BUMP HAZARD CRITERIA DERIVED FROM BASIC GEOLOGIC DATA

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ABSTRACT

The U.S. Bureau of Mines is conducting research to develop a quantitative means of assessing bump-prone geologic conditions using lithologic and topographic information. An engineering software package that includes a spatial relational database, data modeling, and graphic data display is used to apply a set of geologic criteria to assess bump-proneness and produce hazard maps. This paper presents the method and criteria developed through case studies of mine properties in the Pocahontas No. 4 Coalbed in southern West Virginia and the Pocahontas No. 3 Coalbed in western Virginia. Initial results suggest general agreement between the hazard map and field observations. Further development of the criteria and parameter identification are ongoing.

INTRODUCTION

Coal mine bumps are sudden, violent expulsions of coal from a rib or active working face into an adjacent entry or entries. The amount of coal ejected can vary. Small bumps can present a hazard to individual miners, as these events may eject several kilograms of coal under excessive stress. Large bumps can lead to multiple fatalities by generating enough force to eject tons of coal and displace heavy underground machinery.

The literature contains references to bump activity in the United States as early as 1918 (Watts, 1918). Consistent with that long history, a considerable amount of research has been conducted on coal mine bumps. Early work addressed the causes of coal bumps and made recommendations on various mining practices to avert them (Rice, 1935; Holland and Thomas, 1954). Other work focused on the development of mining systems and remediation techniques that could be used safely in bump-prone ground, such as auger drilling and shot firing (Peperakis, 1958; Talman and Schroder, 1958).

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Although some mines have successfully addressed the problem, bumps continue to challenge the coal industry. Goode and others (1984) found that 28 fatalities from 1959 to 1984 could be attributed to bumps. Iannacchione and DeMarco (1992) found that at least one fatality, several injuries, and at least one mine closure were attributable to bumps during the preceding decade. However, with ever-increasing mining depths and faster extraction methods associated with increased productivity, in the future more mines will have to contend with geologic environments with high bump potential.

To effectively control coal bumps, a mine operator should have the means available to (1) anticipate bump-prone ground, (2) design mining systems that can be used successfully in bump-prone ground, (3) monitor the effectiveness of a design once it has been implemented, and (4) remediate situations in which bumps were not anticipated or the employed design proved inadequate. Previous U.S. Bureau of Mines (USBM) research has addressed all four topics to varying degrees. For example, successful mine layout designs have been documented in both room-and-pillar and longwall operations (Campoli and Heasley, 1989;

Campoli and others, 1989), and a general methodology for room-and-pillar mine design in bump-prone ground is available (Campoli, 1994). The present paper describes an ongoing USBM research project aimed at characterizing bump-prone geology and establishing geologic criteria to help mine operators anticipate potentially hazardous bump conditions.

BUMP-PRONE GEOLOGY

Throughout the literature on bumps, there are recurring themes regarding geologic conditions associated with bump occurrences. The most basic assumptions accept that "two geologic conditions have been found to cause the occurrence of bumps in the Eastern United States: (1) relatively thick overburden and (2) extremely rigid strata occurring immediately above and below the mine coalbed" (Campoli and others, 1987). Talman and Schroder (1958) noted the importance of "heavy overburden, an overlying stratum of strong nonelastic rock, a structurally strong coal seam which does not crush easily and yet is the weakest stratum in the series, and a floor stratum of more than ordinary firmness" to the occurrence of bumps. Holland and Thomas (1954) listed "a rather definite set of natural conditions" controlling bump occurrences, including 150 m (500 ft) or more of overburden, a strong overlying stratum immediately above or close to the coal, and a strong floor that does not heave readily.

Various descriptions of bump-prone ground provide some insight as to what constitutes bump-prone geology. However, many questions remain unanswered, e.g., how thick is relatively thick, how rigid is extremely rigid, and how close is immediate? The methodology followed in this study to develop bump hazard criteria was to (1) quantify parameters to represent rules of thumb commonly used to describe bump-prone geology, (2) incorporate the various individual parameters into a single bump hazard index, and (3) evaluate the bump hazard index by contrasting predicted bump-proneness with actual bump experience in mines.

The development and evaluation of the bump hazard criteria were facilitated by a relational database management system operating on a computer workstation. Detailed stratigraphic information on bump-prone mines in the southern Appalachian Coalfield is being compiled in an engineering software package called TECHBASE. TECHBASE is a relational database management system with application packages that can, among other capabilities, store and manipulate stratigraphic data, use various modeling techniques to estimate data in two and three dimensions, and create graphics to display the data as plan-view and cross-sectional maps.

BUMP HAZARD CRITERIA

As mentioned earlier, several geologic factors are historically associated with coal bumps, namely, thick overburden and strong, stiff roof and floor members. The most basic approach to quantifying bump-prone ground, therefore, is to find some means to assign relative measures of (1) overburden thickness, (2) strength of mine roof, and (3) strength of floor. In this analysis, index scales were developed for each of these three parameters. Each scale runs from 0 to 100; the higher the value, the greater the degree of bump-proneness.

The overburden index is calculated by extrapolating top-of-coalbed elevation data from core logs into a grid, matching surface elevation data to the grid, subtracting the top-of-coalbed surface grid from the topographic surface grid, subtracting 150 m (500 ft), and normalizing the data by dividing by a number to arrive at a 0-to-100 scale.

This formula assumes a that minimum overburden of 150 m (500 ft) is needed to initiate a bump. Subtracting 150 m (500 ft) from each overburden value in the grid, then normalizing the data to reduce the effective overburden index to a scale of 0 to 100, where 0 represents 150 m (500 ft) of overburden and 100 represents the maximum overburden present at the site, results in a range of values that all carry bump potential. The overburden index is a rather direct measure of overburden thickness; estimating rock strength using roof- and floor-strength indices, however, is less straightforward.

When working with core logs to develop a hazard criterion for strength and stiffness of the roof and floor, one is immediately faced with the variability of the geologic environment. Many researchers point to the presence of specific sandstone units in the immediate roof and floor of bump-prone mines as providing the strength or stiffness necessary to initiate bumps. However, the presence, absence, and/or continuity of any individual unit in coal-measure rocks are generally unpredictable. Named units in core logs can be inconsistent or nonexistent, depending on the ability and requirement for detail originally assigned to the driller or logger. In addition, sandstone may not be the rock type most directly responsible for bump-prone conditions in every geologic setting.

To overcome these difficulties, a decision was made to develop a geologic criterion based on generic lithologic descriptions, rather than specific lithologic units, and empirical evidence to determine the lithologies most directly related to bumps in each geologic setting. Rather than using named units or beds, code values (Ferm and Weisenfluh, 1981) were assigned to rock types. Code values provide a convenient means of grouping rock types and calculating parameters characteristic of stratigraphic sequences. For example, one approach to estimating the strength of mine roof and floor (and the one used in this study) was simply to determine the percentage of the rock type most directly associated with previous bumps in that geologic setting in an interval above and below the coalbed. Thus, the amount of the targeted rock type present provided a crude measure of mine roof strength or potential to contribute to bump occurrence. Kidybinski (1979) used a similar approach to incorporate a lithologic component into his assessment of "the natural liability of coal to rock bursts."

Roof- and floor-strength indices were calculated in TECHBASE by determining the total thickness of strata identified by three grouped rock-type codes in specified intervals above and below the coalbed. Code group 1 includes sandstones, conglomerates, and sandstones with shale streaks. Code group 2 includes siltstones, sandy shales, and shales with sandstone streaks. Code group 3 is comprised of fine-grained shales, claystones, and coals. This approach eliminated vagaries in named units, the complexity of many lithologic descriptions, and the effect of vertical variability in lithology when deciding which units were to be deemed influential.

A 10-m (33-ft) interval above the coalbed was chosen for examining roof strength. This selection differed from Kidybinski's (1979) recommended interval of 30 m (100 ft). The decision to shorten the interval was made to lessen the effect of averaging the overlying strata to the degree that it began to approach the normal distribution of rock types expected in any given geologic environment. Also considered in the decision was the expectation that using the immediately confining strata as a precursor of bump occurrence was more suited to a hazard index such as this than was using the nature of a large interval of overlying rock. A smaller interval of 3 m (10 ft) was chosen to examine floor strength for more pragmatic reasons—often coreholes do not extend more than a few meters below a coalbed of interest.

The individual index values chosen to represent overburden thickness, roof strength, and floor strength were then combined and averaged to develop a measure of the relative bump hazard. The combined criteria were intended to reflect the conventional wisdom about which geologic conditions constitute bump-prone ground in given geologic settings.

There are, of course, other ways to quantify these parameters. In addition, there are many more parameters that could be quantified and incorporated into a bump hazard index, e.g., roof and floor strength and stiffness as determined by physical property testing, proximity of units of influence to the coalbed, and the number of discrete beds as an indication of the massive nature of the strata. However, before increasing the complexity of the hazard index, the initial criteria are being evaluated by contrasting the predicted hazard level with actual experiences in different geographic locations that have a long history of bump activity.

BUMP-HAZARD ASSESSMENT CASE STUDIES

The bump hazard assessment criteria described above were applied to mine properties in the Pocahontas No. 4 Coalbed in McDowell County, WV, and the Pocahontas No. 3 Coalbed in Buchanan County, VA. The results of this effort are discussed in detail below.

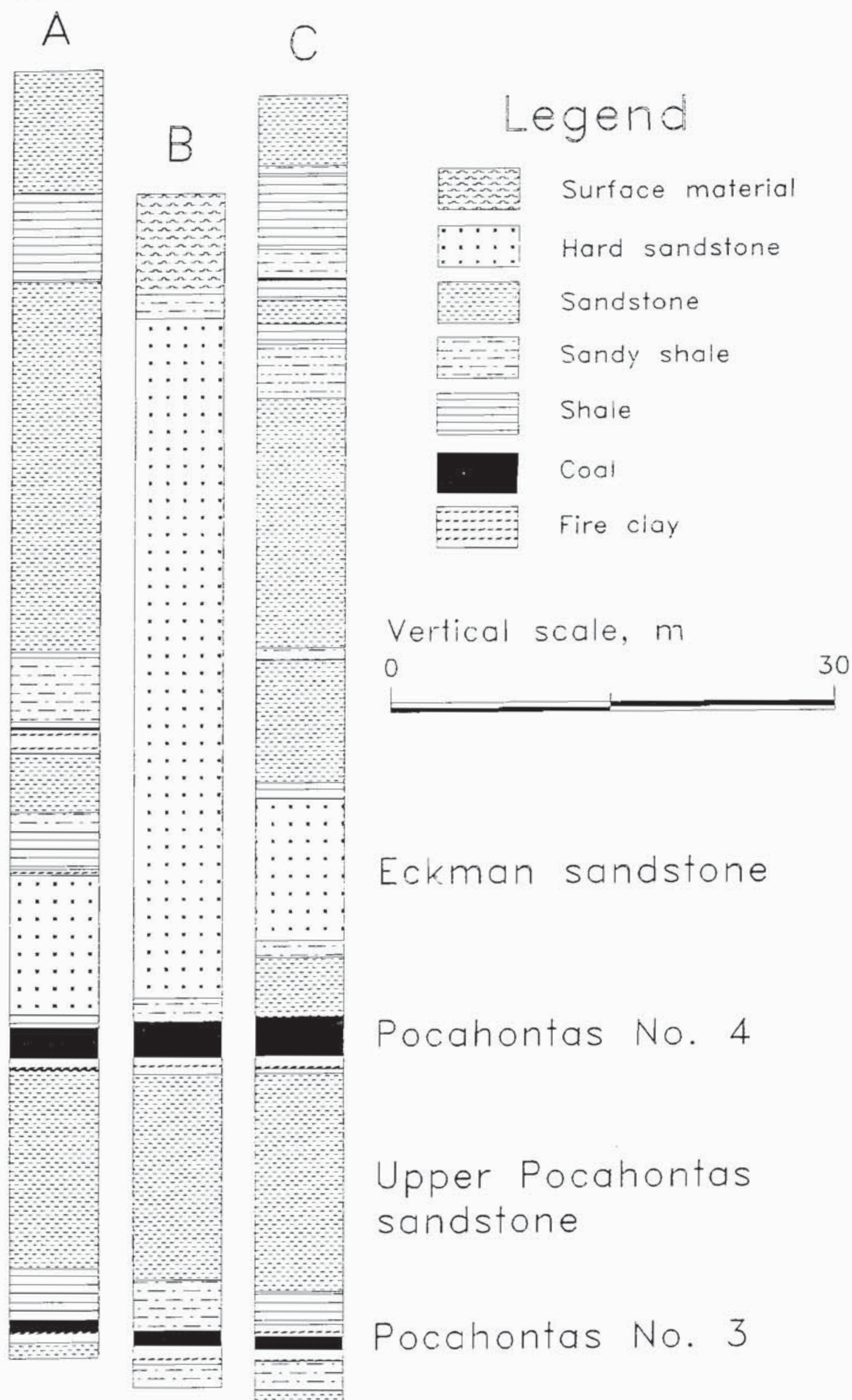
POCAHONTAS NO. 4 COALBED STUDY

The study property in the Pocahontas No. 4 Coalbed in southern West Virginia was first developed in 1903 and ultimately included two mines covering approximately 47 km^2 (18 mi^2). Figure 1 shows the boundary of the mine property, the locations of the diamond coreholes used for the stratigraphic information contained in this paper, and the locations of the three core logs (A, B, and C) shown in figure 2. Also shown in figure 1 is the number of bump occurrences at various locations.

The study property has a long history of coal bumps. The first bumps were reported in the early 1930's. A series of powerful bumps, resulting in many fatalities and serious injuries, occurred from 1945 to 1952. This activity prompted management to aggressively pursue the development of mine designs and remediation techniques, including the successful "thin-pillar" mining method (Talman and Schroder, 1958), to alleviate the problem.

Figure 1
Study Area, Pocahontas No. 4 Coalbed, McDowell County, WV.

Figure 2
Core Logs A, B, and C, Pocahontas No. 4 Study Area.



Geologic Setting

The entire minable extent of the Pocahontas No. 4 Coalbed lies within Wyoming and McDowell Counties of southern West Virginia (Hennen, 1915). Wyoming and McDowell Counties are in the Appalachian Plateau physiographic province, a dissected upland with a regional dip to the northwest of less than 20 m/km (110 ft/mi) that is locally interrupted by small, open folds that trend northeast-southwest (Rehbein and others, 1981).

Topography over the mines is rugged, with deep V-shaped valleys and up to 225 m (740 ft) of relief. The coalbed dips from the southeast to the northwest on the western limb of the Dry Fork anticline. The total change in coalbed elevation is approximately 210 m (690 ft) across the mines. From coalbed outcrop, overburden increases to more than 450 m (1,475 ft) under the peaks and ridges in the west and northwest portions of the mines.

The diamond drill core logs shown in figure 2 illustrate typical stratigraphic sequences across the property. The Pocahontas No. 4 Coalbed falls approximately in the middle of the Pocahontas Formation, a coal-bearing sequence of interbedded sandstone, siltstone, shale, and underclay. The coalbed averages about 2 m (7 ft) thick, but locally thickens to 3 m (10 ft) and thins to 0 m. Roof rock varies from a dark gray shale to a hard, stiff, brown micaceous sandstone. The brown micaceous sandstone varies in thickness from about 15 to 55 m (50 to 180 ft) over the mines and is locally interrupted by thin coal and shale interbeds. The mine floor consists of a 0- to 1.5-m (5-ft) thick shale or underclay that grades laterally to siltstone. Below that is the predominant underlying rock, a hard, stiff, fine- to medium-grained sandstone that ranges in thickness from 15 to 23 m (50 to 75 ft) (Hennen, 1915; England, 1974).

Application of Hazard Criteria

The geologic data covering the study mines are from digitized topographic contours and 67 coreholes with known coordinates and collar elevations. Coalbed elevation, topographic data, and lithologic code groups for the roof and floor were modeled using the triangulation method into 150-m (500-ft) grids.

Overburden Index

The coalbed elevation grid was subtracted from the topographic grid to determine overburden thickness. Actual maximum overburden over the properties is 450 m (1,480 ft). Subtracting the 150 m (500 ft) of overburden required to generate bump conditions resulted in a 150- to 450-m (500- to 1480-ft) range of overburden values to be included in the index. These values were then divided by 3 to arrive at an index that ranged from 0 to 100. The resulting overburden index values are shown as four ranges in figure 3.

The significance of the structural change in coalbed elevation becomes evident when viewing the overburden index map (figure 3). Although the prominent topographic highs are to the south and southeast of the property where folded resistant sandstones crop out at the peak of the Dry Fork anticline, overburden thickness increases to the west and northwest due to the 210-m (690-ft) drop in coalbed elevation along the western limb of the anticline.

Roof-Strength Index

The roof-strength index was calculated as the percentage of sandstone within 10 m (33 ft) of the top of the coalbed. Figure 4 shows the range of index values corresponding to roof strength as contoured from the 150-m (500-ft) grid. Empirical and anecdotal evidence, along with accident reports from the U.S. Mine Safety and Health Administration, indicate that the presence of the brown micaceous sandstone immediately above the coalbed is a strong contributing factor to bumps on this property. The sandstone has a compressive strength of 167 MPa (24,200 psi) and a Young's modulus of 3.56×10^4 MPa (5.16×10^6 psi) (Campoli and others, 1989) and is identified in code group 1. This thick sandstone is widely distributed over the mine property, and the roof-strength index map is a good indicator of the proximity of the sandstone to the top of the coal.

Floor-Strength Index

Figure 5 shows the ranges of index values corresponding to floor strength. The floor-strength index was calculated as the percentage of sandstone within 3 m (10 ft) of the bottom of the coalbed. Based on the assumptions discussed in the section on "Bump-Prone Geology," the predominant underlying sandstone on this property meets the requirement of a strong floor rock to generate bump conditions, having a compressive strength of 150 MPa (21,900 psi), and a Young's modulus of 3.77×10^4 MPa (5.45×10^6 psi) (Campoli and others, 1989). It is identified in code group 1.

Figure 3
Overburden Index, Pocahontas No. 4 Coalbed Study Area.

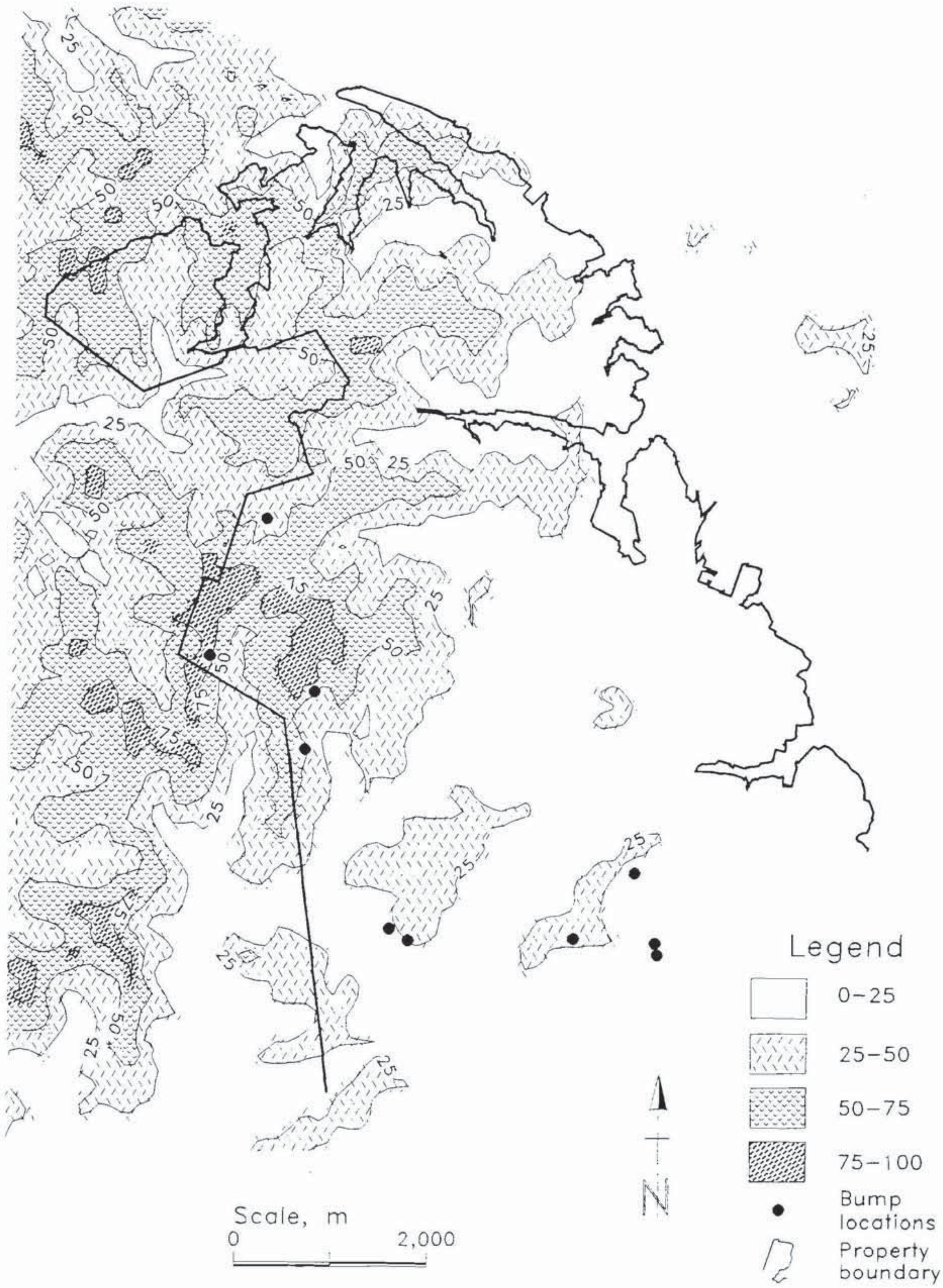


Figure 4
Roof Strength Index, Pocahontas No. 4 Coalbed Study Area.

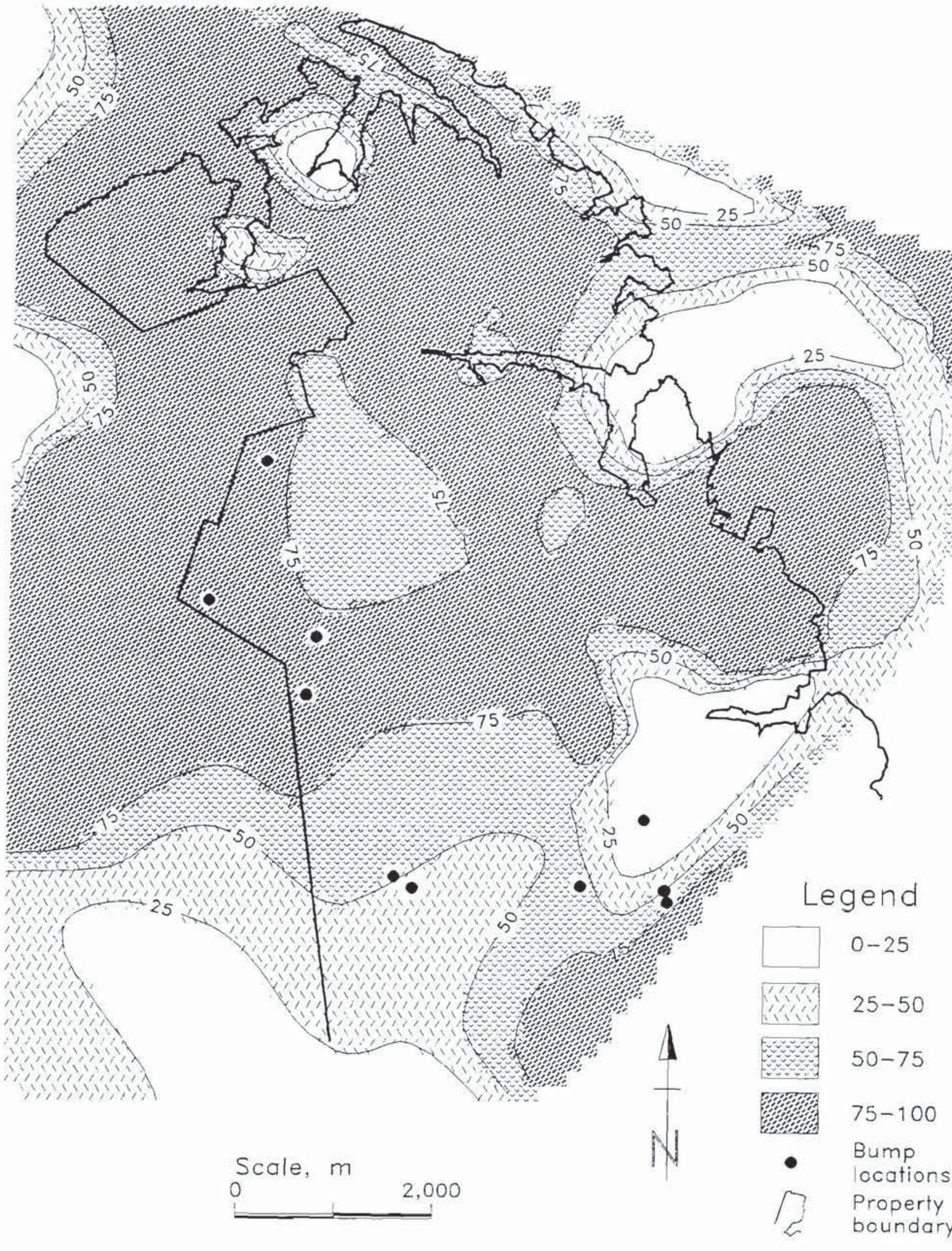
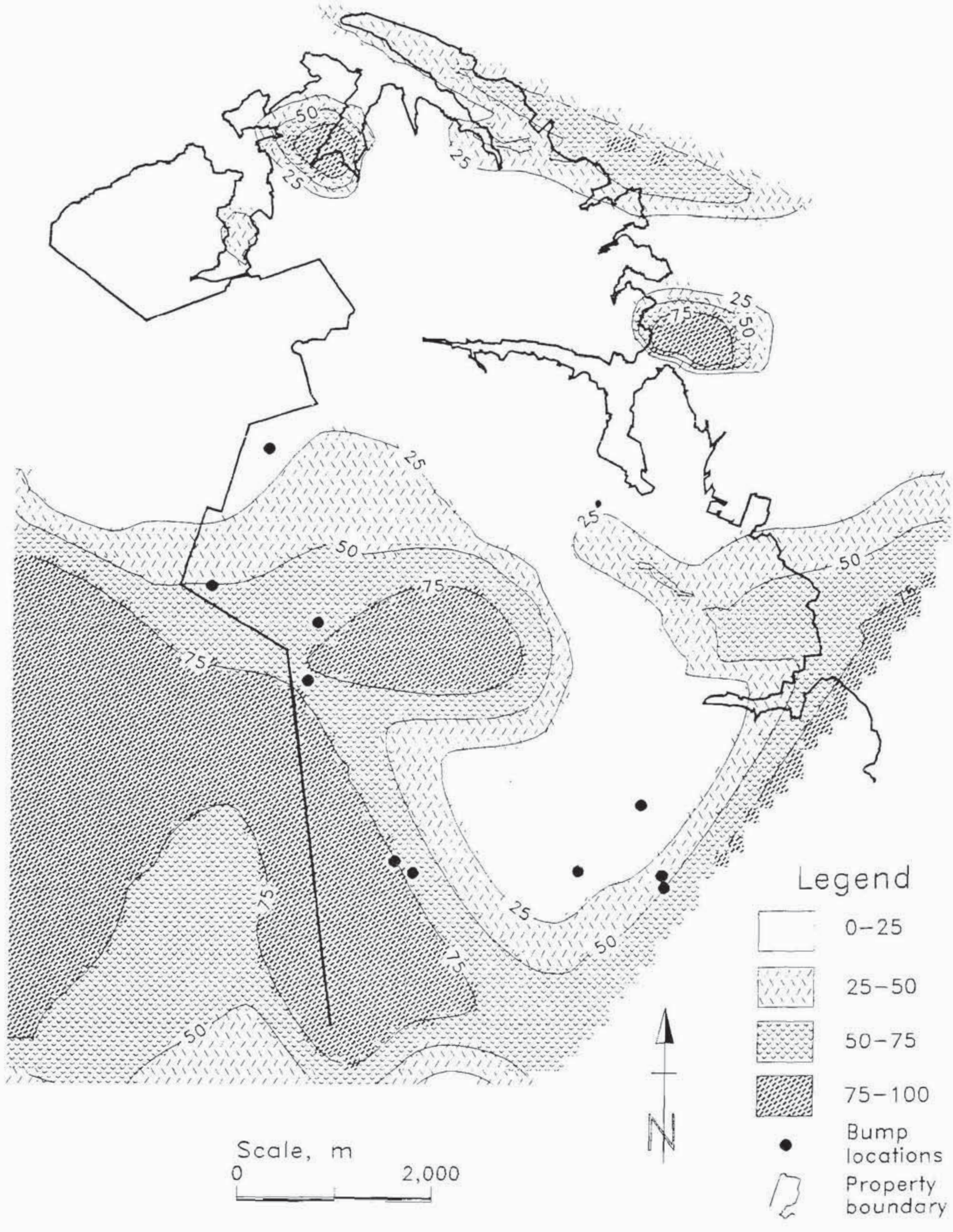


Figure 5
Floor Strength Index, Pocahontas No. 4 Coalbed Study Area.



Assessment of Hazard Criteria and Bump-Hazard Index Map

The following paragraphs and table 1 summarize the information contained in the base map in figure 1 (which shows the number of bump events associated with each general bump location), the individual hazard criteria index maps (figures 3-5), and the combined bump-hazard index map (figure 6).

Large areas of the Pocahontas No. 4 study property fall into the lowest overburden index range (0 to 25), but that does not preclude the potential for bumps because most of these areas are under 150 to 225 m (500 to 745 ft) of overburden (figure 3). In fact, the historical locations of bump-prone areas shown on the map are all in areas of at least 185 m (600 ft) of overburden. While the number of bumps is fairly evenly distributed across the overburden index ranges, there is a strong correlation between increasing overburden index values and the number of bumps per square kilometer of index area mined (table 1).

The distribution of index values for high roof strength is much wider over the property (figure 4). This is a direct correlation to the persistent presence of the brown micaceous sandstone and is an indication of the proximity of the sandstone to the top of the coalbed. As shown in table 1, the distribution of the number of bump events shows a definite increase with increasing roof strength index values. However, the number of bumps per square kilometer of index range mined does not increase proportionately due to the large area of the property within the higher index ranges.

Areas of index values indicating high floor strength are less regularly distributed over the property (figure 5). It is common to have at least 1 m of underclay and shale directly beneath the coalbed on this property (see figure 2). The floor-strength index map, then, is a good indicator of the proximity of the hard sandstone to the bottom of the coalbed. As shown in table 1, the distribution of the number of bump events is not consistent with increasing floor-strength index values, although the greatest number occur in the 50 to 75 range, with a corresponding high ratio of bumps per square kilometer of index area mined.

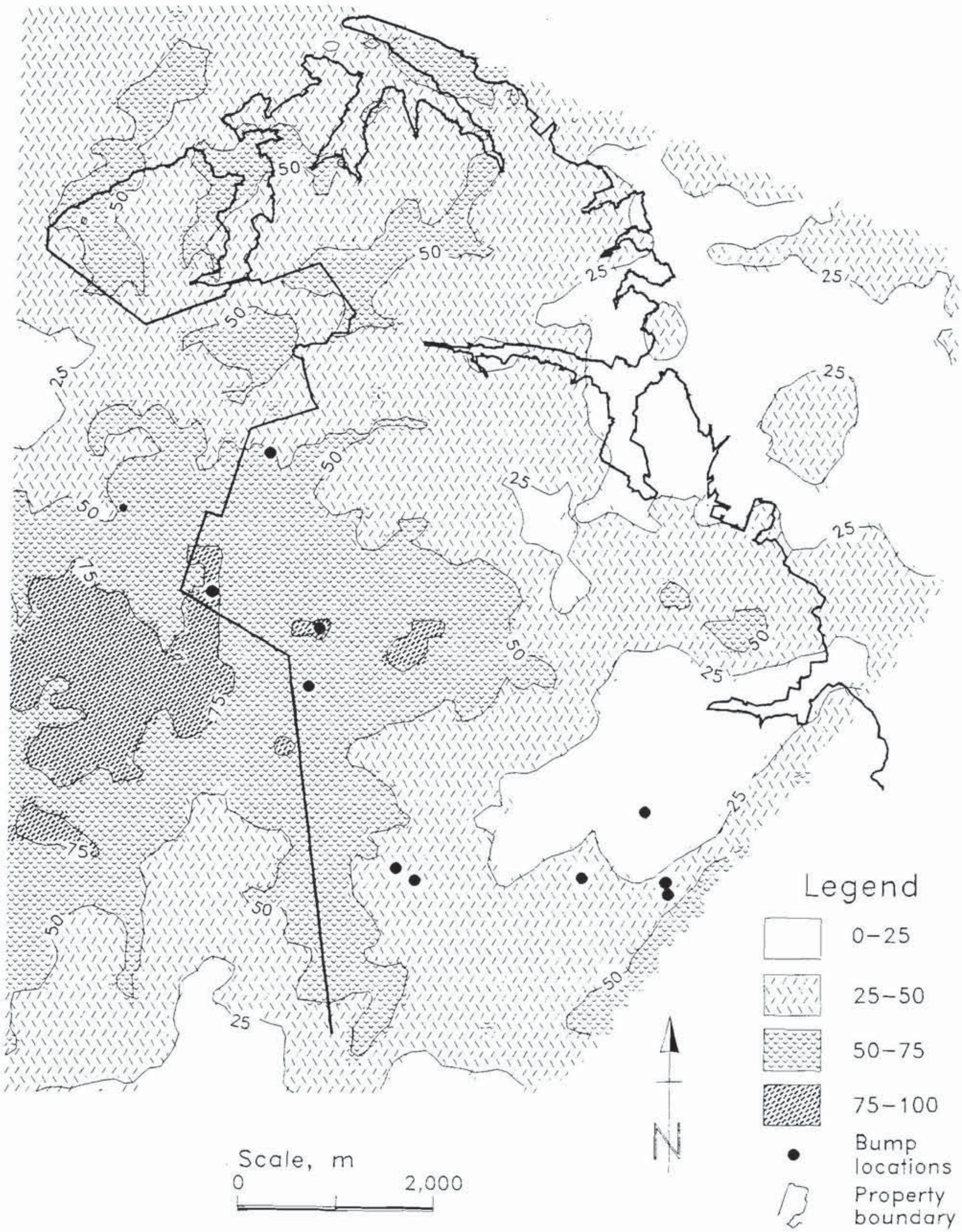
Taken individually, there is a rough correlation between high index values and known bump locations in table 1. However, when the values for the three criteria are combined and averaged to create the bump-hazard index map (figure 6), there appears to be a stronger correlation. Table 1 shows that there is little correlation between the number of bumps per square kilometer of index area mined until the index range reaches 75 to 100, where the ratio increases to 25 to 1.

Although geologic conditions are important contributors to bumps, mining plans and practices are also strongly influential. Holland and Thomas (1954) analyzed 117 bumps and concluded that "most bumps are the result of improper mining methods and practices." Many early bumps at the study property were linked to unfavorable mining practices (Duckwall, c. 1952). In fact, improved mining practices have had a definite effect on the occurrence of bumps; the eventual development of the thin-pillar mining method in the northern half of the study area significantly alleviated bump problems. This area was included, though, in the evaluation of the bump hazard criteria in table 1. Also, the absence of bumps along the central corridor between the two mines where index values range from 25 to greater than 75 corresponds to the absence of retreat mining in extensive development mains and barriers between the mines. Thus, the absence of bumps in areas having high bump index values or the presence of bumps in areas having low bump index values may be the result of the effectiveness of the mining system rather than failure of the criteria to be a true indicator of bump hazard potential.

Table 1.—Number of bumps falling into each index range versus total area of range mined

Index range	Total area of index mined, km^2	Number of bumps within index range	Bumps per square kilometer of index area mined
Overburden:			
0-25	28.0	7	0.25
25-50	12.1	4	0.33
50-75	5.7	5	0.88
75-100	1.2	7	5.83
Roof strength:			
0-25	4.1	2	0.49
25-50	5.9	1	0.17
50-75	12.4	6	0.48
75-100	24.6	14	0.57
Floor strength:			
0-25	24.0	5	0.21
25-50	9.4	2	0.21
50-75	8.5	14	1.65
75-100	5.1	2	0.39
Bump hazard:			
0-25	7.0	2	0.29
25-50	27.7	7	0.25
50-75	11.9	4	0.34
75-100	0.4	10	25.0

Figure 6
Bump Hazard Index, Pocahontas No. 4 Coalbed Study Area.



POCAHONTAS NO. 3 COALBED STUDY

The study site in the Pocahontas No. 3 Coalbed is located in a longwall mine in Buchanan County, VA. Figure 7 shows the mine property boundary, the extent of the mine workings at the time of data collection, the locations of the diamond coreholes used for stratigraphic information presented in this paper, and the locations of the three core logs (A, B, and C) shown in figure 8.

Geologic Setting

The study site lies within the Appalachian Plateau physiographic province. Topography over the property is rugged, with steeply sloped ridges, deep V-shaped valleys, and up to 475 m (1,555 ft) of relief. The coalbed dips from east-southeast to west-northwest. The total change in coalbed elevation is approximately 70 m (230 ft) across the mine. The Pocahontas No. 3 Coalbed does not crop out in the area. Overburden ranges from 300 m (985 ft) under the valleys to 778 m (2,550 ft) under the highest peaks and ridges.

The core logs shown in figure 8 illustrate typical stratigraphic sequences within 50 m (165 ft) above and 5 to 7 m (16 to 23 ft) below the coalbed, which averages about 1.7 m (5.6 ft) thick across the property. The Pocahontas No. 3 Coalbed falls near the bottom of the Pocahontas Formation. The Pocahontas Formation sequence in this area consists of interbedded light gray, fine- to medium-grained sandstones, medium to dark gray siltstones, some dark gray shale, and coal (Nolde and Mitchell, 1984).

The immediate roof rock [within 10 m (33 ft) of the top of the coalbed] varies from a highly bedded quartzarenite sandstone, to dark gray, bedded sandstone, to a very hard, dark gray massive sandy shale (siltstone), to dark gray shale. The sandy shale varies in thickness from 0 to 40 m (130 ft). Overlying the whole mine property is the quartzarenite sandstone that ranges in thickness from 40 to 120 m (130 to 395 ft). The distance from the top of the coalbed to the bottom of the quartzarenite is from 5 to 35 m (15 to 115 ft). The mine floor consists of a very competent siltstone and sandstone with shale streaks.

Application of Hazard Criteria

The geologic data covering the Pocahontas No. 3 study property were collected from 57 coreholes with known coordinates and collar elevations. U.S. Geological Survey digital elevation models (DEM's) were used as surface elevation data. Coalbed elevation data and lithologic code groups were modeled using the triangulation method into 30-m (100-ft) grids to match the DEM data.

Overburden Index

The coalbed elevation grid was subtracted from the DEM grid to determine overburden thickness. Actual maximum overburden over the property is 778 m (2,550 ft). Subtracting the 150 m (500 ft) necessary to initiate bump conditions resulted in 628 m (2,050 ft) of maximum effective overburden. These values were then divided by 6.28 to normalize the data to an index range from 0 to 100. The resulting overburden index ranges are shown in figure 9.

Roof Strength Index

The roof-strength index was calculated as the percentage of siltstone within 10 m (33 ft) of the top of the coalbed. Empirical evidence at the study property indicated that the siltstone immediate roof is the overlying rock type contributing most to the potential for coal bumps. The siltstone forms a smooth, widely jointed roof with little or no bed separation or evident sag. Unconfined compressive strengths of the siltstone range from 93.8 to 167.1 MPa (13,600 to 24,230 psi), and Young's modulus ranges from 2.6 to 5.3 $\times$ 10^4 MPa (3.8 to 7.7 $\times$ 10^6 psi) (Campoli and others, 1990). The overlying quartzarenite's unconfined compressive strength of 199.6 MPa (28,950 psi) is also very high (Campoli and others, 1990), but the thinly bedded nature of the sandstone results in good cavability where it is close to the coalbed, and in some areas it causes mine roof control problems resulting from excessive separation and sag. The percentage of siltstone is identified in code group 2; its distribution within 10 m (33 ft) of the top of the coalbed over the property is shown in figure 10.

Floor-Strength Index

The floor-strength index was calculated as the percentage of siltstone within 3 m (10 ft) of the bottom of the coalbed. Unconfined compressive strengths of the siltstone range from 95.8 to 123.6 MPa (13,900 to 17,920 psi) with an average Young's modulus of 4.8 $\times$ 10^4 MPa (6.9 $\times$ 10^6 psi) (Campoli and others, 1990). Floor strength throughout the mined portion of the property was observed to be high, with no evidence of floor heave or failure along pillar edges in advance of the longwall face (Gauna, 1992). The percentage of siltstone is again identified in code group 2. The distribution of the siltstone within 3 m (10 ft) of the bottom of the coalbed over the property is shown in figure 11.

Figure 7
Study Area, Pocahontas No. 3 Coalbed, Buchanan County, VA.

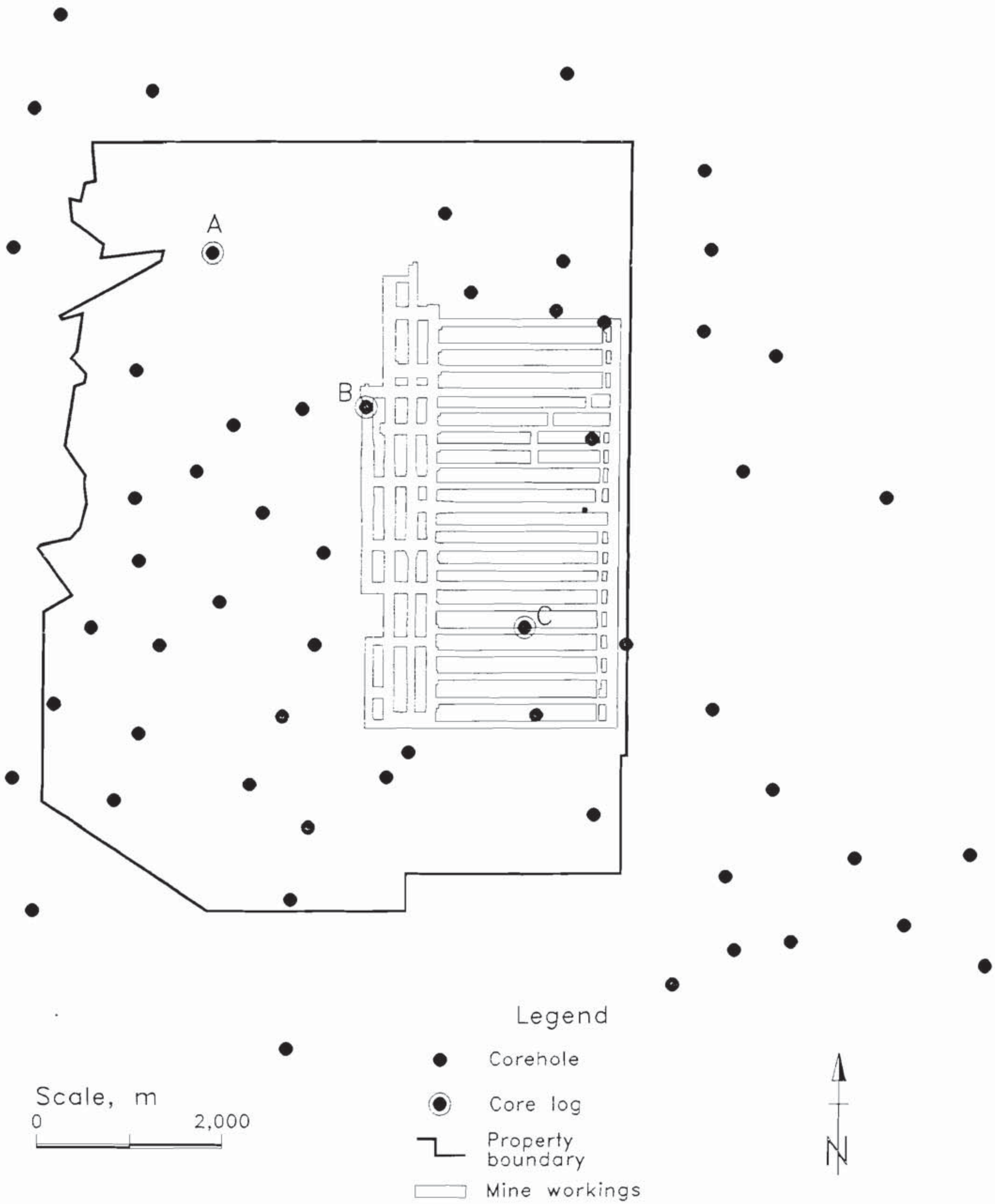


Figure 8
Core Logs A, B, and C, Pocahontas No. 3 Study Area.

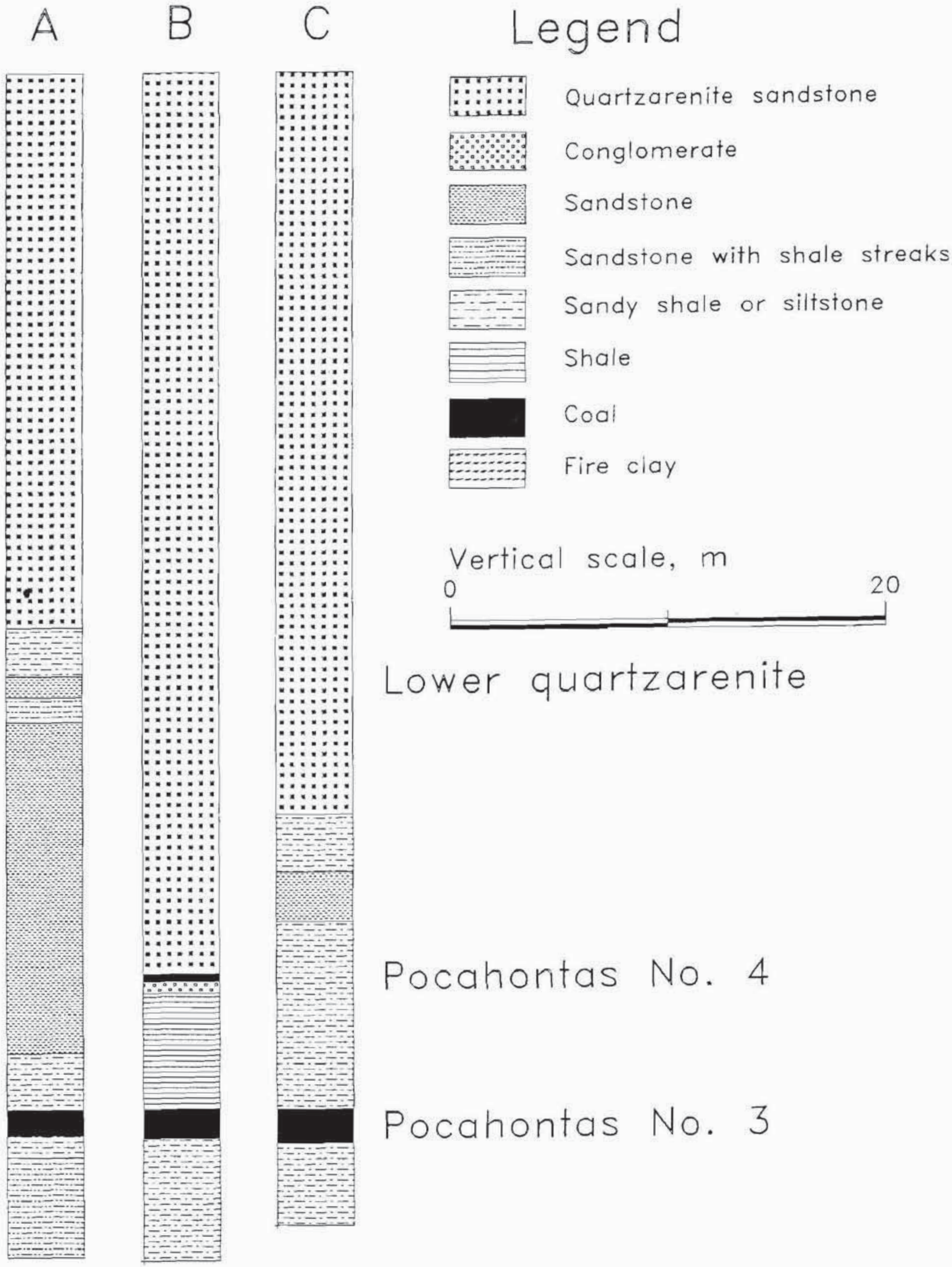


Figure 9
Overburden Index, Pocahontas No. 3 Coalbed Study Area.

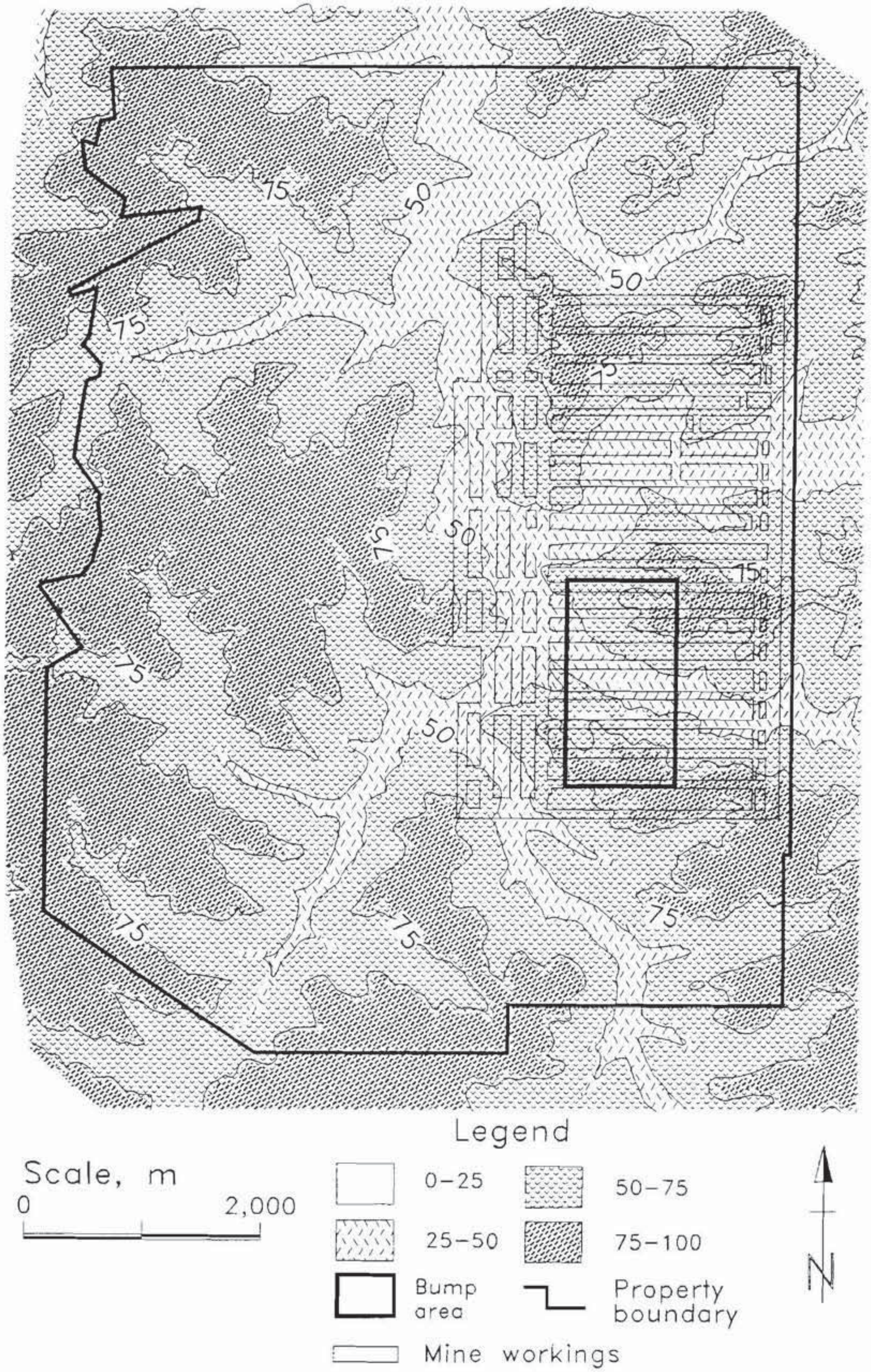


Figure 10
Roof Strength Index, Pocahontas No. 3 Coalbed Study Area.

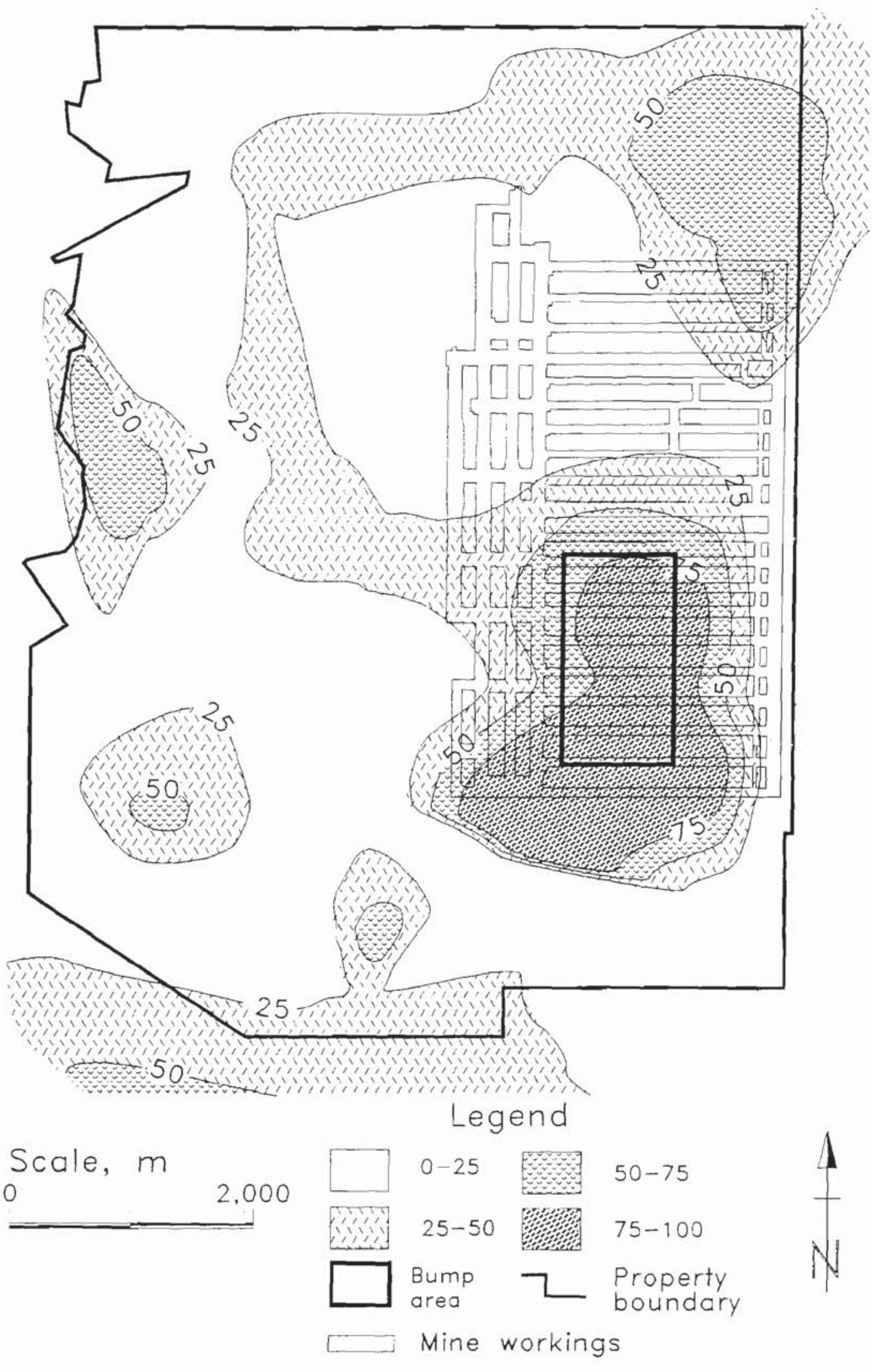


Figure 11
Floor Strength Index, Pocahontas No. 3 Coalbed Study Area.

Assessment of Hazard Criteria and Bump-Hazard Index Map

The significant amount of geologic data covering this property allowed detailed analysis of the geology, and current mining information enabled delineation of a specific area where bump conditions are present. The bump-prone area indicated on the maps has been documented in a previous USBM study (Campoli and others, 1990).

The depth of the Pocahontas No. 3 Coalbed precluded the presence of mine areas falling into the 0 to 25 range of the overburden index (figure 9). Essentially, the entire property is under sufficient overburden to satisfy the condition that deep overburden be present before bumps can be generated. In this case, the overburden criteria simply differentiate between deep versus deeper cover. Although the mine is in the Appalachian Plateau region where peak elevations are approximately equal, the presence of a major stream valley along the eastern half of the property, along with the 70-m (230-ft), east-to-west dip of the coalbed, results in a situation where the largest area of index values in the 75 to 100 range are in the western, unmined portion of the property. The full range of overburden index values lies within the outline of the bump-prone area.

The distribution of high roof-strength index values corresponds neatly with the outline of the bump-prone area (figure 10). The areas of low roof-strength values are areas where the quartzarenite sandstone lies near the top of the coalbed (as in core log B of figure 8) or where the dark gray shale is the predominant immediate roof rock.

Areas of high floor strengths are widely distributed over the mine (figure 11). This finding is consistent with the earlier observation that floor strength throughout the mined portion of the property is high, and there was no evidence of floor heave or failure along pillar edges.

Figure 12 shows the three bump hazard criteria when combined and averaged to form the bump-hazard index map. Correlation between the bump-prone area and areas of high bump-hazard index values is good. Although the northern half of the mine is in the 50 to 75 index range, no bumps have occurred. The relatively high values in this area are the result of the deep cover and a high floor-strength index. The quartzarenite sandstone near the top of the coalbed keeps these values out of the 75 to 100 bump hazard range and would seem to account for the lack of bumps. Figure 13 shows the bump-hazard index map with the areas of solid coal highlighted to reflect more clearly the mining sequence. Two longwalls operate in this mine. Mining began to both the north and south of the two central panel barriers and proceeded in opposite directions.

The panels to the north, to the extent of mining shown, did not experience any bumping of the tailgate pillars or longwall face. In fact, as noted previously, the quartzarenite sandstone is close to the top of the coalbed to the north, and roof stability problems developed in both the headgates and tailgates during extraction of the panels.

Bumping to the south began in the tailgate and at the tailgate side of the longwall face of the second panel and continued with mining of subsequent panels within the area outlined in figures 12 and 13. These events prompted the study by Campoli and others (1990) wherein gate entry design changes eventually controlled bumping at the working face. The tailgate pillars continued to bump behind the face in the gob area, where they posed no danger to miners or equipment.

SUMMARY AND CONCLUSIONS

This paper presents an overview of USBM work in developing a method of assessing coal-bump hazards using basic geologic information. An engineering software package was used to apply a set of geologic criteria to assess bump-proneness and produce hazard maps. The criteria incorporate parameters to reflect overburden thickness and the strength and stiffness of the strata surrounding the coalbed. The roof- and floor-strength indices are a reflection of the percentage of the rock type in the first 10 m (33 ft) of roof and 3 m (10 ft) of floor most directly associated with previous bumps in the given geologic setting.

The bump hazard assessment criteria were applied to mine properties in the Pocahontas No. 4 Coalbed in McDowell County, WV, and the Pocahontas No. 3 Coalbed in Buchanan County, VA. The hazard assessment generally agreed with the information available to document previous bumps on the two properties.

Bump data covering the Pocahontas No. 4 Coalbed study property consisted of historic occurrences that were intense enough to cause fatalities, serious injury, or significant disruption or alteration of existing mining plans and were documented in accident or internal reports.

Figure 12
Bump Hazard Index, Pocahontas No. 3 Coalbed Study Area.

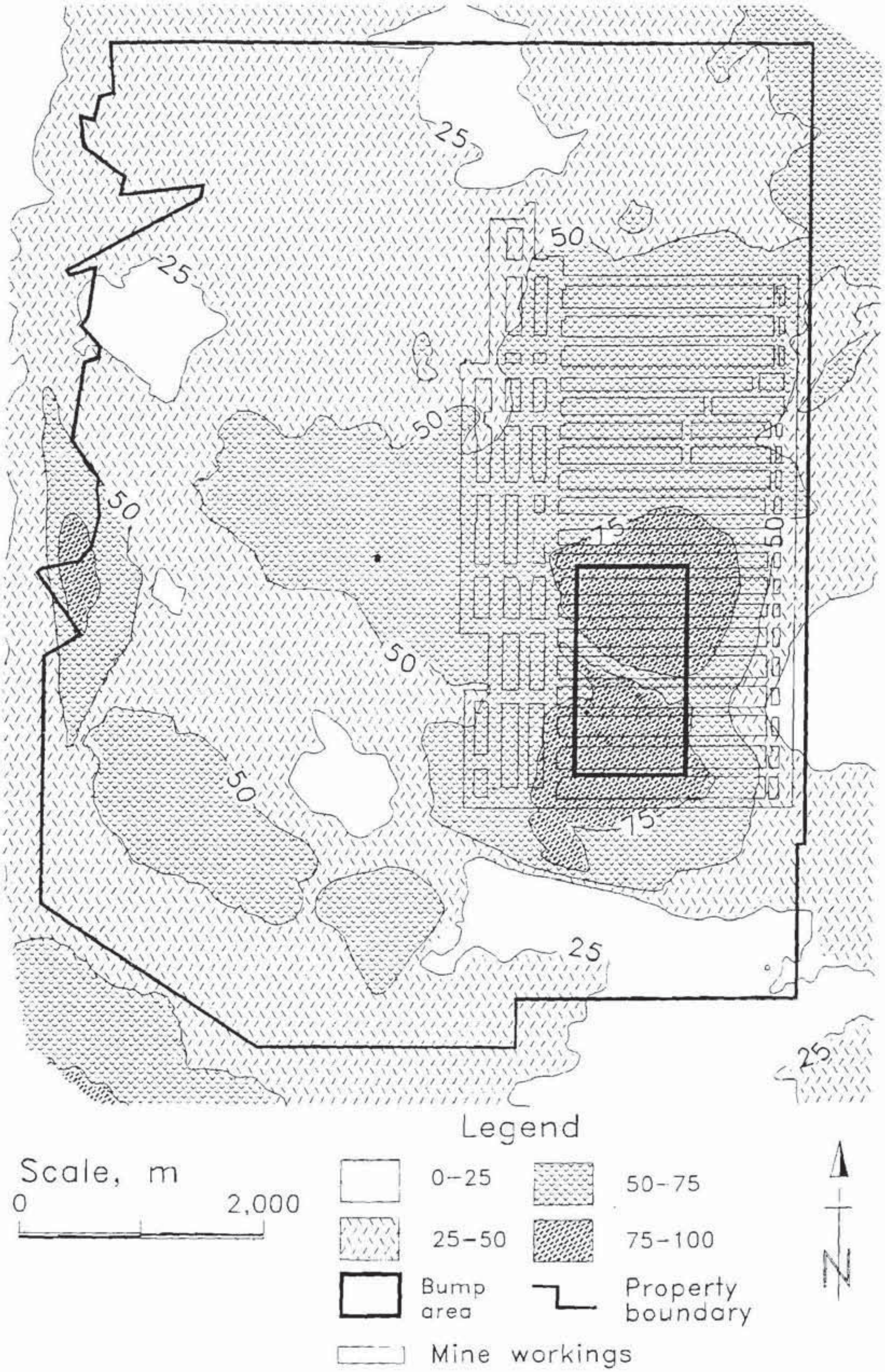
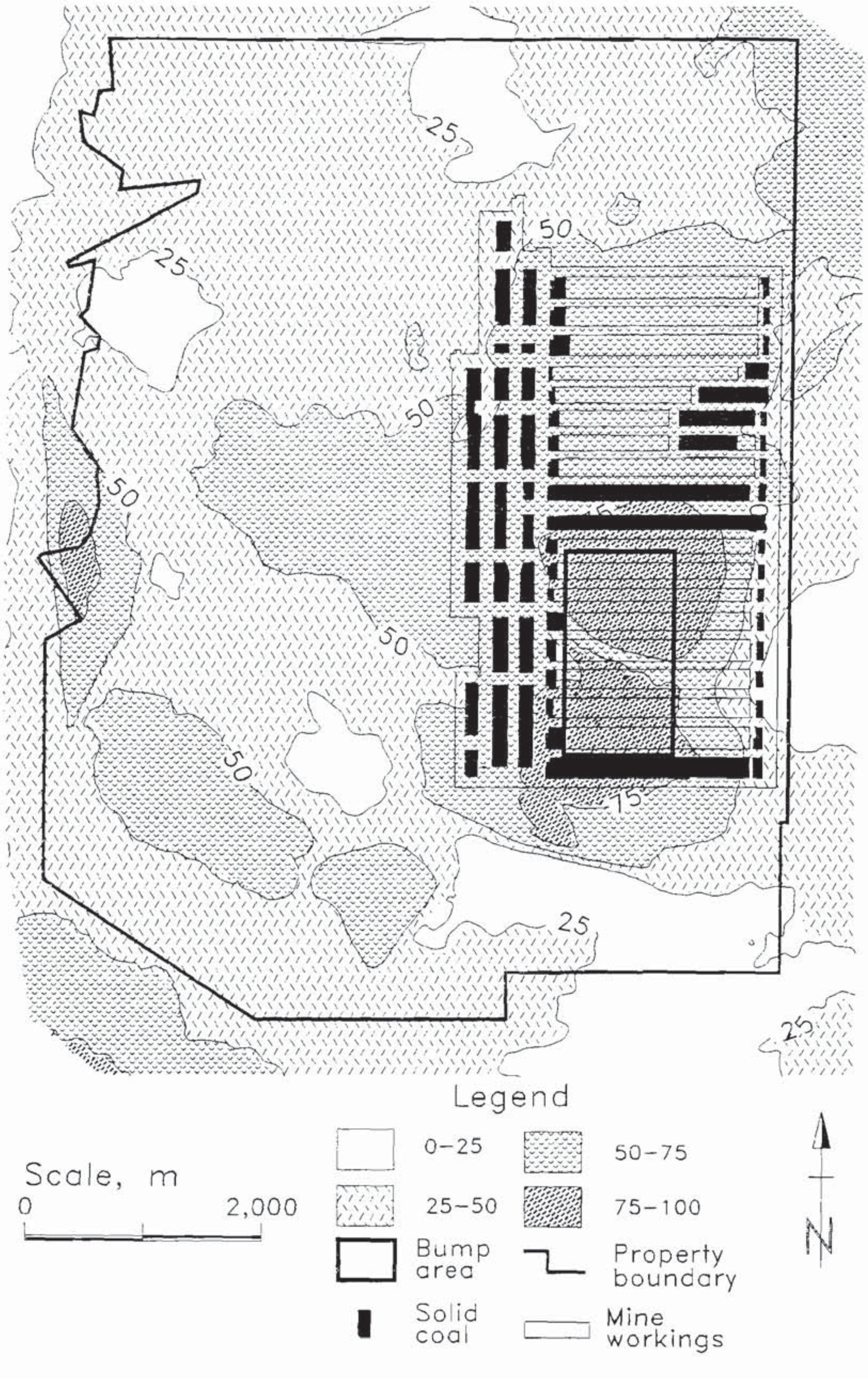


Figure 13
Bump Index Depicting Solid Coal Areas, Pocahontas No. 3 Coalbed Study Area.



Therefore, generalizations about entire areas that could be considered bump prone were not attempted, and correlation to the bump-hazard index map was based on these isolated events. Comparing the number of events in each index range versus the mined area within that range resulted in reasonable agreement between the criteria and bump occurrences.

Data covering the Pocahontas No. 3 Coalbed study property are more current and delineate a specific area where bump conditions are present. Correlation between the highest bump-hazard index values on the map and the outlined area of known bump conditions in the mine is good. Although the northern half of the mine is in the 50 to 75 index range, no bumps have occurred. The relatively high values in this area are the result of the deep cover and a high floor-strength index. The quartzarenite sandstone near the top of the coalbed keeps these values out of the 75 to 100 bump hazard range and would seem to account for the lack of bumps.

Studies of these two properties showed that the development of universal bump hazard criteria based on predetermined lithologic units and applied generically is impractical. However, identification of the rock types most directly related to bumping in a given mining environment and the availability of good corehole data and coverage greatly increase the usefulness of this type of assessment. In addition, although geologic conditions are important contributors to bumps, mining plans and practices are also strongly influential. Thus, the absence of bumps in areas having high bump index values or the presence of bumps in areas having low bump index values may be the result of the effectiveness of the mining system rather than failure of the criteria to be a true indicator of bump hazard potential. As the database of bump-prone regions to which the geologic criteria are applied is broadened, the USBM will continue to develop and improve the criteria to further delineate bump-prone geologic conditions.

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