Mitigation of a Massive Sandstone Channel's Impact on a 1,500–Ft–Wide Longwall Face

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ABSTRACT

This paper presents the implementation and evaluation of the hydraulic fracturing technique and Longwall Visual Analysis (LVA) software to mitigate the impact of a 1,000-ft (305-meter) widemassive sandstone channel on a 1,500-ft-wide (457-m-wide) longwall face. Based on a underground roof geology reconnaissance program, four frac holes were drilled and fraced along the center axis of the sandstone channel. To further provide detailed monitoring of the longwall face, the Longwall Visual Analysis (LVA) software was installed to track the face pressure and cavity formation index. In mid-December 2011, the longwall face approached and entered into the western edge of the sandstone channel. The longwall face mined through the center axis of the sandstone channel in mid-January 2012 and advanced outby the eastern edge of the sandstone channel in early February 2012. Results from daily underground observations and production delay analysis confirmed the effectiveness of the hydraulic fracturing program and the validity of the LVA Software.

INTRODUCTION

A nearly 1000-ft wide sandstone channel was projected to run through the mid panel area of a 1,500 ft (457 m) wide longwall panel in a southwestern Pennsylvania coal mine. This sandstone channel was known to cause serious longwall face roof control problems in the mine's B-panel area in 1998 and 1999; and most recently, it induced many large face cavities and caused substantial production delay in the preceding panel. For the two B panels mined in 1998 and 1999, hydraulic fracturing of the massive sandstone was conducted to facilitate better caving, thus relieving cantilever compressive stress at the longwall face. Vastly improved longwall face condition was observed and four weeks of mining delay due to bad roof condition was eliminated. The implementation of hydraulic fracturing technique, results of underground observation and measurement, and results of numerical modeling were summarized in a paper presented in the 20th International Conference on Ground Control (Su et al., 2001).

This paper presents a summary of the activities that took place over a 4-month period (October 2011 through February 2012) at the CONSOL Energy longwall mine mentioned aboveto improve face condition and safety of underground personnel during mining of the 1,500 ft (457 m) wide longwall panel. The elevated concern for safety was driven by adverse face conditions encountered while mining the preceding longwall panel. Many of the problems were attributed to a thick and massive sandstone channel. A joint task force consisting of Coal Operations Engineering, Pennsylvania Operations Engineering, and CNX Gas personnel was formed in August 2011, which recommended drilling four hydraulic fracturing holes along the center axis of the sandstone channel to reduce pressure and improve face conditions at the 1,500 ft (457 m) wide longwall face. To further provide detailed monitoring of the longwall face and to evaluate the effectiveness of the hydraulic fracturing program, the Longwall Visual Analysis (LVA) software (Hoyer, 2011) was installed in early December 2011 to track the face pressure and cavity formation index along the longwall face.

In mid-December 2011, the 1,500 ft (457 m) wide longwall face entered the western edge of the nearly 1,000 ft (305 m) wide sandstone channel, and the face cleared the eastern edge of the sandstone channel on February 3, 2012. To evaluate the effectiveness of the hydraulic fracturing program and the validity of the LVA software, the Geomechanical Group of Coal Operations Engineering conducted daily face monitoring over a four-week period. The correlations among the observed face conditions, the hydraulic fracturing hole locations and LVA cavity formation prediction will be discussed in this paper.

GEOLOGIC RECONNAISSANCE, SANDSTONE CHANNEL AND GEOTECHNICAL EVALUATION

Upon encountering the massive sandstone channel in the preceding panel in February 2011, a detailed underground geologic mapping program and a detailed underground roof scoping program, which employed a 20 ft (6.1 m) long fiberscope, were initiated in the track entries of the preceding and the current1,500 ft (457 m) wide longwall face. In addition, a sandstone channel projection over the past and current mining areas was constructed from available surface core hole information. Figure 1 shows the projection of the massive sandstone channel (double red lines) over the preceding and current 1,500 ft (457m) wide longwall panels.

To determine the exact location of the sandstone channel and its properties, in-mine roof coring was also conducted by CONSOLCoal Operations Engineering's Geologic, Geomechanical

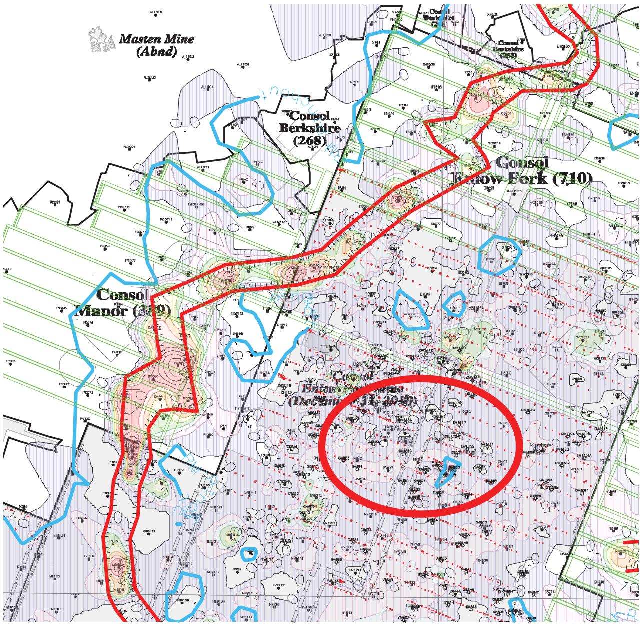

Figure 1. Projection ofmassive sandstone channel.

and Degas groups, which showed that the sandstone channel was nearly 1,000 ft (305 m) wide and more than 60 ft (18.3 m) thick, and the center axis of the sandstone channel is between crosscuts 30 and 29 (Figure 2). The extracted cores were logged and tested for uniaxial compressive strength. As expected, the cores from the center axis of the sandstone channel showed that the sandstone was rather massive and medium- to coarse-grained. Table 1 lists the mechanical properties of the sandstone, which are very similar to the strength results obtained in 1998 and 1999 (Su et al., 2001). Note that although the sandstone was not exceptionally strong (~8,000 psi (~55 MPa) compressive strength), it was medium-to-coarse grained and rather massive and possessed very high flexural rigidity due to its 60 feet (18.3 meters) thickness.

Based on the stress ellipsoid of 5,000 psi (34 MPa) East–West and 3,500 psi (24 MPa) North–South obtained from a prior stress measurement programusing the CSIRO MINIFRAC technique (Su and Hasenfus, 1995), under a cover depth of 700 ft (219 m), horizontal pancake fractures are expected at the selected hydraulic fracturing locations. Due to surface topography and property ownership constraints, four frac wells were planned along the center axis of the sandstone channel (Figure 3).

HYDRAULIC FRACTURINGOFTHE SANDSTONE CHANNEL

Mine management was very concerned over the face width because the 1,500 ft (457m) wide face possesses 400 ft (122 m) more mid-face area compared to the previously employed 1,100 ft (335 m) wide face. Also, due to a shield rotation program, 262 PM4 shields, which were designed for limestone geology and possessed low set load density, were employed at the 1,500 ft (457 m) wide face. As mentioned above, a joint task force consisting of Coal Operations Engineering and Pennsylvania Operations personnel recommended drilling four hydraulic fracturing (frac) holes along the center axis of the sandstone channel.

A drilling program was initiated in mid-October 2011 to drill four boreholes 300 ft (92 m) apart across the 1,500ft (457m) wide longwall panel (Figure 3). The boreholes were drilled from the surface to 5 ft (1.5 m) above the bottom of the sandstone channel. The drill holes were purposely stopped at 5 ft (1.5m) above the bottom of the sandstone channel to avoid penetrating the coal seam, which would then speed up the permitting process. After drilling and setting casing, perforations were shot into the casing at the targeted horizons to pre-fracture the sandstone. The perforation tool was about 4 ft (1.22 m) long and had 4 shot per foot (0.3 m). The estimated shot penetration into the borehole surface was about 26 to 30 inches (0.66 to 0.76 m).Water fracing, as opposed to the nitrogen foam fracing used in 1998, was employed, since enough surface area was present for the water trucks. During the 1998 fracing operations, very limited surface area was present which led to the choice of the more expensive and dangerous nitrogen foam fracing.

The four holes were successfully fraced on November 13 and 14, 2011. Two-stage hydraulic fracturing was conducted in Hole #1, located about 300 ft (92 m) from the tailgate, at 24 and 42 ft (7.3 and 12.8 m) above the bottom of the sandstone channel (Figure 4). Note that the intended frac horizons were initially set at 15 and 30 feet (4.6 and 9.2 m) above the bottom of the sandstone channel. However, due to a 10 ft (3.1 m) discrepancy in measuring the hole depth where the driller measured hole depth from their drill platform instead of the ground surface, the boreholes were actually stopped at approximately 15 ft (4.57 m) above the bottom of the sandstone channel. Similar hole depth measuring discrepancy also occurred at Hole #2. To reduce water usage, one-stage hydraulic fracturing was conducted in Hole #2 at 28 ft (8.5 m) above the bottom of the sandstone, in Hole #3 at 15 ft (4.57 m) above the bottom of the sandstone, and in Hole #4 at 14 ft (4.27 m) above the bottom of the sandstone. The average fracture initiation pressure was about 5,000 psi (34.5 MPa). The average shut-in pressure was about 500 psi (3.45 MPa), indicating the creation of horizontal pancake fractures (Figure 5). Also, the bottom hole frac gradient was large than 1.0, typically indicating the creation of horizontal pancake fractures. The estimated horizontal pancake fracture ellipsoid in each hole was about 250 ft (76.2 m) in the E–W direction and 150 ft (45.7 m) in the N–S direction. The pancake fracture ellipsoid was estimated based on the amount of water used, which averaged about 4,200 gallons per frac initiation and propagation. Well perforations and hydraulic fracturing were conducted by Weatherford and Superior Well Services, respectively. The project was conducted under the supervision of CONSOL PA Operations Engineering and CNX Gas.

FACE MONITORINGAND EVALUATION

To further provide detailed monitoring of the longwall face and to enable the prediction of excessive face pressure and cavity formation, the Longwall Visual Analysis (LVA) software was installed in early December 2011 to track the face pressure and cavity formation index.The LVA software has been used successfully in Australian coal mines to predict roof weighting and longwall face cavity formation over the past few years (Hoyer, 2011). In mid-December 2011, the 1,500 ft (457 m) wide longwall face entered the western edge of the nearly 1,000 ft (305 m) wide sandstone channel, and the longwall face cleared the eastern edge of the sandstone channel on February 3, 2012.

Table 1. Test results from in-mine core samples.

Sample (#)	Rock Type: Sandstone / Coal	Distance Below / Above BOC / TOC (ft)	Axial Tests Estimated Avg. Uniaxial Compressive Strength (psi)	Diametral Tests Estimated Avg. Uniaxial Compressive Strength (psi)
R24	SS GRY	51.9	8,900	4,600
R23	SS GRY	51.8	6,500	2,400
R22	SS GRY	45.9	10,800	7,200
R21	SS GRY	45.8	10,600	7,800
R20	SS GRY	41.8	11,100	5,400
R19	SS GRY FGR MIC STK	41.7	13,800	3,600
R18	SS GRY	37.8	9,700	5,600
R17	SS GRY	37.7	8,500	5,200
R16	SS GRY FGR MIC STK	33.8	11,000	1,400
R15	SS GRY FGR MIC STK	33.7	8,400	1,000
R14	SS GRY	29.5	8,500	5,800
R13	SS GRY	29.4	9,000	5,000
R12	SS GRY	24.4	6,000	4,800
R11	SS GRY	24.3	8,000	5,200
R10	SS GRY	19.9	8,000	5,000
R9	SS GRY	19.8	4,600	5,000
R8	SS GRY	15.9	3,900	5,100
R7	SS GRY	15.8	5,400	5,300
R6	SS GRY	11.1	7,000	5,400
R5	SS GRY	11.0	6,400	5,000
R4	SS GRY	7.6	8,400	3,500
R3	SS GRY	7.5	6,600	1,900
R2	SS GRY MGR FEW MIC STK WBD	3.6	9,700	6,800
R1	SS GRY MGR FEW MIC STK WBD	3.5	8,000	10,500
P8 COAL				
		Sandstone Average	8,283	4,938
		Sandstone Maximum	13,800	10,500
		Sandstone Minimum	3,900	1,000

To evaluate the effectiveness of the hydraulic fracturing program and the validity of LVA software, with assistance from CONSOL Energy's I.E. Group, the Geomechanical Group of Coal Operations Engineering conducted daily face monitoring over a 4-week period. The correlations among the observed face conditions, the hydraulic fracturing hole locations and the LVA cavity formation prediction were recorded daily and are shown in the attached map (Figure 6). Note that the red shaded areas show the locations of the large-chunk sandstone falls at the face, while the brown shaded areas show the locations of the roof coal pot out without sandstone failure. Clearly, Figure 6 indicates that there is a strong correlation between the hydraulic fracturing hole locations and the locations of the large-chunk sandstone falls at the face. Prior to entering into the influence zones of the four frac ellipsoids, severe face pot outs and sandstone failure were present at the 1,500 ft (457 m) wide longwall face, which caused about one week of face downtime in late December 2011. Once the longwall face entered the influence zones of the four frac ellipsoids, roof conditions along the 1,500 ft (457 m) wide longwall face improved considerably.However, face pot outs and minor sandstone failure were still present along the gaps between the frac ellipsoids.

Figure 6 also illustrates that there is a very strong correlation between the LVA cavity index and the observed sandstone falls at the 1,500 ft (457m) wide face.It is important to note that, while the standard LVA cavity index warning is preset at 80%, due to the large tip-to-face distance and low set load density employed by the PM4 shields, the LVA cavity index warning was reset to 40%

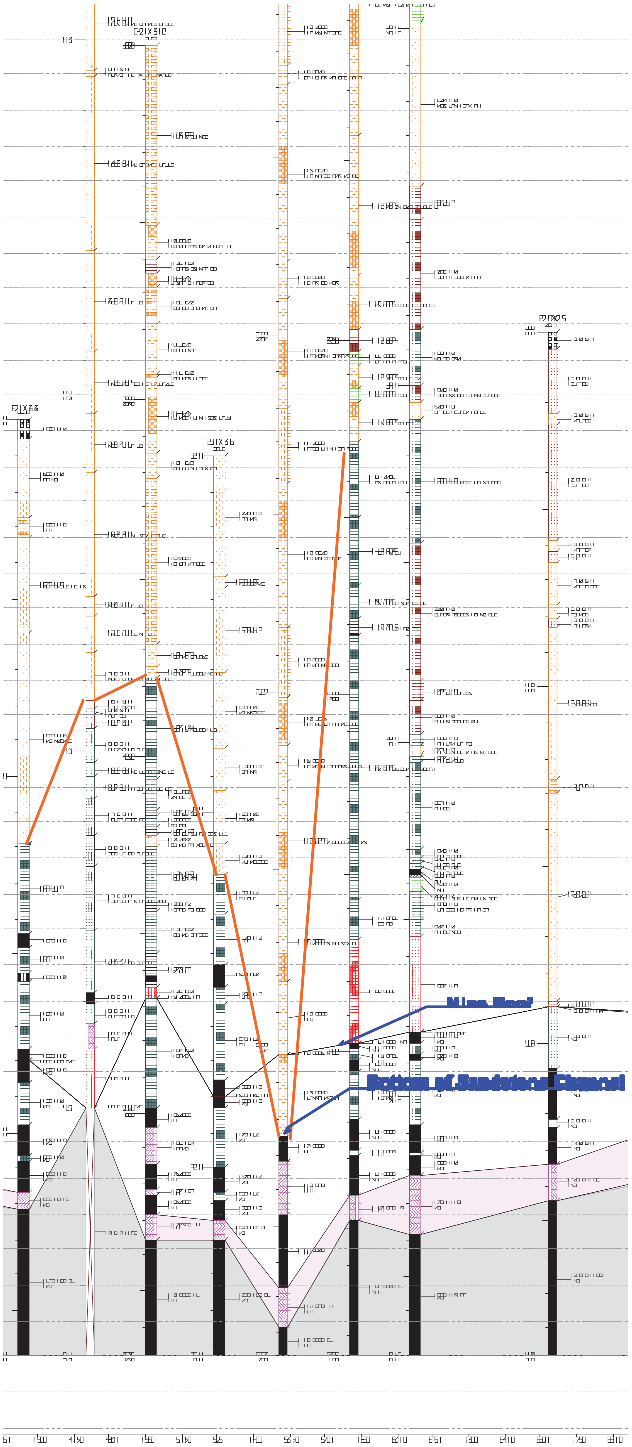

Figure 2. Cross-section of in-mine core and scope holes.

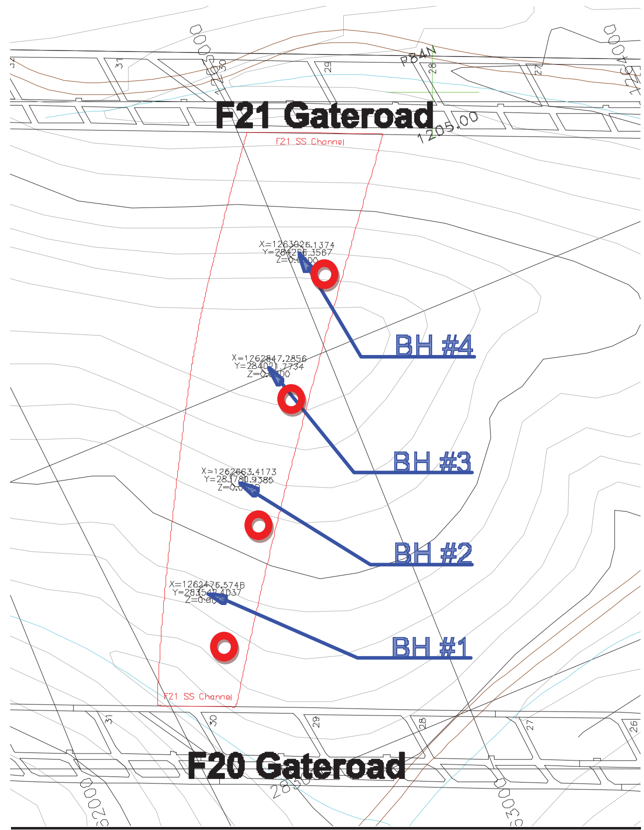

Figure 3. Location of boreholes over the 1,500-ft-wide longwall panel.

for this PM4 face. With this lower cavity index warning, Figure 6 shows that the correlation between the LVA 40% cavity index and the sandstone falls at the 1,500 ft (457 m) wide face is about 80%. After observing the strong correlation and gaining confidence, the LVA information was used by the Mine Longwall Coordinator to successfully guide the longwall face crew to institute double-pull behind the shearer drum to reduce the tip-to-face distance at the critical spots along the longwall face.

CONCLUSIONS

This paper presents the successful implementations of the hydraulic fracturing technique and LVA software to mitigate the impact of a 1,000 ft (305 m) wide massive sandstone channel on a 1,500 ft (457 m) wide longwall face.Based on the results of a month-long monitoring shown in Figure 6, it is apparent that three additional frac holes may be needed to fill the gaps. Alternatively, more water could be pumped into each frac hole to propagate the individual horizontal pancake fractures to enable them to overlap one another. Pumping more water in each frac hole would be much cheaper than drilling three additional frac holes. Sandstone fracing over the next panel, which is scheduled to start on August 15, will adopt the more cost effective method by pumping more water to propagate the pancake fracture in each hole.

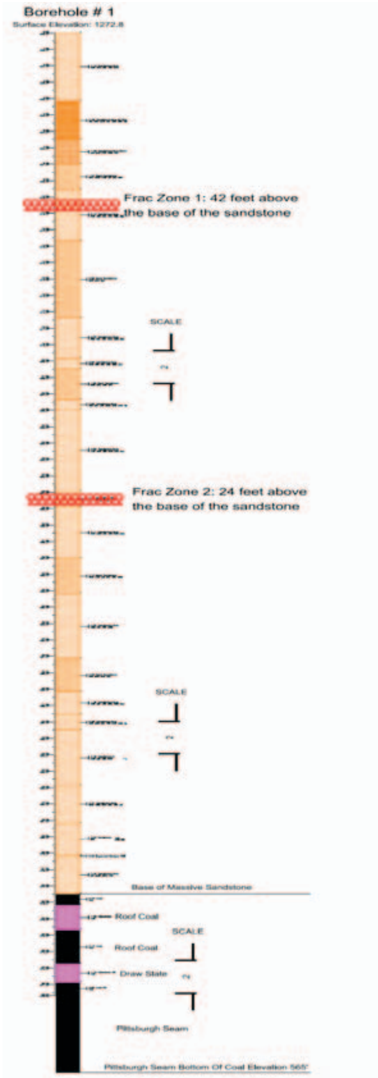

Figure 4. Schematic showing the frac horizons in the sandstone for borehole #1.

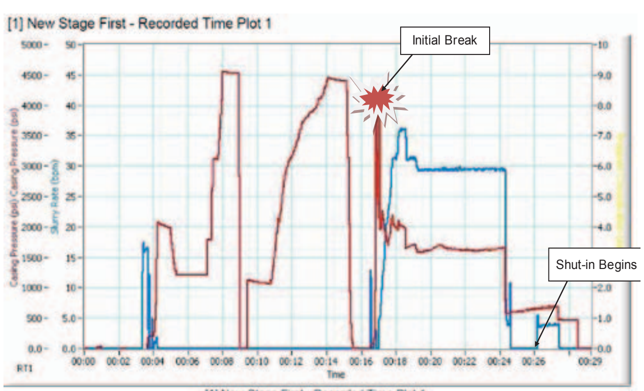

Figure 5. Graph of pressure and water injection rate vs. time for borehole #1, frac 1.

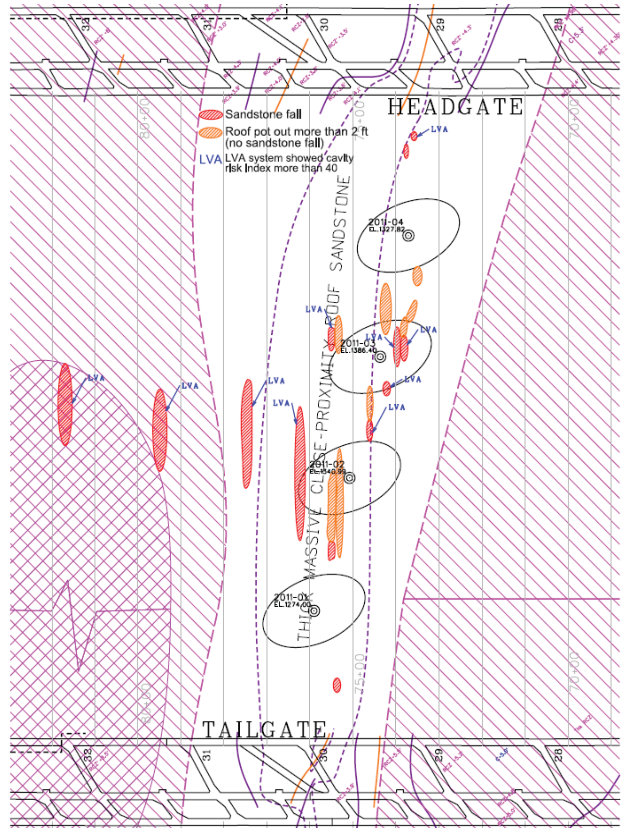

Figure 6. Correlation among the observed face conditions, the hydraulic fracturing hole locations, and LVA cavity formation prediction.

As stated before, the primary purpose of the hydraulic fracturing program is to improve safety for CONSOL underground personnel, since large chunks of sandstone laying on the face conveyor creates tremendous safety hazards. In the end, the hydraulic fracturing program and the application of LVA software have achieved their intended goals of improving safety and increasing productivity at the 1500 ft (457 m) wide longwall face.

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