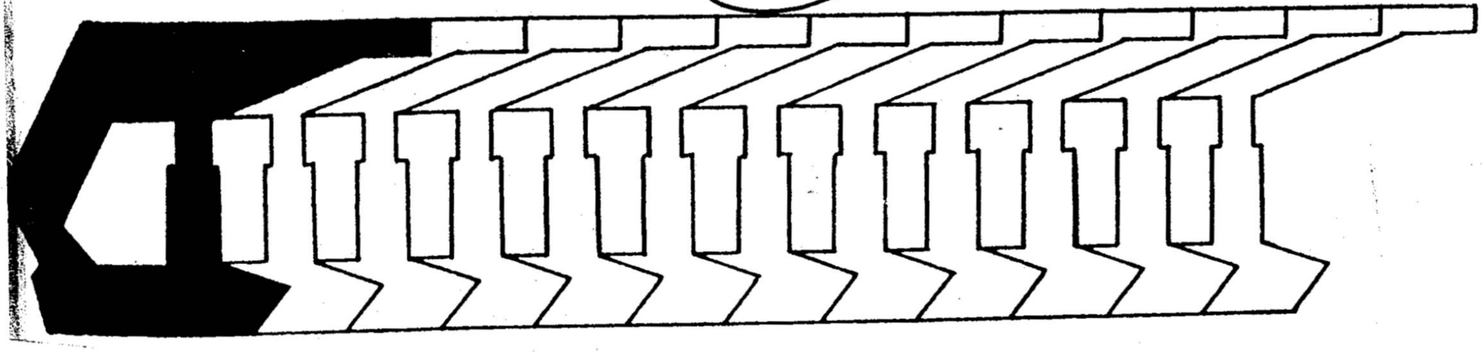
PROCEEDINGS OF THE

1st annual

Conference On Ground Control In Mining

WEST VIRGINIA UNIVERSITY 1981



ABUTMENT PILLAR "NOTCHING" IMPROVES ABUTMENT TUNNEL ROOF CONDITIONS AT THE CAYUGA ROCK SALT MINE

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ABSTRACT

The Cayuga Mine, a deep rock salt mining operation, changed from a standard room and pillar mine design to a yielding pillar/pressure arch design five years ago. In general the roof conditions improved. However, entries adjacent to the abutment pillars continued to fail.

It was noticed that where abutment pillars were accidentally "notched" (by driving cross-cuts one cut into the pillars), the abutment entries had better roof conditions than where there were no "notches". Experiments with intentionally notched abutment pillars showed that notching did improve abutment entry conditions.

During the past four years notch configuration has been varied to suit local ground conditions. Recently, "pre-cutting" of notches has proven itself as a means of protecting abutment entries under severe ground conditions. As an added bonus, the notches improve productivity by providing more places to work and reduce costs because it is not necessary to bolt the notches.

GEOLOGICAL SETTING

Mining is done in one of eight layers of salt which are interlaid with beds of shale and dolomite. The beds are part of the Syracuse salts of late Silurian age. The upper beds are severely distorted but the number 6 salt, which is presently being mined, is fairly consistent in thickness, dipping to the south at 100 feet per mile. See figure 1.

Depth of cover varies from 2300 feet at the shaft near Cayuga Lake to more than 3000 feet under the hills to the east.

MINING METHOD AND EQUIPMENT

Conventional coal equipment is used in a room and pillar layout. The roof is bolted with four to eight foot mechanical bolts on four foot centers with a Fletcher roof bolter. A Fletcher twin-boom face drill is used to drill a blast pattern of 26 1-3/4" diameter, 12-1/2 foot long holes in entries 32 feet wide and 9 - 10 feet high. The face is then undercut with a Joy 15RU undercutter. Anfo is pneumatically loaded into the blast holes, and the headings are shot at shift change. The broken salt is hauled with 5 yard L.H.D.'s to a Stamler feeder-breaker, and then conveyed by belt to an underground preparation plant for crushing and screening before hoisting it to surface.

MINE DESIGN

The original mine design used 32 foot rooms on 120 foot centers, leaving 88 x 88 foot pillars and resulting in 46% extraction. In 1976 all mining was changed to a yeilding pillar/pressure arch design (1). Production panels typically consist of 10 entries 32 feet wide on 56 foot centers, leaving pillars 24 x 24 feet. Extraction ratio within a panel is typically 80%, but has been as high as 87%. Barrier pillars 150 to 250 feet wide are left between production panels.

Development layouts, which provide for airways, travelways, and beltways typically have 3 to 5 entries. These entries usually are 32 feet wide on 56 foot centers with 24 x 24 foot pillars. Separating sets of development entries and separating production panels from the

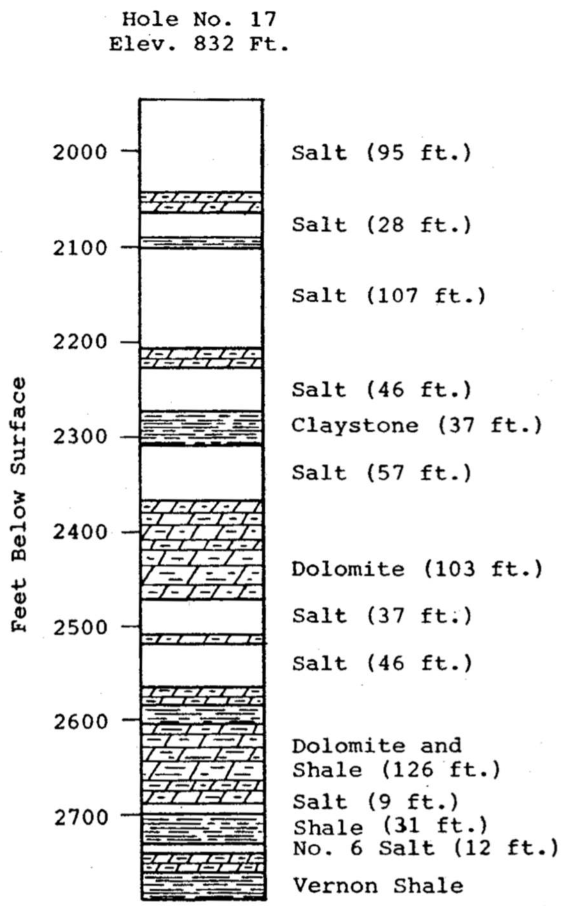


Fig. 1 Partial geologic section showing location of No. 6 salt bed.

development entries are barrier pillars varying from 85 x 150 feet to 185 x 185 feet in size. Overall extraction ratio including developments, production panels, and barrier pillars is approximately 56%.

MODE OF ROOF FAILURE

Pillar failure has not occurred, and floor heave is minor and is not a problem, but loads are too great for the roof rocks and they periodically fail.

It appears as though vertical loading on the pillars causes horizontal expansion, which induces horizontal stresses in the immediate roof. In areas where salt is left in the roof it fails by forming a low angle shear along the rib. The salt roof is then thrust down and sideways, shearing the 3/4 inch roof bolts. Up to 10 inches of horizontal movement has been measured in a room 32 feet wide. See figure 2.

Where mining has removed salt up to the overlying shale, the failure appears as crushing of the shale parallel to the entry, usually about 10 feet from the rib. Where tunnels have caved, there is evidence of a set of opposing wedges thrusting horizontally from each

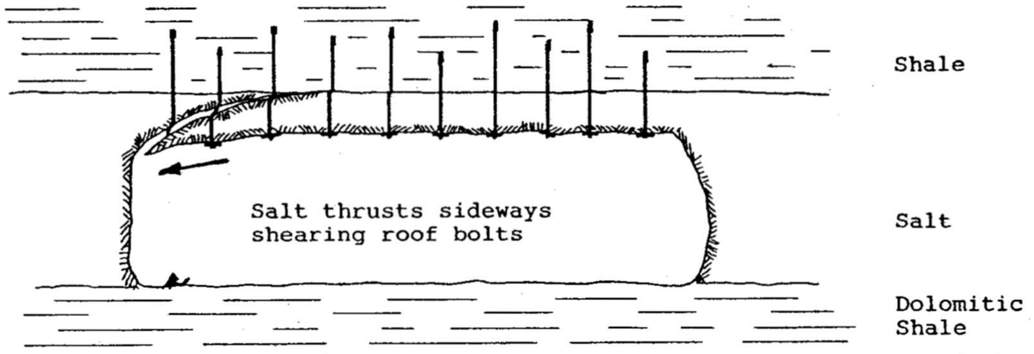


Fig. 2 Cross section of typical roof failure in salt roof.

rib. This horizontal thrusting is evident as much as 12 feet above the original roof. In general, the larger the pillars, the higher the crushing extends into the roof.

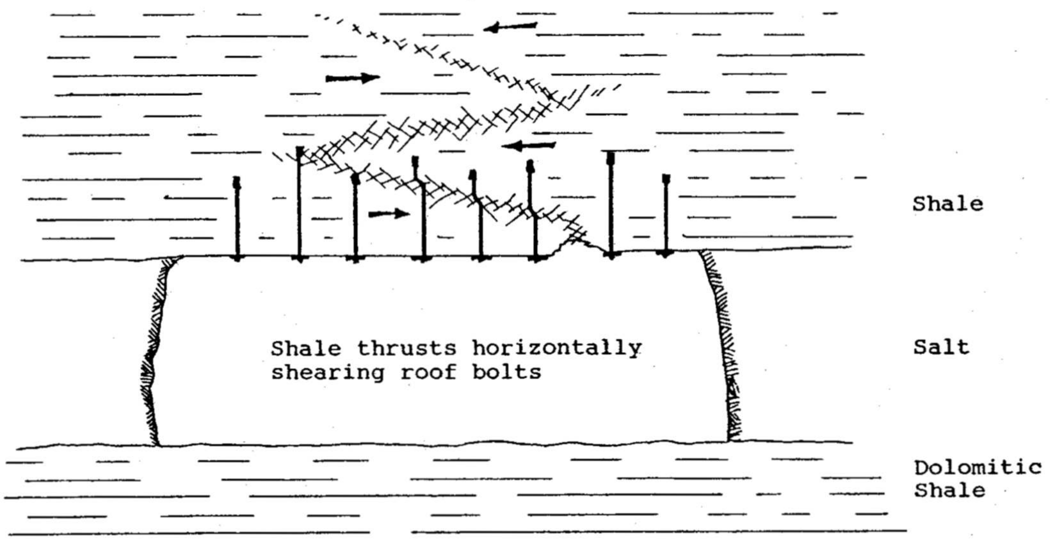


Fig. 3 Cross section of typical roof failure in shale roof.

YIELDING PILLAR/PRESSURE ARCH MINE DESIGN

To correct the roof failure, a stress relief mining system was devised which simulated shallow conditions, though mining was at great depth (1). The theory was that by making pillars very small they would yield, rather than support the high loads that break the roof. At the same time, massive abutment pillars would be provided to support the load shed by the yielding pillars. This would allow high extraction mining within a narrow panel with overburden loads supported by abutment pillars. See figure 4.

This design has allowed mining of ground that previously could not be mined. It was soon learned, however, that tunnels adjacent to abutment pillars behaved as badly as, or worse than, the original tunnels among the 88 x 88 foot pillars. See figure 5.

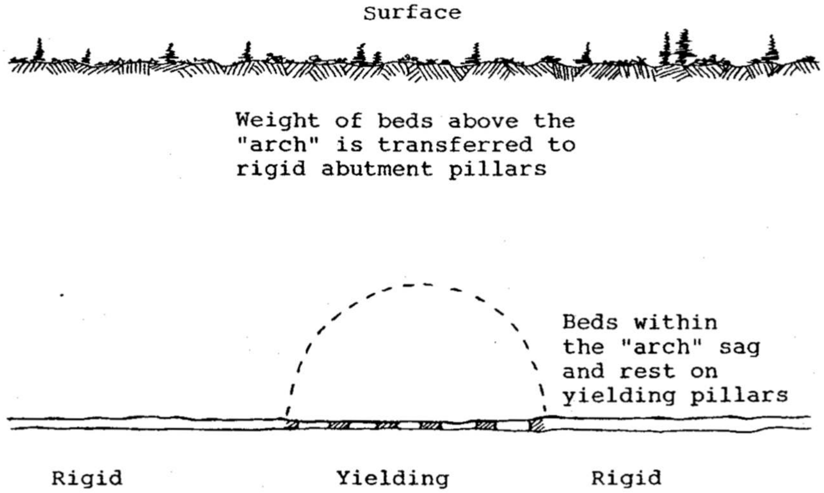


Fig. 4 Principal of yielding pillar/pressure arch mine design.

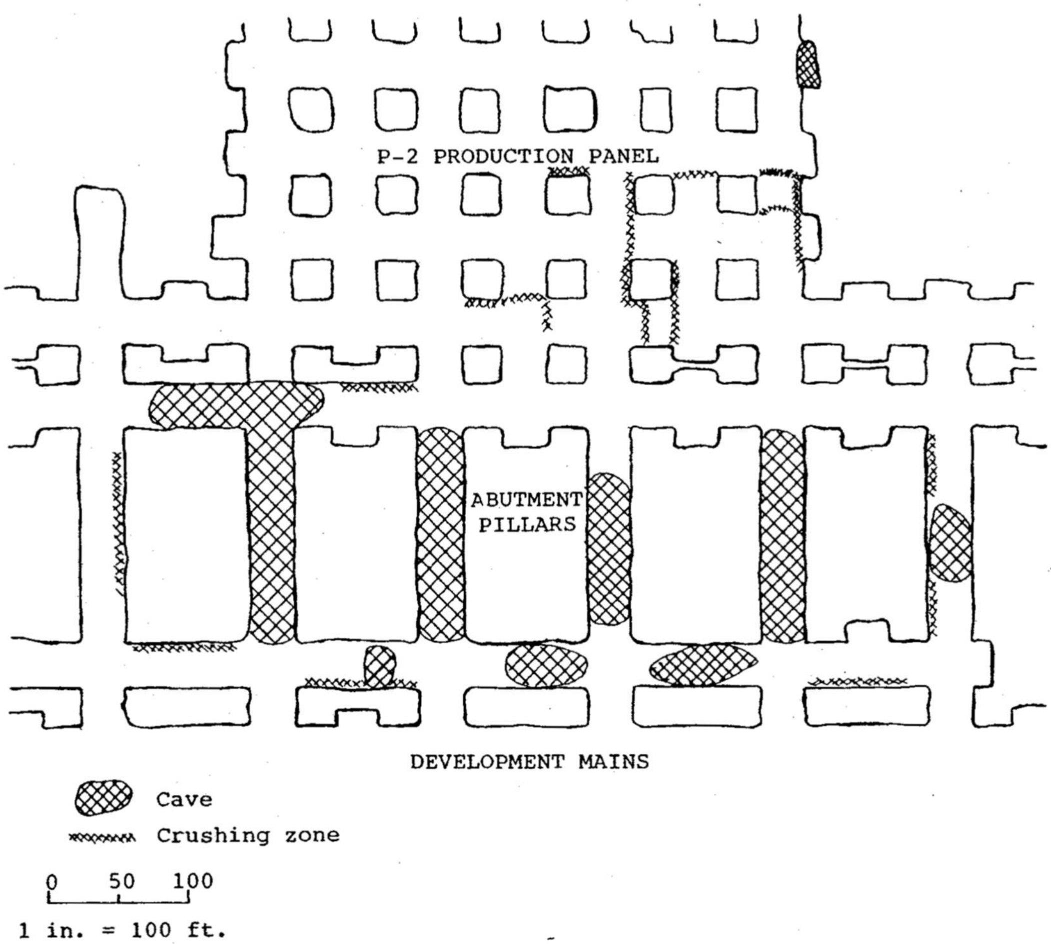


Fig. 5 Map showing caves among large abutment pillars on south end of Panel P-2.

NOTCHING OF ABUTMENT PILLARS

During mining of the second yielding pillar panel (P-1), production crews mistakenly started entries and crosscuts in abutment and transition pillars. It was soon noticed that roof conditions and roof to floor convergence measurements were better near those mistakes than in adjacent areas, as shown in figures 6A and 6B.

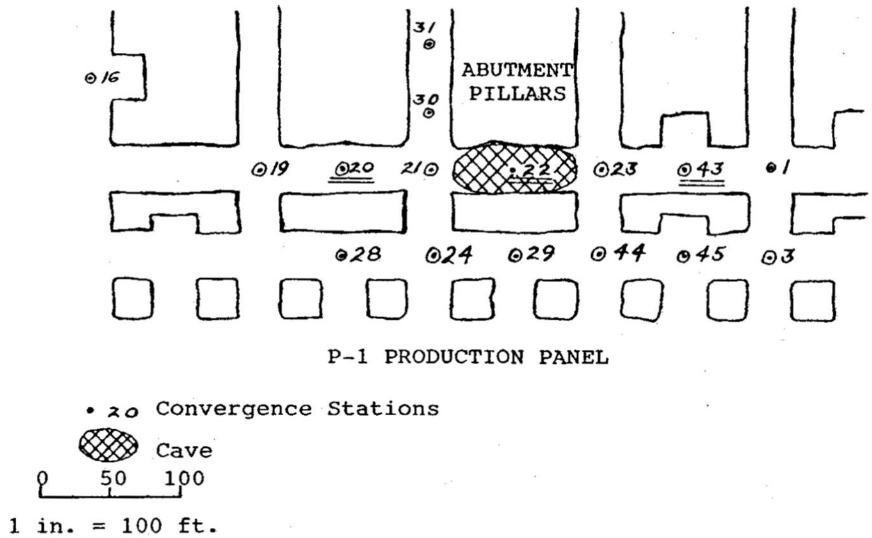


Fig. 6A Map showing location of inadvertent abutment pillar notching and locations of convergence stations.

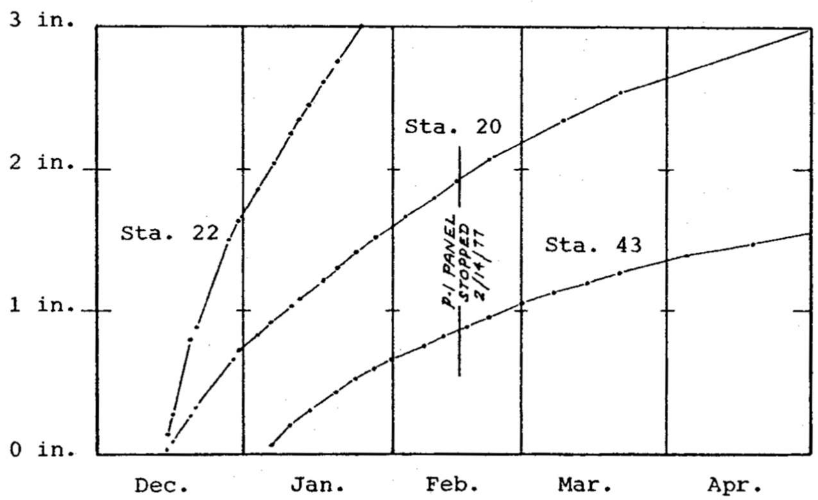


Fig. 6B Graph of roof to floor convergence at stations near inadvertent pillar notching

Mining plans were changed, and all abutment pillars were "notched" purposely. The notching was done by starting a crosscut into the abutment on the same centerline as the crosscut within the panel. These notches were driven as soon as they could be turned, one cut (12 feet), and after mucking out, were left unbolted. Notching the abutments did improve roof conditions somewhat in the abutment entries, provided some cheap muck (no bolting cost), and gave production crews additional places to work.

Careful observation showed that the crushing and shearing was still taking place, parallel to the direction the abutment entry was driven in spite of the notches, but that the position of the crushed zone was changed by the notches. Adjacent a "stub", the crushing was in the entry, but adjacent a notch the crushing was curved into the notch. See figure 7. This led engineering to try driving the notches two cuts deep, so that the crushing zone would move further into the notches and be supported by the stubs.

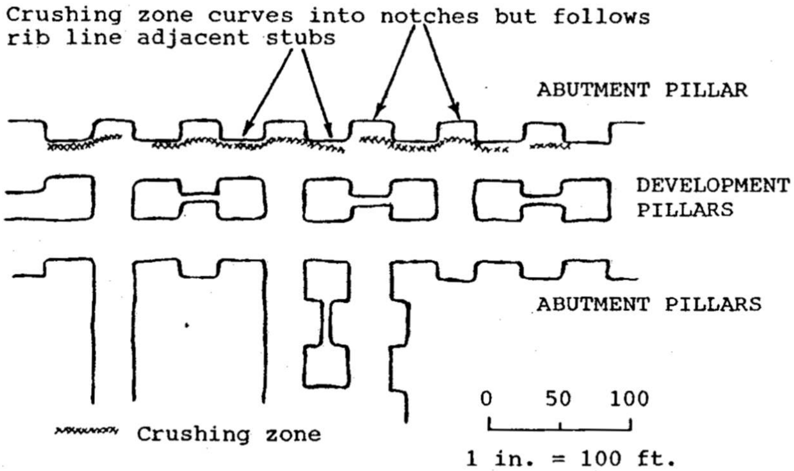


Fig. 7 Map showing change in position of crushing zone in response to notches 12 feet deep.

Mining of panel P-4 was carried out by driving 3 entries north, widening out a "T" east and west and retreating south 8 entries back toward the mains. All entries were 32 feet wide, on 56 foot centers. On advancing the initial 3 entries, notches were driven two cuts deep (23 feet), bolting both cuts. Conditions were good in all 3 entries, with no evidence of shearing or crushing in the roof. See figure 8.

On the retreat, 4 entries were driven on each side of the initial 3, to make one panel 11 entries wide. The initial 3 entries remained in good condition, but shearing occurred at the location of the second cut of the original notches. This showed that driving the notches 2 cuts deep did move the shear zone out of the entry, and over the stubs. See figure 9.

As a result of this, all notches have since been mined two cuts deep (23 feet), with the last cut unbolted (unless the notch is planned to be driven as an entry later or used for storage). Generally, this has proven to protect the abutment entries. Under high stress conditions, notching significantly increases the life of the entries before failure.

PRECUTTING OF NOTCHES

The most recent production panel (P-10) was designed to be 8 entries wide with 36 foot rooms on 60 foot centers, but when severe ground conditions were encountered the panel was reduced to 5 entries. During mining, it was noticed that the 2 abutment entries had crushing and shearing zones their entire length, extending to within 2 or 3 cuts of the face. The notches 2 cuts deep were not providing the necessary relief. To provide for more relief, the notches were driven on 44 foot centers (instead of 60 foot centers) 32 feet wide, leaving stubs only 12 feet wide. Also, the notches were driven 4 cuts deep (46 feet). Because the shearing zone extended to within 2 cuts of the face, it was decided that the relief notch should be turned sooner. To achieve this, the undercutter sumps into and undercuts that portion of the notch that is exposed as the abutment tunnel advances. This provides only

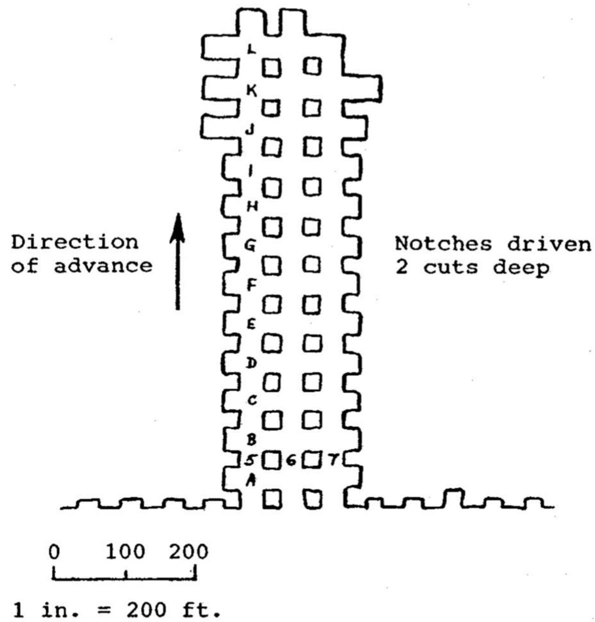


Fig. 8 3 entry development of Panel P-4 using notches 2 cuts deep (23 ft.).

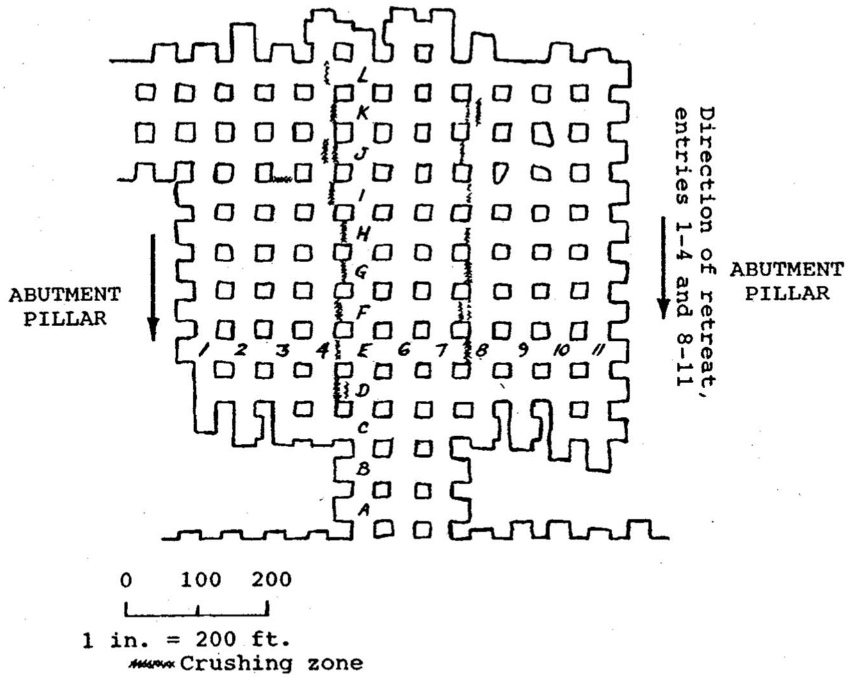
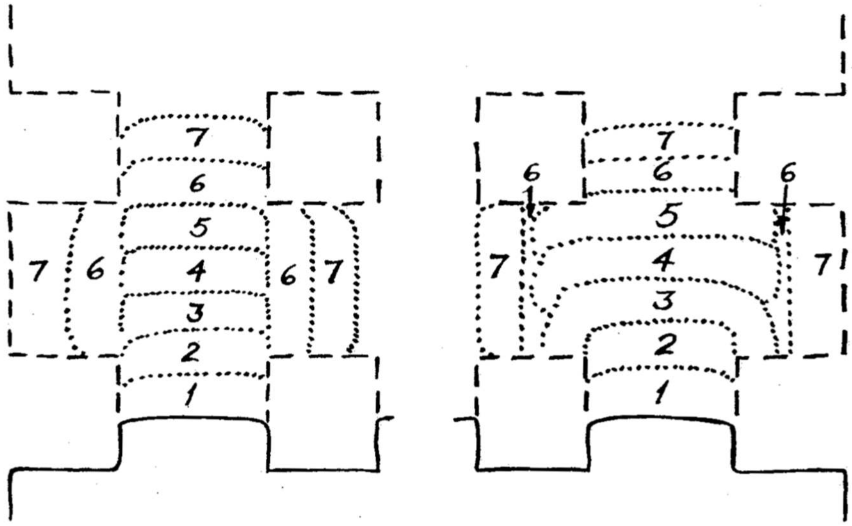


Fig. 9 Map of Panel P-4 near end of mining showing crushing zones located at the back of the development notches (see Fig. 8 for development layout).

some of the relief of a full width notch, but provides it before stresses can cause roof failure. Figure 10 shows how "pre-cutting" is achieved.



A) Conventional sequence of undercuts for crosscuts and notches. Roof crushing begins along rib before cut 6 is turned.

B) "Pre-cut" sequence of undercuts for crosscuts and notches. Stresses are relieved by cuts 3,4, and 5 before roof can fail.

Fig. 10 Plan showing method of "Pre-cutting" crosscuts and notches.

By providing relief sooner, and by mining the notches deeper, roof conditions in pane P-10 dramatically improved. The abutment entries began to behave much as the stress relieved entries within the panel. As further evidence that the shear zone has been moved over the stubs, the back 20 feet of the 4 cut notches typically have been caving within several weeks of mining, yet the abutment entries are in excellent condition. Se figure 11.

It is not known why this notching works so well. A number of factors may be contributing. The effect of notching can be likened to driving a room 78 feet wide, supported on small salt props (the stubs). This additional width may induce tension in the bottom of the roof beam which helps overcome the horizontal compressive stress. Another idea is that the additional span provides for lower compressive strain (inches per inch) by allowing the horizontal deformation to be spread over a greater length of roof. Also, it is suspected that the small stubs create lower horizontal stresses than the large pillars.

CONCLUSION

Where entries adjacent large barrier pillars must be kept open, notching of the abutment pillars has proven to relieve horizontal crushing of the roof. Like any mine design parameter, the notching pattern can be changed to suit local conditions. The notches provide additional places to work, making production crews more effective, and by leaving the back of the notches unbolted and abandoned, additional cost savings can be realized.

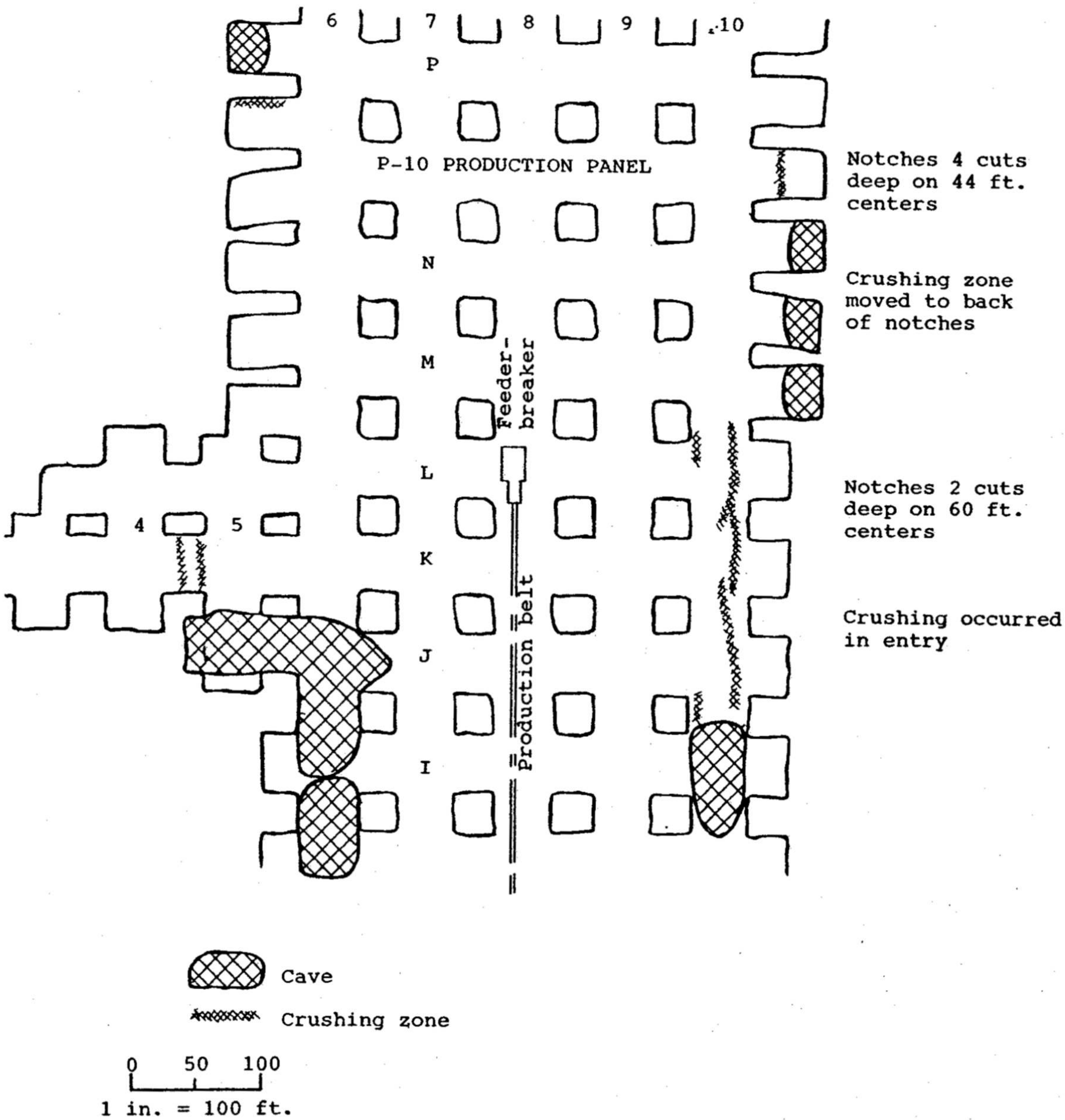


Fig. 11 Map showing dramatic improvement in roof conditions after changing notch layout and beginning "Pre-cutting" in P-10 production panel.

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