Ore pass practice in Canadian mines

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Synopsis

This paper reviews ore pass practice in some Canadian mines in Quebec and Ontario. In particular it reviews ore pass configuration, flow control mechanisms and monitoring practice. A review of the type of problems encountered and the tools to restore flow is also presented.

Ore pass practice in some Canadian mines

Ore pass systems are an integral part of the materials handling system in the majority of Canadian underground mines. This paper presents some observations from a series of in-depth studies in Canadian Mines. The main source of information is a comprehensive study by Hadjigeorgiou and Lessard (2004) in Quebec mines, with further data derived by ongoing investigations in Ontario operations in the Sudbury basin. Extracted ore and tonnage of Quebec operations are summarized in Table I.

Ontario mines included in this investigation are massive deposits of nickel and copper. Daily extraction tonnage ranged from 3 500 to 10 000 tons.

At every participating site, underground assessments were complemented by data collection, and site interviews with key mine personnel from engineering, production, safety and training departments. Collected mine data included design, engineering, problems encountered, and the successes and failures of interventions. During site visits, the best practices for safely removing hang-ups were also recorded.

Ore pass configuration

Excavation method

Ore passes are developed using either mechanical (raise borer) or drill and blast techniques (Alimak, conventional raising and drop raising). In Quebec mines, Alimak raising was used in 63% of driven ore passes while only 3% were raise bored. Conventional and drop raises represent 29% and 5% of the sections, respectively. The dominance of Alimak driven passes over raise bored passes in Quebec mines is attributable to several causes. It ensures a reasonable degree of safety for the miners, while still allowing the installation of support. Furthermore, the ability to drive the Alimak pass from a single access (as opposed to raise boring, which requires that both the bottom and top accesses be developed) and a strong expertise of local mining contractors are also contributing factors.

In the surveyed Ontario mines, raise boring was used for 30% of excavated ore pass sections, while Alimak was used in 39%. The rationale for the use of raise boring was to limit ground disturbance during excavation. A chronological review of ore passes, however, indicated that Ontario mines are moving away from raise boring and using Alimak more widely. In fact close to 70% of recently excavated ore pass sections were driven by Alimak, while only 15% were driven by raise borer. The recent predominance of Alimak raises is attributed to their facility to integrate the installation of ground support during the excavation cycle.

Ore pass section length

There is an inherent relationship between the type of excavation method and section length. Typically, sections excavated by drop raising or conventional raising are shorter than sections driven by Alimak or raise bored, Table II. Atlas Copco (1997) reported the same general trend in other raise applications.

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Table I

Quebec mines participating in the survey

Mine	Type of orebody	Extracted ore	tpd*
Laronde	Massive	Au, Zn, Cu	5000
Louvicourt	Massive	Cu, Zn, Au, Ag	4300
Bousquet II	Massive	Au, Cu	1700
Bouchard-Hébert	Massive	Zn, Cu, Au, Ag	3000
Gonzague-Langlois	Massive	Zn, Cu, Au, Ag	3000
Doyon	Narrow-vein	Au	3500
Mouska	Narrow-vein	Au, Ag	450
Kiena	Massive	Au, Ag	2000
Bell-Allard	Massive	Zn, Cu	2200
Niobec	Massive	Nb	3300

*tons per day

Table II

Excavation methods and recorded sections' length for Quebec mines

Excavation method	Avgerage length (m)	Standard deviation (m)	Maximum length (m)	Minimum length (m)
Alimak raising	106	51	273	30
Conventional raising	48	20	99	10
Drop raising	47	22	90	27
Raise boring	132	62	215	64

The length of ore pass sections in Quebec mines varies widely (from 10 m to 273 m). Most excavated sections were of a length between 30 to 100 m with a mean value of 87 m, Figure 1. Ontario mines report longer sections averaging 108 m with a standard deviation of 60 m. In general it would appear that the average section length in Canadian mines is higher than the 46 m reported by Beus *et al.* (2001) for the United States.

There are several practical and financial considerations that influence the selection of an ore pass length. If, for example, an operation aims to minimize its capitalized development, it will end up driving short ore pass sections, going from one level or sub-level to the next, concurrently as the various levels are entering into production. Quite often a mine that experienced problems when driving and operating long sections will subsequently opt for shorter sections when constructing new ore and waste passes. An excavation of greater length is more likely to intersect zones of poor ground. It also has a higher potential for problems and is harder to bypass. Longer sections may also result in higher material flow velocity in passes operated as flow-through.

Ore pass section inclination

Ore pass inclination in Quebec operations varies between 45° and 90°, with an average inclination of 70°, Figure 2. Interviewed mine personnel provided contradictory justification for the choice of inclination and its desired effect on material flow. The choice for a particular inclination is dictated by the need to facilitate material flow, while at the same time slow it down. Shallow sections may restrict flow, especially if a high proportion of fine material is present, while steeper excavations result in higher material velocities and compaction. It should be noted that all vertical sections are shorter than 100 m.

Ontario mines favor steep ore passes (80º ± 8.3º) in an effort to ensure continuous material flow and limit hang-up occurrences. A statistical analysis, however, can obscure site specific practice. In one particular mine, operating in depth and using multiple ore passes, the average inclination was greater than 87º.

Ore pass section shape

The majority of excavated ore passes are square or rectangular. Circular sections are usually associated with raise boring methods but in some instances, circular sections were excavated using Alimak. In most cases, the main factor dictating the choice between a rectangular and a square section is local mine experience. Circular shape was used based on anticipated higher stress regimes. It is of interest to note that a review of ore pass surveys reveals that under high stress, and with material flowing in an ore pass, a design circular shape is not maintained for long (in unlined ore passes).

Ore pass cross-sectional dimensions

Design dimensions for Quebec operations are given in Figure 3. In the case where the cross-section varies along the length of an ore pass section the smaller dimension, being the most critical, is recorded. In the case of rectangular cross-sections, again the smallest dimension is used. This results in an average dimension of 2.1 m for Quebec mines. Ontario mines have a relatively larger cross-sectional dimension of 2.5 ± 0.6 m. Ore pass size is an important factor influencing material flow. This is reflected in empirical guidelines linking the potential for hang-ups with ore pass size and material size.

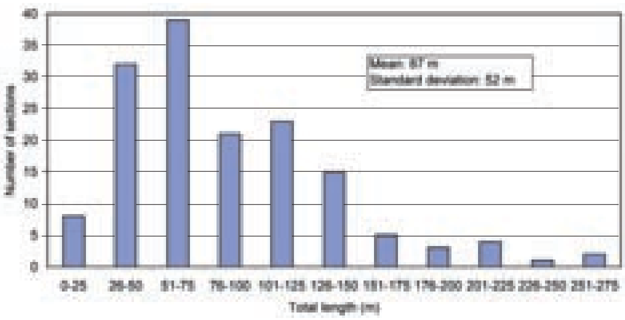

Figure 1—Length of excavated sections for Quebec mines (153)

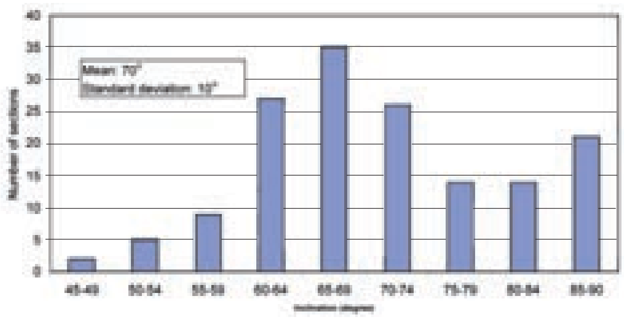

Figure 2—Inclination of excavated sections for Quebec mines (153)

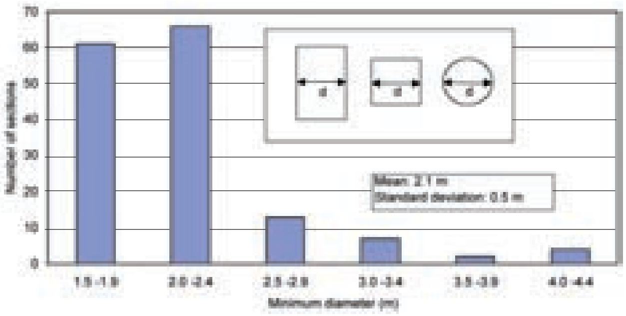

Figure 3—Minimum diameter of excavated sections for Quebec mines (153)

Finger raises

Finger raises are used to funnel material into a pass intersecting two or more production levels. Typically, a finger raise is a square opening with a smaller cross-sectional area than the rockpass it feeds. The most common dimensions for a finger raise are 1.5 and 1.8 m. The majority of ore passes do not employ fingers or rely on a single finger. It is quite unusual to have more than 3 fingers leading into a section.

A review of available cavity monitoring surveys, complemented by on site interviews, suggests that fingers often result in localized impact zones to the detriment of the wall integrity of ore passes. This is usually aggravated if fingers are excavated using longhole blasting that often damages the surrounding rock mass.

Screening of oversize material

Oversize material dumped into the passes may lead to blockages or interlocking hang-ups. This can be avoided by either instructing the mucking crew or by installing the necessary infrastructure to restrict the entrance of the oversize material. Canadian mines use some control of infrastructure for approximately 55% of reported ore pass systems. Typical types of infrastructure are illustrated in Figure 4.

High maintenance costs are often associated with scalpers, since big blocks tend to wedge between the bars. Mucking crews can be 'persuasive' in trying to push the block through the bars with the bucket. This practice damages both the bars and the scoop. Broken and missing bars are often the result of this practice. The ability of a scalper to retain big blocks is therefore greatly diminished. In addition, the intrusion of a bar in the ore pass can lead to severe obstruction further down the system. Another problem associated with the use of scalpers is that big slabs of rock can pass through. Of the three types of boulder retaining infrastructure, grizzlies are the best to keep big blocks out of the passes. Grizzlies require less maintenance than scalpers. The grid dimensions with respect to muck size or bucket size are critical. If the opening is too small, a lot of plugging at the grizzlies will arise, hindering the mucking. Mantles are relatively easier to construct and, given that they allow for larger rock fragments (in excess of 90 cm), they have no additional requirements for rock breakers. This is an advantage for infrastructure costs, but the flow of large rocks in an ore pass can contribute to wall degradation.

Flow control infrastructure

Material flow control infrastructures used in Canadian mines can be classified into 5 categories:

- Control chains are heavy weighed chains suspended from a headblock. They rely on their weight to slow down or regulate the flow of ore from an ore pass. In some instances where an additional level of control over the flow of ore is needed, a hydraulic cylinder can be added.
- Chutes with crash gates are formed by a steel-lined slide to which is attached a steel door (hinged at the top) that physically stops the movement of ore when it is pushed by hydraulic cylinders .The design is simple and efficient, but there are known issues, such as the steel door being kept from closing completely by a big rock
- Chutes with control chains operate on the same principle as crash gates, with the difference that the steel door is replaced by the set of chains. This arrangement solves most of the problems associated with large blocks wedged in the steel door
- Chutes with control chains and gate are a variation on the principle of the chute with control chains in that the material flow is slowed by control chains but it is also further hindered by the gradual lifting of the chute lip or an arc gate. This lifting of the lip effectively reduces the angle of the entire chute arrangement to the point where this angle is less than the natural angle of repose of the material
- Feeders are chutes inclined at an angle higher than the angle of repose of the material. Material flow is restrained by a set of heavy circular chains. When flow has to be restored, the chains are rotated, letting the material slide beneath them.

Chutes with control chains are the most popular flow control infrastructure in Quebec mines, Figure 5.

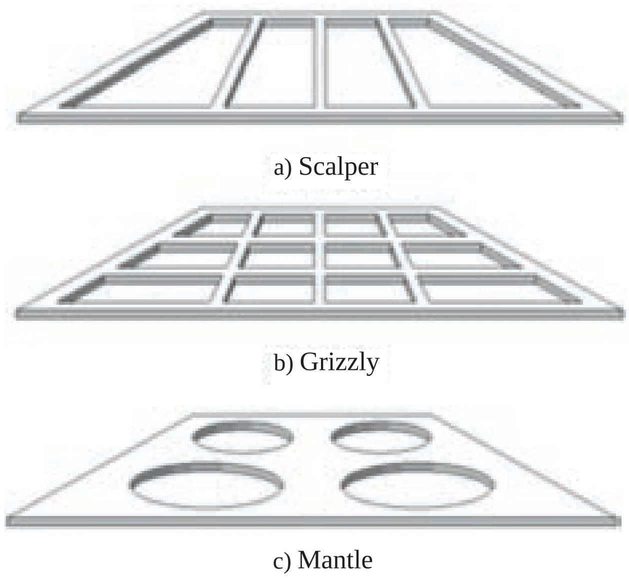

Figure 4—Typical screening infrastructure

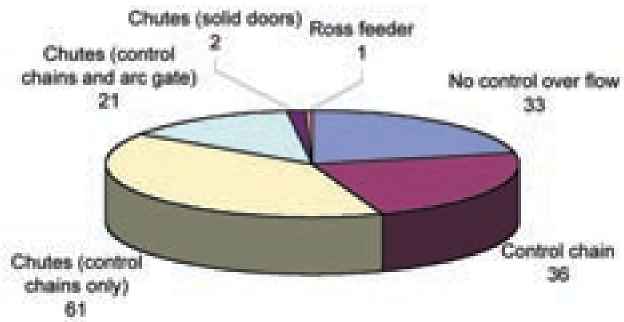

Figure 5—Sections draw control infrastructures for Quebec mines (153 sections)

Table III

Performance of ore passes in Quebec mines

Q Rating	Non-supported	
	# Sections	% Failed
> 5 (fair)	4	0
< 5 (poor)	3	100
Total	7	43
Q Rating	**Reinforced**	
	# Sections	**% Failed**
> 5 (fair)	43	0
< 5 (poor)	50	60
Total	93	32

Reinforcement

Hadjigeorgiou *et al.* (2004) addressed the issues associated with reinforcement and support. In Quebec mines the majority of vertical or inclined excavations are constructed using Alimak, thus facilitating the installation of reinforcement and support.

Resin-grouted rebar constitutes the most popular reinforcement type for ore pass systems. Nevertheless, the most recently developed excavations are reinforced by resin grouted short cable bolts. More recently several Canadian Mines have used resin grouted short cable bolts, for example the Strand-Lok Cable bolt system, as they have been found to dissipate impact shock more efficiently than rigid support systems.

Liners

The relationship between rock mass and ore pass operational failure was addressed for 10 Quebec mines, Hadjigeorgiou and Lessard (2003). Cavity monitoring surveys, volume reconciliation from actual tonnage capacity and/or comments from mine operators were used to quantify the expansion of an ore pass. An ore pass section is considered to have 'failed' if it had expanded to twice its initial volume as recorded in the original layout. The Q system, Barton *et al.* (1974) was used to quantify rock mass quality. The results are summarized in Table III.

Referring to Table III, there is no incidence of uncontrolled ore pass failure in any rockpass section that had a Q value greater than 5. It is suggested that liners should be considered for ground conditions where Q is less than 5.

Ore pass monitoring

Ore pass management necessitates the use of reliable monitoring techniques. Those systems can be either direct or indirect and range from very simple (visual inspections) to fully automated systems (laser). Several mines try to keep an ore pass full as this practice mitigates the results of impact loads on the side walls, and provides a degree of confinement that contributes to the stability of the ore pass. Keeping an ore pass full, or to a certain predefined level, requires strict procedures. Several techniques are available to monitor the level of muck in an ore pass, Table IV.

The available techniques to monitor the integrity of an ore pass are listed in Table V. These are not used on a regular basis but they are often used in response to reported problems of frequent ore pass hang-ups.

The performance of liners in ore passes also has to be monitored on a regular basis. The fact that liners are used in response or in anticipation of problems should justify the use of the monitoring techniques listed in Table VI.

Table IV

Muck level monitoring systems in Canadian ore passes

Type	System	Comments
Direct	Visual	Evaluation of the muck level is performed periodically by supervising personnel. *Inaccurate. Cannot be automated*
	Measuring Tape	A weighted tape is used by supervising personnel to periodically record the muck level. *Cannot be automated.*
	Laser	Laser systems can provide real time muck level readings. Very accurate. Can be automated. *High capital cost. Sensitive to dust.*
Indirect	Tonnage Reconciliation	Subtracting pass capacity and pass output to pass input (scoop buckets). *Highly inaccurate*

Table V

Wall degradation monitoring systems in Canadian ore passes

Type	System	Comments
Direct	Visual	Evaluation of wall degradation from the upper access. *Inaccurate. Pass must be emptied*
	Drilling	Drilling into the pass from nearby drifts to determine an approximate profile. *Pass can be kept full. Provides only localized data. Necessitates access.*
	Camera	A camera is lowered into the pass *Necessitates the use of a buggy. Pass must be emptied.*
	CMS	A cavity monitoring system provides a full 3D profile of the pass *Accurate (occasional blind spots). High capital cost. Necessitates access. Pass must be emptied.*
Indirect	Tonnage reconciliation	Subtracting pass output to pass input (scoop buckets). *Pass can be kept full. Highly inaccurate*

Table VI

Liner wear monitoring systems in Canadian ore passes

Type	System	Comments
Direct	Visual	Visual evaluation of liner wear is performed from the upper access *Inaccurate. Requires access. Pass must be emptied.*
	Wear nails	A system of nails of different lengths is added to the liner during installation. As the liner wears, nails are exposed. *Provides only localized data. Pass must be emptied for reading unless the nails are instrumented*
Indirect	Mill performance	Liner materials such as silica and calcium aluminate can be detrimental to metals recuperation at the mill. Poor recuperation can be caused by liner material failing. *Pass can be kept full. Difficult to track in a multi-pass system*

Ore pass problems

Analysing the causes of degradation is a complex process due to the potential interaction of several mechanisms. Table VII demonstrates the level of degradation observed in the mines. An interesting observation was that seven of the eight ore pass sections that reported a tenfold enlargement from the design volume were used to transfer ore of unit weight greater than 30 kN/m^3. Only 4 of the 31 sections showing an enlargement of two to four times the initial volume came from mines handling ore with a unit weight of 27 kN/m^3. Only two waste pass sections have exhibited an enlargement of two times the initial volume and those examples were located in high stress environments. It is quite possible that there is a relationship between the material unit weight and the degree of observed degradation.

Figure 6 summarizes the perceived degradation mechanisms observed in ore and waste passes in Quebec mines. These have been identified based on information collected at each site. It is noted that quite often there is more than one mechanism at work.

Morrison and Kazakidis (1995) have used data from the Sudbury mining camp to provide a qualitative assessment of the dominant degradation mechanisms. These include: structural failures facilitated by material flow; scaling of walls due to high stresses; wear due to impact loading caused by material flow; wear due to abrasion and blast damage caused by the hang-ups clearing methods.

The importance of driving the rockpasses against the foliation dip has been recognized by Stacey and Swart (1997). The wisdom of this simple design rule has been proven at several sites. Perhaps the most striking example is two ore passes, at two mines in the same structural regime characterizing by steep bedding, Figure 7. The first ore pass excavated at a favourable orientation with respect to the bedding did not run into problems. The second ore pass excavated along the bedding experienced severe degradation. A cavity survey indicated that the ore pass expanded to close to 20 times its original diameter and was subsequently abandoned.

Wall damage attributed to impact loading is most often localized at the intersection of finger raises to the ore pass, Figure 8. In practice it is sometimes difficult to differentiate among damage due to impact, wear or the presence of structural defects in the rock. It is most probable that the presence of structural defects in the rock mass accentuates the influence of impact loading, resulting in more pronounced degradation. The use of 'rock boxes' can reduce impact damage but in most cases impact damage is localized on the ore pass wall facing the finger raise. Constructing a rock box at this location would be impractical, if not unfeasible.

Damage due to wear appears to be of lesser concern in the examined mines. Abrasion rate depends on the abrasiveness of the material and the rockpass walls' resistance to abrasion. In ore passes with relatively few fractures, wear of the walls did not seem to endanger the structural integrity of an ore pass.

Material flow problems

Some types of material flow problems are reported in every mine operating an ore pass system. Hambley (1987) suggests that the transfer of coarse material can result in hang-ups due to interlocking arches, while the transfer of fine material results in hang-ups due to cohesive arches, Figure 9. If flow is not restored there can be significant consequences for the operation. A distinction is made in this paper between blockages: localized in the vicinity of the chute and hang-ups, which are found in the ore pass. This distinction is not universally accepted in Canadian mines.

Hang-ups

In Quebec mines, interlocking hang-ups were more common than cohesive arches, Table VIII. Cohesive hang-ups were

Table VII

Level of enlargement caused by wall degradation (153 sections)

Degree of degradation	Ore pass sections	Comments
Negligible	38.6%	
> 2x original volume	9.8%	
2x original volume	7.8%	Operational failure
5x original volume	12.4%	Operational failure
10x original volume	5.2%	Operational failure
Not defined	26.1%	

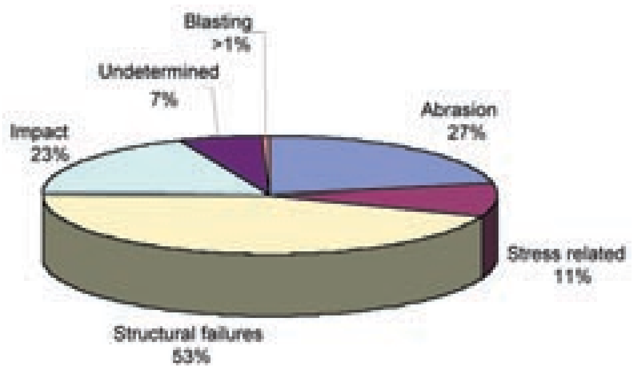

Figure 6—Probable failure mechanisms (153 sections)

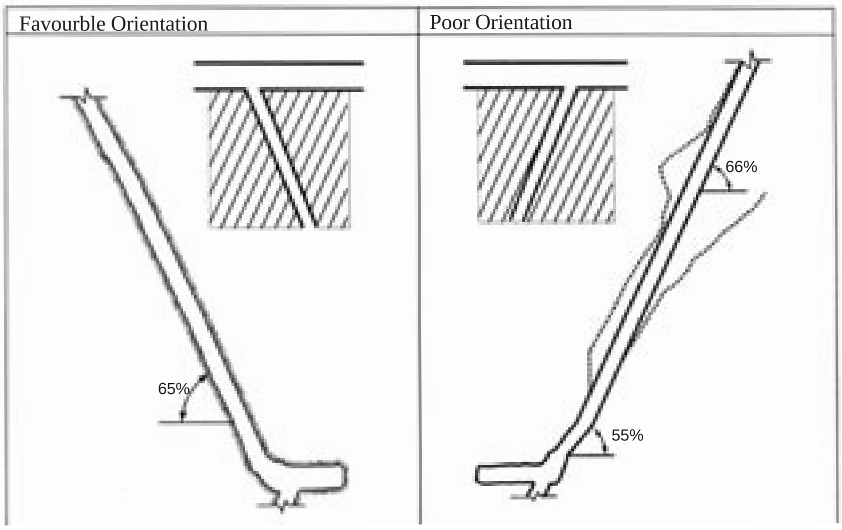

Figure 7—Case studies of ore pass development with respect to bedding

Figure 8—Damage zones in an ore pass

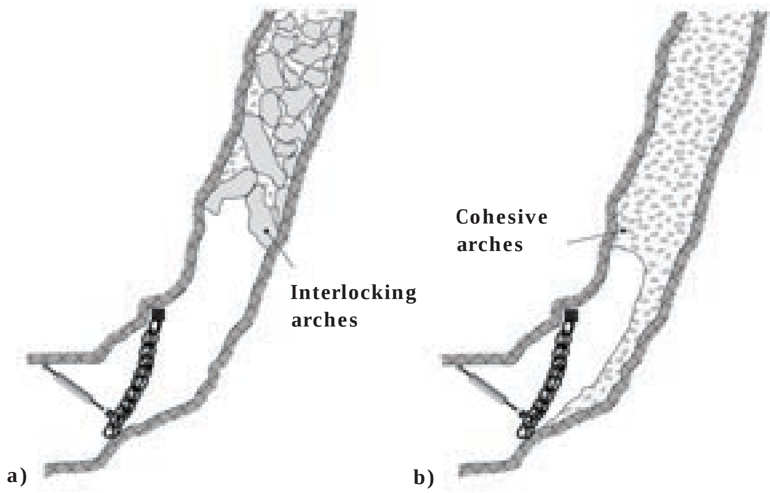

Figure 9—Hang-ups caused by: (a) interlocking arches (b) cohesive arches

Table VIII

Frequency of reported hang-up occurrences in Quebec mines

Frequency	Interlocking hang-ups (number of mines)	Cohesive arches (number of mines)
Never encountered	2	6
Rare (1 < per month)	3	1
Not frequent (1 to 4 per month)	4	2
Frequent (>1 per week)	1	1
Very frequent (> 1 per day)	0	0

observed when mining zinc-rich stopes (often referred to as sticky ore) or when the dilution due to the paste fill is high. A comprehensive review further revealed the interdependence of the frequency of hang-ups and wall degradation.

Blockages

Blockages are the most commonly encountered type of flow disruption in ore pass systems, Table IX. All mines report some type of blockage problems. Flow disruption near the chute may be due to blocks wedged at the restriction caused by the chute throat. Another source of problems is caused by the accumulation of fine or 'sticky' material in or near the chute, on the ore pass floor. This reduces the effective cross-sectional area and results in further blockages.

Hang-up release mechanisms

Restoring material flow is a priority in operating mines. There are several methods employed in Canadian mines and they can be classified as those that employ water and those that rely on explosives, Table X. A complete review of hang-up release techniques is provided by Hadjigeorgiou and Lessard (2004).

Most hang-ups lower than 20 m are brought down by attaching explosive charges on wood or aluminium poles used to push the charge up to the hang-up. A buggy can also be used to facilitate the pushing, Figure 10.

Hang-ups located higher in the pass can be blasted using a 'Sputnik', an air-propelled device that can carry a 12 kg explosive charge up to 100 m high, Figure 11. As a last resort, holes drilled toward the hang-up can be driven and explosive charges set inside the hole, near the supposed hang-up location, Figure 12. If the location of the hang-up is not clearly identified, it may take more than one attempt to restore flow.

Table IX

Frequency of blockage occurrences in Quebec mines

Frequency	Interlocking blockage (number of mines)	Cohesive blockage (number of mines)
Never encountered	0	1
Rare (1 < per month)	1	1
Not frequent (1 to 4 per month)	4	1
Frequent (>1 per week)	4	5
Very frequent (> 1 per day)	1	2

Table X

Methods employed in Canadian mines to restore flow in ore passes

Category	Methods to restore flow
Methods that employ water	Introduction of water from above the hang-up or blockages Introduction of water from a point below the blockage
Explosive-based methods	Close range drilling and use of explosives Drilling from a distance and use of explosives Use of 'Sputnik' or 'Flying Pumpkin' Use of blasting poles

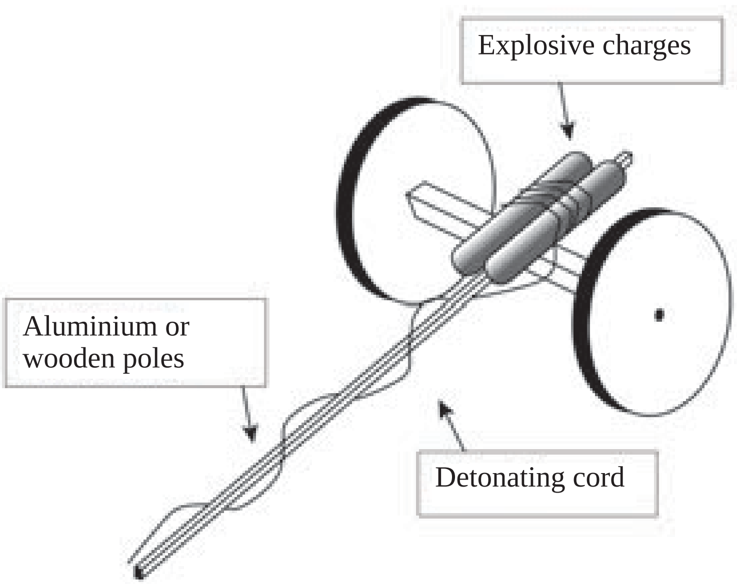

Figure 10—Use of a buggy to drive explosive charges up an ore pass, after Hadjigeorgiou and Lessard (2004)

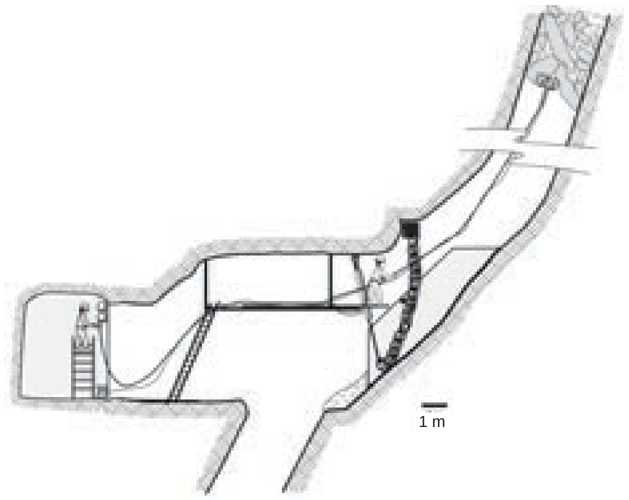

Figure 11—Application of Sputnik to clear an ore pass, after Hadjigeorgiou and Lessard (2004)

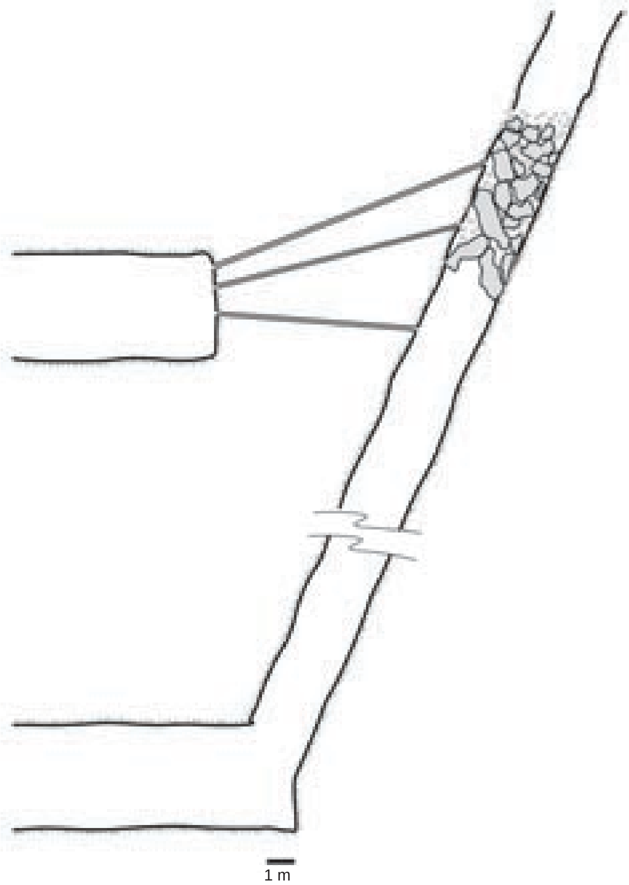

Figure 12—Use of explosives to clear hang-ups high in an ore pass, after Hadjigeorgiou and Lessard (2004)

Cohesive hang ups are difficult to dislodge using explosives. Some operations resort to blowing compressed air through a PVC pipe raised up to the hang-up location or dumping a predetermined amount of water from a point above the hang-up. All mines have strict procedures about the use of water in order to avoid the risks of mud rushes.

Conclusions

This paper illustrates some practices employed in Canadian mines. An analysis of this data has revealed that there is no unique Canadian strategy for Canadian mines. The field data has, however, provided the foundations for developing a series of guidelines for the design and operation of ore pass systems. This information complements numerical experiments investigating hang-up phenomena, Lessard Hadjigeorgiou (2003).

Acknowledgements

The authors would like to thank the Institut de Recherche Robert Sauvé en Santé et en Sécurité du Travail (IRSST) for its financial support. The authors would also like to acknowledge and thank the ground control committee of the Quebec Mining Association and mine personnel at the following operations: Louvicourt, Bell-Allard, Bouchard-Hébert, Langlois, Niobec, Agnico-Eagle Division Laronde, Kiena, Mouska, Doyon and Bousquet II.

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