

Recently developed blasting techniques in frozen iron ore at Schefferville, Québec

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Based on a research program carried out by the Iron Ore Company of Canada in the Schefferville area since 1970, considerable improvements have been made related to the blasting of frozen ore and waste material.

The major areas of improvements are the following:

- (a) Prediction on the three-dimensional distribution of permafrost for each mining area;
- (b) An improved dewatering program and use of liners in the blast holes;
- (c) Determination of rock properties in the laboratory and in the field using seismic techniques; and
- (d) Simulation of blast designs using a computer program. This reduces the number of experimental blasts which would otherwise have to be done in the field using the trial and error approach.

Considerable savings have been realized in the unit cost of blasting in permafrost areas of the mining operation as a result of the research program.

Specific topics where further research work is required are also discussed briefly.

Suite à un programme de recherches réalisées dans la région de Schefferville par la Compagnie Iron Ore du Canada depuis 1970, des améliorations considérables ont été apportées dans le domaine du dynamitage des minerais et des résidus gelés. Les principales améliorations sont les suivantes:

- a) Prévision de la répartition tridimensionnelle du pergélisol dans chaque région minière;
- b) Programme d'assèchement amélioré et utilisation de garnitures dans les trous de mine;
- c) Détermination des propriétés de la roche en laboratoire et sur le terrain au moyen de techniques sismiques;
- d) Simulation de plans de dynamitage par un programme d'ordinateur, permettant de réduire le nombre d'explosions expérimentales qui seraient par ailleurs nécessaires sur le terrain par la méthode d'essais et d'erreurs.

Ce programme de recherches a, par conséquent, permis des économies considérables au niveau du coût unitaire du dynamitage dans les exploitations minières en régions de pergélisol.

Les domaines particuliers dans lesquels des travaux de recherche supplémentaires sont nécessaires sont également brièvement abordés.

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Introduction

The purpose of this paper is to outline the improved blasting techniques for mining frozen ore which have been developed at the Iron Ore Company of Canada's (IOC) operations in Northern Québec and Labrador.

The mining operations are centred around the town of Schefferville, Québec (54° 49' N and 66° 50' W), in the discontinuous zone of permafrost (Figure 1).

Permafrost is present in an area some 25 km north-west of Schefferville where the Fleming-Timmins group of deposits are located. The mean annual air temperature is -4.5°C. The ground temperatures measured in the permafrost areas vary between -4 and 0°C. The maximum measured depth of permafrost in the mining area is 115 m (Brown 1970; Ives 1962). Approximately 25 per cent of the average ore production of 9 million tonnes (t) per year was mined from the permafrost areas between 1974 and 1980.

Since 1956, IOC has been blasting frozen iron ore, first in the Ferriman-Gagnon area during the period 1956 to 1964 and since 1970 in the Fleming-Timmins area (Farnam 1961; Lang 1966). The main problems

encountered in connection with blasting in permafrost were first, caving in of drill holes due to melting of ice during drilling. This resulted in a) higher cost due to redrilling and b) improper placement of explosive charge in the drill holes. Secondly, poor fragmentation provided difficult conditions for excavation especially at the toe of the mining face, and uneven pit floors resulted in reduced production and increased unit cost. In some areas, even if the holes were loaded with more-expensive Hydromex type of slurry explosives as compared to Ammonium Nitrate - Fuel Oil mixture (ANFO), the fragmentation was not satisfactory.

Considerable operating improvements were made while blasting in permafrost during the period 1956 to 1964 by implementing the following techniques and procedures (Mayer 1966):

- (i) Explosives were loaded in the holes soon after they were drilled which avoided the need to redrill holes that had caved in.
- (ii) The drill hole pattern was reduced to 5.5 × 5.5 m from the 7.3 × 7.3 m grid in order to obtain acceptable fragmentation and, hence,

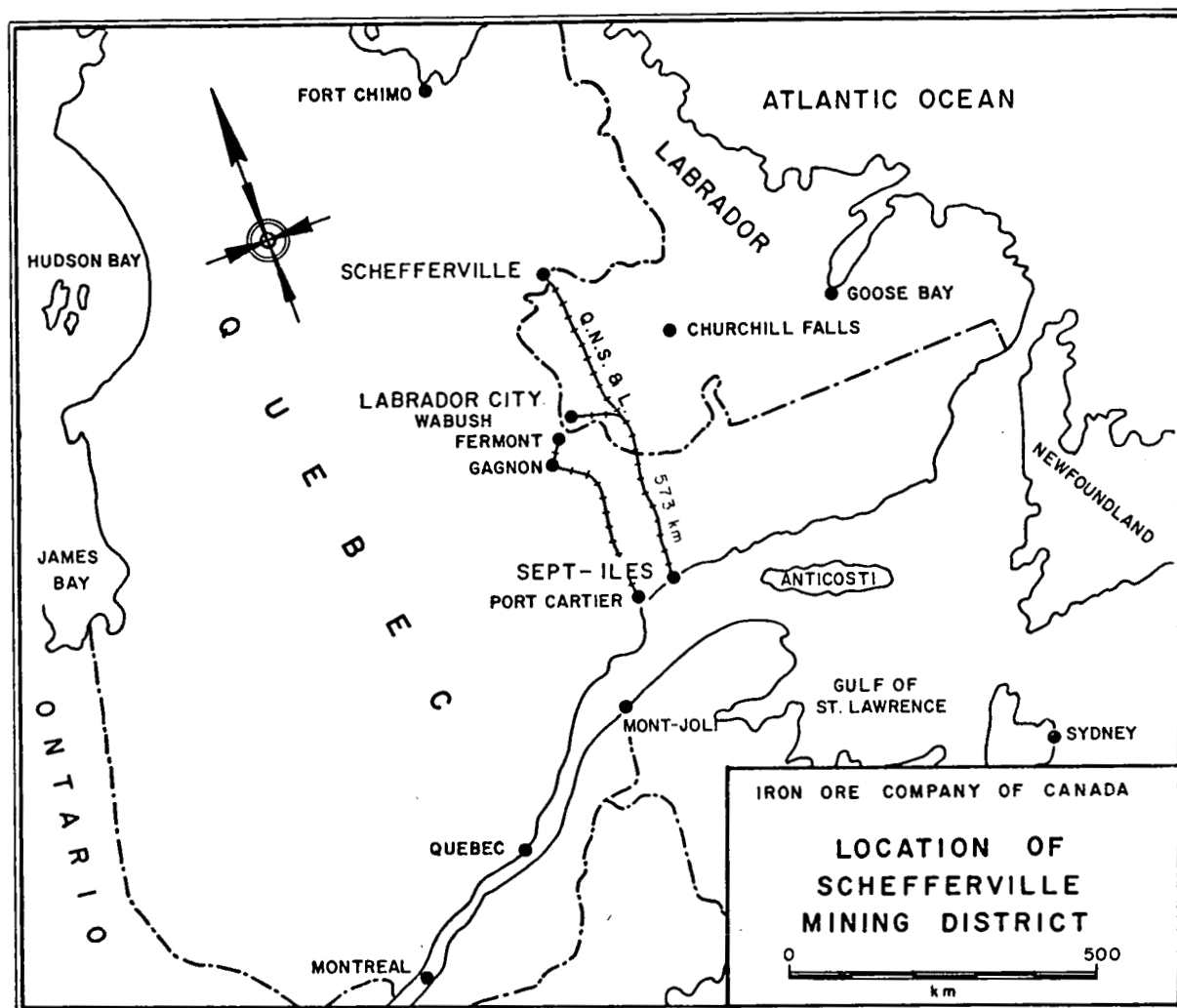


FIGURE 1. Location of Schefferville mining district.

to improve productivity. Higher unit costs resulted.

- (iii) The overall size of blast in permafrost was reduced to a maximum of 3 rows deep (blast) in order to avoid refreezing of blasted ore during the mining period.
- (iv) Additional frost (satellite) holes were drilled and loaded to break the seasonally frozen top layer.
- (v) More-powerful slurry type of explosives were developed in 1959 at Schefferville to fragment the frozen ore and waste material.

In addition to the work done at IOC, a few other very significant contributions have been made in the area of blasting in permafrost (Dick 1969; Lang 1976; Mellor and Sellman 1970; Misnik and Nekrasov 1969; Morrison 1976).

Recent Improvements

Although significant improvements were made during the period 1956 to 1964, serious difficulties were encountered when the mining of frozen ore from the Timmins 1 Mine commenced in 1970. Because of permafrost in the south end of Timmins 1 Mine, productivity was considerably lower and drilling and blasting costs were up to 350 per cent higher than the corresponding unit cost in unfrozen areas. Typical examples of poor and good fragmentation are shown in Figures 2 and 3 respectively. Therefore, in order to improve productivity and reduce the unit cost of drilling and blasting in frozen ore, the following research projects were initiated.

Delineation of Permafrost

Since the active mining area is located in the dis-



FIGURE 2. A typical example of poor fragmentation in frozen material.

continuous zone of permafrost, the frozen and unfrozen areas must be delineated (Garg 1977; Seguin and Garg 1974), so that ground conditions may be predicted before a blast can be adequately designed.

The permafrost prediction program used by IOC is summarized in Table 1. Mapping of ground-ice in active mining faces and in drill holes is undertaken to estimate the quantity and type of ice likely to be encountered during blasting. Details of the techniques used for the three-dimensional delineation program were documented in earlier publications by the author (Garg 1973, 1979). Seismic refraction and electrical resistivity surveys, in particular, have been used to delineate frozen and unfrozen areas.

Based on the interpretation of these survey data and in conjunction with ground temperature data obtained from thermistor cables in deep drill holes and field mapping, the following ground conditions are established for each mining area:

- (i) Whether the ground is frozen, unfrozen, or marginally frozen.
- (ii) Estimate of the percentage of total moisture (ice) content. If the frozen ground has less than 7 per cent moisture (dry permafrost) then there are no



FIGURE 3. A typical example of good fragmentation in frozen material.

'special' problems related to blasting in these areas.

Explosives loading patterns are then adjusted based on the predicted type of ground (frozen or not) and the estimated ground-ice content.

Determination of Rock Properties

As an integral part of the research program, rock properties for both frozen and unfrozen material were measured under controlled laboratory conditions and these were used to interpret the seismic survey data (King and Garg 1980).

The dynamic elastic rock properties calculated from the seismic surveys were used in a computer program that simulates the relationship between rock properties and explosives properties for an assumed blast pattern and explosives loading combinations (Broadbent 1974; Burshtein and Kurochkin 1970; Garg 1973).

Simulation and Design of Blasts

The usual practice followed to improve fragmentation (and to reduce overall drilling and blasting costs) is to adopt a trial-and-error approach in the field.

TABLE 1. Summary of permafrost prediction program

Phase	Scale	Techniques used	Purpose
Regional exploration	1:12,000	Aerial photos use of geomorphological features	1 Preliminary deposit scheduling. 2 Long-range planning of mining access facilities 3 Future permafrost studies
Deposit development	1:1200 1:2400	1 Ground temperature measurements 2 Seismic surveys 3 Resistivity surveys 4 Other geophysical techniques	1 For an economic evaluation of a deposit 2 Facilitates mine planning (Design of slopes and hydrological problems)
Mining (lift by lift)	1:480	1 Seismic surveys 2 Resistivity surveys	1 Outline areas for difficult drilling 2 Prediction of response to blasting

To supplement this approach, a computer program was developed to simulate expected or predicted fragmentation. Input data consist of (a) measured or assumed rock properties, (b) blast geometry, and (c) explosives properties and the loading patterns. Simulation is done for each blast and predicted performance of the simulated blast is calculated with reference to the performance of the last (previous) blast in the same area. The final output from this program includes the unit cost of explosives used in the simulated blast.

The size of a blast in permafrost is dependent on the estimated ice content and is restricted to avoid re-freezing of blasted ore during the mining period. The recommended number of rows to be blasted at a time is three in areas where the ice content exceeds ten per cent. There is no special restriction on the size of blast in areas where dry permafrost conditions exist.

Based on computer simulation and field tests, loading of holes with slurries has been minimized. Several blasts in permafrost with an ice content of seven to ten per cent have been successful using only 0.6 m of Hydromex slurry M210 as a toe load. The rest of the column has been loaded with aluminized ammonium nitrate (Al ANFO) or ANFO, depending on the rock conditions. Only in areas where the ice content is estimated to be higher than ten per cent, a toe load of M210 for the bottom ten feet is used.

Typical blast patterns currently used at IOC in unfrozen and frozen ground are shown in Figures 4 and 5 respectively.

Dewatering of Blast Holes

Water is removed from the bottom of blast holes using a portable pump. Thus ANFO or Al ANFO can be used instead of Hydromex slurries. With the use of double- and triple-walled dry-liners in these holes, the overall usage of slurries in wet holes has been reduced to less than half during the period 1974 to 1979.

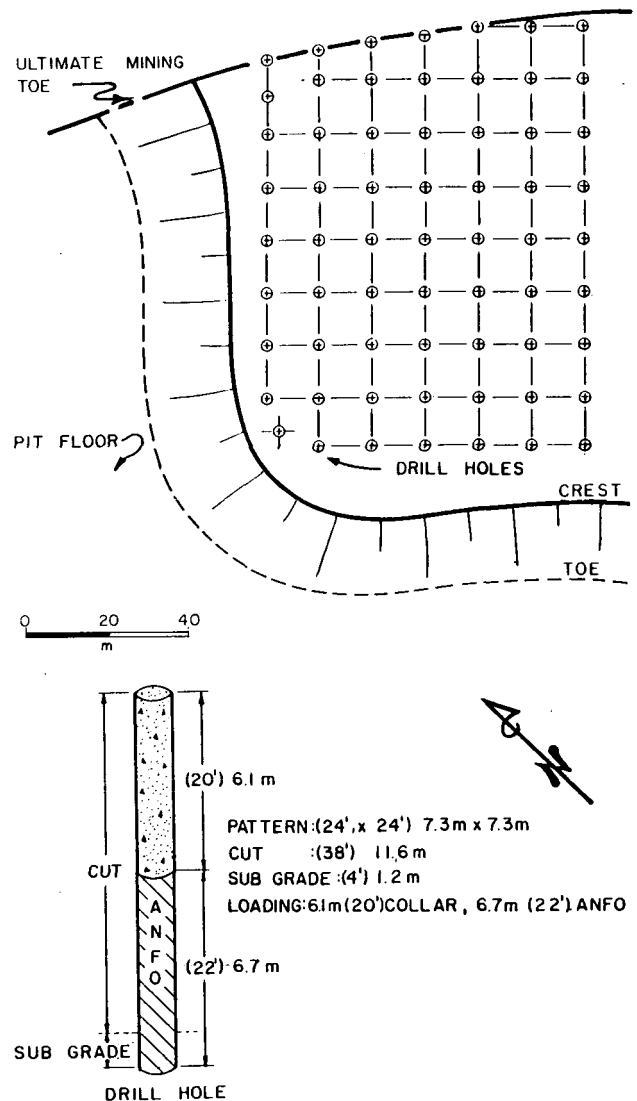


FIGURE 4. Typical blast pattern in unfrozen ground.

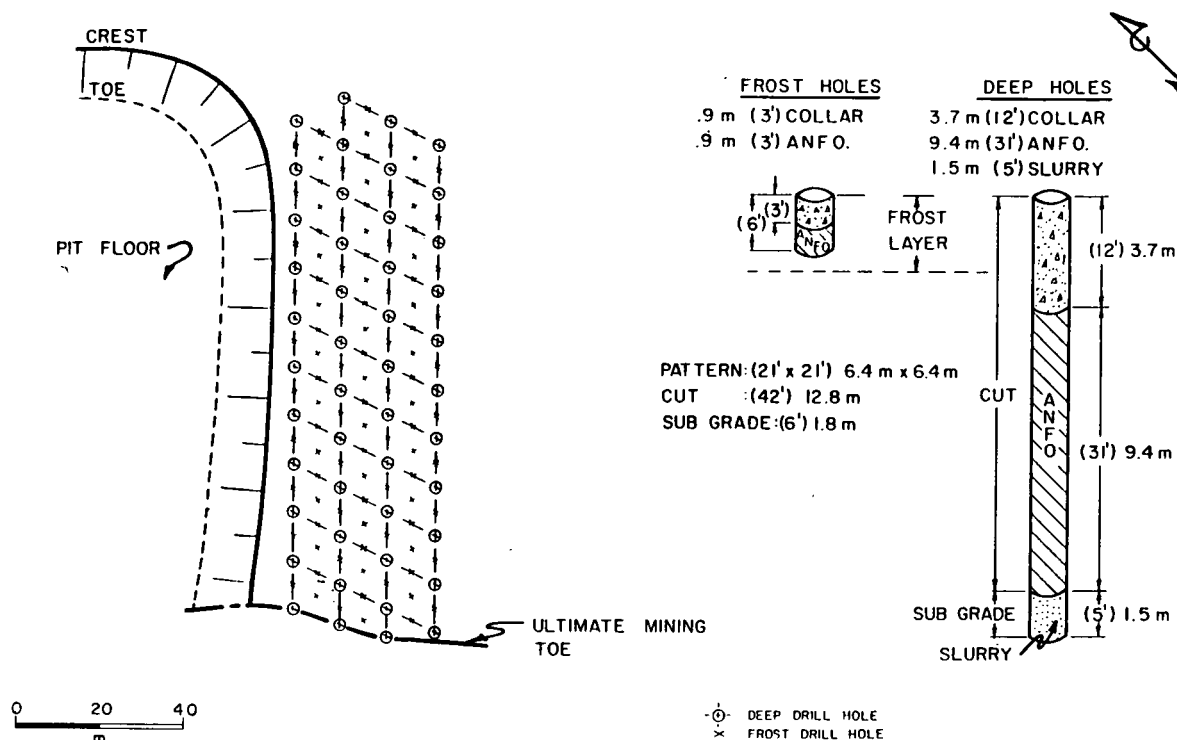


FIGURE 5. Typical blast pattern in frozen ground.

Improved Field Control Procedures

As an integral part of the Blasting Research Program at IOC, the management instituted procedures to improve control in all aspects of drilling and blasting work. This was done to ensure that drilling, loading, and tie-in procedures are followed in the field as they were designed. Also a complete report is prepared on each and every blast made. This report includes, amongst other items, comments on shovel productivity. All these data then are incorporated in the design of subsequent blast(s).

Overburden stripping is done during the period September to November when the ground is thawed to maximum depths. This is to minimize the quantity of material to be drilled and blasted.

Overall Cost Reduction

Based on these improvements, the unit cost of blasting in permafrost has been reduced by half. The cost reduction is mainly due to favourable substitution of lower-cost explosive (ANFO or Al ANFO) instead of using the more expensive Hydromex slurry when blasting in permafrost areas. For example, while 47 per cent of the total explosives used during 1975 were slurries, this figure was reduced to only 10 per cent by 1979.

Areas for Further Research Work

Even though significant improvements have been made in blasting frozen ore by IOC personnel, further research in the following areas is required.

High-Speed Photography

More effort should be devoted to documenting the actual blasting sequence using high-speed photography. Amongst other benefits, the maximum permissible firing delays to be used in achieving improved fragmentation might be determined. In permafrost, too long a delay results in cut-offs and miss holes, while too short a delay results in lack of movement and a poor (chunky) blast.

Down-the-Hole Delays

The potential application(s) of using down-the-hole delays should be explored in blasting frozen material.

Simulation of Geological/Structural Conditions

Efforts should be made to incorporate more fully the data on the orientation of all geological, structural discontinuities (bedding, joint, fault planes), and rock mass strength in the design of blasts (Burkle 1980).

Fragmentation Mechanism

More work is required to better understand the actual mechanism of failure (fragmentation) in frozen rocks.

Determination of Rock Properties

Based on the results of laboratory testing, it seems that the compressional wave velocity is independent of the stress level for frozen rocks. Its significance should be explored with respect to blast designs in permafrost areas.

While the investment in research projects related to blasting in permafrost can be justified based on the cost benefits obtained, there is a serious lack of available 'expertise' in the general area of blasting in frozen ground.

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References

- BROADBENT, C.D. 1974. Predictable blasting with in situ seismic surveys. *Min. Eng.*, April, pp. 37-41.
- BROWN, R.J.E. 1970. Permafrost in Canada: Its influence on northern development. University of Toronto Press, 234 p.
- BURKLE, W.C. 1980. Geology and its effect on blasting. *The Explos. Eng. Suppl.* vol. 3, April, 1980.
- BURSHTIN, L.S. AND KUROCHKIN, A.N. 1970. Study of the physico-mechanical properties of frozen bedrock. *CRREL*, Hanover, pp. 98-106.
- DICK, R.A. 1969. Evaluating blasting techniques in frozen gravel. *Min. Congr. J.*, September.
- FARNAM JR., H.E. 1961. New applications for explosives. *Min. Congr. J.*, March.
- GARG, O.P. 1973. In situ physico-mechanical properties of permafrost using geophysical techniques. *In: Proc. 2nd Int. Conf. Permafrost*. North Amer. Contrib., US Natl. Acad. Sci., Washington, D.C., pp. 508-517.
- . 1977. Applications of geophysical techniques in permafrost studies for subarctic mining operations. *In: Proc. Symp. Permafrost Geophys.*, Vancouver, B.C., October, 1976, N.R.C.C. Assoc. Comm. Geotech. Res., Tech. Memo. No. 119, pp. 60-70.
- . 1979. Mining of frozen iron ore in northern Quebec and Labrador. *Geogr. Phys. Quat.*, vol. XXXIII, pp. 369-376.
- IVES, J.D. 1962. Iron mining in permafrost: Central Labrador-Ungava. *Geogr. Bull.* no. 17, pp. 66-77.
- KING, M.S. AND GARG, O.P. 1980. Interpretation of seismic and resistivity measurements in permafrost in northern Quebec. *In: Proc. Symp. Permafrost Geophys.*, Calgary, Alta., Nov., 1978, N.R.C.C. Assoc. Comm. Geotech. Res., Tech. Memo. No. 128, pp. 50-69.
- LANG, L.C. 1966. Blasting frozen iron ore at Knob Lake. *Can. Min. J.*, August, pp. 49-53.
- . 1976. New permafrost blasting method developed at Asbestos Hill. *Can. Min. J.*, March, pp. 1-8.
- MAYER, P.W.A. 1966. Mining in Canada's Sub-Arctic. The Iron Ore Company of Canada, *CIM Bull.*, December, pp. 1437-1444.
- MELLOR, M. AND SELLMAN, P.V. 1970. Experimental blasting in frozen ground. U.S. Army, *CRREL*, Special Rep. SR 153, 37 p.
- MISNIK, Y.M. AND NEKRASOV, L.B. 1969. Breaking frozen rocks by means of high frequency electric field and mechanical tools. *Soviet Min. Sci.* November/December, pp. 646-650.
- MORRISON, J.R. 1976. Feasibility of using Al/AN/FO for blasting at Schefferville. BSc. Thesis, Queen's Univ., Kingston, April, 1976.
- SEGUIN, M.K. AND GARG, O.P. 1974. Delineation of frozen rocks from the Labrador-Ungava Peninsula using borehole geophysical logging. *In: Proc. 9th Can. Symp. Rock Mech.*, Montreal, December, 1972, pp. 53-75 (publ. Mines Br. E.M.R. Ottawa).