The Interaction of Unique Geology and Retreat Room–and–Pillar Mining on Overburden Barrier Performance at the Grove No. 1 Mine

Anthony T Iannacchione, Associate Professor
Civil and Environmental Engineering
University of Pittsburgh
Pittsburgh, PA

Michael Keener, Graduate Research Assistant
Luke Mignogna, Graduate Research Assistant
Blaise Bucha, Undergraduate Research Assistant
University of Pittsburgh
Pittsburgh, PA

Joe Matyus, Retired
Pennsylvania Department of Environmental Protection
California, PA

Brent Means, Hydrologist/Geochemist
Office of Surface Mining
Harrisburg, PA

ABSTRACT

This study, funded by the Appalachian Research Initiative for Environmental Science (ARIES), examines how mine layout, mining method, and geology interacted to allow water from the Grove No.1 mine pool to discharge into local surface waters. Federal and State regulations prohibit the discharge of acid or iron-producing waters from underground coal mines. Mining companies design barriers around their operations to prevent mine waters from discharging to the surface. The Grove No.1 represents one mine where these designs proved inadequate. Unique geologic conditions at the Grove No.1 mine pool, combined with retreat room-and-pillar mining, contributed to a discharge that required passive water treatment.

INTRODUCTION

The Grove No. 1 Mine (MSHA ID #3602398) was opened in March of 1969 and closed in 2001. There were multiple owners including GM&W Coal Co., Carbolith Extraction Inc., Grove Resources, and Lion Mining Co. The mine is located in Somerset County, Pennsylvania, not far from US Routes 30 and 219 (Figure 1). Grove No.1 mine underlies two watersheds, South Fork Bens Creek and Roaring Run. Both are part of the larger Conemaugh watershed. The Pennsylvania Department of Environmental Protection (PA DEP) has designated South Fork Bens Creek as an exceptional value stream where native brook trout are known to live. The mine was designed as a drift room-and-pillar operation and entered the reserve through portals near the Upper Kittanning coalbed outcrop.

The Upper Kittanning coalbed at the Grove No.1 mine has overburdens ranging from zero at the portals to over 1,000-ft. In this area, the coalbed strikes N70°E and dips an average 15-degrees to the southeast (vertical change of 1,000-ft over 1 mile) as it plunges from highs along the limbs of the Laurel Hill anticline into the bottom of the Johnstown syncline. Initially, mining occurred within the Roaring Run watershed (AREA 1, Figure 1). Sometime in the early 80s, mining began to enter the South Fork Bens Creek watershed (AREA 2 and AREA 3, Figure 1). During the entire active mining period, no discharges were reported into the South Fork Bens Creek watershed.

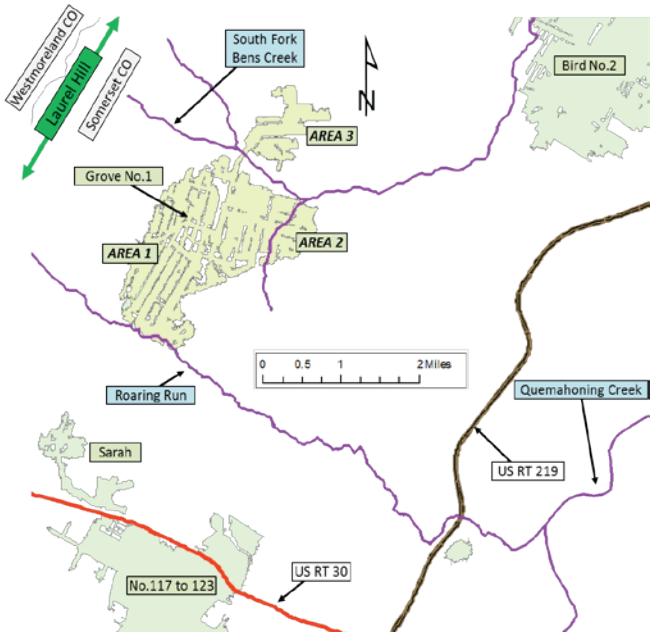

Figure 1. Location of the Grove No.1 adjacent to Laurel Hill Anticline in Somerset County, Pennsylvania and underlying South Fork Bens Creek and Roaring Run. Also shown are the mine portals and the general sequence of mining [numbered areas; AREA 1 being the first, AREA 3 being the last to be mined].

BACKGROUND TO THE DISCHARGE

The Grove No.1 mine closed in 2001. Shortly after, the water level of the mine pool reached an elevation of 1,450-ft (Blue area, Figure 2a). The pool level was controlled by a treatment facility operated by Lion Mining along South Fork Bens Creek. The mine petitioned the PA DEP to allow the mine pool to reach the 1,700-ft level. The petition was approved, and, by June 21, 2001, the pool rose to a reported elevation of 1,700-ft (Purple area, Figure 2a). This elevation was later to be found in error. As shown in Figure 2, the pool elevation is controlled by the Upper Kittanning structure contours (elevation above sea level). In July of 2001, a discharge was reported along South Fork Bens Creek (Figure 2a). A

photograph was taken during the ensuing investigation by Federal and State officials (Figure 2b) capturing the iron-rich discharge upwelling in the bottom of South Fork Bens Creek.

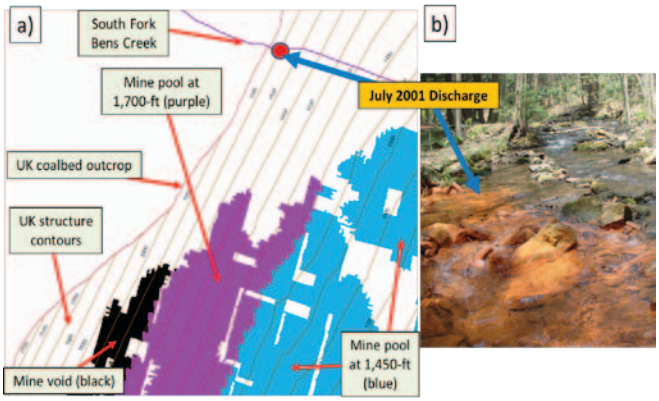

Figure 2. a) Two important mine pool elevations are shown during 2001 (i.e., 1,450-ft in BLUE and 1,700-ft in PURPLE). Also shown is the portion of the mine not filled with water (BLACK). These pool elevations are controlled by the dip of the Upper Kittanning Coalbed (see UK structure contours). b) Photograph of the discharge (June 2001).

The South Fork Bens Creek discharge was not expected for several reasons:

- The Upper Kittanning coalbed outcrop was at 1,730-ft or approximately 30-ft above the elevation of the mine pool.
- The distance from the closest mine workings to the upper reaches of South Fork Bens Creek was over 2,000-ft. (The authors don't know of any other discharge that traveled this far along the strike of the coalbed.)

The PA DEP conducted an investigation to explain and identify the cause of the South Fork Bens Creek mine drainage discharge (Matyus, Kernic, and Koricich, 2002). In this report, the authors found that the mine pool had risen to a maximum elevation of 1,806-ft, producing a hydraulic head difference of an average78-ft between the top of the pool and the seep elevations (multiple seeps were identified in the PA DEP investigation). The report concluded the source of the South Fork Bens Creek discharge was the Grove No.1 mine pool.

The University of Pittsburgh collected information from multiple sources to help analyze the unique geology and complicated mine layouts at the Grove No.1 Mine. This report will help to document how geology and mining layouts can interact to adversely affect the performance of barriers meant to prevent coal mine discharges.

UNIQUE GEOLOGY

The structure of the Upper Kittanning coalbed in the area of the Grove No.1 mine is, indeed, unique. The Laurel Hill Anticline has produced dramatic dips to rock formations along most of its 80-mile length (i.e., West Virginia border in the south to the middle of Indiana County in the north). In many locations, the flank of the Laurel Hill anticline dips at an average rate of 4° (Flint, 1965). However, in some areas, the flank of the Laurel Hill anticline can dip upwards of 60°, especially when faulting is present (Puglio and Iannacchione, 1979). The Upper Kittanning coalbed structure contours for the Grove No.1 mine were collected from official maps submitted by Lion Mining, Inc. and digitized within ArcGIS. A 3-D perspective of the surface topography and structure contours of the Upper Kittanning coalbed are shown in Figure 3. The dips of the Upper Kittanning coalbed within the Grove No.1 mine range from 5 to 30°.

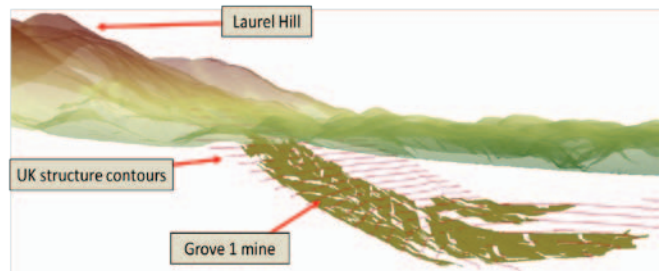

Figure 3. 3-D view of surface topography and Upper Kittanning coalbed structure contours in the vicinity of the Grove No. 1 mine.

Formations that are draped over significant geologic features, such as the Laurel Hill Anticline, will often experience lateral adjustments producing prominent bedding features. Movement is most likely to occur within the softer units, such as the coalbeds, and can be observed as bedding plane faults. One of the authors had an opportunity to perform geological mapping within the Grove No.1 mine in the early to mid-1980s. The results from that mapping exercise were never published, and the files were destroyed when the US Bureau of Mines closed in 1995. Figure 4 is a cartoon that depicts the occurrence of slickensided bedding plane faults and the offsets observed within the clastic dykes that were penetrated by the faults. The bedding plane faults, along which the offsets were observed, were highly slickensided and occurred within the coalbed and the overlying shale members. It is possible that they also occurred within the underlying rock units. These structural features were found throughout this portion of the mine listed as AREA 1 in Figure 1.

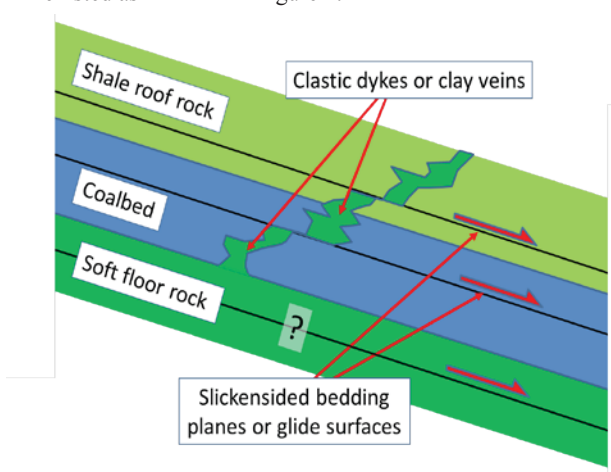

Figure 4. Cartoon of clastic dyke offset along prominent slickensided bedding plane surfaces.

ROOM-AND-PILLAR MINE LAYOUT WITH PILLAR RECOVERY

The significant dips of the Upper Kittanning coalbed affected the room-and-pillar mining method used at Grove No.1 (Figure 5a). The mine had three different mine layout styles:

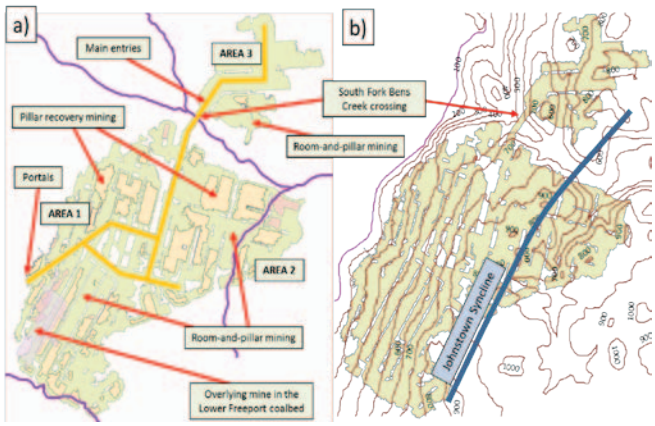

Figure 5. a) Characteristics of the Grove No.1 mine layout, and b) Overburden map.

- AREA 1: Main entries entered the reserve at the portals and quickly drove to the bottom of the Johnstown Syncline. Significant dips require transporting workers and supplies along a roof track-mounted monorail. Track haulage was not feasible in the main entry of AREA 1. Production sections were designed to optimize mine developments with level headings. Overburden ranged from approximately 100-ft to almost 900-ft.
- AREA 2: The main entries entered AREA 2, near the bottom of the Johnstown Syncline, where dips averaged 5°. Here, main entry headings are oriented along the coalbed strike, allowing for track haulage. The developments were mainly south of the main entries. The most striking condition in this area is the significant overburden relative to other areas ranging from a minimum of 600-ft to slightly more than 1,000-ft. Most production panels were eventually subjected to some form of pillar recovery (full or partial). Some full extraction panels lie under South Fork Bens Creek.
- AREA 3: The main entries entered AREA 3 across South Fork Bens Creek to reach additional reserves on the northeast side. The mining method was dominated by room-and-pillar developments. Dips were, on average 5°, and overburdens ranged from approximately 500-ft under South Fork Bens Creek to more than 800-ft under the hill tops. Crossing South Fork Bens Creek was a concern to the PA DEP. They required the mine to minimize coal extract under South Fork Bens Creek. A detailed mining plan was submitted and approved by the PA DEP.

As mentioned previously, the US Bureau of Mines had conducted an investigation at this site. The investigation was focused on determining the cause of the difficult mining conditions encountered while mining in areas of high dip (AREA 1). Of particular concern were the unstable roof conditions in both development and retreating production panels. There was also a small mine in the Upper Freeport coalbed overlying Grove No.1 in this location (Figure 5a). Figure 6 is a cartoon submitted to help explain the reasons for the difficult ground conditions. These conditions were most unstable in the development sections down-dip from an adjacent up-dip pillar recovery section. It is likely that the significant dip of the Upper Kittanning coalbeds (Figure 3) and the presence of laterally persistent slickensided bedding plane faults (Figure 4) facilitated the transfer of overburden load, down-dip from the retreat mining section to the adjacent development section (Figure 6). The eccentric nature of the load applied to the roof, floor, and pillars of the development section most likely overcame the design strength of the pillars and intrinsic roof support.

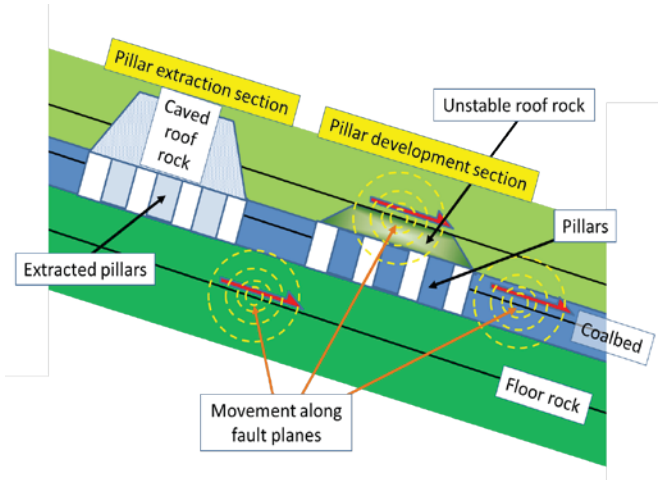

Figure 6. Cartoon of the geologic and mining layouts in adjacent development sections as the down-dip section is advanced while the up-dip section is retreated.

SEISMIC ACTIVITY

Grove No.1 mine has had a history of "alleged" seismicity. The first mention of this is on February 3, 1982, when a magnitude 2.6 event was located near Jennerstown, PA, by the US Geological Survey (Scharnberger, 2003). Jennerstown is only a few miles from the Grove No.1 mine, and this area, according to the Scharnberger report, has not previously registered an earthquake.

In October and November of 1988, Wu, Kravitz, and Hoch (1988) reported a series of "tremors and vibrations" that rocked the surface above the Grove No.1 mine. The Mine Safety and Health Administration (MSHA) conducted an investigation of the reported tremors and vibrations and found that they had occurred 1.5 months before the writing of the memorandum. These events were thought to emanate from the No. 15 Left and between the No. 11 and 12 Left sections. Both of these areas were in the process of recovering pillars under relatively steep ridges (Figure 7). Also, the "safety barrier" (barrier pillar between two pillar recovery sections) had been removed during pillar recovery, something that is different from regular mining procedures.

Other events include the following:

- In 1988, the Forwardstown Area Concerned Citizens Coalition reported more than 150 tremors, quakes, and vibrations in the area of the mine.

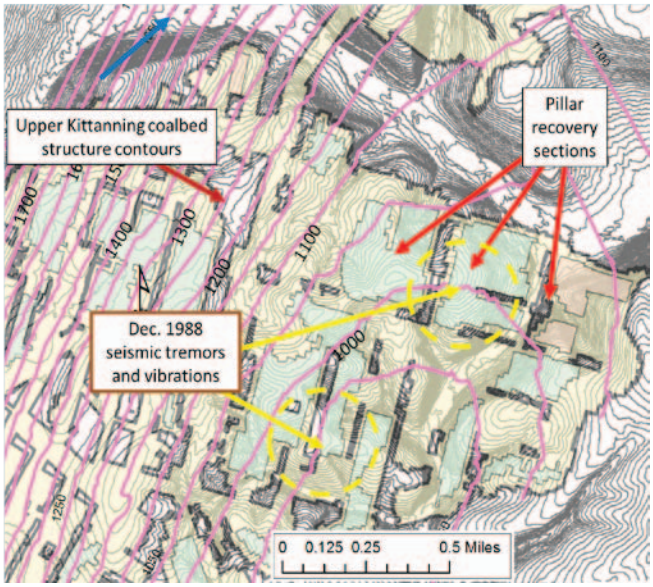

Figure 7. Grove No.1 mine layout showing the pillar recovery areas, Upper Kittanning coalbed structure contours, surface discharge zone, and December 1988 seismic tremors and vibrations.

- On May 14, 1991, an article in the Tribune Democrat stated "tremors felt…stopped after inspection (partial mining)."
- On January 4, 1994, Professor Shelton Alexander at Pennsylvania State University measured magnitudes of 3.1 and 3.2 emanating from the vicinity of the mine.
- On June 1, 1995, (Letter, 1995), the Forwardstown Area Concerned Citizens Coalition reported 44 tremors, quakes, and vibrations since January 4, 1994 (an 18-month period).

While several mechanisms are possible, it seems evident that full extraction mining reactivated movement along preexisting bedding plane faults resulting in significant seismic activity.

It seems the most telling information came from the Wu, Kravitz, and Hoch (1988) report. A direct connection was made between seismicity and pillar recovery activities (Figure 7). While microseismic events are common when full extraction mining takes place, it is uncommon for these events to fall into the range of earthquakes (i.e., Richter magnitudes greater than 2). Therefore, it seems reasonable to conclude that the significant Upper Kittanning coalbed dips, the presence of slickensided bedding plane faults, and the use of full extraction mining, all combined to produce significant damage to the strata adjacent to the Grove No.1 mine.

CALCULATING HYDRAULIC CONDUCTIVITY

Hydraulic conductivity of the rock media at the Grove No. 1 site was calculated using a water balance method along with Darcy's Law. Water balance method is used to first determine infiltration into the mine given pumping rates and mine pool elevation data. The method simply states that inflow to the mine minus outflow from the mine must equal a change in the mine pool. The given data allows an average infiltration into the mine to be calculated (0.327-ft/day/ft^2 of mine area). Assuming this value is constant, infiltration and mine pool elevation data during the time of the discharge is used to determine the discharge flow rate. Hydraulic conductivity can then be calculated using Darcy's Law. Using this method, hydraulic conductivities are calculated to be 6.7 – 18.5-ft/day based on a 30-ft head difference and 2,100 – 3,200-ft length of travel. These values are considerably higher than hydraulic conductivities for coal found in the literature. The values do, however, correspond to the hydraulic conductivity for fractured rock.

PROBABLE CAUSE OF THE SOUTH FORK BENS CREEK DISCHARGE

The PA DEP investigation of the Ben Creek discharge identified seven seeps (Matyus et al., 2002). Chemical analysis from the seeps and the mine pool (BAMR Hole 2) showed similar water chemistry. The elevations for the seven seeps, two piezometers, and two drill holes are listed in Table 1. On May 27, 2002, the PA DEP measured a static mine pool water level of 1,805.9-ft. This would put the mine pool 74 to 83-ft above the seeps.

Table 1. Information on the seeps, piezometers, and drillholes near South Fork Bens Creek.

ID	Surface elevation, ft	Comment
Seep 1	1734.1	
Seep 2	1735	
Seep 3	1735.1	
Seep 4	1731.6	
Seep 5	1723.2	
Seep 6	1723.4	
Seep 7	1723.8	
PZ 1	1710.6	TOC 1711.3, deep aquifers, 1682
PZ 2	1709.8	TOC 1710.6, shallow fractured sandstone aquifer, 1703.1
Degas Hole Mains A	1891.6	TOC 1894.9
BAMR Hole 2	2009.3	Water samples confirmed association with seep

The most logical explanation for the discharge path between the Grove No.1 mine pool and seeps is that the water moved along the strike of the Upper Kittanning coalbed and associated roof and floor strata. This would produce water flow travel distances of 2,300 to 3,200-ft under a hydraulic head averaging 78-ft (Figure 8). Groundwater flow in this area is most likely dominated by open joints, fractures, and bedding planes. This fracture permeability is especially dominant in and near valleys such as South Fork Bens Creek where stress relief fractures are present (Johnson, 1980). The two processes of highly fractured rock close to the surface and 78-ft of hydraulic head probably provided the conduit and the driving force to allow the flow of mine pool water to South Fork Bens Creek. However, it is also possible that significant seismicity at the mine provided sufficient energy to enhance the fracture network hydraulic conductivity. The seismic energy often results

in displacements along pre-existing fractures and bedding planes and can also result in greater water transmissivity.

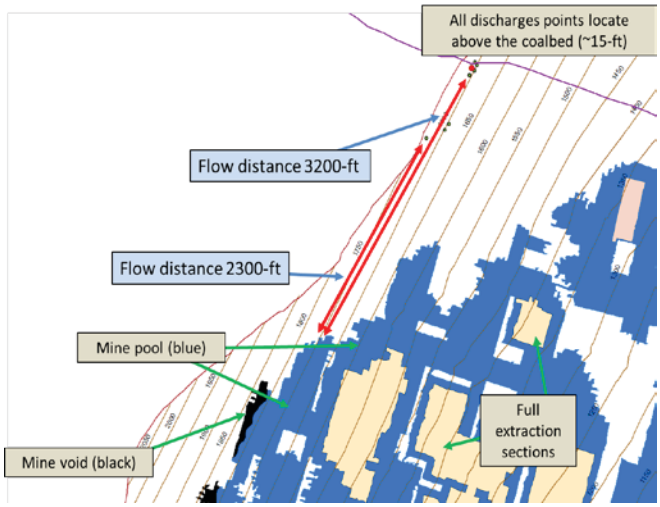

Figure 8. Location of the mine pool at its maximum recorded height of 1805.9-ft and the projected path of water discharge from the mine to the seeps along South Fork Bens Creek.

Seismicity at the Grove No.1 mine is associated with displacements along pre-existing rock bedding planes and both shear and tensile failures within rock layer due to stress-redistribution and stress-relief fracturing (Wyrick and Borchers, 1981). Since natural and mining-induced fractures are common at this mine, it is appropriate to assume that the discharge is dominated by fracture flow. Using the cubic law developed by Romm, widths and apertures of fractures can be calculated from the discharge rate (Romm, 1966). The cubic law is expressed as

$$Q = [(\rho_w * g * b^2)/(12*\mu)]*[(b*w)*(\delta h/\delta L)]$$

Where:

Q = discharge flow, ft^3/s

ρ_w = density of water (1.94-slugs/ft^3)

g = gravitational acceleration (32.17-ft/s^2)

μ = viscosity (2.034×10^{-5}-lbs/ft^2)

b = aperture opening, ft

w = fracture width perpendicular to the flow direction, ft

$\delta h/\delta L$ = hydraulic gradient (0.0143 and 9.38×10^{-3})

The values for fracture width and aperture can be compared to determine the feasibility of mine discharge contributions. Table 2 gives fracture widths and apertures that can accommodate the mine discharge (60-gpm). By observation, a feasible fracture width and corresponding aperture would be a 12-in fracture with a 10.1-mm aperture. Other combinations are also possible. Given that fractures of this size are common near the surface and are capable of conveying the discharge volume, it can be concluded that fracture flow can be a major contributor in the cause of the Grove No.1 discharge.

Table 2. Fracture widths and apertures using Romm Theory.

Fracture Width, in. (mm)	Fracture Aperture, in. (mm)
0.012 (0.3048)	3.98 (101)
0.12 (3.048)	1.85 (47.0)
1.2 (30.48)	0.858 (21.8)
3 (76.2)	0.632 (16.1)
6 (152.4)	0.502 (12.8)
12 (304.8)	0.398 (10.1)
24 (609.6)	0.316 (8.03)
36 (914.4)	0.276 (7.02)
48 (1219.2)	0.251 (6.38)
120 (3048)	0.185 (4.70)
1200 (30480)	0.0858 (2.18)

SUMMARY

The Grove No.1 mine was designed to prevent pooled waters from directly discharging to the surface. All of the mine workings were located below drainage, so the only threat for unwanted discharge was through the overlying strata. After the mine closed and flooded, a major discharge of iron-containing water occurred along South Fork Bens Creek. This was not expected since the only mining that occurred under South Fork Bens Creek was a main entry system used to access reserves to the northeast. These mains, especially under South Fork Bens Creek, were adequately designed and should not have damaged the overlying strata. Therefore, it is highly unlikely that mine waters could flow upward over 300-ft vertically to the surface.

At the time of mining, strata conditions within the Grove No.1 mine were considered to be challenging, especially when development sections were mined down-dip of a pillar recovery panel. The previously mentioned bedding plane slips undoubtedly aided in the down-dip movement of strata that was observed in several of these development sections. It is likely that a portion of the strata within and above the Upper Kittanning coalbed was damaged during both pillar recovery and associated seismic events, allowing water to flow horizontally several thousand feet from the edge of mining to South Fork Bens Creek. This mechanism is important to understand if adequate mine layouts are to be designed in the future that will provide a low risk of mine water discharge to surface waters.

CONCLUSION

The Key Factors responsible for the performance of these barriers was found to be the following:

- Geology: Dips averaging 15 degrees and the associated structures, such as bedding plane slips, were present within the Grove No.1 mine property prior to mining.
- Mine layout: The mine was designed to drive main entries down-dip towards the Johnstown syncline. Development

sections were driven along the strike of the formation on both sides of the main entry. Once a development section was driven to its full length, the panel pillars were recovered.

- Strata control: The combination of high dips, bedding plane slips, and pillar recovery mining methods produced challenging strata control conditions that resulted in tremors and vibrations at the surface. These tremors were large enough to generate significant horizontal and vertical fractures in the overlying strata.
- Mine flooding: When the mine began to flood and fill with water, the mining induced failures provided pathways for the impaired waters to reach Ben's creek.
- Strata barrier design issues: In this case, the strata barrier designed to protect Ben's creek proved inadequate, mainly due to unique rock fracture conditions and bedding plane slippage. When these conditions are encountered in the future, additional thicknesses of strata barriers or restricting pillar recovery mining are recommended.

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