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Standardization of geological and geomechanical assessment at underground coal mines in Canada

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ABSTRACT

Following a dialogue in the Technical Forum meetings in late 1998, a geotechnical assessment project was established. Its objective is "to establish a 'best practice' baseline for both conducting geological and geomechanical assessments and to apply findings in geotechnical design and operation of underground coal mines in Canada and to make the findings readily available via computer database/Internet." It comprises three components: geological assessment, geomechanics baseline study and a web-based geotechnical database. The paper reports on the first two components of the geotechnical assessment project. The work forged further international co-operation between the coal industry and CANMET in Canada and NIOSH in the United States. The paper firstly outlines the underground coal operations in Canada in the late 1990s. It then summarizes the geological assessment, followed by an application of NIOSH geotechnical methodology in a Canadian geotechnical baseline study. The paper concludes with a brief summary and an indication of future direction of the work.

Steve Forgeron
graduated from Saint Francis Xavier University, Antigonish, Nova Scotia, in 1970, with a Bachelor of Science degree in geology. He worked at the Kaiser Celestite Mining operation in Cape Breton from 1970-1976, where he held positions of exploration geologist and eventually, exploration and mining superintendent. Steve joined the Cape Breton Development Corporation in 1976 and has worked in all aspects of coal exploration and mining geology until 2000 when mining operations were shut down. He is currently engaged in activities as a consulting geologist. He is a member of APGNS, CIMM and the Mining Society of Nova Scotia. He is a fellow of CIM and past recipient of the Distinguished Lecturer award.

Chris Mark
entered the mining industry in 1976 as a general underground labourer in a Boone County, West Virginia, coal mine. He subsequently obtained B.Sc., M.Sc. and Ph.D. degrees from Penn State. His contributions to mining engineering practice include the Analysis of Longwall Pillar Stability (ALPS), the Analysis of Retreat Mining Pillar Stability (ARMPS), the Coal Mine Roof Rating (CMRR) and guidelines for control of horizontal stress. Since 1987, he has worked at the National Institute for Occupational Safety and Health (NIOSH) Pittsburgh Research Laboratory. Mark is also co-chairman of the International Conference on Ground Control in Mining, which is held annually in Morgantown, West Virginia.

Introduction

The underground coal mining industry in Canada is small, geographically spread and has recently suffered difficult times not only from complex mining conditions but also through financial challenges. In 1998, CANMET Mining and Mineral Sciences Laboratories (MMSL) closed their Coal Mining Health and Safety Program (CMHS), initiating a new research initiative known as the Underground Coal Mining Safety Research Collaboration (UCMSRC). UCMSRC is a collaborative "in-kind consortium" which brings together all of the principal stakeholders such as industry, labour, regulators, inspectors and universities, in jurisdictions where underground coal mining is active (federal and provincial — Nova Scotia, Alberta and British Columbia).

The purpose of UCMSRC is to provide a forum for dialogue and safety-related research involving stakeholders in Canadian jurisdictions where underground coal mining is active. The organizational structure is relatively simple, comprising firstly, of an executive committee and project teams. Active projects, over the first two years, have included: Technical Forum (ongoing); Use of light alloys; Methane auto shutdown devices; Hazardous location classification and zoning.

David J. Forrester
graduated from the University of Nottingham with a B.Sc. (1971) and a Ph.D in mining engineering (1974). He started with the National Coal Board as a student apprentice in 1967, subsequently working for them as a subsidence engineer, an operational research scientist and a section head on new mine planning. He joined the British Mining Consultants team as a senior mining engineer in 1982 and came to Canada two years later on projects for the Cape Breton Development Corporation. He joined CANMET's Cape Breton Coal Research Laboratory in 1990 where he was group leader/research manager. In 1998, Dave joined Vaughan Engineering Limited as manager of the Sydney Office and is active as project manager on major remedial technology and landfill closure projects and is still involved in mining research.
A member of CIM, Dave is currently Vice-President of District 1, he is a past president of the Mining Society of Nova Scotia (1999-2000), past Chairman of the CIM Coal Division in 1995-1996 and he was a Co-Chair of the Technical Program Committee for the CIM AGM held in Halifax in 1995. He is also a member of the Institute of Civil Engineers in the United Kingdom and a Fellow of the Institute of Mining Engineers, also in the United Kingdom.

Canadian U/G Coal Mines

Location, Ownership and Mining Method of the Underground Coal Mines

The five underground coal mines operating during the time of this project are owned by mining companies located in three distinct geographical areas of Canada. They employ two basic variations of the retreat mining method: room-and-pillar and longwall. These methods are well suited to efficiently maximize the recovery of coal reserves within the geological setting in which they are found (Fig. 1; Table 1).

Geological Setting of the Coalfields

The five mines are located in three different coalfields, each with a unique geological setting. The sedimentary nomenclature and age of the coalfields are summarized in Table 2 and Figure 2. It is apparent that the coals were deposited in environments separated not only in space, but also by vast intervals of time. One of the interesting aspects of this study is an examination of the extent, if any, that these factors have been reflected in conditions experienced during coal mining.

The three principal coalfields where underground coal mining is active are:

1. The *Sydney Coalfield* was formed in a fluvial sedimentary setting on a slowly subsiding coastal plain. Tectonically, the coalfield was not appreciably disturbed. Its structural style is characterized by gentle folding caused by northeast-southwest compression. Remembrance of this tectonic history remains in the form of unrelieved excess horizontal stress at increasing depth. Ground control issues involve sedimentary discontinuities, gas stored in sandstone, thick sandstone beds in the roof strata, adjacent colliery interaction and the effects of horizontal stress (Fig. 3a).

2. The *Comox Coalfield* was formed in a fluvial environment with tentative contact with marine conditions. Its tectonic history is believed to be one of gentle compression followed by extension. These activities have produced a coalfield characterized primarily by normal faulting and an absence of horizontal stress effects at shallow depths. Ground control issues revolve around mine pillar stability adjacent to de-pillaring sections and the difficulty in predicting roof conditions associated with faulting (Fig. 3b).

3. The *Smoky River Coalfield* was also deposited in a fluvial environment. Tectonically, the coalfield is characterized by spectacular examples of sedimentary rock compression and shortening which has left a legacy of intensely folded and thrusted rocks. Ground control issues revolve around ground fracturing and weakening effects associated with tectonic history. Surprisingly, excess horizontal stress has not been identified as a major problem in this coalfield despite the obvious endurance of its prior existence in surface geological structure. It is possible that stress has been consumed in deformation or shed by intense movement along the large thrusting sheets (Fig. 3c).

Standardization of Geological Assessment

The geological assessment study process involved a review of geological information supplied by the mine operators and a visit to each of the mine sites. The findings contain the authors' personal observations and comments derived from this examination.

Standardization may be defined as doing things the same way every time. As regards to geological assessments in underground coal mines, we might infer, from this definition, that geological assessments should all be carried out in the same way, using the same procedures in the three coalfields. However, the authors believe that standardization should not be based on formal adherence to rigid procedure, but rather be grounded on a few basic goal-oriented principles and allow considerable leeway provided for initiatives that recognize the distinctiveness and individuality of each of the coalfields. The objective of geological assessment is to describe and characterize the rock mass by using appropriate exploration techniques and assessment methods. It provides mining and geotechnical engineers with the information they need to carry out their own important roles. It recognizes that geological assessments are part of an on-going process and constitute a continuous cycle of input and feedback where deficiencies are recognized and adjustments are made to improve the process.

Some basic assessment principles include the following:

Principle 1 — Geological assessments are not an end in themselves, but are part of an integrated process whose goal is the creation of mining operations where worker safety is protected and an effective and efficient extraction method is in place.

Principle 2 — The information available from exploration work, such as core drilling and outcrop mapping, must be extracted and used to maximize its contribution to the mine planning process.

Principle 3 — The depositional and tectonic history of the coal seam and its associated rock mass, must be fully investigated to gain some perspective regarding the nature, extent and potential impact of geological discontinuities on mine design.

Principle 4 — Geological data must be quantified, using some rock mass classification system, before it can be effectively used for ground support and mine design purposes.

Principle 5 — The actual performance of ground support systems must be continuously appraised after installation, and detailed geological mapping of underground workings must

Fig. 1. Location of the Sydney, Smoky River and Comox Coalfields.

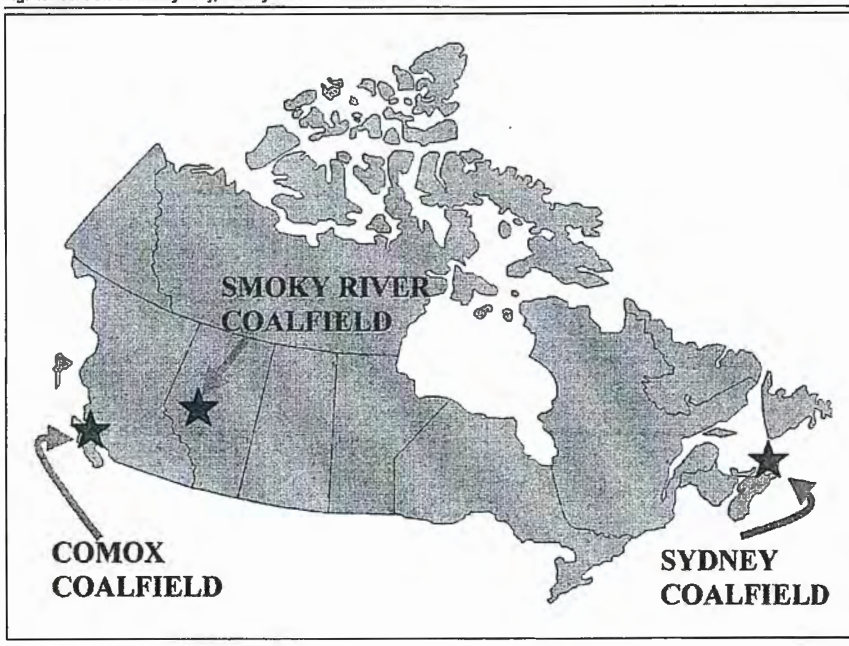


Table 1. Operating underground coal mines in Canada, 1998 to 2000

Mine name	Mine owner	Location	Province	Year opened	Coal seam	Mining method
2 North	Quinsam Coal Corp.	Campbell River	British Columbia	1990	No. 1	Retreat room-and-pillar
4 South	Quinsam Coal Corp.	Campbell River	British Columbia	1998	No. 3	Retreat room-and-pillar
5B-4*	Smoky River Coal Ltd.	Grande Cache	Alberta	1998	No. 4	Retreat room-and-pillar
Prince Colliery	Cape Breton Development Corp.	Point Aconi	Nova Scotia	1976	Hub	Retreat longwall
Phalen Colliery*	Cape Breton	New Waterford	Nova Scotia	1984	Phalen	Retreat longwall

* Closed: Phalen in late 1999; 5B-4 in mid-2000.

be performed to establish the validity of geological and geotechnical models.

Principle 6 — All underground workers should be trained in basic geological and geotechnical principles and receive regular updates as regards to geological conditions and ground support in their mine.

Geomechanics Baseline Studies of Canadian Coal Mines

The purpose of the baseline study was to compare the ground conditions at the Canadian mines to those encountered in the United States. NIOSH methodologies that were employed included:

- The Coal Mine Roof Rating (CMRR) (Molinda and Mark, 1994; Mark and Molinda, 1996)
- The Analysis of Longwall Pillar Stability (ALPS) (Mark, 1992; Mark et al., 1994)
- The Analysis of Retreat Mining Pillar Stability (ARMPS) (Mark and Chase, 1997)
- Horizontal stress mapping (Mark and Mucho, 1994; Mucho and Mark, 1994; Mark et al., 1998)

Cape Breton Development Corporation Prince Mine

The Prince mine was opened in 1974 and is, today, the last mine operating in the Sydney Coalfield. The depth of cover is about 320 m, average seam thickness is 2.3 m and the Hub Seam dips at less than 5 degrees in the current North longwall reserve. There has been no previous mining in the seams above or below Prince mine. The colliery uses the longwall method of coal extraction.

Pillar Design

Two gate entries are driven 4.5 m to 5 m wide for each longwall panel, separated by a 60 m wide abutment pillar (Fig. 4). There are typically no more than two crosscuts (cundies) per panel. The ALPS stability factor (SF) for recent Prince longwalls is approximately 2.3 for tailgate loading. This may be compared to the 1.34 suggested by the United States case history data assuming a CMRR of 30. The Australian ALTS equation (Colwell et al., 1999) suggests that an SF of 1.8 should be adequate.

Horizontal Stress

While there have been no recent in situ stress measurements at Prince, every indication is that the horizontal stresses are similar to those found elsewhere in the Sydney coalfields, with maximum horizontal stress oriented at N60E and 2.5 times the vertical stress. Most of the longwall panels at Prince were oriented

Table 2. Geological age and nomenclature of the coalfields

Coalfield	Group	Formation	Geologic age	Size
Comox	Nanaimo	Comox	Upper Cretaceous (80 000 000 years)	1500 km^2
Smoky River	Luscar	Gates	Lower Cretaceous (100 000 000 years)	550 km^2
Sydney	Morien	South Bar	Carboniferous (300 000 000 years)	600 km^2

Fig. 2. Coal-bearing formation stratigraphy of the Sydney, Smoky River and Comox coalfields.

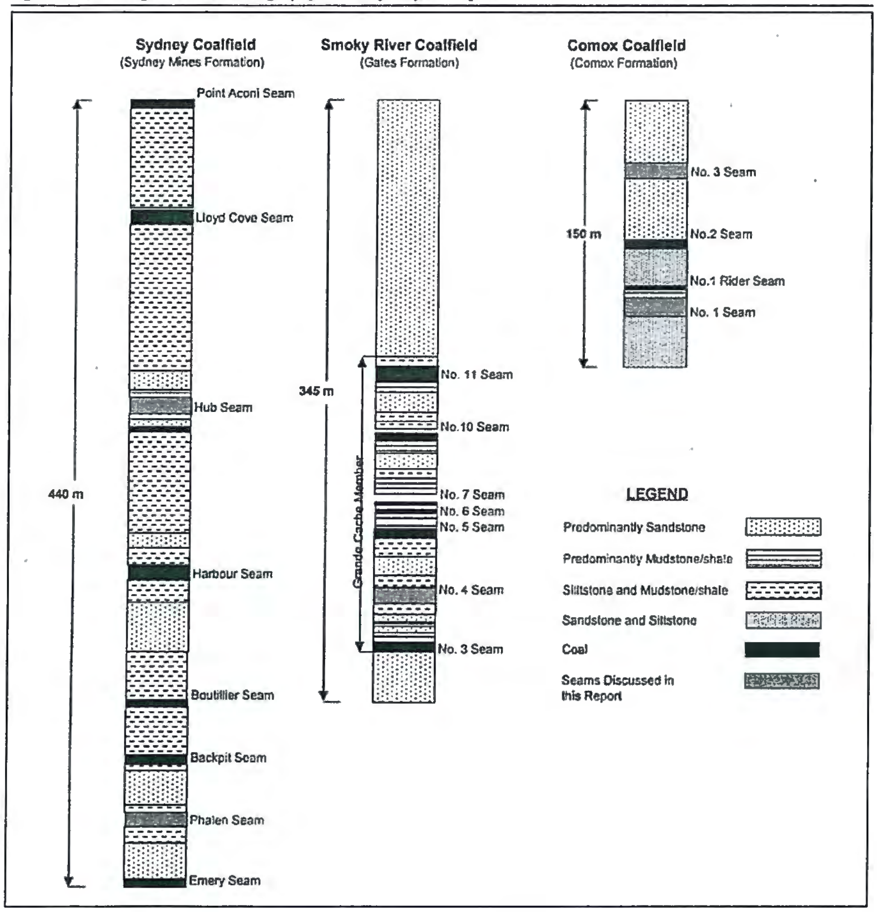
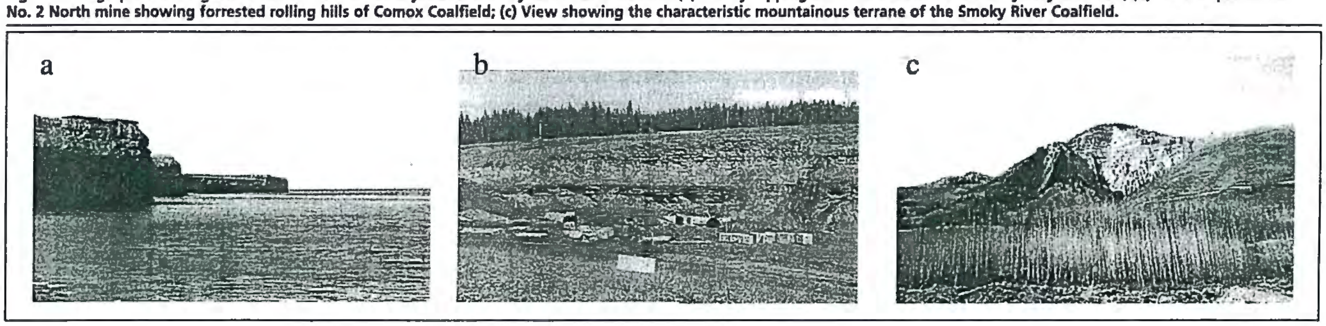


Fig. 3. Photographs showing the contrast of structural style exhibited by the three coalfields. (a) Gently dipping strata characteristic of the Sydney Coalfield; (b) View of portals of No. 2 North mine showing forrested rolling hills of Comox Coalfield; (c) View showing the characteristic mountainous terrane of the Smoky River Coalfield.



N70W, intercepting the maximum horizontal stress at about 50 degrees with significant deformation in roof and the floor development (Fig. 5a). Often, a row of center posts had to be installed within 60 m of the development face. Fortunately, the headgate was shielded from a horizontal stress abutment.

In the late 1990s, Prince implemented a major panel re-orientation such that the 9 East panel was oriented N45E, or just 15 degrees off parallel with the maximum horizontal stress. The development conditions observed there were much improved. Moreover, the headgate in 9 East and in the similarly-aligned North panels should be in a stress shadow (Fig. 5b).

Coal Mine Roof Rating

Two cores of the immediate roof unit show it to be 1.5 m to 1.8 m thick comprising a moisture-sensitive underclay, heavily rooted, with closely spaced bedding. Its unit rating was about 30, before exposure to moisture, and 23 after exposure. In future longwalls, it may be as much as 6 m thick.

Cores show the underclay is overlain by a medium-grained, grey, medium-bedded (10 cm spacing) weak sandstone with a UCS (uniaxial compressive strength) of about 50 MPa. It can contain coal spars and thin shale bands. Its unit rating is in the 45 to 55 range.

When the underclay roof is less than 2 m thick, 2.6 m bolts could be used and the overall CMRR would be about 40. As the underclay thickens, the CMRR reduces to a unit rating of 30 and even lower, when the long-term effect of moisture is considered.

Overall, the CMRR>30 roof at Prince is very weak in comparison with most U.S. or Australian mines.

Roof Support

The primary roof support at Prince is provided almost exclusively by steel sets. The supports are W6*25 beams with W6*15 legs. Their capacity is 12 tonnes yield and 18 tonnes ultimate for a 4.3 m span (assuming an evenly distributed load and a 45 degree load triangle). The mine has been considering the possibility of changing from steel supports to roof bolts as primary roof support. When the mine was first opened, in the 1970s, fully-grouted resin bolts were used in a small area that was mined by room-and-pillar. Reportedly, the bolts worked well when they anchored in a sandstone channel, but several roof falls occurred beneath thick shale roof in the transition zone.

The two-entry longwall system used at Prince is very intolerant of roof falls with new intersections (and no 4-way intersections). To control the roof, the entries need to be as narrow as possible. The authors recommend that extended cuts not be considered and place-changing is not recommended. Long roof bolts could be installed as soon as possible after mining, close to the face, as sole support where the underclay is less than 2 m thick and the sandstone is at least 1 m thick. They would be employed with a surface support (like mesh) to prevent the weak immediate roof from unraveling. Where the sandstone was higher up or thinner, supplemental support (cable bolts or trusses) would probably be required. Roof monitoring would be very important to locate any areas of aggressive roof that required tertiary support. Given the height and narrowness of the entries, pattern rib support are also recommended.

While roof conditions are generally more difficult than encountered in most U.S. mines, entry stability should be easier to maintain at Prince than it was at Phalen. Table 3 compares attributes of the Prince 1 North panel headgate to the Phalen 8 East Bottom where a major roof fall occurred.

Fig. 4. Typical longwall retreat setup in Sydney Coalfield. (a) Typical longwall development sequence; (b) typical longwall setup.

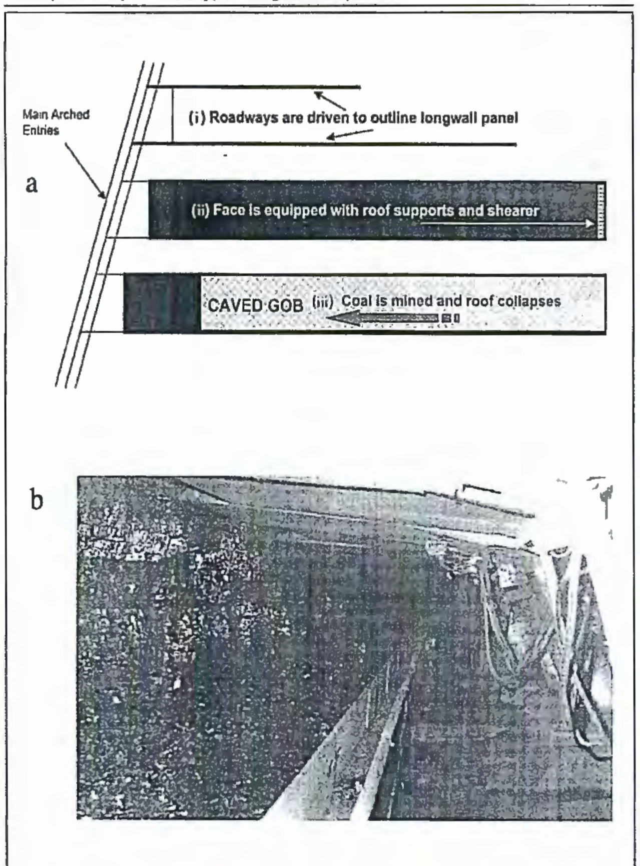


Fig. 5. Reduction of coal seam height caused by changed panel orientation. (a) Roadway closure resulting from driving heading at an unfavourable orientation to direction of principle horizontal stress; (b) improved roadway conditions in heading driven at an orientation favourable horizontal stress.

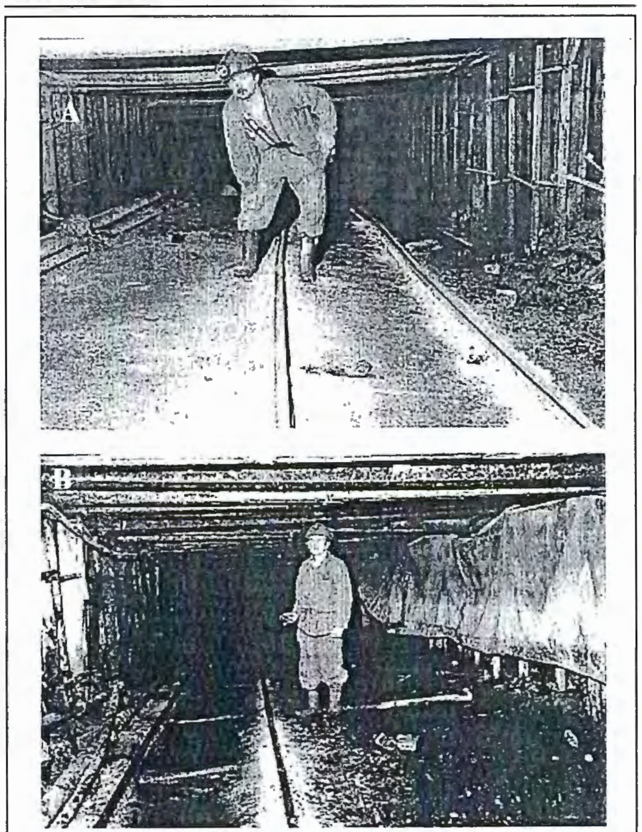


Table 3. Comparison of entry stability issues at Prince and Phalen mines

Issue	Phalen 8E Bottom	Prince 1N
Depth of cover	680 m	320 m
Multiple seam?	Yes	No
Orientation for horizontal stress	Good	Good
Horizontal stress concentration?	Yes	No
Entry width	4.9 m to 5.5 m	4.5 m to 5 m
CMRR	35	30

Four factors (depth, multiple seam interactions, headgate horizontal stress concentration and entry width) are more favourable at Prince. Only one, the CMRR, is somewhat less favourable.

Quinsam Coal Corporation — 2 North and 4 South Mines

Quinsam Coal Corporation has operated underground mines on Vancouver Island since 1991, following several years of surface mining. Production has come exclusively from room-and-pillar mining using continuous miners and shuttle cars. The current active underground operation is the 2 North mine in the 1 Seam. The 4 South mine in the 3 Seam is currently on standby.

Pillar Design

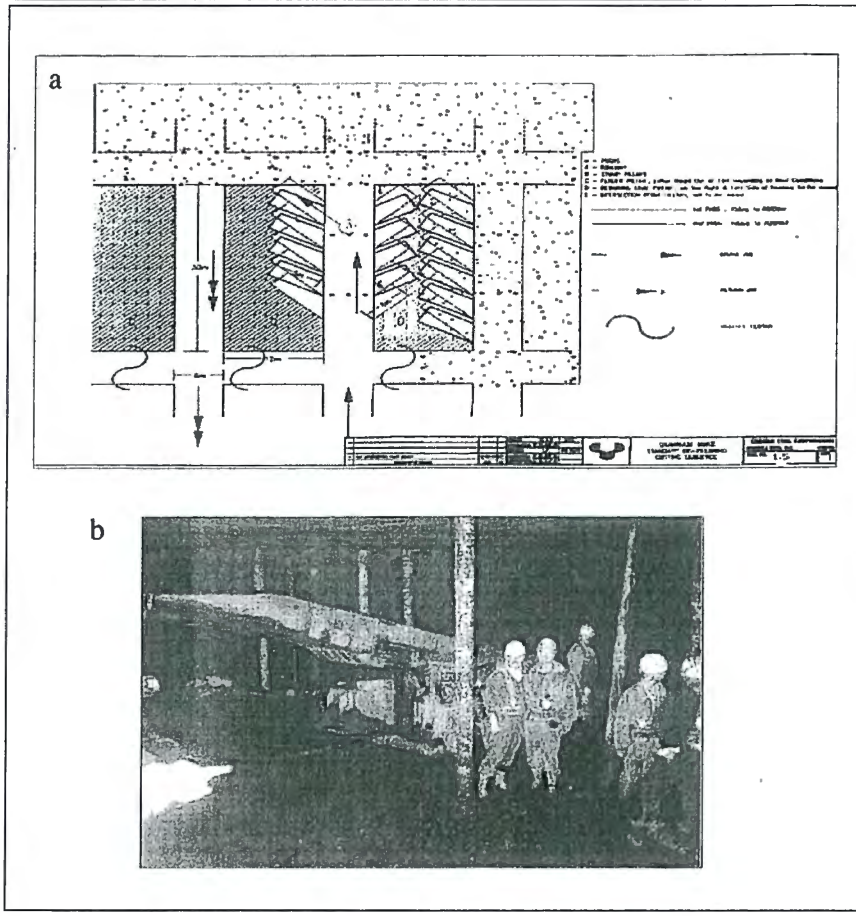
The 1 Seam is 4 m to 5 m thick, and dips approximately 12% (7°) in the current mining area. Entries are mined 6 m wide by 3 m high, with floor coal recovered during depillaring. At the time of the visit, pillar recovery was being conducted in 7 Panel and 8 Panel, however, 9 Panel was being developed. The pillars in the panels are recovered using a Christmas-tree cut sequence (Fig. 6).

The entries in 8 Panel and 9 Panel were developed on 16 m centres, with crosscuts on 36 m centres. The outbye pillars in 7 Panel were originally developed for a split-and-fender mining system and measured approximately 32 m^2.

Cover is relatively light at Quinsam Coal and is reportedly less than 140 m at the 2 North mine. The ARMPS software developed by NIOSH is used as the pillar design guideline at Quinsam. The ARMPS stability factor is well over 2.0 for all phases of the current mining plan at 2 North.

In 4 South, concerns about surface subsidence (under a swampy area) and controlling the caving of the massive sandstone roof have precluded full pillar extraction. Originally, the mine practiced partial pillar recovery with recovery pillars "in line." However, because of localized roof falls which occurred as a result of having the partially depillared areas in line, a "checkerboard" partial pillar pattern was adopted instead. The checkerboard plan successfully mitigated the degree of localized roof falls.

Fig. 6. Typical room-and-pillar retreat setup at Quinsam and Smoky River coalfields. (a) Typical room-and-pillar retreat setup; (b) Typical de-pillaring operation longwall setup.



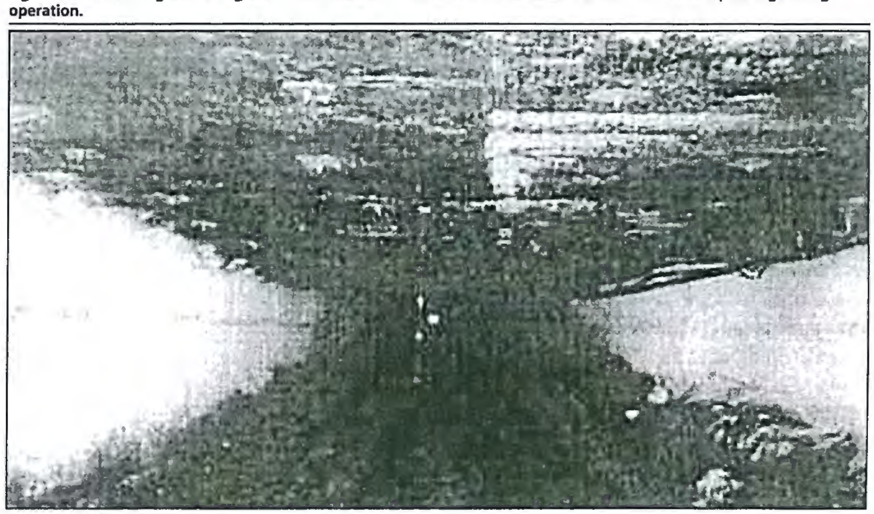
Horizontal Stress

No evidence of horizontal stress was observed at either mine.

Geology and Coal Mine Roof Rating

In general, the No. 1 Seam is overlain by grey shale which grades into a slightly more competent silty shale about 0.6 m up in the roof. The structural competence of the units is reduced in periodic fracture zones which affect 10% to 15% of the roof. The fractures tend to

Fig. 7. Photo showing the strong ribs of No.1 seam at 2 North mine. This area was remote from de-pillaring mining operation.



follow the strike which means that entries driven on strike tend to be somewhat less stable than those driven with the dip. At 2 North mine, the mains have been driven along strike and panels are driven down dip. Using ball peen hammer tests underground and Point Load tests on core, the strength of the upper, siltier shale was judged to be 50 MPa to 70 MPa. Its bedding was closely spaced, but the rock did not fail easily on bedding, instead preferring to create rough fractures through intact material. The overall CMRR was calculated at about 50 and this would be reduced by four points in fracture zones.

A study of experience with extended cuts at 36 U.S. mines found that when the CMRR was greater than 50, cuts deeper than 6 m could almost always be achieved. When the CMRR was less than 38, extended cuts were almost never stable (Mark, 1999). However, extended cut lengths in the United States can be limited by dust control and ventilation issues, particularly where the mine does not employ a blowing face ventilation system with scrubbers on the miner.

In 4 South, the roof is a medium-grained, massive sandstone with only occasional joints. Its strength was estimated at 70 MPa. Overall, the CMRR was estimated at 78 from underground observations and 68 using core data. Most of the layers within the 1 Seam seemed to be relatively hard, dull coal. The roof contact is distinct but very strong and shows no tendency to slip (Fig. 7). About 2 m below the roof, there is a very soft mud seam whose thickness varies over the property. In general, the ribs were almost entirely intact, even at pillar corners.

Roof Support

Roof support at 2 North mine is provided by 2.4 m, 19 mm, Grade 60, torque-tension bolts installed with a 0.6 m of resin anchor resulting in almost 0 .9 m of encapsulation. The break out of the resin mix is achieved with a pinched thread on the roof bolt. The pattern is to install a row of five bolts every 1.2 m. In the United States, a five-bolt pattern would be very unusual where a dual-boom roof bolter is used. Welded wire mesh panels are installed to support any spalling of the lower mudstone that might occur over time due to weathering or due to changing stresses during pillaring. When breaching faults, entry widths are reduced from the nominal 6 m to 5.2 to 5.7 m. "Gripper plates" were used to install the mesh in previously-bolted outbye areas.

Roof support at 4 South is achieved with roof bolts identical to the bolts in 2 North except they are 1.8 m long. The pattern is to install a row of four bolts every 1.2 m. No mesh is used due to the competency of the roof and its resistance to weathering. In general, a roof of this competency would be supported with shorter mechanical shell or fully grouted untensioned resin bolts in the United States.

Retreat Mining

Retreat mining, including pillar recovery and floor mining, is integral to the mining plan at Quinsam Coal. Since the 1998 fatal accident, Quinsam has paid close attention to pillaring procedures. It was impressive that pillaring cut sequences are posted for all crew members to see. When pillars are recovered in fracture zones, the plans are adjusted to leave fenders between cuts and to leave some areas completely. Marking the known fracture traces on the roof and on the maps is also an excellent practice.

The key to successful pillar recovery is to support the intersection. Because of the thick seam and the floor recovery at Quinsam, timbers are used instead of mobile roof supports. Warning timbers are installed at each cut as a visual indication of roof behaviour in the gob, and breaker posts were installed at intersections and in crosscuts to prevent gob over ride. The plans required a substantial final stump to be left when pillar recovery is complete, an excellent practice. U.S. experience indicates that a stump about 3 m^2 should provide effective intersection support without being so strong that it seriously inhibits the roof caving.

Smoky River Coal Corporation 5B-4 Mine

Smoky River Coal Corporation has operated underground mines in the foothills of the Canadian Rockies since 1969. While longwalls have been tried on several occasions, most production has come from room-and-pillar mining using continuous miners and shuttle cars. Mining has been conducted in the 4 Seam in both the Smoky River and Sheep Creek valleys. The recently closed underground operation, the 5B-4 mine, is located in the Smoky River valley slightly to the north of the No. 5-4 mine which contains some of the earliest workings on the property.

Historically, roof conditions have always been more difficult in the Smoky River valley. The original No. 5-4 mine was reportedly "closed within a short period of time due to strata problems" (Grant et al., 1978). Recent mining in the 9G, 9H and LB4 mines were much less troublesome.

Pillar Design

At 5B-4 mine, the reserve was bounded by steeply dipping thrusted zones to the north and south. At the time of the visit, a five-entry main was being driven to the east, with four-entry panels driven up-dip on the right-hand side. The pillars in the panels were being recovered using a Christmas tree cut sequence. The seam in the 5B-4 mine was 3 m to 5 m thick. Entries were initially mined 5 m wide by 3 m high, with floor coal recovered during depillaring. The mining depth for the 4 South Panel was about 275 m, but much of the 5B-4 reserve was under as much as 550 m of cover. None of the previous Smoky River mines have been more than 300 m deep. Extensive analyses of past pillar performance in the 4 Seam have been made using ARMPS (Cain, 1999).

Horizontal Stress

The Smoky River area has clearly been subjected to intense horizontal tectonic pressures, as evidenced by the pervasive thrust faulting. According to data published by the World Stress Map Project (Zoback, 1992), the

Fig. 8. Typical thrust fault found in No. 3 main development entry.

Table 4. Baseline comparison of three Canadian underground coal mines

	Prince	Smoky River 5B-4	2 North Quinsam
Development mining method	Single-entry roadheader	Room-and-pillar continuous miner	Room-and-pillar continuous miner
Retreat mining method	Longwall	Full pillar extraction with floor recovery	Full pillar extraction with floor recovery
Depth of cover	320 m	100 m to 550 m	<140 m
Seam thickness	2.3 m	4 m to 5 m	4 m to 5 m
Dip	<5°	11°	7°
Pillar width	60 m	7 m	10 m
Entry width	4.5 m	4.8 m	6 m
Pillar SF	2.3	>0.7	>2.0
Horizontal stress	High	Low-medium	Low
CMRR	25 to 40	40 to 50	45 to 55
Primary roof support	Steel arches	3.6 m fully grouted roof bolts with steel straps and mesh	2.4 m torque tension bolts, occasional mesh
Rib support	Steel arches	Two 1.5 m bolts with mesh	None
Major ground control problems	Weak roof Horizontal stress Floor heave	Fracture zones Excessive dips Pillar recovery	Faults/fracture zones Pillar recovery

deep borehole breakouts show that the eastern Canadian Rockies are currently subject to the major regional North American stress-field, with the maximum horizontal stress oriented approximately N60E. One underground observation at the No. 2 mine, reported by Jeremic (1985), indicated that the maximum stress was oriented approximately N35E.

At the time of this study, there was relatively little evidence of horizontal stress underground. In one location near the outcrop, a few large roof "pots" were indicative of a N30E horizontal stress. It is possible that as mining progresses into the ridge towards deeper cover, the horizontal stress may increase and rotate towards the regional stress orientation (Fig. 3c).

Coal Mine Roof Rating

In general, the 4 Seam is overlain by shale or carbonaceous shale, which is in turn overlain by a stronger siltstone or sandstone. The structural competence of the units is reduced by periodic fracture zones related to thrust faults (Fig. 8).

At the old 9A mine highwall, the carbonaceous mudstone was 0.6 m to 1.0 m thick. It had a strength of 35 MPa to 75 MPa, was highly laminated and typically contained joints on a 0.6 m to 1.6 m spacing. Within fracture zones, the joint spacing was decreased to less than 0.2 m. Its unit rating was 35 to 40. The strength of the bedded, "wispy" siltstone appeared to exceed 120 MPa. Its unit rating was typically 65, reduced to 55 within fracture zones. Overall, the CMRR ranged between 57 (normal) and 48 (in fracture zones).

The rock types were similar in the 5B-4 mine, except that: the siltstone appeared somewhat weaker (70 MPa to 120 MPa); the mudstone was somewhat thicker; and the fracture zones were considerably more frequent.

The overall CMRR was estimated at 50 for normal conditions and 40 within fracture zones.

Most of the layers within the coal seam were relatively hard, but there were at least five zones of soft, platy, sheared coal in the top 4.3 m. A particularly weak zone occurred at the top of the seam just below the roof shale. These zones facilitate outward movement of the ribs under load.

Roof Support

Mechanical roof bolts provided support in the early days of the Smoky River mines. Numerous roof falls occurred in the No. 5 and No. 2 mines and by 1975, resin bolt trials were initiated (Grant et al., 1978). Conditions improved when mining shifted to the Sheep Creek valley. There, rows of four to six mechanical bolts, 2.4 m long, usually provided adequate support for the 6.7 m wide entries (Cain, 1998).

In the 5B-4 mine, entry widths were reduced to 4.8 m (nominal). The Manager's Support Rules for main entries required fully grouted resin roof bolts, 3.6 m long, installed in rows of four every 1.2 m, with steel straps and mesh. In addition, one or two 1.5 m mechanical rib bolts were installed per row, also with mesh. Support was similar in the short-term roadways, except that 2.4 m mechanical bolts were used in place of the 3.6 m resin bolts. Roof stability monitoring was provided by 2-point telltales which were installed approximately every 60 m.

By U.S. standards, the level of support at 5B-4 is relatively heavy. With a similar CMRR and entry width, 2.4 m bolts would be more typical, although longer bolts might be used in intersections. Currently, 5B-4 employs the same support system in both fracture zones and unfractured ground due to the difficulty in identifying the boundaries of the fracture zones.

Retreat Mining

Retreat mining, including pillar recovery and floor mining, is integral to the mining plan at Smoky River.

Pillar recovery is always hazardous, but under deep cover it appears it becomes even more so. Analysis of recent accidents in the United States mines shows that a disproportionate share of fatalities have occurred in deep cover pillaring operations. During 1998 alone, there were fatal accidents in West Virginia, Kentucky and Colorado (the last was a double fatality). In each case, the cover exceeded 200 m. It is important that every miner know and follow standard pillar recovery procedures to limit their exposure to hazards.

Conclusions and a Baseline Comparison

The three Canadian underground coal mines studied display a wide variety of geologies, mining methods and support techniques. Table 4 sums up the baseline comparison for the three mines.

The mining methods in each coalfield appropriately reflect the prevailing geological and geotechnical conditions. The retreat room-and-pillar mining method provide essential flexibility where seam and roof structure can change quickly, whereas, the longwall mining system is successful in the Sydney Coalfield in the absence of faulting significant folding or other major seam disruptions. Mine safety was paramount at all mines, as was evident in the extensive ground monitoring and geological mapping programs in place and workforce training and communication.

The Prince mine, the only longwall of the three, generally faces the most difficult ground control conditions. Prince has the weakest roof, the greatest level of horizontal stress and usually the greatest cover.

Quinsam 2 North mine, at the other extreme, has the most benign conditions. It is the shallowest of the 3 mines, has the strongest roof and shows no evidence of horizontal stress. It is not surprising that Quinsam uses the least support and the widest entries of the three mines.

The 5B-4 mine at Smoky River falls between the two end points. Fracture zones are common at this mine, reducing the CMRR to near 40. As a result, narrow entries and a high level of roof support were required.

Many of the ground control safety technologies developed in the United States appear to have direct application to Canadian mines. Pillar design and the CMRR seem particularly relevant. There are some aspects of Canadian underground coal mining that seem to be unique. Research in these could be very helpful for the future of the industry. The two most important being: roof bolting in very weak ground (Prince mine); and pillar and floor recovery techniques for thick, dipping seams (Quinsam and Smoky River).

The six geological principles outlined above provide a basis for standardization of approach, focussing on geological and assessment procedures while incorporating flexibility to accommodate the individual characteristics of the industrial coalfields.

References

CAIN, P., 1998. Experience with the First Modern Longwall Installation in Western Canada at Smoky River Coal Limited, Grande Cache, Alberta. Private communication.

CAIN, P., 1999. Developments in coal pillar design at Smoky River Coal Limited. Proceedings, 2nd International Workshop on Coal Pillar Mechanics and Design, NIOSH IC 9448, p. 15-22.

COLWELL, M., FRITH, R. and MARK, C., 1999. Analysis of longwall tailgate serviceability (ALTS): A chain pillar methodology for Australian conditions. *In* Proceedings, Second International Workshop on Coal Pillar Mechanics and Design. NIOSH IC 9448, p. 33-47.

GRANT, F., WIGELSWORTH, R.M. and CHARLTON, K., 1978. Underground strata control with resin grouted roof bolts in McIntyre mine's coal operations. Proceedings, First International Symposium on Stability in Mining, p. 197-213.

JEREMIC, M.L., 1985. Strata Mechanics in Coal Mining. A.A. Balkema, Rotterdam, p. 149.

MARK, C., 1992. Analysis of longwall pillar stability: An update. *In* Proceedings, Workshop on Coal Pillar Mechanics and Design. USBM IC 9315, p. 238-249.

MARK, C., 1999. Application of the coal mine roof rating (CMRR) to extended cuts. Mining Engineering, p. 52-56.

MARK, C. and CHASE, F.E., 1997. Analysis of retreat mining pillar stability. *In* New Technology for Ground Control in Retreat Mining. Proceedings, NIOSH Technology Transfer Seminar, NIOSH IC 9446, p. 17-34.

MARK, C. and MOLINDA, G.M., 1996. Rating coal mine roof strength from exploratory drill core. Proceedings, 15th International Conference on Ground Control, Colorado School of Mines, p. 415-428.

MARK, C. and MUCHO, T.P., 1994. Longwall mine design for control of horizontal stress. In New Technology for Longwall Ground Control: Proceedings, USBM Technology Transfer Seminar, USBM SP 94-01, p. 53-76.

MARK, C., CHASE, F.E. and MOLINDA, G.M., 1994. Design of longwall gate entry systems using roof classification. *In* New Technology for Longwall Ground Control. Proceedings, USBM Technology Transfer Seminar, USBM SP 94-01, p. 5-18.

MARK, C., MUCHO, T.P. and DOLINAR, D., 1998. Horizontal stress and longwall headgate ground control. Mining Engineering, p. 61-68.

MOLINDA, G. and MARK, C., 1994. The coal mine roof rating (CMRR) — A practical rock mass classification for coal mines. USBM IC 9387, 83 p.

MUCHO, T. P. and MARK, C., 1994. Determining horizontal stress direction using the stress mapping technique. *In* Proceedings, 13th Conference on Ground Control in Mining, University of West Virginia, p. 277-289.

ZOBACK, M.L., 1992. Stress field constraints on intraplate seismicity in Eastern North America. Journal of Geophysical Research, 97, p. 11,761-11,782.

NEWS IN BRIEF

25TH PERUVIAN MINING CONVENTION

A close examination of the current state and future outlook of both mining projects and operating units, which were privatized during the last decade in Peru, shall be keynote during the upcoming 25th Peruvian Mining Convention to be held in the city of Arequipa on September 10-14, 2001.

Among other activities, the 25th Peruvian Mining Convention includes the "Entrepreneurial Meeting" which is a first-rate business and technical event featuring the participation of top class executives who will be explaining the conditions under which they received the operating units, amounts they have invested, progress made, obstacles they have encountered and future projects, according to Mario Brescia Cafferata, president of the Organizing Committee, and Ricardo Briceño, responsible for the organization of the "Entrepreneurial Meeting."

The Peruvian Mining Engineers' Convention is a biennial event organized by the Peruvian Institute of Mining Engineers (IIMP). The now traditional convention, which was held for the first time over forty years ago, has gained the reputation of being the country's most important specialized event and one of the leading and best organized in the mining industry worldwide. It is the meeting place *par excellence* to share experiences and technical solutions.

The Organizing Committee has already obtained confirmation of the participation of a number of leading business people charged with the responsibility of directing privatized mining units or projects. Moreover, the convention will be featuring an event whereby a select group of prominent Latin American mining leaders will be sharing their views and experiences on the development of the mining industry within the region, as well as their opinions on investment conditions in Peru.

The convention includes a series of events to be held simultaneously: technical conferences, forums, field visits, social activities and the EXTEMIN specialized mining exhibition. The program, says Brescia, "embraces a number of technical issues, ranging from the phases of exploration to trade and includes views on mining policies and the effects of mining on society. At only two months time away from the programmed date, everything has been organized down to the minimum detail, to ensure that this event meets the expectations of participants and visitors and results in a highly informative, friendly and entertaining week."

For more information, contact: XXV Convención de ingenieros de minas del Perú, Instituto de ingenieros de minas del Perú, Los Canarios 154, Lima 12, Perú; Tel.: (511) 349-4262; Fax: (511) 349-3721.

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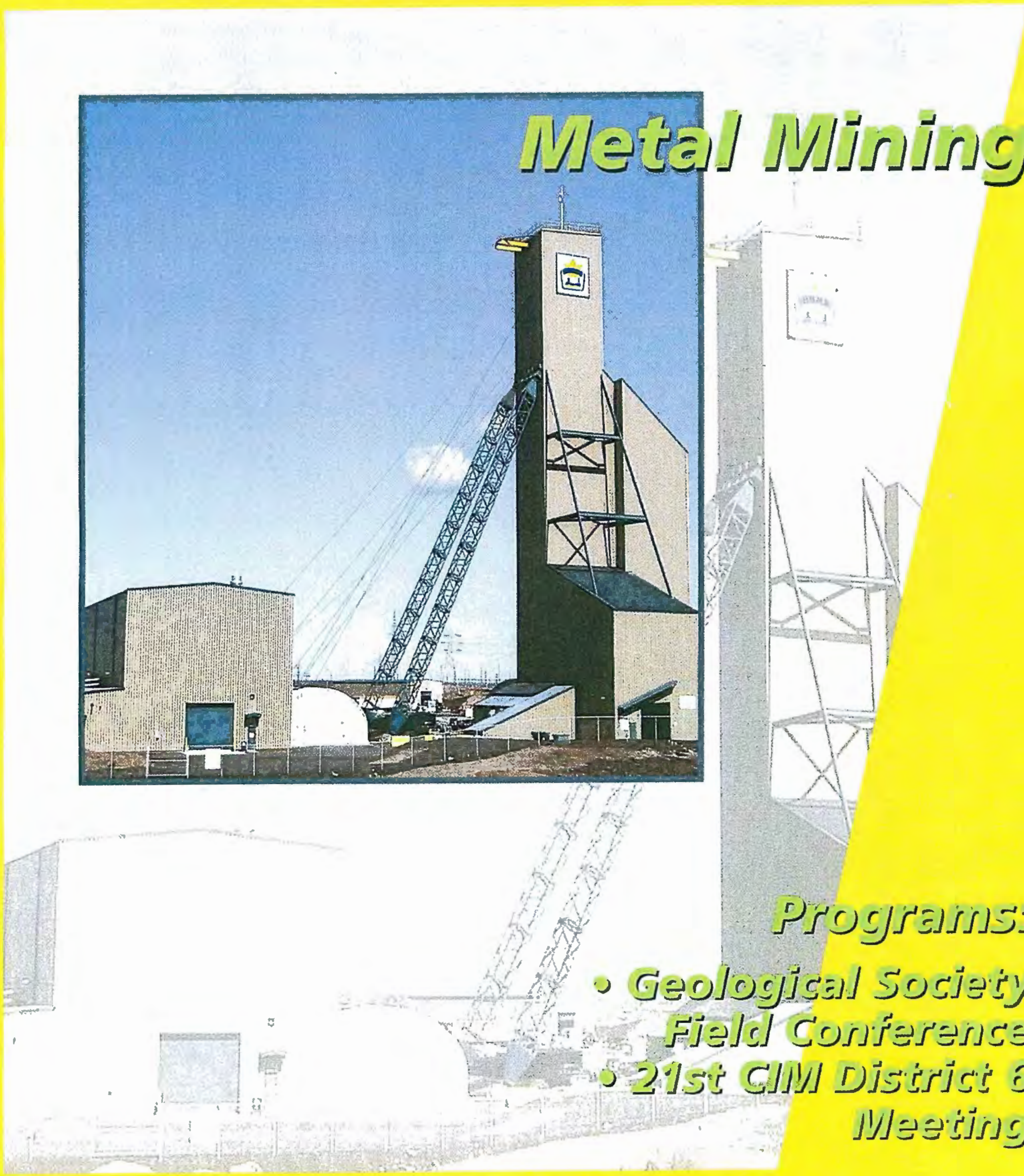

Metal Mining

Programs:

- Geological Society Field Conference
- 21st CIM District 6 Meeting