

**Mining of frozen iron ore in northern Québec and Labrador**  
**L'extraction du minerai de fer gelé au Nouveau-Québec et au Labrador**  
**Förderung von gefrorenem Eisenerz im nördlichen Québec und Labrador**

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Volume 33, numéro 3-4, 1979

URI : <https://id.erudit.org/iderudit/1000371ar>  
DOI : <https://doi.org/10.7202/1000371ar>

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Éditeur(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (imprimé)  
1492-143X (numérique)

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Citer cet article

Garg, O. P. (1979). Mining of frozen iron ore in northern Québec and Labrador. *Géographie physique et Quaternaire*, 33(3-4), 369–376. <https://doi.org/10.7202/1000371ar>

Résumé de l'article

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# MINING OF FROZEN IRON ORE IN NORTHERN QUÉBEC AND LABRADOR

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**ABSTRACT** Mining exploration and production activities in the permafrost regions of Canada have increased rapidly over the last twenty years. This paper deals with the effects of permafrost on mining iron ore in the Schefferville area of Northern Québec and Labrador. Problems associated with drilling and blasting, digging and crushing, transportation and handling of frozen ore are briefly outlined. The three dimensional delineation of frozen ground is achieved by a combination of ground temperature measurements and geophysical techniques. Finally some of the studies that are planned to be undertaken in the Schefferville area are briefly mentioned.

**RÉSUMÉ** *L'extraction du minerai de fer gelé au Nouveau-Québec et au Labrador.* Depuis vingt ans, les activités reliées à l'exploration et à l'exploitation minières ont connu un essor important dans les régions occupées par le pergélisol. Le présent article traite des effets du pergélisol sur l'extraction du minerai de fer dans la région de Schefferville. On y discute des problèmes engendrés par le forage, le minage, l'excavation, le broyage, le transport et le maniement du minerai de fer gelé. On nous explique que l'on peut parvenir à une délimitation tridimensionnelle du pergélisol en effectuant des mesures de température et en appliquant des techniques de géophysique. On parle, enfin, d'un certain nombre d'études que l'on projette d'entreprendre dans la région.

**ZUSAMMENFASSUNG** *Förderung von gefrorenem Eisenerz im nördlichen Québec und Labrador.* Bergwerkerforschungen und Produktionstätigkeit in den Dauerfrost Regionen von Kanada haben in den letzten zwanzig Jahren schnell zugenommen. Diese Studienarbeit behandelt die Einflüsse des Dauerfrostes auf die Eisenerz-förderung in der Schefferville Gegend im nördlichen Québec und Labrador. Probleme im Zusammenhang mit dem Bohren, Sprengen, Graben, und Zermahlen, Transport und Behandlung von gefrorenem Eisenerz werden kurz beschrieben. Die drei-dimensionelle Delineation des gefrorenen Bodens wird durch eine Verbindung von Bodentemperaturmessungen und geophysischen Techniken erreicht. Zum Schluss werden einige der zukünftigen, geplanten Arbeiten in der Schefferville Gegend kurz erwähnt.

## INTRODUCTION

Mining exploration and production activities in the permafrost regions of Canada have increased rapidly over the last twenty years. A brief history of these mining developments in the Canadian arctic and sub-arctic regions has recently been compiled by BROWN (1970) and DUBNIE (1972). Permafrost studies in the Northern Québec and Labrador Region have, until recently, mainly been undertaken in connection with the open pit iron ore mining operations of the Iron Ore Company of Canada (I.O.C.C.) (IVES, 1962; ANNERSTEN, 1964; THOM, 1970). These mining operations are situated in the Labrador Trough between Gagnon and Schefferville (Fig. 1). The present paper will deal with the effects of permafrost on the Schefferville operations which are located within the discontinuous permafrost zone (Fig. 2).

Permafrost studies in the Schefferville area began in 1955 with a joint I.O.C.C. and National Research Council of Canada program in the Ferriman Mine area (BONNLANDER and MAJOR MAROTHY, 1957; IVES, 1962; ANNERSTEN, 1964). In 1967, the focus of interest was transferred to the Timmins area, located approximately 21 km west-northwest of Schefferville, when the decision was made to open the Timmins 1 Mine. An experimental site was established on the Timmins 4 deposit to study the factors affecting permafrost and to develop techniques for delineation of permafrost (THOM, 1970). Since 1970 the Geotechnical Engineering Section of I.O.C.C. has developed a program of routine permafrost delineation in the operating pits as well as determination of the physical properties of frozen rocks (GARG and STACEY, 1972). Permafrost is present in three of the seven open pit mines operating in the Schefferville area during 1978.

## PROBLEMS ASSOCIATED WITH THE MINING OF FROZEN MATERIAL

The main problems associated with the mining of frozen ore, bedrock waste and overburden in the Schefferville region are encountered in: 1) drilling and blasting; 2) digging and crushing; 3) transportation; 4) material handling; 5) construction.

### DRILLING AND BLASTING

During rotary blast hole drilling in frozen ground, considerable heat is generated. This is particularly the case in rocks with high ice contents and when the ground temperature is close to 0°C. Due to this heat generation, ice along the sides of the drill hole melts often causing severe hole caving problems.

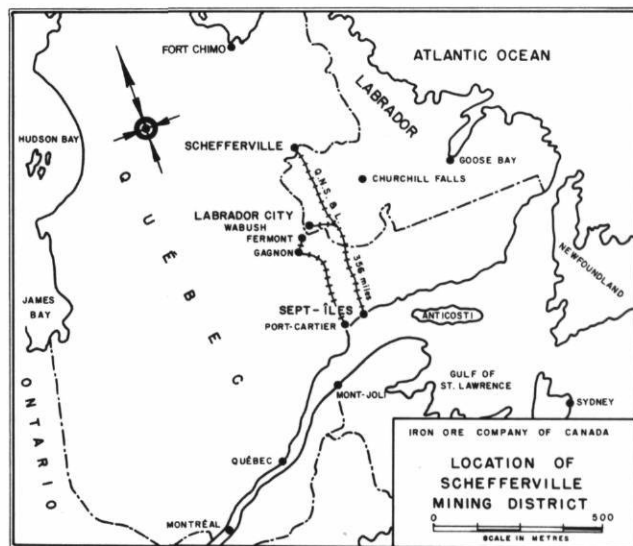


FIGURE 1. Localisation de la région minière de Schefferville.

The second major problem in drilling frozen ore and waste material is caused by the filling of blast holes with water from the nearby talik zones. Because of this flow of water in holes further problems are encountered in terms of melting and caving of holes.

Therefore in practice often several holes have to be drilled before one is suitable for loading with explosives. The overall result is a considerable increase in drilling cost while mining frozen ore.

Ice present in the perennially frozen rocks absorbs a large proportion of the energy generated by the explosives in a blast. Therefore, in order to obtain the required fragmentation, more expensive explosives are needed to break the frozen material compared with the unfrozen material. It has been found that the efficiency of a blast is controlled not only by the total ice content, but also by the type and distribution of the ice.

In the Schefferville area the two main types of ground ice encountered are: a) Segregated ice in the form of ice lenses and veins situated along the joint and bedding planes of rocks. b) Non-segregated ice occupying the pore spaces within the rock mass.

In terms of blasting, both types of ice cause problems in achieving the desired degree of fragmentation. The remedial steps taken to improve fragmentation are: 1) Holes are drilled on a closer pattern and more powerful explosives are required [metallized slurry such as Hydromex M-210 and T-3, as opposed to AN-FO (LANG, 1965)]. 2) Additional shallow holes are drilled to break the near surface material, frozen due to seasonal frost.

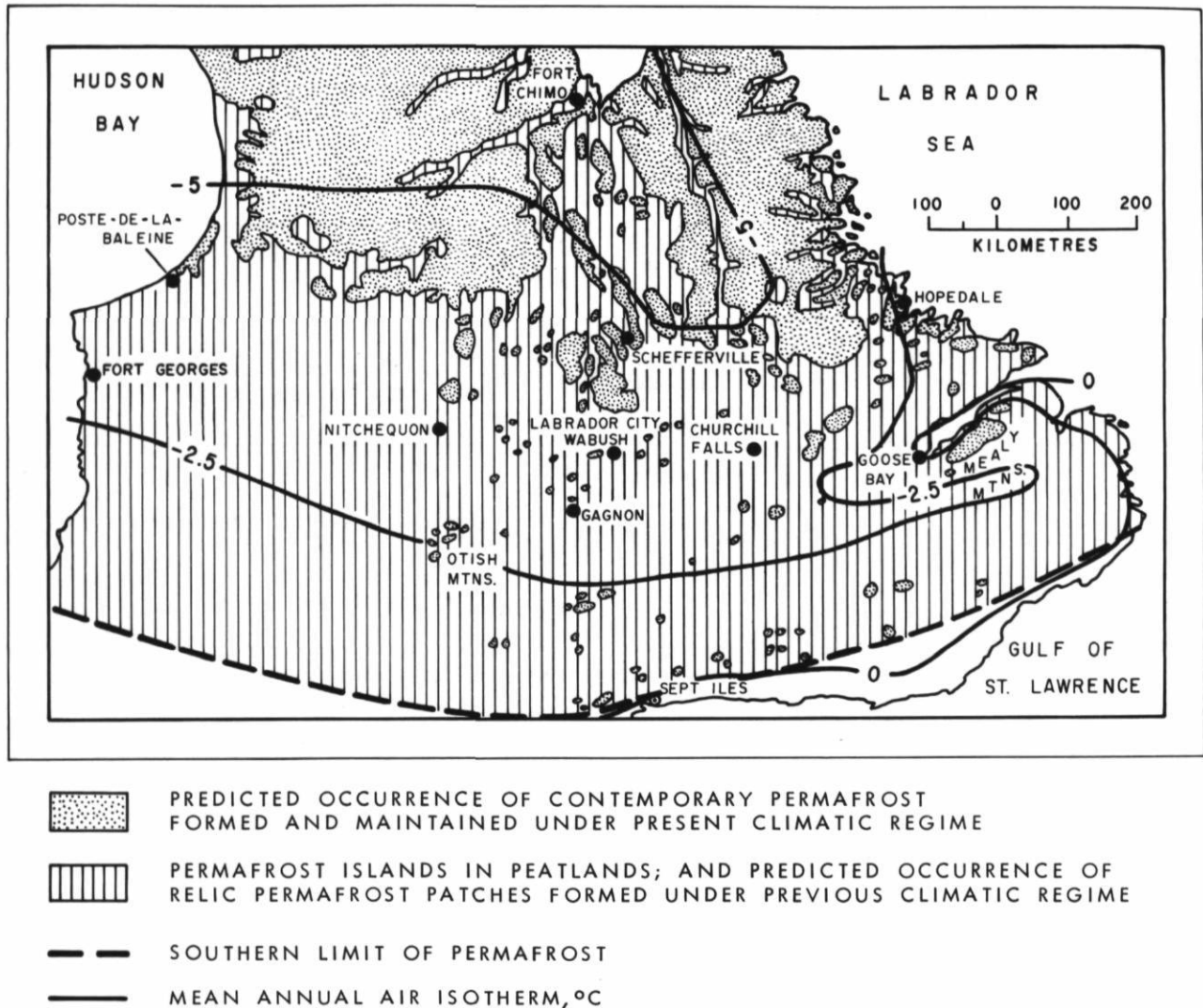


FIGURE 2. Permafrost distribution in Nouveau-Québec and Labrador (after BROWN, 1967, 1978; IVES, 1962).

*La répartition du pergélisol au Nouveau-Québec et au Labrador (d'après BROWN, 1967, 1978; IVES, 1962).*

DIGGING AND CRUSHING

Poor fragmentation due to permafrost produces large blocks of material and an uneven pit floor resulting in reduced productivity. Based on particle size analyses, it is concluded that the percentage of the particles larger than 3.8 cm at the secondary crusher is at least three times more in frozen ore than in unfrozen ore. This is due to the increased hardness and plasticity of the frozen material. Therefore, the cost of crushing the frozen ore on site prior to shipment is increased. Additional problems are encountered due to the blasted material refreezing together and causing bridging in the crusher feed hoppers.

TRANSPORTATION

Two problems are usually encountered during the transportation of frozen ore from the producing mines in Schefferville to Sept-Îles, Québec, 575 km to the south. These are: 1) Thawing of ore en route to Sept-Îles due to warmer weather which results in "sticky" ore, difficult to remove from the rail car. 2) Freezing of the ore to the sides and bottoms of cars at the beginning and the end of the ore season in April and November, when the air temperatures are below 0°C. This necessitates breaking the bond between the ore and the car by warming with propane heaters before the ore can be dumped.

## MATERIAL HANDLING

In addition to the above mentioned problems, there are the following handling problems which also contribute to the increased cost of mining the frozen ore in the Schefferville area.

- 1) The surface and near surface runoff in the permafrost areas lead to an open pit acting as a sump (NICHOLSON and LEWIS, 1976; NICHOLSON, 1978). The runoff water flows over the permafrost surface and enters the pit. The presence of water on the pit floor results in thawing of the permafrost and leads to difficult operating conditions.
- 2) Unfrozen overburden may normally be stripped without blasting, but frozen overburden must be drilled and blasted prior to its removal.
- 3) The stockpiles in Sept-Îles may freeze if not insulated during the cold winter months.
- 4) The low grade ore which was uneconomical in the 1950's and 60's was stockpiled in dumps to various heights. Presently some of these 'waste' piles which are being mined have been found to be frozen to a depth of 6 to 9 m. The most likely reason for the presence of permafrost in these piles is the lack of snow cover due to strong winds during winter months. Therefore these piles have to be insulated with a snow cover and also tractors are used to push the thawed material in layers of 0.5 -1.0 m thick at a time. This facilitates mining of frozen ores from these piles without having to drill and blast.

## CONSTRUCTION

The presence of permafrost has created problems in the selection of construction sites. The active layer can prove to be an unstable base for buildings and railways. During the construction of the railway from Sept-Îles to Schefferville, and of feeder lines and facilities near the Schefferville townsite in the early fifties, permafrost was encountered (PRYER, 1966), ice rich material had to be excavated and the sites filled with dry rock.

### TECHNIQUES USED IN DELINEATION OF PERMAFROST

A summary of the permafrost prediction program at the Iron Ore Company of Canada appears in Figure 3. Ground temperature measurements and various geophysical techniques have both been used in this program.

#### 1) GROUND TEMPERATURE MEASUREMENTS

The relationship between snow depth, vegetation and the presence of permafrost has been described by NICHOLSON and GRANBERG (1973). During the late fifties, thermocouples were used in drill holes as temperature sensors. However, since 1971, thermistors mounted on multi-conductor cables have been used in nearly all holes. Thermistors were preferred over thermocouples for the following reasons: a) Higher

<u>PHASE</u>	<u>SCALE</u>	<u>TECHNIQUES USED</u>	<u>PURPOSE</u>
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 Ground temperature measurements	① For an economic evaluation of a deposit
	1 : 2400	② Seismic surveys ③ Resistivity surveys ④ Other geophysical techniques	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

FIGURE 3. Summary of permafrost prediction program.

*Le programme d'étude du pergélisol.*

sensitivity to changes in temperature. b) Compactness, and simplicity in mechanical design. c) Availability of an accurate read-out system (precision bridge) capable of providing satisfactory temperature measurements for extended periods of time in cold winter months. Most of the recent predictive work based on ground temperature measurements is summarized in another paper in this volume (NICHOLSON, 1979).

2) GEOPHYSICAL TECHNIQUES

The following three types of geophysical surveys are commonly used to delineate permafrost in the mines. The results are plotted on maps at a scale of 1:480 or 1:1,200. a) Seismic surveys. b) Resistivity surveys. c) Borehole logging. The applications of seismic and resistivity surveys in the mining of frozen iron ore are listed in Figure 4.

a) Seismic Surveys

Seismic refraction surveys using a multi-channel seismograph are carried out to delineate overburden depths and the permafrost table. In order to avoid dip effects, the geophone arrays are oriented parallel to the strike. The depths to the various layers are calculated by using the standard relationships between the velocities and the critical distances (DOBRIN, 1960). These surveys are undertaken preferably in August and September when most of the seasonal frost from the previous winter has disappeared.

Figure 5 shows an example of a typical time distance plot obtained from the seismic surveys.

Interpretation of the data is based on three broad groups of velocities, namely: 1) <1070 m/sec for unfrozen overburden. 2) 1070-1800 m/sec for frozen overburden and leached unfrozen rock. 3) >1800 m/sec for bedrock, with velocities in frozen bedrock being up to three times those for the same material in an unfrozen state.

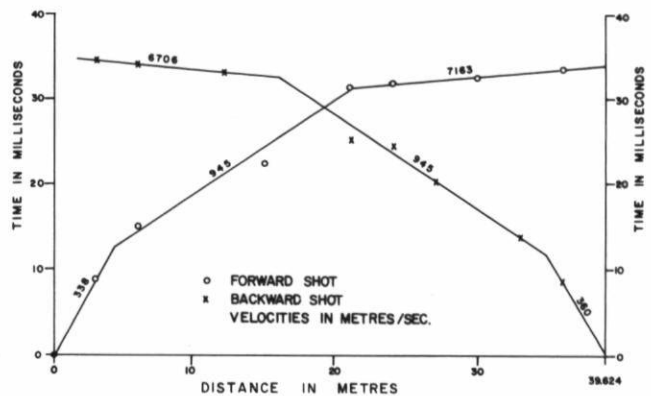


FIGURE 5. A typical distance time plot from seismic survey. *Courbes caractéristiques d'un rapport distance-temps obtenu à partir d'un sondage sismique.*

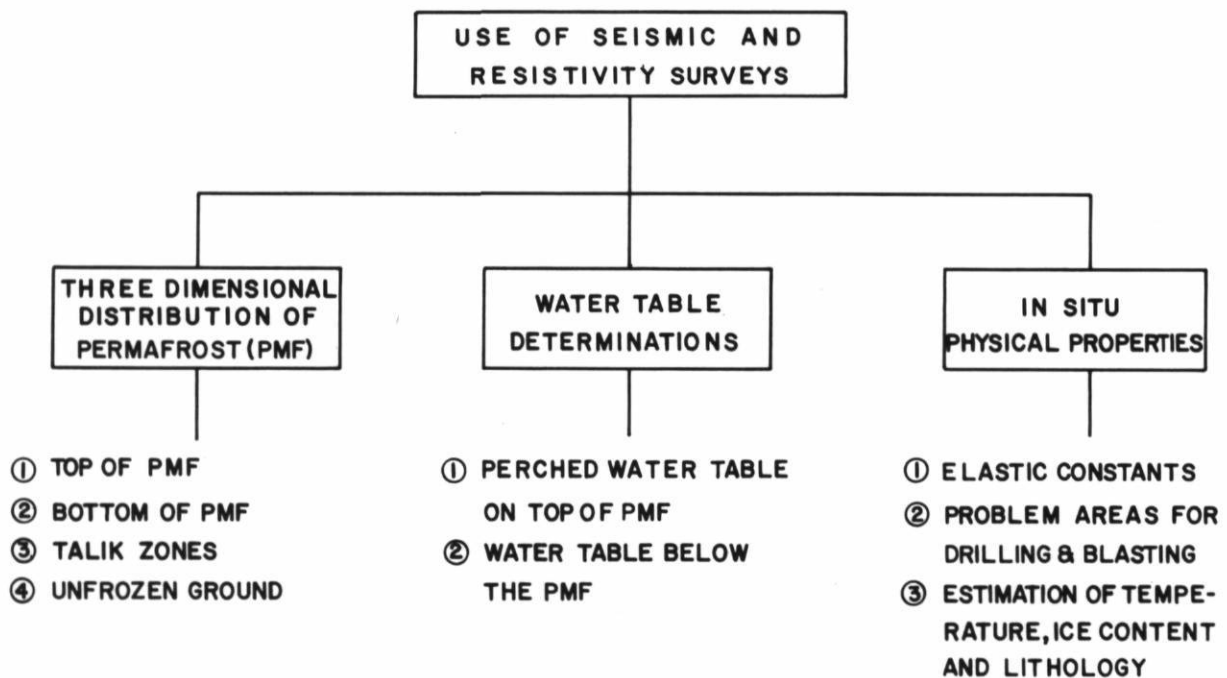


FIGURE 4. Applications of geophysical techniques in the mining of frozen ore.

*Les applications de techniques géophysiques à l'extraction du minéral gelé.*



Based on the above interpretation procedure the depth to the permafrost table at the survey locations is obtained. Seismic surveys are being used on a routine basis in the Schefferville area to determine the permafrost table and to obtain the physico-mechanical properties of the material (GARG, 1973).

b) Resistivity Surveys

Resistivity surveys using a Soiltest R-60 dc system are performed to delineate the base of the permafrost. The survey lines are oriented parallel to the strike of the geological formations. Although both Wenner (horizontal profiling and vertical sounding) and Schlum-

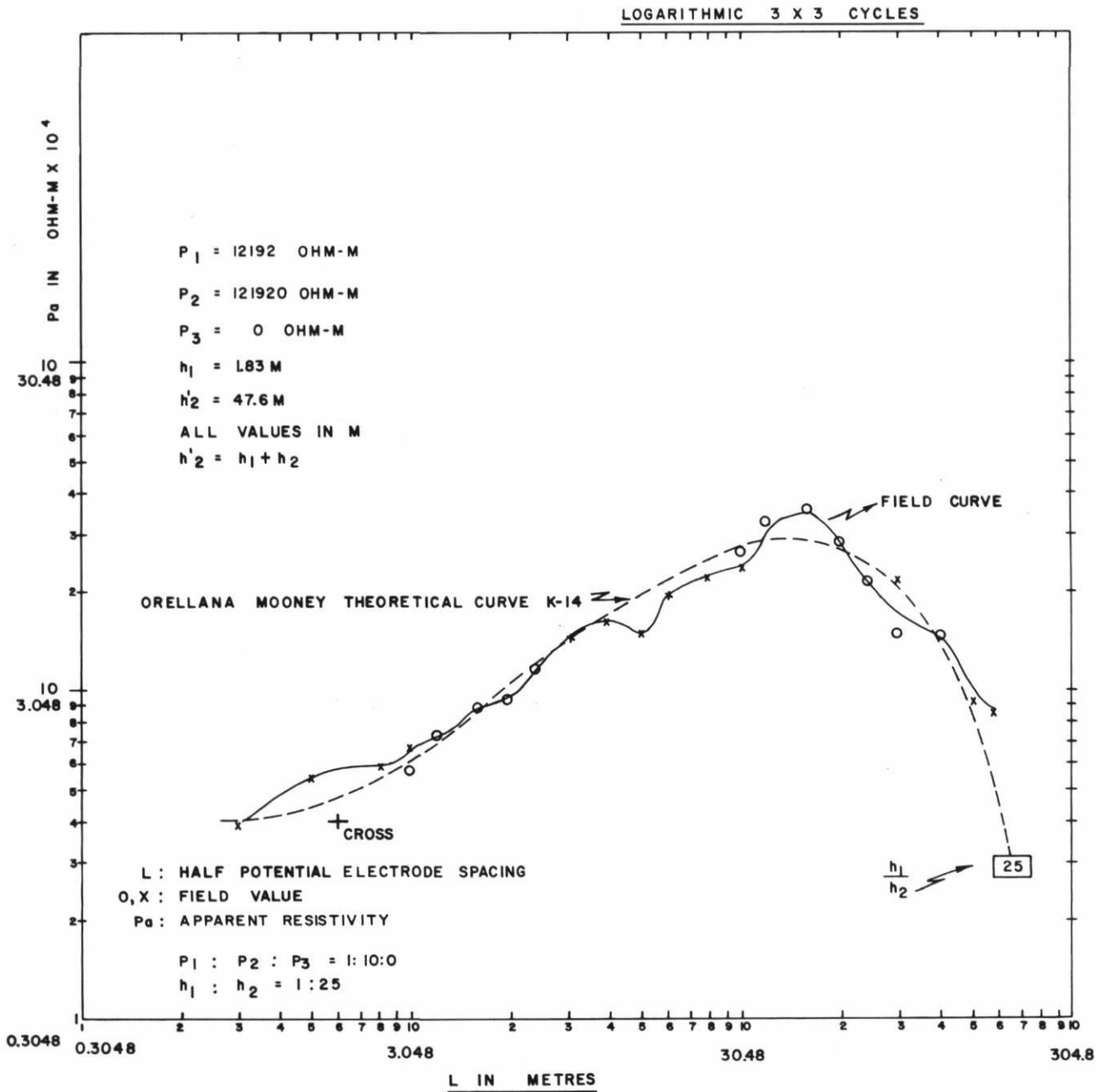


FIGURE 6. A typical plot of field resistivity data.

*Courbes caractéristiques obtenus à partir de données sur la résistivité.*

berger configurations were tested and found to be satisfactory, the latter was preferred because of its lower sensitivity to lateral inhomogeneities. Since the aim of the resistivity surveys is to obtain the depth to the base of permafrost, an expanding electrode configuration is used.

Based on the data from field surveys, plots of calculated apparent resistivity values versus the electrode spacing used in the survey were prepared on log-log paper. A typical plot of field resistivity data is shown in Figure 6. These plots were interpreted using Orellana and Mooney two and three layer master curves. The maximum depth of penetration obtained in the permafrost is about 50 m using the above instrumentation. However, greater depths of penetration to 80 m have been achieved in the permafrost areas of Schefferville using a high power ac transmitter (SEGUIN and GARG, 1972). It should be mentioned that the depths to the base of permafrost obtained from the dc resistivity surveys in areas of known geology correlate fairly well (within 15 percent) with depths obtained from temperature measurements.

#### c) Borehole Logging

The initial attempt to evaluate the use of borehole logging techniques in the delineation of permafrost was made in 1971 (WYDER, 1972). The logging was done with equipment built to NIM specifications by Gearhart-Owen Industries Inc. It was concluded that the dry-hole resistivity and natural gamma logging tools offered the best potential for the delineation of permafrost and the stratigraphic correlation respectively. Based on a subsequent study, it was concluded that higher electrical resistivity and negative self potential values obtained from logging could successfully delineate permafrost at depth (SEGUIN and GARG, 1972).

### RESULTS OF INVESTIGATIONS

The delineation of permafrost in an area with an orebody has the following practical applications in the development and production of ore. These, in time sequence, are: 1) Delineation of areas where development trenching is feasible. 2) Determination of expected ground conditions during development drilling. 3) Economic planning of mining operations, particularly with respect to production drilling and blasting costs. 4) Delineation of areas of the pit wall which are likely to be affected by permafrost. This is required for the design of pit slope angles. 5) Operational planning of areas where free digging is possible during dirt stripping. Digging of frozen overburden requires drilling and blasting. 6) Delineation of areas of potential water problems during operations. 7) Broad delineation of the

blasting patterns and charges to be used. 8) Outlining the areas of potential problems in drilling and blasting during mining stage.

For some of these applications only the depth to the top of the permafrost is required, whereas for others, only the depth to the base of permafrost is required.

As part of the overall program of predicting the behaviour of frozen material including slope stability during the mining operations on a 12 m lift, the following physico-mechanical properties of frozen rocks have also been measured in the laboratory: 1) thermal conductivity; 2) sonic velocity; 3) electrical resistivity; 4) compressive and shear strengths. These studies have helped in optimization of the mining operations.

### SUMMARY AND CONCLUSIONS

To date the main efforts in the Iron Ore Company of Canada's permafrost program have been aimed at the three dimensional delineation of permafrost in the Schefferville area. Permafrost prediction on small, medium, and large scales are required respectively for the three distinct phases of the open pit mining operations, *i.e.*, exploration, development and mining. Geophysical techniques, mainly seismic and resistivity surveys are used extensively for delineation of frozen ground in the operating mines.

Some of the studies that are planned include: 1) The measurement of the reduction in strength of the thawed material from the pit walls; 2) Effect of permafrost on surface water and groundwater movement in the area of mines; 3) Strength properties of frozen rocks in relation to fragmentation of ore during blasting.

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