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REPORT OF INVESTIGATIONS/1995

Evaluation of an Alternative Longwall Gate Road Design

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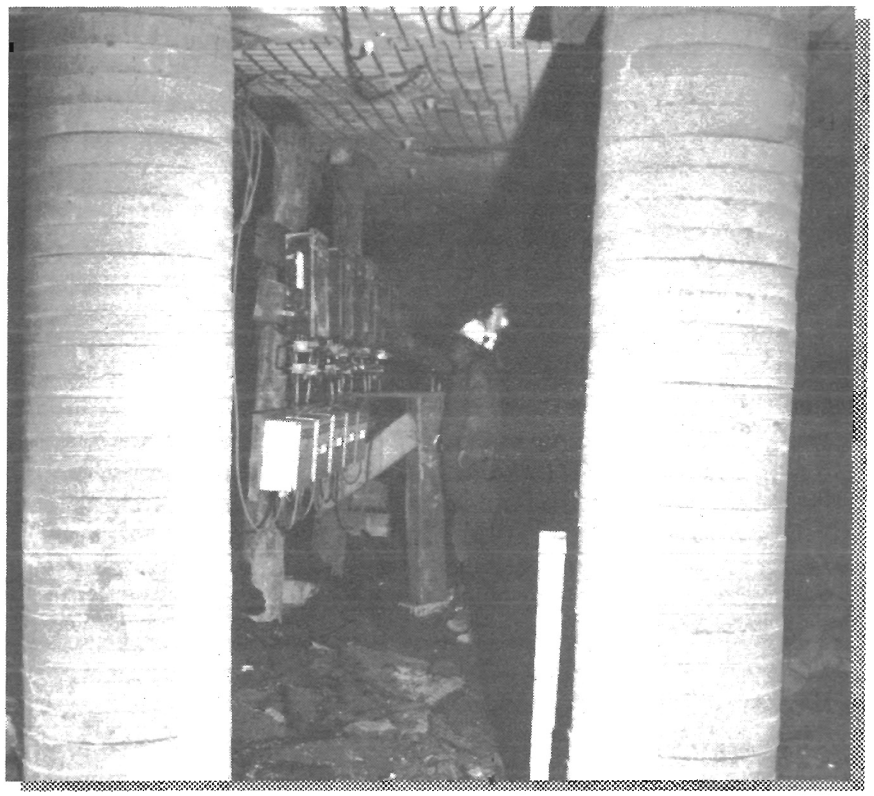

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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Cover: U.S. Bureau of Mines researchers maintaining tailgate instrumentation site.

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UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary

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Rhea L. Graham, Director

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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Metric Units

m	meter	t	metric ton
MPa	megapascal		

U.S. Customary Units

ft	foot	s	second
h	hour	st	short ton
psi	pound per square inch		

EVALUATION OF AN ALTERNATIVE LONGWALL GATE ROAD DESIGN

By John P. McDonnell,[1] David P. Conover,[1] and Robert M. Cox[1]

ABSTRACT

This U.S. Bureau of Mines report describes the results from an in-mine investigation of an alternative longwall gate road design. The coal mine operator modified the pillar layout (reversed the location of the big and small pillars) in a portion of a three-entry longwall gate road area. The modified pillar layout was an attempt to reduce stress and, subsequently, stress-related ground control problems (cutter roof and dynamic floor heave events) in the tailgate region during "second-panel" mining.

The results from borehole pressure cells installed in the modified gate road area showed that the ground pressures in the panel edge and adjacent small pillar were significantly reduced during second-panel mining compared with ground pressures experienced in the typical pillar layout gate road areas. The reduced stress levels around the tailgate entry adjacent to the second panel, as compared with the tailgate stress levels with the typical pillar arrangement, contributed to improved tailgate ground conditions in the test pillar zone.

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INTRODUCTION

Mining companies in conjunction with U.S. Bureau of Mines (USBM) researchers are continually attempting to improve longwall gate road design, specifically tailgate entries, to minimize ground control problems and support requirements, and to promote safer underground working conditions. The tailgate entry, which experiences extreme loading and closure conditions during "second-panel"[2] mining, is especially critical to the efficient extraction of coal from the longwall operation because of ventilation and escapeway considerations.

Improvements to gate road design include changing pillar configurations and sizes, varying support types, and trying different combinations of pillar arrangements and support types. This report discusses the results of a modified pillar arrangement at a high-production longwall mining operation. The study was conducted in an underground coal mine in western Colorado that typically produces 10,890 t (12,000 st) in a 10-h production shift.

The study area consisted of a 300-m (1,000-ft) section of gate road that incorporated a modified pillar arrangement in an effort to reduce stress in the tailgate entry adjacent to the longwall panel. The modified pillar arrangement differed from the typical pillar arrangement at this mine in that the small and big pillar locations were reversed; the new arrangement located the small pillar adjacent to the tailgate edge of the longwall panel. The modified pillar arrangement was chosen so that the small pillar adjacent to the tailgate edge of the panel and the panel edge would yield in advance of mining. The resulting stress reduction would then help to reduce-stress related ground control problems in the tailgate entry outby the longwall face.

The gate road area with the modified pillar arrangement was instrumented by the USBM to monitor stress changes in the pillars and panels during first- and second-panel mining to quantitatively assess the effect of reversing the pillars. Data from the modified pillar test site were then compared with results from previous gate road instrumentation sites from the same mine in gate road areas with the typical pillar arrangement.

MINE SITE DESCRIPTION

Ground control instrumentation was installed at an underground coal mining operation in western Colorado as part of a major research effort to detect ground control hazards, in near real time, during rapidly advancing longwall operations.[3,4] Figure 1 shows a layout of the mine including the general location of longwall panels and the nine instrumentation sites that were monitored using the USBM-developed Ground Control Management System (GCMS) during panels 1 through 5 mining. This report describes the results from instrumentation site 7 and compares those results with pillar and/or panel pressure results from sites 2, 4, 6, 8, and 9. Sites 1 and 3 data are not included in this comparison since the pillar arrangement includes two big pillars and no small pillar, which is not the typical gate road pillar arrangement.

The longwall panels at the study mine have been mined sequentially in a north-to-south direction. Longwall panel retreat takes place from west to east and all five panels were about 195 m (640 ft) wide by approximately 3,050 m (10,000 ft) long. Gate road development typically consists of a three-entry small-big combination pillar system with 5.5-m (18-ft) wide entries. The gate road entries are numbered 1 through 3 from south to north, with entry 1 close to the tailgate edge of the panels, entry 2 in the middle, and entry 3 close to the headgate end of the panels. In the typical pillar arrangement, the small pillar, generally 9 to 10 m (30 to 35 ft) wide, is adjacent to the headgate (between entries 2 and 3) with the big pillar, approximately 24 to 28 m (80 to 90 ft) wide, adjacent to the tailgate (between entries 1 and 2). Crosscuts were spaced on 31-m (100-ft) centers. As longwall mining progressed at the study mine, the pillar dimensions have varied and the crosscut spacing has increased to 61 m (200 ft) for the big pillars.

During development of the panel 4 headgate (panel 5 tailgate), at the site 7 location shown in figure 1, the pillar

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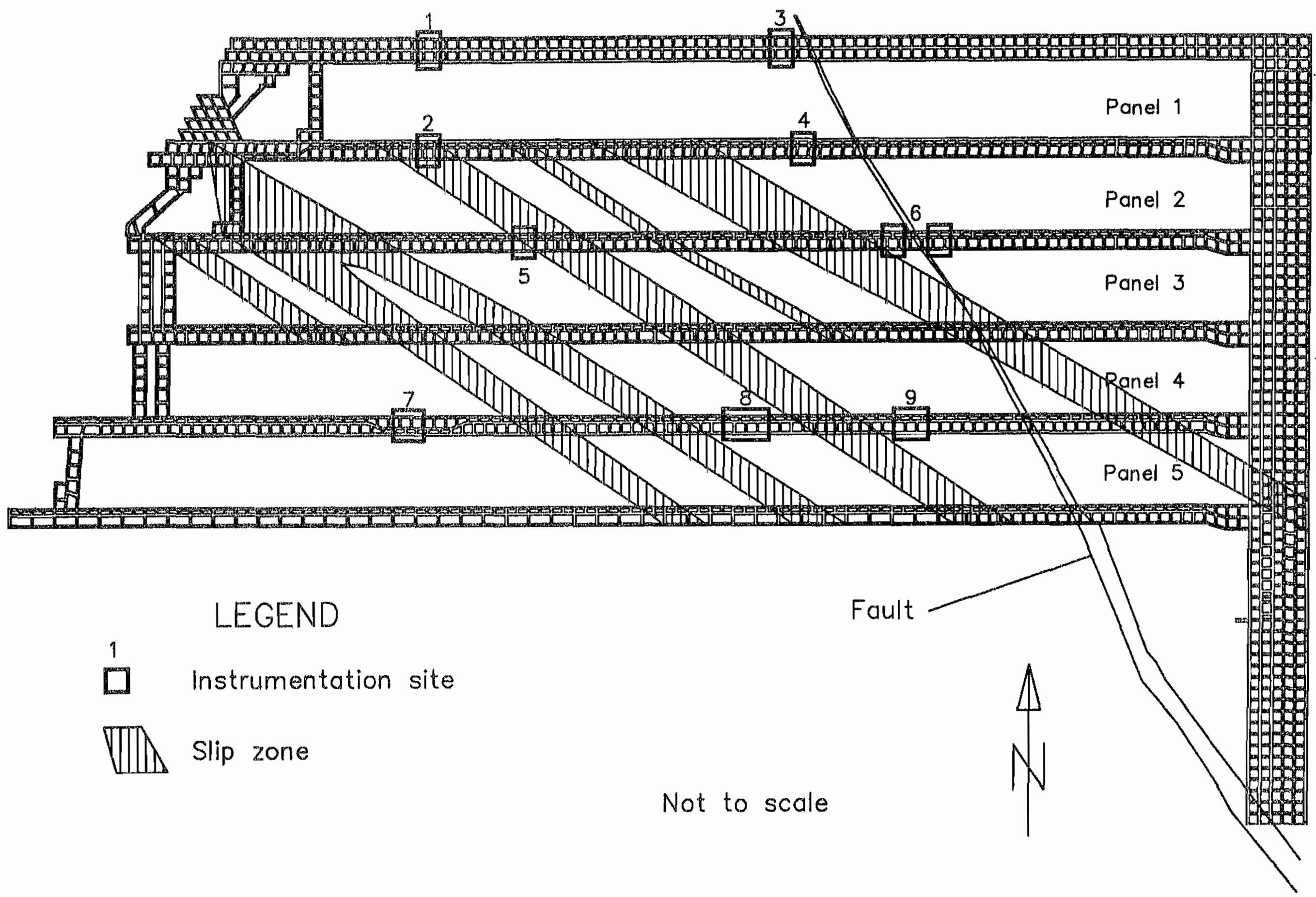
[2]"Second longwall panel" refers to the second longwall face to mine past the gate road section, not necessarily "panel 2." Similarly, "first-panel" mining refers to the first panel face to mine past the gate road area, not necessarily "panel 1."

[3]Conover, D., K. Hanna, and T. Muldoon. Mine-Wide Monitoring Applications in Ground Control Research. Paper in Proceedings of the 9th Conference on Ground Control in Mining (Morgantown, WV, June 4-10, 1990), ed. by S. S. Peng. Dep. of Min. Eng., WV Univ., Morgantown, WV, 1990, pp. 135-141.

[4]Hanna, K., and R. Cox. Automated Ground Control Management System for Coal Mine Hazard Detection. Paper in Proceedings of the 2nd International Conference on Mine Mechanization and Automation (Lulea, Sweden, June 7-10, 1993). Balkema, 1993, pp. 681-689.

Figure 1



General mine layout with instrumentation site locations.

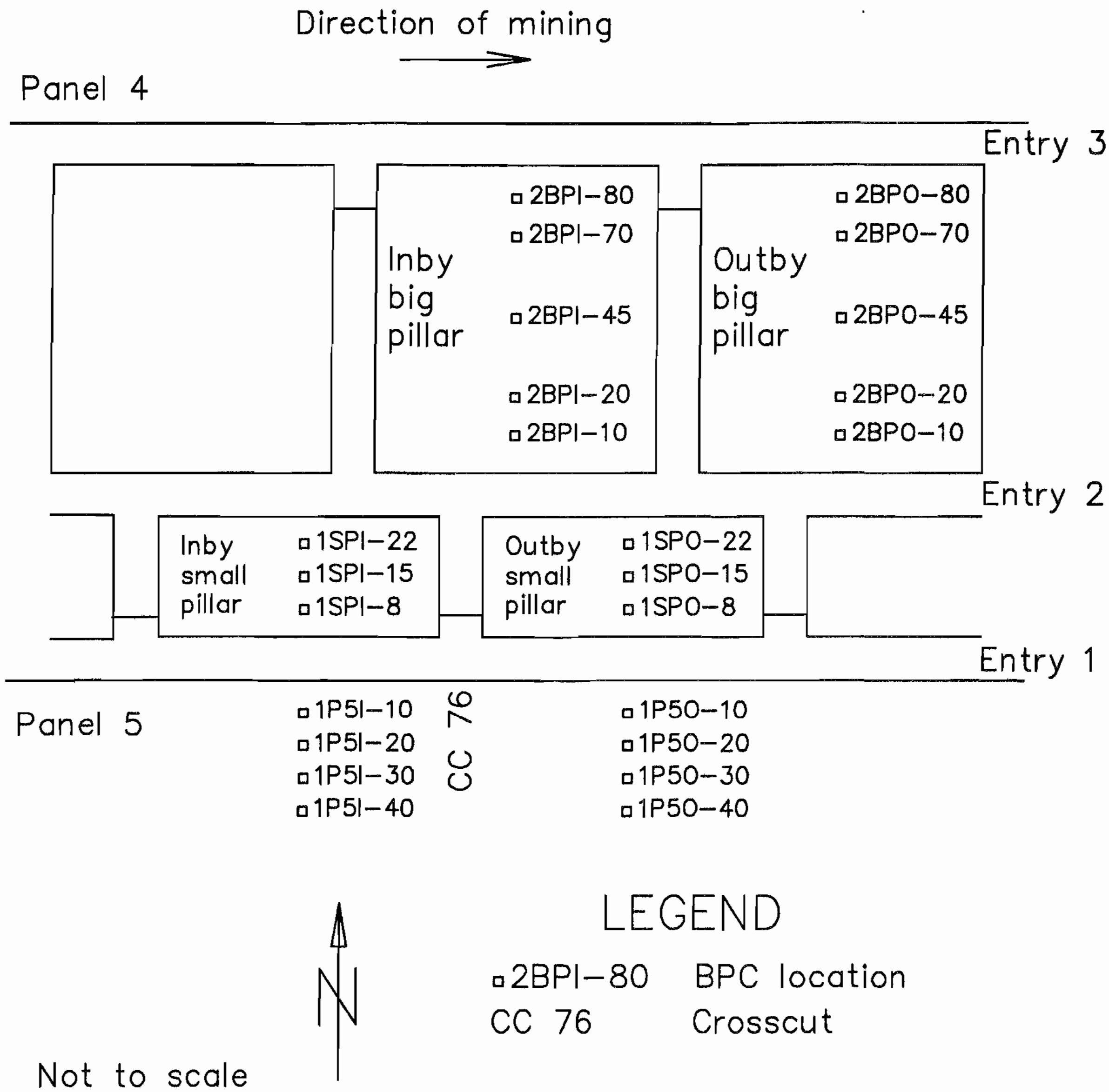
layout was modified so that the big pillar was located adjacent to the headgate (between entries 2 and 3) and the small pillar adjacent to the tailgate entry (between entries 1 and 2). Secondary support in the panel 5 tailgate entry 1 consisted of two rows of concrete donut cribs spaced on 1.5-m (5-ft) centers. No additional secondary support was installed in entries 2 and 3.

The coal seam in the mine area is about 340 m (1,100 ft) deep, 2.9 m (9.5 ft) thick, and dips 5° to the northwest. The mine area is dissected by a strike-slip fault oriented about N. 30 W. and several joint-shear zones oriented about N. 60 W., as shown in figure 1. The long-wall face cleat system strikes about N. 45 W., roughly parallel to the dip of the coal seam.

INSTRUMENTATION LOCATION AND DESCRIPTION

Pressure monitoring instrumentation, to measure changes in vertical loading on the mine structure, was installed in the pillars and panel 5 at site 7, located as shown in figure 1. Details of the instrumentation location are shown in figure 2. Hydraulic borehole pressure cells (BPC's) were installed to measure pillar and panel pressure changes at site 7 during longwall mining of panels 4 and 5. The BPC labelling system describes the instrument location, drill set-up location, and depth of cell placement into the borehole. For example, 1SPI-22 references the

Figure 2



Site 7 instrumentation location and description.

BPC installed from entry 1 into the small pillar on the inby side of the instrumentation site to a depth of 6.8 m (22 ft). Similarly, 2BPO-45 is the cell installed from entry 2 into the big pillar on the outby side of the test site to a depth of 13.7 m (45 ft).[5] The instrumentation were installed prior to panel 4 mining and were monitored until panel 5 was mined past the instrumentation site. A pressure sensor attached to each BPC was connected to the GCMS, which transmitted the BPC data continuously, at 6-s intervals, from the underground test site to the mine surface and the Denver Research Center mine monitoring laboratory.[6]

[5]SP and BP refer to small and big pillar, respectively, while I and O in the BPC label refer to inby and outby pillar or panel locations.

[6]Hanna, K., K. Haramy, and T. Ritzel. Automated Longwall Mining for Improved Health and Safety at the Foidel Creek Mine (SME Annual Meeting, Denver, CO, Feb. 25-28, 1991). SME preprint 91-165, 1991, 8 pp.

PILLAR LOADING BEHAVIOR

Each BPC was installed at an initial set pressure between 6.9 and 10.3 MPa (1,000 and 1,500 psi), which corresponds to the estimated overburden pressure. BPC pressures after installation were evaluated for each of the cells to compare ground pressure changes resulting from both panel 4 and 5 mining.

RESULTS FROM ALTERNATIVE PILLAR LAYOUT DURING PANEL 4 MINING

Figures 3 and 4 illustrate BPC pressure changes at site 7 as a result of panel 4 mining. Figure 3 shows the vertical-stress-change history of the inby and outby small pillars, and figure 4 shows the results of the big pillars. Site 7 monitoring during panel 4 mining began soon after panel 4 start-up and continued until panel 4 had been mined a considerable distance past (or outby) the site. BPC pressures at site 7 stabilized after panel 4 had mined about 518 m (1,700 ft) past the site, and monitoring of site 7 was discontinued until panel 5 mining began. Periodic checks of the BPC pressures during the remainder of panel 4 mining indicated only minor pressure changes throughout site 7.

While panel 4 was retreated past the site 7 area, significant pressure changes occurred in the panel 4 side of the big pillars with moderate pressure increases observed in the small pillars and the entry 2 side of the big pillar. Figure 4*A* shows that the BPC 3 m (10 ft) from the entry 3 side of the inby big pillar (2BPI-80) dropped pressure when the panel 4 face was about 183 m (600 ft) outby the BPC instrumentation location. This type of pressure decrease indicates yielding of the entry 3 edge of the inby big pillar.

In general, as a result of panel 4 mining, load increased on both the big and small pillar. The load increase on the big pillar, nearest to panel 4, exceeded the load increase experienced by the small pillar that was closer to panel 5. Minor yielding of the inby big pillar (panel 4 edge) also occurred. Results from the BPC's installed in panel 5 indicated only very minor pressure changes in panel 5 as a result of panel 4 mining.

RESULTS FROM ALTERNATIVE PILLAR LAYOUT DURING PANEL 5 MINING

The main purpose for the instrumentation installed in site 7 was to quantify and assess the ground pressure changes associated with the reversed pillar layout, and to monitor the behavior of the reversed pillar arrangement and the condition of tailgate entry 1 during panel 5 mining. Figures 5, 6, and 7 provide BPC results as panel 5 mined through site 7. When the panel 5 face was more than 152 m (500 ft) inby the first row of small pillar cells, BPC pressures began to change noticeably. Referring to figure 5*A*, pressure in the entry 1 edge of the inby small pillar (1SPI-8) began to decrease, whereas load increases were observed in the core (1SPI-15) and entry 2 edge (1SPI-22) of the inby small pillar. As panel 5 mining continued, pressure changes occurred on the entire instrumentation array.

While the panel 5 face was still 91 m (300 ft) inby the first row of pressure cells, pressure increased significantly in the core of the inby small pillar (1SPI-15) (figure 5*A*), entry 1 edge of the outby small pillar (1SPO-8) (figure 5*B*), and the entry 3 side of both big pillars (2BPI-70 and 2BPO-70) (figure 6). In addition, pressure decreases were observed in both sides of the inby small pillar (1SPI-8 and 1SPI-22) (figure 5*A*) and the entry 2 side of the outby small pillar (1SPO-22) (figure 5*B*).

When the panel 5 face was still more than 61 m (200 ft) from the inby row of BPC's, the inby small pillar core pressure increased to approximately 69 MPa (10,000 psi), whereas pressure continued to decrease on the edges of the pillar. In fact, pressures continued to change even several hours after mining had stopped. Approximately 10 h after a production shift ended, the pressure decreased on all three BPC's in the inby small pillar while the longwall face was still idle.

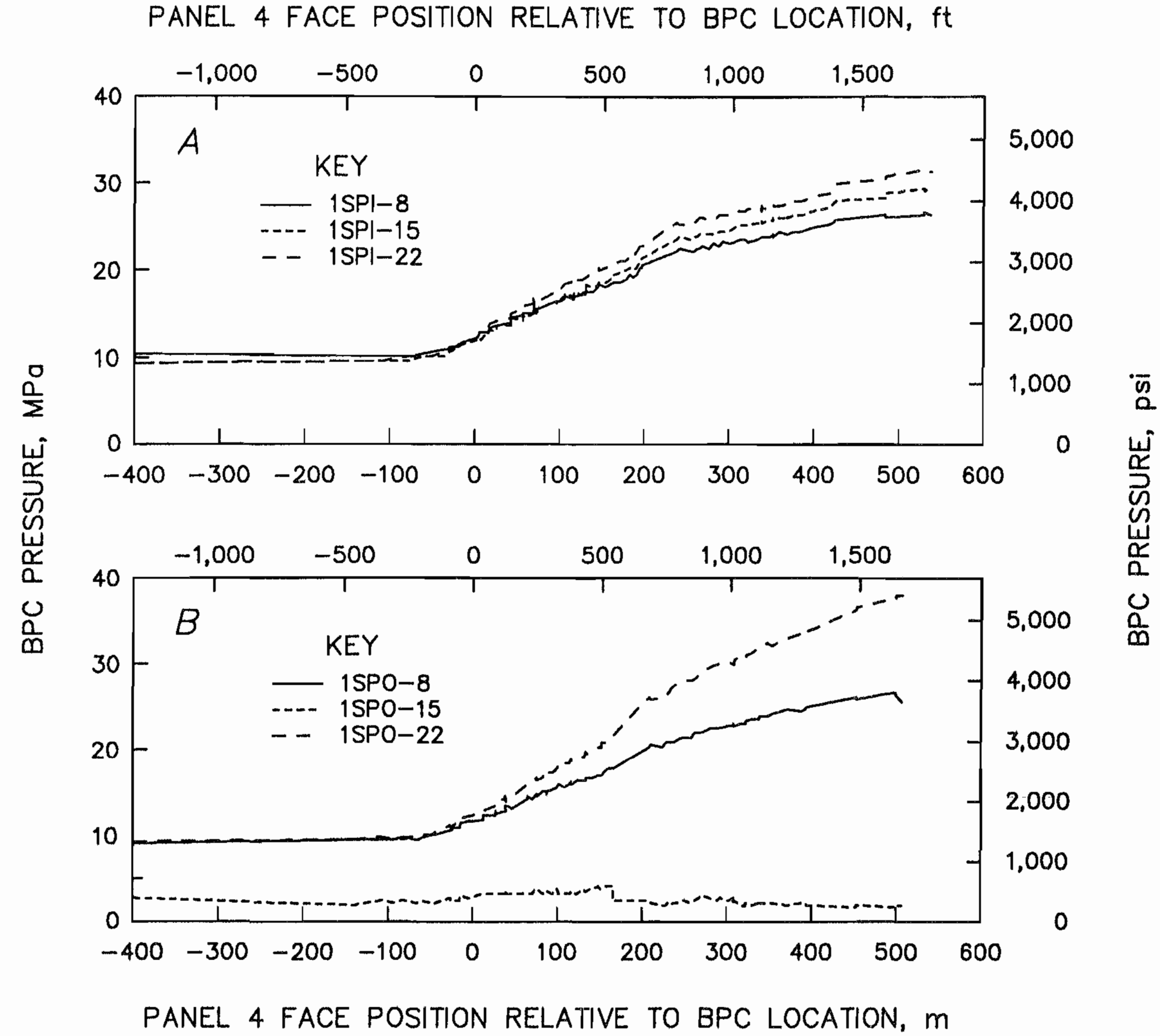
As the panel 5 face sat idle for a week due to longwall mechanical problems, with the longwall face still 67 m (220 ft) inby the test site, pressure continued to increase in the core (1SPO-15) and entry 1 side (1SPO-08) of the outby small pillar, whereas pressure decreased in the entry 2 side of the outby small pillar (1SPO-22). Additionally, referring to figure 6, pressure increased in the center of the inby big pillar (2BPI-45), with pressure decrease noted in the entry 2 side of the inby big pillar (2BPI-10).

When mining resumed after the idle week, significant pressure increases were observed in the panel 5 BPC's (figure 7) as the longwall face mined within 61 m (200 ft) of the test site. However, as the face approached to within about 24 m (80 ft), the pressure in the panel edge began to decrease. Detailed pressure changes in the panel 5 BPC's are illustrated in figure 8. The tailgate edge of panel 5 at site 7 (1P5I-10 and 1P5O-10) experienced a pressure decrease when the face was still more than 12.2 m (40 ft) inby the BPC location.

When the panel 5 longwall face mined even with the outby row of panel 5 BPC's, only two BPC's were still indicating high pressure, 2BPI-45 and 2BPO-45. At this point, data collection from site 7 was discontinued.

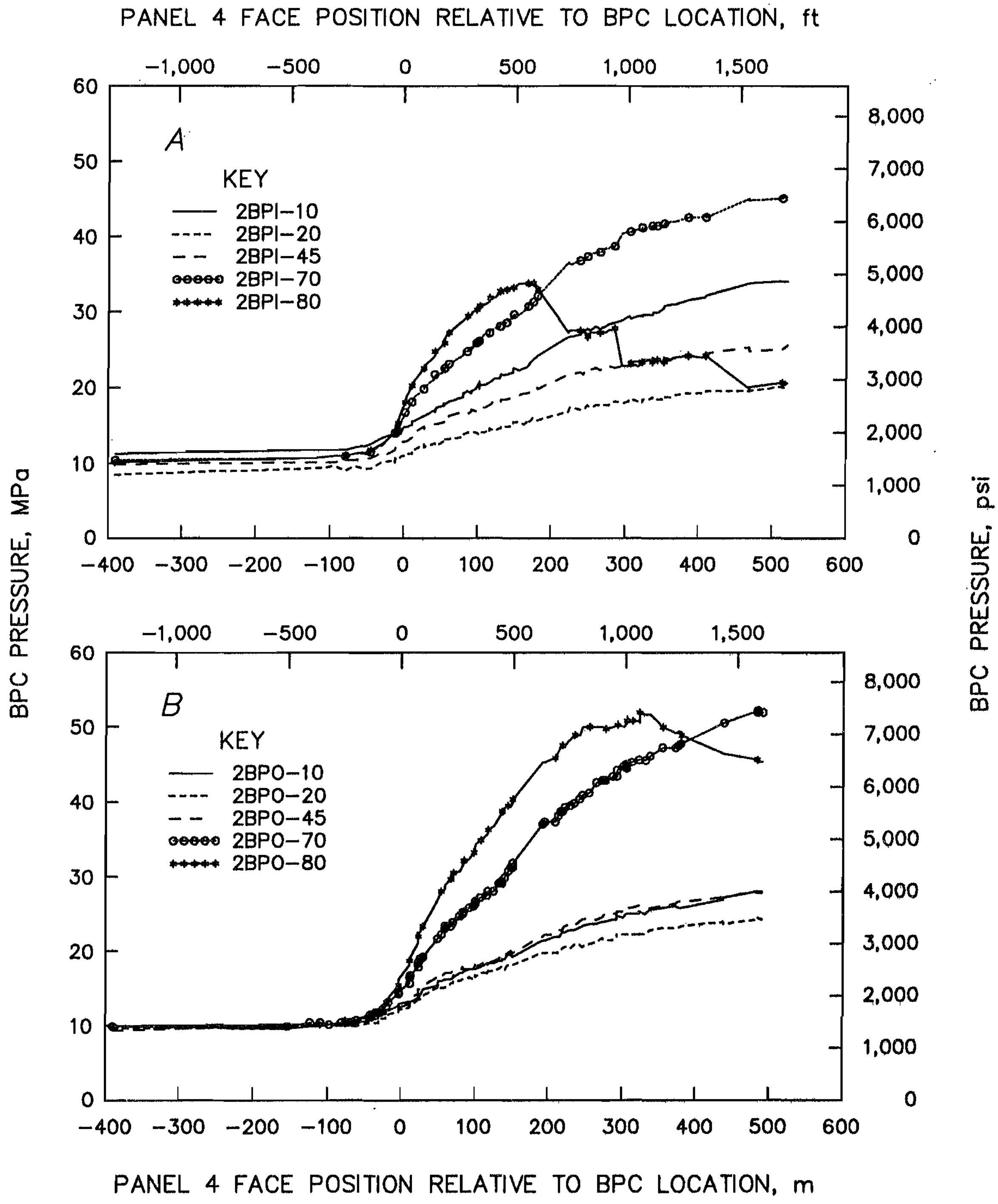
Entry closure adjacent to the BPC instrumentation sites, measured manually as panel 5 was mined past site 7, showed that entry 1 outby the face converged only about 0.15 m (0.5 ft).

Figure 3



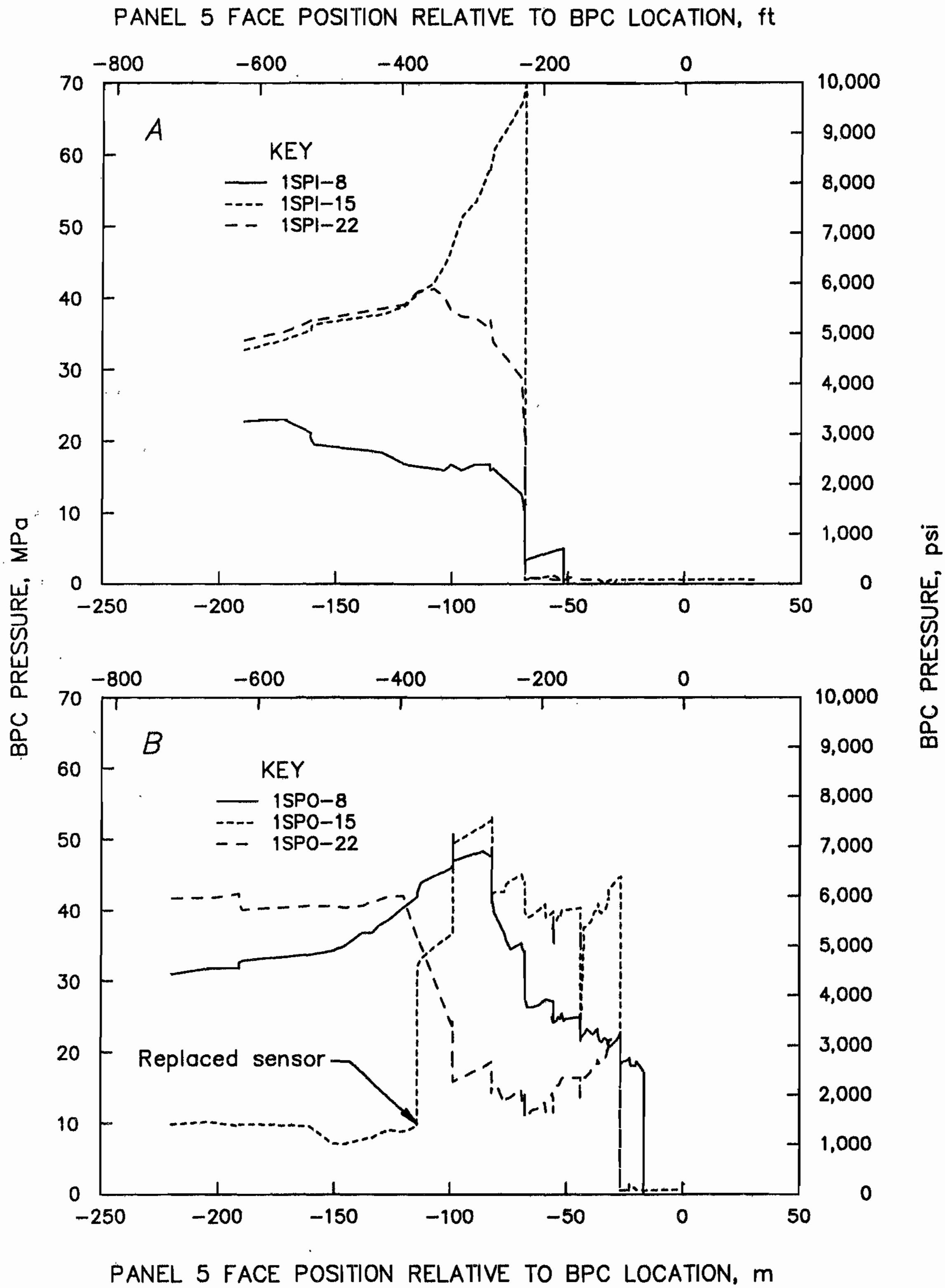
Site 7 small pillar BPC results during panel 4 mining. A, BPC results from the inby small pillar; B, BPC results from the outby small pillar.

Figure 4



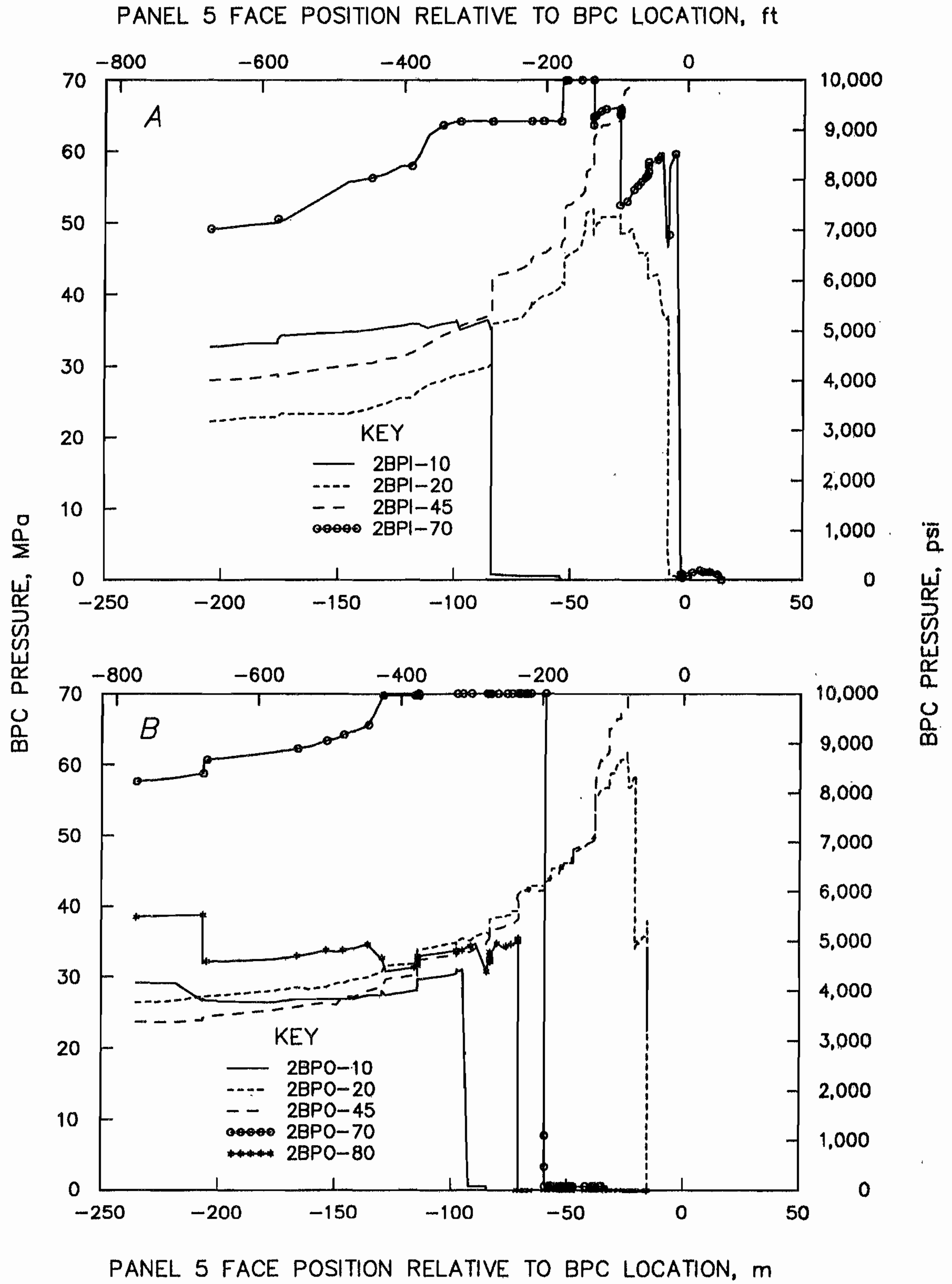
Site 7 big pillar BPC results during panel 4 mining. A, BPC results from the inby big pillar; B, BPC results from the outby big pillar.

Figure 5



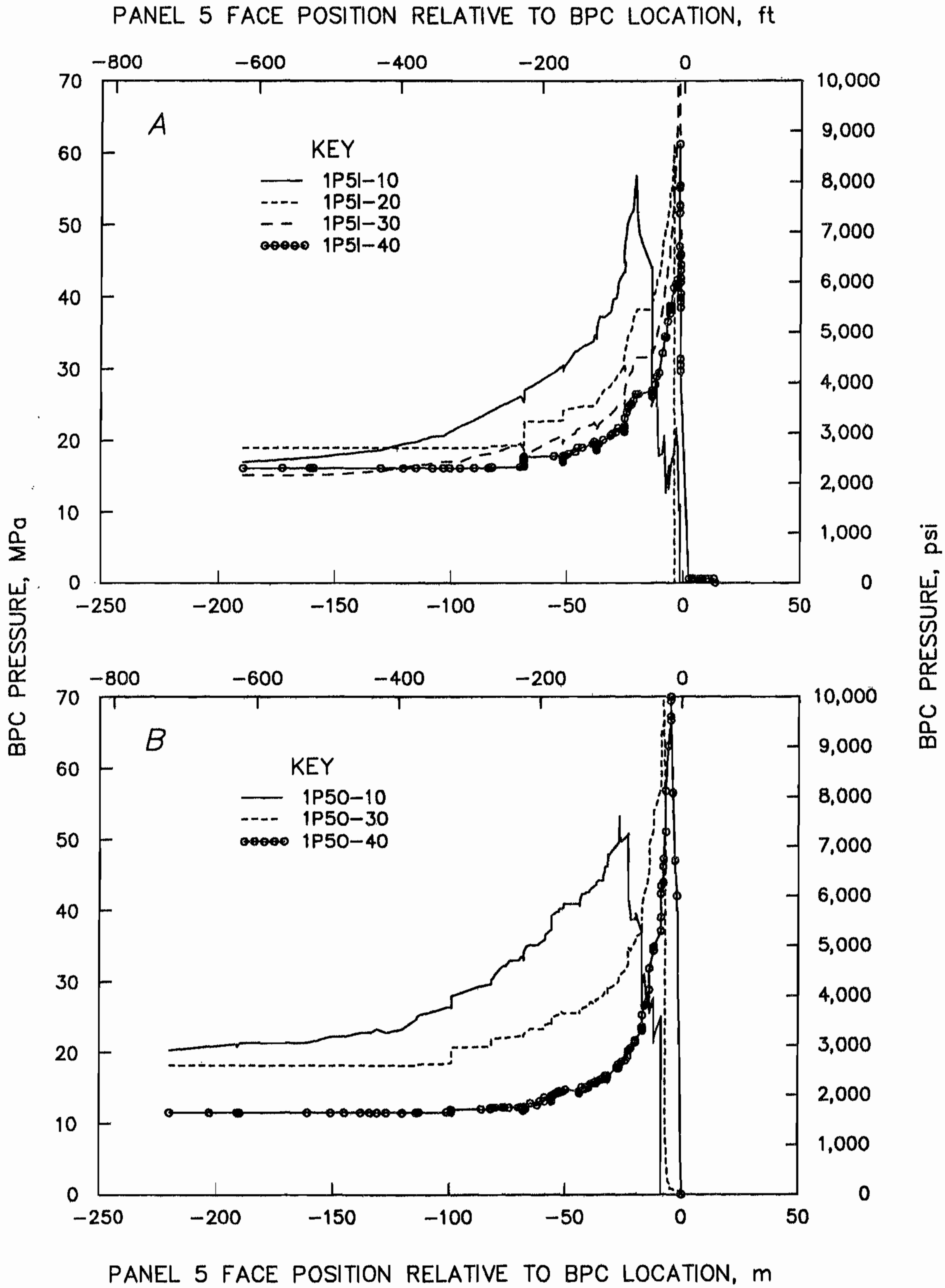
Site 7 small pillar BPC results during panel 5 mining. A, BPC results from the inby small pillar; B, BPC results from the outby small pillar.

Figure 6



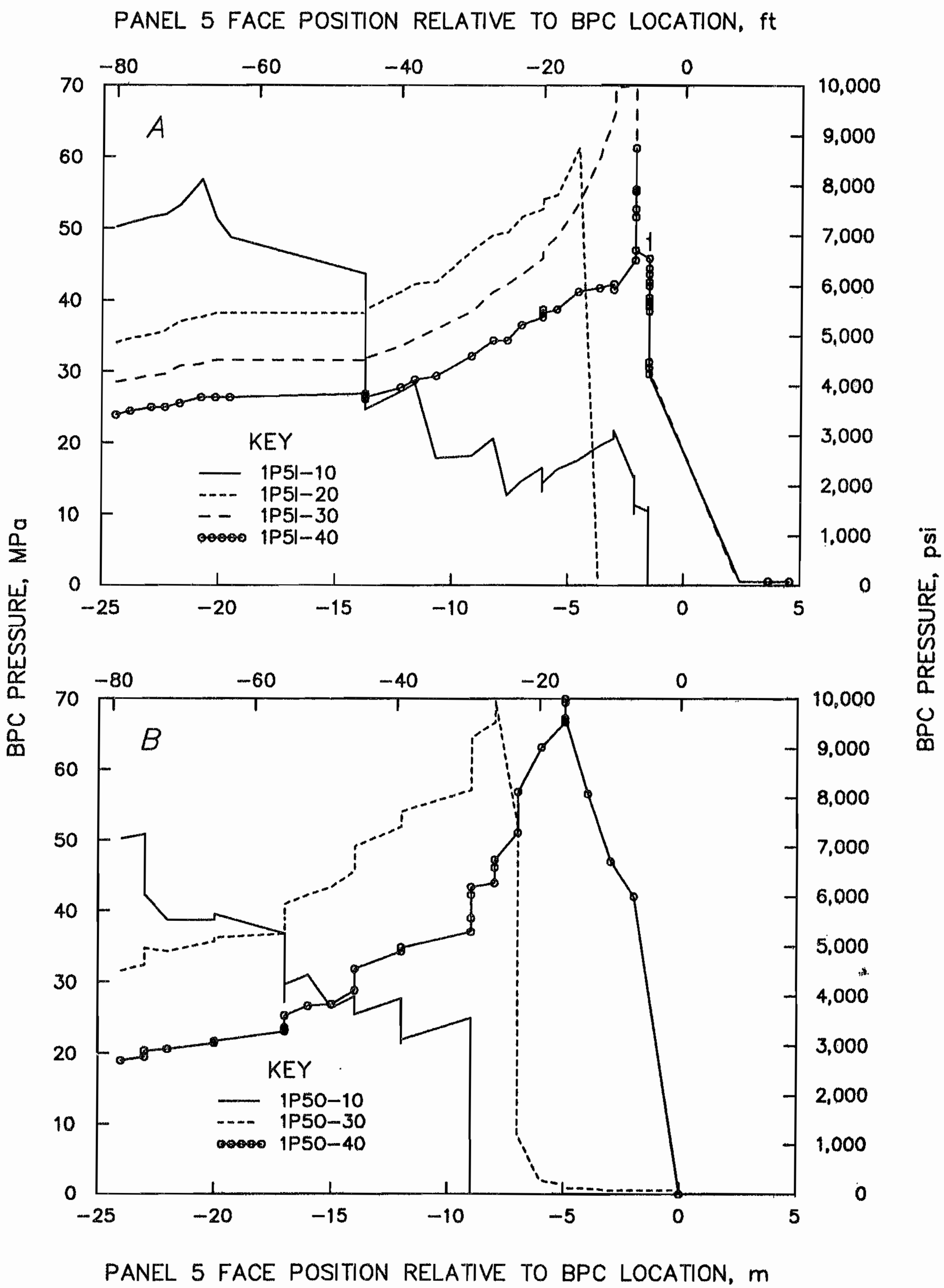
Site 7 big pillar BPC results during panel 5 mining. A, BPC results from the inby big pillar; B, BPC results from the outby big pillar.

Figure 7



Site 7 panel 5 BPC results during panel 5 mining. A, BPC results from the inby row of panel 5 cells; B, BPC results from the outby row of panel 5 cells.

Figure 8



Detail results from panel 5 BPC's during panel 5 retreat past site 7. A, BPC results from the inby row of cells; B, BPC results from the outby row of cells.

EVALUATION OF TEST SITE PERFORMANCE

Figure 9 shows the overall yield sequence (based on BPC pressure decreases) of test site 7 with respect to different panel 5 face positions. Figure 9*A*, for example, shows the panel 5 face position on February 11 at the end of the day shift; the only zone yielded at this point was the entry 3 edge of the inby big pillar. By February 18 at the end of the day shift, figure 9*B*, the yielded zones included the inby small pillar and the entry 2 and 3 edges of the inby big pillar. Small pillar yielding, combined with a yielding in the panel 5 edge, outby the face was observed in the site 7 BPC behavior. Yielding of the coal structure around the tailgate entry immediately outby the face occurred as a result of the modified pillar arrangement. The result of the modified pillar layout was a stress-relieved tailgate entry ahead of (outby) the longwall face. As indicated in the earlier figures, both sets of small pillar cells at site 7 had already dropped pressure when the panel 5 face was approximately 61 m (200 ft) inby the respective row of cells. The abutment loads created by longwall mining were transferred to the big pillar away from the entry 1 adjacent to panel 5 as noted in the BPC pressure changes (decreased pressure in the small pillar coinciding with pressure increases in the big pillar). As a result, the pressure around the tailgate entry 1 adjacent to panel 5 was reduced during panel 5 mining at the test pillar zone.

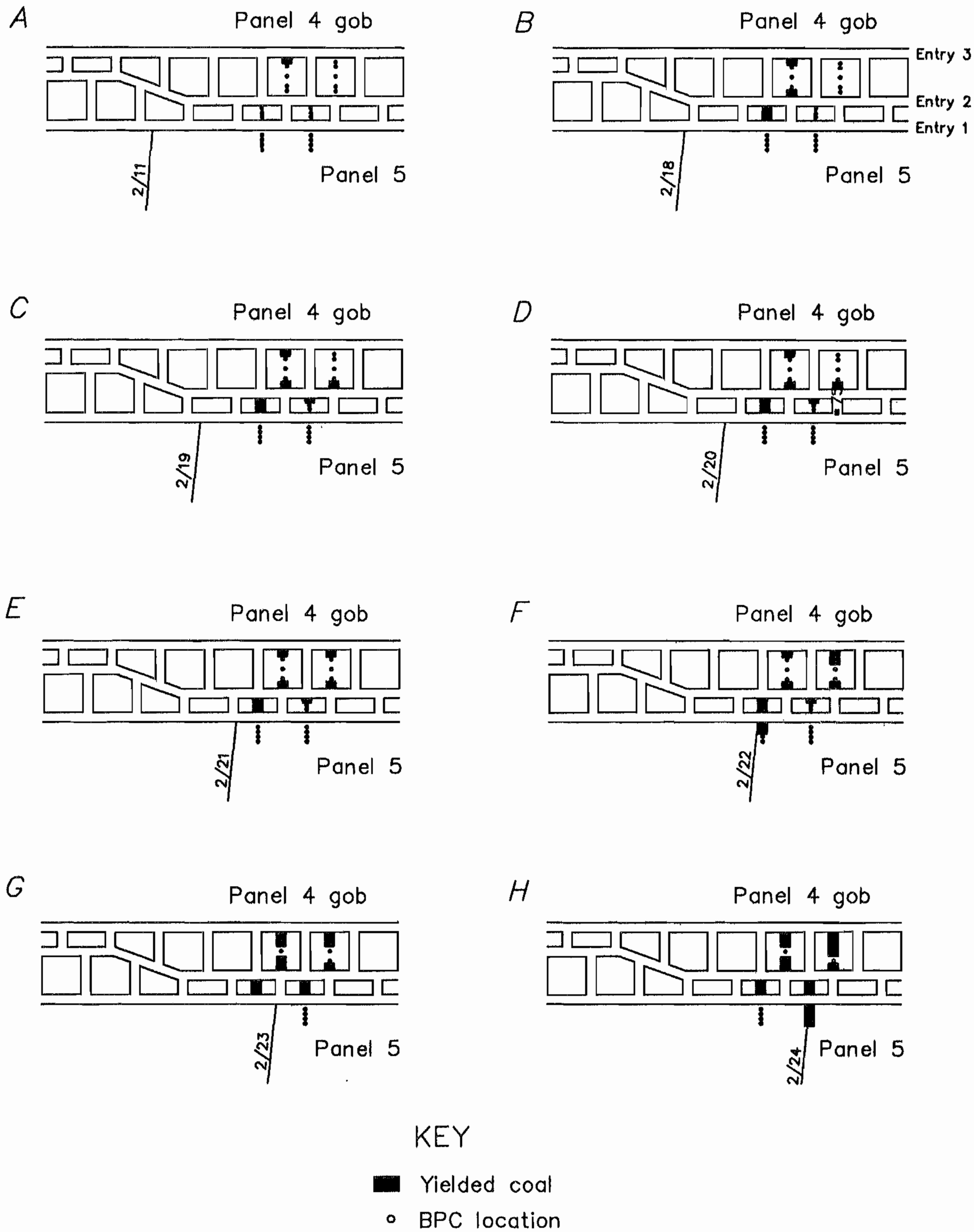
The results from test site 7 were compared with combined results from previous instrumentation sites at different locations in the mine with the more typical pillar arrangement (sites 2, 4, 6, 8, and 9 in figure 1). Instrumentation layouts at the particular sites were similar to the site 7 instrumentation location with BPC's installed in the pillars and panels. Figures 10 and 11 show a summary of BPC data from the other instrumentation sites during second-panel mining[7] to illustrate the difference between the typical pillar behavior and the modified pillar area results. In contrast to the site 7 results during panel 5 mining, the combined second-panel BPC data indicated high pressure near the panel edge even as the second panel mined through the BPC instrumentation; there was no pressure decrease in the second-panel edge out ahead of the face. In fact, the second-panel BPC's typically maintained pressure until the longwall shearer cut through the instrumentation.

USBM and mine personnel conducted on-site observations of tailgate conditions throughout longwall mining at the study mine. At each gate road instrumentation site with the typical pillar layout during second-panel mining, significant cutter-type roof problems were observed within 23 m (75 ft) outby the face at the panel-roof line. Cutter-type roof problems and floor heave in the zone immediately outby the tailgate end of the longwall panel face were observed at numerous locations during longwall panel mining at the study mine. Although panels 2, 3, and 4 had experienced cutter-type roof failures and dynamic floor-heave events at the panel-tailgate edge outby the face, the roof and entry conditions outby the panel 5 face through the site 7 gate road area were generally good.

High pressures, as measured by BPC instrumentation, surrounded the tailgate entry during second-panel mining through all the gate road test areas with the typical pillar arrangement (sites 2, 4, 6, 8, and 9). Conversely, the measured pressure in the mine structure around the tailgate entry at site 7 during panel 5 mine-through was considerably less. The abutment loads from longwall mining at site 7 were shifted away from the tailgate entry and the panel edge and were being carried by the big pillar core and the panel, away from the tailgate entry.

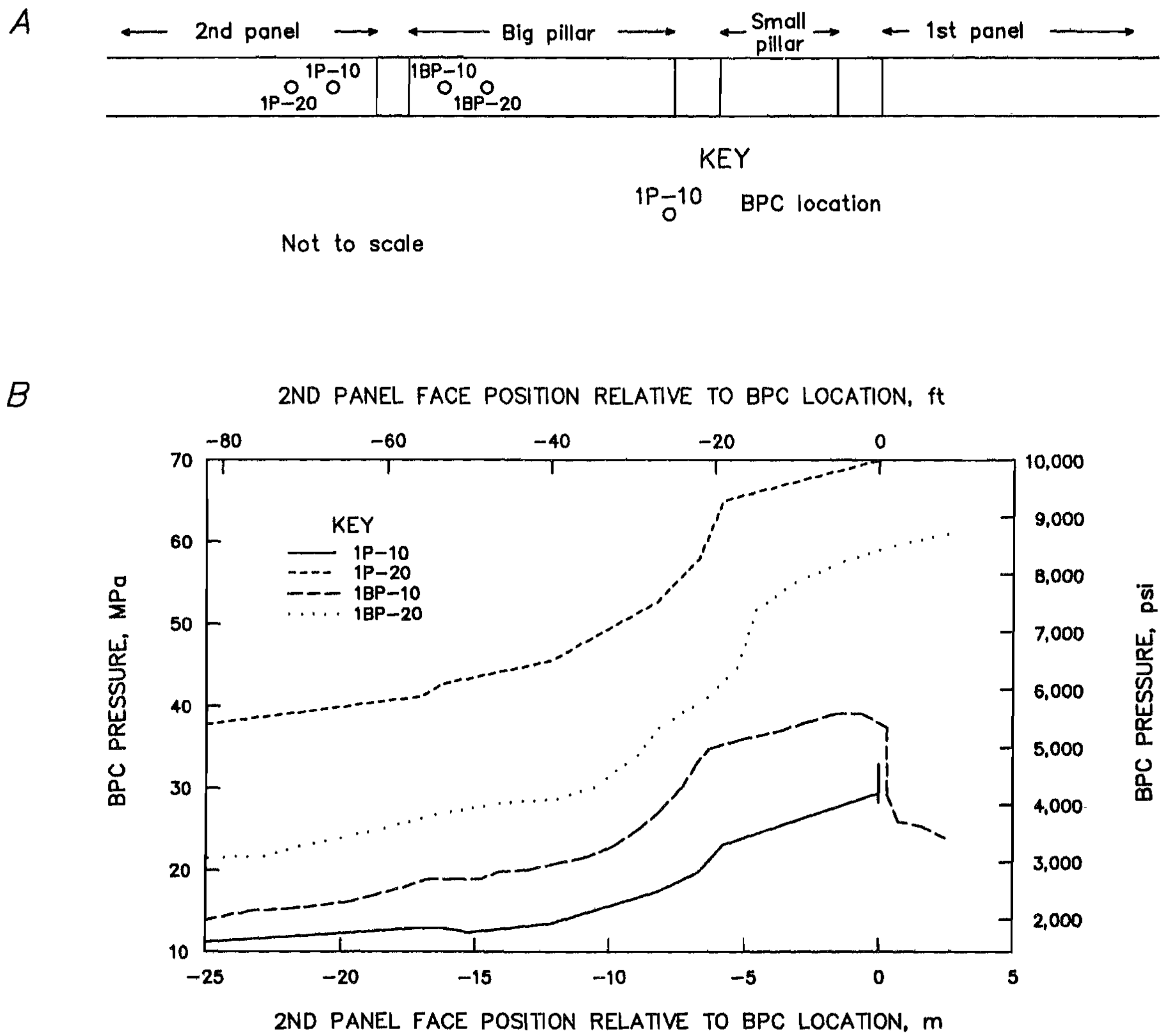
[7]Using test site 7 as an example, first-panel mining would be panel 4 mining while second-panel mining would be panel 5 mining. Similarly, for test site 4, first-panel mining would be panel 1 mining while second-panel mining would be panel 2 mining.

Figure 9



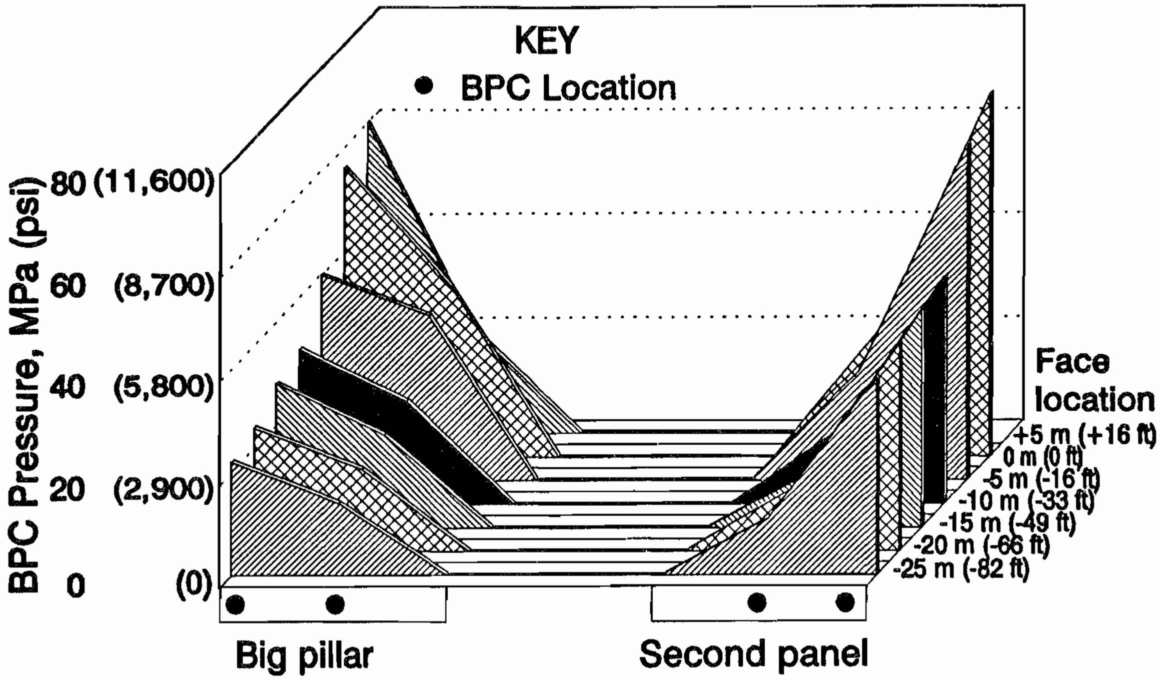
Overall yield sequence of site 7 during panel 5 mining. Face positions are given at the end of the day-shift from 2/11 to 2/24/93.

Figure 10



Combined BPC results from typical pillar gate road instrumentation sites during second-panel mining. A, General cross section of typical pillar layout; B, average BPC results from typical pillar instrumentation sites.

Figure 11



Three-dimensional plot of combined BPC results from typical pillar gate road instrumentation sites during second-panel mining.

SUMMARY

The USBM has demonstrated that simple in-mine instrumentation (BPC's) provide valuable load transfer-related information in the assessment of gate road designs. The study mine incorporated a modified pillar arrangement in a 300-m (1,000-ft) section of gate road to reduce stress-related ground control problems around the tailgate entry; the small-big pillar layout was reversed to a big-small pillar arrangement. Previous longwall panels at the study mine experienced cutter-type roof failures at the panel-edge tailgate-entry roof and dynamic floor heave events outby the tailgate end of the face as a result of pillar and/or panel stress and sustained vertical loading on the mine structure. BPC instrumentation recorded reduced pressure levels in the mine support structure (panel and pillars) surrounding the tailgate entry outby the face as a result of the modified pillar layout when compared with the typical pillar arrangement. Good tailgate conditions were observed as panel 5 was retreated through the modified pillar layout area. Reduced stress levels in the panel and pillars ahead of the longwall face, at the very least, had no adverse effect on the entry behavior and contributed to improved tailgate conditions such as no panel-edge roof cutter and minimal floor heave.

While discussing pillar arrangements with the mine operators, it was determined that an important criteria for using the typical pillar arrangement is the effect on gate road development time. Every longwall operation has problems maintaining gate road development ahead of longwall advance. At the study mine, the typical pillar arrangement facilitated faster gate road development. Thus, the typical pillar layout was used instead of the modified pillar arrangement.