GROUND CONTROL IN MINING 15TH

INTERNATIONAL CONFERENCE

Proceedings

15th International Conference on Ground Control in Mining

Golden, Colorado
August 13-15, 1996

Editors

Levent Ozdemir
Kanaan Hanna
Khamis Y. Haramy
Syd Peng

Colorado School of Mines

THE INFLUENCE OF MASSIVE SANDSTONES IN THE MAIN ROOF ON LONGWALL SUPPORT LOADING

by

A.M. Richardson, *Associate*
L.J. Gilbride, *Engineer*

Agapito Associates, Inc.
Grand Junction, Colorado

and

J. Trackemas, *Manager, Technical Services*
J. Mercier, *Geologic Supervisor*

Cyprus Plateau Mining Corporation
Price, Utah

ABSTRACT

The significance of a massive sandstone unit in the immediate roof to longwall support weighting is well known. If the unit lies in the main roof above the zone of caving, its influence becomes more difficult to calculate using traditional methods. Much of the reserves at Cyprus Plateau's new, multi-seam Willow Creek Mine are located in the A Seam. The massive Kenilworth Sandstone is typically situated 21.3 m (70 ft) above the A Seam in the main roof and is on average 14.6-m (48-ft) thick, ranging to 29.0-m (95-ft) thick. This paper describes the application of distinct-element modeling to determination of the appropriate yield capacity for supports at Willow Creek. The modeling was determined to be useful for understanding support loading mechanisms and as an aid to engineering judgment in selecting supports.

INTRODUCTION

Cyprus Plateau Mining is presently developing coal reserves on Willow Creek Reserve in the Book Cliffs Coalfield of Utah, with longwall production set to commence in early 1997. Figure 1 shows the location for the Willow Creek Mine. Current plans call for initial mining in the D Seam, with subsequent mining of the K Seam and bulk of the reserves in the A Seam. Cover depths exceeding 609.6 m (2000 ft) are expected to create challenging mining conditions such as those presently experienced by other deep operators in the Book Cliffs/Wasatch Plateau Coalfields. These depths combined with variable topography and thick sandstone units in the stratigraphic sequence can complicate ground control, and careful attention to rock mechanics aspects of mine design is warranted.

One important consideration that received particular attention at Willow Creek involved the potential for increased longwall face support weighting due to sandstone units in the overburden. The A Seam, where the primary reserves are located, is overlain by the Kenilworth Sandstone, a thick unit that merited a detailed investigation. Although the general question of calculating support weighting is well addressed in the technical literature, the specific contribution of an overlying sandstone unit located in the main roof some distance above the seam is less well understood. This paper looks at the potential contribution of such a unit to support weighting.

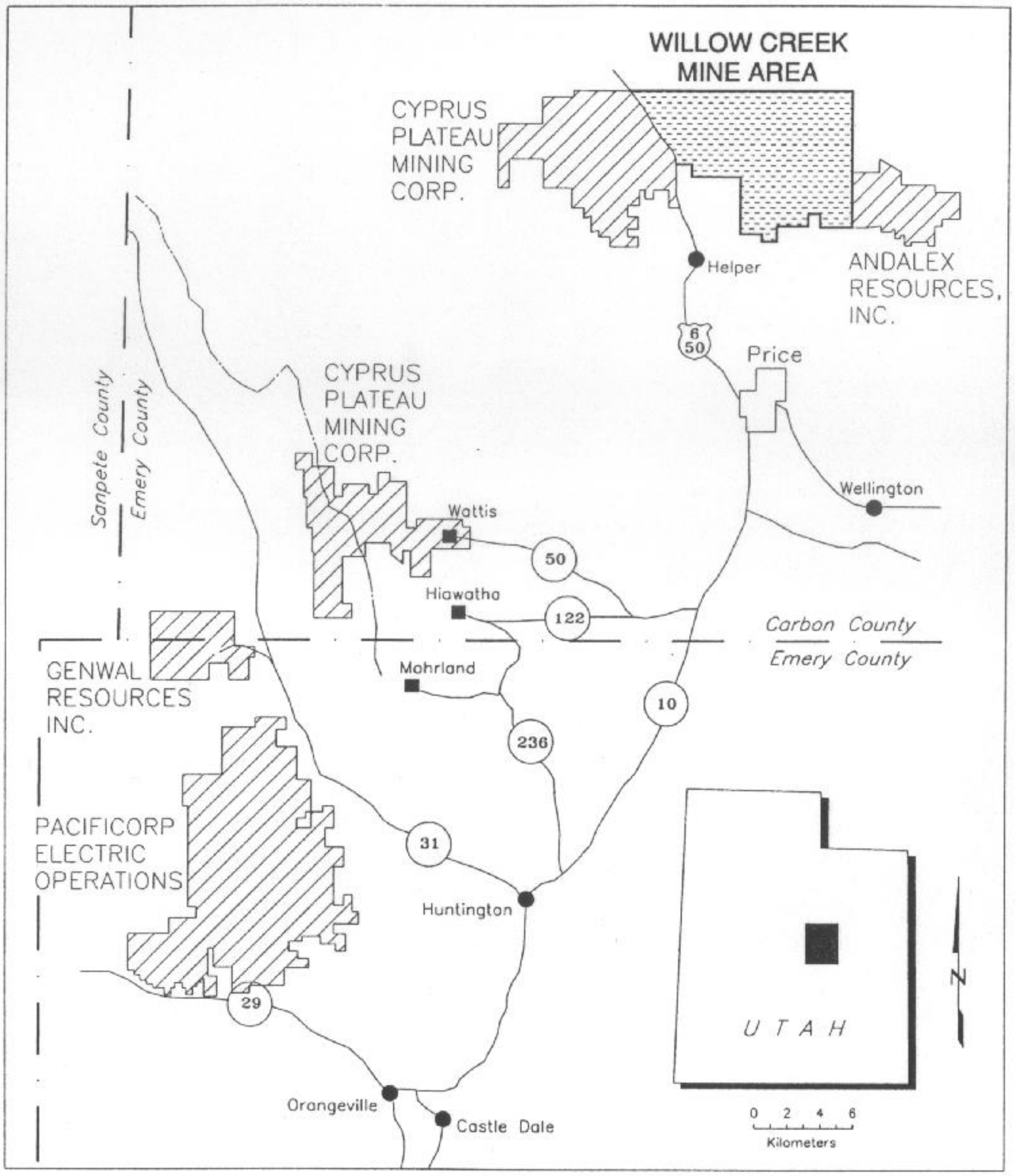

Figure 1. Willow Creek Mine Location

GEOMECHANICAL ENVIRONMENT

Factors Influencing Support Weighting

Many factors influence support weighting, the most important of which include:

- seam thickness,
- bulking characteristics of immediate roof,
- cover depth and abutment stress,
- strength and stiffness of immediate roof members,
- jointing in immediate roof, and
- cleat density in coal.

Seam thickness and bulking characteristics affect the height of the caved zone, and thereby the thickness of the shelf which the shields must support. The cover depth and consequent abutment stress induces cleavage in the immediate roof over the face and promotes caving. Strong massive members in the immediate roof can inhibit caving, and excessive weighting of supports has been reported under these conditions. When massive strata are combined with widely spaced major joint sets that are parallel or subparallel to the face, large interlocking blocks can form causing problematic support loading.

Support weighting is not a constant but varies during the mining cycle. The mean support load density is the average pressure exerted on the roof over the entire mining cycle. In the United Kingdom, a mean support load density of 9.8 t/m^2 (1 T/ft^2) has been shown to adequately control the roof strata. Under typical United States' conditions, much greater support load densities from 58.6 to 117.2 t/m^2 (6 to 12 T/ft^2) are required (Peng 1978).

The considerable depth of the D, K and A seams, typically ranging from 487.6 to 853.4 m (1600 to 2800 ft) or more, is not anticipated to lead directly to longwall support weighting problems although it will affect pillar design and conditions in the gate road. Peng (1978) asserts that there is no discernible relationship between depth of seam and face convergence. After caving has initiated, support weighting is principally dependent upon the size and geometry of loading blocks. Block size is determined by the lithologic and natural discontinuity conditions in the roof and induced fracturing. Sliding, sagging and bed separation occur beneath a pressure arch spanning from consolidated gob some distance inby the face to the front abutment ahead of the face.

At Willow Creek, the depth of cover and abutment stresses are expected to be conducive to caving in the immediate roof. Favorable triaxial stress conditions and high forward-abutment stresses are expected to induce fractures in the strata at or ahead of the face favorable to caving and beneficial for reducing support loading. The tectonic conditions in the Book Cliffs and Wasatch Plateau Coalfields, where isotropic horizontal stress is comparable to the vertical stress, are conducive to the formation of mining-induced fractures above the supports. These fractures are expected to be inclined at subvertical angles, as illustrated in Figure 2. The angle from vertical will be dictated by the magnitude of shear stress induced by differential horizontal movement between the coal seam and the contrastingly stiff first stratum (Peng 1978). Combined with the generally horizontal weakness planes, these fractures will contribute to systematic caving thereby limiting the distance of the shelf overhanging the powered supports in the gob region. Strata overhang in the immediate roof is assumed not to exceed 3.1 m (10 ft) for typical conditions.

A shelf defined by natural and induced fractures will decouple from the intact surrounding rock mass and will be isolated from the *in situ* stress field. This mechanism is portrayed in Figure 2. Support weighting becomes a function of the interaction between the shelf and the gob, independent of the stress within and around the pressure arch over the panel. Local evidence for this mechanism is provided by the successful implementation of shields throughout Carbon and Emery Counties, Utah, with yield capacities ranging from 381.8 to 618.1 t (420 to 680 T) under maximum cover ranging from 304.8 to 762.0 m (1,000 to 2,500 ft). If the full *in situ* stresses were to be carried by these supports without failure, for representative canopy bearing areas of 7.9 m^2 (85 ft^2), minimum loads would range from 6,078.1 t (6,700 T) to over 15,240.7 t (16,800 T). Unrealistic loads of this scale would necessitate shield capacities nearly an order-of-magnitude larger than currently manufactured. At Sunnyside, effective caving was achieved at depths up to 914.4 m (3,000 ft) under ridges with shields in the 444.5-t (490-T) class, light by today's standards. Conversely, there are documented cases of shields going solid at shallow depths. The "decoupling mechanism" provides the basis for all support loading models subsequently discussed.

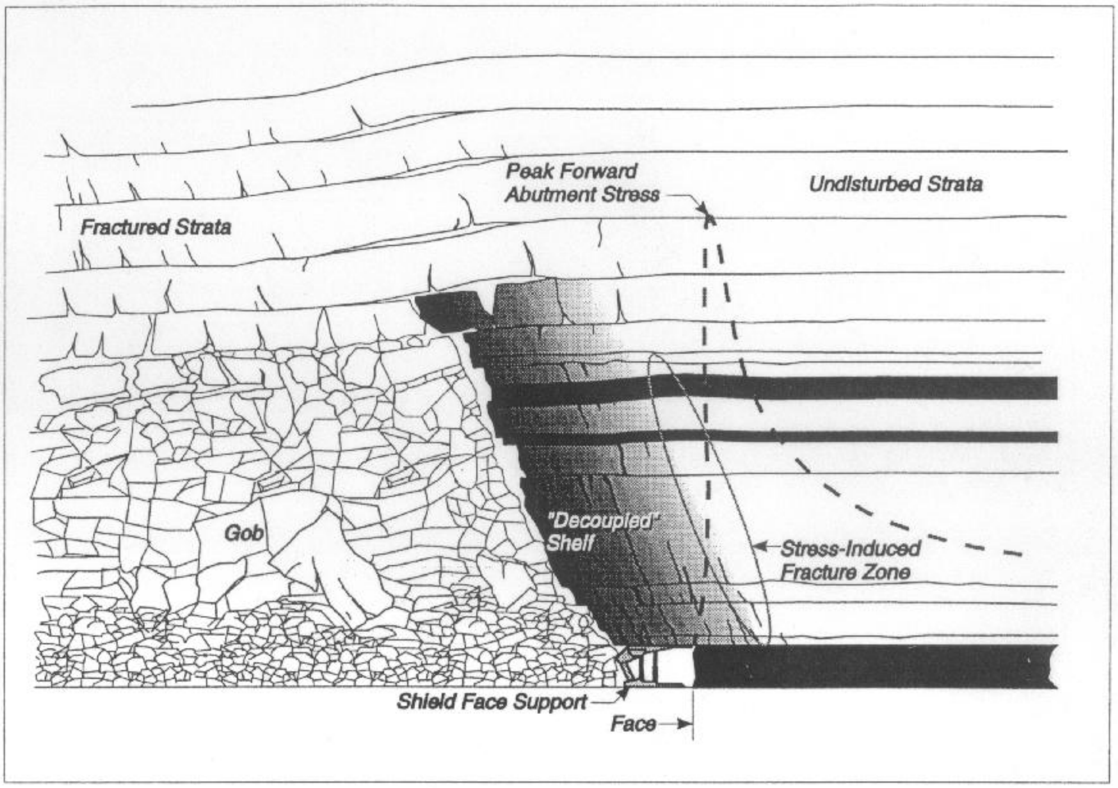

Figure 2. Idealized Shield Loading Mechanism

Geologic Environment

The reserves under investigation lie in a typical Book Cliff sequence of Upper Cretaceous sandstone, siltstone, mudstone and coal, as illustrated in Figure 3. On the Willow Creek property, three primary seams (D, K, and A) contain minable coal distributed between three secondary seams (C, B, and Sub3). Mining will proceed from the top D Seam and progress downward to the underlying K Seam and, eventually, the bottom A Seam.

Strata on the property strike approximately east-west and dip to the north at 8.5 degrees. As is typical of the Blackhawk Formation, the coal-bearing section is characterized by lenticular and discontinuous lithologic continuity. Minable coals are generally defined as large pods, 2.1 m (7 ft) or greater in thickness, which may not be economically present everywhere on the property. As will be noted, lithologic units which are characteristically strong/stiff members (see Figure 3) are principally thick, planar marginal marine sandstones (Kenilworth and Aberdeen Sandstones) or massive, stacked fluvial sandstones (Castlegate Sandstone). Silt-sized material is common in the non-sandstone units.

The Kenilworth Sandstone is characterized by a well-sorted, medium- to fine-grained, massive, cross-bedded sandstone in the upper 85% of the unit. The Castlegate Sandstone (167.6 m/550 ft) can be described as moderately to poorly sorted (silty to medium grained) stacked fluvial sandstone sequences, with common silt to mud on cross-bedding and transitional bedding. Both units are prominent, resistant cliff-formers as shown in Figure 3.

No major faulting is indicated in the proposed mine area. Field work (Anderson 1991; Mercier 1995) defined the principal discontinuity patterns on the property and showed that joint

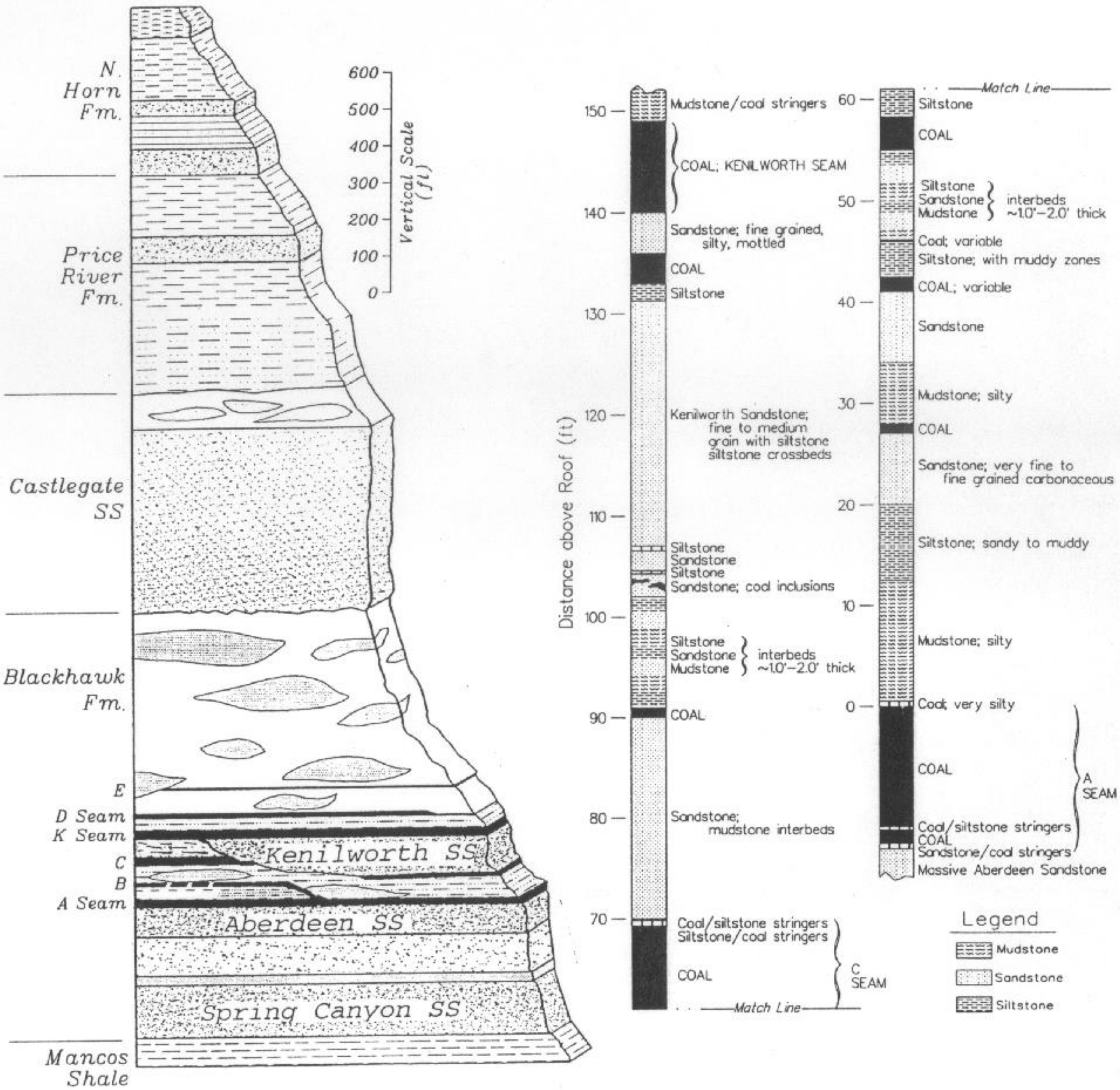

Figure 3. Typical Willow Creek Lithologic Columns (1 m = 3.28 ft) (Note: Exact details vary.)

density is highly dependent on the lithologic unit studied (thin, fine-grained units have higher fracture density than thick, homogeneous sandstones). Maximum horizontal stresses, as determined by overcoring and observation, appear to be oriented N°30W to N°60W.

Recent core drilling shows discontinuity development as fairly common bedding plane separations and rare to moderately rare sub-vertical, slightly irregular joints in sandstones. Vertical joints, however, have been very rarely seen in the fine-grained (silt and mudstone) units. Secondary infilling (calcite) occurs in about 50% of the vertical fractures noted. Clay-rich strata commonly exhibit sub-horizontal slickenside development.

The thick cliff-forming units of the Castlegate Sandstone occur in the overburden of all seams and will affect overall load transfer in the mines. However, they are sufficiently far removed from the primary seams (greater than 10 times the seam thickness) to exclude them as significant sources of weighting for longwall supports. A possible exception of sandstone weighting lies above the A Seam.

A-Seam Support Weighting Environment

The geologic environment in the vicinity of the A Seam is predicted to be the most severe in terms of support weighting. The potential for superincumbent loading from the massive overlying Kenilworth Sandstone, beginning on average 24.7 m (81 ft) above the A Seam, is a unique characteristic that distinguishes the powered support demands for the A Seam from those in the D and K seams.

The mechanism for caving of the intervening strata (averaging 24.7-m/81-ft thick) above the A Seam and below the base of the Kenilworth Sandstone most likely will be similar to that anticipated for the D and K seams as all three contain comparable lithologic interbeds directly above the seams, as shown in Figure 3. Caving above the A Seam is expected to terminate at the base of the Kenilworth Sandstone if not otherwise arrested by material bulking. Above the A-Seam panels, potential exists for subsidence of large Kenilworth Sandstone blocks from a massive unit averaging 14.6-m (48-ft) thick.

The length of these blocks was conservatively assumed to be determined exclusively by regional jointing. The ability of longwall mining to propagate regular fractures entirely through the Kenilworth blocks may be attenuated by the intervening strata. Because joint orientation and spacing data for the Kenilworth Sandstone is limited, the typical joint pattern capable of fully segregating blocks in the Kenilworth Sandstone is taken to range from 0.3 to 10.1 m (1 to 33 ft), dipping 5° to 7° from vertical, based on discontinuity patterns in neighboring geologic units on the Willow Creek property (Anderson 1991). Consideration of only natural discontinuities is conservative in terms of shield weighting, producing larger, heavier Kenilworth blocks than for conditions of combined natural and mining-related fractures.

Only the underlying Spring Canyon Sandstone of the Blackhawk Formation is known to possess a pronounced north-south joint trend, which would be parallel to the longwall faces planned for the A Seam. The major fracture trend for the property, N60°W, and the secondary trend, N75°E (Anderson 1991), are both oblique to the planned longwall faces in the A Seam. Consequently, fractures angled from 60° to 75° from the north-south oriented face will, most likely, define the geometry of the Kenilworth Sandstone blocks, resulting in oblique loads transferred to the powered supports.

The Kenilworth Sandstone presents the potential to increase A-Seam support weighting by imparting an additional surcharge on the shelf already partly supported by the shields. This increase in load is expected to be offset by passive support provided by the gob to both the shelf immediately above the shields and the underside of the Kenilworth Sandstone, as illustrated in Figure 4. Simultaneously, the cantilevered loading by the overlying Kenilworth Sandstone will promote rotation of both block sets into the gob, further mobilizing gob support and relieving shield loading.

Support Loading Cases

A unique model representing worst-case shield loading can never be determined prior to mining because of geologic uncertainties. Geologic factors are the least predictable, most variable and most influential in terms of shield loading. Nevertheless, at Willow Creek the available data point toward particular features, as previously discussed, that constrain the diversity of potential loading mechanisms. To account for geologic variability, four model

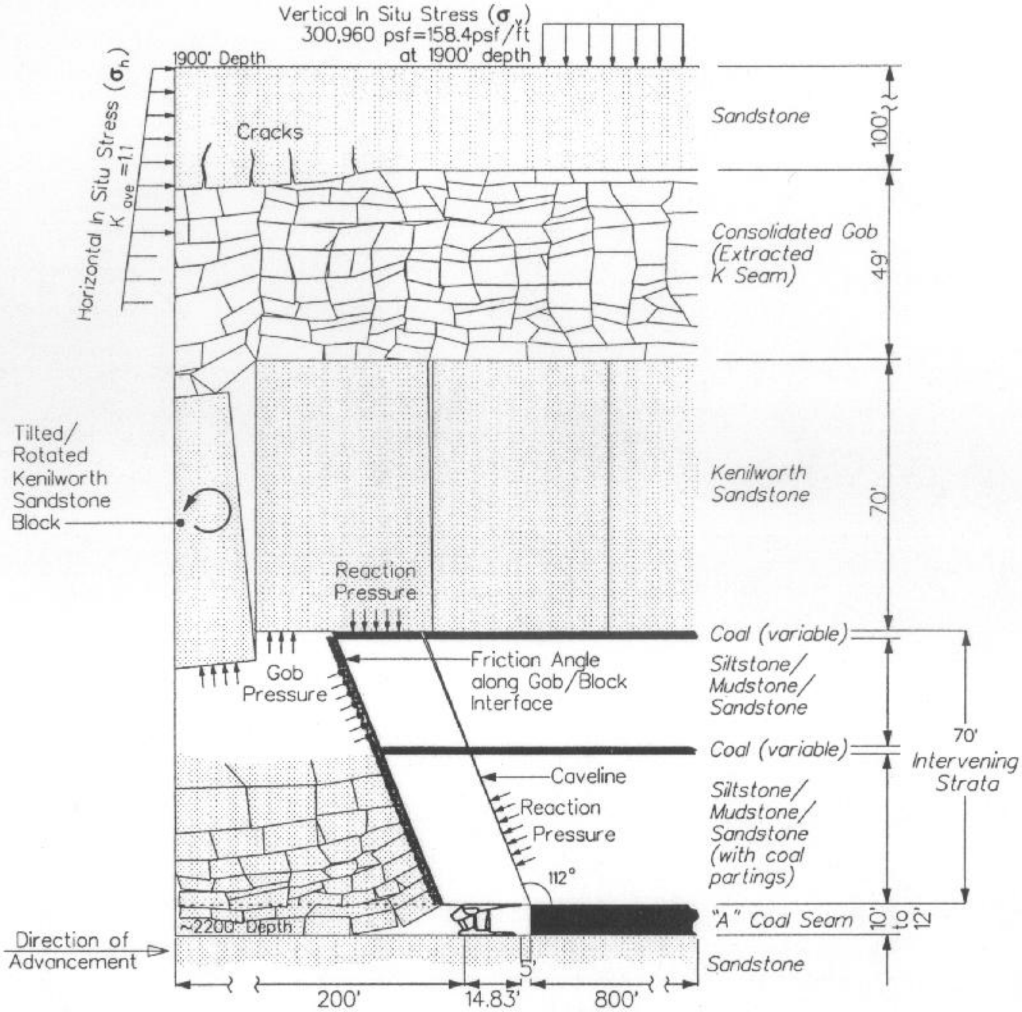

Figure 4. Illustration of Periodic Weighting by the Kenilworth Sandstone (1 m = 3.28 ft; 1 MPa = 20,890 psf)

geometries considered "most probable" were investigated (illustrated in Figure 5), representing two possible combinations of extremes (Cases 1 to 4) for the Kenilworth block lengths (W = 9.8' ~~0.9 m/3 ft~~ or 16.8 m/55 ft) and the A-Seam mining height (h = 3.1 m/10 ft or 3.7 m/12 ft). Case 5 represents the condition of an unfractured, continuous Kenilworth Sandstone sagging onto the intervening strata.

The shelf, or lower weighting block, was fixed at 9.08-m (29.8-ft) long and 21.3-m (70-ft) tall, with a 3.1-m (10-ft) overhang into the gob and a 1.5-m (5-ft) overhang in the front of the support canopy. This represents the largest, most extreme dimensions anticipated for the lower weighting block in areas overlain by the Kenilworth Sandstone. The Kenilworth block widths were selected to represent the most probable extremes that will be encountered during mining, from the best-case scenario (W = 2.98 m/9.8 ft) to the most undesirable condition (W = 16.8 m/55 ft). Although the maximum Kenilworth Sandstone true joint spacing is not expected to exceed 10.1 m (33 ft), the probable oblique orientation of these joints with respect to the longwall face will produce blocks that overhang the gob as much as 16.8 m (55 ft), as compared to 10.1 m (33 ft).

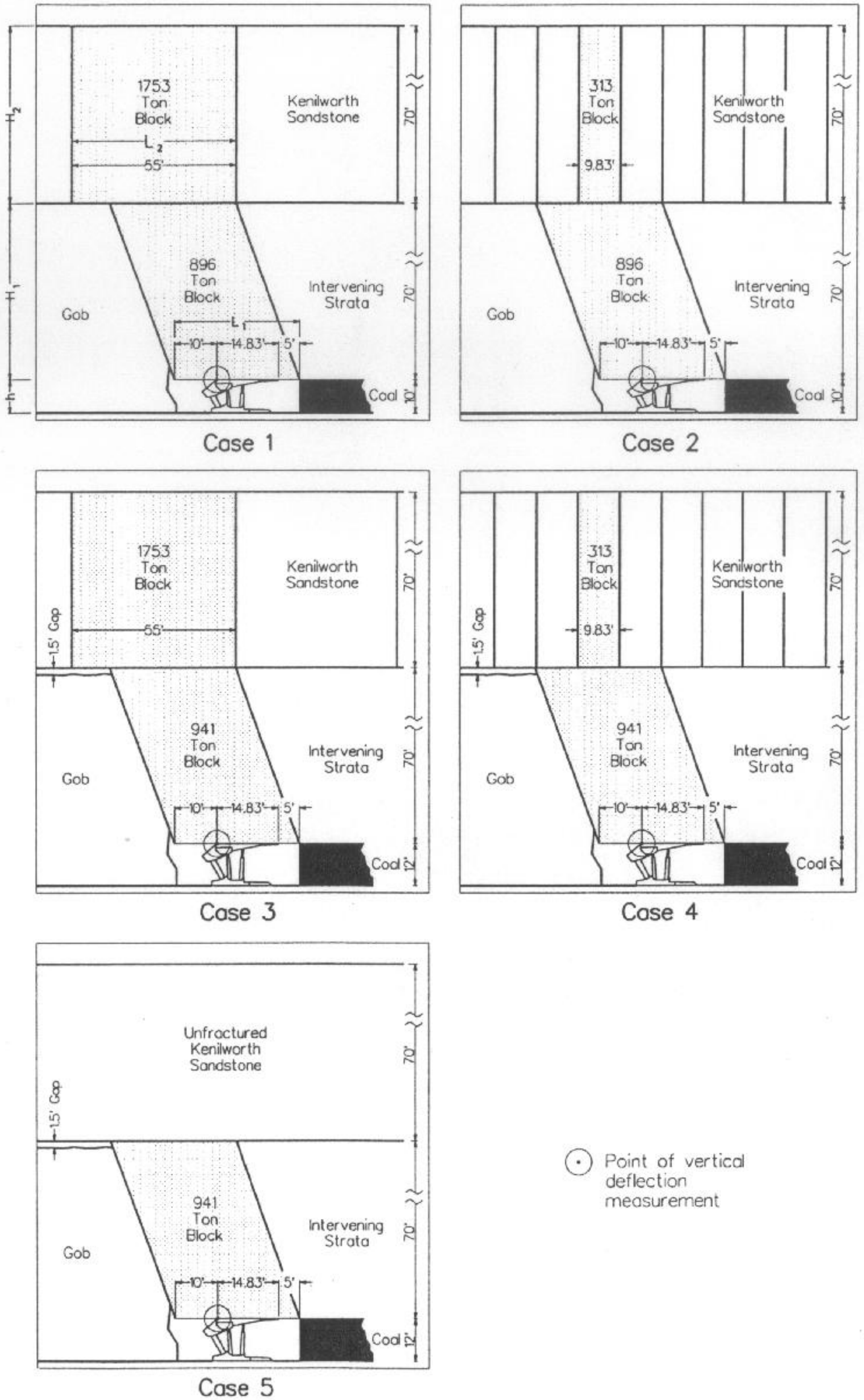

Figure 5. Support Weighting Models Considered (1 m = 3.28 ft; 1 t = 1.1023 T)

The A-Seam mining height determines the height of the gob in the models. A conservative bulking factor of 1.15 is assumed for the lithologic conditions at the Willow Creek property, producing caving heights of 20.4 and 24.4 m (67 and 80 ft) for a 3.1- and 3.7-m (10- and 12-ft) mining height, respectively. Caving is assumed to be limited to an average value of 21.3 m (70 ft) above the top of the A Seam, i.e., bounded by the base of the Kenilworth Sandstone. Because of the natural lithological contrast, both the 3.1- and 3.7-m (10- and 12-ft) mining geometries are assumed to cave to the base of the Kenilworth Sandstone, i.e., for the entire 21.3 m (70 ft) of intervening strata above the A Seam. Based on the volume expansion for a 1.15 bulking factor, the gob (1) will expand to fill the entire extracted plus caved volume, as for the 3.1-m (10-ft) mining height, or (2) will produce a 0.45-m (1.5-ft) void at the top of the gob, beneath the Kenilworth Sandstone, as for 3.7-m (12-ft) mining height.

The Kenilworth Sandstone is taken to be 21.3-m (70-ft) tall in the model representing a more conservative condition than the average. Although the Kenilworth Sandstone approaches 29.0-m (95-ft) tall within the panel boundaries to the east, extreme thicknesses combined with the 21.3-m (70-ft) intervening strata composite thickness in the model exceed the range of conditions expected to be encountered during mining.

SIMPLIFIED SUPPORT DESIGN

A simplified calculation was performed based on an adaptation of the methods proposed by the U.S. Bureau of Mines (USBM) (Barry *et al.* 1969) as described in Peng (1978) and Peng and Chiang (1984). The USBM method estimates support load based on the static weight of a block representing the immediate roof that must be supported. In this instance, this refers to the block(s) containing the intervening strata. The modification to this method for this analysis includes the addition of the static weight of the Kenilworth Sandstone block(s) above the intervening strata block(s) in the estimation of the support load. The yield capacity of the supports is therefore calculated by

$$W = L_1 H_1 cg + L_2 H_2 cg$$

where L_1 = horizontal length of the lower block
= length of shield + front/rear overhang = 9.092 m (29.83 ft),
H_1 = height of lower block = 21.3 m (70 ft),
L_2 = horizontal length of Kenilworth Sandstone block = 2.98 or 16.7 m (9.8 or 55 ft),
H_2 = height of Kenilworth Sandstone block = 21.3 m (70 ft),
c = centerline spacing of shields = 1.752 m (5.75 ft) (typical), and
g = weight density of rock = 2537 kg/m^3 (158.4 lb/ft^3).

For this approach, the coal mining height does not influence support load because caving is assumed to proceed to the base of the Kenilworth Sandstone (21.3 m/70 ft above the top of the A Seam) for Cases 1 through 4. As such, Cases 1 and 3 (W = 16.8 m/55 ft) both result in a yield capacity of 2449.4 t (2700 T). Cases 2 and 4 (W = 2.98 m/9.8 ft) require a support yield capacity of 1723.7 t (1900 T). These analyses assume no support from the gob or neighboring blocks which could partly alleviate the load on the supports. Consequently, predicted yield capacities are likely to be unrealistically high.

It should be noted that this method will not achieve static equilibrium unless the center of gravity of the loading blocks are vertically aligned with the resultant support vector. Other simplified methods exist that consider moments as well as dead load forces. However, the problem is statically indeterminate and not amenable to simplification.

BLOCK MODEL ANALYSIS

Numerical Model Development

The two-dimensional computer code UDEC (Itasca 1993) was used to explore support loading mechanisms not considered in the simplified method analysis, specifically, (1) block translational-rotational effects, (2) *in situ* stress, (3) support resistance, (4) frictional resistance, (5) passive resistance provided by the gob and (6) active support provided by surrounding blocks. The UDEC program, based on the distinct-element method, is uniquely suited to analyze the weighting mechanisms of longwall supports because block behavior predominates and very large displacements occur during the caving process. This method differs from boundary- and finite-element models traditionally employed in rock mechanics, permitting the discrete behavior of blocks of rock to be more completely considered. The algorithm is based upon the laws of motion and a force-displacement law specifying the interaction between the blocks, which may be rigid or deformable. The five UDEC models created are based on the same geometrical assumptions for the simplified method (Figure 5), but allow for much more complex interactions between the blocks in the rock mass and, thus, solution of the statically indeterminate problem.

Figure 6 is a detail of the typical UDEC model face region showing the finite-difference mesh within each discrete block. Table 1 summarizes the mechanical properties assigned to each geologic unit in Figure 6. Natural and mining-induced joints are considered to exhibit no tensile or cohesive strength for conservatism, with only frictional forces acting along discontinuities in a compressive environment. A 20° friction angle was estimated for interfaces between Kenilworth Sandstone blocks as these are naturally occurring joints. This value is assumed not to diminish to a residual value after large-scale displacement due to the preservation of large-scale asperities along the discontinuity surfaces. A friction angle of zero between the gob-block interfaces has been determined to yield the most realistic, and most conservative, system response. This implies newly formed gob tends to roll, slide and/or continue to rubblize when in contact with partly-supported blocks, consequently providing an insubstantial resistive force.

Gob stiffness in the model is scaled to the degree of estimated consolidation. Newly formed gob immediately above the A Seam (up to 21.3 m/70 ft) is assumed highly disturbed and relatively unconsolidated, attaining only 15% of the stiffness eventually developed after long-term consolidation. Consolidated gob, above the Kenilworth Sandstone, from K-Seam mining is assumed disturbed only locally behind the A-Seam face (approximately 76.2 m/250 ft) before recompacting sufficiently to transmit full overburden load to the underlying Kenilworth Sandstone.

Shield support is simulated by a constant stress applied to the base of the loading blocks over the shield contact area, as depicted in Figure 6. Support resistance remains constant with vertical displacement to represent yield-load response of the shields. In the absence of natural support contributed by the surrounding environment, which is mobilized by block movement, support capacities less than those determined by the simplified method (i.e. less than the dead weight of the blocks) would cause the shields to compress until "going solid." Alternatively, the UDEC models allow these resistance forces to develop in conjunction with more realistic support loads. Necessary shield load and displacement capacity can be evaluated by examining the modeled maximum downward movement of a specified loading block for a given yield load. Modeled roof convergence, though a function of the block displacement sequence imposed by the model and not a direct representation of the actual roof deflection, provides a relative measure of roof stability.

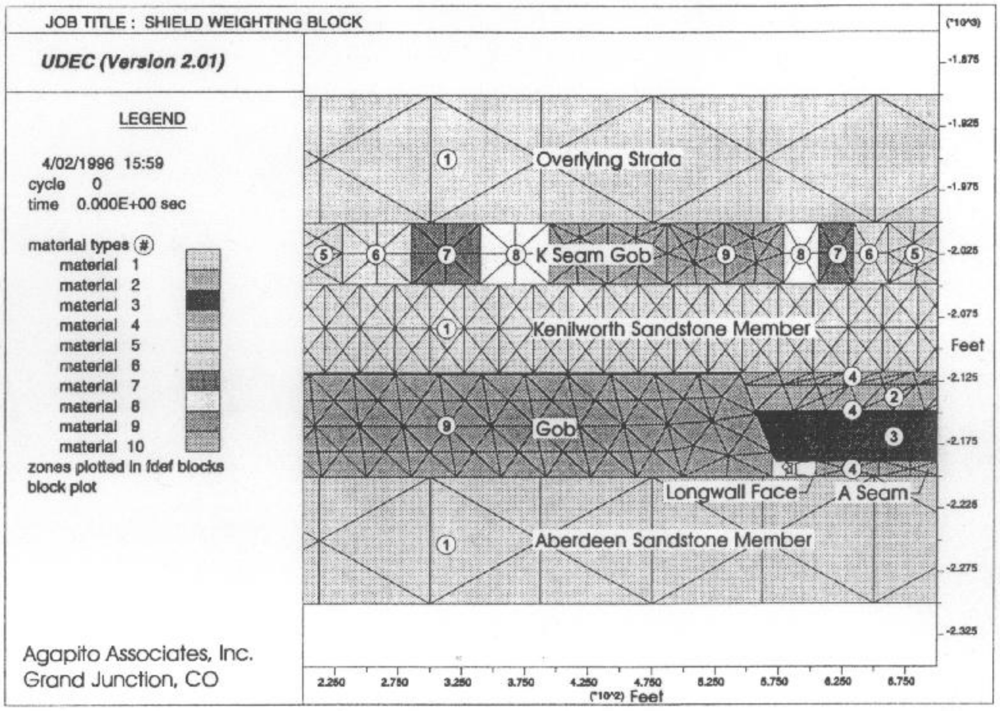

Figure 6. Detail of Face Region of UDEC Model Showing Finite-Difference Mesh and Material Numbers Corresponding to Table 1 (1 m = 3.28 ft)

Table 1. UDEC Model Material and Joint Properties

	Material								
Parameter	1	2	3	~~4~~ 5	~~5~~ 4	6	7	8	9
Material Description[1]	SS	Layer C SS/Ms/St	Layer E SS/Ms/ St/Coal	Gob BC=100%	Coal	Gob BC=85%	BC=65%	BC=40%	BC=15%
						(BC = *bearing capacity)*			
Material Model Type	Linearly Elastic, Isotropic					Strain Hardening			
Specific Gravity	2.54[2]	2.54[2]	2.54[2]	1.64[2]	1.60[2]	1.64[2]	1.64[2]	1.64[2]	1.64[2]
Poisson's Ratio	0.25	0.29	0.30	0.35	0.30	0.35	0.35	0.35	0.35
Young's Modulus, E (GPa)	6.895[2]	8.274[2]	7.584[2]	6.895[2]	1.379[2]	6.205[2]	4.826[2]	2.758[2]	1.379[2]
Joint Model Type	Elastic-Plastic with Coulomb Slip Failure								

[1]*SS=Sandstone; Ms=Mudstone; St=Siltstone* [2]*Properties chosen to be consistent with regional values.*

Numerical Model Results

The model results suggest that the majority of shelf support is provided by the gob and frictional forces along discontinuities, thus alleviating considerable direct load on the shields. The shield support in each case acts initially to mobilize gob and frictional forces by inducing rotation of the loading blocks into the gob resulting in large frictional forces above the face region. Without shield resistance, negligible gob or frictional forces develop and blocks are free in the model. Figure 7 illustrates this mechanism in the absence of shields; displacement vectors (arrows) identify the direction and relative extent of block movement while shaded contours

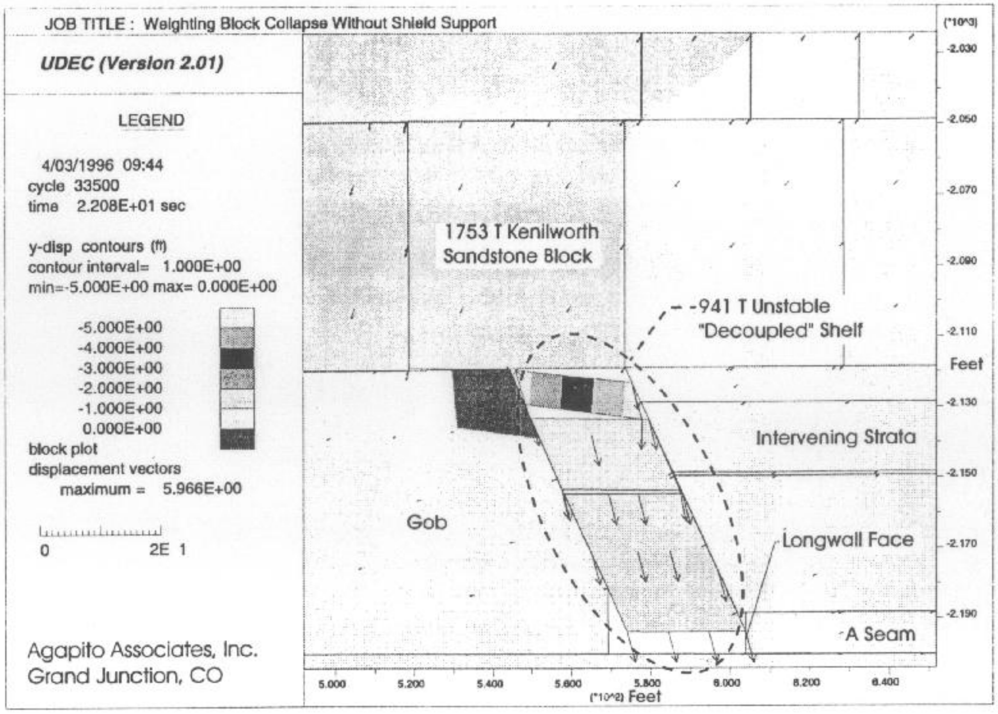

Figure 7. Displacement Vectors and Vertical Displacement Contours Illustrating Instability of the "Decoupled" Shelf in the Absence of Any Shield Load (1 m = 3.28 ft; 1 t = 1.1023 T)

illustrate the vertical displacement throughout the model. Figure 8 provides an exaggerated representation of large-scale block translation, rotation and elastic-plastic distortion in the typical model. This figure shows the progressive collapse of Kenilworth Sandstone into the gob and increasing consolidation of the gob away from the face. Close examination of the displacement vectors illustrates the counter-clockwise rotation of the shelf into the gob.

The numerical results of the UDEC analysis are summarized in Figure 9. Support load for a 1753-mm (69-inch) wide canopy is plotted versus modeled roof convergence for Cases 1 through 4. Case 5, where no superincumbent loading results from the Kenilworth Sandstone, is also plotted. It may be concluded from the inclined, linear portions of the load-displacement curves in Figure 9 that roof support at the face is maintained for Cases 1 through 4 when support yield capacities exceed 272.7 t (300 T). Although up to 330 mm (13 inches) of roof convergence does occur before stability of the immediate roof is achieved, equilibrium can be imposed on the system with mean load densities above 34.18 t/m^2 (3.5 T/ft^2).

For the Case 5 situation, where the Kenilworth Sandstone acts as a continuous member, a 589.7-t (650-T) support load (74.21 t/m^2/7.6 T/ft^2) is necessary to maintain roof stability. Greater support is required than for Cases 1 through 4 because of a concentration of stress through the continuous Kenilworth "beam" cantilevered past the shield loading blocks. Fracturing of the Kenilworth Sandstone relieves this load concentration.

From Figure 9, mining height is observed to have an influence on the ability to control roof convergence. A 5% to 20% increase in modeled roof convergence results from an increase in mining height from 3.1 to 3.7 m (10 to 12 ft). For a given mining height, the 16.8-m (55-ft) wide Kenilworth blocks (Cases 1 and 2) cause approximately near zero to 20% greater modeled roof convergence versus the 2.98-m (9.8-ft) wide blocks (Cases 3 and 4).

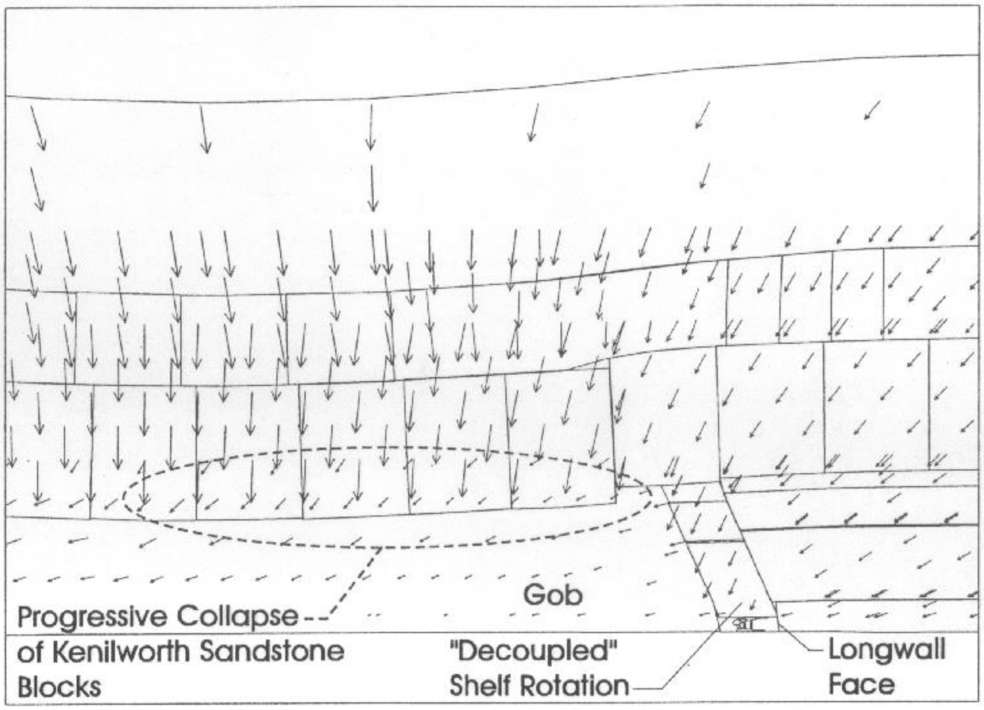

Figure 8. Displacement Vectors Illustrating Collapse of Kenilworth Sandstone Blocks into the Gob

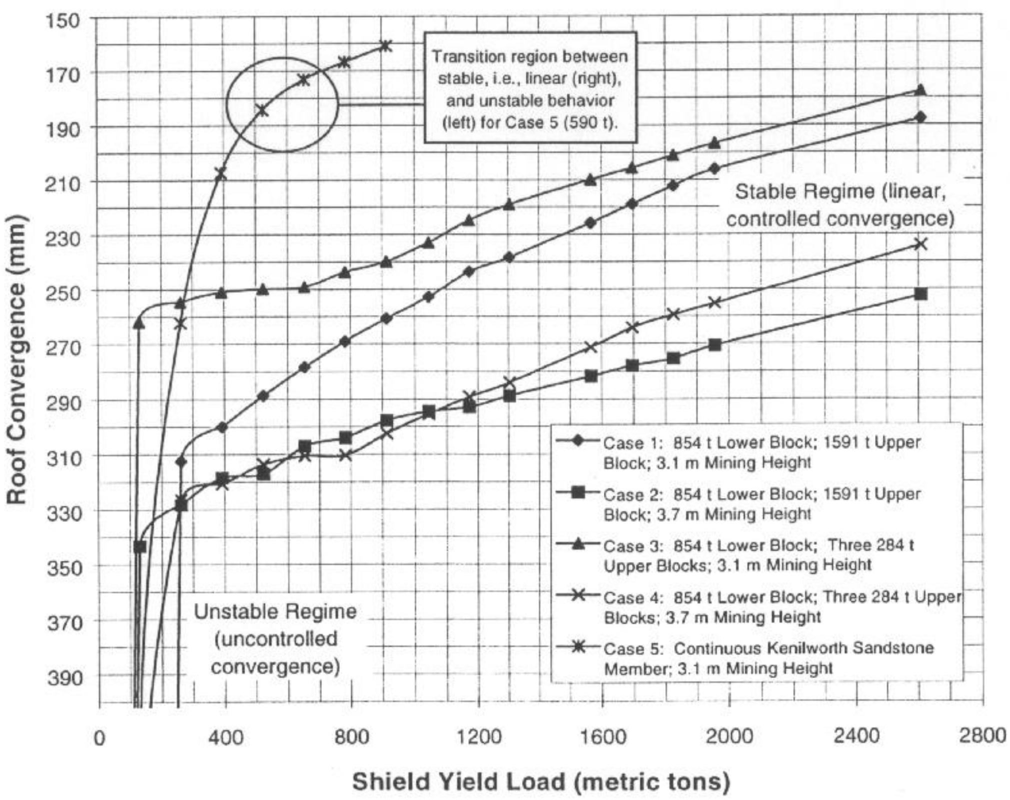

Figure 9. UDEC Modeled Shield Load versus Displacement (Roof Convergence) for the Loading Cases Show in Figure 5

Cases 1 through 5 are all considered extreme circumstances and, as such, designs based on their responses are expected to be highly conservative. When subject to loading by the Kenilworth Sandstone, the models suggest modest improvement in roof displacement will be realized with larger supports; modeled roof convergence ranges from 254 mm (10 inches) to 330 mm (13 inches) for supports yield capacities ranging from 453.6 to 907.2 t (500 to1000 T).

Although block modeling indicates that potential improvement in roof convergence alone does not warrant larger capacity supports, several additional roof control factors must be considered. The UDEC block analysis neither considers dynamic loading of the supports due to the sudden collapse of blocks in the immediate and main roofs ("bounce loading") nor considers the advantage of greater support capacity to induce fractures in the immediate roof that may reduce the size of weighting blocks. Dynamic loads imparted to the supports due to large detachments of Kenilworth Sandstone blocks have the potential to be quite large and, as such, merit consideration of a large reserve support capacity.

Additionally, potential exists for caving higher than 21.3 m (70 ft) above the A Seam for locations where the intervening strata ranges from 21.3- to 45.7-m (70- to 150-ft) thick. Under these circumstances, higher caving may result in a taller shelf directly above the supports requiring additional support capacity. In fact, consideration of some extreme shelf heights calculated using a bulking factor of 1.15 lead to the ultimate recommendation of 698.5-t (770-T) supports for a 3.1-m (10-ft) seam, and 839.1-t (925-T) supports for a 3.7-m (12-ft) seam, as shown in Table 2.

Table 2. Recommended Shield Capacities

Seam	Mining Height (m)	Yield Capacity (t)	Load Density* (t/m^2)
D, K & A	3.1 (10 ft)	698.5 (770 T)	88.86 (9.1 T/ft^2)
D, K & A	3.7 (12 ft)	840.8 (925 T)	106.43 (10.9 T/ft^2)

* *Based on 7.9 m^2 (85 ft^2) canopy bearing area.*

SUMMARY AND CONCLUSIONS

Summary

Available geologic data from the exploration drilling program was reviewed for the presence, geometry and spatial distribution of massive strata in the three primary seams (D, K and A) that might affect cavability and influence weighting on longwall supports. Interbedded sandstones, siltstones and shales above the K and D seams are expected to cave readily, and no massive strata were identified in the immediate sequence above these seams. Attention was focused on the massive portion of the cliff-forming Kenilworth Sandstone which is 14.6-m (48-ft) thick on average and is located 24.7 m (81 ft) above the A Seam. The range of thickness is from 0 to 29.0 m (95 ft), and it lies from 16.8 to 46.6 m (55 to 153 ft) above the A Seam. There is a trend towards greater Kenilworth Sandstone thickness to the east near the boundary adjacent to the Andalex lease.

Because of its thick, massive character and its proximity, it is anticipated that the Kenilworth Sandstone above the A Seam has the potential to cause periodic weighting on the longwall supports, especially with the greater caving heights associated with a 3.7-m (12-ft) mining height. To investigate this, conservative analyses of the support-loading situation for 3.1- and 3.7-m (10- and 12-ft) seam heights were conducted using both simplified methods and computerized block models.

Conclusions

In conclusion, we have found that block analysis has been a useful supplement to experience in selecting support capacities. Although assumptions are required in this type of modeling, the method provides an accurate, mechanically correct analysis once these assumptions are made. This enables engineering judgment to be applied in a more focused manner than traditional methods, which are mechanically oversimplified. It must be remembered that any calculations are secondary to actual caving experience in the seam, only becoming useful when site-specific experience does not exist.

The results of the block analysis indicate that periodic weighting of the supports may occur, causing shields to be on yield for support resistances within a practical range (453.6 to 907.2 t [500 to 1000 T]). However, the analysis suggests that the Kenilworth Sandstone is sufficiently removed from the A Seam to allow development of considerable support from the gob, thus minimizing the potential for shields "going solid." In this situation, the contribution to support weighting from the Kenilworth Sandstone was not the controlling factor in determining support capacity; consideration of extreme cases of shelf loading lead to the recommendation of 839.1-t (925-T) supports.

In addition to limiting deflections, high capacity supports provide flexibility to handle dynamic loading, facilitate caving by providing stiffer roof support, and offer increased durability. These factors help justify the additional capital expenditure over low-capacity supports. Following further study to consider these factors, Cyprus will place an order for 839.1 t (925 T) supports to use at Willow Creek.

As a footnote, Andalex has recently initiated longwall mining in the Aberdeen Seam (A Seam) adjacent to the Willow Creek Mine. They report no problems with excessive support weighting or caving on their first panel.

REFERENCES

Anderson, P.B. (1991). *Fracture Study on the Blackhawk East Property, Utah.* Letter report for Cyprus Coal Company.

Barry, A.J., O.B. Nair and J.S. Miller (1969). *Specifications for Selected Hydraulic-Powered Roof Supports: With a Method to Estimate Support Requirements for Longwalls.* U.S. Bureau of Mines, IC-8424.

Itasca (1993). Universal Distinct Element Code, Version 2.0, User's Manual. Minneapolis, MN: Itasca Consulting Group, Inc., pp. 1-J52.

Mercier, J. (1995). [Personal Communication. Geologic Supervisor, Cyprus Plateau Mining Corporation, Price, UT.]

Peng, S.S. (1978). *Coal Mine Ground Control.* Wiley, 450 p.

Peng, S.S. and H.S. Chaing (1984). *Longwall Mining.* Wiley, 708 p.