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Practical Approach to Mine Design at the Cayuga Rock Salt Mine

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ABSTRACT

The Cayuga Mine in upstate New York is the deepest rock salt mine in North America. In 1975, mining had reached depths of 840 m (2,800 feet) resulting in severe ground problems. The original mine design consisted of a conventional room and pillar method utilizing 26.7 x 26.7 m (88 x 88 feet) pillars on 36.4 m (120 feet) centers. Mining height ranged from 2.4 to 3 m (8 to 10 feet). Many roof falls were encountered, some as large as 60 m (200 feet) in length and 3.6 m (12 feet) high. It appeared that no rock bolt system was capable of supporting the roof and action needed to be taken to insure the ability to continue safely mining the deposit.

In 1976, a straight forward approach to rock mechanics was instituted starting with an observation stage involving the mapping

of ground conditions for the entire mine. The observation phase gave clues to what factors may be contributing to the problem. Next, simple rock mechanics instruments were installed, many of which were constructed in-house. Next, design changes were instituted based on real measurements and results were then measured.

As a result of utilizing a practical approach to rock mechanics, a yielding pillar design was developed with great success. Currently pillars are 4.5 x 4.5 m (15 x 15 feet) on 13.6 m (45 foot) centers and roof bolt support has been significantly reduced. Not only is the roof much safer to mine under but productivity has increased, mining costs have decreased, and ventilation has been made easier and more effective with the shorter breakthroughs of the current design.

INTRODUCTION

Mining began on Cayuga's lowest level in 1968 utilizing a typical room and pillar design for rock salt mines. The rooms were 9.7 m (32 feet) wide and averaged 2.7 m (9 feet) in height. The pillars were 27 x 27 m (88 x 88 feet) square and the extraction ratio was 46 %. Conventional mining equipment was used consisting of a Joy 15 RU undercutter, a Fletcher twin boom facedrill, a Fletcher single boom roofbolter, Wagner ST-5 LHD's and a Stamler feeder breaker. Mechanically anchored roofbolts 2.1 and 2.4 m (7 and 8 feet) long were installed on 1.2 m (4 foot) centers. A mining unit consisted of 17 entries on 36.4 m (120 feet) centers.

Production was 3,300 tons per day operating 3 shifts per day. In about 1974, uncontrolled roof falls began to occur seriously injuring one miner. In May of 1975, the entire mining front was shut down for safety reasons. After a month of lost production, mining began in another part of the mine. One year later this mining front was also threatened by failing roof. At this time, the operation turned its attention to rock mechanics to seek improvements in ground control.

At that time, the engineer on staff, along with Jack Parker and Associates, started the beginnings of a rock mechanics program which would prove to be instrumental to the success of the operation. Several months were spent thoroughly mapping roof failures throughout the entire lower level taking note of the mode, shape and direction of the failures. Two significant observations were made: 1. Mining conditions on the lower level (#6 salt bed) were favorably influenced by the mining on the upper level (#4 salt bed) 91 m (300 feet) above. (See Figure 1) 2. The mode of failure was such that, although the floor did not heave and the pillars did not fail, the load was apparently too great for the roof rocks resulting in shearing along the top of the pillars. Once the shear took place, it was a matter of time until roof bolts failed and a roof fall occurred. Some falls were over 80 m (220 feet) in length and ranged from .9 to 3.6 m (3 to 12 feet) in height. It was theorized that vertical loading on the stiff pillars resulted in horizontal stresses in the roof rocks great enough to fail the roof rocks in shear. Horizontal shifts in the roof rocks were observed to be as much as 31 centimeters (12 inches). (See Figure 2)

The solution seemed to be related to the stiffness of the pillars. It was thought that if the pillars were small enough they would yield and not accept as much vertical loading, thus significantly reducing the horizontal thrusting in the roof (Barrientos and Parker, 1974). There were some critical questions to be answered. Could loads be transferred from an area of yielding pillars to an area of stiffer pillars resulting in a bridging effect over the yielding pillar zone? If so, could a stress relief style of mining be utilized by manipulating the sizes of the pillars? In essence, could high production areas with very high extraction be created without roof problems? Could abutment zones be created in such a way that they would handle high vertical loads without the roof hazards experienced in the old design of larger stiff pillars? The answers to these questions could mean the solution to a very serious problem. The success of the operation was hinging on the fact that a better mine design was needed.

The mine took a practical approach to rock mechanics. It was thought that it would be better to use the mine as the laboratory by taking many simple measurements to determine how the rocks were behaving than to thoroughly analyze rock samples in a laboratory to provide parameters for a theoretical model. The latter approach tends to be costly and at times is not very useful. Specimens taken out of the mine don't always represent the true nature of the rock "in situ" and loading conditions experienced in the mine usually cannot be duplicated in the laboratory. This is especially true in rock salt. It was felt that the better approach would be to get many crude but inexpensive measurements right in the mine.

TECHNIQUES

An invar steel "Reed" type convergence rod (See Figure 3) was purchased and closure stations were installed in the existing design. Background measurements were needed to compare the results of any changes. Pillar expansion was also measured by borehole extensometers (B.H.E.) as shown in Figure 4, which were built in-house at very little cost. Once some base line measurements were taken, an experiment was set up to try to determine the effect(s) of yielding pillars. A summer student was then hired to help install and monitor instruments.

The first experiment involved splitting existing large pillars (27 x 27 m (88 x 88 feet)) into smaller yielding pillars (8.5 x 8.5 m) (28 x 28 feet). A site was selected near the mining front far enough from the effects of mining yet close enough to tram the muck to the feeder breaker. The measured closure rates and B.H.E. results clearly indicated that the smaller pillars did yield to their core and a transfer of load did take place from the smaller pillars to the adjacent larger pillars. General observations showed that roof conditions among the newly created smaller pillars were quite good while conditions in the surrounding area deteriorated with a roof fall occurring adjacent to the test (Petersen, et al., 1977). Based on the encouraging results of pillar splitting, a panel 61 x 182 m (200 x 600 feet), and referred to as the "NE experiment", was mined utilizing 8.5 m (28 feet) square pillars and 9.7 m (32 feet) wide entries. The results were equally encouraging and productivity was enhanced by the higher extraction ratio and shorter trams. In fact, results were so encouraging that the 8.5 x 8.5 m (28 x 28 feet) pillars were further reduced to 4.2 x 8.5 m (14 x 28 feet) by undercutting and blasting (shown in Figure 5). The additional salt was mucked out as extra production, enhancing the miners production bonus, which also created enthusiasm among the miners (Petersen, et al., 1979). Management was convinced, based on measurements and visual observations, that the yielding pillar concept was in fact doing what was presupposed. It was evident that a stress relief style of mining had been developed and the decision was made to mine the southeast quadrant (SE) in this fashion thereby affording more learning opportunities as mining progressed. In the meantime the existing mining front to the south had hit a major geological discontinuity bringing production to a grinding halt. With no other area of the mine ready for production, it was decided that all production would come from the SE quadrant utilizing the yielding pillar concept and the large pillar design was abandoned.

For the next seven years, a variety of yielding pillar configurations were tried off of the sides of a development system extending 2100 m (7,000 feet) to the east. The development consisted of 3 sets of 3 entries 9.7 m (32 feet) wide with pillars being 7.3 x 7.3 m (24 x 24 feet). Each set of 3 entries were separated by a barrier pillar roughly 45 x 45 m (150 x 150 feet) as shown in Figure 5. Conditions in the center entry were excellent. However, conditions along abutment zones were, at times, poor. Softening the edge of the abutment pillars by mining notches into them greatly improved their condition. A total of 15 production units were mined off of the development in pursuit of the best combination of pillar size, panel width, and abutment size. This mining is shown in Figure 5.

RESULTS

Rock mechanics measurements and mapped observation led to the following conclusions about mine design. Pillar size within the mining unit had the greatest impact of roof conditions. Each time the pillar size was reduced, the roof conditions improved. Currently, mining is done with 4.5 x 4.5 m (15 x 15 feet) pillars in a mining height of 3.6 m (12 feet). The performance of a yielding pillar is mostly dependent upon the width to height ratio. Therefore, mining height must be taken into account when designing the yielding pillar. It was found that a width to height ratio (w/h) greater than 3 was too stiff. Experience in another rock salt mine showed that a width to height ratio less than 1 can lead to excessive pillar slabbing and ultimately pillar failure.

Entries along stiff abutment zones tended to perform poorly and at times would fail. It was found that notching the abutment was an effective stress relief technique and when done right abutment entry conditions greatly improved (Plumeau and Petersen, 1981). The primary purpose of the abutment zone is to provide support for the transferred load. As panels were stacked up side by side in sequence, the load transfer across various abutment widths to the next panel was measured by closure points. As shown in Figure 6, it was found that a minimum width of 76 m (250 feet) was a good size to use to carry the overburden loads and to isolate one panel from another.

It was also found that the wider the mining panel, the greater the closure was within the panel. It was theorized that if the zone of yielding pillars got too wide the bridging effect over the panel would be lost subjecting the yielding pillars to excessive loading, which would be undesirable. An attempt was made to approach this critical width and an area called P-3 was mined out 210 x 210 m (700 x 700 feet) with 7.2 x 7.2 m (24 x 24 feet) pillars (see Figure 5). Even though mining pressures at the face were high, causing some problems, the area remains stable even today (13 years later). It was concluded that a maximum panel width of 150 m (500 feet) was a good rule of thumb to follow.

Once the SE quadrant was no longer economical to mine, plans were made to mine the NW quadrant utilizing a design derived from the seven years of development and experimentation in the SE quadrant. Development of the NW quadrant began in 1984 starting near the shafts, and was in essence the start of a new mine. It was decided to mine the main 4550 m (15,000 feet) to the boundary utilizing a six entry system with 6.1 x 6.1 m (20 x 20 feet) pillars on 15.1 m (50 foot) centers. This was completed in 1990 and is shown in Figure 7. During the development, an occasional production unit was mined on the advance to subsidize production quotas. However, most of the salt deposit was left to be mined on a retreat from the boundary back to the shaft, leaving mining induced problems behind. The latest production panel was a nine entry system utilizing 4.5 x 4.5 m (15 x 15 feet) pillars on 13.6 m (45 foot) centers. The panel is 148 m (490 feet) wide including 15 m (50 feet) of notching on each side. The abutment zone is designed to be 91 m (300 feet) wide.

CONCLUSIONS

Mining conditions with the yielding pillar design in the NW quadrant are excellent, even in the outside entries along the abutment zones. Productivity has been increased by over 60% and is at an all time high, in part due to the new mine design. The improved roof conditions have lessened the need for roof support, have virtually eliminated falls of ground, and have significantly reduced injuries due to falls of ground, or scaling. In addition to better roof conditions, the design has lent itself to easier ventilation, shorter hauls to the feeder-breaker, and shorter equipment moves from one entry to the next. The practical approach to mine design by mapping observed ground conditions and by taking simple measurements has handsomely paid off at the Cayuga Mine.

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Illustration Captions

Figure 1 Partial geologic section showing location of No. 4 and No. 6 salt bed.

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

Figure 3 "Reed" type convergence rod.

Figure 4 "Homemade" borehole extensometer.

Figure 5 Map showing SE quadrant of the Cayuga Mine.

Figure 6 Influence across abutment pillars.

Figure 7 NW quadrant mining.

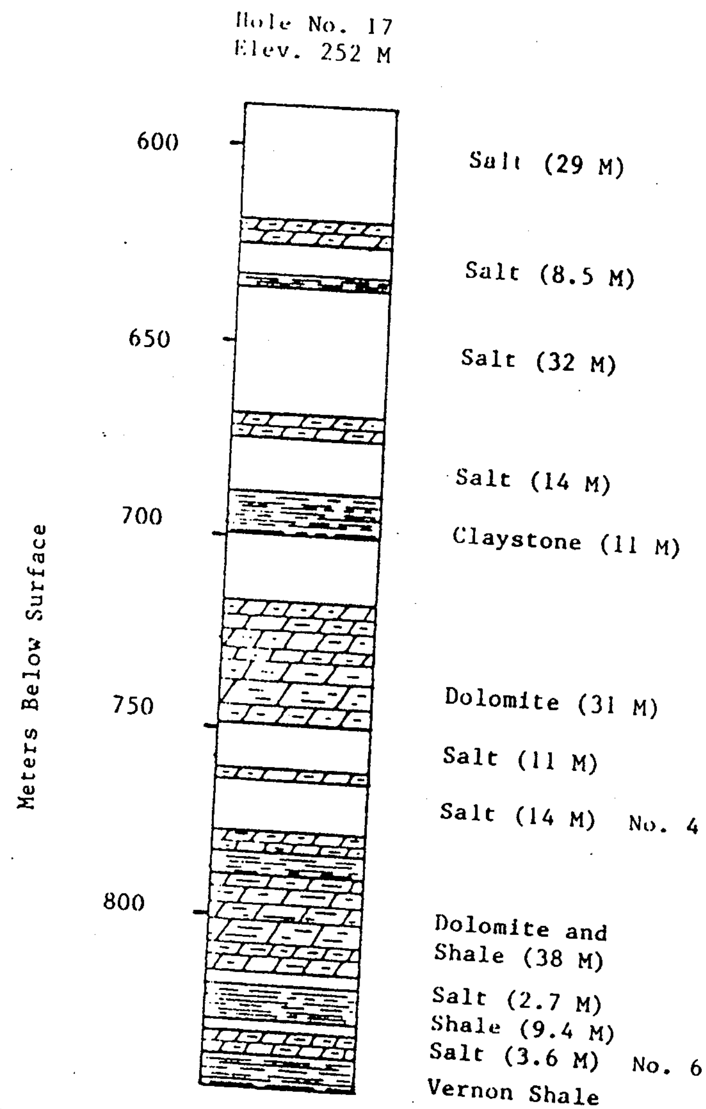

Fig. 1 Partial geologic section showing location of No. 4 and No. 6 Salt Bed

Petersen

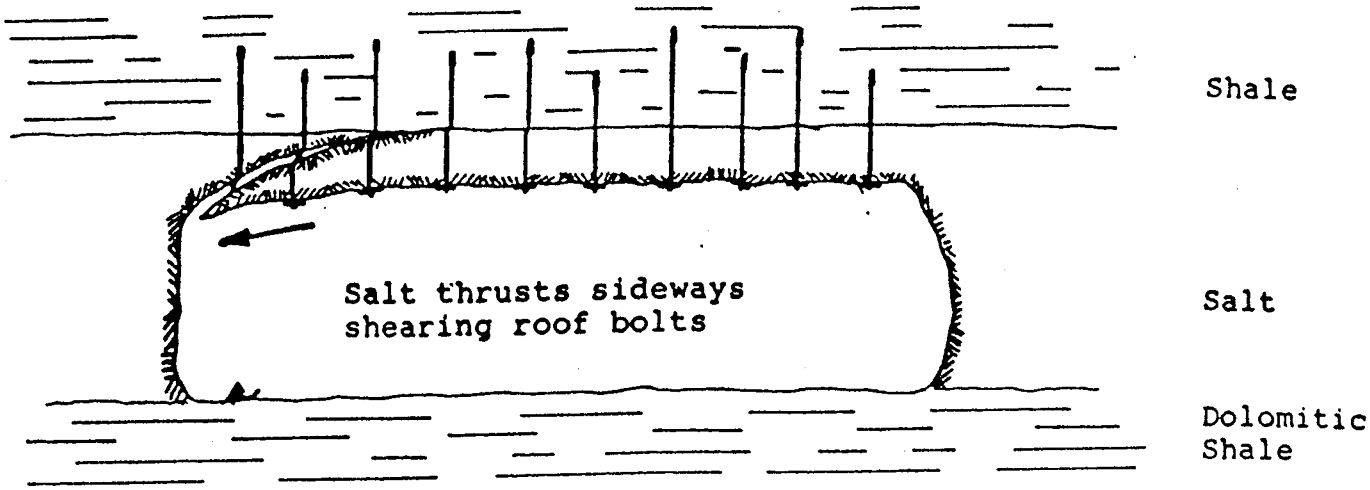

Fig. 2 Cross section of typical roof failure in salt roof.

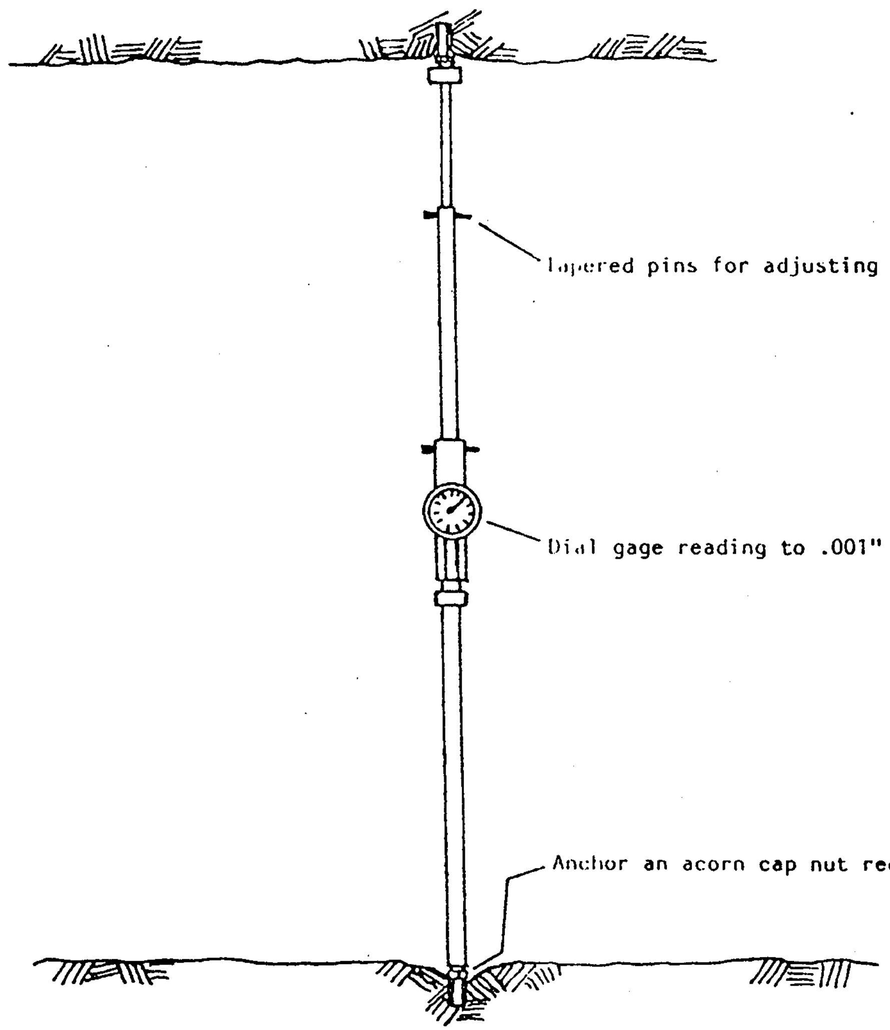

Fig. 3 Reed Type Convergence Rod

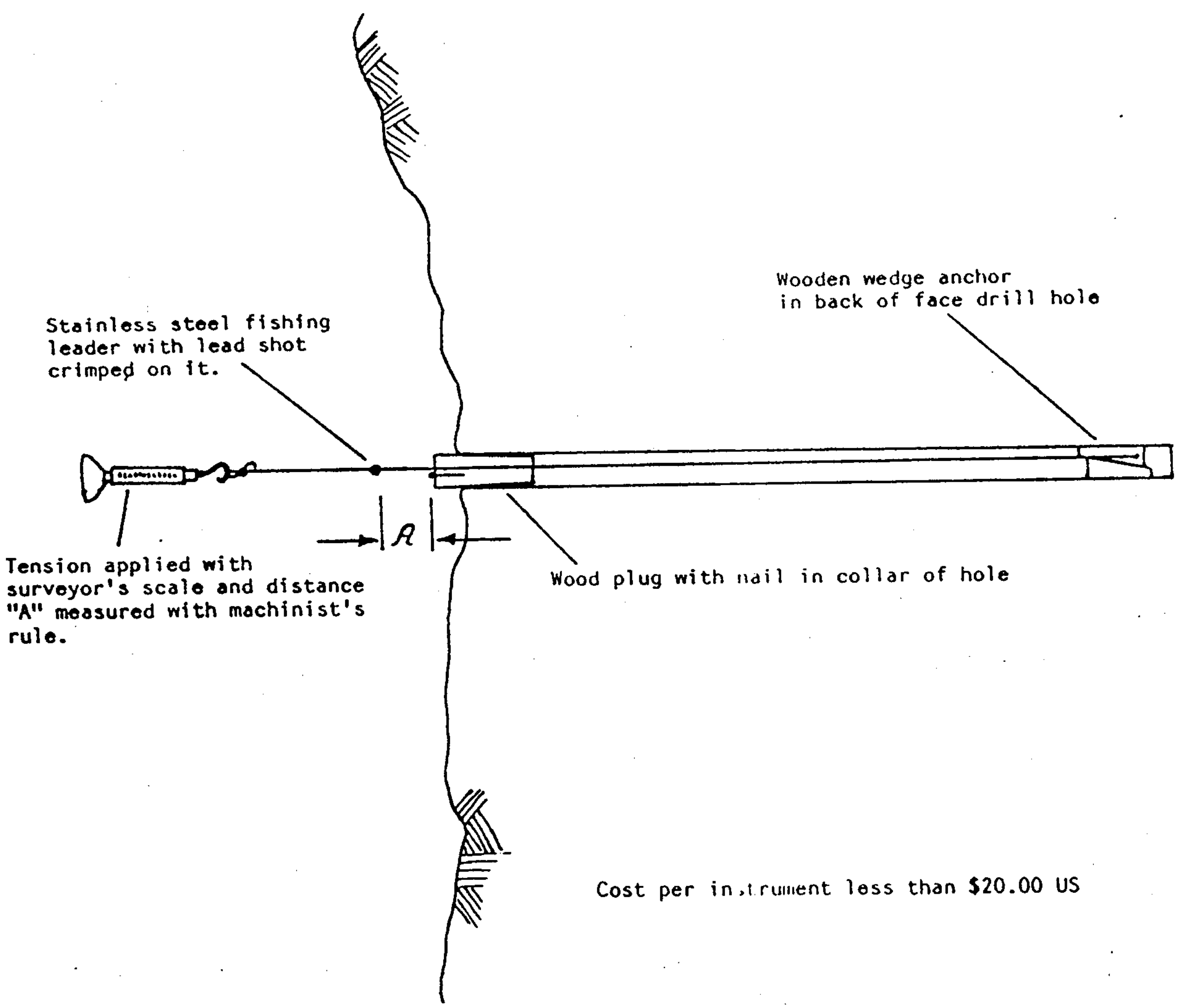

Fig. 4 Home - Made Borehole Extensometer

Petersen

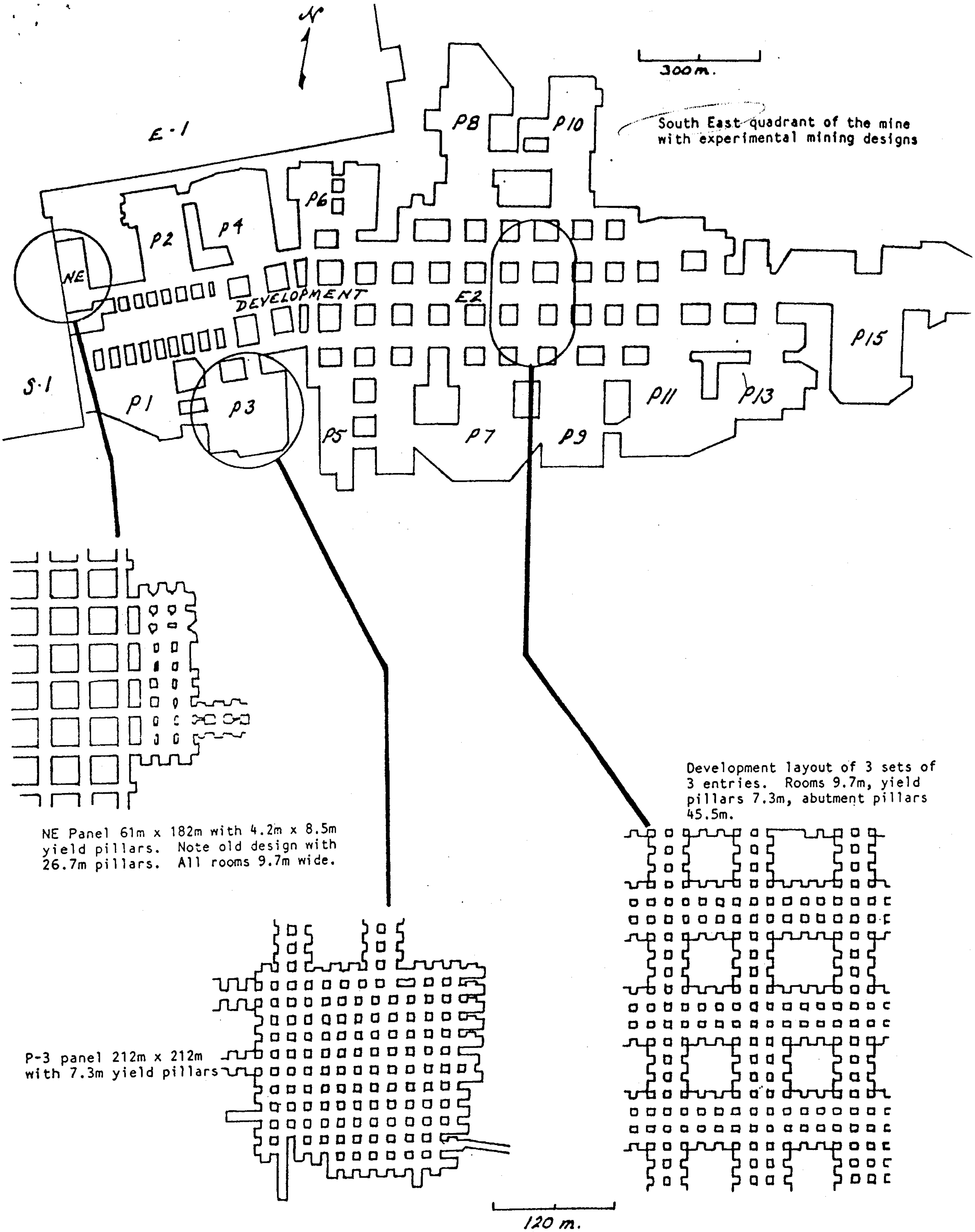

Fig. 5

Petersen

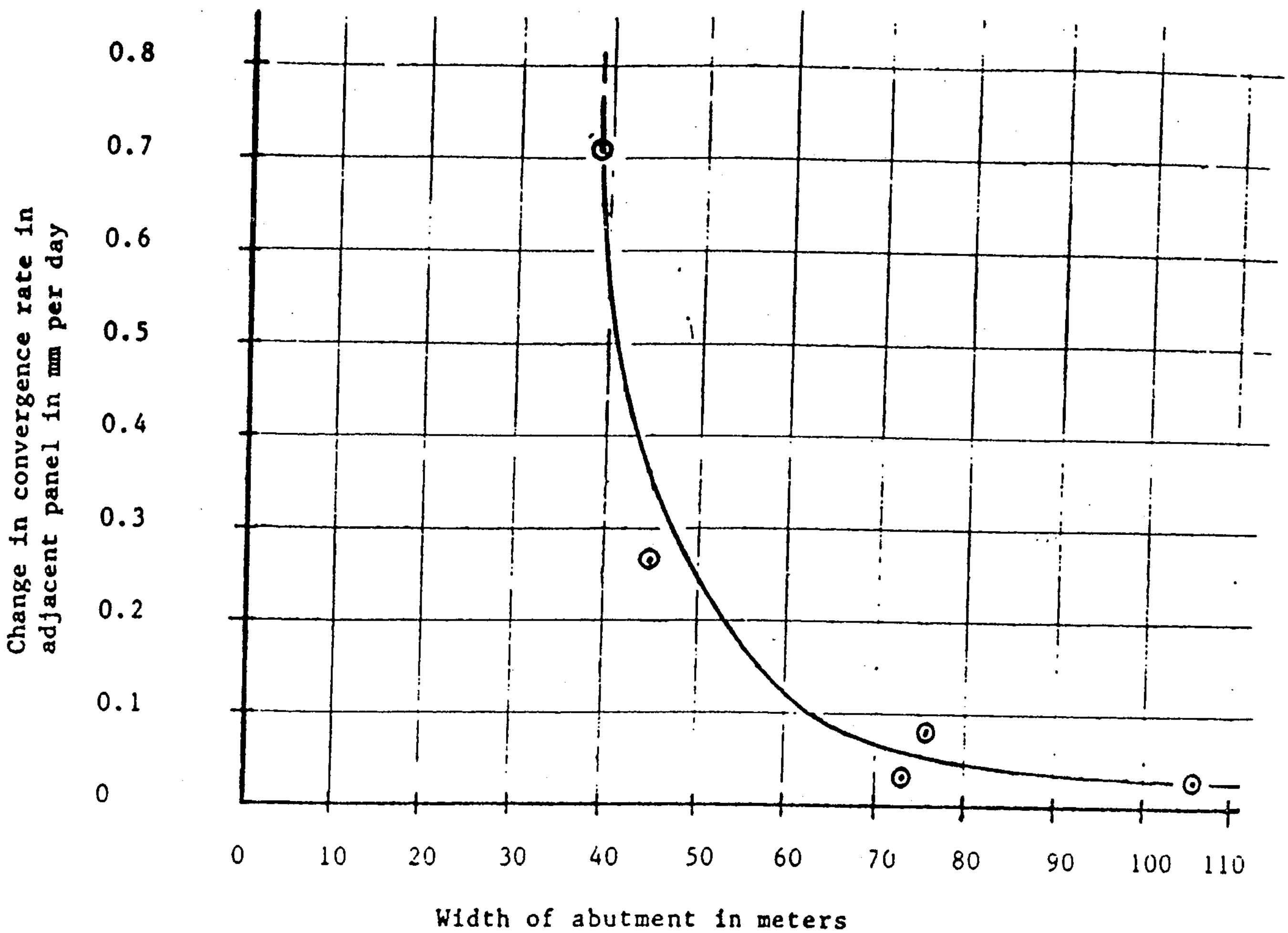

Fig. 6 Influence across abutment pillars

Petersen

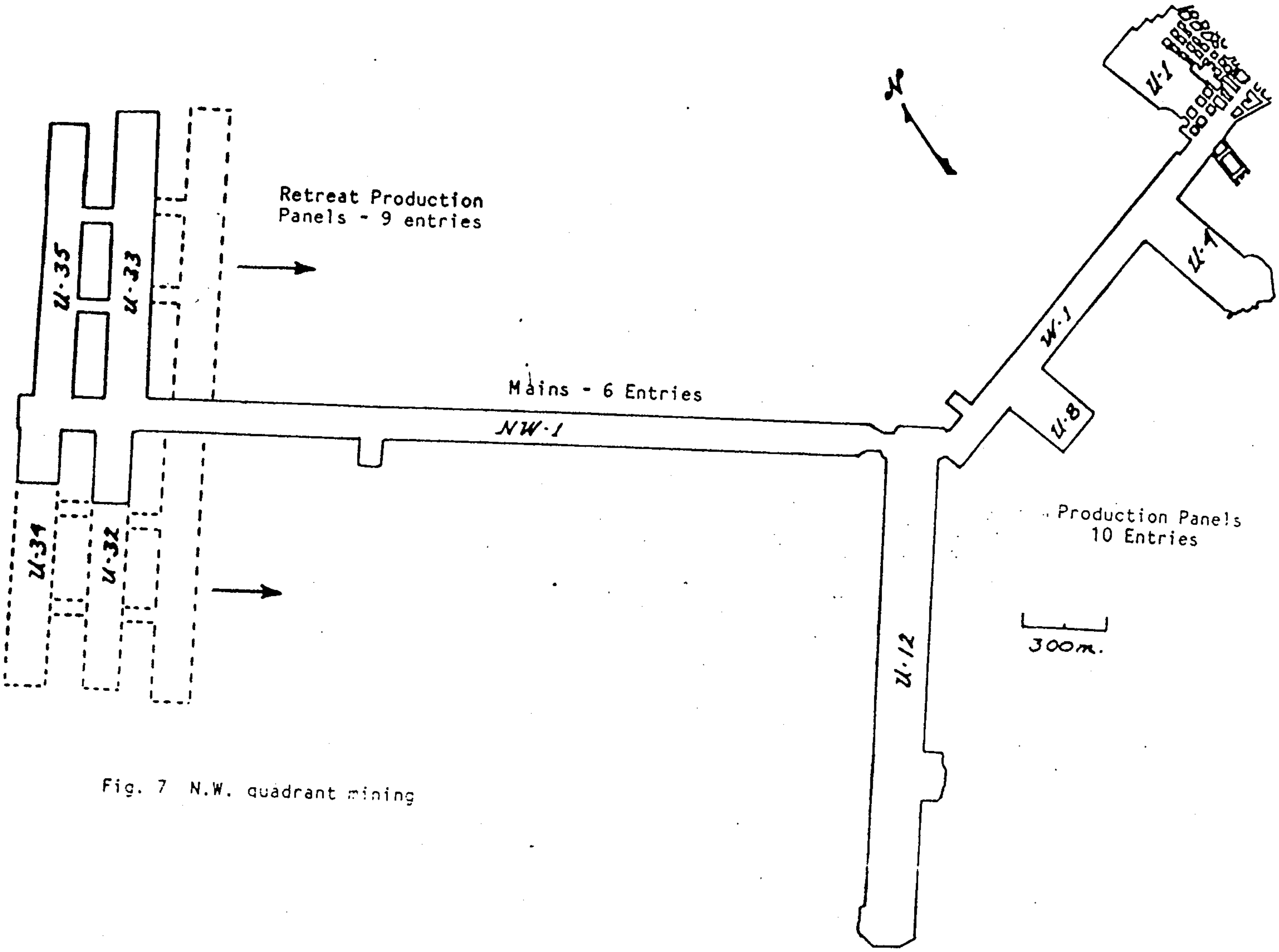

Fig. 7 N.W. quadrant mining

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