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Geologic Factors in Predicting Coal Mine Roof-Rock Stability in the Upper Kittanning Coalbed, Somerset County, Pa.

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GEOLOGIC FACTORS IN PREDICTING COAL MINE ROOF-ROCK STABILITY IN THE UPPER KITTANNING COALBED, SOMERSET COUNTY, PA.

by

A. T. Iannacchione,[1] J. P. Ulery,[1] D. M. Hyman,[1] and F. E. Chase[1]

ABSTRACT

Roof-rock instability in advancing sections of underground coal mines is a major contributing factor to accidents resulting in fatalities and injuries. Such roof-rock conditions can also result in loss of production due to additional cleanup time and increased amounts of reject material. The Bureau of Mines is investigating fundamental geologic factors affecting coal mine roof-rock instability in order to develop techniques to predict zones of potential unstable roof-rock.

Two distinct directional trends of unstable shale roof-rock in a mine working the Upper Kittanning Coalbed are delineated: one trend is associated with the sandstone-shale transition zone, the other with a fault system. The unstable shale roof-rock associated with the transition zone, a consequence of differential compaction, is comprised of slickensided roof-rock. Whereas, the unstable shale roof-rock associated with the fault system, a consequence of structural deformation of the strata, is comprised of fault planes. These faults, small in comparison to the sandstone-shale transition zone, are difficult to delineate with a standard drilling program. Trends of the transition zone associated with the sedimentary facies change are projected into unmined portions of the coalbed with the aid of exploration core data.

INTRODUCTION

The Bureau of Mines is investigating fundamental geologic factors that influence coal mine roof-rock stability (7, 13, 17, 20-22, 26).[2] There is presently a lack of practical information detailing how local and regional geologic settings affect the distribution, frequency, and magnitude of roof falls in U.S. coal mines. Techniques and methodologies to predict the occurrence of unstable roof-rock usually require detailed surface and in-mine geologic mapping, extensive exploration core hole data, and an understanding of

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[2]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

the stratigraphy and structure of the area. A schematic outlining the methodology used in this study is presented in the appendix (fig. A-1).

The Bureau is presently evaluating these techniques and methodologies at two locations in Somerset County, Pa. (fig. 1). Each study has a number of tasks:

1. Choose a site (relatively new mine so that predictive techniques can be evaluated).

2. Establish geologic data-base (acquire core hole data and construct isopach maps).

3. Conduct detailed in-mine investigations and mapping.

4. Establish the geological criteria that influence roof-rock in unmined portions of the coalbed, and

5. Evaluate the success and effectiveness of the study.

This investigation was conducted on a relatively new mine, approximately 5 years old, working the Upper Kittanning Coalbed in Somerset County, Pa. The cooperating company also plans to open a mine directly south of the mine under investigation. The Upper Kittanning Coalbed in this area is a metallurgical-grade coal that has been used for coke making and steam generation. It is generally very friable and ranges in thickness from 42 to 58 inches (107 to 147 cm.) Overburden (fig. 2) ranges from zero at the outcrop to less than 600 feet (183 m).

When this mine was first opened, a competent sandstone top provided an excellent roof-rock. However, as development advanced beyond this competent sandstone, incompetent shale was encountered. The Bureau's mission has been to determine the characteristics of the unstable roof-rock and to predict the occurrence of other areas of unstable roof-rock in advance of mining.

ACKNOWLEDGMENTS

The authors are grateful for the full cooperation of both Solar Fuel and Lunar Mining, Inc. In particular, G. Knouff, N. Yonko, E. Smith, D. Miller, R. Kolesko, and W. Lenman of Solar Fuel supplied administrative and engineering assistance. The authors also thank E. Yanzetich, R. Corl, and W. Click of Lunar Mining, Inc., for their special interest and support given to the project. Acknowledgment is made to D. G. Puglio, L. V. Wade, and M. Deul of the Pittsburgh Research Center for the advice and guidance during the preparation of the manuscript.

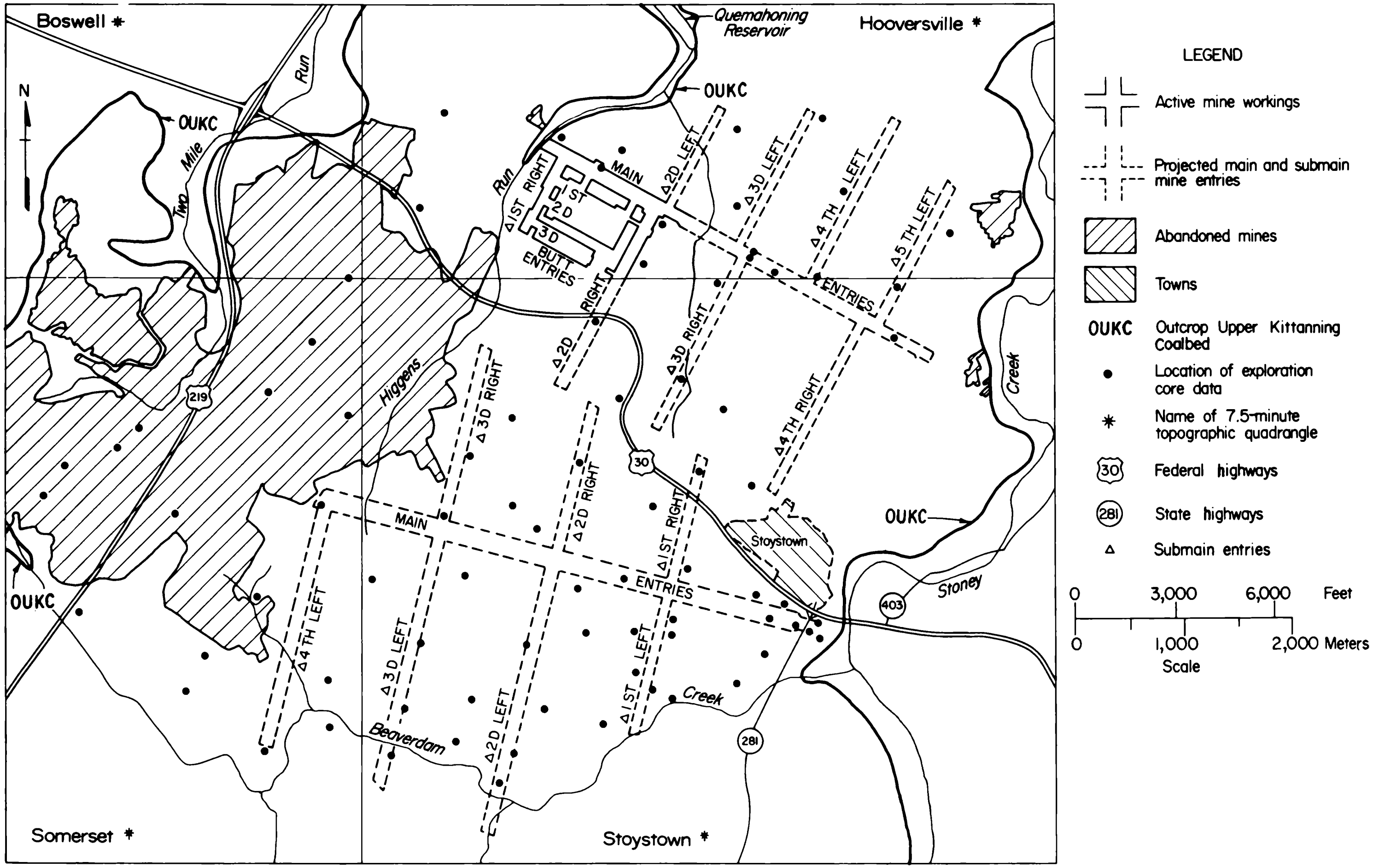

FIGURE 1. - Location of study area and of active, projected, and abandoned mine workings in the Upper Kittanning Coalbed.

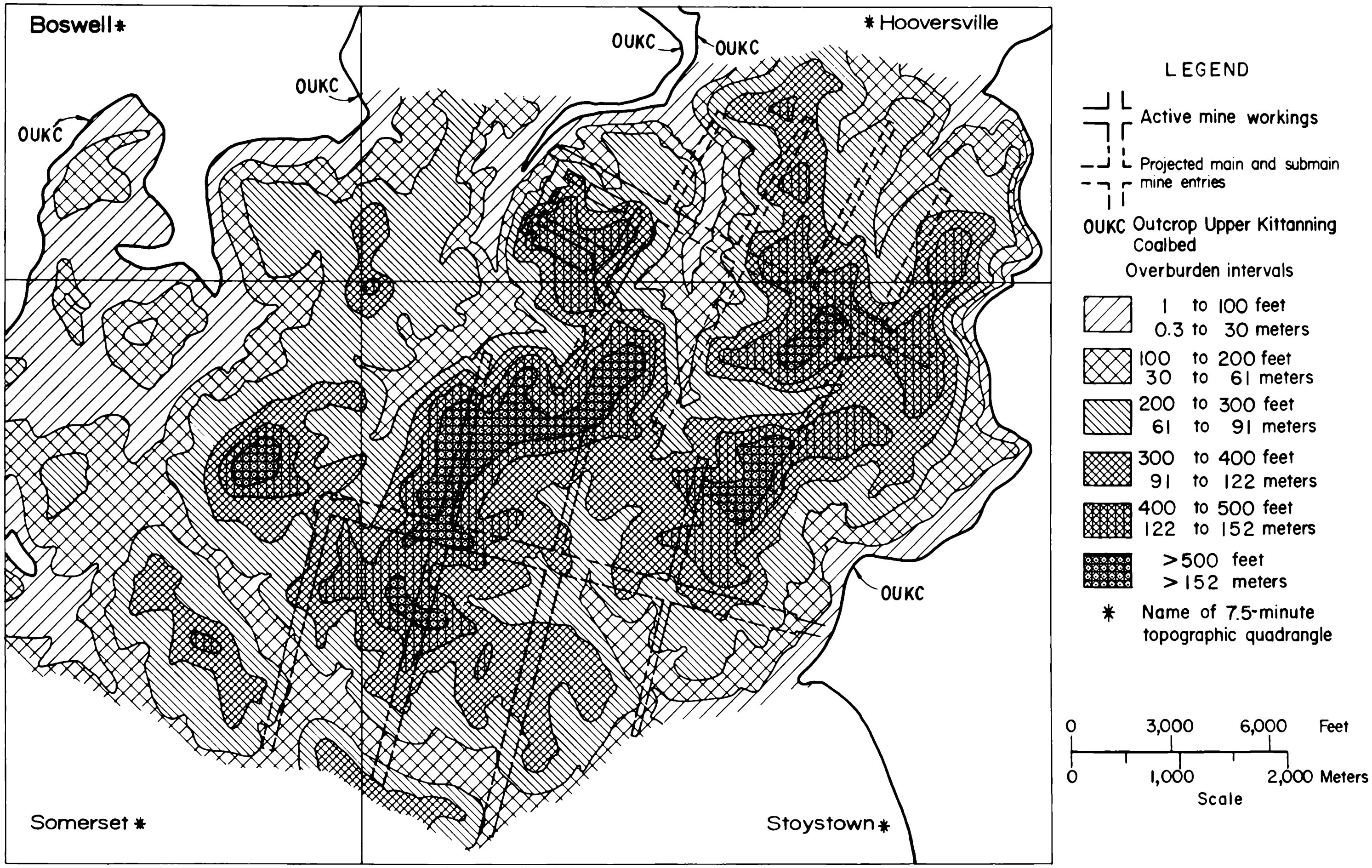

FIGURE 2. - Overburden map above the Upper Kittanning Coalbed.

MINING AND ROOF SUPPORT SYSTEMS

A continuous mining system is used in developing the main and submain entries with these entries outlining panels. Butt entry development off submain entries is followed by retreat mining. Panel development is accomplished by driving butt entries between submain entries (fig. 1). Butt entries are then pillared and retreated before starting the next panel. Partial and full retreat mining systems have been used. During retreat mining, rooms are driven into barrier pillars between butt entry sections. Pillars are then pulled, incorporating barrier into adjacent retreated sections (gob).

Rooms are driven 18 to 20 feet (5.5 to 6 m) wide on 80 foot (24 m) centers, with crosscuts perpendicular to headings. Recently, 60° angles with alternating crosscuts have been initiated in the main entries in response to changing roof-rock conditions (see enlarged detail, fig. 12). Continuous miners and belt haulage are used to cut and haul the coal from the working faces.

There are four basic roof support systems in operation: wood crossbars and posts, roof bolts (mechanical and resin types) through crossbars, full roof bolt pattern, and cribbing. Under competent sandstone roof-rock wood cross bars and posts are used. Generally, two roof bolts are placed into each crossbar when 1 to 3 feet of shale occurs between the coalbed and sandstone roof-rock to retard slacking. Roof bolts on 4-foot centers are used in competent shale roof-rock. Combinations of cribbing, roof bolts, and wood crossbars and posts are used when incompetent shale with a high frequency of slickensided planes is encountered. Generally, 5/8-inch-diameter mechanical expansion shell roof bolts with a length of 48 inches (122 cm) are used. Recently, full-column resin anchored roof bolts have been used with good results wherever shale is the dominant roof-rock.

STRATIGRAPHY

The Upper Kittanning Coalbed and associated roof and floor rocks are part of the Kittanning and Freeport Formations (Allegheny Group--Pennsylvanian System (fig. 3)). Ferm (6) and Williams (36) showed that the sedimentary facies encountered in the Kittanning and Freeport Formations represents deposition in a deltaic environment, where a somewhat low rate of detrital sediment influx permitted the establishment of vast swamps. The complexity of the depositional environments in the delta (9) accounts for the extreme local and regional lithologic variation that characterizes these formations.

A sedimentary facies map (fig. 4) using data from over 70 exploration core holes was constructed for the study area. Three basic roof-rock types are identified: a thick sandstone (Freeport Sandstone); a thick, dark-gray laminated shale; and a lateral transition zone between the sandstone and shale sedimentary facies. This transition zone is generally comprised of slickensided shale with some thin sandstone stringers.

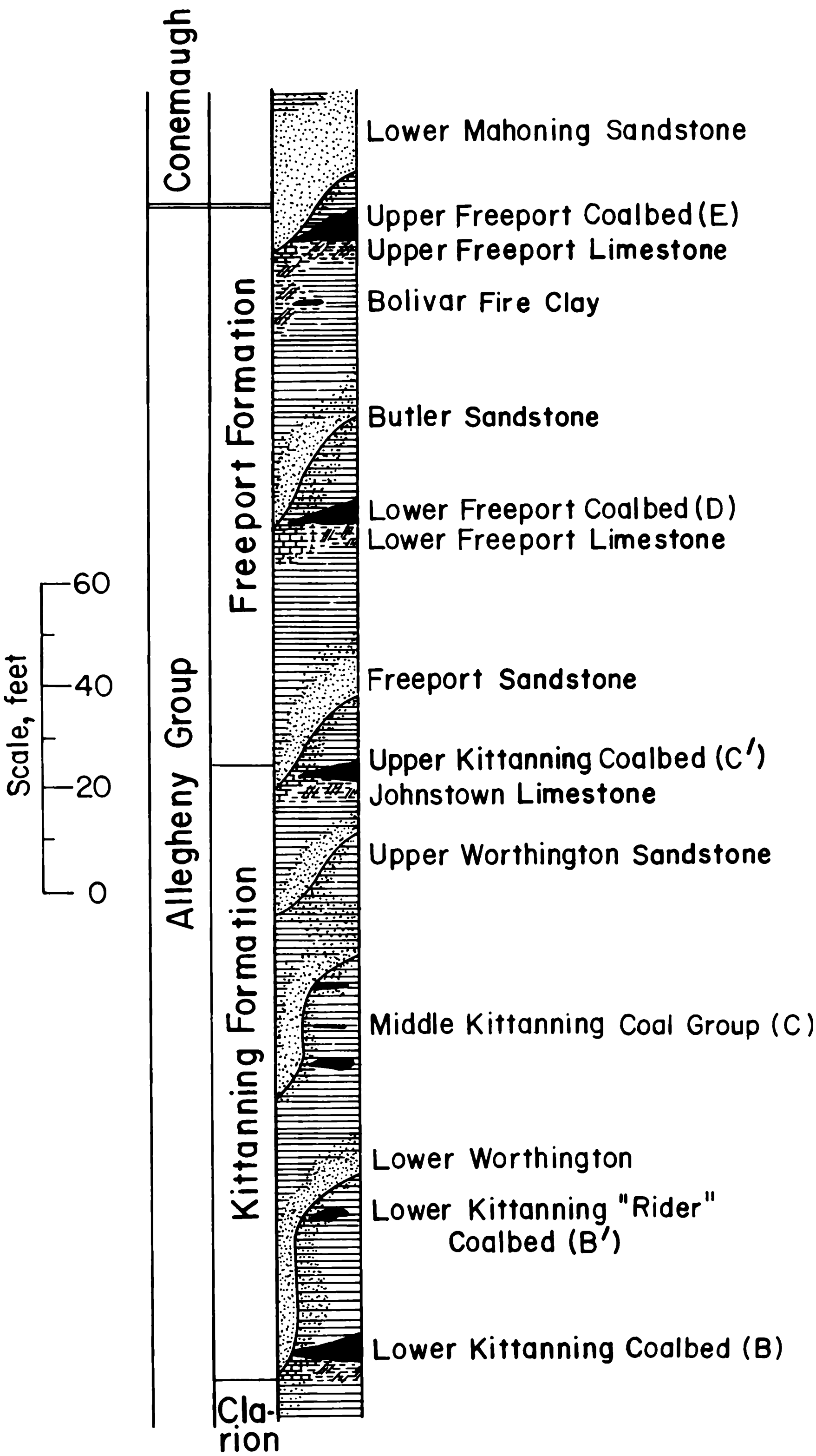

FIGURE 3. - Generalized straitigraphic column of the Freeport and Kittanning Formations. Parenthetical letters indicate alphabetical names of coalbeds.

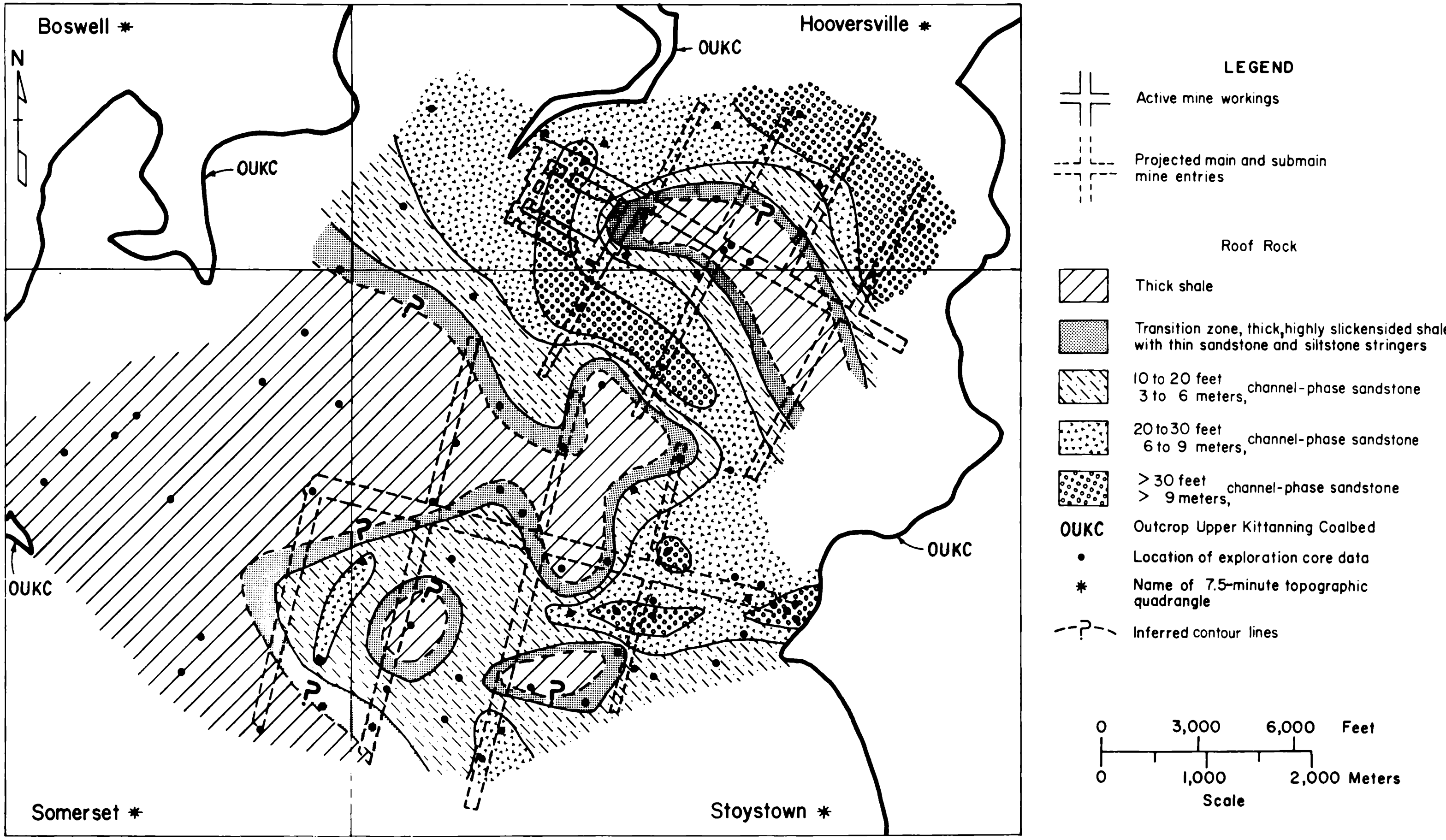

FIGURE 4. - A sedimentary facies map indicating the projected roof-rock types up to 30 feet above the Upper Kittanning Coalbed.

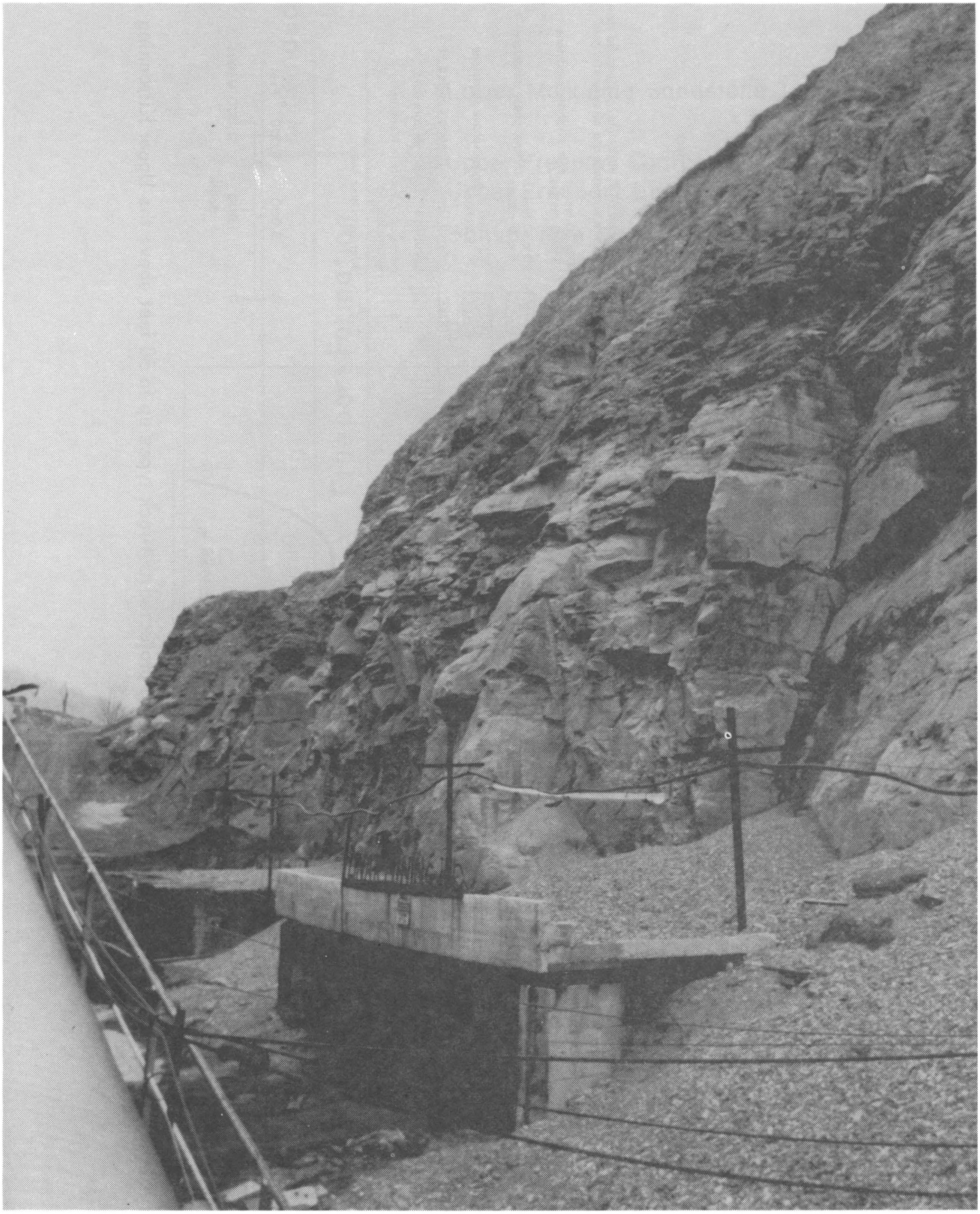

FIGURE 5. - Photograph of the channel-phase Freeport Sandstone showing the massive, cross-bedded, and fining upward sequence above the mine mouth of the active workings of the study mine.

The Freeport Sandstone in the study area varies in thickness ranging from 10 to 50 feet (3 to 15 m), and generally resembles a shoestring configuration. The sandstone-shale contact, where observed, was well defined and generally slickensided. Large crossbeds, fining upward sequence, scouring, coalified plant fossils, and shale nodules characterized this unit as a high-energy channel-phase sandstone (fig. 5). The switchback in the course of the channel cutting across the active mine workings probably represents a meander in the ancient river system. However, the main channel seems to split into several smaller channels across the projections of the new mine to the south of the active mine (fig. 4). The effect these changes in the geometry of the channel-phase sandstone will have on trend prediction is unknown (see section on Prediction of Unstable Roof-Rock Areas in Advance of Mining).

STRUCTURAL SETTING

Folding and Faulting

In western Pennsylvania fold and fault intensities decrease toward the northwest (fig. 6). Generally, intense folding (Valley and Ridge Province) is

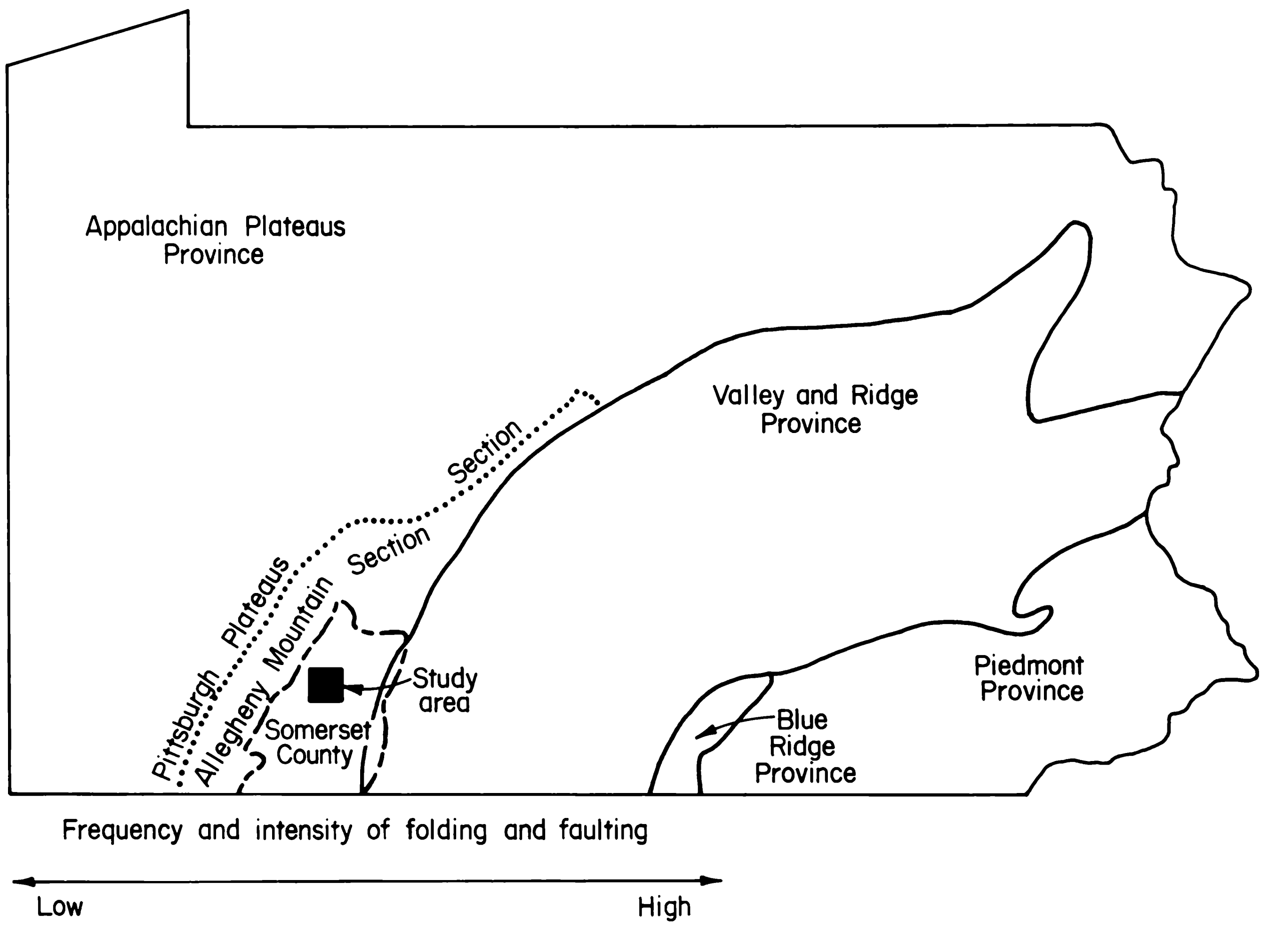

FIGURE 6. - Physiographic location of the study area.

characterized by asymmetric en echelon folds (with large structural relief) and associated thrust, reverse, normal, and wrench faults (1, 3, 34). Gentle folding (Pittsburgh Plateaus Section of the Appalachian Plateaus Province) is characterized by folds with little structural relief and a general lack of faulting (34). The study area, which is located in the Allegheny Mountain Section of the Appalachian Plateaus Province, lies between these two extremes. Gentle folds like the Somerset Syncline and intense folds with associated faulting such as Chestnut Ridge and Laurel Hill Anticlines (30, 33) characterize the study area. Figure 7 is a structure contour map on the base of the Upper Kittanning Coalbed in northern Somerset County. The Upper Kittanning Coalbed dips range from approximately horizontal at the bottom of the Somerset Syncline to nearly 20° along the flanks of Laurel Hill Anticline. No evidence of faulting within the Pennsylvanian System of this area has been identified to date. However, Cate (2), Fettke (8), and Gwinn (11) have mapped faults of significant displacement in the Oriskany Sandstone (Devonian System). These faults, shown in figure 7, occur along the axes of Laurel Hill Anticline and Boswell Dome.

Folds and the appearance of faults within the Devonian System in the Allegheny Mountain Section of Pennsylvania have been explained by Gwinn (11):

> Paleozoic rocks were transported westward along nonoutcropping low-angle detachment thrust faults referred to as decollement zones. The major folds were formed in passive response to steplike upward shearing of the decollement zones from a Mid-Cambrian shale zone in the Valley and Ridge Province up through competent carbonate rocks into the Upper Ordovician or Silurian Systems beneath the Plateau. The folds evidence shortening of the stratified sequence superincumbent on the sole thrusts.

A cross section (fig. 8) through the study area illustrates the authors' view of Gwinn's hypothesis. Data concerned with the location and dip of faults were taken from Cate (2). Notice the depressed fault blocks along the Laurel Hill Anticline. Faults bounding the axial depressed zones, both reverse and normal, reflect a thrust of the anticlinal limbs toward the anticlinal crests. These thrusts probably extend down to the decollement zone and are directly linked to the formation of the Appalachian Mountains (10, 15, 28). The forces responsible for this Paleozoic deformation in the Allegheny Mountain Section probably were due to the northwestward upthrust of a wedge of Blue Ridge and western Piedmont rocks (2, 32).

Fracture Systems

Lineaments, joints, and cleat were studied to determine the orientations of fracture systems in the strata of the active mine workings. Although fractures are not primary factors affecting roof-rock stability, they are often associated with an increase in instability of roof-rock. It was found that there is a correlation between the strike of the local anticlines and synclines and the orientations of lineaments, joints, and coal cleat within the study area. The composite strike of the Laurel Hill Anticline, Johnstown Syncline, Boswell Dome, Somerset Syncline, and Negro Mountain Anticline is

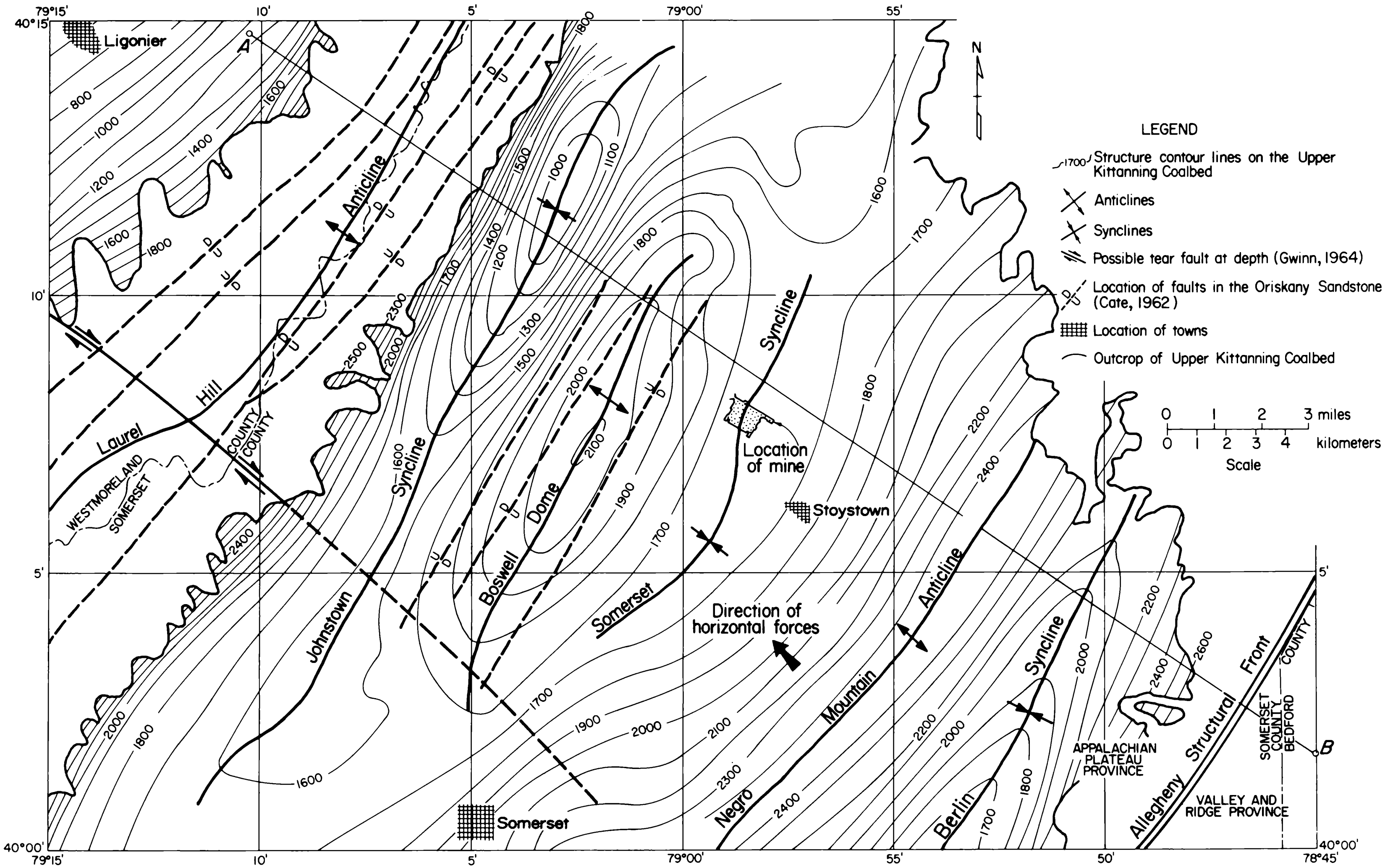

FIGURE 7. - Structure contour map on the base of the Upper Kittanning Coalbed and location of faults in the Oriskany Sandstone approximately 8,000 feet below the Upper Kittanning Coalbed in northern Somerset County, Pa.

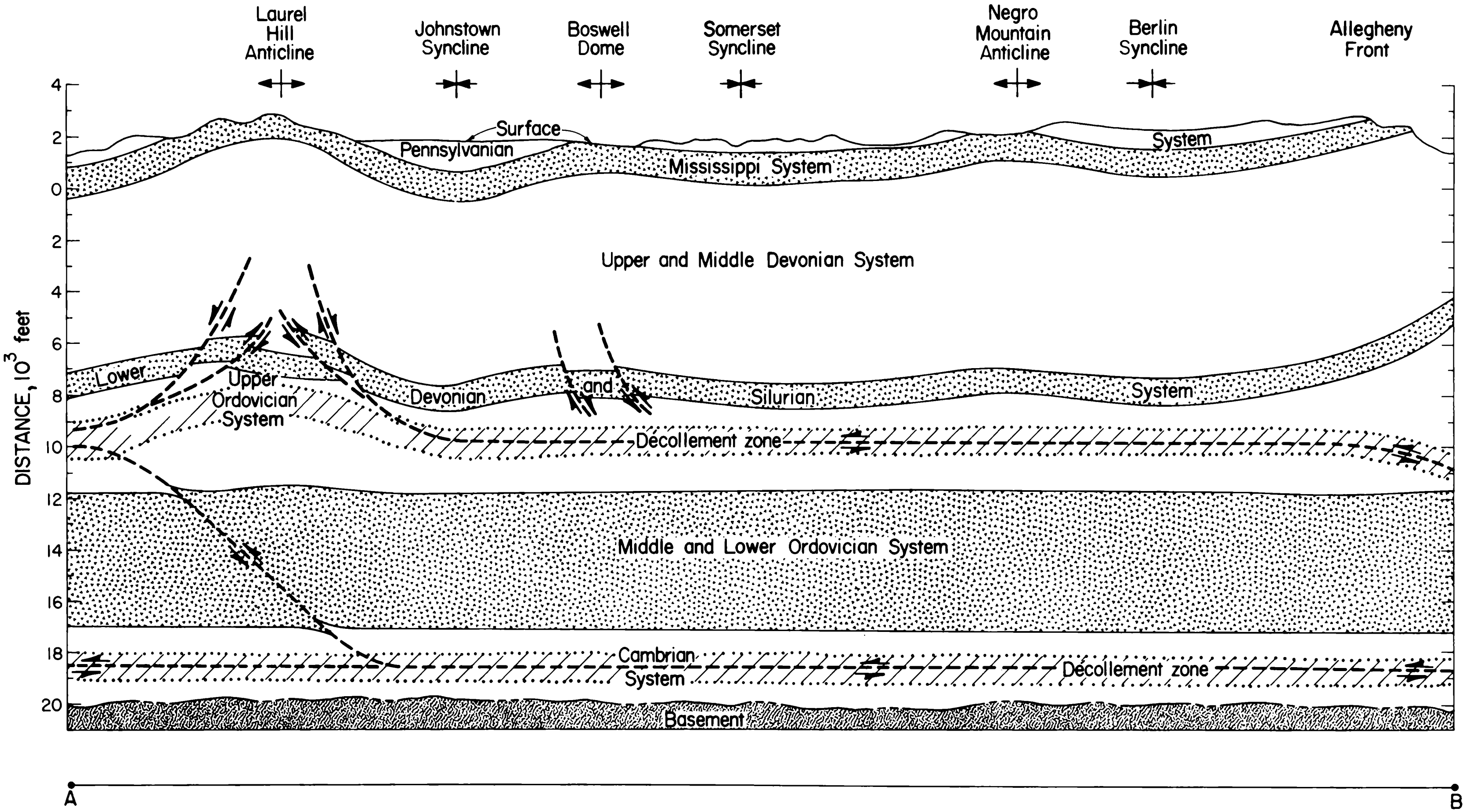

FIGURE 8. - Generalized cross-sectional view of Paleozoic rocks in northern Somerset County, Pa., showing the position of the decollement zones and associated faults. Location of A-B cross section is shown in figure 7.

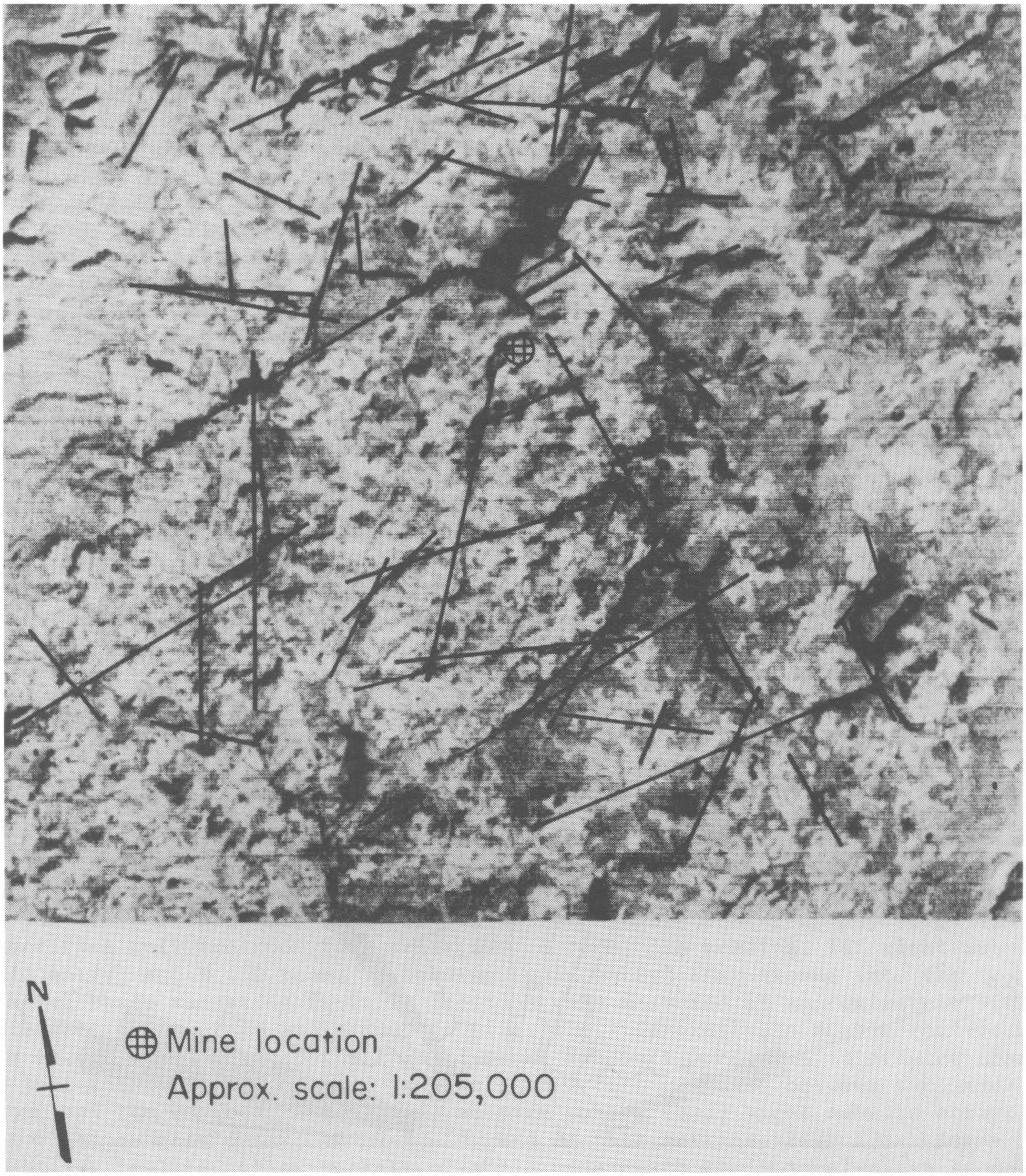

FIGURE 9. - Location and orientation of lineaments in northern Somerset County, Pa.

approximately N 37° E. Major lineament trends were observed to be centered about N 72° W, N 37° E, and N 75° E. Dominant joint, coal cleat, and slickensided plane orientations were measured to be between N 60° W to N 32° W and N 48° E to N 74° E within the active workings of the study mine. All fracture systems including joints, cleat, and lineaments have a systematic trend in the northwest-southeast direction, approximately N 72° W to N 27° W. A nonsystematic trend approximately perpendicular to the systematic trend was found to range from N 37° E to N 75° E. Systematic trends are generally perpendicular to structural trends and represent extension fractures; nonsystematic trends are generally parallel to regional structural trends and represent release fractures (24). This indicates that the same tectonic forces responsible for the folding and faulting of the Allegheny Mountain Section (fig. 8) influenced the orientation of the fracture systems of this area. Measurements were analyzed using a system devised by Diamond (4).

Lineament trends were determined using six Landsat imagery covering Somerset County, Pa. Color infrared aerial photography was examined but added no significant additional information in the lineament analysis of this area. Figure 9 is one of these Landsat scenes with the locations and orientations of major observed lineaments. One hundred (100) lineaments from six images representing spring, summer, fall, and winter seasons from 1973 to 1976 were observed, traced, and plotted on a rose diagram (fig. 10). There have been many studies (5, 16, 25, 31) indicating the possible relationship of unstable

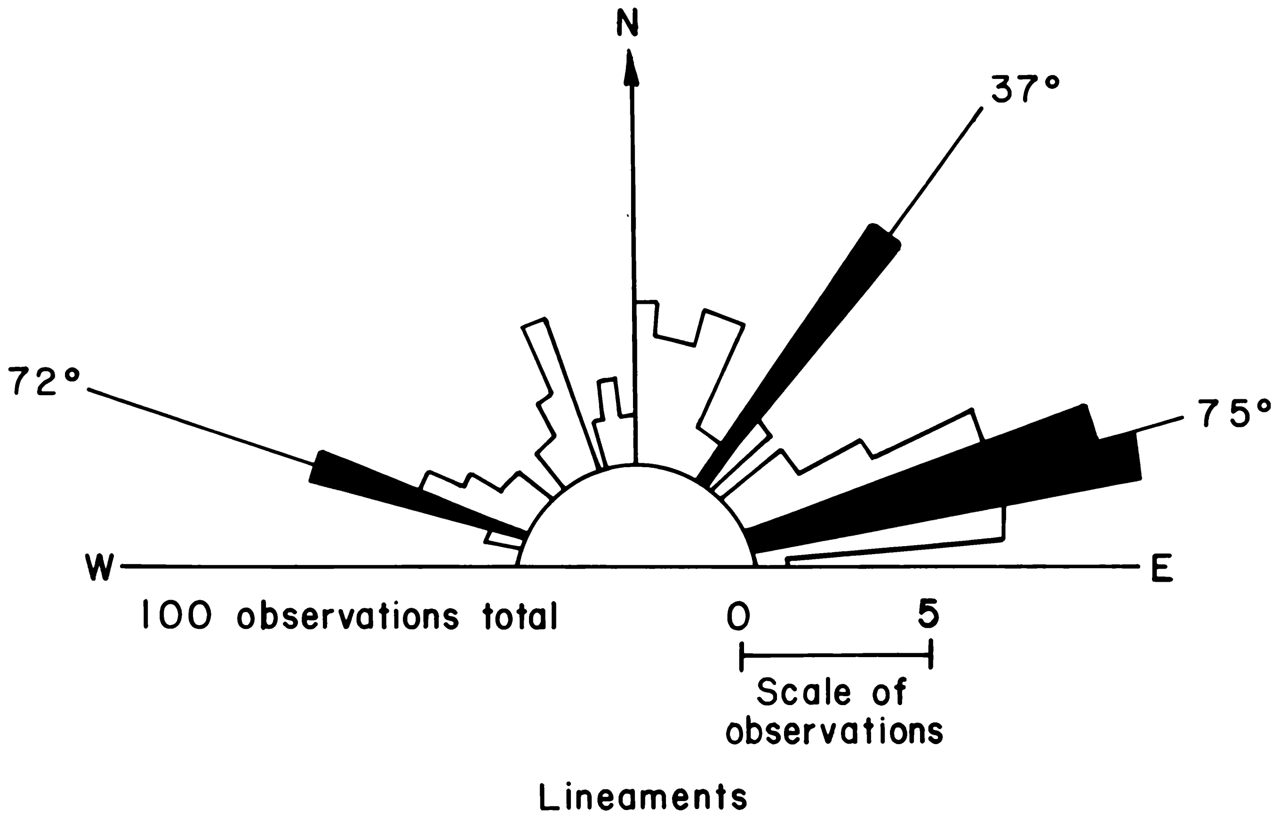

FIGURE 10. - Rose diagram of the lineament orientations in northern Somerset County, Pa.

roof-rock in mines beneath these lineaments. Since none of the lineaments observed passed through the active mine workings, no determination of the affect of lineaments on roof-rock instability was made. Joints were observed and measured in the limestone floor and shale roof-rock. Over 150 readings were measured throughout the active mine workings. Figure 11 is a rose diagram of the joints, cleats, and slickensided plane oreintations. Cleat is the natural fracture system in coalbeds and is analogous to joints. The dominant fracture plane is referred to as the face cleat (N 60° W and 27° W, fig. 11); the secondary fracture plane is referred to as the butt cleat (N 44° E and n 72° E, fig. 11). Normally occurring at right angles to each other, face cleats are analogous to systematic rock joints; butt cleat are analogous to nonsystematic rock joints (23-24).

GEOLOGICAL FACTORS AFFECTING ROOF-ROCK STABILITY

The physical condition of the roof-rock strata determines the type of support needed to maintain a stable roof in a coal mine if we ignore depth of cover and width of opening. Roof-rock stability can be affected by sedimentary facies changes and/or structural deformation in the coal-bearing strata. Many sedimentary facies changes, like the changes in roof-rock types across the study mine (fig. 4), are large-scale mappable features and therefore predictable if enough exploration data are available. Much less is known about the occurrence, geometry, and frequency of structural deformation features in the Allegheny Mountain Section. Observations of unstable roof-rock areas in this study (fig. 12) have enabled the authors to correlate roof-rock instability with either sedimentary facies changes and/or structural deformation of rock strata.

Effects of Sedimentary Facies Changes

Detailed geological mapping of the Upper Kittanning Coalbed and associated strata in the study mine indicates that more than 95% of the unstable roof-rock areas examined were within the shale sedimentary facies. A comparison of the shale isopach map (fig. 13) with the unstable roof-rock map (fig. 12) identifies only two roof fall areas (No. 8 room, 5th heading, 1st right submain entry, and No. 2 room, 2d heading, main entry) that extend into the channel-phase sandstone facies. Sections were measured at approximately 700 intersecting headings and crosscuts (fig. 13). Generally, a stable roof-rock was encountered wherever the channel-phase Freeport Sandstone is greater than 10 feet thick and where there is less than 2 feet of shale between the sandstone and the coalbed (main entry, at mine mouth, to 2d right submain entry; 1st right submain entry; and 1st, 2d, and 3d butt entries--fig. 12). Occasionally, isolated thick pockets of shale underneath the channel-phase sandstone facies have caused localized roof support problems (No. 27 to No. 29 rooms, 8th and 9th headings, 2d butt entry, and No. 14 to No. 16 rooms, 4th and 5th headings, 3d butt entry--fig. 12).

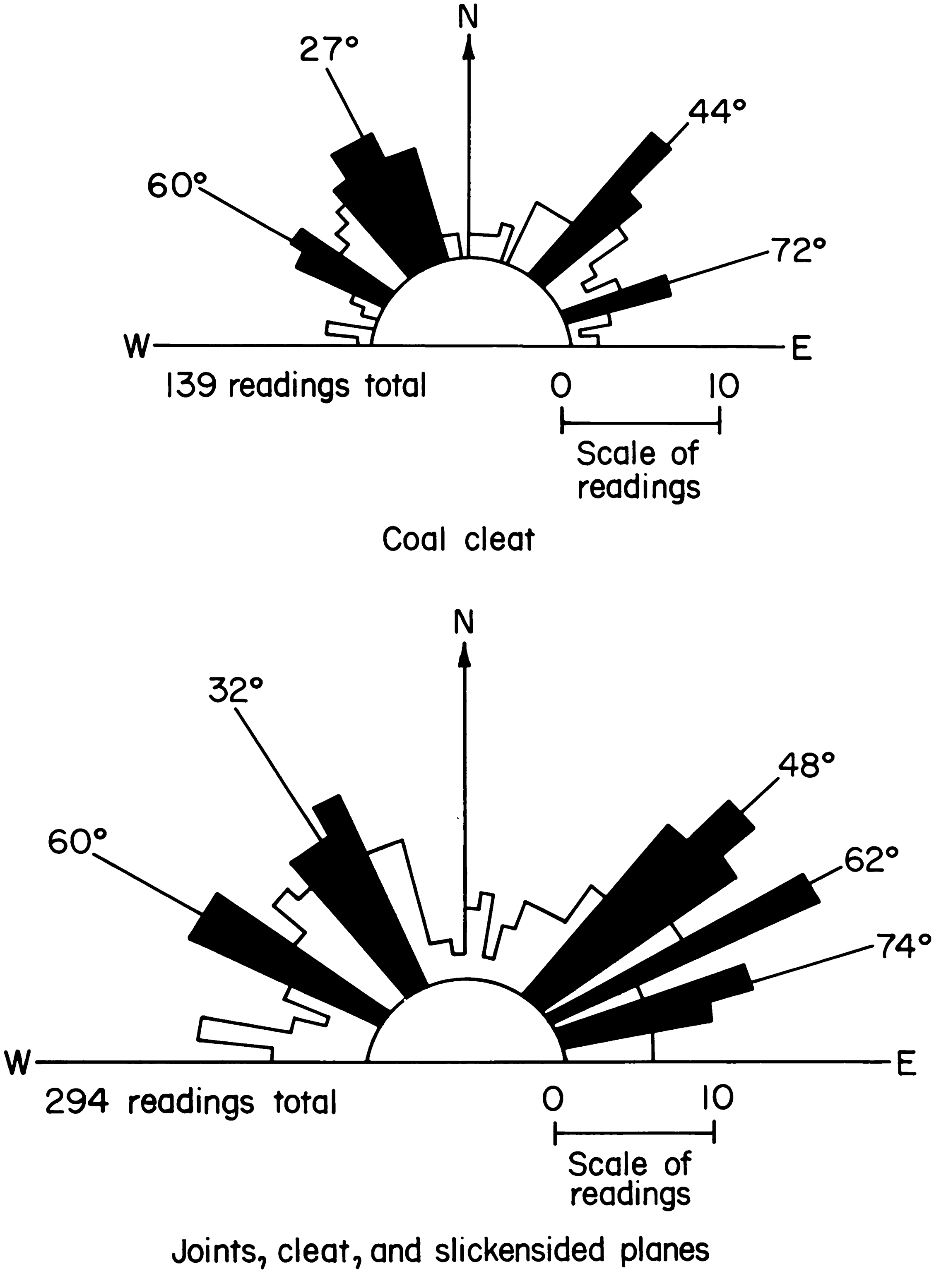

FIGURE 11. - Rose diagram of fracture orientations in the active workings of the study mine.

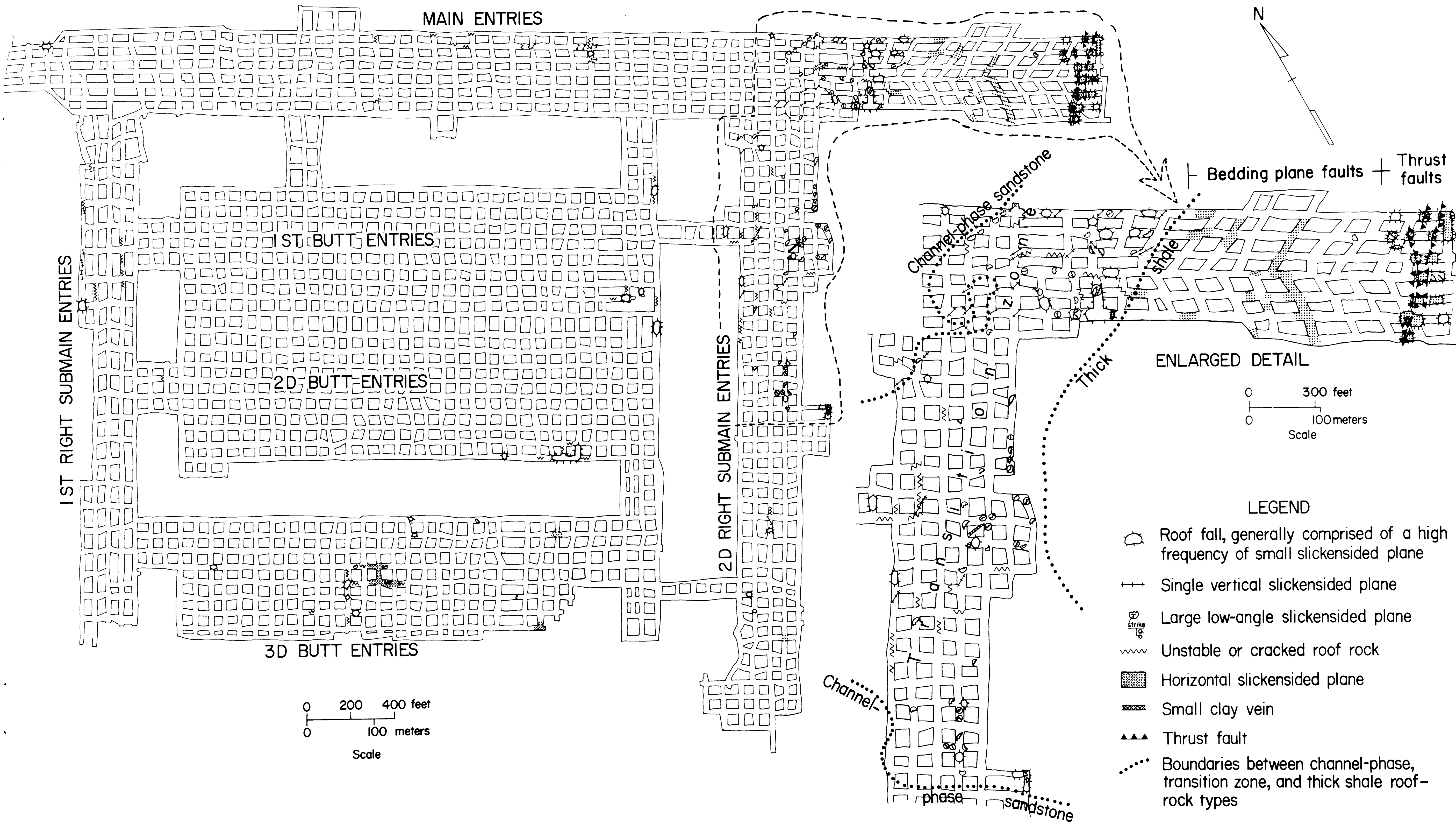

FIGURE 12. - Location and characterization of unstable roof-rock areas in the active workings of the study mine.

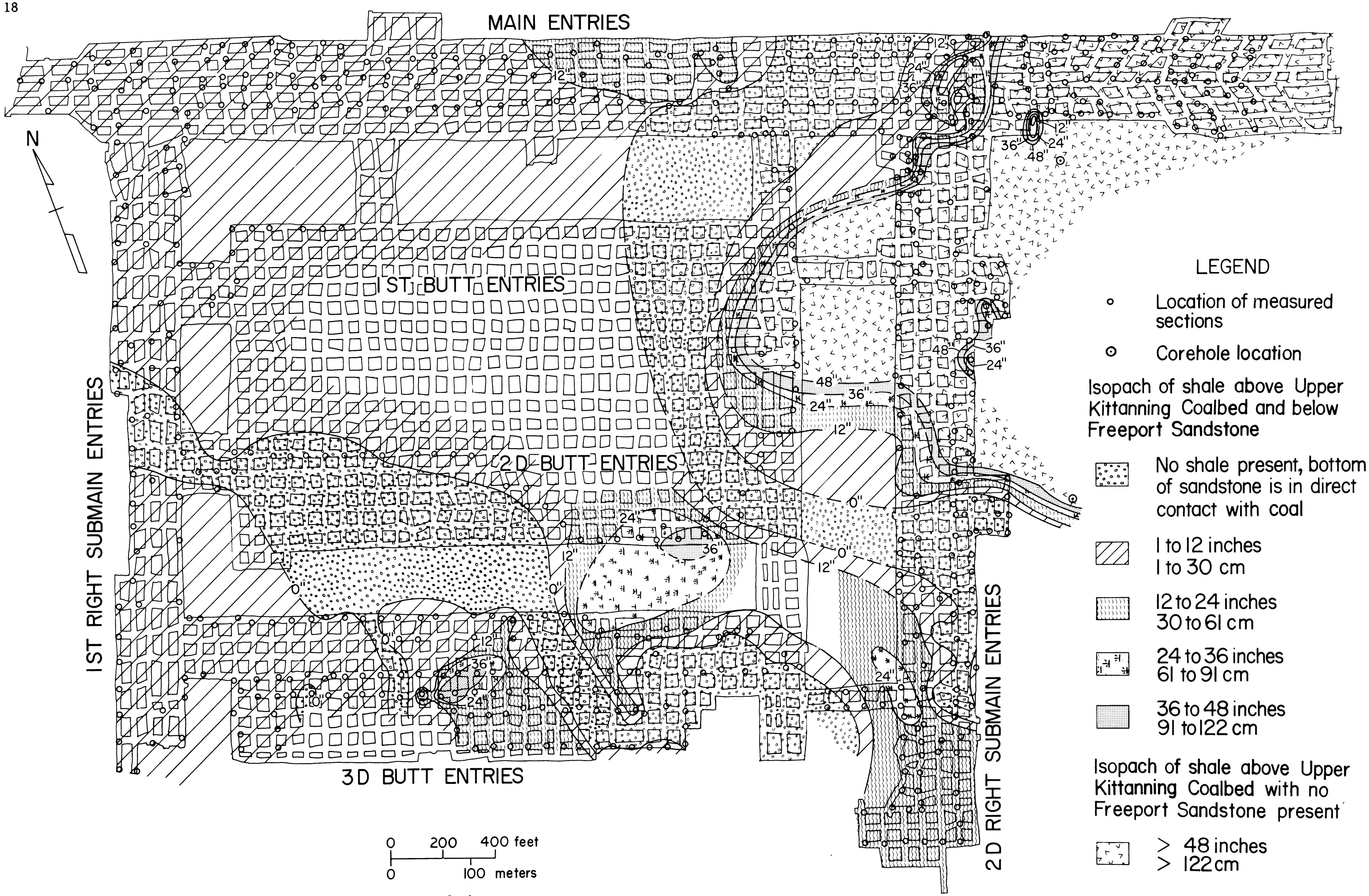

FIGURE 13. - Sedimentary facies isopach map of the shale above the Upper Kittanning Coalbed.

Two distinct trends of unstable shale roof-rock are shown in the enlarged detail of figure 12. One trend has both high-frequency, small slickensided roof-rock (fig. 14) and large, low-angle slickensided planes (fig. 15) found almost exclusively in the transition zone adjacent to the channel-phase sandstone. The second trend has horizontal slickensided planes (fig. 16) and roof falls associated with thrust faulting (fig. 17) exclusively within the thick shale sedimentary facies. The first trend associated with the sandstone-shale sedimentary facies change is a result of differential compaction, while the second trend of unstable roof-rock, confined to the shale sedimentary facies, is a result of regional structural deformation.

The dominant strikes of the large, low-angle slickensided planes located within the transition zone (fig. 18) were examined to determine the relationships of these slickensided planes to other geologic factors. Dominant strikes of locally grouped slickensided planes are subparallel to one another. However, the dominant strikes of all slickensided planes (N 49° E, N 62° E, and N 77° E) are subparallel to the strikes of surface lineaments (N 37° E and N 75° E) and coal cleat (N 44° E and N 72° E). Because the high-frequency, small slickensided roof-rock and low-angle slickensided planes are generally confined to the transition zone, we believe sedimentary facies changes with resulting differential compaction is the dominant factor in the formation of these slickensided planes. The alinement of the strike of these planes with the strike of structures, such as anticlines, synclines, and fracture systems, indicates that structural deformation may have also played an important role in their formation. This would seem reasonable owing to the close proximity in geologic time of the deposition, burial, and structural deformation of coal-bearing strata of the Allegheny Mountain section (2, 34-35).

Structural Deformation

Small-scale thrust and bedding plane faults have been mapped in the active workings of the study mine. The authors believe this faulting is related to the previously discussed large-scale structural deformation of the entire Allegheny Mountain Section. The faults observed in the coalbed and associated strata have small displacements, measured in inches. Faults at depth in the Allegheny Mountain Section have large displacements, tens of feet to hundreds of feet. Structural deformation of the coal-bearing strata in the study area is undoubtedly responsible for roof-rock instability associated with faulting encountered in the underground mine.

FIGURE 14. - Photograph of small, high-frequency, randomly oriented, slickensided planes in the transition zone of the study mine.

FIGURE 15. - Photograph of large, low-angle, slickensided plane with a measurable strike and dip in the transition zone of the study mine.

FIGURE 16. - Photograph of horizontal slickensided plane within shale roof-rock of the main entries.

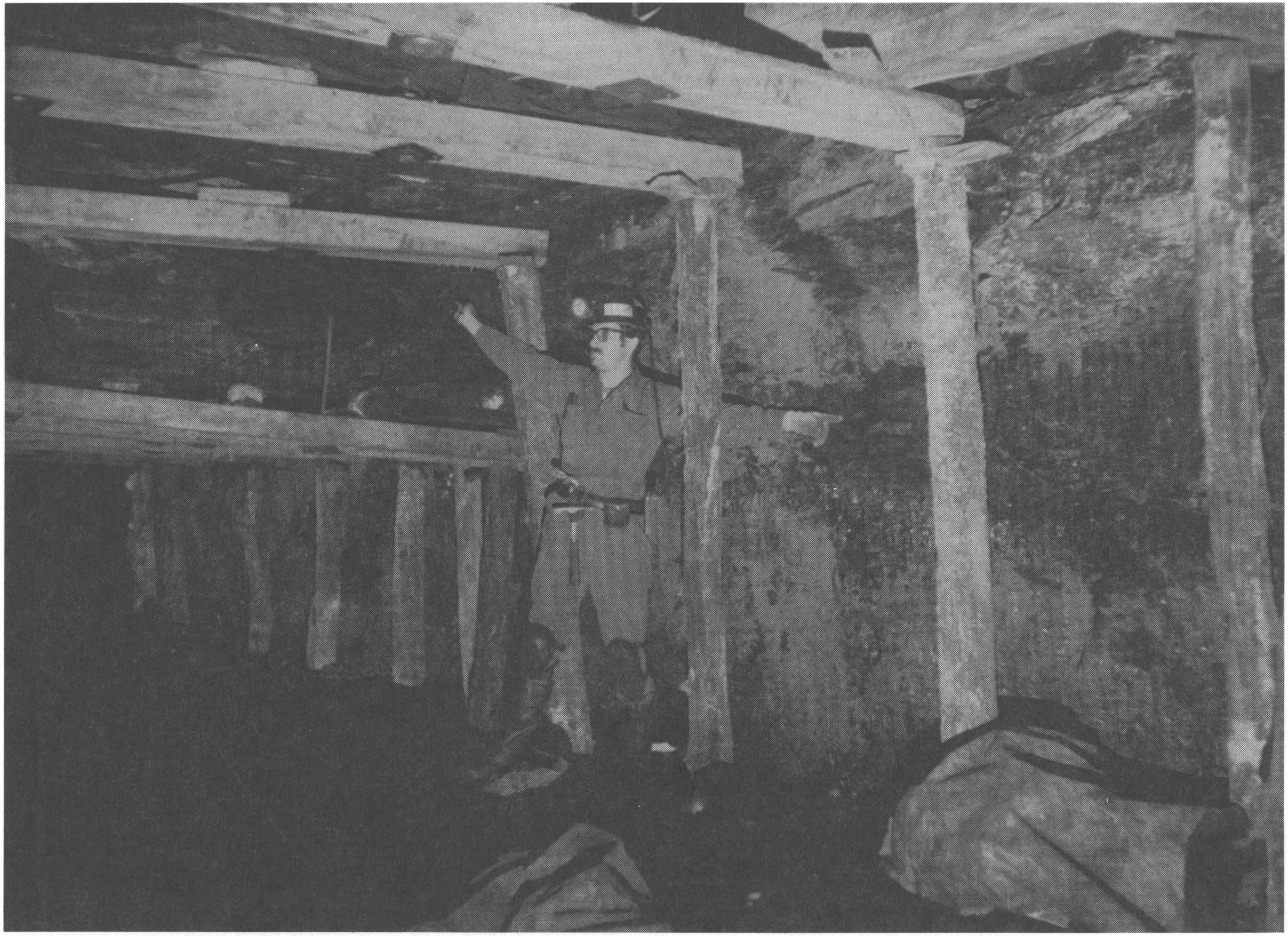

FIGURE 17. - Photograph of thrust fault and associated roof fall within shale roof-rock of the main entries.

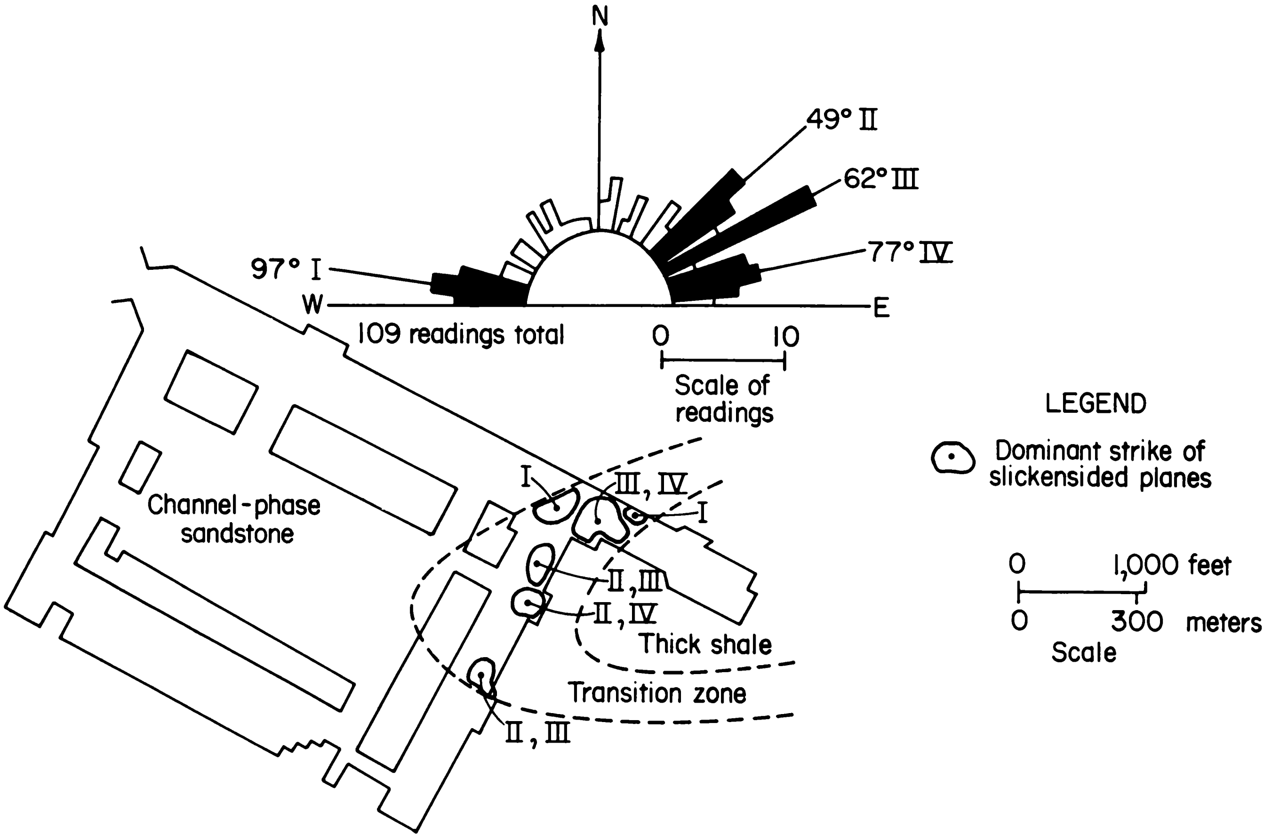

FIGURE 18. - Rose diagram and the location of the dominant strike of the large, low-angle, slickensided planes located within the transition zone of the study mine.

Observations of this phenomenon have been reported in several Bureau of Mines reports. A strip mine working the Upper Freeport Coal Group on the down-thrown side of a strike-fault zone along the eastern flank of the Chestnut Ridge Anticline (29) exposed coalbed dips ranging from 12° to 47° SE in a distance of 2,000 feet (600 m). Three thrust faults of 1 to 3 feet (0.3 to 1 m) displacement were observed on this steep dip slope. Seven thrust faults, similar in character to those observed in the strip mine, were encountered in three underground mines located several miles to the west of Chestnut Ridge Anticline in Indiana and Armstrong Counties, Pa. (29). Several normal faults were also observed in a mine working the Lower Kittanning Coalbed in Cambria County, Pa. (14). All the observed thrust faults in both surface and underground mines are characterized by (1) small displacements (fig. 19), (2) strikes subparallel to the strike of the surrounding strata, (3) a 1- to 3-inch-thick (2.6- to 7.7-cm) fault gouge along the fault plane (fig. 20), and (4) dips of faults cutting across the coalbed at 20° to 45° angles (fig. 21).

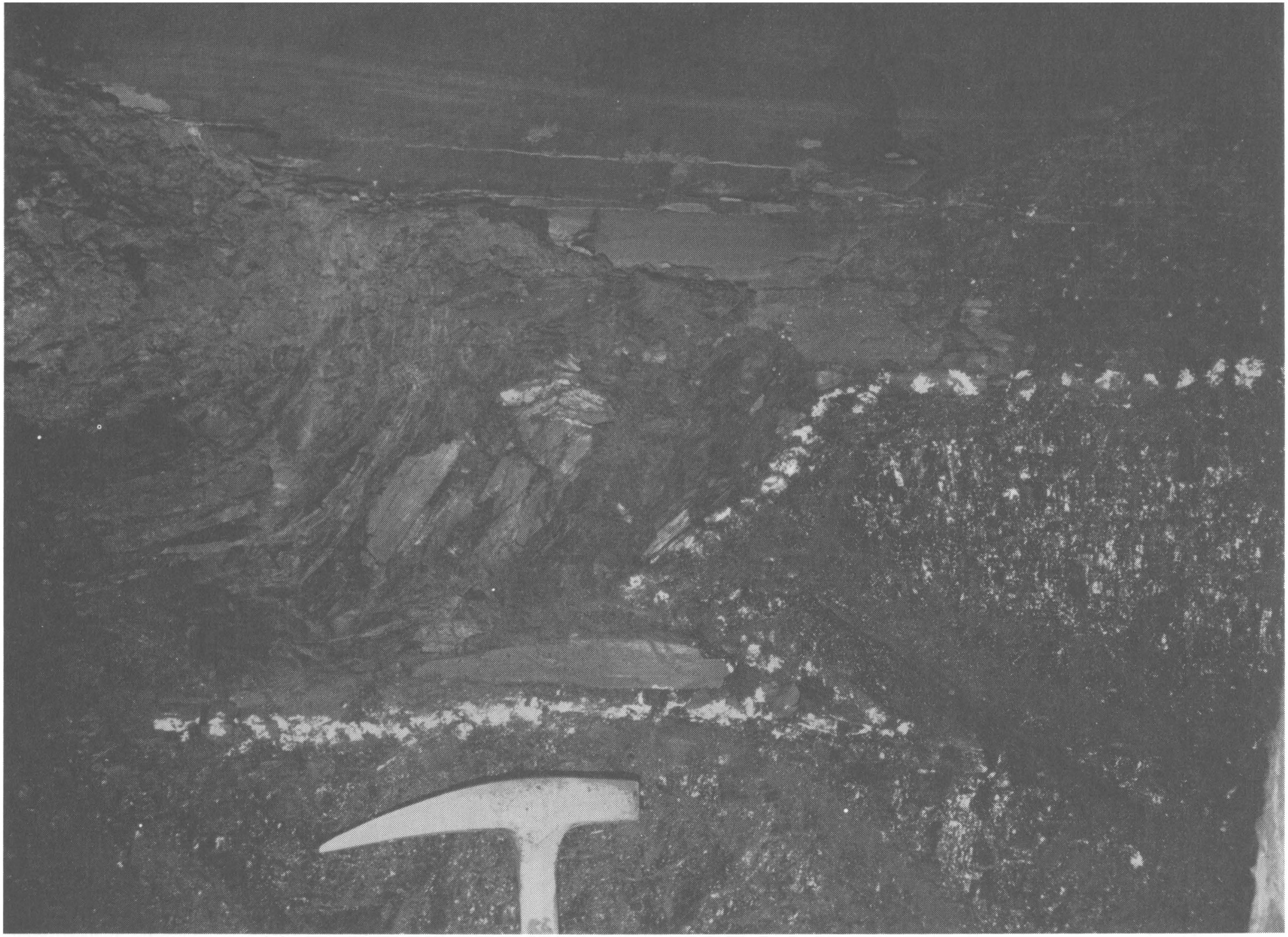

FIGURE 19. - Photograph of thrust fault with structurally disturbed coal and shale roof-rock.

FIGURE 20. - Photograph of thrust fault showing 1- to 3-inch (2.6- to 7.7-cm) fault gouge along thrust plane.

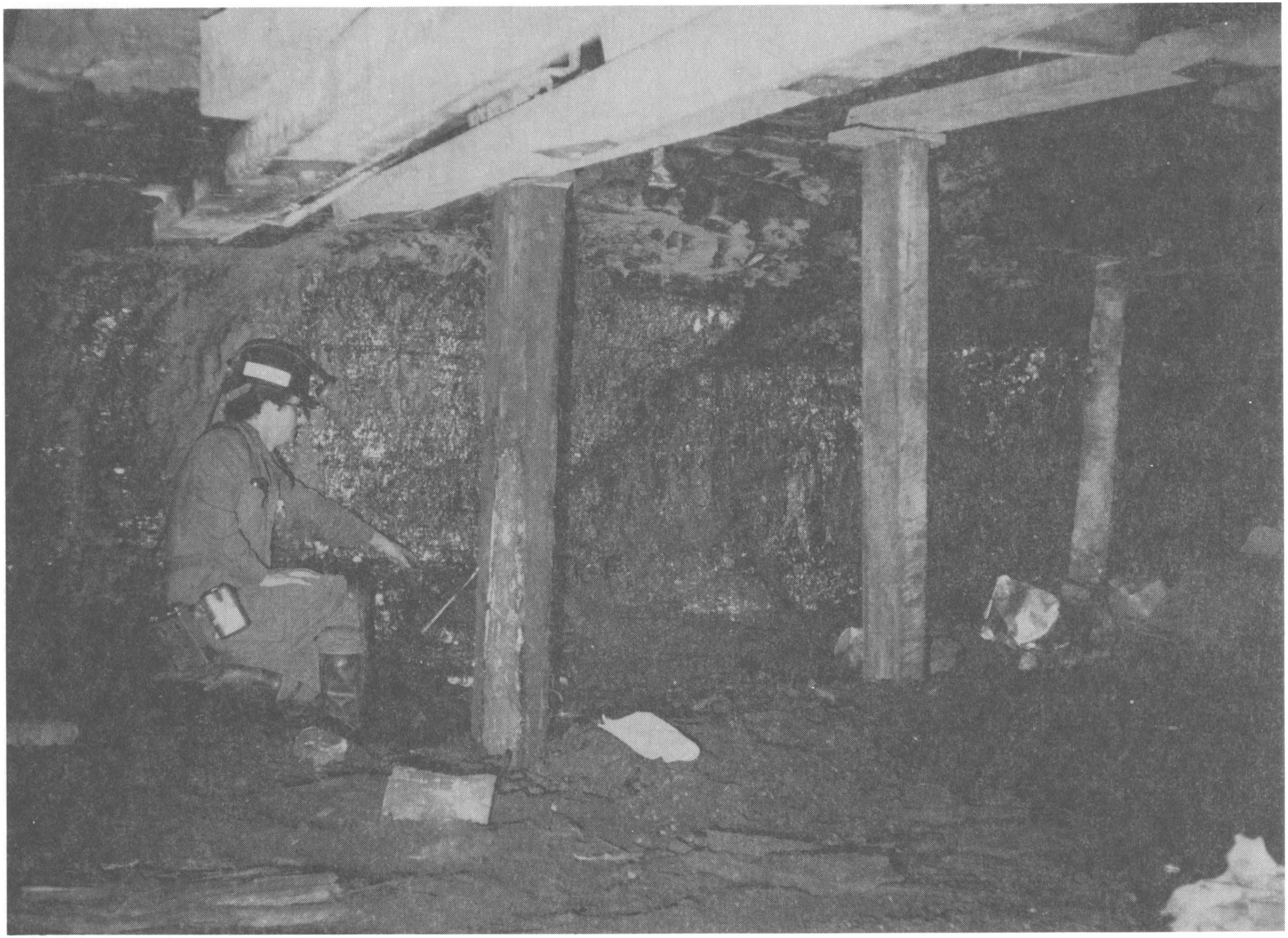

FIGURE 21. - Photograph of thrust fault cutting across the Upper Kittanning Coalbed at a 45° angle.

Bedding plane (horizontal slickensided planes) and thrust faults have been observed and mapped within the advancing main entries of the study mine (No. 47 to No. 55 rooms, 1st to 7th headings, main entry (fig. 12)). Figure 22 shows the location of seven cross sections constructed across thrust-faulted areas of the main entry. As many as three distinct faults cut across the advancing main entries. The dips of two of these faults reverse across the main entries from southeast to northwest with no change in the general strike of the fault system (fig. 22). Two faults are mapped in the 1st, 2d, 3d, 6th, and 7th headings, while three faults are mapped in the 4th and 5th headings. It appears the first thrust fault inby the 5th heading changes to a bedding plane fault in the 6th heading. The first and second faults outby the 4th, 5th, and 7th headings have thrust strata in both directions over a block of coal (cross sections A-A', C-C', and D-D' of fig. 23).

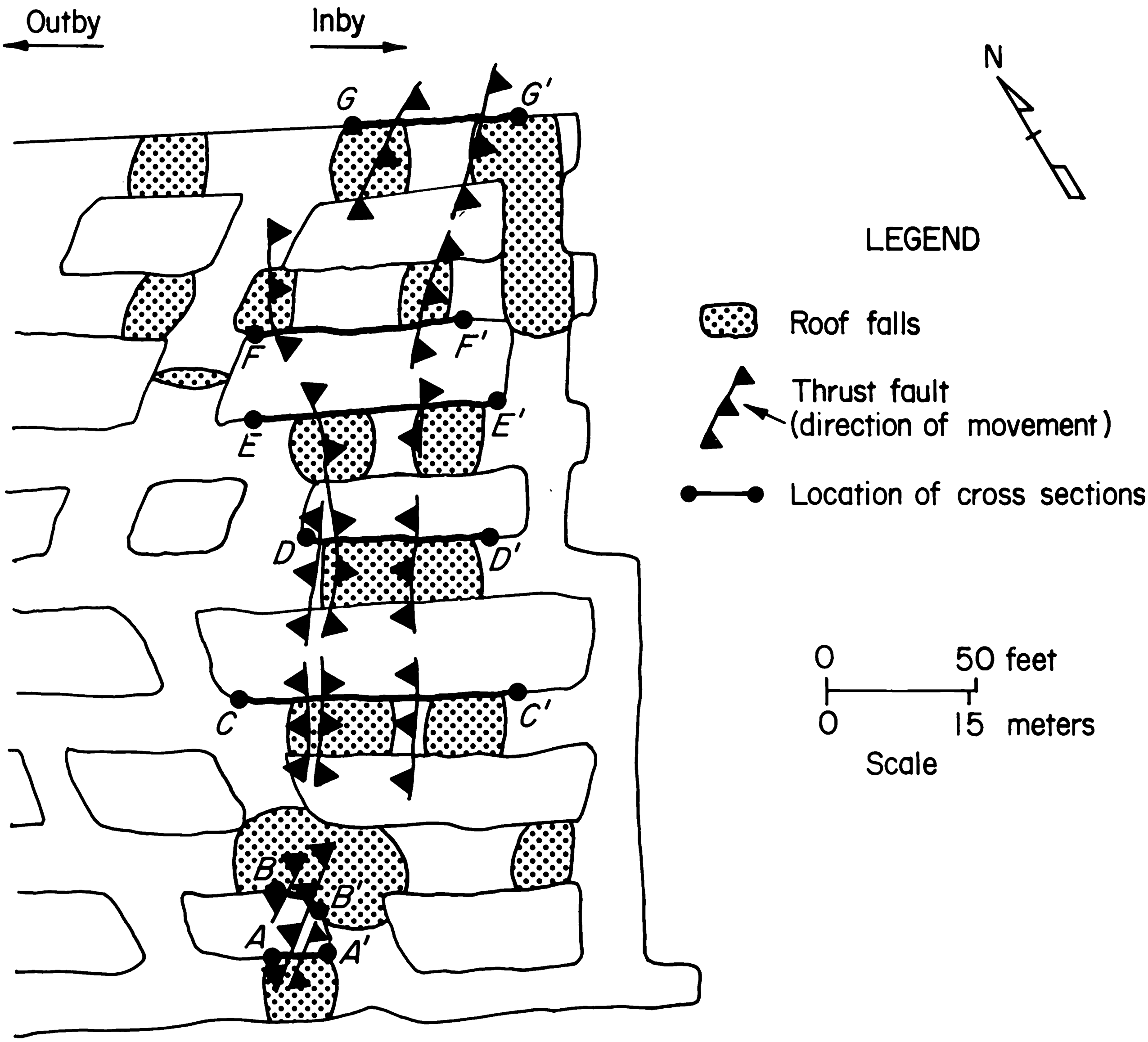

FIGURE 22. - Location of thrust faults, roof fall areas, and cross sections in the advancing main entries of the study mine.

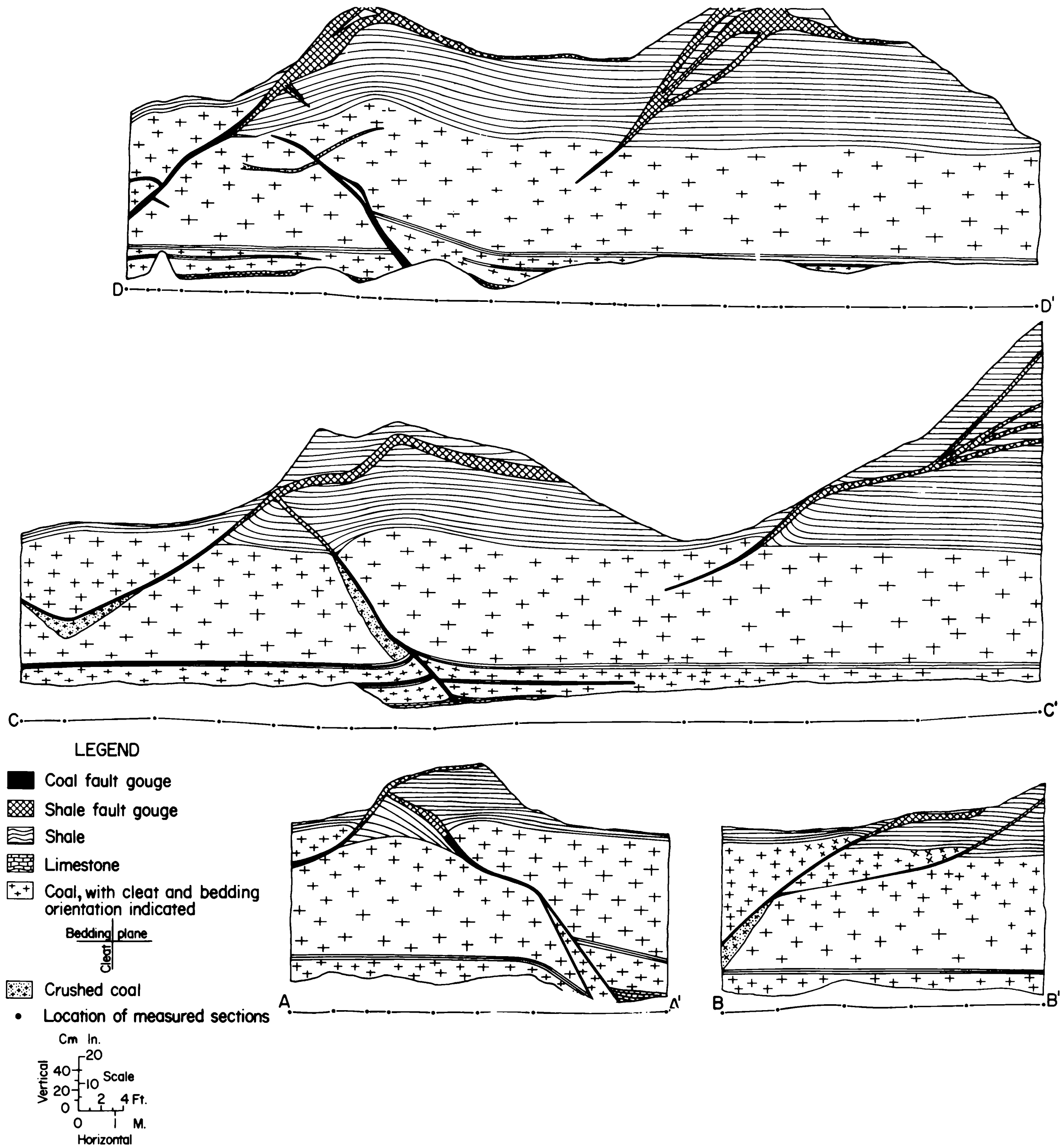

FIGURE 23. - Cross-sectional view of the thrust faults encountered in headings 4 through 7 of the advancing main entries of the study mine.

Cross sections (figs. 23 and 24), compiled from mapping along the ribs of headings cut by the thrust faults, show the presence of bedding and coal-cleat deformation associated with faulting. Figure 19 is a photograph of a fault plane and associated roof-rock deformation. Many faults have well-developed slickensided surfaces. All thrust fault planes extended into the shale

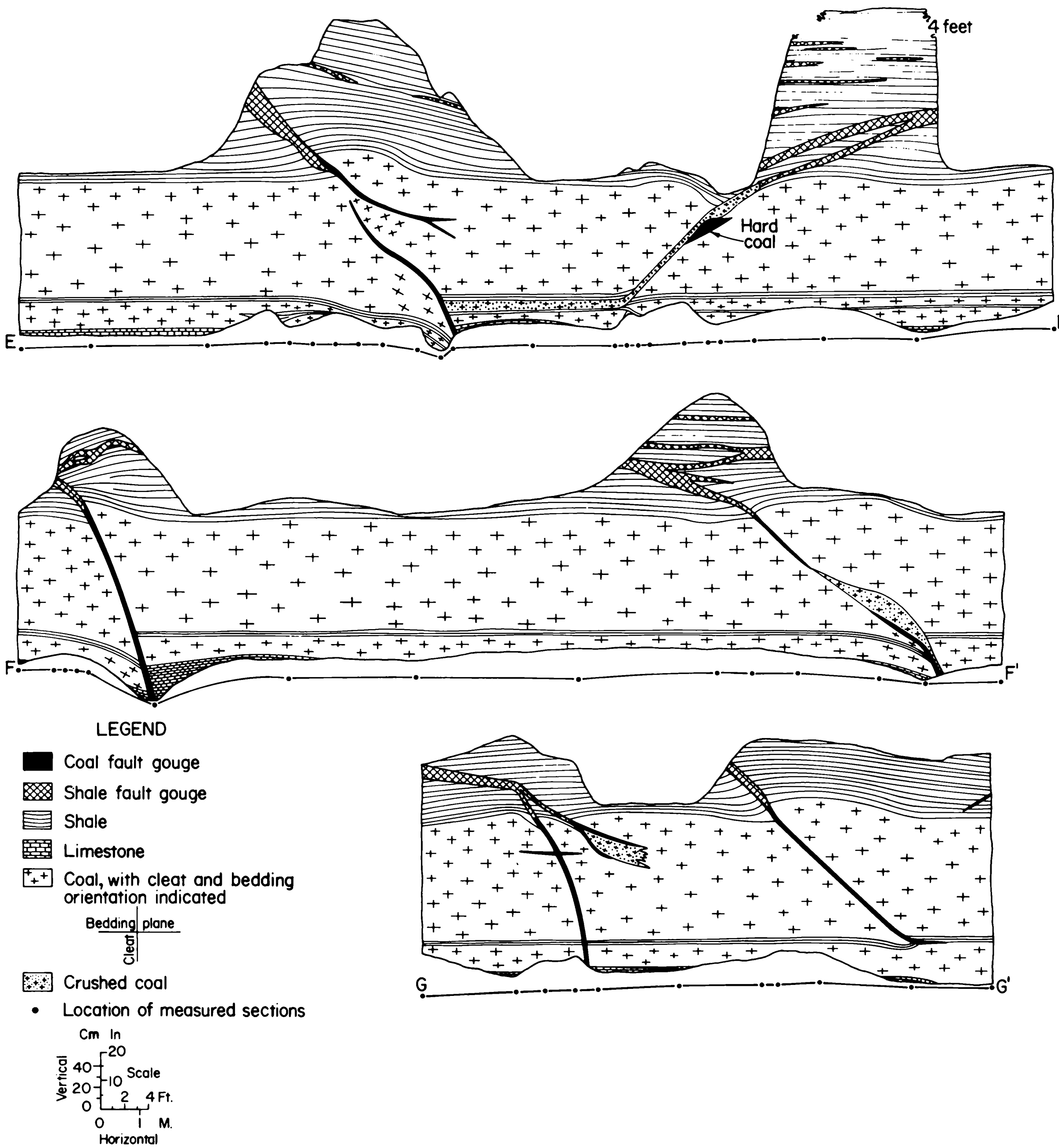

FIGURE 24. - Cross-sectional view of the thrust faults encountered in headings 1 through 3 of the advancing main entries of the study mine.

roof-rock where most became bedding plane faults. An extension of this persistent horizontal fault system has been mapped as much as 800 feet northwest to 100 feet southeast of the thrust fault system. The bedding plane fault (fig. 25) is bounded above and below by horizontal slickensided planes and can have anywhere from 0 to 4 inches (10.2 cm) of fault gouge (crushed shale). The roof bolters refer to the bedding plane fault as the "breaker," because of the ease in drilling through this zone.

FIGURE 25. - Photograph of the bedding plane fault associated with thrust faults. Notice the horizontal slickensided plane and fault gouge.

PREDICTION OF UNSTABLE ROOF-ROCK IN ADVANCE OF MINING

Observations of unstable roof-rock areas in the study mine indicate roof-rock instability is associated with either sedimentary and/or structural deformation of rock strata. Some 95% of all unstable roof-rock areas are located within the sandstone-shale transition zone and the thick shale sedimentary facies. Two distinct trends of unstable shale roof-rock are recognized: the transition zone, adjacent to the channel-phase sandstone, comprised of both high-frequency, slickensided roof-rock and large-angle slickensided planes; and the structurally disturbed thick-shale roof-rock associated with thrust and bedding plane faults (fig. 12). Figure 26 is a generalized cross section showing the relationships between slickensided and faulted roof-rock with sedimentary facies changes and structural deformation. Because the sandstone-shale transition represents a large-scale sedimentary facies change, projection of transition zone into unmined portions of the coalbed with the aid of exploration core data is possible. Not enough data on the size, geometry, and distribution of faults are known to project their trends into unmined portions of the mine property. Faults are smaller geological features than sandstone-shale transition zones and need detailed examination and data to identify their characteristics. In contrast to this the sandstone-sedimentary facies changes can be delineated by any properly trained mine personnel with a good drilling program. Therefore, only the trends of unstable roof-rock associated with the sedimentary facies change are mapped (fig. 27).

Projected areas of incompetent shale roof-rock associated with the sandstone-shale transition zone above the active and projected mine workings of the study are shown in figure 27. The main entries projections of the active mine cross the transition zone twice, while the main entries projections of the new mine to the south of the active mine will cross the transition zone as many as three times (fig. 27). Since the mine is entirely dependent on the main entries, they must be supported and maintained if the mine is to remain safe and productive. It is essential to locate main entries in competent roof-rock. If roof support problems occur in advancing submain entries, development of panels can fall behind retreat sections, hampering production goals. Once panels are outlined by main and submain developments, major geologic features affecting roof-rock stability should have been identified and mapped. If advancing main and submain development is to keep pace with panel extraction, it is necessary to know of hazardous mining conditions before the continuous miner encounters them.

Roof-rock instability has been associated with the sandstone-shale transition zone by several investigators (12, 14, 18-19, 26-27). However, quantitative analysis of the characteristics, locations, and areal extent of unstable roof-rock areas is lacking. More detailed documentation is needed to determine the relationship of the geometry of the channel-phase sandstone with the frequency and orientation of slickensided, unstable shale roof-rock in these areas.

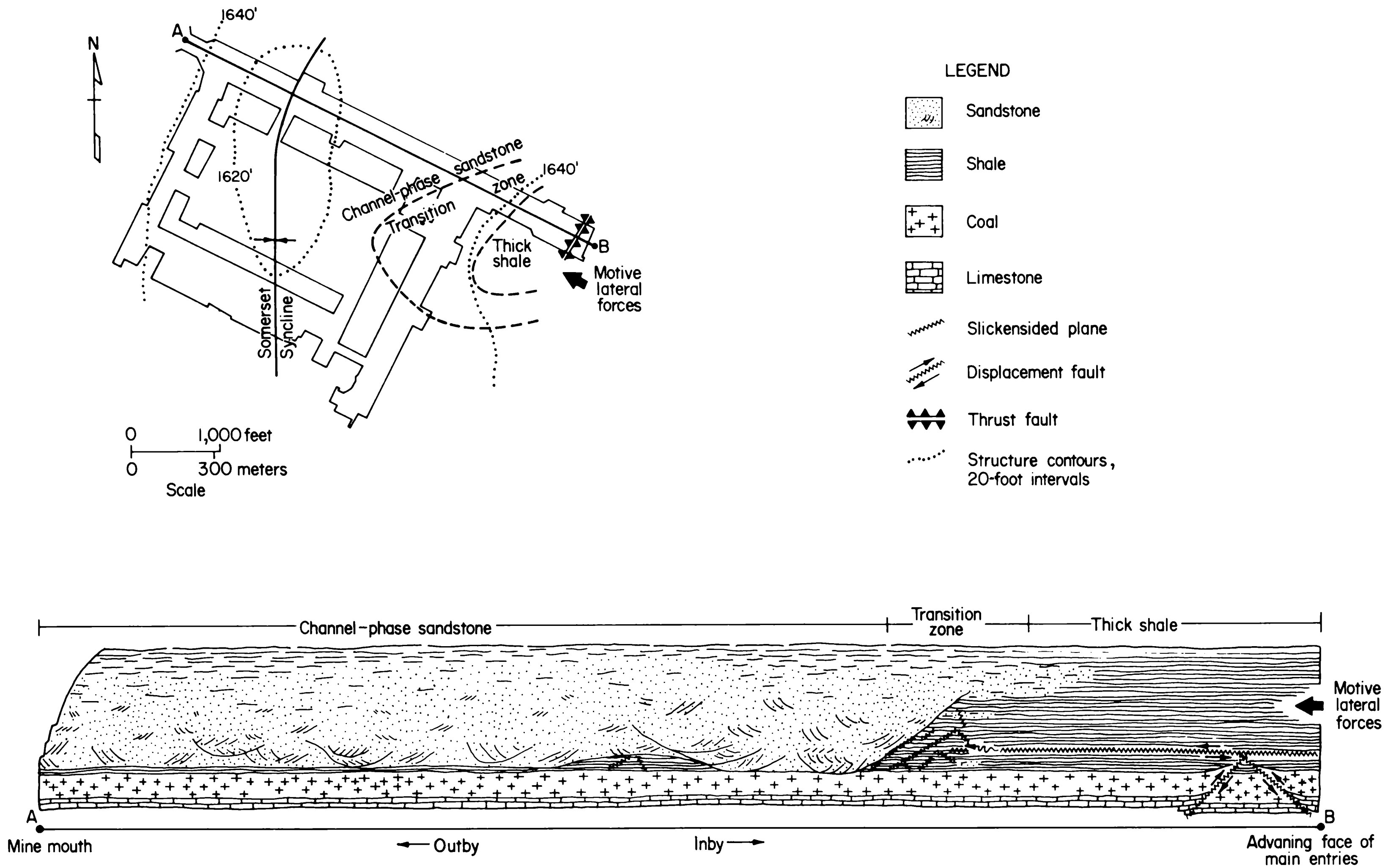

FIGURE 26. - Generalized cross-sectional view of the coalbed and associated roof-rock along the main entries from the mine mouth to the face indicating the presence of sedimentary and structural deformation in the coalbed and shale and lack of deformation in the sandstone.

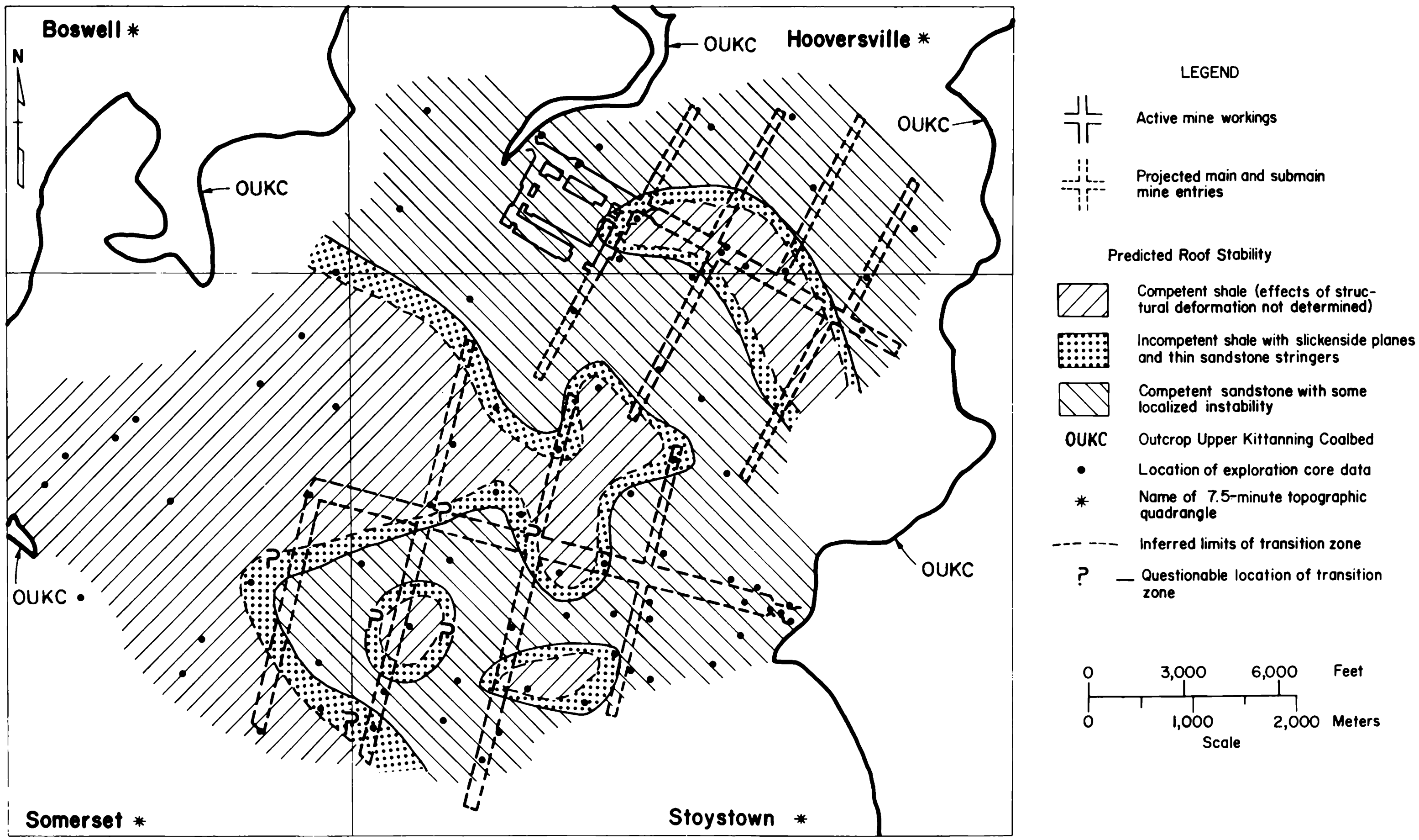

FIGURE 27. - Projected areas of incompetent shale roof-rock associated with the sandstone-shale transition zone above the active and projected mine workings of the study mine.

BENEFITS OF GEOLOGIC STUDIES TO THE MINING INDUSTRY

This type of geologic study provides both short- and long-term benefits to the mining industry. In the short term, detailed mapping enables the mine operator to better understand the characteristics and trends of the mine roof-rock. Specific types of roof support,--such as post and crossbars and resin roof bolts--, have demonstrated histories of effectively controlling particular types of roof conditions; therefore, the most appropriate roof support systems can be matched with the expected roof-rock types. Knowing these characteristics and trends aids in determining approximate strengths of roof-rock over retreat panels and estimating possible failure time between removal of pillars and collapse of overburden. Developing mapping techniques will also enable the mine operators to identify faulted strata as the zone is approached and entered by advancing sections. This advance warning will alert mine personnel of the probability of encountering unstable roof-rock ahead so that enhance safety procedures and appropriate support systems can be implemented.

Long-term benefits will include the ability to project trends of certain kinds of unstable roof-rock types, similar to the unstable roof-rock trends associated with the sandstone-shale transition zone of this study. This information will also aid in projecting main and submain entries under the most competent roof-rock. MSHA roof support plans also can be designed to match the most effective roof support system with the expected roof-rock types. This would be an improvement to the uniform roof support system used by most mine operators.

SUMMARY AND CONCLUSIONS

The Bureau of Mines is establishing fundamental geologic factors affecting coal mine roof-rock stability in order to develop practical techniques to predict zones of potential unstable roof-rock. This study was conducted at a 5-year-old mine with a 20-year reserve. A geological data base was established by constructing regional maps from exploration core hole information. The following important geologic characteristics were delineated by in-mine mapping:

1. Three distinct mappable sedimentary facies are present; the channel-phase Freeport Sandstone, the sandstone-shale transition zone, and the thick shale.

2. Of the unstable roof-rock areas, 95% are within the sandstone-shale transition zone and the thick shale sedimentary facies.

3. Two distinct trends of unstable shale roof-rock are delineated. One trend is associated with the sandstone-shale transition zone, the other with the structural deformation of the strata.

4. The unstable shale roof-rock associated with the sandstone-shale transition zone is comprised mainly of high-frequency, slickensided roof-rock and large, low-angle, slickensided planes.

5. Some of the areas of unstable shale roof-rock, disrupted by thrust and bedding plane faults, are related to structural deformation of the strata.

6. All thrust fault planes are found to extend into the shale roof-rock where most level off into bedding plane faults.

7. Composite strikes of orientations of large, low-angle, slickensided planes, lineaments, and coal cleats in the study area are subparallel to systematic and nonsystematic fracture trends associated with the Appalachian Mountains.

Conclusions drawn from this investigation are--

1. Unstable roof-rock areas are associated with distinctly mappable sedimentary facies and/or structural deformation of strata and are therefore predictable (given significant geologic information).

2. Sedimentary facies changes with resulting differential compaction is the dominant factor in the formation of large, low-angle, slickensided planes with some additional influences from structural deformation of rock strata.

3. The sandstone-shale transition zone represents a large-scale sedimentary facies change. Projections of this zone into unmined portions of the coalbed with the aid of exploration core data was demonstrated.

4. Detailed mapping has indicated the presence of small-scale thrust and bedding plane faults within the coal-bearing strata. This faulting is related to the large-scale structural deformation of the entire Allegheny Mountain Section. This deformation of the coal-bearing strata in Somerset, Fayette, Cambria, and Indiana Counties, Pa., is probably responsible for numerous unstable roof-rock areas in underground coal mines.

5. Because these faults are small-scale geologic features, they are difficult to find with a standard drilling program. Also little is known as to their occurrence, size, and geometry.

6. Similar studies must be conducted for individual mine properties in different areas because mappable conditions and characteristics change rapidly from one coal region to another.

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APPENDIX

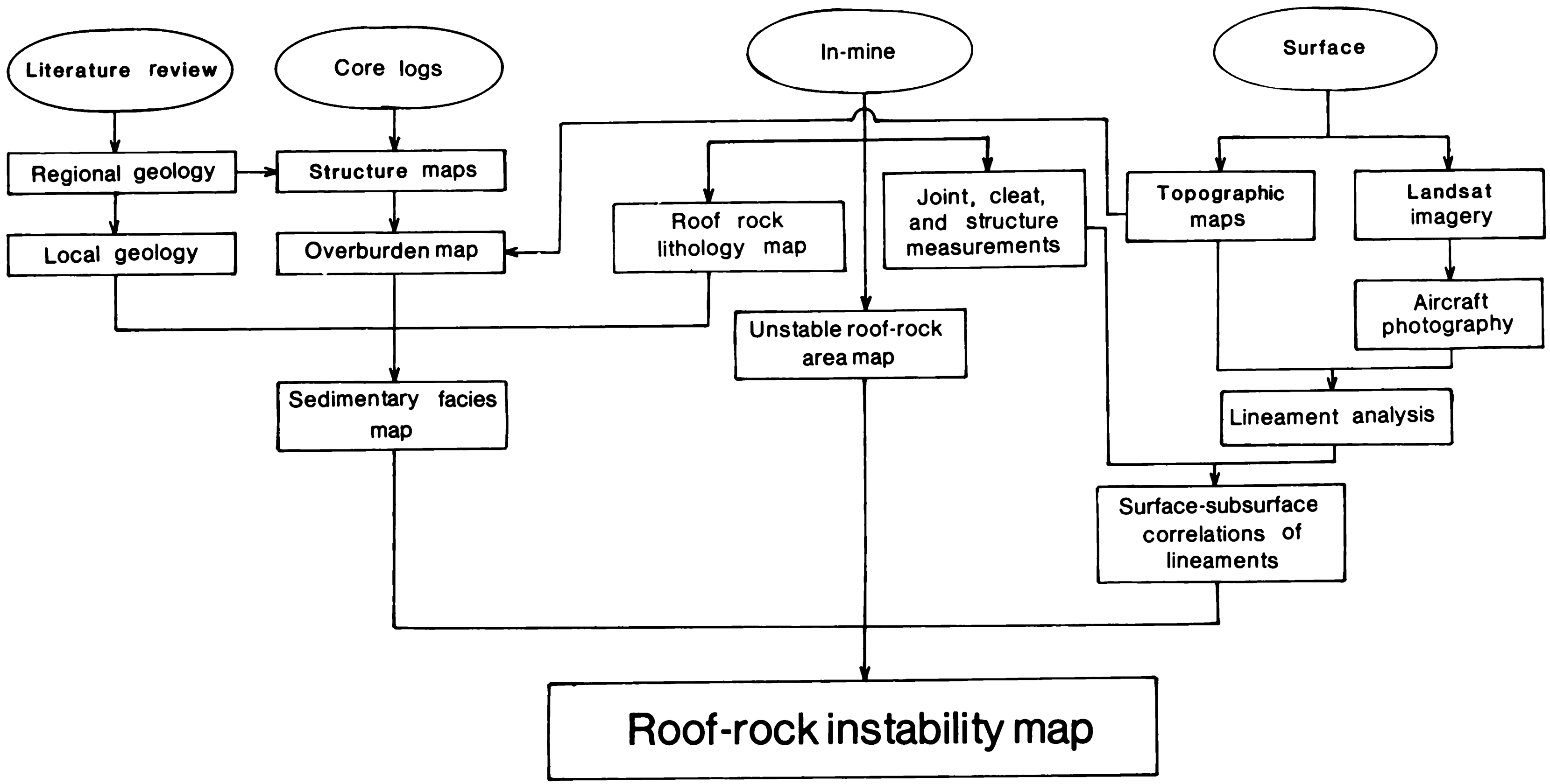

FIGURE A-1. - Schematic of methodology for generating roof-rock instability maps.

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