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# PREDICTING PROBABLE ROOF FALL AREAS IN ADVANCE OF MINING BY GEOLOGICAL ANALYSIS

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## ABSTRACT

Surface fracture trace density, changes in roof rock type, and topographic unloading due to drainage were mapped for the mining areas located in the Blacksville-Osage, W. Va., quadrangles to investigate their influence on mine roof falls. Using these factors, a technique was developed to predict probable roof fall areas ahead of projected mining operations. As a feasibility test of this proposed technique, areas were delineated where one, two, and all three of these factors were operating to formulate a "potential hazard map" for comparison with roof fall observations that were made. The limited evidence suggests that in combination these factors are reliable predictors of where roof falls are likely to occur. This technique promises to be a useful tool in planning mining operations.

## INTRODUCTION

Roof fall studies in coal mines have established the fact that a significant number of occurrences are attributable to certain geologic features and conditions (7, 11, 18, 20).[4] Factors cited as contributing to roof falls are listed as follows:

1. Bedding planes and joints.
2. Planes of weakness, faults, and discontinuities.
3. Fracture systems underlying stream channels.
4. Ground water seepage through fracture zones.
5. Gas and water pressure in the strata overlying shale in the mine roof.

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[1] Geologist.
[2] Research physicist.
[3] Research supervisor.
[4] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

6. Voids in roof rock caused by oxidation of pyritic veins.

7. Presence of clays in floor and roof layers, particularly montmorillonite and expandable illite.

8. Clay veins in the roof and coal.

9. Shale or sand lenses in the roof.

10. Thin sections of draw slate in the roof.

11. Fossils imbedded in roof rock.

12. Stresses in the rock.

Factors 1 through 6 were identified nearly 30 years ago by Dr. A. J. W. Headlee of the West Virginia Geological Survey (7), who pointed out that fractures played a very contributory role in occurrence and frequency of roof falls. His investigation showed that the intensity of the fracture system influenced the amount of the fall; his conclusions indicated that no one single factor could be used to prevent roof falls. Since then, C. E. Wier of the Indiana Geological Survey (20) identified six major types of roof falls that were attributable to factors 1, 6, 7, 9, 10, and 11, and investigated rock properties such as modulus of rupture that might be used to predict areas of roof falls. He pointed out that both lateral and vertical variability in roof rock properties are important factors in roof stability and concluded that no single physical or chemical parameter seems to control roof falls.

B. H. Kent of the U.S. Geological Survey (11) has identified geologic factors 2 and 8-11 as contributing causes to coal mine roof falls in southwestern Pennsylvania. His observations indicate that shale roof falls are of two main types: (1) those in deformed shale bordering thick sandstone lenses and (2) those in jointed shale areas remote from sandstone lenses. Roof rock failure in marginal zones is attributed to differential compaction and stresses concentrated in shales surrounding the less compactible sandstone lenses. In shale areas remote from the sandstone lenses, roof falls in the shale occur more frequently along mine passageways oriented northeast following the butt cleat of the coal. This observation is consistent with a study of geologic factor 12 by the Continental Oil Co. at the Humphrey No. 7 mine in Mt. Morris, Pa. (18). Here, the predominant occurrence of roof falls was along entries driven in an N-S direction, with virtually no problems in the main haulageway driven in an E-W direction. Subsequent calculation of in situ stresses by the use of hydraulic fracturing pressure data disclosed the orientation of the principal horizontal compressive stress to be nearly E-W. To prevent roof falls, roof supports were positioned closer together in the N-S direction.

In spite of the new studies that have recently been completed, no suitable technique has been developed that utilizes all known causes of roof falls and predicts where roof falls might occur in advance of mining. Accordingly, this study was conducted to determine if most or all of the 12 contributing factors stated earlier could be reduced to three or four common denominators which could be mapped by a combination of old and new geologic tools. As a new tool, airborne remote sensing surveys (1, 8-9, 13-15, 17) were used to map fracture systems which are often related to stress orientation, structural weaknesses, and clay veins found within the coalbed. The old tools of lithofacies and thickness mapping were used to generate additional information. Efforts were directed at predicting the relative stability of roof rock over large areas as an aid in planning future mining operations.

## ACKNOWLEDGMENTS

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## EXPERIMENTAL CONSIDERATIONS

The investigative approach adopted was to map surface geological features and subsurface geologic structure in areas where mining has already been completed and some roof falls have been documented. The objective was to determine the feasibility of predicting probable areas of roof falls in the region ahead of projected mining operations. Particular emphasis was placed on the establishment of directional surface features, interpreted from aerial photos, as reliable indicators of zones where roof falls are more likely to occur. In the sections that follow, the procedures employed and the results obtained are described.

### Structure and Lithofacies Mapping

In figure 1, depicting structure on the base of the Pittsburgh coal, the axes of anticlines and synclines trend approximately N 35° E - S 35° W. The amplitude of folds increases in magnitude from west to east across the two quadrangles. In the study area, the principal horizontal stress was measured by Parsons (18) and found to be oriented in a direction N 84° W. The coal face cleat direction of N 72° W shows a rotation of the principal stress direction of 12° since the structures were folded during the Permian period. These stresses in geologic time often alter the fabric of the rocks and develop sets of fractures (2, 16). Further observations have shown that rock units that are platelike (wider than thick) display synclinal fractures that are opened toward the bottom of the bed and anticlinal fractures that are closed in the same position. This may lead one to speculate that in synclinal areas the roof would have more of a tendency to fail due to fractures and the reverse Keystone effect (3, 19).

The lithofacies map in figure 2 was compiled from core log data supplied by Consolidation Coal Co. and by consultation and comparison with maps prepared by Conti, Hughart, and Kirr (5-6, 10, 12) in Master's thesis work at West Virginia University. Most roof falls reported in this area involve less

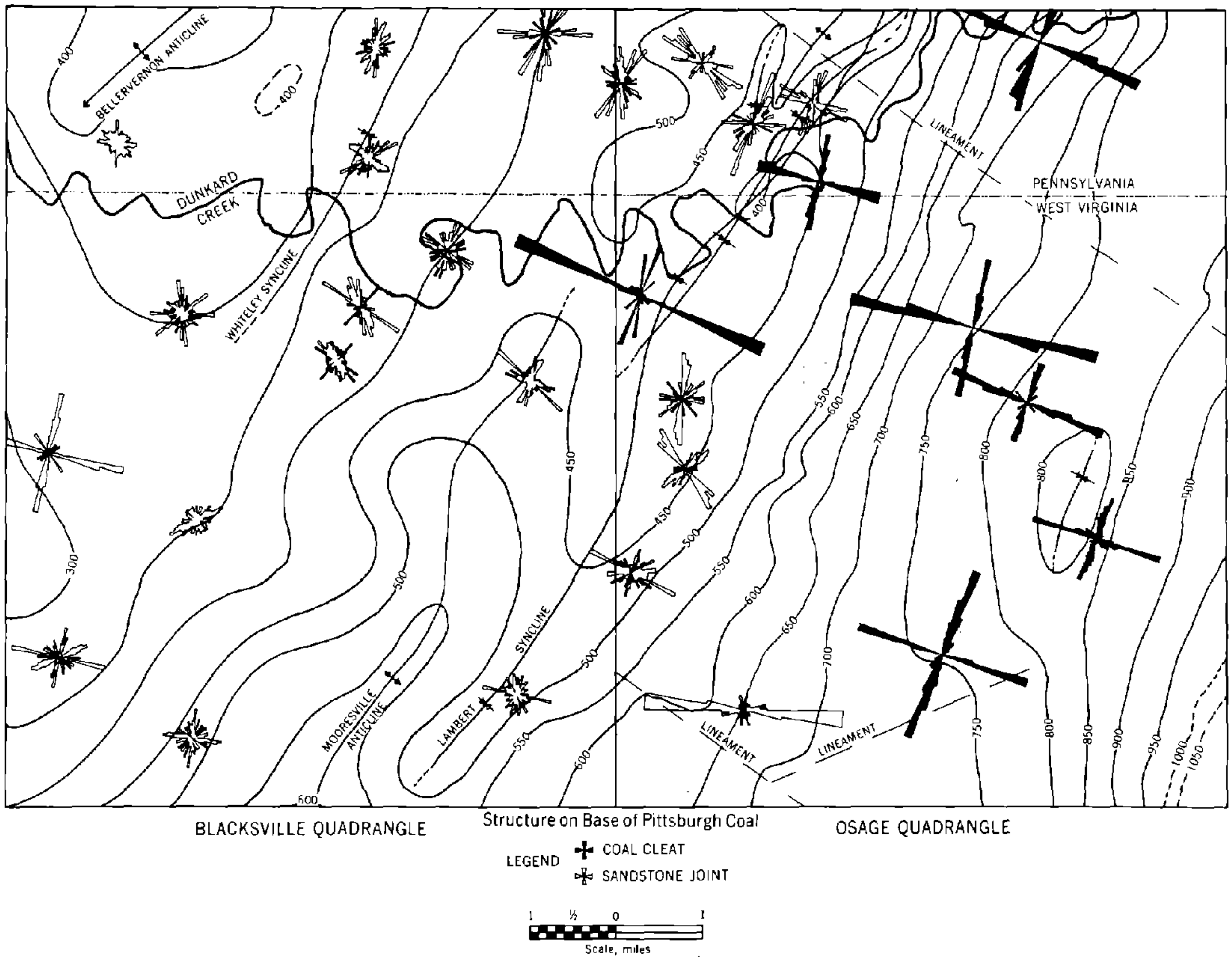



FIGURE 1. - Structural contours on the base of the Pittsburgh coal with joint frequency diagrams and postulated lineaments (after Donaldson, Conti, Kirr, and Hughart).

than 40 feet of strata above the Pittsburgh coal. The interval between the Pittsburgh coal and the Redstone coal is generally 30 to 40 feet, so the mapped interval comprises the rocks most often involved in roof falls. By mapping the dominant rock type of this interval, a general appraisal of roof stability can be made as depicted in figure 3. This diagram presents the results of a limited number of tensile strength measurements made on shales, sandy shales, calcareous shales, coarse, medium, and fine grained sandstones, sandy and argillaceous limestones, and relatively pure limestones. The Brazilian-type (line load) tensile strength test was selected because it is believed to give a more accurate value for this type of failure. With reference to figure 3, it can be seen that the lower values of tensile strength suggest that in some cases decreases in overburden thickness of only 250 feet could contribute to the occurrence of roof falls.

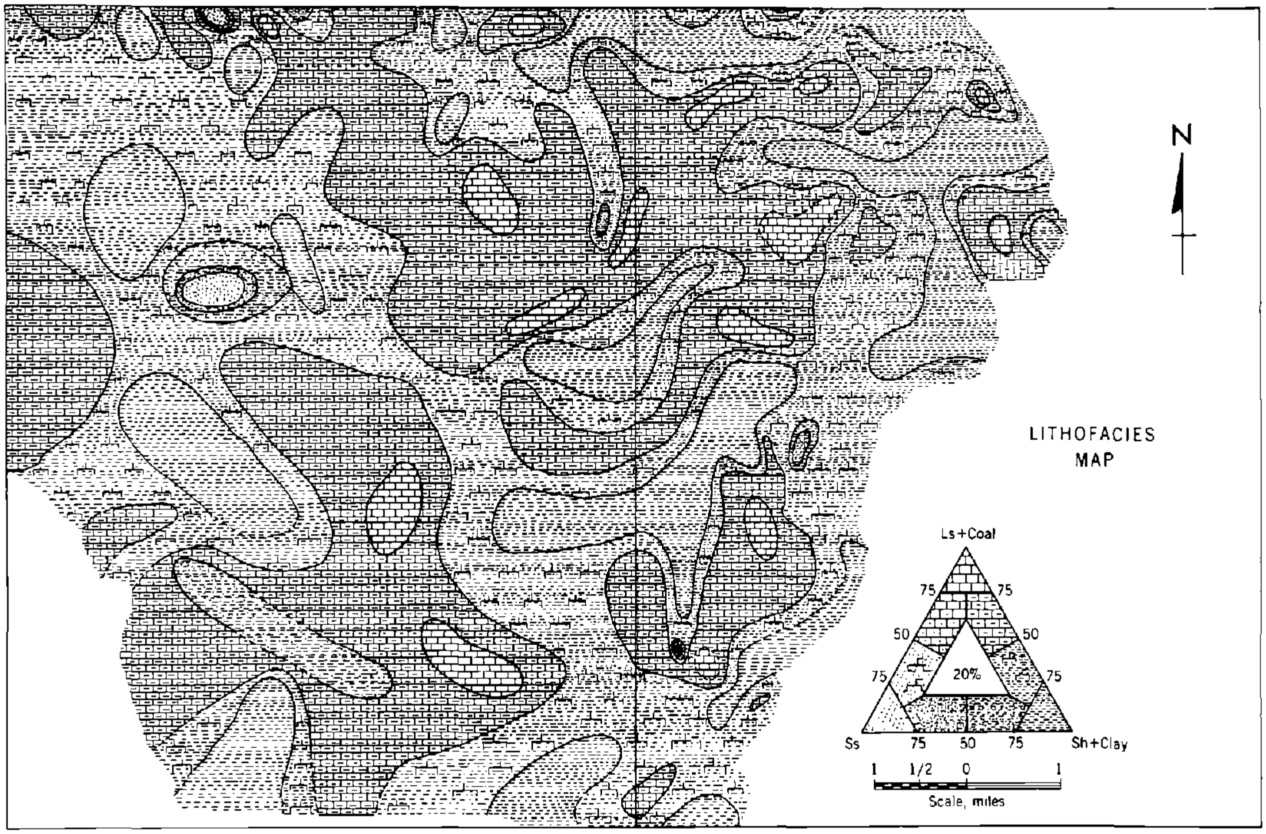



FIGURE 2. - Map showing dominant rock type in the interval between the Pittsburgh coal and the Redstone coal (after Donaldson, Kirr, and Hughart).

Drainage and Overburden Thickness Mapping

It is now generally recognized that the direction of stream flow is nearly everywhere partially controlled by joints so that an analysis of drainage should correspond to an analysis of joint systems in the area (4, 8).

In figure 1, both surface joint and coal cleat orientations are shown for the various locations in which they were observed. Coal cleat orientation in the Osage quadrangle shows a face cleat of N 70°-80° W. The joint orientations in sandstones and shales of parts of both quadrangles parallel this trend. These same trends are consistent with the dominant directions assumed by streams feeding the Dunkard Creek in this area.

The quarrying action of streams parallel to a joint set or a zone of joint concentration (fracture zone) is much more efficient than when the stream segment is moving in a random direction. Thus, streams which flow for considerable length down a dip slope usually cut deeper stratigraphically than streams flowing more parallel to the strike of the bedding. By erosion, a

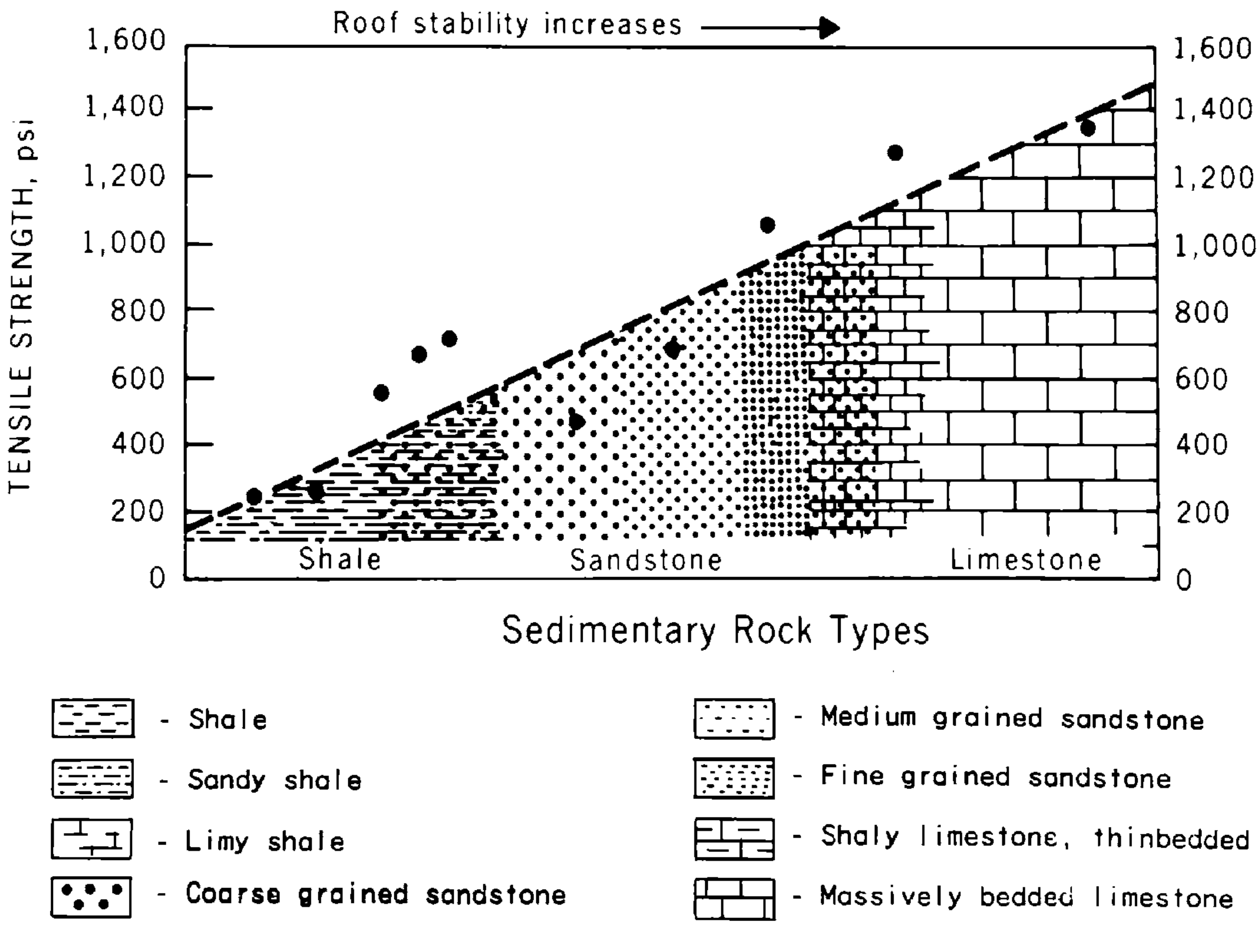



FIGURE 3. - Relationship of rock type, tensile strength, and roof stability. Tensile strength measurements were Brazilian-type line load on 2- by 1-inch disks.

stream unloads overburden in the valleys and produces an unbalance of forces which may result in portions of the stream valley being placed under relative tensional stresses. Figure 4 is an overburden thickness map depicting areas where the greatest tensile stresses due to topographic unloading may be expected. The quarrying action of streams to off-load the strata and produce local tensional effects parallel to the stream has allowed deep penetration of jointing along these trends and at the same time, percolation of surface water downward to the coalbeds. As the water passes through the various layers, it takes different minerals and ions into solution. In northern West Virginia, the Redstone limestone (found immediately below the Redstone coal) lies 20 to 40 feet above the Pittsburgh coal in many areas; in this instance, the waters percolating downward dissolve $CaCO_3$ and reprecipitate it in the shales above the coal and in the coal cleat itself. There is a good possibility that ion exchanges between the water and the clays in the shales and mudstones over the roof coal alter the strength of the rock; the clay may also swell from the inclusion of water into the clay lattice, thus producing an additional stress that could lead to roof falls when the area beneath is mined.


BLACKSVILLE QUADRANGLE | OSAGE QUADRANGLE

FIGURE 4. - Map of thickness of overburden over Pittsburgh coal.

Figure 5 is a diagrammatic sketch illustrating how the roof rock is placed in relative tension in the center of the unloaded stream valley by compressive stress acting through the platelike unit. This sketch also illustrates the potential roof fall hazard areas created by fracture zones (in this case the stream has been controlled by fracture zone), by stream unloading, and by facies changes (presence of sandstone channel to produce fracturing due to differential compaction between shale facies and sandstone facies). It should be noted that jointing related to stress release from removal of

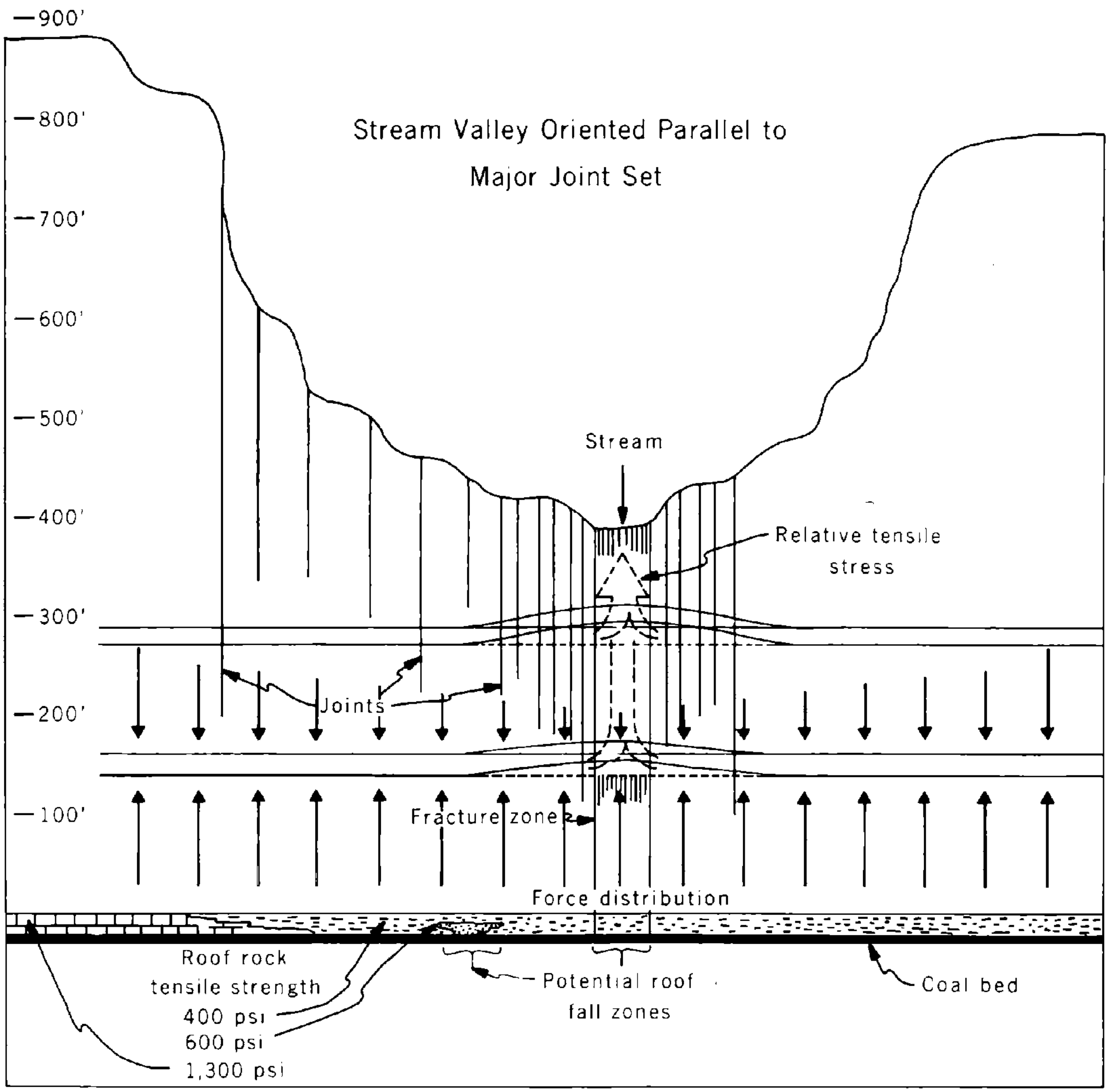
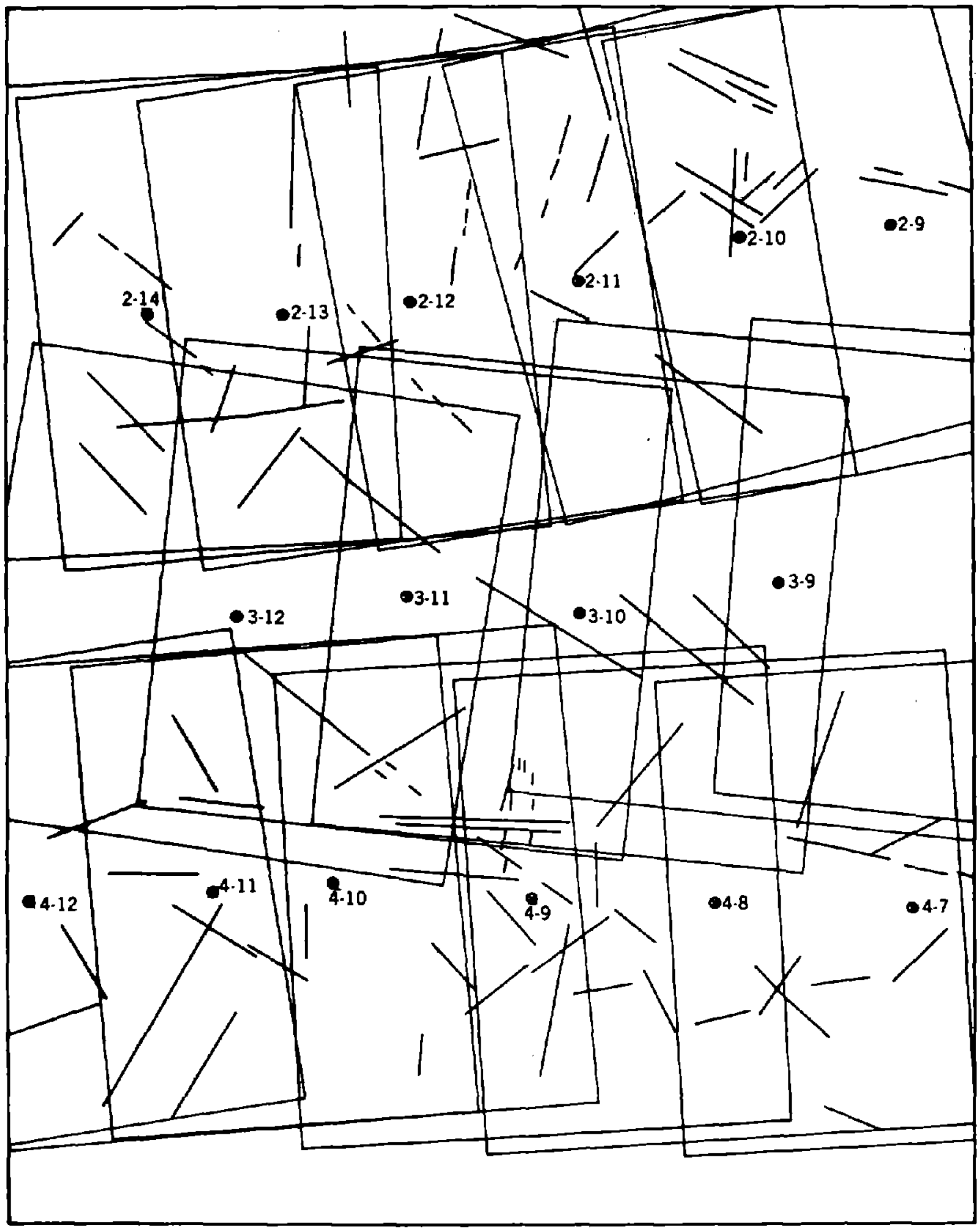



FIGURE 5. - Schematic diagram of postulated mechanism of creation of fracture zones and potential roof fall zones by erosion of overburden.

overburden has a higher frequency in the center of the valley under the stream and decreases in frequency approaching the hilltop.




BLACKSVILLE 7-1/2' QUADRANGLE

AERIAL PHOTO LOCATION MAP

FIGURE 6. - Illustration of techniques used to accurately transfer data from aerial photographs to a 7-1/2-minute topographic map base. Dots indicate the center of each 9- by 9-inch aerial photograph.

## Fracture Trace Mapping

In this feasibility study, black and white infrared photos were examined for fracture traces and lineaments over the Osage and Blacksville quadrangles of northern West Virginia. This area covers the surface over all or portions of five coal mines operating in the Pittsburgh coal.

Interpretation of the aerial photos begins with the location of the flight line path for each series of photos. Figure 6 shows the center and orientation of each 9- by 9-inch aerial photo on the U.S. Geological Survey 7-1/2-minute topographic map. Comparison of the photo location of lineaments with the plotted location on the topographic map insures accurate transfer of data and elimination of lineament mislocation due to distortion in the photograph.

Fracture traces were mapped using a mirror stereoscope and annotated on stable plastic overlays for transfer to a topographic map base. Figure 6 also

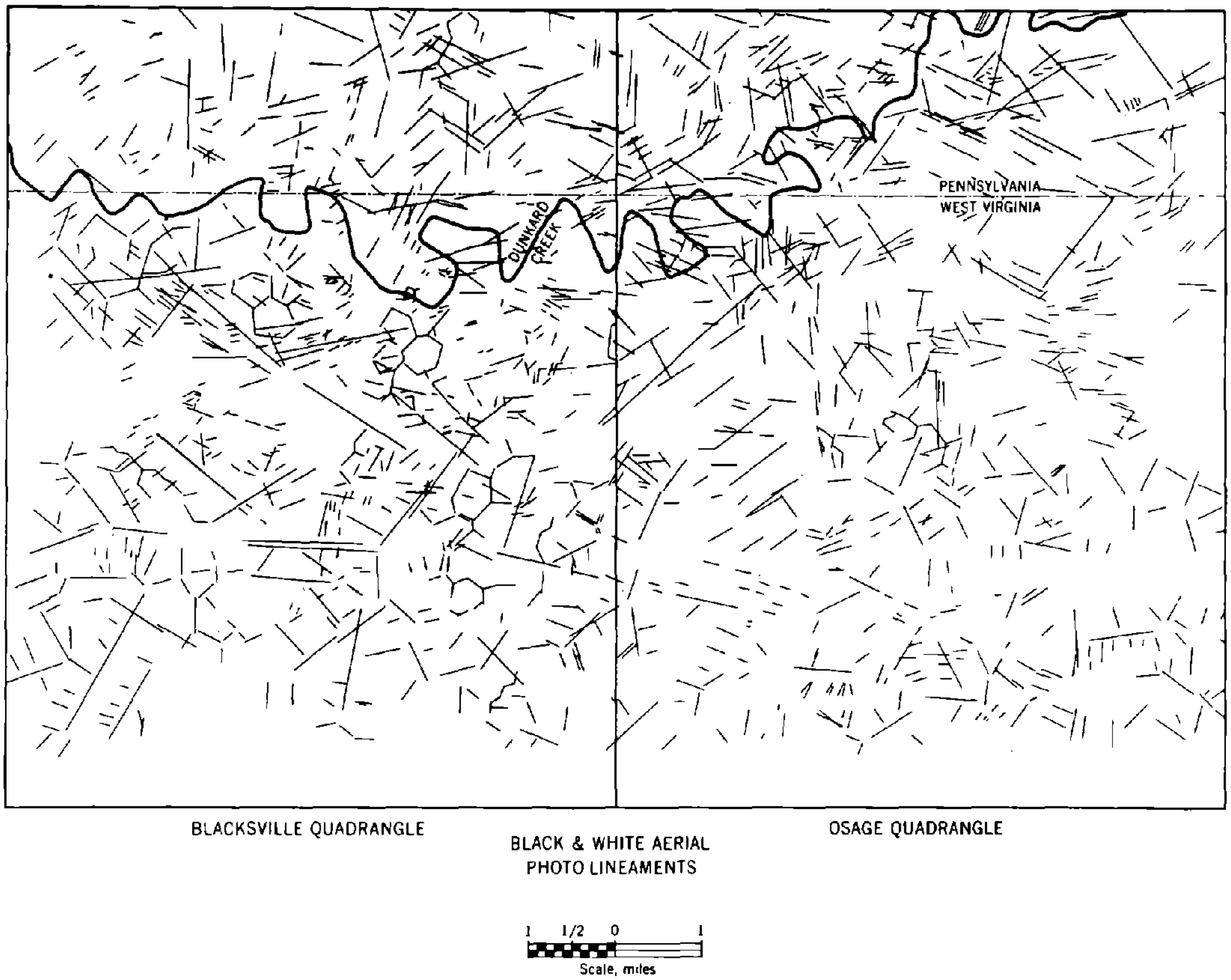



FIGURE 7. - Map of fracture traces and lineaments annotated from black and white infrared aerial photographs.

illustrates the transfer of annotated lineaments to the topographic base map. Figure 7 shows the annotated fracture traces on the 1:24,000 scale topographic map base for the Osage and Blacksville quadrangles.

After the fracture traces were annotated on the base map, a 1-inch square grid overlay was placed over the map, the number of fracture traces in each grid (2,000 feet by 2,000 feet) was annotated at the center, and equal density contour lines were drawn to make the fracture trace density map shown in figure 8. A contour interval of three fracture traces was used since the maximum number counted was 12 per unit area. A value of six or more fracture traces per unit area was selected as being a significant density which might affect subsurface rock mass behavior.

## PROPOSED PREDICTION TECHNIQUE

A general examination of the lithofacies map led to the postulation of the paleochannel system which is believed to have been operating during Pittsburgh-Redstone time (fig. 9). We believe the general outline of these

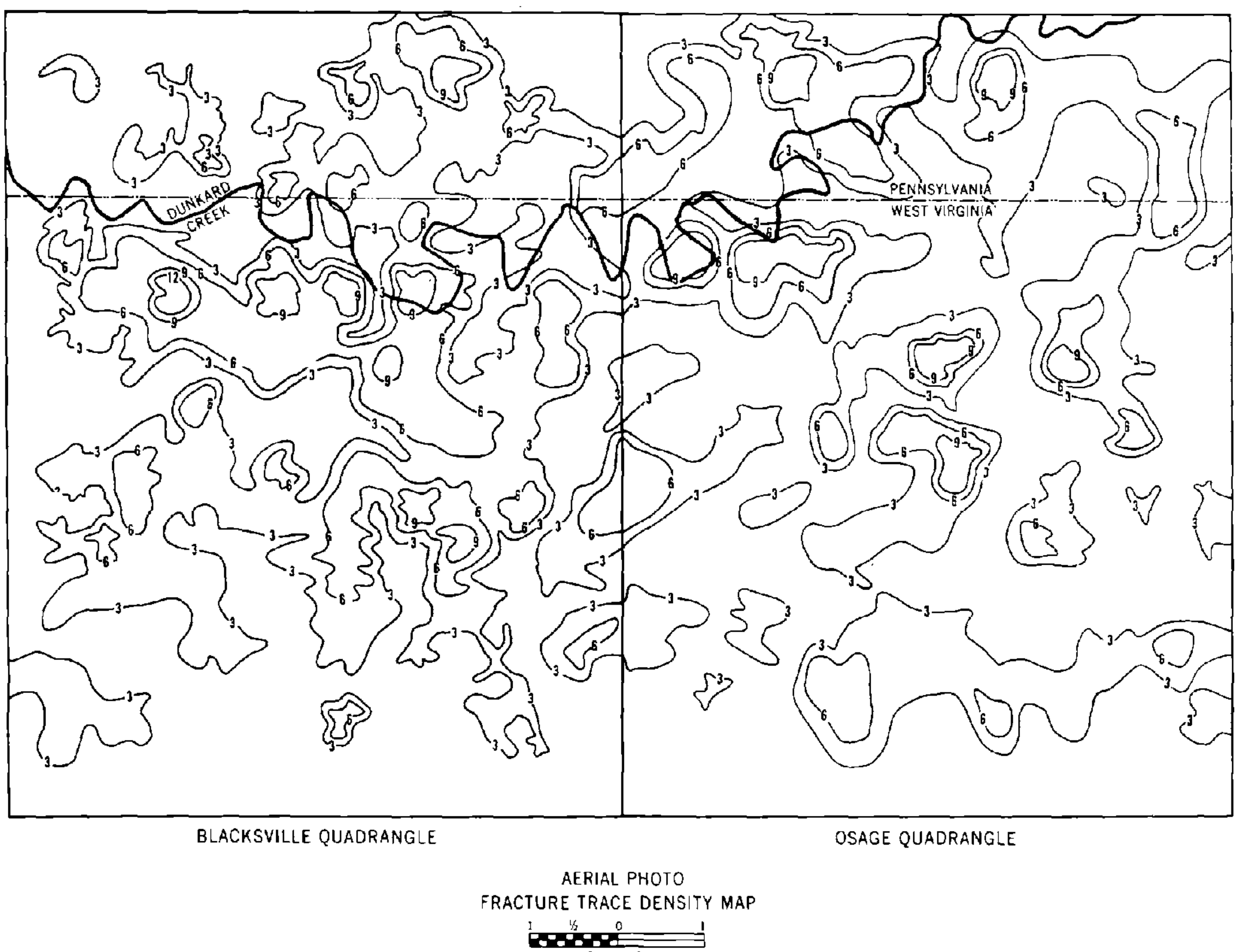



FIGURE 8. - Contours of equal values of fracture trace densities as mapped from aerial photographs.

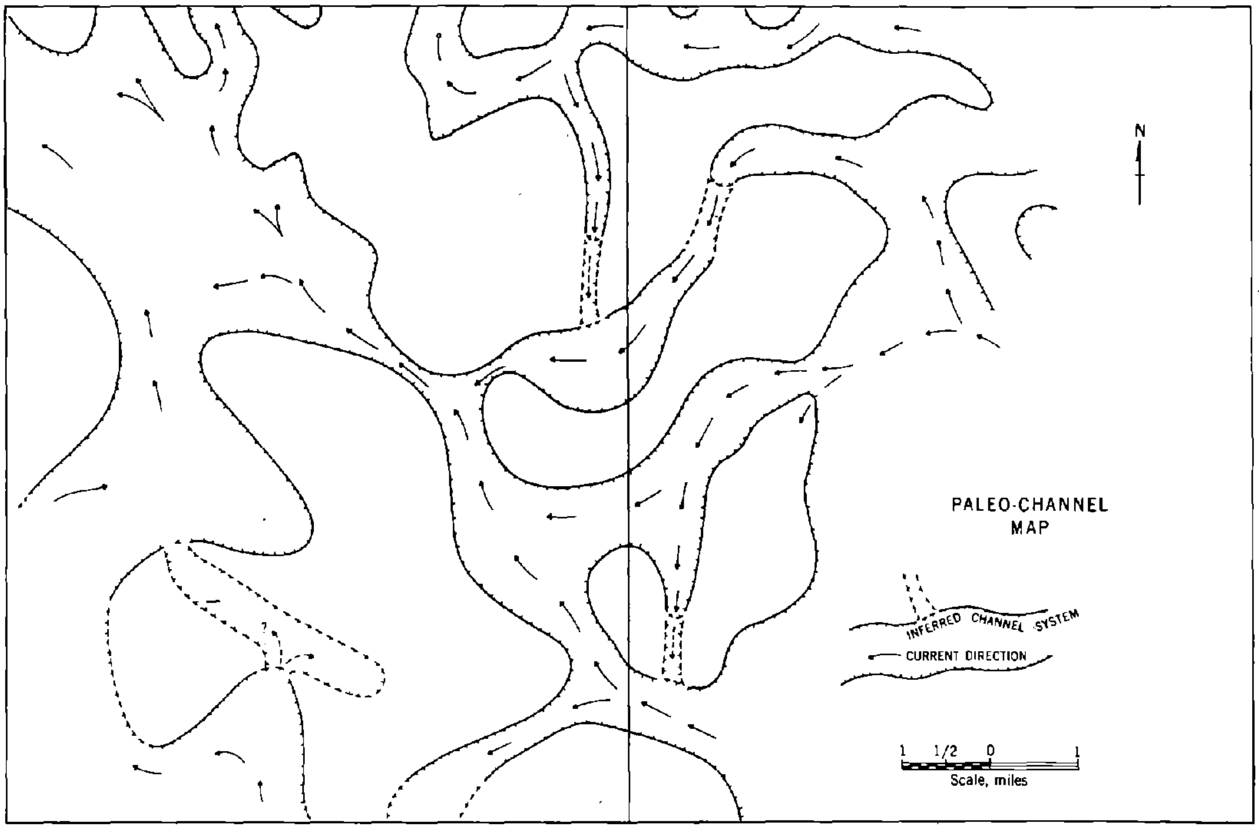



FIGURE 9. - Position of sediment distribution channels during Pittsburgh-Redstone time interpreted from lithofacies maps.

paleochannels represents the area within which small narrow sandstone channels might be found and thus areas of potential fracturing due to differential compaction. So this map provides a starting point for mapping all other geologic factors that might contribute to roof falls.

A clear acetate overlay was placed over the superposed structure, and fracture trace density, overburden thickness, lithofacies and paleochannel maps, and the limits of each geologic factor were outlined. First, all areas of six or more fracture traces were outlined. Then all areas of low tensile strength facies, such as mudstones, shales, and sandy shales (inferred paleochannel areas), were outlined. Next, all areas where 200 feet or more of overburden had been removed above the coal were outlined.

The final map (fig. 10) allows us to define areas in which either one, two, or three geologic factors that contribute to roof falls may be present. This gives us the ability to assess the degree of potential hazard which may exist at any particular area to be mined.

This system of mapping the degree of potential roof fall hazard can be applied in different areas where different sets of geologic factors may be contributing to roof falls other than the ones mapped in this study.

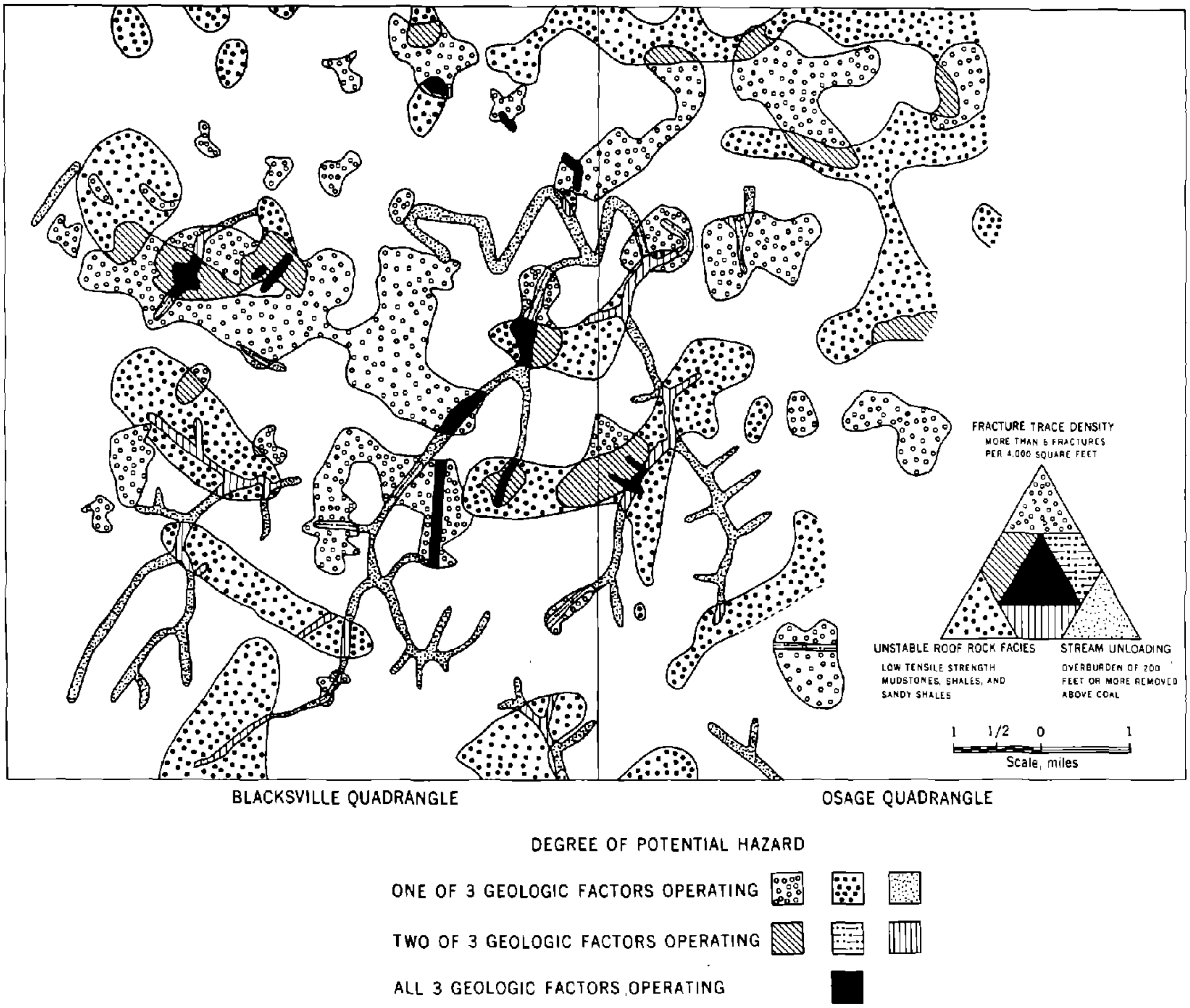



FIGURE 10. - Potential hazard map showing location and degree (seriousness) of hazard.

## DISCUSSION

In the search for a usable technique for planning mining operations in a geologically safe (no adverse or strong structural complications) area, some surface features and some subsurface observations have been studied at one time or another with perhaps some degree of success but never with complete confidence. Consequently, this study was conducted to determine the feasibility of using surface features in conjunction with roof rock facies, subsurface structure, and topographic unloading due to drainage to predict areas where mine roof falls might occur.

In pursuit of this goal, maps of surface joints, lineaments, and the fracture trace density were made and the results were compared with stream drainage, overburden thickness, and facies changes in areas where mining has already been completed and some roof fall data have been documented. From limited roof fall information available for Pursglove No. 15 mine near Osage, W. Va., some evaluation of the usefulness of the map can be made. Figure 11 shows five areas identified by Christopher Coal Co. engineers as being bad roof areas.

In area 1, two geologic factors are involved in the bad roof areas. These are unstable roof rock facies and stream unloading. In area 2, most of the bad roof area is not identified by any of the three geologic factors mapped, but bad roof rock facies is indicated in part of the area. Area 3 seems to be related to overburden removal, and most of the roof falls were located under a stream. In area 4, the single factors of roof rock facies and stream unloading are found as well as combinations of the two. In area 5, we have single, double, and triple combinations of geologic factors to indicate a very high degree of potential hazard.

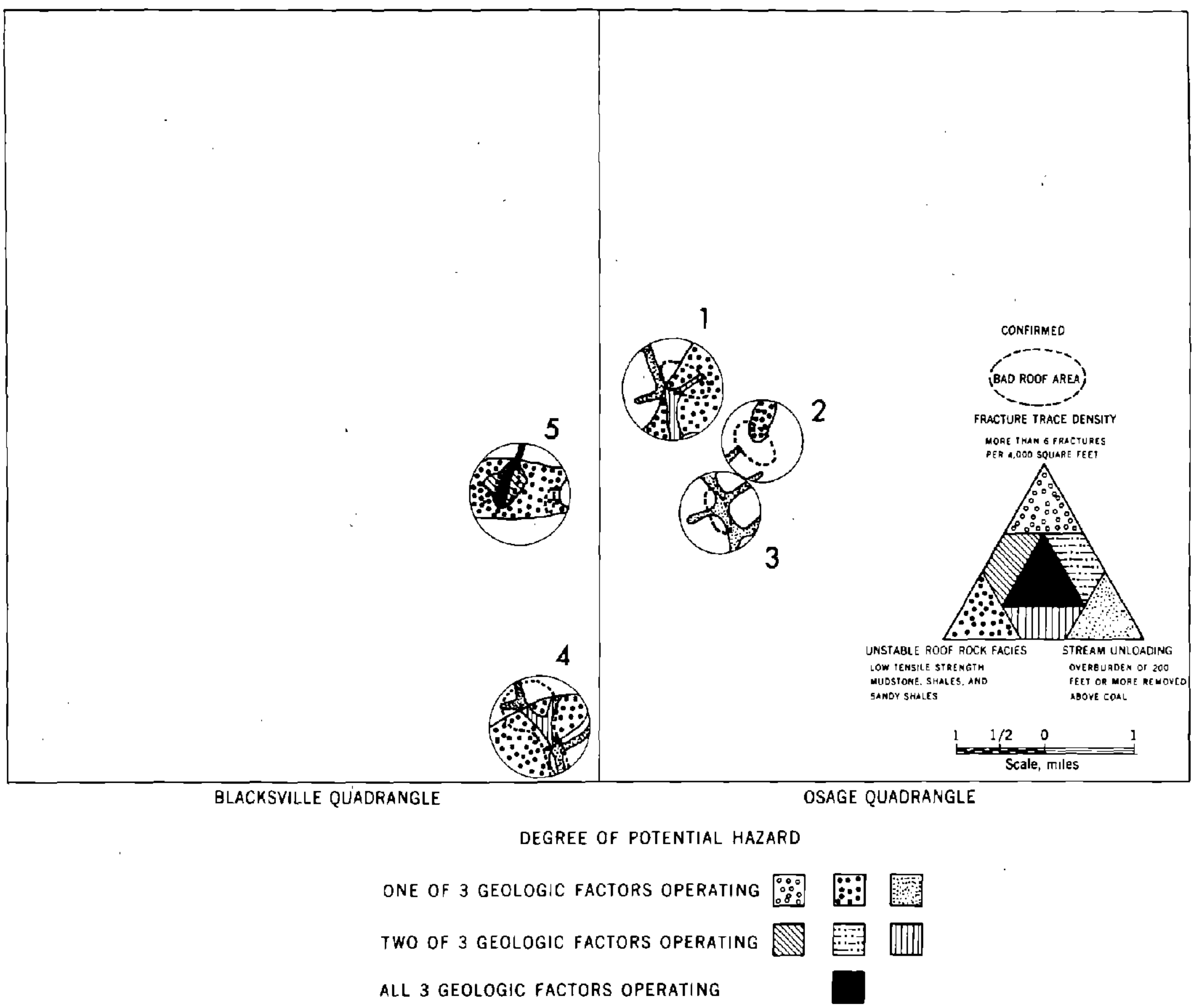



FIGURE 11. - Comparison of degree of hazard mapped with location of roof-fall areas.

In this study some degree of hazard was identified in some portion of an area of actual roof falls in all cases, although area 2 was not very well indicated. A second degree hazard was indicated in three cases (areas 1, 4, and 5), and the third or highest degree of hazard was indicated in area 5. We believe that a mining engineer with such a map available for consultation could perhaps be forewarned to the point where closer inspection of the area during actual mining operations would help him to decide if additional roof control measures were needed and perhaps with experience the type of additional support that would be required. Experience could also help to refine the map if very close scrutiny is made of roof falls to determine if other geologic factors can be identified.

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