RI 9267

REPORT OF INVESTIGATIONS/1989

Hillseam Geology and Roof Instability Near Outcrop in Eastern Kentucky Drift Mines

By Gary P. Sames and Noel N. Moebs

BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

Report of Investigations 9267

Hillseam Geology and Roof Instability Near Outcrop in Eastern Kentucky Drift Mines

By Gary P. Sames and Noel N. Moebs

UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary

BUREAU OF MINES
T S Ary, Director

Library of Congress Cataloging in Publication Data:

Sames, Gary P.
Hillseam geology and roof instability near outcrop in eastern Kentucky drift mines / by Gary P. Sames and Noel N. Moebs.

(Report of investigations; 9267)

Bibliography: p. 32

Supt. of Docs. no.: I 28.23:9267.

1. Mine roof control. 2. Joints (Geology)-Kentucky. 3. Outcrops (Geology)-Kentucky. 4. Coal mines and mining-Kentucky. I. Moebs, Noel N. II. Title. III. Series: Report of investigations (United States. Bureau of Mines); 9267.

TN23.U43 [TN288] 622 s-dc20 [622'.28] 89-600173

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS—Continued

Page

TABLE

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	in	inch
ft^3	cubic foot	pct	percent
h	hour	st	short ton

HILLSEAM GEOLOGY AND ROOF INSTABILITY NEAR OUTCROP IN EASTERN KENTUCKY DRIFT MINES

By Gary P. Sames[1] and Noel N. Moebs[1]

ABSTRACT

This U.S. Bureau of Mines study was conducted in eastern Kentucky drift mines as part of an ongoing research program to characterize the outcrop barrier zone. "Hillseams" were identified as the dominant geologic cause of roof instability unique to the outcrop barrier zone, with many roof fall injuries and fatalities attributed to them. Hillseam is the eastern Kentucky miners term for weather-enlarged tension joints that occur in shallow mine overburden where surface slopes are steep. Hillseams are most conspicuous within 200 ft laterally of a coalbed outcrop and under 300 ft or less of overburden. Hillseams form by stress relief, and therefore tend to parallel topographic contours and ridges. They can intersect at various angles, especially under the nose of a ridge, and create massive blocks or wedges of roof prone to failure. Examples of hillseams are described in both outcrop and in coal mine roof to establish their geologic character and contribution to roof failure.

[1]Geologist, Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

The U.S. Bureau of Mines has investigated coal mine roof instability since its inception in 1910 (*1*)[2] and has issued many publications on the causes of instability and methods of improving support as shown in reference 2 and subsequent compilations. However, the factor of geologic variables and their bearing on roof falls has not been fully appreciated until recently, and techniques for identifying and analyzing these variables are only now emerging.

Nearly all roof failures can be placed in one of two principal categories: geology related and stress related (*3*). The Bureau is identifying and assessing the geologic features commonly associated with roof failure and studying those that constitute the most important causative factors in roof falls. The importance of each feature may, of course, vary from one district to another.

Many minor geologic structures are encountered in Appalachian coal mines. These include paleochannels, claystone dikes, slickensides, joints, slumps, faults, kettlebottoms, and horsebacks. Some of these are described in previous Bureau publications as to their character and effect on mine roof (*4-5*). Most are either syngenetic or diagenetic in origin; that is, they are nontectonic, having formed contemporaneously with deposition or shortly thereafter during compaction and consolidation. Hillseams are one of the rare examples of a roof structure formed long after consolidation.

Unweathered intraformational joints are found in every mine where thick, massive strata occur. They commonly form a boundary of a roof fall but generally are not a causative factor. Joints are reported to play a much greater role in roof failure in the Western United States than in the Eastern United States (*6*).

Highly weathered joints, or hillseams, do adversely affect mine roof stability in areas of high topographic relief, such as in Mine Safety and Health Administration (MSHA) District 6 in eastern Kentucky (fig. 1). In this district, drift or hilltop mining is practiced almost exclusively, and hillseams (also called mountain breaks or mudseams in miner's terminology) have contributed to many roof support problems, especially near the outcrop barrier zone. At least four fatal accidents and two serious injuries were attributed to hillseam-related roof falls in MSHA District 6 during the 1980-85 period, one fatality in 1986, and two fatalities in 1987.

In addition to hillseam-related roof falls in underground coal mines, strip mine highwall stability is, to a large degree, adversely affected by the presence of hillseams. Figure 2 shows a nearly vertical strip mine highwall formed by one of several large, parallel hillseams. While hillseams may facilitate highwall removal, they can also be extremely hazardous, forming undetected, freestanding slabs or wedges of rock that can topple forward or slump into the excavation without warning.

Hillseams also constitute a hazard in deep roadcuts that parallel surface contours. While deep-seated rockslides are rare (*7*) they typically involve excavated slopes in which large wedges of rock, separated from the valley walls by near vertical stress relief joints (hillseams), slide or hinge over into the excavation. Figure 3 shows such a situation in which a large wedge of rock, separated from the wall of a roadcut by a hillseam, is unsupported and may slide or topple towards the pavement without warning.

The main objective of this report is to describe the geologic character of, and types of roof failure associated with, hillseams. Examples of hillseams exposed at the surface and in underground mines in eastern Kentucky are presented. This information should be helpful to operators and enforcement personnel in their efforts to recognize and anticipate hazardous roof conditions caused by the presence of hillseams.

The long-range goal of this ongoing research program is to provide improved roof support methods and mine planning recommendations based on this geotechnical characterization of hillseams and further characterization of the outcrop barrier zone.

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

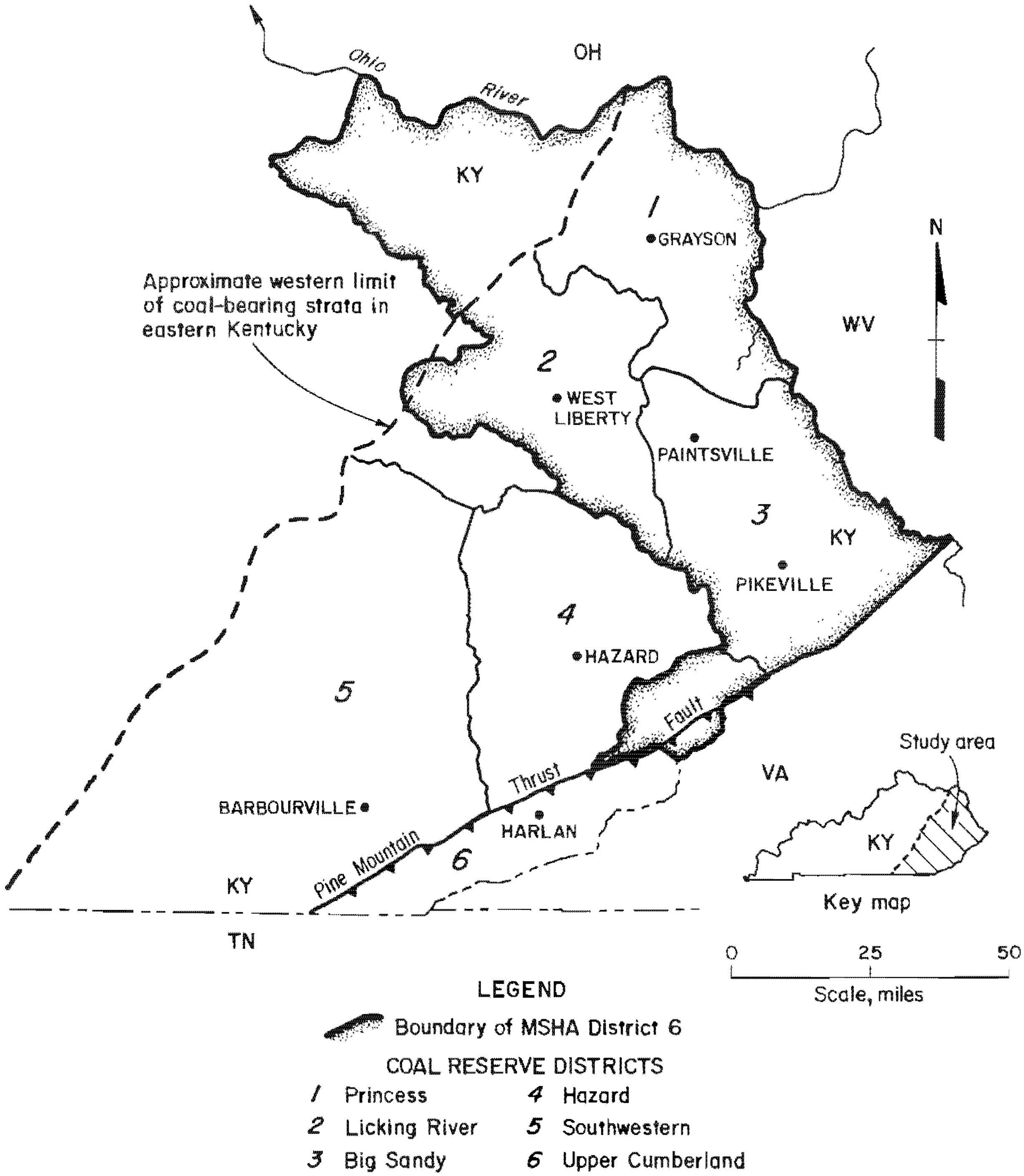

Figure 1.–Eastern Kentucky coal reserve districts and MSHA District 6.

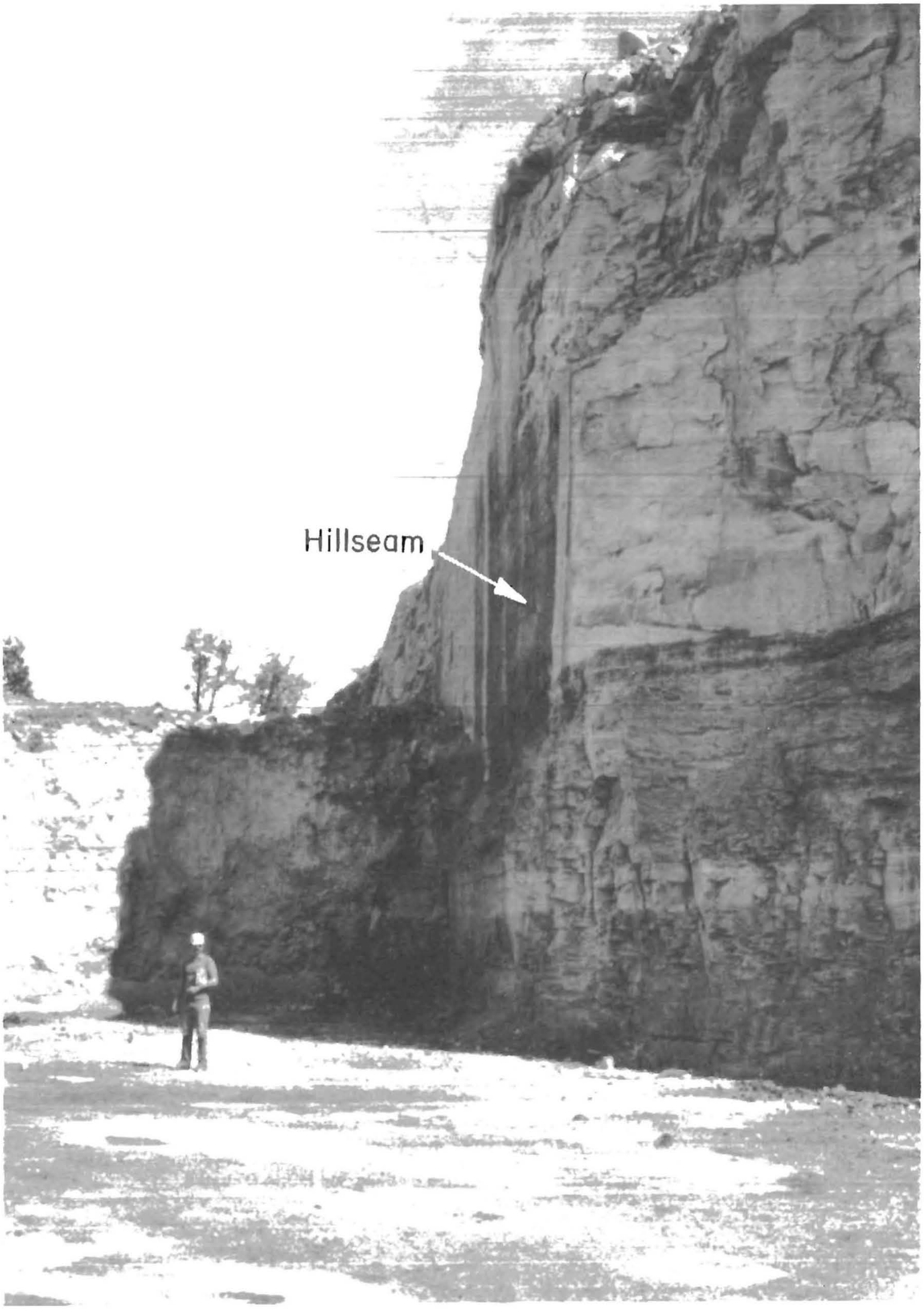

Figure 2.-Hillseam in strip mine highwall.

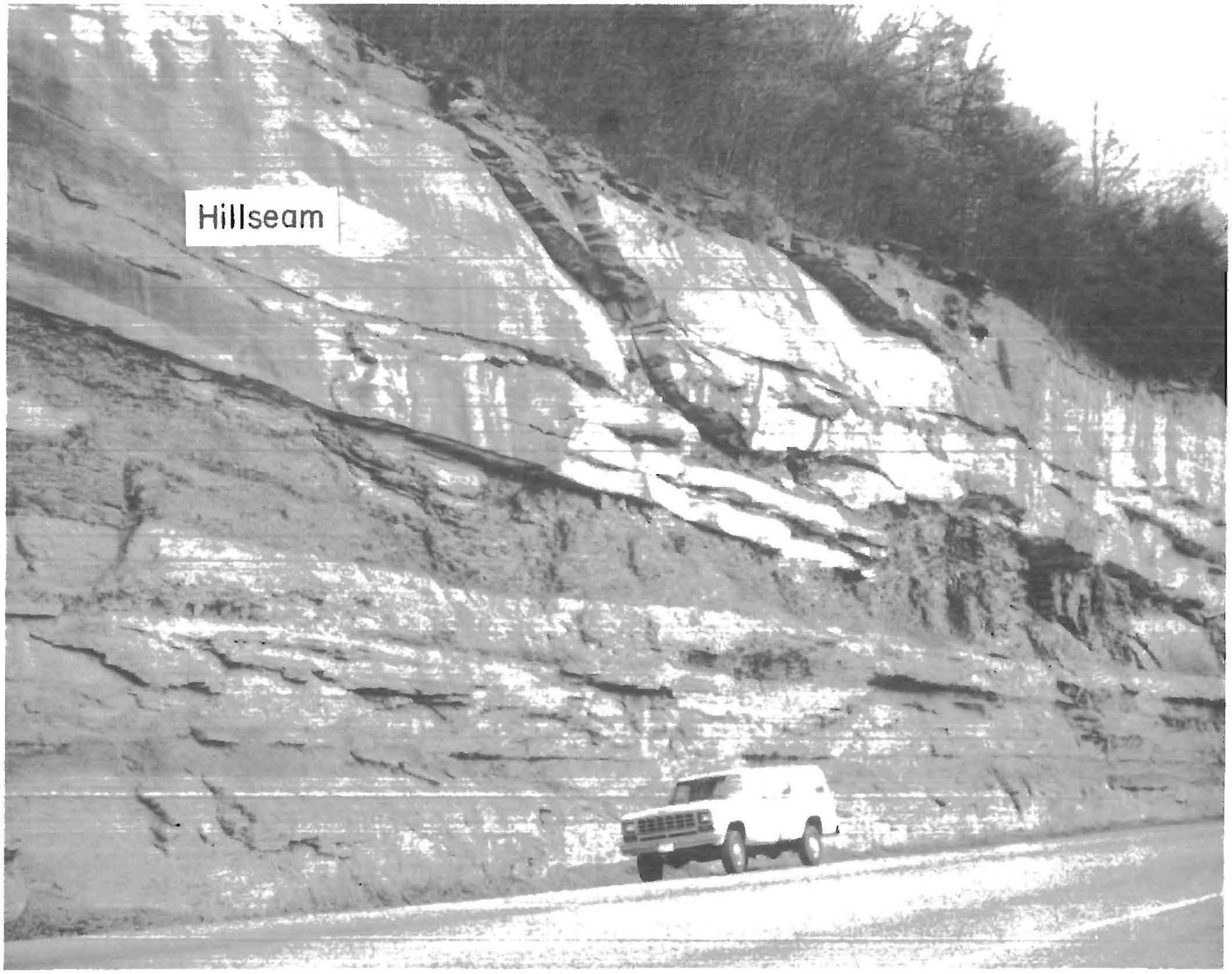

Figure 3.–Hillseam in wall of roadcut.

GEOLOGIC SETTING

This study was centered in MSHA District 6 in eastern Kentucky (fig. 1). District 6 encompasses 15 of the 35 coal-producing counties in eastern Kentucky. District 6 is in the Cumberland Plateau, an area of sharp ridges, V-shaped valleys, and high topographic relief, commonly of 400 to 600 ft.

The plateau is underlain by rocks of the Lower and Middle Pennsylvanian Series consisting predominantly of sandstone and shale, with smaller amounts of claystone and coal. Some of the economically important coalbeds in these series are listed in figure 4.

Structural dips of the rock strata seldom exceed 1°. Topsoil is thin and weathering extends to varying depths, generally not more than a few feet on hillsides but much deeper along joints.

The heavily wooded hillside slopes are generally very steep, but do vary over rock strata of contrasting strengths and resistance to weathering. Slopes on soft claystone and shale, for example, range from 9 to 27 pct (5°-15°). Slopes on more resistant silty shale and sandstone common to the study area range from 38 to 57 pct (21°-30°). Thick sequences of resistant sandstone tend to form very steep slopes or cliffs. Rock slope failures at massive sandstone cliffs occur as a result of sliding or rotation of large blocks facilitated by jointing (fig. 5).

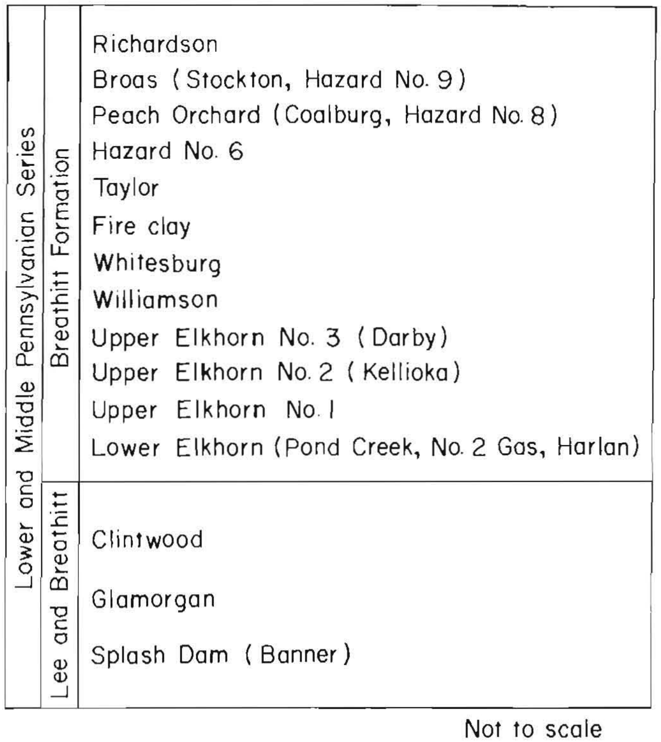

Figure 4.–Generalized column of coalbeds in study area.

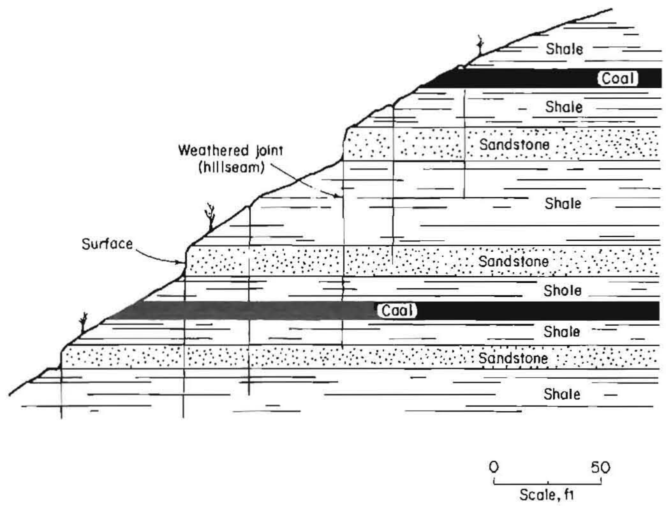

Figure 5.–Profile of hillseam occurrence.

HILLSEAMS

DESCRIPTION AND OCCURRENCE

The term hillseam is used by eastern Kentucky coal mine personnel to describe almost any form of a weathered joint that occurs in the mine roof. Joints occur throughout the shallow overburden of eastern Kentucky, separating the strata into blocks or wedges. Except for bedding planes, joints are the most important structural feature in the characterization of shallow rock mass in the region. They are nearly vertical and perpendicular to the bedding planes and allow ground water to percolate downward from the surface, which accelerates the weathering process in the fracture walls. Some evidence of weathering is necessary to distinguish hillseams from mining-induced cracks in the roof.

Hillseams vary widely in character. They commonly consist of a near-vertical joint or zone of closely spaced joints that are weathered, as indicated by iron oxide discoloring, mud, or softening of the adjacent rock. Figure 6 shows a common type of hillseam in outcrop. The intensity and width of weathering varies greatly with rock type, with shale weathering more readily than sandstone. The weathering results in the alteration of the walls of the joint that may be extensive enough to permit a sizable influx of water (fig. 7) and mud from near the surface into mine workings.

Hillseams range from little more than an iron- or mud-stained crack in the mine roof to zones 1 to 2 ft wide consisting of intensely weathered rock, or rock fragments and mud. Many hillseams appear to be narrow zones of closely spaced, weathered joints (fig. 8), but in reality, originate as a single joint. Weathering progresses irregularly into the walls of the joint, separating parallel slabs of rock in progressive stages (fig. 9).

The character of a hillseam and the intensity of weathering can change abruptly along strike, or remain constant for many feet. Most hillseams are straight, but a few are curved. Some gradually diminish along strike and disappear, some are terminated by other hillseams, and others intersect (fig. 10). Hillseams almost always terminate against a coalbed, or continue through the coal as a minor fracture, and reappear in the strata below (fig. 11).

Figure 6.–Parallel weathering exposed in silty shale highwall.

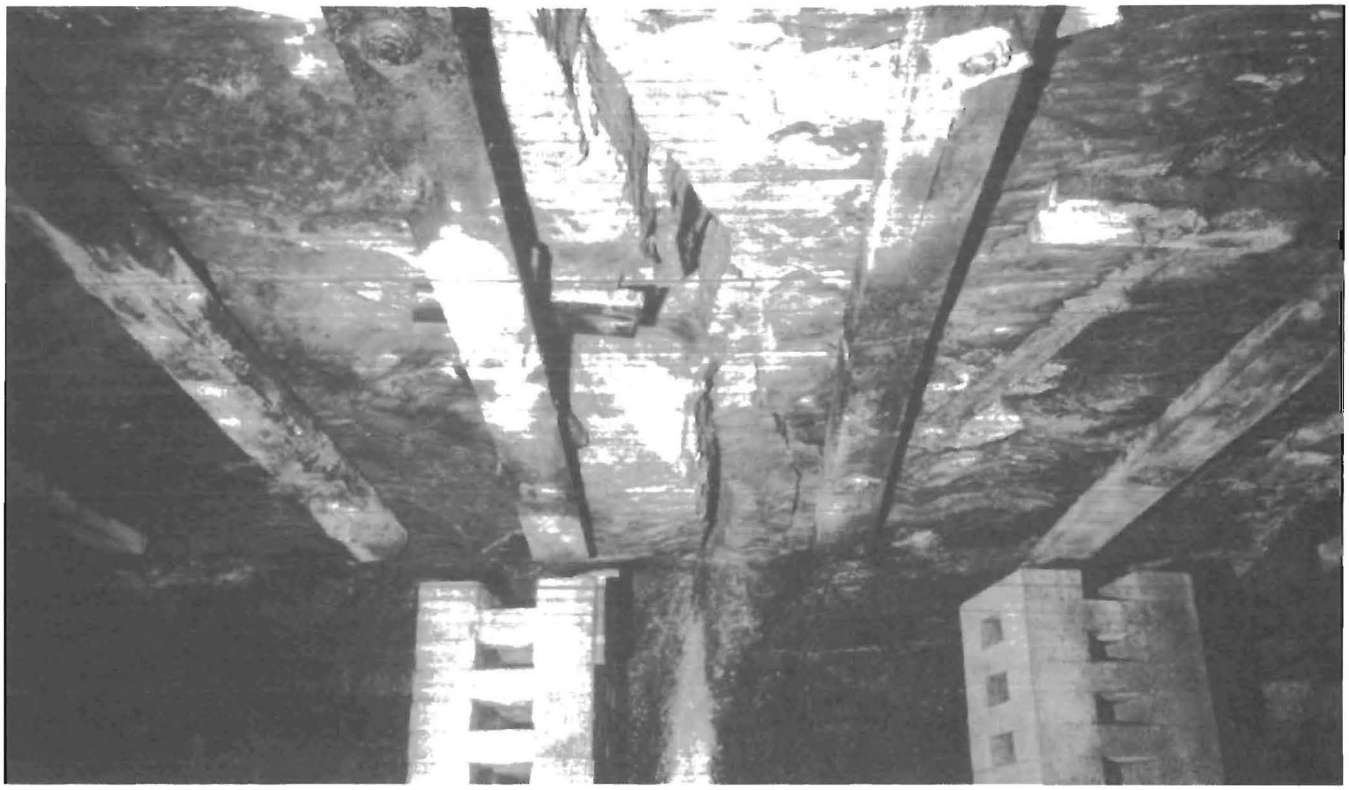

Figure 7.-Rib stained by ground water channeled by hillseam.

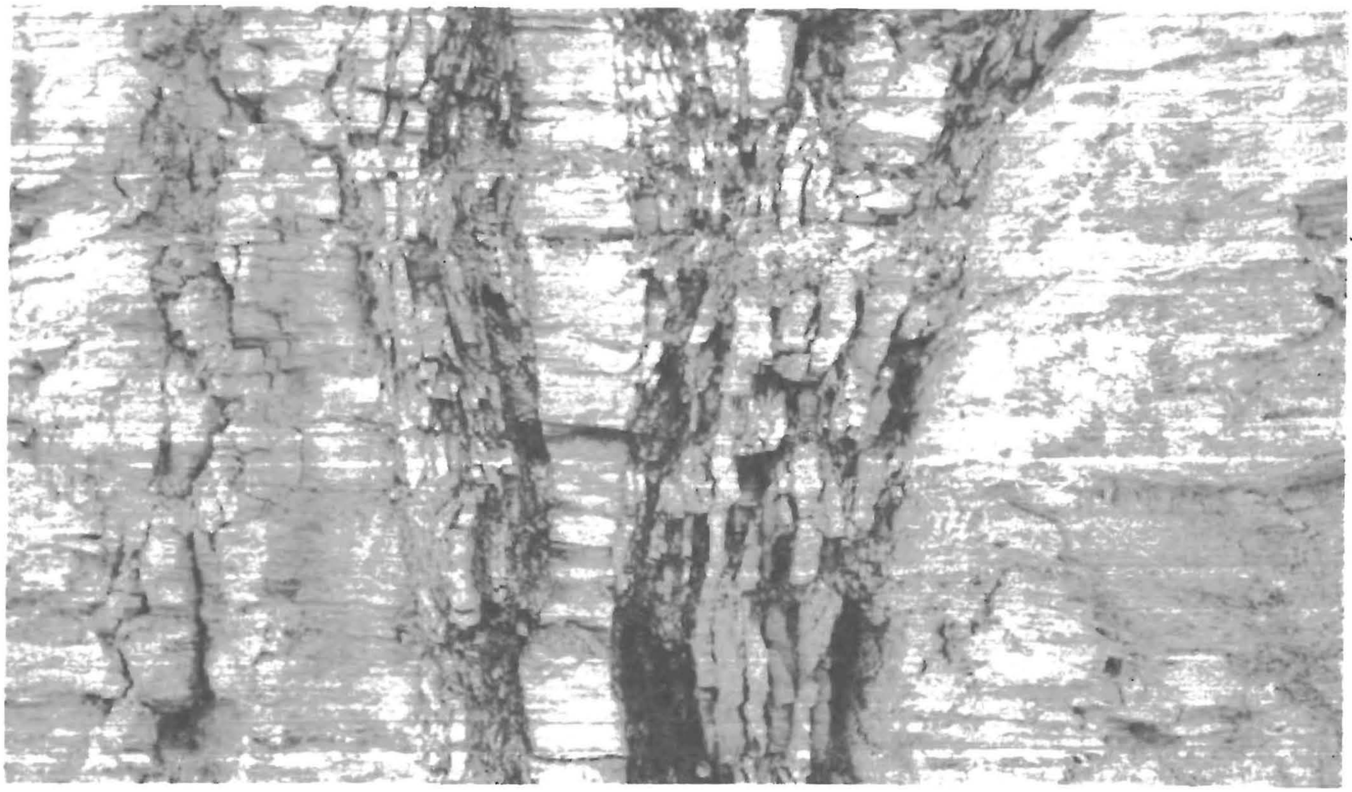

Figure 8.-Details of hillseam structure.

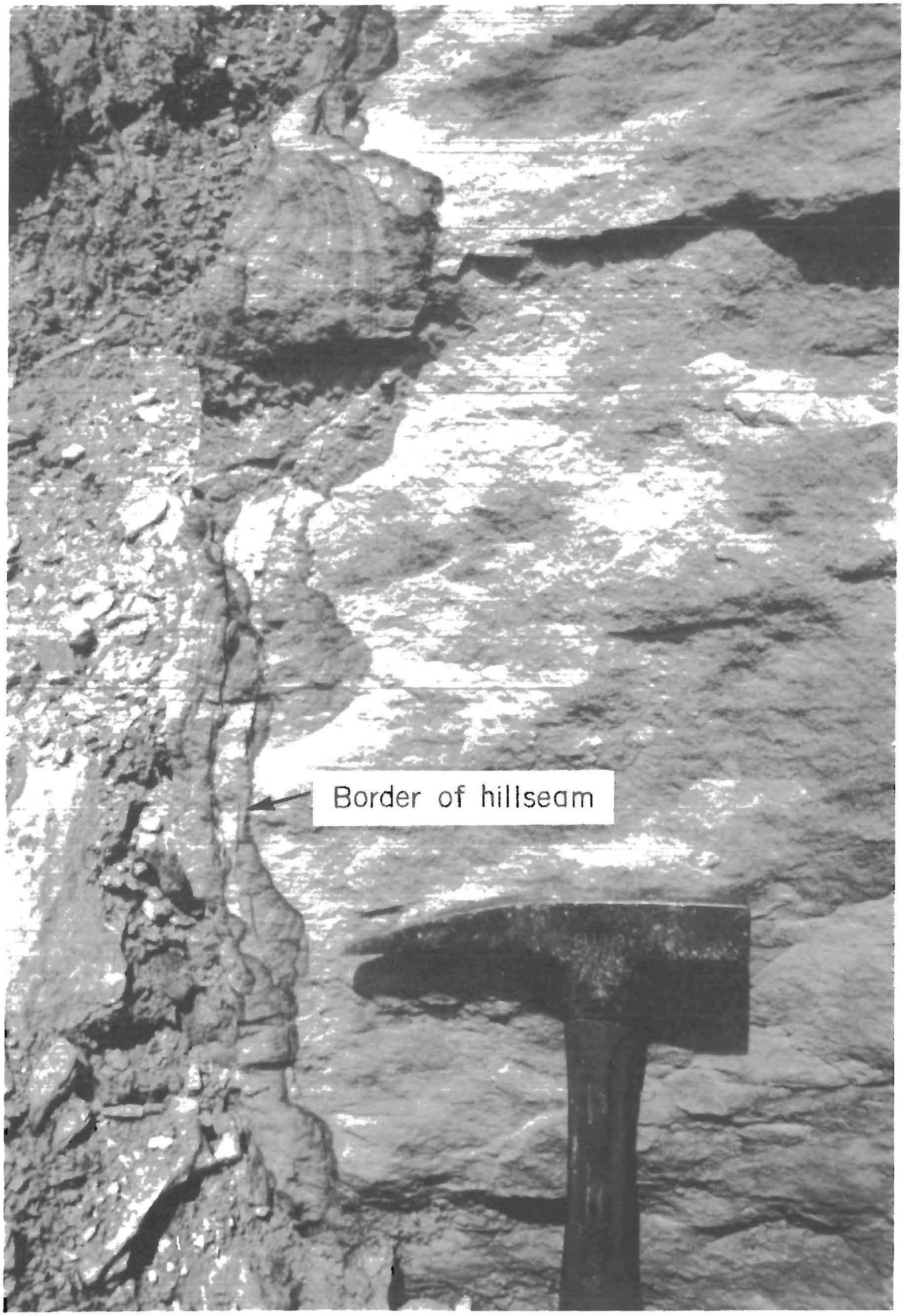

Figure 9.–Incipient parallel weathering in hillseam formation.

Figure 10.–Intersection of hillseams in mine roof.

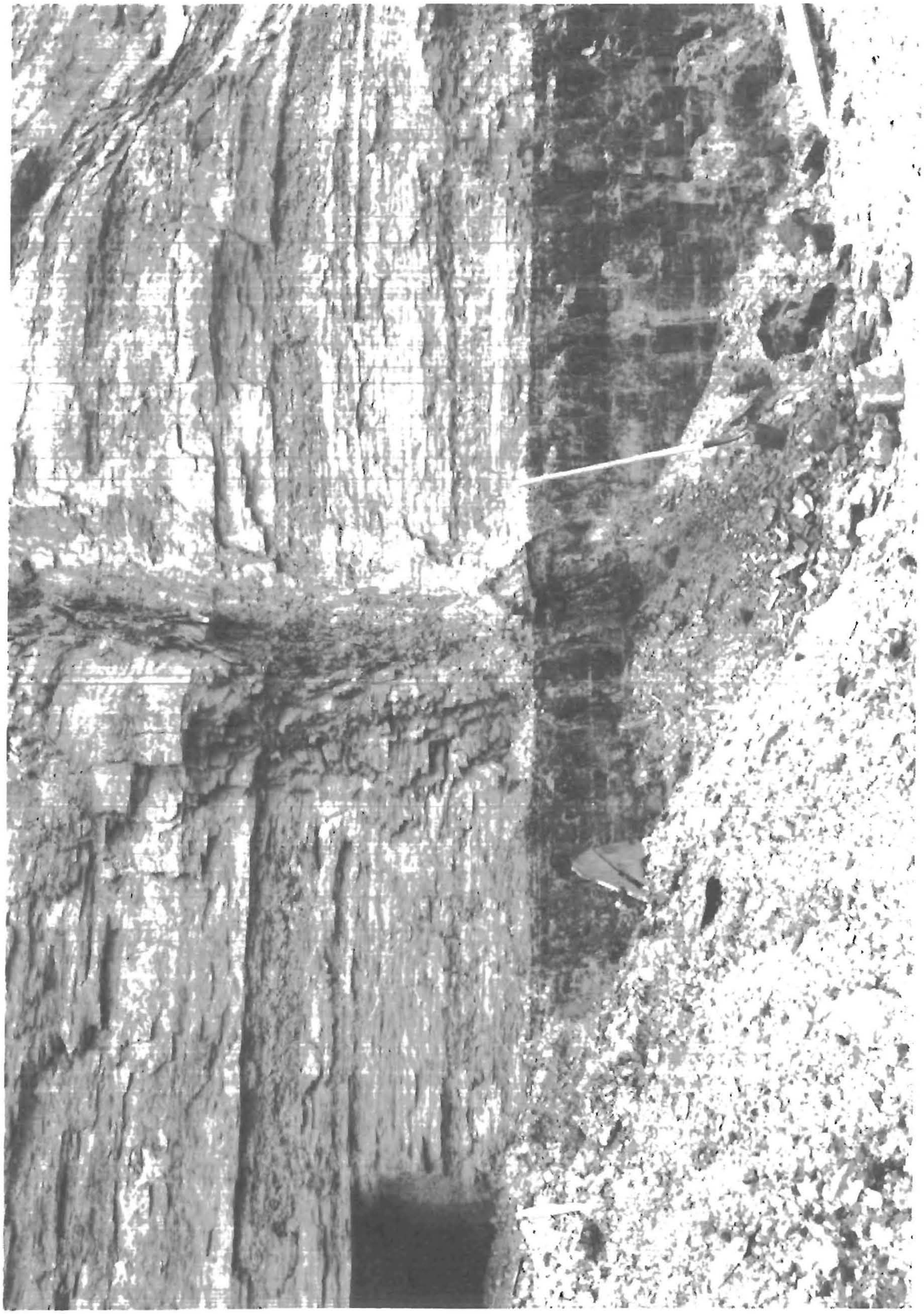

Figure 11.-Hillseams terminating at coalbed.

This is attributed to the contrast in mechanical and weathering properties between the coal and the surrounding sandstone or shale.

In order to compare the character and occurrence of hillseams at separate localities in the Big Sandy Coal Reserve District, the following four sites, with large, unweathered outcrop exposures were selected for detailed observations (fig. 12):

1. Route 645 roadcuts near Inez, Martin County.
2. Martin County Coal Corp. (MCC) strip mine highwalls near Inez, Martin County.
3. Route 80 roadcut near Martin, Floyd County.
4. Route 23 Pikeville canyon roadcut,[3] Pikeville, Pike County.

These sites are separated from each other by distances up to 30 miles. At each site, measurements were made of the strike, dip, and width of hillseams, along with notes on their general character. Seldom were more than three or four dozen measurable hillseams exposed at any one site, so no statistical analyses were attempted. Nonetheless, the major directional trend was always easily obtained and the dip rarely diverged more than 5° from vertical.

Each site was situated differently with respect to the major structural elements of the region (fig. 13). Local geologic structure is very subtle, and no meaningful relation to the hillseams was detected at any of the sites.

The most striking feature at each of the four sites was the absence of well-developed, unweathered, regional, systematic rock joints. In contrast, hillseams could be found with ease at almost any outcrop.

The following discussion briefly summarizes the findings at each of the four sites. The hillseam trend, surface contour trend, and exposure orientation data for the four study sites are listed in table 1.

[3]Because of its depth, this roadcut is locally referred to as a canyon.

Table 1.–Hillseam trend, surface contour trend, and exposure orientation data at four study sites

Study site and roadcut or highwall trend	Surface contour trend, +15°	Number of hillseam orientations																	
		North to east orientation--									North to west orientation--								
		0°-10°	10°-20°	20°-30°	30°-40°	40°-50°	50°-60°	60°-70°	70°-80°	80°-90°	0°-10°	10°-20°	20°-30°	30°-40°	40°-50°	50°-60°	60°-70°	70°-80°	80°-90°
Site 1:																			
N-S	E-W					3	4	5	3				3	4	1	1			
N 20° W	N 45° E		1	3	5	1				3	1		1				3	3	2
N-S	E-W	1	1								1			1	1		7	9	6
N-S	E-W				2	3	2		2	2					2	2	4	2	1
Site 2:																			
N 18° E	N 20° E	1			6	6	5	3	3	2	2		4	7		1	2	1	2
E-W	N 65° W	3	7	5	6	8	4	4		4	4		2	2	3		3	5	5
N 45° E	N 15° E		8	8	10	10	9	4							4		1		1
E-W	N 80° E						3	7	13	9		1	1		1	1	1	4	8
Site 3: N 45° W . .	N 25° E	2	3	17	22	4	1		2			1				2	2	1	
Site 4: N 20° E . .	E-W						1	1	16	23		1					2	9	14

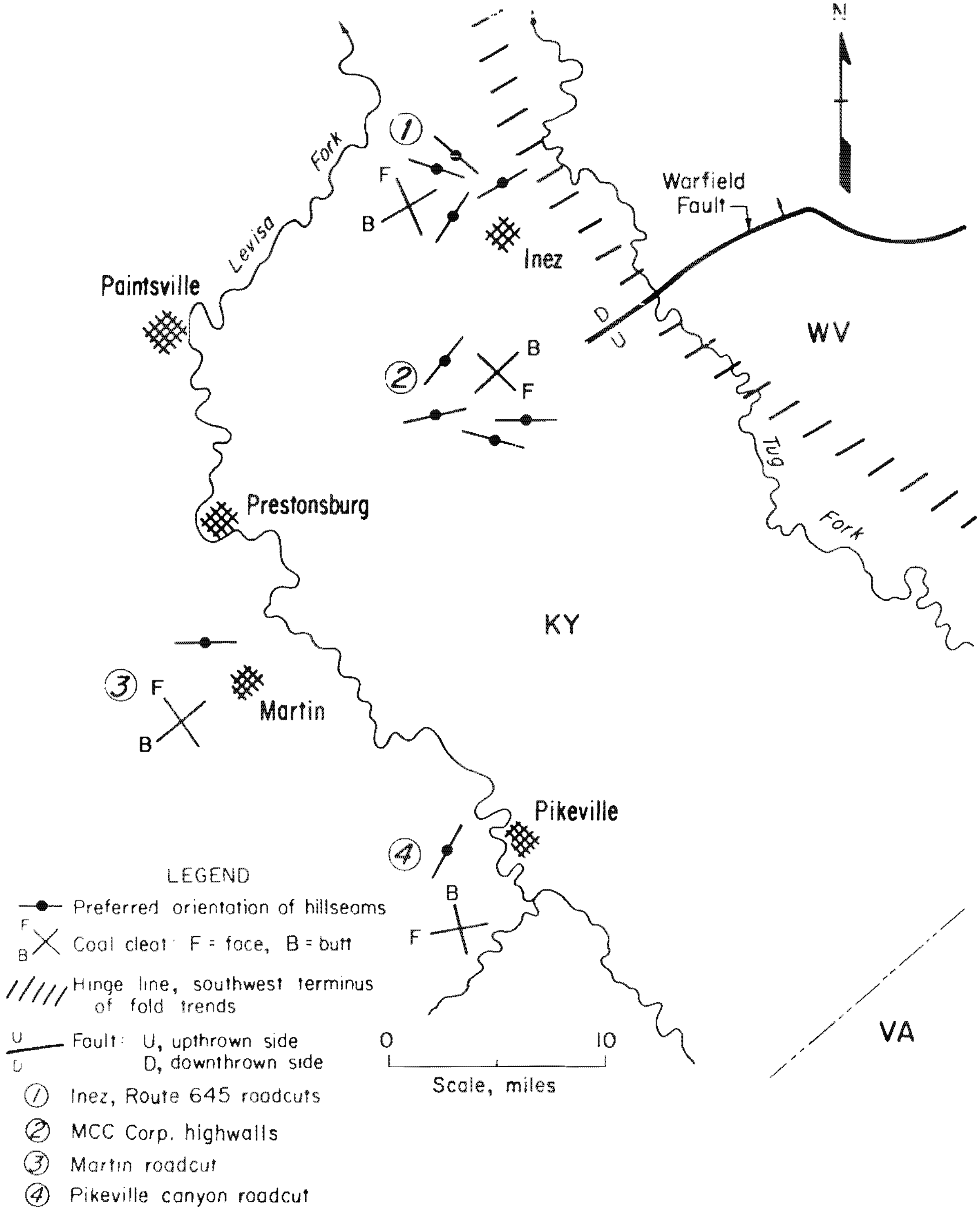

Figure 12.–Hillseam trends in exposures in Big Sandy District.

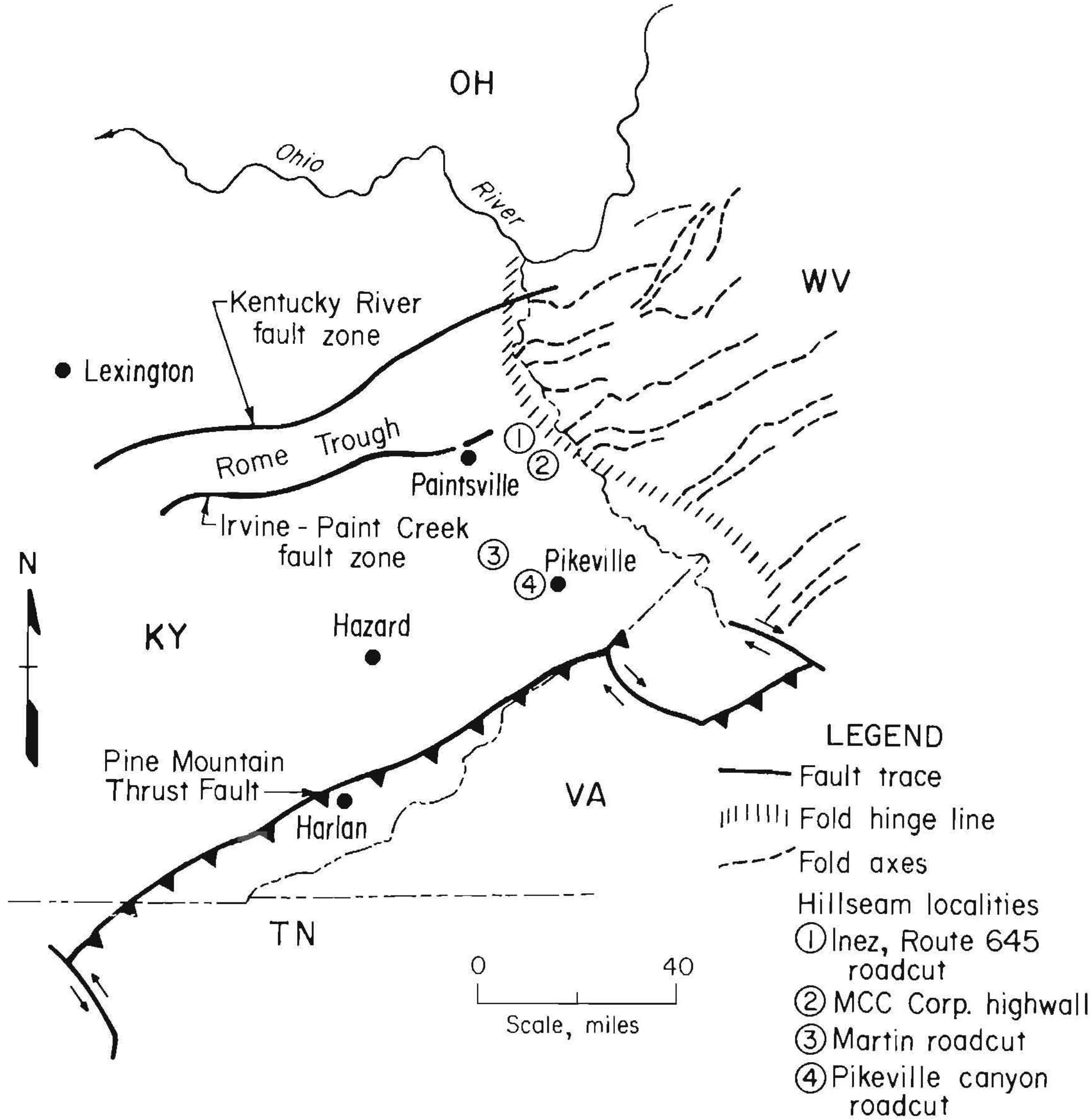

Figure 13.–Major structural elements in eastern Kentucky.

SURFACE EXPOSURES

The hillseam exposures at the four site 1 roadcuts on Route 645 near Inez, Martin County, were in interbedded shales and sandstones. The average strike of the hillseams examined at the roadcuts are shown in figure 12. Each roadcut transects a topographic ridge. The dominant hillseam trends at each paralleled the surface contours (perpendicular to the roadcut) and did not correspond to either the face or butt cleat measured in exposed coalbeds or to the very subtle structure in the vicinity.

The hillseam exposures at site 2 were in four MCC Corp. strip mine highwalls composed of both sandstone and shale. The preferred direction of the hillseams at each location fell largely within the same trend as the highwalls and contours and showed no clear relation to coal cleat or local structure (fig. 12).

The hillseam exposures at site 3 are in a large roadcut (some 250 ft high) along Route 80 near Martin, Floyd County, in interbedded shales and sandstones (fig. 14). The trend of the roadcut, N 20° E, is generally perpendicular to the trend of the topographic ridge and

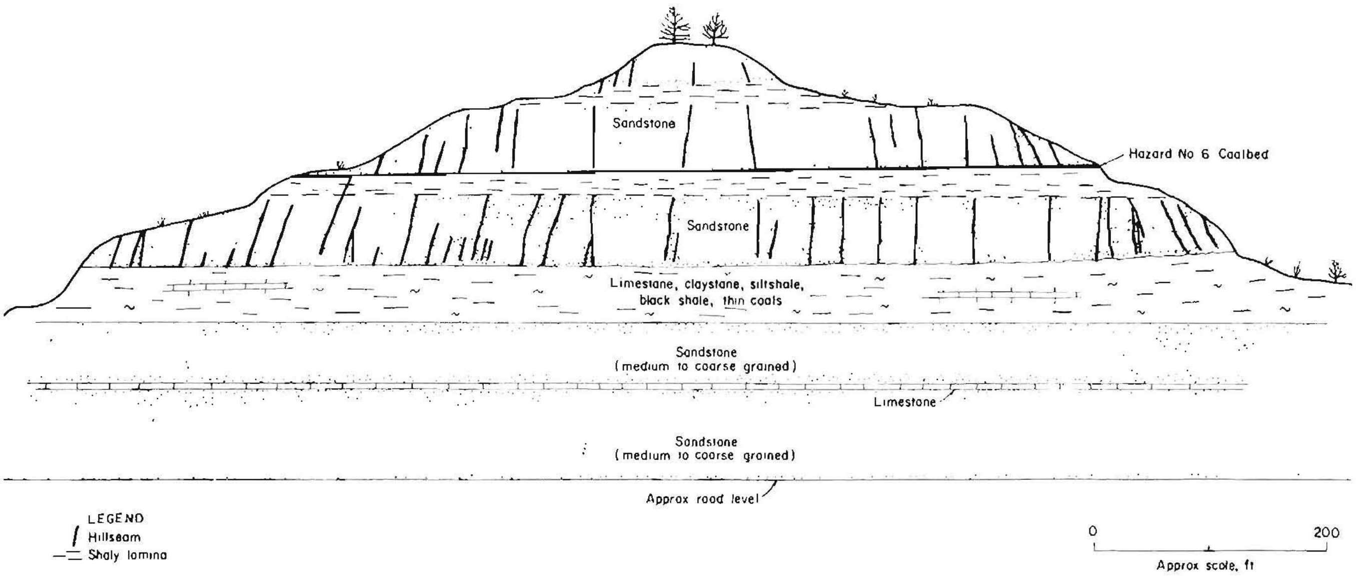

Figure 14.–Highwall exposure in Route 80 Martin roadcut.

the overall trend of the surface contours. The preferred direction of the hillseams, about E-W (fig. 12), closely parallels that of the surface contours. No common rock joints were observed and no relation to coal cleat or local structure was evident.

Site 4 is an immense roadcut some 450 ft high on Route 23-460 that cuts off a Levisa Fork meander (fig. 15). Locally referred to as the Pikeville canyon, this roadcut is largely fresh and unweathered, exposing sandstones, conglomerates, some shale, and coal, and provides exceptional hillseam exposures. Figure 16 is a general view of the northeast wall showing the occurrence of all the well-developed hillseams.

The preferred direction of hillseams in the canyon shows a strong maximum at N 20°-40° E (figs. 12 and 17). This closely approaches the dominant trend of surface contour lines but appears unrelated to the coal's face or butt cleats. The Pikeville canyon and site 3, near Martin, afford an opportunity to examine two of the largest and most informative exposures of hillseams in the Big Sandy Reserve District.

ORIGIN

Hillseams were identified in shallow overburden under high topographic relief at each of the sites investigated. The hillseam directional trends differed from locality to locality and lacked a consistent relationship to early regional stresses. These facts suggest a recent and local stress relief origin, rather than one of regional tectonics. The strong tendency of the hillseams to parallel the surface contours at each site also strongly points to a nontectonic, geomorphic origin.

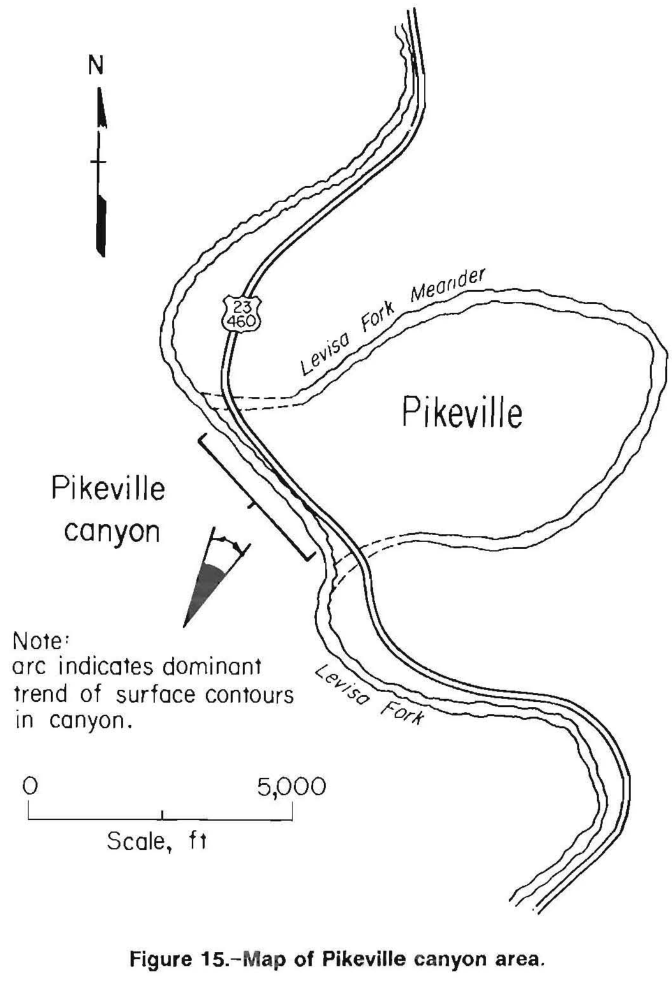

Figure 15.–Map of Pikeville canyon area.

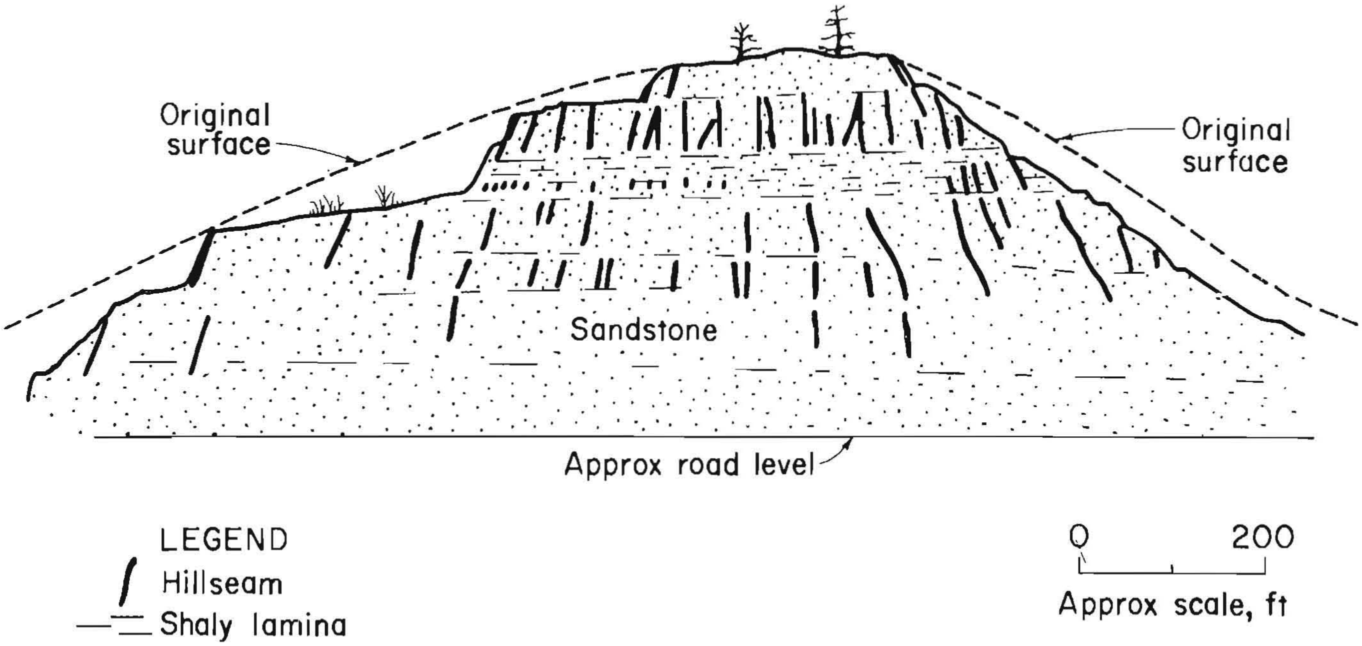

Figure 16.–Highwall exposure in Pikeville canyon roadcut.

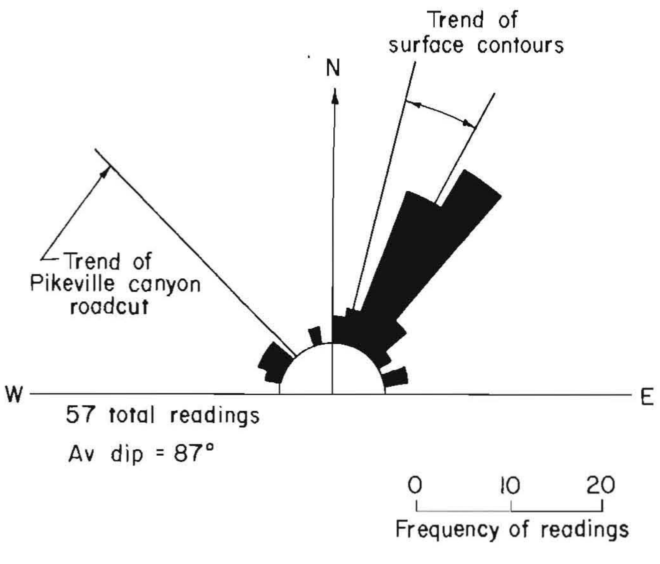

Figure 17.–Rose diagram of Pikeville canyon hillseams.

Wise, DiMicelli, and Baginsky (*8*) analyzed brittle fracture patterns in roadcuts along Route 23-460 and the Levisa Fork of the Big Sandy River in eastern Kentucky and found semi-independent orientation domains for the common rock joint, the coal cleat, and the hillseams. They used the term "joint zones" when referring to hillseams and ascribe the following character and occurrence to them:

1. Near vertical zones of intense strata bound jointing.
2. Average width about 8 in.
3. Typical lateral spacing of 16 to 100 ft.
4. Vertical extent of 32 to 65 ft.
5. Local splaying and curving.
6. Deviation from vertical close to outcrop and more closely spaced laterally.
7. Terminate at coalbeds but reappear below, with no sign of disruption in the coal.
8. Disappear at a depth of about 300 ft below the crest of a hill or at shallower depths on either side.
9. Tendency to parallel dominant topographic contour lines of a valley.

They concluded that the common rock joint and coal cleat orientation patterns were related to subtle fold patterns evident in structure contour maps. However, they also concluded that the hillseams appear to be a nontectonic, geomorphic phenomenon produced by gravitational spreading of stratabound mechanical units.

The authors concur in the preceding descriptions and origin, although the hillseams are not entirely stratabound. In some instances they extend upward to the surface through strata of different lithology. Also, a typical lateral spacing may be inaccurate. At most exposures the hillseams are more concentrated near the outcrop. As the distance from outcrop increased, the distance between the hillseams also increased. Additionally, existing joint systems aligned with the developing valley tend to also be affected by the gravitational formation process.

Unrug and Mateer (*9*) also describe hillseams as being tensile in origin and definitely related to the stress field changes resulting from reduced lateral constraint of the coal measure deposits by the erosion that formed the deep narrow valleys characteristic of the area.

Gray, Ferguson, and Hamel (*7*) show an illustrated example of a deep-seated rockslide involving an excavated slope of about 45° in which a vertical joint, trending parallel to the valley wall, formed near the crest of the cut slope prior to the slide. While this joint occurred near Pittsburgh, PA, the development of a vertical joint attributed to stress relief in bedrock closely resembles the apparent development of hillseams in eastern Kentucky. Martin and Miller (*10*) emphasize the importance of hydrostatic pressures in tension cracks in initiating such failure.

Hillseams originate as tension cracks, which are an indication of a deep-seated hillside slope failure. The process of hillseam formation is best summarized as a combination of valley stress relief through erosion and incipient valley wall jointing, followed by weathering along developed fractures. This should provide further insight for anticipating hillseams in mining situations.

ROOF FAILURE

The occurrence of one or more hillseams in mine roof, whatever their character or orientation, weakens the roof. The presence of even barely detectable hillseams warrants close scrutiny because of their tendency to change in character along strike by increasing in degree of weathering, curving, and splaying into groups of parallel hillseams.

Narrow hillseams that strike transversely to openings generally are the least troublesome. Two solid beams remain in the roof that are supported at both ends by the adjacent coal ribs. Very wide, intensely weathered hillseams transverse to openings tend to spall or fail in small slabs between splaying joint surfaces, but without severely affecting overall roof stability.

Hillseams that parallel openings create a serious hazard by interrupting the beamlike span of roof that normally supports the overlying rock, leaving a cantilever (fig. 18). This situation calls for detailed observations, immediate judgment, and remedial action in terms of supplementary support, especially when the hillseam may be heavily weathered and broken just beyond the face.

Parallel or intersecting hillseams in the same entry can be disastrous (see "Examples in Mine Roof" section). Intersecting hillseams break the roof into separate wedges and blocks. In this situation the possibility exists that the roof might fail en masse between the hillseams (which can extend upward to near the surface), generating an enormous deadweight. If the roof is a thin-bedded sandstone or shale, the roof might break to only a short distance above the immediate roof, or wherever a weakly bonded stratum occurs. Because roof falls invariably involve complex failure modes that are difficult to predict, it is impossible to determine to what height the roof fall will break once failure starts.

DETECTION

The visual detection of hillseams in mine roof immediately on exposure is essential to the prevention of roof support problems and should be a priority of operating personnel. Training and experience are valuable in ascertaining the orientation and character of each particular hillseam, which should then be recorded on the mine map for reference.

The advantages of detecting hillseams in advance of mining are evident. Entries can be projected to avoid them, to intersect them at right angles with staggered crosscuts to minimize their weakening effect on the roof, and to penetrate through them as quickly as possible. Also, special precautions can be exercised by mine personnel and appropriate supplementary support planned in advance.

While there is a possibility that the use of aerial photographs, outcrop mapping, and earth resistivity measurements might have potential, to date no proven method is available to detect hillseams in advance of mining. However, some general comments can be made on the probability of encountering them.

First, almost every drift mine in MSHA District 6 has encountered hillseams close inby the portal and in entries that approach close to outcrop. In general, the hillseams occur mostly within 200 ft of coal outcrop and, therefore, under about 77 to 116 ft of overburden, given the hillside slope conditions of the district, which range from 21°-30° (fig. 19). This relationship is supported by evidence from large roadcuts.

Second, because hillseams develop by stress relief, they tend to parallel the dominant topographic contour lines and ridges (*8*). The nose of a ridge is a special case. At the nose, stress relief acts parallel to both the ridge and the nose. This action results in intersecting hillseams, often under the lowest cover in the mine (see following section).

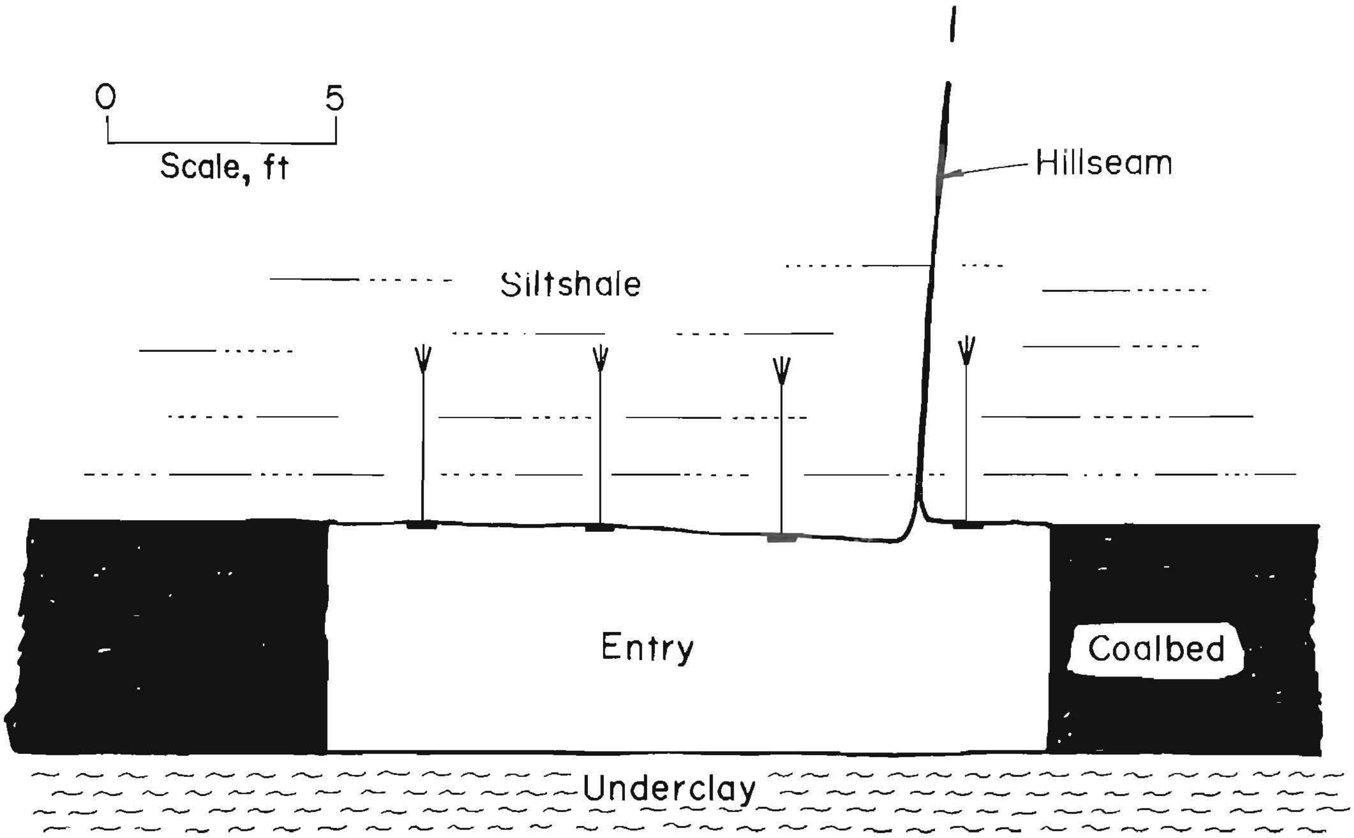

Figure 18.-Cantilevered mine roof formed by hillseam paralleling entry.

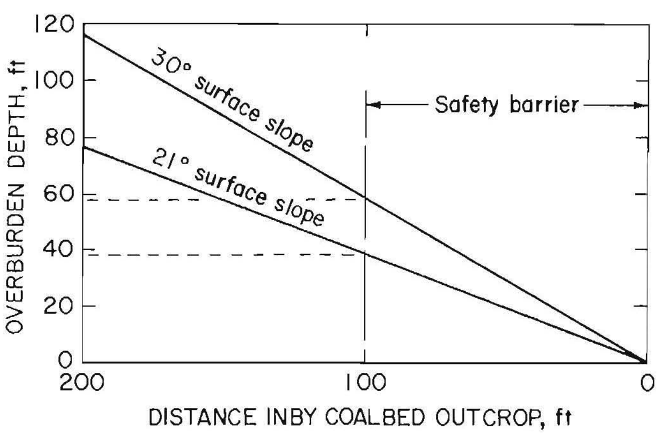

Figure 19.-Overburden thickness versus distance from outcrop.

EXAMPLES IN MINE ROOF

Hillseams are encountered and successfully supported many times in eastern Kentucky. The proper caution during mining, installation of adequate support, and sometimes favorable geologic conditions account for this. However, because of the difficulty in accurately assessing the hazard potential of every hillseam, occasional roof failures do occur.

While the weakening effect of hillseams on mine roof was described briefly in a previous section of this report, the problem can be best presented through the use of some examples from actual mining operations. Six such examples are described in the following sections. Three are roof falls attributed to the presence of hillseams which resulted in a serious injury or fatality. The consequences of underestimating the potential hazard of hillseams, or providing inadequate support, are strikingly illustrated by these 3 roof fall accidents. However, all six examples show some of the variations to be expected in the character and occurrence of hillseams.

The examples of hillseam-related roof fall accidents do not always precisely represent the underground situation. Cleanup and roof re-support are not always necessary after roof falls, and, consequently, a geologic description of the site is not always possible or safe to obtain. Neither can the sequence of events leading up to an accident always be determined accurately, either because witnesses are not certain as to details or they did not survive the roof fall. Some allowances are made for these shortcomings in the reporting of almost any roof fall accident, including those in the following sections.

Example 1

County: Martin

Coalbed: Stockton, 52 in

Overburden: At accident site, 40 ft

Mining method: Conventional room-and-pillar

Roof: Main, massive sandstone, 10 ft; immediate, silty shale, 24 in

Hillseam-related injury: Roof fall fatality

Summary: The portal of this mine was driven into the nose of a ridge and advanced for 1,500 ft parallel to the topographic contours on each side of the ridge (fig. 20). Hillseams were abundant for the first 100 ft inby the portal; however, some persisted parallel to the main entries for over 300 ft and contributed to the collapse of a large section of roof. Further inby the outcrop, the roof was largely free of hillseams because of the greater thickness of overburden.

In one area of the mine, the outer entry of the mains was adjacent to the 100-ft-wide outcrop barrier. Hairline cracks in the roof were the first indication of roof support problems. As the entry was advanced, the cracks gradually increased in width and intensity of weathering until two intersecting hillseams were exposed that followed the trend of the entry and the contour of the ridge.

The roof in the vicinity was supported with full-column resin roof bolts with wooden half headers and metal straps across the hillseams. The roof collapsed soon after development in a massive wedge-shaped fall between the hillseams. A breakthrough was driven to connect with the far end of the entry. As it was being bolted, a second fall occurred that resulted in a fatal injury 2 ft inby the last row of permanent supports. A third fall occurred near the far end of the entry shortly afterward (fig. 21).

The entire wedge-shaped fall of roof between the intersecting hillseams was estimated to consist of 5,139 ft^3 of rock weighing 385 st. Figures 22 and 23 show two views of the fall. This weight over an entry length of 50 to 80 ft far exceeded the support capacity of the installed bolts and straps. If the magnitude of the fall could have been anticipated by a greater awareness of the roof structure, additional supplementary support could have been installed.

This example of hillseam related roof failure is common in situations where the entries tend to parallel the surface contours and failure occurs in long massive wedges of roof. The overburden at this roof fall site was about 40 ft (fig. 24).

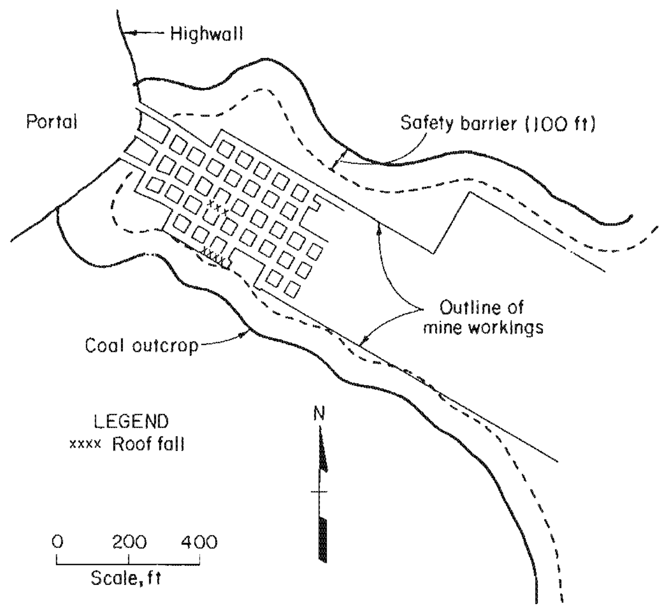

Figure 20.–Map of example 1 mine workings.

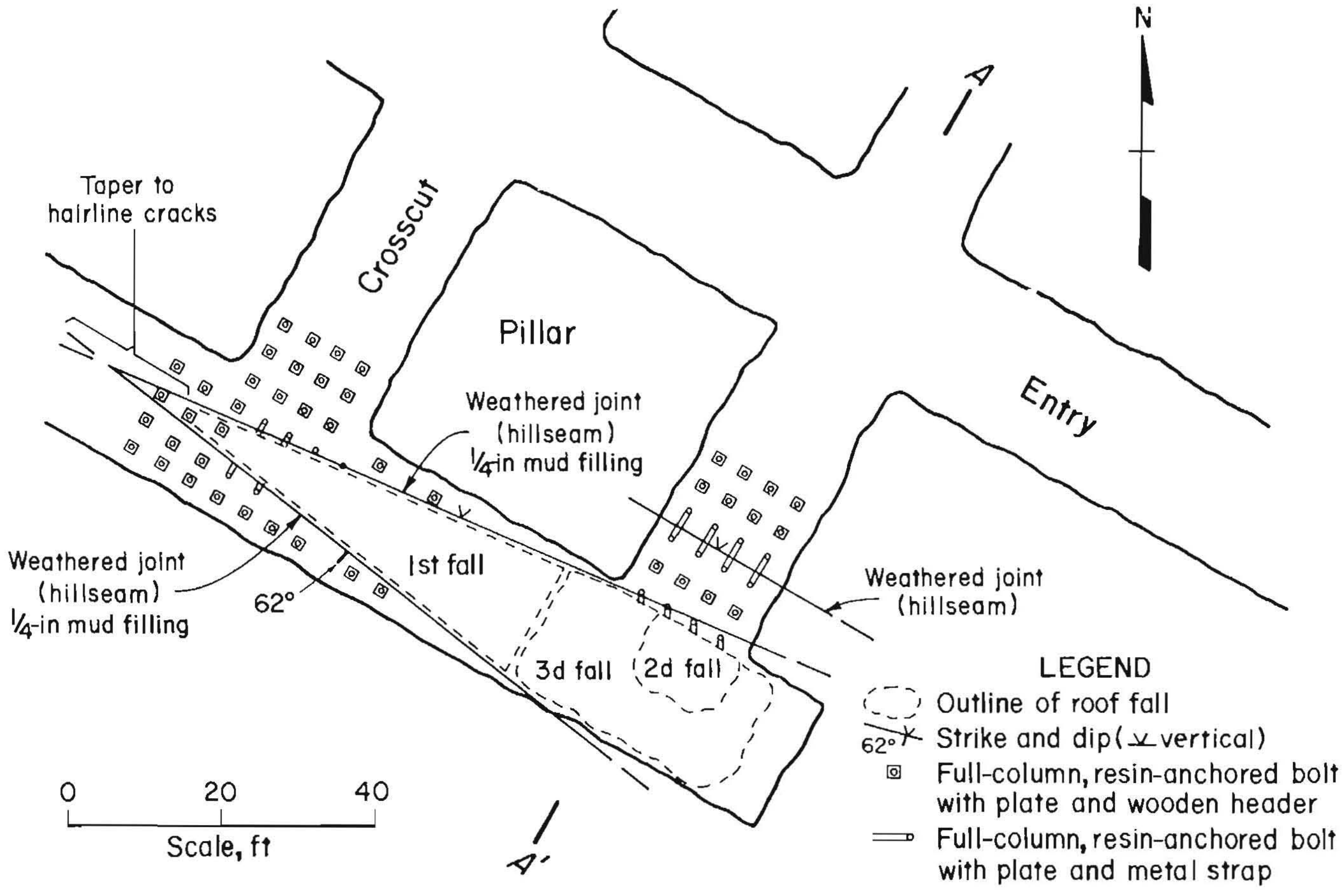

Figure 21.–Roof falls in example 1 mine.

Figure 22.–North side of roof fall in example 1 mine.

Figure 23.-Apex of roof fall in example 1 mine.

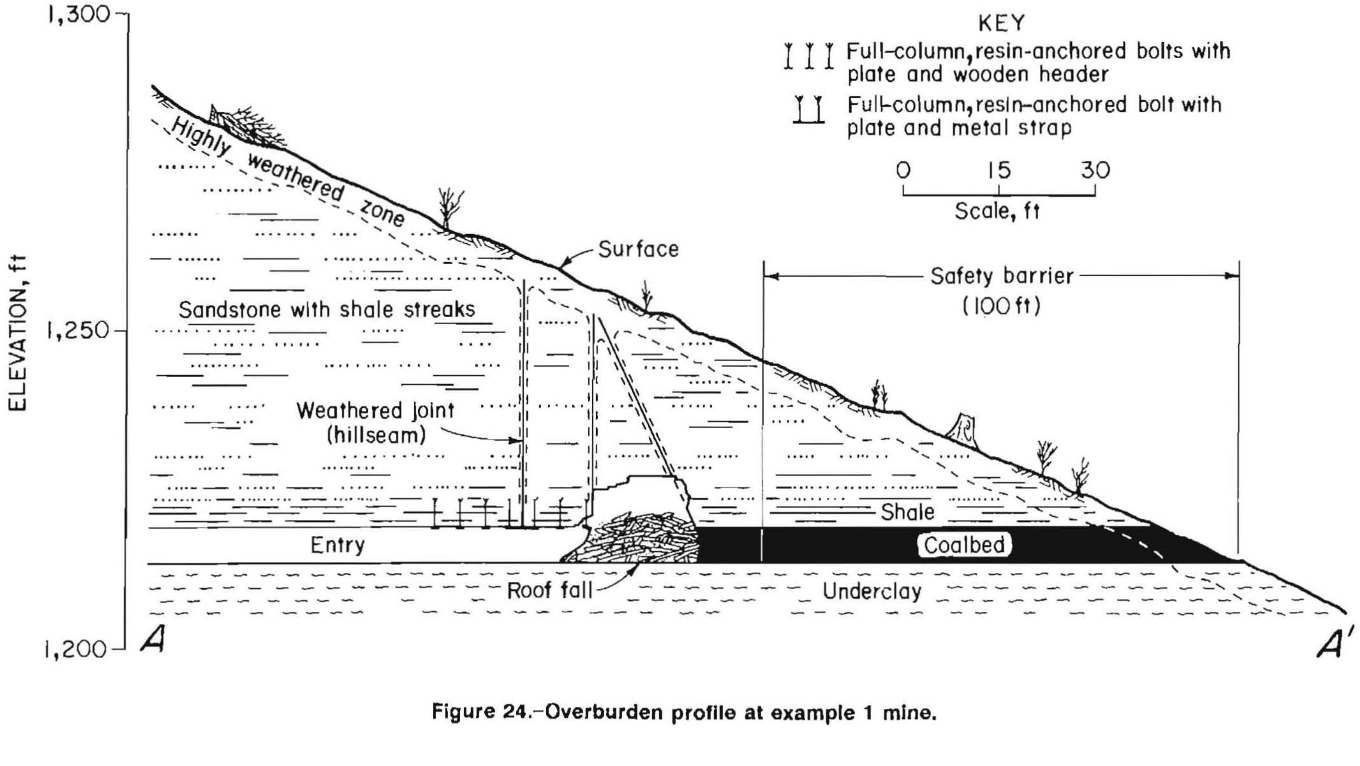

Figure 24.-Overburden profile at example 1 mine.

Example 2

County: Martin

Coalbed: Stockton, 60 in

Overburden: At accident site, 50 ft

Mining method: Conventional room-and-pillar

Roof: Main, massive sandstone, 10 ft; immediate, shale, 18 in

Hillseam-related injury: Roof fall fatality

Summary: The portal of this mine was driven into a strip mine highwall 600 ft from the head of a small stream valley. The mine workings were advanced for some 1,500 ft to the safety barrier surrounding the periphery of the property (fig. 25). Hillseams were encountered in the portal area and again at two locations near the barrier 1,500 ft inby the portal. At one location, entries were stopped 70 to 100 ft short of the barrier because of hazardous roof related to hillseams. At a second location, a breakthrough was being mined when a massive block of roof collapsed into the intersection without warning, instantly killing a miner. The roof was weakened by two hillseams that ran parallel with the entry and two that cut across the entry (fig. 26) forming the boundaries of a rectangular mass of roof rock. The roof, including 3 to 4 in of headcoal, was supported by 36-in resin-anchored bolts. The hillseams were concealed by the headcoal.

The entire rectangular-shaped fall of roof between the intersecting hillseams was estimated to consist of 13,500 ft^3 of rock weighing about 1,000 st, far in excess of the support capacity of the bolts and straps.

This example of hillseam-related roof failure is similar to that of example 1, where the problem is chiefly the failure to detect and then anticipate the inherent hazard of hillseams. In example 2, tension acting outward at both the nose and sides of the ridge resulted in intersecting hillseams. Failure in both instances occurred as the roof rock separated from overlying rock along a bedding plane (fig. 27), overcame the friction along the vertical hillseam surfaces, and dropped into the void left by removal of the supporting coal. The metal straps in each case offered little restraint.

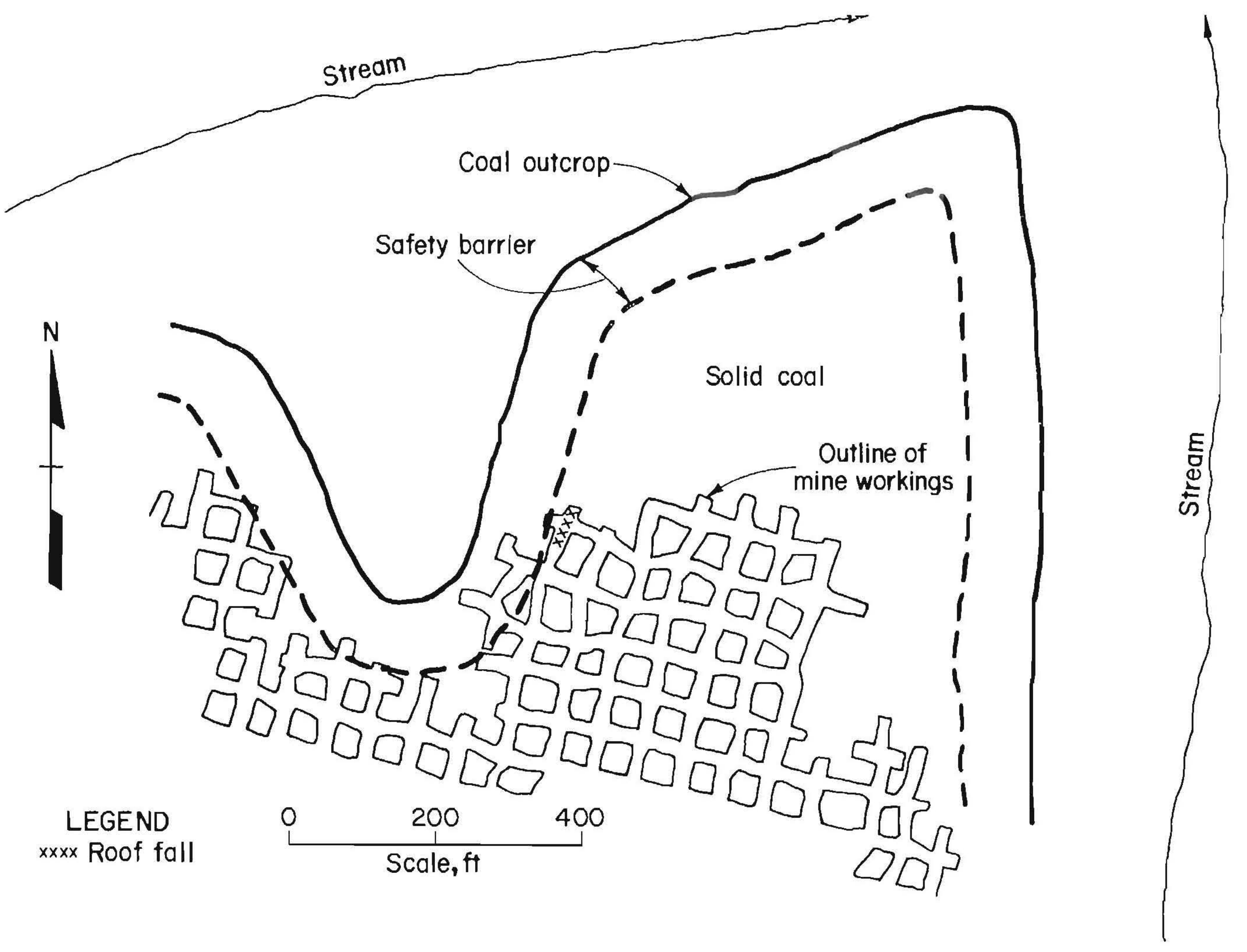

Figure 25.–Map of example 2 mine workings.

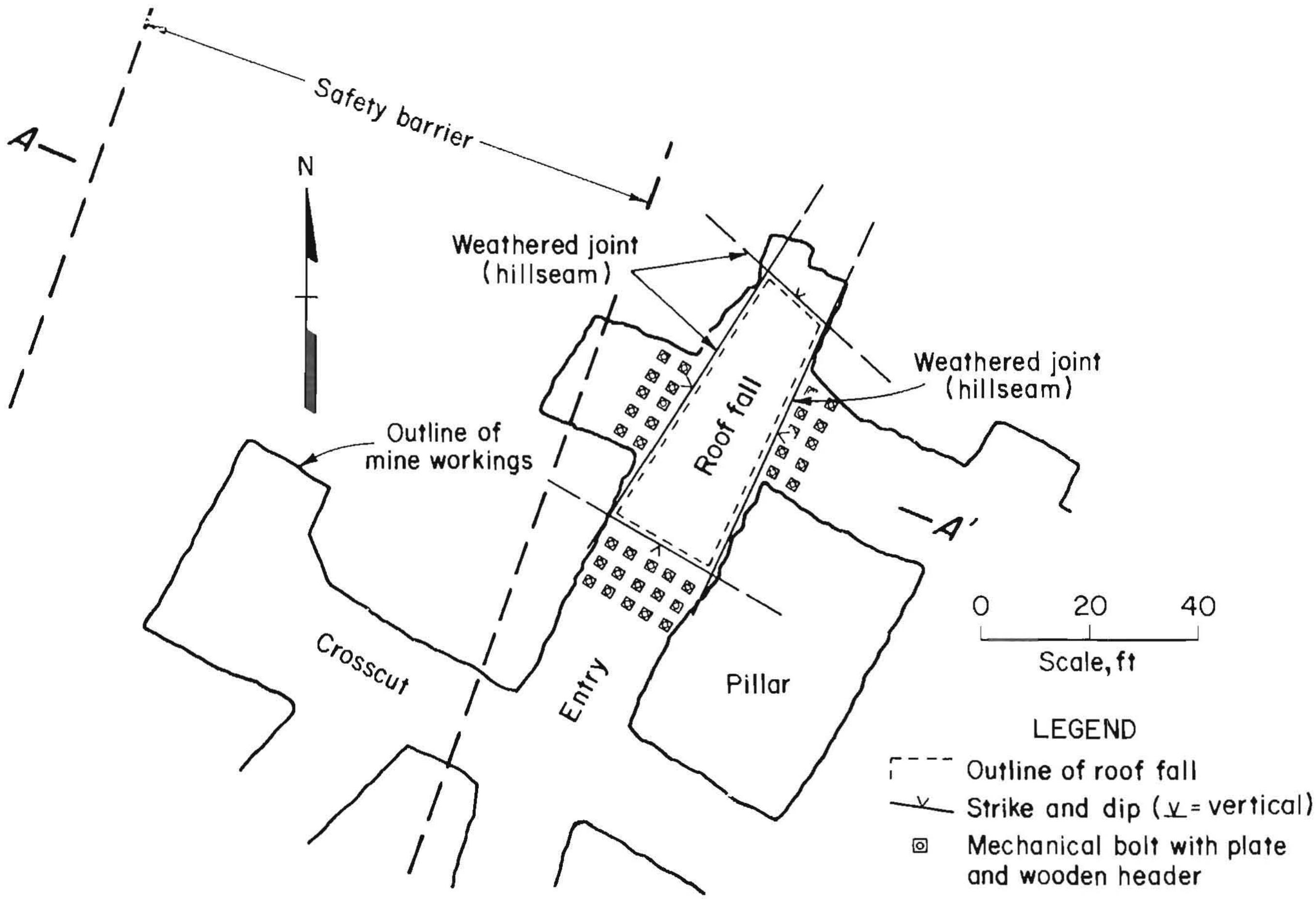

Figure 26.-Map of roof fall site in example 2 mine.

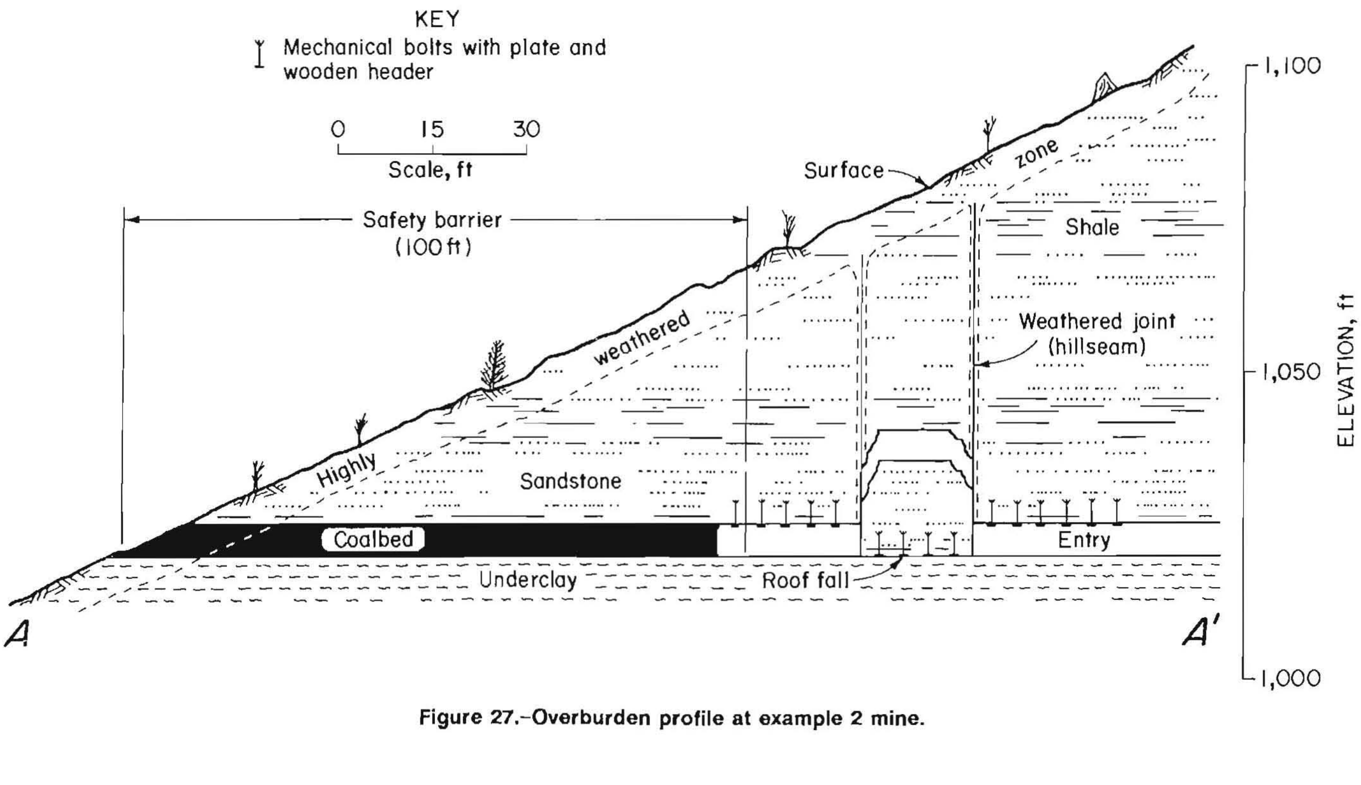

Figure 27.-Overburden profile at example 2 mine.

Example 3

County: Harlan
Coalbed: B (Kellioka), 38 in
Overburden: At accident site, 120 ft
Mining method: Conventional room-and-pillar
Roof: Main, massive sandstone, thickness unreported; immediate, shale, thickness unreported
Hillseam-related injury: Roof fall fatality
Summary: This drift mine was opened at a highwall on the side of a ridge and developed under the nose of the ridge (fig. 28). Retreat mining with full-pillar extraction was in progress using breaker posts. The scoop was removing the last remaining coal from the punchthrough of a pillar split. A hillseam along the inby (south) rib was inspected a short time before, but it showed no movement. Small fragments of rock began to dribble from one of three hillseams located at the intersection opening into the pillar split. Immediately thereafter, the roof between the hillseams collapsed with a loud rasping noise and sparks were emitted from the ruptured metal straps that were installed across one of the hillseams.

The roof fail size was 35 by 22 by 1 to 5 ft and weighed an estimated 95 st. A scoop operator was trapped in the scoop cab by the fall for 2 h. A miner who was observing the roof while the scoop was loading coal was caught under the edge of the fall and fatally injured. The accident was attributed to the second mining being conducted under known adverse roof conditions (hillseams). The increase of load on the roof due to removal of the supporting coal dislodged the segment of roof bounded by the three hillseams.

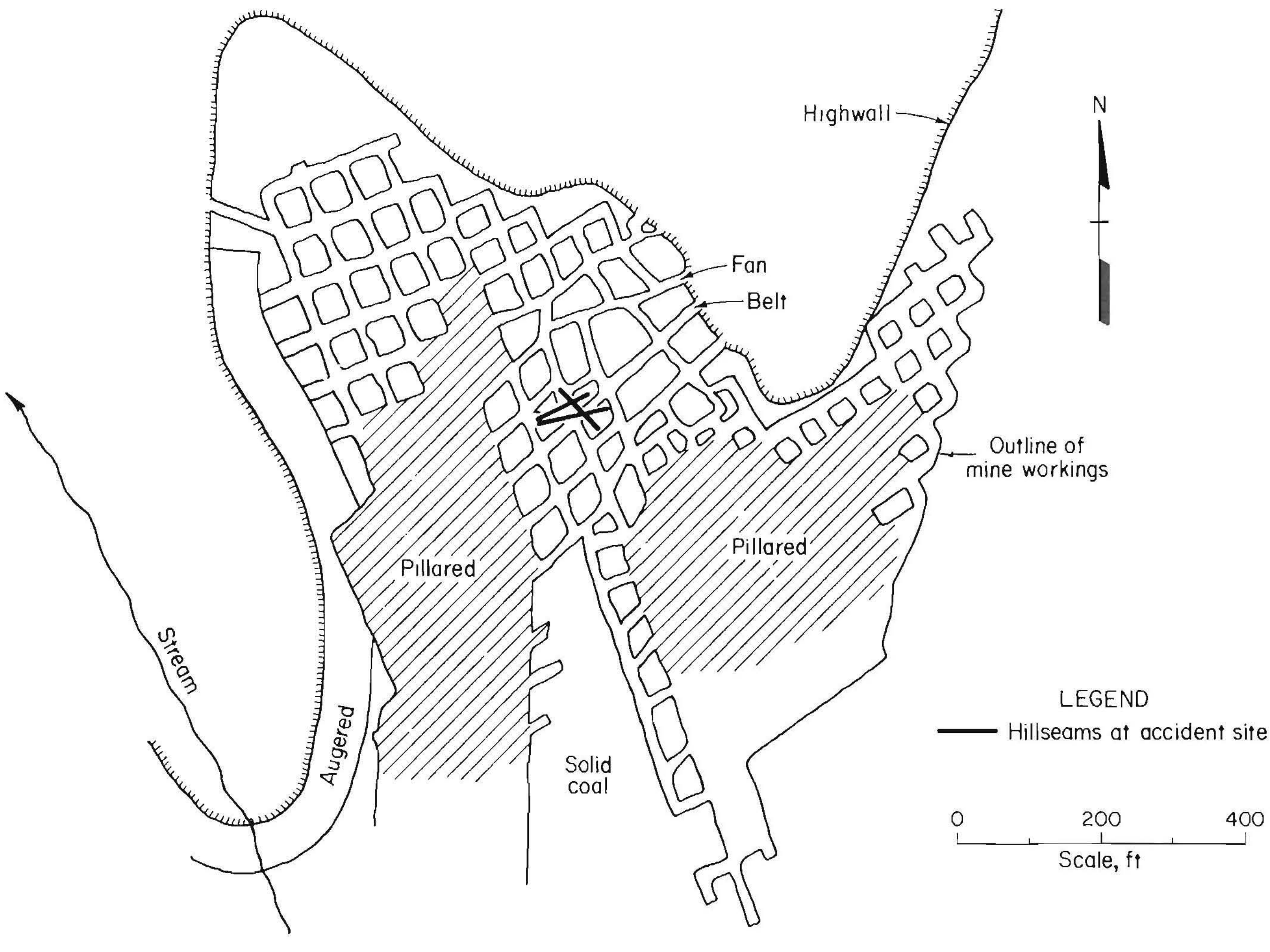

Figure 28.–Map of example 3 mine workings.

Example 4

County: Pike

Coalbed: Elkhorn No. 3, 41 in

Overburden: Range, 0 to 550 ft

Mining method: Conventional room-and-pillar

Roof: Main, sandstone, 15 ft; immediate, laminated sandstone and shale, 7 ft

Hillseam-related injury: None

Summary: The portals of this mine were opened in a highwall at a small nose in a ridge and driven straight for 1,200 ft before turning. Hillseams were encountered for some 300 ft inby the portals (375 ft inby the original coal outcrop), most trending perpendicular to the mains (fig. 29). The most severe roof problems occurred within 220 ft of the portals where the overburden was fractured and heavily weathered (fig. 30) and at the first crosscuts 80 to 100 ft inby the portals. Two of the crosscuts could not be completed because of the zone of hillseams and weathering. Despite attempts at supplementary support, the roof in both crosscuts collapsed. The roof for 120 ft inby the fan was supported with cribbing to prevent failure. Figures 31 and 32 illustrate roof conditions in the vicinity of some hillseams in this mine.

A diagram of hillseams exposed in a highwall near the mine portals shows that the hillseams follow a preferred direction that generally parallels the trend of the surface contours (fig. 33).

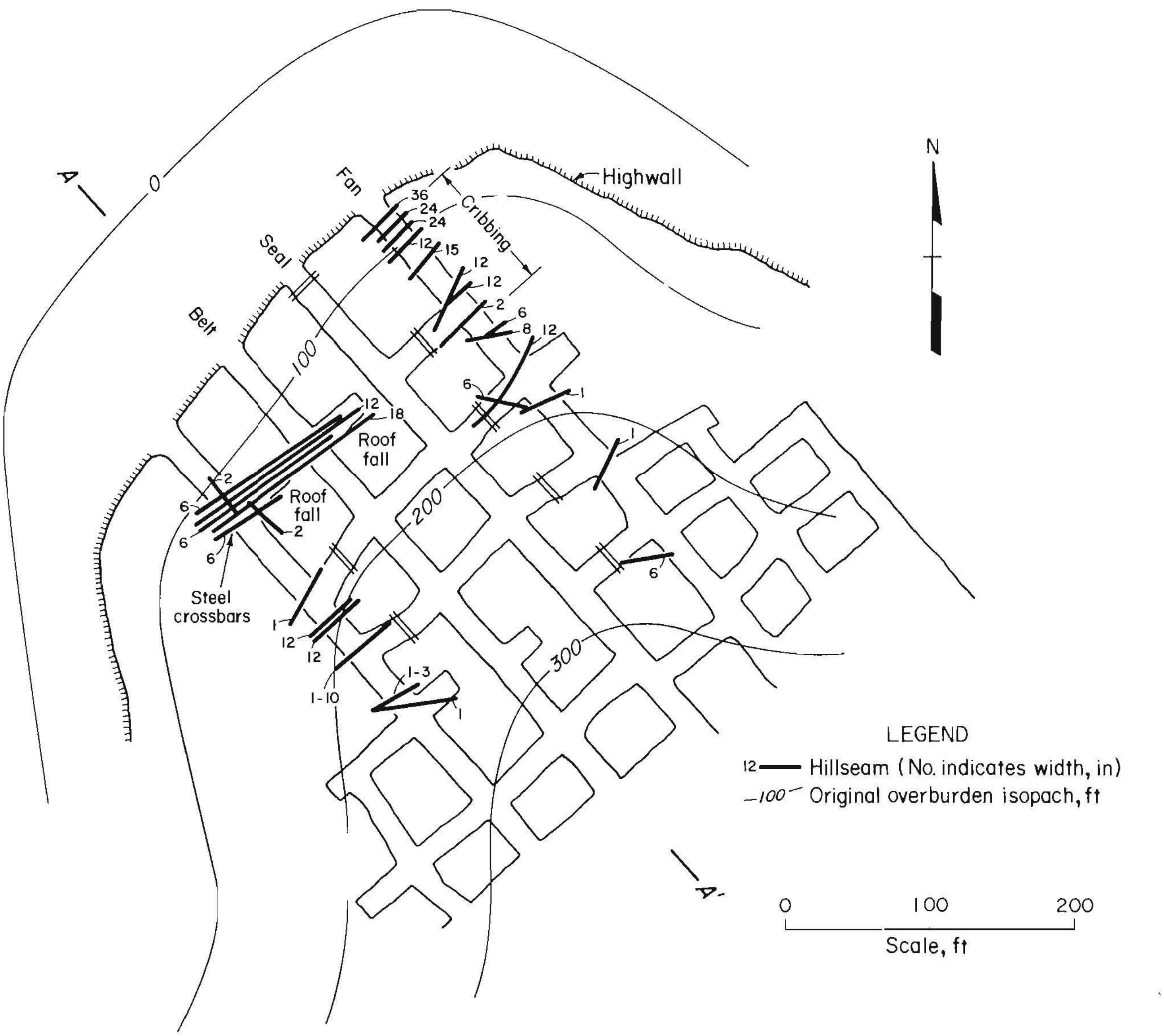

Figure 29.–Map of example 4 mine portal area.

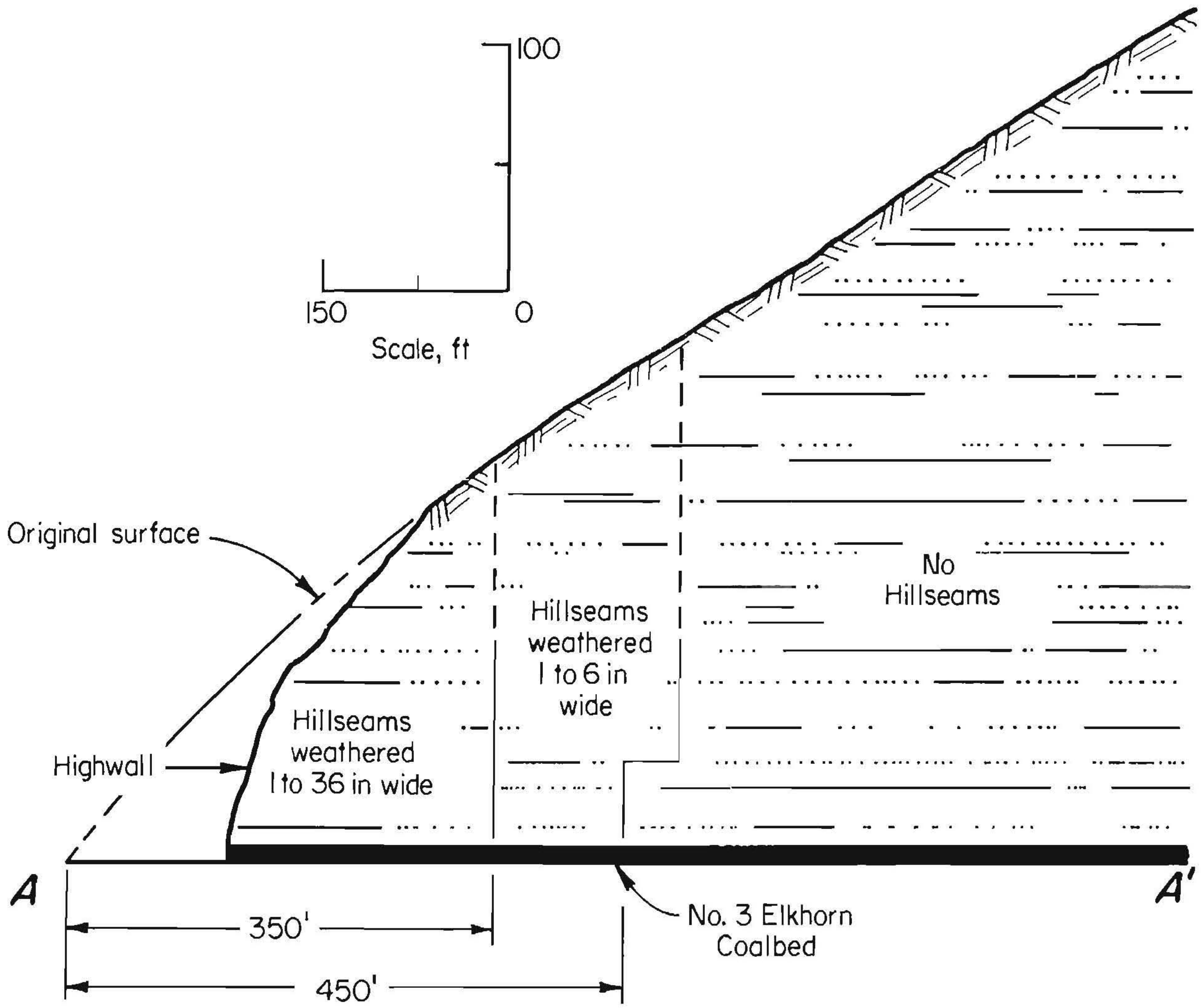

Figure 30.-Overburden profile at example 4 mine.

Figure 31.-Unstable roof in example 4 mine intersection.

Figure 32.-Hillseam-related roof fall forming roof brow.

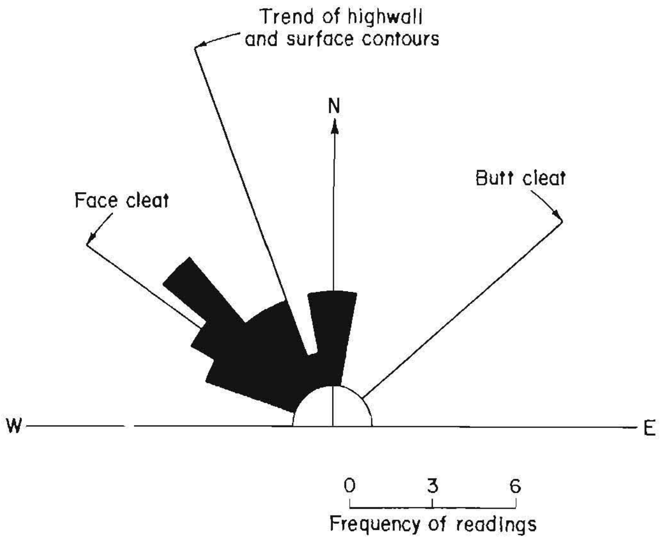

Figure 33.-Rose diagram of hillseam trends at example 4 mine.

Example 5

County: Martin
Coalbed: Coalburg, 52 in
Overburden: Range, 0 to 230 ft
Mining method: Conventional room-and-pillar
Minimum roof support: 60-in bolts on 5-ft centers
Roof: Main, massive sandstone, 20 to 25 ft; immediate, laminated sandstone, 1 to 2 ft
Hillseam-related injury: None

Summary: This mine consists of a complex of portals, mains, and isolated producing sections (only one portal area was selected for study). The portals were opened in a highwall at the nose of a ridge and driven straight for more than 1,000 ft. The highwall strata consisted of a thick, massive sandstone with a few hillseams 1 to 8 in wide. Hillseams were encountered for some 550 ft inby the portals, or 715 ft inby the original coal outcrop (fig. 34). The most severe problem with hillseams occurred within 415 ft of the original coal outcrop (fig. 35).

Generally, roof conditions in the area studied were very good with a minimum of supplementary support required at wide hillseams. No roof falls have occurred although at least two pressure breaks (long, mining-induced tension

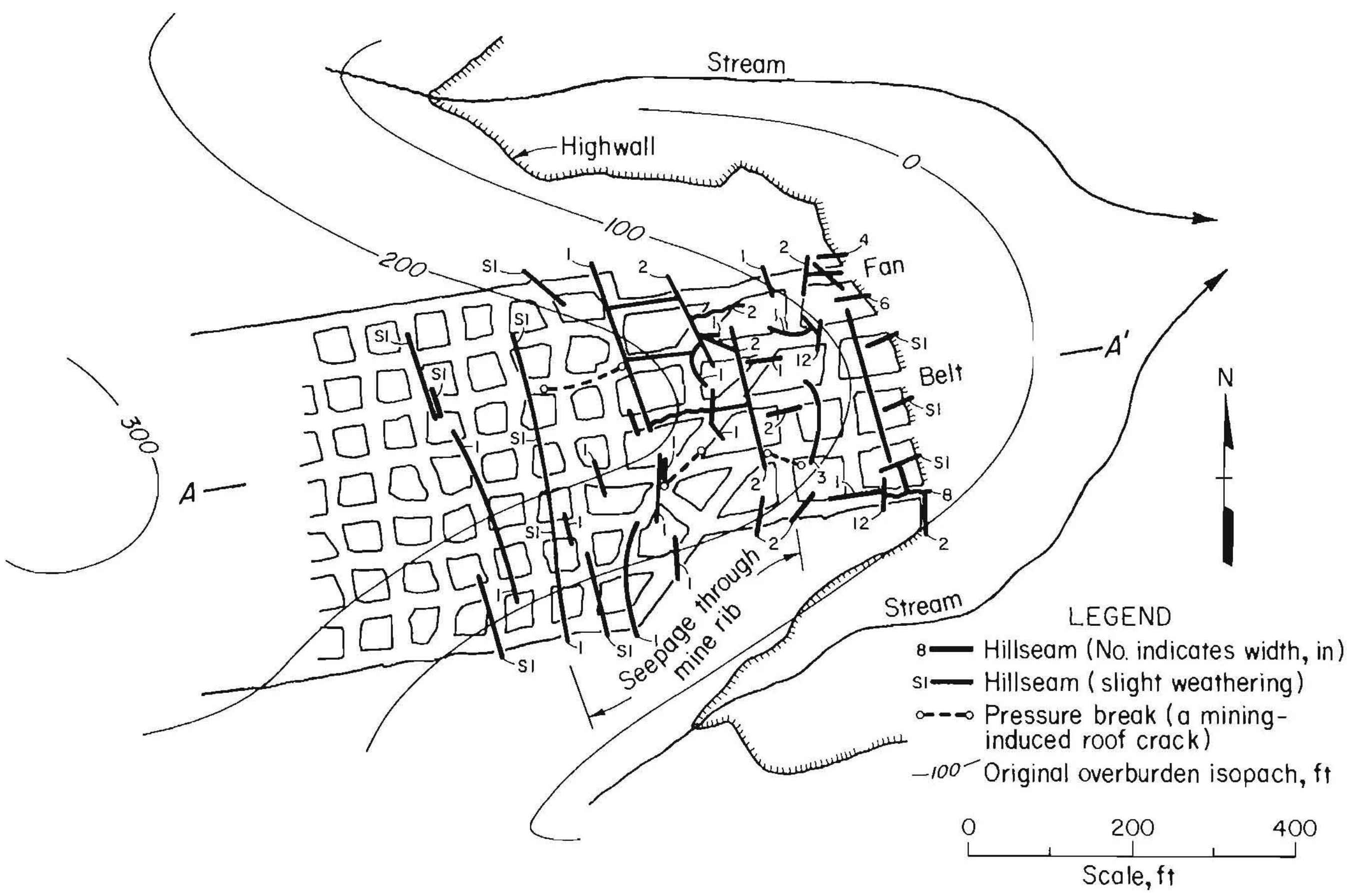

Figure 34.-Map of example 5 mine portal area.

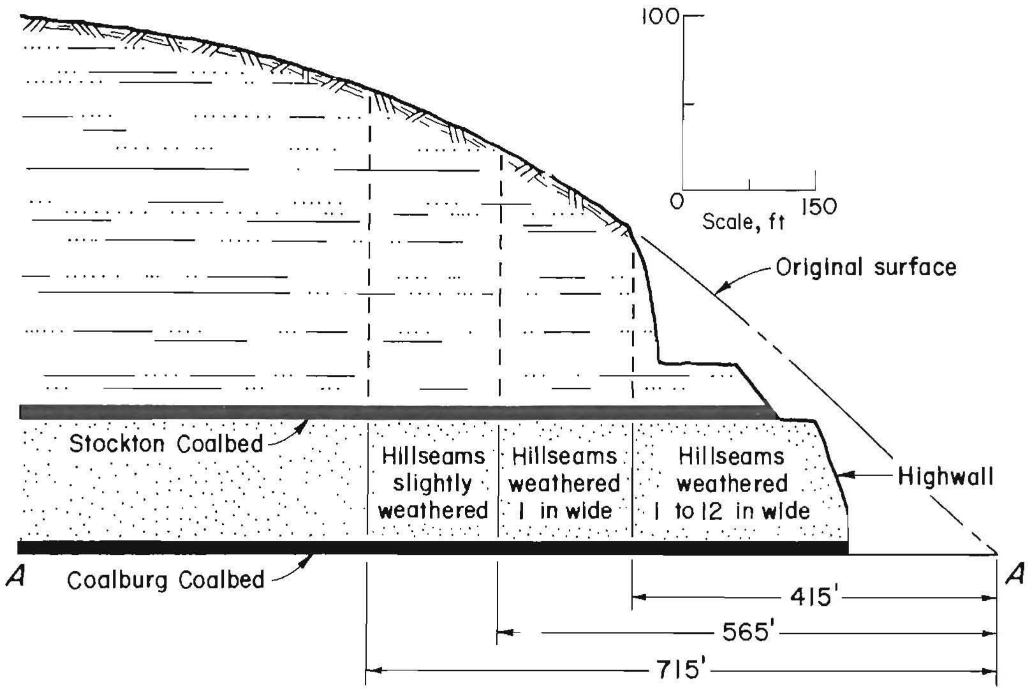

Figure 35.–Overburden profile at example 5 mine.

cracks) have developed in the area; however, the possibility of a roof fall between hillseams can never be fully discounted.

A rose diagram of hillseam orientations in the study area inby the portals (fig. 36) indicates that the hillseams tend to follow a narrow preferred orientation that lies about midway in the broad range of surface contour directions around the nose of the ridge. Actual underground mapping in figure 34 shows the intersecting nature of the hillseams in the most outby portion of the development entries directly under the nose of the ridge.

Example 6

County: Martin
Coalbed: Stockton, 60 in
Overburden: Range 0 to 240 ft
Mining method: Continuous miner, room-and-pillar
Roof: Main, thick- and thin-bedded sandstone, 15 to 20 ft; immediate, silty shale, 5 to 6 ft
Hillseam-related injury: None
Summary: The portals of this mine were opened in a highwall and driven straight for over 1,000 ft. Hillseams were encountered for about 400 ft inby the portal under a maximum of 200 ft of overburden and tended to parallel surface contours (fig. 37). The most severe roof support problems occurred within 175 ft of the portal (fig. 38) where hillseams were mud filled and up to 12 in wide. Steel crossbars usually were employed for roof support.

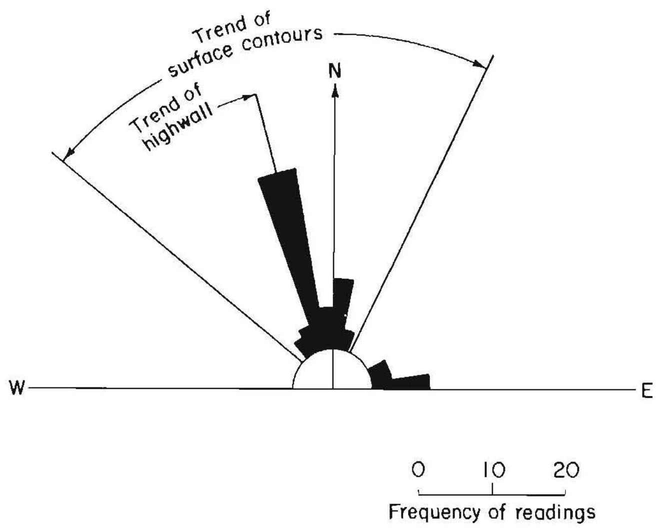

Figure 36.–Rose diagram of hillseam trends at example 5 mine.

A diagram of the hillseams exposed in the highwall at the portals indicates that most parallel the general east-west trend of an irregular highwall and the surface contours (fig. 39). Many of the hillseams in the highwall did not penetrate down to the coalbed and were not observed in the mine roof, suggesting that the main roof may be weakened by hillseams that cannot be detected in exposed mine roof.

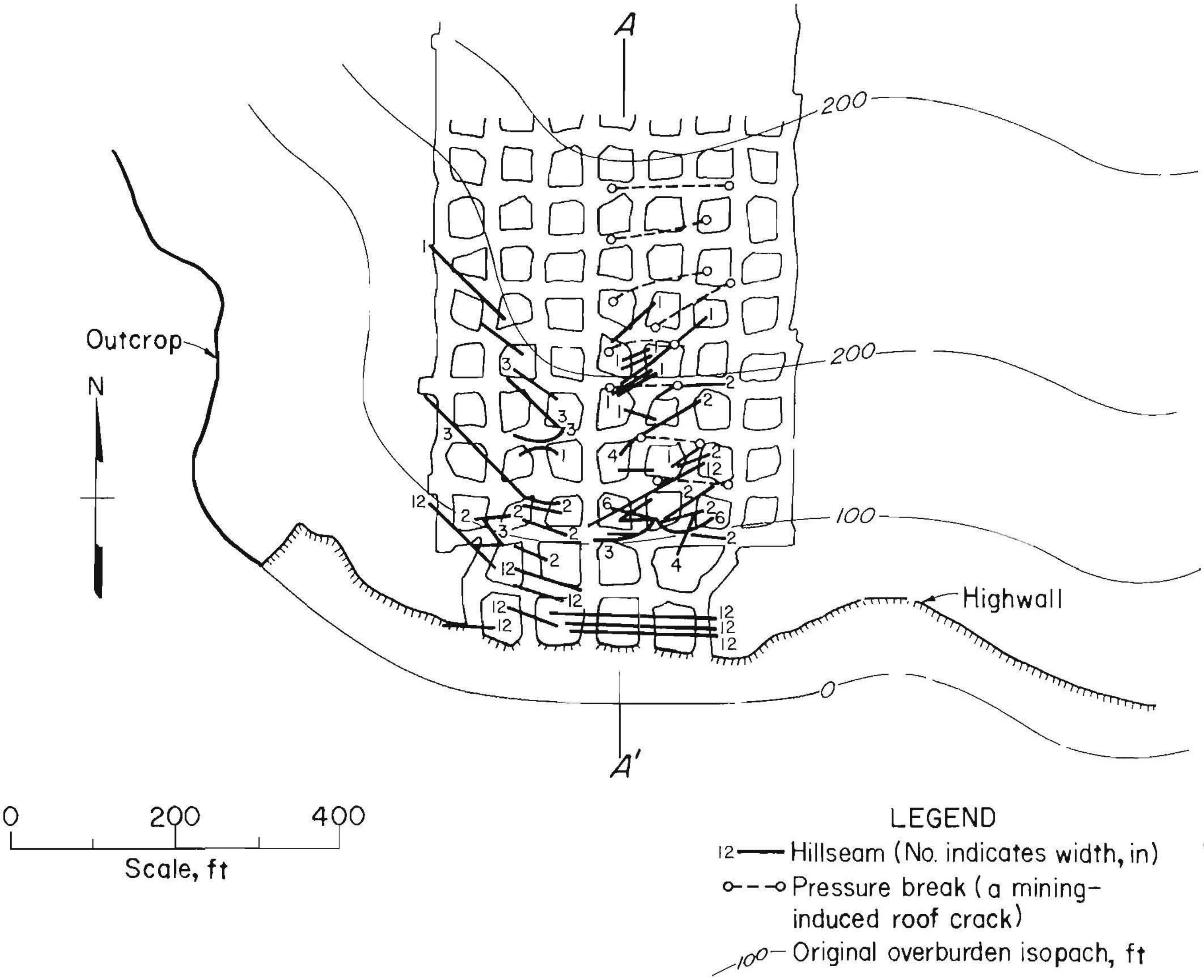

Figure 37.–Map of example 6 mine portal area.

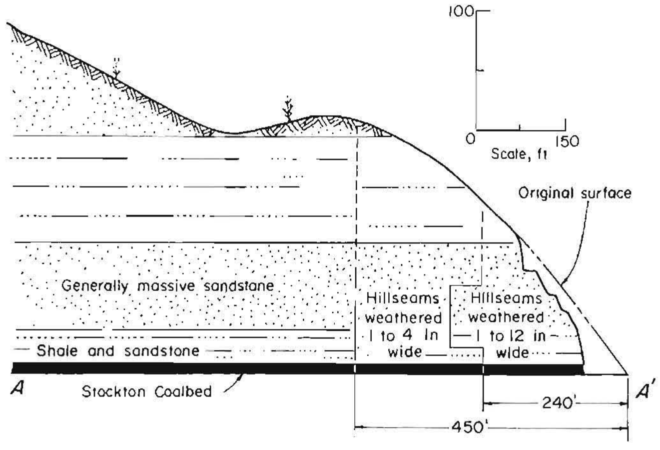

Figure 38.–Overburden profile at example 6 mine.

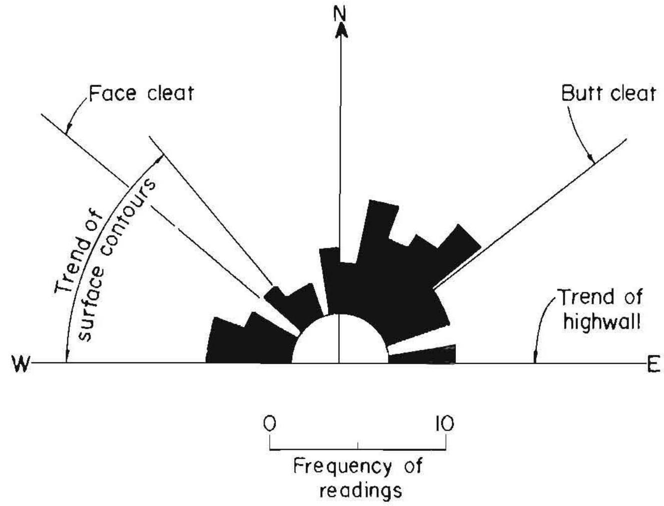

Figure 39.–Rose diagram of hillseam trends at example 6 mine.

SUMMARY AND CONCLUSIONS

This study of the outcrop barrier zone focused on the geologic character of hillseams, the dominant geologic cause of roof instability unique to this zone. The occurrence of hillseams and weathering near outcrop are crucial ground control factors in drift mines. The geologic data compiled during this study of hillseams and the outcrop barrier zone lead to the following conclusions:

1. Hillseams in eastern Kentucky are weather-enlarged tension joints that occur in shallow mine overburden where surface slopes are steep. They occur with the greatest frequency and severity within 200 ft laterally of the coalbed outcrop, then decrease in frequency and severity to about 700 ft inby outcrop and under 300 ft or less of overburden. Most are vertical, but a small percentage dip up to 25°. Most are straight, but some are curved. Some intersect and some terminate at other hillseams.

2. Because hillseams develop by stress relief, they tend to parallel the dominant topographic contour lines and ridges. However, in the nose of a ridge stress relief acts parallel to both the ridge and the nose. This action results in intersecting hillseams.

3. Hillseams generally extend to the surface as indicated by the initial inflow of mud and water into mines. Weathering can extend laterally from hillseams along bedding planes, especially in soft rock types such as claystone and shale.

4. Fine-grained rock such as shale and claystone is more affected by the progressive weathering in hillseams than is coarse-grained rock such as sandstone and siltstone. In all rock types the character and intensity of hillseams can change abruptly along strike, or remain constant for many feet.

5. Generally, hillseams are poorly developed in coalbeds. A thin layer of coal or drawslate can obscure those in the mine roof, allowing them to go undetected unless roof support problems develop. Evidence such as iron or clay stains, weathering, or water in the mine roof should be regarded as a possible indication of a hillseam.

6. The occurrence of one or more hillseams in mine roof, whatever their character or orientation, weakens the roof. Narrow hillseams that strike transversely to openings generally are the least troublesome. Very wide, intensely weathered hillseams transverse to openings tend spall or fail in small slabs between splaying joint surfaces. Hillseams that parallel openings create a serious hazard by interrupting the beamlike span of roof, leaving a cantilever. Parallel or intersecting hillseams in the same opening break the roof into separate wedges and blocks.

7. Intersecting hillseams constitute a major roof-fall hazard because failure generally occurs as a thick, massive block or wedge of roof. Roof failure at intersecting hillseams generally occurs with no warning indicators and cannot be anticipated.

8. Extensive stripping of the coal and overburden at a proposed portal site will eliminate the most severe hillseam conditions in an area that is often under the least cover in the mine.

REFERENCES

1. Greenwald, H. P., E. R. Maize, I. Hartmann, and G. S. Rice. Studies of Roof Movement in Coal Mines. 1. Montour 10 Mine of the Pittsburgh Coal Co. BuMines RI 3355, 1937, 41 pp.

2. Stratton, H. J. List of Publications Issued by the Bureau of Mines From July 1, 1910, to January 1, 1960. BuMines Spec. Publ., 1960, 826 pp.

3. Moebs, N. N., and R. M. Stateham. Coal Mine Roof Instability: Categories and Causes. BuMines IC 9076, 1986, 15 pp.

4. Chase, F. E., and G. P. Sames. Kettlebottoms: Their Relation to Mine Roof and Support. BuMines RI 8785, 1983, 12 pp.

5. Moebs, N. N., and J. L. Ellenberger. Geologic Structures in Coal Mine Roof. BuMines RI 8620, 1982, 16 pp.

6. Sames, G. P., and R. B. Laird. Geologic Conditions Affecting Coal Mine Ground Control in the Western United States. BuMines IC 9172, 1988, 30 pp.

7. Gray, R. E., H. F. Ferguson, and J. V. Hamel. Slope Stability in the Appalachian Plateau, Pennsylvania and West Virginia, U.S.A. Paper in Rockslides and Avalanches, Volume 2: Engineering Sites, ed. by B. Voight. Elsevier, 1980, pp. 447-471.

8. Wise, D. U., L. J. DiMicelli, Jr., and P. Baginsky. Brittle Fracture Patterns on a Traverse of the Big Sandy Gas Field, Kentucky. Paper in Proceedings, Symposium on Western Limits of Detachment and Related Structures in the Appalachian Foreland (GSA S. E. Sec. Meet., Chattanooga, TN, Apr. 6, 1978). WV Univ. (Morgantown, WV), 1980, pp. 133-148.

9. Unrug, K. F., and R. S. Mateer. In-Situ Stress in Relation to Topography and Major Fractures in Rocks: An Example from Martin County, Eastern Kentucky. Paper in the Proceedings of the International Symposium on Application of Rock Characterization Techniques in Mine Design (New Orleans, LA, Mar. 1986). Soc. Min. Eng. AIME (Littleton, CO), 1986, pp. 237-244.

10. Martin, G. R., and P. J. Miller. Stability of Slopes in Weathered and Jointed Rock. Paper in Proceedings, Symposium on Stability of Slopes in Natural Ground (Nelson, New Zealand, Nov. 8-9, 1974). N.Z. Inst. Eng. (Wellington), 1974, v. 1, Issue 5(G), pp. 7.1-7.13.

☆ U.S. GOVERNMENT PRINTING OFFICE: 611-012/00,116

INT.BU.OF MINES,PGH.,PA 28984