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GEOLOGIC FACTORS RELATED TO COAL MINE ROOF FALLS IN WISE COUNTY, VIRGINIA

Robert C. Milici, Thomas M. Gathright II,
Barry W. Miller, and Marvin R. Gwin

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TABLE OF CONTENTS

Page No.

ABSTRACT 1

INTRODUCTION 3

ACKNOWLEDGEMENTS 13

STRATIGRAPHY 14

Lee Formation: 14

Norton Formation: 15

Gladeville Sandstone: 16

Wise Formation: 17

Harlan Formation: 18

STRUCTURAL GEOLOGY 19

Major structures: 19

GEOLOGIC FEATURES IN COAL MINE ROOF STRATA 22

Common stratigraphic sequences in coal bed roof rock: 22

Structure in coal beds and roof rock: 24

Generalized roof classification: 26

Roof Instability Index: 35

Fracture analysis: 40

LANDSAT AND AIR PHOTO LINEAMENTS 48

Subsidence: 55

DESCRIPTION OF COAL BEDS 57

Jawbone coal bed: 57

Raven coal bed: 59

Lower Banner coal bed: 63

Upper Banner coal bed: 68

Page No.

Splash Dam coal bed: 76

Edwards coal bed: 78

Norton coal bed: 78

Dorchester coal bed: 79

Clintwood coal bed: 84

Imboden coal bed: 86

Kelly coal bed: 90

Upper Standiford coal bed: 90

Taggart coal bed: 92

Phillips coal bed: 96

Parson coal bed: 96

High Splint coal bed: 96

RECOMMENDATIONS AND CONCLUSIONS 98

REFERENCES 99

ILLUSTRATIONS

Page No.

Figure 1. - Location of decollement in Pennsylvanian strata in the southern Tennessee coal field and in Wise County, Virginia..... 4

Figure 2. - Generalized geologic map of the Pine Mountain block, showing Wise County, Virginia..... 5

Figure 3. - Locations of Wise County coal mines visited during current study..... 12

Figure 4. - Major structural features of Wise County, Virginia 20

Figure 5. - Common stratigraphic sequences in coal field strata..... 23

Figure 6. - Generalized diagrams of roof types..... 29

Figure 6A. - Type A roof. Type A roof occurs where there is a bedding fault in shale or siltstone on the top of the coal. Gently to moderately dipping extensional or contractional faults extend into the roof, producing numerous polished and slickensided surfaces with films of powdery fault gauge. Major falls can form between slickensided fault planes..... 29

Figure 6B. - Type B roof. An example of a type B roof would be a rider seam in the main roof. Major falls could occur where the roof pulled from the rider..... 29

Page No.

Figure 6C. - Type B roof. An example of a type B roof would be thinly interbedded sandstone and shale in the immediate and main roof. Major roof falls could occur if thinly bedded rock of contrasting lithologies separated along bedding surfaces. 29

Figure 6D. - Type C roof. Irregular base of channel sandstone is at or near top of coal. Small falls commonly occur where shale breaks away from between sandstone channel lobes or load casts. 30

Figure 6E. - Type Cb roof. Sandstone channel cuts down with steep or moderate declivity to top of coal. Major falls may form along the sharply contrasting shale-sandstone boundary, especially if there are zones of weakness within the shale, such as a rider seam in the main roof..... 30

Figure 6F. - Type AC roof. A bedding fault at the top of the coal, with its associated extensional and contractional faults, polished surfaces and slickensides may result in major falls bounded laterally by the fractures and at the top by the sandstone channel bottom..... 30

Figure 6G. - Type Sh roof. Unfractured shale..... 31

Figure 6H. - Type SS roof. Unfractured or massive sandstone. 31

Figure 7. - Stratigraphic variation of Roof Instability Index in Wise County, Virginia..... 39

Page No.

Figure 8A. - Cleat and joint trend map of Wise County, Virginia 41

Figure 8B. - Fracture trends in southwest Virginia coal mines 42

Figure 8C. - Orientation of all fractures measured in the Holton Complex, Paramount No. 7, Paramount No. 6, and Betty B No. 9 coal mines. Horseback orientations are shown around the perimeter; fold (+) and fault (□) orientations are plotted on stereo-net 43

Figure 8D. - Orientations of all fractures measured in the Wentz No. 1, Paramount No. 1, Minutemen-Hustler coal mines and Upper Banner coal mines (combined) east of Coeburn Fault. Horseback orientations are shown around the perimeter; fold (+) and fault (□) orientations are plotted on stereo-net..... 44

Figure 8E. - LANDSAT lineament map showing only prominent lineaments visible in three or more LANDSAT scenes. Mine identification number followed by triangle indicates that LANDSAT lineament intersects mine workings; square indicates that LANDSAT lineament(s) are less than 500 feet from mine workings. The remaining mines don't have prominent lineaments within 500'. Rose diagram, upper left, shows trend distribution of the prominent LANDSAT

Page No.

lineaments in Wise County with the dominant average fault, fold, and fracture trends measured in the mines..... 49

Figure 8F. - Air-photo linear map of Wise County showing linear, topographic low features observed stereoscopically (light line) and those LANDSAT lineaments or lineament segments that correlate with air-photo linears. Correlation between measured fracture trends in the mines and air-photo linears within 2 kilometer radius of the mines was random..... 50

Figure 9. - Generalized distribution of roof types in the Little David and Edison Coal Company #2 mines, Jawbone seam..... 58

Figure 10. - Geologic features and roof types in the Fountain Bay Mining, Inc. No. 001 and No. 002 mines, Raven seam..... 60

Figure 11. - Generalized distribution of roof types in the Minutemen-Hustler (Raven seam), JMG No. 4 and Crockett No. 3 (Lower Banner seam) mines..... 64

Figure 12. - Geologic features of Black and White Mine, Lower Banner coal bed..... 66

Figure 13. - Generalized distribution of roof types in the BBB and Bear Branch Coal Co. mines..... 69

Page No.

Figure 14. - Generalized distribution of roof types in the Betty B No. 3 and Bullion Hollow No. 19 coal mines 71

Figure 15. - Generalized distribution of roof types in the Betty B No. 4 mine 73

Figure 16. - Generalized distribution of roof types in the RBJ Coal Co., Paramount No. 1 and Betty B No. 9 coal mines 75

Figure 17. - Generalized distribution of roof type in the Betty B No. 8, Betty B No. 2, Jackson Coal Co., and Paramount No. 7 coal mines 77

Figure 18A. - Geologic features and roof types of the Bullitt coal mine, Dorchester seam 80

Figure 18B. - Decollement above coal seam in Bullitt Mine, Dorchester coal seam and Prescott No. 2 Mine, Imboden seam 82

Figure 19. - Generalized distribution of roof types in the Paramount No. 6, Paramount No. 8, Sylvia Ann and Kelly Energy Co. coal mines 85

Figure 20. - Geologic features of the Crossbrook "A", Arno, and Prescott No. 2 coal mines, Imboden seam .. 87

Figure 20A. - Bedding decollement above the Imboden coal bed, Prescott No. 2 Mine 88

Page No.

Figure 21. - Generalized distribution of roof types in the Elkins 10A, Elkins 6A, Elro Coal Corp. No. 3 and Shelton Coal Corp. No. 4 coal mines..... 91

Figure 22. - Generalized distribution of roof types in the Holton Marker and Holton Taggart coal mines, Taggart seam 93

Figure 23. - Generalized distribution of roof types in the Wentz and Wentz 1B coal mines, Taggart seam.. 95

TABLES

Page No.

Table 1.- Stratigraphic nomenclature and coal mines studied in Wise County, Virginia 10

Table 2.- Classification of immediate roof type in coal mines in southwestern Virginia..... 27

Table 3.- Roof types and coal bed deformation in coal mines studied in Wise County, Virginia 28

Table 4.- Roof instability indices for some coal beds in Wise County, Virginia..... 36

Table 5.- Spatial relationship between LANDSAT lineaments and mines having A or AC roof types..... 53

ABSTRACT

Geological features related to coal mine roof falls in Southwestern Virginia include, bedding plane faults and associated slickensided extensional and contractional faults in and above coal beds, structural development of coal rolls, interlayering of contrasting rock types, development of sandstone channels, shear planes related to differential compaction, closely spaced near vertical joints and combinations of above.

In the mines visited (38 in and adjacent to Wise County) the roof was classified geologically at stations along selected traverses, and generalized maps were prepared showing stable, unstable and intermediate type roof. A roof instability index was prepared for mines in which 15 or more stations were established. The RII, a ratio between unfavorable and favorable roof types, indicates that in some places the Dorchester, Imboden, Banner, and Raven coal beds contain incipient bedding decollements. Roof fall and horseback trends commonly follow longitudinal and transverse fracture trends which were mapped underground.

A detailed study of LANDSAT and short air photo lineaments shows that there is a general correlation between areas of lineament concentration and roof falls; but in the areas studied lineaments cannot be used to predict specific locations and trends of roof falls. There is no apparent

correlation between fracture trends measured in mines and trends of LANDSAT and air photo lineaments.

Unstable roof is most commonly associated with extensively faulted and slickensided shale and with boundaries between sandstone channels and adjacent shale. In mines with an abundance of fractures and sandstone channels detailed geologic mapping is a useful tool in predicting trends of unstable roof, so that mine entries can be oriented across those trends.

INTRODUCTION

Virginia has a statistically high number of roof fall fatalities when compared with other coal mining states in the southern and central Appalachians. Unlike the coal fields in neighboring states, however, almost all of the southwest Virginia coal field lies in the Appalachian thrust belt; specifically on and adjacent to the Pine Mountain block. Because of this relationship it was anticipated that some of the coal beds in southwestern Virginia would contain bedding parallel faults similar to those described in the southern Tennessee coal field along and adjacent to both the Sequatchie anticline and to the eastern Cumberland Escarpment (Nelson, 1925, Glen, 1925; Stearns, 1954, 1955; Wilson and Stearns, 1958; Milici, 1963, 1970; Milici and Leamon, 1975; Harris and Milici, 1977) (Fig. 1).

Figure 1. Location of decollements in Pennsylvanian strata in the southern Tennessee coal field and in Wise County, Virginia.

Wise County is a major coal-producing county in southwestern Virginia (Fig. 2). Almost all of the county lies

Figure 2. Generalized geologic map of the Pine Mountain Block, showing location of Wise County, Virginia

between the Pine Mountain fault, where it crops out along the northwest edge of the Pine Mountain block in adjacent Letcher and Harlan counties, Kentucky, and the Powell Valley anticline along the southeast flank of the coal field. The principal structure of the coal field in this area is the broad syncline, part of the Middlesboro syncline, which lies between

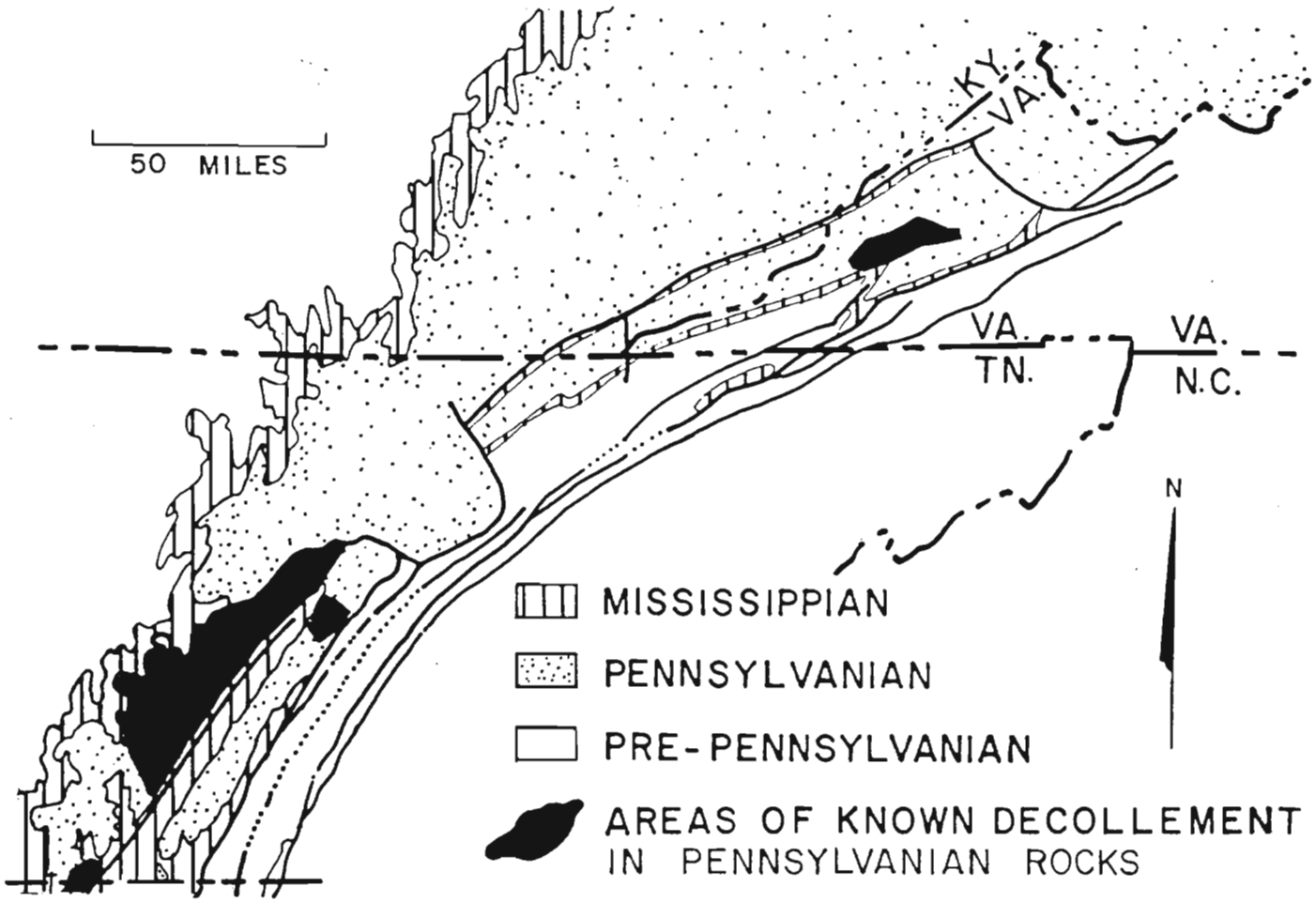


Figure 1. Location of decollement in Pennsylvanian strata in the southern Tennessee coal field and in Wise County, Virginia.

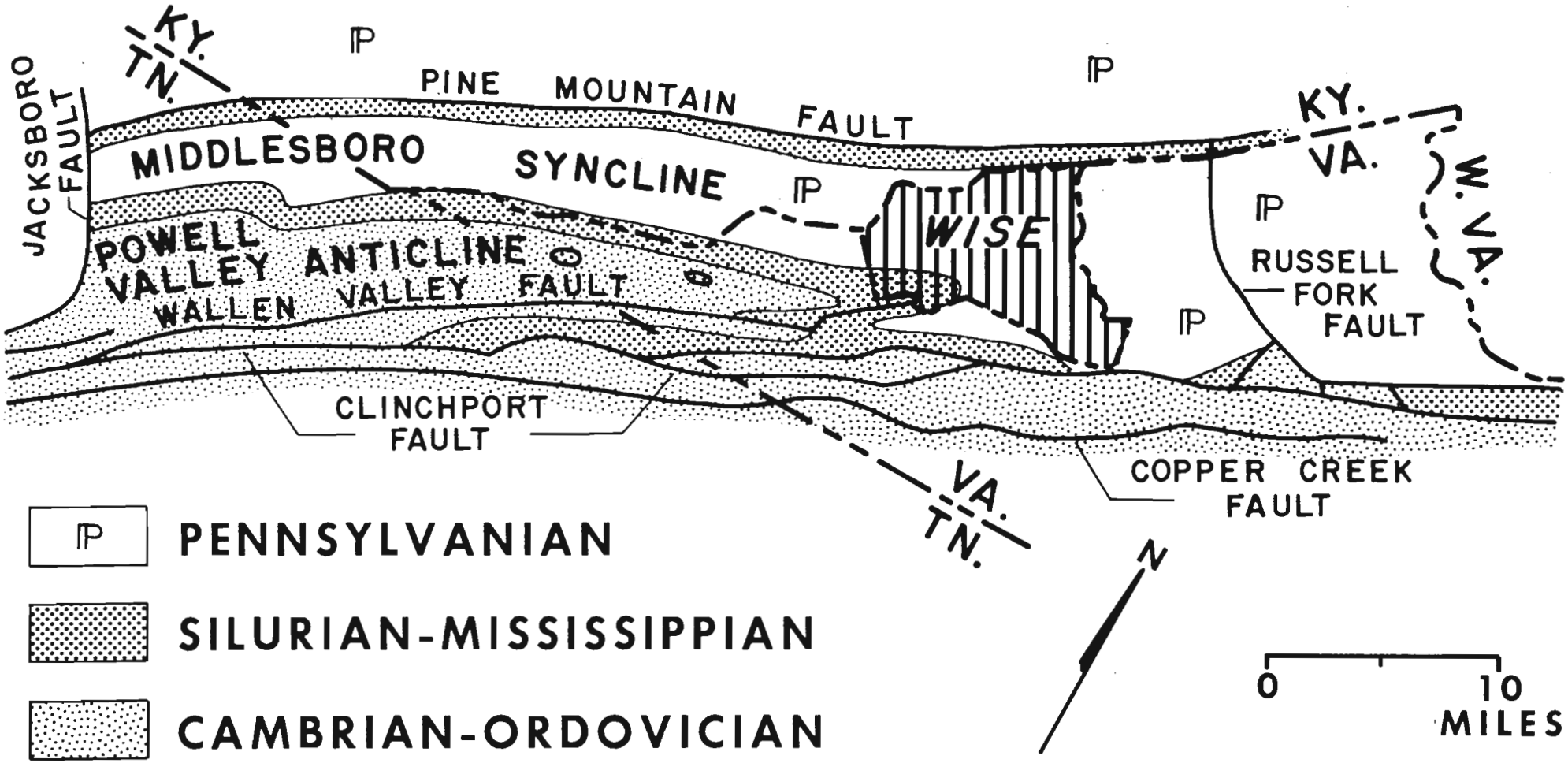


Figure 2. Generalized geologic map of the Pine Mountain Block, showing location of Wise County, Virginia.

the Powell Valley anticline on the southeast and the upturned toe of Pine Mountain block to the northwest. Youngest beds preserved (Harlan Sandstone) lie in the synclinal trough along Black Mountain along the Virginia-Kentucky border, about halfway between the Pine Mountain fault and the Powell Valley anticline. In detail, structure of the coal field is complex, with prominent north-oriented cross structures interrupting the generally northeast trend of regional structure contours (Eby, 1923).

The last comprehensive report on the geology and mineral resources of Wise County was by Eby (1923). R. L. Miller (1969) and M. S. Miller (1974) described the stratigraphy of Carboniferous formations in southwestern Virginia. Gathright (1981) described the results of a detailed analysis of Landsat and air photo lineaments prepared for adjacent Lee County, Virginia. Englund, 1974, 1979, and Englund,et.al.,1979 described the stratigraphy and depositional environments of some Pennsylvanian rocks in Virginia and adjacent West Virginia.

The geology of underground room-and-pillar coal mines in the Appalachians has been described by several workers. Hylbert (1976, 1978, 1980) described the geology of roof hazards in selected coal mines in eastern Kentucky. He found that there was a 50-65 percent coincidence of lineament intersections with roof falls. He also correlated roof falls with sandstone-shale boundaries, rider coal beds,

jointing, shallow overburden, "slips," soft sediment deformation, and sequences of thin bedded sandstone. Some of the mines he studied are on the Kentucky portion of the Pine Mountain block.

Bad roof conditions related to faulted coal have been described in coal mines near Rockwood, Roane County, Tennessee by Glenn (1925, p. 399). In this area coal normally 4 feet thick is squeezed into rolls 30 to 40 feet thick and even up to 120 feet thick. Nelson (1925, p. 153) described tectonically overthickened coals near Orme, Marion County, Tennessee, where the seam ranges from a thin lead to 23 feet thick. More recently, Harris and Milici (1977) described in detail the geologic structures associated with decollement in coal beds within the Gizzard and Whitwell formations near Dunlap, Sequatchie County, Tennessee. Roof strata in mines in the coal in the Whitwell Formation near Dunlap have been reported to be tectonically broken and difficult to support. Ferm and others (1978) studied roof falls in underground mines on the Pocahontas No. 3 seam in southern West Virginia and southwestern Virginia. They identified "...slickensides arising from different geologic causes..." as a major contributor to roof falls. They found slickensided rocks that are associated with slumped deposits, fire clay, sandstone-shale or fire clay contacts, and the sides of kettlebottoms.

In addition, they described "...cross bedded sandstones with abundant shale, coal, and ironstone pebbles as a secondary cause of roof problems." Iannacchione and others (1981) studied geologic factors related to roof-rock stability in the Upper Kittanning coal bed in Somerset County, Pennsylvania. They related unstable roof conditions mainly to slickensided zones formed by bedding plane and inclined thrust faults, and to the transition zone between sandstone and shale in the coal mine roof. They found a correlation between the strike of local geologic structure and orientations of lineaments, joints and coal cleat, although they did not note a correlation of lineaments with roof falls. Moebs and Ellenberger (1982) reported on geologic structures in coal mine roof. They described the effects of paleochannels, scours, pinchouts, slickensides, clay veins, crevasse plays, and joints on coal mine roof stability.

The purpose of this current study was to identify and describe the major geologic factors which contribute to roof falls in southwestern Virginia coal mines. In most of the mines visited roof bolts, either conventional or epoxy, are the primary method of roof support, with or without steel or wood straps. In some places posts and caps were routinely used. In other places the roof was supported by timbers. Cribs were used generally in areas of bad top, especially where rock debris from old falls was cleared away and additional roof support was required.

Roof falls occur more commonly in conventionally bolted areas where geologic structures reduce the overall strength of roof rock below that usually encountered

in mining. The nature of these geologic discontinuities was determined by visiting and describing both stable areas and areas of roof falls in underground mines, describing linear features observed on LANDSAT imagery and air photos (Gathright, 1981), describing geologic structures observed in strip mines and by attempting to relate those features observed on imagery and photos with those observed in surface and underground mines. Initial studies permitted the development of a roof type and roof fall classification, a classification which was revised continuously as the study progressed. Mines visited during the course of this study are listed in Table 1 and their locations are shown in Figure 3.

Structural and stratigraphic data was collected every 800 to 1000 feet along underground mine traverses or at more frequent intervals if geologic conditions changed. These data include measurements of face and butt cleats, joints, cleavage, faults and axial surfaces of folds. These data have been compiled on stereo-graphic equal area nets, as poles to fracture or fold surfaces, for each mine or for each coal seam, depending on the amount of data available. The trends of linear mine roof falls and "horsebacks" (elongate wedge-shaped rock fall) were also measured and plotted as trend directions on the circumference of the stereo-nets. In addition, the same structural data was collected from strip mine exposures above underground mines that were investigated.

Table 1. Stratigraphic nomenclature and coal mines studied in Wise County, Virginia.

Figure 3. Locations of Wise County coal mines visited during current study.

Table 1.- Stratigraphic nomenclature and coal mines studied in Wise County, Virginia

SYSTEM	SERIES	FORMATION	COAL BED AND SYMBOL	MINES VISITED	MAP NO.
		Harlan Formation			
	MIDDLE	Wise Formation	High Splint - hs	Shelton No. 4	10
			Morris - m		
			Pardee (Parsons)-pa	Elro No. 3	17
			Upper Phillips - up	Elkins 6A	16
			Low Splint - ls		
			Taggart - t	Holton Holton Marker Wentz No. 1 Wentz No. 1B	1 2 7 8
			Taggart Marker -tm		
			U. Standiford- us (U.Wilson)	Elkins 10A	15
			L.Standiford - ls (L.Wilson)		
			Kelly - ky	Sylvia Ann No. 2 Kelly Energy	14 18
			Imboden - i	Arno Prescott No. 2 Crossbrook - A	4 5 6
			Rocky Fork - rf		
			Addington - a		
			Clintwood - c	Paramount No. 8	13
			Blair - b		
			Lyons - 1		
			Dorchester - d	Bullitt Paramount No. 6	3 12

Table 1. (cont.)

PENNSYLVANIAN		Gladeville Sandstone			
	LOWER	Norton Formation	Norton - n	Paramount No. 7	11
			Edwards (Hagy?)-e	Jackson	26
			Splash Dam - sd	Betty B. No. 8	33
				Betty B. No. 2	36
			Upper Banner - ub	Paramount No. 1	19
				RBJ	22
				Bear Branch	23
				Triple B	24
				Bullion Hollow No. 19	27
				Betty B. No. 9	32
				Betty B. No. 4	34
				Betty B. No. 3	35
			Lower Banner - lb	JMG No. 4	25
				Black and White No. 1	28
				Crockett No. 3	9
			Kennedy - kd		
			Raven - r	Fountain Bay No. 1	20
				Fountain Bay No. 2	21
				Minutemen-Hustler	31
			Jawbone - j	Little David	29
				Edison No. 2	30
			Tiller - t		
		Lee Formation			

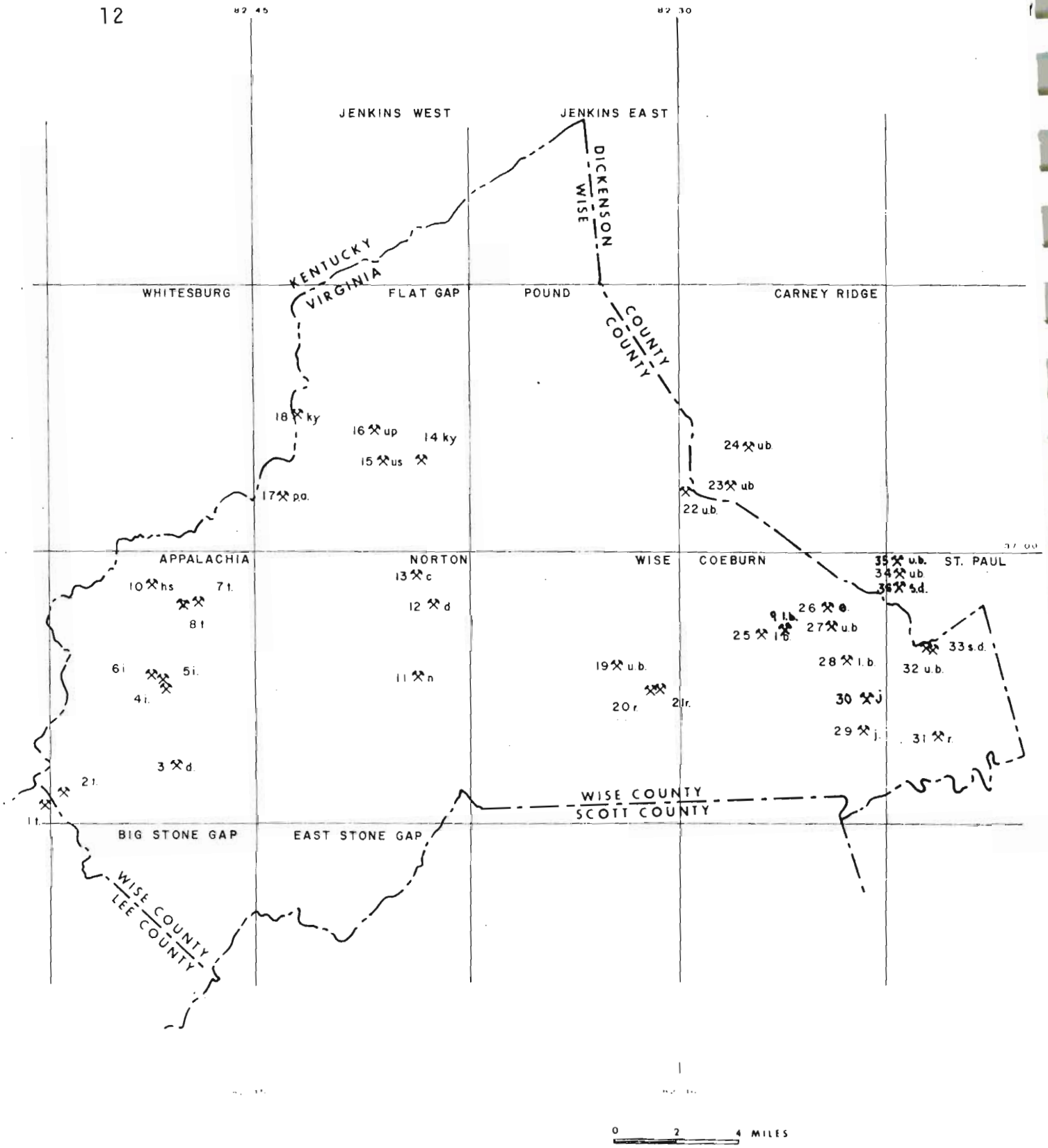


FIGURE 3. - LOCATIONS OF WISE COUNTY COAL MINES VISITED DURING CURRENT STUDY.

ACKNOWLEDGEMENTS

The writers were introduced to underground mine mapping methods by Gregory C. Smith and John C. Ferm, University of Kentucky, Lexington.

Paramount Mining Corporation provided Division of Mineral Resources personnel with Annual and Hazard Training; Penn Virginia Corporation, Virginia Iron Coal and Coke Company, and Paramount Mining Corporation assisted Division personnel underground. The Division is indebted to Westmoreland Coal Company for assistance in many of their mines which were visited in the course of this study. Particular thanks are due to William D. Shupe, Penn Virginia Corporation, who spent many hours with Division personnel underground in Westmoreland Coal Company coal mines.

The writers were assisted underground by Charles B. Stanley and James F. Woodruff, Virginia Polytechnic Institute and State University, and Timothy L. Shy, Michigan State University.

Finally, the Division acknowledges the cooperation and encouragement received from the Virginia Division of Mines and Quarries, McLynn Sharpe, Chief Mine Inspector.

STRATIGRAPHY

The Pennsylvanian system in Wise County, Virginia, is divided into the Lee, Norton, Gladeville, Wise, and Harlan formations (Campbell, 1893) (Table 1). For recent summaries of this stratigraphy see R. L. Miller (1969), M. S. Miller (1974) and Englund (1979 a, b). The principal coal-bearing formations in Wise County are the Norton and Wise formations, and during the course of this study we visited mines in 16 seams in these two formations.

Lee Formation: The Lee Formation (Campbell, 1893) was named for Lee County, Virginia but has its type section designated in Big Stone Gap in Wise County. In southwestern Virginia, the formation consists of quartzose sandstones and conglomeratic sandstones which intertongue and grade laterally into shales and siltstones, some marine and some coal-bearing. Englund (1964) divided the Lee into seven members, the Pinnacle Overlook, Chadwell, White Rocks Sandstone, Dark Ridge, Middlesboro, Hensley, and Bee Rock Sandstone members. The first three are of Mississippian age and intertongue with the Bluestone or Pennington formations. The remaining formations are considered Pennsylvanian in age (Englund, 1979 a, b).

R. L. Miller (1969) presents a description of the Lee type section in Big Stone Gap. There the formation consists of nearly 1600 feet (1596 feet measured) of quartzitic sandstone, with some quartz pebble and shale pebble-to-cobble conglomerate interlayered with shale, siltstone and coal.

In its type section the upper quartzose sandstone, the Bee Rock Sandstone Member, is 95± feet thick (Miller's unit 40, 1969, p. 35). Units 37, 38, and 39 are herein equated to Englund's Hensley Member (mostly covered) and the remainder of the formation to the Middlesboro Member. The Hensley Member is about 400 feet thick and the Middlesboro member about 1100 feet thick in the type section. M. S. Miller (1974) and Englund (1979 a, b) described the facies relationships at the top of the Lee in southwestern Virginia, where both the Bee Rock Member and the underlying Hensley grade laterally into the Norton Formation, generally to the northeast.

Norton Formation: The Norton Formation (Campbell, 1893) consists of shale, siltstone, sandstone and coal beds between uppermost quartzites of the Lee Formation below, and the Gladeville Sandstone above. Identification of the Gladeville Sandstone is the key to a proper division of the coal-bearing Norton and Wise formations, and R. L. Miller (1969, p. 11-18) described the Gladeville problem in considerable detail. Norton sandstone units are more impure than those of the Lee and contain a greater abundance of argillaceous, micaceous, or feldspathic material.

R. L. Miller (1969) described the Norton as ranging from 790 feet to about 1175 feet in Wise County, but considered it to be generally between 840 and 970 feet. The thickness of the Norton, however, is directly related to the presence or absence of the underlying Bee Rock Sandstone, so that the

Norton includes more strata in southeastern Wise County than it does in the northern part of the county. Where the base of the Norton is limited by the top of the Middlesboro Sandstone Member, rather than the Bee Rock Sandstone Member of the Lee, it includes the Tiller, Jawbone, Raven, Aily and Kennedy coal beds (M. S. Miller, 1974, Fig. 47, p. 72, p. 101).

Gladeville Sandstone: The Gladeville Sandstone (Campbell, 1893) consists of 32 to 55 feet of massive to cross-bedded, white, medium to coarse grained sandstone. Some beds contain scattered muscovite flakes, carbonized plant remains and a few flattened pellets or angular pebbles of medium gray shale. In some places the formation is partly feldspathic (R. L. Miller, 1969).

The Gladeville Sandstone is a key marker bed between the Norton and Wise formations in much of Wise County. It lies generally in the stratigraphic interval between the Norton and Dorchester coal beds, although R. L. Miller (1969, p. 17) has restricted the unit to the uppermost sandstone in this zone. R. L. Miller (1969) designated a section along U. S. Highway 23 at the south edge of Wise as the type section and Miller and Roen traced the Gladeville from its type area south through Blackwood, Appalachia and Big Stone Gap to the north edge of the Big Stone Gap quadrangle. The Gladeville interval

is covered near Appalachia so that detailed stratigraphic correlations in western Wise County are less than certain (R. L. Miller, 1969, p. 11-18).

Wise Formation: The Wise Formation (Campbell, 1893) lies between the Gladeville and Harlan Sandstones, with its top at the top of the High Splint (No. 12) coal. The formation consists of thick sequences of sandstones, siltstones, shales, and coal beds. Resistant sandstone units generally less than 45 feet thick consist of crossbedded to massive fine to medium grained feldspathic sandstone with locally abundant mica flakes (R. L. Miller, 1969). R. L. Miller (1969) named four of the five prominent sandstone members in the Wise, the Robbins Chapel, Keokee, Clover Fork, and Marcum Hollow Sandstone members. The uppermost sandstone member was named the Reynolds by Ashley and Glenn (1906, p. 43). Detailed correlations in between sections of the Wise are difficult even over short distances and in the type section of the Wise Formation along Virginia Highway 160 between Appalachia and the top of Black Mountain, R. L. Miller (1969) did not recognize the Robbins Chapel and Keokee.

In the type section of the Wise Formation, the Clover Fork consists of 40 feet of massive, brownish gray, cliff-forming sandstone. The Marcum Hollow Sandstone is comprised of 75 feet of massive, medium to coarse grained micaceous cliff-forming sandstone with shaly partings. Marine markers within the Wise are the Kendrick Shale of Jillison (1919) and the Magoffin Beds of Morse (1931). R. L. Miller (1969)

described the Kendrick Shale as consisting of 5 to 10 feet of dark gray to nearly black, locally silty shale. The unit is calcareous and fossiliferous, containing small brachiopods, and in places in Lee County contains oval limestone concretions with cone-in-cone structure. In the type section of the Wise Formation, the shale is 317 feet thick and is described as blue-gray with marine fossils near the middle of the formation. The Magoffin Beds of Morse (1931) are a distinctive and reliable key marker in the upper half of the Wise Formation. The unit is generally thin and consists of 1 to 2 feet of nearly black dense, hard limestone with white brachiopod fossils.

The Wise Formation at its type section, in western Wise County, is 2,268 feet thick.

Harlan Formation: The Harlan Formation (Campbell, 1893) is composed of some 600 feet of strata above the High Splint coal bed on Big Black Mountain. The formation contains a basal sandstone of variable thickness which is from a few inches to about 20 feet above its base. R. L. Miller (1969) reports the sandstone as ranging from 17 to 30 feet thick in two localities, and as fine-to-coarse grained and pebbly. The remainder of the formation is a heterogeneous mixture of sandstone, siltstone, shale and coal. The name of the formation is from Harlan County, Kentucky, but it has a type locality in Isom Rock Spur, a prominent spur of Big Black Mountain in Wise County, Virginia.

STRUCTURAL GEOLOGY

Major Structures: Wise County lies entirely upon the Pine Mountain block and contains the major cross strike elements of that structure, the Powell Valley anticline and Middlesboro syncline (Campbell, 1893, p. 20). The structure has been described many times in the geological literature, and recent summaries are provided by Froelich (1973) and Harris and Milici (1977). More detailed structural descriptions and regional structural contours of Wise County are provided in Eby (1923).

The Powell Valley anticline represents the westernmost tectonic ramp in southwestern Virginia. The Pine Mountain fault rises from lower decollement in Cambrian shales, flattens across the crest of the anticline, and then appears to descend westward into Devonian shales beneath the Middlesboro syncline to where it is exposed in Kentucky along the flanks of Pine Mountain.

Figure 4. Major structural features of Wise County, Virginia.

The core of the Powell Valley anticline is warped because of subsurface duplication along a buried thrust, the Bales thrust of Harris (1967). At the head of Powell Valley the anticlinal axis divides, with one axis trending toward Ramsey and the other trending due east into the area a little west of St. Paul.

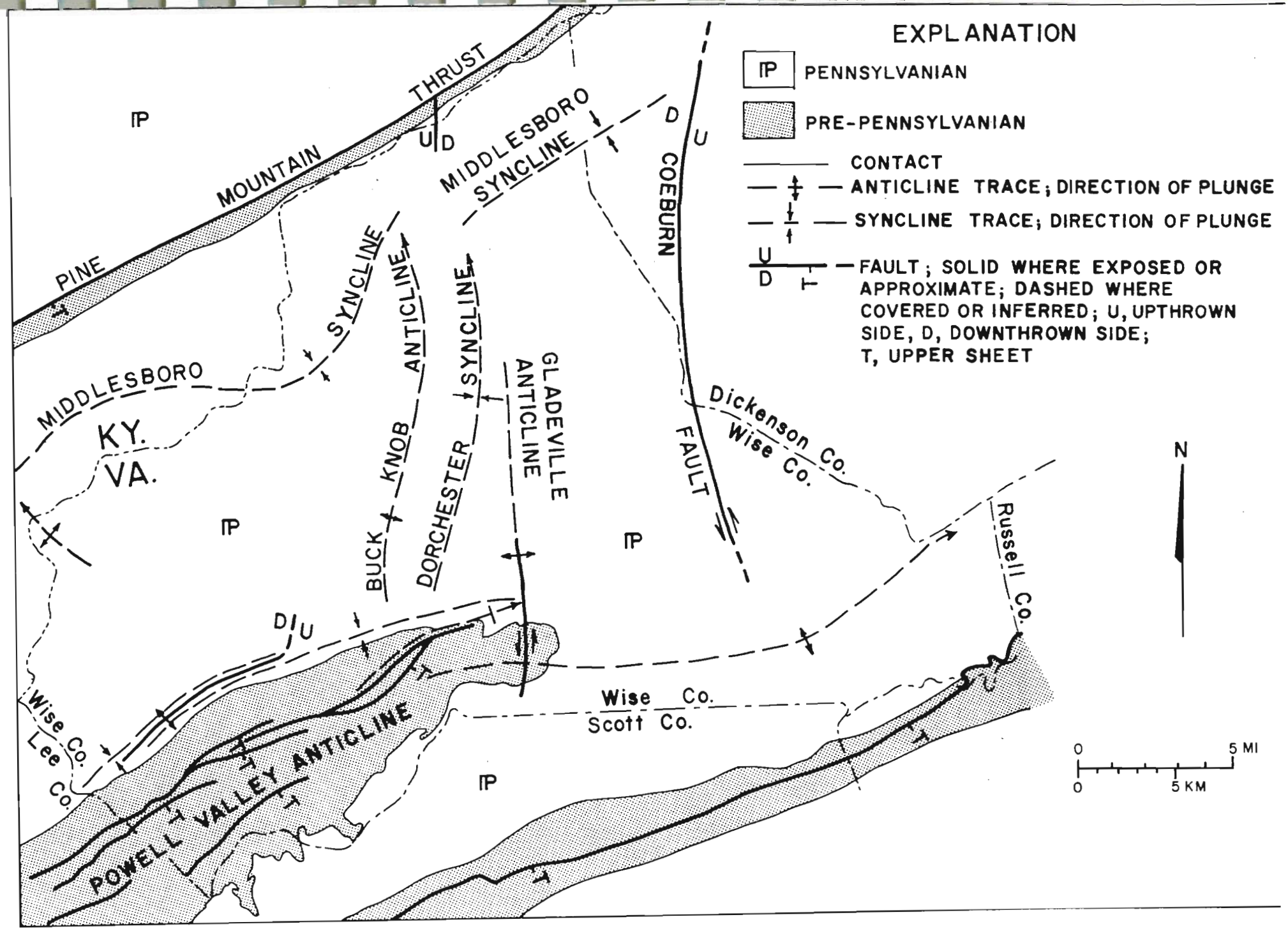


Figure 4. Major structural features of Wise County, Virginia.

The Middlesboro syncline is not a simple structural downwarp. Rather, it contains numerous diversely trending anticlines and synclines over much of its length. In Wise County, the generally northeasterly trending axis of the Middlesboro syncline is deflected sharply to the north by cross structures which appear to be limited to the coal field north of the Powell Valley anticline. These are the Buck Knob anticline, Dorchester syncline and Gladeville anticline. These structures are described in Eby (1923), and the reader is referred there for more details.

In general, these northerly oriented cross structures are reflected by orientations of minor structures observed in some mines, such as Prescott No. 2, near the middle of the Middlesboro syncline.

GEOLOGIC FEATURES IN COAL MINE ROOF STRATA

Common stratigraphic sequences in coal bed roof rock: Common roof stratigraphy observed during the current study included: 1) coarsening upward sequences, 2) sandstone channels, 3) thin bedded sandstones (in beds up to 2 feet thick), 4) thick shale-siltstone sequences, and 5) other variations of the more common sedimentary sequences, including rider seams.

Coarsening upward sequences are recognized in coal mine roof rock either by utilizing available drill hole data or by examination of fall areas which have stoped upward from a few feet to a few tens of feet into the top. These sequences, as their name suggests, consist of dark shale at the base which gradually grades upward into coarser beds with an increase of dark gray to medium gray siltstone and laminae of very fine grained light gray sandstone. With an increase in sandstone content and grain size, the strata grade upward through rippled laminations and thin beds of sandstone and shale in equal amounts to beds composed almost entirely of rippled to even bedded thin bedded sandstone (Fig. 5).

Figure 5. Common stratigraphic sequences in coal field strata.

Sandstone channels are generally composed of fine to coarse grained, massively bedded to cross bedded sandstones in irregular shaped, elongate bodies which cut through enclosing finer beds down to and even through coal beds (Fig. 5B). In places channels are common in the roof from a few feet to

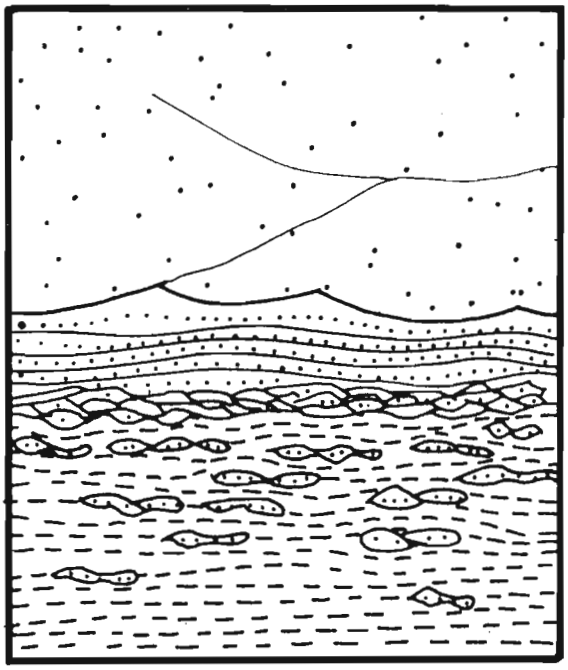


Figure 5A. Generalized diagram of coarsening upward sequence

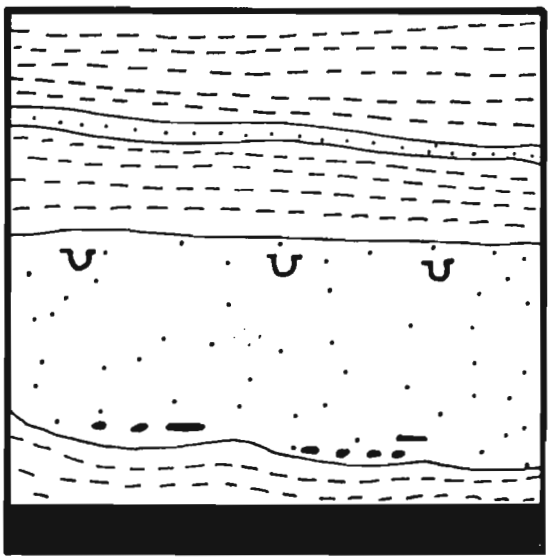


Figure 5B. Generalized diagram of channel sandstones

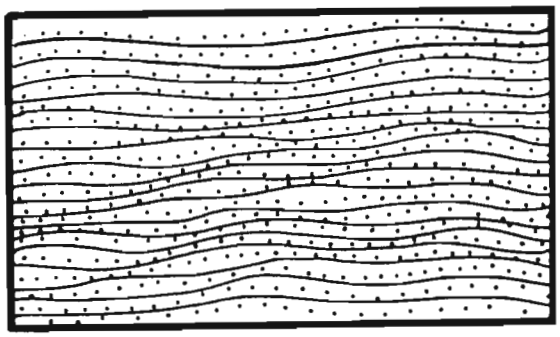


Figure 5C. Generalized diagram of thin bedded sandstone

several tens of feet of the top of the coal bed. Basal contacts of sandstone channel bodies are sharp. Where channels extend to the top or even into or through the coal beds, their lateral boundaries are sharp and are commonly inclined at moderate or steep angles. At their upper contacts channels may give way abruptly to finer rocks, or the boundary may be gradational.

Thin bedded sandstone roof is characterized by gently inclined to subhorizontal sandstone beds which may be either parallel laminated or rippled. Partings or thin interbeds of shale are common (Fig. 5C).

Thick shale-siltstone sequences are generally homogeneous for several tens of feet to where they coarsen upward gradually or are terminated by sandstone channels or coal beds. Depending upon local variations, stratification of these bodies may vary from good to poor.

Other common stratigraphic variations which contribute to roof instability include ironstone nodules, fossilized tree trunks (kettle bottoms), coal bed rider seams and seat earth in the immediate roof and overburden.

Structure in coal beds and roof rock: Structures commonly observed in coal mines in southwestern Virginia include: 1) planar fractures, such as cleats and joints, 2) bedding parallel faults within or at the top of coal beds, 3) low to moderate angle faults within coal beds or in the immediate roof, 4) folded beds associated with faulting within coal beds or in the immediate roof and 5) broad, gentle folding of individual coal beds.

Face and butt cleat attitudes were measured in each of the mines visited. In general, coal cleat within most of the mines visited was moderately well to well developed, except where cleat was destroyed by subsequent deformation. Other planar fractures, such as joints are difficult to identify in underground mines because they are commonly closed, widely spaced and tend to be masked by other structures. Joints are readily recognizable, however, in surface mines, where they are exposed in near vertical, moderately weathered highwalls.

Depending upon their trends, fractures observed underground in Wise County may be divided into longitudinal, transverse and diagonal groupings. Longitudinal fractures are generally aligned toward the northeast, parallel with regional structural strike. Transverse fractures are aligned generally to the northwest, whereas diagonal fractures are oriented more northerly.

Bedding parallel faults (decollements) tend to occupy carbonaceous shale partings or thin beds within coals or at the tops of coal beds. These faults are characterized by thin zones of intensely crushed, slickensided rock, generally with relict deformed bedding. In some places the deformation suggests simple differential subhorizontal sliding. In some places, beds are duplicated by the faulting, and subsidiary faults rise at low-to-moderate angles into the immediate roof. In other places, bedding parallel faults within shale partings in the coal beds are deflected diagonally across upper benches of the coal and flatten into shales at the top of the

coal bed. Faults associated with subhorizontal sliding are both extensional and contractional and may incline either toward or away from the direction of tectonic transport.

The net effect of this type of decollement and related faulting is to produce a roof that contains an abundance of slickensided surfaces, some with films of white, powdery fault gouge, and some with an abundance of fault-induced folds.

Broad, gentle folds in underground coal mines are commonly portrayed by structural contours on the tops of coal beds. The degree of slope is low, however, so that these folds rarely have an effect on roof stability.

Generalized roof classification: Table 2 summarizes that generalized roof classification used in this report, which is based upon geologic features in the immediate and main roof. Table 3 shows the distribution of roof types and coal bed deformation in Wise County mines. The Type A roof (Fig. 6A) is generally caused by small-to-moderate scale

Table 2. Classification of immediate roof type in coal mines in southwestern Virginia.

Table 3. Roof types and coal bed deformation in coal mines studied in Wise County, Virginia.

Figure 6. Generalized diagrams of roof types.

bedding faulting at the top of coal beds. Bedding surfaces and low-to-moderate angle fault surfaces in the immediate and main roof are polished, slickensided, and may contain films of powdery fault gouge. Faults are either extensional or contractional and surfaces intersect to form obtuse angles. Drag

Table 2. - Classification of immediate roof type in coal mines in southwestern Virginia.

Roof Type	Description
A	Roof surface uneven, slickensided and polished by faulting. Failure occurs along slickensided and polished surfaces.
B	Roof is composed of rock which tends to break along subhorizontal bedding planes, cross beds, rider seams, shale and clay partings and other stratigraphic zones of weakness, excluding those related to channel sandstones. Includes soft sediment slump features.
C	Roof consists of channel sandstone with irregular base. Channel bottoms, load casts and other protuberances extend downward into shale above coal. Differential compaction may result in numerous slickensided and polished fractures in shales and siltstones between tops of coal beds and channel bottoms.
Cb	Channel boundary condition in immediate roof occurs where sandstone cuts down sharply through shale and siltstone to or near the top of a coal bed.
SS	Stable sandstone roof occurs where undeformed planar bedded sandstone with few zones of stratigraphic weakness lies directly on coal.
Sh	Stable shale roof occurs where undeformed planar bedded shale or siltstone constitutes immediate roof. These may be bases of coarsening upward sequences or relatively homogeneous strata which contain few zones of internal weakness.
Ash	Roof is intermediate between major roof types; it contains some polished and slickensided beds, but not to a large degree.
AB	Slickensided surfaces related to faulting in shale intersect zones of stratigraphic weakness.
AC	Slickensided surfaces related to faulting in shale intersect channel bottoms or sides.

MAP NO.	COAL BED	MINE NAME	RII	ROOF TYPES	COAL BED DEFORMATION
10	High Splint	Shelton #4		SS ASh	NONE OBSERVED
17	Parson	Elro #3		Sh	LOCAL IN SEAM MIDDLE & TOP
16	Phillips	Elkins 6A		C Sh,SS	NONE OBSERVED
2	Taggart	Holton Marker		Cb, Sh	NONE OBSERVED
1		Holton Taggart	0.304	C,Cb, Sh,SS ASh	LOCAL IN SEAM MIDDLE
7		Wentz 1	0.611	A,B, Cb, Sh,SS,AC,	LOCAL IN SEAM MIDDLE & TOP
8		Wentz 1B	0.125	Cb, Sh,SS	LOCAL IN ENTIRE SEAM (FAULT)
15	Upper Standiford	Elkins 10A		C Sh	NONE OBSERVED
18	Kelly	Kelly Energy		B, Sh ASh	NONE OBSERVED
14		Sylvia Ann #2		Sh	NONE OBSERVED
4	Imboden	Arno	0.917	A,B,C Sh AC, ASh	LOCAL NEAR BOTTOM
6		Crossbrook A		A, Cb, Sh,SS	MODERATE IN SEAM MIDDLE
5		Prescott #2	1.276	A,B.C.Cb, Sh,SS,AC, ASh	EXTENSIVE IN SEAM MIDDLE, LOCAL NEAR BOTTOM & TOP
13	Clintwood	Paramount #8		B.C, SS	NONE OBSERVED
3	Dorchester	Bullitt	2.77	A,B,C,Cb, Sh,SS,AC, ASh	EXTENSIVE IN MIDDLEMAN, MODERATE NEAR BOTTOM
12		Paramount #6		A, Sh, ASh	EXTENSIVE IN MIDDLEMAN, LOCAL IN COAL MIDDLE
11	Norton	Paramount #7	0.071	A, Sh, ASh	EXTENSIVE IN SEAM MIDDLE, LOCAL NEAR TOP & BOTTOM
26	Edwards	Jackson Coal		Sh, ASh	LOCAL NEAR TOP & MIDDLE
36	Splashdam	Betty B #2	0.182	A,B, Sh, ASh	LOCAL NEAR TOP
33		Betty B #8	0.143	B,C, Sh,SS, ASh	LOCAL NEAR TOP
24	Upper Banner	BBB		B, Sh, ASh	NONE OBSERVED
23		Bear Branch		Sh, ASh	NONE OBSERVED
35		Betty B #3		B, SS, ASh	MODERATE IN SEAM BOTTOM, LOCAL IN TOP
34		Betty B #4	0.152	B,C,Cb, SS, ASh	LOCAL IN LOWER BENCH & ENTIRE SEAM (FAULT)
32		Betty B #9	0.769	A,B, ASh	MODERATE IN MIDDLE, LOCAL IN TOP & BOTTOM
27		Bullion Hollow #19	0.727	A,B,C,Cb, Sh,SS,AC, ASh	EXTENSIVE IN UPPER BENCH, LOCAL IN MIDDLEMAN & LOWER BE
19		Paramount #1	1.5	A,B, Sh, A ASh	LOCAL IN SEAM MIDDLE
22		R.B.J.	0.083	A, C, Sh,SS, ASh	EXTENSIVE IN MIDDLEMAN, LOCAL IN UPPER BENCH
28	Lower Banner	Black & White	0.41	A,B, Sh, ASh	LOCAL IN ENTIRE SEAM
9		Crockett #3		Sh, ASh	LOCAL IN LOWER BENCH & MIDDLEMAN
25		JMG #4		A, Sh, ASh	MODERATE IN ENTIRE SEAM
21	Raven	Fountain Bay 002		C	MODERATE IN ENTIRE SEAM
20		Fountain Bay 001	1.3	A, C, AC, ASh	EXTENSIVE IN ENTIRE SEAM
31		Minutemen - Hustler No.1		A, ASh	EXTENSIVE IN ENTIRE SEAM
30	Jawbone	Edison #2		A, Sh,	EXTENSIVE IN UPPER BENCH
29		Little David		A,B, Sh, ASh	EXTENSIVE IN ENTIRE SEAM

Table 3. - Roof types and coal bed deformation in coal mines studied in Wise County, Virginia.

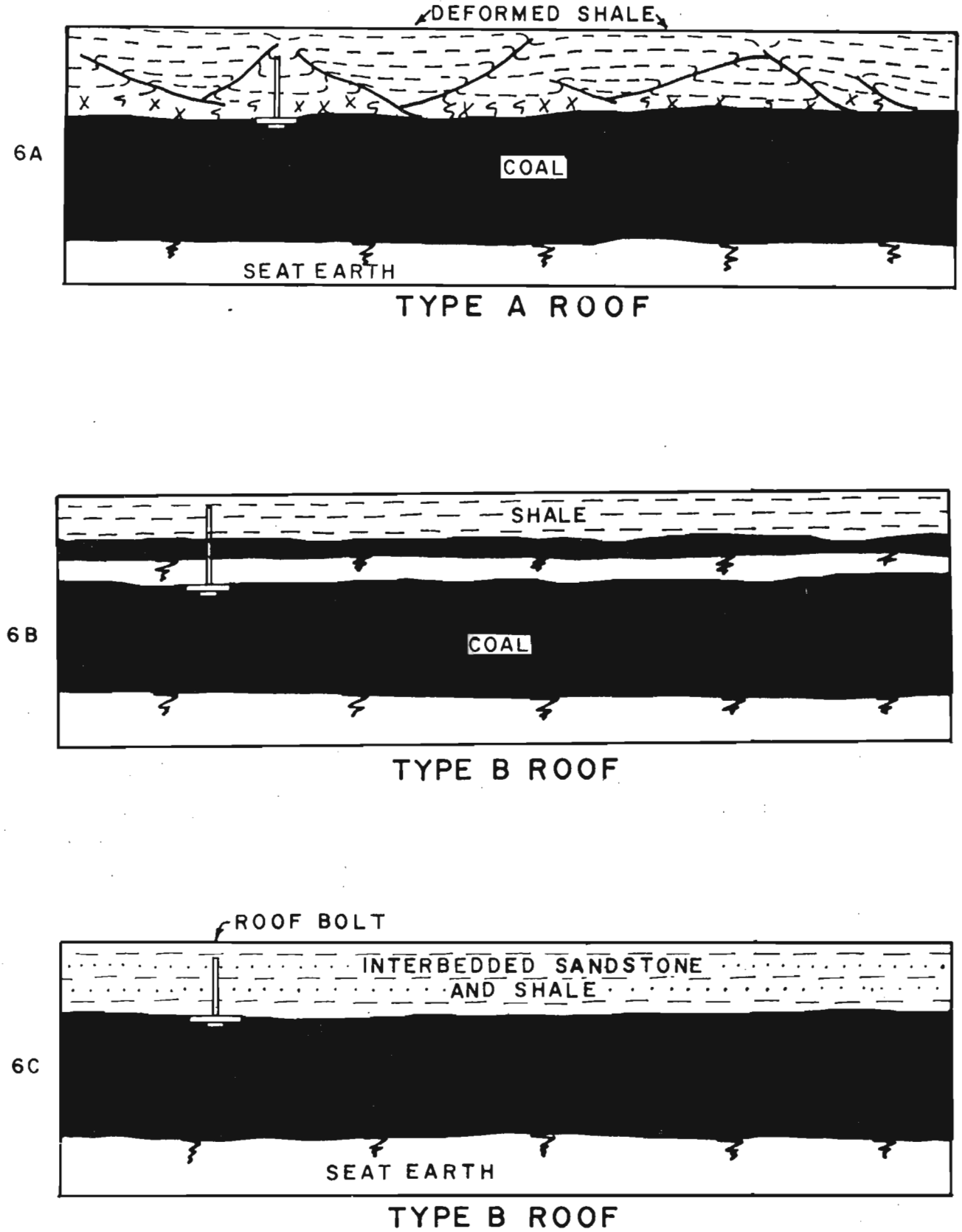
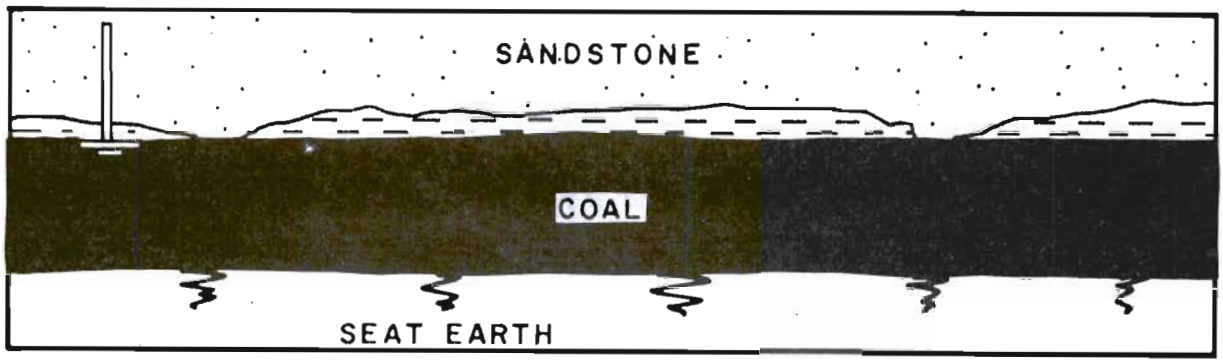


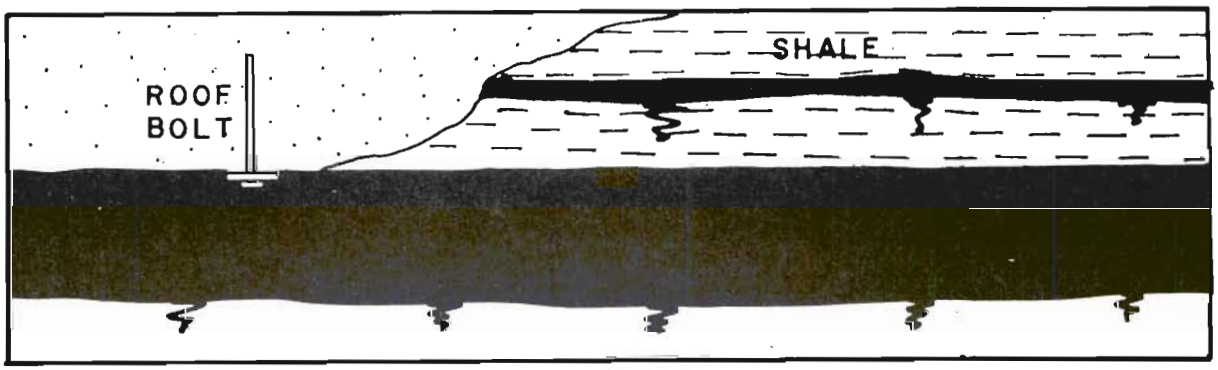
Figure 6. Generalized diagram of roof types.

6D



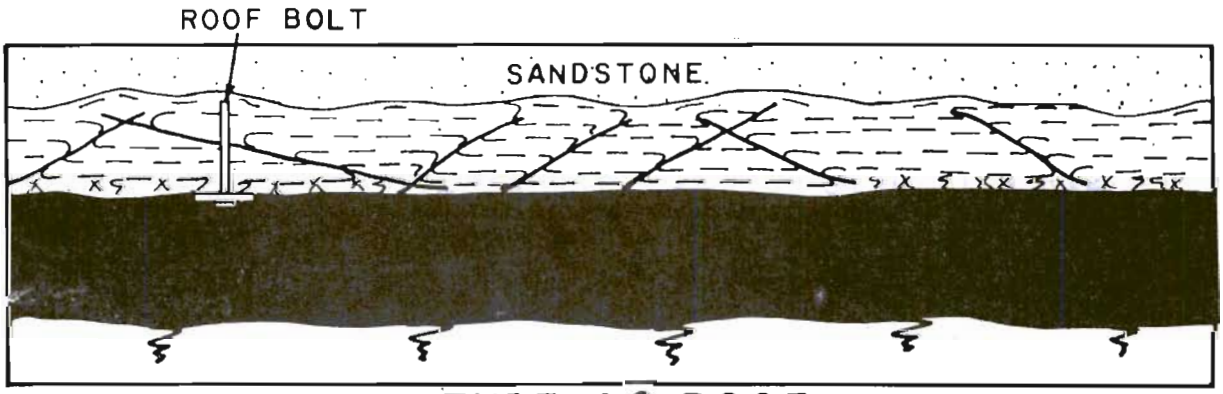
TYPE C ROOF

6E



TYPE Cb ROOF

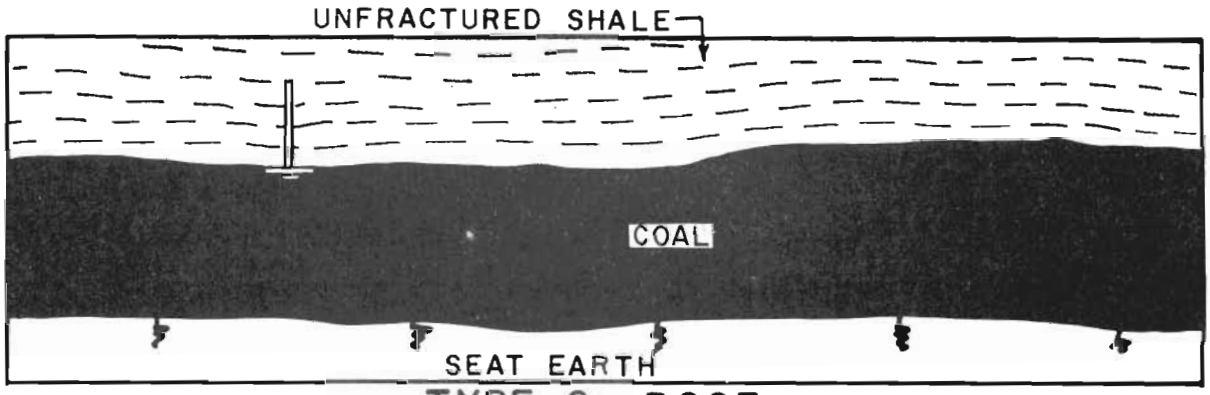
6F



TYPE AC ROOF

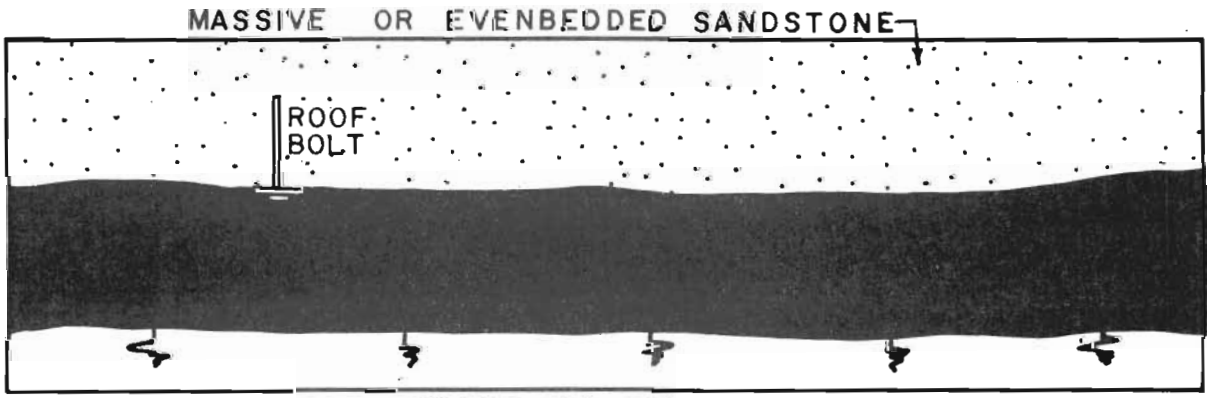
Figure 6. Generalized diagrams of roof types (cont.).

6G



TYPE Sh ROOF

6H



TYPE SS ROOF

Figure 6. Generalized diagram of roof types (cont).

folds are commonly associated with contractional faults. Thrust faults in the immediate roof, with displacements of a few inches to several feet, flatten downward into the shale or into interbedded shale and coal at the top of the coal bed. Deformation at the top of the coal bed ranges generally from a fault gouge less than one inch thick to a faulted and folded zone a foot or two thick, although in places the zone may be thicker. Thin fault zones usually consist of crushed shale, although thicker zones may exhibit complex folding and duplication of beds.

Roof falls associated with this roof type are bounded by the low-to-moderately dipping slickensided fractures which extend upward from the bedding thrust into the roof. The falls range from small horsebacks to elongate features which may be many tens of feet long and extend upward into the roof up to a few tens of feet.

Roof classified as Type B contains zones of stratigraphic weakness, excluding the special cases associated with channel deposits, and failure is related to separation along those zones of weakness in the immediate or main roof. Examples of this type of roof would be the occurrence of rider seams in the main roof a few feet above the coal bed; slickensided seatearth and rider coal beds in the immediate roof (Fig. 6B); planar bedded or cross bedded sandstones which contain weak partings of shale and siltstone (Fig. 6C); coarsening upward sequences which are generally less than 10 feet thick, and soft sediment slump deposits, which may or may not contain

numerous slickensides. A roof with an abundance of kettle bottoms would also be classified as a type B roof. Kettle bottoms, defined as, "a smooth rounded piece of rock, cylindrical in shape, which may drop out of the roof of a mine without warning (MESA, 1977)," result from such things as standing fossilized tree stumps or ironstone cobbles or boulders in the immediate roof.

The type C roof (Fig. 6D) occurs where sandstone channels extend downward almost to the top of the coal. The base of the sandstone is irregular and separated from the coal by a foot or two of shale. The shale commonly contains slickensides which may have been formed by differential loading and compaction by the overlying sand during deposition. Falls associated with the type C roof are generally small and result from the scaling off of small irregular masses of shale from the base of the channel-fill sandstone.

Channel boundary roof (type Cb, Fig. 6E) occurs along the broadly sinuous edges of channel sandstones where they descend into the immediate roof or are in the main roof a few feet above the coal. The moderately-to-steeply inclined contact between channel sandstones and adjacent shales and siltstones forms a marked discontinuity in the roof which can be very difficult to hold by conventional roof bolting techniques. In some mines channel boundaries serve as the loci for more than one major roof fall.

Stable sandstone, siltstone and shale roof rock (types SS, Sh-Figs. 6G and 6H) contains few structural and stratigraphic zones of

weakness, so the roof bolting can form a suitable beam in the main roof, or at least suspend weaker beds in the immediate roof from more competent units in the main roof. All gradations exist between stable and unstable roof types. For example, in some places stable shale, siltstone roof may change gradually along an entry into a type A roof, first with observable polishing on unfolded bedding surfaces, then with a regular increase in folding and faulting to areas where the immediate roof is composed entirely of slickensided and polished faults and folds. The roof thus grades from a type Sh into ASh and then into a type A roof along the entry. In other places type A shale or siltstone roof may intersect sandstone channels where they cut downward near the immediate roof, thereby forming an intermediate type AC roof (Fig. 6F). In this situation, channels compound the structural weakness of the roof because they combine the deleterious effects of extensively broken and slickensided shales with those of irregular channel bases or lateral channel boundaries.

Roof Instability Index: Based upon observations made in the mines a roof instability index was made for many of the coal beds studied (Table 4). The roof instability index is equal

Table 4. Roof instability indices for some coal beds in Wise County, Virginia.

to the number of observations made in areas of unstable (poor and intermediate roof conditions) roof conditions divided by the number of observations made in areas of relatively stable roof. Because stations were established more or less systematically in the mines the RII should be a fair approximation of coal bed roof conditions. It is undoubtedly biased a little to the high side because of the natural tendency of the geologists to visit and describe areas of poor roof. In defining the index, type C and ASh roof are considered good roof because roof control problems in these areas are relatively minor.

$$RII = \frac{A + B + Cb + AC + AB}{SS + Sh + C + ASh}$$

Coal beds which contain significant areas of bad top related to geological factors generally have a RII of 0.4 or more. Because the index for a coal bed is in part related to local geologic structure, it cannot be applied on a regional basis. If sufficient stations are established in each mine then the index can be calculated on a mine-by-mine basis. For this paper it was decided arbitrarily to use a minimum of 10 stations to calculate an instability index either for a mine or coal bed.

ROOF TYPE (RII)

A	B	C	Cb	SS	Sh	ASh	AB	AC
High Splint Coal Bed								
				1		1		
Parson Coal Bed								
					5			
Phillips Coal Bed								
		1		6	1			
Taggart Coal Bed (0.24)								
14,6*	5,2*	15,6*	14,7*	21	55	24,5*	1	1
Upper Standiford Coal Bed								
		1			3			
Kelly Coal Bed (0.91)								
	1				10	1		
Imboden Coal Bed (0.43)								
43,21*	3,1*	12,5*	4,3*	6	12	12,2*		8,3*
Clintwood Coal Bed								
	1	1	1					
Dorchester Coal Bed (2.0)								
91,49*	3,3*	12,5*	5,5*	3	3	21,1*		9,2*

A	B	C	Cb	SS	Sh	ASh	AB	AC
				Norton Coal Bed		(0.07)		
1,1*					13	1,1*		
				Edwards Coal Bed				
					4	2,2*		
				Splash Dam Coal Bed		(0.16)		
	1	2		1	5	2,2*		
				Upper Banner Coal Bed		(0.46)		
25,18*	9,8*	17,2*	6,4*	20	23	36,4*	2,2*	2
				Lower Banner Coal Bed		(0.41)		
6,4*	1,1*				9	8,3*		
				Raven Coal Bed		(1.06)		
18		8				10		1
				Jawbone Coal Bed		(0.375)		
2,2*	1,1*				5	3,1*		

Coal Bed Name (Instability Index)

$$\text{Instability Index} = \frac{A + B + Cb + AC + AB}{SS + Sh + C + ASh}$$

Table 4. Roof instability indices for some coal beds in Wise County, Virginia. Number of stations for each roof type are shown in the columns for each coal bed.

Starred numbers are numbers of falls or horsebacks observed in each roof type.

Individual mines were further subdivided into areas of poor, intermediate and good roof. Areas of poor roof are those with obvious problems, where there are major roof falls and/or numerous horsebacks associated with stratigraphic and structural discontinuities in the roof. Areas of intermediate roof contain the geologic conditions which are conducive to bad top, but which for some reason had not failed. Good roof shows little or no evidence of failure and contained few geologically induced discontinuities.

Roof instability, as estimated from the RII, appears to be concentrated in two principal stratigraphic zones in Wise County, Virginia. From an analysis of the data it was determined that an RII of 0.4 or less indicated that a mine (or coal bed) had a generally good roof. In contrast, mines (or coal beds) with indices greater than 0.4 generally have intermediate to poor roof (Fig. 7).

Figure 7. Stratigraphic variation of Roof Instability Index in Wise County, Virginia.

Generalized mine maps showing the distribution of roof types were prepared from a limited number of stations established in each mine, and from engineering data provided on the mine maps. Boundaries and trends of contacts are interpolated from available data and are only approximate. Detailed mine mapping of each entry and cross cut was not done in the mines visited during this study.

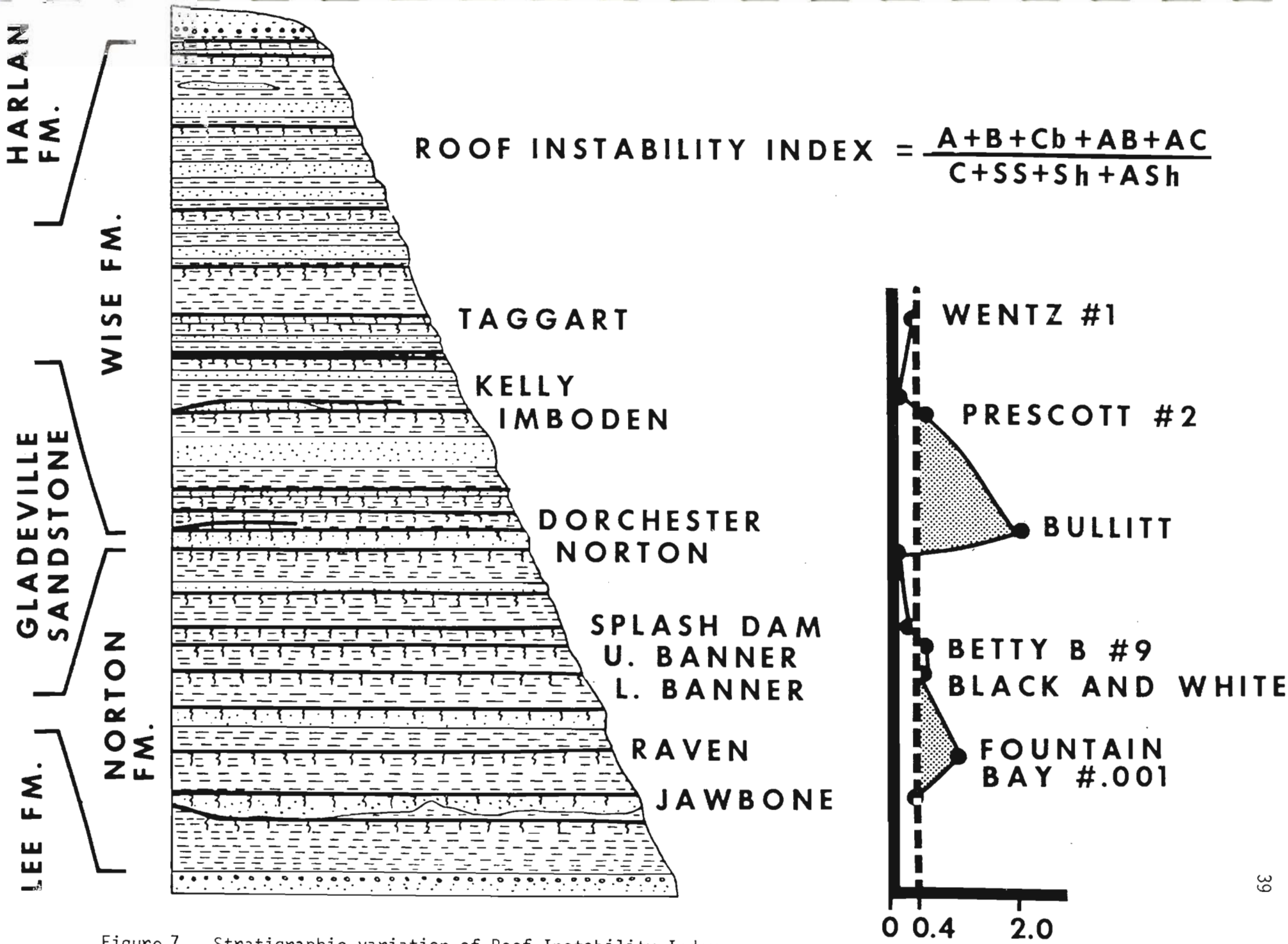


Figure 7. Stratigraphic variation of Roof Instability Index in Wise County, Virginia.

Fracture analysis: A cleat and joint trend map (Figure 8A) and a cleavage and fault trend map (Figure 8B) were prepared.

Figure 8A. Cleat and joint trend map of Wise County, Virginia.

Figure 8B. Fracture trends in southwest Virginia coal mines.

The major maxima of face cleat, systematic joints, fracture cleavage, and faults are subparallel to parallel throughout the area studied, and are parallel to the trend of the Powell Valley anticline. In addition, the major maxima of butt cleat, transverse joints and minor maxima of cleavage and faults are subparallel and approximately normal to the trend of the axial surface(s) of the Powell Valley anticline.

Both cleats and joints are truncated or offset by cleavage, and faults and are modified by the small-scale folds observed in the mines. It is apparent that folds, faults and cleavage postdate joint and cleat development.

Comparison of low-angle fracture trend maxima and the trends of fractures involved in mine roof falls and "horsebacks" (Figs. 8C, 8D) indicates a direct relationship between

Figure 8C. Orientation of all fractures measured in the Holton Complex, Paramount No. 7, Paramount No. 6, and Betty B No. 9 coal mines. Horseback orientations are shown around the perimeter; fold (+) and fault (□) orientations are plotted on stereo-net.

Figure 8D. Orientations of all fractures measured in the Wentz No. 1, Paramount No. 1, Minutemen-Hustler coal mines and Upper Banner coal mines (combined) east of Coeburn Fault. Horseback orientations are shown around the perimeter; fold (+) and fault (□) orientations are plotted on stereo-net.

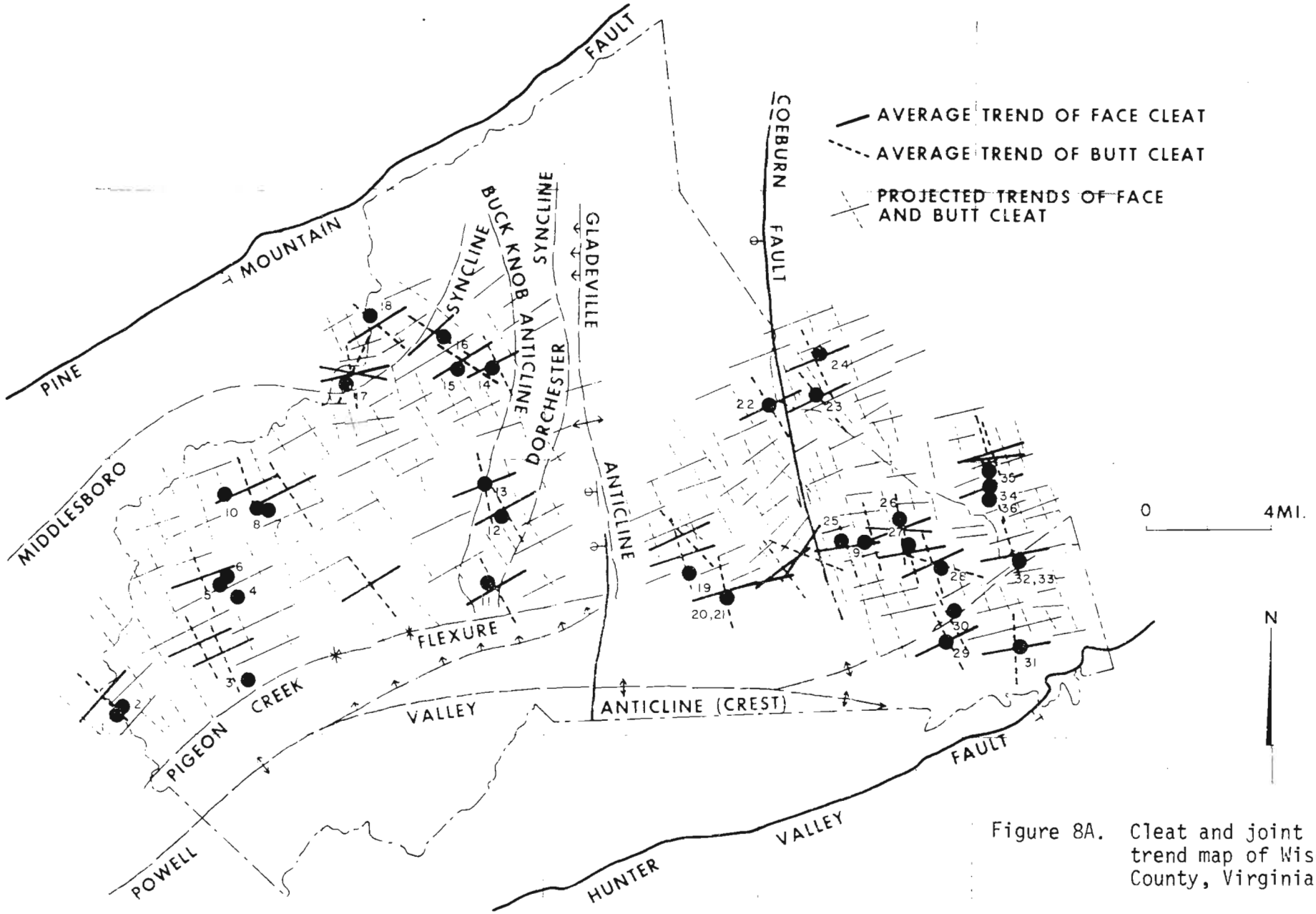


Figure 8A. Cleat and joint trend map of Wise County, Virginia.

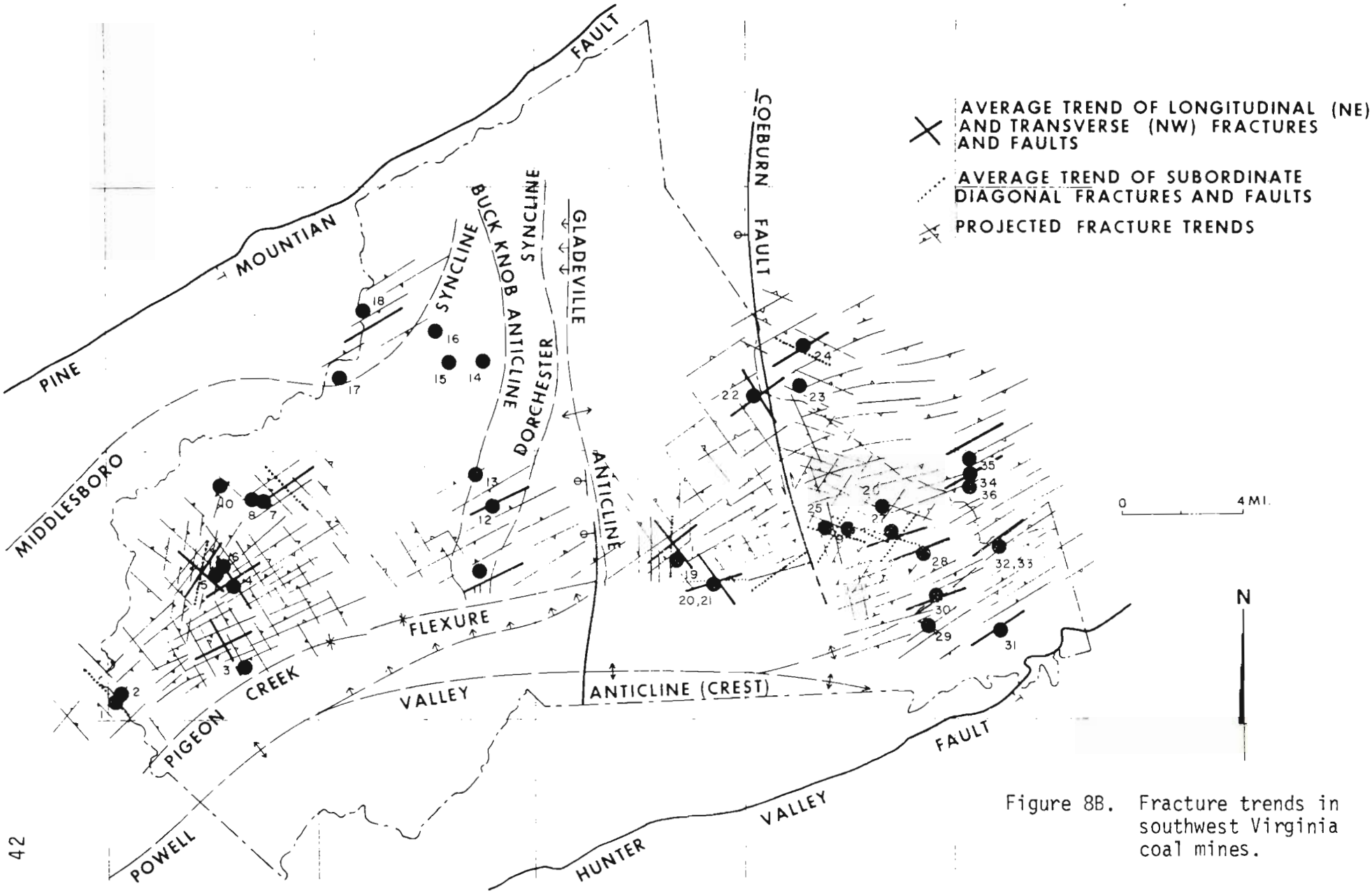


Figure 8B. Fracture trends in southwest Virginia coal mines.

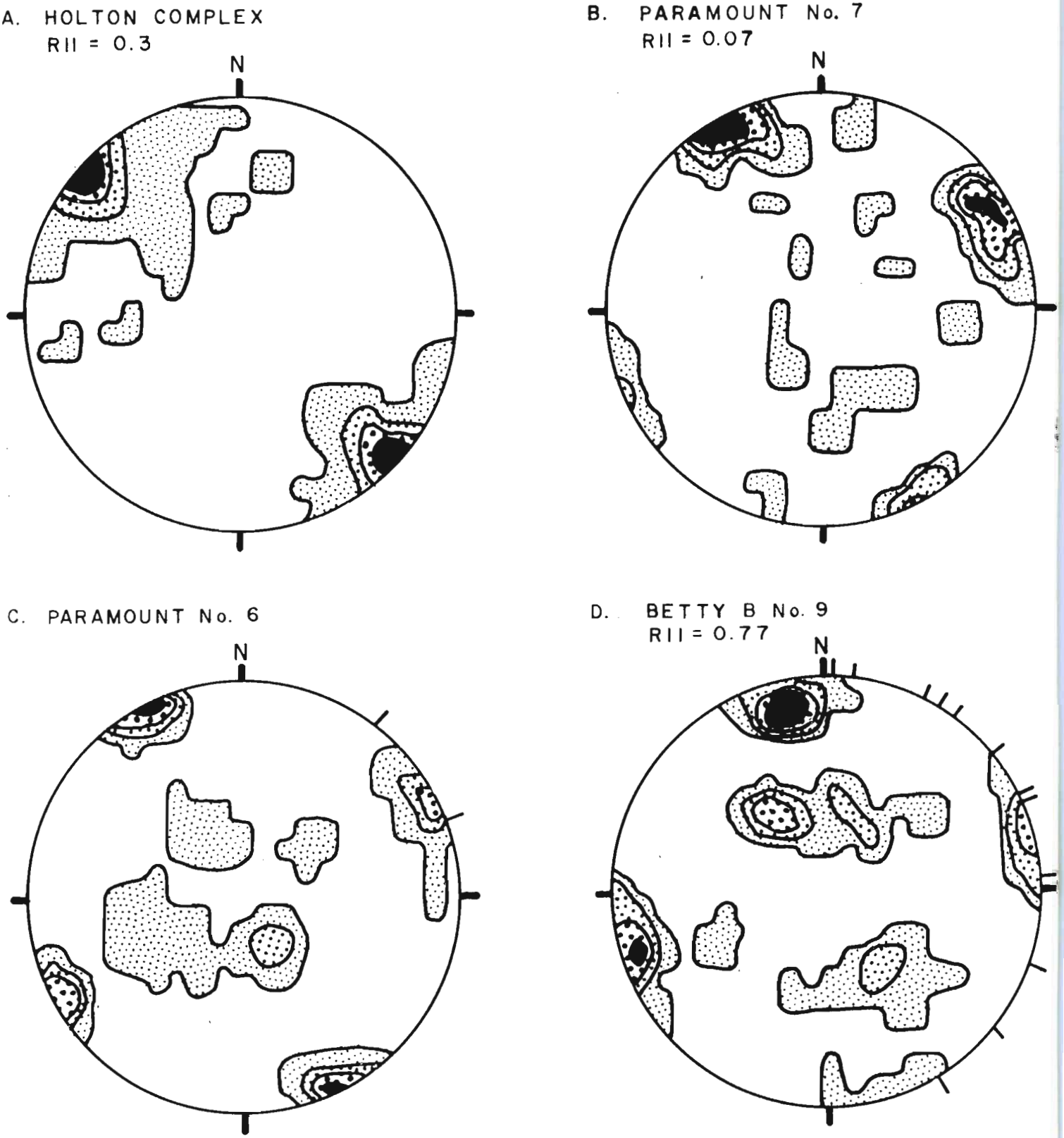


Figure 8C. Orientation of all fractures measured in the Holton Complex, Paramount No. 7, Paramount No. 6, and Betty B No. 9 coal mines. Horseback orientations are shown around the perimeter; fold (+) and fault (□) orientations are plotted on the stereo-net.

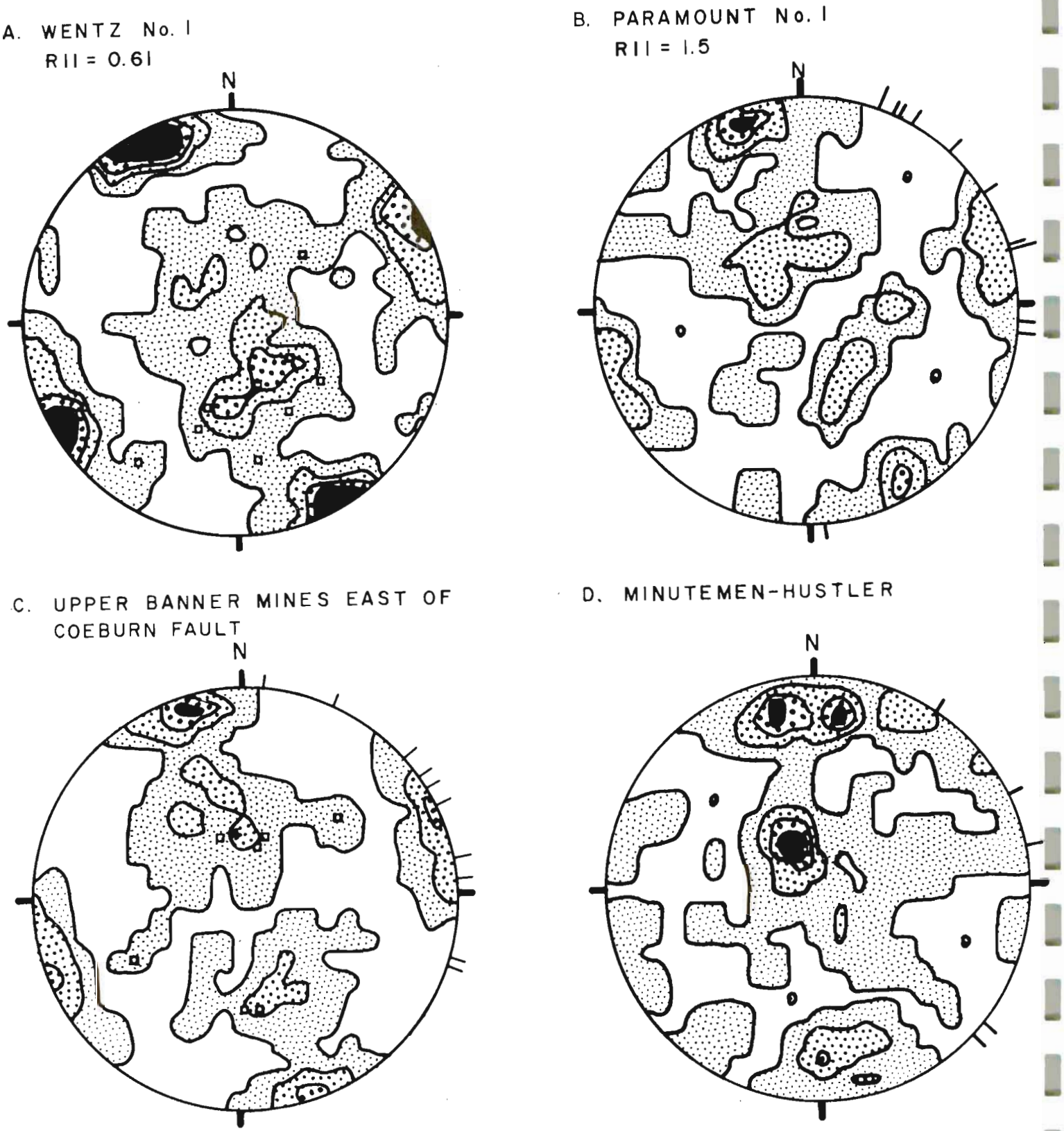


Figure 8D. Orientations of all fractures measured in the Wentz No. 1, Paramount No. 1, Minutemen-Hustler coal mines and Upper Banner coal mines (combined) east of Coeburn Fault. Horseback orientations are shown around the perimeter; fold (+) and fault (□) orientations are plotted on the stereo-net.

low-angle fracture trend maxima and the orientation of roof falls and "horsebacks."

In some mines, such as the Holton Complex, Paramount No. 7 and Paramount No. 6, there are few low-angle fractures in the roof and the roof is fair to good. Stereographic projections of fracture orientations in these mines are comparatively simple (Fig. 8C). The Betty B No. 9 mine stereonet shows a greater number of low-angle fractures than the others and the mine has a higher roof instability index (RII = 0.77).

In other mines, such as Wentz No. 1, Paramount No. 1, Minutemen-Hustler and in some mines in the Upper Banner coal bed, fracture orientations range widely (Fig. 8D). The RII exceeded 0.4 in two of these mines, where there were sufficient stations established (0.6 in Wentz No. 1, 1.5 in Paramount No. 1).

Where abundant surface and deep mine structural data are available, as at Bullitt Mine, it is apparent that the intensity of cleavage and fault and fold development decreases both horizontally westward from the steep west limb of Powell Valley anticline and upward into younger strata in this area. Strip mine highwalls near the flexure between the west limb of Powell Valley anticline and the Middlesboro syncline have a well-developed zonation of fractures. Northeast trending zones of low-angle (20-30 degrees) contractional fractures and faults alternate with zones of well-developed northeast trending systematic joints (extensional). The fractures in these zones may be related to a decollement in or at the top of the

Imboden and Kelly coal beds, which have been mined out in the immediate area above Bullitt mine. Similar fracture zonation occurs in the same area both above and below the Wilson coal seams which are about 220 feet above the Imboden coal seam. The Taggart and Low Splint coal seams lie above the northwestern entries of Bullitt Mine approximately 900 feet above the Dorchester seam. No evidence of low-angle fractures was found in the Taggart and Low Splint strip mine highwalls, indicating the absence of decollement surfaces in these coal seams. Drift mines in the Taggart seams to the southwest (Holton Complex) and to the northeast (Wentz 1B) do not have decollements visible in the workings.

In eastern Wise County the coal mines are near the southeastern edge of the coal fields and close to the Hunter Valley Fault. Decollements are present in most of these mines and generally the deformation associated with the decollements is more intense than that seen in the northern and western portions of the county. Many of the eastern mines are too small to provide sufficient structural data for mine roof stability indices, but most mines in the Jawbone, Raven, and Lower and Upper Banner seams have more splay thrusts in the seam and roof rocks and more evident displacement above the decollements than seen in the northern or western mines.

Subordinate low-angle fracture trends are present in most mines in the eastern half of the county and in the Prescott #2 and Crossbrook mines in the western part of the county (Fig. 8B). The additional fracture set(s) significantly

increase roof instability where they occur with the northeast and northwest trending sets found in many mines. An additional fracture set greatly reduces the length of strut that can be formed with roof bolt support and may require an alteration in mine design to avoid driving entries parallel to the additional fracture set.

LANDSAT AND AIR PHOTO LINEAMENTS

One major goal of this project is to determine if there is any relationship between lineaments observed on LANDSAT imagery and geologic features that cause instability in coal mine roof rock in the Virginia coal fields. Geologic mapping and systematic data collection in 36 coal mines provided structural and stratigraphic data on many roof falls and on extensive areas of both "good" and "bad" mine roof conditions.

Lineament maps derived from LANDSAT imagery and maps of air-photo derived topographic linears were completed prior to the field studies and were used in the field to search for geologic features that could be related to the lineaments but without notable success.

The LANDSAT imagery used to prepare the lineament map of Wise County (Fig. 8E) was visually selected from the

Figure 8E. LANDSAT lineament map of Wise County with rose diagram of lineament trends.

imagery library at NASA, Greenbelt, Maryland. It was selected on the basis of contrast, resolution, the absence from cloud cover and completeness of coverage. The best MSS scenes available (September, 1980) for each of the four seasons for bands 5 and 7 and all cloud-free and haze-free RBV fall and winter scenes were obtained for evaluation.

A map of the linear topographic low features in Wise County (Fig. 8F) was prepared from quadrangle centered,

Figure 8F. Air-photo lineament map of Wise County.

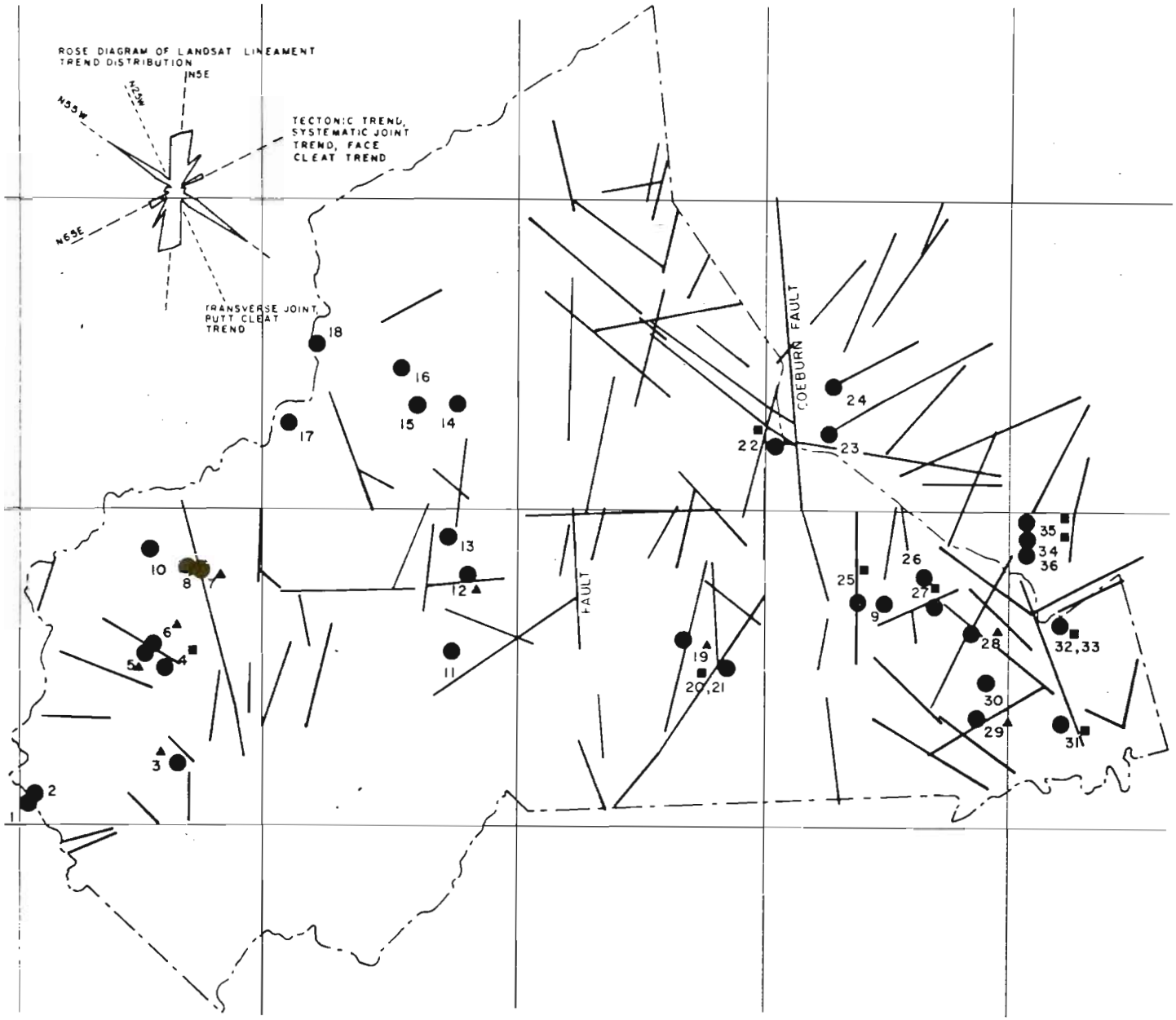


Figure 8E. LANDSAT lineament map with rose diagram of lineament trends.

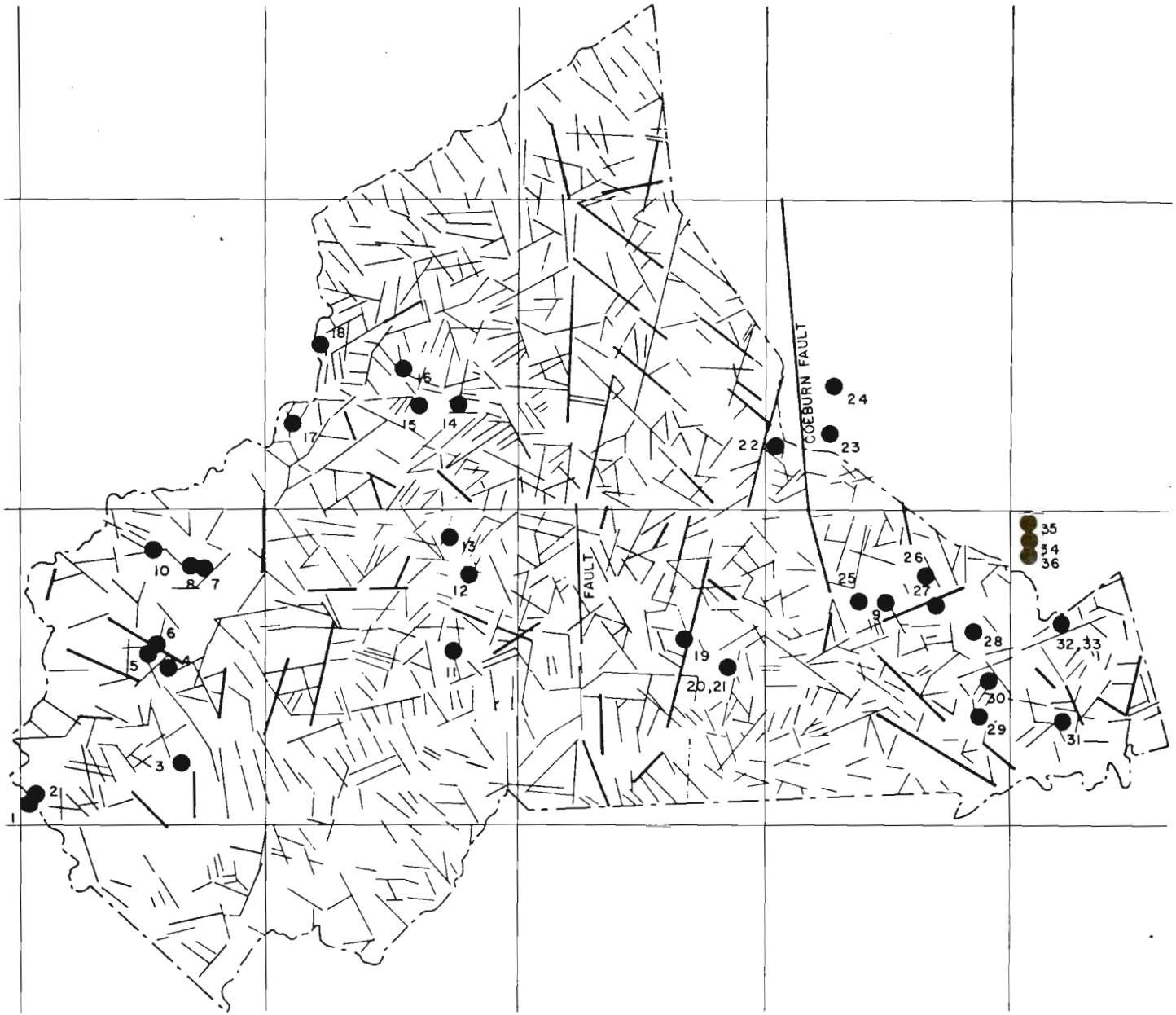


Figure 8F. Air-photo linear map of Wise County.

1:80,000 scale, stereo-pair, panchromatic air-photos viewed with an Old Delfe Scanning stereoscope. Most linear low topographic features observed were less than 3 kilometers in length except for those trending NW, N to NNE, or ENE. Some linear lows having these trends ranged up to more than 8 kilometers in length and were congruent with the LANDSAT lineaments. Those linear topographic features corresponding to LANDSAT lineaments or segments of LANDSAT lineaments are shown as heavy lines in Fig. 8F. Comparison of Figures 8F and 8E indicates that not all linear topographic features were recognized as lineaments on the LANDSAT imagery and that many of the LANDSAT lineaments were not recognized as continuous linear topographic features. The same suites of long linears or lineaments were recognized on both types of imagery.

The LANDSAT lineament map of Wise County shows the location of lineaments observed in three or more scenes of MSS or RBV imagery at 1:250,000 scale by both observers. From the map it is apparent that there are several parallel or subparallel sets of lineaments in the county. A rose diagram of the lineament trend distribution was constructed from these data and shows major lineament trend maxima at N55W and between N5W and N15E. Minor lineament trend maxima occur at approximately N60E, N35E and N85E. These maxima and subordinate peaks include the trends of the Coeburn Fault (Johnston and others, 1975) and the west flank of the Gladeville anticline and associated fault(s) (N5W-N15E) (Fig. 8B). Lineaments parallel to the faults may indicate the presence

of other small displacement faults or small folds but no field data have been found to substantiate the presence of these structures.

The two major lineament trends (N55W and N5E) parallel the primary shear couples postulated for a wrench-fault system in which the principal fold trend is N65E (Moody and Hill, 1956). Structural data from this study indicates that the rocks in Wise County have been subjected to contractional stress both across strike and along strike (Fig. 8B). Also, the Pine Mountain block is known to be entirely fault bounded and to have moved differentially. This structural environment suggests that strike slip faulting within the Pine Mountain block may exist and that the Coeburn and Rocky Face faults and the unnamed fault west and south of Wise are possible examples of wrench-fault tectonics.

Correlation between LANDSAT lineaments and mine roof conditions are difficult to assess. Where poor mine roof conditions coincided with LANDSAT lineaments, structural evidence from the individual mines indicated the cause for poor mine roof conditions related to structures developed from horizontal slippage along decollement surfaces. Conversely, if the mine roof instability indices of all mines intersected by lineaments shown on Figure 8E are compared with the roof instability indices of mines that have no LANDSAT-derived lineaments, a correlation is obtained. The average RII for the mines having LANDSAT lineaments intersecting them is 1.234 (mines 3, 5, 7, 19, 20, 28 and 32, Table 3) as opposed to an

average RII of .300 for mines not intersected by lineaments (1, 4, 8, 11, 22, 27, 33, 34 and 36, Table 3).

Roof Type	Number of Mines	Mines Crossed by LANDSAT Lineaments	Mines Near LANDSAT Lineaments	Mines More Distant from LANDSAT Lineaments
Type A & AC (extensive)	13	7	4	2
Type A & AC (local)	5	2	1	2
Type B, C, SS, Sh, Cb, ASh	18	0	3	15

Table 5. Spatial relationship between LANDSAT lineaments and mines having A or AC roof types.

The data displayed in Table 5 suggest that there may be some relationship between LANDSAT lineament location and the development of structures that form a type A roof. Nearly all mines had some areas of ASh roof, indicating a weak structural development related to minor horizontal slippage in coal seams throughout the county and/or the development of slip surfaces and slickensides in shale because of differential compaction

Geologic features related to LANDSAT lineaments have not been identified, either in the field or from analysis of structural

data. A very general correlation between mines with A or AC type roofs and the presence of lineaments at or near these mines was made. Of the 13 mines having extensive A or AC type roof, 11 are intersected by or are very close to LANDSAT lineaments. Of the 18 mines having no A or AC type roof, only 3 are near lineaments. The remaining 5 mines studied have local development of A or AC roof and 3 are intersected by or are near LANDSAT lineaments. Within the mines there is only random correlation between A and AC roof distribution and the projected location of the lineaments.

Two north trending lineaments are congruent with the Coeburn fault (Johnston and others, 1975) and a fault(s) of unknown extent that locally coincides with the west flank of the Gladeville anticline. The trend of these faults lies within the N5W-N15E trend maxima of the LANDSAT lineaments (Fig. 8E). Some evidence for left-lateral strike-slip movement on these faults has been found on the Coeburn fault (Charles Stanley, personal communication) and on the unnamed fault. LANDSAT lineament population density is greatest in eastern Wise County, where most coal mines have decollements and considerable areas of A or AC roof. Lineament density is least in the north central portion of the county, where decollements and A or AC type mine roofs are rare.

A comparison of air-photo linear trends within a 2 kilometer radius of each mine shows only random correlation

with fracture trends measured in the mines. Similarly, rose diagrams constructed from air-photo linear features for quadrangle sized areas are dissimilar and do not correlate with known fracture trends, either in the mines or on the surface. Air-photo linear density is greatest in the west-central portion of Wise County. Mines 11-18 are located in this area and all have relatively good roof conditions for those mines studied. In this area of higher density air-photo linears there are few linears that exceed 3 kilometers in length, with most in the .5 to 2.5 kilometers range. In both the eastern and western portions of the county, good mine roof conditions occur locally and may be accompanied either by high or by low density air-photo linear populations.

It can be concluded from this study that LANDSAT and air-photo lineaments cannot be used to predict specific occurrences of roof falls. High concentrations of lineaments, however, appear to be related to general areas of greater roof instability.

Subsidence: Recognizable subsidence features formed from collapsed coal mine workings are rare and difficult to recognize on the ground surface. Reports of open cracks, slump blocks or foundation or highway damage in Wise County are few. Three known areas of subsidence were examined with 1:80,000 scale air photos with no success in recognizing any subsidence features.

Several factors negate the use of remote sensing imagery for use in recognizing subsidence features in Wise County

and most other areas of the southwest Virginia coal fields. First, old, collapsed mine workings exposed in strip-mine high-walls show a rapid upward decrease of fractures and fracture displacement above mined-out seams, indicating that only shallow mine workings are likely to have visible subsidence features. Because of this, the areas of potential subsidence are small due to steep terrane in the area. Only a small percentage of the mine workings are less than 200 feet below ground level. This condition reduces the area that could undergo subsidence to narrow, sinuous, steeply sloping areas above the outcrop of the mined-out coal seam. The difficulty experienced in locating subsidence features in the field suggests that their identification on air photos, even of much larger scale than those used, would be very difficult. Second, most of the area is forest-covered, which greatly reduces the visibility of ground surface features. Those areas not covered by forest are either urbanized or industrialized to the point that land modification tends to obscure subsidence features.

The use of LANDSAT imagery of the southwest Virginia coal fields to identify subsidence features is limited by the resolution of the imagery. The area covered by a single pixel is much larger than the largest subsidence feature observed in Wise County.

DESCRIPTIONS OF COAL BEDS

Jawbone coal bed: Two small mines were visited in the Jawbone coal bed, the Edison Coal Company No. 2 and the Little David Coal Company Mine (Fig. 9). Common roof types in these coals

Figure 9. Generalized distribution of roof types in the Little David and Edison Coal Company #2 mines, Jawbone seam.

are A, B, and Sh (Table 3). Coal thickness ranges from about 31 inches to 92 inches. Faulting is common within the coal bed, the cleat is deformed, and in places the coal bed may be tectonically overthickened. An instability index of 0.38 was calculated for the coal bed, but there were not sufficient stations to calculate the index for each mine visited.

The main roof of the Edison No. 2 mine (Fig. 9A) consists of a sequence which coarsens upward from medium dark gray shale at the base to medium dark gray siltstone with sandstone laminations and then to light gray, fine grained cross bedded sandstone. The transition from shale to siltstone takes place in a distance of about 6 feet. The coal bed in the mine is generally fractured and in places is slickensided.

A major roof fall in this mine extends upward for about 5 feet and occupies an entire intersection in the left entry two breaks from the portal. The fall is related to numerous fractures in the main roof, and although slickensides and polished beds are not in evidence, the fall is classified as a type A. Elsewhere, the roof contains few fractures and is relatively stable.

KEY TO MINE MAPS

ROOF TYPE	ROOF CONDITION
SHALE - SILTSTONE - SANDSTONE TYPE A, B, Cb, AB, AC w/HORSEBACKS & ROOF FALLS	POOR
SHALE - SILTSTONE GENERALLY TYPE A, B, Cb, AB, AC	INTERMEDIATE
SHALE - SILTSTONE TYPE ASh, Sh	GOOD
SANDSTONE TYPE: SS - GOOD	
C - INTERMEDIATE	

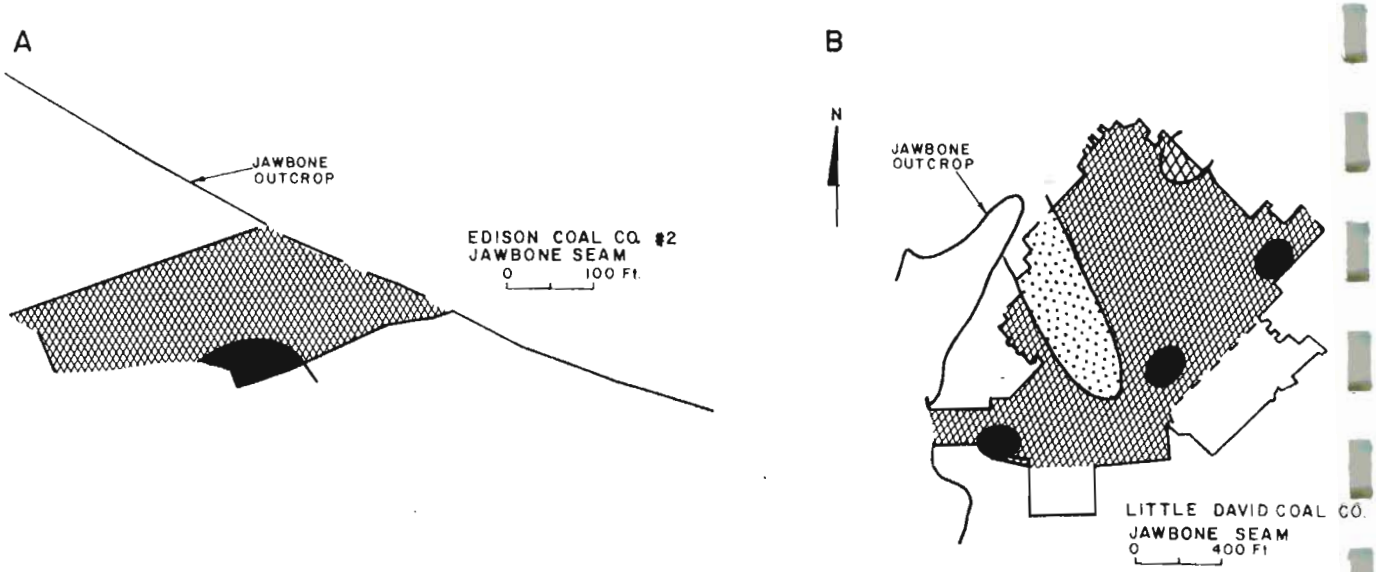


FIGURE 9. - GENERALIZED DISTRIBUTION OF ROOF TYPES IN THE LITTLE DAVID AND EDISON COAL COMPANY No. 2 MINES, JAWBONE SEAM.

A. - EDISON COAL CO. No. 2 MINE, JAWBONE SEAM.
B. - LITTLE DAVID COAL CO. MINE, JAWBONE SEAM.

The Little David mine roof consists generally of olive gray shale, in places with plant fragments and ironstones (Fig. 9B). The coal bed in the Little David mine is extensively sheared and slickensided. In places faults within the coal propagate upward into the overlying roof strata, resulting in numerous slickensided and polished surfaces, and generally forming a type ASh roof. In one place, near the entry, shale containing plant fragments has broken along the bedding and fallen out between the bolts, producing a small fall. In other places faulting in the coal bed and immediate roof has resulted in type A falls and horsebacks which extend up to several feet into shale roof.

A prominent channel sandstone occupies part of the mine, but appears to have contributed little to roof instability. It is possible that future mining could encounter combinations of A, C and Cb conditions which would make roof control difficult in local areas.

Raven coal bed: Roof conditions in the Raven coal bed were studied in the Fountain Bay No. 001, Fountain Bay No. 002 (Fig. 10), and Minutemen-Hustler No. 1 mines (Fig. 11) (Table 1). Roof types include A, ACb, C, Sh, SS, and ASh (Table 3). Coal thickness ranges from about 12 inches to

Figure 10. Geologic features and roof types in the Fountain Bay Mining, Inc. No. 001 and No. 002 mines.

90 inches. In the mines visited faulting is common within the coal bed so that in places it is tectonically thickened

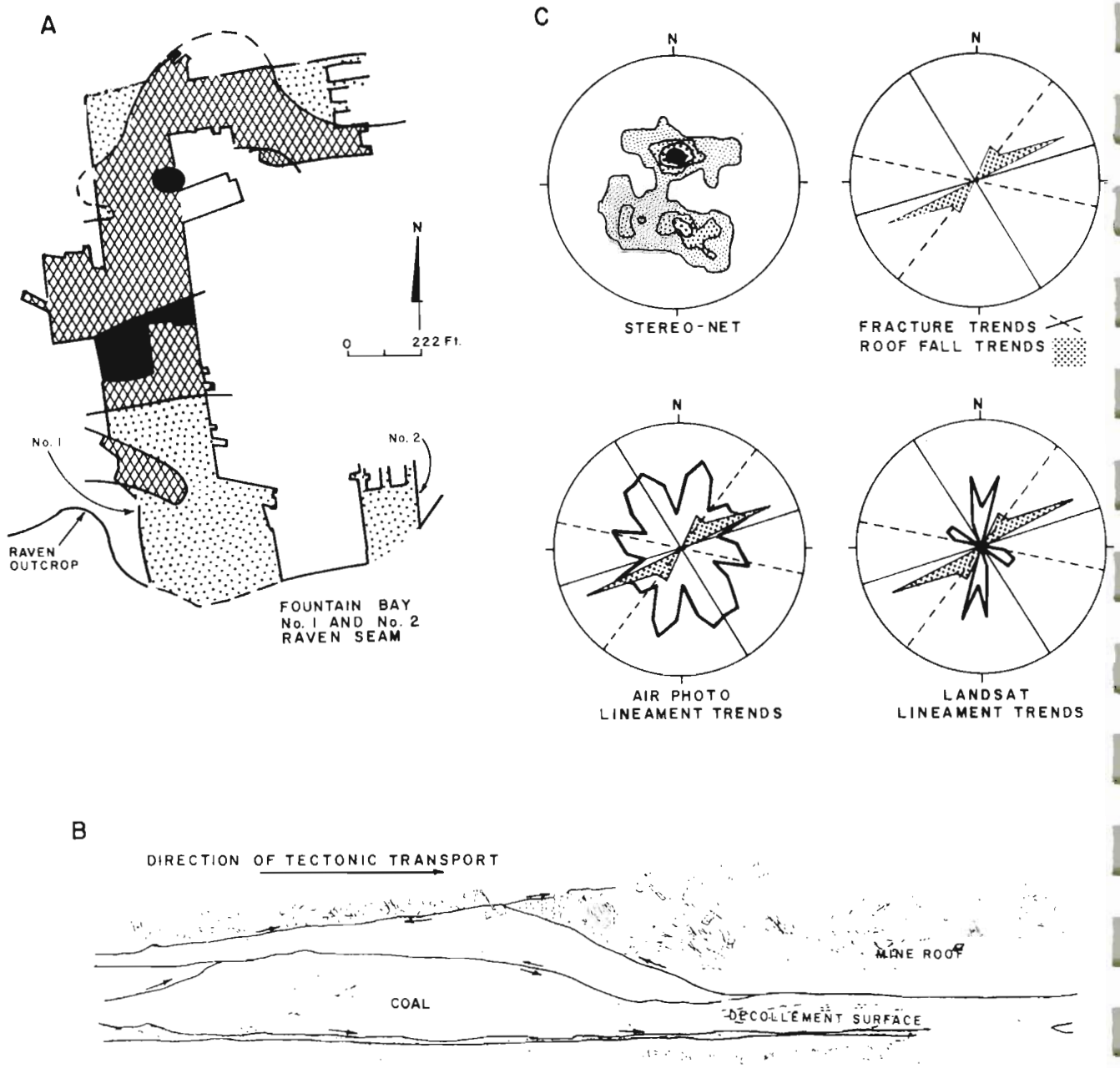


FIGURE 10. - GEOLOGIC FEATURES AND ROOF TYPES IN THE FOUNTAIN BAY MINING, INC. No. 001 AND No. 002 MINES, RAVEN SEAM.

A. - GENERALIZED ROOF TYPES.
B. - DIAGRAM OF COAL ROLL IN FOUNTAIN BAY No. 001 COAL MINE.
C. - FRACTURE AND LINEAMENT TRENDS IN THE FOUNTAIN BAY No. 001 MINE.

and thinned. Much of the coal is also intensely sheared and folded. An overall instability index of 1.06 was calculated for the Raven coal bed.

The roof of the Fountain Bay No. 001 mine consists of sandstone, shale, and siltstone. The roof is classified mostly as type A in the shale and siltstone because of the abundance of faults, folds, and slickensided surfaces. In some places, where the structure is relatively slight, the roof is classified as ASh. Where channel sandstones enter the immediate roof and extend downward to within a foot or two of the top of the coal the roof is classified as a type C, and channel boundaries combined with type A slickensided roof result in places in ACb conditions. In places the sandstone is broken by numerous closely spaced joints. The coal bed is generally deformed throughout the mine and contains numerous zones of intense crushing, faulting, and folding. In general, the cleat has been destroyed near faults in the coal. In some places the coal bed, together with surrounding strata, is faulted and folded into recumbent anticlines and synclines. In other places folds are isoclinal. A roof instability index of 1.3 was calculated for this mine.

In one place in the mine, about 7 breaks in from the portal in the number one entry, the coal bed is tectonically deformed into an overthickened roll (Fig. 10B). The coal bed on the flanks of this anticlinal structure has been tectonically thinned so that part of the mine roof has foundered into the vacated space. The coal bed is then overridden by another

subhorizontal thrust. This tectonic thinning and thickening of the coal bed has been facilitated by a bedding plane fault zone near the base of the coal and by faulting in the shale middleman. The roof is extensively deformed by slickensided and polished fractures which extend into the mine from this point for 7 more breaks, to where a channel sandstone enters the immediate roof. Outby the coal anticline, deformation becomes almost entirely restricted to the shale middleman within the coal bed.

Fracture analysis of mine roof fractures shows that the general direction of tectonic transport is almost due north, (Fig. 10C), reflecting the location of the mine adjacent to the east-trending nose of the Powell Valley anticline. The main horseback, roof fall trends appear to be a compromise between the two northeast trending sets of fractures. Short air-photo lineaments correspond a little with fracture and roof fall trends, and LANDSAT lineament trends show little tendency to coincide with either fractures or roof falls.

The Fountain Bay No. 002 mine is a small mine with a sandstone channel extending down almost to the top of the coal bed. The coal bed is internally sheared and in one place is broken by a small fault which thrusts coal and shale over roof rock. The coal bed is most commonly faulted near its base, in the middleman and upper bench of coal, and in the claystone overlying the coal. Except where it is faulted the sandstone roof is generally stable. About a foot of shale, or a little more, is in the immediate roof below the channel sandstone,

and the roof is classified as a type C. There were not enough stations described in this mine to calculate an instability index.

Like the other two mines visited in the Raven coal, the Minutemen-Hustler mine (Fig. 11A) is characterized by an extensively deformed coal bed. When it was visited the mine

Figure 11. Generalized distribution of roof types in the Minutemen-Hustler (Raven Seam), JMG No. 4 and Crockett No. 3 (Lower Banner Seam) mines.

had been developed beneath a roof which consisted of fractured, slickensided and polished shale or siltstone. The roof is classified either as A or ASh, depending upon the degree of deformation, and horsebacks and roof falls within the mine are associated with tectonically deformed roof.

In the Raven coal bed roof falls and horsebacks are common where there is bedding decollement within the coal or in the overlying strata. Channel boundaries contribute considerably to the instability of adjacent faulted and folded shales. Where sandstone channels approach the top of the coal there is danger of pieces of shale a foot or more thick falling out between the bolts. This danger is increased in areas where the shale contains an abundance of slickensided and polished surfaces.

Lower Banner coal bed: Mines visited in the Lower Banner coal bed were JMG No. 4, Black and White No. 1 and Crockett Coal Company No. 3 (Table 3). All of these mines are relatively small and roof types in them vary from A, Sh to ASh

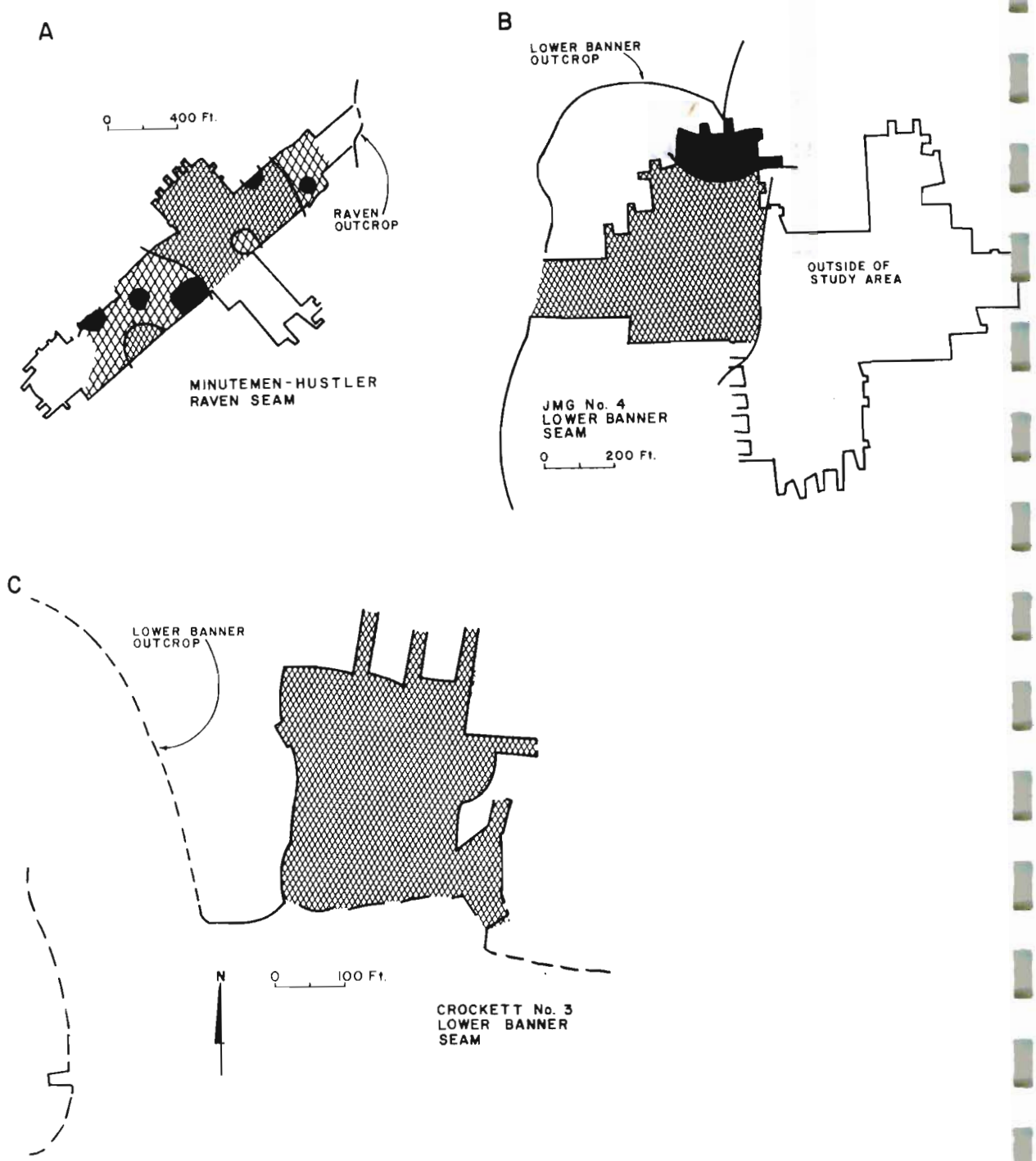


FIGURE 11. - GENERALIZED DISTRIBUTION OF ROOF TYPES IN MINUTEMEN-HUSTLER (RAVEN SEAM), JMG No. 4 AND CROCKETT No. 3 (LOWER BANNER SEAM) MINES.

A. - MINUTEMEN-HUSTLER MINE, RAVEN SEAM.
B. - JMG No. 4 MINE, LOWER BANNER SEAM.
C. - CROCKETT No. 3 MINE, LOWER BANNER SEAM.

and B. Coal thicknesses range generally from 12 to 85 inches. In places, the Lower Banner is faulted so that the coal is tectonically thickened and thinned and its contained middleman is extensively deformed.

The JMG-4 mine (Fig. 11B) has a shale roof and roof type is predominantly Sh. In one part of the mine the coal bed is folded, fractured, and tectonically overthickened and the roof is extensively folded. In this area the roof grades from Sh to ASh and A with an increase of slickensided surfaces.

The Crockett Coal Company #3 mine (Fig. 11C) is a small mine with a shale roof type. Tectonic deformation in this mine is relatively slight so that the roof is classified as Sh. In places, however, the shale is slightly fractured, slickensided and may contain small horsebacks.

The roof of the Black and White mine (Fig. 12A) consists of claystone, shale or siltstone which is generally classified

Figure 12. Geologic features of Black and White Mine, Lower Banner coal bed.

as either ASh or Sh. The mine has a roof instability index of 0.41. In one place the roof falls out between bolts in relatively small pieces where claystone pulls apart because of coal partings along bedding surfaces, and the roof is a type B. The coal bed in the Black and White No. 1 mine contains a prominent middleman which ranges in thickness from a foot or so to almost 4 feet. Subhorizontal faulting is common within this middleman so that in some places the claystone and the overlying rider are broken and repeated by faulting. Because of this fault the coal bed is commonly thickened and thinned.

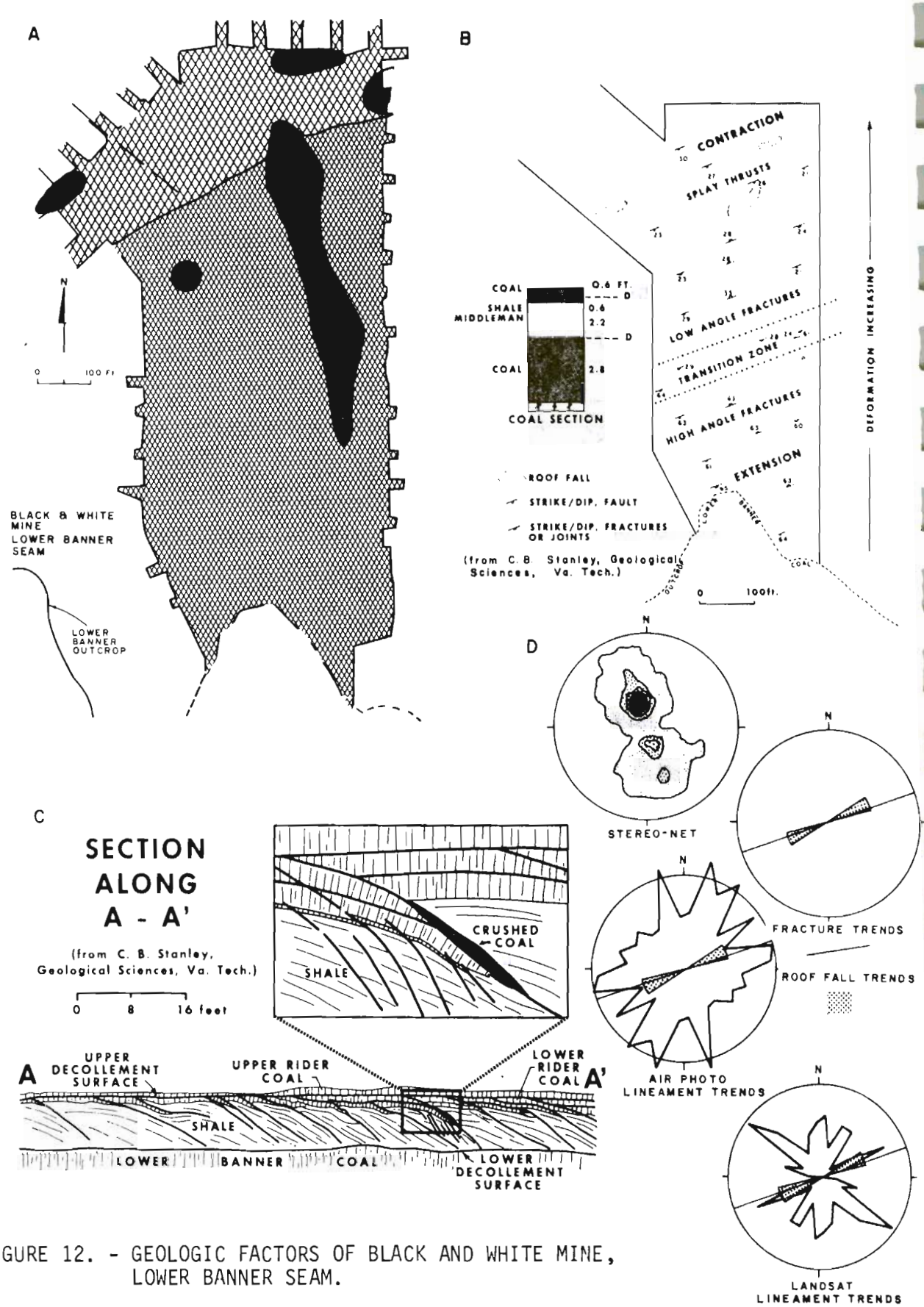


FIGURE 12. - GEOLOGIC FACTORS OF BLACK AND WHITE MINE, LOWER BANNER SEAM.

A. - GENERALIZED DISTRIBUTION OF ROOF TYPES IN BLACK AND WHITE MINE.
B. - STRUCTURE MAP OF BLACK AND WHITE MINE.
C. - CROSS-SECTION OF DEFORMED COAL BED.
D. - RELATIONSHIPS OF HORSEBACK/ROOF FALL TRENDS TO FRACTURE, SHORT AIR PHOTO AND LANDSAT LINEAMENT TRENDS.

Interestingly, in much of the mine the upper bench of the rider seam which overlies the middleman has a well developed blocky cleat.

The Black and White mine can be structurally zoned into areas of high angle fractures, transition zone, low angle fractures and splay thrusts (Fig. 12B). Deformation of the coal bed increases progressively into the mine, so that major roof falls are associated with the zone of splay thrusts. Decollement within the coal bed lies generally at the base of the middleman and within the upper bench of coal, although locally faulting extends upward into the roof.

In places the shale middleman is overthickened structurally, with numerous splay thrusts rising diagonally through the shale and flattening in the decollement in the rider seam.

Tongues of coal have been broken from the rider and thrust downward into the middleman, so that tectonic shortening is entirely between the two decollement surfaces (Fig. 12C).

Fracture analysis shows that the direction of tectonic transport lies generally to the northwest (Fig. 12D). Fracture trends measured within the mine generally coincide with roof fall and horseback trends. Short air photo lineament trends appear to show little relationship to roof fall/horseback trends, and the latter show a coincidence with one of the minor LANDSAT lineament trends observed near the mine.

Coal mines which we visited in the Lower Banner seam have relatively good, stable shale roofs, even though there is abundant faulting and folding within the coal bed. It should be recognized, however, that faulting within the coal

in places breaks up into the roof, thereby forming hazardous areas in which to work.

Upper Banner coal bed: Eight mines were visited in the Upper Banner seam, BBB, Bear Branch, Betty B No. 3, Betty B No. 4, Betty B No. 9, Bullion Hollow No. 19, Paramount No. 1 and the R.B.J. Mine. Coal thickness in these mines ranged from about 27 to nearly 83 inches. Roof types encountered were wide ranging, but the most common are A, B, C, SS, Sh, and ASh. In some places the coal bed is faulted generally subparallel to bedding; in other places it is relatively undeformed.

The roof of the BBB mine is shale or claystone (Fig. 13A). Plant fossils, including fossil roots, are common, and in

Figure 13. Generalized distribution of roof types in the BBB and Bear Branch Coal Co. Mines.

some places the roof rock is a seatearth. The seatearth is commonly slickensided and unstable, forming a B-type roof. Slickensided rock was observed to have fallen in two places, resulting in both an elongate horseback about 30 feet long parallel to the number 4 entry, and a moderate-sized type-B roof fall about 80 feet long in the adjacent Number 5 entry and cross cut. Where slickensided seatearth is in the immediate roof the roof is classified as ASh. Elsewhere, it is Sh type roof.

The Bear Branch coal mine was a small mine being driven along four entries that extended into the mountain about three breaks at the time it was visited (Fig. 13B). The roof

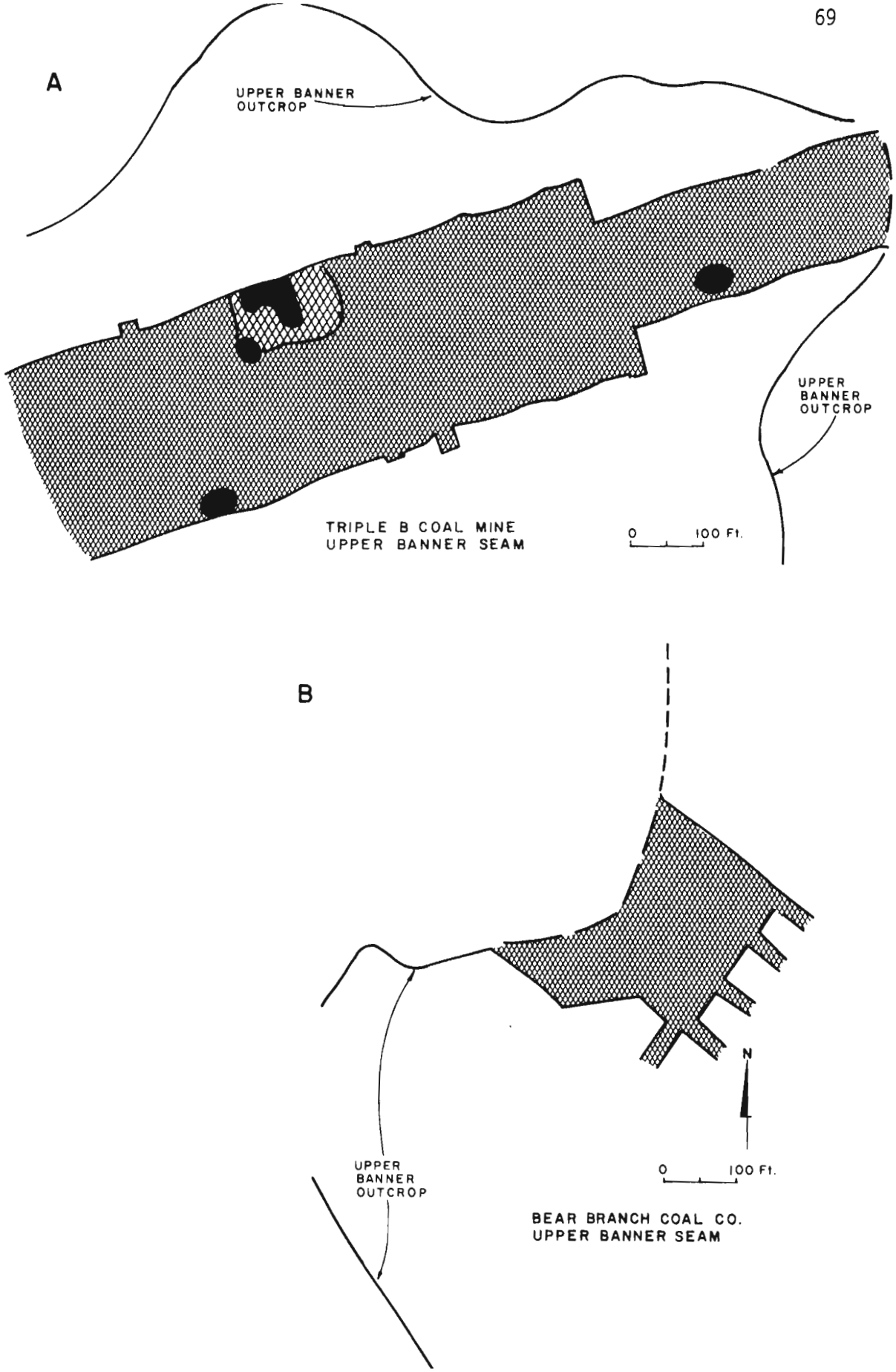


FIGURE 13. - GENERALIZED DISTRIBUTION OF ROOF TYPES IN THE BBB AND BEAR BRANCH COAL COMPANY MINES.

A. - BBB MINE, UPPER BANNER SEAM.
B - BEAR BRANCH MINE, UPPER BANNER SEAM.

rock encountered in the mine is shale, which exhibited some polishing or slickensides. Roof types ranged from Sh to ASh. No roof falls were observed.

The roof of the Betty B No. 3 coal mine is primarily in shale with some claystone (Fig. 14A). Deformation within

Figure 14. Generalized distribution of roof types in the Betty B No. 3 and Bullion Hollow No. 19 coal mines.

the coal bed ranges from slight fracturing to zones of moderate shearing and slickensiding, suggesting some differential horizontal movement. Roof type is generally classified as ASh because of slickensides in the roof rock. In one place, where weak shale and claystone were falling between the bolts, the roof was classified as type B. The coal bed is commonly fractured and slickensided. Major areas of bad mine roof (Fig. 14A) were inaccessible and their location was plotted from large-scale mine maps.

The Bullion Hollow No. 19 mine has a heterogeneous roof composed of lithologies ranging from claystone to shale, siltstone and sandstone (Fig. 14B). The dominant roof lithology, however, is sandstone. The mine has a roof instability index of 0.73. Roof types include A, B, C, Cb, SS, Sh, AC, and ASh. Shale roof types range from A to ASh, depending upon the abundance of fractures, and sandstone roof types are C, Cb, and SS. Two channel boundary roof falls were observed, where two to three feet of siltstone had fallen out to a sandstone channel edge. Small type C horsebacks

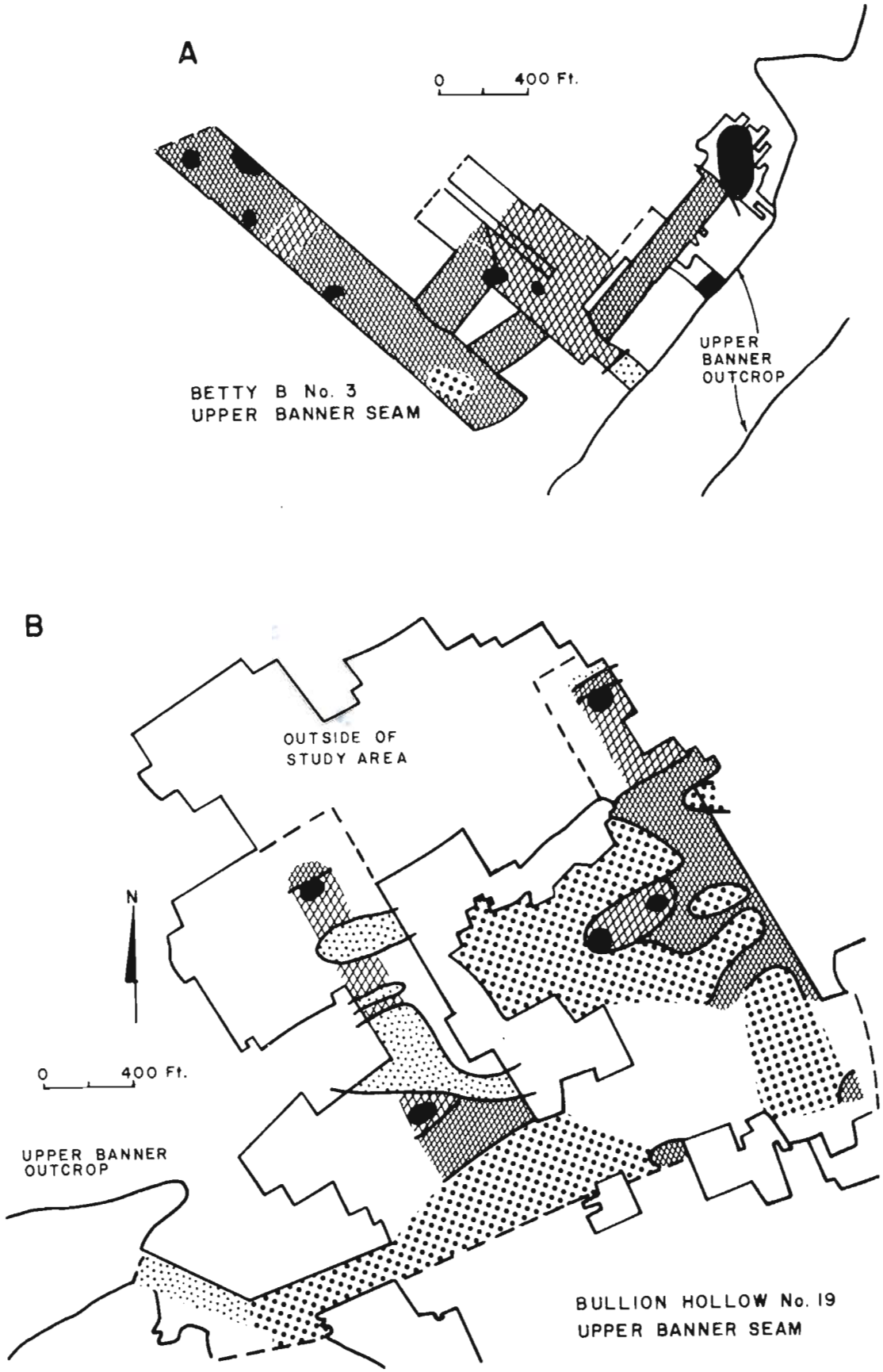


FIGURE 14. - GENERALIZED DISTRIBUTION OF ROOF TYPES IN THE BETTY B No. 3 AND BULLION HOLLOW No. 19 COAL MINES.

A. - BETTY B No. 3 COAL MINE, UPPER BANNER SEAM.
B. - BULLION HOLLOW No. 19 MINE, UPPER BANNER SEAM.

were observed in two places where fractured shale and siltstone had fallen from the base of a sandstone channel. ASh type roof falls were observed in two places. In one, faulting and folding extended from the coal up into siltstone, forming a horseback, and in the other, fractured roof shale fell out forming a horseback.

The Betty B No. 4 roof is composed principally of sandstone, although in some places it is underlain by thin shale in the immediate roof (Fig. 15). The mine has a roof in-

Figure 15. Generalized distribution of roof types in the Betty B No. 4 mine.

stability index of 0.15. In a few places the sandstone is replaced laterally by shale at the top of the coal bed. The sandstone roof is classified as either C or SS, depending upon the presence or absence of shale in the immediate roof. Type Cb roof was observed in three places. Shale roof contains slickensides sufficient to warrant classification generally as type ASh. Roof falls in the Betty B No. 4 mine are generally related to stratigraphic (type B) or boundary (type Cb) conditions. Two Cb type roof falls were observed where fractured, slickensided, and sheared shale pulled away from adjacent sandstone bodies, and two type B roof falls in sandstone roof are related to a rider seam and shale within the sandstone channel in one place, and to rafted coal in the other.

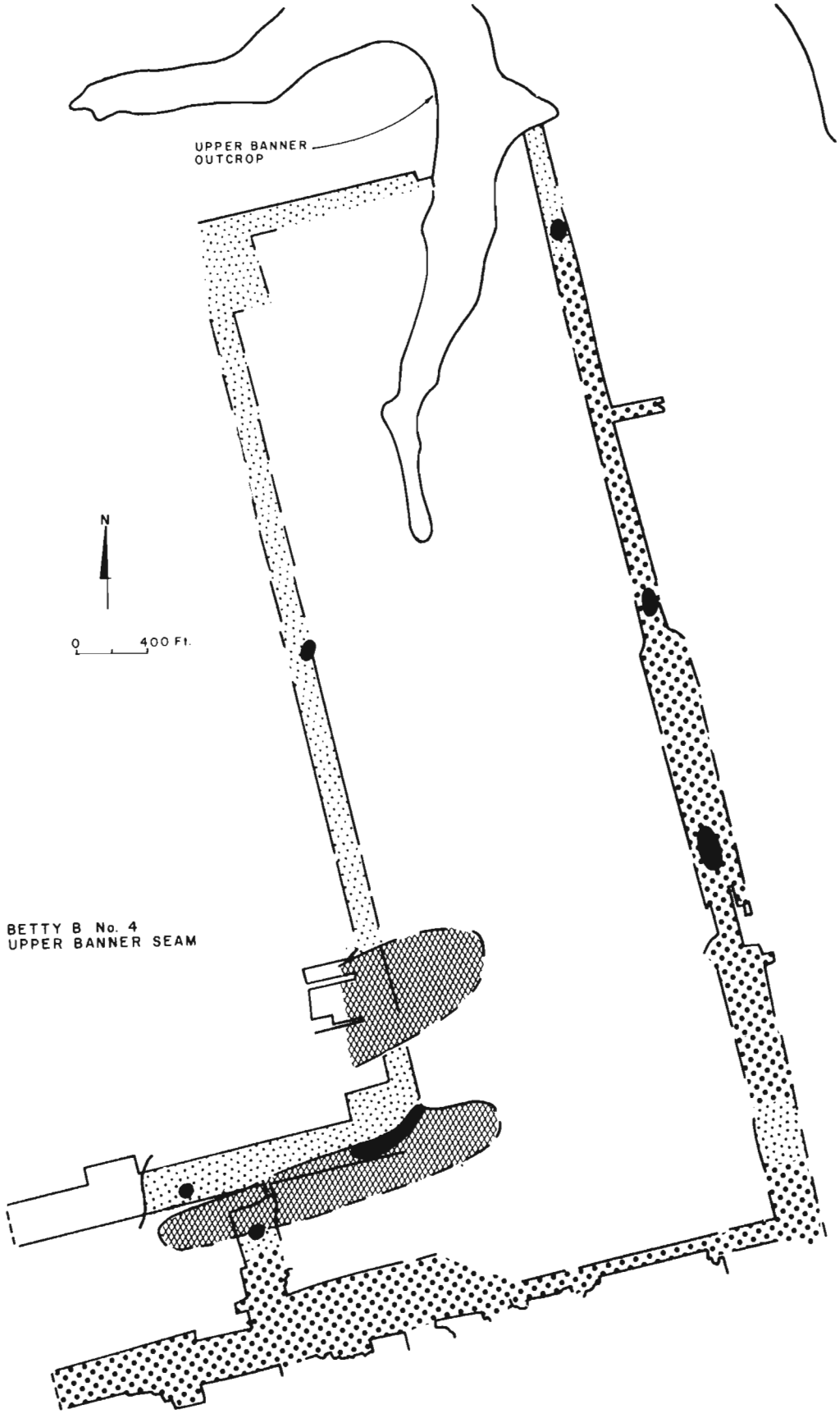


FIGURE 15. - GENERALIZED DISTRIBUTION OF ROOF TYPES IN THE BETTY B No. 4 MINE, UPPER BANNER SEAM.

The roof in the RBJ coal mine is principally shale with minor amounts of sandstone (Fig. 16). The mine has a roof

Figure 16. Generalized distribution of roof types in the RBJ Coal Co., Paramount No. 1 and Betty B No. 9 coal mines.

instability index of 0.08. Most of the shale is stable, although in a few places it contains enough slickensides to be classified as either ASh or A. The coal bed middleman is generally fractured, suggesting some small horizontal bedding plane slippage. In four places channel sandstones were observed cutting down to or near the top of the coal bed, generally forming type C and SS roof.

The Paramount Coal Co. No. 1 mine has a roof essentially composed of shale, with minor amounts of siltstone and sandstone (Fig. 16B). The mine has a roof instability index of 1.5. Roof types include A, B, Sh, ASh, AB, AC. Although the coal bed exhibits deformation in a few places, where it contains fractures and thin crushed zones, it is generally little deformed tectonically. Roof structure is the principal cause of instability. Type A falls are dominant, followed by B and then by ASh and AB horsebacks or falls. B-type roof falls occur in areas where there are thin rider seams or an abundance of plant fossils in the immediate roof.

The Betty B No. 9 mine roof was developed primarily in shale with minor amounts of sandstone at the time it was visited (Fig. 16C). Slickensides are common in the shale so that the roof was classified almost entirely as ASh or A. The

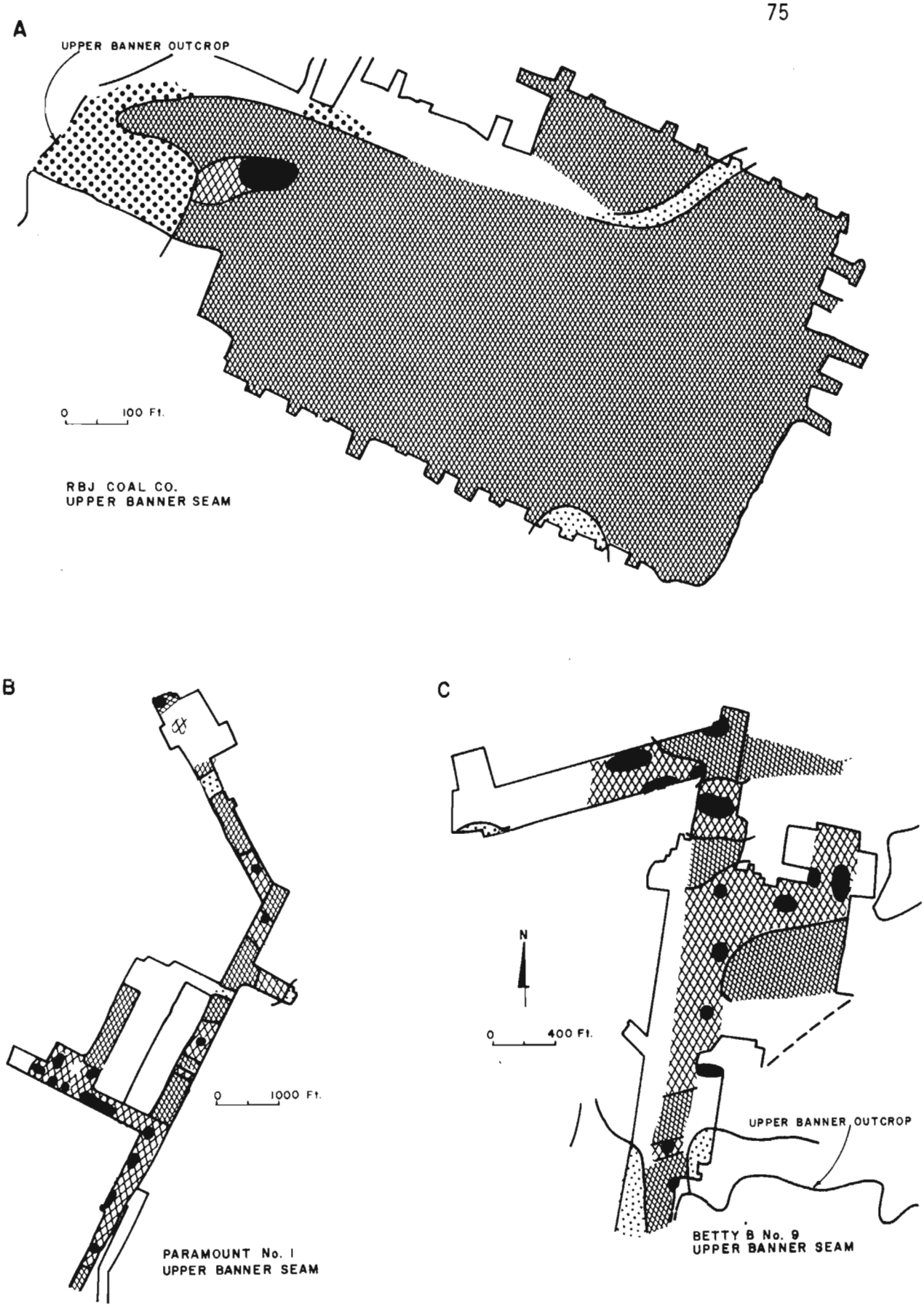


FIGURE 16. - GENERALIZED DISTRIBUTION OF ROOF TYPES IN THE RBJ COAL CO., PARAMOUNT No. 1 AND BETTY B No. 9 COAL MINES.

A. - RBJ COAL CO., UPPER BANNER SEAM.
B. - PARAMOUNT No. 1 COAL MINE, UPPER BANNER.
C. - BETTY B No. 9 MINE, UPPER BANNER SEAM.

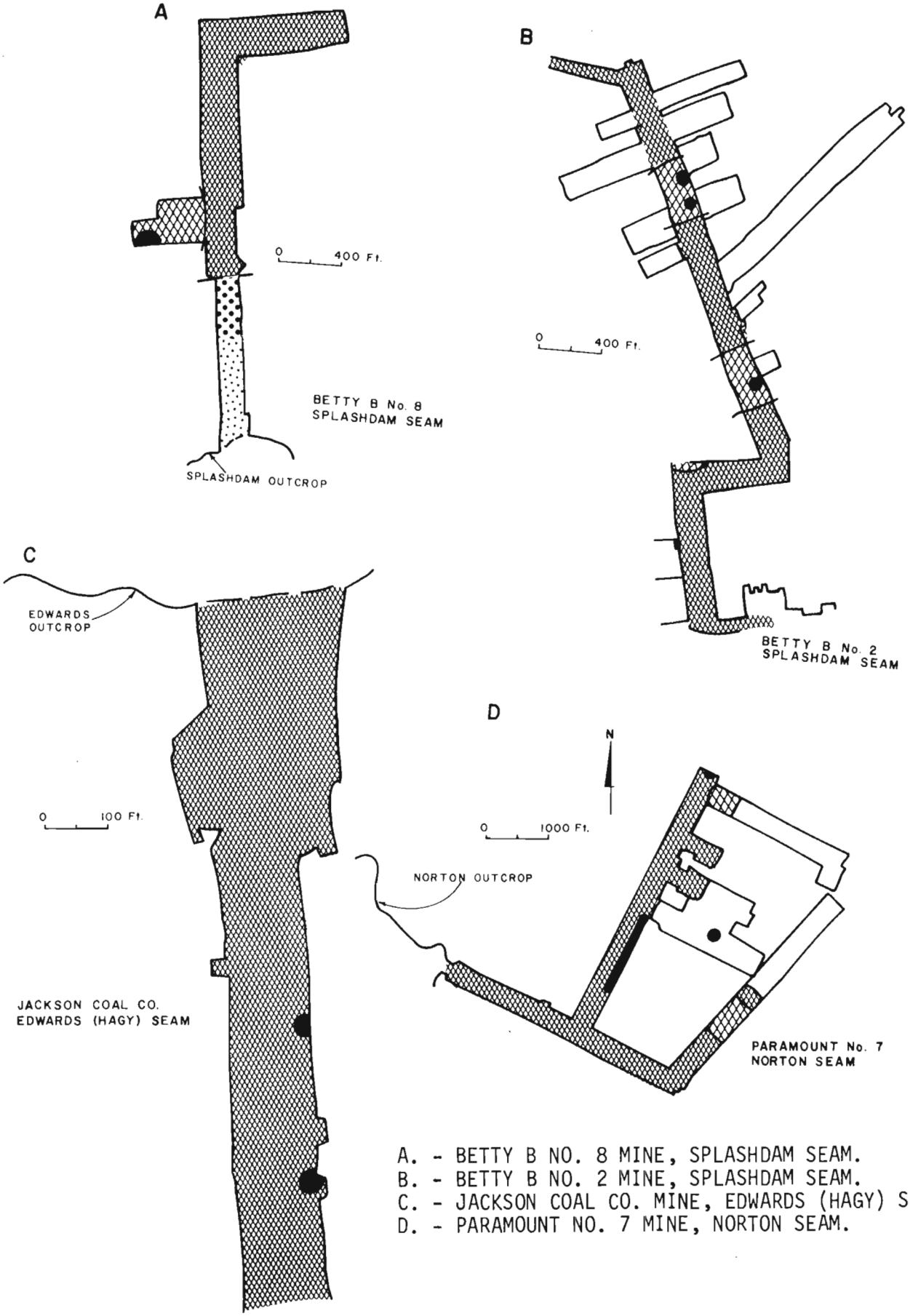
mine has a roof instability index of 0.77. The coal bed is fractured in many places and in several areas contains faults which are both parallel to bedding and cross cutting into the overlying roof rock. Roof disturbances range from small horsebacks to falls which extend into the main roof up to 10 feet above the coal. Almost all of the roof falls and horsebacks are related to the slickensided fractures. In one place, however, coal spars in the shale have contributed to roof instability, resulting in an AB type roof.

Splash Dam coal bed: Two mines, Betty B No. 2 and Betty B No. 8 were visited in the Splash Dam coal bed (Fig. 17). The coal bed ranges from about one and one-half to three and

Figure 17. Generalized distribution of roof types in the Betty B No. 8, Betty B No. 2, Jackson Coal Co., and Paramount No. 7 coal mines.

one-half feet thick and in the mines visited was generally undeformed.

The predominant roof lithology in these two mines is shale, although in about one-third of the Betty B No. 8 mine (Fig. 17A) a sandstone and siltstone-filled channel cuts to the top of the coal bed. In the Betty B No. 8 mine, B type roof occurs in areas where thin coal is interlaminated with soft shale. In general, roof falls are small and horsebacks are few in number and the immediate roof of this coal bed is stable. In one place in the Betty B No. 2 mine, however, (Fig. 17B) a small fault cuts up through the coal into the roof, causing a localized type A roof fall. In another place



A. - BETTY B NO. 8 MINE, SPLASHDAM SEAM.
B. - BETTY B NO. 2 MINE, SPLASHDAM SEAM.
C. - JACKSON COAL CO. MINE, EDWARDS (HAGY) SEAM.
D. - PARAMOUNT NO. 7 MINE, NORTON SEAM.

FIGURE 17. - GENERALIZED DISTRIBUTION OF ROOF TYPES IN THE BETTY B No. 8, BETTY B No. 2, JACKSON COAL CO., PARAMOUNT No. 7 COAL MINES.

a B-type roof fall has occurred in blocky, sulfidic shale. Betty B No. 2 mine has a roof instability index of 0.18 and the Betty B No. 8 mine has an index of 0.14.

Small horsebacks are related to slickensided zones in the roof, and the one small roof fall in blocky shale in Betty B No. 2 shows no obvious geologic features which would cause the structural weakness there.

Edwards (Hagy) coal bed: One small mine, the Jackson Coal Co. mine, was visited in this seam (Fig. 17C). In general, both the coal bed and overlying shale roof show little or no evidence of deformation. The roof is generally stable and classified as Sh, although in two places small horsebacks were formed by intersecting fractures in the immediate roof.

Norton coal bed: One coal mine, Paramount No. 7, was visited in the Norton coal bed (Fig. 17D). Although the roof generally consists of stable shale (type Sh) the coal bed is commonly slickensided, sheared or crushed throughout much of the mine. The mine has a roof instability index of 0.07. Separation along bedding surfaces in the immediate roof results in small B-type failures, and up to 3 feet of roof have been taken during mining to alleviate the problem.

The mine is developed along the trough of the Dorchester syncline and at a relatively shallow depth. The axis of the syncline trends generally north-northwest. A major roof fall, approximately 1400 feet long is in the No. 5 entry on the northwest side of the mine. The fall is continuous for about

21 breaks and was followed shortly by slippage of adjacent roof an inch or two toward the trough of the syncline over its supporting coal pillars. Similarly, cutters (vertical tension cracks) have developed along the entries driven along the southwest limb of the syncline and these, too, are associated with a little subhorizontal slippage of the roof over the coal bed toward the synclinal trough.

The cause of the major roof fall and cutters is not clearly understood. Subhorizontal slippage of the roof, however, is probably related to expansion which resulted from release of residual stresses within immediate roof strata.

Dorchester coal bed: Two mines were visited in the Dorchester coal bed, Westmoreland Coal Company's Bullitt Mine, and Paramount Coal Company's Mine Number 6 (Figs. 18, 19). The geology of the immediate roof is markedly different

Figure 18A. Geologic features of the Bullitt coal mine.

in each of these mines even though they both are in the same seam. The Bullitt mine has a wide variety of roof types, the most common consisting of A, ASh, and C, whereas Paramount No. 6 roof exhibited little deformation and was classified almost entirely as Sh with minor areas of ASh. Dorchester coal bed thicknesses range from 3 to 7 feet.

The Bullitt mine was studied by making observations at 186 stations in accessible parts of the mine (Fig.18A). In general, the roof consists of shale or siltstone which in

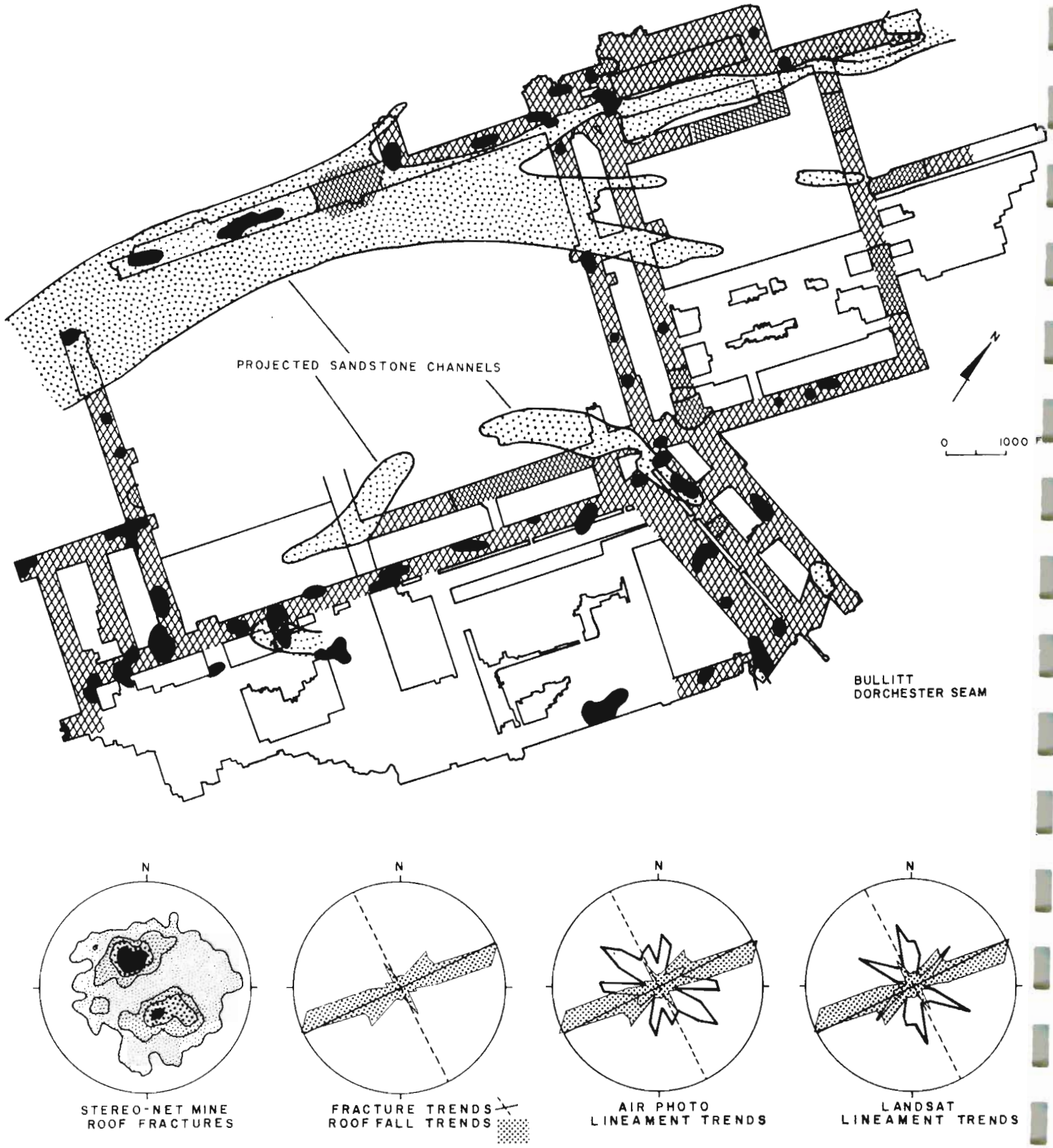


FIGURE 18A. - GEOLOGIC FEATURES AND ROOF TYPES OF THE BULLITT COAL MINE, DORCHESTER SEAM.

places coarsens upward into sandstone or is abruptly scoured by channel sandstones. The mine has a roof instability index of 2.77. The mine is located a short distance from the sharply upturned northwestern limb of the Powell Valley anticline and almost everywhere within the mine there is evidence of tectonic deformation both in the immediate roof and in a middleman of crushed shale several inches thick. In most places slickensides are abundant where the immediate roof is composed of siltstone and shale. A subtle bedding decollement occurs at the top of the main coal bed throughout much of the mine, generally below a one-to-two foot thick zone of sulfurous shale that is thinly interbedded with coal (Fig. 18B).

Figure 18B. Decollements above the coal seam in Bullitt mine, Dorchester coal seam and Prescott No. 2 mine, Imboden seam.

The decollement is characterized by a thin zone of highly fractured shale. Beds above the decollement show small to moderate amounts of low displacement extensional and contractional faults. Where these faults are abundant and have propagated up into the roof they form slickensided discontinuities which cause major problems in roof control.

Fracture trends within the mine are oriented both to the northeast and northwest, with the direction of tectonic transport to the northwest (Fig. 18A). Roof falls and horsebacks are elongated along the northeast trending set of fractures. Short air photo lineaments generally are not aligned with roof fall/horseback trends, and only a small

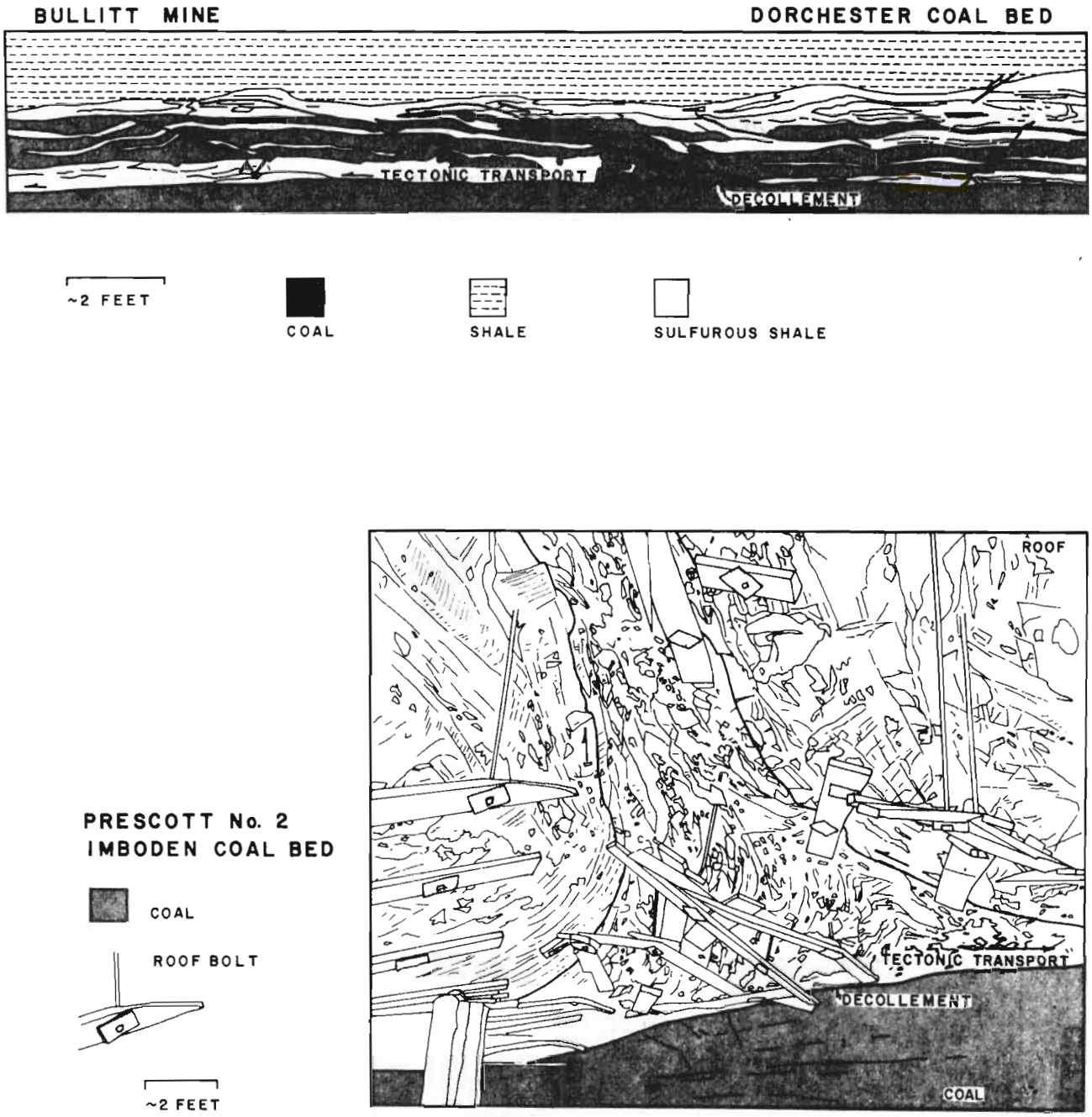


FIGURE 18B. - DECOLLEMENTS ABOVE THE COAL SEAM IN BULLITT MINE, DORCHESTER COAL SEAM AND PRESCOTT No. 2 MINE, IMBODEN SEAM.

LANDSAT lineament peak coincides with a minor roof fall/ horseback trend (Fig. 18).

Roof falls tend to occur in clusters of two or more which generally occupy areas ranging from a few hundred feet or up to a thousand feet long. The greatest concentration of roof falls is in the southeastern part of the mine, in the area adjacent to the northwest limb of the Powell Valley anticline, especially along Main South, 3 Main West and No. 1 left. These are type A falls directly related to slickensides formed by tectonic slippage within and adjacent to the coal bed.

A secondary concentration of roof falls is associated with a large channel which runs along the northwestern boundary of the mine, generally along and parallel to No. 3 North and No. 3 South. In this area tectonic slickensiding in roof shales and siltstones is combined with lithologic contrasts along channel boundaries, producing a multitude of channel boundary roof falls.

Roof falls and high stress conditions which occur near the northwestern extension of 3 Main West and the southwestern extension of No. 3 South are most likely enhanced by stresses transmitted through barrier pillars in the overlying Imboden coal bed. The Imboden is separated from the Dorchester by approximately 450 feet of strata in this area. The roof falls in these areas are in sandstone and are classified as type B. Apparently the sandstones, which normally would have formed a competent roof, separated along carbonaceous bedding

planes because of the additional stresses transmitted through the pillars.

When visited, the Paramount No. 6 mine roof was driven entirely in shale and siltstone which exhibited little evidence of tectonic deformation (Fig. 19A). In some places within the mine, however, the claystone middleman within the

Figure 19. Generalized distribution of roof types in the Paramount No. 6, Paramount No. 8, Sylvia Ann and Kelly Energy Co. coal mines.

coal bed and some of the coal was crushed, folded and faulted. Roof type within Paramount No. 6 was classified primarily as Sh, with some areas classified as ASh.

Clintwood coal bed: One small mine, Paramount No. 8 (Fig. 19B), was visited in the Clintwood coal bed. The mine showed little evidence of tectonic deformation, either within the coal bed or in the immediate roof. Rooted claystone both overlies the coal and occurs as a middleman which separates the coal into two benches within the mine. The upper claystone in places is overlain by a thin rider seam and then by a channel sandstone. The generally weak nature of the claystone and rider in the immediate roof has resulted in a B-type roof over much of the mine. As a result, this claystone and rider is commonly taken down during mining to minimize the danger of roof falls. Elsewhere within the mine a channel sandstone cuts down to the rider, resulting in Cb and C type roof.

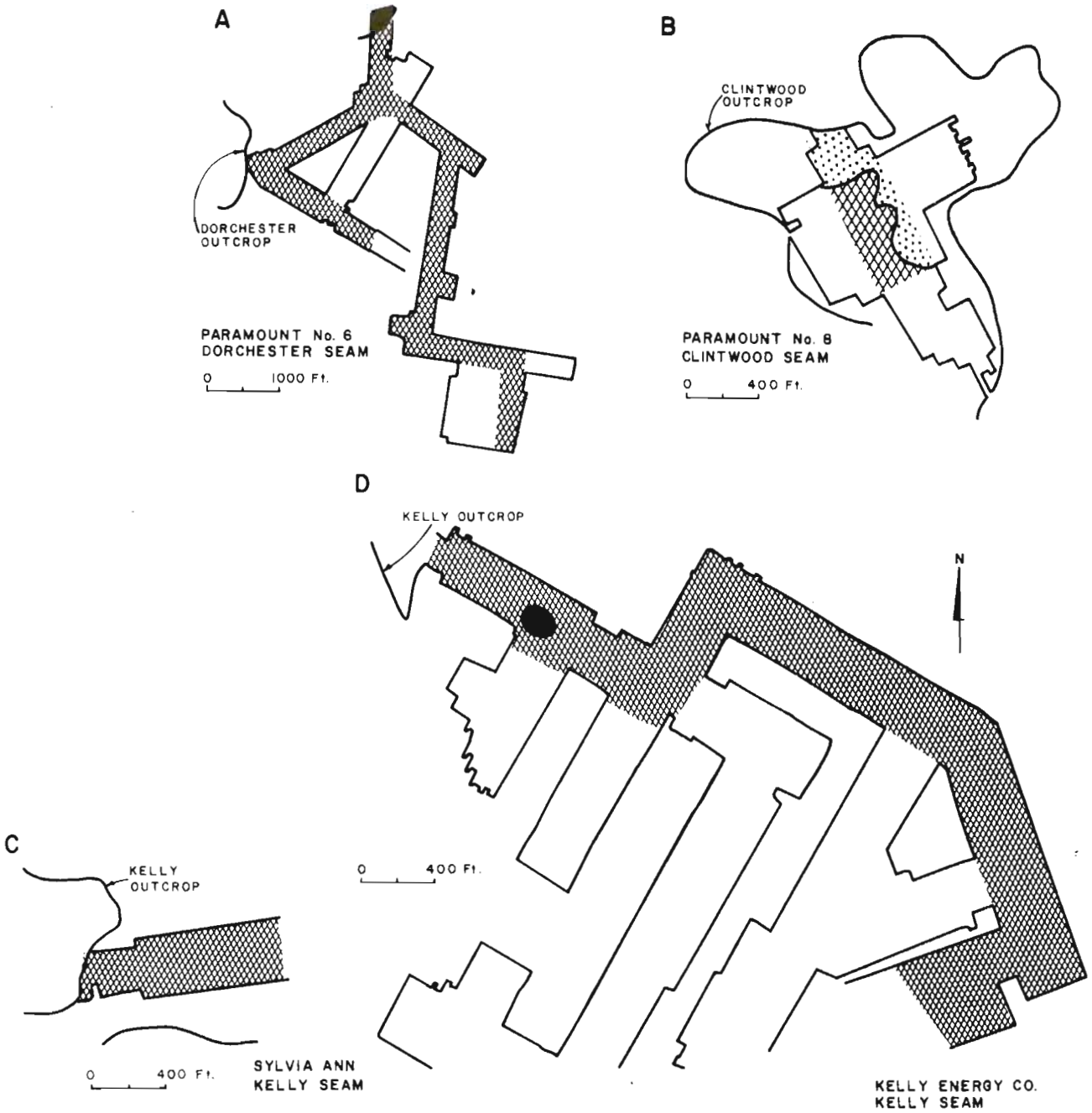


FIGURE 19. - GENERALIZED DISTRIBUTION OF ROOF TYPES IN THE PARAMOUNT No. 6, PARAMOUNT No. 8, SYLVIA ANN, AND KELLY ENERGY CO. COAL MINES.

A. - PARAMOUNT MINING CORPORATION MINE No. 6, DORCHESTER COAL SEAM.
B. - PARAMOUNT MINING CORPORATION MINE No. 8, CLINTWOOD COAL SEAM.
C. - SYLVIA ANN No. 2 COAL MINE, KELLY SEAM.
D. - KELLY ENERGY CO. COAL MINE, KELLY SEAM.

In general, the roof is stable in the Paramount No. 8 mine, especially where care is taken to remove the upper claystone and rider during mining.

Imboden coal bed: Three mines in the Imboden coal bed were visited in the course of this study, the Crossbrook "A", Arno, and Prescott No. 2 (Fig. 20). Coal thicknesses range from about a foot to over 15 feet thick under unusual geologic

Figure 20. Geologic features of the Crossbrook "A", Arno, and Prescott No. 2 coal mines.

conditions, but generally range from 3 to 5 feet thick in this bed. The Crossbrook "A" mine roof is composed mostly of dark gray shale, some carbonaceous and rooted, and commonly fractured and slickensided. In places within the mine a channel sandstone cuts down to within a few feet of the top of the coal. Type A roof predominates within the mine, where slickensides are abundant in the shale. Type Cb roof and AC roof occur along boundaries of channel sandstones and where faults in the shale in the immediate roof cut several feet upward to the base of a channel sandstone.

The Arno mine roof consists mostly of gray carbonaceous shale with small fractures and slickensided surfaces. Roof type is commonly either A or ASh. The mine has a roof instability index of 0.92. In places, channel sandstones cut downward to near the top of the coal bed, resulting in C and AC type roof. In the areas of type C roof, about 4 feet of shale falls between bolts, exposing the base of the channel sandstone. As a result, in some places as much as 3 feet of

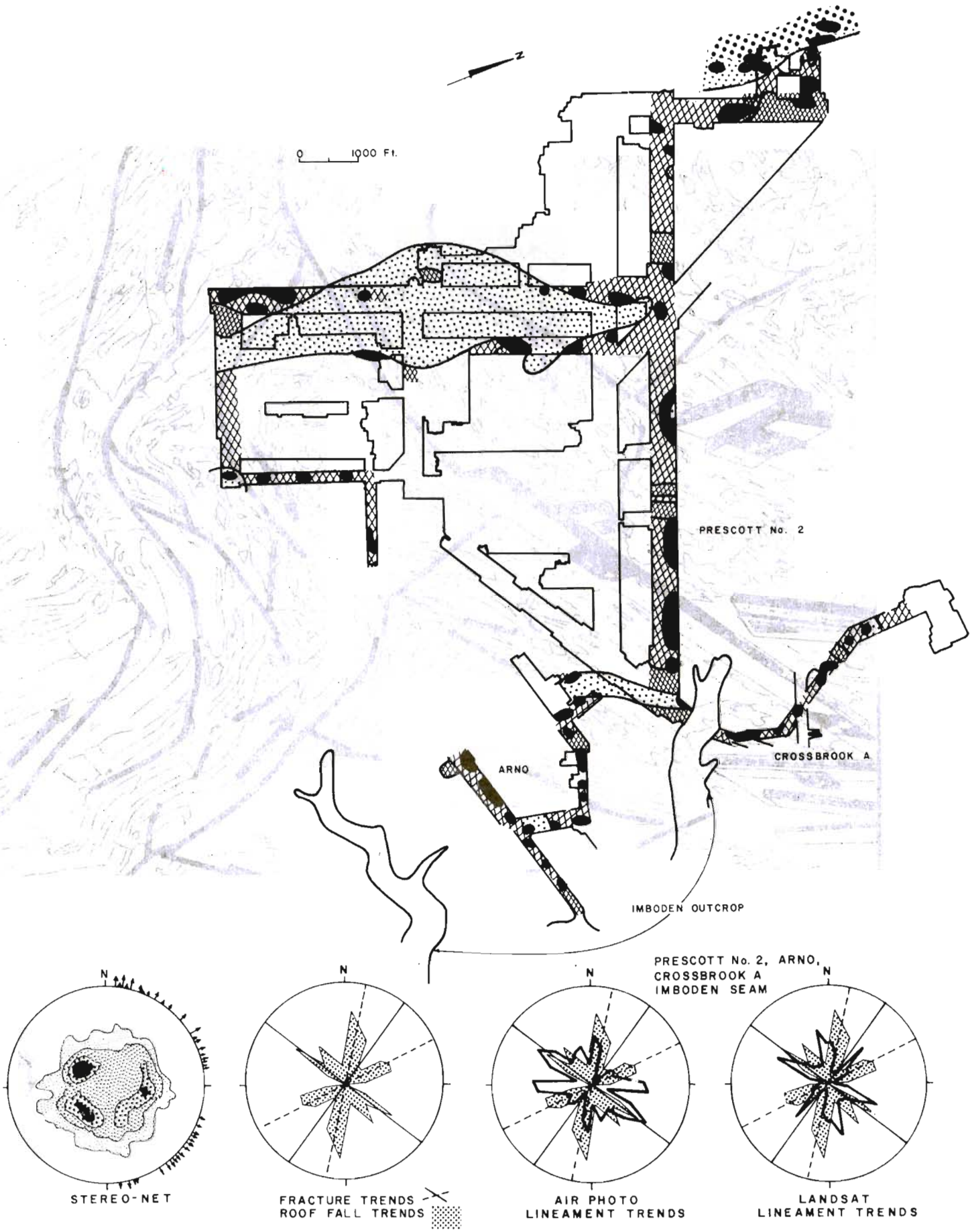


FIGURE 20. - GEOLOGIC FEATURES AND ROOF TYPES OF THE CROSSBROOK "A", ARNO, AND PRESCOTT No. 2 MINES, IMBODEN SEAM.

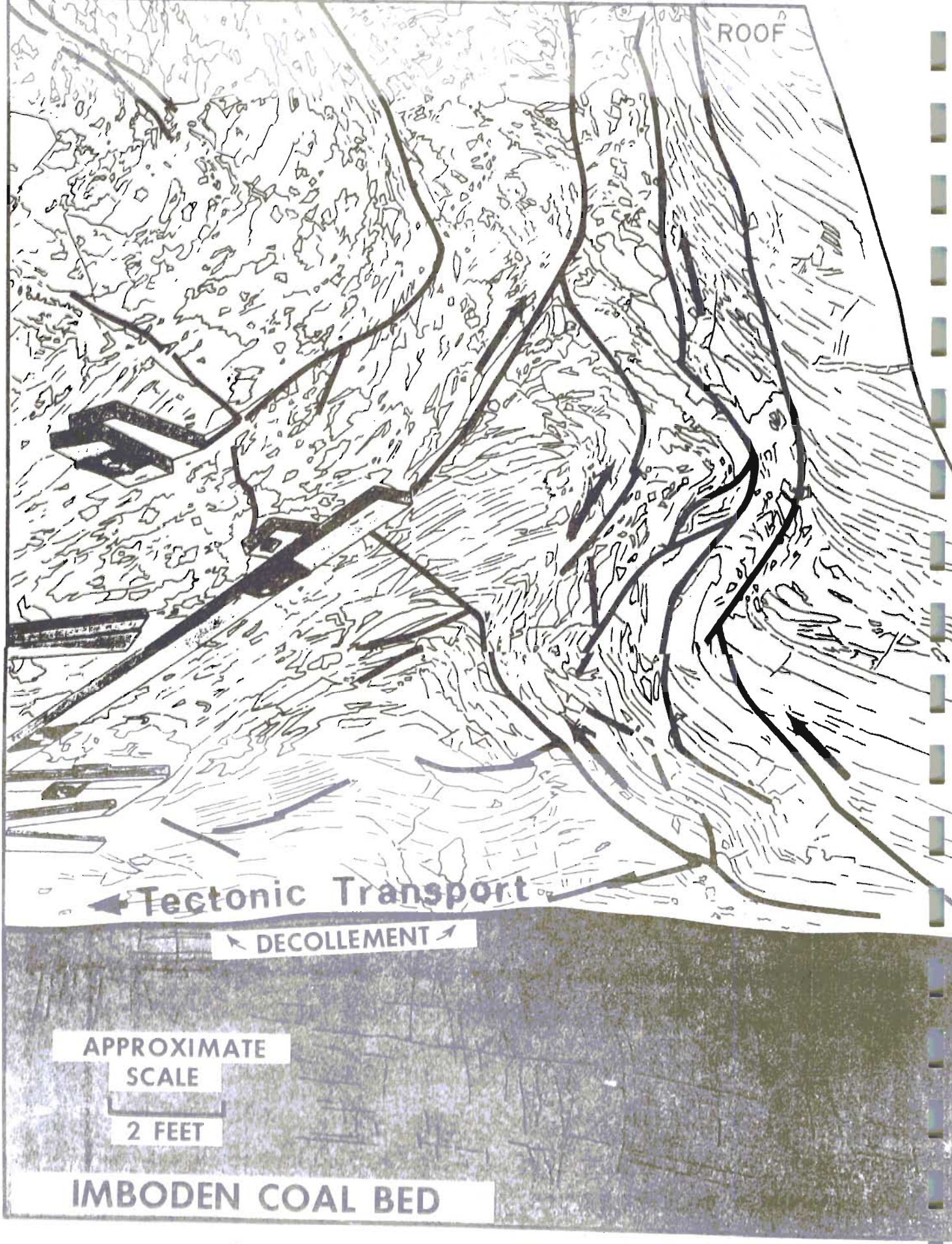


FIGURE 20A. - BEDDING DECOLLEMENT ABOVE THE IMBODEN COAL BED, PRESCOTT No. 2 MINE.

shale is taken with the coal where it cannot be successfully pinned to the overlying sandstone channel. Type B roof was observed in one place where thin sandstones are interbedded with shale. In general, the coal bed is little deformed in the Arno mine, although in places the lower bench of coal and middleman is sheared.

The Prescott No. 2 mine roof consists generally of dark gray shale and channel sandstone. Both the roof and the coal bed are deformed in many places throughout the mine by tectonic folds and faults. The mine has a roof instability index of 1.28. Slickensides are abundant in the shales, resulting in widespread distribution of type A and ASh roof and associated falls. Type C roof is common where channel sandstones cut down near to the top of coal, type Cb along the sandstone boundaries and type AC where faulted and slickensided zones in shale in the immediate roof extend up to the base of an overlying sandstone channel. Type B roof occurs either where the immediate roof contains a thin rider seam or roof shales contain an abundance of plant fossils.

There is abundant evidence of bedding decollement at the top of the Imboden coal bed in the Prescott No. 2 mine. Folded and faulted shale extends upward into the roof in places for a few tens of feet in places where the underlying coal shows little or no deformation (Figs. 18B and 20A). These folds commonly verge toward the southeast, opposite the direction of tectonic transport.

Major fracture trends are generally to the northeast and northwest, and there appears to be four main directions of

fractures (Fig. 20). Roof falls and horsebacks follow three of these four fracture trends, and they appear to be reflected by orientations of the short air photo lineaments. LANDSAT lineament trends, however, do not appear to coincide with roof fall/horseback trends observed in the mine.

In the mines visited in the Imboden coal bed there is abundant evidence of tectonic deformation, both in the coal bed and in the immediate roof. Tectonically induced type A roof falls and horsebacks are common. Roof conditions are exacerbated where channel sandstones cut into or near the immediate roof.

Kelly coal bed: Two small mines in the Kelly coal bed were visited during this study, the Sylvia Ann No. 2 and Kelly Energy mines (Figs. 19C, D). The Sylvia Ann No. 2 mine roof consists of medium gray shale, in places with numerous plant fossils, and was classified generally as Sh. The Kelly Energy mine roof consists generally of medium gray shale, in places with a thin (less than one-half inch) claystone layer between the top of the coal and the base of the shale. Plant fossils are abundant locally and may cause a type B roof. In one place within the Kelly Energy mine the immediate roof consists of slickensided shale which is gently folded, and was classified as ASh.

Upper Standiford coal bed: One small mine, the Elkins No. 10A mine, was visited in the upper Standiford coal bed (Fig. 21A).

Figure 21. Generalized distribution of roof types in the Elkins 10A, Elkins 6A, Elro Coal Corp. No. 3 and Shelton Coal Corp. No. 4 coal mines.

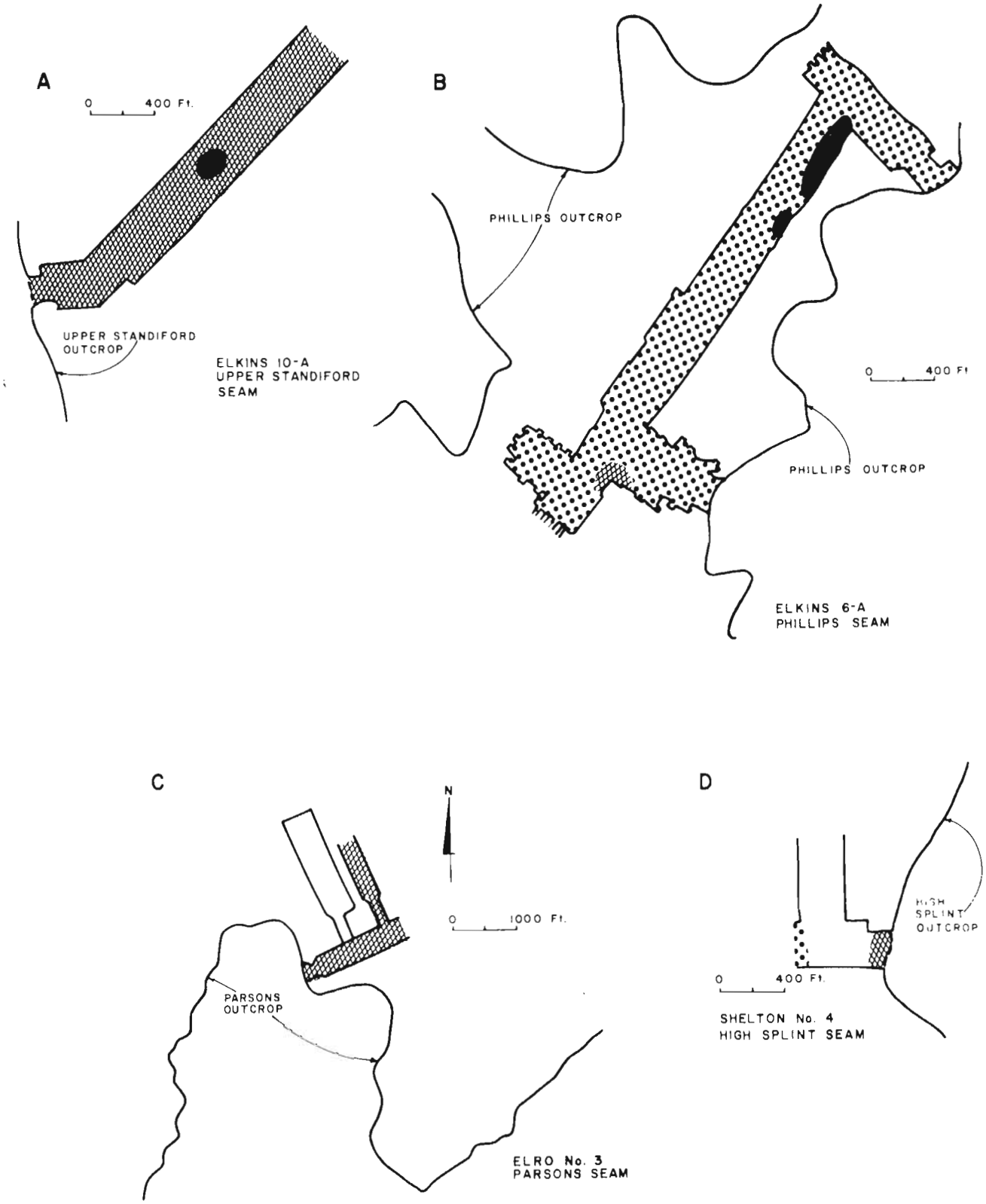


FIGURE 21. - GENERALIZED DISTRIBUTION OF ROOF TYPES IN THE ELKINS 10A, ELKINS 6A, ELRO No. 3, AND SHELTON COAL CORP. No. 4 COAL MINE.

A. - ELKINS 10A MINE, UPPER STANDIFORD SEAM.
B. - ELKINS 6A MINE, PHILLIPS SEAM.
C. - ELRO No. 3 MINE, PARSONS SEAM.
D. - SHELTON No. 4 MINE, HIGH SPLINT SEAM

The immediate roof in the mine consists of shale or claystone with little or no evidence of tectonic deformation. In one place within the mine a broad shallow type C roof fall was observed where a sandstone channel cut to within 3 feet of the top of the coal bed. Gentle folds in the shale beneath the sandstone probably were caused by differential loading during deposition of the channel-fill sands.

Taggart coal bed: Four mines were visited in the Taggart coal bed, Holton Marker, Holton Taggart, Wentz 1 and Wentz 1B. The Holton Marker was developed after strip mining and is now connected with the Holton Taggart mine but has a separate ventilation system (Fig. 22). For the purposes of this paper the Holton Marker is considered together

Figure 22. Generalized distribution of roof types in the Holton Marker and Holton Taggart coal mines.

with the discussion of the Holton Taggart mine.

The Holton Taggart and Holton Marker mine roof shows little or no evidence of tectonic deformation. The roof instability index for these mines is 0.30. Slickensided surfaces (slips) were observed in a few places in shale roof rock, but appear to be related either to local faulting or to differential loading of overlying sandstone beds. In some places strata in the roof coarsen upward from shale to rippled or finely cross bedded sandstone. In other places, sandstone channels cut sharply into underlying shales.

Roof type consists of B, C, Cb, SS, Sh, and ASh. Areas of unstable roof are related primarily to boundary conditions

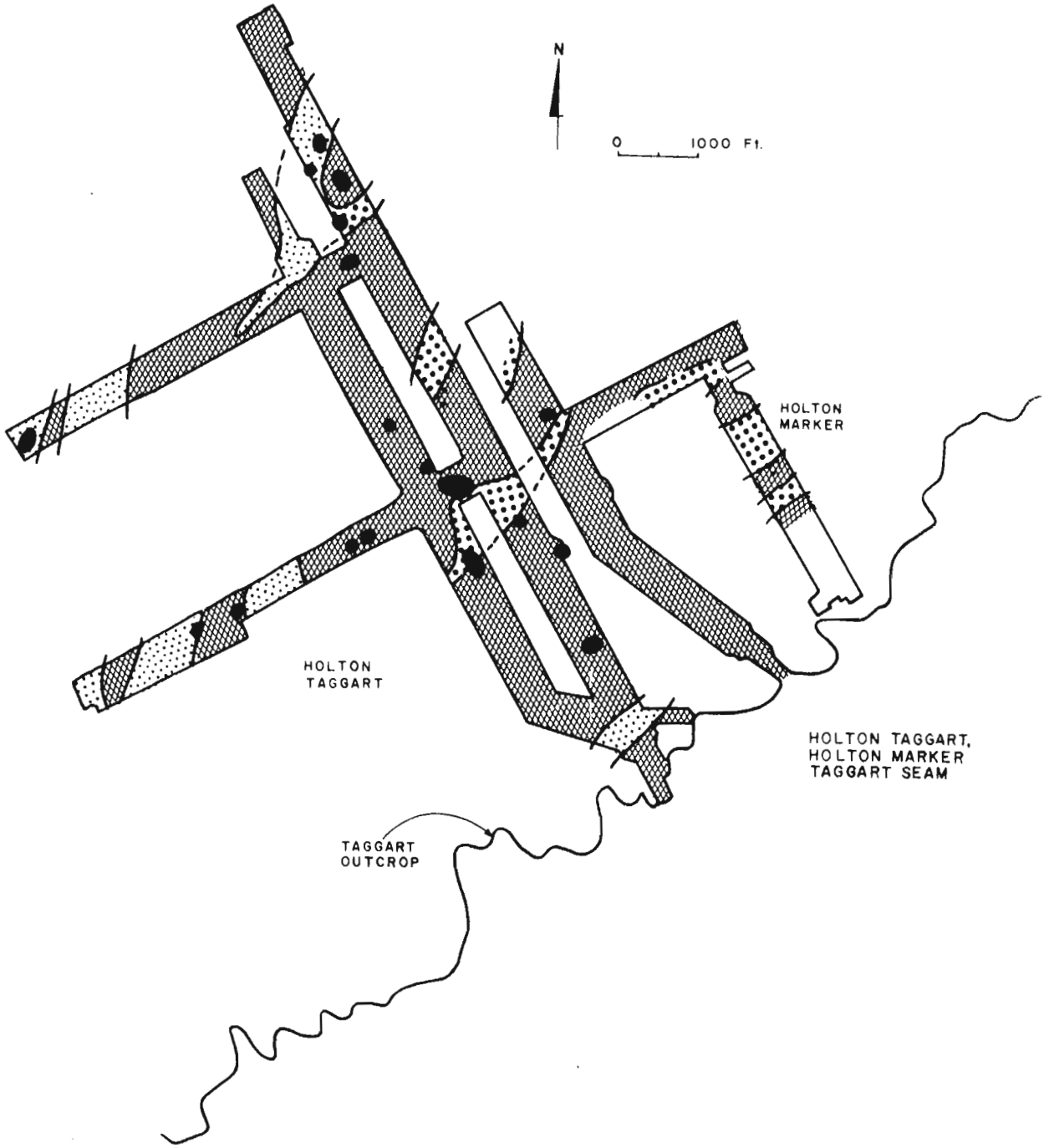


FIGURE 22. - GENERALIZED DISTRIBUTION OF ROOF TYPES IN THE HOLTON MARKER AND HOLTON TAGGART COAL MINES, TAGGART SEAM.

between sandstone and shale units (type Cb). Smaller areas of unstable roof are related either to sandstones a foot or so above the coal (type C), rooted claystones above the main coal bed (type B), or slickensided areas in shale roof rock (type ASh).

The Wentz 1 mine roof consists primarily of shale and siltstone, with only a little sandstone in the western part of the mine (Fig. 23). The roof instability index for this mine is 0.61. Slickensided surfaces are common in the shale

Figure 23. Generalized distribution of roof types in the Wentz and Wentz 1B coal mines.

and siltstone roof so that much of it was classified as A or ASh. B-type roof was observed in three places where shale coarsened upward to sandstone, and Cb type roof was observed in three places in the western part of the mine. Unstable roof was associated chiefly with type A slickensides. Type Cb and B roof falls are relatively minor in this mine.

The Wentz 1B mine roof consists almost entirely of stable sandstone (type SS), in places separated from the coal bed by a few inches to a few feet of stable shale. The roof instability index for this mine is 0.13. Cb roof conditions and shale were observed in the immediate roof a thousand feet or so inby the portal.

Overall unstable roof in the Taggart seam is about equally attributed to types A, C, and Cb roof conditions. Slickensided, type A, roof together with channel boundary roof conditions constitutes the greatest hazard in coal mines in the Taggart seam.

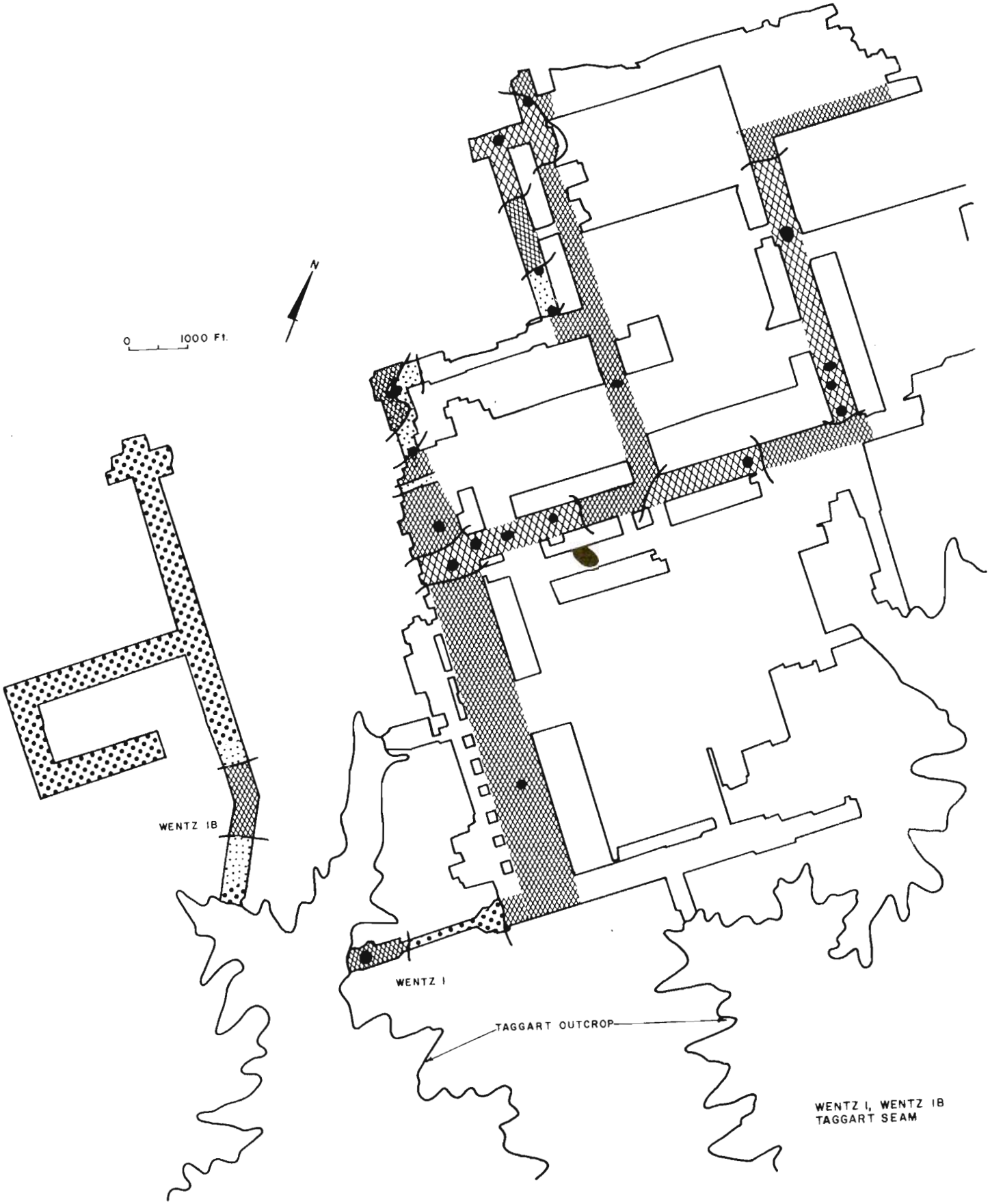


FIGURE 23. - GENERALIZED DISTRIBUTION OF ROOF TYPES IN THE WENTZ 1 AND WENTZ 1B COAL MINES, TAGGART SEAM.

Phillips coal bed: One small mine, the Elkins No. 6A mine, was visited in the Phillips coal bed during this study (Fig. 21B). The roof of the mine is dominantly sandstone, but in places with a thin shale between it and the top of the coal bed. There is a type C horseback in one place, where shale has pulled away from the overlying sandstone. In another place, where closely placed joints are parallel to an entry, the sandstone roof has fallen for a distance of 4 breaks.

Parson coal bed: One small mine in the Parson seam, the Elro Coal Corporation Mine No. 3, was visited during this study. The roof of the mine is composed of gray siltstone with locally abundant plant fossils. Slickensides were observed in places in the immediate roof and the coal bed is locally sheared in the middle. The deformation is slight, however, and does not appear to contribute significantly to roof instability. The roof of this mine was classified as type Sh.

High Splint coal bed: One small mine, the Shelton Coal Corp. Mine No. 4, was visited in the High Splint coal bed. At the entrance of the mine, in the high wall, a large sandstone body is separated from the top of the coal bed by 1 to 5 feet of shale. Slickensides are locally developed, forming a few small horsebacks, but the roof is generally in good condition. In this area the roof was classified as ASh. At the time the mine was visited, the working face was eight breaks from the entrance. In the vicinity of the face the roof consists of sandstone and was classified as SS.

The mine is above old works, and differential stresses because of pillared vs. non-pillared areas below has caused the coal bed to separate in some places from sandstone roof rock by as much as two inches. In other places nearby the ribs show evidence of pressure.

RECOMMENDATIONS AND CONCLUSIONS

Based on this study it is recommended that:-

1) A manual be prepared for coal miners which explains in layman terms how to recognize geologic features which contribute to roof falls.
2) An audio-visual presentation be prepared for use in Annual Training and other Safety courses for coal miners.
3) That studies be made on methods of supporting areas of bad roof caused by specific geologic conditions.
4) That DMR personnel work with and train coal mine operators, geologists, engineers, and safety personnel of mining companies in recognition of geologic features related to areas of bad roof conditions in coal mines.
5) That DMR personnel continue its roof fall study in the remainder of the Virginia coal field. Coal mine personnel have expressed an interest in working with the Division of Mineral Resources in each of the areas noted above.

In general, it is concluded that specific geologic conditions cause abundant, major structural and stratigraphic discontinuities in coal mine roof strata. These discontinuities contribute markedly to poor roof conditions. With training, coal miners can readily identify these conditions and take steps to minimize their effects.

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