want zones" or structural features.

2. If the mine under consideration is currently operating, mine mapping in terms of measured rib sections, sandstone roll trends and rock jointing directions provide information for roof rock projections in advance of mining. If possible, dividing the roof into categories based on rock type and stability may make possible the projection of units of roof rocks in advance of mining. As mining progresses, it is very important to record relevant information as to roof stability, actual roof falls, rib conditions and floor conditions. A checklist for this purpose is advisable and plotting should be done on mine maps. Coal sections and engineering surveys also provide coal bed elevation and coal thickness information useful for structure contour and isopach mapping.

3. An evaluation of roof falls is important. It may be possible to relate roof falls to a common controlling factor or factors such as rock type, overburden thickness, areas of stress or structural direction and/or frequency.

4. If possible, an evaluation by remote sensing techniques is highly desirable. This information may be used in conjunction with in-mine data for projection pur-purposes.

5. Advancing panels should be oriented so that parallelism of roof rolls and structural features with heading directions is avoided.

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GLOSSARY OF TERMS

Axis—A line, real or imaginary, passing through a body or system around which the parts are symmetrically arranged.

Azimuth—The geographic orientation of a horizontal line given as an angle measured clockwise from north on a 360° basis.

Band-A wavelength interval in the electromagnetic spectrum. In landsat, the bands are designated by specific wavelength intervals at which images are acquired.

Braided stream—A stream that branches and interlaces producing a network or braided appearance.

Brunton compass—A small pocket compass with sights and a reflector attached. Used in trend analysis of geologic features.

Butt cleat—A short, generally irregular cleavage plane in a coalbed, usually oriented at right angles to the face cleat and sometimes terminating against it.

Carboniferous—The Mississippian and Pennsylvanian geologic periods combined.

Claystone—Rock in which clay is present or which is largely composed of clay and generally lacks shaly bedding.

Coal Cleat—Joints along which the coal fractures. There are usually two cleat directions developed perpendicular to each other.

Coarsening-upward sequence (cycle)—A vertical section of rocks in which the texture (grain size) becomes coarser upward. Bed thickness often increases upward also.

Correlation—The determination of the equivalence of stratigraphic features in seperated areas.

Crevasse—A wide breach or crack in the bank or natural levee of a river.

Cross-bedding—An internal arrangement of the layers in a stratified rock, in which laminae or cross-strata are inclined to the original depositional surface, or to the dip or contact of the formatation.

Cutter—Fracture or shear zones that commonly develop in brittle rock due to excessive stress along pillar lines in underground mines.

Densitometer—A device used to measure the opacity of a small area of specified size on a photographic transparency or print. The measurement may be a meter reading or an electronic signal.

Density, of images—A measure of the opacity or darkness of an image.

Density slicing (or Level slicing)—An operation performed by an instrument (usually electronic) called a level slicer which scans a photograph or transparency and converts the continuous gray tone of the image into a series of density intervals or slices. These gray levels are displayed as a series of isodensity "contours" using a discrete color to describe each level of gray in the original picture.

Differential compaction—The relative change in thickness of sediment after burial due to reduction in pore space.

Dip—The angle at which a stratum or any planar feature is inclined from the horizontal. The dip is at a right angle to the strike.

Drift mine—The extraction of coal above drainage using underground methods by mining laterally from the coal exposure (outcrop) rather than by vertical shaft or slope methods.

Earth Resource Observation System (EROS)—Administered by the U.S. Geological Survey.

Earth Resources Technology Satellite (ERTS)—Now called Landsat.

Enhancement—The process of altering the appearance of an image so that the interpreter can extract more information. Enhancement may be done by digital or photographic methods.

Face cleat—A well-defined joint or cleavage plane in a coal seam. The major joint in a coal seam.

Fault—A fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

Fining-upward sequence (cycle)—A vertical section of rocks in which the texture (grain size) becomes finer upward. Bed thickness often decreases upward also.

Floodbasin—The tract of land actually covered by water during the highest known flood.

Gray scale—A calibration of gray tones ranging from black to white.

Ground truth (or ground data)—The collection of geophysical, geographic, geologic, pedalogic, hydrologic or other data on or near the surface of the earth, in contrast to the information collected by airborne or satellite remote sensing systems.

Imagery—The visual representation of energy recorded by remote sensing instruments.

Immediate roof—Includes roof rock directly overlying the mined coal. Composition is essentially shale (slate), coal rash, claystone and siltstone.

Interdistributary bay—A bay area between deltaic distributaries.

Ironstone—A general term for iron-rich, rounded or ellipsoid-shaped nodules or lenses commonly found in immediate roof shales and is often a component of "lag gravel" in sandstone units.

Isopach map—A map that shows the varying of the interval (thickness) between two designated stratigraphic units or horizons.

Joint—Fracture in rock, generally more or less vertical or transverse to bedding, along which no appreciable movement has occurred.

Kettlebottom—A part of the roof of a coal seam, resembling the bottom of a kettle and easily loosened without warning, leaving a smooth cavity in the roof. Kettlebottoms represent fossilized tree trunks.

Lag gravel—Coarse-grained material that is rolled or dragged along the bottom of a stream at a slower rate than the finer material, or that is left behind after currents have winnowed or washed away the finer material. Commonly found in the basal portions of sandstone units. Usually comprised of ironstone nodules, coal and shale pebbles.

Lambert conic conformal projection—A map projection on which all geographic meridians are represented by straight lines that meet at a common point outside the limits of the map, and the geographic parallels are represented by a series of arcs having this common point as a center. Meridians and parallels intersect at right angles on the earth and angles are correctly represented on the map (or projection).

Laminated—Said of a rock (such as shale) that consists of laminae or that can be split into thin layers.

Landsat—An unmanned, earth-orbiting NASA satellite that transmits multi spectral images in the 0.4-1.1um region to earth receiving stations (formerly called ERTS).

Levee (stream)—An embankment of sediment bordering one or both sides of a river channel.

Lineament—A linear topographic or tonal feature on the terrain recorded in images and/or maps that may represent a zone of structural weakness.

Linear—An adjective that describes the straight-line (or geometric) nature of features on the terrain, images or maps.

Lithology (Lithologic Studies)—The description of rocks, esp. sedimentary clastics and esp. in hand specimen and in outcrop, on the basis of such characteristics as color, structure, mineralogic composition and grain size.

Low-sun-angle photography (or imagery)—Satellite images or aerial photographs acquired in the morning, or winter when the sun is at a low evaluation above the horizon.

Main roof—The roof rock found above the immediate roof. Composed essentially of sandstone in eastern Kentucky.

Multispectral Scanner System (MSS)—Scanning system of Landsat that acquires images by an array of detectors or four optical energy wavelength bands in the visible and reflected IR regions. It is a line scanning device which employs an oscillating mirror to continuously scan perpendicular to the satellite's platform flight path. Platform motion provides the along track progression of scan lines.

Nonsystematic joint—A joint that does not cross other joints and often terminates at bedding surfaces. Faces are irregular and often curved.

Overburden—The rock or sediment overlying a particular rock layer, in this case a coal bed.

Overthrust fault (overthrust)—A low-angle thrust fault of large scale, generally measured in miles.

Registration—The process of superposing one or more images on topographic base maps so that equivalent geographic points coincide. Registration may be done digitally or photographically.

Representative sedimentation unit—A vertical sequence of rock, representing one or more cycles of deposition, that is characteristic of the mining area and is categorized for roof stability and environmental interpretations.

Rib section—A measured section of the coal rib. Includes mined coal, immediate roof and lower part of main roof if exposed.

Rider coal—A thin unminable coal found closely above a thicker minable coal bed. Normally only a few inches thick.

Roof roll—A downward projection of the main roof clastic sediments which replace only the upper layers of the coal bed, or may be separated from the coal bed by immediate roof strata.

Room-and-pillar mine—An underground mine in which sets of entry rooms (usually 4, 5 or 6) are connected by crosscuts or breaks (often at 90° angles) leaving pillars of coal for roof support.

Sandstone channel—A sandstone body, elongate in shape, and considered an ancient buried watercourse. It is represented by stream deposits of sand and gravel and commonly forms the roof roll and "want" in zones of mines.

Sandstone roll—A roof roll composed of sandstone.

Sandstone roll axis projection map—A map in which the long axes of sandstone rolls are projected using mapped sandstone rolls supplemented by isopach data. Used in premining analysis.

Scan line—The narrow strip on the ground that is swept by the instantaneous field of view (IFOV) of a detector in a satellite scanner system.

Shear fracture—Fracture that results from opposed stresses that tend to displace one part of a rock mass past the adjacent part.

Slickenside ("slip")—Polished and striated (scratched) surface that results from friction along a plane. The movement can be very slight.

Stratigraphic section (geologic section)—Any sequence of rock units found in a given region either at the surface or below it (as in a drilled well).

Stratigraphy—The branch of geology that deals with the origin, occurrence, environment, thickness, lithology, composition, fossil content, age history and paleographic conditions of generally sedimentary rocks.

Strike—The bearing (from north) of the outcrop of an inclined bed or structure on a level surface. It is perpendicular to the direction of the dip. Also, the bearing of a horizontal trace on the bedding plane.

Structure (structural studies)—The general disposition, attitude, arrangement or relative positions of the rock masses in a region or area. Includes the analysis of faulting, folding and jointing of rocks.

Structure contour map—A map that portrays the subsurface configuration of structure of a unit by means of contour lines.

Sun azimuth angle—Angle in degrees measured in the horizontal plane clockwise from true north on a 360^{o} basis.

Sun elevation angle—Angle of the sun above the horizon measured in degrees.

Syncline—A fold in rocks in which the strata dip inward from both sides toward the axis.

Systematic joint—Joint that occurs in sets or patterns. It crosses other joints and exposed rock units and is oriented perpendicular to the boundaries of the constituent rock unit.

Transparency—A positive or negative image on a transparent photographic material that will transmit light.

Trend—A general term for the direction or bearing of a geological feature of any dimension, such as sandstone roll, joint or sole mark.

Washout (want)—A channel cut into or through a coal seam at some time during or after the formation of the seam, and generally filled with sandstone.

The Appalachian Development Center was established in 1978 as Morehead State University's regional service arm. Committed to economic, social, and educational development in partnership with the people and institutions of Appalachian Kentucky, the center's major program areas are:

Business Development
Regional Research
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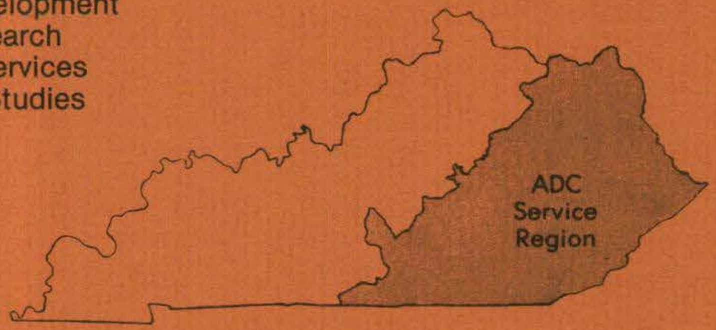
Appalachian Studies



About the Author

David K. Hylbert was born in the Appalachian community of Fayetteville, W. Va. Much of his childhood was spent in the southeastern Ohio area surrounding Zanesville. He earned both his bachelor of science and master of science degrees in geology from Ohio University in 1961 and 1963, respectively. He received his Ph.D. in geology in 1976 from the University of Tennessee. David has been employed at Morehead State University since 1963 and currently holds the position of Professor of Geosciences in the Department of Physical Sciences. He has worked with the U.S. Geological Survey on a part-time basis in publishing several geologic maps for portions of Eastern Kentucky. Between 1973 and 1981, he served as Project Director for several contracts between the U.S. Bureau of Mines and Morehead State University. The research dealt with the geologic aspects of coal mine roof control. He served as a consultant to the University of Kentucky's Institute for Mining and Minerals Research between 1978 and 1981. He has two publications in **Mining Engineering** and was selected as the Distinguished Researcher at Morehead State University in 1982.