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IRON ORE COMPANY OF CANADA

GEOTECHNICAL ENGINEERING

PERMAFROST STUDIES

A REPORT ON

"SUMMARY OF THE PERMAFROST STUDIES

IN THE SCHEFFERVILLE AREA"

MAY 1, 1974

PREPARED AS AN INPUT TOWARDS

CHAPTER 11 ON RESOURCE DEVELOPMENT

(PART II - MINING) AND

CHAPTER 5 ON SITE INVESTIGATIONS

(GEOPHYSICAL SURVEYS)

OF THE PERMAFROST ENGINEERING MANUAL

BEING COMPILED BY THE NATIONAL RESEARCH

COUNCIL OF CANADA, OTTAWA

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This is a Geotechnical Engineering Report.

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INTRODUCTION

1.1 General

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 (5) and Dubnie (7). From both these publications it becomes clear that a major contribution to studies in the discontinuous permafrost zone has resulted from the observations in the Central Labrador - Ungava Peninsula region. These studies have been undertaken in connection with the open pit iron ore mining operations of the Iron Ore Company of Canada (I.O.C.C.). The mining operations in the Labrador Trough are centered around the town of Schefferville ($54^{o}49'$N, $66^{o}50'$W) in Northern Quebec and lie within the discontinuous zone of permafrost (16) (see Figure 1). The general topography of the area is one of parallel ridges and valleys. Permafrost occurs at higher elevations.

1.2 History of Permafrost Investigations

Permafrost studies in the Schefferville area began in 1955 with a joint I.O.C.C. and National Research Council program in the Ferriman Mine area. This was the first mine where extensive permafrost was encountered in development trenches and continued to a depth of approximately 250 feet. Studies in the Ferriman area continued until the mid 1960's, largely in the form of a joint I.O.C.C.- McGill University project with technical advice from the Division of Building Research of the National Research Council. The details and the results obtained from these studies have been reported by Bonnlander and Major-Marothy (3), Ives (14) and Annersten (1).

In 1967, the focus of interest was transferred to the Timmins area, located approximately 13 miles west-northwest of Schefferville, when the decision was made to open the Timmins 1 mine. The realization that of a total of some 40 deposits, approximately half are expected to be wholly or partially affected by permafrost, led to the establishment of an experimental site on the Timmins 4 deposit. The purpose of this site was to study the factors affecting permafrost and to develop techniques for delineation of permafrost (18,22,23). In addition to continuing these studies, the Geotechnical Engineering section has developed, between 1970-73, a program of routine permafrost delineation for the operating pits as well as determination of the physical properties of frozen rocks (10).

CHAPTER 5 SITE INVESTIGATIONS

2.0 GEOPHYSICAL SURVEYS

2.1 Distribution of Permafrost

In order to evaluate the various deposits from an economic aspect, and schedule the introduction of new deposits into the operation, delineation of permafrost on a regional and deposit scale is essential. Furthermore, if the operating and handling costs are to be kept to a minimum, the distribution of permafrost within a 38 foot mining lift must also be known. It is with these objectives that the Geotechnical Engineering Section of the Iron Ore Company of Canada has developed a three phase program of permafrost delineation and determination of the properties of frozen rocks. The three phases are:

1) Regional Exploration Phase
2) Deposit Development Phase
3) Mining Phase

Each stage produces a prediction aimed at a specific phase of decision making. A summary of the prediction program appears in Figure 6.

2.1.1 Techniques Used in Delineation of Permafrost

The two geophysical techniques used most commonly in the delineation of permafrost in the Schefferville area are:-

1) Seismic Surveys
2) Resistivity Surveys

In addition, borehole logging techniques have been used on a limited basis in the delineation program.

2.1.1.1 Seismic Surveys

Seismic refraction surveys with an S.I.E. RS-4 multichannel 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. A typical plot depicting the relationship between the first arrival time of the signal, and the shot-detector (geophone) distance is shown in Figure 4. The depths to the various layers are calculated by using the standard relationships between the velocities and the critical distances (6). These surveys are undertaken preferably in August and September when most of the groundfrost is no longer present.

Interpretation of the data is based on these following broad groups of velocities:

1) $< 3,500$ ft/sec for unfrozen overburden

2) 3,500 to 6,000 ft/sec for frozen overburden and leached unfrozen rock.

3) $> 6,000$ ft/sec for bedrock, with velocities in frozen bedrock being up to 3 times those for the same material in an unfrozen state.

Based on the above interpretation procedure the depths to the permafrost table at the locations of the survey are obtained (9).

Seismic surveys are being used on a routine basis in the Schefferville area for determining the top of permafrost and for obtaining the physico-mechanical properties of the material (11).

2.1.1.2 Resistivity Surveys

Resistivity surveys using a Soiltest R-60 dc system are performed in order 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 Schlumberger 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.

An example of the plot of calculated apparent resistivity values versus the electrode spacing used in the survey on log-log paper is shown in Figure 5. These plots are interpreted using Orellana and Mooney two and three layer Master Curves. The maximum depth of penetration obtained in permafrost is in the order of 150 feet using the above instrumentation. However, greater depths of penetration in the order of 250 feet have been achieved in the permafrost areas of Schefferville using a high power ac transmitter (20).

It should be mentioned that the depths to the base of permafrost obtained from the resistivity surveys in areas of known geology correlate within 15 percent with depths obtained from temperature measurements.

2.1.1.3 Borehole Logging

The initial attempt to evaluate the use of borehole logging techniques in the delineation of permafrost was made in 1971 (24). 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 (20).

Finally, the results from a recent study suggest that uphole wave-front (seismic) shooting techniques also have potential for determining the bottom of permafrost in the Schefferville area (13).

2.122 Results from Permafrost Prediction Program

Permafrost investigations for a particular deposit such as Fleming 3 constitute the second of the three phased delineation program (8).

During this stage the aim is to delineate permafrost in three dimensions using geophysical methods and ground temperature measurements from thermocable installations.

Seismic surveys provide the depths to the permafrost table and resistivity surveys are used for determining the base of the permafrost. An example of the results obtained from resistivity surveys for Fleming 3 is shown in Figure 8. The map is subdivided into four zones (9). These are:-

i) unfrozen

ii) unfrozen to 70'feet talik but possible permafrost below 70 feet.

iii) Permafrost with a base between 100 and 150 feet.

iv) Permafrost with a base greater than 150 feet.

The delineation of permafrost in a deposit at this stage has the following practical applications in the development and production of an ore body. These, in order of time are:-

i) Delineation of areas where development trenching is feasible.

ii) Expected ground conditions during development drilling.

iii) Economic planning of mining operations, particularly with respect to production drilling and blasting costs.

iv) Delineation of areas of the pit wall which will be affected by permafrost. This is required for the design of pit slope angles.

v) Operational planning of areas where free digging is possible during dirt stripping.

vi) Delineation of areas of potential water problems during operations.

vii) Broad delineation of the blasting patterns and charges to be used.

For some of these applications only the depth of the permafrost table is required, whereas for others only the depth to the base of permafrost is required. Keeping these separate purposes in mind, two different plans can be drawn. Figure 7 is a contoured plan of the depth to the permafrost table. This also delineates areas of frozen overburden which generally require drilling and blasting. Figure 8 shows the estimated base of the permafrost, as interpreted from the resistivity survey.

2.2 Ice Occurrence and Distribution

An understanding of the nature of permafrost and its relationship to the material affected by it is required for a possible solution to any of the problems caused by permafrost. Therefore, observations regarding the type and distribution of ice have been made on a regular basis in the operating pits such as Timmins 1 and Fleming 3. These observations indicate a definite relationship between the lithology and moisture content of the rocks and the nature of permafrost. The highly leached porous ores generally contain less than 5 percent moisture (by weight) and ice is rarely visible, even with a hand lens. The material is well bonded by minute crystals of ice present in pore spaces. In such cases the presence of permafrost must generally be confirmed by temperature measurements.

In the lower grade ore material and waste wall rocks which are more massive and have a distinct fracture pattern, ice is generally present as sheets and lenses (1/2" or more in thickness) parallel to the bedding and joints (Figure 2). The moisture content shows variations with rock type, with average values being in the 10-15 percent range (by weight) and local maxima as high as 30 percent (by weight) in slates. Ground temperatures in permafrost vary between 25° and 32° F. Although no definite measurements have been taken, it seems likely that a portion of pore water in most of the rock types must remain unfrozen at the range of temperatures encountered in the Schefferville area.

It should be emphasized that at any given depth there is very little temperature difference between rock types. A strong correlation exists between the moisture (ice) content, and the form of ice for a particular rock type. The mining problems caused by the presence and distribution of permafrost are discussed in Chapter 11.

CHAPTER 11 RESOURCE DEVELOPMENT

3.0 OPEN PIT MINING IN PERMAFROST

3.1 Exploration (Techniques for Delineation)

As outlined in Figure 6 the distribution of permafrost at the exploration stage of the open pit mining is required for:

a) Preliminary deposit scheduling

b) Long range planning of mining access facilities and

c) Selection of areas where future detailed permafrost studies are required.

In order to achieve the above objectives a study of the topography, vegetation, snow cover and the surficial features indicative of permafrost is undertaken in the area.

3.1.1 Vegetation and Snow Cover

It is fairly well established that topography, vegetation, snow cover, drainage and mean annual air temperature are the controlling factors in the distribution of permafrost in the discontinuous zone (4). Based on the earliest study undertaken in the Schefferville area, it was concluded that the quickest way to predict the location of permafrost was through the analysis of the topography and vegetation (3). Based on recent studies, the critical snow depth for the maintenance of permafrost in the Schefferville area has been found to be approximately 27 inches (12, 17).

Although snow is the most important parameter in the distribution of permafrost, the widespread application of the concept of critical snow cover is still in the process of refinement. Therefore it is necessary at this time to place great emphasis on temperature measurements at depth.

3.1.2 Temperature Measurements

The initial temperature measurements in the Schefferville area were made using thermocouples as sensors. Thermocables having 12 thermocouples per cable were initially installed in oil-filled holes lined with plastic tubing. The instruments used to measure the temperatures were a Speed-o-max recorder and a Honeywell potentiometer (21). In the next series of installations in 1968, thermocables were enclosed in rubber hose and inserted in drill holes, which were filled with sand. This was done primarily to reduce the risk of loss of oil and inflow of water to the plastic-lined tubes. The Honeywell potentiometer was used in the measurements. The accuracy of the potentiometer was estimated to be 0.2°F to 75 feet with increasing inaccuracy to about 0.6°F at 200 feet

(21, 22). Apart from the need to improve upon the accuracy of the temperature measurements using a potentiometer, its use for extended periods of time during the cold winter months posed practical problems, such as the freezing of the ice bath and the variation of the emf of the standard cell.

Thermistors mounted on multi-conductor cables have been used in all the holes since 1971. Thermistors were preferred over thermocouples for the following reasons:-

1) Higher sensitivity to changes in temperature.
2) Compactness, and simplicity in mechanical design.
3) Availability of an accurate readout system (precision bridge) capable of providing satisfactory temperature measurements for extended periods of time in cold winter months.

The accuracy of the temperature measurements using thermistors depends on the accuracy of their calibration. The thermistors used since 1971 are accurate to ± 0.005°F.

The end product of the regional exploration phase is a 1" = 1000 feet scale permafrost prediction map. The estimated accuracy of the 2-dimensional prediction is in the order of ± 500 feet or better.

3.2 Production (Problems Associated with the Mining of Frozen Material)

3.2.1 Drilling and Blasting

The heat generated during rotary blast-hole drilling with air circulation in permafrost particularly with high ice contents and temperatures close to 32°F, causes the ice on the sides of the hole to melt. This leads to severe caving. Also, the filling of blast holes with water from the nearby talik zones of limited extent further aggravates the problems of melting and caving, and often several holes have to be drilled before one is suitable for loading.

Ice present in the permanently frozen rocks absorbs a large proportion of the energy generated by the explosives in a blast

Therefore, in order to obtain the required fragmentation, far more explosives are needed to break the frozen material as 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 practice, a more dense blast hole pattern and a more powerfullexplosive (Metallized Slurry such as Hydromex as opposed to AN-FO) is required (2,15). This results in an increase in the cost of the blasting operation.

Poor fragmentation due to permafrost produces large blocks of material and uneven pit floor topography and results in a reduction of production rates.

3.2.2 Processing (on site) - Crushing

Problems are encountered due to the blasted material refreezing together and causing bridging in the crusher feed hoppers. Based on a study conducted on the crushability index it was concluded that the percentage of the particles larger than 1 1/2 inches at the secondary crusher is at least three times greater in frozen material 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.

3.2.2.1 Construction of Structures on Site

The presence of permafrost has created problems in the selection of construction sites. The active layer over permafrost provides an unstable base for buildings and railroads.

During the construction of the railroad from Sept-Iles to Schefferville (19), other rail facilities, and the Schefferville townsite, permafrost was encountered. The ice rich material was excavated and the site filled with dry unfrozen rock.

Site investigation of the proposed location of the Timmins Mine service garage proved the existence of extensive zones of ice rich permafrost with an unstable active layer. Further site investigations, including ground temperature measurements located a permafrost free area. The building was constructed in 1968 and no problems have been encountered with the foundations.

3.2.2.2 Material Handling

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

1) The surface and near surface runoff conditions in the permafrost areas lead to an open pit acting as a sump. 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-Iles may freeze if not insulated during the cold winter months. A program has been initiated in Sept-Iles to monitor the temperature changes in the stockpiles:

a) with natural snow cover

b) with an artificial snow cover which has been put in place early in the winter before heavy snow occurs, and before frost has had the opportunity of penetrating very far.

These problems can only be controlled by careful planning and closely controlled operating procedures. Therefore the delineation of permafrost on a regional and deposit scale as well as on a 38 foot mining lift is essential.

3.2.3 *Transportation*

Two problems that are usually encountered during the transportation of frozen ore from the producing mines in Schefferville to Sept-Iles, Quebec, 360 miles away are:

1) Thawing of ore en route to Sept-Iles results in wet 'sticky' ore which is difficult to remove from the rail car.

2) During the beginning and the end of ore season when the air temperatures are still below 32°F, the ore freezes to the sides and the bottom of cars. This necessitates breaking the bond between the ore and

the car by heating with propane heaters before the ore can be dumped.

3.3 Techniques Used in the Delineation of Permafrost at the Mining Phase

In addition to carrying out the geophysical surveys for each 38 foot lift prior to mining, temperature measurements are made both in the pit walls and floors and in blast holes during the mining phase (see Figure 6) of the permafrost program. These temperature measurements involve the use of portable thermistor probes specially developed for this purpose (Figure 3).

In the pit floor, holes are drilled to between 2 and 5 feet using either a steel rod or a Cobra drill. Temperature stability is generally reached within 20 minutes, although in cases of exceptional ground disturbance this can be extended to 2 hours.

In the 9 7/8 inch blast holes the thermistor probe is mounted on copper wire in a bell shaped insulator. This insulates the probe from the air temperature in the drill hole. The major problem experienced in temperature measurements involve ensuring that the results are not affected by outside influences such as air temperature, surface water and heat generated during drilling.

The results of this third and the final stage of investigation for the permafrost delineation are:-

1) a plan showing the distribution of permafrost which outline the areas of potential problems in drilling and blasting.

2) the distribution of permafrost on a 1 in=40 ft scale geological cross section which contains the designed pit limits. Examples of these are shown in Figure 9 and 10 respectively.

In addition to temperature measurements in the pit face, pit floor and blast holes, observations on the type, quantity and distribution of ice in the various rocks are also made on a lift by lift basis during the excavations in the pit. This allows evaluation of the accuracy of the permafrost delineation and makes available supplementary information required for a complete understanding of the behaviour of frozen material for future mining operations in permafrost.

As a part of the overall program of predicting the behaviour of frozen material during the mining operations on a 88 foot lift, the following physical and 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.

It is hoped that these studies will help in the optimization of the mining operations.

4.0 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 predictions on three different scales are required for three distinct phases of the open pit mining operations i.e. exploration, development and mining. However limited efforts have also been made towards:

1) the determination of physical and mechanical properties and the behaviour of frozen material and

2) the monitoring of blasts in permafrost.

REFERENCES

1) Annersten, L.J. (1964): Investigations of Permafrost in the Vicinity of Knob Lake, 1961-62. McGill Sub-Arctic Research Paper 16, p. 51-143.

2) Bauer, A. et al (1965): How I.O.C. Puts Crater Research to Work. Engineering and Mining Journal, V. 166, No. 9 Sept. 1965, pp. 117-121.

3) Bonnlander, B. and Major-Marothy, G.M. (1957): Report on Permafrost Investigations 1956-57. Internal Report of the Iron Ore Company of Canada.

4) Brown, R.J.E. (1960): The Distribution of Permafrost and its Relationship to Air Temperature in Canada and the USSR. Arctic Vol. 13. No. 3.

5) ____________ (1970): Permafrost in Canada: Its Influence on Northern Development. University of Toronto Press.

6) Dobrin, M. (1960): Introduction to Geophysical Prospecting. McGraw-Hill Book Company, Second Edition.

7) Dubnie, A. (1972): Northern Mining Problems with Particular Reference to Unit Operations in Permafrost. Technical Bulletin TB 148 of the Mining Research Centre-EMR, June 1972.

8) Garg, O.P. (1971): Permafrost Prediction for Fleming 3 Deposit. Internal Report of the Iron Ore Company of Canada, March 1971. Technical Services Report No. 6907-5.

9) __________ (1971): Permafrost Delineation in Fleming 3 Using Geophysical Techniques. Internal Report of the Iron Ore Company of Canada, December 1971. Technical Services Report No. 6907-6.

10) Garg, O.P. and Stacey, P.F. (1972): Techniques Used in the Delineation of Permafrost in the Schefferville, P.Q. Area. Proceedings of a Seminar on the Thermal Regime and Measurements in Permafrost. National Research Council. Technical Memorandum No. 108.

11) __________(1973): In situ Physico-mechanical Properties of Permafrost Using Geophysical Techniques. Proceedings North American Contribution, Second International Conference on Permafrost. National Academy of Sciences. Washington D.C.

12) Granberg, H. (1973): Indirect Mapping of Snow Cover for Permafrost Prediction at Schefferville, P.Q. Proceedings North American Contribution, Second International Conference on Permafrost. National Academy of Sciences, Washington, D.C.

13) Hunter, J.A.M. (1973): Seismic Up-Hole Wave Front Experiments in Permafrost, Schefferville, Quebec. Preliminary Report Submitted to the Iron Ore Company by the Geological Survey of Canada.

14) Ives, J.D. (1962): Iron Mining in Permafrost, Central *Labrador - Ungava. Geographical Bulletin*, No. 17, p. 66-77.

15) Lang, L.C. (1965): Pit Slope Control by Controlled Blasting, Canadian Mining Journal, V. 86, No. 12, Dec 1965.

16) Mayer, P.W.A. (1966): Mining in Canada's Sub-Arctic - The Iron Ore Company of Canada, CIMM Bull. No. 656, Dec., 1966, pp. 1437-1441.

17) Nicholson, F.H. and Granberg, H.B. (1973): Permafrost and Snow Cover Relationships near Schefferville. Proceedings North American Contribution, Second International *Conference on Permafrost. National Academy of Sciences*, Washington, D.C.

18) ______________ and Thom, B.G. (1973): Studies at the Timmins 4 Permafrost Experimental Site. Proceedings North American Contribution, Second International Conference on Permafrost. National Academy of Sciences, Washington, D.C.

19) Pryer, R.W.J. (1966): Mine Railroads in Labrador - Ungava. In Permafrost: Proceedings of an International Conference. National Academy of Sciences, Washington, D.C.

20) Seguin, M.K. and Garg, O.P. (1972): Delineation of Frozen Rocks from Labrador - Ungava Penninsula Using Borehole Geophysical Logging. Paper Presented at the 9th Canadian Symposium on Rock Mechanics held in Montreal on Dec. 13-15, 1972.

21) Thom, B.G. (1969): Permafrost in the Knob Lake Iron Mining Region; Proceedings of the 3rd Canadian Conference on Permafrost. National Research Council. Technical Memorandum No. 96.

22) __________(1969): New Permafrost Investigations Near Schefferville, P.Q. Rev. Géogr. Montr., 1969, Vol. XXIII, No. 3, P. 317-327.

23) __________(1970): Comprehensive Report on Timmins 4 Permafrost Experimental Site. Internal Report of the Iron Ore Company of Canada. Technical Services Report No. 6907-4.

24) Wyder, J.E. (1972): Report of Borehole Geophysical Logging at Iron Ore Company of Canada, Schefferville P.Q. August 1971. Part of the Geological Survey of Canada. Project 680035.

FIGURE 2

OCCURRENCE OF ICE ALONG THE BEDDING
AND JOINTS

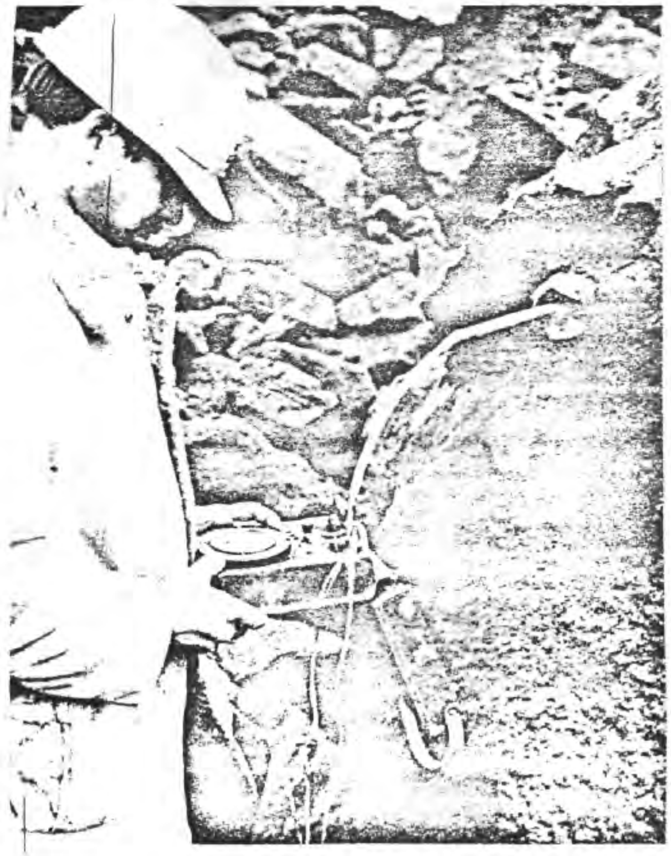

FIGURE 3

MEASURING THE TEMPERATURE IN A PIT FACE USING A THERMISTOR PROBE DEVELOPED BY THE GEOTECHNICAL ENGINEERING SECTION, IRON ORE COMPANY OF CANADA.

FIGURE No. 6

SUMMARY OF PERMAFROST PREDICTION PROGRAM

PHASE	SCALE	TECHNIQUES USED	PURPOSE
Regional exploration	1" = 1000'	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" = 100' 1" = 200'	① Ground temperature measurements ② Seismic surveys ③ Resistivity surveys	① For an economic evaluation of a deposit ② Facilitates mine planning (Design of slopes and hydrological problems)
Mining (lift by lift)	1" = 40'	① Seismic surveys ② Resistivity surveys	① Outline areas for difficult drilling ② Prediction of response to blasting

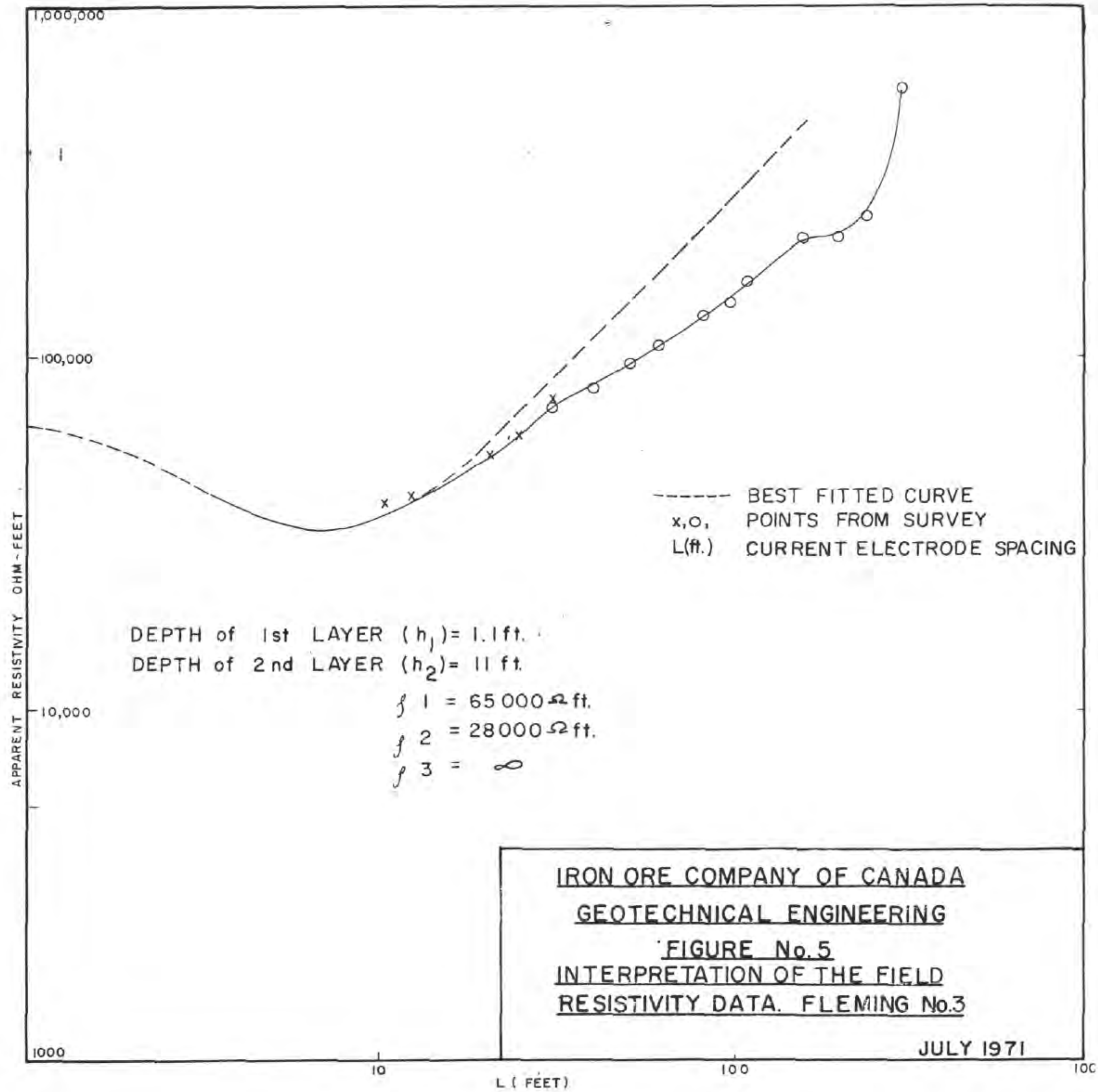

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FIGURE No. 5

INTERPRETATION OF THE FIELD RESISTIVITY DATA. FLEMING No.3

JULY 1971

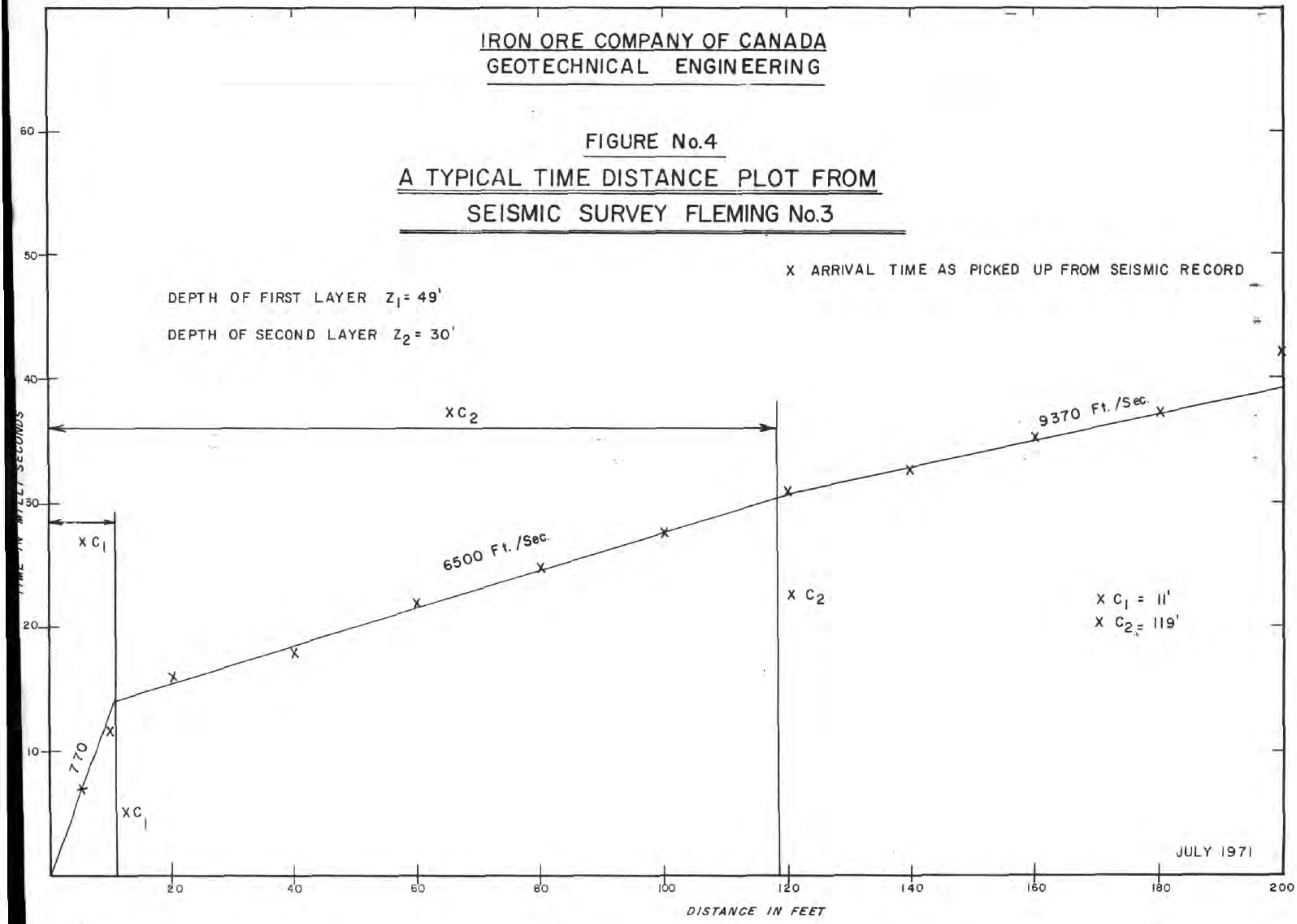
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FIGURE No.4
A TYPICAL TIME DISTANCE PLOT FROM
SEISMIC SURVEY FLEMING No.3
X ARRIVAL TIME AS PICKED UP FROM SEISMIC RECORD
DEPTH OF FIRST LAYER Z1 = 49'
DEPTH OF SECOND LAYER Z2 = 30'
XC2
XC1
770
6500 Ft./Sec.
9370 Ft./Sec.
X C2
X C1 = 11'
X C2 = 119'
JULY 1971
60
50
40
30
20
10
20
40
60
80
100
120
140
160
180
200
DISTANCE IN FEET