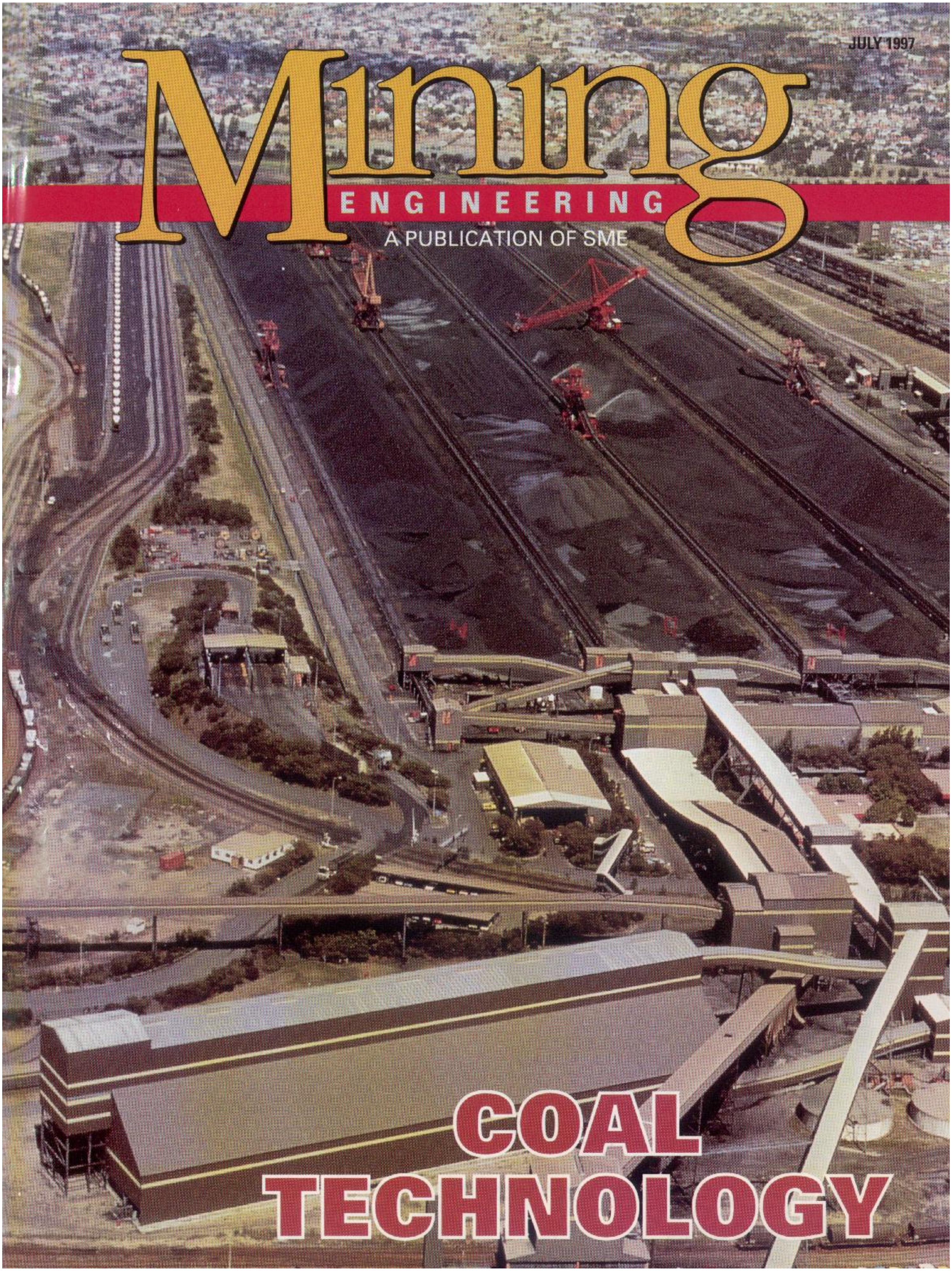
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Dealing with coal bursts at Deer Creek

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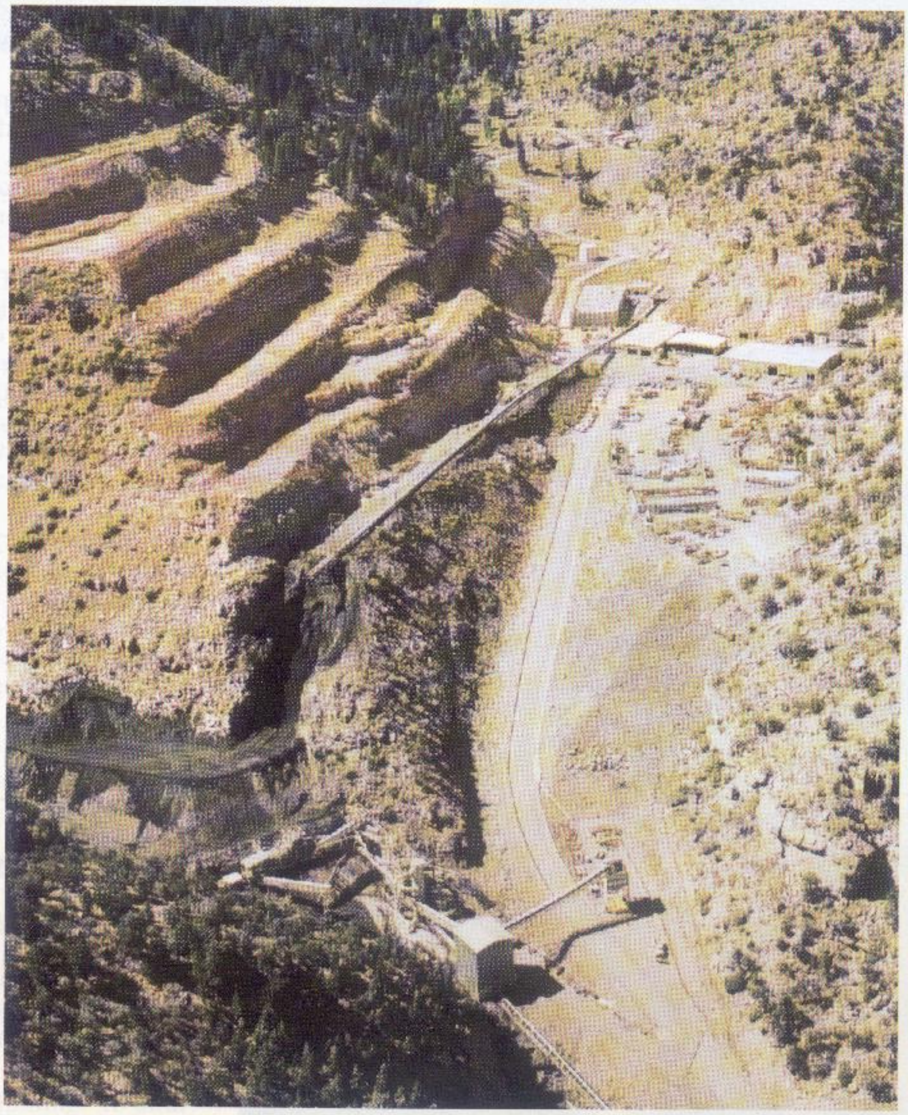

Aerial view of Energy West's Deer Creek coal mine in Utah's Wasatch Plateau. The introduction of a two-gate entry system at the mine has been a major factor in minimizing gate pillar coal burts.

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Energy West Mining operates the Deer Creek and Cottonwood/Trail Mountain coal mines in the Wasatch Plateau about 40 km (25 miles) southwest of Price, UT. The Deer Creek Mine extracts the Upper Blind Canyon seam and the Cottonwood/Trail Mountain Mine extracts the Hiawatha seam 12 to 36 m (40 to 120 ft) below. Both seams average about 2.8 m (9 ft) in thickness. Cover depths exceed 550 m (1,800 ft) in a large portion of the unmined reserve.

Stability problems at Deer Creek are mostly due to coal bursts caused by high stresses associated with deep cover and sandstone channels. Most of the bursts have occurred in gate pillars and, to a lesser extent, at the longwall face and during development.

The introduction of a two-entry gateroad system with 9-m- (30-ft-) wide yield pillars has been a major factor in controlling and minimizing gate pillar

Table 1

Material properties for major geologic units*.

Geologic unit	Uniaxial compressive strength (MPa)	Young's Modulus (GPa)
North Horn, Price River, Blackhawk Formations	106	31.0
Castlegate sandstone, Star Point sandstone	169	40.7
Mancos shale	71	15.2
Blind Canyon coal seam**	37	5.3

*after Jones et al., 1988.
**after J.F.T. Agapito and Associates Inc., 1993.

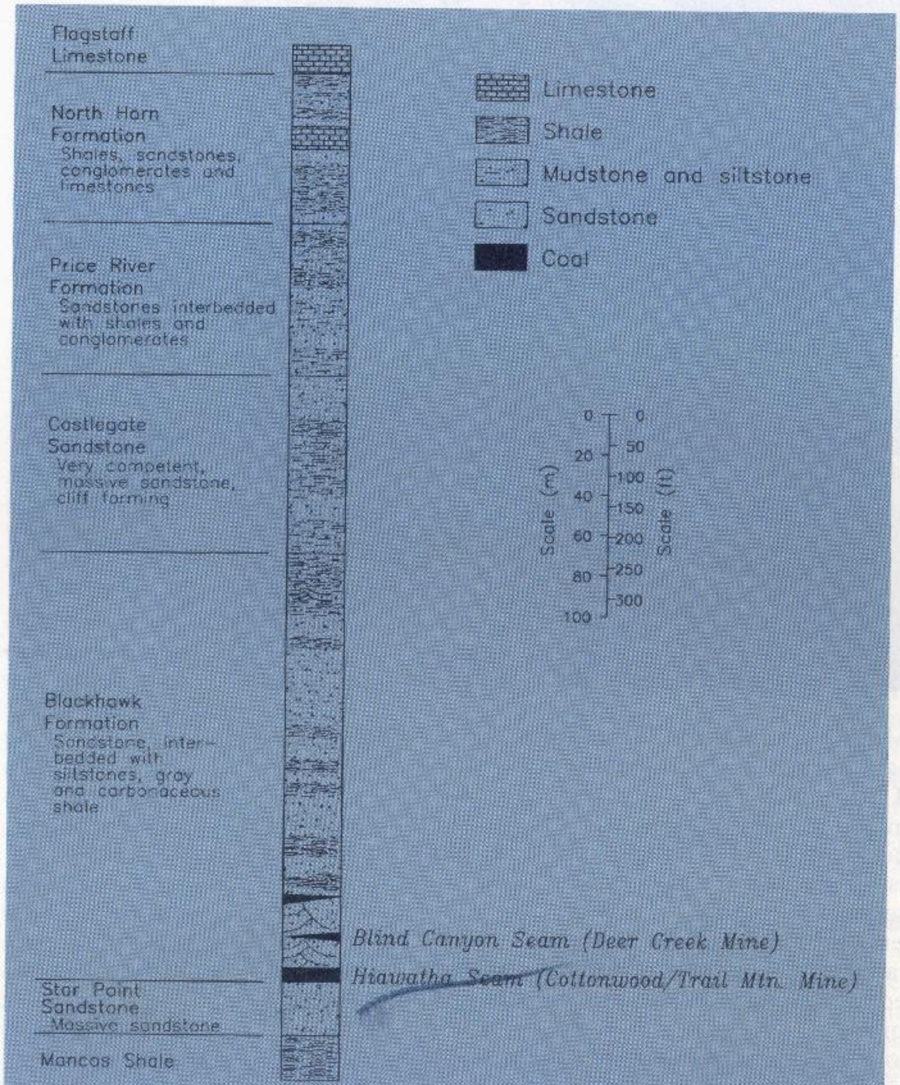
bursts (Agapito et al., 1988). However, some bursting began to occur in the 9-m- (30-ft-) wide pillars as cover depths reached 550 to 610 m (1,800 to 2,000 ft). This was due to more rapid and higher abutment loading in areas with very strong roof and stiff floor.

Associated with the gate pillar bursts at depth and more difficult to deal with has been face bursting. Experience at Deer Creek indicates that face bursts occur at depth and mostly near the tailgate when mining the third longwall in a series of panels. Face bursts decrease significantly during mining of the fourth longwall. It is believed that the bursts are due to an increase in side abutment stresses caused by a widening of pressure arching formed by the interlocking and bridging of blocks of very competent strata.

Computer-aided back analyses were used to investigate the stresses associated with numerous face bursts that occurred while mining a third longwall in a panel section at depths of 610 m (2,000 ft).

FIG. 1

Generalized stratigraphic column.



Burst-prone geology

The coal seams mined by Energy West occur at the base of the Blackhawk Formation in the Mesaverde Group of the Cretaceous Period. Figure 1 shows the location of the seams in a generalized stratigraphic column.

The overburden contains numerous sandstone beds, some of which are thick and competent. The 60-m- (200-ft-) thick Castlegate Sandstone lies 275 m (900 ft) above the mine. It forms the vertical escarpments seen on the surface along the perimeter of the plateaus. Uniaxial compressive strength tests of this sandstone showed values as high as 169 MPa (24,500 psi) (Jones et al., 1990). The topography is rugged with sharp elevation differences between the plateau tops and valley streams.

The tendency for wide arch formation in the strong sandstones is shown in Fig. 2. This arch is at least 120-m- (400-ft-) wide and was formed in the Star Point Sandstone below the coal seams. Wider arches probably form in the Castlegate sandstone under confined overburden conditions.

The Deer Creek Mine is located on the flanks of a northeast-southwest trending syncline in a nearly flat-lying seam area with dips of only 2° to 3°. A few north-south trending faults cut through the property. The major joint system reflects this orientation. A complex fault system, the Roan's Canyon fault, separates the existing mine from most of the coal reserve to the north and is adjacent to the study area. This fault system is oriented northeast-southwest. It is a major structural feature associated with large water inflows and difficult ground conditions.

Many areas of the mine have characteristic burst-prone geology:

- Very competent immediate roof and floor sandstone/siltstone that load the coal and resist breakage.
- Numerous sandstone channels

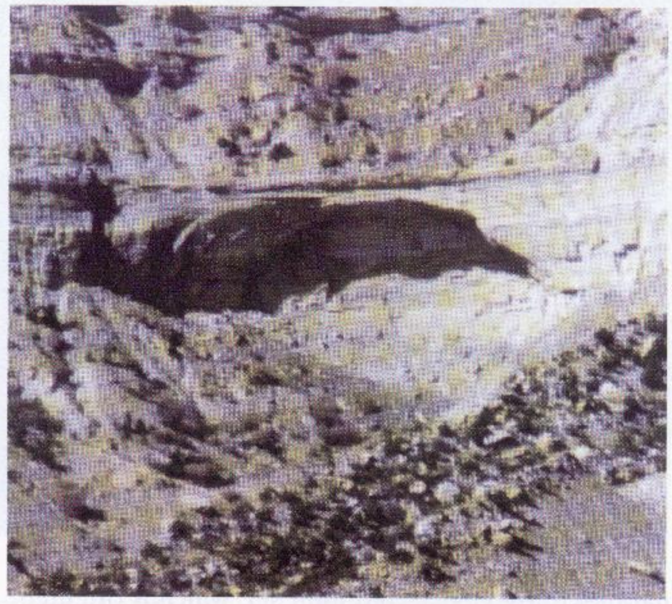
Table 2

Input parameters for stress analysis.

Young's Modulus of roof (GPa)	27.6
Poisson's ratio of roof	0.15
Young's Modulus of coal (GPa)	1.4
Peak strength of unconfined coal (ribs) and 9-m-wide pillars (MPa)	27.6
Residual strength of 9-m-wide pillars (MPa)	4.8
Post-peak strength modulus of 9-m-wide pillars (MPa)	-0.7
Specific weight of overburden (kg/m^3)	2,435
Depth of cover (m)	518 to 670
Seam height (m)	2.4

FIG. 2

A 120-m- (400-ft-) wide arch in the Star Point sandstone.



that cause high stress concentrations.

- Strong, brittle coal that absorbs high stresses and then tends to fail suddenly.
- Thick, competent overburden strata that tend to bridge and interlock creating high abutment stresses.
- Deep cover.

In some areas of the mine, the immediate roof and floor are formed by soft shales and sandstones. This presents a different set of ground problems. Many roof falls have been caused by soft carbonaceous mudstone roof often associated with poor consolidation and water at channel margins. Soft shales are also encountered in the floor but this can often be beneficial for reducing burst potential by allowing strain and stress relief.

Table 1 shows laboratory uniaxial compressive strength and Young's modulus values for the major geologic units and for the Blind Canyon seam coal.

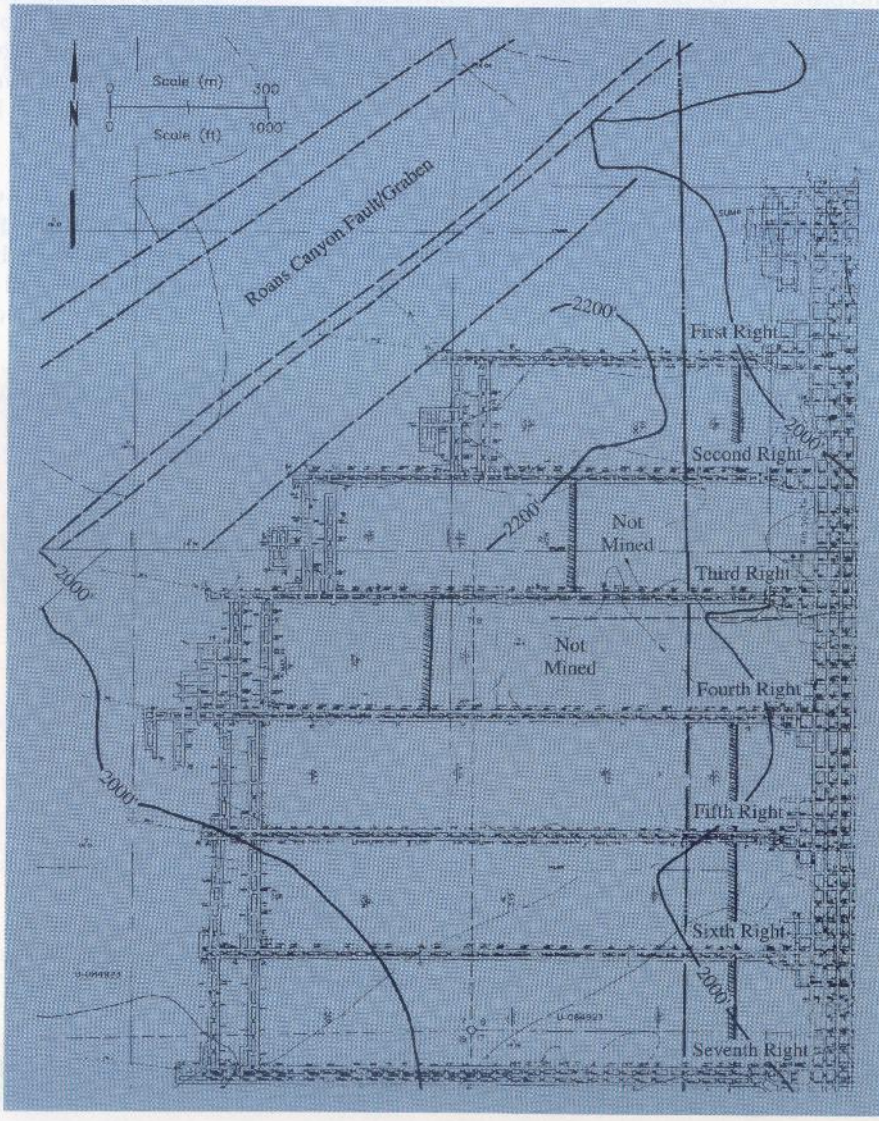
Difficult ground conditions in the study area

The longwalls investigated in this study area are located in the Fourth South block, an area near the Roan's Canyon fault (Fig. 3). Complex and adverse geologic conditions were encountered during development and mining. In addition to deep cover exceeding 610 m (2,000 ft), the immediate roof was formed by widespread sandstone channels and by thinly laminated carbonaceous shales, mudstones and rider seams. Large volumes of water were encountered when fracture systems connected to the Roan's Canyon fault were intercepted. Inflows of 9,500 L/m (2,500 gpm) were measured. This was probably a record from a single source for the Wasatch Plateau mines.

Longwall faces were oriented

FIG. 3

Fourth South panel area.



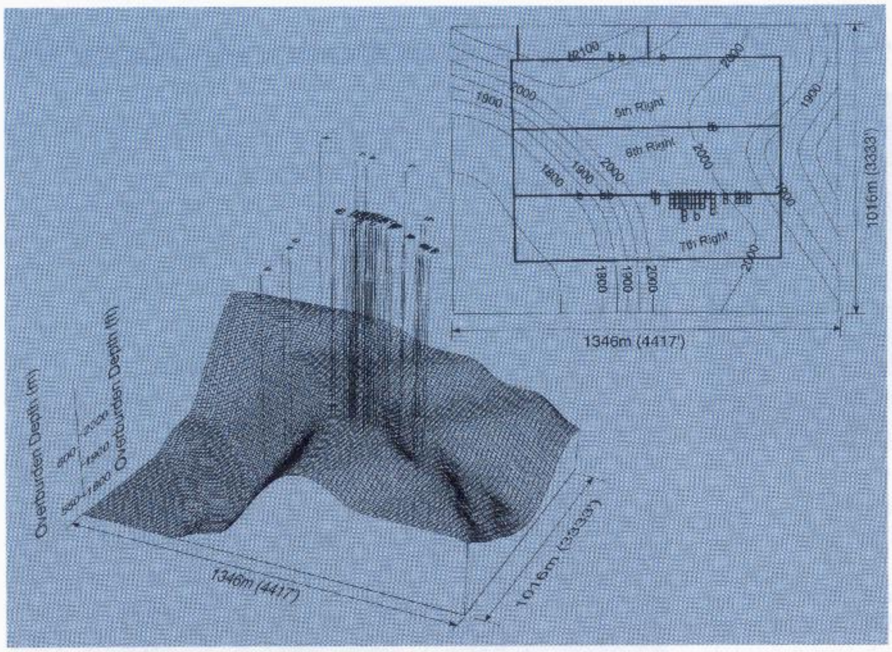


FIG. 4

Burst location in relation to cover depth.

parallel to the major roof joint set, which is oriented about at north 5° west and has an average 2.4 m (8 ft) spacing. This orientation was adopted to facilitate caving and reduce burst potential. Figure 3 shows the longwall layout in the Fourth South. Large channel scours reduced the coal seam height significantly. This prevented mining of a large area in the Third and Fourth Right longwalls and hindered caving development. Fifth Right was the first longwall in the block to attain the planned length of 915 m (3,000 ft).

Face bursts in seventh right longwall

Several bursts happened during development and mining of the Fourth South block before mining the Seventh Right longwall. Two chain pillar bursts occurred during bleeder development, completely filling the entries. One of these bursts registered a 3.2-Ritcher magnitude at the University of Utah seismograph. However, consistent and numerous face bursts occurred only in the Seventh Right longwall.

The location of the bursts in relation to the cover depth is shown in Fig. 4 and the roof geology and burst location in the Fourth to Seventh Right longwalls is shown in Fig. 5. Longwall faces were 225-m- (740-ft-) wide. The gates were developed with 6-m- (20-ft)-wide entries and 9-m-wide x 24-m-long (30- x 80-ft) pillars.

Consistent face bursting began after the Seventh Right longwall had retreated 457 m (1,500 ft) and the cover depth had increased to 610 m (2,000 ft). Most of the face bursts occurred along a 60-m (200-ft) length

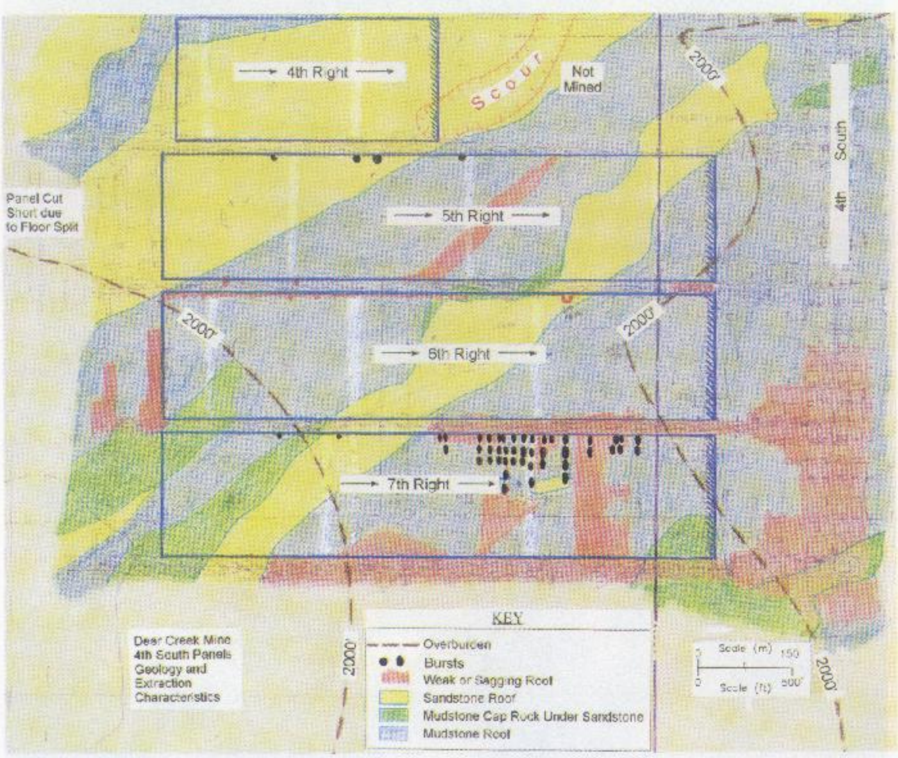


FIG. 5

Roof geology and burst.

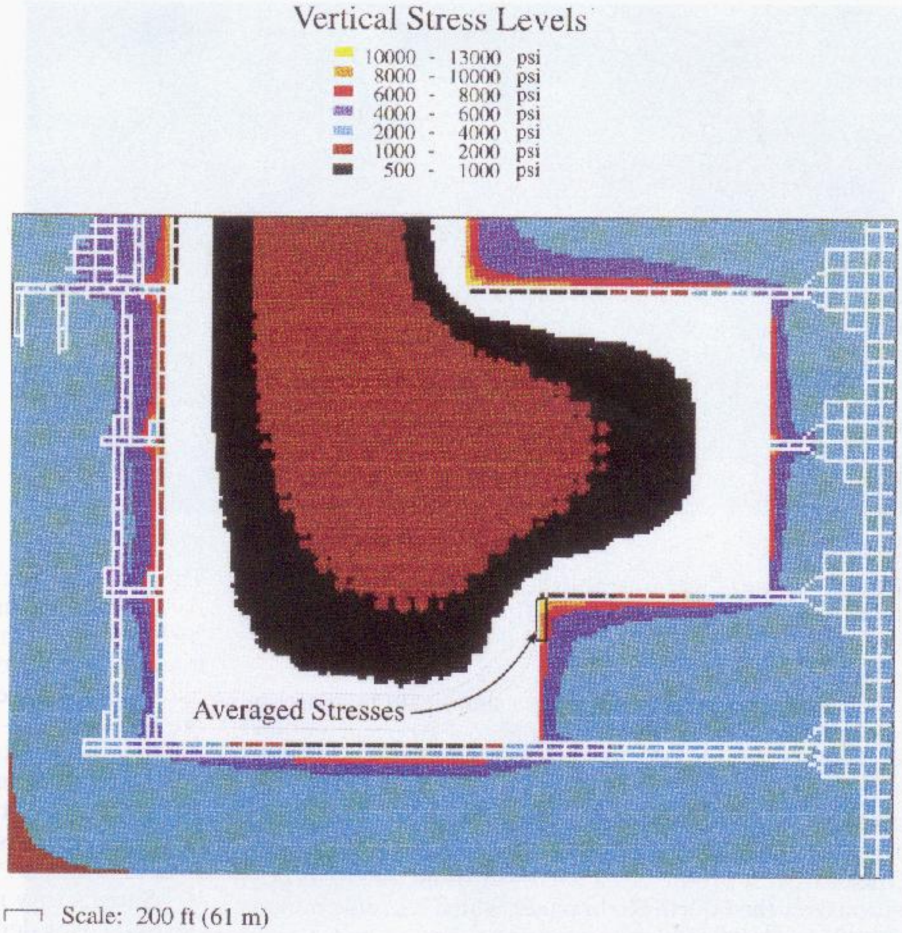


FIG. 6

Vertical stress distribution for 579-m (1,900-ft) face position at the Seventh Right longwall.

from the tailgate. There were no tailgate pillar bursts and yielding proceeded in three to four pillars ahead of the face. Mined-out panel width was 515 m (1,690 ft) from the fifth to seventh tailgate.

Back-analysis of stresses

Stresses were calculated with the quasi three-dimensional computer code EXPAREA (St. John, 1978). This code uses the displacement-discontinuity technique for modeling excavations of large, tabular, seam-type deposits. It incorporates linear elastic, elastic-plastic, elastic-strain softening (yield) and bilinear-backfill constitutive models for representation of confined coal, gateroad pillars, rib and gob.

EXPAREA capabilities have been improved during the last 17 years by Agapito Associates. The code has been used in many different types of mines. Previous work at Deer Creek provided an opportunity for model verification with stress analysis results comparing closely to stress measurements (Agapito et al., 1988). In this study, model calibration was made through observation of gate pillar yielding ahead of the face.

Vertical stresses were calculated for five face positions in Sixth and Seventh Right at 244, 320, 442, 579 and 670 m (800, 1,050, 1,450, 1,900 and 2,200 ft) from the starting room, respectively. Table 2 summarizes the input parameters used in the analyses.

Plan view, color-coded stress distributions were obtained for each face position for the 579 m (1900 ft) face position at Seventh Right longwall (Fig. 5). Stresses were calculated at 6-m (20-ft) spacings, the element size. The abutment locations are seen, including pillar yield ahead of the face. The tailgate face area is an obvious abutment.

For a more detailed evaluation of face burst-prone stress, the average stresses were calculated in a 60-m-long x 12-m-wide (200- x 40-ft) area near the tailgate (Fig. 6). Most of the bursts occurred in this area.

Figure 7 shows the relation between the stresses on the 60- x 12-m (200- x 40-ft) area and the five face positions for the Sixth (second panel) and Seventh Right panels (third panel). The cover depth is also shown at each face position.

The results indicate how cover depth and gob width influenced stresses on the face. In the first two face positions, stresses are higher for the Sixth Right than Seventh Right because of higher cover depths of 55 and 34 m (182 and 111 ft), respectively. In the third and fourth face positions, cover depths are nearly equal with differences of only 3 and 10 m (10 and 34 ft), respectively.

The influence of gob width on the stresses is seen with burst-prone stress levels of 59 MPa (8,500 psi) in Seventh Right. Bursting stopped just before the last face position at stress levels just below 59 MPa (8,500 psi). The Seventh Right panel was 14 m (45 ft) deeper than the Sixth Right panel at this position.

Subsidence measurements

Aerial photogrammetric surveys with annual helicopter reconnaissance flights are used to measure and monitor surface subsidence at the Energy West Mines. Reading points were established generally on a 61-m

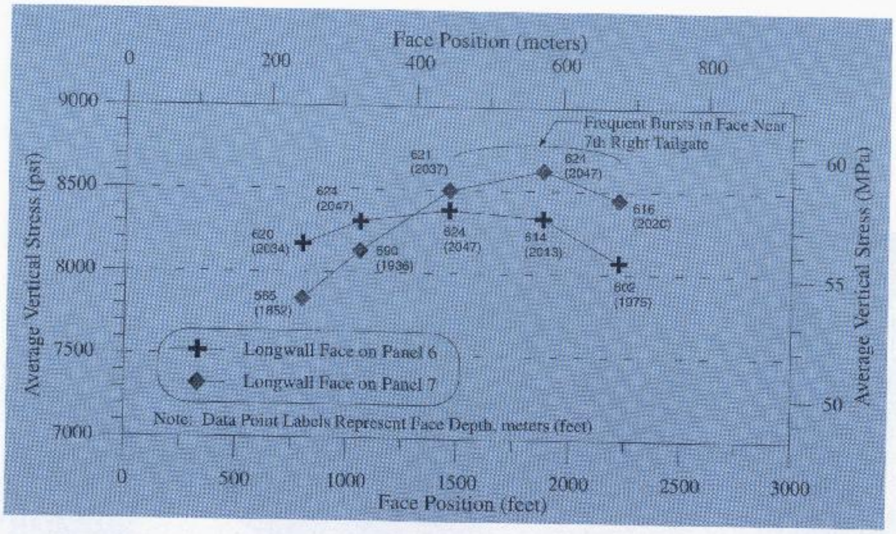


FIG. 7

Relation between stresses on a 60-m-long x 12-m-wide (200- x 40-ft) face area, depth and face position.

Reading points were established generally on a 61-m (200-ft) grid. Two profiles, north-south and east-west, were established over the Second through Seventh Right panels.

Measurements indicate that a significant increase in subsidence from about 1 to 2 m (3 to 7 ft) occurred between the 1991 and 1992 surveys when the Seventh Right panel was mined. Figure 8 shows the north-south and east-west profiles. The north-south profile shows a wide basin with 2 to 2.4 m (7 to 8 ft) vertical subsidence. The east-west profile has a narrower basin due to its position over the Fourth Right panel, which was only mined for 427 m (1,400 ft) due to scouring.

Critical widths probably were reached with a subsidence factor of about 0.8 (ratio of maximum vertical subsidence to mining height) when the width and length of the gob were about equal to the cover depth. A critical subsidence width is usually defined as the width of a mined area required to cause the maximum possible subsidence of one point in the surface. A supercritical width occurs when more than one point at the surface reaches maximum subsidence. Supercritical widths were reached in the north-south line due to the flat bottom profile. Subsidence has been stable since 1992. Figure 8 also shows a plan view of the subsidence zone from the 1995 survey — a broad trough running in a north-south direction.

It is possible that arching in the subsiding strata and the abutment at the face were reduced once the critical width was reached. Unfortunately, mining in the area stopped with the Seventh Right (third completely extracted longwall). However, the subsidence behavior in this area seems to support experience from other areas of the mine of improved ground conditions when a fourth longwall was mined.

Need to minimize side abutments at depth

Increasing the panel widths from 225 to 260 or 275 m (740 to 850 or 900 ft) may allow critical widths to be reached after mining the second longwall. The time needed to attain critical width would be reduced, as well as the pressure arching time. The tailgate/face abutment loading in the second longwall may be reduced and spread over a larger area further along the face causing lower stresses.

Longwall widths have been increasing with time. This allows higher production and resource recoveries. Average widths increased from 213 m (698 ft) in 1991 to 246 m (808 ft) in 1996. Presently, there are about 10 longwalls with 305 m (1,000 ft) or wider faces.

High capital expenditures are needed for increasing the face width — not only for longwall equipment, but also for belts and other haulage equipment, ventilation, etc. Such changes need careful planning and engineering, particularly the assessment of geologic impacts on stability in mines with complex geology, such as Deer Creek.

Satisfactory mitigation of higher gate/face stresses beyond cover depths of 610 to 670 m (2,000 to 2,200 ft) may be difficult without barrier pillars between panels to minimize the side abutments.

Destressing may also minimize side abutment stresses at the face. But these techniques have been applied in only a limited number of cases. They have not yet demonstrated satisfactory results under continuous operating conditions. A problem is that destressing techniques can hinder operations and can be hazardous if not properly implemented. For example, the use of destressing in the Price area mines has been limited to the Castlegate No. 3 Mine where it was applied unsuccessfully. It was deemed hazardous by miners who tried it, due to bursts induced by drilling.

Conclusions

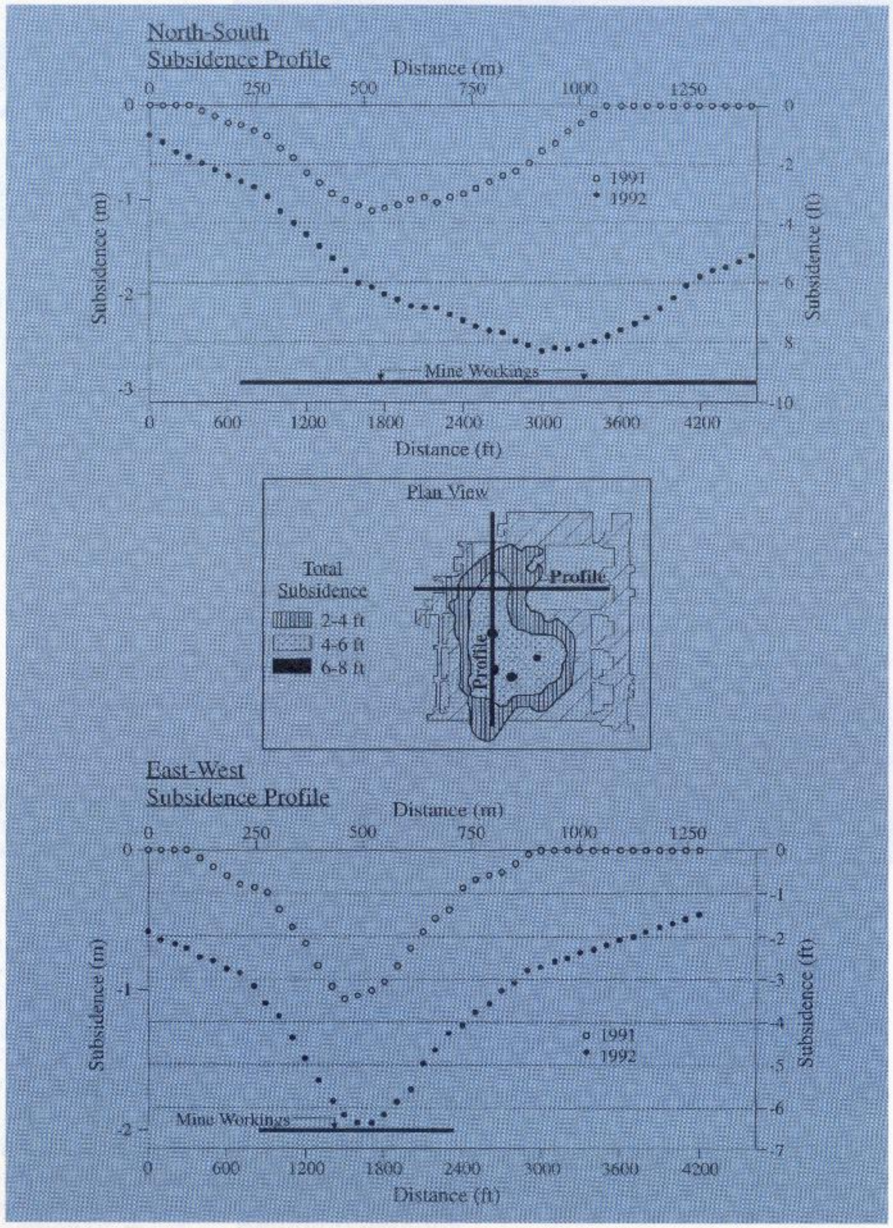
High stresses associated with deep cover and sandstone channels have caused severe burst problems at the Deer Creek Mine. The geology is burst-prone with very competent roof and floor siltstones and sandstones in many areas, numerous sandstone channels, strong and brittle coal and thick, competent overburden strata.

Bursts have occurred mostly in gate pillars and, to a lesser extent, in the longwall faces. The use of a two-entry gateroad system has helped reduce the number of bursts. However, burst frequency began to increase as cover depths reached 550 to 610 m (1,800 to 2,000 ft), especially at the face. These bursts are more difficult to mitigate than gate-pillar bursts. They hinder operations to a greater extent and occur in an area where more people may be exposed.

Face burst events and severity usually increase when mining the third longwall in a series of panels. The mechanism causing the increase in bursts is due to pres-

FIG. 8

Subsidence profiles and location.



sure arching formed by the interlocking of large blocks of competent subsiding strata. The 60-m- (200-ft-) thick Castlegate sandstone probably plays an important role in the bridging of the strata due to its high strength and large structural block characteristics.

Ground conditions in the Fourth South longwall area, near the Roan's Canyon fault, were the most difficult so far experienced at the Deer Creek Mine.

Consistent face bursting began in the Seventh Right longwall, the third completely recovered panel in the Fourth South block. This occurred when the face had retreated 457 m (1,500 ft) and cover depth was about 610 m (2,000 ft). Most of the bursts occurred in the 60-m (200-ft) length near the tailgate. There were no tailgate pillar bursts and pillar yielding was "smooth," proceeding in three to four pillars ahead of the face.

A back-analysis calibrated with the gate pillar yielding was conducted to evaluate the burst-prone stresses in a 60-m-long x 12-m-wide area (40- x 200-ft) area at the face. The results showed how depth and gob width (abutment) influenced the stress levels in the bursting zone. Although cover depths were about equal for the Sixth and Seventh Right longwalls (the Second and Third panels), the stress levels in the Seventh Right longwall increased above the Sixth Right longwall. This was due to the increasing gob width (arching) triggering numerous bursts.

Surface subsidence measurements indicated that critical widths were reached after mining the Seventh Right longwall with a subsidence factor of 0.8 when the gob width and length were about equal to the cover depth. It is possible that arching in the subsiding strata may be reduced once the critical subsidence width is reached. Experience in other areas of the mine indicates that this may be the case.

Increasing face widths from 225 to 260 or 275 m (740 to 850 or 900 ft) may reduce the impact of the gob abutment by reducing the time needed to achieve critical subsidence from the second to the third longwall. Wider longwall faces, however, increase the chance of sandstone channel interception often associated with bursts.

Satisfactory mitigation of higher tailgate/face stresses beyond cover depths of 610 to 670 m (2,000 to 2,200 ft) may be difficult without barrier pillars between panels to minimize the side abutments. Destressing may mitigate high stresses at the face. However, these techniques need further development before they can be routinely adopted. ■

Acknowledgments

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References

Agapito, J.F.T., Maleki, H.N., and Moon, M., 1988, "Two-entry longwall gate road experience in a burst-prone mine," American Mining Congress, Mine-Expo International 88, Vol. 2, p. 271-292.

Jones, R.E., et al., 1990, "Sandstone escarpment stability in vicinity of longwall mining operations," *Rock Mechanics Contributions and Challenges*, Hustrulid and Johnson, eds., Balkema, Rotterdam, p. 555-562.

McGunegle, B.F., 1993, "Coal core testing," J. F. T. Agapito and Associates Inc., report to Interwest Mining Inc., July.

St. John, C.M., 1978, "Program EXPAREA — A computer program for analysis of test scale underground excavations for disposal of radioactive waste in bedded salt deposits," ORNL Sub 7118/2, Oak Ridge National Laboratories, April.