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Title page

CANMET'S IN SITU RESEARCH ON SURFACE CROWN PILLAR STABILITY

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ABSTRACT

CANMET has undertaken, since 1985, a major research thrust into the subject of surface crown pillars. In order to respond to the void of knowledge existing, a research program was undertaken to address the fundamentals involved with the unique, wide ranging and complex problems related to these mining structures.

In situ research, aimed at addressing the fundamental character of pillar settings, critical stability parameters and failure mechanisms, is only a portion of CANMET's effort on the subject.

This presentation endeavours to outline the nature and purpose of this research. It is wide ranging, dealing with several of the surface crown pillar design elements: identification of deposit and regional characteristics, geotechnical investigations, monitoring and pillar recovery. CANMET's work on the stability of mine pillars is described and the outline of future research is presented.

KEYWORDS: Surface crown pillars, in situ testing, diamond drilling, geotomography, stress measurements, mass modulus of elasticity, monitoring.

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LA RECHERCHE EN PLACE DU CANMET
SUR LA STABILITÉ DES PILIERS DE SURFACE

M.C. Bétournay*

RÉSUMÉ

Le CANMET a entrepris, depuis 1985, une campagne importante de recherche sur le sujet des piliers de surface. Pour combler le manque de connaissances existant, un programme de recherche fut adopté pour solutionner les problèmes uniques, complexes et variés de ces structures minières.

La recherche faite en place par le CANMET, (une partie des efforts voué aux piliers de surface) est orientée vers le caractère fondamental des situations, paramètres critiques de stabilité et mécanismes de rupture retrouvés aux sites.

Cette présentation a pour but de décrire les concepts et les objectifs de cette recherche. Celle-ci est de grande envergure, touchant à plusieurs éléments de conception de piliers de surface: identification des caractéristiques régionales et du dépôt, investigations géotechniques, suivi d'ouvertures, et récupération de piliers. Le travail de recherche fait par le CANMET sur les piliers de surface de diverses mines est également présenté, de même que le plan pour la recherche à venir.

MOTS CLÉS: Piliers de surface, essais en place, forages au diamant, géotomographie, mesures de contraintes, module d'élasticité du massif, suivi des ouvertures.

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INTRODUCTION

In 1985, CANMET began a major research thrust into the subject of surface crown pillars. These are the rock bodies overlying the uppermost stopes of a mine, serving to permanently or temporarily ensure the stability of surface elements, figure 1.

It became evident, from the beginning, that hardly any information existed that could begin to expose the scope and complexity of the subject as we know it today.

Table 1 shows the range of characteristics related to surface crown pillars of Canadian mines. The 24 hard rock mines surveyed show that deposits dip steeply, and are covered by considerable overburden. Alteration of the rock is often pronounced and hangingwall/footwall have little competence. At least two or three joint families and faults occur at each locality.

Surface crown pillars can be found in many geological contexts (intrusive terrains, schistose conditions, sedimentary settings) in single or multiple occurrences or even at the bottom of open pits, figure 2.

Further evidence of the scope of the subject is seen in the number of disciplines to consider when understanding the nature and behaviour of these mining structures.

In situ geophysical, rock mechanics and soil mechanics techniques provide mass behaviour data, lab testing of rock and soils yield material properties. Analytical, probabilistic, empirical and numerical methods are used to evaluate rock mass and soil mass stability. Mining methods are reviewed for their effects on stability of the opening and the support required to maintain terrain integrity. Monitoring and instrumentation techniques are applied to match the evaluation and nature of ground movements (rock and soil).

The complexity of the subject is related to the singularity of

FIGURE 1. DEFINITION OF A SURFACE CROWN PILLAR

"SURFACE CROWN PILLAR": A ROCKMASS OF VARIABLE GEOMETRY, MINERALIZED OR NOT, SITUATED ABOVE AN UPPERMOST STOPE OF THE MINE, WHICH SERVES TO PERMANENTLY OR TEMPORARILY ENSURE THE STABILITY OF SURFACE ELEMENTS. (1)

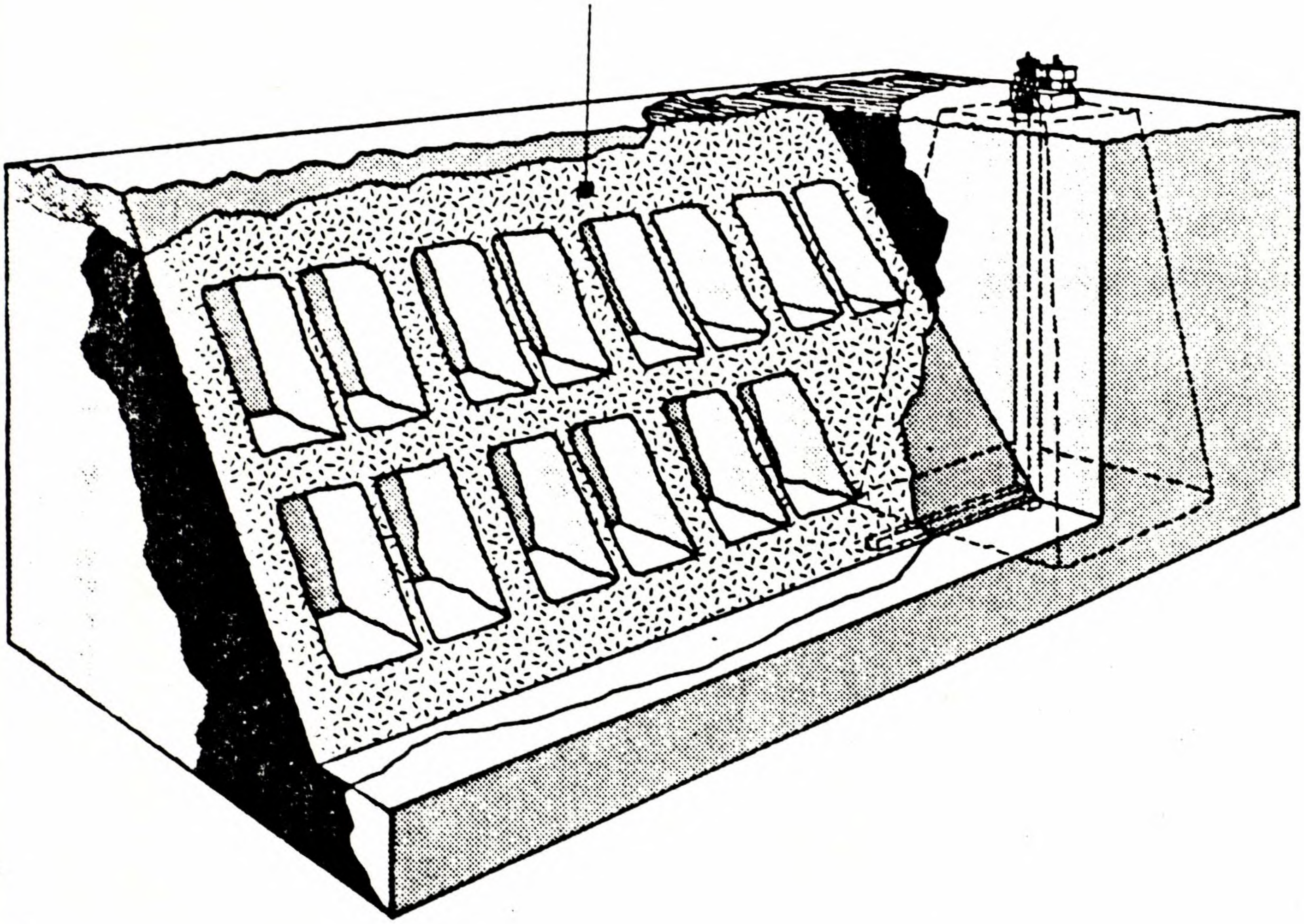


Table 1. Basic Characteristics of Surface Crown Pillars of Hard Rock Mines (1)

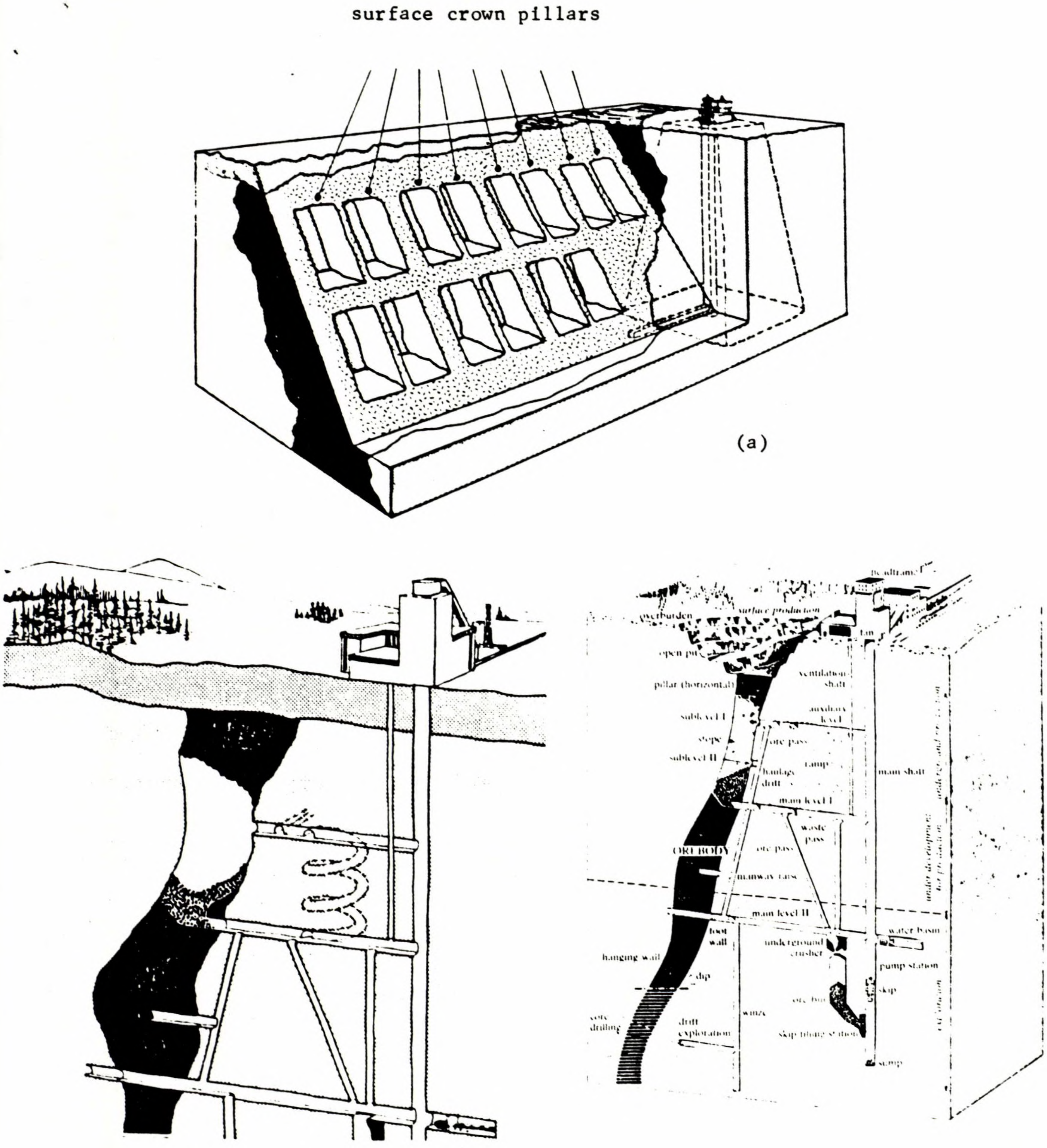
MINE	1	2+	3+	4	5	6	7	8	9	10+	11	12	13	14	15	16	17	18+	19	20	21	22	23	24
Items																								
* BODY OF WATER (m)			3	(3)	-	-	-	7.6	-	( )	( )	-	20	-	-	-	-	-	11	-	-	-	13	-
* OVERBURDEN (m)	(8)	(7)	27	36	4	15	5	20	17	16	20	15	3	5	30	9	1.5	(2)	5	-	45		19	(9)
Substantial clay deposits			*	*				*	*		*	*		*								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



(a)

(b)

(c)

Figure 2. Surface crown pillar settings: (a) multiple occurence, (b) single occurence, (c) single occurence at the base of an open pit in (8).

each case and to the number of, and interelationship of, parameters affecting the general stability for the entire pillar setting.

While examining the subject, one is constantly reminded that designing these surface structures using deep level compression pillar formulation is inappropriate. In fact, these pillars will have a tendency to behave more in a passive fashion, where tensile and shear failure will predominate in a horizontal mass.

CANMET, in order to respond to the lack of knowledge on the subject, has begun a program of research into the fundamentals, to provide the industry with a working handbook which will outline the benefits of research, case studies, development of design philosophy and methods needed on a day-to-day basis by the mining industry for the safe and economical dimensioning of surface crown pillars.

In its research CANMET attempts, in particular, to address the fundamental character of pillar settings, and in general the stability of all types. Parameters critical to the stability of these pillars are addressed. The subject treated in this presentation relates to in situ research carried out by CANMET. Particular to this type of research, these are the elements currently treated:

1. Recognition of site, stability conditions and parameters of active mines
2. In situ stress measurements at shallow levels
3. Mapping of discontinuities in 3-D
4. Development of new drilling techniques to sample weak rock
5. Pillar modulus of elasticity
6. Development of monitoring instruments for weak rock masses
7. Development of a mining method to recover surface crown pillars with prediction and control of caving overburden

Other current research carried out at CANMET consists of:

1. Modelling pillar failure mechanisms in weak schistose

terrain

2. Calculation of the zone of broken rock around an uppermost opening (depending on mining method, rock mass quality and stress level)
3. Development of probabilistic design methods

All of CANMET's research relates to the design steps for surface crown pillars (1), figure 3. This design process will be used to present and explain the in-situ research elements.

CURRENT IN SITU SURFACE CROWN PILLAR RESEARCH

Identification of Deposit and Regional Characteristics

Research that can help establish existing material quality has centered around providing representative samples for geomechanical testing of soil and rock material.

Ordinarily, rock can be sampled in accessible areas by diamond drilling. In weak material, such as altered rock or highly schistose rock, very poor samples, if any, are recovered; the damage imposed on the sample renders them unrepresentative. CANMET has sponsored contract research on new diamond drilling methods (2). The results have shown that near complete recovery of altered rock in an undisturbed state is possible by using stepped lateral discharge bits, reduced fluid pressure and a fluid composed of compressed air and polymer (making a "foam"), figure 4, table 2.

Similar results were obtained independently by Hydro-Quebec in rigid, stony till, by using the same technique but with a different fluid additive, bentonitic mud, froth by compressed air (3).

Sampling for geomechanical testing is not the only reason for carrying out proper coring techniques. Often, by using single barrel drilling, joint features are erased or damaged by rotation of the core

SIMPLIFIED FLOW CHART OF SURFACE CROWN PILLAR DESIGN

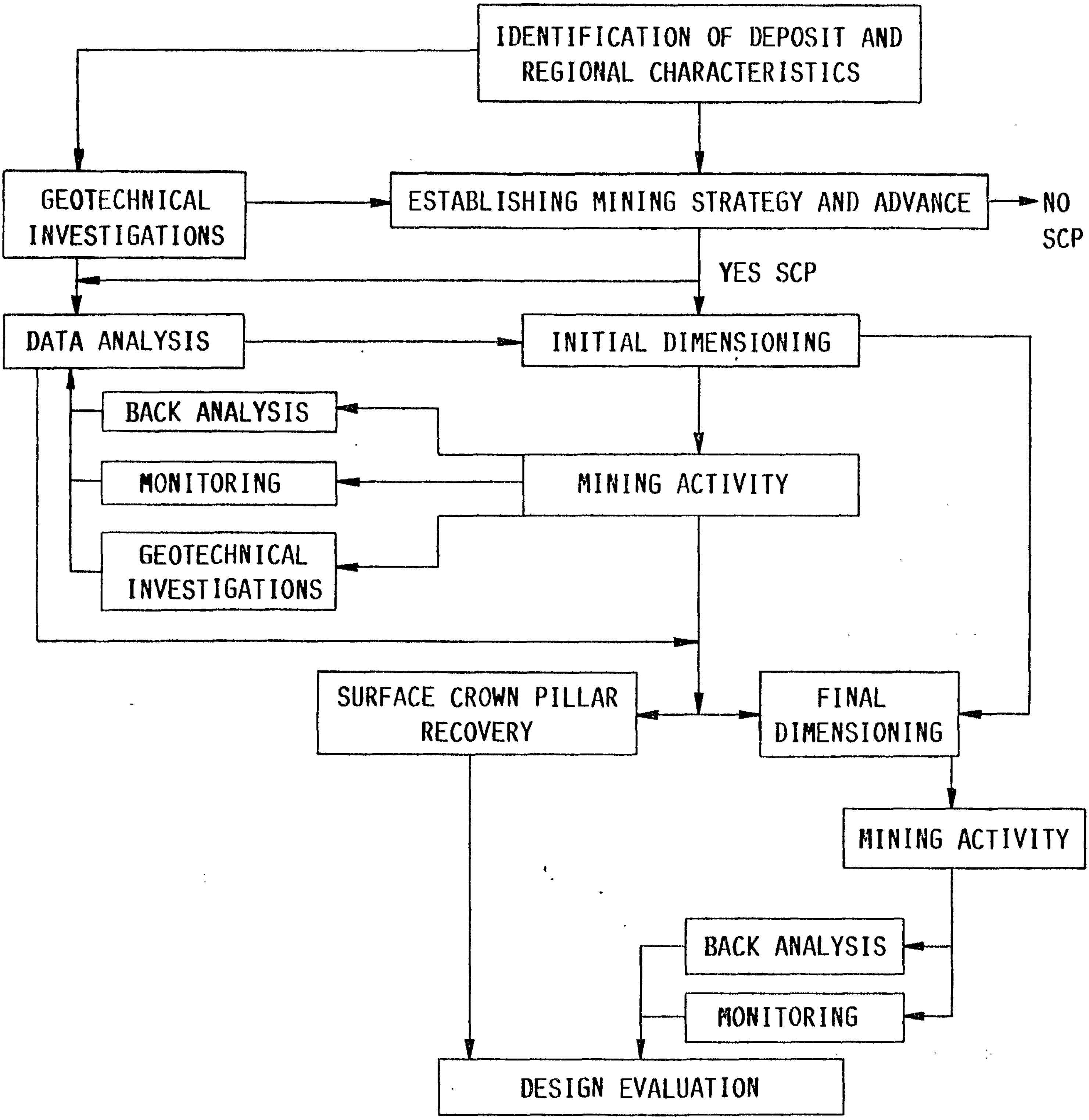


FIGURE 3

CHANGE IN SYSTEM COMPONENTS TO IMPROVE CORE QUALITY & QUANTITY

BIT TYPE

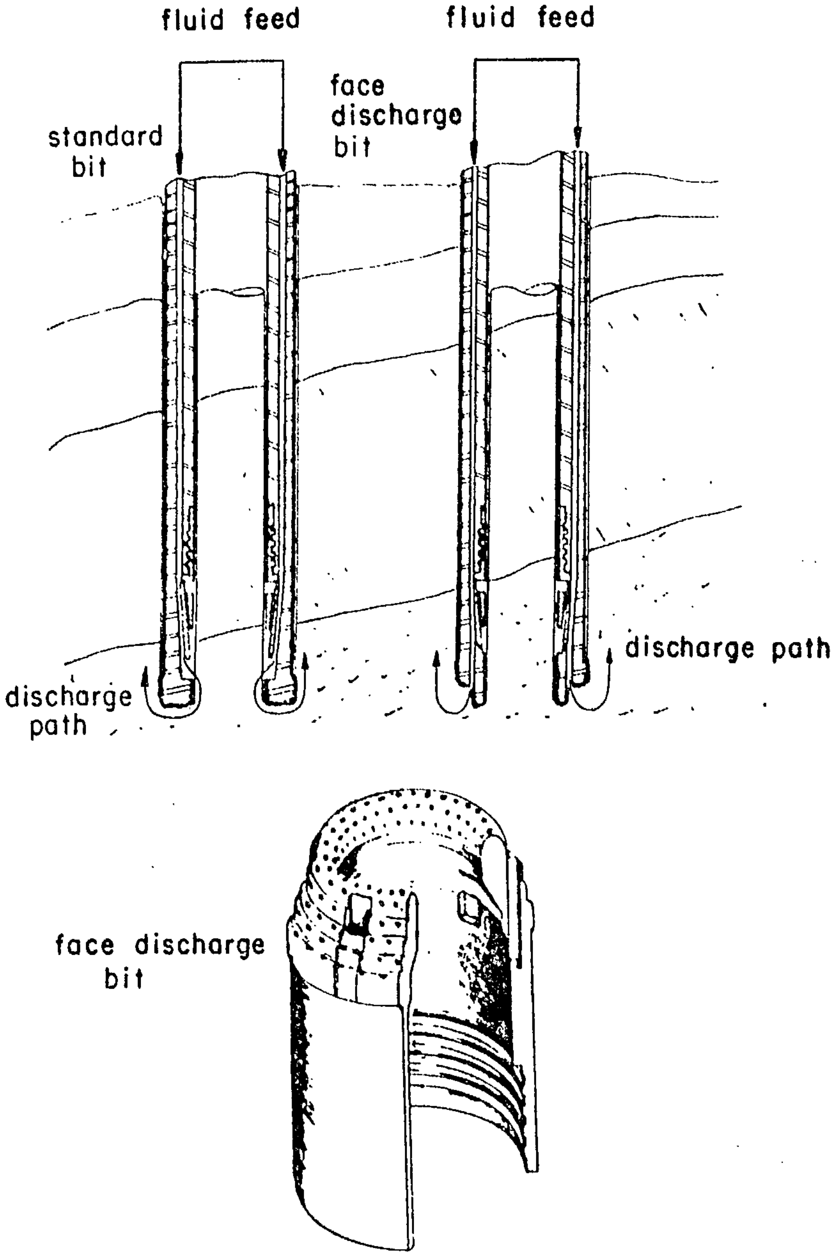


Figure 4. Improvement of core recovery by reducing flow damage with the use of a face discharge bit (9).

BOREHOLE DESIGNATION	MATERIAL TYPE	BARREL	BIT	ADVANCE	FLUID TYPE	FLUID PRESSURE	FLUID FLOW	RECOVERY	SAMPLE CONDITION
SELBAIE MT-11	DECOMPOSED AND KAOLINIZED VOLCANIC TUFF BRECCIA W_c=10-20%	DOUBLE, TRIPLE	FACE DISCHARGE, STANDARD	5cm/MIN	WATER	4.2 MPa	?	<30%	HARD PIECES RECOVERED, VERY FEW SOFT PIECES
SELBAIE MT-10		TRIPLE	FACE DISCHARGE	5cm/MIN	WATER	1.7-2.0 MPa	?	<30%	HARD PIECES RECOVERED, VERY FEW SOFT PIECES
		TRIPLE	FACE DISCHARGE	3cm/MIN	POLYMER MUD + WATER	3.5 MPa	?	<60%	HARD PIECES AND SOME SOFTER PIECES
		TRIPLE	FACE DISCHARGE	3-5 cm/MIN	AIR +) F POLYMER) O MUD +) A WATER) M	1.7-2.0 MPa	7.51/MIN	>90%	HARD PIECES, KAOLINITIC MATERIAL, DISINTEGRATED FINE ROCK IN CLAYEY SILT
SELBAIE MT-12		TRIPLE	FACE DISCHARGE	3-5 cm/MIN	AIR +) F POLYMER) O MUD +) A WATER) M	1.7-2.0 MPa	7.51/MIN	>90%	HARD PIECES, KAOLINITIC MATERIAL, DISINTEGRATED FINE GRAINED ROCK IN CLAYEY SILT
HYDRO-QUEBEC	TILL - 40% COBLE STONES + 10-40% SAND, GRAVEL, SILT + 1-12% CLAY	TRIPLE	FACE DISCHARGE	1.3-3 cm/MIN	AIR OR WATER OR FOAM	0.9-1.1	30-35 1/MIN	0-30%	ONLY LARGE PIECES RECOVERED, HIGHLY DISTURBED DAMAGE TO SOIL MASS, HYDROFRACTURING
		TRIPLE	FACE DISCHARGE	1.3-3 cm/MIN	FOAM INCLUDING LOW VISCOSITY BENTONITIC/POLYMER MUD	0.2-0.6 MPa	18-40 1/MIN	50-90%	SAMPLES DISTURBED; HYDROFRACTURING OF THE MASS
		TRIPLE	FACE DISCHARGE	1.3-3 cm/MIN	FOAM INCLUDING HIGH VISCOSITY BENTONITIC MUD	0.2-0.25 MPa	?	100%	CORE UNDISTURBED; SOIL MASS UNDISTURBED

Table 2. Summary of research campaigns on improving core recovery and quality for altered rock and till (9).

pieces, figure 5. Double or triple barrel coring will provide less damaged core which can be used for rock mass characterization and shear tests. The innovative CANMET drilling techniques will improve recovery of joint infillings. Intact core will lead to a better understanding of mass behaviour.

Geotechnical Investigations

Perhaps the most important element in the design of surface crown pillars relates to the quantitative geotechnical data used in almost all subsequent design steps.

CANMET's research in this domain has one definite objective: to identify and describe the parameters critical to suface crown pillar stability. Three elementary considerations are being studied: the actual distribution of joints in 3-D, the natural and induced stresses around the surface crown pillars and the modulus of deformation of the pillar mass.

In a domain where tensile and shear behaviour will dictate the nature of instabilities, it is necessary to identify discontinuity relationships and anomalous zones. This will clarify what failure mechanisms can occur and where they occur. What is just as important, is coverage of all the pillars and openings as well as their surroundings, in 3-D to obtain accurate coverage. Conventional techniques only yield limited information which must then be extrapolated statistically in 2-D to provide qualitative information.

a) 3-D pillar condition

One can appreciate that more precise dimensioning for stability will be obtained (especially numerical modelling) with complete knowledge of existing discontinuities. The nature of actual joint intersection, density, length and orientation will clearly spell out how and where the mass is broken up. Such effective remote detection in advance of

Figure 5. Erasing of joint roughness from the use of single barrel diamond drilling (9).

excavation will make mining and ground control less of a "wait and see" proposition.

New geophysical techniques are being used in this respect. The contractual mandate given to Dr. P. Young of Queen's University by CANMET is to map, in 3-D, the discontinuities greater than 1 m and anomalous zones of a given rock mass. The research will be performed with readily available equipment and will be documented in user's manuals and scientific reports.

Tomographic imaging techniques will be used. The potential for borehole radar use will also be examined. These methods allow for detecting changes in rock mass integrity away from boreholes or surface opening while still utilising the known borehole information for interpretational control.

By using cross hole surveys (figure 6) with transmitters and receivers at several elevations in the borehole (figure 7) a multitude of signals are so carried in a high percentage of a definite rock mass volume.

A review of relevant geophysical methods has outlined their critical aspects in regards to characterizing discontinuities and anomalous rock quality (4). The seismic parameters most readily measured and imaged in geotomography are compressional and shear wave velocity and attenuation. Because velocity and attenuation do not correlate significantly in rock masses, this offers two independent means of identifying variations. But difficulties such as discontinuity induced anisotropy render reliable imaging difficult to achieve.

Although velocity does decrease with density of jointing and material quality, it is difficult to specifically identify characteristics. It is also difficult to distinguish rock types with certainty. A noticeable breakthrough however is that shear waves have been shown to be more sensitive to fracturing than compressional waves.

Seismic wave amplitude is reduced (attenuation) when waves travel

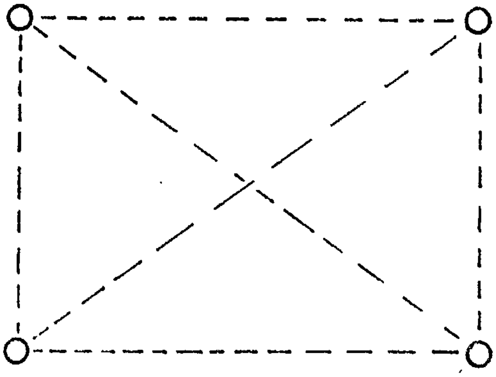


Figure 6. Plan view of borehole location for crosshole seismic transmission planes.

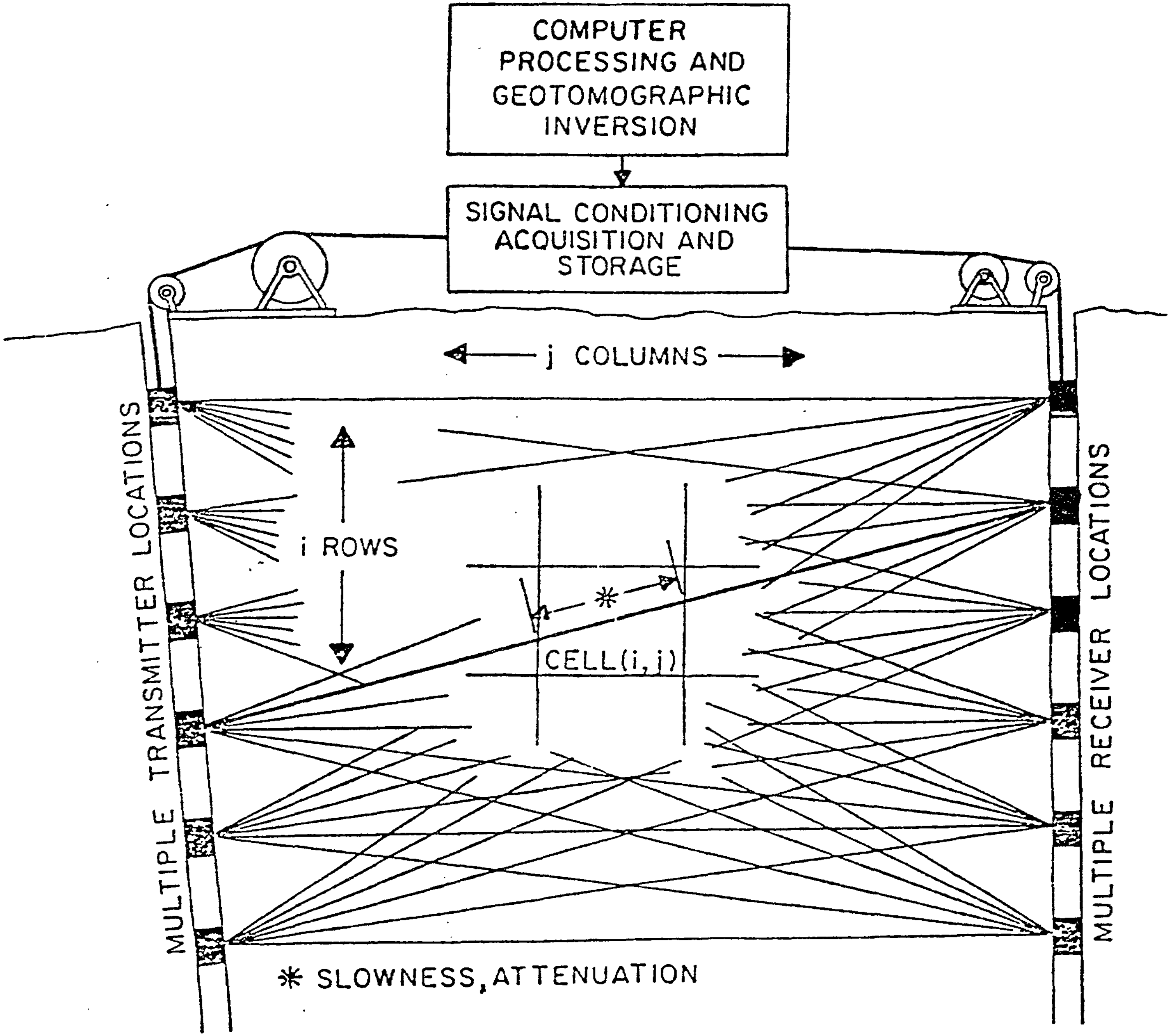


Figure 7. Coverage of transmission plane with several seismic signals from borehole sources, in (8).

across fractures. These attenuation effects are strongly frequency dependent being greater for higher frequency data. Also, increasing the porosity or fluid saturation of rock generally increases its attenuative properties. Dry rock attenuates p-waves more easily and saturated rock attenuates s-waves more readily. Closed fractures while being transparent to normally incident p-waves, significantly attenuate s-waves. Attenuation is more sensitive than velocity is to fracture density.

Lower stress environments such as surface crown pillars are ideal for attenuation because of higher porosity/saturation of the rock mass, greater degree of fracturing. Comparison of p-wave transmission and s-wave stopage can indicate discontinuous areas. The aperture of the discontinuity will control the frequency attenuated. Thus, it is only through a number of image interpretation that seismic parameters will be reliable tools.

b) In situ stress measurements

One of the great unknowns related to the stability of near surface openings has to do with the state of stress within the surrounding rock mass. Are the lateral in situ stresses high near surface (as predicted (5)) or does a gravity setting predominate?

When gravity predominates, jointing represents the main stability element. Thus joint characteristics such as orientation, nature of the intersections, orientation, length, and infilling all come into play, recognizably so in the context of larger openings intersecting more joints than smaller openings.

Natural stresses in the Canadian Shield provide larger horizontal than vertical stresses. An effective lateral confinement is thus given to the rock mass. Depending on the orientation of the opening in this stress field, and its geometry and size, stress redistribution in the surface crown pillar can be compressive and provide sufficient confinement to prevent gravitational loosening of the rock mass (figure 8).

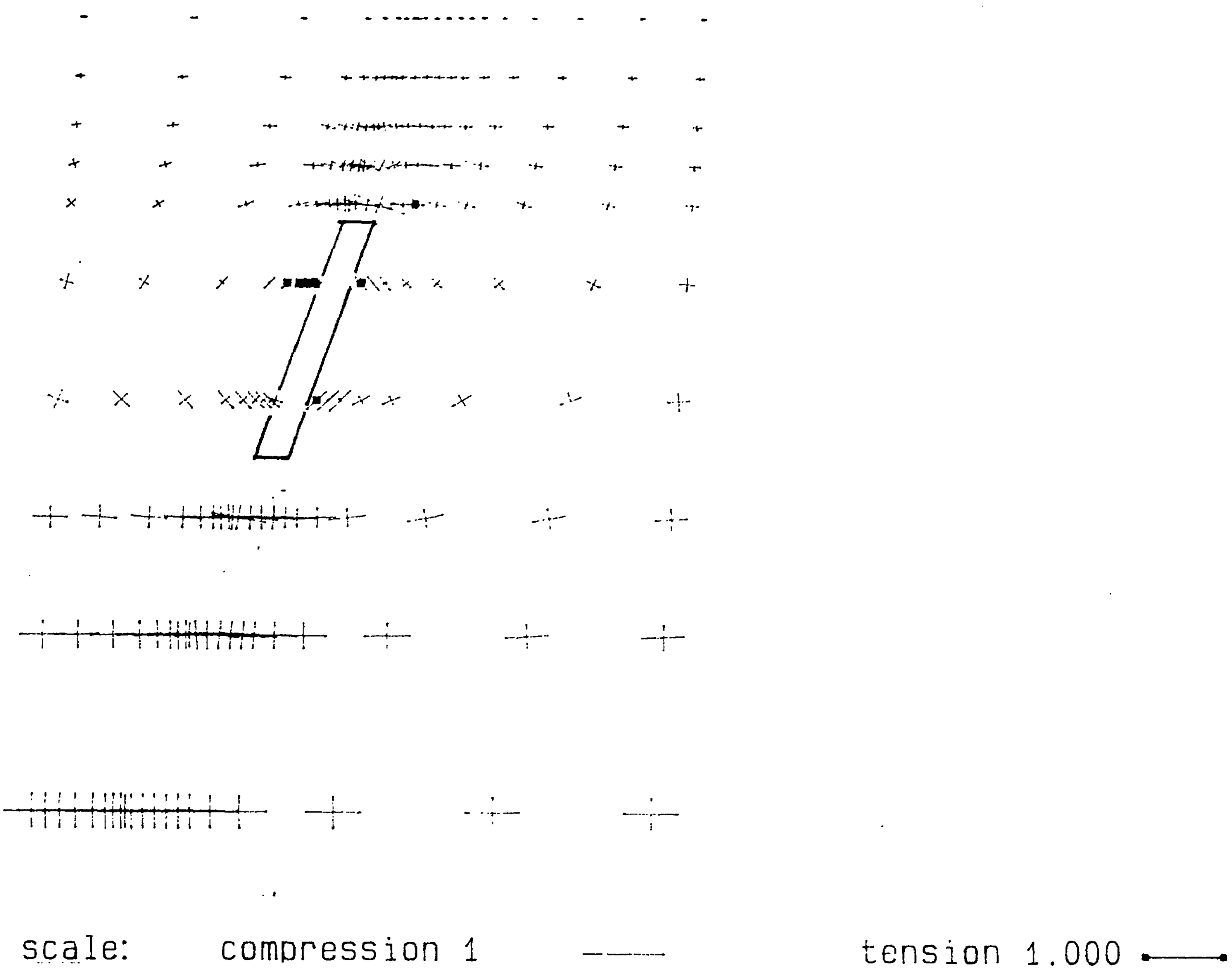


Figure 8. Stress redistribution around a near-surface opening and in a surface crown pillar (10).

It thus becomes important to know what value natural stresses exhibit in the shallow reaches of the Canadian Shield. Also important are the stress values found in widely contrasting local settings such as pyrite/quartz orebodies surrounded by weak schists.

Once these natural stresses are known, calculation of stress redistribution within a given excavation setting can be predicted by numerical modelling or measured by other stress surveys.

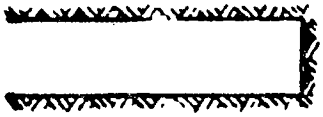
Measurements will be carried out from outcrops. Doorstopper type strain measuring cells (figure 9) will be used at depth ranging from 15 to 30 feet.

c) Modulus of elasticity

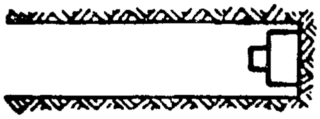
Even though rock quality information is obtained from core examination or geophysical surveys, direct testing for rock mass behaviour is still the only way to obtain quantitative deformation measurements for a rock volume.

Trow Associates have been given a contract mandate by CANMET to obtain representative values of deformation for weak rock settings of surface crown pillars. These settings were chosen for two reasons. They represent worst ground control problems for surface crown pillar stability and have not been described scientifically, thereby leaving numerical modelling or other forms of stability consideration without valid material information. Four sites were chosen:

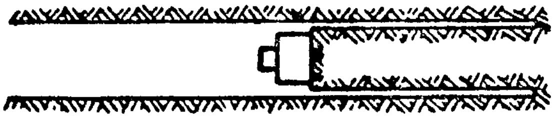
1. Belmoral Mine (gouge filled talc-biotite-schist with quartz pods)
2. Bousquet Mine (seriate schist with massive pyrite orebody)
3. Chimo Mine (metavolcanic rock, quartz orebody, graphite hanging and footwalls)
4. Pamour Mine (metasediment rock).



a) BX hole drilled to required depth, flattened and polished (diam. 0.06 m).

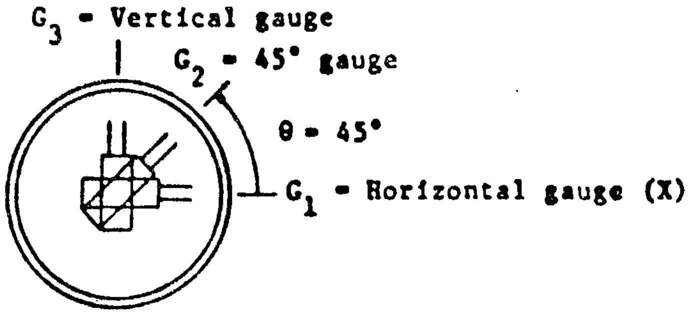


b) Strain cell bonded to end of hole.



c) Overcored strain cell.

d) Recovered test piece with strain cell.



e) Strain gauges on doorstopper face, glued to the polished rock face.

Figure 9. Doorstopper type strain measuring cell for in situ stress measurements.

Though rock quality can be evaluated from core, using a dilatometer or in weak rock a pressuremeter, figure 10, will specify behaviour coupled with quality, e.g. with Q, RQD, etc.

This work is an extension of the weak rock dilatometer tests carried by CANMET at Selbaie where high fracturing and highly altered rock occur. CANMET has also carried out dilatometer tests in good ground such as the Pierre Beauchemin surface crown pillars.

This research also allows us one of the rare opportunities to compare the modulus of elasticity obtained from laboratory tests (intact rock), rock quality based empirical approaches (rock mass) and dilatometer tests (rock mass).

Monitoring

The process of dimensioning a surface crown pillar is not finished with the creation of a near-surface opening with a chosen geometry and rock thickness between it and overlying elements such as overburden, surface installations, etc.

Monitoring, visually (if possible) and with instrumentation, must be performed. Failures should be detected to prevent degradation leading to problem situations which may be partial or complete pillar collapse.

Two instruments have been applied in the context of weak rock mass stability. Both can be characterized as extensometers measuring the deformation created around an opening.

The first instrument, developed jointly by CANMET, Les Mines Selbaie and Strata Engineering (6), was placed in a 7.5 m thick surface crown pillar. The pillar was composed of highly altered rock (kaolinized matrix with remmant rock pieces). Readings in the surface crown pillar were required to monitor stability and confirm numerical modelling predictions.

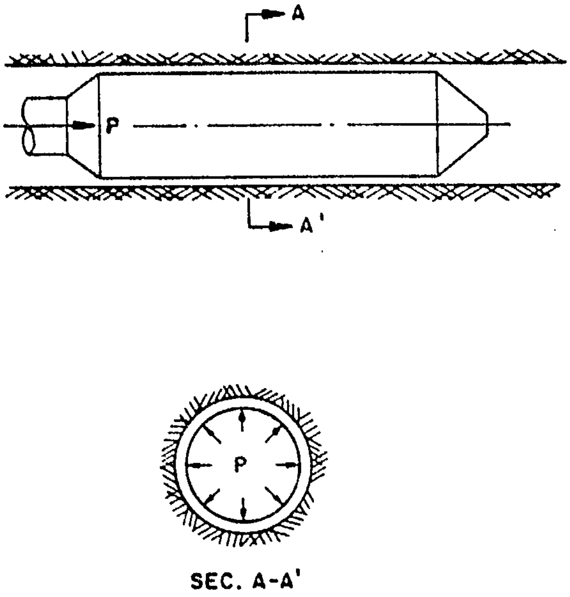


Figure 10. Schematic representation of a dilatometer and the distribution of pressure in the borehole during a test.

Such material had been known to fail in a progressive, tensile fashion. The instrument was required to monitor failures in the pillar above the opening due to gravity and stope excavating effects, and was required to respond to the following criteria:

1. The instrumentation must be shock-proof;
2. The reference anchoring system must hold-in this material;
3. The instrumentation must be economical to replace, or be sufficiently low cost during the excavation process;
4. Readings should be measureable in the millimeter range, on a continuing basis;
5. The instrumentation should measure the relative movement of the exposed surface crown pillar;
6. The instrumentation must be read from a distance because gaining access to the stope would be impossible after the floor had been blasted into the stope below.

Blasting of the floor, precluded using electrical type instruments because wiring could be dislodged or broken during blasting. The non-electrical, mechanical type instruments were also rejected due to the problem of gaining access to the stope after the stope had been completely excavated. A custom built extensometer, relying on dial gauge indications of displacement, was adopted.

The instrument provides for measurement of movement at the back, bottom of the surface crown pillar, relative to a fixed point. This point represents the grouting level of a cable bolt, 6 m into the back with the last 2 m of the 8 m anchored length grouted. The cable bolt extends into the opening where, below the stope back a steel plate is affixed. The movement is seen as that of the first 6 m of back relative to this plate, or base line, figure 11. A hole collar with four spring loaded bars for maintaining a stable assembly, is the second surface (besides the baseline), against which the dial measures movement.

The 50 mm diameter dial gauge, precise to 25 μm, can be read to the nearest tenth of a millimeter with a transit telescope at distance of

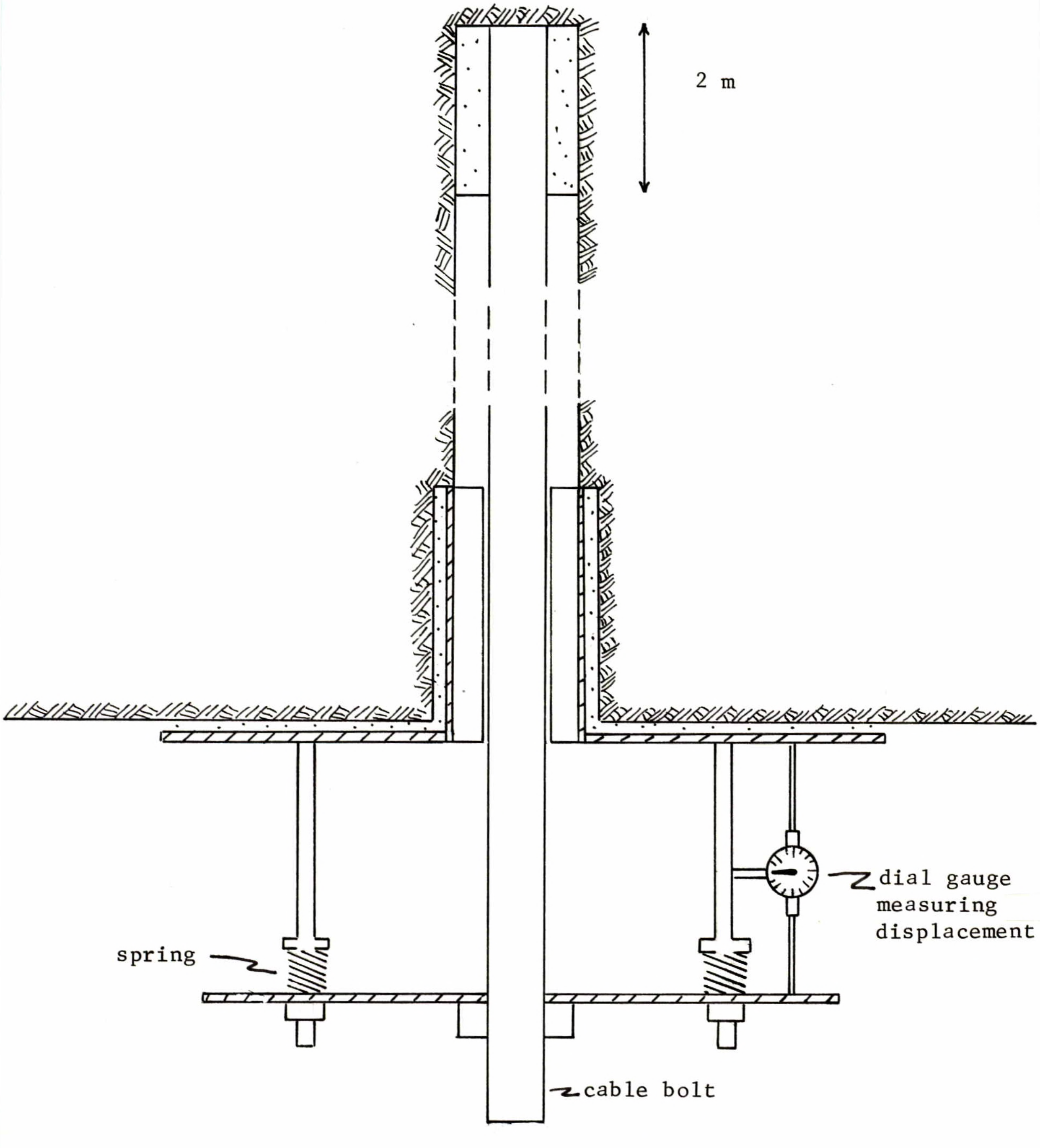


Figure 11. Sketch of weak rock extensometer used at Les Mines Selbaie in the surface crown pillar.

over 50 m.

Figure 12 indicates the location of 10 such extensometers at the Selbaie mine.

The second instrument, perfected by the US Bureau of Mines, is a multiple point (anchor) extensometer installed in boreholes oriented towards and ending near existing or future openings.

The instrument was employed because its advantage was in providing better anchoring in a weak, gouge filled mica schist. The reference anchors were set in place by means of inflatable copper flatjacks shaped in a circular fashion, figure 13. This system would provide less opportunity for reference point loosening or slippage compared to conventional anchoring systems.

Pillar Recovery

Canadian mine settings are such that large amounts of overburden usually cap the bedrock. This, in the past, has meant that valuable ore was either left in a stable surface crown pillar or that costly soil removal and/or dewatering and/or soil stabilization techniques were used to recover the ore in the pillar by open pit methods or blast aided recovery in the upper opening (7). When overburden thicknesses reach considerable proportions, the pillar must be left behind.

A new approach to this problem is being applied at Les Mines Selbaie. Surface crown pillars are being completely recovered under dewatered overburden more than 40 m thick. Research is carried out to predict and control the caving of the overburden as a retreat mining method is applied to recover the pillar, figure 14.

This research has drawn on separate sources of information, namely, numerical modelling using three dimensional large strain finite element techniques, settlement above single openings and gravity flow into

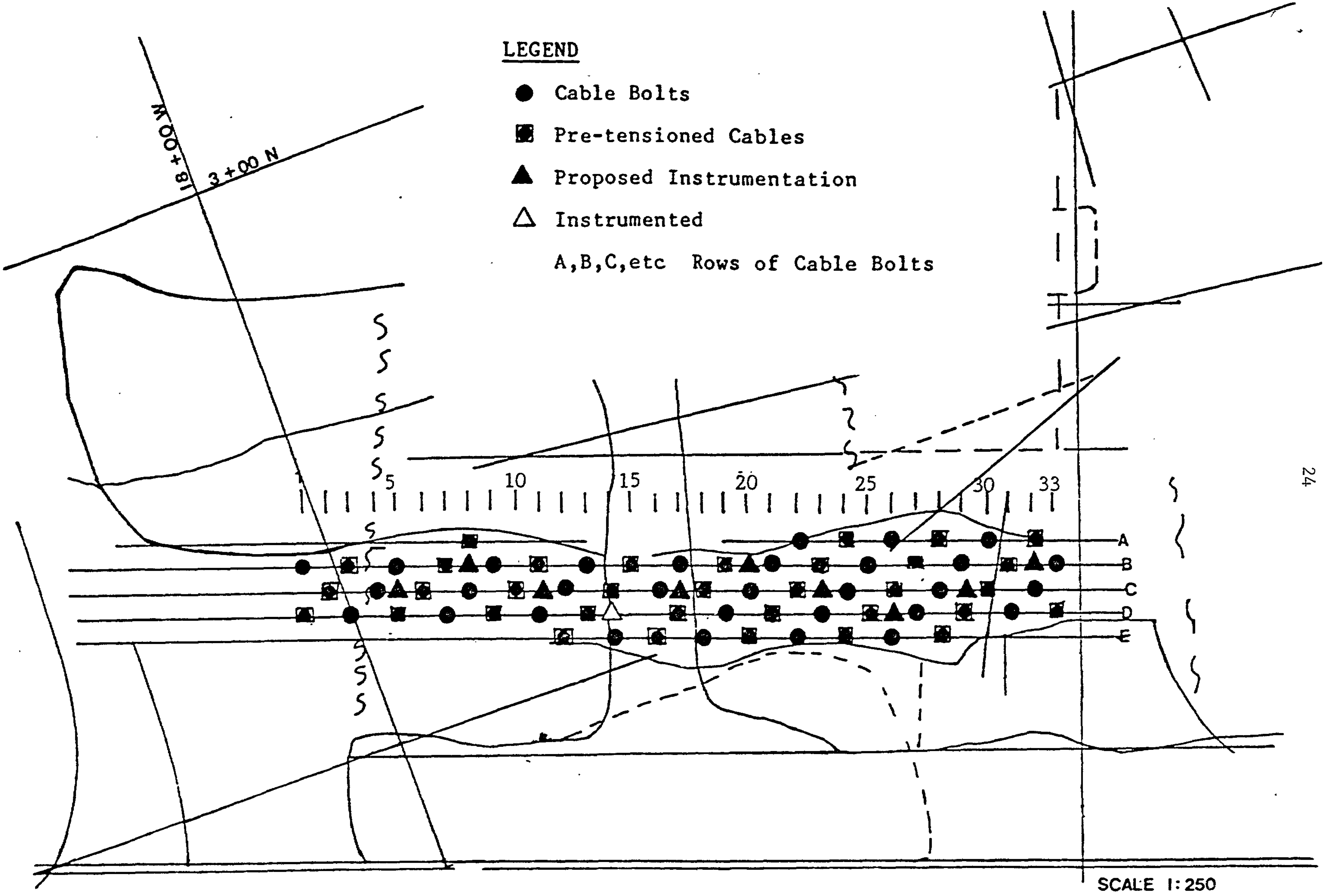


Figure 12. Selbaie mine plane indicating the location of weak rock extensometer in the stope back (6).

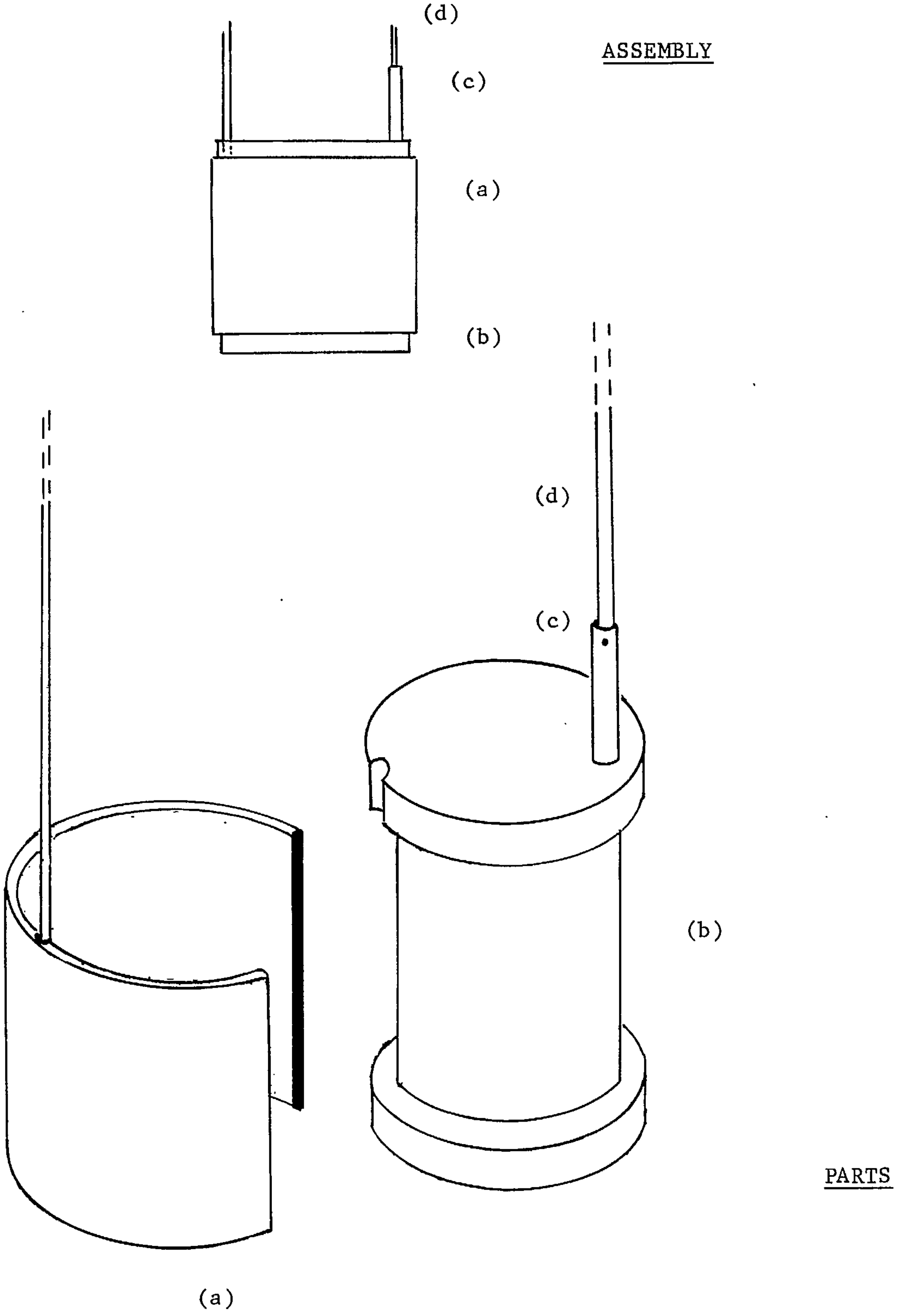


Figure 13. Anchoring system for the USBM extensometers. (a) wrap-around flat-jack with hydraulic line for inflating; (b) machined PVC core; (c) core-fiberglass rod connector; (d) fiberglass rod for measurement of displacement.

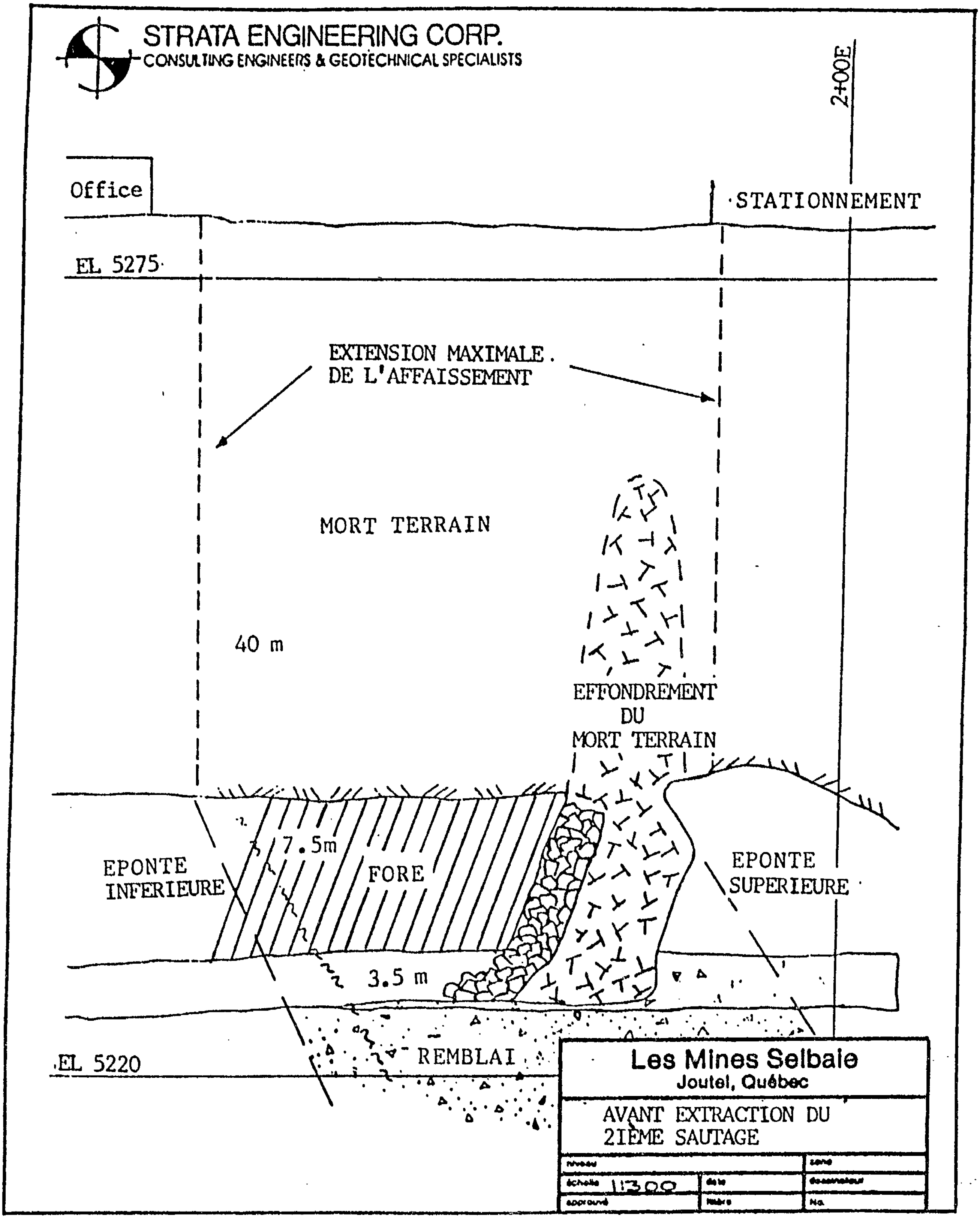


Figure 14. Selbaie mine tranverse section showing surface crown pillar, overburden, retreat recovery method and possible outline of overburden caving (11).

openings with consideration of bulking factors. The analytical feasibility stage predicted that the important parameters in the determination of surface subsidence magnitude are the size of the underground opening and the flow characteristics of overburden soils, including their bulking properties. The greater the soil bulking and cohesion, the less the expected flow and settlement.

At the present time some surface crown pillars have been recovered with little damage to the lowest soil unit, a dense sandy silt. The soil water content, adding apparent cohesion, has been sufficient to make the soil arch and remain stable.

CASE STUDIES

CANMET has embarked on a number of research stability projects with mines.

Table 3 provides a summary of mine specific elements related to surface crown pillar stability. It is immediately evident that these detailed case studies cover a wide range of pillar and upper opening geometry as well as rock mass setting and quality.

CANMET's role has been to, first and foremost, describe in situ conditions, evaluate potential instabilities and failure mechanisms. The mines represent sites with special conditions.

Where a stability analysis mandate was given to CANMET, the applicable design steps were undertaken.

These detailed case studies will be added to the 24 already gathered, Table 1. With these, CANMET now possesses very advanced knowledge on various mine and surface crown pillar aspects, from a vast section of Canadian hard rock mines. This experience is continually transfered through publications such as the surface crown pillar handbook and contacts with mine operators.

TABLE 3
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[0,×]	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[0,×]	Created	4	12-15 m	80°	3-6 m	Quartz vein	100
Belmoral[0,×]	Planned	N/A	N/A	70°	3-5 m	Chloritized talc-calcite-biotite schist	0.1

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

TABLE 3 (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[0,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[0,x]	Weak immediate hanging wall and foot wall	Core in-situ	---	---	---	---	Stope back-filling and open pit extraction
Belmoral[0,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

CANMET'S FUTURE IN SITU RESEARCH

While the subject of surface crown pillars is vast and in need of a large degree of research, CANMET has identified some in situ projects for the near future for the mining industry:

1) Continuing to follow the stability of existing pillars is important; gathering evidence of stability and failure mechanisms with the correct applicable dimensioning and monitoring techniques will be performed.

2) New monitoring tools are also required. Evaluation of water pressure and its effects on pillar stability must be considered. Variation in stress conditions and location with time must also be captured.

3) Ground support in weak rock masses must maintain a tightly interlocked mass. Research is required to assess the effect of various support techniques so that partial or general degradation leading to failure can be avoided.

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