PILLAR RECOVERY AT THE BUICK MINE

by

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INTRODUCTION

The Buick mine, located 195 kilometers (120 miles) southwest of St. Louis in the Viburnum Trend, is owned and operated by Homestake Mining Company. The mine produces lead and zinc ore from a room and pillar mining method at a depth of approximately 335 m (1100 ft).

The Buick orebody typically averages 60 to 120 m (200 to 400 ft) in width with ore thicknesses ranging from 2.4 to 36.6 m (8 to 120 ft). The mine is divided in two; the halves are referred to as the North mine and South mine orebodies. The North mine orebody contains the higher grade ore; however, the developed reserves for the South mine orebody comprise about 60 percent of the total developed reserves for the Buick property. Existing pillars represent one-third of the total developed reserves.

SCOPE

The developed ore reserve grade is dropping at Buick because most of the ore being mined is coming from the South mine, which has a 6 percent lower grade than the North mine. To offset this lower grade, a pillar recovery program has been initiated for the North mine so that the mill feed grade can be maintained. The objective was to recover at least 75 percent of the contained metal without disturbing the overlying Davis Shale. The 75 percent metal recovery translates into approximately 50 percent pillar recovery if only selected pillars are mined. One constraint on the pillar recovery is that the Davis Shale must not be disturbed to the point that aquifers above it might be affected. This is more confining, from a design standpoint, than not allowing any detectable surface subsidence.

Approximately ninety percent of the mining at Buick is done on mineral leases owned by the United States government. Current government regulations do not prohibit surface subsidence.

Work that has been done to determine what appropriate amount of pillar recovery can be accomplished without disturbing the Davis Shale near its contact with the overlying aquifers is described in this paper.

Call & Nicholas, Inc. was employed by the Buick mine staff to work with its personnel in designing and testing a pillar recovery progam.

PILLAR RECOVERY PROGRAM

The pillar recovery program included the following steps:

1) define possible areas for initial mining;

2) collect pertinent geotechnical data and analyze to determine which pillars to recover;

3) mine the test area and monitor ground movement; and

4) repeat steps 2 and 3 as new conditions are encountered (i.e., different geometry or geology).

The initial mining area was chosen in areas where pillar heights were less than 11 m (35 ft) and where a failure would not affect a large area of the mine. The area tested, Area 5, is in the northern end of the South mine and is isolated on the eastern edge (Figure 1).

The geotechnical data to be collected included geology cross-sections, geologic structure, rock strengths, and in-situ stress measurements. The pillars to be recovered were deter-

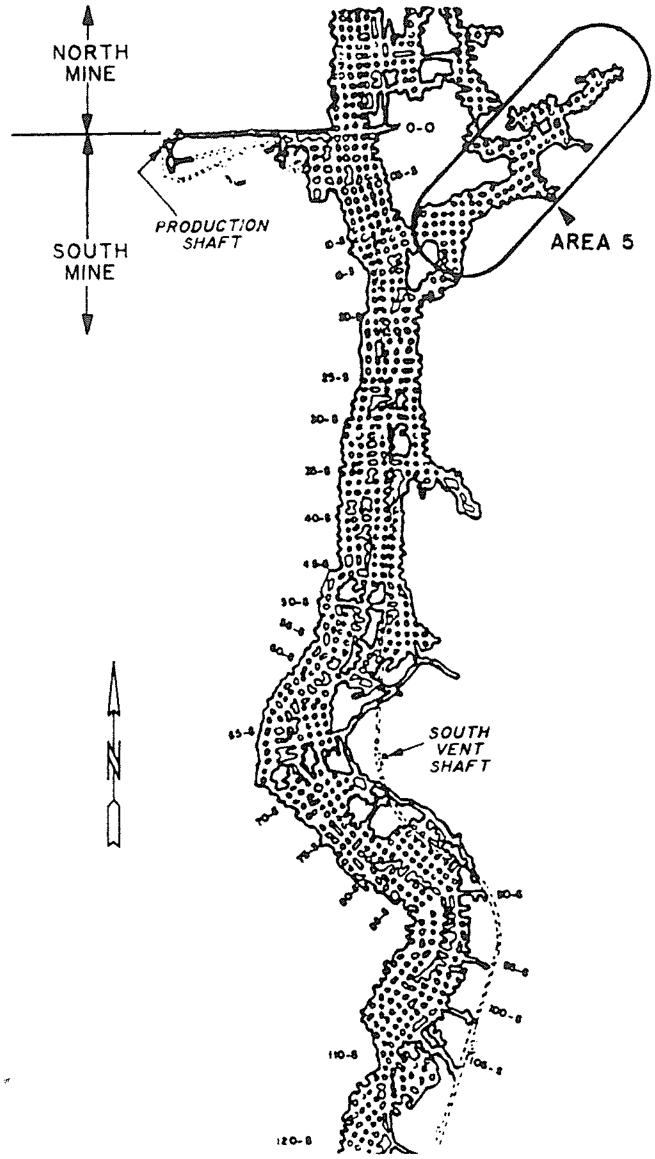


Figure I. Location of Area 5: Buick Mine.

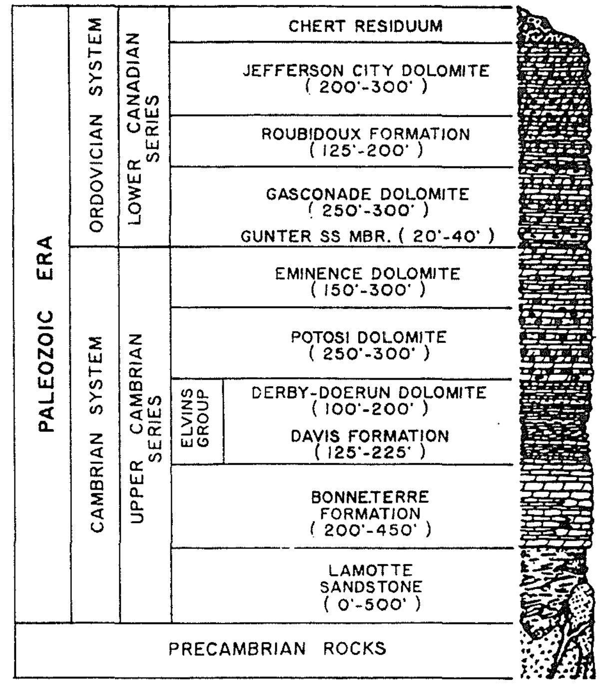


Figure 2. Generalized Stratigraphic Column of Viburnum Trend Area (from Hayes, 1961).

mined based on the maximum roof span attainable and maximum load carrying capacity.

The pillars in Area 5 are currently being mined, with a recovery of over 75 percent expected. Rock movement monitoring is being done concurrently with mining.

GEOLOGY

Figure 2 shows a typical stratigraphic section in the area of the Buick mine. The ore zones generally occur in the upper 10 m (100 ft) of the brecciated reef Bonneterre Formation. The Bonneterre Formation is approximately 91 m (300 ft) thick and is underlain by the Lamotte Sandstone. Above the Bonneterre, the Davis Shale is approximately 46 m (150 ft) thick and is overlain by various types of dolomites for 259 m (850 ft) to the surface.

Figure 3 details the geologic units in the Bonneterre Formation. The highest grade ore occurs mainly in the C1 through C4 beds. These calcarenite beds range from brecciated to bedded. Above the C4 bed is a series of units referred to as the variable beds, V-1 through V-4. They are interbedded green fissile shales, carbonates, and pebble conglomerates. Throughout the ore zone, and especially in the variable beds, are partings of insoluble beds which form planes of weakness.

The Davis Formation is a green fissle shale similar to that found in the variable units. It ranges from 3 to 25 m (10 to 80 ft) from the top of the ore zone.

DATA COLLECTION OF AREA 5

Geology: Geologically, Area 5 is somewhat anomalous because of the narrow 55 m (180 ft) width (Figure 1) and its stratigraphic location (Figure 3). The average pillar grade is 15 percent Pb and 4 percent Zn, and the pillars are all less than 35 ft high. The rock is brecciated but well healed, exhibiting bedding only in the back. The Davis Formation is approximately 25 m (80 ft) above the roof in Area 5.

Geologic Structure: Because of brecciation and rehealing, there was little structure to map; however, most of the pillars included a thin (2 m) layer of bedded dolomite. We noted how much of the pillar was comprised of this bedded zone and its location within the pillar height. Within these bedded units the structure data was mapped using the cell mapping technique (Call & Nicholas, 1980). Cell mapping consists of measuring the mean orientation, fractures per foot for a joint set, and the longest joint observed. The Schmidt

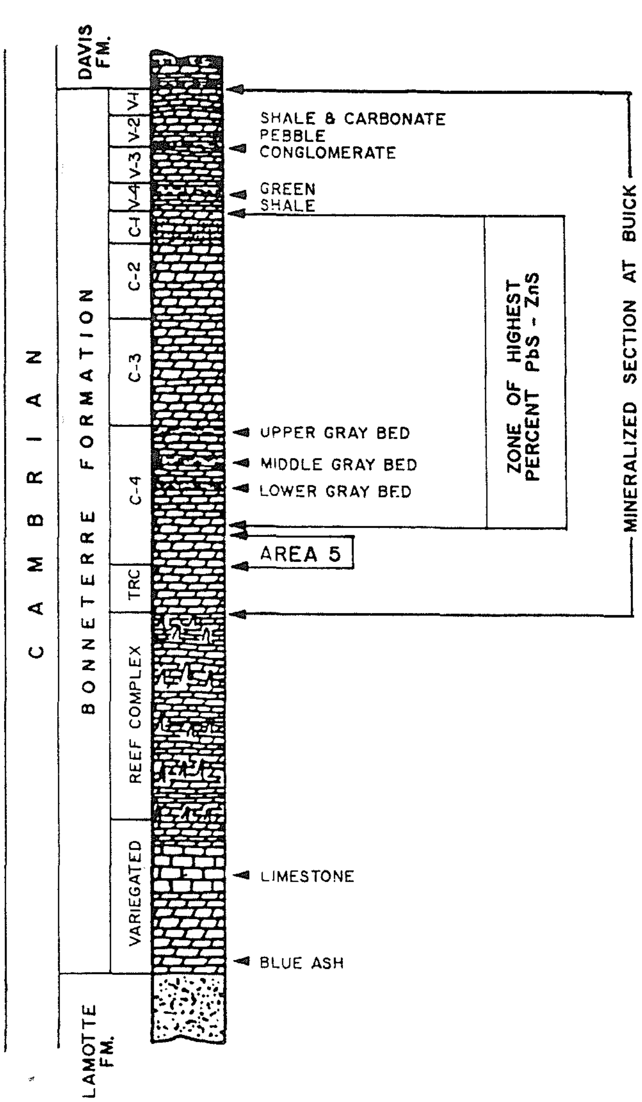
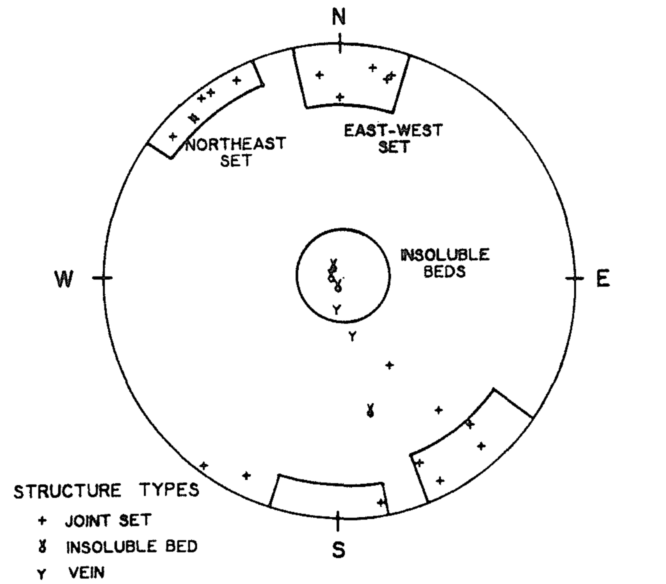


Figure 3. Stratigraphic Column of the Bonneterre Formation at the Buick Mine.



LOWER HEMISPHERE EQUAL AREA SCHMIDT PLOT

SET NAME	DIP DIRECTION	DIP	SPACING (METERS)	LENGTH (METERS)
NORTHEAST	322	89	0.43 (1.4 FT)	1.74 (5.7 FT)
EAST-WEST	181	78	0.12 (0.4 FT)	0.55 (1.8 FT)
INSOLUBLE BEDS	16	8	3.96 (13.0 FT)	6.77 (22.2 FT)

Figure 4. Structure Data for Area 5: Buick Mine.

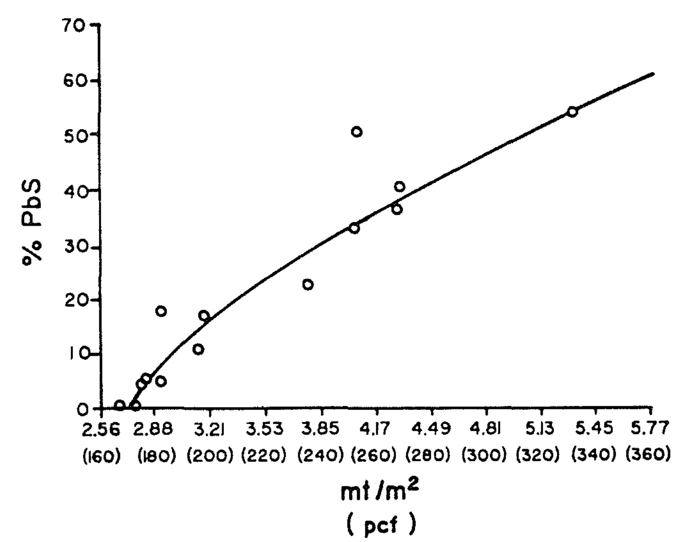


Figure 5. % PbS vs Density.

plot (Figure 4) shows the plotted data and a summary of the joint characteristics.

In addition to the structure mapping, three vertical holes were core drilled into the roof of Area 5 (Figure 9) to determine the distance to the Davis Shale and to obtain information on the characteristics of the roof material. From the drill core the RQD, average core length, percent broken zone, the rock hardness, and the average spacing of the insoluble beds were determined. The RQD's and percent broken were found to be similar between the calcarenite beds and the variable shale beds; this was not expected. It has not been observed elsewhere in the mine.

Rock Strengths: Strength testing of drill core included uniaxial compression, triaxial compression, Brazilian disk tension, point beam tension tests, and direct shear tests. The units tested included ore, calcarenite, variable shale units, and Davis Shale. Because of the soft nature of the ore, an attempt was made to correlate ore grade with the rock properties. Correlations were found to exist between

Density and % Lead (Figure 5)
Density and Compressive Strength (Figure 6)
Density and Young's Modulus (Figure 7).

Poisson's Ratio was found to be independent of density (Figure 8). Based on this work the ore zone was divided into three groups for reporting strengths. Table 1 summarizes the results of the rock strengths for Area 5.

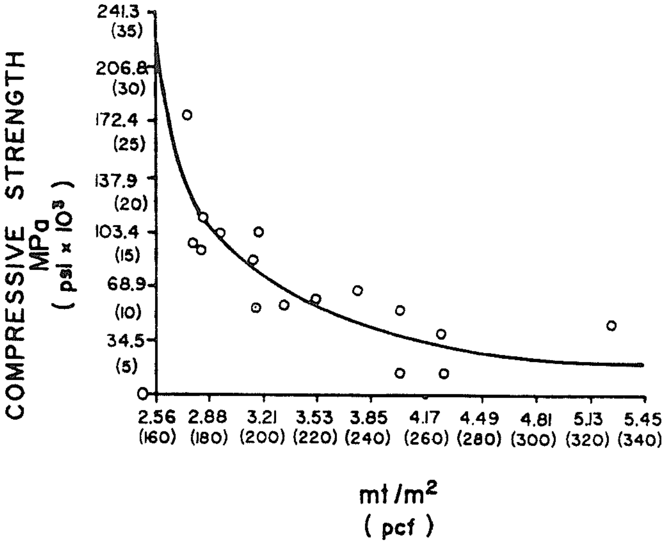


Figure 6. Compressive Strength vs Density.

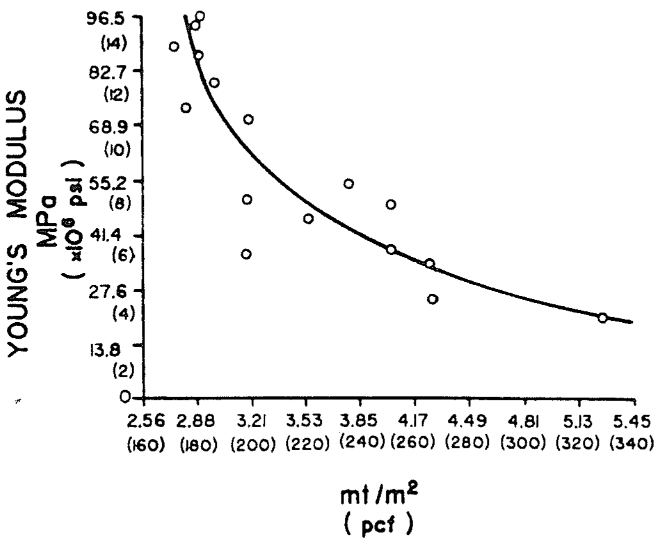


Figure 7. Young's Modulus vs Density.

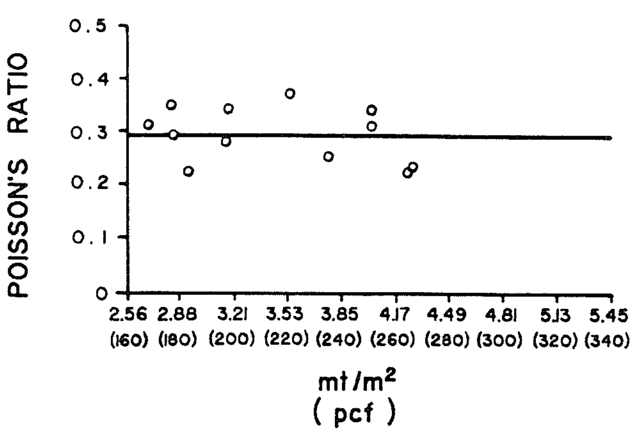


Figure 8. Poisson's Ratio vs Density.

In-Situ Stress: In-situ stress measurements were made in four pillars in Area 5 (Figure 9). The overall purpose of these measurements was to determine the present vertical load on the pillar. Measurements were taken on two sides of the pillar, with at least three stress measurements made on each side. The "Leeman" doorstopper technique was used. The measurements were done at various depths into the side of the pillar to determine the distance to the confined core of pillar (Wilson, 1972).

The vertical stress in the pillar was less than the overburden load based on the tributary-area basis; however, this was expected. The horizontal stress in the pillar was 1 1/2 to 2 times the vertical stress on the pillar. Because the pre-mine stress was not measured, we have assumed that the vertical stress is equal to the overburden load and the horizontal stress equals the vertical stress. Measurements from mines in the area indicate that the horizontal stress is approximately twice the vertical stress.

Hydrologic Conditions: Area 5 is basically depressurized with minimal dripping of water from the roof. The mine is currently pumping 200 ℓ/sec (3200 gpm), indicating the ore zone and immediate roof are probably depressurized.

ANALYSIS FOR PILLAR RECOVERY IN AREA 5

The pillar recovery is a function of maximum room width and the load-carrying capacity of the pillars. The analysis consisted of determining

1) the load the pillars are currently carrying;
2) the maximum load the pillars can carry;
3) the maximum unsupported roof span; and
4) which pillars could be recovered based on the pillar layout.

Present Load on Pillars

From the stress measurements it was determined that those pillars near the abutment are carrying a load equal to a rock column height of around 154 m (505 ft) and that those near the center of the opening are carrying a load equal to a rock column height of around 172 m (565 ft). Using empirical data from coal primarily, the expected height of load was 122 to 145 m (400 to 475 ft). We believe the greater arch height results because the pillars are much stronger than they need to be and are, therefore, carrying more load; i.e., the pillars have not yielded. For this initial work, the load heights determined from the stress measurements were used for determining pillar recovery; the actual load heights may be more in the range of those predicted from the empirical data once the pillars have yielded.

The current load on the pillars in the center of Area 5 is 140,000 mt (154,000 tons), based on the stress measurements.

Load-Carrying Capacity of Pillars

The load-carrying capacity of pillars was calculated using Wilson's (1972) pillar analysis. Wilson's analysis was used because it incorporates the rock strengths of the material and does not use any empirical constants. Wilson believed that the pillar has two zones: (1) an outer fiber that carries little load and (2) a confined core where most of the load is carried. Using the friction angle, outer fiber strength (compressive strength of the rock mass), and the pre-mine stress condition, the distance to the confined core and load-carrying capacity of the pillar can be calculated.

The calculations using the laboratory data indicated that the distance to the confined core is around .6 to 1 m (2 to 3 ft) for a 9 m (30 ft) high pillar. However, data from the in-situ stress measurements indicate a distance of 1.7 to 2.5 m (5.6 to 8.1 ft). Accepting the in-situ measurement as our best estimate, the outer fiber strength used was reduced; so the distance to the confined core was in the range measured. The difference between the calculated and measured might be explained by the age of the pillars (15 years) and the type of blasting.

Rock properties used for the pillars that averaged between 10 and 23 percent combined Pb-Zn were as follows:

Table 1

ROCK STRENGTH SUMMARY

*Previous CNI shale testing

Rock Type	Density mt/m^3	% Pb Range	Uniaxial Compressive Strength (MPa)	Tensile Strength (MPa) Parallel to Bedding	Tensile Strength (MPa) Normal to Bedding	Young's Modulus (GPa)	Poisson's Ratio	Intact Rock Shear Strength Friction Angle	Intact Rock Shear Strength Cohesion (MPa)	Fracture Shear Strength Friction Angle	Fracture Shear Strength Cohesion (MPa)
Ore											
Group I	2.80	0-10	119.0	9.0	NT	84.0	.29	61.1	15.1	NT	NT
Group II	3.27	10-23	75.3	8.1	NT	44.1	.36	59.7	10.4	NT	NT
Group III	4.04	>23	38.9	3.7	NT	38.6	.27	NT	NT	NT	NT
Calcarenite	2.77	0	116.4	7.4	5.4	83.4	.34	66.0	13.6	38.2	0.15
Variable	2.77	0	117.7	11.0	6.6	74.4	.35	64.7	14.1	NT	NT
Davis Shale*	2.68	0	21.6	4.2	0.3	35.1	.13	36.0	4.7	23.7	0.03

*NT (not tested)

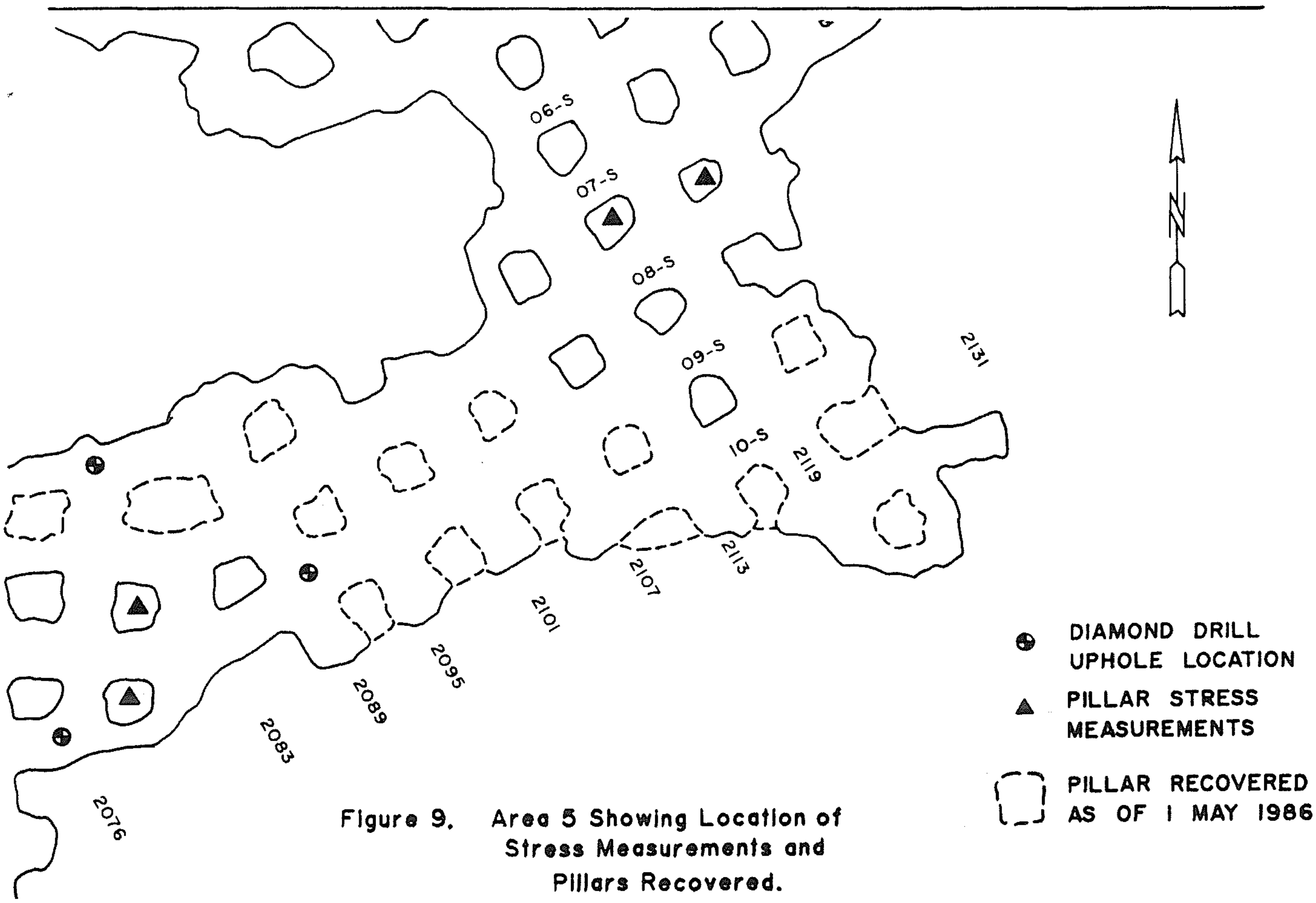


Figure 9. Area 5 Showing Location of Stress Measurements and Pillars Recovered.

Friction Angle: 59.7°
Outer Fiber Strength: 1 psi
Stress Ratio (σ_H/σ_V): 1

The average pillar in Area 5 is 8.2 m (27 ft) with an average height of 9 m (30 ft). Using Wilson's analysis, this pillar would have an average load-carrying capacity of 506,000 mt (558,000 tons). Therefore, the pillars currently have a safety factor of approximately 3.6 and could carry up to an additional ~~123,000~~ mt (404,000 tons). 366,440

Pillar Spacing (Roof Analysis)

Based on the load-carrying capacity of the existing pillars, attainable average pillar spacing is around 33 m (110 ft). However, it must be determined if the roof can support itself over this span. The maximum unsupported roof span was evaluated using the following three approaches:

1) the beam analysis with failure by tension in the center or compression on the ends;

2) shearing along vertical joints; and

3) a finite element analysis.

All of the roof analyses are sensitive to the horizontal stress. As previously discussed, the horizontal stress has been assumed to equal the vertical stress; however, the horizontal stress may be higher, as at other operations in the district.

Beam Analysis

The roof at Buick can be analyzed as a beam. The input parameters required were

Beam Thickness: assumed mean spacing of insoluble beds (3.6 m (12 ft)) but calculated for various thicknesses

Tensile Strength: assumed zero but test results indicate the insoluble beds do have some tensile strength

Compressive Strength: reduce uniaxial strength from lab results by 86 percent, based on side effects (Bieniawski, 1968)

Horizontal Stress: assumed equal to overburden stress

Density: 2.7 mt/m^3 (173 pcf)

Effects of Overlying Beds: assumed load on beam was equal to a beam thickness of 1/3 the span

All of the above assumptions are reasonable though conservative.

The beam was analyzed for tensile failure at the center and compressional failure on the ends (Figures 10 and 11). Based on the assumption of hydrostatic stress, a maximum room width of 36.6 m (120 ft) is the result from the tensile failure analysis, and 37.8 m (124 ft) is the result from the compressional failure analysis.

Shearing at Ends

The roof could fail along the near-vertical joints, which assumes that the rock between the vertical joints is rigid. The resisting force is the shear strength along the joints, and the input parameters are

1) shear strengths of natural cross-joints and

2) horizontal stress.

For a hydrostatic stress condition, a room width of 312.5 m (1025 ft) could be attained (Figure 12). This analysis results in limiting roof

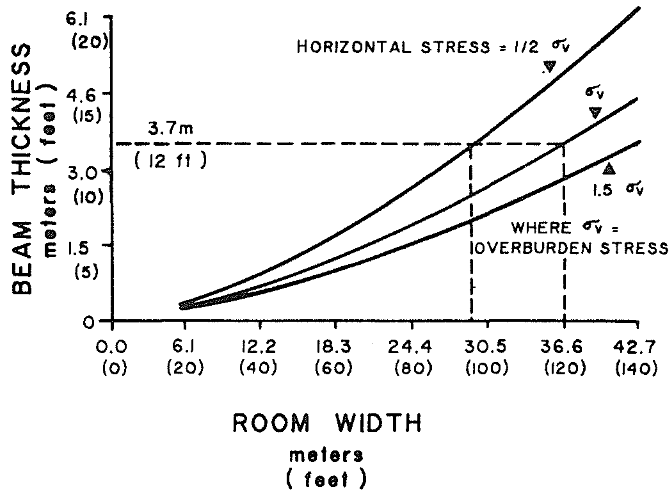


Figure 10. Beam Thickness vs Room Width for a Tensile Failure at the Center of the Beam.

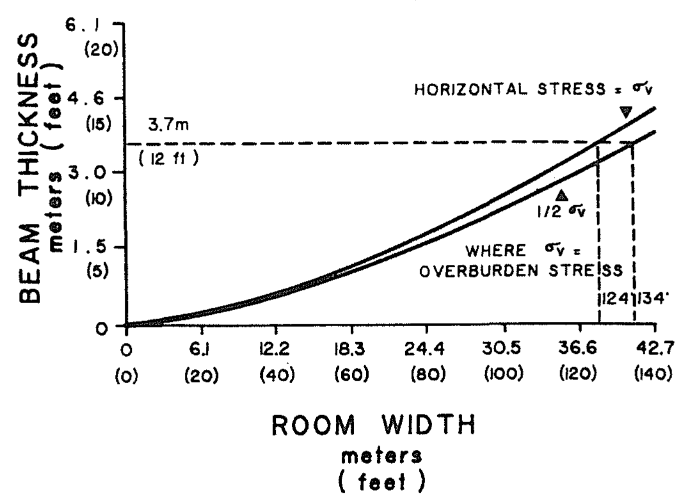


Figure 11. Beam Thickness vs Room Width for a Compression Failure at the Ends of the Beam.

spans only if the horizontal stress is much less than hydrostatic.

Finite Element Analysis

A finite element analysis was also conducted for various room widths (spans). The strengths used for this analysis are presented in Table 2.

The Young's Moduli and Poisson's Ratios used in the analysis are the result of adjustments to the laboratory data so that it more closely reflects the behavior of the rock on a larger scale. These adjustments are based on Bienawski's (1976) rock mass rating (RMR) for each unit, which incorporates the effects of fracture intensity, continuity, strength, and orientation.

The friction angle and cohesion for the calcarenite and variable units represent a combination of 23 percent intact rock strength and 87 percent fracture strength. The rationale for this is that the vertical joint set could form a continuous path for shearing if failure through 23 percent intact rock occurs. The tensile strength

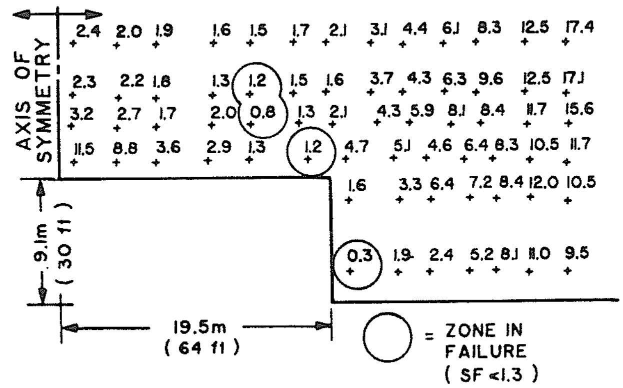


Figure 13. Safety Factor Plot of a 128 ft wide Room - Finite Element Analysis - Horizontal Stress Equal to Vertical Stress: Buick Mine, Area 5.

of the variable and calcarenite units was reduced by 50 percent, assuming that half of the insoluble beds parted during drilling; i.e., zero tensile strength. The horizontal stress condition used was hydrostatic.

Using these strengths and elastic properties, the opening does not show failure until it exceeds a width of 39 m (128 ft); i.e., at 39 m (128 ft) the roof was near limiting equilibrium and at 51 m (168 ft) it failed (Figures 13 and 14). Additional analyses at higher horizontal stress ratios indicated significantly wider room widths could be attained.

Conclusions

Based on these analyses, the maximum roof span was initially limited to 39.6 m (130 ft). With the present design pillar spacing of 18.3 m (60 ft), every other pillar could be recovered.

PROPOSED RECOVERY PILLARS

As indicated above, the roof span was limited

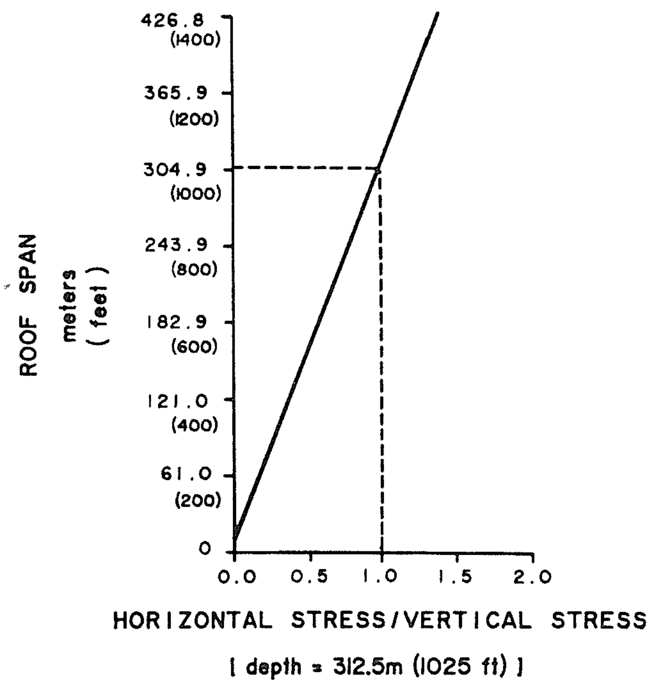


Figure 12. Roof Span vs Horizontal/Vertical Stress Ratio for Shearing at the Ends.

Table 2

PROPERTIES USED FOR FINITE ELEMENT ANALYSIS

Rock Type	Young's Modulus (GPa)	Poisson's Ratio	Friction Angle(deg)	Cohesion (MPa)	Tensile Strength (MPa)
ore (group II)	53.0	.29	59.7	0.01	8.13
calcarenite	47.5	.34	44.7	3.32	2.69
variable	45.5	.35	44.4	3.42	2.69
Davis Shale	11.0	.25	36.0	4.68	0.34

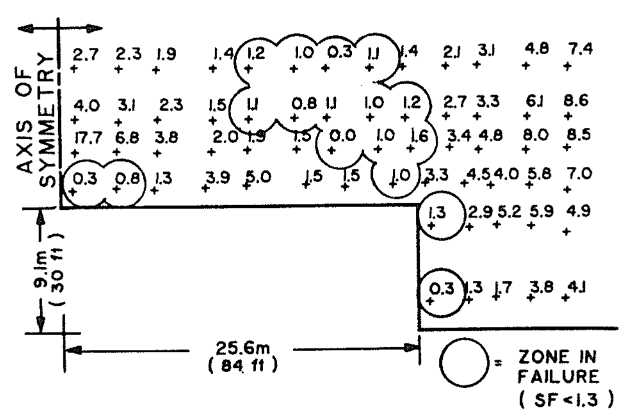


Figure 14. Safety Factor Plot of a 168 ft wide Room - Finite Element Analysis - Horizontal Stress Equal to Vertical Stress: Buick Mine, Area 5.

to 39.6 m (130 ft). From the pillar analysis, a 33 m (110 ft) pillar spacing was feasible. Therefore, an average pillar recovery of 50 percent for wide (+80 m) mining areas where the pillar heights do not exceed 9 m (30 ft) is feasible. Because of the limited width in Area 5, a pillar recovery of approximately 76 percent should be attainable.

MONITORING

Monitoring is being done using roof survey targets, hydraulic pressure cells, borehole extensometers, and tape extensometers.

The goal in monitoring is to ensure safety of men and equipment, plus to help in understanding how the ground responds during mining. It also serves as a check of the analysis.

Roof survey targets are used to monitor the roof displacement. These targets are rebars anchored at various depths, .3 m, 1.6 m, and 3 m (1, 5, and 10 ft), with bicycle reflectors attached. This system was selected over borehole extensometers because people are not allowed in an area where pillars have been recovered. The accuracy of this technique is ±.25 cm (±0.1 in.). Problems with the bicycle reflectors being destroyed during pillar blasting have arisen.

Hydraulic pressure cells were installed in numerous pillars to measure the change in vertical stress and to identify where the load is being transferred.

Initially, vertical convergence of the pillar was monitored using a tape extensometer and steel pins. However, pillar recovery operations adjacent to monitored pillars were resulting in damage to the pins. In order to have some measure of pillar deformation, borehole extensometers were installed to measure horizontal pillar displacement. Single position extensometers are manufactured at the mine. The extensometers measure .6 m (2 ft) and 3 m (10 ft) into the pillar. The collar anchor has been counter sunk to protect the equipment.

RESULTS TO DATE

Pillar recovery began in September 1985; to date 18 pillars have been recovered (Figure 9).

Initial roof spans were in the range of 24.4 m (80 ft). The roof displacement that did occur was less than the survey accuracy. The hydraulic pressure cells showed no change in stress, indicating that either the cells were not functioning or the change in stress was insignificant and all the load was being transfered to the abutments.

The roof span was increased to 36.6 m (120 ft), and again there was no measurable roof displacement or stress change in the pillar. Consequently, the span was increased to 48.8 m (160 ft). At the 48.8 m (160 ft) span a slab 3 m (10 ft) thick, 12 m (40 ft) wide, and 61 m (200 ft) failed either immediately or shortly after one of the pillars was recovered.

The slab that failed was not continuous across the full span but rather a brow that had been supported by the pillars. This brow type failure exists elsewhere in the mine. Options being considered to support these brows include long cable bolts and mining only partial pillars in the brow area.

SUBSIDENCE

As stated at the beginning of this paper, the principal design consideration was to minimize disturbance of the Davis Shale, which in turn should preclude any detectable surface subsidence. However, should the load on the pillars exceed their capacity and an area fail, the expected subsidence would be in the range of 35 to 55 percent of the mining height, 7 m (23 ft) to 17.5 m (55 ft) (Abel & Lee, 1984). Based on these values, it will be important to maintain roof stability during the pillar recovery process.

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