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COAL BUMPS IN AN EASTERN KENTUCKY USA LONGWALL COAL MINE 1989 TO 1997

John Hoelle[1]

ABSTRACT: Coal mines in southern West Virginia, south-western Virginia and eastern Kentucky have experienced coal bumps at least since 1933. Most of the bumps have occurred due to high cover, strong roof and floor strata and stress concentrations due to the mining sequence. A longwall mine in eastern Kentucky first experienced coal bumps on the tailgate side of the longwall face in 1989. The bumps continued until 1996. The bumps were the result of:

- thick overburden up to 670m.
- strong roof and floor (strata strengths up to 177 MPa UCS and elasticity modulus up to 33.1 MPa
- previous over-mining in places
- sandstone channels

Not all characteristics occurred simultaneously. The bumps produced seismic events recorded up to 4.3 (Richter scale magnitude), and damaged pillars that were up to 45 by 46 m in size.
During the eight years that the bumps occurred, a large quantity of data was obtained in an effort to develop methods to predict an event, and reduce or eliminate the bumps.

- In-situ strength properties of floor, coal and roof strata
- Lab testing of floor, coal and roof samples
- Monitoring gate road pillar response with stress metres, extensometers and convergence stations
- Shield leg response
- Monitoring in an effort to determine precursors was conducted using a digital microseismic monitoring system.
- Back calculation of gate road pillar strength

A number of different remedies were trialled in an effort to eliminate or decrease the severity of the bumps.

- The gate road longwall design was varied
- Pillar size and shape
- 3 and 4 entry gate road designs
- water infusion in longwall panels,
- hydraulic induced face bumps,
- disruption of the roof strata

A yield-abutment-yield pillar design was the most effective method in reducing the affect of bumps by moving the events onto the abutment pillars, but the bumps were never eliminated and adequate precursors and advanced warnings were never achieved.

INTRODUCTION

This mine is in a region that was characterised by deeply incised valleys and high ridges which were over 640 m above the stream valley bottoms. The strata is predominantly sandstone and there are a number of coal seams above and below drainage. Room-and-pillar mines in the immediate area of the subject mine recorded bumps as far back as 1933 (Coughlin and Rowell, 1993, Holland, 1942) and probably bumps were experienced in the years prior to 1933. The mine started in 1972 as a room-and-pillar drift mine and was developed as a longwall mine starting in 1981. Longwall reserves were exhausted in late 1997 and the mine closed in the first quarter of 1998 when economic reserves were exhausted. The coal seam was the Harlan seam and ranged in thickness from approximately

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2.5 to 3.7 m in economical mining thickness. The seam occurred in four benches and in some areas, the parting between the upper bench and the three lower coal benches or the parting between the lower bench and the three upper benches became too thick to mine. A typical section is shown in Figure 1. The seam dipped 2 to 3 degrees to the south. The access portals were drift portals with four additional sets of intake and return portals – all drifts were located at the north-end of the reserve. The overburden gradually increased as mining advanced to the south with overburden thicknesses up to 670 m.

Based on movement of the coal pillars along coal bench-parting contacts and information from nearby mines, there was a regional stress field to the north-east, which trended approximately N55E. Three in-situ stress tests were conducted at the mine. There were five groups of panels with the last three shown in Figure 2. Group 3 is shown with five panels (numbered 1 through 5) and Group 4 had four panels (numbered 6 through 9 in Figure 2). Group 5 is shown with 11 panels. The panel widths were 152 m for Group 3 and 4 shown in Figure 2. Panels 1 through 11 in the last group were 183 m wide.

The first bump in this mine occurred in April 1989 and the last bump occurred in May 1996. There have been a number of papers published on the bumps that have occurred at this mine (Coughlin and Rowell, 1993, Heasley and Zelanko, 1992, Mark and DeMarco, 1992, Rowell, and Lemons, 1991, and Zalenko, Rowell and Barczak, 1991, Hoelle 2008). The major bumps that occurred are summarised in Table 1. A major bump was defined when mining had to be stopped, a significant quantity of coal was displaced, equipment damaged, ventilation disruption or similar criteria. A minor bump consisted of noise, small quantities of coal displaced, ground bounce, but no major large coal moved or equipment damaged. The terms were very subjective and the definitions were not well defined.

This paper is a presentation of what occurred in this mine, what mitigating efforts were attempted, and the success of these efforts.

Table 1 - Summary of major bump events

Panel No. (Group-panel)	Date	Seismic Magnitude	Overburden thickness m (ft)
3-3	18 Apr 89	N-A	357 (1,170)
3-3	8 May 89	N-A	396 (1,300)
3-4	22 Nov 89	2.3	488 (1,600)
4-2	25 Jul 90	N-A	674 (2,210)
4-2	8 Oct 90	N-A	668 (2,190)
4-3	11 Jan 91	N-A	543 (1,780)
5-6	3 Aug 94	3.5	646 (2,120)
5-6	5 Oct 94	3.6	640 (2,100)
5-7	23 Dec 94	3.5	518 (1,700)
5-7	19 Jan 95	3.7	594 (1,950)
5-7	11 Mar 95	4.0	518 (1,700)
5-8	22 Jul 95	3.4	518 (1,700)
5-8	5 Aug 95	2.8	579 (1,900)
5-9	25 Oct 95	4.3	502 (1,650)
5-10	19 April 96	3.7	495 (1,625)
5-10	4 May 96	3.7	533 (1,750)
5-10	13 May 96	3.5	572 (1,875)
5-10	16 May 96	2.0	579 (1,900)

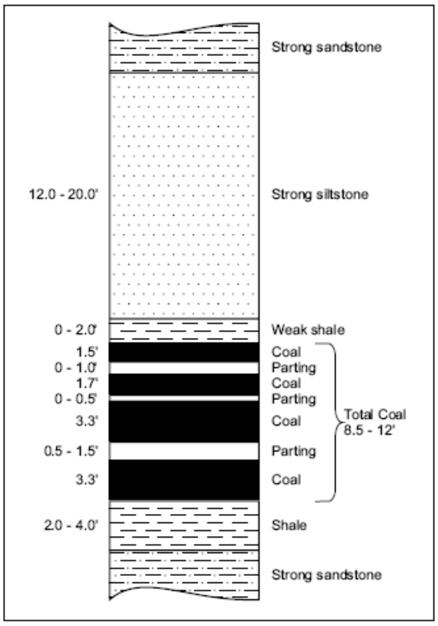

Figure No 1 - Typical stratigraphical section

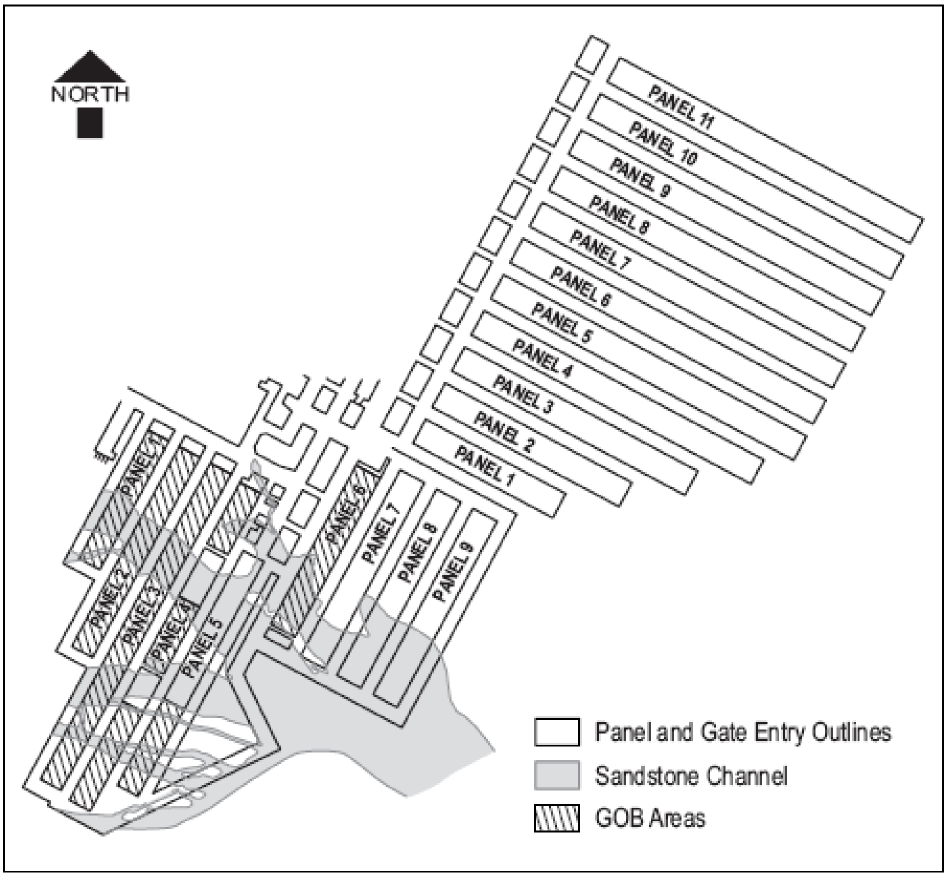

Figure No 2 - Mine plan for Groups 3, 4 and 5

HISTORY OF BUMPS

The initial two groups of longwall panels were mined without incident. The approximate maximum cover thickness in the first set of panels was 457m and 579m in the second set of panels. These panels were located north of the Group 3 panels shown in Figure 2.

The first set of 9 panels in Figure 2 was a three-entry abutment-yield configuration, although the "yield" pillar was not designed as a yield pillar. Mine personnel referred to these smaller pillars as yield pillars or as the "small" pillars. The first two panels had pillar sizes of 2m wide by 30m long (abutment pillar) and 17 m wide by 30.5 m long for the smaller pillar. The abutment pillar was adjacent to the previously mined panel. The maximum cover was 610 m, although the subsequent bumps did not occur in the areas of highest cover. The first bump was encountered in the panel 3 of longwall panels in April 1989. The bump occurred on the edges of a sandstone channel that cut into the upper portion of the coal seam. The shearer was heavily damaged and removed from the mine for major repairs.

A second large bump occurred in May 1989 when the longwall face exited the same sandstone channel. The shearer was heavily damaged and was removed from the mine for major repairs. At that time, mine personnel believed that the bumps were the result of the sandstone channel when the sandstone comprised the immediate roof. In order to avoid this situation, the mine began to move the longwall around the known locations of sandstone channels since these appeared to be the cause of the bumps. Figure 2 shows the approximate location of the sandstone channels. A third bump occurred in the panel 4 in November 1989. The bump occurred as the longwall face was approaching but not under a sandstone channel. The shearer was heavily damaged and an in-panel move around the projected sandstone was conducted and the panel 4 finished without incident. After the first bump had occurred, the abutment pillar sizes between panels 4 and 5 were increased to 30.5 m wide by 30.5 m long with the smaller pillar width increased to 18 m. The pillar sizes for all of the groups are summarised in Table 2. Two of the abutment pillars in the headgate of Panel 4 were instrumented with an array of borehole platen flatjacks, coal pillar extensometers and convergence stations (Zalenko, Rowell and Barczak, 1991). The abutment pillars in the panel 4 headgate were increased to 33.5 m wide. Microseismic geophones were installed in the tailgate and headgate of panel 4 and shield support leg pressure response data was collected and analysed (Zalenko, Rowell and Barczak, 1991).

Table 2 - Summary of gate road configuration and pillar sizes

Group	No. of Panels in Group	Configuration	Abutment Dimension (Width by length) m(ft)	Small pillar (Width by length), m (ft)
1	4	3-entry abutment-yield	29 x 29 (95 x 95)	15 x 29 (50 x 95)
2	4	3-entry abutment-yield	29 x 29 (95 x 95)	15 x 29 (50 x 95)
3	2	3-entry abutment-yield	25 x 30.5 (85 x 100)	16.8 x 36.5 (85 x 100)
3	1	3-entry abutment-yield	30.5 x 30.5 (100 x 100)	18.3 x 30.5 (60 x 100)
3	1	3-entry abutment-yield	33.5 x 30.5 (110 x 100)	18.3 x 30.5 (60 x 100)
4	4	3-entry abutment-yield	42.7 x 36.5 (140 x 120)	15.3 x 36.6 (50 x 120)
5	2	4-entry yield-abutment-yield	47.5 x 47.5 (156x156)	12 x 47.5 (40 x 156)
5	1	4-entry yield-abutment-yield	46.4 x 47.5 (152 x 156)	12 x 47.5 (40 x 156)
5	7	4-entry yield-abutment-yield	45 x 46.3 (147 x152)	12 x 46.3 (40 x 152)

The instrumented pillars indicated that the pillars were failing prior to the bumps and that stress loading was being shifted across the gate road pillars onto the longwall panels, indicating that the pillars were of insufficient size to control stress override. The first three bumps occurred within 12 m of the tailgate, which apparently agreed with the load shedding of the tailgate pillars. Review of the data indicated that the shield leg pressures did not indicate any significant change in pressure. The microcosmic activity, while showing an increase in the number and intensity, did not produce an obvious precursor.

Panel 5 of Group 3 was only partially mined with no bump occurrences and the longwall moved to the Group 4 set of 4 panels. There were some changes in Group 4. The gate road pillar sizes were increased to 36.5 m long by 42.7 m wide and 36.5 m long by 12 m wide. Again the "yield" pillar was not designed as a true yield pillar. The maximum approximate cover was a little over 670 m and the high cover areas flagged. This group of panels had adverse room-and-pillar mining barrier pillars and goaf (gob) areas approximately 40 m above the longwall mine and these areas were flagged.

The high cover and the projections of the sandstone channels indicated that there was still a potential for coal bumps. In an effort to reduce the potential for bumps, water infusion into the panel was initiated. Horizontal holes were drilled into the panel ahead of mining and water infused into the panel. The depths of the holes ranged from 21 to 95 m and were drilled from both the tailgate and headgate. In addition, the face of the longwall panel was hydro-fractured when the face appeared to be hard and standing straight. Due to the height of the seam and the overburden thickness, the panel face normally spalled readily. However, when the panel was taking weight and being loaded, the face stood straight with no spalling. The headgate entries of Panels 2, 3 and 4 were instrumented with convergence stations and one abutment pillar was instrumented with stress meters. Plexiglas shields were hung along the shield walk way to protect personnel from coal that may be ejected from the face. In order to try to reduce the affect of hanging roof, attempts were made to create a"pre-split" line along the tailgate and through the shields along the face. The tailgate holes could not be loaded. The holes along the shield line were drilled between the shields (on 1.5-metre centres, the shield width). The holes were shot; however, the height of the disrupted strata did not appear to be sufficient to initiate caving.

Mining started in April 1990 in Group 4 and the first panel (panel 6 in Figure 2) was mined without major incident but there were two minor bumps near the beginning of the panel. The second panel (panel 7 in Figure 2) had 2 minor bumps and then a large bump after mining a short distance into the panel, with the bump damaging the shearer. Since this bump was under the same sandstone channel feature that was affiliated with the bumps in Group 3, the decision was made to move the longwall around the sandstone channel. Seven more minor bumps occurred before two large bumps occurred on the 8th October 1990 when the face was under a high mountain peak as well as under a barrier pillar that was in the overlying adverse mine. At about the same time, an abutment pillar in the headgate bumped, totally destroying the integrity of the pillar. No additional bumps occurred during mining of the rest of the panel. The bumps that occurred in the longwall panel were within 46 m of the tailgate

The third panel (panel 8 in Figure 2) was started inbye the sandstone channel. There were no bumps until the panel was under a barrier pillar in the overlying adverse mine when a minor bump followed by a major bump approximately 46 m from the tailgate. The decision was made to conduct an in-panel move around the high cover area that caused the bumps in the second panel. This also avoided the area of the previously destroyed abutment pillar in the tailgate. There were no further bumps in the rest of panel 8 or in panel 9.

The Group 5 set of 11 panels was started in October 1991. These panels were oriented at 90^{o} to the orientation of the first four set of panels, as shown in Figure 2. Since a large number of bumps occurred in Group 4, the size and configuration of the gate road pillars were evaluated and major changes were made. The abutment pillars were designed as a 4-entry yield-abutment-yield arrangement. In the initial two panels, the gate road pillars were designed with the length at 47.5 m and the width at 12 and 47.5 and 12 m respectively. As part of this re-design, the smaller pillars were designed as true yield pillars. The length of the pillars was shortened to 46 m in the third panel and the 4th through the 11th abutment pillars were 45 m long by 46 m wide. The yield pillars remained 12 m wide. The pillar configurations are summarised in Table 2. The memory cut capabilities of the shearer continued to be used in the Group 5 panels.

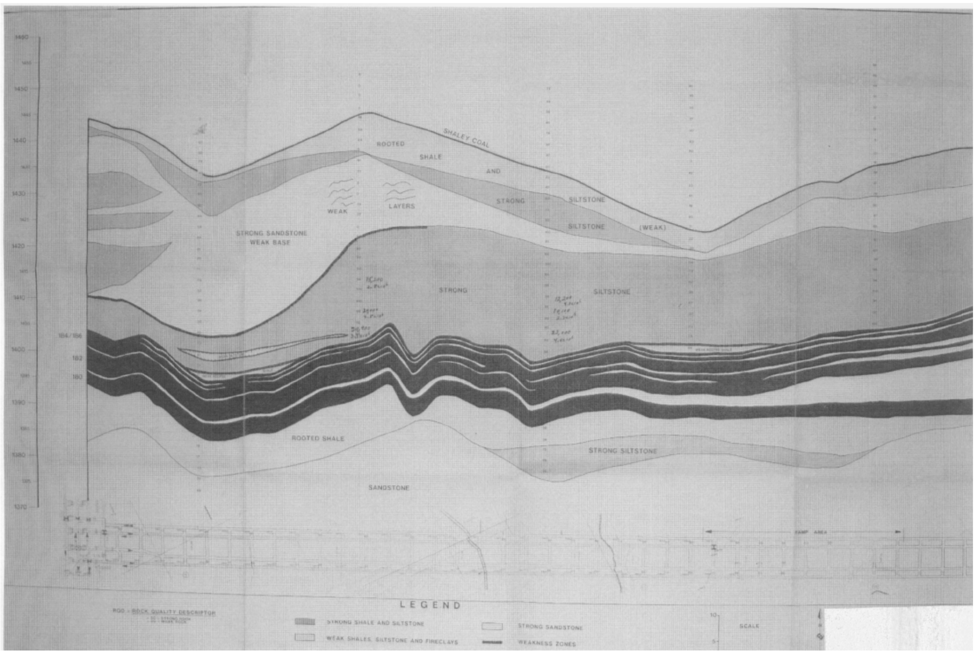

Figure 3 - Profile of gateroad

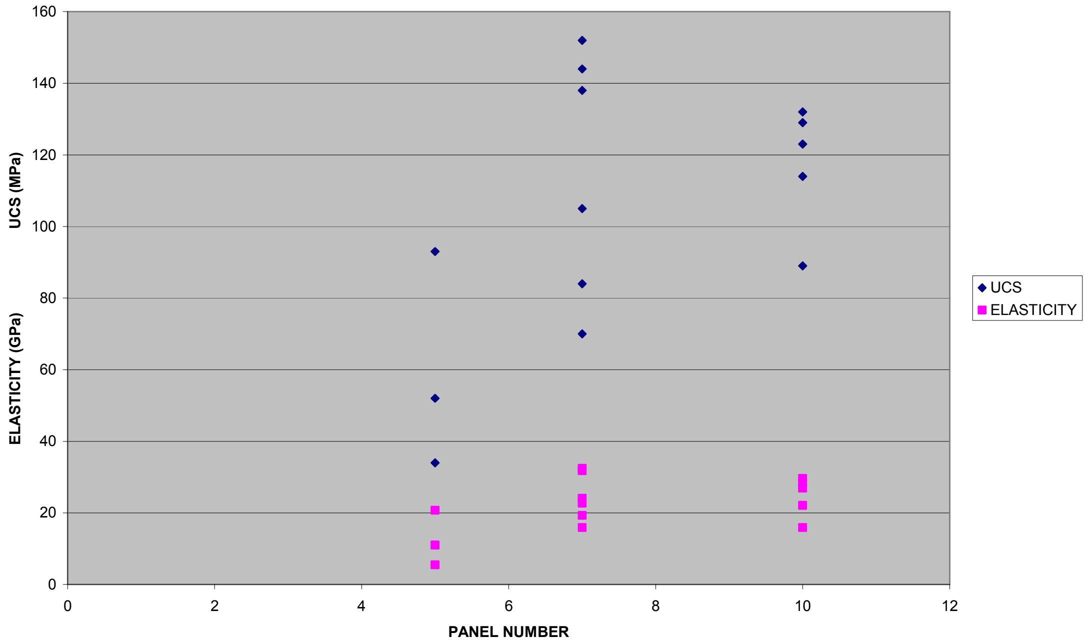

Figure 4 - Roof rock strengths

Starting with the panel 3 headgate, core holes were drilled 2.5 to 3.0 m into the floor and 12 to 15 m into the roof from the gate roads. The purpose of this was to determine if thick sandstone roof strata was present. A strong sandstone on or near the coal was not encountered; however a strong siltstone did occur within 0.6 m of the coal seam. A typical profile from the drilling is shown in Figure 3. Along with strata identification, RQD's were recorded and starting with the fifth panel, samples were tested for UCS and Young's modulus strength characteristics. The test results are illustrated in Table 3. The UCS strengths and the Young's modulus increased from south to north and from west to east. Figure 4 illustrates the increase in UCS and Young's modulus. The first five panels were bump-free even though the overburden thicknesses were up to 670 m. Because the first five panels were bump free, it was decided that the abutment pillars were properly designed to prevent bumps from occurring.

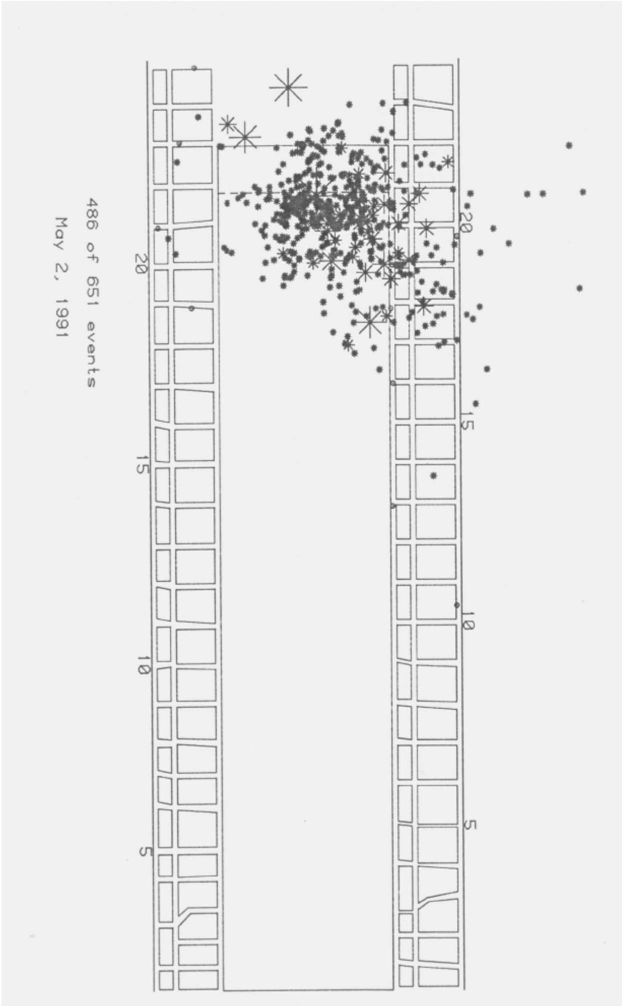

Figure 5 - Microseismic activity, Group 4, Panel 4

The first bump in the Group 5 set of panels occurred on 3rd August 1994 in an abutment pillar next to the longwall tailgate in panel 6 when the overburden reached 646 m. Four additional bumps in abutment pillars occurred in this panel with the cover over 640 m. The seismic Magnitudes ranged from 3.0 to 3.6. After the second bump, hydro-fracturing of the face was conducted every third cut, memory cutting was again initiated, and shearer initiation of the shields commence when the shearer was past the 131 m mark towards the tailgate (of a 183-metre wide face). Many of the abutment pillar failures were accompanied by short-term reversal of ventilation, high dust levels and air blasts, some of which tumbled personnel.

Panel 7 had seven significant bumps in abutment pillars adjacent to the active longwall when the cover thickness was approximately 640 metres. The Magnitude events ranged from 2.8 to 4.0. The panel was stopped approximately 520 m from the recover room due to the number of bumps on the tailgate abutment pillars. Panel 8 had two significant bumps in abutment pillars adjacent to the active longwall when the cover thickness exceeded 580 m. The Magnitudes ranged from 2.8 to 3.0. There were several shearer-initiated bumps at the face. Panel 9 had one significant bump in an abutment pillar and several face bumps near the tailgate. The abutment pillar event registered a Magnitude of 4.3. Panel 10 had three significant bumps. These bumps occurred when the cover exceeded 488 m. The bumps occurred at a lower cover thickness than previously experienced, possibly due to the increased strength

SUMMARY

During the eight years that these bump events were occurring, geological/geotechnical characteristics of the strata and of the coal pillars were obtained. A number of methods to prevent or reduce the affect of the bumps were trialled.

- In-situ strength properties of floor, coal and roof strata were obtained (Zalanko, Rowell and Barczak, 1991).
- Lab testing of floor, coal and roof samples was conducted (Zalanko, Rowell and Barczak, 1991, Newman and Hoelle, 1993).
    - A systematic program of obtaining coal strengths for the four benches and the partings between these benches was conducted. The results of this program are discussed in reference 8.
    - Lab strength characteristics were obtained from roof strata samples from an in-mine exploratory drill program.
- Gate road pillar response was monitored using stress metres, extensometers and convergence stations (Zalanko, Rowell and Barczak, 1991). The results were somewhat inconclusive. Either the longwall moved around the area being monitored or the signal was lost from the monitors at the time data was most important.
- Shield leg pressures were monitored (Zalanko, Rowell and Barczak, 1991). Three sets (located near the headgate, middle of panel face and near the tailgate) were fitted with data loggers which recorded the hydraulic leg pressures. A precursor of impending bumps or high stress was not noted.
- Geologic mapping of thick sandstone layers was conducted by in-mine mapping and in-mine exploratory drilling.
- Potential high stress areas of high cover and adverse conditions due to over mining were flagged.
- Extensometer data obtained in the panel 5 of Group 3 indicated a yield zone on the periphery of the abutment pillars of up to 5 m (Zalanko, Rowell and Barczak, 1991)). Auger drilling conducted during the hydrofracturing process in the face in panels in Group 4 and 5 indicated that the stressed coal core was approximately 5 m from the face.
- Starting with some of the initial bumps, the mine obtained the Magnitude for each from seismic stations located at the University of Kentucky in Lexington and VPI in Blacksburg Virginia. The Magnitude for some of the major events is listed in Table 1.
- The US Bureau of Mines installed geophones in the head and tail gates starting in Panel 4 of Group 3 with the objective of determining if precursors of events could be obtained. An example of the number of events that were recorded in one of the panels (Group 4, panel 4) is shown in Figure 5. However, a definitive precursor was never determined (Coughlin and Rowell, 1993). Microseismics were recorded from mid 1989 until mid 1993.
- The size and configuration of the gate road pillars were adjusted several times.
- Water infusion ahead of the face did not appear to have an affect; possibly due to the water infusion having to occur well in advance of the longwall. There was no noticeable increase in water content when these areas were mined through.
- Hydro fracturing of the face was affective if done before the stresses built up
- Attempts to stop hanging roof over the shields were not successful
- Use of memory cut and shearer initiation of shields reduced personnel exposure

There was not a single cause for the bumps that occurred from 1989 to 1997. Almost all of the major bumps that occurred in Groups 3 and 4 occurred on the tailgate portion of the longwall panel. The major bumps that occurred in Group 5 were on the abutment pillars. The main causes appeared to be:

- Overburden thickness
- Thick strong sandstone as immediate roof, possibly creating hanging roof over gob
- A strong siltstone or sandstone present as the main roof, with a high elastic modulus or a high UCS value
- Thickness of the main roof
- Adverse over mining configuration
- Tailgate lagging behind headgate creating a stress point
- Rapid mining into the stressed panel core

Table 3 – Lab strength test results, in-mine exploration program

Panel	Strata type	Above seam m (ft)	UCS MPa (psi)	E GPa (psi x10^6)	RQD
5	siltstone	0.6- 4.9 (2 to 16)	53 (7,500)	11 (1.6)	78 -100
5	siltstone	0.6 – 4.9 (2 to 16)	35 (5,000)	6 (0.8)	78 -100
5	siltstone	0.6 – 4.9 (2 to 16)	93 (13,500)	21 (3.0)	78 -100
7	siltstone	0 – 6.1 (0 to 20)	105 (15,200)	1.9 (2.8)	76 -100
7	siltstone	0 – 6.1 (0 to 20)	138 (20,000)	24 (3.5)	76 -100
7	siltstone	0 - 6.1 (0 to 20)	144 (20,900)	22.8 (3.3)	76 -100
7	siltstone	0 -6.1 (0 to 20)	84 (12,200)	32.4 (4.7)	84 -100
7	siltstone	0 -6.1 (0 to 20)	70 (10,100)	15.9 (2.3)	84 -100
7	siltstone	0 -6.1 (0 to 20)	152 (22,000)	31.7 (4.6)	84 -100
10	sandstone	0 -6.1 (1 to 20)	89 (12,900)	15.9 (2.3)	67 -100
10	siltstone	0 – 1.5 (0 to 5)	132 (19,200)	26.9 (3.9)	62 - 85
10	sandstone	1.5 -6.1 (5 to 20)	114 (16,600)	22.0 (3.2)	50 -100
10	sandstone	1.5 -6.1 (5 to 20)	129 (18,700)	30 (4.3)	50 -100
10	sandstone	1.5 -6.1 (5 to 20)	123 (17,900)	28.3 (4.1)	50 -100
10	shale	2.1 – 5.8 (7 to 19)	177 (25,700)	31 (4.5)	52 -77
10	siltstone	0 -1.1 (0 - 4)	117 (16,900)	33 (4.8)	65

However, not all of the features listed above were required to create a bump situation. While a high cover thickness was a common feature, bumps occurred under thicknesses varying from 488 to 670 m. There were instances where a bump occurred unexpectedly since the cover height was less then what was anticipated to cause a bump. The mine was never able to totally eliminate the bumps, but a combination of gate road design, reducing the stressed face by hydro fracturing and limiting the exposure to personnel by memory cut and shield initiation by the shearer greatly reduced the affect on mining.

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