

**GUIDANCE MANUAL**  
**Outcrop Barrier Design**  
**for Above Drainage Coal Mines**

January 2007 by  
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OFFICE OF SURFACE MINING RECLAMATION AND ENFORCEMENT  
UNITED STATES DEPARTMENT OF THE INTERIOR



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## EXECUTIVE SUMMARY

Outcrop barrier pillars serve to impede the uncontrolled flow of water out of above-drainage underground coal mines. When mines are abandoned and active dewatering stops, water may accumulate in underground mine workings. This water may exert significant hydrostatic pressure on the outcrop barrier and overburden. If the outcrop barrier or overburden is of insufficient width or thickness, the outcrop barrier or the overburden may fail allowing a sudden release of water to the surface. This event is termed a blowout. Blowouts may cause flooding, erosion, landslides, and pollution. In some instances, blowouts have caused significant property damage and death.

This manual provides guidance on planning, designing, evaluating, and inspecting coal mine outcrop barriers to address the problem of mine blowouts associated with above-drainage underground coal mines. It is intended as an aid for State, Federal, and industry personnel. It discusses state-of-the-art methods and site-specific factors that should be considered in designing outcrop barriers and evaluating their adequacy, such as: hydrostatic pressure, roof failures; subsidence; and natural geologic weaknesses of the coalbed and associated weathered rock strata near the surface. It also considers the effects of man-induced factors such as coal pillar recovery, augering, and road construction. Therefore, anyone evaluating, designing, or developing outcrop barriers must develop a working knowledge of all these factors and evaluate their effect on outcrop barriers. The topics discussed in this manual provide the working knowledge for this evaluation. This manual will provide necessary information and identify corrective or preventive steps to prevent blowouts. Many blowouts are caused by weakened and fractured overburden strata above the barrier and adjacent areas, combined with a build-up of hydrostatic head. Therefore, it is important to collect, analyze, and verify all the available information about the characteristics of the overburden and maximum hydrostatic head. The result of the analysis will provide necessary information and identify corrective or preventative steps, for existing or new outcrop barriers respectively.

The following are recommended procedures and steps to ensure adequate outcrop barrier design and performance:

- **Planning and Design:**  
For new mines, outcrop barriers should be designed for site-specific conditions. For existing or abandoned mines, outcrop barriers should be evaluated based on design requirements for new operations.
- **Implementation:**  
For new mines, ensure that design requirements are followed. For existing and abandoned mines, identify and implement remedies for weak outcrop barriers that do not meet design requirements.
- **Monitoring:**  
Periodically inspect and monitor outcrop barriers for performance.
- **Analysis:**  
Evaluate inspection results for potential problems.

- **Maintenance:**  
Repair or remedy problems as soon as they become evident.

The information in this manual is based on the field experience and applied research of technical personnel from federal and state agencies, industry, and academia. As the Appalachian coal region (AR) is historically linked to blowout problems, it is the source of the majority of information regarding this subject. However, the information on hydrologic considerations, geologic factors, and material strength determinations is also applicable to outcrop barriers outside of Appalachia.

# INTRODUCTION

## Purpose of the Manual

The purpose of this manual is to describe the many factors affecting the stability of coal outcrop barriers, and to provide guidelines on the design, evaluation, and inspection of coal mine outcrop barriers used in above-drainage underground coal mines. This work was conducted as a result of numerous barrier blowouts that have occurred in the Appalachian states over the past several years.

## Buchanan County Blowout

On May 13, 1995, pressure from a water-filled underground coal mine in Buchanan County, Virginia, caused a “blowout” or sudden release of mine pool water through the hillside above the mine. The blowout resulted in the fatality of a young woman who lived in a home down-slope of the blowout. The force of the water made a channel down the hillside approximately ten feet deep. Immediately after the accident, the Virginia Department of Mines, Minerals and Energy (VADMME) and the Office of Surface Mining and Reclamation Enforcement (OSM) performed investigation.

This Buchanan County mine is a “down-dip” mine, as shown in Figure 1. Down-dip mines use a coal outcrop barrier to retain any water that accumulates in the mine. Prior to the passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA), above-drainage underground coal mining in the AR was done “up-dip” where feasible, to allow the water entering the mine to flow out by gravity to save pumping costs. However, after the passage of SMCRA, this practice decreased due to environmental considerations, and the number of down-dip mines increased. Several up-dip mines still exist.

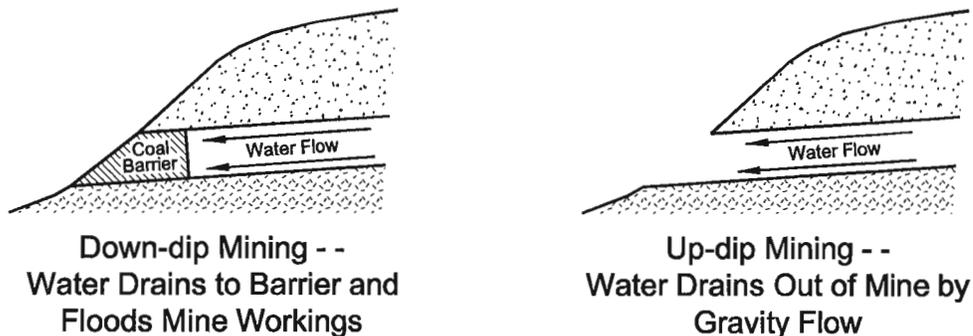


Figure 1. Diagram showing up-dip and down-dip mining.  
The arrows show the direction of water flow.

After a down-dip mine closes and dewatering activity ceases, the mine workings often become flooded and the overburden becomes saturated. At several locations, such water-filled abandoned mines are used as reservoirs for municipal water supplies

(Lessing and Hobba, 1981; Mull et al., 1981). However, these flooded mines also become a source of potential blowouts. Without adequate coal outcrop barriers, seepage from water-filled mines may result in erosion and landslides, and in severe cases, a catastrophic failure in the form of a blowout through the outcrop barrier, mine seal, or weaknesses in the overburden.

### **Geologic and Mining Details of the Buchanan County, Virginia Blowout**

First mining (development) at the blowout site took place in 1985, with a second phase of mining (pillar recovery) in 1991. The mining occurred in the Jawbone Coalbed. The Jawbone Coalbed is about 4 ft thick; it is underlain by a 4 ft thick shale unit and overlain by 2.5 ft thick shale followed by a sandstone unit. The bedrock strata was overlain by a thick colluvium that was eroded at the site.

During the blowout, water had broken through the overlying shale unit to leave an opening 6 ft wide and 3 ft high (see Figure 2). Two joints were observed in the sandstone unit overlying the shale. It is likely that these joints had also extended into the shale that was removed during the blowout. The remaining coal outcrop barrier was approximately 4 ft high, 11-13 ft wide at the base, and 2 ft thick at the top. After the blowout, 3 ft of impounded water remained behind the outcrop barrier. The total horizontal distance through the base of the combined coal outcrop barrier and colluvium was about 55 ft (see Figure 2). Two large subsidence cracks were observed in the vicinity of the blowout; they were 130 ft and 205 ft in length and contained soil and vegetation.

Two possible causes of the blowout were investigated:

- 1) Failure of the wet seals due to roof fall in the mine, followed by a sudden increase in the hydrostatic head) and/or,
- 2) Seepage through the overburden above the outcrop barrier, followed by erosion and landslide of saturated material. The overburden above the outcrop barrier consisted of fractured shale and sandstone and a layer of colluvium (soil).

A detailed field investigation indicated that:

- 1) The coal outcrop barrier remaining at the site appeared to be intact, and this suggested that it had not failed.
- 2) The wet seals that had been installed in the Jawbone workings to drain impounded water showed no indication of any unusual discharges prior to the blowout. The hydrostatic head at the site of the blowout was estimated to be about 8 ft.
- 3) The strata above the coal unit became saturated and failed causing a surface landslide, which reduced the amount of effective confining overburden. The

remaining overburden was not sufficient to contain the excess hydrostatic pressure, and a rapid discharge of water followed as a blowout.

As a result of this investigation it was determined that the blowout occurred through weaknesses in the overburden (see: Design of Outcrop Barriers, page 26).

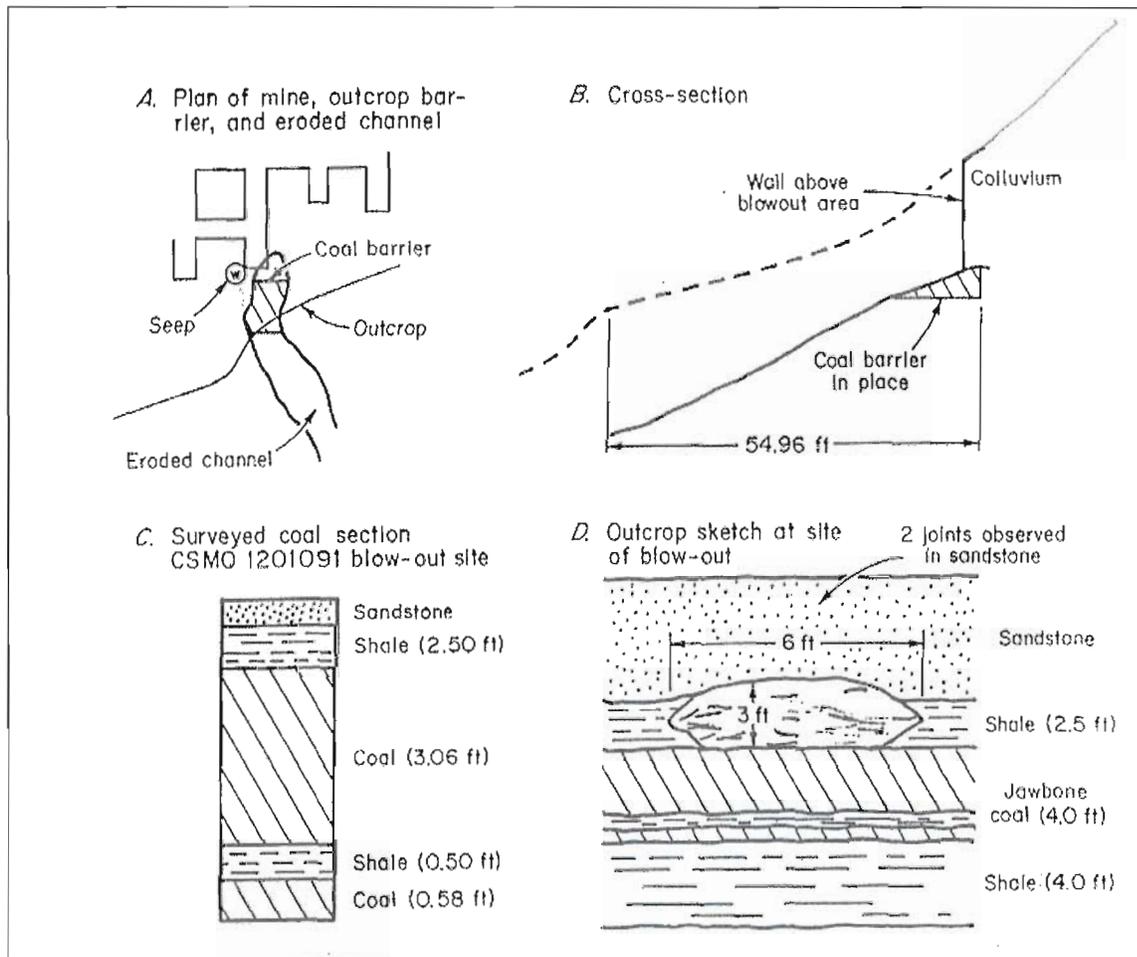


Figure 2. Geologic and mining details of blowout at Dominion Coal Corporation's Buchanan County, Virginia Mine (CSMO 1201091). Adapted from Virginia Department of Mines, Minerals and Energy (1995) Technical Report 1754. A. Plan; B. Cross-section.; C. Stratigraphic section; D. Sketch of disrupted strata at site.

## National Blowout Survey

After the Buchanan County blowout, OSM conducted a nationwide survey to evaluate the scope of the blowout problem. Because the AR is historically linked to blowouts, it is the source for most of the technical information. The survey found that there were 16 blowouts in Kentucky and West Virginia in the two year survey period.

After compiling the results of the blowout survey, OSM staff in cooperation with State and Federal agencies presented their recommendations to the OSM Director in the "Report of Findings on Blowouts Due to Outcrop Barriers" (Office of Surface Mining, *et al.*, 1996). One of the recommendations in the report called for development of a guidance manual on design, evaluation, and inspection of mine outcrop barriers used in above-drainage underground coal mines. That recommendation resulted in this manual for use by state, federal and industry personnel who are responsible for designing, permitting, evaluating, and inspecting outcrop barriers at above drainage underground coal mines.

A significant amount of geologic and hydrogeologic information has become available over the last several years, which contributes greatly to our understanding of coal-bearing rocks and the conditions associated with natural fracture systems and mining. Use of this information, along with improved engineering practices, can minimize the conditions that lead to mine blowouts in the future. Many significant published works are available, including the following:

- Brown, R.L., and Parezik, R.R, 1971
- Ferguson, H.F., 1967
- Harlow, G.E., and LeCain, G.D., 1991
- Kipp, J.A., Dinger, J.S., 1987
- Lloyd, O.B., and Reid, M.S., 1990
- Minns, S.A., 1993
- Price, W.E., Mull, D.S., and Kilburn, C., 1962
- Stach, E., 1982
- Stone, R., and Snoeberger, D.F., 1976
- Stone, R., and Snoeberger, D.F., 1980
- Weinheimer, R.L., 1983
- Wyrick, G.C., and Bochers, J.W., 1981

## **GEOLOGIC, HYDROLOGIC AND MINING FACTORS AFFECTING OUTCROP BARRIER BLOWOUTS**

Background information to familiarize the reader with the present understanding of the various factors which impact outcrop barrier stability is presented below. This information is not meant as a substitute for field evaluations or a review of the available literature. The reader is encouraged to examine the references cited to better understand the complexities of the problem. The following geologic, hydrologic and mining factors can potentially contribute to a blowout:

### **Coal Characteristics**

Coal in the outcrop barrier may become weak due to fracturing and/or weathering and a blowout through direct openings in the coal to the mine pool may result.

### **Mining Effects**

Blasting can also weaken an outcrop barrier to the point of failure. Second mining (removing pillars or partial mining) near the outcrop barrier pillar can also weaken the outcrop barrier and/or any remaining pillars due to the additional stresses resulting from second mining. If fireclay or claystone is present in the floor, the floor can weaken after flooding causing the pillars to sink and the outcrop barrier to become unstable.

### **Roof Falls**

Roof falls can create rock debris dams in the mine or can block drain pipes in wet seals resulting in an increase in volume of water in the mine. Roof falls can also cause a temporary increase (surge) in hydrostatic pressure (see Figure 3). Roof falls in the entries near the outcrop barrier can create openings to the surface and/or fracture the overburden (see Figure 3) thereby releasing the impounded water to the surface, which can cause a blowout; or, such roof falls can cause the impounded water behind the outcrop barrier to seep to the surface, saturating the soil, which can lead to landslides and a possible blowout.

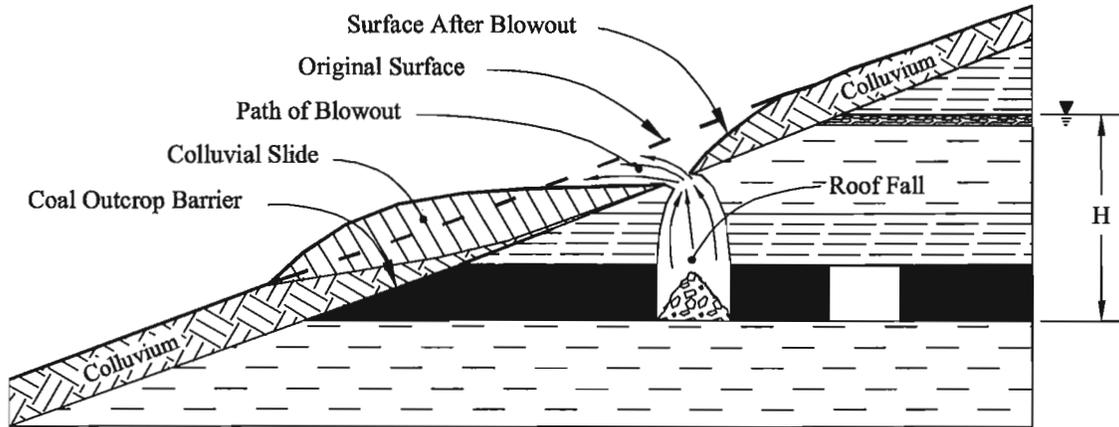


Figure 3. Mine blowout caused by roof fall.  $H$  = Hydrostatic head.

## Multiple Seam Mining

Multiple seam mining can create conditions for potential blowouts in the lower seam if the upper seam is flooded and connections between the two seams develop through fracturing or strata failure which can increase the hydrostatic head in the lower seam.

## Overburden Thickness

The thickness and the condition of the overburden play an important role in the design of outcrop barriers. After mine closure and inundation, the hydraulic forces generated may become strong enough to exert an uplifting force on the overburden. If the overburden is shallow, water may seep over the top of the coal and drain through the overburden strata. This may eventually cause the overburden to fail if the seepage leads to saturation of the overburden, erosion and/or landslides, resulting from the buoyancy forces exceeding the resisting forces.

## Physical Properties of Overburden (strength, permeability)

The physical properties of the strata surrounding the outcrop barrier strongly influence its performance. The permeability of the surrounding strata increases after mining due to opening or widening of the existing joints and fractures, which increase seepage of water into the overburden (see Figure 4). Increased water seepage decreases overburden strength thereby reducing the resistance to the hydrostatic pressure potential failure.

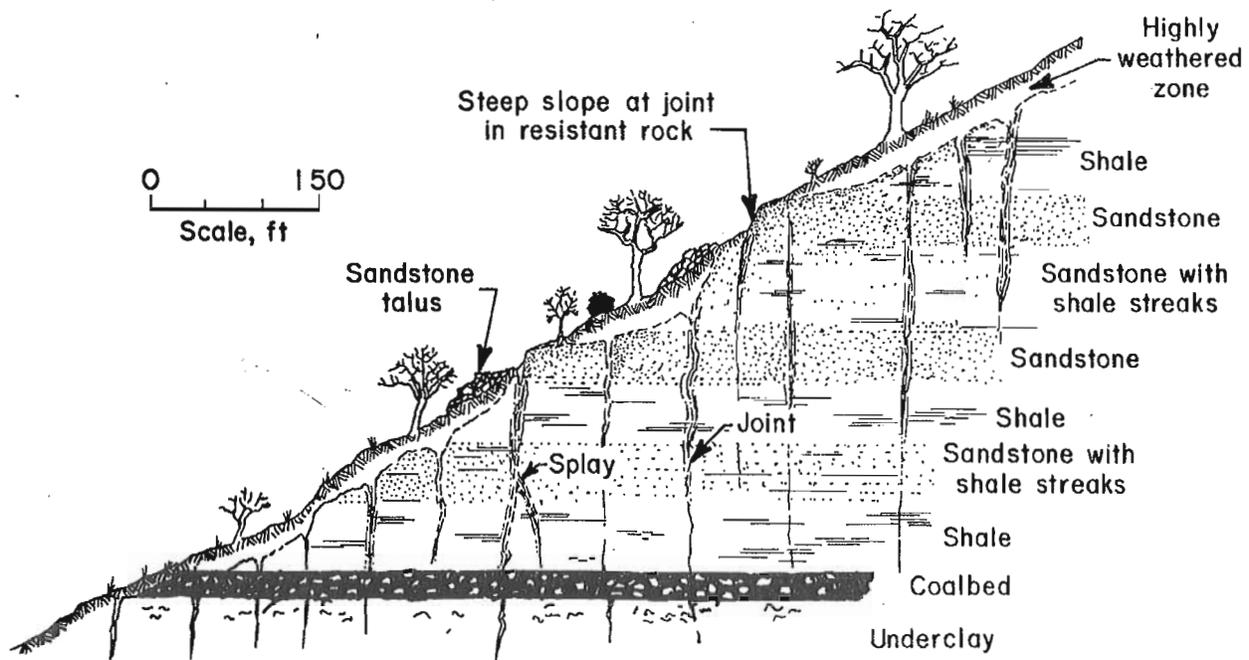


Figure 4. Typical cross-section of hill slope showing stress-relief joint distribution (Sames and Moebs, 1992).

In the AR, overburden strata within 200 feet laterally of the outcrop and less than 300 feet in thickness are usually highly fractured, jointed, and weak; therefore, their impact on the stability of the outcrop barrier should be considered (Sames and Moebs, 1989).

### Surface Slope, Weathering and Soil Condition

Outcrop barrier design generally considers horizontal confining distances. However, the effective confining vertical overburden thickness above a coal outcrop barrier under steep slope conditions will be 45 to 65 percent less than the horizontal outcrop barrier distance. The surface slopes in the central Appalachian region typically vary between 21 to 30 degrees. If an outcrop barrier is sized between 50 to 100 feet in width, the range of possible overburden thicknesses above any impounded water in the workings is between 17 to 58 feet. Figure 5 assumes that no weathered overburden is present.

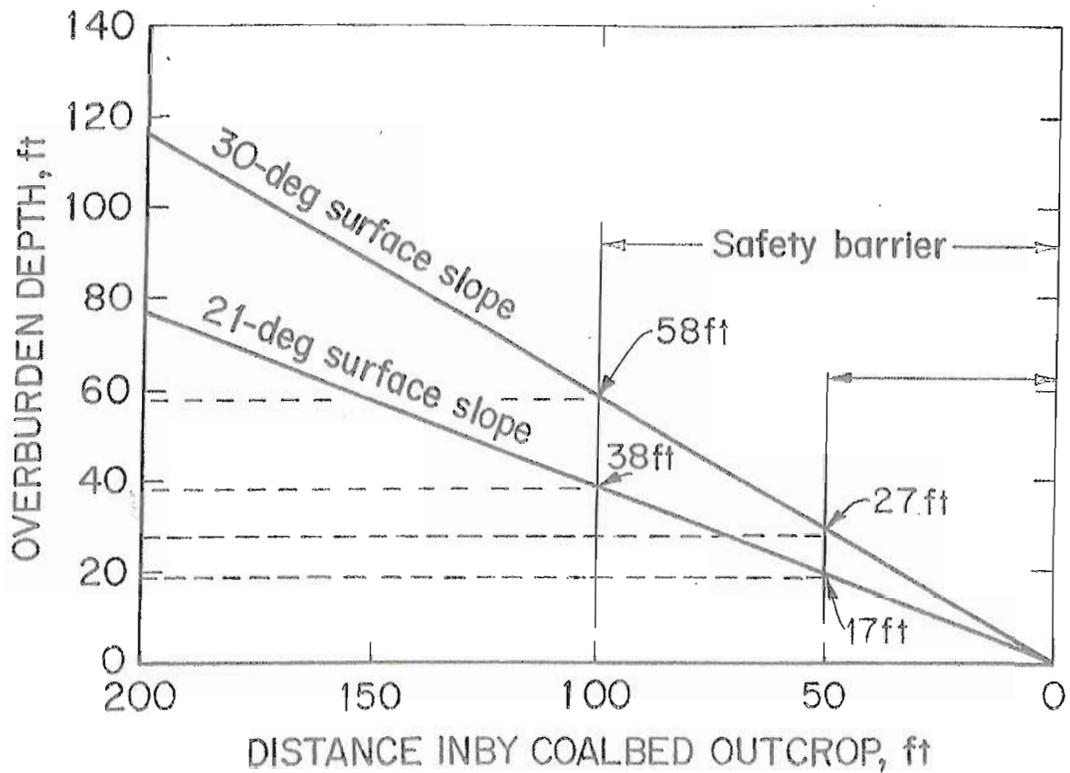


Figure 5. Relationship between surface slope and outcrop barrier width (BuMines, 1995).

Any depth of significant weathering and soil formation also reduces the effective confining overburden. Figure 6 illustrates how weathering can reduce the effective overburden thickness; it shows an actual field example of overburden conditions above a mine in eastern Kentucky. For a 21 degree slope, the 50 ft wide outcrop barrier would have an effective overburden thickness of only 12 ft; whereas, the total overburden thickness is 17 feet.

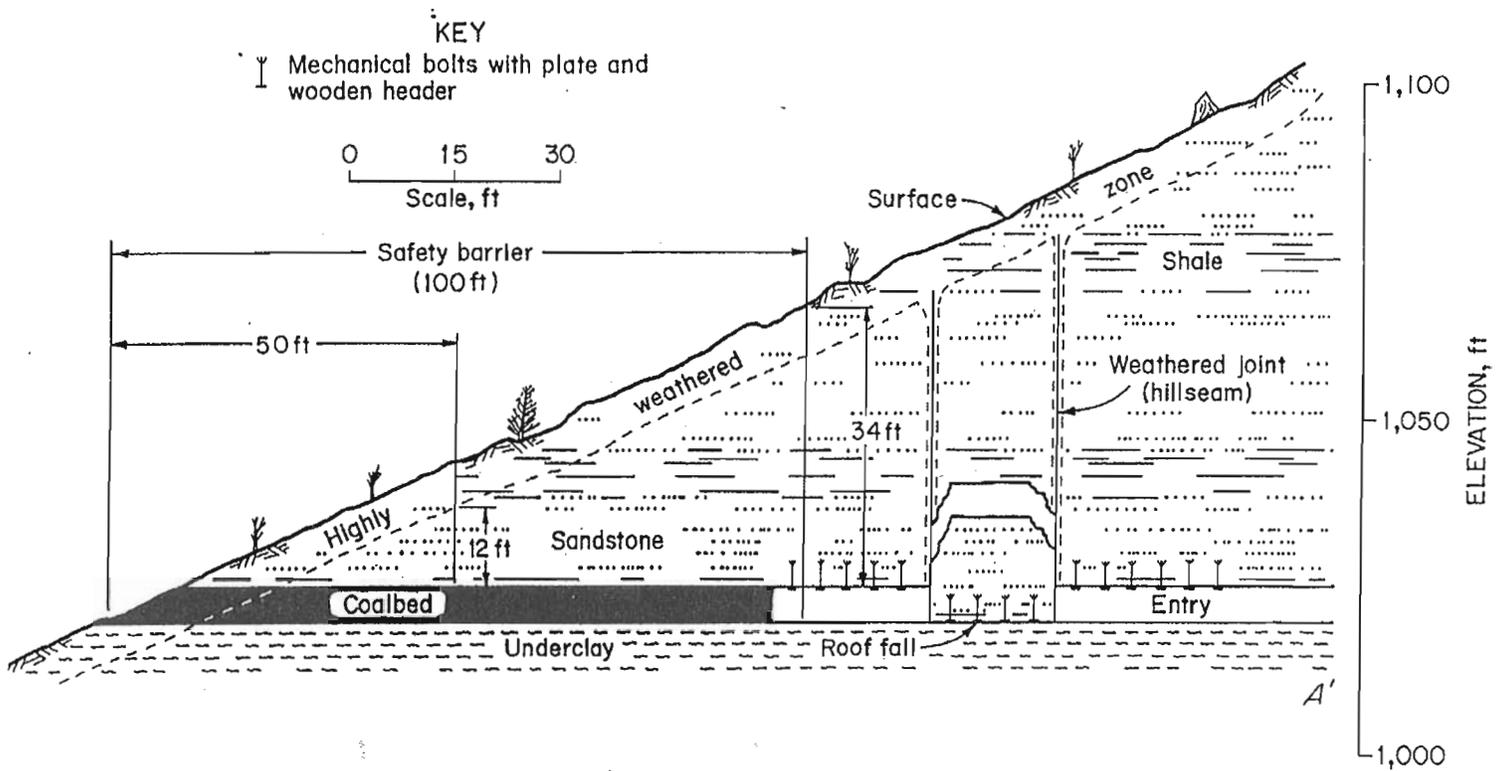


Figure 6. Effect of weathering on overburden thickness (BuMines, 1995).

All mines intersect fractures and weathered bedrock as the mine workings approach the outcrop, which can enhance recharge from water stored in an overburden aquifer. Most rock and coal within approximately 200 feet of the ground surface are weathered and fractured, which can reduce its strength drastically, which must be taken into consideration when designing outcrop barriers. The presence of any weathered and/or fractured rock and soil in the overburden can cause the impounded water to seep out and weaken the outcrop barrier.

Steep slopes in the AR may be marginally stable under natural conditions; any changes in the stress distribution can add to slope instability, leading to a large landslide failure. Landslides of this type, near the coal outcrop, can be related to saturated conditions caused by seepage of impounded water. These slides do not affect bedrock, and therefore the outcrop barrier, directly, but they do remove overlying mass and increase the risk of a blowout through the overburden strata. Conversely, shallow slopes, which are also common in the AR, may result in thin overburden conditions which can promote leakage to the surface; the resulting erosion of surface soils can cause a blowout.

## Hydrostatic Head

The maximum potential hydrostatic head behind an outcrop barrier is estimated by finding the difference in elevation between the bottom of the coal seam at the mining side (inside edge) of the outcrop barrier to the top of the saturated overburden as shown in Figure 7.

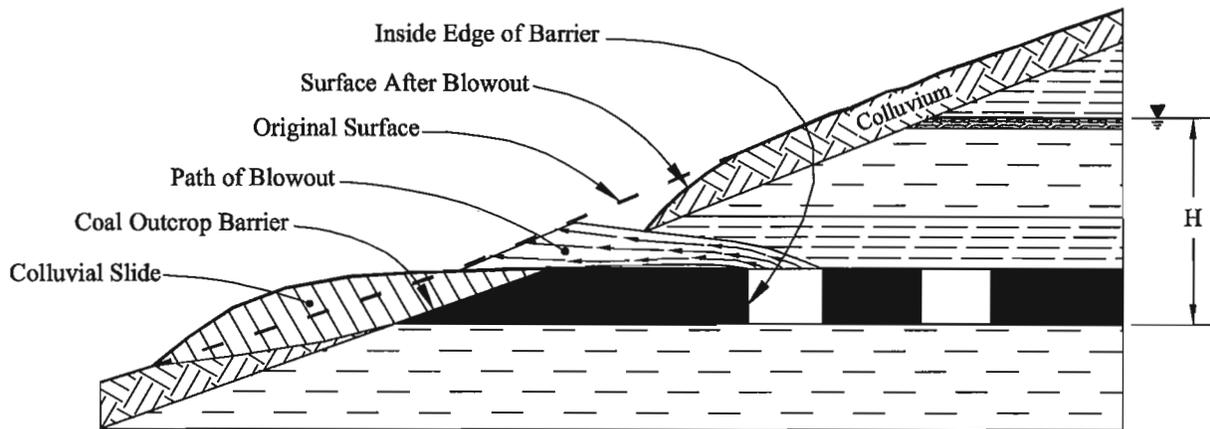


Figure 7. Blowout caused by hydrostatic head that is higher than the topographic surface immediately behind the outcrop barrier.  
 H = Hydrostatic head.  
 (adapted and modified from Bukovansky et al., 1983)

Any massive roof failure can instantaneously increase the hydrostatic head in a flooded mine. Therefore, it is necessary to include all reasonable provisions for such geologic and hydrogeologic factors, and to include a safety factor for any unanticipated changes in mine conditions

## Hydrogeologic Conditions of Active and Abandoned Flooded Mines

Hydrogeologic conditions can affect the hydrostatic head of a flooded mine. A significant under-estimation of the head potential can result from factors to account for all unknown or unforeseen factors, such as hydraulic connection to above/adjacent flooded mine workings or surface water entering the mine through natural fractures, or fractures caused by mine subsidence.

The most probable factors affecting outcrop barriers are illustrated in Figure 8. The reader should note that there are other scenarios leading to mine blowout situations that are not represented in this example. The hydrostatic head potential (A) represents the level to which water could rise in the mine and overlying strata. If water is allowed to rise to the maximum head potential shown, it would fill the void space in the mine and the overburden, and would also have enough head to exit the mine along highly-conductive pathways in the overburden along the hill slope. If near-surface fractures are sufficiently interconnected (B), a pathway may result that will allow water to discharge from the mine. A seep or spring may develop, leading to slope saturation and, in turn, leading to slumps or landslides. In the severe case shown here, a blowout occurs when the water pressure exceeds the lithic support of the

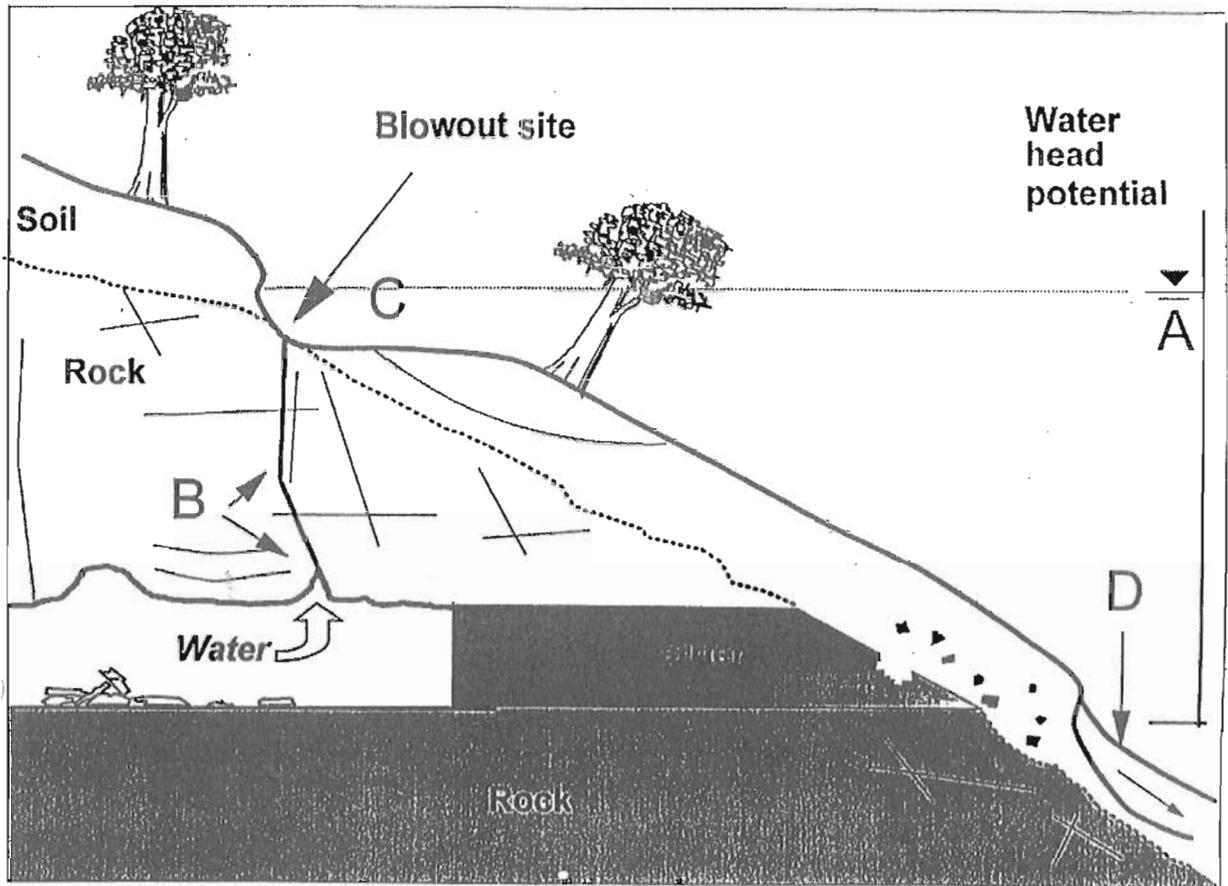


Figure 8. Schematic (conceptual) diagram showing geologic and hydrogeologic factors that can contribute to mine blowouts.  
 A --- hydrostatic head (water head potential) measured in the mine.  
 B --- fractures connecting the mine workings to the ground surface.  
 C --- blowout site.  
 D --- landslide caused by mine leakage

overburden (C). Springs or seeps can also form along the outcrop of rider seams a short distance above the elevation of the main seam being mined. At the coal outcrop barrier, water under pressure can move through highly-conductive cleats or joints in coal. If steady and substantial leakage occurs, earth movements such as landslides and slumps can result (D). In extreme cases where the coal outcrop barrier width is inadequate, water may move through the cleat or fracture with sufficient velocity to cause erosion (piping) of the coal, resulting in an outcrop barrier blowout. The blowout may also occur along the contact of the roof or floor rock and the coal seam if the contact between the coal and surrounding rock is incompetent. Overlying soil is usually not effective in restraining the mine water. The thickness of the soil along hill slopes can be quite variable, and cannot always be accurately estimated without performing site-specific tests, such as soil borings. Estimating soil cover by examining the surface topography or slope angles from maps is not recommended. Thin or non-cohesive soils

are poor barriers to water movement, especially when saturated. Therefore, soil should not be considered an adequate hydraulic barrier.

## **FAILURE MECHANISMS**

In order to better understand the techniques that could be used to assess potential blowout hazards, it is first necessary to have an understanding of the processes which cause blowouts to occur. Possible failure mechanisms include: those that involve excess hydrostatic pressure directed upward (hydrostatic uplift), resulting in localized modes of failure as overtopping blowout and piping; those where the hydrostatic pressure is directed horizontally along a sliding surface and those that involve landslides associated with slope failure. Also, under certain conditions, blowouts can result from sudden roof falls which cause a surge in hydrostatic pressure.

### **Roof Falls**

Blowouts can be caused by a roof fall in an entry near the outcrop in shallow overburden, as has been discussed earlier (see Figure 3).

### **Hydrostatic Uplift**

The material above the outcrop barrier may be subject to an uplifting force when the hydrostatic pressure becomes greater than the resisting weight of the overburden. When the overburden fails to contain the uplifting force exerted on it, a blowout will result.

### **Overtopping blowout**

Overtopping blowouts can occur when the hydrostatic head is higher than the topographic surface immediately behind the outcrop barrier, and seepage pathways develop, causing an opening to the surface (see Figure 7).

### **Piping**

Piping can occur when geologic discontinuities are present in the overburden (such as joints and fractures near the surface); these features can provide pathways for water flow that can gradually compromise outcrop barrier instability. Mine water will seep to the surface if the water level of the mine pool is higher than the surface elevation at the inside edge of the barrier pillar. Possible pathways to the surface can be vertically or horizontally oriented along planes of weakness such as intraformational joints, stress-relief joints, and bedding interfaces. Piping through these interfaces can gradually increase the opening and may cause a blowout (see Figure 9).

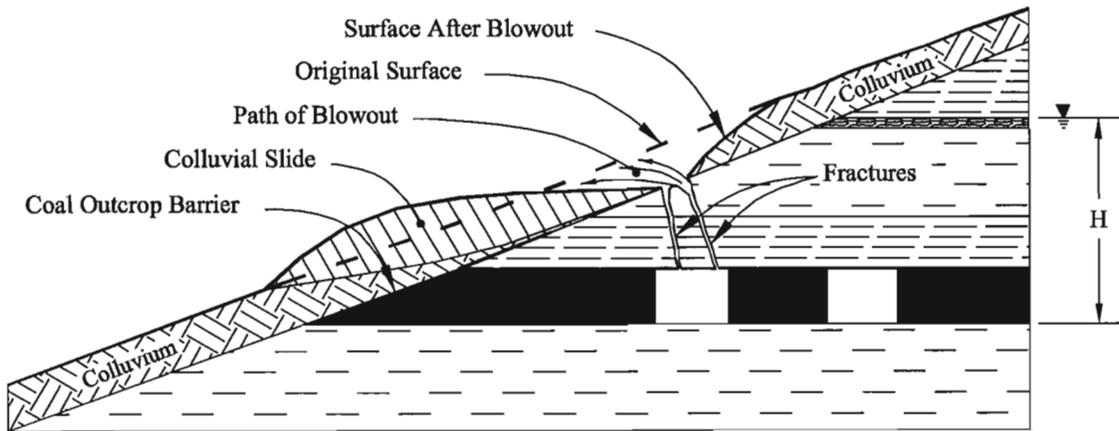


Figure 9. Mine Blowout caused by piping,  $H$  = Hydrostatic head

## Landslide

A landslide associated with slope failure is another mechanism that can cause outcrop barrier instability. Mining near an outcrop influences the stress distribution in the adjacent slope. Natural slopes may be marginally stable, and any changes in the stress distribution can add to slope instability. Any geologic condition which supports the flow of water from behind an outcrop barrier to the surface will cause soil saturation. This saturation, and the freeze-thaw cycles of surface soils, can further weaken the slopes and cause slides. These slides do not directly affect the bedrock, and therefore the outcrop barrier, but they do remove overlying mass and can increase the risk of overburden blowouts.

## Sliding Wedge Failure

A failure of this type occurs when increased hydrostatic pressures along a coal-floor interface with low shear strength combine with near vertical stress-relief joints or subsidence fractures that extend to the surface (see Figure 10).

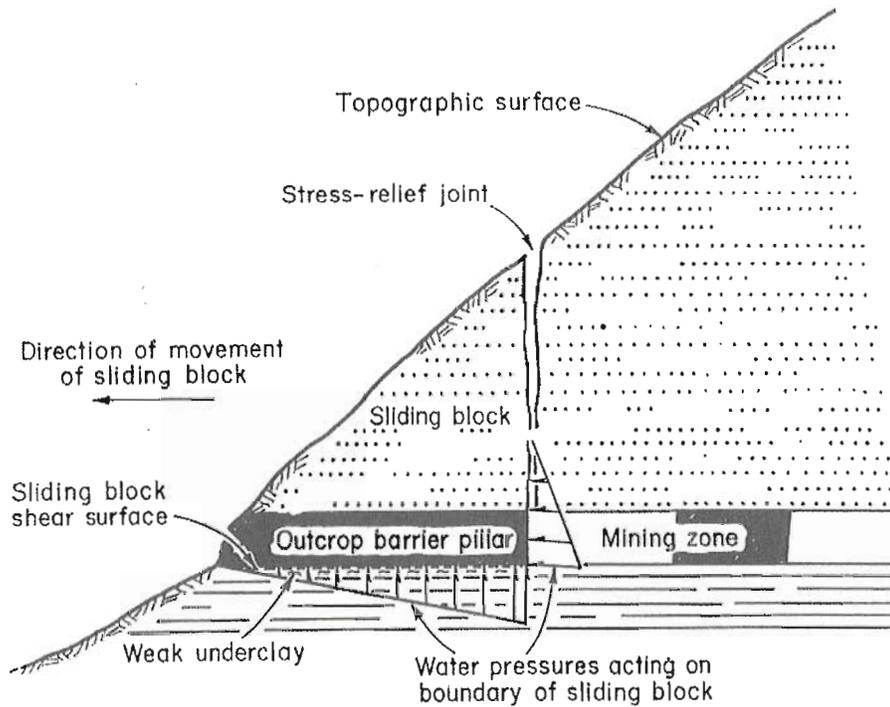


Figure 10. Mine blowout caused by sliding wedge failure (adapted from Bukovansky et al., 1983).

# REGULATORY GUIDELINES FOR COAL MINE OUTCROP BARRIERS

Applicable federal and state regulations pertaining to outcrop barriers are outlined below. The Federal regulations address the environmental and safety aspects relating to impounded water. They do not specifically provide design requirements for outcrop barriers for above drainage underground coalmines. However several state regulatory authorities (SRA) within the AR, where blowout problems occur, have recognized the need for design requirements and have implemented regulatory guidelines.

## Federal Regulations

Federal regulations require impoundment of water at the underground coal mines where the mine will discharge acid and/or iron containing water. As a result of this requirement, mine water at these mines is not approved to be freely discharged to the surface by gravity. Instead, the water accumulates at the lowest elevation in the mine and is pumped out, treated and then discharged into the streams. This is referred to as “down-dip” mining (see Figure 1). See §516(b) (12) of SMCRA (Public Law 95-87); and 30 CFR 817.41.

## State Regulatory Guidelines

SRA's in Kentucky, Pennsylvania, Virginia, and West Virginia have implemented different regulatory practices for outcrop barriers and mine seals. Tennessee does not have a state program; therefore, OSM regulates this activity. The state guidelines are summarized below.

### Kentucky

State regulation, 405 KAR 18:010 Section 6, effective December 12, 1994, which is based on Kentucky Reclamation Advisory Memorandum #114, (Kentucky Department for Surface Mining and Enforcement, 1994a, b) requires the width of the outcrop barrier to be at least 50 ft plus H, where H = maximum hydrostatic head in feet.

### Pennsylvania

Guidelines, written in 1983, address problems relating to acid mine drainage (Pennsylvania Department of Environmental Resources, 1983), including outcrop barriers. The barriers along coal outcrops should be at least 200 feet wide; or, they may be designed at 50 feet wide plus one foot for every foot of hydrostatic head, whichever is greater. Weathered, fractured or unconsolidated material should not be included when sizing the barrier width.

## **Tennessee Federal Program (OSM)**

Gravity discharges of water from an underground mine may be allowed if the coalseams are not acid-producing or iron-producing (30 CFR 817.41i). However up-dip mining has been strongly discouraged in the past and no instances of approved up-dip mining by OSM are known. Should a review of the proposed mine plan reveal a potential for mine blowouts, the requirements in the following references must be applied.

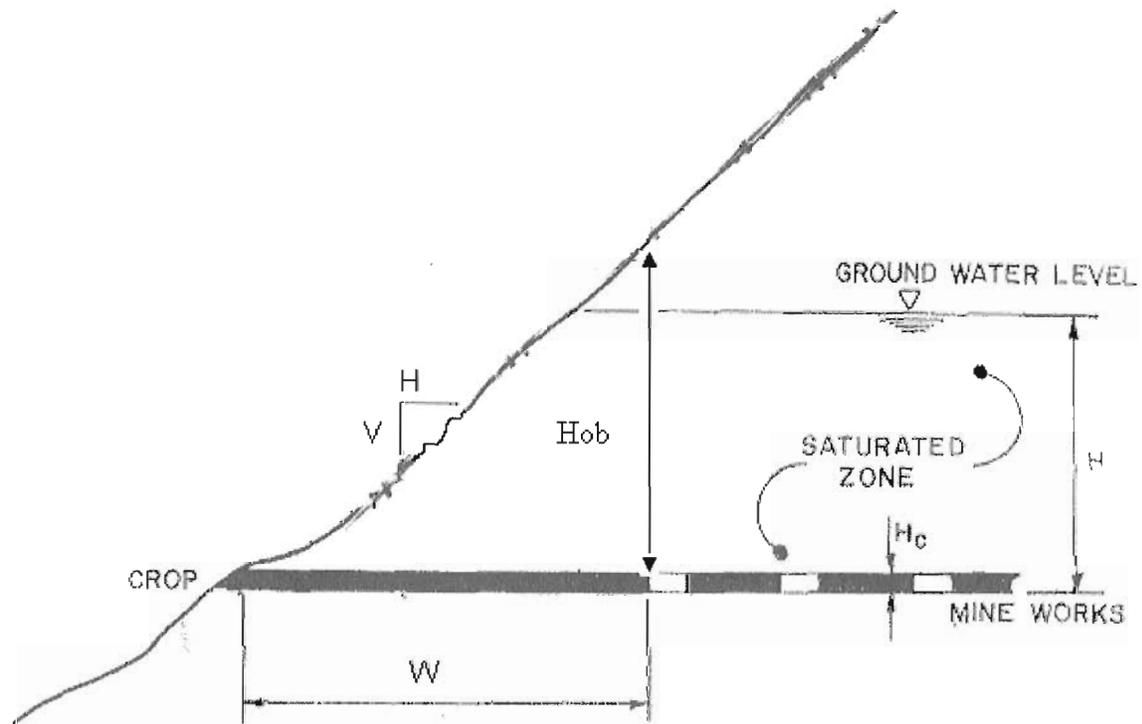
Kentucky Reclamation Advisory Memorandum, RAM #114 (1994a), Water Blowouts at Underground Coal Mines-Outcrop Barriers;

Pearson, et al. (1981), Outcrop Barrier Design Guidelines for Appalachian Coal Mines, prepared for the U.S. Bureau of Mines, 166 pp.

## **Virginia**

In 1996, the Virginia Department of Mines, Minerals and Energy (1996), passed an amendment to Sections 784.14(g) and 817.41(i) outlining three methods for assessing outcrop barriers to prevent mine blowouts. They are:

- 1) Installation of down-dip dewatering devices to prevent water accumulation in the area of an underground mine, where blowout potential could develop.
- 2) Use of "Rule-of-Thumb" method – This option would allow the underground operator to design a protection barrier which at a minimum, encompasses 100 feet of vertical overburden, or a horizontal barrier equal to 50 feet plus the maximum hydrostatic head (see Figure 11).
- 3) An operator may design a barrier with less horizontal and vertical distances than the Rule of Thumb method if the design is based on a detailed site investigation.



$S$  = GROUND SLOPE  $H:V$   
 $H_c$  = COAL BED THICKNESS  
 $H$  = HYDROSTATIC HEAD (FT)  
 $W$  = BARRIER WIDTH (FT) =  $H + 50$  ft  
 $H_{ob}$  = Overburden Thickness  $\cong 100$  ft

Figure 11. Illustration of Rule of Thumb formula  
(modified after Geological Consulting Services, Inc., 1988)

### West Virginia

West Virginia Division of Environmental Protection (1996) guidelines require that the operator must insure that the outcrop barrier is of sufficient width to support the overburden and prevent failure and sudden release of water due to maximum hydrostatic pressure. The outcrop barrier design must be based on sound engineering principles. If necessary, an overburden blowout and stability analysis must be performed and included as part of the permit. When the analysis indicates the coalseam is the weakest point, the "Rule of Thumb" method is used. When an underground active mine is adjacent to an abandoned inundated mine, the effect of additional head of water must be considered in the design of internal and outcrop barriers.

# DESIGN OF OUTCROP BARRIERS

## Introduction

This section provides guidelines, suggestions, engineering fundamentals, and reference sources for the design of outcrop barriers. Both empirical and site-specific approaches are described and exemplified. Existing methods of estimating barrier widths are described in Pearson et al. (1981); these methods are largely a result of experience gained from designing outcrop barriers in the Appalachian coalmines.

It is important to note that this document serves only as supplemental aid, and does not replace policies, guidelines and regulations developed by the respective SRAs. See Regulatory Guidelines for Coal Mine Outcrop Barriers in the manual on page 23, which summarizes the various methods currently in use by the SRAs in Kentucky, Pennsylvania, Tennessee, Virginia, and West Virginia.

The ideas and materials presented here, as well as the entire document, are not intended to replace a site-specific field examination and the appropriate design process resulting from that investigation. Instead, this manual serves as an additional tool for the user when dealing with the design of outcrop barriers, or the analysis of existing outcrop barriers. Mine closure planning and engineering design should, if possible, minimize the hydrostatic head after mine closure, as well as provide competent design of outcrop barriers.

## Empirical Barrier Design Methods

### Mine Inspector's or Ashley's Formula

Ashley's Formula (Ashley, 1930) was established by a seven member commission for the Commonwealth of Pennsylvania for incorporation into state law. The primary objective of the commission was to develop a design for coal barriers to impound water and protect active underground workings from inundation. From the findings of the commission, the minimum width of the barrier is expressed as:

$$W = 20 + 4T + 0.1D \quad \text{Equation 1}$$

Where:

W = width of coal barrier

T = thickness of the coalseam, and

D = water head, all units in feet

This formula was developed as a means to size coal barriers for adjacent underground workings in the anthracite coalfields of Pennsylvania and was not intended to size outcrop barriers. It has been used in some instances for its design; however, it does not take into account many of the factors which influence the outcrop barrier stability. Therefore, its applicability for outcrop barrier design is not recommended.

## Rule of Thumb Formula

The most commonly used method for computing the outcrop barrier width is the “Rule of Thumb” formula, which was developed based on the experiences of mining professionals in the AR and field tested before validation.

$$W = 50 + H \quad \text{Equation 2}$$

Where:

W = outcrop barrier width, feet.

H = the maximum hydrostatic head possible against the barrier, feet.

Figure 11 is an illustration of the “Rule of Thumb” parameters. In its simplest form, H is the vertical distance from the base of the barrier to the maximum expected water level. The barrier width (W) generated by Equation 2 represents a horizontal distance between the inside edge of the outcrop barrier pillar to the top edge of the barrier pillar where it intersects the surface. Weathered coal and colluvial soil must not be included in the barrier width. Second mining within 200 feet of the inside edge outcrop barrier must not be conducted and the pillars must be designed for long-term stability. This will prevent unnecessary cracking of the overburden and seepage paths for the impounded water. This formula is most commonly used for computing an outcrop barrier width in the AR. Mining experts agree that this method provides an adequate barrier. It is easier to use than a site specific method and is inexpensive. Recent blowout investigations have revealed that, in all cases examined, Rule of Thumb designed barriers were adequate; the blowouts occurred from causes discussed in this manual. However this formula does not take into account many geologic factors affecting barrier stability.

## Site-Specific Design for Outcrop Barriers

A site-specific design approach incorporates a comprehensive assessment of the various geotechnical factors and possible failure mechanisms discussed above (see Geologic, Hydrologic and Mining Factors Affecting Outcrop Barrier Blowouts, page 12 and Failure Mechanisms, page 20). A few SRAs have also incorporated a site-specific design approach into their barrier design practices as an alternative to the Rule of Thumb method (see Regulatory Guidelines for Coal Mine Outcrop Barriers, page 23).

Site specific design of new outcrop barriers or evaluation of existing outcrop barriers should include a thorough field and laboratory investigation of the planned (or existing) barrier site, including an analysis of rock strengths and material durability. Design procedures should address all probable failure modes.

An important contributing factor to mine blowouts that should be incorporated into the analysis is the potential development of landslides initiated by hydrostatic forces resulting in surface slope failure, either acting alone or in conjunction with the other modes of failure (see: Geologic, Hydrologic and Mining Factors Affecting Barrier Blowouts, page 12).

The 1981 report, *Outcrop Barrier Design Guidelines for Appalachian Coal Mines*, (Pearson et al., 1981), is considered the most comprehensive compilation on outcrop barriers. The report includes analysis of mathematical design models to calculate outcrop barrier widths to protect against blowouts that may occur by:

- Hydrostatic uplift (Vertical displacement) and
- Wedge type failure

The site-specific design results described below are compared to the Rule of Thumb method. In these examples, different slope angles have also been used to demonstrate the effect of slope.

The following discussion of site specific methods of barrier design demonstrates that different design methods can yield different results. However, due to the potential danger to the public, the most conservative method should be applied. Appendices A and B provide detailed derivations of equations 3 and 4 that are discussed below.

### **Analysis of Outcrop Barrier Failure by Hydrostatic Lift of Overburden**

Post-blowout studies confirmed by witnesses reveal that when an overburden blowout occurs, generally, the forceful release of water is in a vertical direction (Geological Consulting Services Inc., 1988 and Pearson et al., 1981). The reports indicate that the failure zone lies in the near-vertically inclined fracture and joint systems.

The purpose of performing an analysis of an overburden blowout by hydrostatic lift is to determine the point beyond which the upward buoyant forces of the impounded water exceed the effective weight of the overlying overburden. The analysis essentially calls for the determination of the combined overburden and coal thickness necessary to offset the anticipated buoyant forces due to hydrostatic head of the water impounded behind the barrier. These offsetting forces are assumed to exist inside the barrier at the mining side (inside edge) of the coal barrier (see Figure 7), where most of the observed failures appear to have been initiated. The combined thickness of the overburden and coal, together with a surface slope factor, are the major factors that determine the outcrop barrier width using Equation 3, below; the controlling factors that determine the coefficients of Equation 3 are the additional factors of the unit weights of coal, overburden and water (see Appendix A).

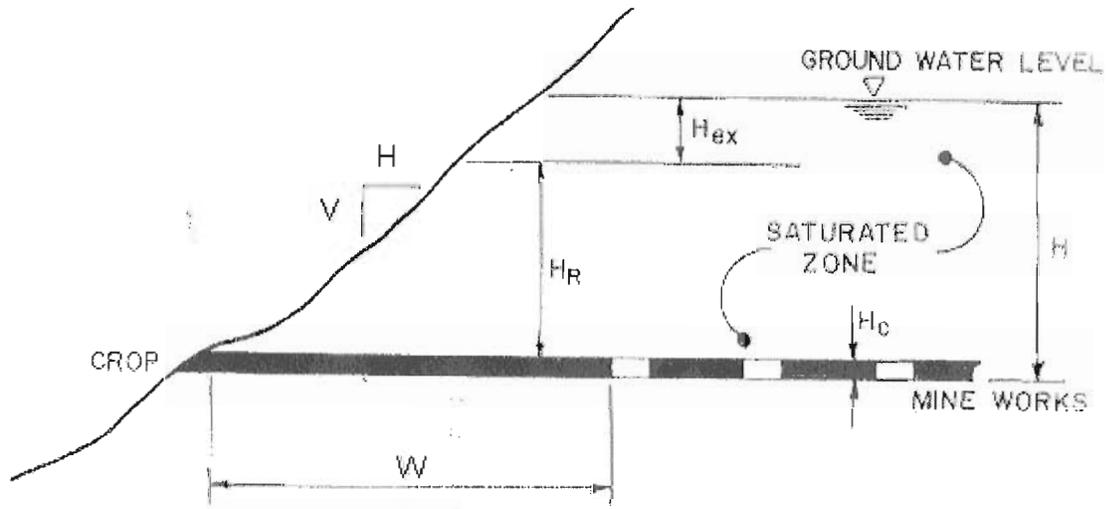
$$W = S (0.385H_c + 0.48H) \quad \text{Equation 3}$$

Where:

- |                |   |  |
|----------------|---|--|
| W              | = | Barrier Width, feet                    |
| S              | = | Slope, horizontal over vertical (H: V) |
| H <sub>c</sub> | = | Coalseam thickness, feet.              |
| H              | = | Total Hydrostatic Head, feet.          |

It is assumed that the overburden is saturated vertically to the level of the hydrostatic head. Cohesion and friction angle of the overburden, although always present, are not considered. Because of this, the equation is conservative.

Equation 3 was developed by GCSI (Geological Consulting Services Inc., 1988). The GCSI analysis used its own computational procedures (see Appendix A for details) to determine the outcrop barrier width required to protect against a blowout caused by overburden failure by hydrostatic lift (see Figure 12 and Appendix A)

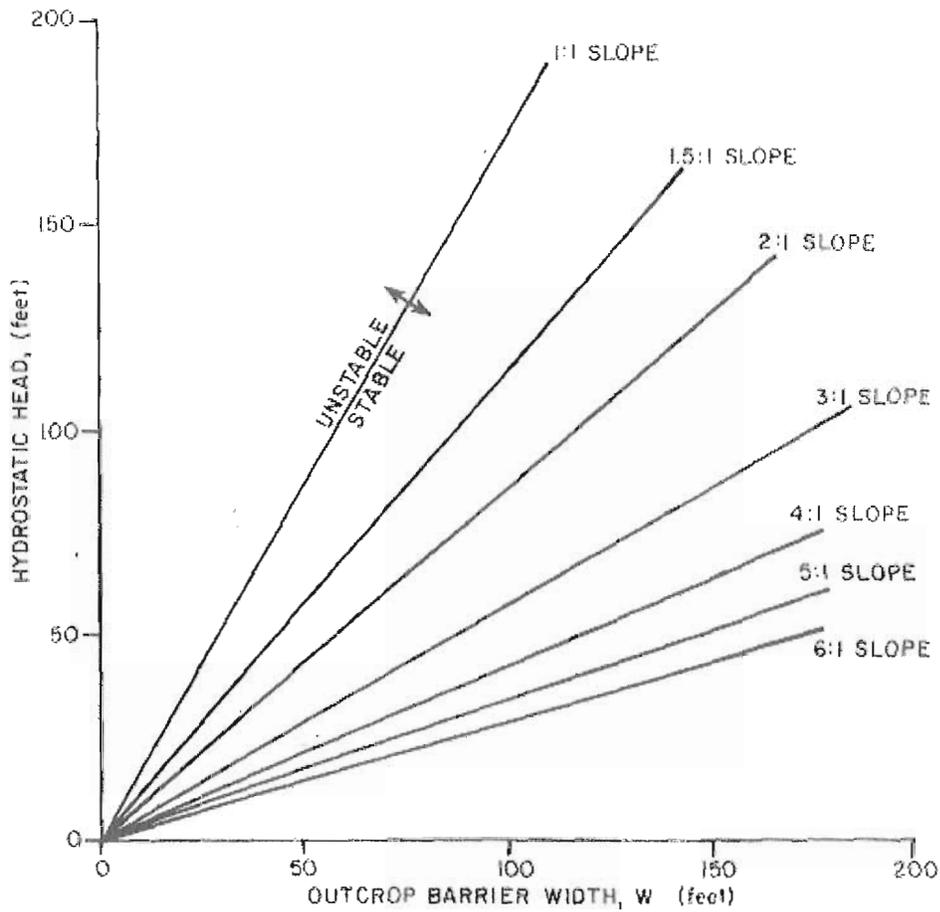


- $S$  = GROUND SLOPE H:V
- $H_C$  = COAL BED THICKNESS
- $H_{ex}$  = EXCESS HYDRAULIC HEAD (FT)
- $H_R$  = ROCK COLUMN (INTERSTITIAL MATERIAL)
- $H$  = HYDROSTATIC HEAD (FT)
- $W$  = BARRIER WIDTH (FT)

Figure 12. Outcrop barrier width design using Uplift Failure Formula (modified after Geological Consulting Services, Inc., 1988).

Solving for  $W$  (barrier width) determines the equilibrium state of the buoyant and pressure forces against the thickness of coal and the overburden. A factor of safety of at least 1.5 is recommended.

The following examples were taken from a report of an actual barrier investigation performed by GCSI (1988). The results were compared to the results obtained using the Dames and Moore (Pearson et al., 1981) analysis, using Figure 13, and to the Rule of Thumb formula.



NOTE:

FOR EACH OVERBURDEN SLOPE, THE UNSTABLE BARRIER WIDTH IS ABOVE THE LINE AND THE STABLE BARRIER WIDTH IS BELOW THE LINE.

Figure 13. Outcrop barrier width estimated by overburden blowout analysis for various slopes using Dames and Moore Design (modified after Pearson et al., 1981).

**Example 1:**

Assume that in designing an outcrop barrier, W, the following values are given: Coal thickness  $H_c = 7$  feet; Hydrostatic head,  $H = 31$  feet, and the H:V ratio is 2.24:1. Using Equation 3 above, the calculated value of the outcrop barrier, W, is:

$$W = 2.24 \times (0.385 \times 7 + 0.48 \times 31) = 2.24 \times 17.575 = 39.36 \text{ or } 39 \text{ ft}$$

This represents the barrier at the point of equilibrium. Next a 1.5 safety factor is added by multiplying the barrier size at equilibrium by 1.5:

$$W = 39 \times 1.5 = 58.5 \text{ or } 59 \text{ ft.}$$

The results obtained using the same data and different formulas are compared below; a 1.5 safety factor is also included in the Dames and Moore result, and the Rule of Thumb result incorporates its own safety factor:

Comparison of Results for Example 1	
GCSI Equation (Equation 3; Figure 12 )	barrier width = 59 feet
Dames and Moore Graph (Figure 13 ; Pearson et al., 1981)	barrier width = 65 feet
Rule of Thumb Equation (Figure 11 ; Equation 2)	barrier width = 81 feet

As discussed earlier, the Rule of Thumb equation was derived empirically. Because of this, one would expect a more conservative value than for site-specific design methods, such as those used by GCSI or Dames and Moore.

It is important to note that the Rule of Thumb method does not consider field conditions except hydrostatic head; therefore, its use can mislead the designer. The following example provides evidence of the shortfall of relying on the Rule of Thumb method.

**Example 2:**

With the same assumptions as above for coal thickness and hydrostatic head, i.e., 7 feet and 31 feet respectively, but with a more gentle slope ratio (H:V) of 5:1, which is a 20 percent slope, the values for W are as follows:

Using GCSI Equation

$$W = 5 \times (0.385 \times 7 + 0.48 \times 31) = 87.8 \text{ or } 88 \text{ ft.}$$

Providing for a 1.5 safety factor,

$$W = 88 \times 1.5 = 132 \text{ ft.}$$

This result is compared to those obtained from the graph developed by Dames and Moore and the Rule of Thumb Formula in the table below:

Comparison of Results for Example 2	
GCSI Equation (Equation 3, Figure 12)	barrier width = 132 feet
Dames and Moore Graph (Figure 13; Pearson et al., 1981)	barrier width = 150 feet
Rule of Thumb Equation (Equation 2; Figure 11)	barrier width = 81 feet

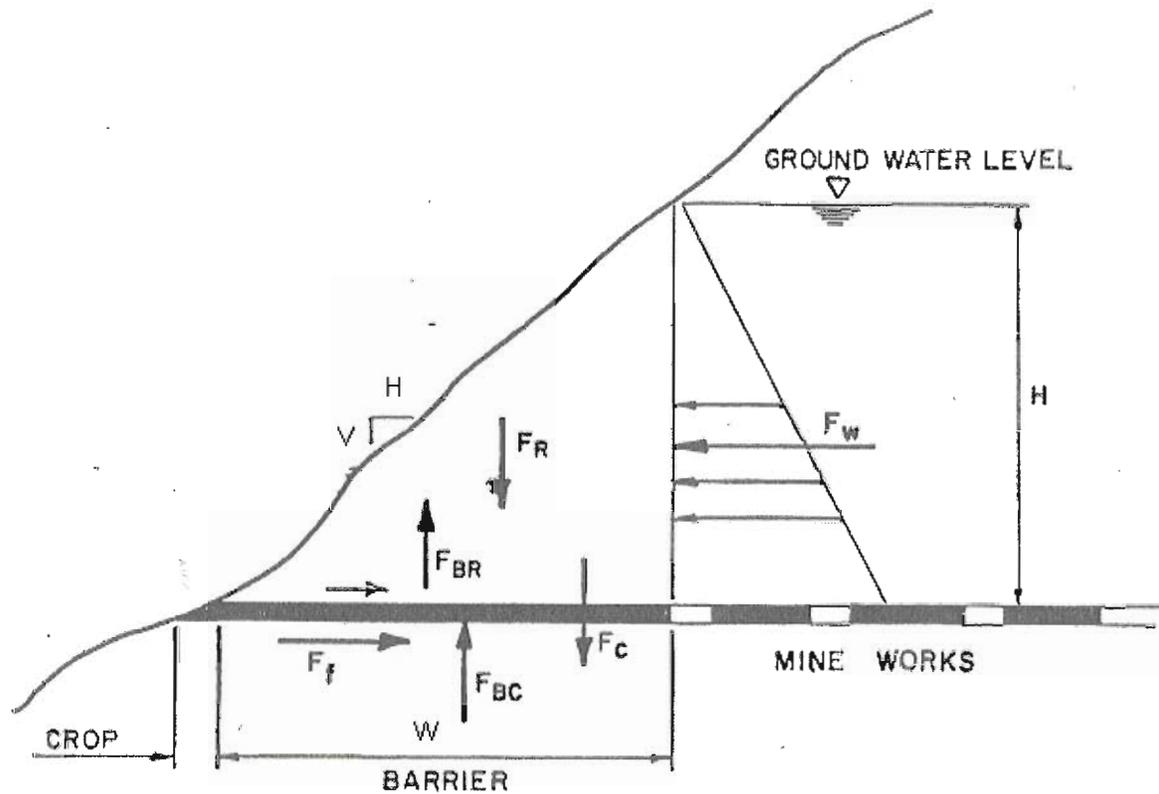
The Rule of Thumb barrier width is significantly smaller than the barrier widths using other two approaches; these results indicate the potential hazards of omitting a detailed site investigation and relying solely on the rule of thumb approach.

## **Analysis of Outcrop Barrier Failure by Sliding Wedge Stability**

The assumptions used in this example are listed below (see Figure 14). These are typical but conservative assumptions. They can be changed if field data is available.

- The area to be evaluated is saturated vertically to the point of hydrostatic head (this is a conservative assumption)
- Joint patterns and stress relief fractures lie vertically.
- Bedding planes are approximately horizontal.
- There is no cohesion between the joints and bedding planes.
- There is no friction within the vertically inclined joints or fractures.
- The horizontal sliding surface will be the one demonstrating the lowest angle of internal friction.
- The internal angle of friction applied here is 50 degrees for bedrock, 35 degrees for coal and 29 degrees for the coal/underclay contact. The sliding surface is therefore assumed to be along the coal underclay horizon. These angles and the sliding surface can be changed based on site-specific information, if available.

Figure 14 is a diagram for sliding wedge stability analysis showing the various force components acting on the coalseam and the overburden. There are no known occurrences of sliding wedge barrier blowouts.



- S     GROUND SLOPE H:V
- H     HYDROSTATIC HEAD
- $F_w$      HYDROSTATIC FORCE
- $F_R$      ROCK WEIGHT
- $F_C$      COAL WEIGHT
- $F_f$      FRICTION FORCE
- $F_{BR}$      BOUYANCY AGAINST ROCK
- $F_{BC}$      BOUYANCY AGAINST COAL
- W     BARRIER WIDTH

Figure 14. Outcrop barrier design using sliding wedge failure formula (modified after Geological Consulting Services, Inc., 1988).

The following equation was developed by GCSI (1988) to determine the outcrop barrier width to protect against wedge type failure (see: Appendix B):

$$31.2 H^2 = (51.3 (W^2/S) + 17.6H_cW + 8.8Hc^2S) \tan \Phi \quad \text{Equation 4}$$

Where:

- H = Hydrostatic Head in feet
- W = Barrier Width in feet

- S = Surface Slope H: V
- H<sub>c</sub> = Coal Seam Height
- Φ = Internal Angle of Friction

Substituting the values from Example 1, we get:

$$31.2 \times 31^2 = (51.3 (W^2/2.24) + (17.6 \times 7W) + (8.8 \times 7^2 \times 2.24)) \tan \Phi$$

W (barrier width) can be determined by solving this quadratic equation or by trial and error method.

W represents the equilibrium state when the hydrostatic forces acting on the outcrop barrier are equal to resisting sliding forces. The barrier width obtained by applying Equation 4 is multiplied by a safety factor of 1.5. The following example demonstrates the application of this equation.

### Example 3

The parameters used in this example are the same as used in the Overburden Failure analysis in Example 1, with the addition of an internal angle of friction of 29 degrees (Equation 4)

$$31.2 H^2 = (51.3 (W^2/S) + 17.6H_cW + 8.8H_c^2S) \tan \Phi$$

Solving for W results in a barrier width, W, of approximately 46 feet. When a 1.5 safety factor is added W becomes 69 feet.

This result is compared with those obtained from Dames and Moore (Pearson et al., 1981) graph (see Figure 13), and the Rule of Thumb formula (with their respective safety factors included):

Comparison of Results for Example 3	
GCSI Equation (Equation 4, Figure 14)	barrier width = 69 feet
Dames and Moore Graph ( Figure 13; Pearson et al., 1981)	barrier width = 65 feet
Rule of Thumb Equation (Equation 2; Figure 11)	barrier width = 81 feet

The barrier width would be 59 feet if GCSI Equation 3 for hydrostatic lift failure is used, see page 28.

Table 1 shows the barrier width obtained, using Figure 13, for different surface slopes and hydrostatic heads. The example given below illustrates the use of this table:

Slope	Factor*	Hydrostatic Head (ft)				Outcrop Barrier Width
		50	100	150	200	
1:1	0.59	29.5	59	88.5	118	
1.5:1	0.86	43	86	129	172	
2:1	1.25	62.5	125	187.5	250	
3:1	1.74	86.9	173.8	261	348	
4:1	2.4	120	240	360	480	
5:1	3	150	300	450	600	
6:1	3.54	177	354	531	708	

\* Factor is defined as the slope for the corresponding line in Figure 13

Table 1 Outcrop barrier widths for various values of hydrostatic head and slope (Pearson, et al., 1981)

**Example 4:** Determination of Barrier Width using Table 1.

Given: Maximum hydrostatic head = 100 feet  
 Surface Slope = 2:1

The barrier width using table 1 is found in row 3 (2:1 slope) under column 4 (100 foot hydrostatic head) to be 125 feet

## EVALUATION OF EXISTING OUTCROP BARRIERS

It is as important to evaluate existing outcrop barriers for their ability to resist failure as it is to successfully design new outcrop barriers. The purpose of this evaluation is to identify potential factors that, if left uncorrected, may contribute to an outcrop barrier blowout. Several factors that could cause blowouts of outcrop barriers were discussed earlier. The same factors used for new outcrop barriers are also relevant to existing outcrop barriers. They include barrier thickness; overburden depth; hydrostatic head behind the barrier; and geotechnical properties of the overburden above the barrier.

Generally, the potential for existing outcrop barrier blowouts relates only to those above-drainage mines that impound water. Water can be impounded in mines that are abandoned, inactive, or active with inactive areas. Traditionally, coal outcrop barriers were designed to provide a sufficient thickness of overburden for mine entry stability. Barriers designed for this purpose perform well during active mining. But after mines are closed, water may accumulate behind these barriers and create a potential hazard. This potential is compounded when dewatering ceases as a result of mine abandonment and a hydrostatic head develops.

Specific evaluation criteria are shown below. For more information see: Geologic, Hydrologic and Mining Factors Affecting Barrier Blowouts, page 12.

### Barrier Width

- Determine the barrier width from the latest available mine maps.
- Exclude the weathered rock from the barrier width.
- Delineate the barrier on mine maps as accurately as possible considering coal elevations, the outcrop contour lines, and the barrier width.
- Check the overburden above the outcrop barrier for signs of weathering.

### Hydrostatic Head

- Verify the outcrop contour lines on a mine map using land surveys or GPS measurements in order to estimate hydrostatic head after the mine is closed.
- Examine the mine maps to see if there are any flooded abandoned mine workings above or below the mine barrier. This can affect the hydrostatic head.
- Check for any evidence of aquifers above the barrier from which the water can seep into the mine after it is closed. Use the aquifer elevation above the abandoned mine to estimate the likely hydrostatic head which can build up behind the barrier. This is a worst case scenario.

## Physical and Geological Properties of Overburden Strata

- Determine the nature of floor strata in the entries near the barrier, including the presence of fireclay or claystone in the floor.
- Determine the presence of any weathered and/or fractured rock or unconsolidated soil in the overburden strata above the barrier and the mine workings. In the AR, overburden strata within 200 feet laterally of the outcrop and less than 300 feet in thickness are usually highly fractured and jointed; therefore, their impact on the barrier should be considered (Sames and Moebs, 1989).
- Identify any faults or geological anomalies in the overburden above the barrier and the mine workings close to the barrier.
- Identify any roof falls in the entries near the barrier from the mine maps.
- Identify any surface subsidence close to the barrier.

## Mine Maps

Verify that all mine maps:

- are certified by a Registered Professional Engineer,
- show the date of abandonment and last survey,
- show coalseam contours, and
- show the elevation of the lowest point in the mine.

## Mine Development Effects

There are several mining-related factors which must be considered when evaluating the stability of the barrier:

- Review the mine map to find the type of mining done near the outcrop barrier e.g. room and pillar (development or pillaring), and its impact on the barrier pillars.
- Review the mine map for any roof falls in the mine workings near the barrier and their potential impact on the barrier.
- Review the mine map to find if there are any active or abandoned mines above, below, or in the adjoining area, and whether they are dry or flooded.
- Determine if there are any auger holes, punch mines and adits in the barrier; they will make the barrier pillars weaker.
- Determine if any blasting was done within 100 feet of the barrier; such close proximity blasting will make the barrier pillars weaker.

## Field Investigation

The field inspection verifies and supplements the information obtained when reviewing the mine plan, mine history, and mine maps. It alerts the evaluator to deviations from the information shown on the maps. The field investigation should include the following:

- Determine the minimum overburden thickness above the mine workings closest to the mine side of the barrier (see Figure 6).
- Inspect the surface area close to the proposed outcrop barrier for natural benches and other surface features (e.g. road cuts) that could reduce the overburden thickness.
- Verify the correct location of the outcrop on the mine maps using land or GPS surveys. Usually, the outcrop is plotted by mine surveyor from the topographic maps.
- Look for evidence of any water seepage above the barrier and from adjacent mine workings. Determine the quantity discharge and its location.
- Determine if there are any adits or auger holes in the mine barrier not shown on the map.
- Identify any other features which may impact the integrity of the barrier.
- Look for evidence of subsidence or sinkhole cracks or other zones of weakness in the overburden above mine workings adjacent to the barrier.

## **SUMMARY AND CONCLUSIONS**

There are several factors that must be considered when evaluating outcrop barriers. One must consider geology, hydrologic systems, development of hydrostatic forces, effects of surface and underground mining and other dynamic forces occurring as a result of a combination of all of these factors. Therefore, anyone evaluating, designing, or inspecting outcrop barriers must have a working knowledge of these forces and their effect on the outcrop barriers. The topics discussed in this manual provide the working knowledge for this evaluation

Most mining industry experts feel that coal barriers determined using the Rule of Thumb formula provide adequate protection against blowouts, based on their field experience; however, this formula does not take into account many geologic factors affecting barrier stability. Many blowouts are caused by weakened and fractured overburden strata above the barrier and adjacent mine workings, combined with a build-up of hydrostatic head after the mines are shut down, as has been confirmed by recent blowout investigations. Therefore, it is important to collect, analyze, and verify all the available information about the characteristics of the overburden and maximum hydrostatic head. The result of the analysis will provide necessary information and identify corrective or preventative steps for existing or new outcrop barriers, to be taken to prevent blowouts. The most important step for new outcrop barriers is to provide for increased barrier width to avoid or compensate for weakened and fractured overburden strata above the barrier and the adjacent mine workings. For both existing and abandoned mines, identify and implement remedies for weak outcrop barriers that do not meet design requirements.

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## APPENDIX A

### Analysis of Outcrop Barrier Failure by Hydrostatic Lift of Overburden

#### Derivation of Equation 3

See Figure A1 for parameters and assumptions used to develop equation 3. These are typical but conservative assumptions. They can be changed if field data is available.

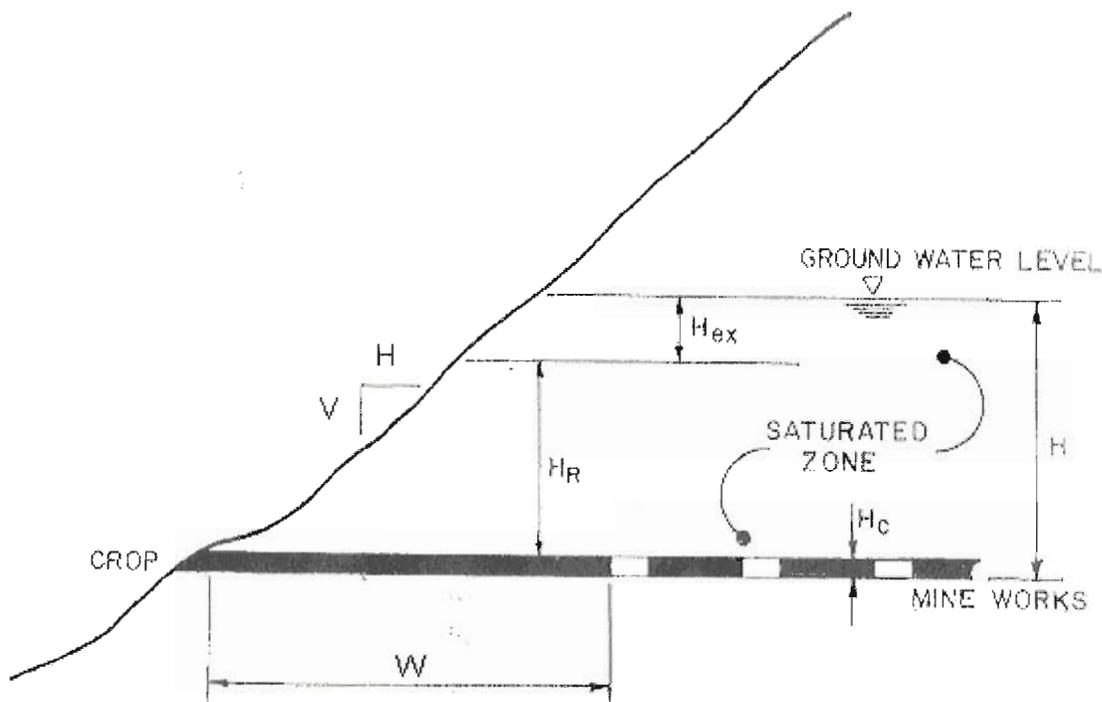


Figure A1. Hydrostatic Lift Failure Design (modified after Geological Consulting Services, Inc., 1988).

Where:

$S$	=	Slope H: V
$H$	=	Hydrostatic Head, ft.
$H_c$	=	Coals Thickness, ft.
$H_{ex}$	=	Excess Hydraulic Head, ft.
$H_R$	=	Overburden Height (interstitial material), ft.
$\#_C$	=	Coals Unit Weight (80 lbs/ft <sup>3</sup> )
$\#_R$	=	Overburden Material Unit Weight (130 lbs/ft <sup>3</sup> )
$\#_W$	=	Unit Weight of Water (62.4 lbs/ft <sup>3</sup> )
$W$	=	Barrier Width, ft.

For unit column:

$$W_C = \text{Submerged Weight of Coal} = H_C (\#_C - \#_W) = 17.6 H_C$$

$$W_R = \text{Submerged Weight of Overburden Material}$$

$$= H_R (\#_R - \#_W) = 67.6 H_R$$

$$W_{ex} = \text{Excess Hydraulic Pressure}$$

$$= H_{ex} (\#_W) = 62.4 H_{ex}$$

Therefore at equilibrium

$$W_{ex} = W_C + W_R$$

$$= 62.4 H_{ex} = 17.6 H_C + 67.6 H_R$$

$$H_{ex} = 0.28 H_C + 1.08 H_R$$

$$\text{But } H_w = H_{ex} + H_R + H_C$$

Therefore:

$$H_w = 1.28 H_C + 2.08 H_R$$

Solving for  $H_R$ :

$$H_R = (H_w - 1.28 H_C) / 2.08 = 0.48 H_w - 0.615 H_C$$

And:

$$W = S(H_C + H_R)$$

Therefore:

$$W = (S)H_C + 0.48 H_w (S) - 0.615(S)H_C$$

OR

$$\mathbf{W = S [(0.385 H_C + 0.48 H_w)] \text{ expressed in feet} \quad \text{Equation 3}}$$

Solving for W (barrier width) determines the equilibrium state (safety factor of one) of the buoyant and pressure forces against a unit column of coal and overburden material. Also, a factor of safety of at least 1.5 is recommended.

The application of equation # 3 is demonstrated below:

Given:

$$\text{Coalseam height, } H_C = 7 \text{ ft.}$$

Hydrostatic head, H = 31 ft.  
Surface slope, S = 2.24:1

Substituting these values in equation # 3 the outcrop barrier (W) will be:

$$W = 2.24 (0.385 \times 7 + 0.48 \times 31) = 2.24 \times 17.575 = 39.36 \text{ or } 39 \text{ ft.}$$

This represents the barrier at the point of equilibrium. Multiplying 39 by 1.5 safety factor, the barrier width (W) will be:

$$W = 39 \times 1.5 = 58.5 \text{ or } 59 \text{ ft.}$$

No outcrop coal or soil should be included in the barrier width.

## APPENDIX B

### Analysis of Outcrop Barrier Failure By Sliding Wedge Stability

#### Derivation of Equation 4

The following assumptions were made to develop equation 4. These are typical but conservative assumptions. They can be changed if field data is available.

- The study zone is saturated (as noted earlier, this is conservative) vertically to the point of hydrostatic head.
- Joint patterns and stress relief fractures lie vertically.
- Bedding planes are approximately horizontal. There is no cohesion between the joints and bedding planes.
- There is no friction within the vertically inclined joints or fractures.
- The sliding surface will be the one demonstrating the lowest angle of internal friction.
- The internal angle of friction for this case is assumed to be 50 degrees for bedrock, 35 degrees for coal and 29 degrees for the coal/underclay contact. The sliding surface is therefore assumed to be along the coal underclay horizon. These angles and sliding surface can be changed based on site-specific information, if available.

The following parameters and symbols are used in the calculations (see Figure B1).

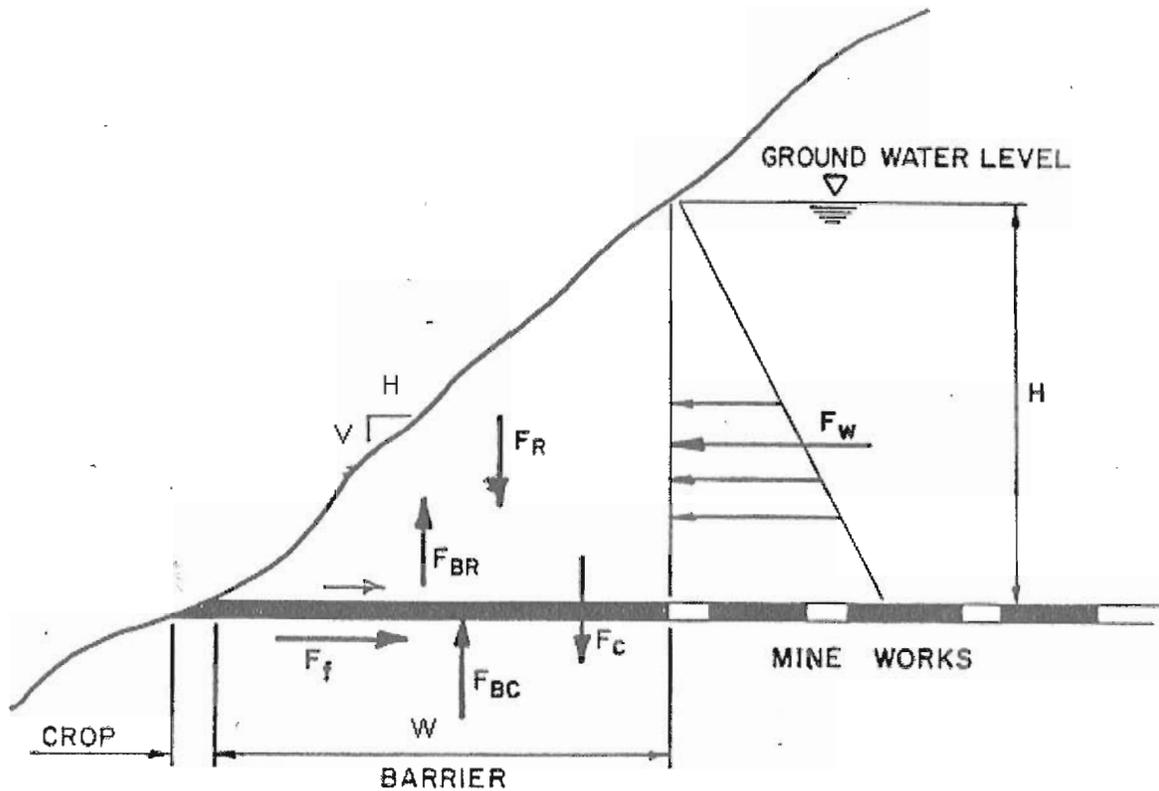


Figure B1. Sliding Block Wedge Failure Design (modified after Geological Consulting Services, Inc., 1988).

Where:

- S = Surface Slope H : V
- $H_R$  = Height of Overburden, ft.
- H = Hydrostatic Head, ft.
- $H_C$  = Coalseam Height, ft.
- $F_W$  = Water Thrust, lbs
- $F_R$  = Weight of Rock Mass, lbs.
- $F_C$  = Weight of Coal Mass, lbs.
- $F_{BR}$  = Buoyant Force on Rock, lbs.
- $F_{BC}$  = Buoyant Force on Coal, lbs.
- $F_f$  = Resisting Friction Force lbs.
- W = Barrier width, ft.
- $\#_W$  = Unit Weight of Water (62.4 lbs /ft<sup>3</sup>)
- $\#_R$  = Unit Weight of Rock (165 lbs/ft<sup>3</sup>)
- $\#_C$  = Unit Weight of Coal (80 lbs/ft<sup>3</sup>)
- $\emptyset$  = Internal Angle of Friction (29<sup>0</sup>)

$$F_F = F_W \text{ (Equilibrium Condition)}$$

But:

$$F_W = \frac{1}{2} (H^2)(\#W) = 31.2(H^2)$$

And:

$$F_F = [(F_R - F_{BR}) + (F_C - F_{BC})] \text{ Tan}\emptyset$$

If:

$$F_R = \frac{1}{2} H_R W \#_R$$

But:

$$H_R = L/S$$

Then:

$$F_R = \frac{1}{2} (W^2/S)(\#_R) = 82.5(W^2/S)$$

And:

$$F_{BR} = \frac{1}{2} (L^2/S)(\#_W) = 31.2(W^2/S)$$

Then:

$$(F_R - F_{BR}) = 51.3(W^2/S)$$

If:

$$F_C = \#_C H_C W + \frac{1}{2} (H_C)^2 S \#_C = 80 H_C W + 40 (H_C)^2 S$$

And:

$$F_{BC} = \#_W H_C W + \frac{1}{2} (H_C)^2 2 \# W = 62.4 H_C W + 31.2 H_C^2 S$$

Then:

$$(F_C - F_{BC}) = 17.6 H_C W + 8.8 H_C^2 S$$

Therefore,

$$31.2(H)^2 = (51.3(W^2/S) + 17.6 H_C W + 8.8 (H_C)^2 S) \text{ Tan}\emptyset \quad \text{Equation 4}$$

By reducing this equation to a quadratic equation or using a "trial and error" approach and inserting necessary values, W (equivalent to the barrier width, expressed in feet, less outcrop coal) can be determined. Here, W represents the equilibrium state (safety factor of one) of the hydrostatic thrust versus resisting friction forces for a coal barrier, with a rock overburden, resting on underclay. Only competent coal should be considered for barrier width, any soil or outcrop coal must be excluded. Please note if the overburden consists of both rock and soil, the values for the unit weight of both the rock and the soil should be used to derive a new equation.

The application of equation # 4 is demonstrated here by an example:

Given:

Coal thickness, $H_c$	= 7 ft
Hydrostatic head, H	= 31 ft
Surface slope, S	= 2.24:1
Calculate barrier width, W	

Substituting these values in equation # 4, the barrier width (W) will be:

$$W = 31.2(31)^2 = [(51.3 (W^2/2.24)] + [17.6(7) W + 8.8(7)^2(2.24)] \tan 29$$

Solving W results in a barrier width, W, of approximately 46 feet. Multiplying 46 by a 1.5 safety factor results in a barrier width = 69 ft.