STABILITY OF SURFACE CROWN PILLARS IN SHEARED TERRAINS WITH WEAK HANGING WALL AND FOOT WALL

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ABSTRACT

Sheared terrains with weak schists, are common in Canadian mine settings and around near surface openings.

This presentation describes typical ground control problems associated with these environments. These problems and actual failures are used to describe the cross section of failure modes in hanging wall and crown areas of near surface openings.

The physical modelling technique is discussed. This method, when it uses scaling laws, is the best means of obtaining failure mechanisms and extent of failure for a particular setting. This information can then be used advantageously in numerical modelling for more precise global stability assessments.

KEYWORDS: surface crown pillars, sheared terrains, weak hanging wall, weak foot wall, failure mode, field observations, base friction model

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LA STABILITÉ DES PILIERS DE SURFACE EN TERRAINS CISAILLÉS AVEC ÉPONTES PEU COMPÉTENTES

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RÉSUMÉ

Les terrains cisaillés, avec des schistes faibles, sont communs dans les mines canadiennes et leurs ouvertures souterraines peu profondes.

Cette présentation touche aux problèmes de terrains typiques associés avec ces terrains. Des problèmes et des cas de ruptures vécus sont utlisés pour présenter l'éventail de modes de rupture dans les régions de l'éponte supérieure et de la couronne d'ouvertures peu-profondes.

La technique de modélisation physique est discutée. Cet méthode, avec l'application de réduction échelonnée, est la meilleure façon d'obtenir les modes de rupture et leurs étendues pour un cas précis. Ces informations peuvent alors être incorporées dans la modélisation numérique pour donner un apperçu détaillé de stabilité.

MOTS CLÉS: piliers de surface, terrains cisaillés, épontes peu compétentes, mécanisme de rupture, observation en place, table à friction

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INTRODUCTION

Canadian mine operators have faced a variety of geological settings and a wide cross section of ground control problems, tables 1 and 2.

In the case of surface crown pillars it has become important to establish what failure modes are possible and how to prevent ground control problems that could lead to failure (whether progressive, localized, complete, etc.).

Ground that has been sheared by intense faulting represents one of the weakest and most difficult terrain to excavate in. Typically, the hangingwall, footwall and occasionally the ore zone, consists of a fine micaceous schist with varying proportions of talc and/or clay gouge. To cite a few examples, there are the Bousquet and Dumagami mines with such hanging walls and foot walls, surrounding a massive pyrite orebody, and the Belmoral mine, with disseminated ore and hanging wall/foot wall all within a weak schist zone.

This presentation will deal with surface crown pillar stability considerations for this type of terrain. In particular, the following elements will be treated:

1) Description of observable behaviour;
2) Failure mechanisms;
3) Physical modelling for evaluation of global stability.

DESCRIPTION OF OBSERVABLE BEHAVIOUR

The ground problems encountered at such sites are attributable to: the material's properties, weakening effects of discontinuities and excavating effects.

In the case of the Bousquet and Dumagami mines, large scale

Table 1. Basic Characteristics of Surface Crown Pillars of Hard Rock Mines (1)

MINE	1	2+	3+	4	5	6	7	8	9	10+	11	12	13	14	15	16	17	18+	19	20	21	22	23	24
Items																								
* BODY OF WATER (m)			3	(3)	–	–	–	7.6	–	( )	( )	–	20	–	–	–	–	–	11	–	–	–	13	–
* OVERBURDEN (m)	(8)	(7)	27	36	4	15	5	20	17	16	20	15	3	5	30	9	1.5	(2)	5	–	45		19	(9)
Substantial clay deposits			*	*				*	*		*	*		*								N/A	*	
* FORM OF THE DEPOSIT – tabular	*				*												*				*		*	
– single vein			*	*				*	*	*	*		*		*			*						
– multiple veins		*				*	*							*					*	*		*		
– mass												*				*								*
*Pronounced alterations	*			*	*			*						*			*		*		*		*	
*Walls of low competence	*	*	*		*			*					*	*	*	*			N/A	N/A	N/A	N/A	*	*
*Walls of high competence						*	*			*									N/A	N/A	N/A	N/A		
DIP (degrees)	70°	70°	65°	45°	72°	80°	80°	90°	45°	70°	80°	85°	45°	85°	75°	75°	33°	70°	70°	60°	50°	75°	30°	
IMPORTANT FAULT(S)		*	*	*		*		*	N/A	*	*	*	*		*	*		*	N/A	N/A	*	*	N/A	*
NUMBER OF WELL DEFINED JOINT FAMILIES	N/A	2	3	N/A	2	2	3	N/A	N/A	N/A	N/A	N/A	N/A	2	N/A	N/A	1	3	N/A	N/A		N/A	N/A	3
* MAIN MINING METHOD – stope and pillars																	*							
– shrinkage stoping					*	*	*		*													*		
– cut-and-fill			*					*					*						*		*		*	
– blasthole stoping	*	*		*						*		*		*	N/A	*		*		*				
* Surface installations on pillar(s)						*	*			*							*				*			

N/A not retrieved, or not available

() removed

(+) pillar(s) separating open pit from underground opening

\- not applicable

TABLE 2
SURFACE CROWN PILLAR RELATED FEATURES,
CANMET CASE STUDIES

Mine	Pillar Status	Number of Pillars Created[Ø]	Pillar Thickness	Orebody Dip	Orebody Thickness	Pillar Rock Type	Q[*]
Niobec[+]	Created	55	37-68 m	90°	25-100 m	Massive limestone	40
Pierre Beauchemin[+]	Created	10	30 m	40°	5-12 m	Intact/altered tonalite and diorite	11
Selbaie[o,×]	Created/ Recovered	12	7.5 m	55°	10-30 m	Heavily altered, fractured rhyolite	0.06
Holt-McDermott[±]	Created	1	40 m	70°	3-8 m	Intact/altered basalt	1.6
Sigma[o,×]	Created	4	12-15 m	80°	3-6 m	Quartz vein	100
Belmoral[o,×]	Planned	N/A	N/A	70°	3-5 m	Chloritized talc-calcite-biotite schist	0.1

* NGI rock mass quality rating
Ø to date
\+ full stability program
× contract work
o internal research
± expert evaluation
N/A not applicable

TABLE 2 (Cont'd)
SURFACE CROWN PILLAR RELATED FEATURES,
CANMET CASE STUDIES

Mine	Major-stability Consideration	Research Carried Out					
		Rock Mass Characterization	In Situ Testing	Material Testing	Modelling	Monitoring	Recovery
Niobec[+]	Unjointed rock	Core and in-situ	Ground Stresses	Tensile, Compression, Shear Tests	Numerical	Stress, Displacement	N/P
Pierre Beauchemin[+,x]	Weak fault zones	Core and in-situ	Dilatometer, Ground Stresses	Tensile, Compression, Shear Tests	Numerical	Displacement, Water-table	N/P
Selbaie[°,x]	Soil-like Material	Core and in-situ	Dilatometer, Ground Stresses	Tensile, Compression Tests	Physical, Numerical	Displacement, Water-table	Modelling, of retreat with no overburden removal
Holt-McDermott[±]	Hanging wall fault; ravelling orebody and footwall	In-Situ	---	---	Numerical	(Planned) Displacement	N/P
Sigma[°,x]	Weak immediate hanging wall and foot wall	Core in-situ	---	---	---	---	Stope back-filling and open pit extraction
Belmoral[°,x]	Caving conditions, schist and hanging wall	Core and in-situ	Dilatometer	Tensile, Compression, Shear Tests	Physical, Numerical	Displacement	N/P

N/P Not planned

shearing of felsic volcanics have given rise to the formation of thin plates paralleling the orebody in the foot wall and hanging wall. The dip of these features is 80°.

These plates become thinner in the immediate orebody surroundings. In the Bousquet case these areas are composed of talc sericite schist, almost fully micaceous. Deeper in the hanging wall and foot wall the schist gives way to plates (< 2 cm) of foliated felsic volcanics. The Dumagami situation is similar except that the weak schist area is limited to a width of less than 5 m, and that the schist is more rigid.

Severe closure of openings occur at Bousquet both from buckling of weak schist, figure 1, and shearing movements along schistocity planes. Dumagami witnesses a lesser buckling mode, but the presence of joints, especially the sub-horizontal provide venues for splitting and sliding. In both cases, the gold bearing pyrite vein(s) remain stable.

The mining method used in these operations is sublevel retreat using waste rock for filling stopes.

The Belmoral ore zone (3-8 m wide, dipping 70°) is situated in a wide weak talc-biotite schist zone, 10-15 m wide. At each lateral boundary of this schist lies a 1 m wide a stiff biotite-quartz schist. A granodiorite pluton hosts this series of rocks. The immediate granodiorite hanging wall is dissected into small (< 0.5 m^3) blocks with biotite covered faces, which are bounded by joint families, three of which dip steeply.

Ground problems at Belmoral are related to material buckling, shearing and ravelling. The extent of these vary with the percentage of felsic schist components: the more the quartz content (can vary, 0-70%) the more the stope back is stable. With low or little quartz, the material disintegrates into small weak blocks (< 0.5 m^3). The presence of pervasive chlorite gouge worsens the situation.

Subhorizontal and subvertical joints facilitate detachments in

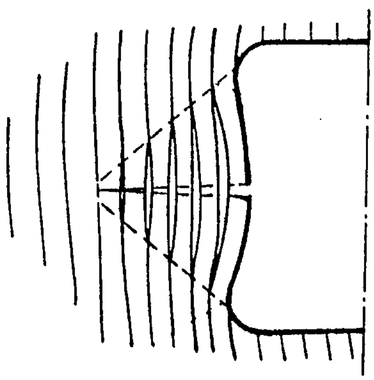


Figure 1. Buckling mode for weak schist layers; the layer thickness in the case of Bousquet and Dumagami is small.

the crown; subhorizontal joints permit buckling or detachment of the stiff quartz-biotite schist.

FAILURE MECHANISMS

The common denominator in these settings are the planes of discontinuity and weakness provided by the schist.

Two main surface crown pillar failure mechanisms will be examined:

1) Related to hanging wall movement.
2) Related to crown movement.

Hanging Wall Movement

Hanging wall failures are not failures of the actual crown rock but at its periphery. This underlines the need to visualise surface crown pillar stability as that of the area surrounding all of the near-surface opening.

Chimneying failures, figure 2, in the proximal hanging wall have occurred in 1988 at Belmoral and Bousquet. These are progressive failures where upward migration of ravelling of small size material occurs. The broken material does not choke the cavity off. There also is the possibility that the 1980 Belmoral accident was of this nature.

Such localised failures are common and are usually expected in weak soil-like material. The vertical outline of the cave remains much the same over its height. The Belmoral and Bousquet failures followed this pattern.

A large scale hanging wall failure, figure 3, is believed to have been responsible for the cave-in of an uppermost stope of the Rivière Héva

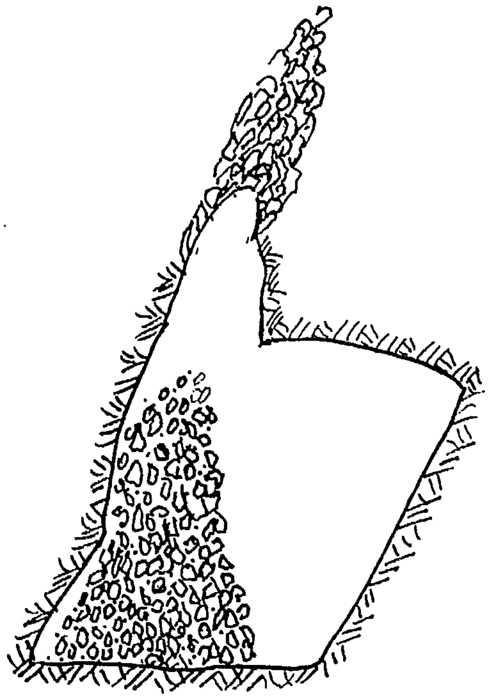


Figure 2. Hanging wall chimneying failure.

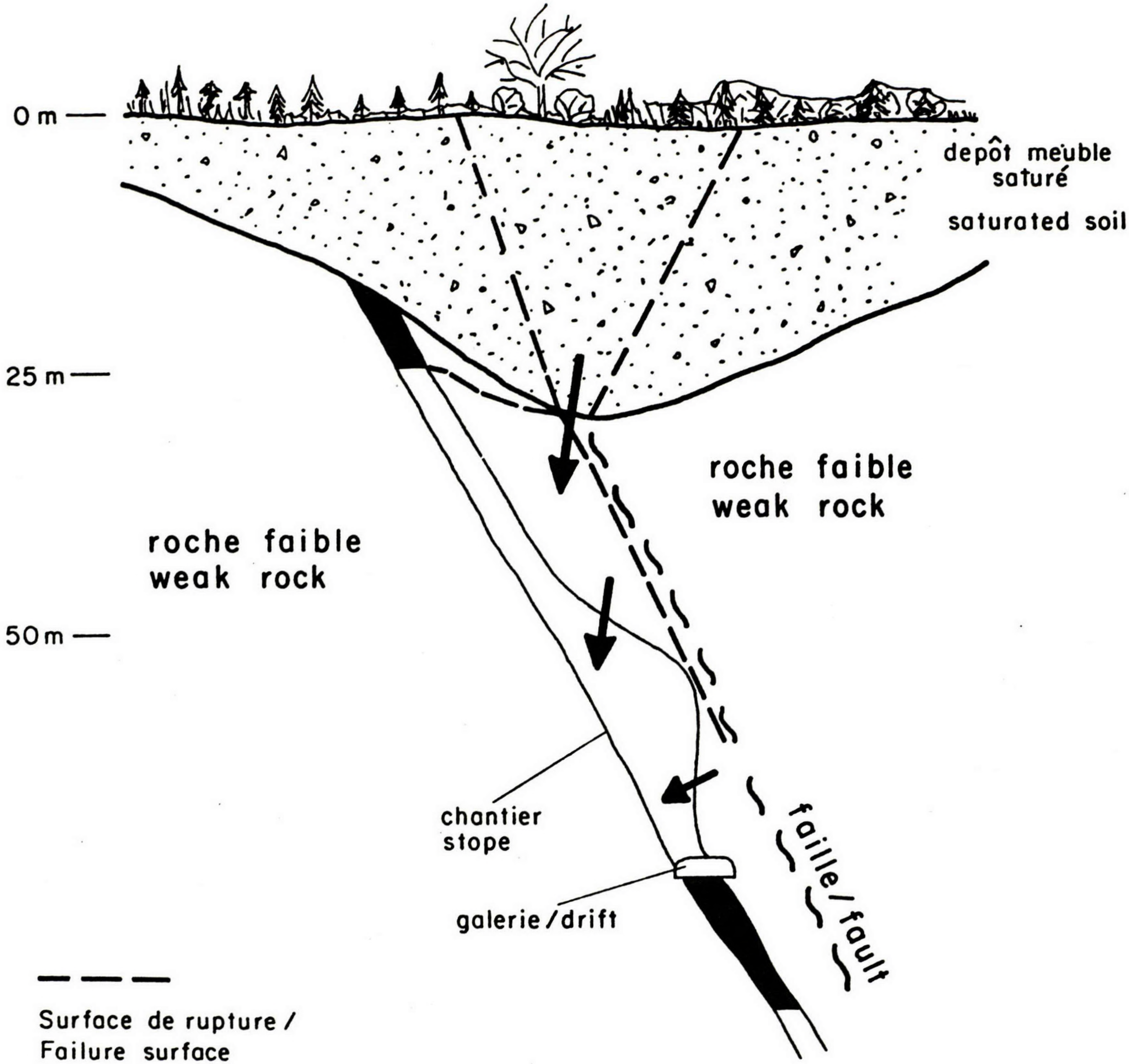


Figure 3. Possible hanging wall failure mode of the Riviere Heva, surface crown pillar, during rehabilitation.

mine, during mine dewatering. In the hanging wall a deep seated fault plane, dipping 60°, is thought to have failed and led to the degradation of the remaining thin bedrock until soil flowed into the mine.

Buckling of hanging wall (and foot wall) schistose layers lends to the reduction of support at the side of the openings. The process of buckling can be very rapid, leading to failure in one or two days. Leaving high openings such as stopes (temporarily with no lateral support in the case of a retreat mining method) causes rapid and important degradation. This would in effect enlarge the opening and affect the crown and make hanging wall (or foot wall, with subvertical dips) chimneying possible.

Hanging wall caving at Belmoral has involved the weak immediate granodiorite as well as the main schist. The Bousquet and Dumagami problems have been limited to the schist area.

Crown Movement

In weak rock the crown of an opening will be subjected to failures until a stable arch is formed, figure 4. The smaller the dimension of the falling material the smoother the arch line. In this case careful perimeter blasting should be applied as to restrict the degree of secondary fracturing. In the Belmoral case, current blasting practices badly break up the ground deep into the crown. An overhand cut and fill method, without the use of perimeter blasting, is utilized.

The gouge-rich, quartz-poor schists at that site could behave in a plastic fashion yielding crown displacements respecting Terzaghi types of behaviour, figure 5. The actual movement/failure plane would be far into the back of the crown depending on the degree of plasticity.

The redistribution of natural stresses in the crown can be beneficial, but in very weak material, its confining effects could be dissipated. Historically, if the natural stresses were high enough, they could have caused "stripping" or tensile cracking across the schistocity,

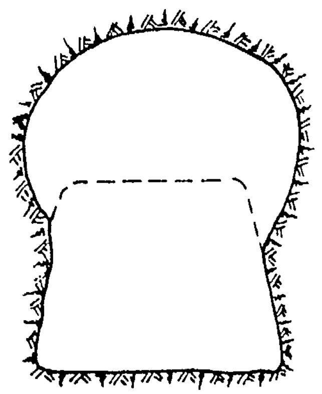


Figure 4. Crown failure in weak material leading to a stable arch.

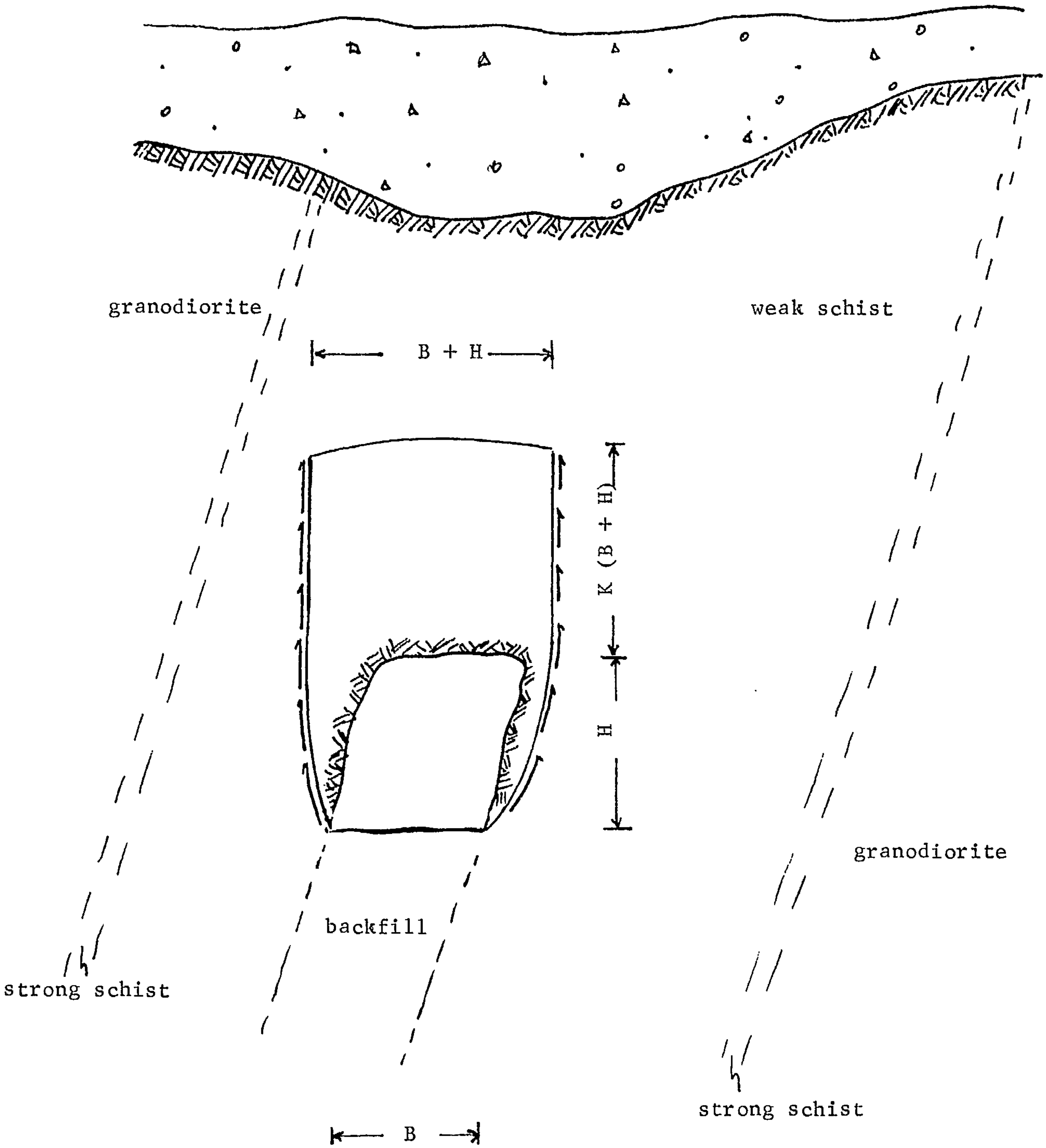
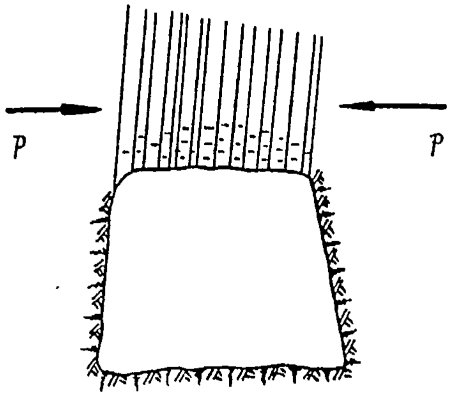
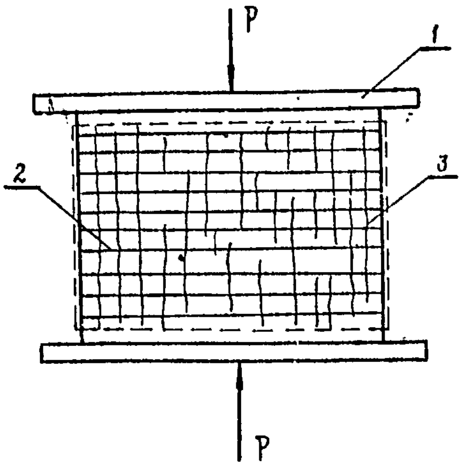


Figure 5. Definition of a Terzaghi failure surface in a gouge-rich schist, Belmoral mine. The constant K is dependent on the material.





1 Loading platens
2 Lamination and parting
3 Tensile fissure

Figure 6. Roof stripping from the action of in situ stresses; laboratory test simulating stripping mechanisms in weak, laminated material (3).

figure 6. This in turn would adversely affect the opening as soon as it is created. Discontinuities are so oriented at the Belmoral mine.

Sudden failure of the entire crown into the opening or plug failure, figure 7, is possible when subsidence is controlled by some planar structural feature such as a fault which provides a plane of weakness whose shear strength is overcome at some critical stage of mining. The conditions are at their worse when weak material such as talc, biotite or clay gouge line the planar feature and water pressure originating from surface, are also present. Again, the effect of ground stresses must also be considered in stabilizing this situation.

PHYSICAL MODELLING

There are several varieties of physical models. The base friction model, figure 8, is used widely to reproduce the effects of gravity in 2-D models of rock excavations. The body force of gravity is simulated by the drag of a sand belt moving along the underside of the model.

CANMET has started a campaign of base friction tests to obtain representative failure mechanisms around near-surface openings in weak rock with surface crown pillars. Base friction modelling offers a simple and representative means of examining problems in a preliminary fashion that is too complicated for rigid and complex mathematically based calculations.

Physically scaled models will be used in this program. Without a scaled model, the proposition of base friction tests only yield remote approximations at best, nothing to be useful as a starting point for the selection of and guidance of a numerical model. With dynamic similitude, a model can reproduce deformation and failure of a discontinuous rock mass and indicate not only areas of concern but their extent as well.

To date only the Belmoral case has been examined. Effects of the location of the opening with respect to the hanging wall or foot wall, the

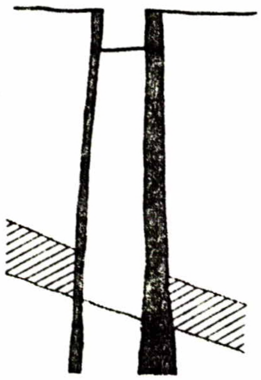


Figure 7. Example of a crown pillar plug failure, weak and planar hanging wall and footwall (4).

Figure 8. Results of a base friction test on a mine scale model with schist; a) to b) shows the progression of the failure mechanism with motion of the driving basal sandpaper (5).

opening size, gouge proportion, and crown thickness, are being monitored as well as the location and extent of failure surface and failure progression.

Table 3 shows the three materials modeled and the properties that had to be scaled down. Some properties did not have to be scaled down as they did not come into play dynamically, e.g. the granodiorite is not expected to fail in compression, tension, nor would it mobilize its modulus of elasticity; only joint behaviour is examined.

The schist zone remains the main area of concern. The model material must satisfy not only strength and length scaling but also density, failure mode and joint behaviour.

Under contractual obligations, base friction modelling of the altered rock surface crown pillars of the Selbaie mine, figure 9, confirmed hanging wall degradation and explained the chimneying failures which occurred there in 1984, 1987 and 1988.

TABLE 3
ENUMERATION OF IN SITU MATERIALS STABILITY PARAMETERS AND THEIR NUMERICAL VALUES
AND SCALED DOWN MODEL MATERIALS AND THEIR NUMERICAL VALUES

In Situ Material	Granodiorite	Boundary H.W. and F.W. Schist	Weak Ore Zone Schist
Stability parameter to model, in situ value	1) joint angle of friction	1) tensile strength 2) modulus of elasticity 3) joint angle of friction	1) tensile strength 2) plasticity 3) plane of schistocity angle of friction 4) joint angle of friction

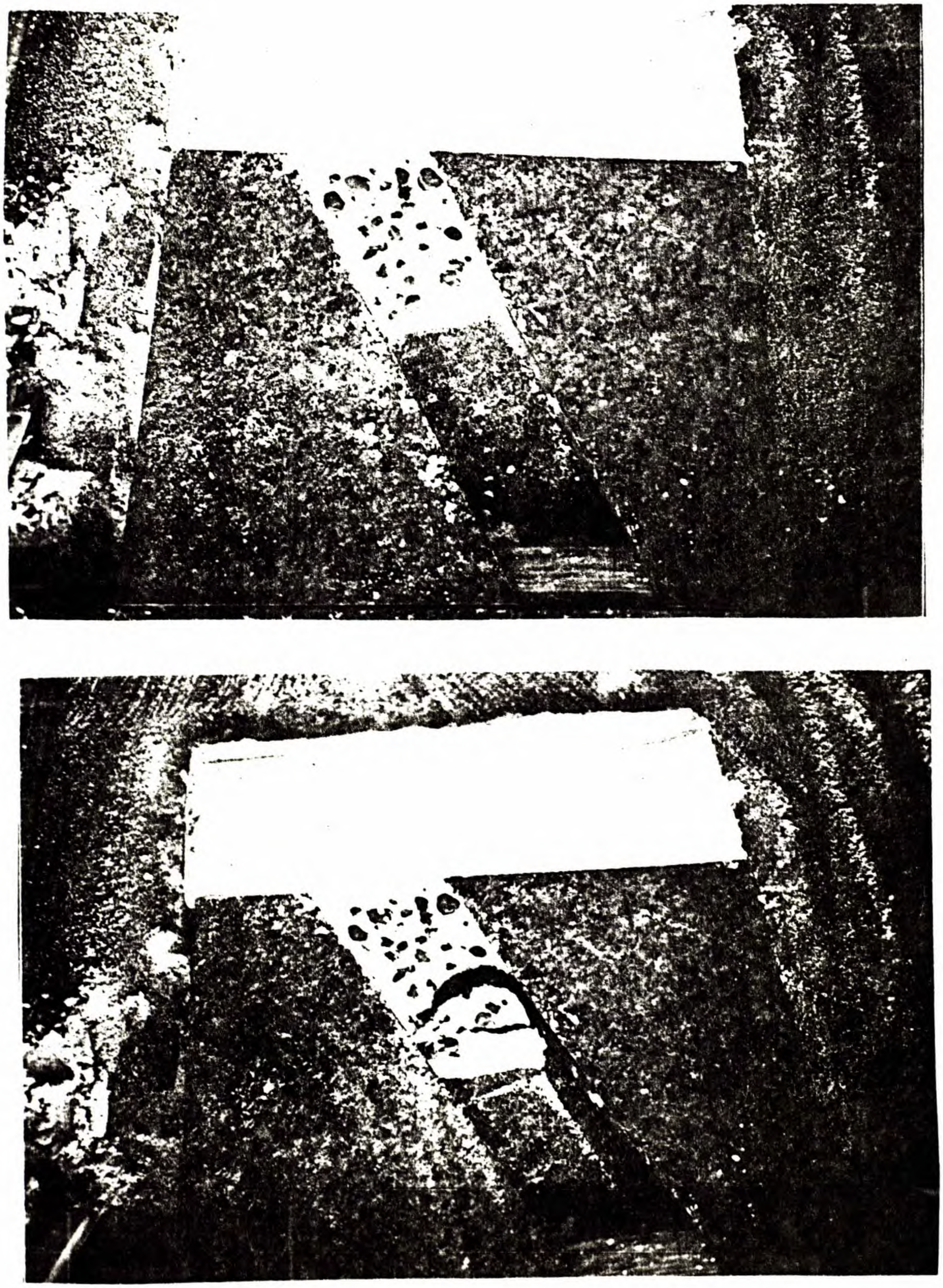


Figure 9. Base friction modelling of the Selbaie surface crown pillar. Cross section showing altered rock of the pillar and overburden. The failure, progression on the hanging wall, was very similar to a cave-in in a stope (6).

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