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APPENDICES

TO

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PHASE 1A

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APPENDIX

Electromagnetic Methods for Mapping Shallow Permafrost

by

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January 1977

Paper presented to the 46th Annual International Meeting of the Society of Exploration Geophysicists, Houston, Texas, October, 1976. Submitted for publication to Geophysics, January, 1977.

ABSTRACT

Information about the distribution of permafrost is vital to the safe design of proposed northern gas pipelines. In the southern fringe of the discontinuous permafrost zone proposed pipelines will traverse many boundaries of frozen and unfrozen ground and these boundaries must be mapped before final design. In this area, the thickness of permafrost is typically 1 to 10 m. In the last two years, new equipment for shallow exploration have been developed and tested for mapping permafrost in the Mackenzie Valley at sites from approximately Fort Simpson, N.W.T. to Zama, Alberta.

Two electromagnetic techniques were tested, radiohm and inductive coupling methods. Radiohm methods were tried in the VLF (15-30 khz) and LF (200-400 khz) band. The LF equipment because of its limited skin depth was found to map shallow permafrost well. The problem with LF radiation was the limited coverage of existing transmitters in the Arctic. An inductive coupling system consisting of horizontal co-planar loops, separated by 3.7 m on a fiberglass boom, and operating at a frequency of 40 khz, also was found to accurately delineate permafrost.

Measurements with LF radiohm and inductive coupling equipment showed identical trends along a traverse. By integrating terrain typing with geophysical interpretation, the thickness of permafrost could be obtained to an accuracy of ± 30 percent from a single measurement with the inductive coupling system.

INTRODUCTION

Proposed northern gas pipeline routes plan to refrigerate the gas to temperatures below $0^{o}C$ from Prudhoe Bay, Alaska to certain locations, further south, of which the temperature of the gas will be above $0^{o}C$. The geotechnical reason for chilling the gas is to prevent thaw of permafrost and subsequent settlement of a buried line. Chilling of the gas in the line would allow it to be buried in ground condition, where the Alyeska oil line is elevated.

From its point of origin at Prudhoe Bay, proposed gas line routes first pass through the continuous permafrost zone. The thickness of permafrost in this zone is considerably larger than the depth influenced by the temperature field of the chilled gas line. In this zone, the gas line will encounter but few geotechnical problems and the thickness of permafrost is of no great interest to pipeline engineers. However, further south all lines will traverse certain mileages in the discontinuous permafrost zone. Here the pipe will cross many boundaries of frozen and unfrozen ground. Where a chilled line is laid in unfrozen ground, the potential for frost heave exists, which requires special mitigating measures; corrolary thaw settlement demands attention where a warm line traverses frozen ground. To make decisions on the last point of chilling and to plan geotechnical mitigating measures against frost heaving or thaw settlement, it is important to accurately map the boundaries of frozen and unfrozen ground in the discontinuous zone.

The investigations reported here are for the specific geotechnical objective to map permafrost along the pipeline right-of-way in the discontinuous permafrost zone; that objective requires continuous, high-resolution data for several hundreds of miles at relatively low cost.

REVIEW OF THE LITERATURE

Much progress has been made in the past five years in deriving permafrost information from geophysics. On land, electrical and electromagnetic methods rather than seismic methods are most often used in geotechnical investigations. Electromagnetic methods are found to have advantages over electrical methods in the Arctic. The two main reasons are that (a) electrical methods require low resistance-contact with the ground and this is difficult to establish when the surface is frozen and snow covered, and (b) the lateral resolution of ground conditions obtainable with galvanic methods is often inadequate in the discontinuous zone.

Electromagnetic methods that have been used to map permafrost fall in two categories:

(a) Plane Wave Methods

The source of electromagnetic fields are distant transmitters or natural telluric currents. Koziar and Strangway (4) tested magneto-telluric methods in the audio-frequency range in the Mackenzie Delta, N.W.T., Canada. They measured the apparent resistivity at 11 frequencies from 10hz to 10khz. The depth of permafrost was on the order of 100 m, and that depth was derived within reasonable accuracy by fitting a two-layer resistivity model to the experimental data.

Hoekstra and Sellmann (1975) used VLF methods to map permafrost in the vicinity of Fairbanks, Alaska. In sections of fine-grained sediments, permafrost could be delineated from VLF radiohm measurements.

(b) Inductive Coupling Methods

The resistivity of ground can also be obtained from a measurement of the mutual coupling between two loops (Keller and Frischknecht, 1966). Daniels et al. (1975) used a large source (2000 ft. perimeter) and receiver loop (1000 ft. perimeter). The separation distance between loops ranged from 1 to 4 kilometers and measurements were made at frequencies varying between 200 hz to 20 khz. They found that the permafrost depth could be derived from soundings by using a two-layer resistivity model. Andrieux et al. (1975) used a similar approach, source and receiver were separated by 300 to 400 m and the frequency was varied between 35 hz to 17 khz. They concluded from their interpretation, that resistivity variations within the permafrost can be as important as the resistivity changes from frozen to unfrozen ground. Sinha (1976) published extensively the theorectical modeling curves, showing the response of different loop configurations above homogeneous and layered ground.

EXPERIMENTAL METHODS

Two electromagnetic methods were tested in this project, radiohm and inductive coupling methods. The principles of each method have been described in detail elsewhere (Sinha, 1976; Hoekstra, 1975) and here only the results of computer model studies are used to support the decisions made during the course of the investigation, and the procedures employed for data interpretation.

All tests were made in the discontinuous permafrost zone along the proposed Arctic Gas pipeline route at over a hundred sites between approximately Fort Simpson, N.W.T. and Zama, Alberta. Preliminary measurements with galvanic methods showed that the resistivity of frozen ground within the area typically varies from 100 ohm-m to 5000 ohm-m, and the resistivity of the underlying unfrozen ground from 10 to 50 ohm-m.

Radiohm Methods

It soon became evident from computer modeling and field data that VLF radiohm measurements were not well suited for mapping shallow permafrost. In Figure 1, the apparent resistivity at VLF is computed for two-layer permafrost situations. Since much of the permafrost encountered in the Mackenzie Valley, south of Fort Simpson, N.W.T. is less than 10 m thick, the VLF radiohm method clearly is not overly sensitive to shallow permafrost. This conclusion was verified by field measurements. Typical VLF apparent resistivites over unfrozen and frozen ground varied from 10 to 60 ohm-m. It was difficult to separate resistivity variations caused by changes in soil type from those caused by frozen or unfrozen conditions. The VLF resistivity over sections of frozen ground were often only 5 to 15 ohm-m higher than in adjacent sections of unfrozen ground.

Better sensitivity for delineating permafrost can be expected at higher frequencies, because of a decrease in skin depth. Figure 2 shows values for two-layer permafrost situations computed for a frequency in the LF band. The LF data are indeed more sensitive to shallow permafrost. In the computations both conduction and displacement currents are considered, but since there is inadequate knowledge about the relative dielectric constants of frozen ground at LF frequencies, displacement currents cannot be properly accounted for in modeling. An LF radiohm apparatus was designed and built by Geonics Ltd. The equipment is similar in its principle of operation as the Geonics EM16R. The electric field is measured by probes spaced 3 m apart. Several components must be changed in the instrument to tune it to a particular frequency.

Inductive Coupling Methods

The characteristics of the inductive coupling system tested are given in Table I. The instruments measure the quadrature phase component of mutual coupling. In Figure 3, the computed ratio of the magnitude of the quadrature phase component of the secondary magnetic field and the magnitude of the primary field at the receiver coils is plotted versus the resistivity of homogeneous ground for the EM31. Over layered ground an apparent resistivity is defined as the resistivity of homogeneous ground that would give the same quadrature phase response as the one measured. In Figure 4, the computed response over two-layer permafrost is given for the EM31. The data show that this system is sensitive to the presence of shallow frozen ground.

The effective depth of exploration of the EM31 is difficult to define, because it depends on the resistivity of the ground as well as on the sequence of resistivity layering. For the permafrost situations modeled in Figure 4, the instrument readings with the EM31 can be seen to measurably respond to changes in permafrost thickness up to at least 10 m.

RESULTS

Figure 5 shows typical results obtained with LF radiohm and the EM 31 along a section of discontinuous permafrost in the Mackenzie Valley. The data show identical trends in the apparent resistivity profiles, which gives confidence in both methods of resistivity mapping, since frequency and current flow in the ground differ markedly.

Also shown on Figure 5 is the delineation of frozen ground derived from the resistivity survey. The delineation assumes that resistivity variation in this section is caused by frozen or unfrozen conditions, and not by differences in material type. In much of the terrain in the Mackenzie Valley, differences caused by material type are readily recognized by proper use of other terrain information. The delineation of frozen versus unfrozen ground was validated by 43 drillholes, and by numerous other observations. For example, the ground in this area of the discontinuous permafrost zone is unfrozen under shallow lakes and ponds.

An example of EM31 and LF data over an area, where changes in ground conditions cause part of the resistivity variations, is given in Figure 6. In this section, sand dunes are encountered overlaying the till. There is no difficulty in recognizing the presence of the sand dunes, and they also show up clearly in the resistivity profiles. However, at stations 480, and 600 meters, resistivity highs are encountered apparently not connected with sand dunes. Drillholes were placed at these locations and it was determined that these resistivity highs are due to frozen ground in till. Geophysical surveys in this section served the purpose of alerting to changes in ground conditions, where drillholes should be placed.

Figure 4 shows that three ground parameters determine the value of ρ_a, i.e. ρ_1, ρ_2, and d_1. An important objective in surveying is to obtain an estimate of d_1 and this requires that ρ_1 and ρ_2 are evaluated independently. In electromagnetic soundings ρ_1, ρ_2 and d_1 are often obtained by making measurements at several different frequencies and/or transmitter-receiver separations; that requires station by station measurements. Our approach at this time has been to obtain ρ_1, ρ_2 from test hole and other terrain information. Figure 7 illustrates this last point further. In a traverse across a section of discontinuous permafrost, sharp resistivity contrasts occur at the interface of frozen and unfrozen ground. The value of ρ_2 (the resistivity of unfrozen ground underlaying the frozen ground) was assumed to be equal to the apparent resistivity measured over a section of unfrozen ground (e.g. at station 500). Subsequently, ρ_1 and d_1 were obtained by calibrating computer modeling of two-layer ground to test hole data.

Along the entire Arctic Gas pipeline route the terrain has been classified according to the geological origin of the surficial materials. It soon became apparent that the resistivities ρ_1 and ρ_2 are characteristic of the terrain type. Figure 8 shows a comparison between the depth of permafrost from borehole data and geophysics

(EM31 data) in three different terrain types. Using these calibration curves it appears that permafrost depth can be estimated to ± 30 percent. Moreover, at later stages in the project considerably more borehole data will become available to improve calibration. Integrating the geophysical interpretation with terrain typing is a practical approach, because for major projects such as pipelines, roads and railway corridors, terrain typing preceeds geophysical surveys.

Although with time, the methods of data processing will be improved, a detailed meter by meter delineation of hundreds of miles of pipeline right-of-way will require that a simple interpretation (in terms of presence or absence, and thickness of permafrost) is adopted. The accuracy of determining the thickness of permafrost can also be improved by making simultaneous measurements with two systems with different effective depths of exploration. That approach will be field tested in 1977.

The LF frequency band is assigned to non-directional beacons (NDB's) for navigational aids. Typically, LF transmitters operate at an output power below 10 kw. The effective coverage for measurements on the ground wave seldom exceed a radius of 75 km. There are, therefore, large areas in the Arctic where no coverage from existing transmitters is available. Although erecting transmitters for surveying is economically feasible, obtaining the necessary permits requires much persistence.

The EM31 instruments proved practical in Arctic operation. The instrument is carried by an operator in the manner shown in Figure 9. Clearly, if the terrain is suitable and a right-of-way is cleared, the instrument could be mounted on a carriage or sled for continuous surveying. The calibration of the inductive coupling systems causes at the moment the greatest difficulty. In an airborne system (e.g. a "bird" towed by helicopter), the equipment is calibrated by taking the system to an altitude where coupling due to ground currents become effectively zero. The only method for calibrating ground equipment used so far, has been to calibrate the instrument over ground of known resistivity. The instrument response curve of figure 3 shows that calibration is best done over ground of high resistivity (> 1000 ohm-m), where the quadrature phase response would be less than 10^3 ppm. The problem is that ground of 1000 ohm-m and uniform with depth may not be found in a particular survey area.

CONCLUSIONS

Two electromagnetic types of equipment were found to accurately delineate the boundaries of frozen and unfrozen ground in areas of shallow permafrost. The equipment items were the Geonics EM31 and a LF radiohm unit. The success of both methods is to a large extent related to the effective depth of exploration. The effective depth of exploration should be within a factor 2 of the average expected permafrost depth in the area. If the depth of exploration is much greater than (3x) the average permafrost depth, resistivity variation caused by stratigraphic changes below the permafrost can complicate interpretation.

Because coverage from existing transmitters in the Arctic is limited, the EM31 is preferred as a survey instrument. Moreover, it can be sled mounted to obtain a continuous resistivity profile. Measurements with the EM31 can provide the geotechnical engineer, at least, the following information:

a) extrapolation of permafrost conditions between drillholes
b) a warning of drastic changes in permafrost conditions between drillholes.

When the instrument measurements are integrated with available surficial geology and terrain information and test hole data, the depth of permafrost was estimated within an accuracy of ±30 percent by using two-layer computer models. The intepretation of geophysical data can be e more reliable by sounding at different frequencies or by measurements at different transmitter-receiver separations.

ACKNOWLEDGEMENT

The geophysical investigations to test and develop inductive coupling systems have benefited much from the help of Dr. A. K. Sinha and Mr. L. S. Collett of the Geological Survey of Canada. Dr. Sinha provided us with the complex computer programs to model layered ground.

Mr. D. McNeill, of Geonics Ltd. contributed much of his experience about inductive coupling systems to the project.

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TABLE 1

Major Characteristics of Inductive Coupling System (Geonics EM31)
Tested for Mapping Shallow Permafrost

Instrument	Transmitter-Receiver Separation	Frequency	Quantity Measured	Coil Orientations
Geonics, EM31	3.7 m	40khz	quadrature phase response	horizontal co-planar

FIGURE LEGEND

Figure 1

The computed apparent resistivity, ρ_a, for the radiohm methods at VLF (18.6 khz) as a function of the thickness of frozen ground for two values of frozen ground resistivity (ρ_1) in the winter.

Figure 2

The computed apparent resistivity, ρ_a for the radiohm method at LF (375 khz) as a function of the thickness of frozen ground for two values of frozen ground resistivity (ρ_1) in the winter.

Figure 3

The quadrature phase response of the EM31 as a function of the resistivity of homogeneous ground.

Figure 4

The computed relation between the quadrature phase response of the EM31 and the depth of permafrost for several resistivity profiles typical of permafrost in the winter.

Figure 5

Measured values of apparent resistivity with LF radiohm (375 khz) and inductive coupling (EM31) over a section of discontinuous permafrost. The delineation of frozen versus unfrozen ground is also shown.

Figure 6

Measured values of apparent resistivity with LF radiohm (375 khz) and inductive coupling (EM31) over a section of discontinuous permafrost with sand dunes overlaying till. The delineation of frozen versus unfrozen ground is also shown.

Figure 7

Apparent resistivity (EM31) and land form profiles across a section of discontinuous permafrost. In some areas there is a good correlation between vegetation type and the presence or absence of permafrost.

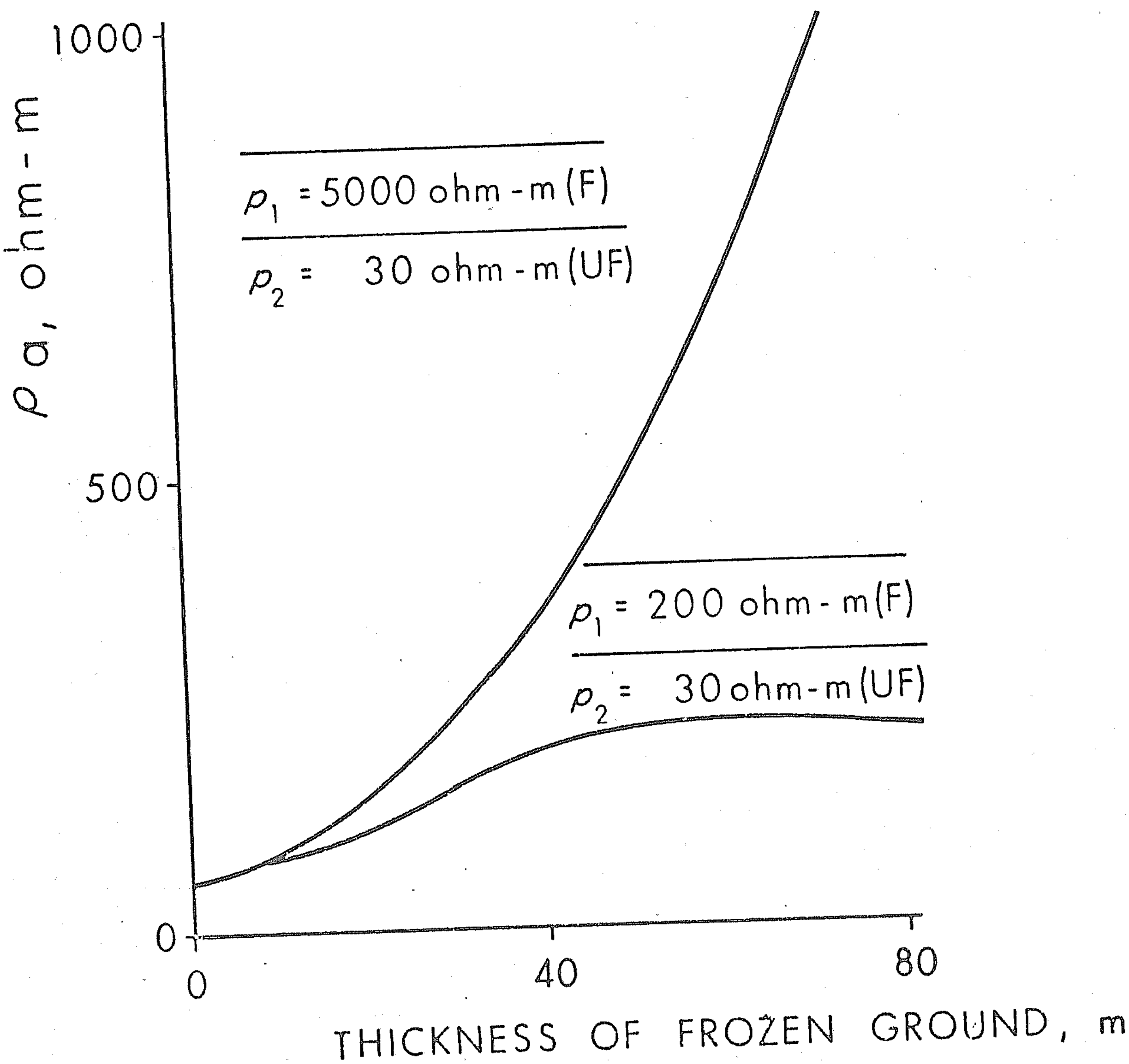
Figure 8

Comparison of permafrost depth derived from borehole information and resistivity surveys. In different terrain types, different resistivity profiles were modeled to obtain a best fit between borehole and geophysical interpretation. (RKM = till, DL = Deltaic deposits)

Figure 9

Schematic diagram of the manner in which the EM31 is carried by an operator.

Figure 1. The computed apparent resistivity ρ_a, for the radiohm method at VLF (18.6 khz) as a function of the thickness of frozen ground for two values of frozen ground resistivity (ρ_1) in the winter.



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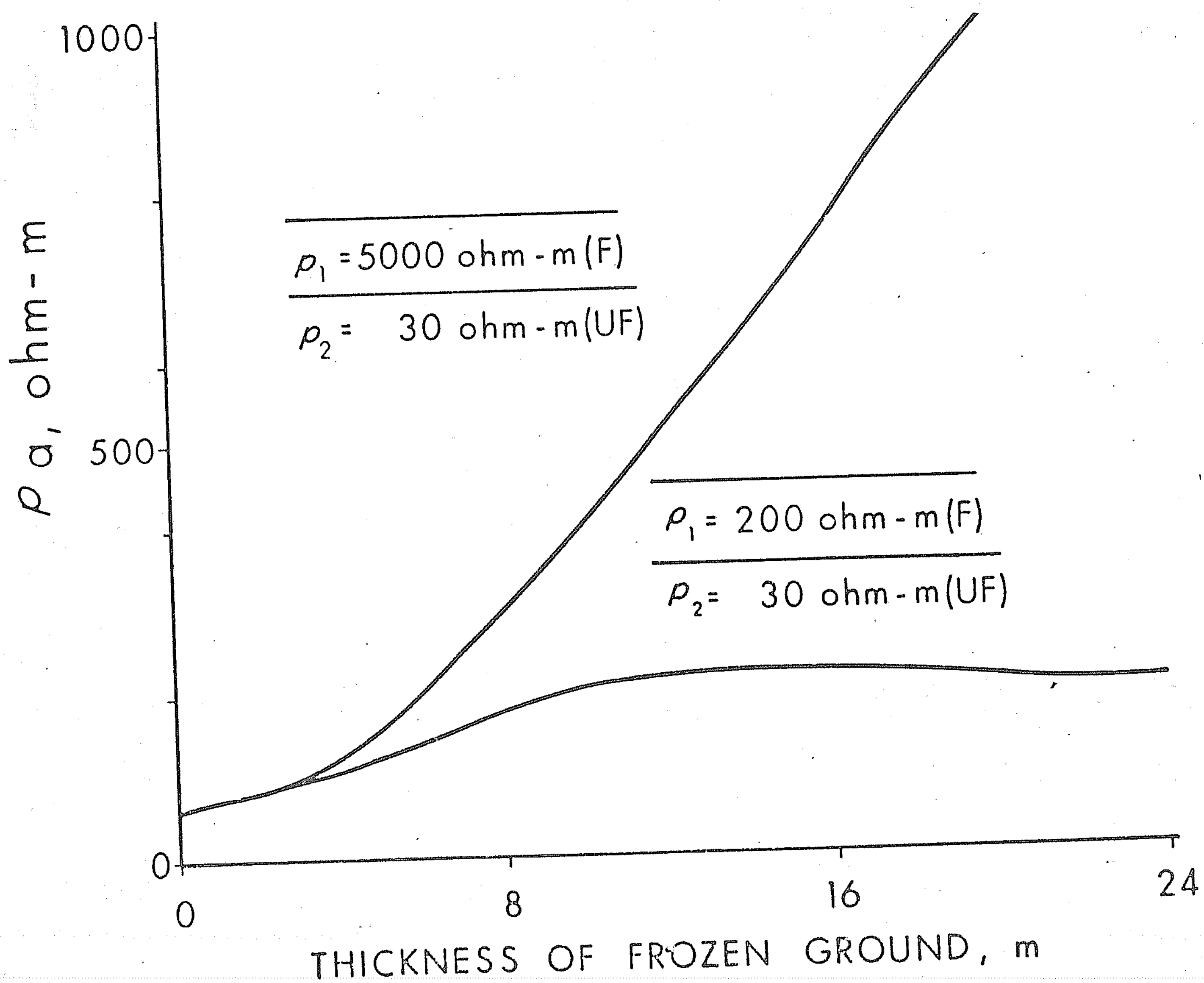

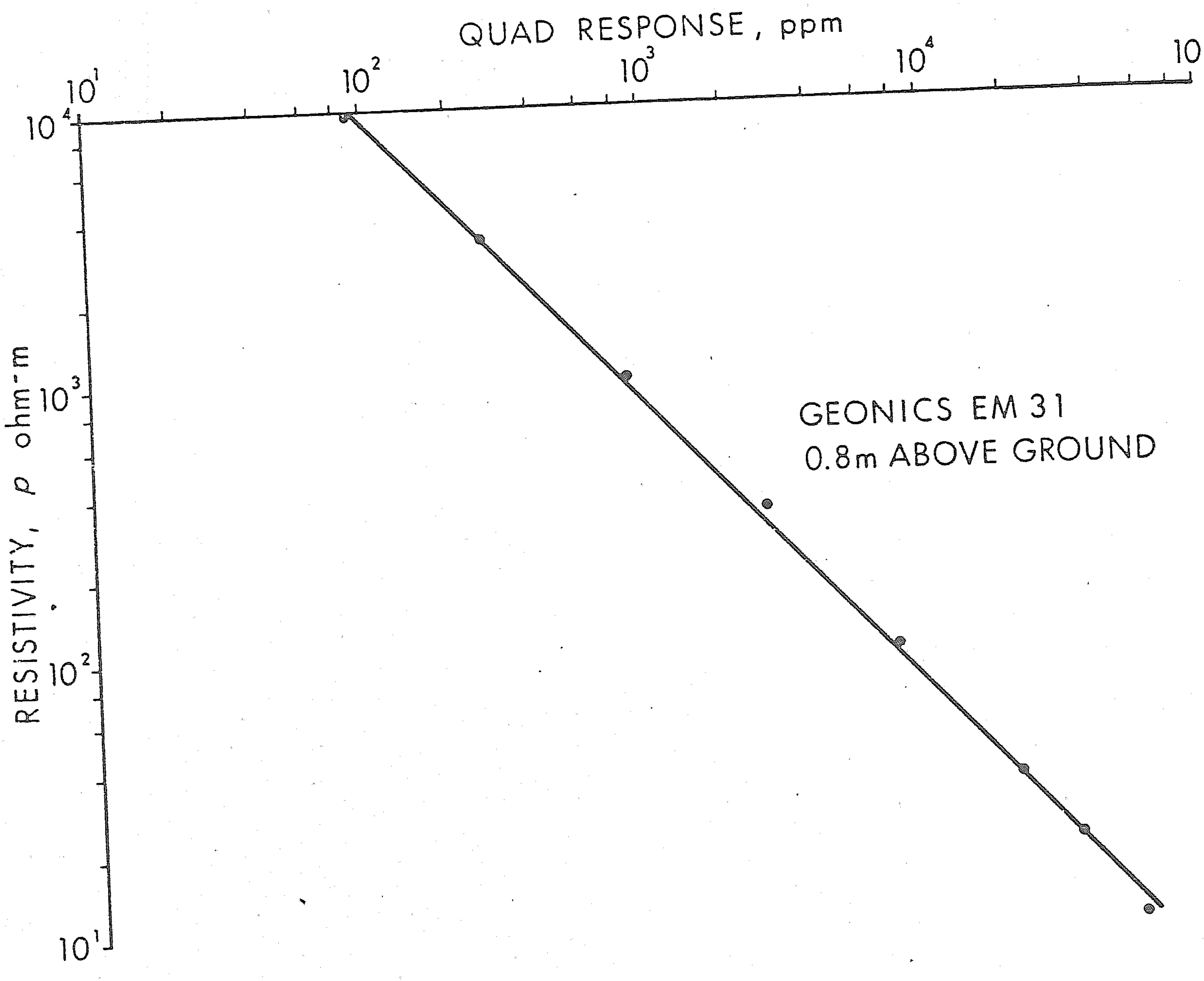

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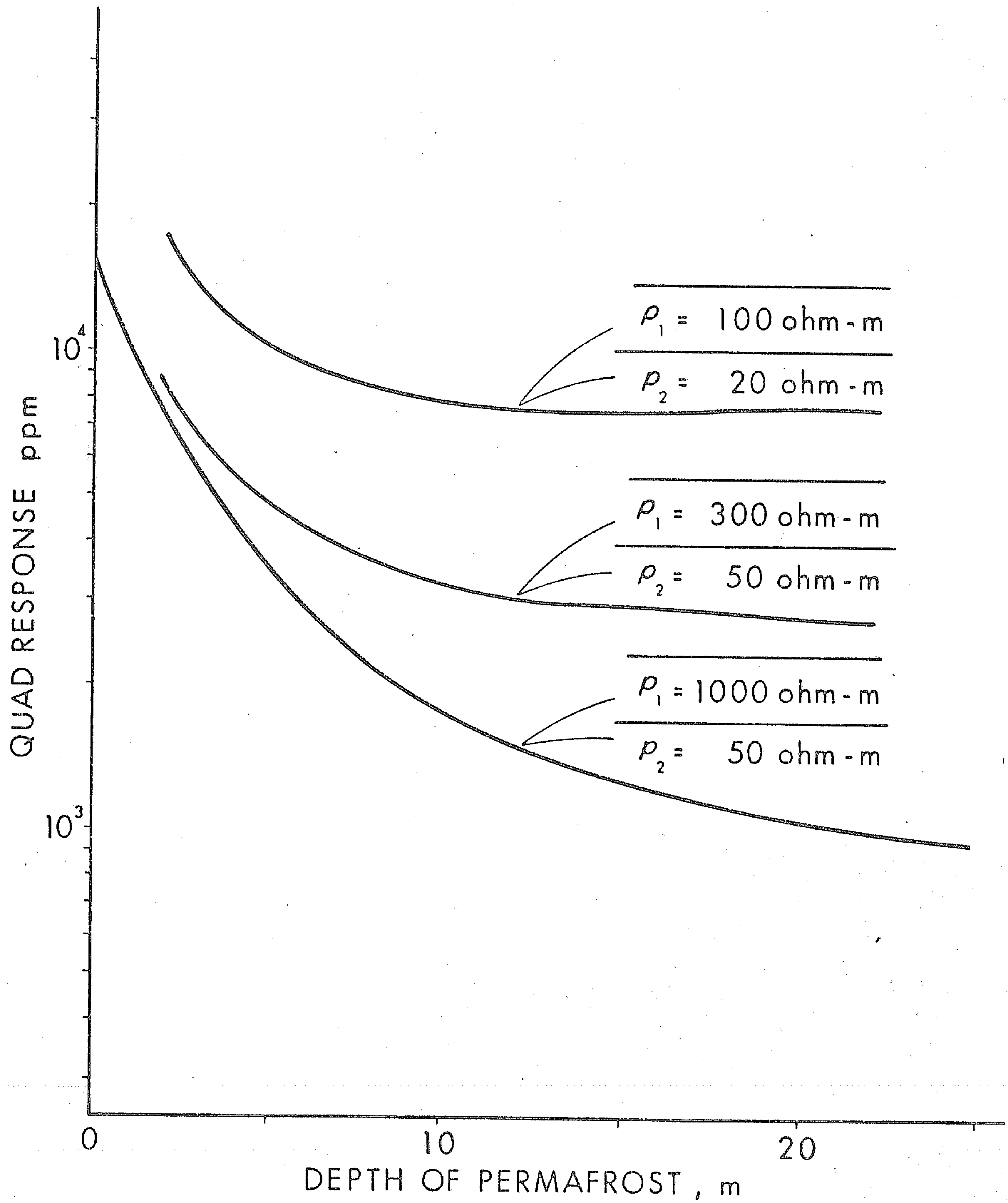

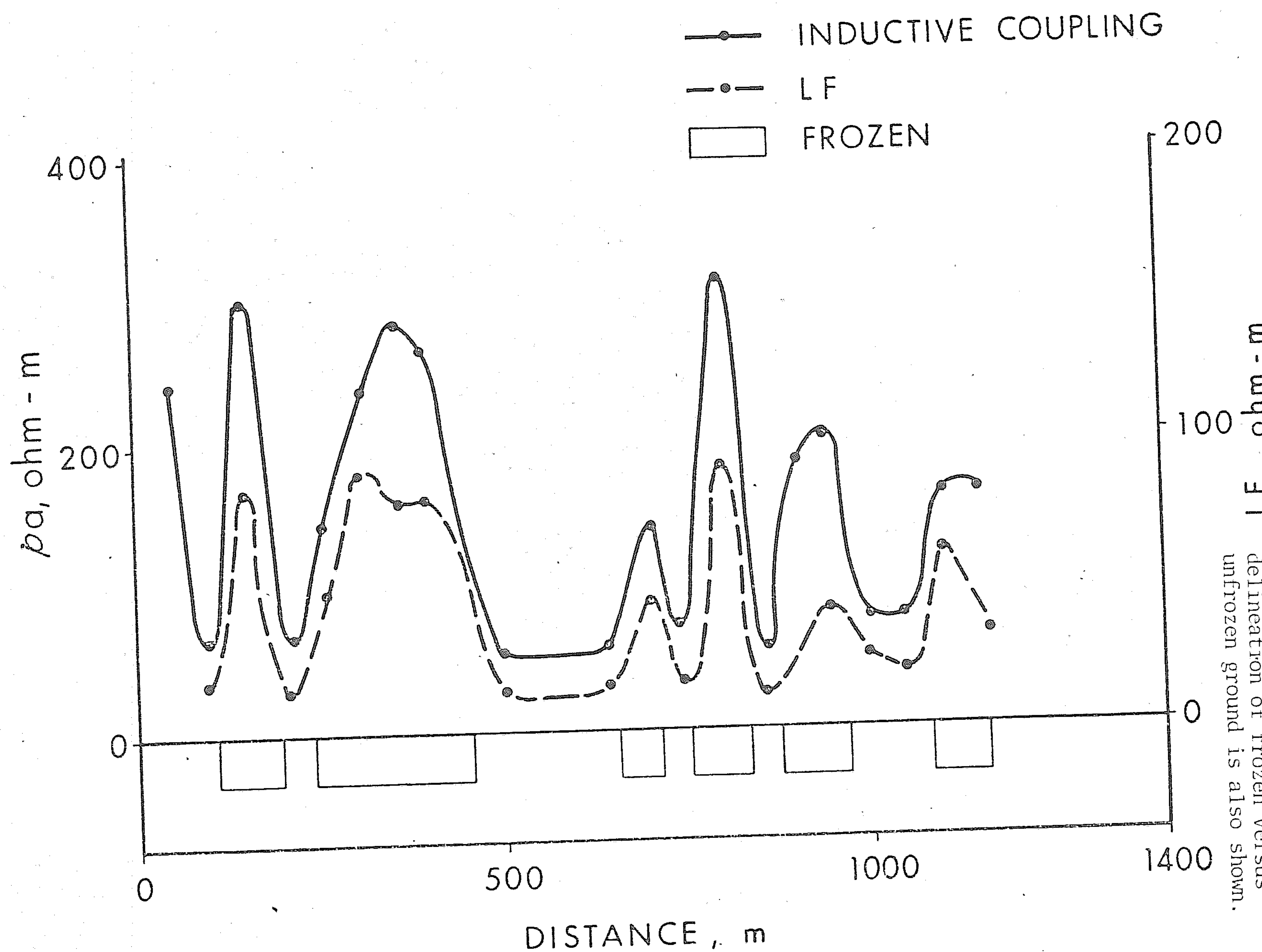

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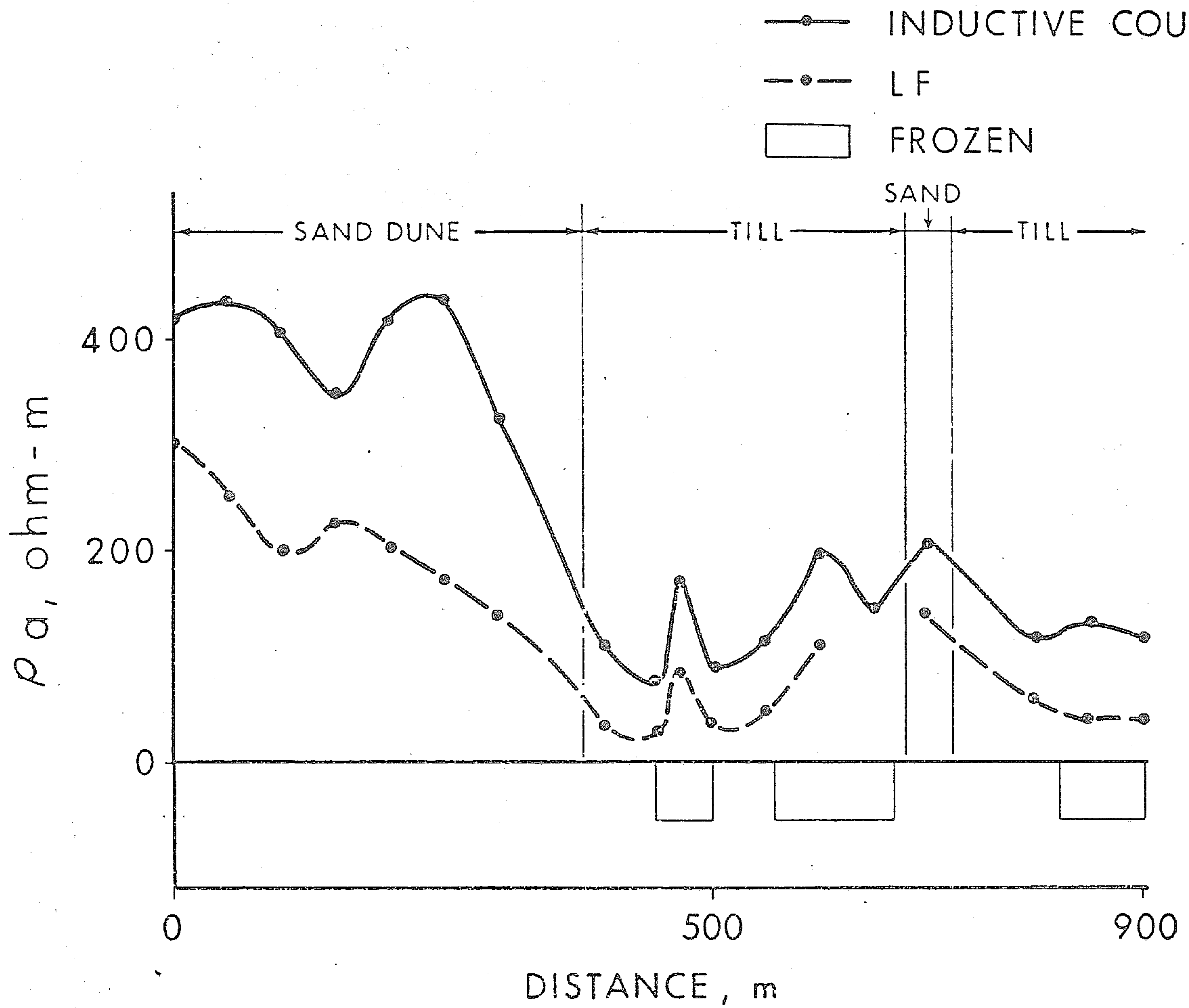

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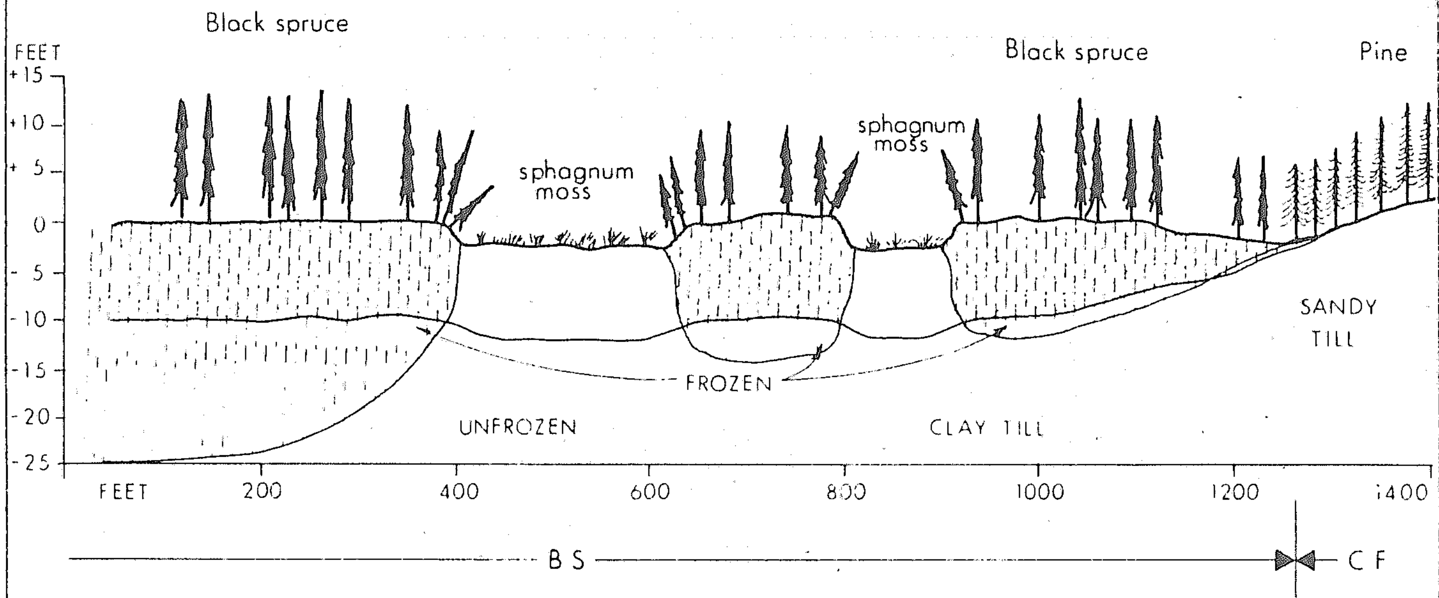

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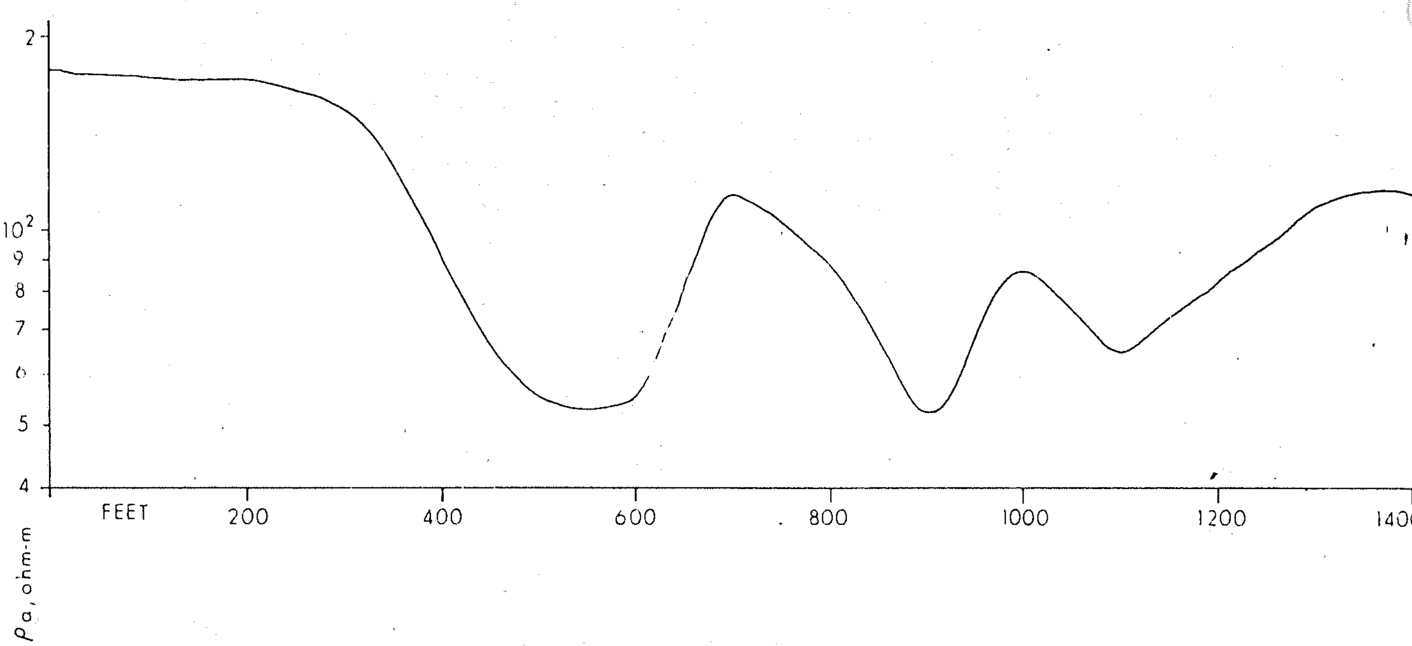

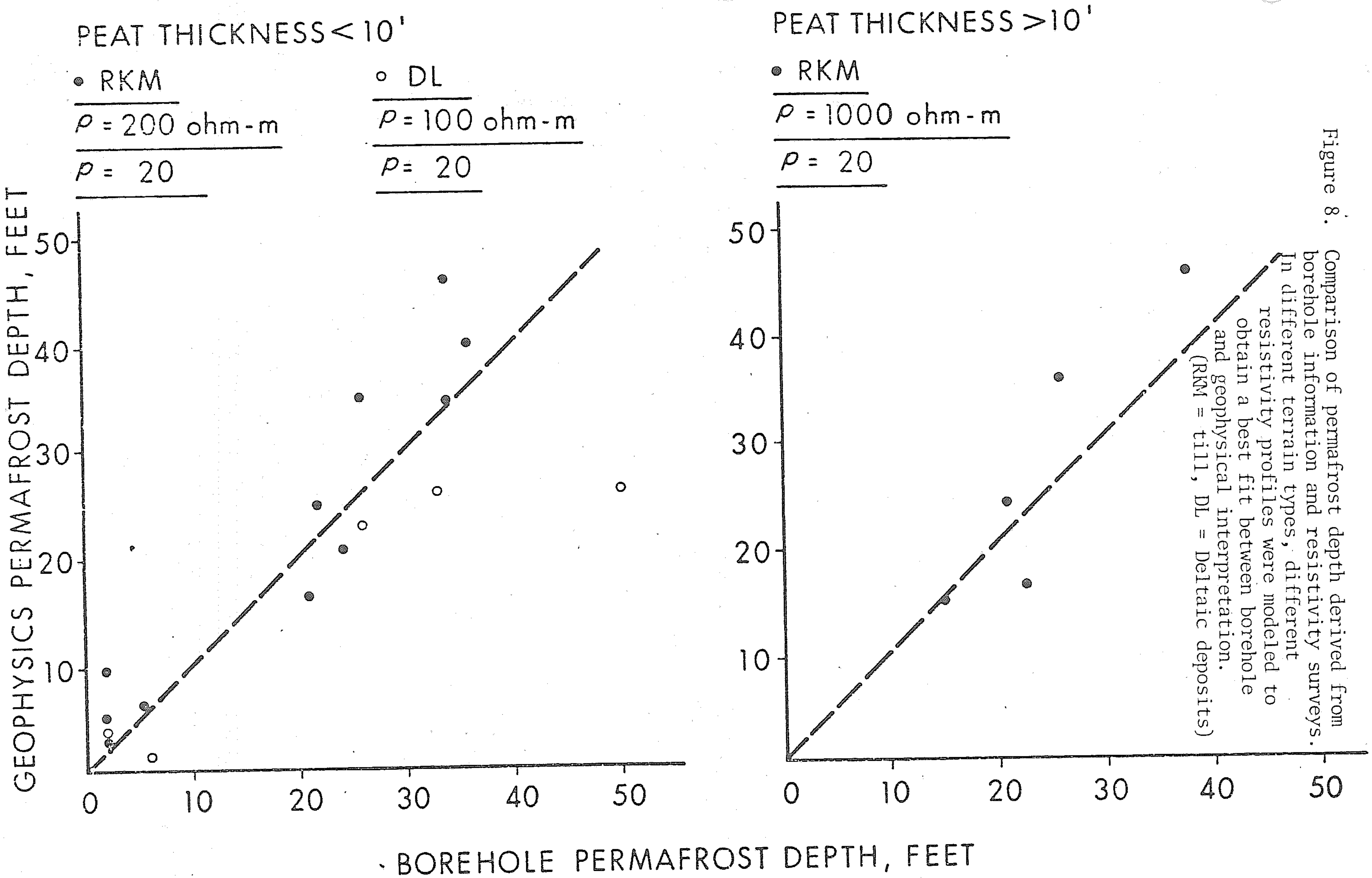

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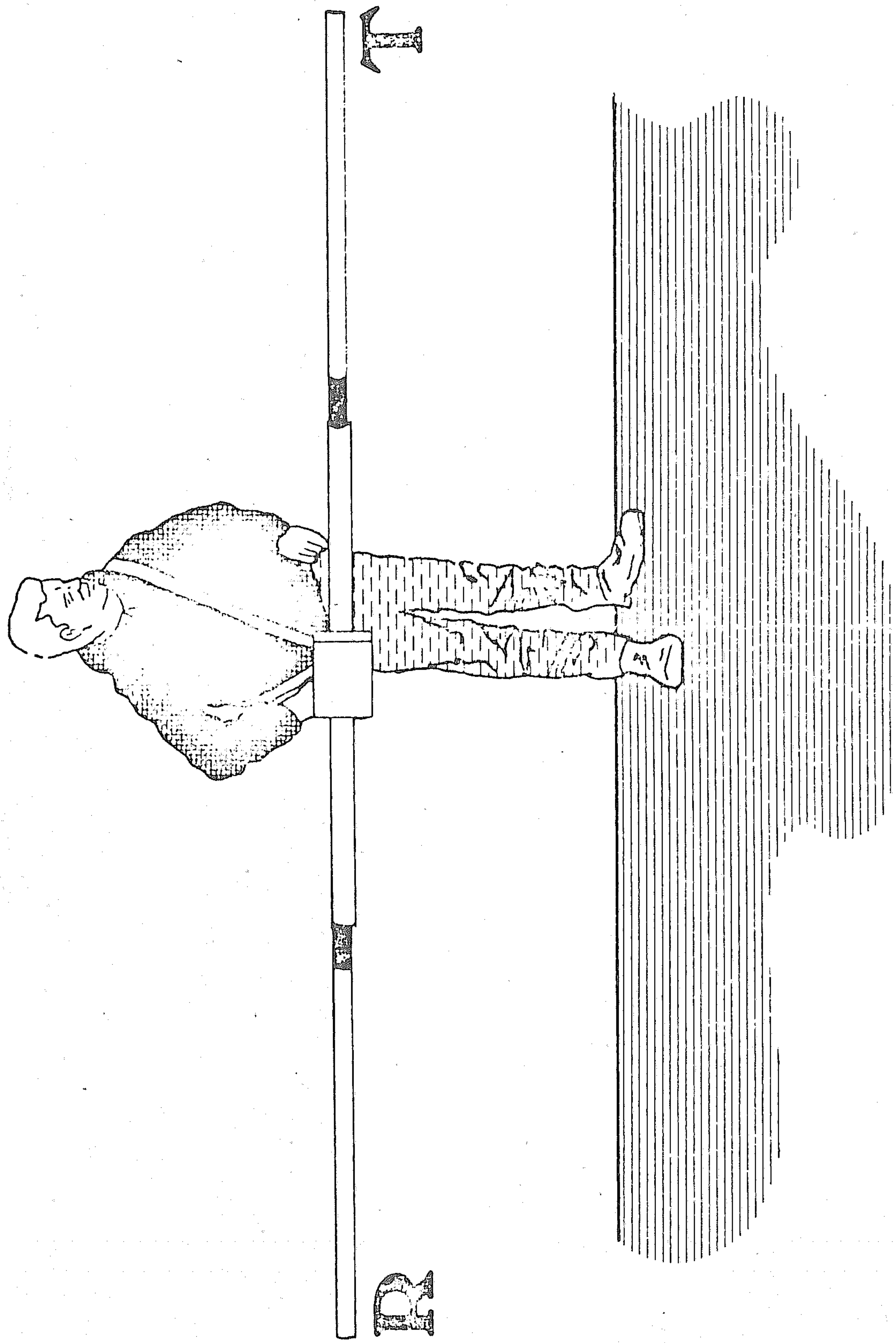

APPENDIX

GEOPHYSICAL METHODS IN SUPPORT OF SUBSURFACE EXPLORATION FOR THE ARCTIC GAS PIPELINE

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Calgary, Alberta

February, 1977

1. INTRODUCTION

The purpose of this report is to provide background information on the proposed use of geophysics in subsurface exploration of permafrost. In particular, it is the objective of this report to show that:

a) the proposed use of geophysics by Arctic Gas is a logical extension of work conducted over the last decade.

b) the new equipment to be used in the geophysical surveys have undergone substantial field testing. Geophysical data have been correlated with existing ground truth data.

c) the results of the tests warrant the confidence to be placed in the new geophysical methods for serving the purpose of:

   1) extrapolating information between test holes.

   2) accurately locating boundaries between frozen and unfrozen ground.

   3) alerting to sudden changes in subsurface conditions.

   4) optimizing test hole location and spacing.

In Chapter 2, a brief explanation for our selection of electrical resistivity rather than seismic methods for mapping permafrost is found. A brief review of existing knowledge about the electrical resistivity of frozen ground is also included.

Chapter 3 discusses the different geophysical techniques available for measuring the electrical resistivity of the ground, and the research undertaken by NESCL to further the development of some of the techniques.

Chapter 4 shows the results obtained during field testing and compares geophysical interpretations of permafrost parameters with existing ground truth.

The use we propose to make of geophysics in determining permafrost parameters is taken up in Chapter 5.

2. GEOPHYSICAL METHODS AND THE PROPERTIES OF FROZEN GROUND

2.1 Seismic Methods

In engineering geophysics on land, two geophysical methods are dominantly used in subsurface exploration, electrical and electromagnetic and seismic methods. Because engineering is mainly concerned with shallow exploration (<100 ft) seismic refraction rather than seismic reflection techniques are employed. Figure II-1 shows, schematically, the path of propagation of reflected and refracted waves. The reason for having to use refraction seismic in engineering geophysics is that for shallow exploration, the reflected wave arrives at the geophone placed on the surface, in the same time interval, as other events, such as surface waves, and direct waves. Shallow reflection events are, therefore, very difficult to recognize.

Refraction seismic is frequently used in engineering to determine depth to bedrock. It has one severe limitation in subsurface exploration; that limitation is that refraction surveys can only be conducted when the velocity of propagation of seismic waves increases with depth. For example, in figure II-2, layer 2 has a velocity, V2, which is less than the velocity of the first layer, V1, and as a result no refracted wave returns to the surface from the boundary of layer 1 and 2. Layer 2 can not be recognized in refraction seismic surveys.

Unfortunately, a decrease in seismic velocity with depth is common in permafrost situations, because frozen ground has a higher velocity than the unfrozen ground beneath it. Also, the velocity in frozen ground decreases with increasing temperature. Figure II-3 illustrates this with typical data from the literature (Nakano, 1975).

Therefore, seismic methods have little use in mapping permafrost over land. The geophysical methods used in subsurface exploration for engineering purposes in permafrost have been mainly electrical and electromagnetic methods.

2.2 The Electrical Resistivity of Frozen and Unfrozen Ground

Electrical and electromagnetic geophysical methods for exploration in permafrost can only be successful if frozen and unfrozen ground have different resistivities. The literature is abound with information on this subject. (e.g. Parkhomenko, 1967, Dement'ev, 1959, Hoekstra et. al., 1975). Figure II-4, summarizes the relation between resistivity and temperature for several soils and one rock type. The data show:

a) that the resistivity of frozen ground is always higher than that of the same ground in the unfrozen state.

b) that the resistivity increases in frozen soil when the temperature is lowered. Frozen ground close to $0^{o}C$ may have a resistivity only slightly higher than that of unfrozen ground.

Ice content also has a large influence on the resistivity of frozen ground. Figure II-5 shows the relation between ice content and resistivity, measured in-situ in the walls of a tunnel excavated in Fairbanks Silt. Since much frozen ground particularly in the first 10 to 30 feet contains excess ice, there is often a large contrast in resistivity between frozen and unfrozen ground. A similar relation between ice content and resistivity is reported by Larin et. al., (1973).

In summary, many investigations in the U.S.S.R. and North America have established that frozen and unfrozen ground can be distinguished by their values of electrical resistivity.

When careful work is done in a particular geological setting, it is often possible to delineate regions of high ice content from regions of low ice content.

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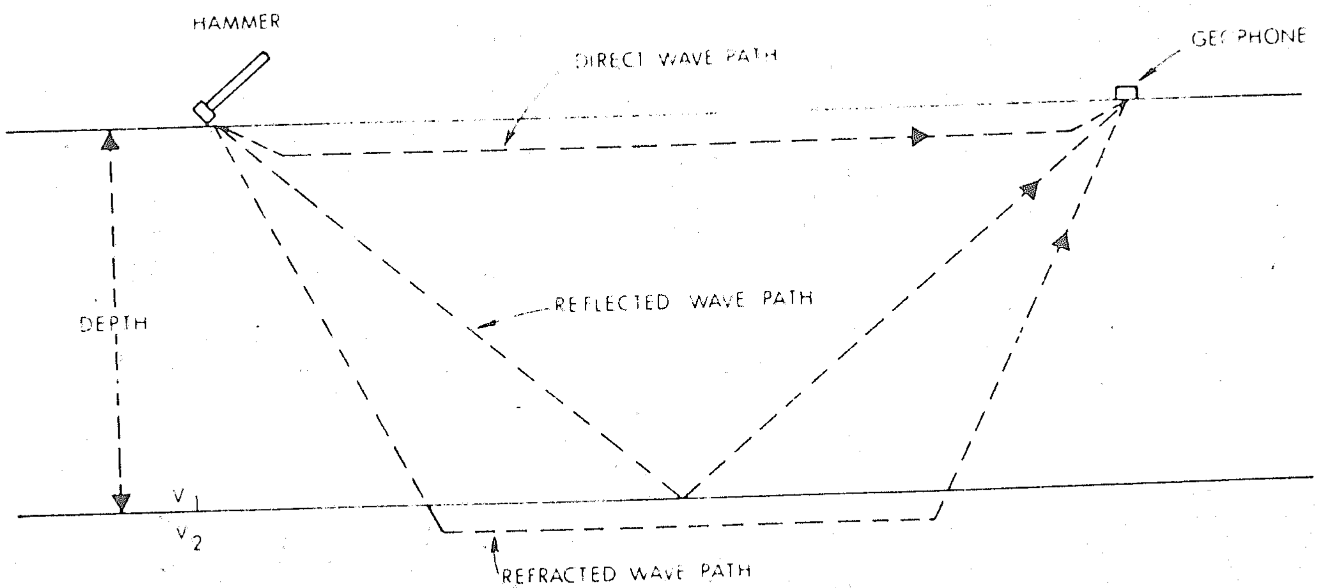


Figure II-1. Illustration of direct, reflected, and refracted wave paths in two-layer ground.

Figure II-2.

Seismic wave paths for the low-velocity-layer problem.

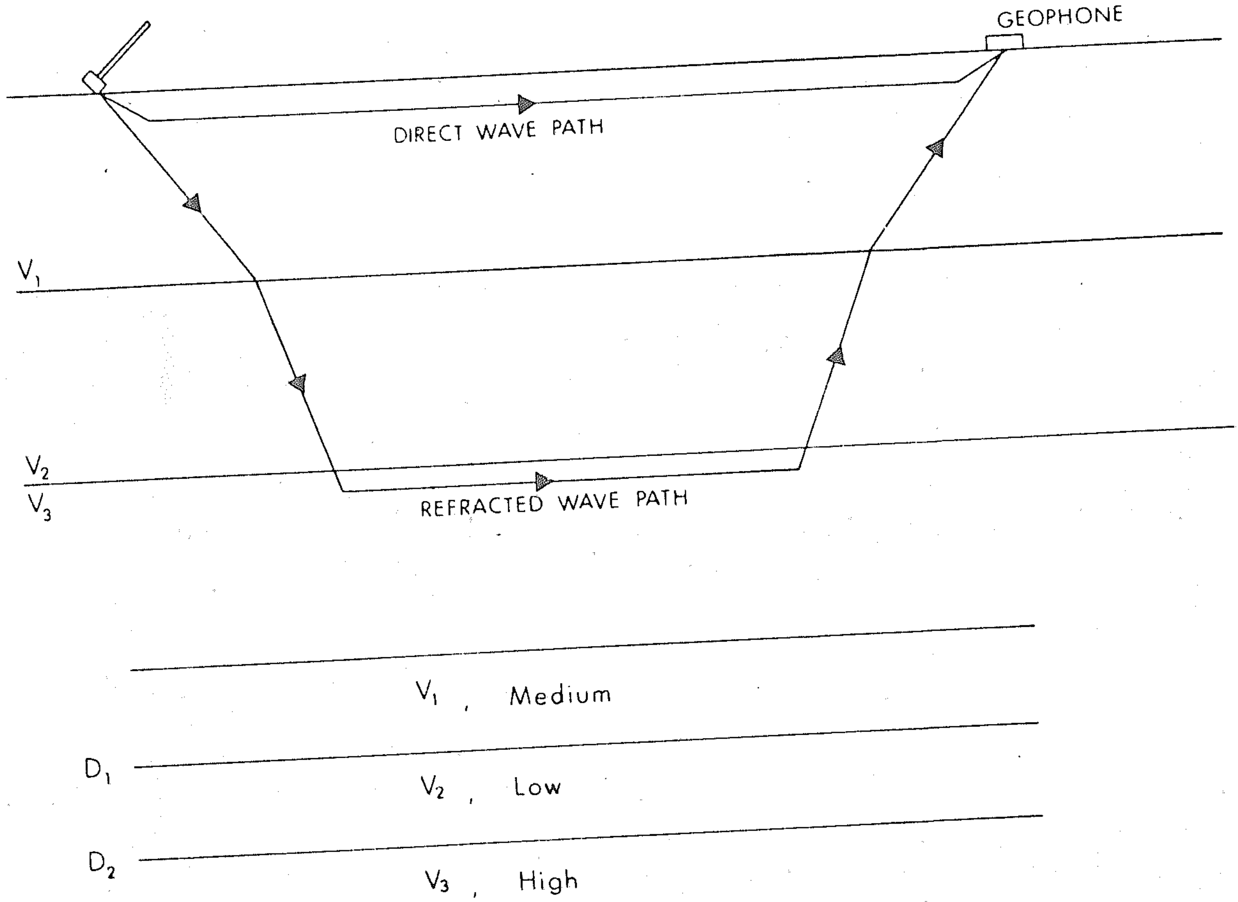


Figure II-3

The Compressional Wave Velocity of Several Soils as a Function of Temperature. (Nakano et al., 1973)[3]

A is a sand, B is a silt, and C is a clay soil.

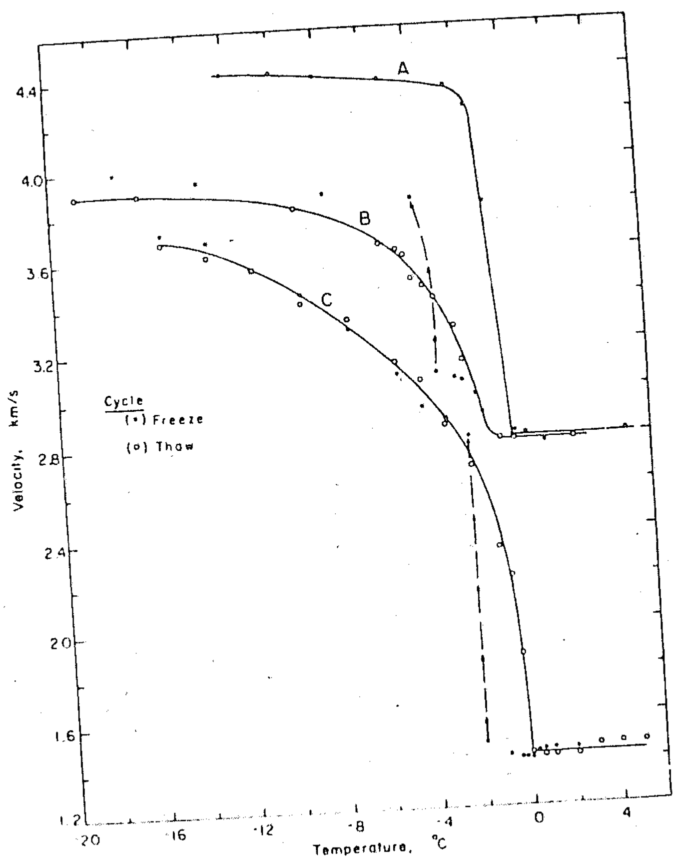


Figure II-4

The Resistivity of Several Soils
and One Rock Type as a Function of
Temperature (Hoekstra et al., 1975)[2]

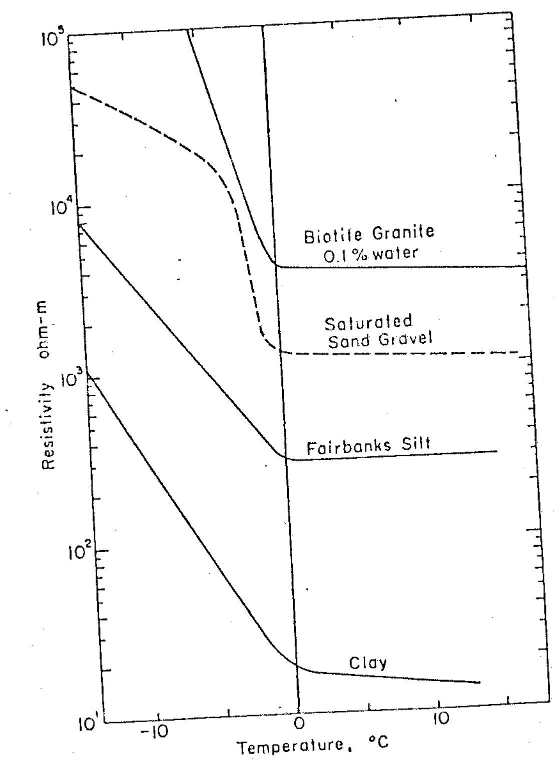
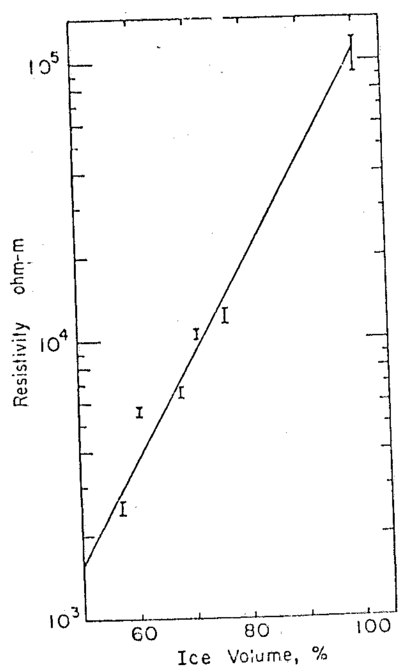


Figure II-5

The Resistivity of Frozen Silt as a Function of Ice Content (Hoekstra et al., 1975)[2]



3. TECHNIQUES FOR MEASURING THE ELECTRICAL RESISTIVITY OF GROUND

The electrical resistivity of ground can be measured by several different techniques. These techniques differ in ease of operation, productivity of surveying and depth of exploration. Some of the techniques to be discussed have only become available for routine field use in the last 2 to 5 years.

3.1 Galvanic Resistivity Measurement (Keller and Frischknecht, 1966)

The conventional technique for measuring the resistivity of ground, and the one most often employed in the past and at present is the galvanic technique.

In galvanic resistivity measurements, current is driven into the ground from a generator between two current probes, and the voltage induced in the ground is measured between two other probes. The probes can be arranged in many different configurations, but the geometry used in our field work is shown in figure III-1. It is called a Schlumberger array. In figure III-1, I_1 and I_2 are the current probes; P_1 and P_2 are the voltage probes.

The resistivity of the ground is calculated from the ratio of voltage between P_1 and P_2 and the current flow between I_1 and I_2. The equation from which the resistivity is computed is given by:

$$\rho_a = 0.5 \left(\frac{L^2}{a} - \frac{a}{4}\right) 2\pi\frac{V}{I}$$

where V is voltage between P_1 and P_2

I is current flow between I_1 and I_2

L and a are spacings defined in figure III-1

ρ_a is the apparent resistivity of ground.

The depth of exploration is increased by enlarging the spacing between the current electrodes, that is by increasing the L spacing. The effect of increasing the L spacing is that the current will penetrate further into the ground, so that deeper subsurface layers will influence the value of resistivity measured at the surface. The value of resistivity obtained at the surface over layered ground is determined by all subsurface layers penetrated by the current lines. The value of resistivity measured at the surface is therefore called the apparent resistivity, ρ_a. Figure III-2 is a typical example of the variation in ρ_a with L spacing over two-layer ground. At small L spacings, ρ_a equals ρ_1 and the current lines are confined to the first layer. When the L spacing is increased, and the current lines penetrate into the second layer, the value of ρ_a changes; and at large L spacings ρ_a equals ρ_2.

Frozen ground poses several specific problems to the use of galvanic measurements. In order to have current flow into the ground the contact resistance of the probes with the ground must be kept low. In the winter when the ground is frozen, probe contact resistance is a difficult problem to overcome. In the summer, when the active layer is thawed, the contact resistance problems are removed, and good resistivity measurements over frozen ground can be made. Much use is made of this method for mapping permafrost in the U.S.S.R.

Two types of surveys are made with Schlumberger arrays. They are:

3.1.1 Vertical Soundings

In vertical soundings, ρ_a is measured at the same location as a function of L spacing and the measurement often allows a computation of the thickness of permafrost. Figure III-3 shows computed examples of what typical vertical soundings along the Mackenzie corridor will look like over frozen and unfrozen ground in the summer. The initial linear increase in ρ_a over frozen ground with L spacing is due to the active layer; the decline in ρ_a at larger L spacings is caused by unfrozen ground underlying the permafrost. The computed data show that:

(a) at virtually all L spacings, frozen (F) and unfrozen ground (UF) can be readily distinguished by Schlumberger soundings,

(b) to obtain the thickness of permafrost from a vertical sounding one cannot take the inflection point in the graph as a measure of thickness, because the thickness of permafrost would be seriously overestimated, (e.g. 20m versus 5m). It is necessary to use computer processing of the data to obtain permafrost thickness.

Vertical soundings for mapping permafrost thickness in the discontinuous zone have disadvantages. To make vertical soundings over permafrost (e.g. 20m in thickness), requires a spacing between the two outer current probes of at least 150m. It is common to find lateral variations in permafrost over such distances, and lateral variations cause uncertainties in interpretation. Also the productivity of surveying is slow, perhaps 15 soundings a day.

3.1.2 Horizontal Profiling

In horizontal profiling, measurements at one L spacing are made at many different locations in an area, or along a line, so that the resistivity of the ground is measured to approximately the same depth. From figure III-3 it is evident that this can be an effective way to delineate permafrost. For example, if a fixed L spacing of 5m is chosen, values of ρ_a of

50 ohm-m and 410 ohm-m would be measured over unfrozen and frozen ground respectively. Horizontal profiling is extensively used in the U.S.S.R. to map permafrost.

3.1.3 Summary Galvanic Techniques

In summary, although galvanic measurements can be good, and accurate techniques for measuring the electrical resistivity of the ground, their application to surveys for engineering purposes in permafrost has severe draw backs. These draw backs are:

a) surveys cannot be performed in winter when the ground is frozen or snow covered.

b) the lateral resolution of this method in locating changes in subsurface conditions is on the order of 15m to 30m. This is inadequate for locating the many transitions between frozen and unfrozen ground.

c) the productivity of surveying is low.

3.2 Non-contact Techniques for Measuring Electrical Resistivity

Because of the increased demand for subsurface exploration in permafrost regions, there has been considerable efforts made by government agencies and industries to develop methods for measuring the electrical resistivity of frozen ground which would remove some of the drawbacks of galvanic measurements. In particular, techniques were sought:

a) that do not require low contact resistance with the ground; techniques that can be used in the winter when the ground is frozen.

b) that have better resolution of local changes in subsurface conditions than galvanic techniques.

Two techniques came about after several years of development that satisfy the above criteria, radiohm and inductive coupling techniques. Over the past two years, Arctic Gas has helped the development of these new geophysical techniques along by awarding contracts for designing and building special equipment.

3.2.1 Radiohm Methods (Collett et. al., 1967; Hoekstra et. al., 1975).

Radiowaves propagating over the earth's surface are influenced by the nature of the subsurface, and from measurements on the radio ground wave, the resistivity of the ground can be derived. The sources of radiowaves used in field work are existing transmitters such as the U.S. Navy station NLK, operating at 18.6 khz out of Jim Creek, Washington, and airport navigational beacons (NDB), such as FS, operating at 375 khz located at Fort Simpson, N.W.T.

The electromagnetic field vectors of a transmitter are shown in figure III-4. At the ground surface, there are three field vectors: a horizontal radially oriented electric field, E_r; a horizontal, azimuthally oriented magnetic field, H_ϕ; and a vertical electric field, E_z. All three field vectors decay in amplitude with increasing distance from the transmitter and are affected by daily changes in the ionosphere and the nature of the path between transmitter and measurement station. The basis for obtaining a local measurement of ground resistivity is illustrated in figure III-5, where a wave is shown propagating over a change in ground conditions. Changes in local subsurface conditions cause only perturbations in amplitude and phase of E_r, while local changes do not affect E_z and H_ϕ. Therefore, by measuring the ratio $\frac{Ez}{H_\phi}$. called surface impedance, a measurement of the local resistivity of the ground is obtained. The factors of path of propagation, topography, and daily variation in field strengths equally influence E_z, H_ϕ, and E_r, and are eliminated in a ratio measurement.

Figure III-4 illustrates that the field vectors E_r and H_ϕ penetrate vertically into the ground, and attenuate with depth. The depth of exploration of this method is related to the attenuation of the wave in the ground, and the depth of exploration is approximately 0.5 - 0.8 times the skin depth. The skin depth of the radiation is defined as the depth of ground which attenuates a wave 37 per cent. The skin depth depends on frequency and resistivity and the dependence is shown in figure III-6. The skin depth decreases with increasing frequency and decreasing resistivity. The frequency bands in which measurements are made are VLF (very low frequency) and LF (low frequency).

In North America, sufficient field strength at VLF (15-30 khz) is available for radiohm measurements virtually everywhere. The field strength is provided by powerful U.S. Navy transmitter situtated on the Atlantic and Pacific Coast. The LF frequency band (200-400 khz) is assigned to airport Non-Directional Beacons. (NDB's). These beacons often operate at low power, so that there are large areas of the Arctic where there is insufficient field strength to make LF radiohm measurements.

The equipment required for radiohm measurements is basically a receiver, that can separately measure the electrical and magnetic fields. Commercial equipment for making radiohm measurement was available in 1975 in the VLF band only. Arctic Gas in 1975 awarded a contract to Geonics Ltd. of Toronto, Ontario for the building of an LF radiohm unit similar in operation to the VLF equipment. The weight of both LF and VLF instruments are under 15 lbs., and they can be operated by one person.

Figure III-7 shows a schematic of the VLF insrument. Coil A is first used to establish the transmitter direction by nulling the field received in the coil. Coil A is then switched off, and the ratio of Ex, measured between two probes spaced 10m apart, and Hy, measured with Coil B, is determined by adjusting the amplitude and phase dials until an audio null is attained. The instrument reads directly in resistivity and phase. The LF prototype equipment is similar in operation to the VLF unit; the audio tone has been replaced by a meter for nulling. A measurement takes about 2 minutes to complete.

Over homogeneous ground, the resistivity measured with radiohm equipment is equal to the ground resistivity, but over layered ground an apparent resistivity is measured and computer modeling is required to resolve the layering in the ground. In figure III-8, ρ_a is modeled at VLF (18.6 khz) for summer (s) and winter (w) conditions using typical resistivity values encountered in the Mackenzie Valley. The data for permafrost are computed for two different thicknesses of the active layer. The computed data illustrate several points:

1) that VLF surveys will look too deep for areas from Fort Simpson south, because the permafrost is typically less than 10m thick.

2) The influence of the active layer in the summer is small. VLF measurements can be used to indicate depth of permafrost in both summer and winter in areas where permafrost thickness is larger than about 20 m.

In figure III-9 ρ_a is modeled at a LF frequency of 375 khz, the frequency of the Fort Simpson beacon. The computed data show that an LF frequency is ideally suited for measuring shallow permafrost. The active layer has a significant influence on resistivity so it is best to make measurements in the winter.

Surveying with radiohm methods has three main advantages over galvanic probe methods.

1) The determination of E_r is a voltage measurement; so that virtually no current needs to flow between the probes and the ground. Probes can therefore be inserted in the snow cover, and surveys can be made when the ground is frozen.

2) Figure III-6 shows that the depth of penetration of VLF surveys is often 50m or more. To obtain a depth of penetration of 50m with the galvanic method, spreads are required over distances of at least 150m, and over such distances permafrost conditions frequently are variable. The radiohm method, on the other hand, maps ground conditions on a much more local scale ($25m^2$); therefore, a local resolution is maintained with deep exploration.

3) The productivity of measurements of the radiohm method is greatly increased when compared to the galvanic method, and the necessary crew size is reduced to two men from three or four. Depending on the terrain and the distance between measurement points, 50 to 200 locations can be measured by a two-man crew in a day.

The disadvantage of the radiohm technique is that the depth of exploration depends on frequency and ground resistivity (see figure III-6) and the choice of frequency is usually limited to one VLF and one LF transmitter. In the galvanic probe method, the depth of exploration is chosen by changing the electrode spacing.

3.2.2 Inductive Coupling Methods (Keller and Frischknecht, 1966)

The inductive coupling techniques tested for permafrost mapping basically differ from radiohm methods in three aspects:

1) When two loops, one a transmitter, the other a receiver, are suspended above the ground, the received signal is the sum of the primary field - the field that would be present in free space - and the secondary field - the field specifically due to the presence of ground. In most cases, the magnitude of the primary field is many times larger than that of the secondary field, so that it is difficult to accurately measure the part due to the ground. The secondary field has a component inphase and a component in quadrature (90° out) phase with the transmitted signal. The primary field, however, is all inphase. The quadrature phase component of the secondary field can, therefore, be measured with much greater accuracy than the inphase component, and the prototype instrument measures the quadrature phase component only.

2) The depth of exploration of the two-loop system is mainly determined by the frequency and the separation distance of the two loops. When the frequency and the spacing between the loops are chosen so that the skin depth of the radiation (see figure III-7) is at least five times the loop separation, there is a near linear relation between the quadrature phase response of the secondary field and the resistivity of ground. In figure III-12, the relation between quadrature phase response (in parts per million of primary field) is plotted as a function of the resistivity of uniform ground for the system shown in figure III-10.

The depth of exploration of our inductive coupling systems depends mainly on the separation distance of the two horizontal loops. The effective depth of exploration is about two times the separation distance between the center of the loops, or approximately 7.5m for the EM31 shown in Figure III-10. The EM34 shown in Figure III-11 can be operated at separation distances of 15.24m and 30.48m, so that exploration depths of up to 60m can be achieved. NESCL has awarded a contract for an instrument with a loop separation of 9.4m (30 ft.), and an exploration depth of about 18.8m (60 ft.), for use in mapping permafrost thicknesses between 8m (25 ft.) to 18m (60 ft.). This instrument will be delivered in April, 1977.

Figure III-12 shows the relation between resistivity of homogeneous ground and instrument readings. When the ground consists of layers with different resistivity, the response can also be computed (Sinha, 1976). Figure III-13 shows the response of the EM31 for resistivity layering typical of permafrost in the winter.

The inductive coupling system appears to be the most convenient and most productive way of ground resistivity mapping. The advantages are:

a) No contact with the ground is required.

b) The instrument is selfcontained and does not require the field from a distant transmitter.

c) A continuous record of ground resistivity along a traverse can be obtained if so required.

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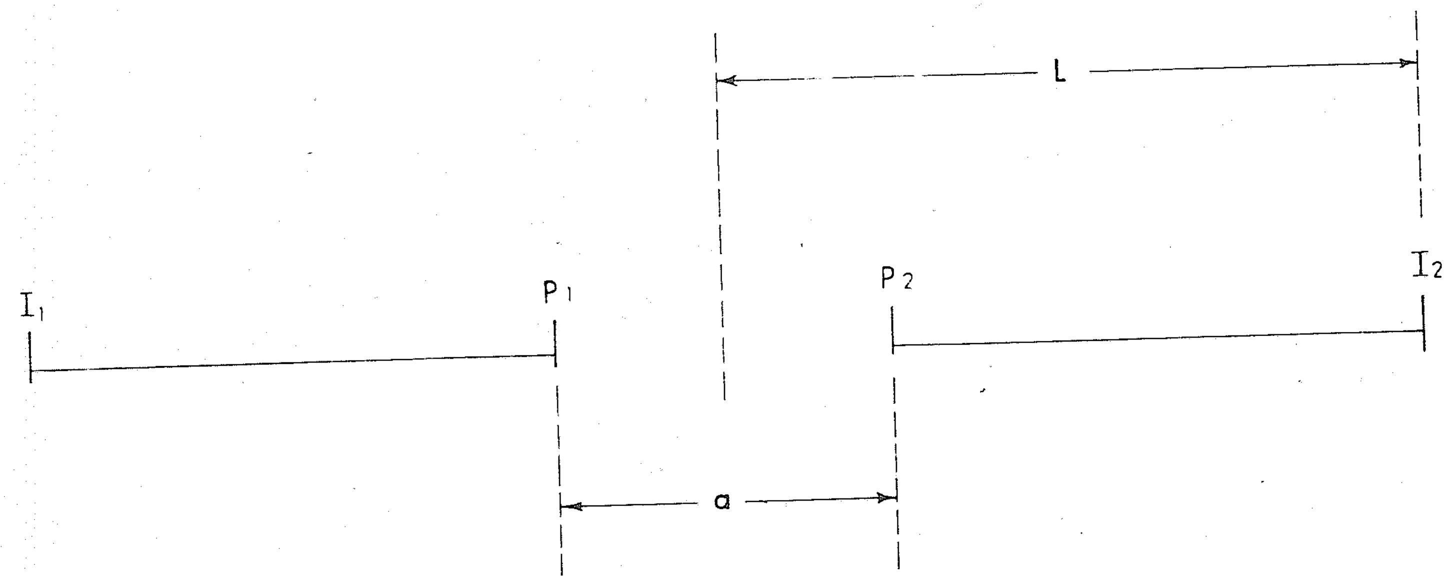


SCHLUMBERGER ELECTRODE CONFIGURATION

Figure III-1

SEPTEMBER 1975

NORTHERN ENGINEERING SERVICES COMPANY LIMITED

CANADIAN ARCTIC GAS STUDY LIMITED

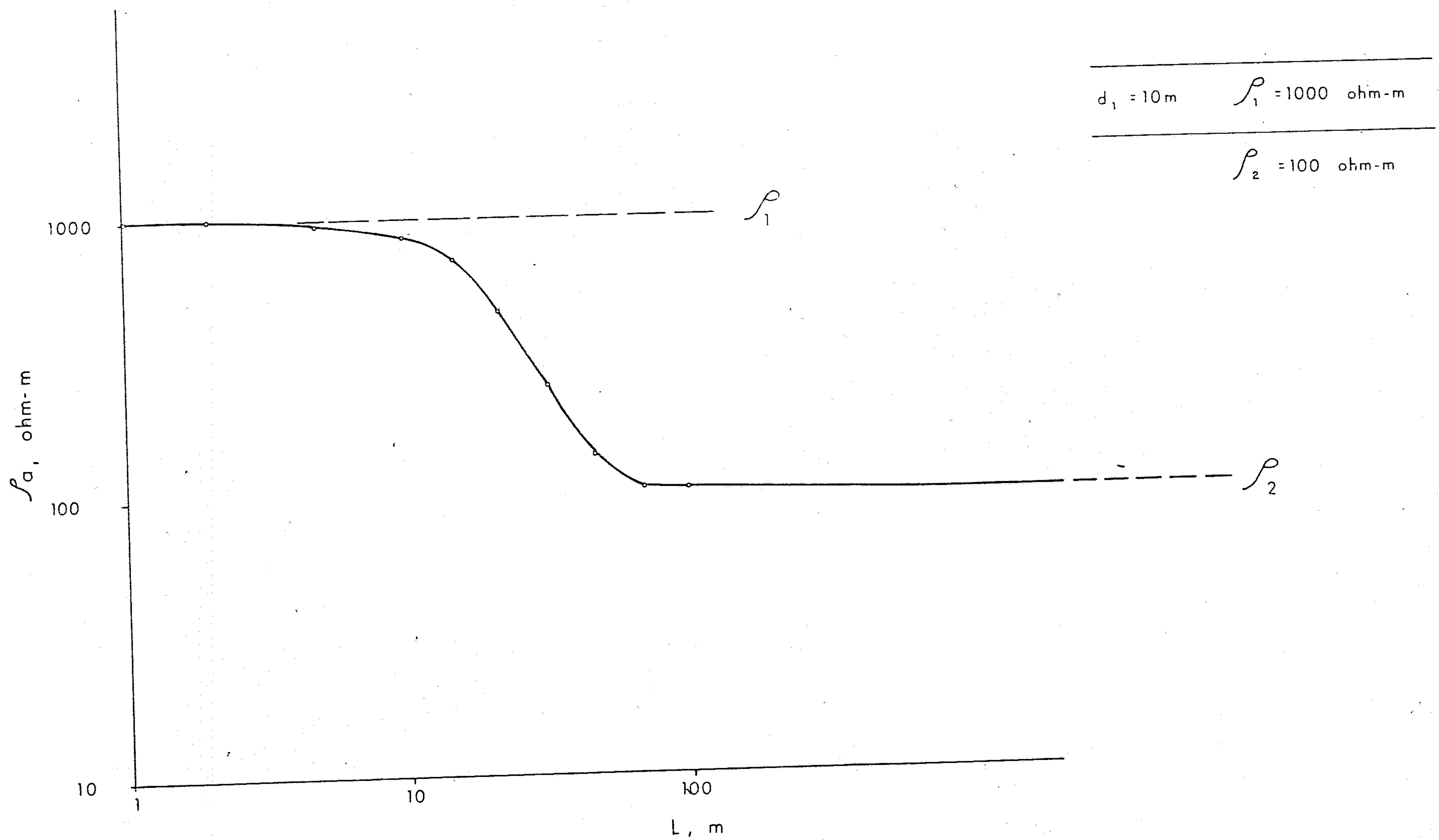
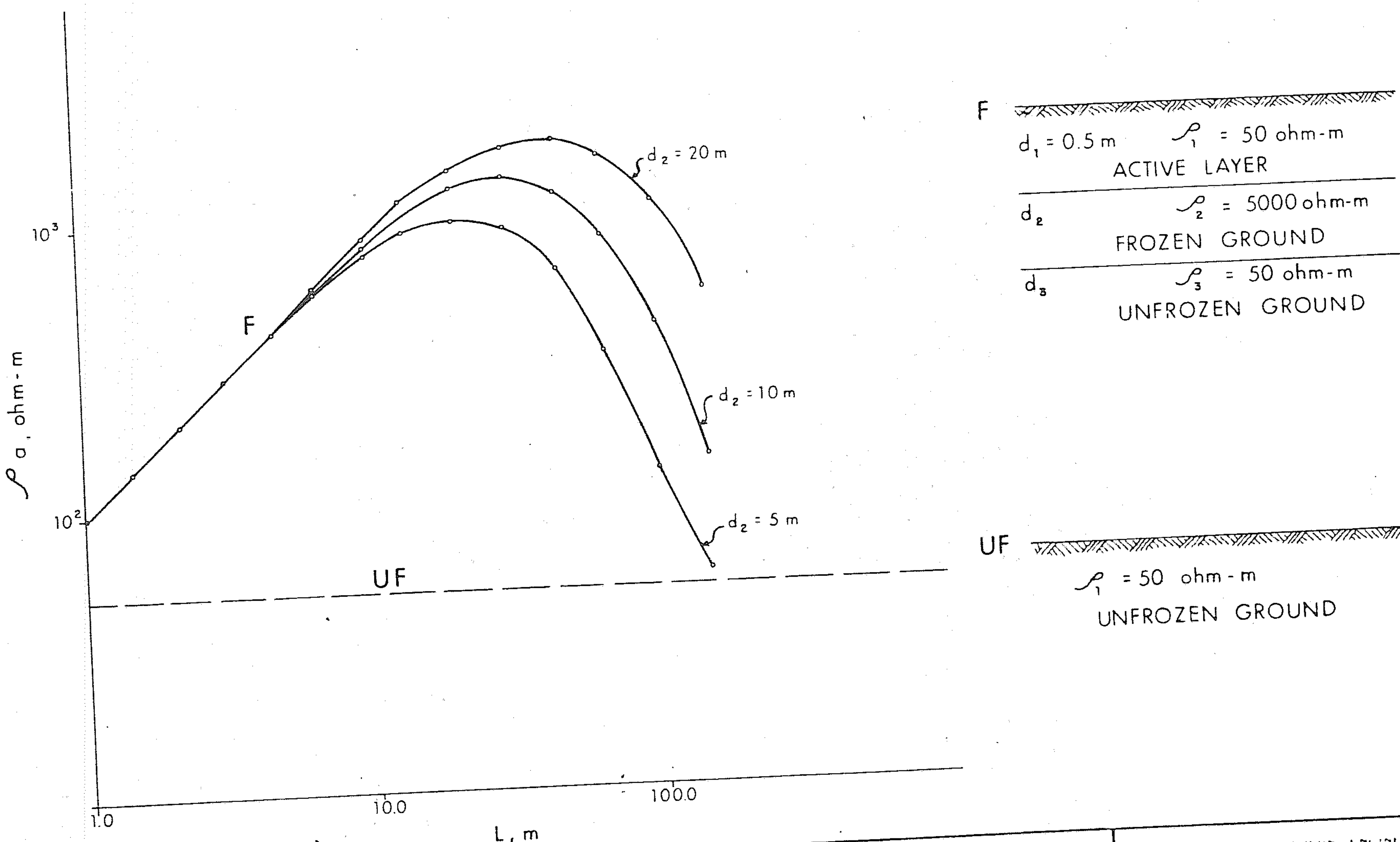


Figure III-2	EAST FORT SIMPSON REALIGNMENT
NOVEMBER 1975	TWO-LAYER SCHLUMBERGER SOUNDING

CANADIAN ARCTIC GAS STUDY LIMITED



EAST FORT SIMPSON REALIGNMENT

THREE-LAYER SCHLUMBERGER SOUNDING

Figure III-3

NOVEMBER 1975

CANADIAN ARCTIC GAS STUDY LIMITED

Figure III-4

The Electromagnetic Field Vectors of a Vertically Polarized Radio Groundwave

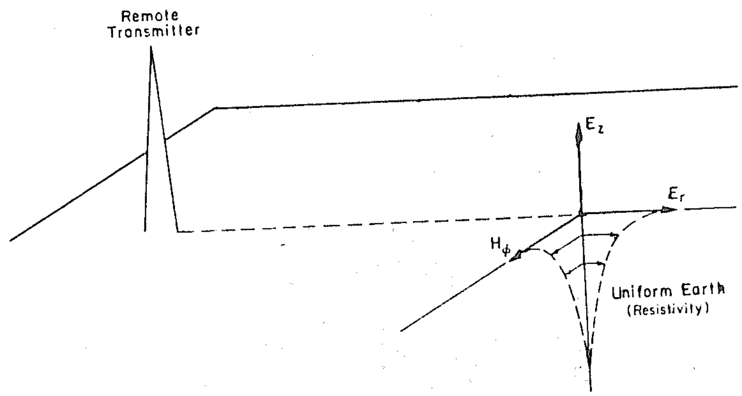
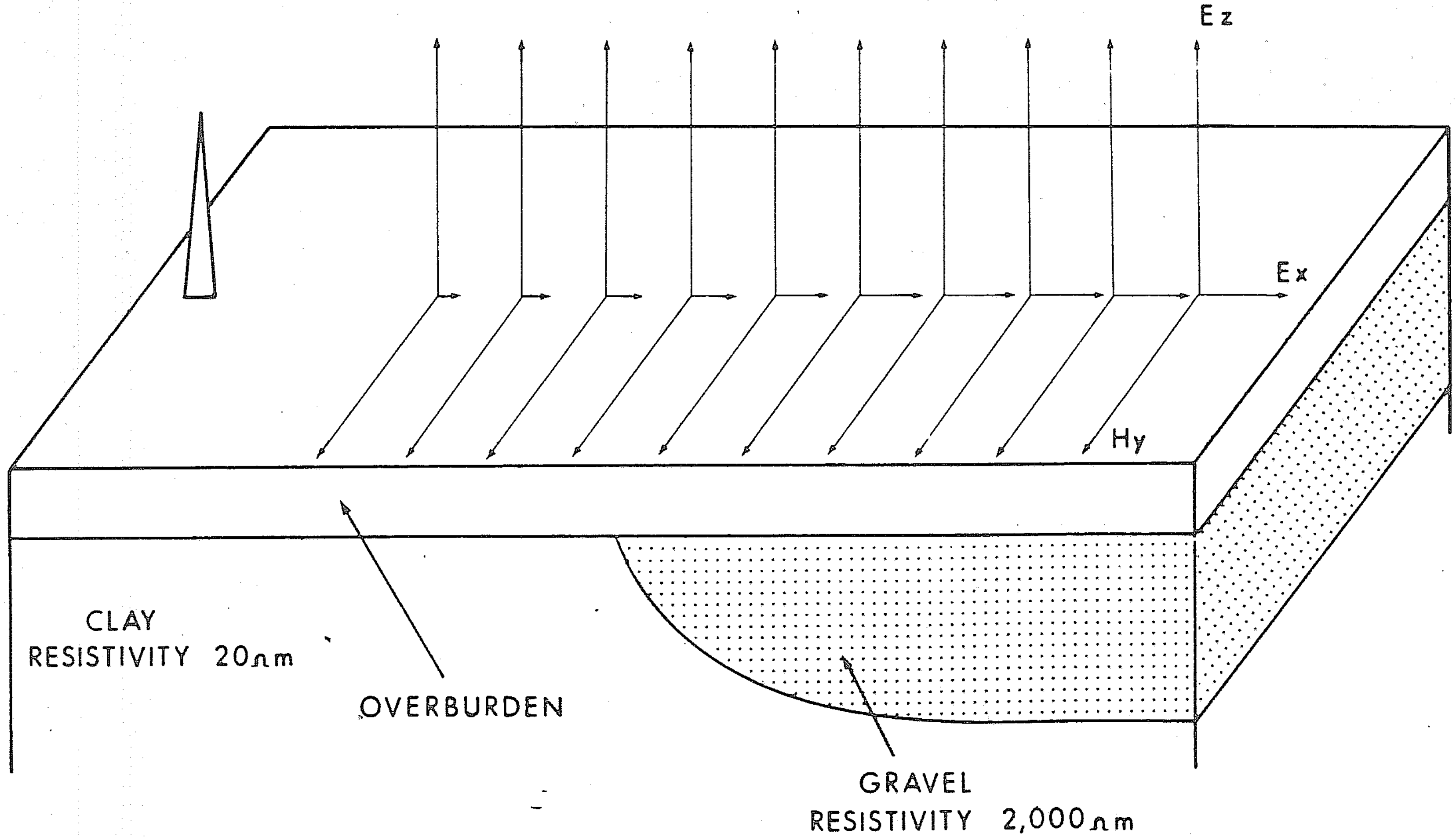


Figure III-5

Schematic Diagram of the Perturbations in the Electromagnetic Field Vectors when a Wave Propogates over Changes in Subsurface Conditions



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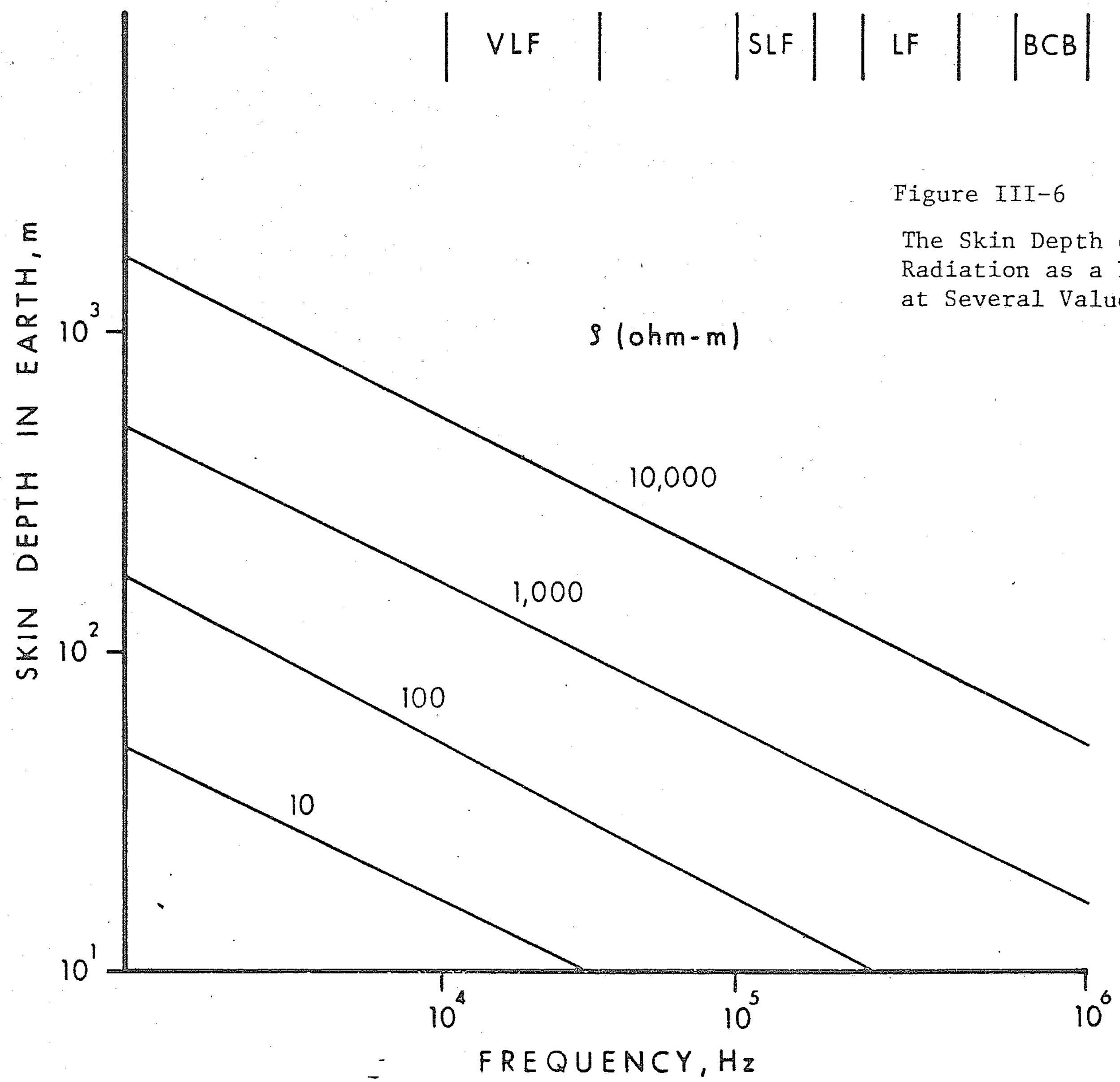


Figure III-6

The Skin Depth of Electromagnetic Radiation as a Function of Frequency at Several Values of Resistivity

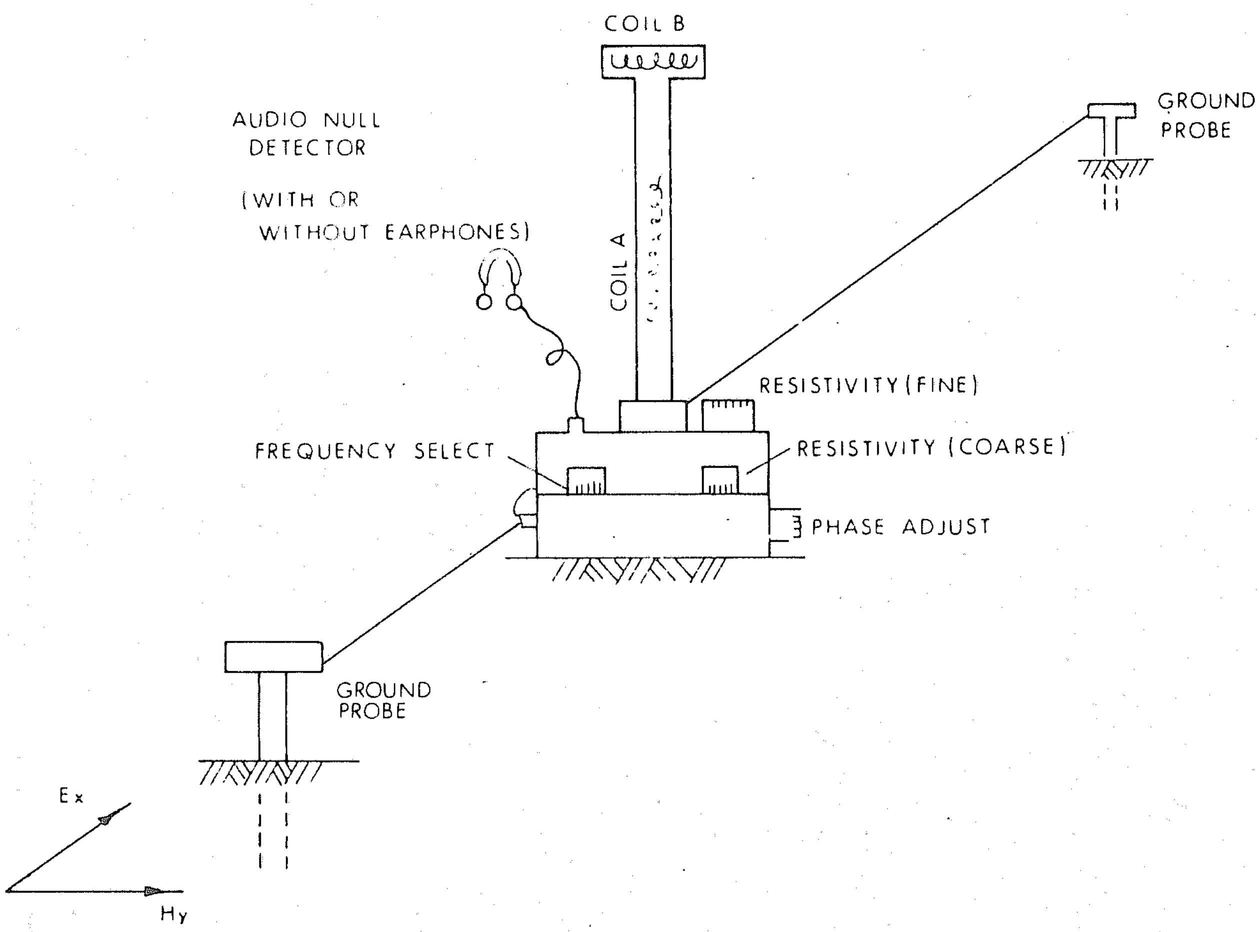


Figure III-7 Schematic of VLF

Figure III-8

The computed apparent resistivity ρ_a, for the radiohm method at VLF (18.6 khz) as a function of the thickness of frozen ground for two values of frozen ground resistivity (ρ_1) in the winter.

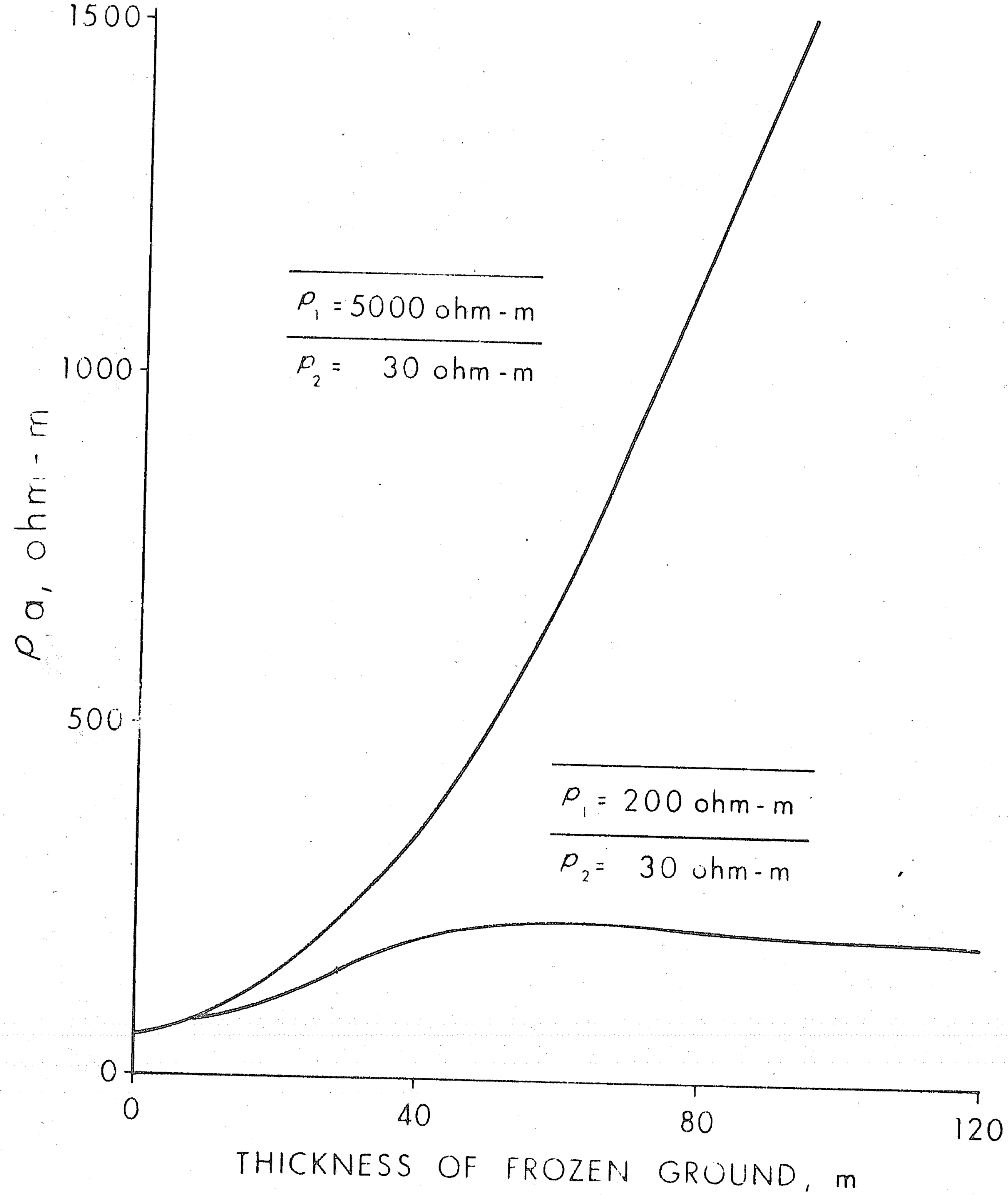


Figure III-9

The computed apparent resistivity, ρ_a for the radiohm method at LF (375 khz as a function of the thickness of frozen ground for two values of frozen ground resistivity (ρ_1) in the winter.

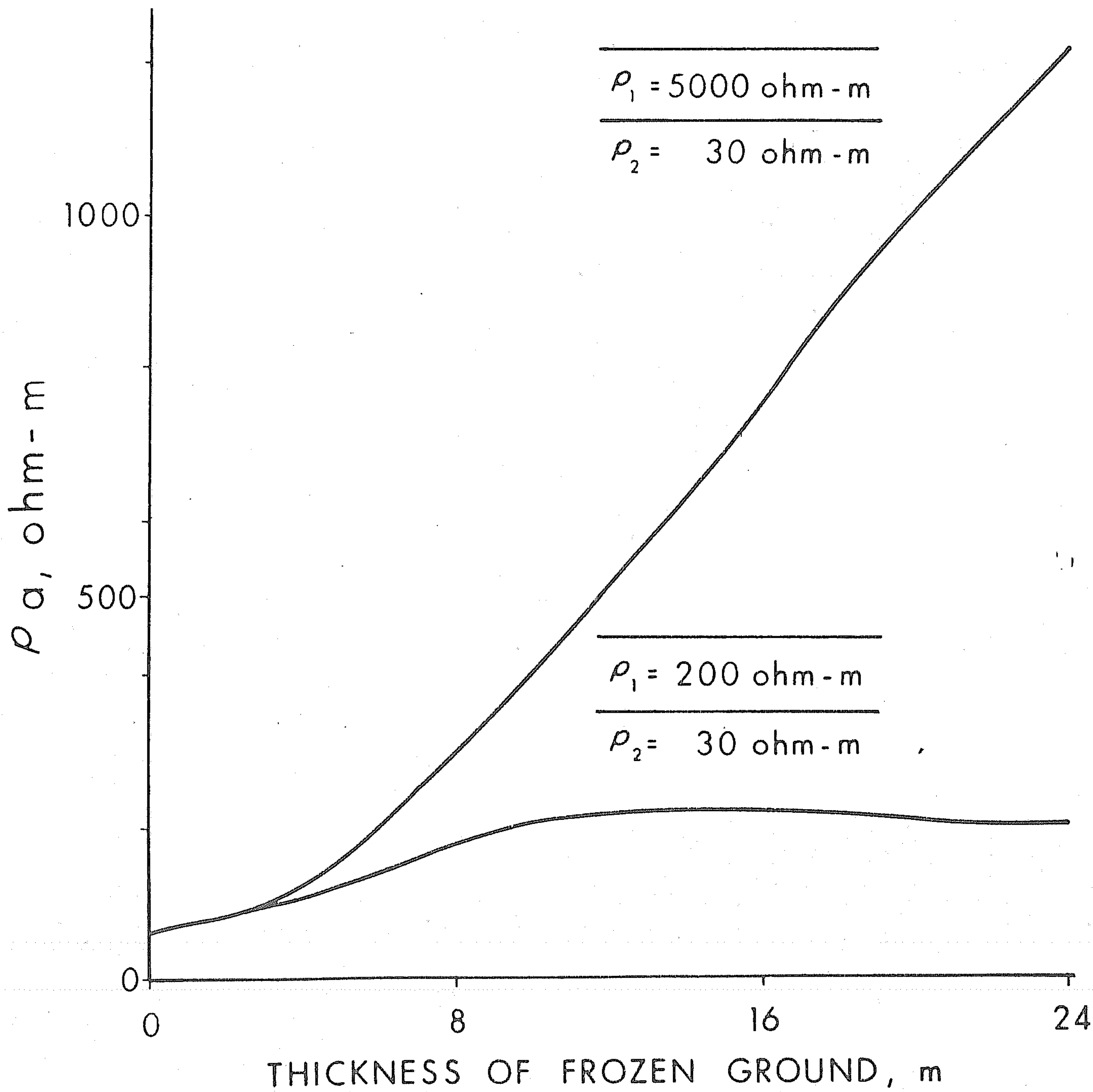
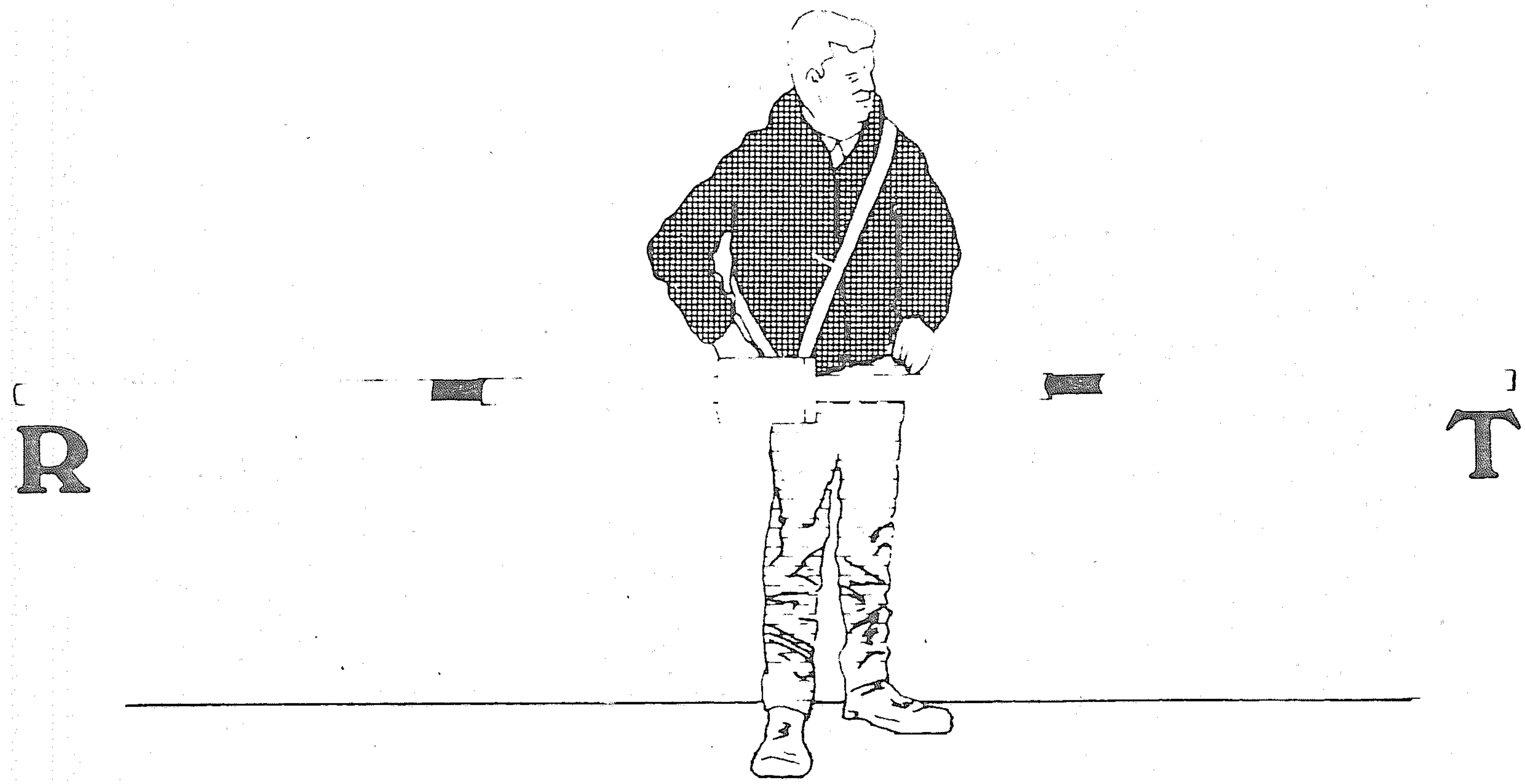


Figure III-10

Schematic diagram of the manner in which the EM31 is carried by an operator.



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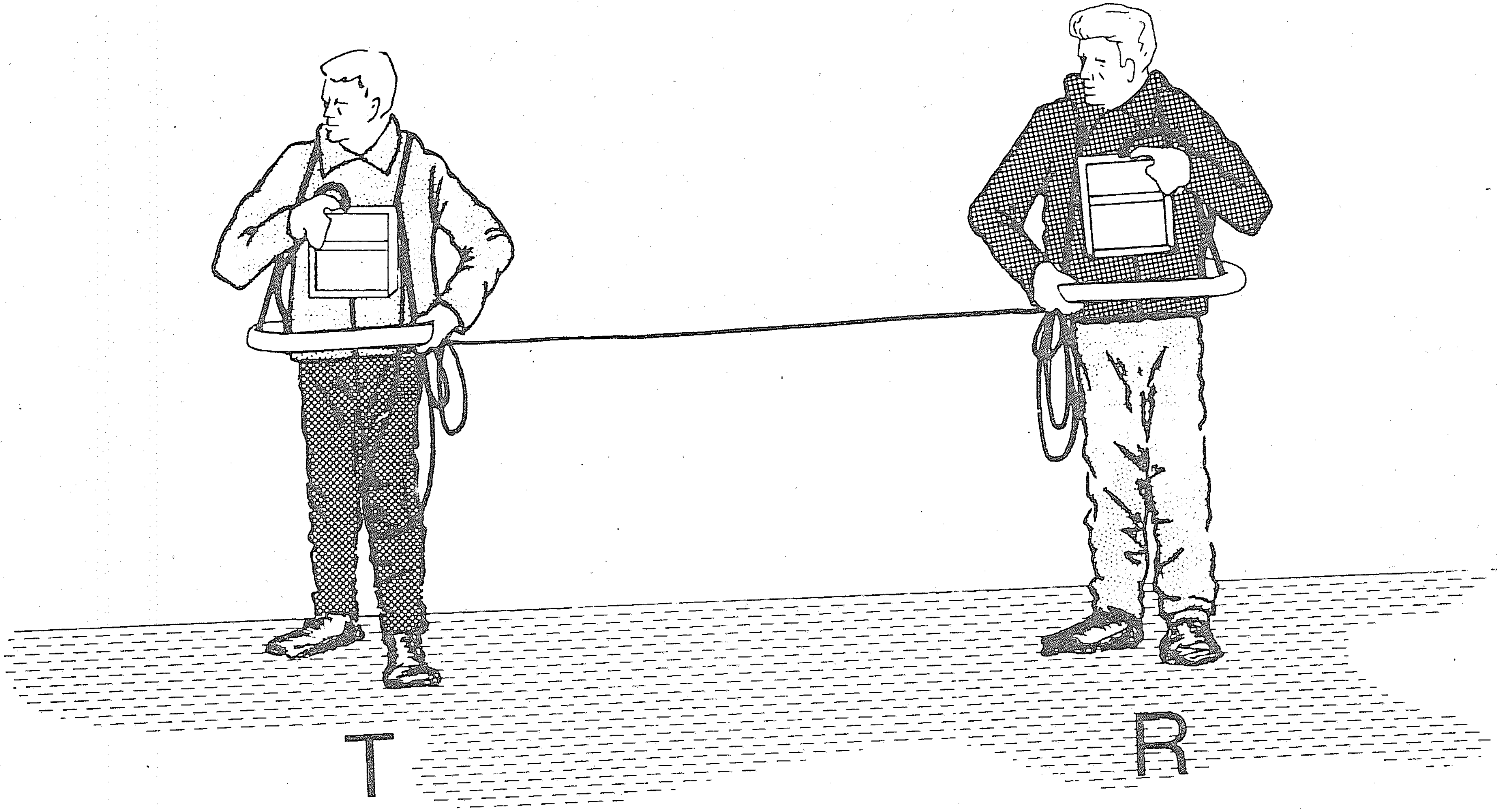


Figure III-11

Schematic Diagram of EM34

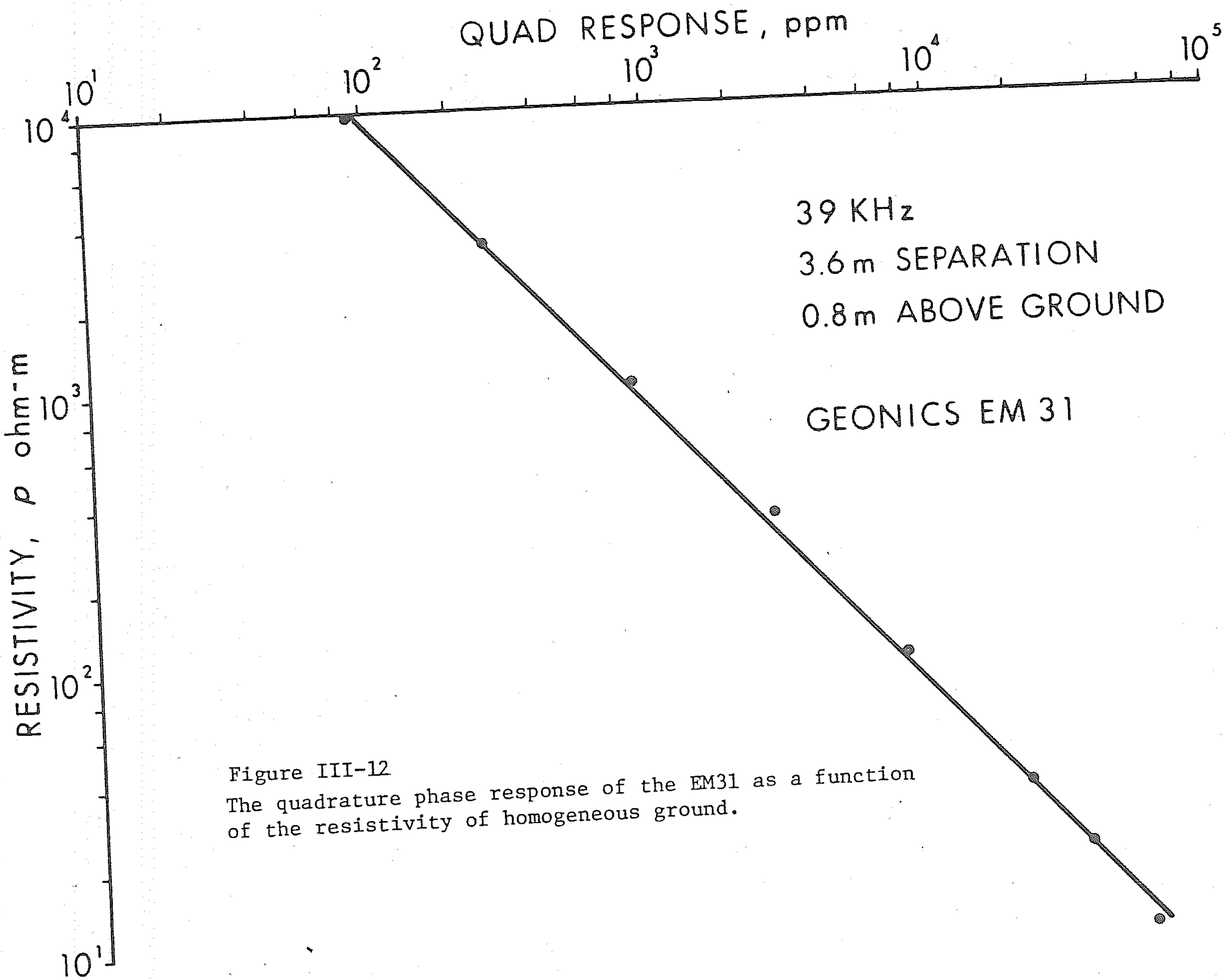
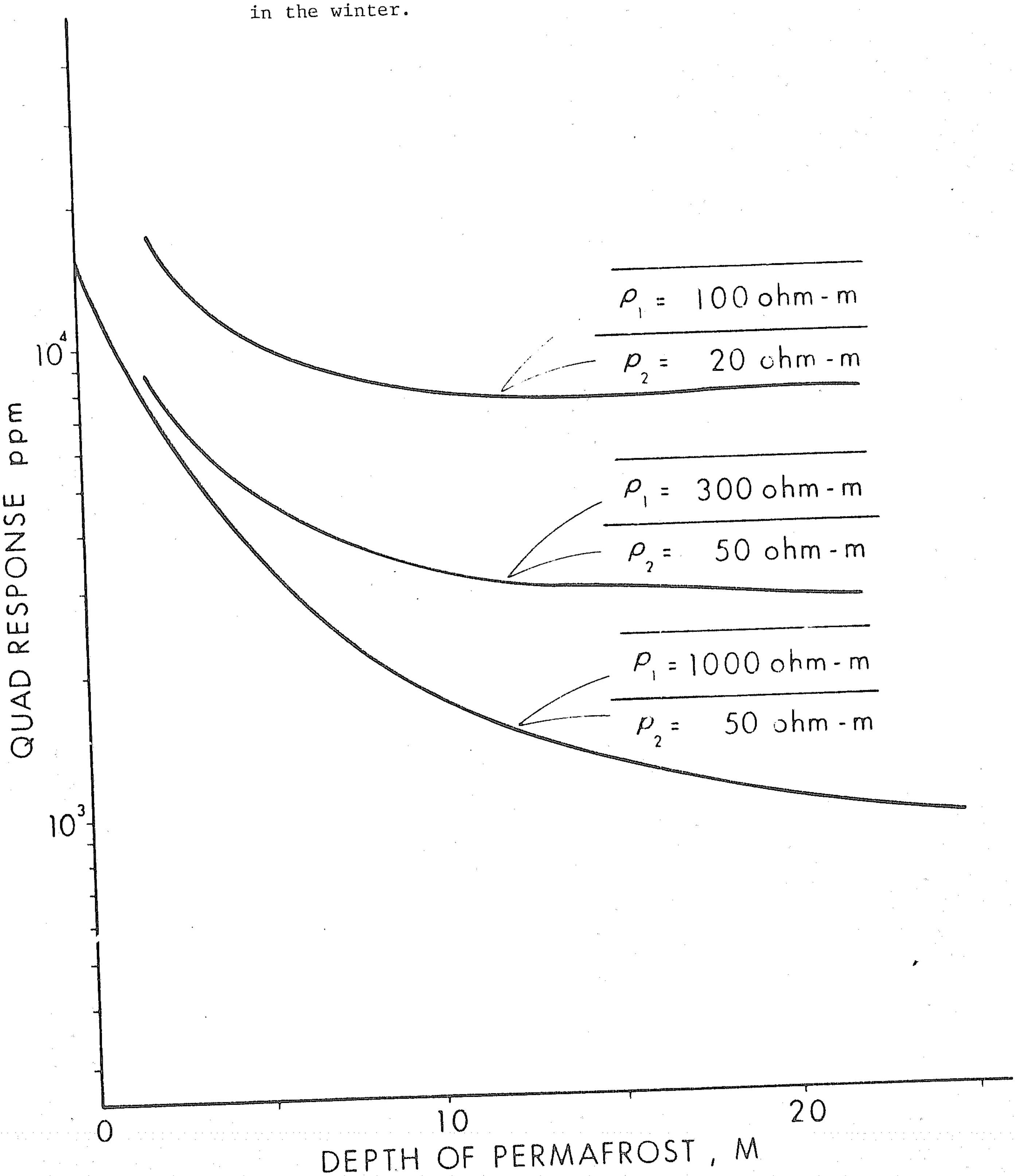


Figure III-12
The quadrature phase response of the EM31 as a function of the resistivity of homogeneous ground.

Figure III-13

The computed relation between the quadrature phase response of the EM31 and the depth of permafrost for several resistivity profiles typical of permafrost in the winter.



4. RESULTS OF FIELD TESTING AND SURVEYS

4.1 Objectives and Scope of Work

The field work over the past two years had two objectives:

a) to prove that the different techniques for measuring the electrical resistivity of ground yield similar results.

b) to perform field tests to ascertain to what extent different geophysical techniques could lower the cost and improve the quality of subsurface exploration for various ground parameters.

Field trials were made to determine if the following geotechnical objectives could be derived from geophysics:

a) delineation of the boundaries of frozen and unfrozen ground.

b) measurement of the thickness of frozen ground.

c) determination of the location of unfrozen zones under the rivers of the Arctic coastal plain in the winter.

d) determination of the extent and depth of gravel deposits.

4.2 Comparison of Results Between Different Techniques

Figure IV-1 and Figure IV-2 show the results of linear traverses with LF radiohm and inductive coupling methods (EM31) over sections of discontinuous permafrost south of Fort Simpson, N.W.T.

The following observations can be made from that data:

a) the trend in the resistivity profiles and the location of the anomalies, is identical for the radiohm and inductive coupling methods. The resistivity highs all occur at the same locations. This gives confidence in both techniques of resistivity mapping. The instruments operate at greatly different frequency (LF radiohm, 375 khz, EM31, 40 khz), and the current distribution induced in the ground is also dissimilar between both techniques. Therefore the fact that both techniques show identical trends is substantial proof that the theory and equipment design which is basic to the two techniques is sound.

The values of apparent resistivity measured in both techniques differ, but that is expected, because both instruments have different depths of exploration. Only over ground which is uniform with depth should resistivity values be identical.

b) The resolution of detecting sudden changes in subsurface conditions is about $\pm$ 5M (15 ft.). That is an improvement over the conventional probe method by at least a factor three.

U.S.A. CRREL in 1976 also began an extensive testing program comparing VLF and LF radiohm, inductive coupling (EM31), and galvanic measurements. The results were reported by Sellmann et al, 1976. These data show that the agreement between the electrical resistivity values obtained with different methods is very good.

4.3 Delineating the Boundaries of Frozen and Unfrozen Ground from Electrical Resistivity Methods

Figure IV-1 shows a traverse over ground of similar soil type. Because frozen ground has much higher resistivities than unfrozen ground, it is to be expected that the resistivity highs are caused by the presence of frozen ground, and the boundaries of frozen ground are delineated in Figure IV-1. Figure IV-2 is an example of a situation where changes in soil type cause part of the resistivity variations. Resistivity highs are encountered over sand dunes, which are usually unfrozen south of Fort Simpson N.W.T., and over permafrost in till. The anomalies at station 480 and 600 are apparently not related to sand dunes. Drill holes placed at such locations found permafrost. This is an example where geophysics served the purpose of alerting to anomalies where drill holes should be placed.

In the spring of 1976, geophysical traverses were followed by the placing of approximatelv 43 drill holes at locations of geophysical measurements. An important objective of that drilling program was to check the delineation of permafrost from geophysical interpretations.

Table IV-1 summarizes the comparison between test hole log and geophysical interpretation. There is agreement in 22 out of 25 test holes listed. The remaining 18 test holes of the 1976 spring program are holes placed so close to the holes listed in Table IV-1, that they do not provide independent checks. At three sites, geophysical interpretations could not be made with certainty, because variations in soil stratigraphy also caused resistivity variations. Some of the geophysical profiles over the sites checked by test holes are given in the report, "Geotechnical Data Report, Permafrost Distribution: Willowlake River, N.W.T. to Zama Lake, Alberta".

In addition to test hole data, there are numerous other observations that can be used as ground truth. For example, ground is unfrozen under ponds and fens south of Willowlake River, and these events also should be consistent with geophysical data. All of the ground truth collected has confirmed that permafrost boundaries can be accurately delineated by electrical resistivity surveys.

4.3 Estimating the Thickness of Frozen Ground from Geophysical Surveys

The computer model curves in Figure III-8, III-9, and III-12, show that 3 ground parameters determine the apparent resistivity, the resistivity of unfrozen ground, ρ_2, the resistivity of frozen ground, ρ_1, and the thickness of frozen ground, d_1. To obtain d_1 from a single measurement of apparent resistivity requires that other methods must be used to determine ρ_1 and ρ_2. The approach that we have taken at this time is to chose values for ρ_1 and ρ_2, at locations of test holes, so that the permafrost depth obtained from geophysical interpretation agrees with the depth found in test holes. It is anticipated that values of ρ_1 and ρ_2 are characteristics of terrain types, so that an established correlation between test holes and geophysics can be extrapolated within a terrain unit. Figure IV-3 compares the results of the data available so far. When more test hole data becomes available the agreement can probably be considerably improved.

Again, in addition to test hole data, other information can be used to obtain values for ρ_1 and ρ_2. Unfrozen ground adjacent to frozen ground should yield an independent value of ρ_2.

Moreover, measurements with two instruments with different depth of exploration would yield additional information.

An example of a survey with several instruments is shown in Figure IV-4, for an area north of Willowlake River, N.W.T. at approximately MP 576. Traverses are shown with VLF (phase and resistivity), the EM31, and EM34 at 15.24m loop separation.

The interpretation of permafrost thickness is consistent with all four readings.

In summary, our geophysical results so far indicate that it will be possible to estimate permafrost thickness to $\pm$ 30 per cent, when some test hole data are available for calibration. When more drill hole data become available, improvements in estimates will be possible. Furthermore, we expect at least to recognize from geophysical surveys areas where sudden changes in permafrost thicknesses take place.

4.4 Mapping Unfrozen Zones Under Rivers of the Arctic Coastal Plain in the Winter

During the period of April 1 to May 21, 1976, geophysical surveys were conducted at 11 rivers on the Arctic Coastal plain in the Yukon Territory and Alaska. The objectives of the survey were:

a) to determine if shallow unfrozen subsurface channels in the riverbed are connected to open water leads and icings.

b) to determine the availability of water from rivers.

c) to establish a methodology for investigating ground water on Arctic rivers.

Measurements were made with the EM31 and VLF radiohm.' Figure II-5 and Figure IV-6 show results over sections in the west channel of the Sagavanirktok River near Prudhoe Bay, Alaska. Sixteen test holes were placed during this program to check the geophysical interpretations.

The geological cross sections derived from test hole data indicate the depth of ice, frozen gravel, and unfrozen gravel.

Because no casing was used, the holes in thawed gravel sometimes needed to be discontinued at shallow depth when caving occurred. In frozen gravel, the depth of the holes was 40 ft. (12m).

There is a good qualitative agreement with the EM31 response and the test hole data. At all sites where thawed ground occurs within 30 ft. (10m) from the surface, the response is in excess of 0.2, and is between 0.1 and 0.2 when unfrozen ground is not found within the first 30 ft. (10m). The response increases when unfrozen ground is found closer to the surface.

The VLF radiohm data also corresponds well with test hole data. The VLF readings rapidly decrease when taliks are encountered within the first 40 ft. At test hole TH-14, VLF data indicate a talik at depth greater than 40 ft. (12m).

From the results shown in Figure IV-5 and IV-6 and many other traverses across rivers on the Arctic coastal plain, it was concluded that non-contact electrical resistivity surveys locate areas under the river where unfrozen zones (taliks) can be found. Once such areas have been pinpointed they can be further explored by drilling.

4.5 Geophysical Exploration for Gravel Deposit

One of the common uses of electrical resistivity mapping has been in support of exploration for granular deposits. Unfortunately, during the NESCL borrow program in the summer of 1975 the geophysical instrumentation for non-contact exploration was not yet available, nor had crews been adequately trained in geophysical measurements.

The new equipment items were, however, tested on gravel deposits near Calgary, and on a deposit near Fort Simpson, N.W.T. Figure IV-7 shows a resistivity profile across a section of the Standard General, Ogden Pit. The resistivity profile has been interpreted in terms of depth of granular material. The gravel deposit can be seen to sharply terminate near station 400. The interpretation corresponded well with available ground truth at the pit.

Figure IV-8 shows resistivity profiles with VLF radiohm and the EM31 over deposit FS-13 near Fort Simpson, N.W.T. The location of three test holes is also shown. The data obtained with the EM31 and the VLF show resistivity highs where the deeper gravel is located. The high values of resistivity obtained with the EM31 in one section indicates that the deposit there, is at least 30 ft. in depth. From the VLF profile one can derive the approximate lower boundary of gravel. Again the important information from geophysical traverses is that it indicates where the test holes should be placed, and over what area certain test hole information can be extrapolated.

So far no frozen gravel deposits have been investigated, and to what extent geophysical surveys can aid in the exploration of frozen deposits is not yet known.

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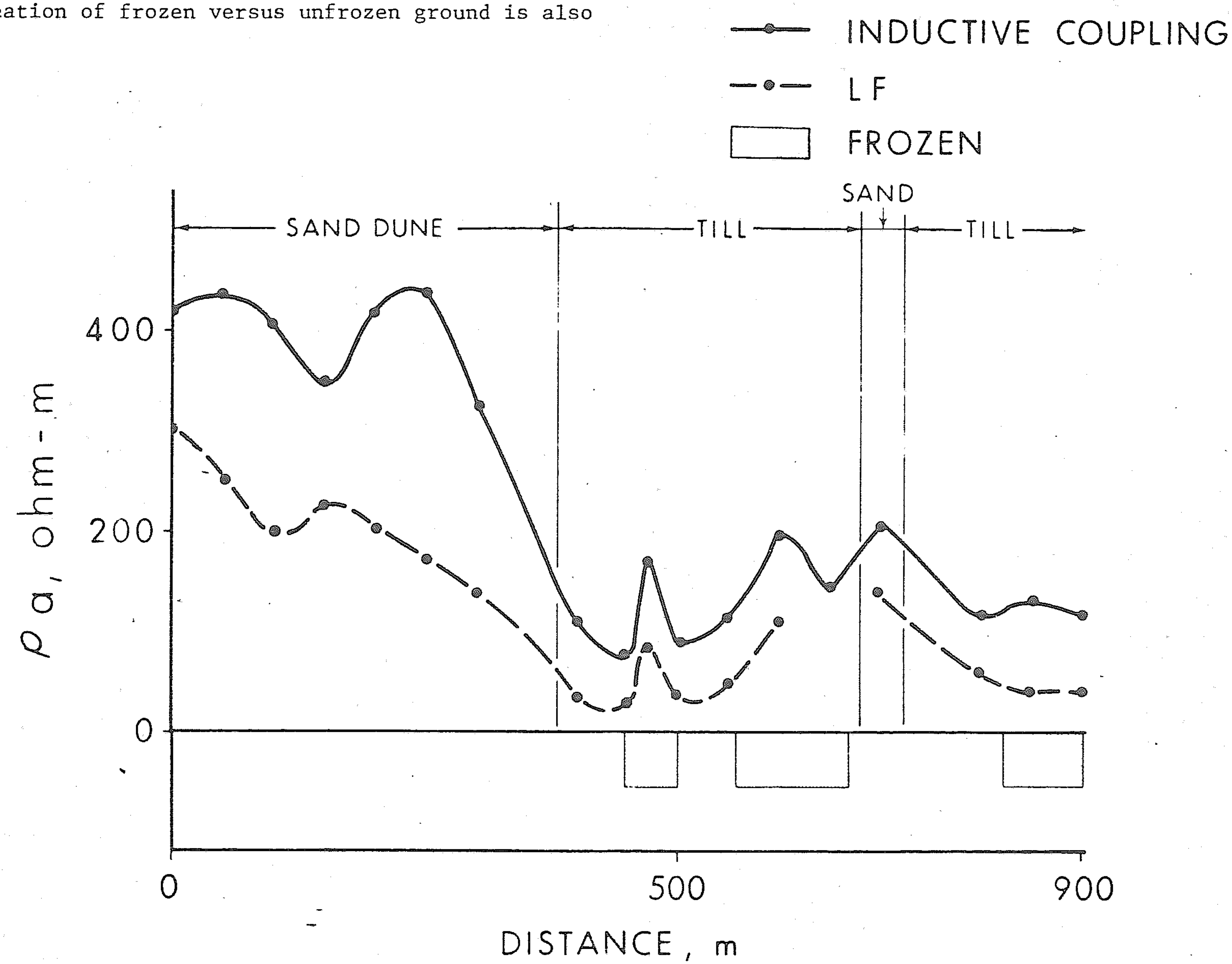
NESCL, Geotechnical Data Report; Permafrost Distribution: Willowlake River, N.W.T. to Zama, Alberta, February, 1977.

Figure IV-1

Measured values of apparent resistivity with LF radiohm (375 khz) and inductive coupling (EM31) over a section of discontinuous permafrost with sand dunes overlaying till. The delineation of frozen versus unfrozen ground is also shown.



easured values of apparent resistivity with LF ra ohm (375 khz) and inductive coupling (EM31) over a sec on of discontinuous permafrost. The delineation of frozen versus unfrozen ground is also shown.

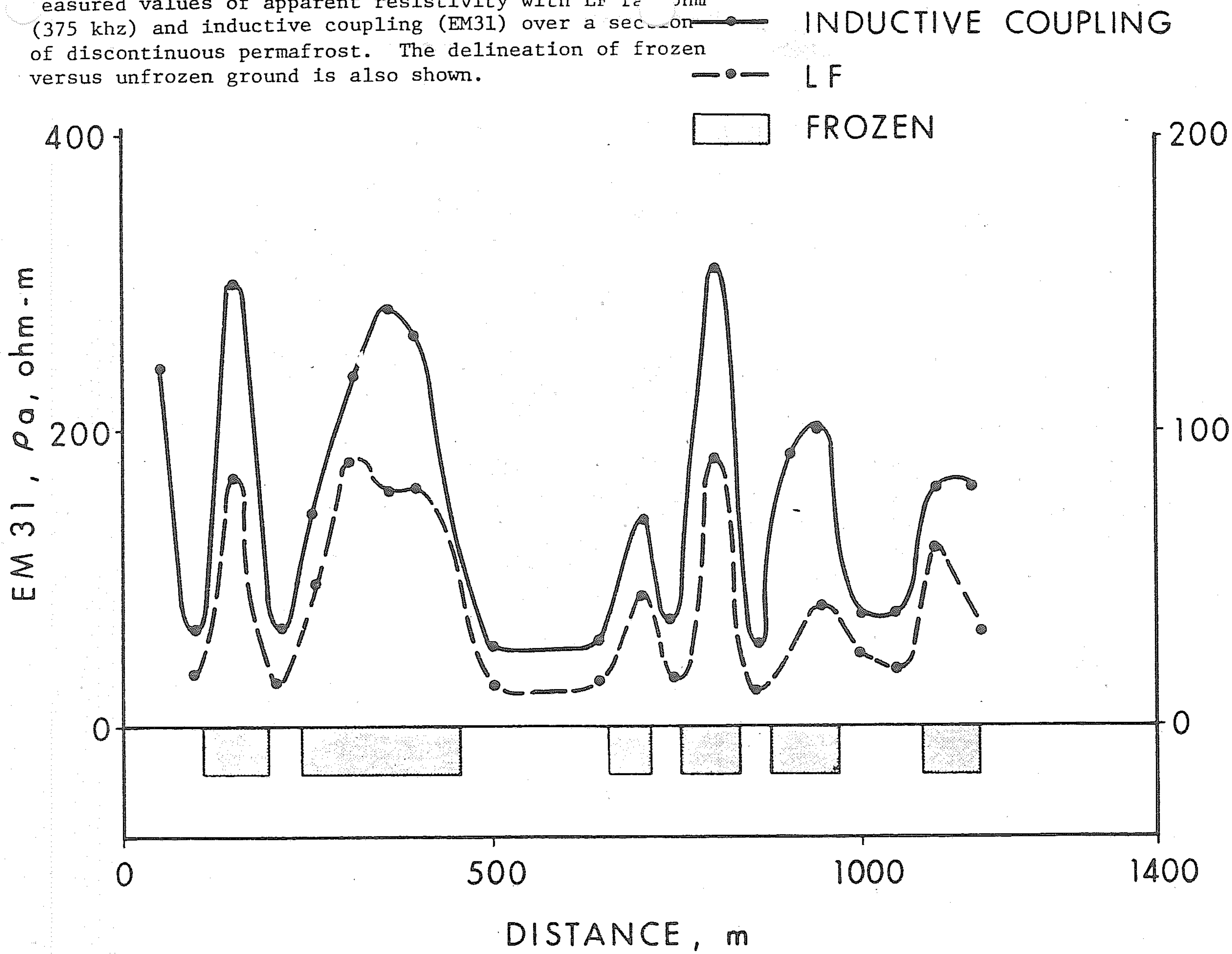
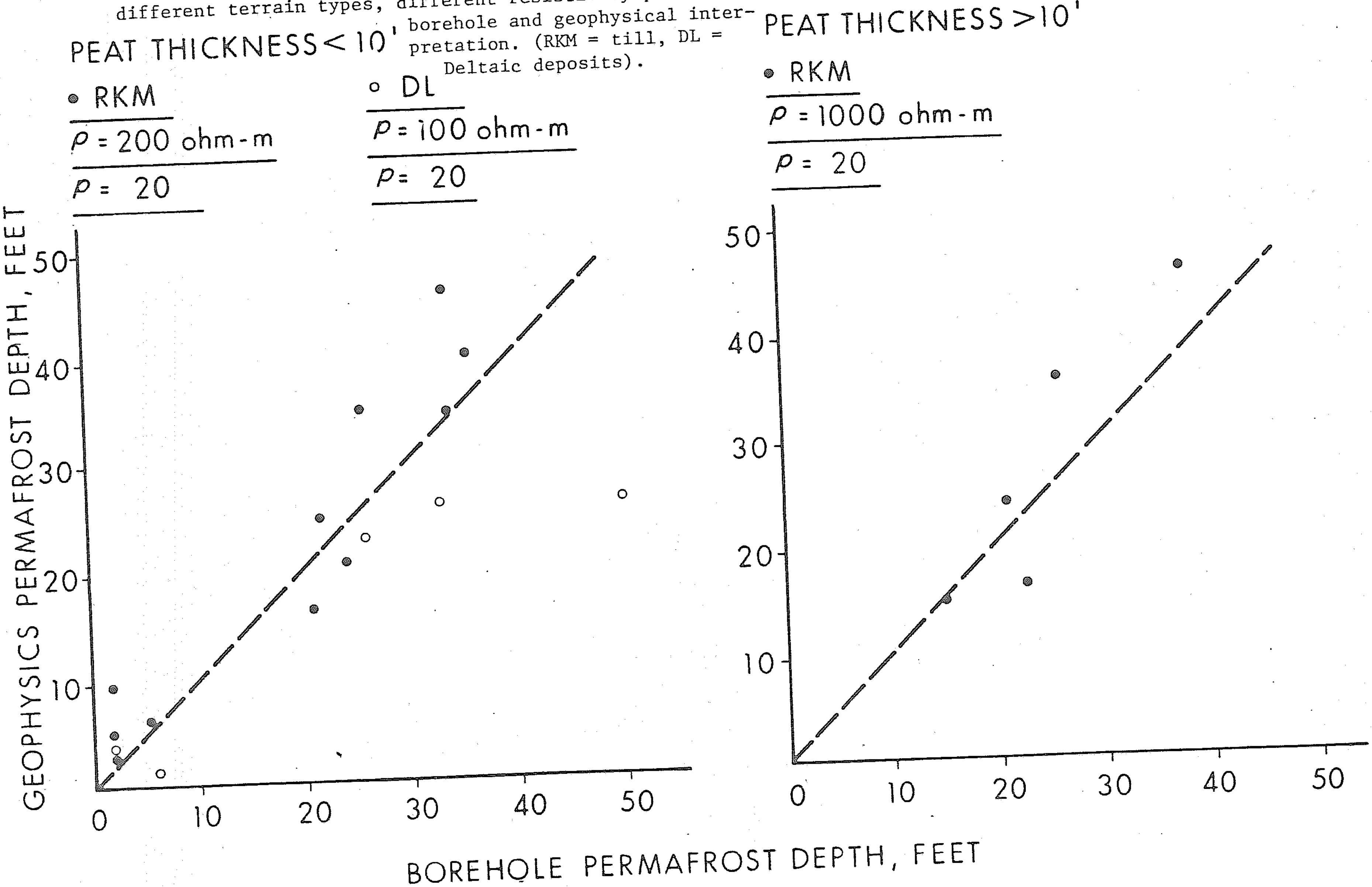


Figure IV-2

Comparison of permafrost depth derived from borehole information and resistivity surveys. In different terrain types, different resistivity profiles were modeled to obtain a best fit between borehole and geophysical interpretation. (RKM = till, DL = Deltaic deposits).



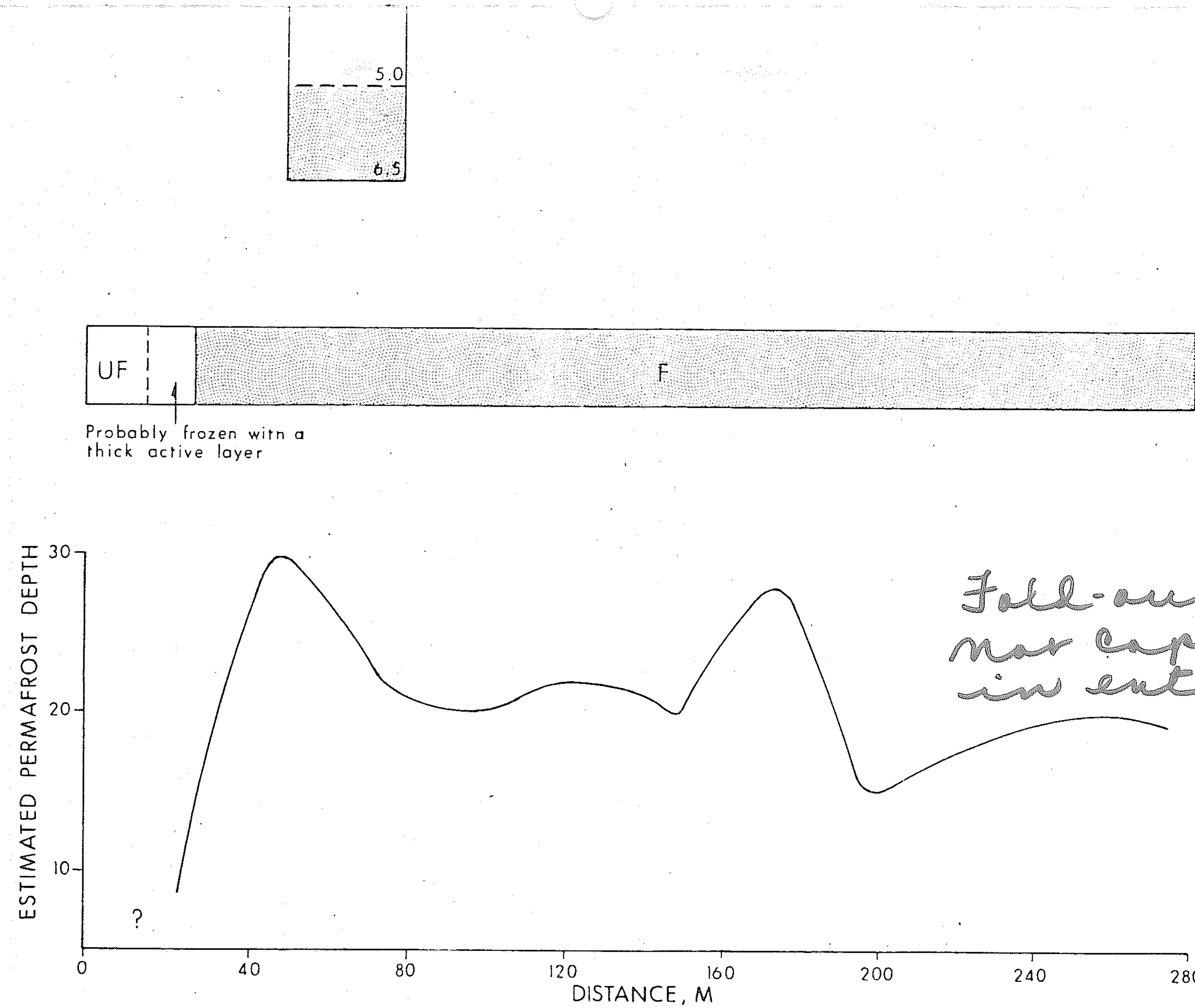


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FIGURE IV-4

PERMAFROST MAPPING

SALINE RIVER TO WILLOWLAKE RIVER, N.W.T.

SITE No. 36

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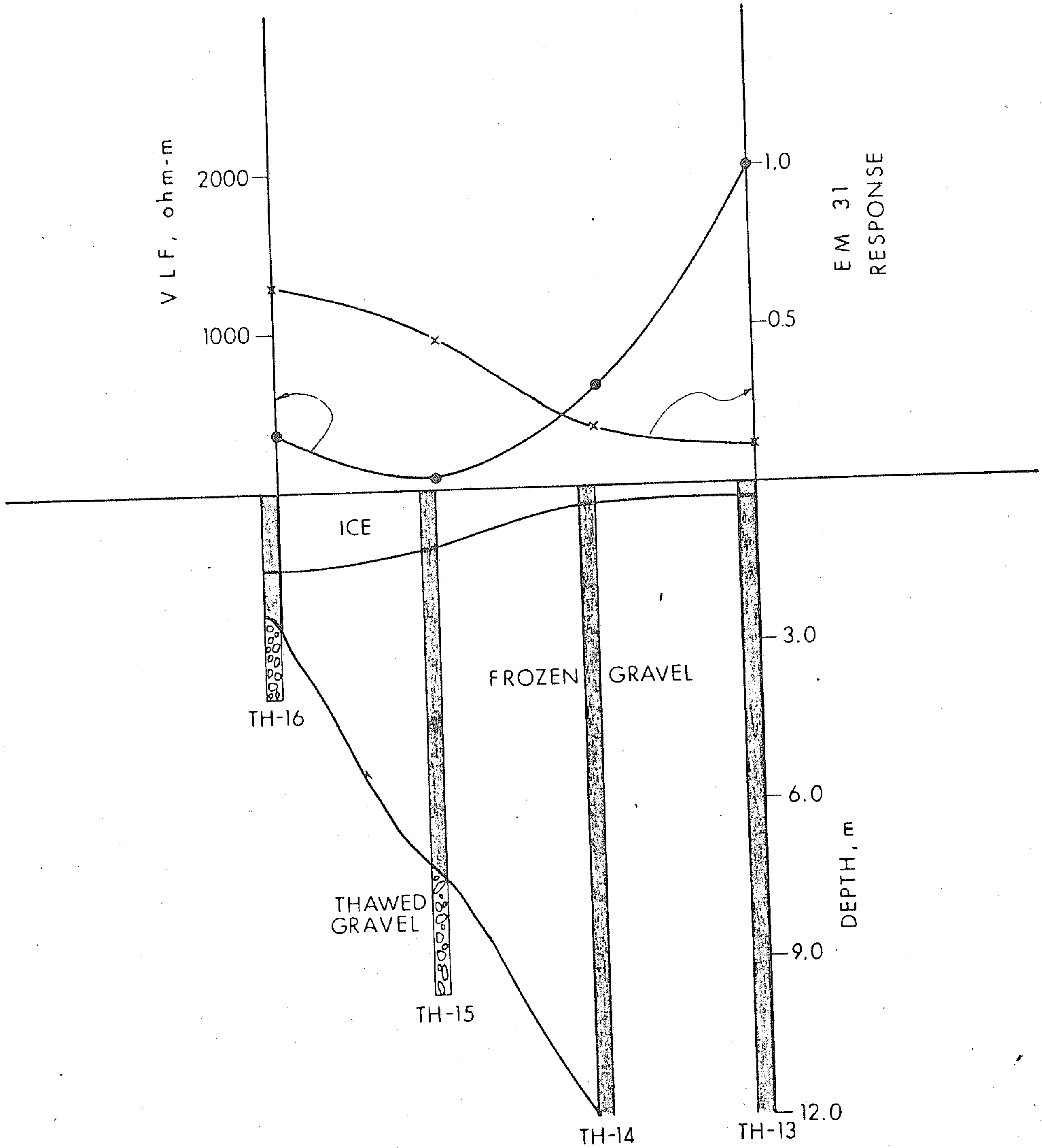

Figure IV-5
Results of test hole data,
VLF radiohm and EM31 measurements
across an unfrozen zection in the
west channel of the Sagavanirktok
River behind the Kodiak Co.

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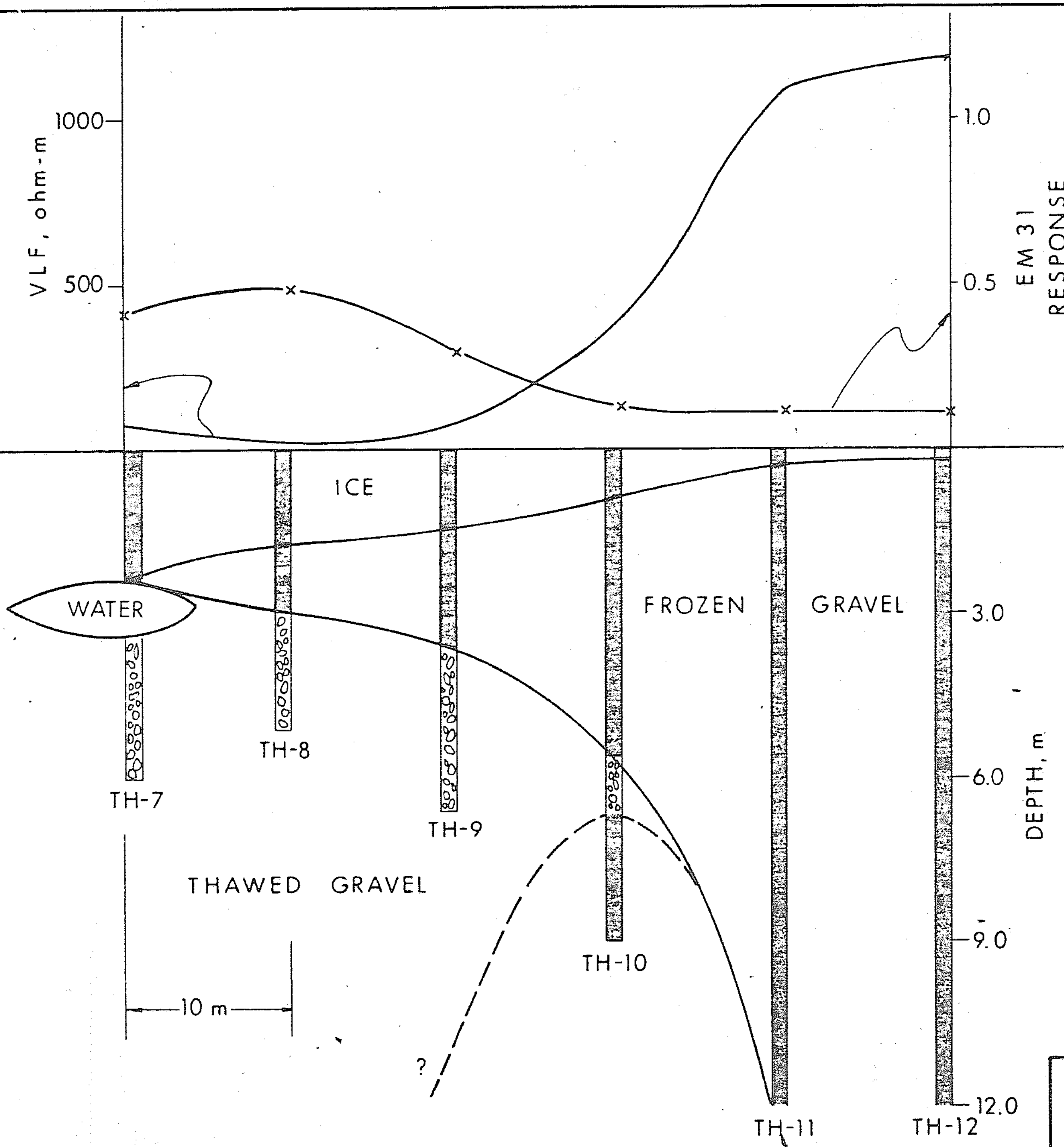

Figure IV-6
Results of test hole data, VLF radiohm and EM31 measurements across an unfrozen section in the west channel of the Sagavanirktok River behind the Kodiak Co.

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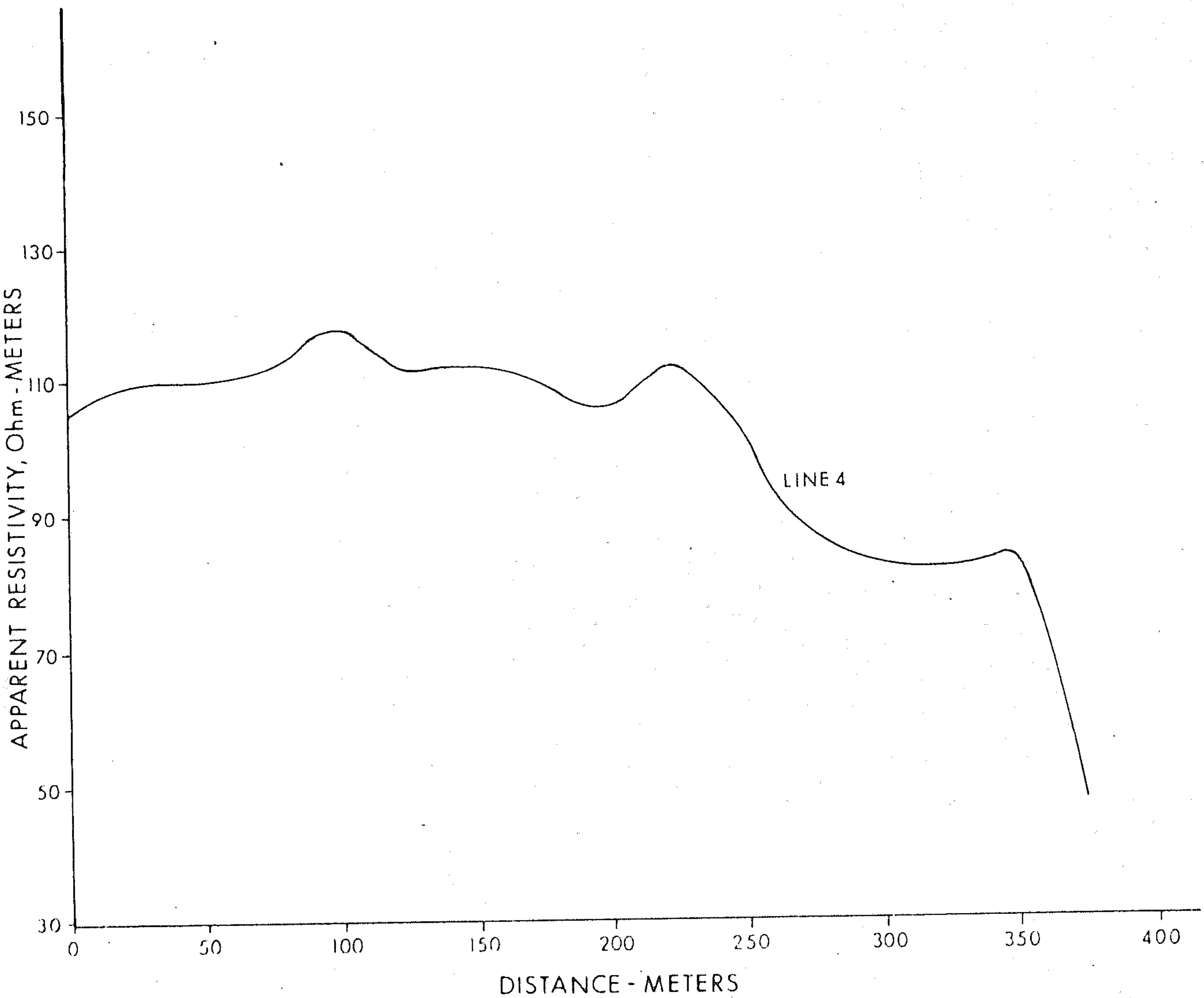

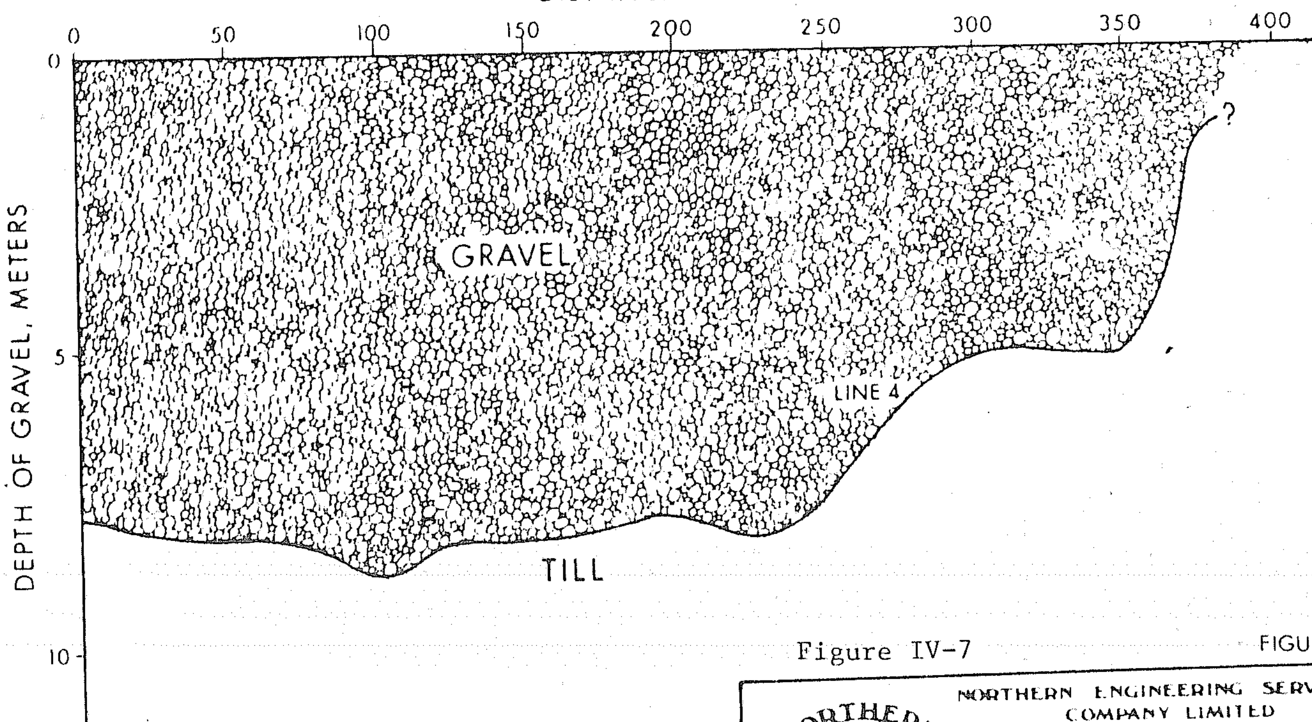

PIT No. 2
STANDARD GENERAL
OGDEN PIT, NORTH WALL

Figure IV-7

FIGURE 4

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Figure IV-8

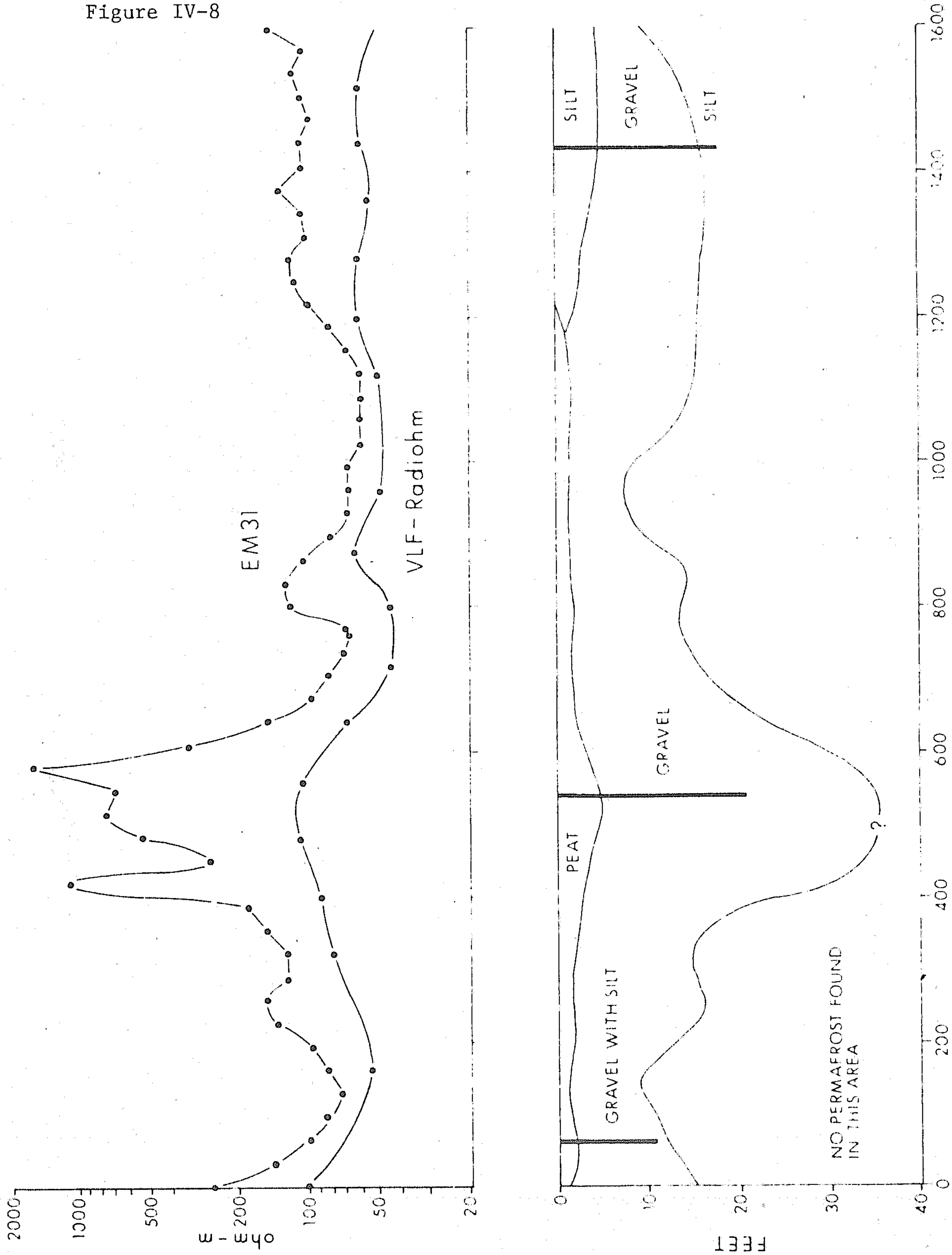
EM31
VLF- Radiohm
ohm - m
2000
1000
500
200
100
50
20
FEET
0
10
20
30
40
SILT
GRAVEL
SILT
GRAVEL
PEAT
GRAVEL WITH SILT
NO PERMAFROST FOUND
IN THIS AREA
?
0
200
400
600
800
1000
1200
1400
1600
FEET

Table 4-1. Comparison of permafrost delineation from test hole log and geophysical interpretation*.

Site No.	Test Hole No.	Station No.	Frozen (F) or Unfrozen (U) Geophysics	Frozen (F) or Unfrozen (U) Test Hole	Agreement Yes	Agreement No
N76-3	N76-3-1	0+50	?	U		
N76-5	N76-5-1	0+14.5	U	U	X	
	N76-5-2	0+25	F	F	X	
N76-8A	N76-8A-1	1+15	U	U	X	
	N76-8A-2	1+15.5	U	U	X	
	N76-8A-4	1+10	U	U	X	
N76-8B	N76-8B-2	0+50	F	F	X	
	N76-8B-3	0+35	U	U	X	
N76-10	N76-10-1	0+30	F	F	X	
	N76-10-2	0+08	F	F	X	
N76-14	N76-14-1	1+00	F	F	X	
N76-15	N76-15-2	0+60W	U	U	X	
	N76-15-3	0+25W	F	F	X	
	N76-15-4	0+37W	F	F	X	
N76-19	N76-19-2	0+45W	F	F	X	
N76-21	N76-21-1	0+60S	F	F	X	
	N76-21-2	0+25E	F	F	X	
N76-22	N76-22-1	0+17N	U	U	X	
	N76-22-2	0+15N	U	U	X	
	N76-22-3	0+30N	F	F	X	
	N76-22-4	0+50N	F	F	X	
N76-23	N76-23-1	0+65N	?	U		
	N76-23-2	0+40N	F	F	X	
	N76-23-3	0+25N	F	F	X	
N76-24	N76-24-1	0+80S	?	U		
	N76-24-3	1+100S	F	F	X	
	N76-24-4	0+90S	F	F	X	

* Frozen ground less than 1 m thick is considered due to seasonal frost, and permaftost is considered absent.

5. CONCLUSIONS AND OUTLOOK

Research and development by government agencies and industries in geophysical methods for electrical resistivity measurements of ground have resulted in two new techniques, radiohm and inductive coupling. Field tests with these instruments have shown that they have the following advantages over conventional methods:

a) They can be used when the ground is frozen and snow covered, the best time for field surveys in permafrost regions.

b) The productivity of surveying has been improved over conventional methods by at least a factor 10.

c) The resolution for detecting local changes in subsurface conditions has been improved by at least a factor 3.

d) A continuous resistivity profile can be obtained.

In applying electrical resistivity mapping to subsurface exploration, field tests showed that geophysical surveys can lower the cost and improve the quality of subsurface exploration for the following geotechnical objectives:

a) delineating boundaries of frozen and unfrozen ground

b) determining the thickness of frozen ground

c) locating unfrozen zones under rivers of the Arctic coastal plain in the winter.

d) making inventories of unfrozen granular deposits.

The best use of geophysical surveys is made when it is closely integrated with geological office and field studies, and drilling. Once a pipe center line has been cleared, plans are to haul a sled with two inductive coupling systems over the pipe center line, and record two resistivity profiles continuously. One of the systems will be the EM 31, (depth of exploration 7.5 to 10m), and one system with an exploration depth up to 18 - 20m (60 ft). The system with deeper exploration depth will be delivered in early April 1977, and will subsequently be field tested. The concept is illustrated in Figure V-1.

Subsequent to the geophysical surveys drill holes will be placed to calibrate geophysical interpretations and to check out anomalies in the geophysical profiles. The continuous geophysical profile will allow a continuous extrapolation of test hole information.

The geological terrain mapping will allow segmentation of the route in divisions of similar geological origin. For each division, such characteristics as soil type, stratification and ice content may then be established.

The transmittal of terrain and subsurface data in convenient forms to those responsible for design and construction is as much a concern to us as the collection of the data. Terrain typing, the presence or absence of permafrost and test hole data are presently being entered in computer files. The experience so far has been that computer storage and data manipulation allows us to quickly respond to requests for terrain data, and to supply those data in convenient formats.

Prepared by: ______________________
J. Henderson

Approved by: ______________________
P. Hoekstra, Ph.D.,P.Eng.

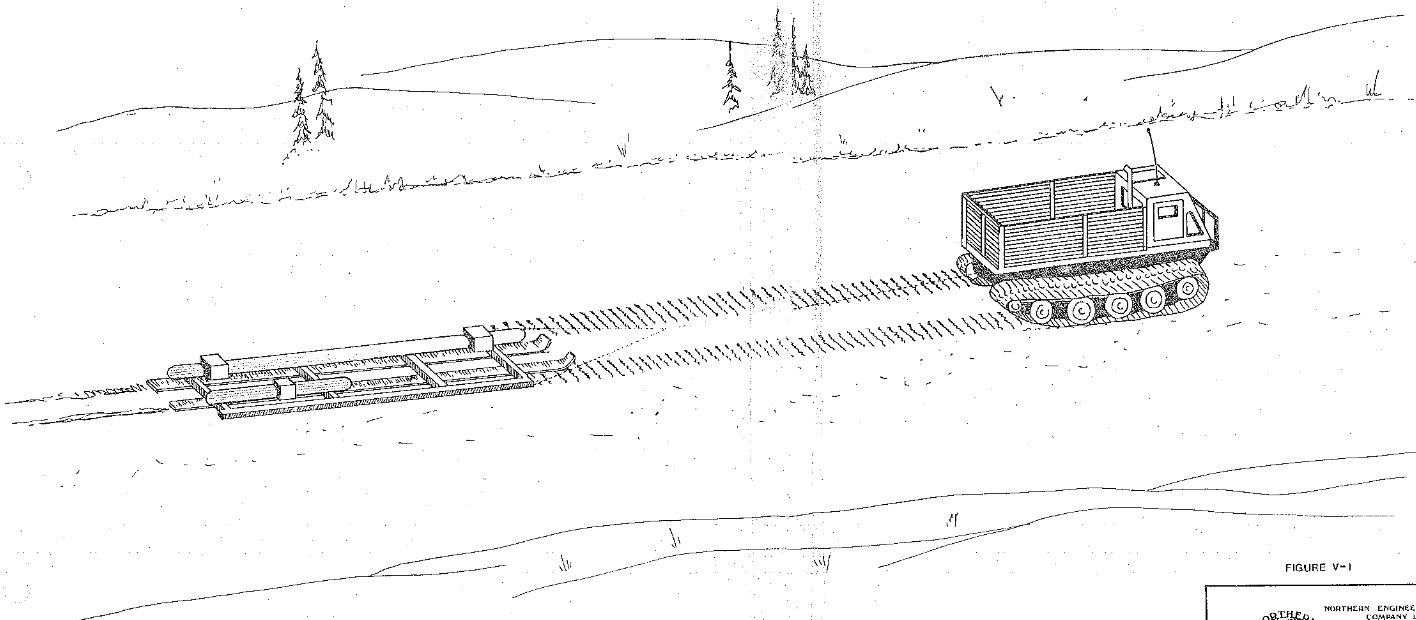

FIGURE V-I

1976 SPRING TIRRAIN INVESTIGATION
FORT SIMPSON N.W.T. TO ZAMA LAKE, ALBERTA
SCHEMATIC CONCEPT FOR GEOPHYSICAL SURVEYS ALONG RIGHT OF WAY

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TABLE 1

Summary of Mileages in Different Categories of Thickness of Permafrost along the Arctic Gas Pipeline right-of-way from Compressor Station MO6 (MP 262.9) to Compressor Station MF15 (MP 660.8)*

Cooling study at 15A

Full chilled

From Station	6	7	8	9	10	11	12	13	14	Total Miles
At MP	262.9	310.0	356.9	400.2	446.4	489.8	534.3	583.1	625.3	
To Station	7	8	9	10	11	12	13	14	15	
At MP	310.0	356.9	400.2	446.4	489.8	534.3	583.1	625.3	660.8	
Distance Between Stations, Miles	47.1	46.9	43.3	46.2	43.4	44.5	48.8	42.2	35.5	397.9
Miles of Unfrozen Ground, Including Rivers	16.3	6.1	8.1	3.1	5.3	4.0	15.4	17.2	14.0	89.5
Miles of Frozen Ground Less than 15 Ft. thick	3.3	3.3	3.3	3.3	2.7	5.3	4.7	3.3	4.0	33.2
Number of Sections of Unfrozen Ground and Frozen Ground Less Than 15Ft. Thick	40	43	59	62	82	334	366	422	426	
Number of Interfaces	80	86	118	124	164	668	732	844	852	
Miles of Frozen Ground 15 Ft. to 25 Ft. Thick	1.8	3.7	4.8	8.0	8.3	16.2	13.4	10.0	7.5	73.7
Miles of Frozen Ground 25 Ft. to 60 Ft. Thick	3.7	9.4	11.2	18.0	20.0	14.8	12.0	9.0	7.0	105.1
Miles of Frozen Ground Greater than 60 Ft. Thick	22.0	24.4	15.9	13.8	7.1	4.2	3.3	2.7	3.0	96.4
River Crossing, Miles	0.27	0.10	0.13	0.10	0.33	-	0.35	0.23	0.06	1.6
Mileages where Bedrock is within 20 Ft. of the Surface and Ground is unfrozen or frozen less than 15 Ft. Thick	7.0	3.0	3.2	1.0	0.0	0.0	0.0	1.8	1.5	17.5

* Information derived from boreholes listed on Table 2

Northern Engineering Services

TABLE 2

References of boreholes used for terrain studies, Willowlake River to Fort Good Hope.

E. W. Brooker and Associates Ltd.
Geotechnical Investigation, Mile 650-724.7 for Department of Public Works, 1972.

R. M. Hardy and Associates Ltd.
"Geotechnical Investigation, Mackenzie Highway, Mile 544-635" for Department of Public Works, 1972-73.

Underwood McLellan and Associates Ltd.
"Geotechnical Investigation, Proposed Mackenzie Highway, Mile 450-545" for Department of Public Works, 1972-73.

Templeton Consultants Ltd.
"Preliminary Soils and terrain investigation program Mile 100-520 of proposed pipeline route" for Alberta Gas Trunk Line Co. Ltd. (Gas Arctic Project), 1971.

E. W. Brooker and Associates Ltd.
"Geotechnical Report, Terrain Investigation Proposed Arctic Gas Pipeline Route" for Gas Arctic - Northwest Project Study Group, 1972.

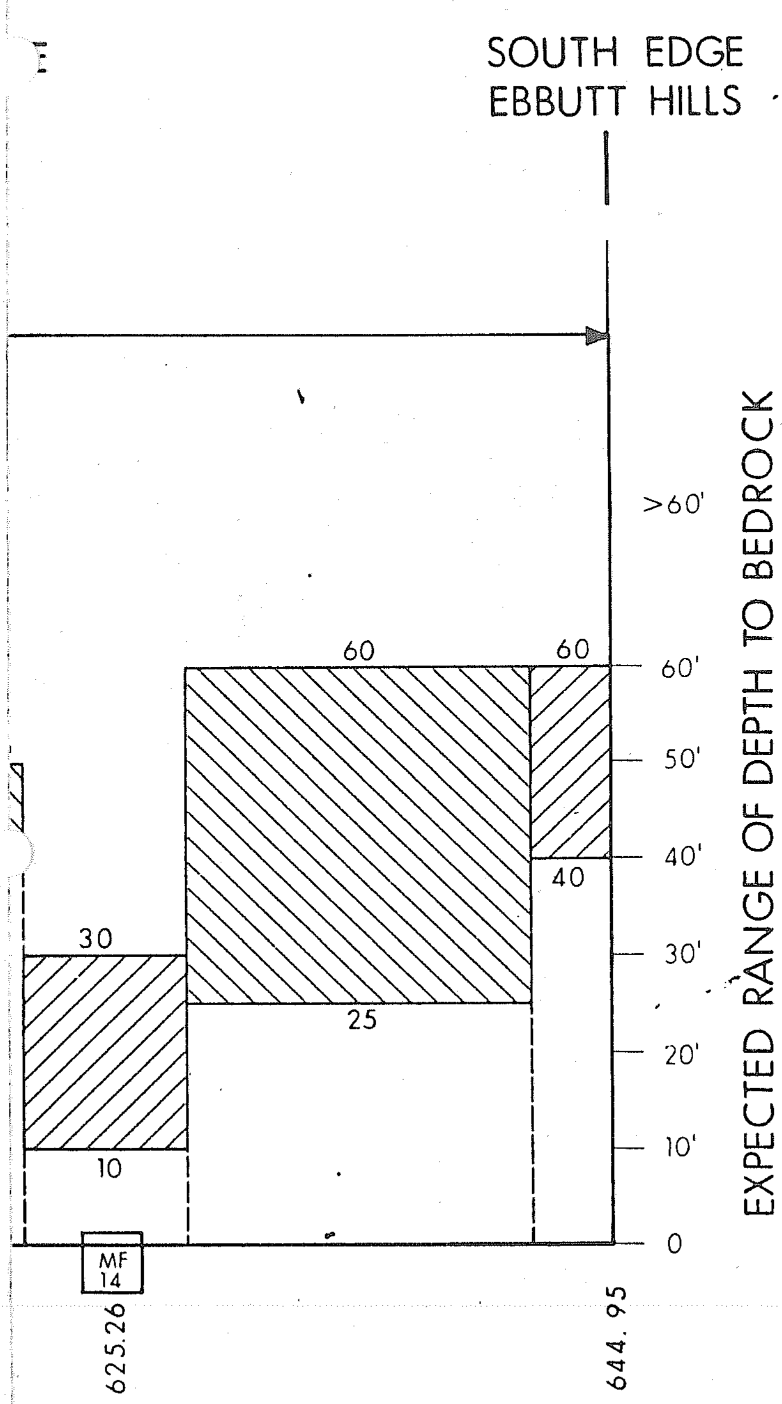
Ripley Klohn and Leonoff Alberta Ltd.
"Prudhoe Bay, Alaska to Alberta/N.W.T. Border" for Mackenzie Valley Pipeline Research Ltd., 1970.

Blackwell, J.M., and Watson, G.H.,
"Mackenzie Delta Section - Mackenzie Valley Pipeline Research Ltd., 1972.

Templeton Engineering Co.
"Permafrost Regression Studies, Norman Wells and Fort Simpson, N.W.T." for Alberta Gas Trunk Line Co. Ltd. - Gas Arctic - Northwest Project Study Group, 1970.

Geophysical Field Investigations at 40 sites along the proposed Arctic Gas route between Willowlake River, N.W.T. to Saline River, N.W.T.

3BUTT HILLS



3	4	5	6
	20	70	100 Show >40'

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APPENDIX 3 FIGURE 1

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
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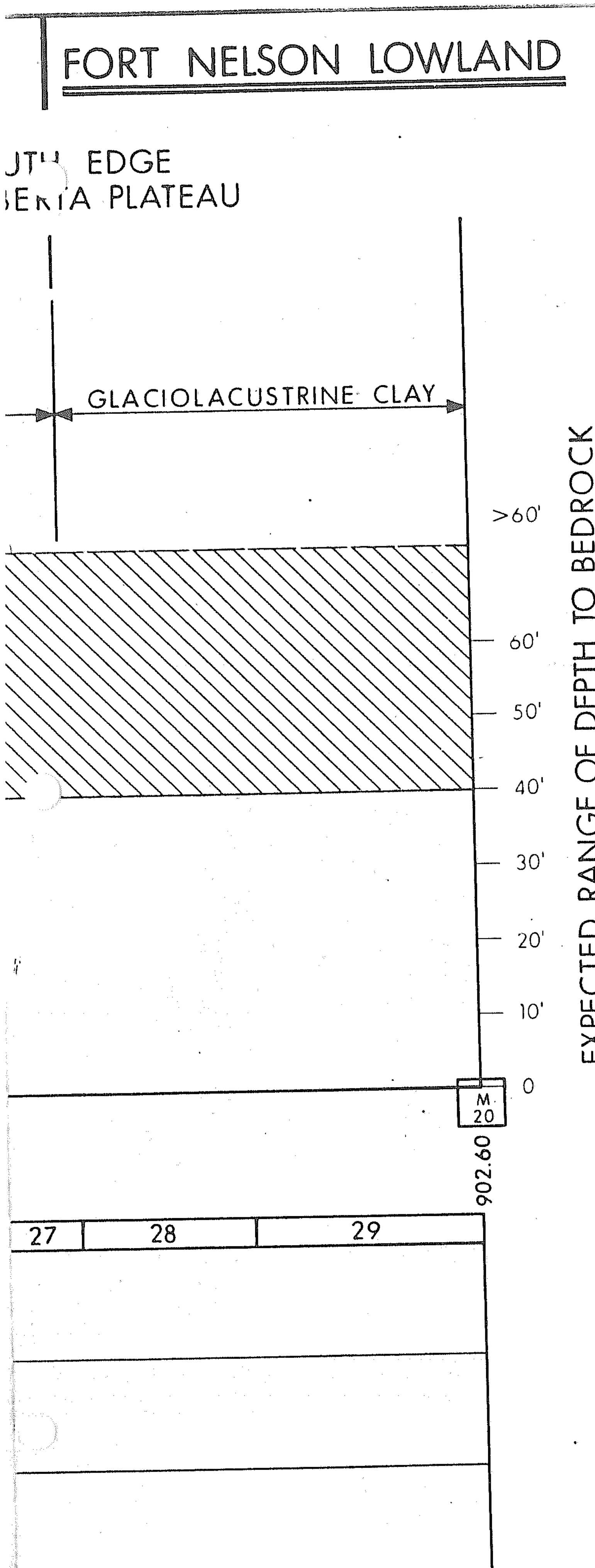
CANADIAN ARCTIC GAS STUDY LIMITED

EXPECTED RANGE — DEPTH OF BEDROCK

FORT GOOD HOPE TO ZAMA LAKE



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APPENDIX 3 FIGURE 2

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EXPECTED RANGE — DEPTH OF BEDROCK

FORT GOOD HOPE TO ZAMA LAKE

TABLE 1 - SUMMARY OF FREEZING TEST DATA

Test	Terrain Type	Depth ft	Pressure psf	Lensing Heave Rate ft/yr	Total Heave Rate ft/yr	Duration of Test (min)	Period Over Which Heave Rates Calc. (min)
N76-8B-3U9 (1)	DL	22.5	3600	0.1	0.1	8817	6000 - 8817
N76-8B-3U9 (2)	DL	23.0	2880	0.16	0.16	12804	8500 - 12804
N76-8B-3U10 (1)	DL	23.5	4320	0.34	0.34	11590	6600 - 11590
N76-8B-3U10 (2)	DL	24.0	5040	0.09	0.1	14025	3000 - 7000
N76-23-3U3 (1)	RKM	25.0	2880	0.86	0.85	8219	7259 - 8219
N76-23-3U3 (2)	RKM	25.5	4032	0.28	0.38	6665	5825 - 6665
N76-23-3U4 (3)	RKM	26.0	2880	0.08	0.10	8229	7644 - 8229
N76-23-3U4 (4)	RKM	26.5	3600	0.53	0.55	14405	9000 - 11000
N76-23-3U4 (5)	RKM	27.0	4032	0.36	0.32	10166	9326 - 10166
B8A-1U3 (1)	RKM	17.5	2880	1.08	1.17	9623	2750 - 4000
B8A-1U3 (2)	RKM	18.0	3456	0.75	0.77	8190	7005 - 8190
B8A-3U6 (1)	RKM	17.8	4032	0.30	0.29	5505	4065 - 5505
B8A-3U6 (2)	RKM	18.3	3024	0.64	0.60	9687	8517 - 9687
N75-SH1-U3 (1)	MRD	8.0	3024	0.0	0.01	11176	9136 - 11176
N75-SH1-U3 (2)	MRD	8.5	4032	0.0	0.06	11168	9728 - 11168
N75-SH1 (3)	Slurry	-	2016	0.13	0.14	14006	11486 - 12566
N75-SH1 (4)	Slurry	-	3024	0.08	0.09	18510	16250 - 17500
NRSH-1	Slurry	-	504	0.32	0.35	14240	10250 - 12845
NRSH-2	Slurry	-	1008	0.21	0.22	12564	10044 - 11124
NRSH-4	Slurry	-	504	0.22	0.18	8586	5500 - 8500
RSHC-1	Slurry	-	1728	0.38	0.41	12581	10061 - 11141
RSHC-2	Slurry	-	3456	0.13	0.17	11061	9021 - 9621
RSHC-3	Slurry	-	4032	0.13	0.15	12500	9980 - 11060
RSHF-1	Slurry	-	3024	0.24	0.27	18641	14880 - 16800
RSHF-3	Slurry	-	2016	0.44	0.47	14031	9500 - 12500

DL - Deltaic fine sand overlying layered silt and clay.
RKM - Lodgement till; silty clay matrix with variable amount of sand, gravel, pebbles, cobbles, boulders.
MRD - Mackenzie River Delta; layered silt and clay, occasional layer of fine sand.
Slurry - MRD remoulded.

TABLE 2. THAW SETTLEMENT

SEGMENT	DISTANCE MILES	PERMAFROST MILES	SPECIAL SUPPORT MILES	DEEP BURIAL AVERAGE DEPTH FROM ORIGINAL GROUND SURFACE TO BOTTOM OF PIPE 12 ft. (or less) MILES	16 ft. MILES
MP 661-MP 683	22	7.0	0.7	4.2	2.1
MP 683-MP 723	40	4.6	3.2	0.5	0.9
MP 723-MP 807	84	16.6	0.9	8.3	7.4
MP 807-MP 881	74	37.3	14.8	7.5	15.0
TOTAL	220	65.5	19.6	20.5	25.4

TABLE 3(a) SEGMENT: MP 661 - MP 683

TEST HOLE NO.	TERRAIN TYPE	PEAT DEPTH (ft)	PERMAFROST DEPTH (ft)	SETTLEMENT OF PIPELINE FOR INDICATED BURIAL DEPTH (ft) 8'	12'	16'
N75-6A-1	RKM-BS	12.1	15.6	1.9	0.5	0
N75-6B-1	RKM-BS	7.8	16.3	1.3	0.7	0.1
N75-TSF-6B-1	RKM-PT	4.8	43.0+	0.4	0.3	0.2

TABLE 3(b) SEGMENT: MP 683 - MP 723

TEST HOLE NO.	TERRAIN TYPE	PEAT DEPTH (ft)	PERMAFROST DEPTH (ft)(1)	SETTLEMENT OF PIPELINE FOR INDICATED BURIAL DEPTH (ft)(2)		
				8'	12'	16'
N76-6-1	DL-Sand Dune	0.5	15.0	2.0	0.7	0
N75-4B-1	DL-PT	7.3	18.5+ (50.0)	1.0 (3.1)	0.4 (2.6)	0.2 (2.3)
N75-4B-2	DL-PT	4.0	20.4+ (50.0)	0.6 (1.2)	0.3 (1.0)	0.1 (0.8)
N75-4D-1	DL-PT + Trees	4.3	20.5	2.1	1.6	0.8
N76-5-2	DL-BS	8.0	33.0	11.1	8.2	5.9
N75-5A-2	DL-BS	10.5	23.4+ (50.0)	4.9 (8.3)	3.5 (6.9)	1.9 (5.2)
N75-TSF-13-1	DL-Trees	0.5	52.5	11.0	10.8	10.5
N75-TSF-13B-1	DL-BS	13.5	42.0	15.8	14.5	13.1
N76-8A-3	DL-BS	7.5	24.0	8.5	5.5	1.7
N76-8B-2	DL-Trees	0.5	50.5	9.2	9.1	8.9
N73-101	RKM-BS	10.0	17.5	1.6	0.7	0.2
N73-102	RKM-BS	15.5	19.0	3.2	1.9	0.7
N73-103	RKM-BS	10.0	9.0	0.3	0	0
N73-104	RKM-BS	14.0	18.0	3.2	1.9	0.5
N73-105	RKM-BS	5.0	25.5+ (50.0)	0.6 (1.2)	0.3 (0.9)	0.3 (0.8)

(1) Number shown ( ) is assumed depth for permafrost

(2) Number shown ( ) is settlement to assumed permafrost depth

TABLE 3(c) SEGMENT: MP 723 - MP 807

TEST HOLE NO.	TERRAIN TYPE	PEAT DEPTH (ft)	PERMAFROST DEPTH (ft)(1,3)	SETTLEMENT OF PIPELINE FOR INDICATED BURIAL DEPTH (ft)(2) 8'	12'	16'
N76-10-1	RKM(AB)-BS	6.5	34.0	2.1	1.1	0.7
N76-10-2	RKM(AB)-BS	4.0	18.3	0.8	0.2	0.1
N76-14-1	RKM-BS	3.0	27.0+ [33.5]	0.8	0.7	0.6
N75-TSF-21A-1	HM-BS	9.0	18.5	3.3	2.1	0.8
N76-15-3	RKM-BS	4.6	26.0	0.7	0.4	0.3
N76-15-4	RKM-BS	2.8	22.0	0.5	0.3	0.2
N75-EB-1	RKM-BS	8.0	14.5+ (40.0)	2.2 (4.7)	0.3 (2.8)	0.0 (2.6)
N75-EB-3	RKM-BS	10.7	18.0+ (40.0)	4.1 (12.8)	2.6 (11.3)	0.8 (9.5)
N75-EB-8	RKM-BS	10.3	19.0+ (40.0)	4.4 (5.7)	2.8 (4.0)	0.7 (1.9)
N75-EB-13	RKM-BS	8.5	13.0+ (40.0)	1.2 (1.7)	0.0 (0.6)	0.0 (0.5)
N75-TSF-22-1	RKM-BS	9.5	19.0	5.3	2.6	0.5

(1) Number shown ( ) is assumed depth for permafrost

(2) Number shown ( ) is settlement to assumed permafrost depth

(3) Number shown [ ] is based on geophysics survey

TABLE 3(d) SEGMENT: MP 807 - MP 881

TEST HOLE NO.	TERRAIN TYPE	PEAT DEPTH (ft)	PERMAFROST DEPTH (ft)(3)	SETTLEMENT OF PIPELINE FOR INDICATED BURIAL DEPTH (ft) 8'	12'	16'
N76-19-2	RKM-BS	11.0	22.5	3.0	1.7	0.6
N76-21-1	RKM-BS	23.0	38.5	10.0	8.3	7.0
N76-22-3	RKM-BS	7.0	24.3	1.7	0.4	0.2
N76-22-4	RKM-BS	5.6	33.0	3.5	1.7	0.5
N76-23-3	RKM-BS	13.3	21.0	5.1	3.8	2.4
N76-24-2	RKM-BS	8.5	27.8+ [44.6]	2.3	1.0	0.8
N76-24-3	RKM-BS	7.0	34.0	3.7	2.3	0.9

(3) Number shown [ ] is based on geophysics survey

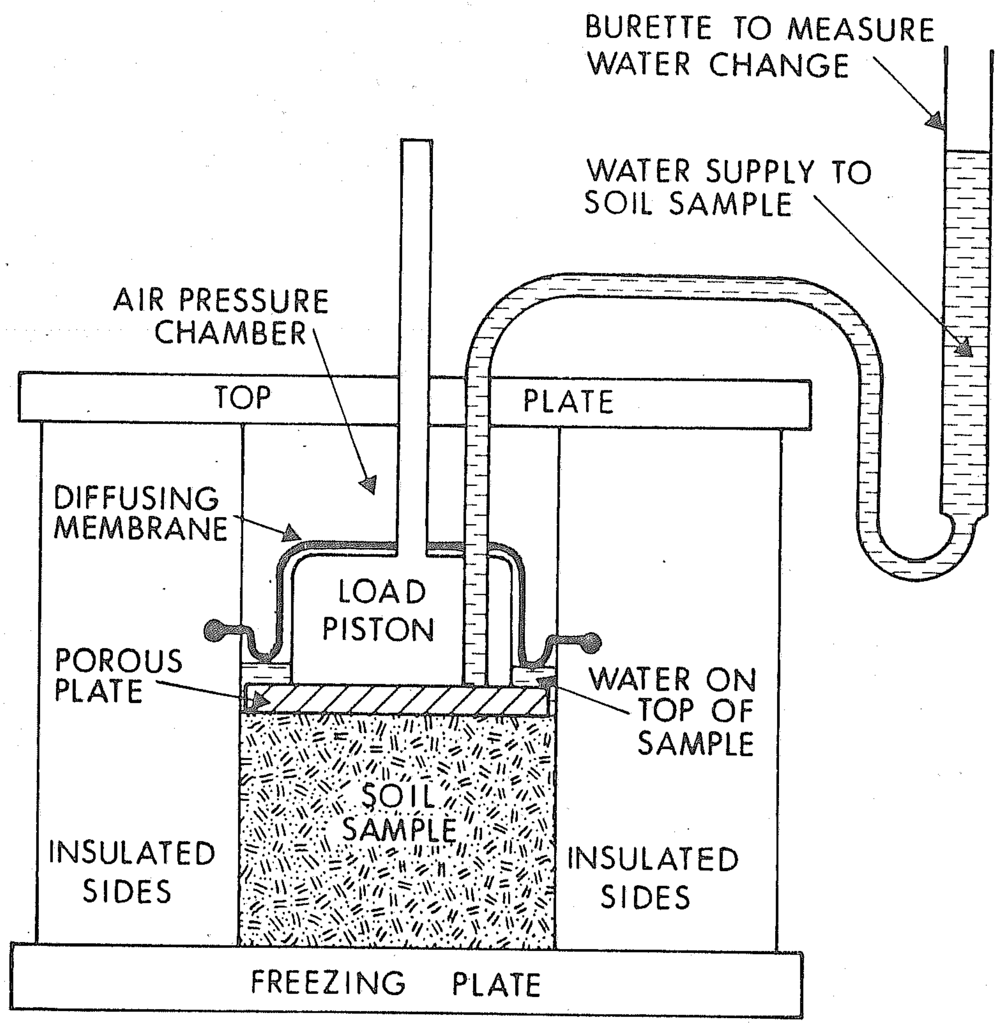


FIG. 1 FROST HEAVE TEST CELL

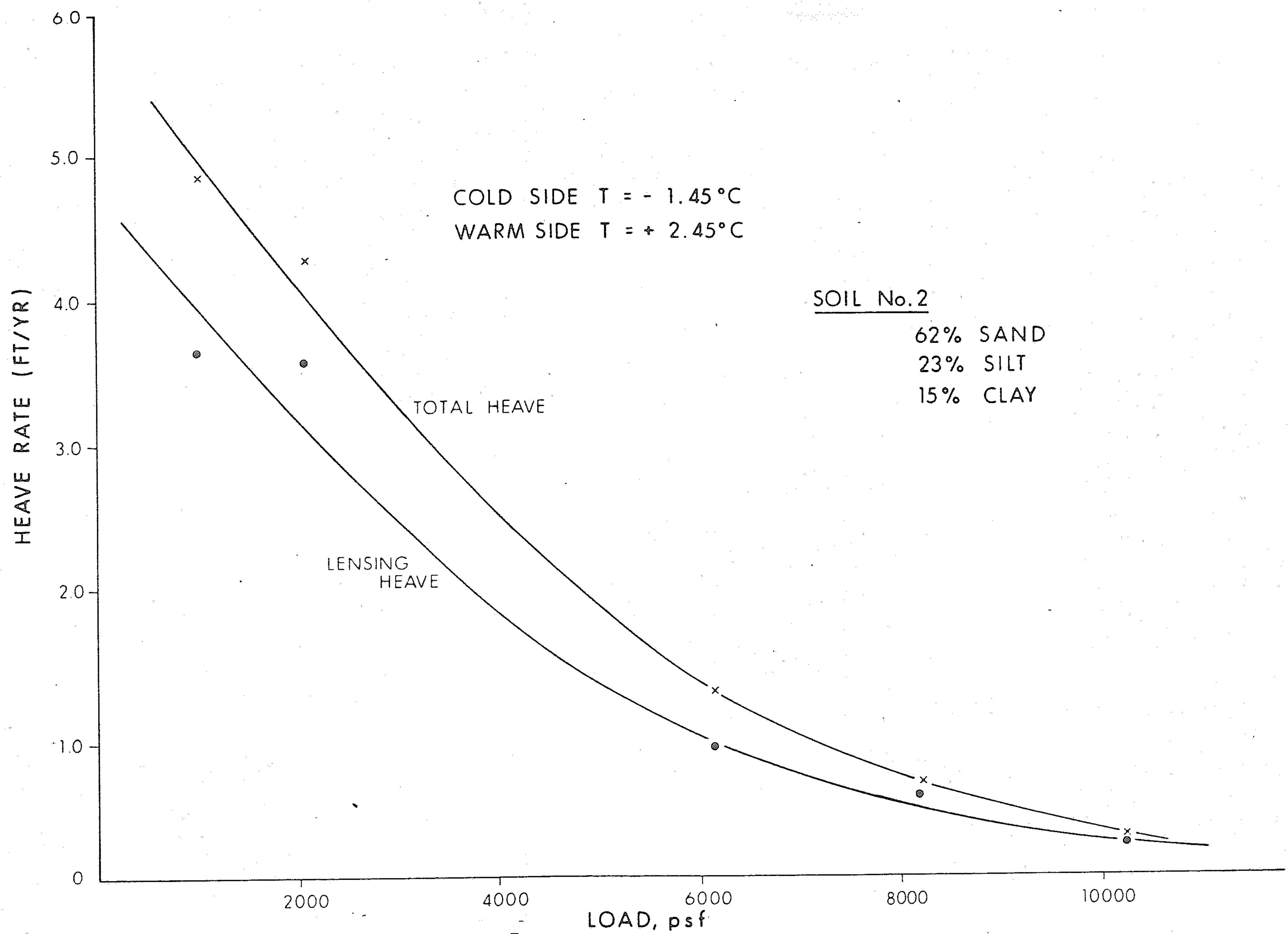


FIG. 2 HEAVE RATE VERSUS LOAD
(DATA FROM M. E. PENNER N.R.C)

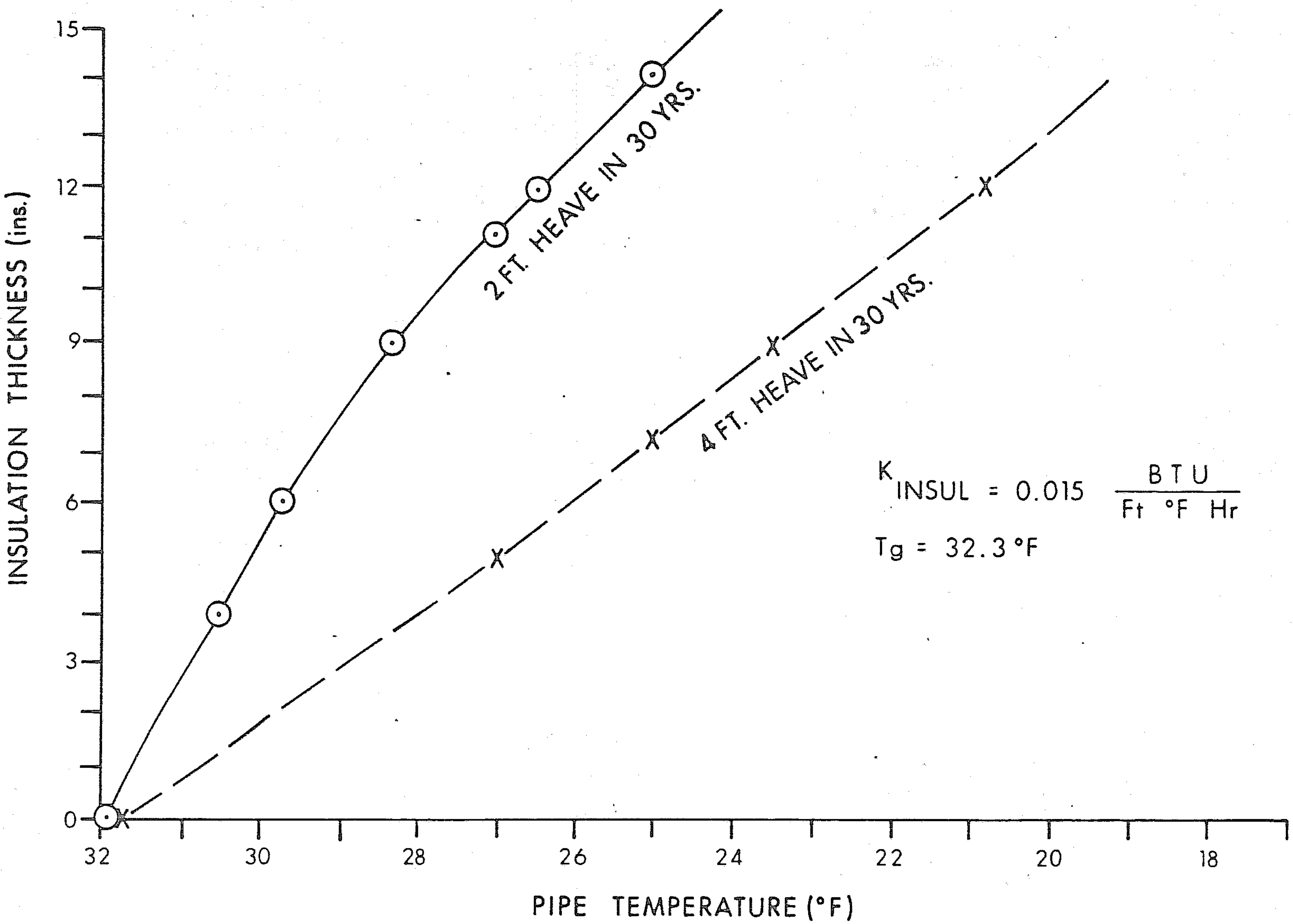


FIG. 3 INSULATION THICKNESS REQUIRED
FOR
MAXIMUM POTENTIAL HEAVES OF 2 AND 4 FEET IN 30 YEARS

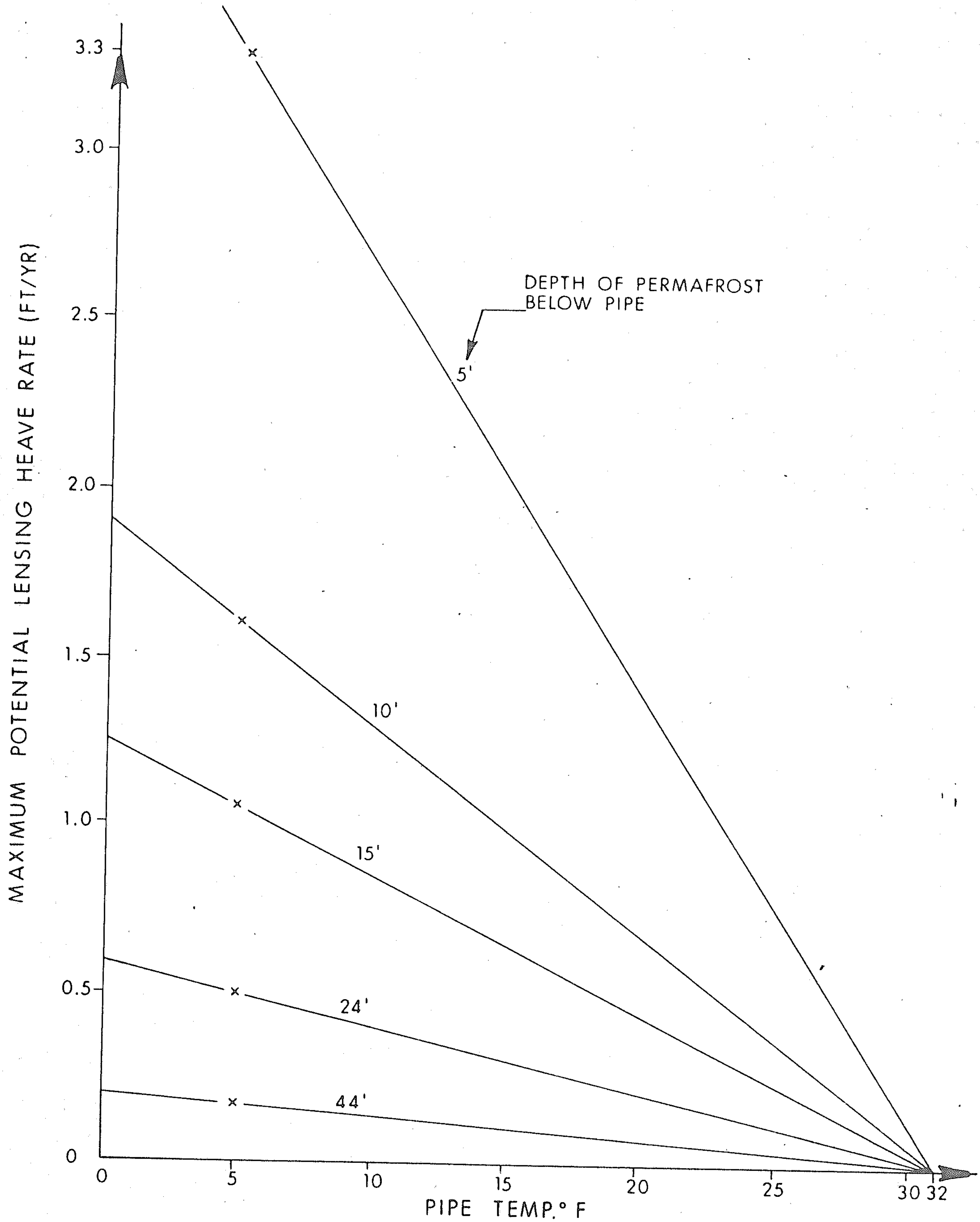


FIG. 4 LENSING HEAVE RATE UNDER SHALLOW PERMAFROST – NO INSULATION

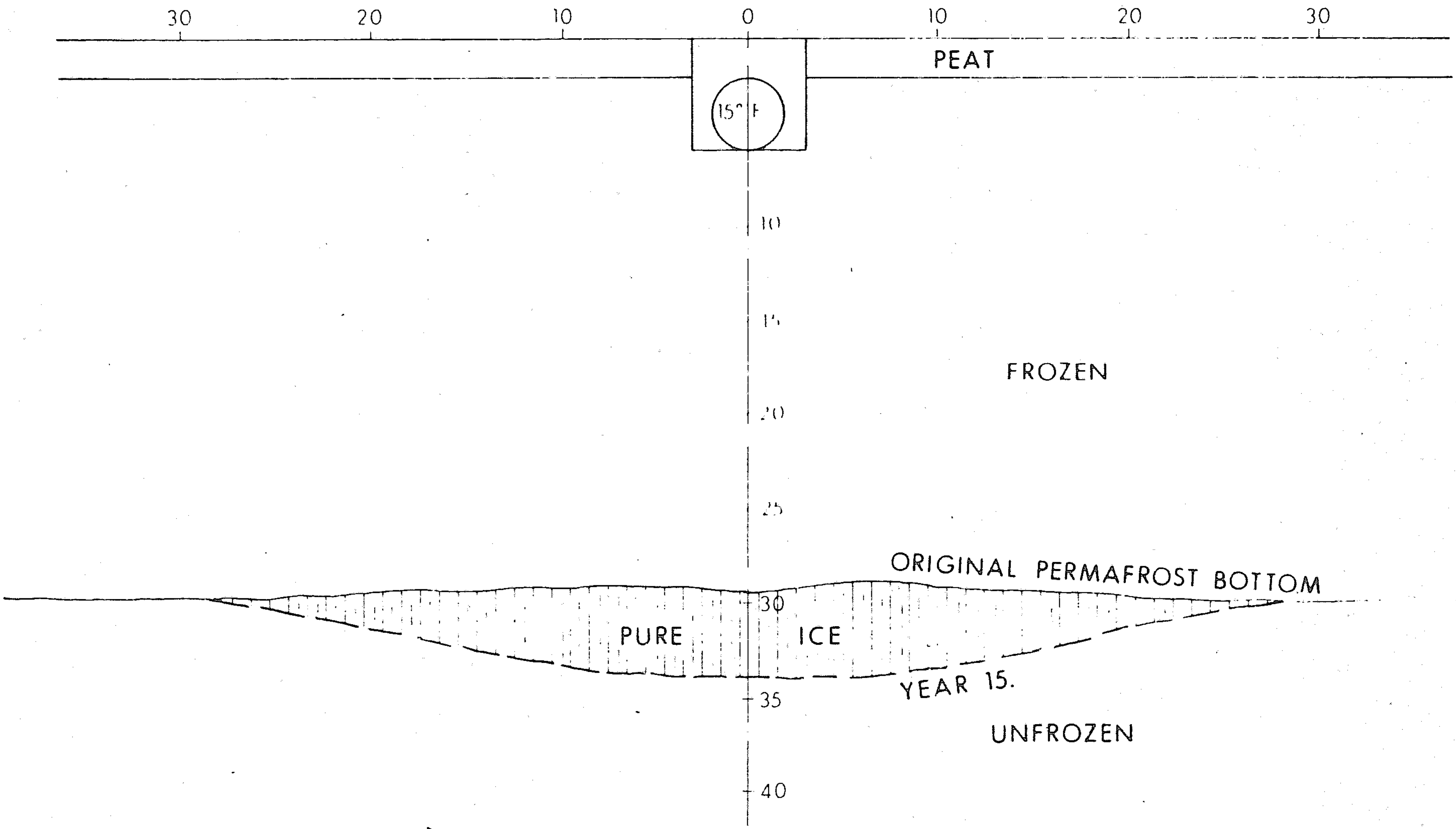


FIG. 5. MAXIMUM POTENTIAL LENSING HEAVE UNDER 30' PERMAFROST FOR 15°F PIPE

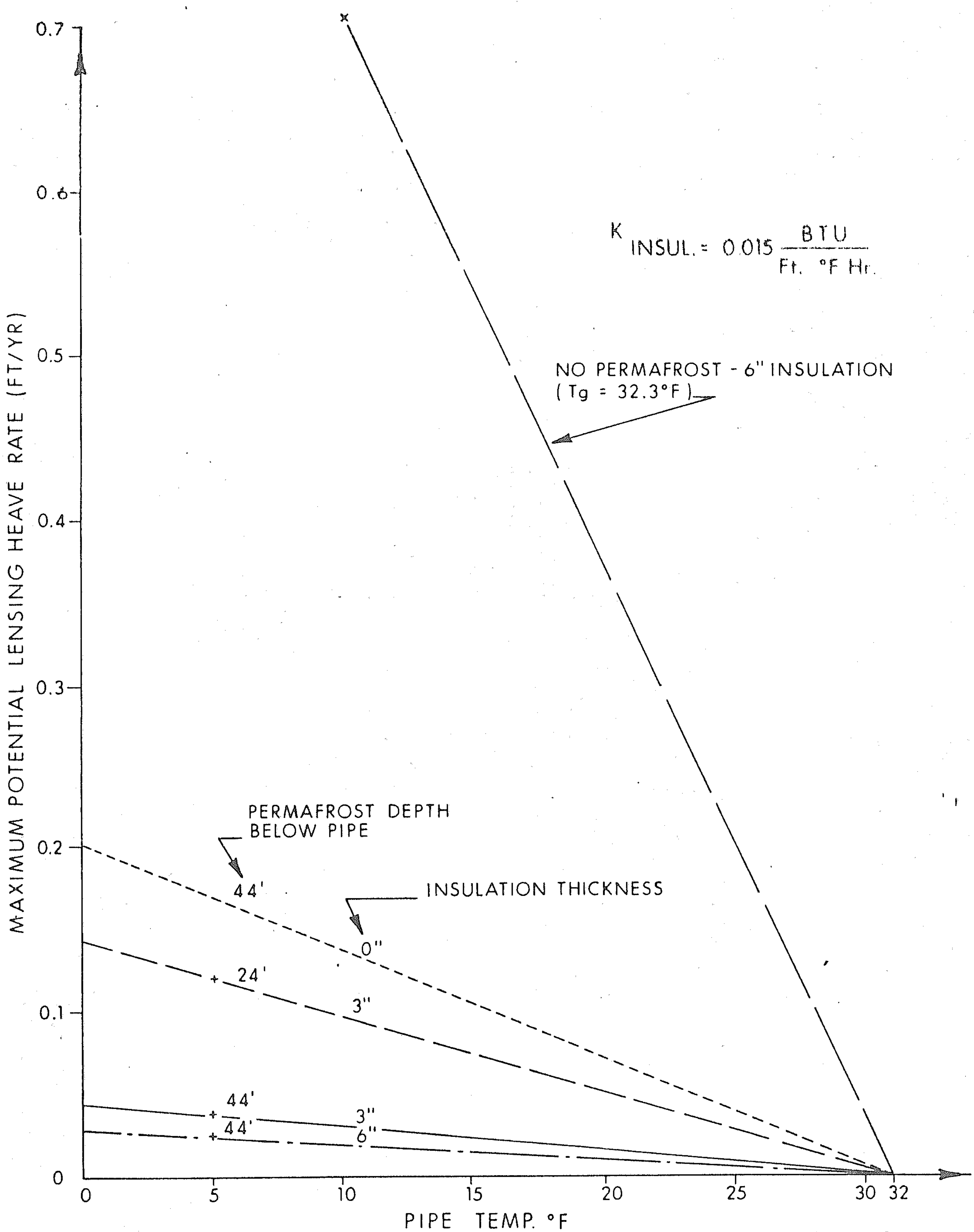


FIG. 6 MAXIMUM POTENTIAL LENSING HEAVE RATES

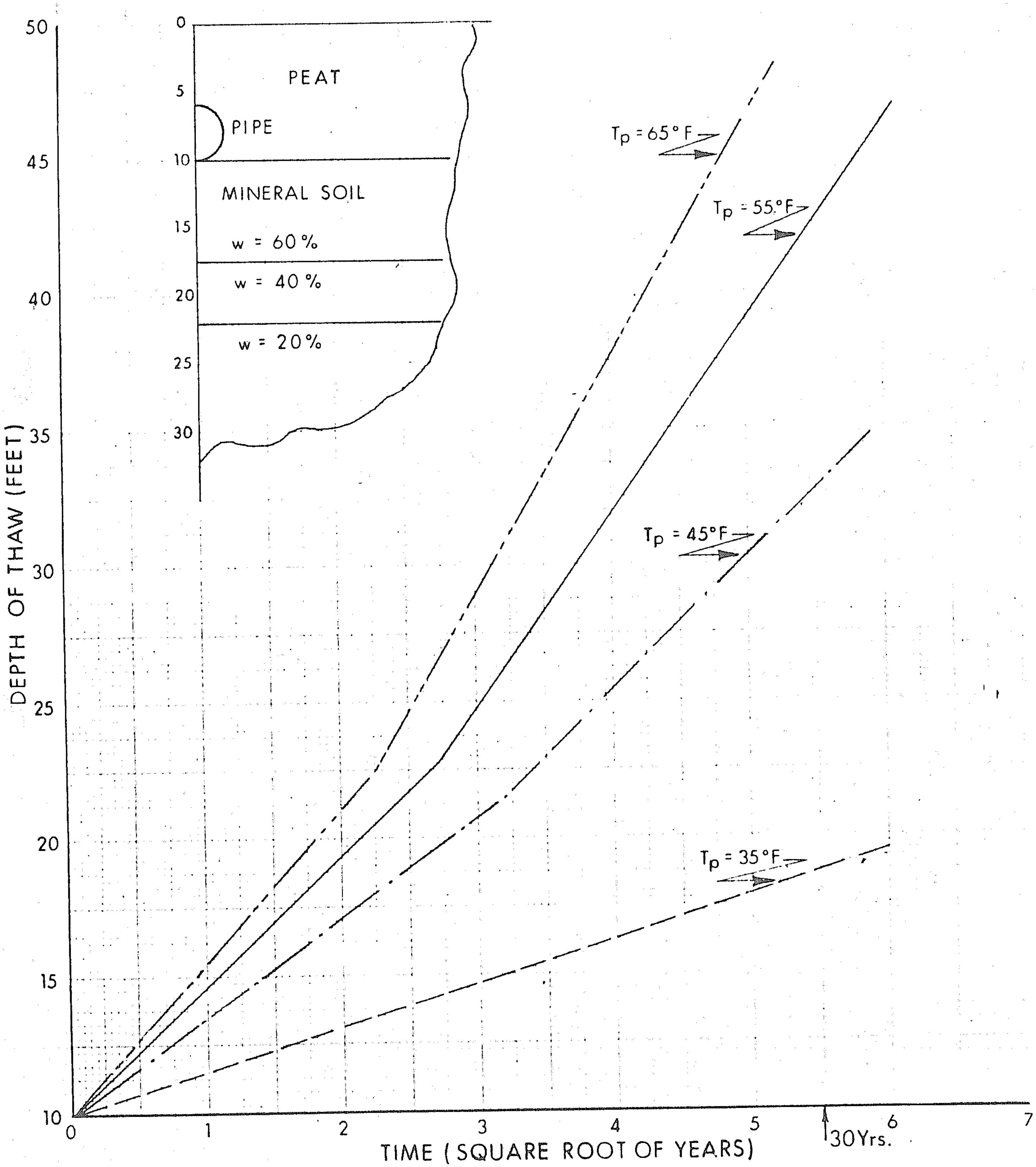


FIG.7 DEPTH OF THAW UNDER PIPE

$$S = A_o X + a_o \int_o^X (P + \gamma' x)\, dx$$

WHERE:

S = TOTAL THAW SETTLEMENT

A_o = OBTAINED FROM FIGURES 9, 10 AND 11

X = THAW DEPTH

a_o = OBTAINED FROM FIGURES 12, 13 AND 14

P = EFFECTIVE LOAD ON SOIL LAYER

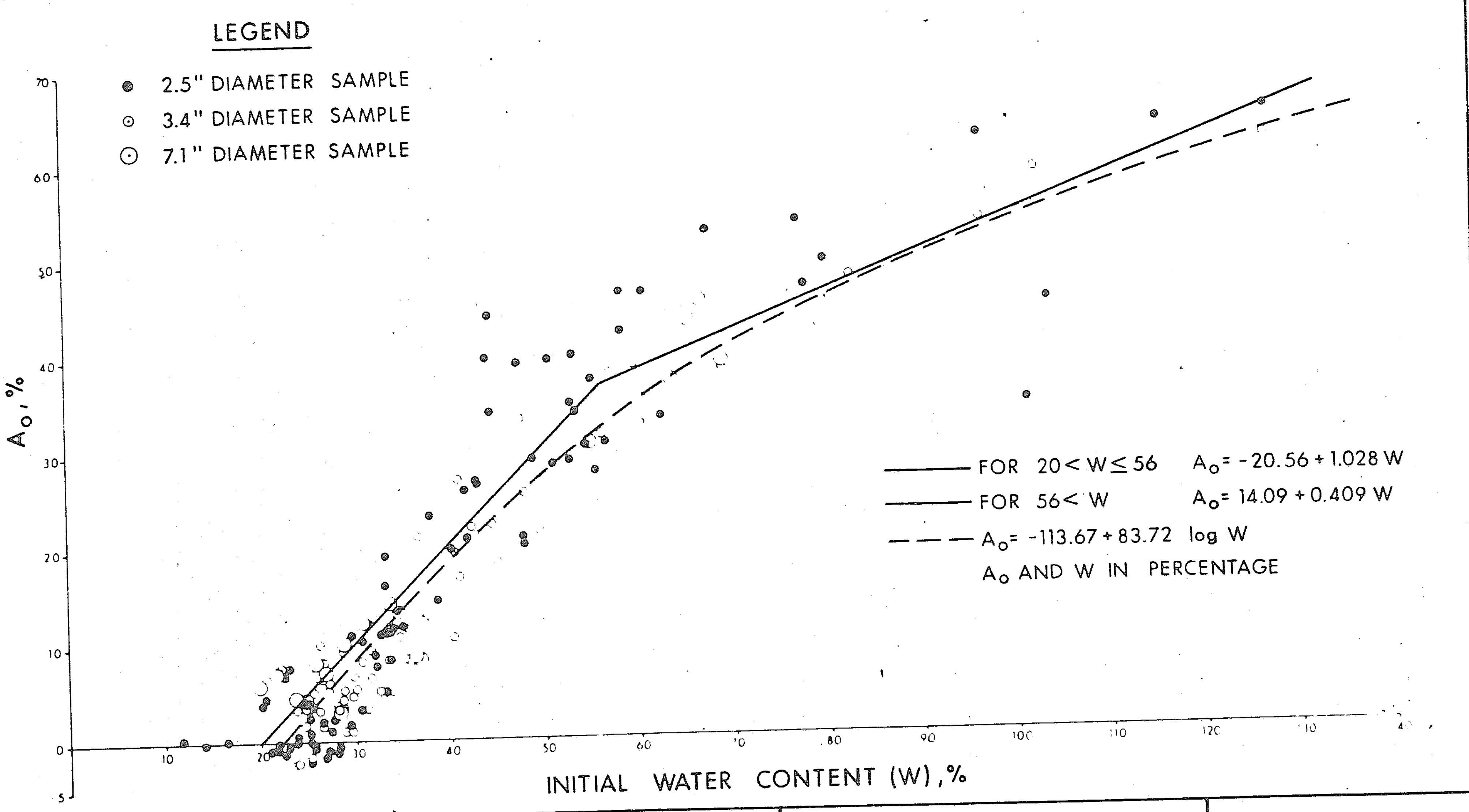
γ' = SUBMERGED UNIT WEIGHT OF SOIL

x = DISTANCE BELOW GROUND SURFACE

NOTE 1 ON FIGURES 9 TO 14, FOLLOWING, THE SOLID LINE HAS BEEN ADOPTED FOR THAW SETTLEMENT ANALYSIS. THE DOTTED LINE IS BASED ON REGRESSION ANALYSIS.

NOTE 2 WHERE MORE THAN ONE LAYER OF SOIL IS PRESENT THEN THE TOTAL SETTLEMENT IS OBTAINED BY CALCULATING THE SETTLEMENT OF EACH LAYER AND THEN ADDING THEM TOGETHER.

DETAILS OF THAW SETTLEMENT CALCULATION	NORTHERN ENGINEERING SERVICES COMPANY LIMITED CANADIAN ARCTIC GAS STUDY LIMITED	FIGURE 8



A_o VERSUS WATER CONTENT
FOR FINE-GRAINED SOILS

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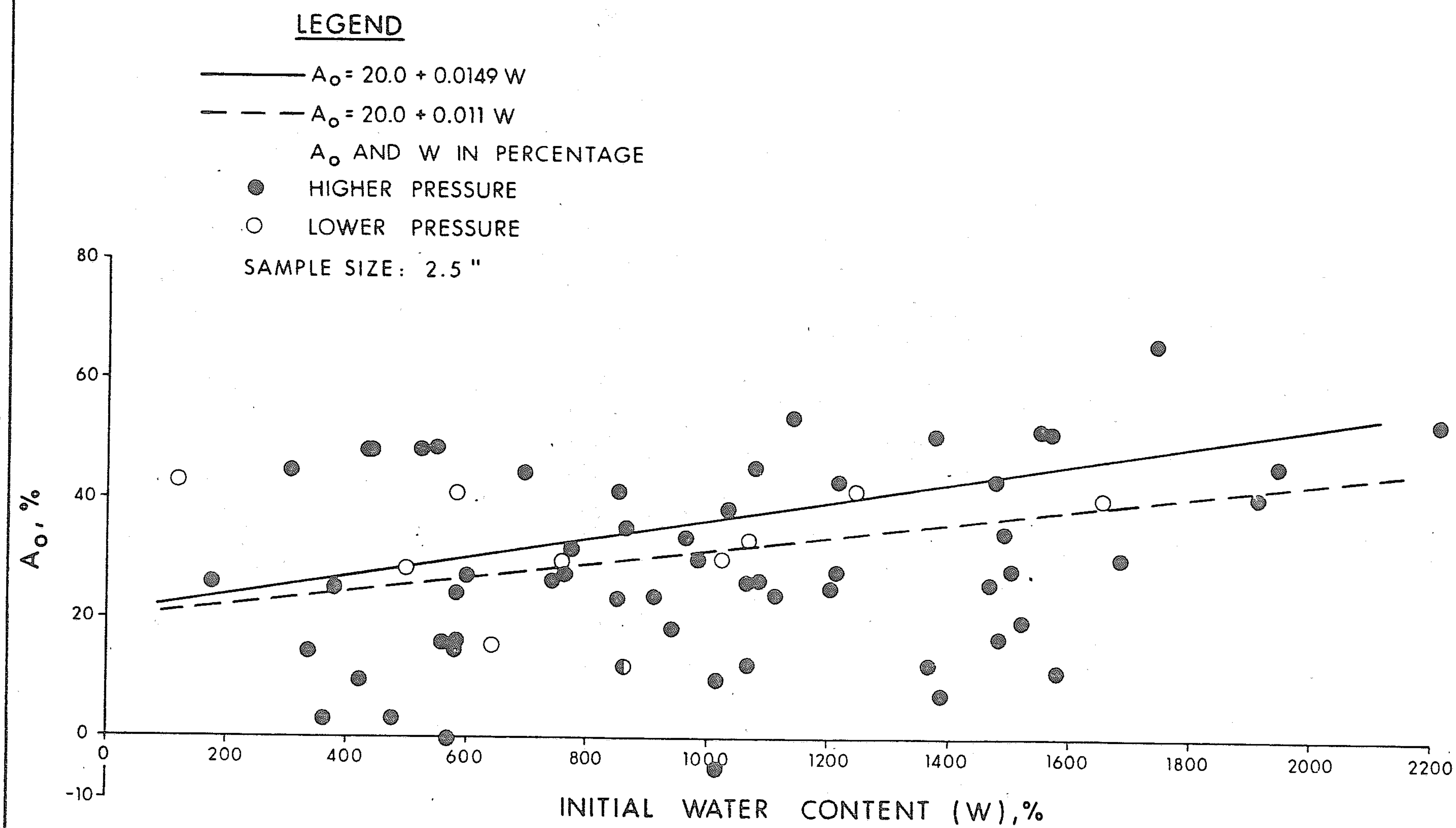
ENGINEERS FOR
CANADIAN ARCTIC GAS STUDY LIMITED

FIG. 9



A_o VERSUS WATER CONTENT FOR PEAT

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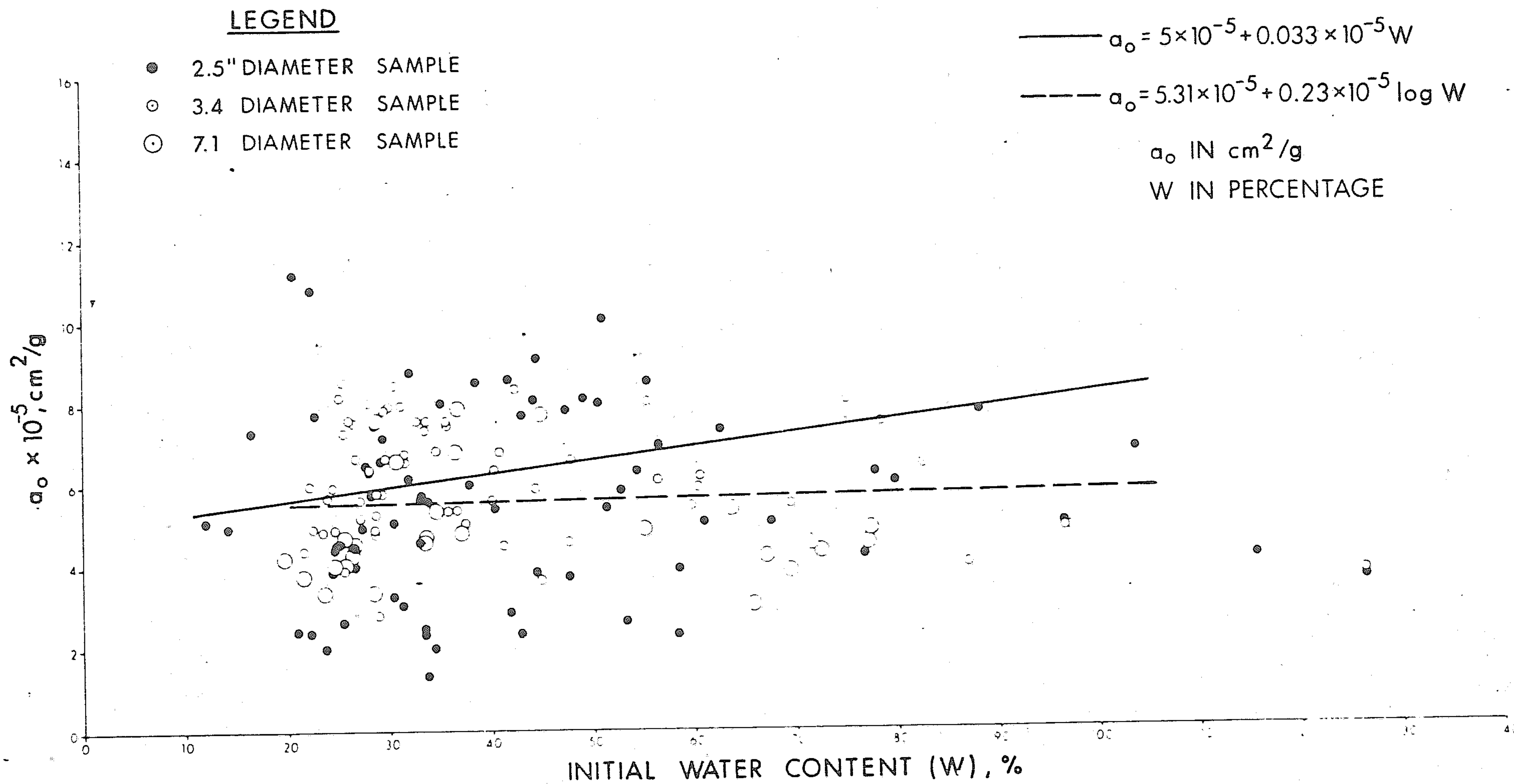
FIG. 11



a_o VERSUS WATER CONTENT
FOR FINE - GRAINED SOILS

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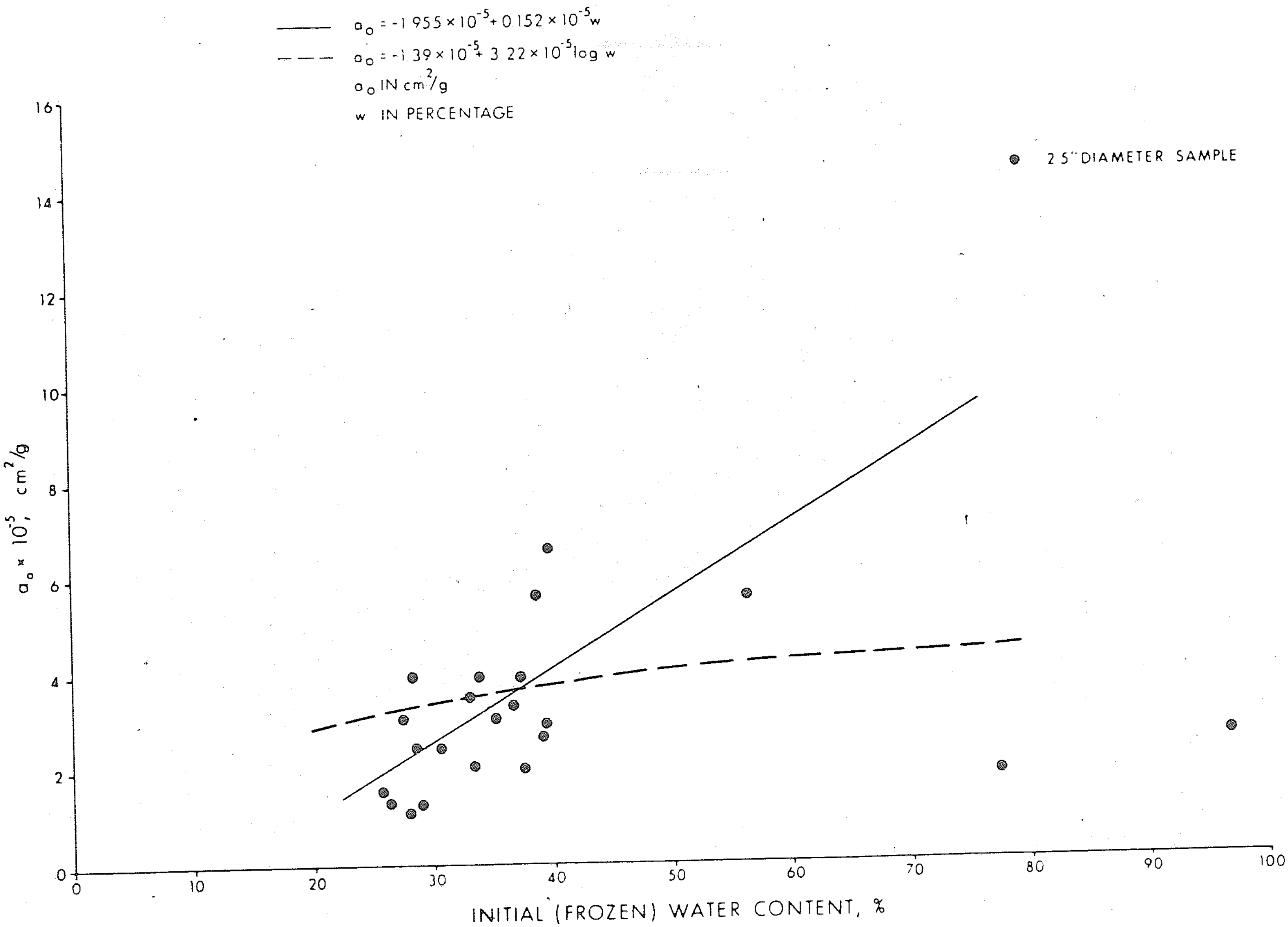
FIG. 12



a_o VERSUS WATER CONTENT FOR COARSE-GRAINED SOILS

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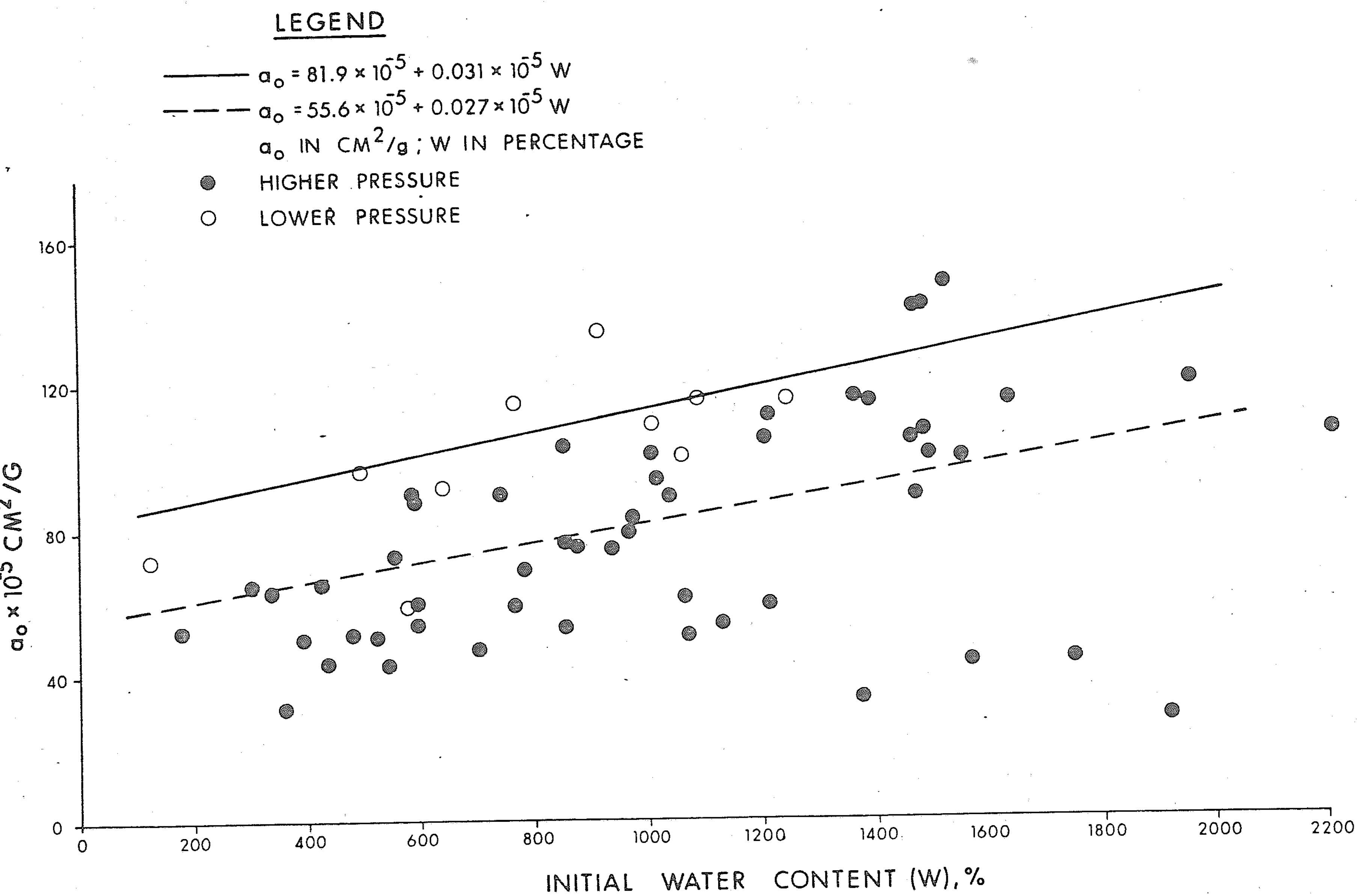
ENGINEERS FOR
CANADIAN ARCTIC GAS STUDY LIMITED

FIG. 13



a_o VERSUS WATER CONTENT
FOR PEAT

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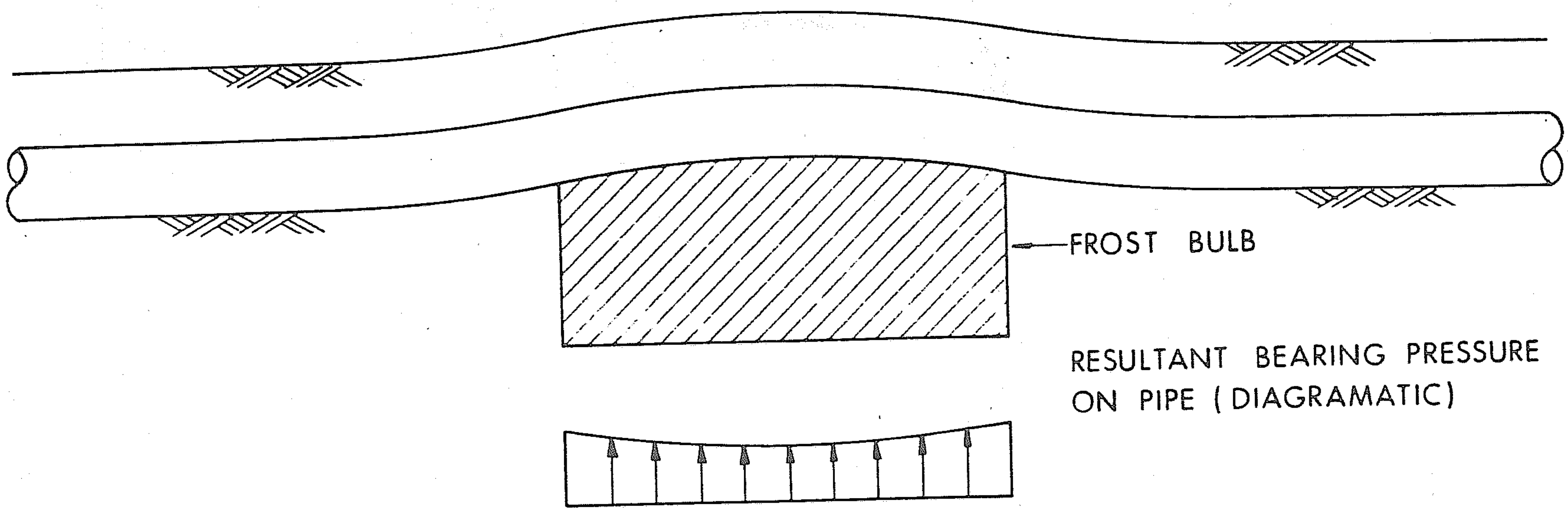
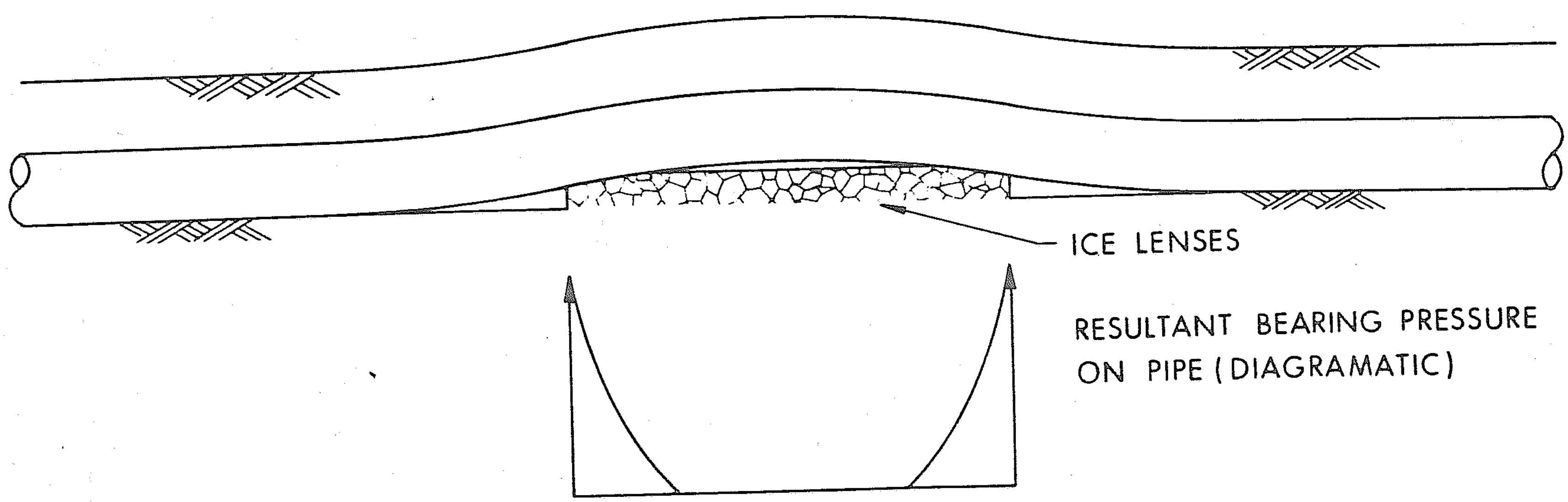
FIG. 14

FIGURE 1



A: PIPE SUBJECTED TO VARIABLE HEAVE RATE AS A FUNCTION OF EFFECTIVE PRESSURE IN THE SOIL.



B: INSULATED PIPE SUBJECTED TO CONSTANT HEAVE RATE.

FIGURE 2

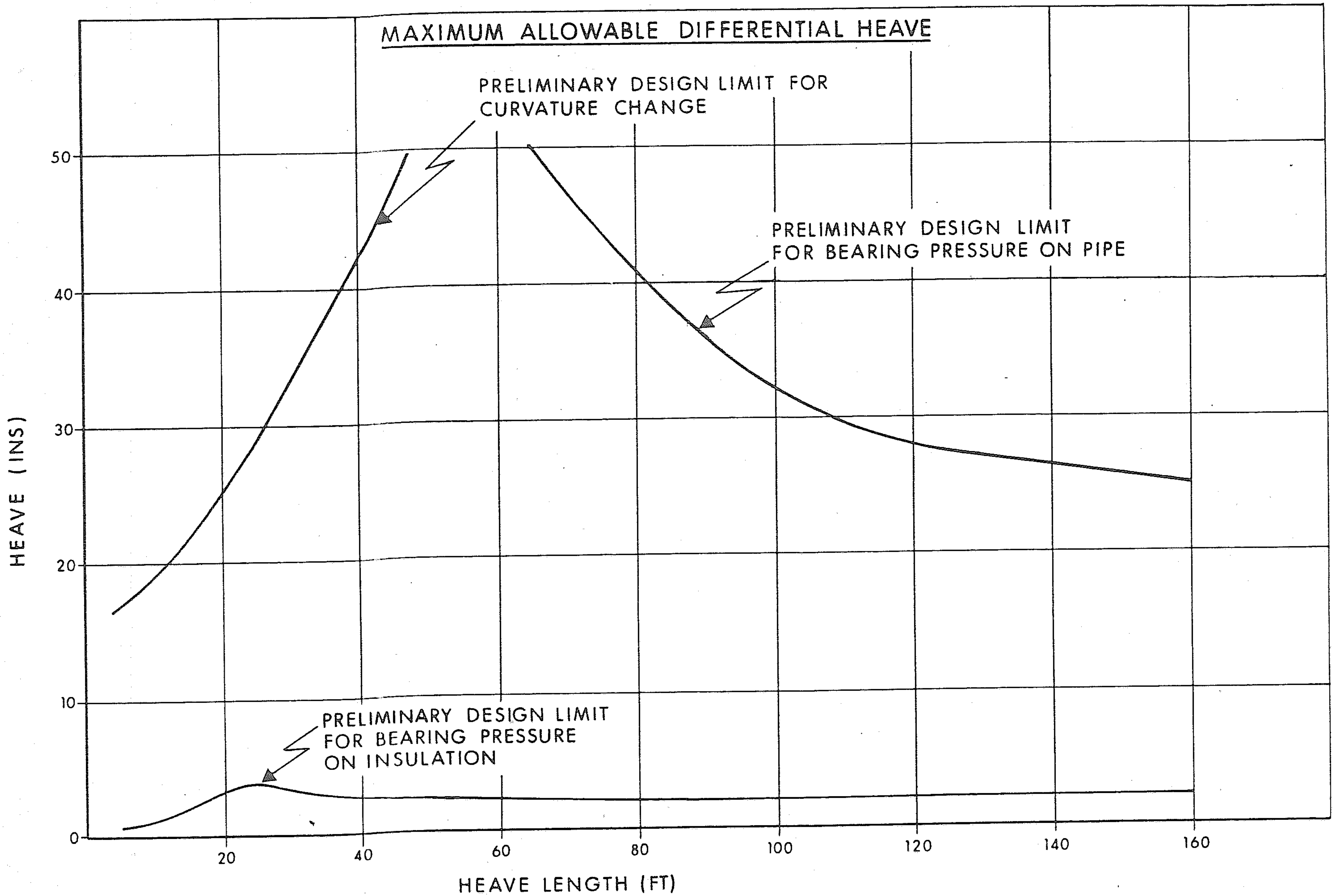

MAXIMUM ALLOWABLE DIFFERENTIAL HEAVE
PRELIMINARY DESIGN LIMIT FOR CURVATURE CHANGE
PRELIMINARY DESIGN LIMIT FOR BEARING PRESSURE ON PIPE
PRELIMINARY DESIGN LIMIT FOR BEARING PRESSURE ON INSULATION
HEAVE (INS)
0
10
20
30
40
50
HEAVE LENGTH (FT)
20
40
60
80
100
120
140
160

FIGURE 3

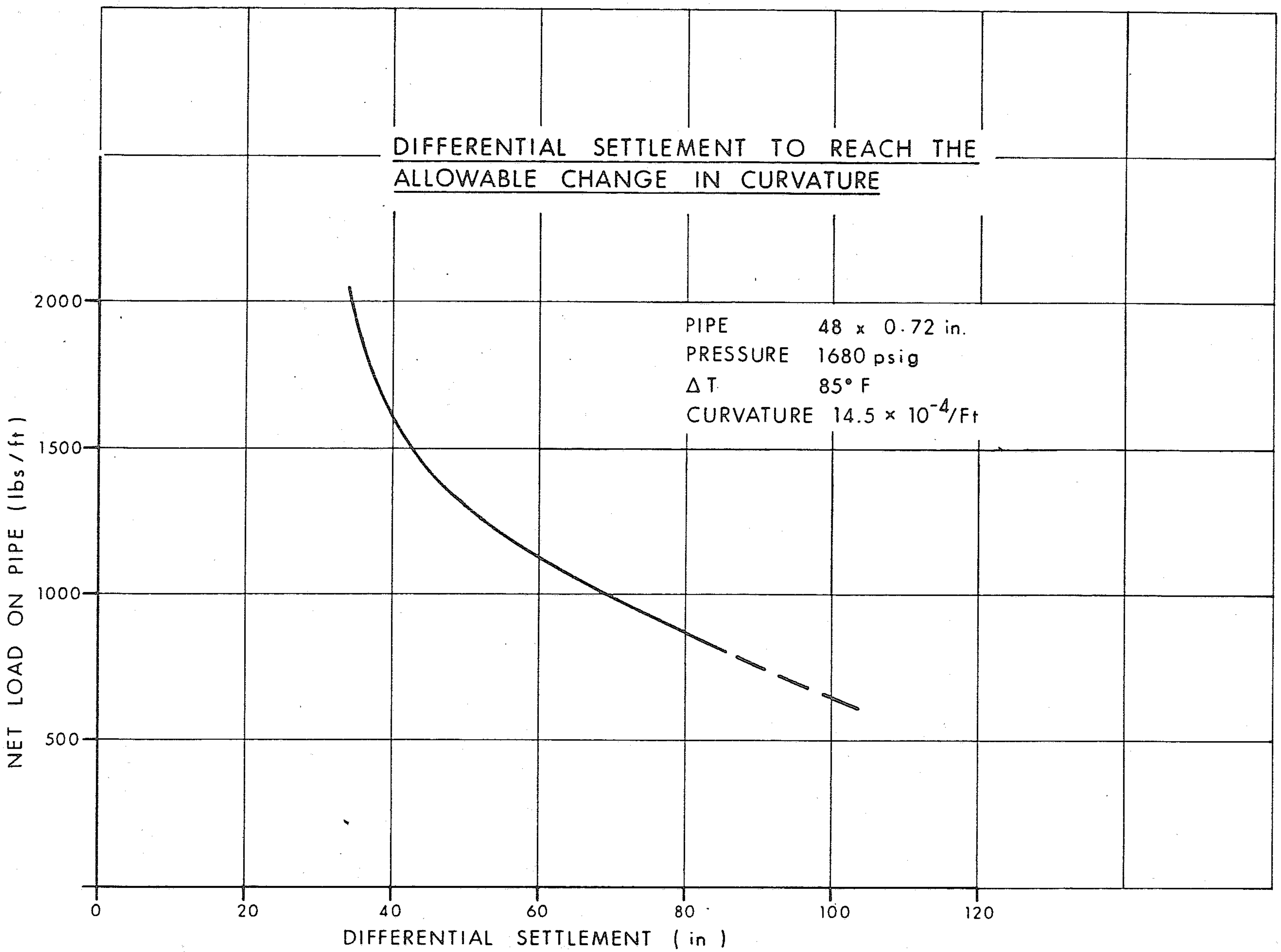

DIFFERENTIAL SETTLEMENT TO REACH THE ALLOWABLE CHANGE IN CURVATURE
PIPE 48 x 0.72 in.
PRESSURE 1680 psig
ΔT 85° F
CURVATURE 14.5 × 10^-4/Ft
NET LOAD ON PIPE (lbs / ft)
2000
1500
1000
500
0
20
40
60
80
100
120
DIFFERENTIAL SETTLEMENT (in)

FIGURE 4

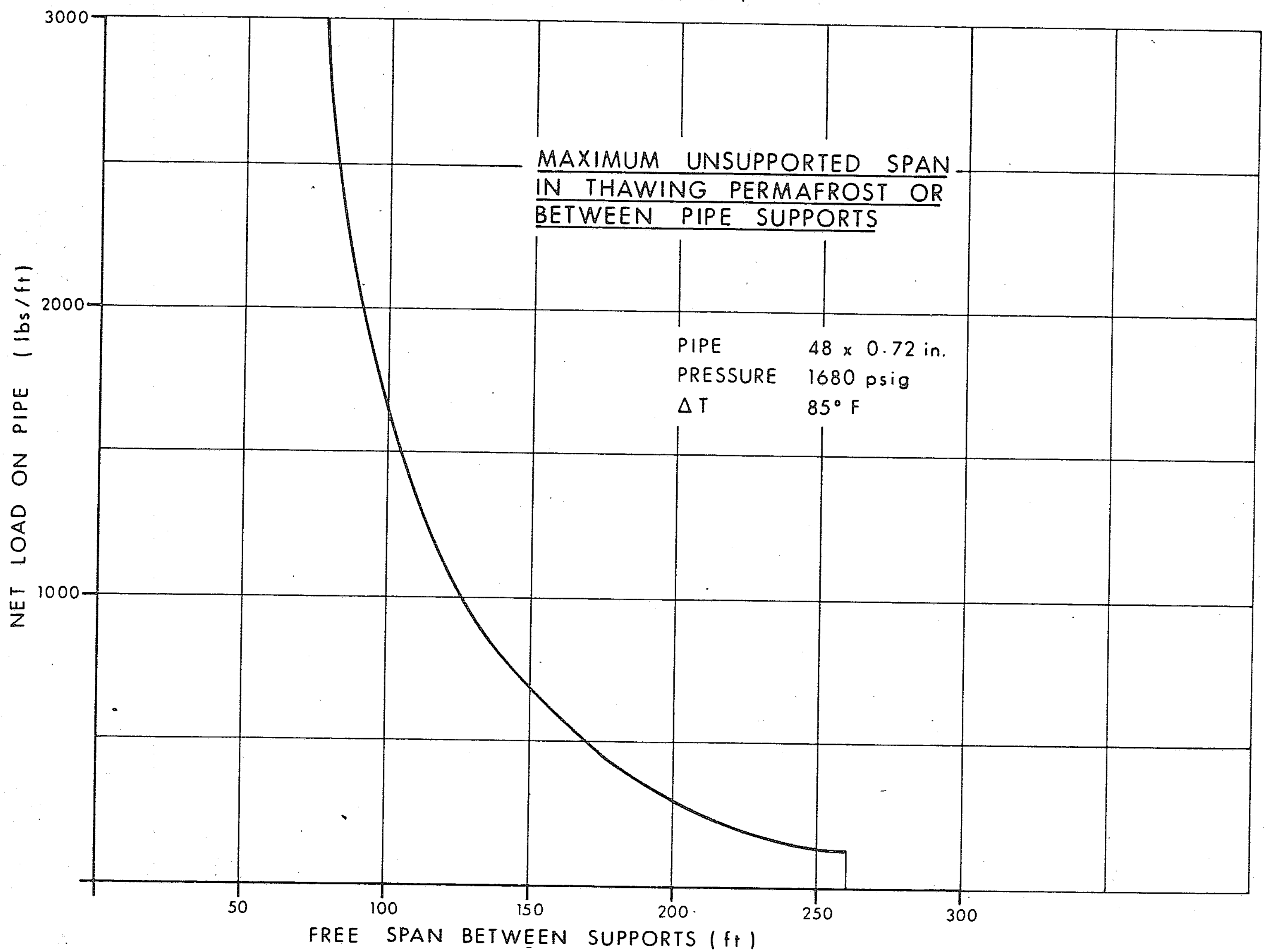

MAXIMUM UNSUPPORTED SPAN IN THAWING PERMAFROST OR BETWEEN PIPE SUPPORTS
PIPE 48 x 0.72 in.
PRESSURE 1680 psig
ΔT 85° F
3000
2000
1000
NET LOAD ON PIPE (lbs/ft)
50
100
150
200
250
300
FREE SPAN BETWEEN SUPPORTS (ft)

FIGURE 1

SCHEMATIC DESIGN
HEAT TRACED AND INSULATED CHILLED PIPE
FOR UNFROZEN SITES AND PERMAFROST SHALLOWER THAN 15FT.

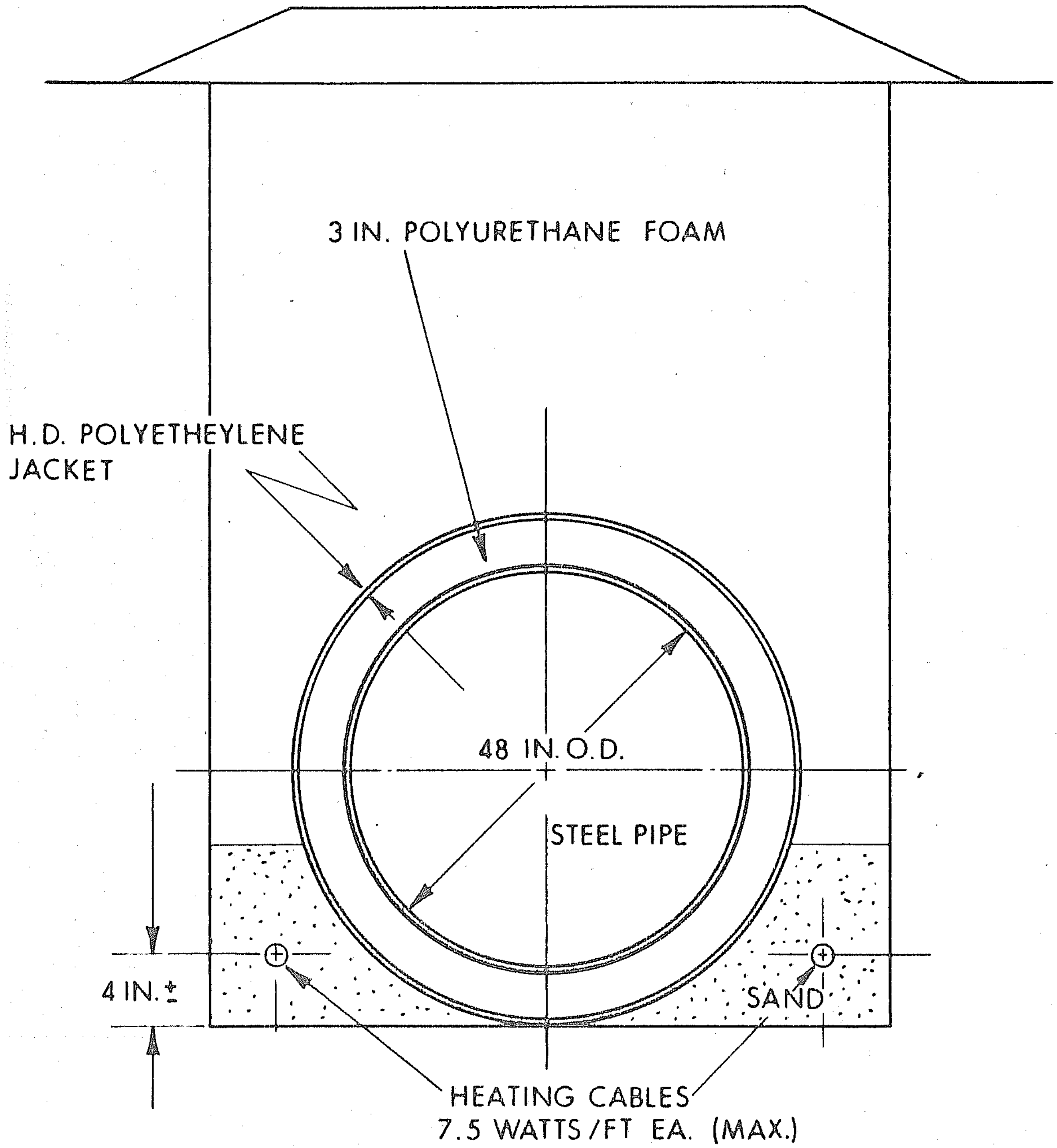


FIGURE 2

SCHEMATIC DESIGN
DEEP HEATED UNINSULATED CHILLED PIPE
FOR PERMAFROST DEEPER THAN 15 FT.

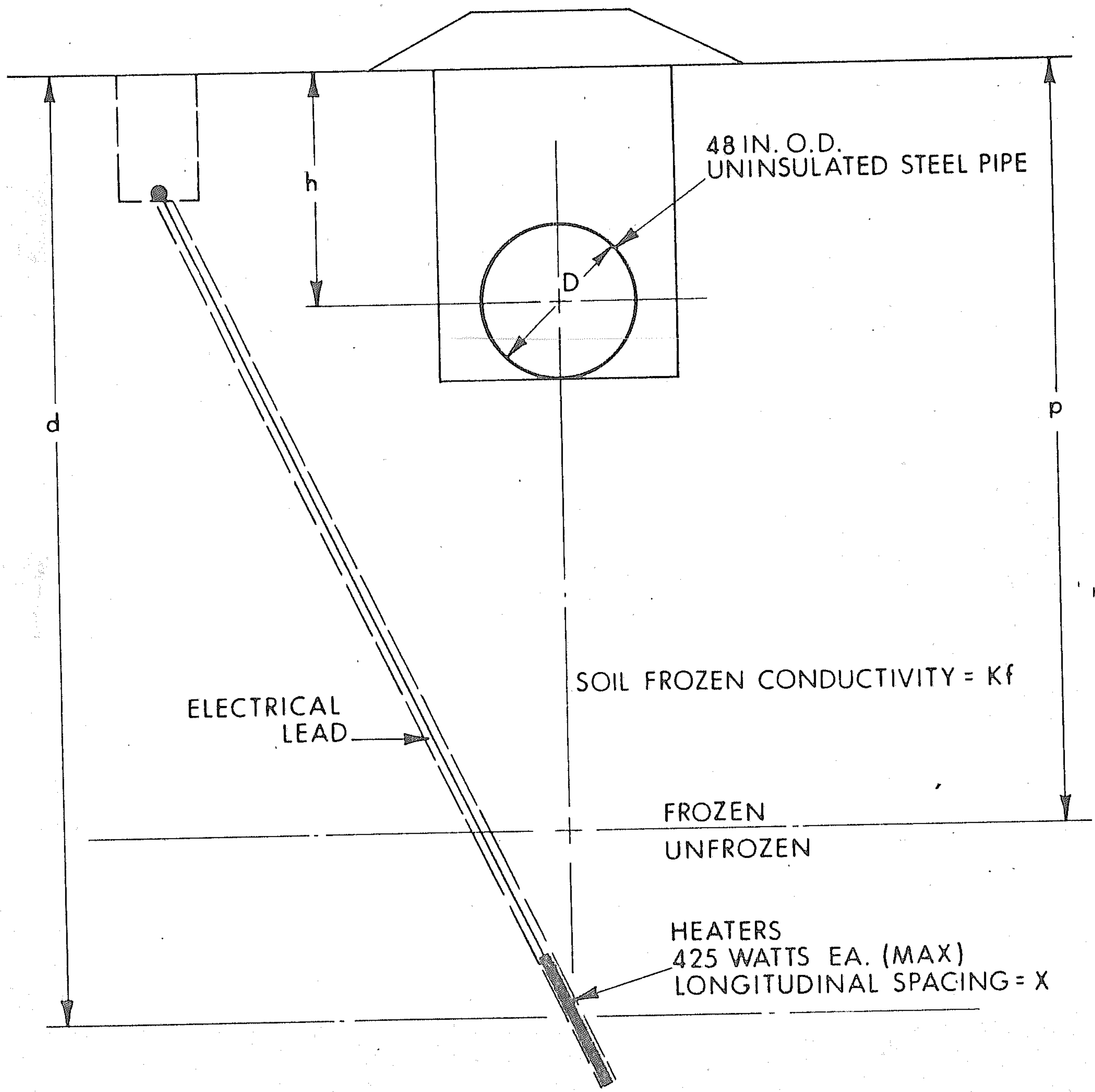
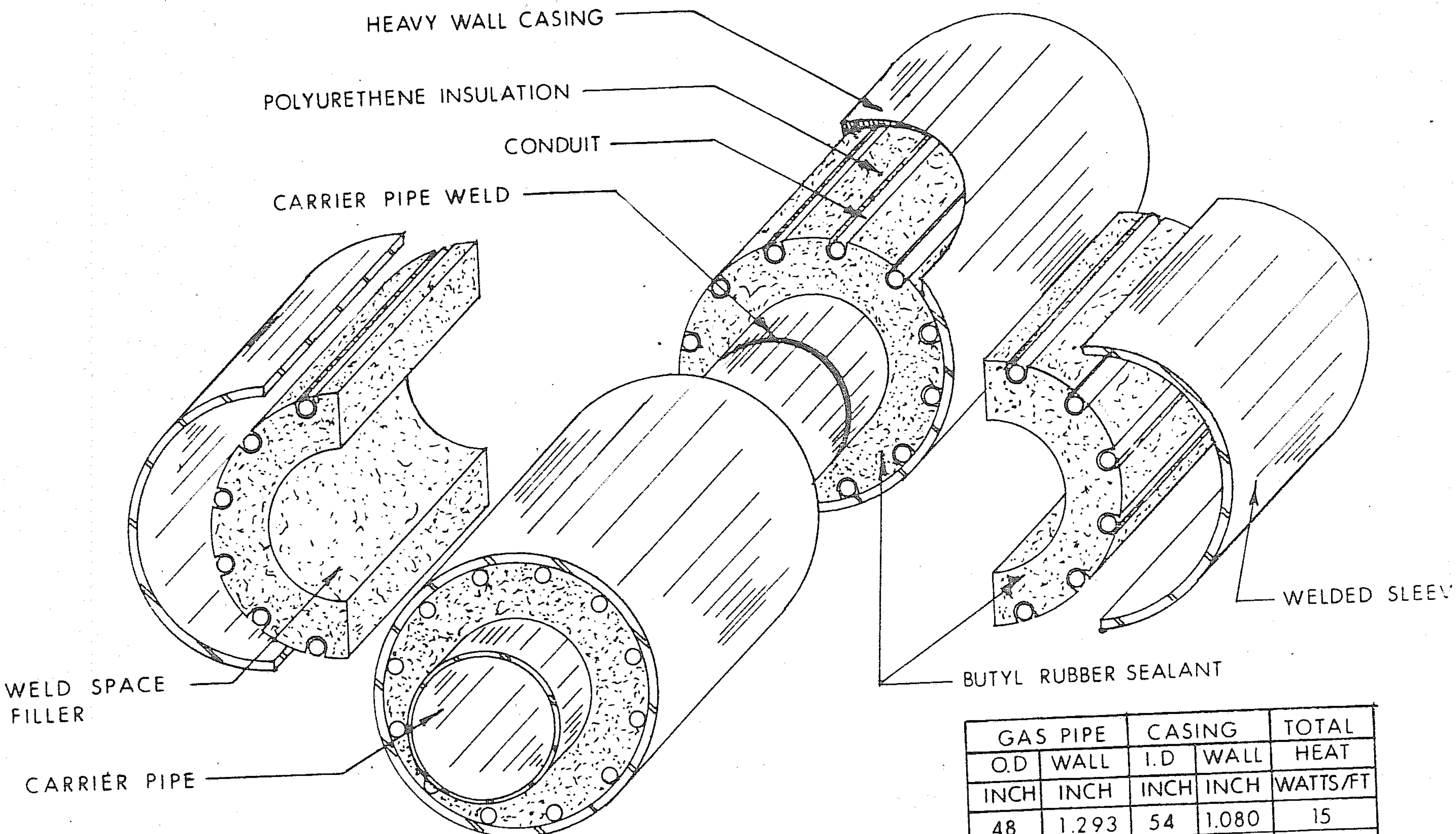


FIGURE 3.

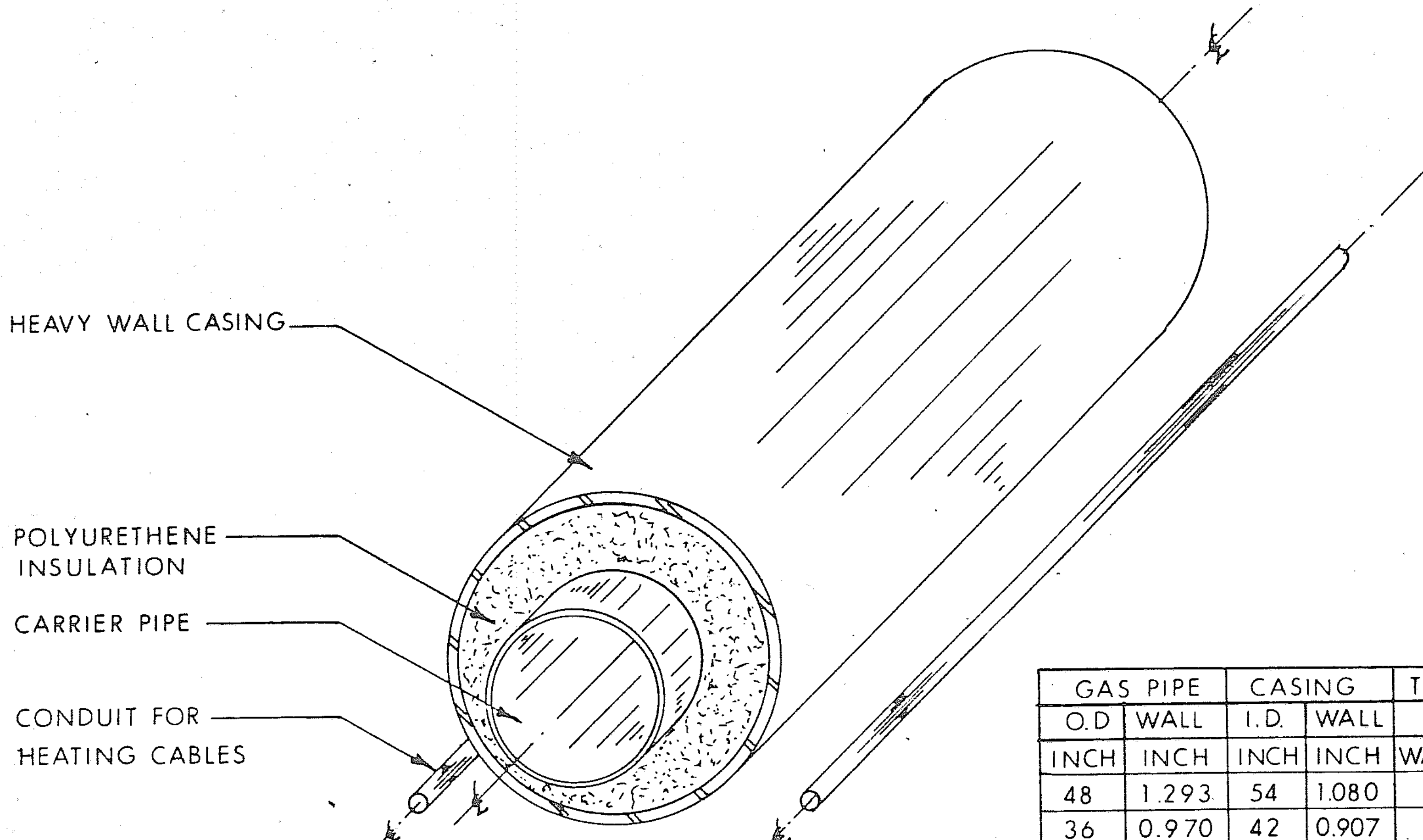
SCHEMATIC DESIGN
LONG RIVER CROSSING



GAS PIPE		CASING		TOTAL
O.D	WALL	I.D	WALL	HEAT
INCH	INCH	INCH	INCH	WATTS/FT
48	1.293	54	1.080	15
36	0.970	42	0.907	11
24	0.647	30	0.727	8

FIGURE 4.

SCHEMATIC DESIGN
SHORT RIVER CROSSING



GAS PIPE		CASING		TOTAL
O.D	WALL	I.D.	WALL	HEAT
INCH	INCH	INCH	INCH	WATTS/FT
48	1.293	54	1.080	15
36	0.970	42	0.907	11
24	0.647	30	0.727	8

FIGURE 1

LONG TERM STEADY STATE THERMAL REGIME

INSULATED AND HEAT TRACED PIPE

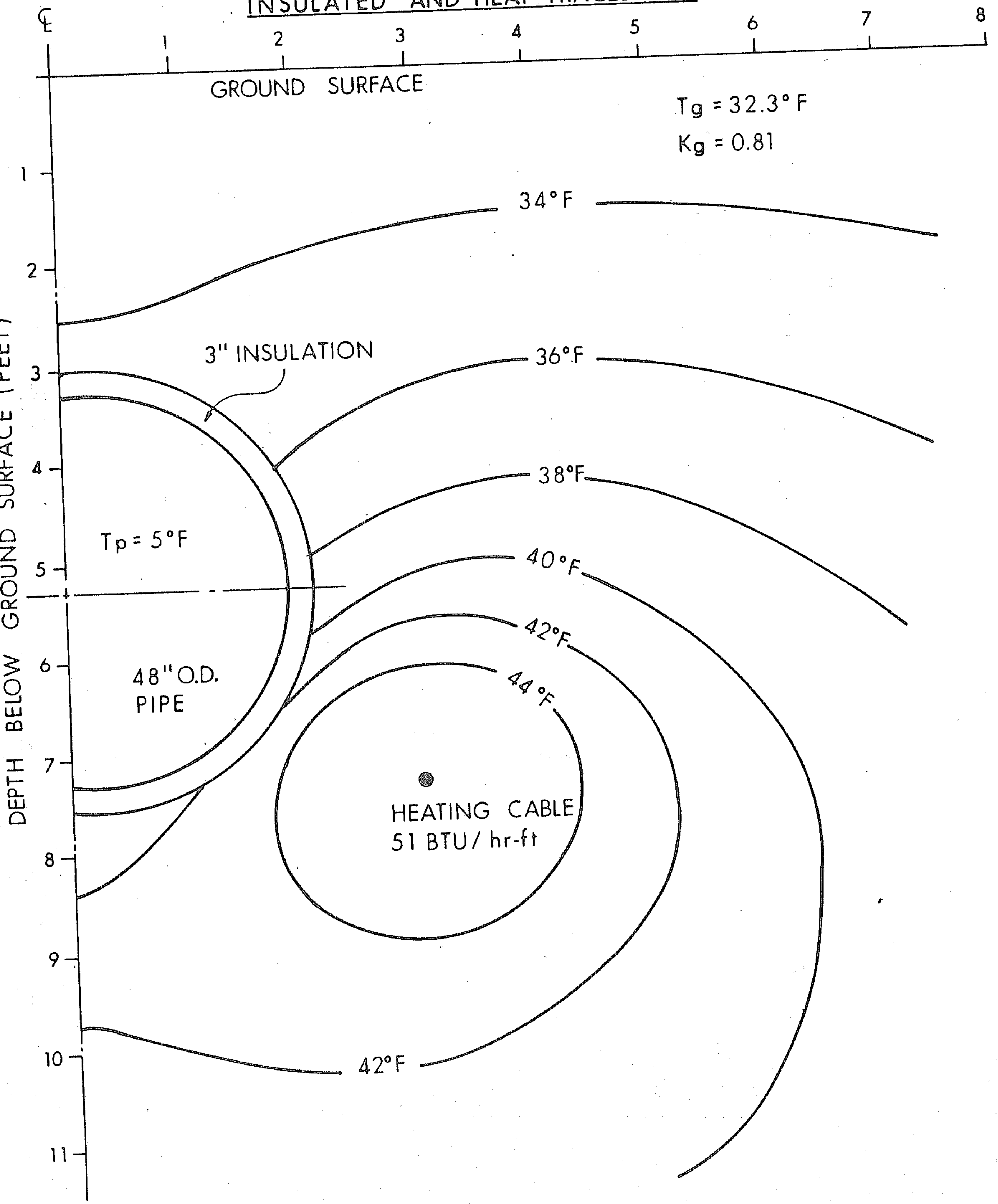
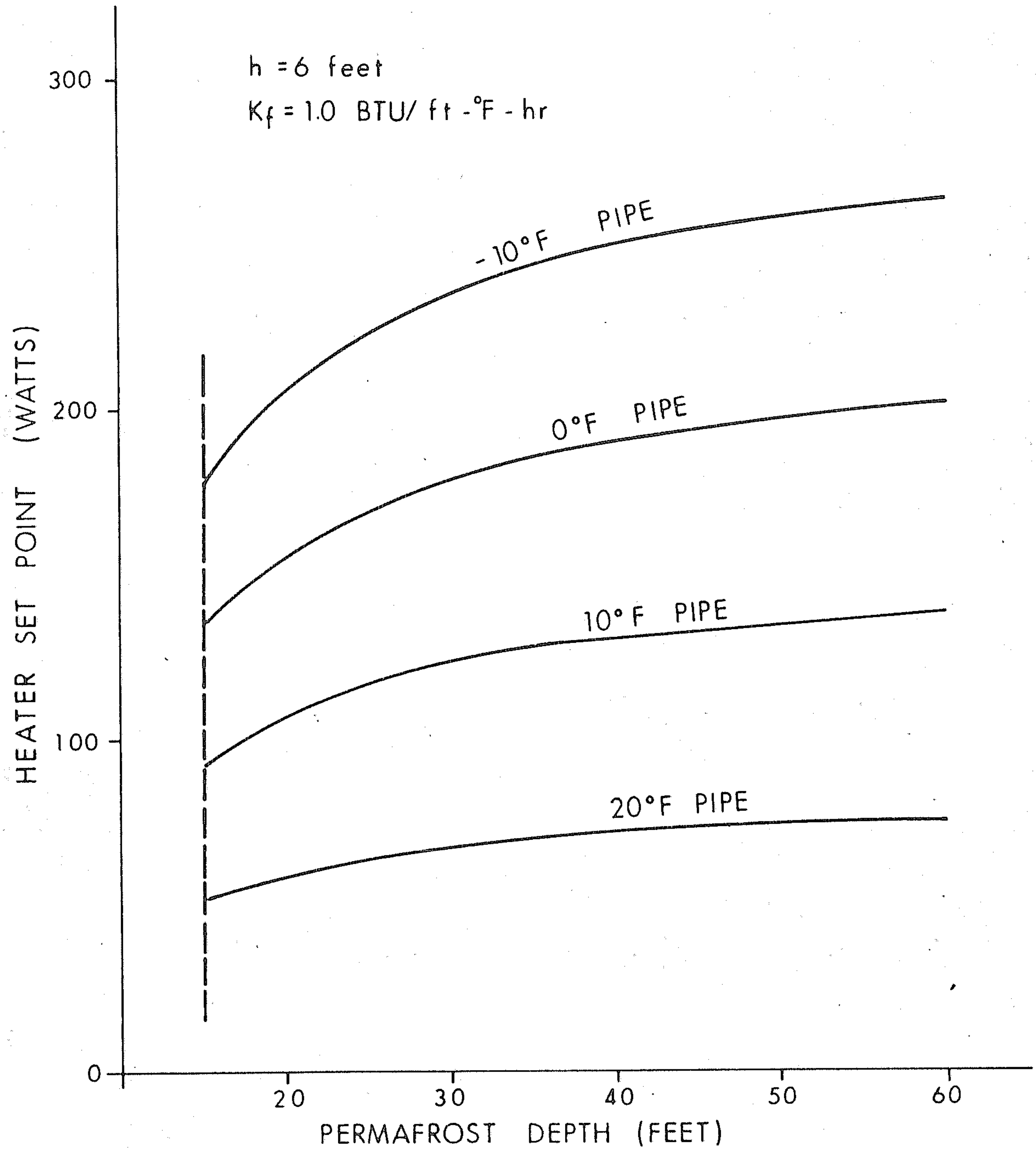


FIGURE 3

DEEP HEATER

PRELIMINARY SET POINTS



SPACING:	$x = p - h$	(feet)
DEPTH:	$d = p + \frac{x}{2}$	(feet)
POWER:	$W = 7\ (32 - T_p)\ K_f \left(1 - \frac{h}{p}\right)$	(Watts)

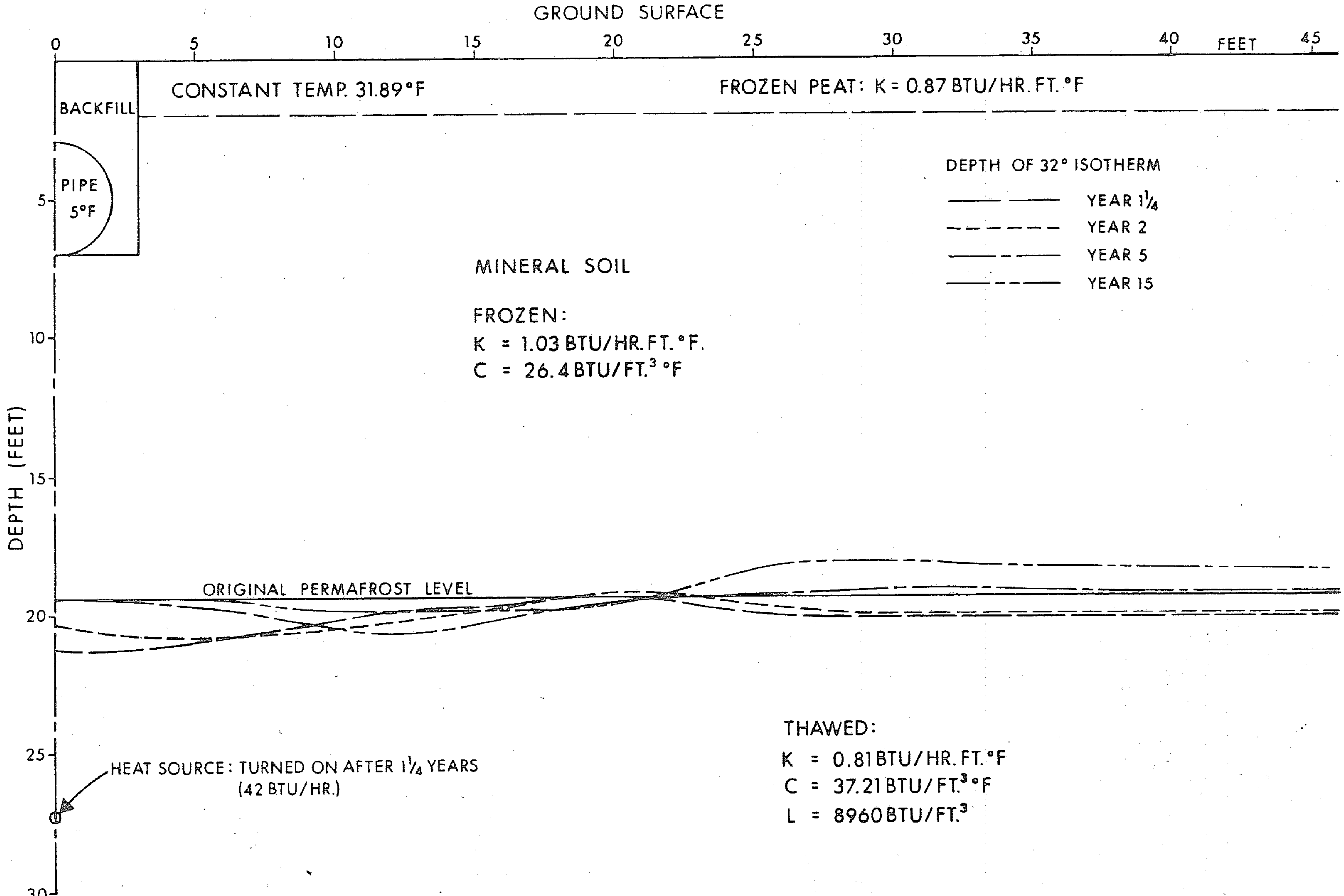


FIGURE 5. AVERAGE ELEVATION OF BOTTOM OF PERMAFROST

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PHONE (306) 634-5701

Edmonton, Alberta
28 January, 1977

Northern Engineering Services Limited
635 - 6th Avenue, S. W.
CALGARY, Alberta
T2P OT5

Attention: Mr. Graham King

Dear Graham:

Re: Effects of AC Power Line
Along Pipe Line Route

This is further to our telephone conversation of 27/1/77.

It is my understanding that you are considering the feasibility of running up to 400 miles of 15 KVA power line along the pipe line right of way between Station 6 and Station 15.

Some years ago, I carried out a study on the potential problems associated with the proximity of high voltage AC power lines to coated buried pipelines.

Based on the available data to that time (1967), it was my conclusion that there would be no corrosion problems due to induced AC on a pipe line parallel to or crossing an HV AC power line provided cathodic protection is maintained on the pipe line to normally accepted criteria (ie. 850 mV negative to $CuCuSO_4$.

I have generally kept abreast of the literature since that time and have had no reason to modify or change this conclusion.

There are some potential hazards to the pipe line or to pipe line personnel where pipe lines are laid parallel to high voltage AC power lines. These are:

1) Voltages caused on the pipeline by capacitive coupling or induction could lead to annoying shocks and in extreme cases could be lethal

. . . 2

to persons making contact with the line. The extreme example is the hazard to welders working on a section of line up on skids and out of contact with ground. To deal with this problem, the best approach is frequent grounding of the pipe either by installing ground mats at valves and other regular points of contact or by installing temporary grounds for pipe up on skids during construction.

2) Fault currents due to malfunctions or switching in the power line and lighting surges. These have been known in rare cases to cause damage to the coating on the pipe and even to the pipe wall itself. Where the potential magnitude of this problem is significant, it can be minimized by use of electrolytic grounding cells or polarization cells which permit flow of AC current while blocking DC currents which would cause difficulty in maintaining cathodic protection.

I would suspect that the probability of these effects on a 15 KV line would be quite minor. Most concern in the industry has been directed to power lines rated at 100 KV or more. This aspect in as far as magnitude of probable induced voltages and magnitude of fault currents should be checked with your power transmission people.

For your additional background in this matter, I am enclosing a copy of a recent article by E. A. Cherney and D. J. Carrigan of Ontario Hydro. It will be noted that the power line on which they were experimenting was rated at 230 KV.

We trust this background will be of assistance.

With best regards,

Yours very truly,

CAPROCO CORROSION PREVENTION LTD.

F. W. Hewes, P. Eng.
Managing Director

FWH/cdw
Encl.

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PHONE (306) 634-5701

Edmonton, Alberta
28 January, 1977

Northern Engineering Services Limited
635 - 6th Avenue, S.W.
CALGARY, Alberta
T2P 0Z5

Attention: Mr. G. King

Dear Graham:

Re: Corrosion Control Recommendations
<u>Thermally Insulated Main Line Sections</u>

During our meeting of 14/1/77 in Calgary you described and showed me diagrams of a number of main line insulating systems being considered for control of frost problems.

It is my purpose in this letter to give recommendations on the corrosion control measures to be followed with these systems.

The alternatives have been arbitrarily divided into three types, based on corrosion control considerations.

Basically I cannot visualize any problems in maintaining adequate corrosion control with any of these approaches.

I trust this is what you require at this time.

With best regards,

Yours very truly,

CAPROCO CORROSION PREVENTION LTD.

F.W. Hewes

F.W. Hewes, P. Eng.
Managing Director

FWH/nah
Attach.

ATTACHMENT

RECOMMENDATIONS

(1) *TYPE I SYSTEM*

(a) *Description*

- *Steel outer casing*
- *Heat trace cables or conduits outside casing in contact with soil.*

(b) *Recommendations*

(i) *Coat main line steel pipe in mill using fusion bond epoxy system.*

(ii) *Coat outer steel casing externally in mill using fusion bond epoxy system.*

(iii) *Coat all conduits or cables externally.*

(iv) *At each end of each insulated section, install preformed heat shrink sleeve extending over the end of the casing and along the carrier pipe. This must be done before the bonding of the casing to the carrier pipe as described in (v) below.*

(v) *Bond steel casing to carrier pipe at each end of each insulated section using thermite weld system and insulated copper cables sized appropriately for length of cased section. (Note maximum size of thermite weld cartridge to be used is 15 grams. Copper lead strands must be separated into bundles to enable this size of cartridge to be used.) All thermite weld connections must be very carefully coated.*

(vi) *Coat all field welds on carrier pipe using field applied fusion bond epoxy powder system before installing thermal insulation over the weld area.*

(vii) *Coat all field welds on outer casing pipe using either field applied fusion bond epoxy powder system or a heat shrink sleeve.*

(viii) *Bond coated metallic conduit or cable sheaths into casing pipe at suitable intervals using insulated copper cable and thermite weld connections using the same precautions as in (v) above.*

(2) TYPE II SYSTEM

(a) Description

- Steel outer casing
- Heat trace conduits inside the casing (aluminum conduits)

(b) Recommendations

(i) As for Type I.

(ii) As for Type I.

(iii) Conduits do not need to be coated externally for corrosion reasons.

(iv) As for Type I.

(v) As for Type I.

(vi) As for Type I.

(vii) As for Type I.

(3) TYPE III SYSTEM

(a) Description

Polyethylene - Butyl outer sheath over polyurethane insulation.

Heat trace cables or conduits (if any) outside of outer sheath and in contact with soil.

(b) Recommendations

(i) As for Type I.

(ii) Coat all conduits and cables externally.

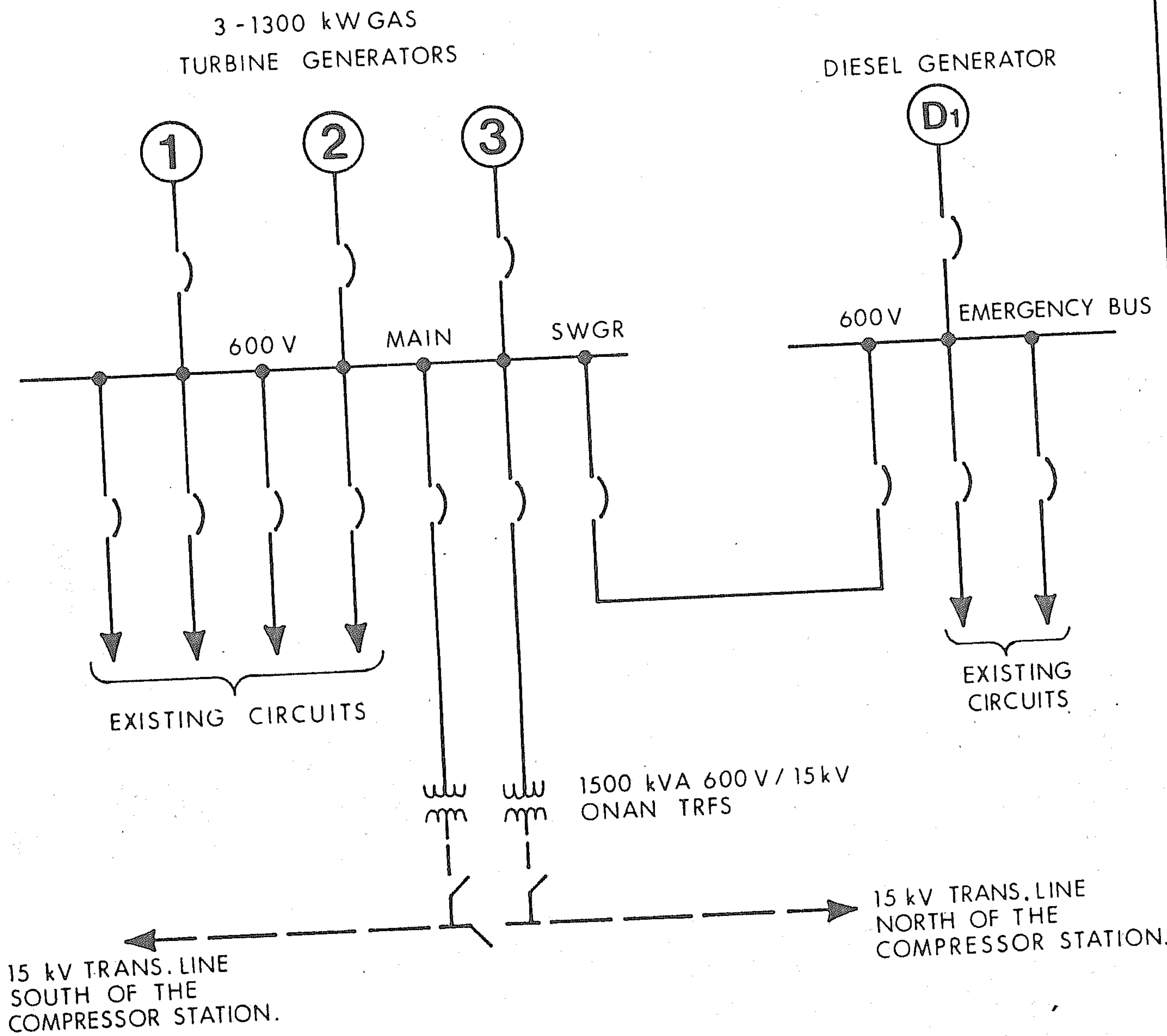
(iii) Coat all field welds on carrier pipe using field applied fusion bond powder system before installing thermal insulation over the weld area.

(iv) Bond coated metallic conduit or cable sheaths into the carrier pipe at suitable intervals to provide protection along with main line or alternatively provide for separate protection of these facilities using sacrificial anodes or impressed current systems as practical. (See Note 1 Below).

NOTE

(1) The heat trace conduits will have to be protected and can be protected readily by the methods shown. The best approach in any particular section will depend on such conditions as:

Length of Conduit Run
Resistivity of Soil
Availability of AC Power.



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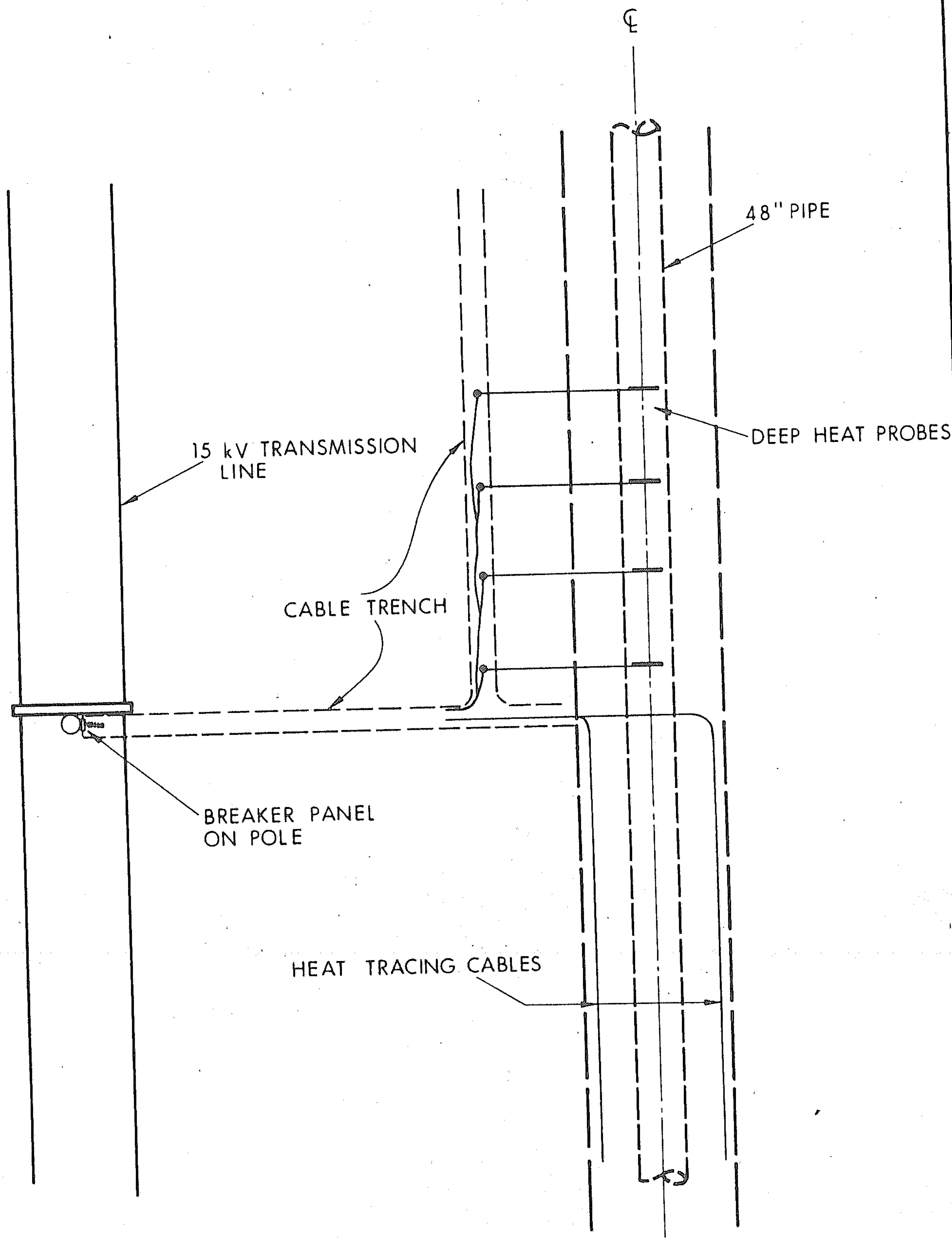
COMPANY LIMITED

FROST HEAVE REDESIGN
COMPRESSOR STATION [illegible]
SINGLE LINE DIAGRAM

FIGURE 1



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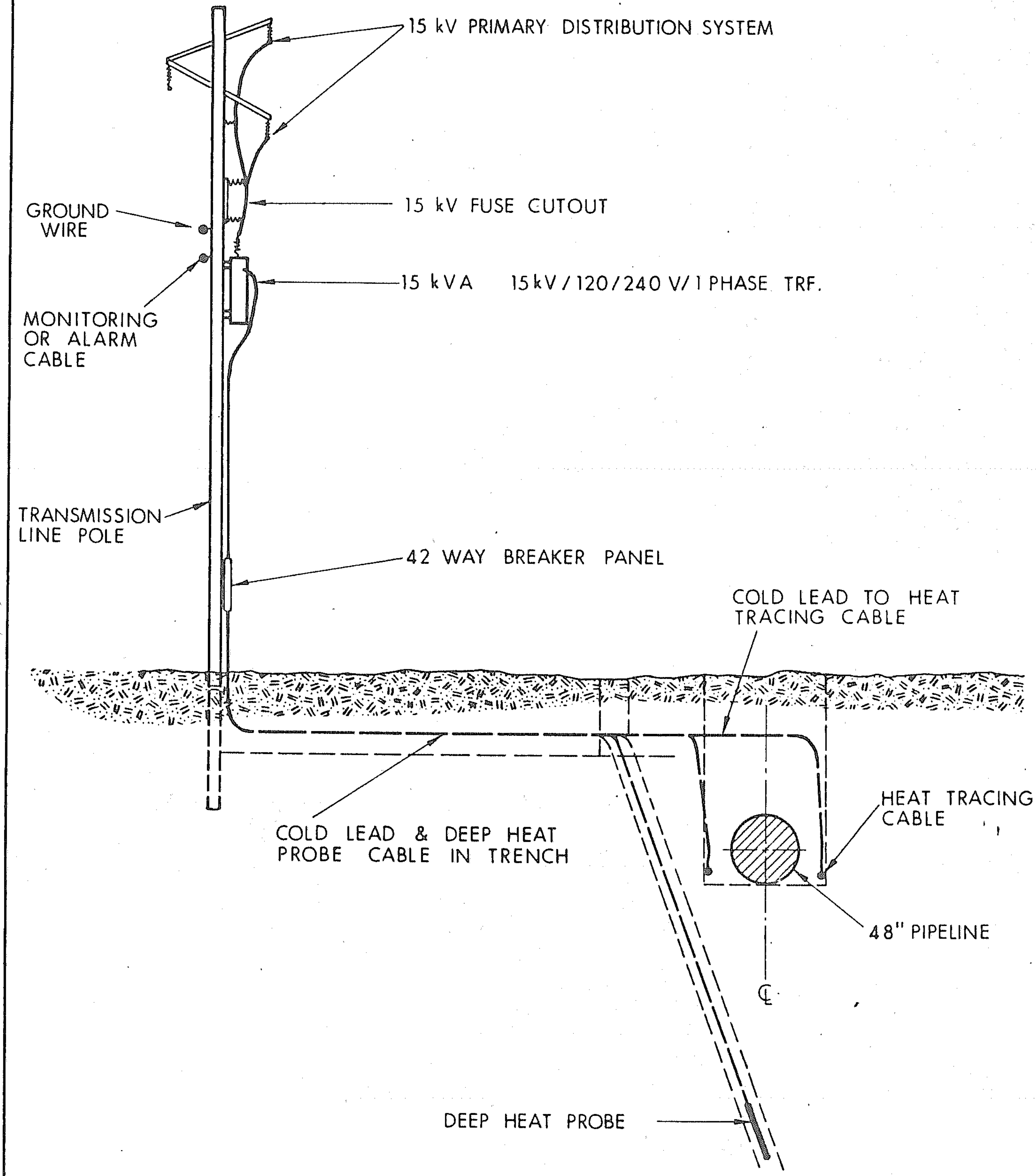
FROST HEAVE REDESIGN
PLAN OF
PIPELINE HEATING SYSTEM

FIGURE 2



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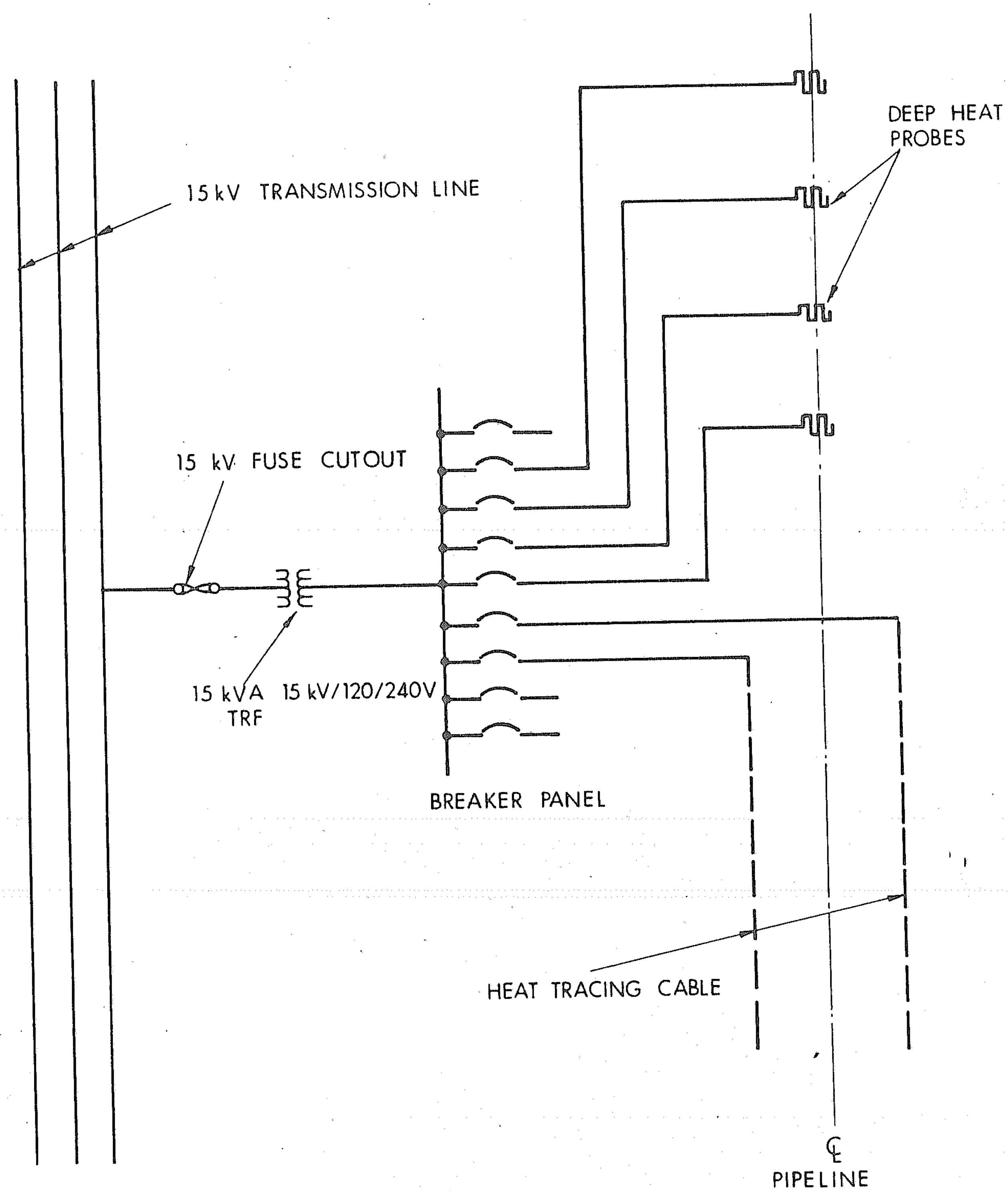
FROST HEAVE REDESIGN
CROSS SECTION OF
PIPELINE HEATING SYSTEM

FIGURE 3



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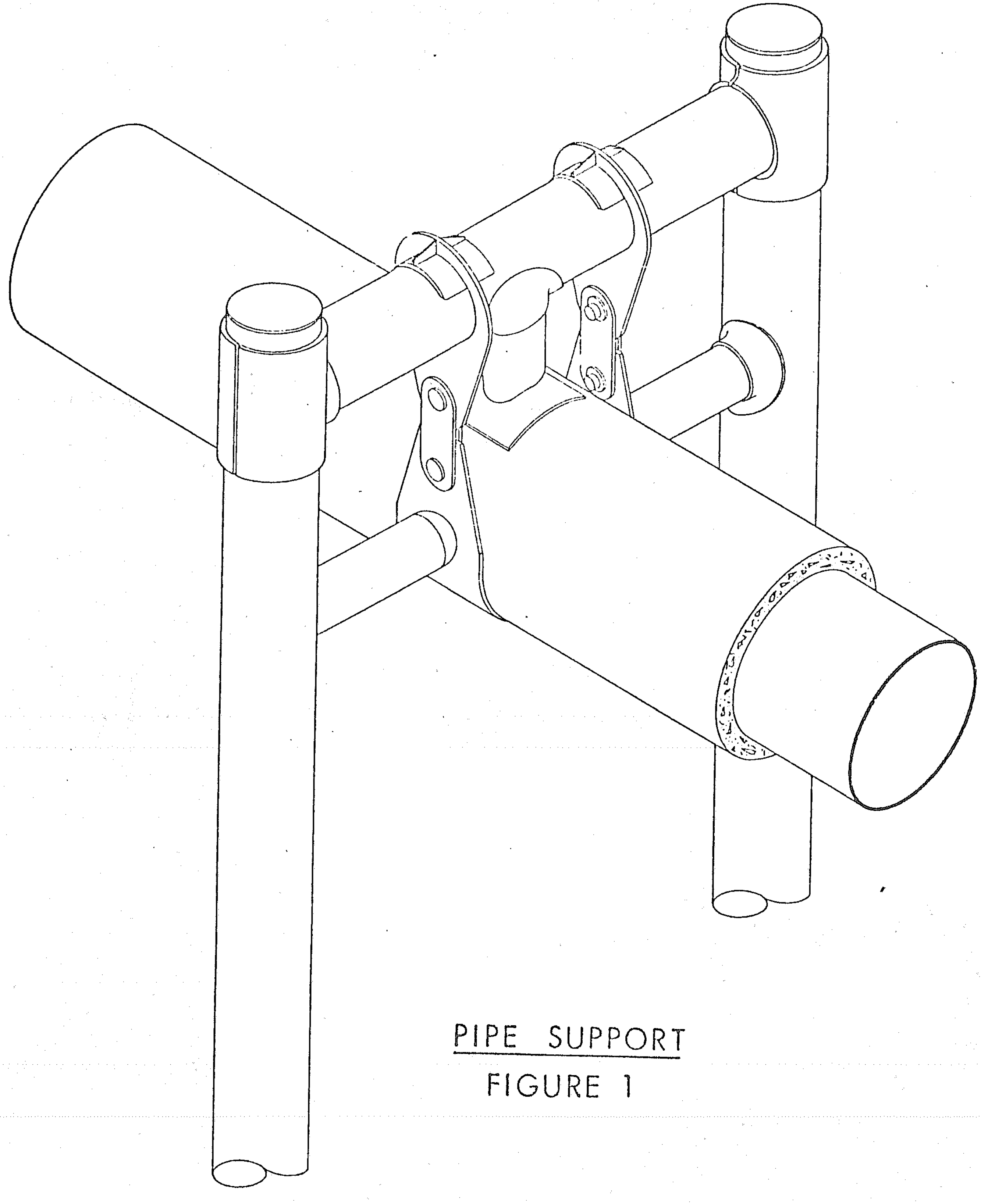
FROST HEAVE REDESIGN SINGLE LINE DIAGRAM

FIGURE 4



PIPE SUPPORT

FIGURE 1

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Edmonton, Alberta
28 January, 1977

Northern Engineering Services Limited
635 - 6th Avenue, S. W.
CALGARY, Alberta
T2P OT5

Attention: Mr. J. Price

Dear Jasper:

Re: Corrosion Prevention
Pile Systems

This is further to my discussions with you and Mr. Reid on 14/1/77 in Calgary, on the subject of protection of piling used for support of buried main line piping.

The main recommendation I have in this respect is to ensure that the pile assemblies are electrically isolated from the main line pipe steel.

It would appear that a measure of protection for the piling structure would also be advisable to ensure against corrosion attack which might lead to mechanical weakening on the structure over the life of the pipeline. For this purpose, I would suggest you consider fabricating the piling structure out of precoated pipe (eg. coated with fusion bond epoxy). The areas of coating damage resulting from transportation, fabrication and installation could then be taken care of by arbitrary installation of two 17# packaged, magnesium anodes for each pile structure.

The weld areas and areas of coating damage could be coated on site but this would not significantly affect the anode life and is not, recommended.

Coating applied to pipe on a regular production run basis should cost in the range $0.45 to $0.50 per square foot. The anodes, packaged would cost of the order of $35.00 each FOB Edmonton and would weigh about 50 lbs. each.

. . . 2

— OTHER OFFICES —

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TELEX 2127

LONDON, ENGLAND
PHONE 01-262-1005
TELEX 21792

I trust this is the information you require at this point.

With best regards,

Yours very truly,

CAPROCO CORROSION PREVENTION LTD.

F. W. Hewes, P. Eng.
Managing Director

FWH/cdw

TABLE 1

Summary of Design Quantities, M-06 to MF-15
(miles)

From	M-06	M-07	M-08	M-09	M-10	M-11	M-12	MF-13	MF-14	
To	M-07	M-08	M-09	M-10	M-11	M-12	MF-13	MF-14	MF-15	Total
Length	47.1	46.9	43.3	46.2	43.4	44.5	48.8	42.2	35.5	397.9
Insulated and heat-traced pipe	13.1	7.1	9.2	6.5	9.3	15.6	26.6	26.5	24.5	138.4
Bare Pipe	33.7	39.7	34.0	39.6	33.8	28.9	21.8	15.5	10.9	257.9
Insulated and heat-traced river crossings	0.3	0.1	0.1	0.1	0.3	-	0.4	0.2	0.1	1.6
Total pipe	47.1	46.9	43.3	46.2	43.4	44.5	48.8	42.2	35.5	397.9
Heat Probes										
Operating Year 1	1.8	3.7	4.8	8.0	8.3	16.2	13.4	10.0	7.5	73.7
Operating Year 3	-------------------			unallocated		-----------------------				30.0
Operating Year 5	-------------------			unallocated		-----------------------				15.0
Total										118.7

TABLE 2

River and Stream Crossings Requiring Insulation and Heat Tracing

Crossing	Pipe OD	Frost-Susceptible Width (ft.) Integral Heat Tracing	Frost-Susceptible Width (ft.) Separate Heat Tracing
Prudhoe Bay to CD-07	48"	-	-
CD-07 to CD-08			
Channel	48"		200
Moose Channel	48"		500
Channel	48"		150
Ministicoog Channel	48"		300
Channels (2)	48"		700
West Channel	36"	2 x 1,300	
Channel	36"		2 x 150
Shallow Bay	36"	2 x 26,250	
Channels	36"	2 x 1,100	
Channel	36"	2 x 1,100	
Channel	36"		2 x 800
Channel	36"	2 x 1,500	
Pond	36"	2 x 1,000	
North Reindeer Channel	36"	2 x 3,000	
Channel	36"		2 x 250
Pond	36"		2 x 700
Channel	36"		2 x 200
Channel	36"	2 x 1,900	
Channel	36"		2 x 250
Pond	36"		2 x 700
Channel	36"		2 x 700
Channel	36"		2 x 300
Langley Island Channel	36"	2 x 4,500	
Pond	36"	2 x 1,100	
Niglintgak to Richards Island			
Kumak Channel	24"	2,500	
Kanguk Channel	24"		700
Channel	24"		100
Kuluarpak Channel	24"		700
Taglu to Tununuk Junction			
Channel	48"		150
Harry Channel	48"		400
Channel	48"		250
Channel	48"		200
Lake	48"		100
Yaya Channel	48"		500

TABLE 2

River and Stream Crossings Requiring Insulation and Heat Tracing (Continued)

Crossing	Pipe OD	Frost-Susceptible Width (ft.) Integral Heat Tracing	Frost-Susceptible Width (ft.) Separate Heat Tracing
Tununuk Junction to MD-01			
Creeks (2)	48"		250
East Channel	48"	2 x 3,300	
Parsons Lake to Parsons Lake Junction	30"	-	-
MD-01 to MD-02	48"	-	-
MD-02 to MD-03			
Pond	48"		400
Creek	48"		100
MD-03 to M-04			
Creeks (4)	48"		400
Thunder River	48"		100
M-04 to M-05			
Thunder River Trib.	48"		100
Creeks (3)	48"		300
M-05 to M-06			
Creek	48"		150
Tieda River	48"		300
M-06 to M-07			
Hare Indian River	48"	1,000	
Creek	48"		50
Tsinta Creek	48"		50
Creek	48"		50
Snafu Creek	48"		50
Creek	48"		200

TABLE 2

River and Stream Crossings Requiring Insulation and Heat Tracing
(Continued)

Crossing	Pipe OD	Frost-Susceptible Width (ft.) Integral Heat Tracing	Frost-Susceptible Width (ft.) Separate Heat Tracing
M-07 to M-08			
Creek	48"		50
Donnelly River	48"		200
Hanna River	48"		150
Oscar Creek	48"		150
M-08 to M-09			
Bosworth Creek	48"		200
Canyon Creek	48"		300
Christina Creek	48"		200
M-09 to M-10			
Nota Creek	48"		100
Jungle Ridge Creek	48"		200
Creeks (4)	48"		250
M-10 to M-11			
Creek	48"		50
Little Smith River	48"		400
Creeks (3)	48"		250
Saline River	48"		800
Creeks (5)	48"		250
M-11 to M-12			
Creeks (3)	48"		150
M-12 to MF-13			
Whitesand River	48"		500
Ochre River	48"		300
Creeks	48"		500
Smith River	48"		300
Creeks (4)	48"		250

TABLE 2

River and Stream Crossings Requiring Insulation and Heat Tracing
(Continued)

Crossing	Pipe OD	Frost-Susceptible Width (ft.) Integral Heat Tracing	Frost-Susceptible Width (ft.) Separate Heat Tracing
MF-13 to MF-14			
Creeks (3)	48"		300
Willowlake River	48"		800
Creek	48"		100
MF-14 to MF-15			
Trail Creek	48"		100
Creeks (2)	48"		200
Total	24"	2,500	1,500
	36"	85,500	8,100
	48"	7,600	13,000
Grand Total		95,600	22,600

TABLE 3

Deep Burial and Pile Support Quantities,
South of Milepost 661
(miles)

Milepost	Permafrost	Deep Burial less than 12'	Deep Burial 16'	Pile Supports
661-683	7.0	4.2	2.1	0.7
683-723	4.6	0.5	0.9	3.2
723-807	16.6	8.3	7.4	0.9
807-881	37.3	7.5	15.0	14.8
Total	65.5	20.5	25.4	19.6

January 1977

TABLE 1
PROJECTED AVERAGE-DAY GAS VOLUMES
(MMcfd at 60°F and 14.73 psia)

	Operating Year 1	2	3	4	5
Prudhoe Bay to Tununuk Jct.					
Prudhoe Bay Supply	-	2,000.0	2,000.0	2,250.0	2,250.0
Fuel Used in Alaska	-	-	-	-	-
Delivery at Alaska-Yukon Border	-	2,000.0	2,000.0	2,250.0	2,250.0
Fuel Used in Yukon	-	5.4	5.4	6.0	6.0
Fuel Used in N.W.T.	-	.5	.5	5.7	5.7
Delivery to Tununuk Jct.	-	1,994.1	1,994.1	2,238.3	2,238.3
Mackenzie Delta to Caroline					
Niglintgak Supply	175.0	175.0	210.0	245.0	315.0
Taglu Supply	700.0	700.0	840.0	980.0	1,260.0
Total Delivery to Tununuk Jct.	875.0	2,869.1	3,044.1	3,463.3	3,813.3
Fuel Used at Station MD-01	-	7.8	8.1	7.0	7.5
Parsons Lake Supply	375.0	375.0	450.0	525.0	675.0
Fuel Used in N.W.T.	10.9	51.5	59.6	96.8	119.4
Delivery to Westcoast	239.3	248.3	287.4	318.1	354.7
Fuel Used in N.W.T.	-	6.9	8.5	5.6	7.2
Fuel Used in Alberta	9.0	36.8	42.6	67.2	86.4
Delivery to Caroline	990.8	2,892.8	3,087.9	3,493.6	3,913.1
Caroline to Alberta-B.C. Border					
Caroline Supply	-	617.0	617.8	686.4	686.3
Fuel Used in Alberta	-	.2	.2	.3	.3
Delivery to ANG at Alberta-B.C. Border	-	616.8	617.6	686.1	686.0
Caroline to Monchy					
Caroline Supply	990.8	2,275.8	2,470.1	2,807.2	3,226.8
Fuel Used in Alberta	-	4.6	5.7	13.6	18.8
Delivery to TCPL	990.8	892.7	1,083.9	1,263.6	1,678.4
Fuel Used in Saskatchewan	-	3.8	4.2	3.4	3.7
Delivery to Monchy	-	1,374.7	1,376.3	1,526.6	1,525.9
System Summary (MMcfd)					
Total Supply	1,250.0	3,250.0	3,500.0	4,000.0	4,500.0
Total Fuel	19.9	117.5	134.8	205.6	255.0
Total Delivery	1,230.1	3,132.5	3,365.2	3,794.4	4,245.0
System Summary (Btu* x 10^9)					
Total Supply	1,306.9	3,602.9	3,864.3	4,412.7	4,935.4
Total Fuel	20.8	130.5	149.0	227.3	280.3
Total Delivery	1,286.1	3,472.4	3,715.3	4,185.4	4,655.1
Delivery H.H.V. (Btu*/ft^3)	1,045.5	1,108.5	1,104.0	1,103.0	1,096.6

*Dry Basis at 14.73 psia

TABLE 2
PROJECTED AVERAGE ANNUAL GAS VOLUMES
(Bcf at 60°F and 14.73 psia)

	Calendar Year					
	1982	1983	1984	1985	1986	1987
Prudhoe Bay to Tununuk Jct.						
Prudhoe Bay Supply	–	368.0	730.5	745.8	821.8	821.8
Fuel Used in Alaska	–	–	–	–	–	–
Delivery at Alaska-Yukon Border	–	368.0	730.5	745.8	821.8	821.8
Fuel Used in Yukon	–	1.0	2.0	2.0	2.2	2.2
Fuel Used in N.W.T.	–	.1	.2	.5	2.1	2.1
Delivery to Tununuk Jct.	–	366.9	728.3	743.3	817.5	817.5
Mackenzie Delta to Caroline						
Niglintgak Supply	32.2	63.9	66.1	78.8	93.8	115.1
Taglu Supply	128.8	255.7	264.2	315.4	375.0	460.2
Total Delivery to Tununuk Jct.	161.0	686.5	1,058.6	1,137.5	1,286.3	1,392.8
Fuel Used at Station MD-01	–	1.4	2.9	2.9	2.6	2.7
Parsons Lake Supply	69.0	137.0	141.5	168.9	200.9	246.4
Fuel Used in N.W.T.	2.1	11.5	19.3	24.0	36.7	43.6
Delivery to Westcoast	44.0	89.0	93.1	106.8	118.4	129.6
Fuel Used in N.W.T.	–	1.3	2.6	2.9	2.1	2.6
Fuel Used in Alberta	1.7	8.5	13.8	17.1	25.7	31.6
Delivery to Caroline	182.2	711.8	1,068.4	1,152.7	1,301.7	1,429.3
Caroline to Alberta-B.C. Border						
Caroline Supply	–	113.5	225.4	229.8	250.7	250.7
Fuel Used in Alberta	–	–	.1	.1	.1	.1
Delivery to ANG at Alberta-B.C. Border	–	113.5	225.3	229.7	250.6	250.6
Caroline to Monchy						
Caroline Supply	182.2	598.3	843.0	922.9	1,051.0	1,178.6
Fuel Used in Alberta	–	.8	1.7	2.6	5.3	6.9
Delivery to TCPL	182.2	343.8	337.7	406.9	486.8	613.0
Fuel Used in Saskatchewan	–	.7	1.4	1.5	1.3	1.4
Delivery to Monchy	–	253.0	502.2	511.9	557.6	557.3
System Summary						
Total Supply	230.0	824.6	1,202.3	1,308.9	1,491.5	1,643.6
Total Fuel	3.8	25.3	44.0	53.6	78.1	93.2
Total Delivery	226.2	799.3	1,158.3	1,255.3	1,413.4	1,550.4

TABLE 3

COMPRESSION EQUIPMENT REQUIREMENTS

Station Number	Milepost	Compression Unit Horse-power (ISO)	Refrigeration HP (ISO) per Station	Total Number of Compression Uni Proposed for Operating Year				
				1	2	3	4	5
Prudhoe Bay to Tununuk Junction								
CA-05	223.80	30,000	17,000	–	1	1	1	1
CD-08	372.37	30,000	17,000	–	–	–	1	1
Mackenzie Delta to Tununuk Junction								
None								
Tununuk Junction to Caroline								
MD-01	43.45	30,000	34,000	–	1	1	1	1
MD-02	90.85	30,000	17,000	–	–	–	1	1
MD-03	126.97	30,000	17,000	–	1	1	1	1
M-04	177.10	30,000	17,000	–	–	1	1	1
M-05	219.62	30,000	17,000	–	1	1	1	1
M-06	262.86	30,000	17,000	–	–	–	1	1
M-07	310.00	30,000	17,000	1	1	1	1	1
M-08	356.89	30,000	17,000	–	–	1	1	1
M-09	400.23	30,000	17,000	–	1	1	1	1
M-10	446.37	30,000	17,000	–	–	–	1	1
M-11	489.83	30,000	17,000	1	1	1	1	1
M-12	534.23	30,000	17,000	–	–	1	1	1
MF-13	583.14	30,000	–	–	1	1	1	1
MF-14	625.26	30,000	–	–	–	–	1	1
MF-15	660.79	38,000	–	1	1	1	1	1
MF-15A	699.96	38,000	6,400	–	–	1	1	1
MF-16	735.38	38,000	6,400	1	1	1	1	1
MF-17	768.82	38,000	6,400	–	–	–	1	1
MF-18	809.85	38,000	6,400	1	1	1	1	1
MF-19	856.64	38,000	6,400	–	–	1	1	1
M-20	901.16	38,000		1	1	1	1	1
M-21	941.84	38,000		–	–	–	1	1
M-22	982.14	38,000		–	1	1	1	1
M-23	1,020.29	38,000		–	–	1	1	1
M-24	1,062.47	38,000		1	1	1	1	1
M-25	1,108.23	38,000		–	–	–	1	1
M-26	1,148.80	38,000		–	1	1	1	1
M-27	1,190.20	38,000		–	–	1	1	1
M-28	1,229.68	38,000		1	1	1	1	1
M-29	1,263.21	38,000		–	–	–	1	1
M-30	1,310.69	38,000		–	1	1	1	1
M-31	1,353.10	38,000		–	–	1	1	1
M-32	1,391.17	38,000		1	1	1	1	1
M-33	1,429.60	38,000		–	–	–	1	1
Caroline to Coleman								
None								
Caroline to Monchy								
E-01	98.39	38,000		–	1	1	1	1
E-03	191.23	38,000		–	–	1	1	1
E-05	295.57	38,000		–	1	1	1	1

Note:
- Station MF-15 will have a heater for gas heating.
- Stations M-20 through M-33, inclusive, will have air-cooled heat exchangers for gas cooling.
- Stations M-07 and M-11 are prebuilt in Year 1 to accommodate construction resource limitations.

TABLE 4

SUMMARY OF COMPRESSION FACILITY REQUIREMENTS

	Incremental Number Proposed for Operating Year				
	1	2	3	4	5
Compressor Stations	9	11	9	10	0
Compressor Units					
38,000 ISO hp (gas)	7	5	6	5	0
30,000 ISO hp (gas)	2	6	3	5	0
17,000 ISO hp (propane)	2	5	3	4	0
6,400 ISO hp (propane)	2	0	2	1	0
Total Units	13	16	14	15	0
Installed ISO Horsepower					
Gas (10^3 ISO hp)	326	370	318	340	0
Propane (10^3 ISO hp)	47	85	64	74	0
Total (10^3 ISO hp)	373	455	382	414	0

	Total Number Proposed for Operating Year				
	1	2	3	4	5
Compressor Stations	9	20	29	39	39
Compressor Units					
38,000 ISO hp (gas)	7	12	18	23	23
30,000 ISO hp (gas)	2	8	11	16	16
17,000 ISO hp (propane)	2	7	10	14	14
6,400 ISO hp (propane)	2	2	4	5	5
Total Units	13	29	43	58	58
Installed ISO Horsepower					
Gas (10^3 ISO hp)	326	696	1,014	1,354	1,354
Propane (10^3 ISO hp)	47	132	196	270	270
Total (10^3 ISO hp)	373	828	1,210	1,624	1,624

GGK/ej
December 31, 1976

TABLE 5

COMPARISON OF NEW AND OLD DESIGNS NEAR LAST POINT OF COLD FLOW

Station		Milepost			Compression (hp)			Chiller (hp)		
Old	New	Old	New	Change	Old	New	Change	Old	New	Change
M-12	M-12	534.23	534.23	0	30,000	30,000	0	17,000	17,000	0
ME-13	MF-13	583.14	583.14	0	30,000	30,000	0	17,000	0	-17,000
ME-14	MF-14*	621.80	625.26	+3.46	30,000	30,000	0	17,000	0	-17,000
ME-15	MF-15*	673.97	660.79	-13.18	30,000	38,000	+8,000	17,000	0	-17,000
Non-exist	MF-15A*	-	699.96	-	-	38,000	+38,000	-	6,400	+6,400
ME-16	MF-16*	719.46	735.38	+15.92	30,000	38,000	+8,000	0	6,400	+6,400
ME-17	MF-17*	755.29	768.82	+13.53	30,000	38,000	+8,000	0	6,400	+6,400
ME-18	MF-18	809.85	809.85	0	55,000	38,000	-17,000	0	6,400	+6,400
ME-19	MF-19	856.64	856.64	0	55,000	38,000	-17,000	0	6,400	+6,400
M-20	M-20	901.16	901.16	0	55,000	38,000	-17,000	-	-	0

* New station sites

-01	E - 02	E - 03	TOTALS
98.39	147.25	191.23	
010	2,360	2,410	

LEGEND

IPELINE

TATION WITH CENTRIFUGAL - GAS TURBINE GAS OMPRESSION & CENTRIFUGAL - GAS TURBINE ROPANE COMPRESSION FOR GAS CHILLING.

TATION WITH CENTRIFUGAL - GAS TURBINE GAS OMPRESSION & CENTRIFUGAL - GAS TURBINE ROPANE COMPRESSION FOR GAS COOLING.

TATION WITH CENTRIFUGAL-GAS TURBINE GAS OMPRESSION & GAS TO AIR DIRECT HEAT XCHANGE FOR GAS COOLING

TATION WITH CENTRIFUGAL - GAS TURBINE AS COMPRESSION

AS MEASUREMENT STATION

PELINE PRESSURE

AS FLOWING VOLUME (14.73 PSIA & 60°F)

DE VALVE FOR FUTURE DELIVERIES

RESSURE REGULATING FACILITY.

Fold out

NOTES:

- HEATER LOAD GIVEN IN MMBTU/HR.
- •• HEATER CAPACITY GIVEN IN MMBTU/HR.

DESIGNED BY:	NORTHERN ENGINEERING SERVICES COMPANY LIMITED CALGARY ALBERTA	
DRAWN BY: D.C.	ENGINEERS FOR	
CHECKED BY: A K	CANADIAN ARCTIC GAS PIPELINE LIMITED	SCALE: N.T.S.
ENGINEERS APP: T. Hurl	FLOW DIAGRAM	DATE: JANUARY, 1977
	MAXIMUM CAPACITY	PROJECT No. 18111
PROJECT MANAGER: G King	AVERAGE SUMMER CONDITIONS - OPERATING YEAR 1	DRAWING No. 4-0229-6001-2 REV. -C

:-01	E - 02	E - 03	TOTALS
98.39	147.25	191.23	
1,010	2,360	2,410	

LEGEND

PIPELINE

STATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION & CENTRIFUGAL - GAS TURBINE PROPANE COMPRESSION FOR GAS CHILLING.

STATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION & CENTRIFUGAL - GAS TURBINE PROPANE COMPRESSION FOR GAS COOLING

STATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION & GAS TO AIR DIRECT HEAT EXCHANGE FOR GAS COOLING

STATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION

GAS MEASUREMENT STATION

PIPELINE PRESSURE

GAS FLOWING VOLUME (14.73 PSIA & 60°F)

SIDE VALVE FOR FUTURE DELIVERIES

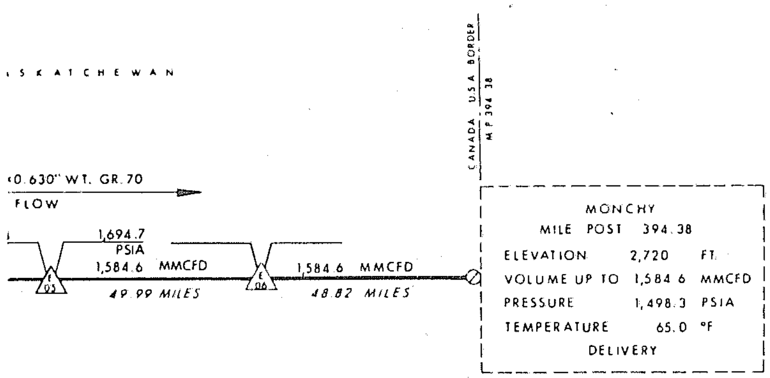
PRESSURE REGULATING FACILITY

Fold over

NOTES:

- * HEATER LOAD GIVEN IN MMBTU/HR
- ** HEATER CAPACITY GIVEN IN MMBTU/HR

DESIGNED BY: JH	NORTHERN ENGINEERING SERVICES COMPANY LIMITED CALGARY ALBERTA	
DRAWN BY: NF	ENGINEERS FOR	
CHECKED BY: AY	CANADIAN ARCTIC GAS PIPELINE LIMITED	SCALE: N.T.S.
ENGINEER'S APP: T. Heal	FLOW DIAGRAM	DATE: JANUARY, 1977
	MAXIMUM CAPACITY	PROJECT No: 18111
PROJECT MANAGER: T. King	AVERAGE WINTER CONDITIONS - OPERATING YEAR 1	DRAWING No: 4-0229-6002-2-C REV:



01	E - 02	E - 03	E - 04	E - 05	E - 06	TOTALS
98.39	147.25	191.23	236.03	295.57	345.56	
10	2,360	2,410	2,390	2,520	3,150	
1				1		2
00				38,000		
00				38,000		76,000
866				21,613		52,479
526.6				1,589.9		
6.9				5.3		12.2
619.7				1,584.6		
291.8				1,243.1		
597.7				1,695.5		
1.31				1.36		
41.6				42.7		
80.5				87.3		
61.8				87.3		
413				0		6,413
0				0		0
0				0		
0				0		0
0				0		0

LEGEND

IPELINE

TATION WITH CENTRIFUGAL - GAS TURBINE GAS OMPRESSION & CENTRIFUGAL - GAS TURBINE ROPANE COMPRESSION FOR GAS CHILLING.

TATION WITH CENTRIFUGAL - GAS TURBINE GAS OMPRESSION & CENTRIFUGAL - GAS TURBINE ROPANE COMPRESSION FOR GAS COOLING.

TATION WITH CENTRIFUGAL - GAS TURBINE GAS OMPRESSION & GAS TO AIR DIRECT HEAT XCHANGE FOR GAS COOLING

TATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION

GAS MEASUREMENT STATION

IPELINE PRESSURE

GAS FLOWING VOLUME (14.73 PSIA & 60°F)

IDE VALVE FOR FUTURE DELIVERIES

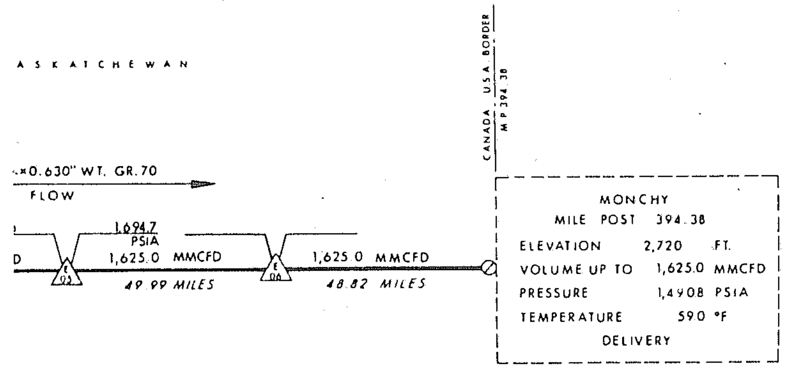
RESSURE REGULATING FACILITY.

Fold over

NOTES:

- HEATER LOAD GIVEN IN MMBTU/HR
- •• HEATER CAPACITY GIVEN IN MMBTU/HR

DESIGNED BY: AK	NORTHERN ENGINEERING SERVICES COMPANY LIMITED CALGARY ALBERTA	
DRAWN BY: DC	ENGINEERS FOR	
CHECKED BY: [signature]	CANADIAN ARCTIC GAS PIPELINE LIMITED	SCALE: N T S
ENGINEERS APP: [signature]	FLOW DIAGRAM	DATE: JANUARY, 1977
PROJECT MANAGER: G King	MAXIMUM CAPACITY	PROJECT No 18111
	AVERAGE SUMMER CONDITIONS - OPERATING YEAR 2	DRAWING No 4-0229-6003-2-C REV



-01	E - 02	E - 03	E - 04	E - 05	E - 06	TOTALS
98.39	147.25	191.23	236.03	295.57	345.56	
,010	2,360	2,410	2,390	2,520	3,150	
1	-			1		2
,000				38,000		
,000				38,000		76,000
,859				25,459		60,318
694.6				1,630.9		
7.3				5.9		13.2
687.3				1,625.0		
,254.9				1,185.1		
694.7				1,695.5		
1.35				1.43		
·39.4				37.4		
82.2				88.8		
82.2				88.8		
0				0		0
0				0		0
0				0		
0				0		0
0				0		0

LEGEND

'IPELINE

;TATION WITH CENTRIFUGAL - GAS TURBINE GAS :OMPRESSION & CENTRIFUGAL - GAS TURBINE 'ROPANE COMPRESSION FOR GAS CHILLING.

.TATION WITH CENTRIFUGAL - GAS TURBINE GAS :OMPRESSION & CENTRIFUGAL - GAS TURBINE 'ROPANE COMPRESSION FOR GAS COOLING.

;TATION WITH CENTRIFUGAL-GAS TURBINE GAS :OMPRESSION & GAS TO AIR DIRECT HEAT :XCHANGE FOR GAS COOLING

.TATION WITH CENTRIFUGAL - GAS TURBINE ;AS COMPRESSION

;AS MEASUREMENT STATION

IPELINE PRESSURE

;AS FLOWING VOLUME (14.73 PSIA & 60°F)

IDE VALVE FOR FUTURE DELIVERIES

RESSURE REGULATING FACILITY.

Fold out

NOTES:

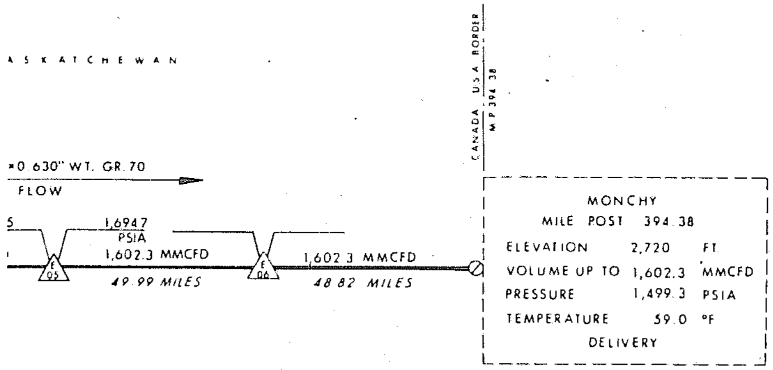
- • HEATER LOAD GIVEN IN MMBTU/HR
- •• HEATER CAPACITY GIVEN IN MMBTU/HR

DESIGNED BY A.K.
DRAWN BY NORM
CHECKED BY
ENGINEERS APP A. K
PROJECT MANAGER G. King

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

FLOW DIAGRAM
MAXIMUM CAPACITY
AVERAGE WINTER CONDITIONS - OPERATING YEAR 2

SCALE: NTS
DATE: JANUARY 1977
PROJECT No 18111
DRAWING No. 4-0229-6004-2-C
REV



-01	E - 02	E - 03	E - 04	E - 05	E - 06	TOTALS
98.39	147.25	191.23	236.03	295.57	345.56	
)10	2,360	2,410	2,390	2,520	3,150	
1		1		1		3
)00		38,000		38,000		
)00		38,000		38,000		114,000
)16		32,517		11,315		78,848
381.6		2,874.1		1,606.0		
7.5		7.2		3.7		18.4
374.1		2,866.9		1,602.3		
200.0		1,312.3		1,441.3		
594.2		1,698.4		1,695.5		
1.33		1.29		1.18		
36:3		47.6		51.9		
76.9		84.6		75.1		
61.2		65.8		75.1		
'56		6,968		0		12,724
0		0		0		0
0		0		0		
0		0		0		0
0		0		0		0

LEGEND

PELINE

'ATION WITH CENTRIFUGAL - GAS TURBINE GAS
OMPRESSION & CENTRIFUGAL - GAS TURBINE
ROPANE COMPRESSION FOR GAS CHILLING.

'ATION WITH CENTRIFUGAL - GAS TURBINE GAS
OMPRESSION & CENTRIFUGAL - GAS TURBINE
ROPANE COMPRESSION FOR GAS COOLING

'ATION WITH CENTRIFUGAL - GAS TURBINE GAS
OMPRESSION & GAS TO AIR DIRECT HEAT
XCHANGE FOR GAS COOLING

'ATION WITH CENTRIFUGAL - GAS TURBINE
AS COMPRESSION

AS MEASUREMENT STATION

PELINE PRESSURE

AS FLOWING VOLUME (14.73 PSIA & 60°F)

DE VALVE FOR FUTURE DELIVERIES

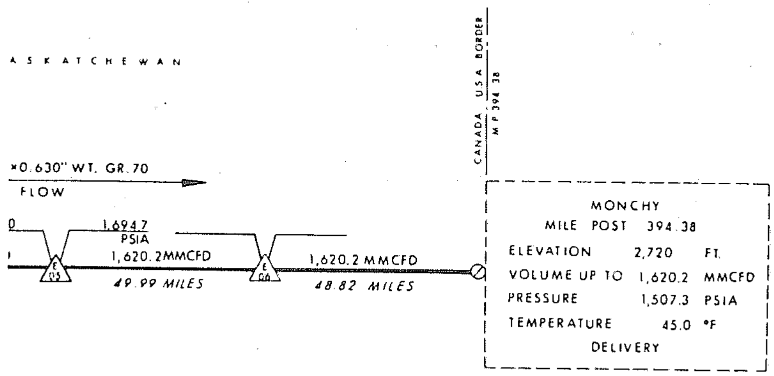
'ESSURE REGULATING FACILITY.

Fold over

NOTES:

* HEATER LOAD GIVEN IN MMBTU/HR
** HEATER CAPACITY GIVEN IN MMBTU/HR

DESIGNED BY A.V.	NORTHERN ENGINEERING SERVICES COMPANY LIMITED CALGARY ALBERTA		
DRAWN BY D.C.	ENGINEERS FOR		
CHECKED BY	CANADIAN ARCTIC GAS PIPELINE LIMITED	SCALE: N.T.S.	
ENGINEERS APP. A.	FLOW DIAGRAM	DATE: JANUARY, 1977	
	MAXIMUM CAPACITY	PROJECT No. 18111	
PROJECT MANAGER	AVERAGE SUMMER CONDITIONS - OPERATING YEAR 3	DRAWING No. 4-0229-6005-2-C	REV.



-01	E - 02	E - 03	E - 04	E - 05	E - 06	TOTALS
98.39	147.25	191.23	236.03	295.57	345.56	
010	2,360	2,410	2,390	2,520	3,150	
1		1		1		3
000		38,000		38,000		
000		38,000		38,000		114,000
817		28,385		10,645		79,847
913.7		2,905.2		1,623.8		
8.5		6.6		3.6		18.7
905.2		2,898.6		1,620.2		
171.3		1,348.4		1,444.9		
623.0		1,698.3		1,695.4		
1.39		1.26		1.17		
34.5		41.9		40.9		
81.1		74.4		63.2		
60.0		60.0		63.1		
881		5,505		0		13,386
0		0		0		0
0		0		0		
0		0		0		0
0		0		0		0

LEGEND

PELINE

TATION WITH CENTRIFUGAL - GAS TURBINE GAS OMPRESSION & CENTRIFUGAL - GAS TURBINE ROPANE COMPRESSION FOR GAS CHILLING.

TATION WITH CENTRIFUGAL - GAS TURBINE GAS OMPRESSION & CENTRIFUGAL - GAS TURBINE ROPANE COMPRESSION FOR GAS COOLING

TATION WITH CENTRIFUGAL - GAS TURBINE GAS OMPRESSION & GAS TO AIR DIRECT HEAT XCHANGE FOR GAS COOLING

TATION WITH CENTRIFUGAL - GAS TURBINE AS COMPRESSION

AS MEASUREMENT STATION

PELINE PRESSURE

AS FLOWING VOLUME (14.73 PSIA & 60°F)

DE VALVE FOR FUTURE DELIVERIES

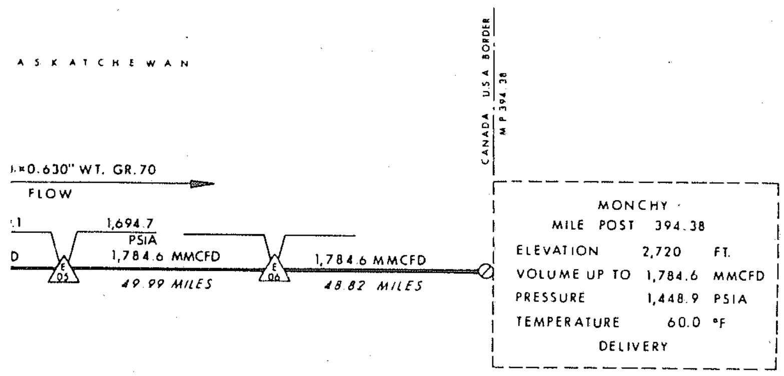
ESSURE REGULATING FACILITY.

Fold over

NOTES:

- * HEATER LOAD GIVEN IN MMBTU/HR
- ** HEATER CAPACITY GIVEN IN MMBTU/HR

DESIGNED BY A.V.	NORTHERN ENGINEERING SERVICES COMPANY LIMITED CALGARY ALBERTA ENGINEERS FOR CANADIAN ARCTIC GAS PIPELINE LIMITED	
DRAWN BY WJ		
CHECKED BY GM		SCALE N.T.S.
ENGINEERS APP. A. V.	FLOW DIAGRAM MAXIMUM CAPACITY AVERAGE WINTER CONDITIONS - OPERATING YEAR 3	DATE JANUARY, 1977
		PROJECT No. 18111
PROJECT MANAGER G. King		DRAWING No. 4-0229-6006-2-C REV.



-01	E - 02	E - 03	E - 04	E - 05	E - 06	TOTALS
98.39	147.25	191.23	236.03	295.57	345.56	
,010	2,360	2,410	2,390	2,520	3,150	
1		1		1		3
,000		38,000		38,000		
,000		38,000		38,000		114,000
,762		32,476		16,690		81,928
,280.9		3,273.7		1,789.1		
7.2		7.2		4.5		18.9
273.7		3,266.5		1,784.6		
344.9		1,350.3		1,367.6		
,699.4		1,699.4		1,695.6		
1.26		1.26		1.24		
43.4		46.1		48.7		
76.4		78.8 *		79.3		
62.3		64.9		79.3		
,096		5,856		0		11,952
0		0		0		0
0		0		0		
0		0		0		0
0		0		0		0

LEGEND

'IPELINE

;TATION WITH CENTRIFUGAL - GAS TURBINE GAS ;OMPRESSION & CENTRIFUGAL - GAS TURBINE 'ROPANE COMPRESSION FOR GAS CHILLING.

;TATION WITH CENTRIFUGAL - GAS TURBINE GAS ;OMPRESSION & CENTRIFUGAL - GAS TURBINE 'ROPANE COMPRESSION FOR GAS COOLING.

;TATION WITH CENTRIFUGAL - GAS TURBINE GAS ;OMPRESSION & GAS TO AIR DIRECT HEAT :XCHANGE FOR GAS COOLING

;TATION WITH CENTRIFUGAL - GAS TURBINE ;AS COMPRESSION

;AS MEASUREMENT STATION

'IPELINE PRESSURE

;AS FLOWING VOLUME (14.73 PSIA & 60°F)

.IDE VALVE FOR FUTURE DELIVERIES

'RESSURE REGULATING FACILITY

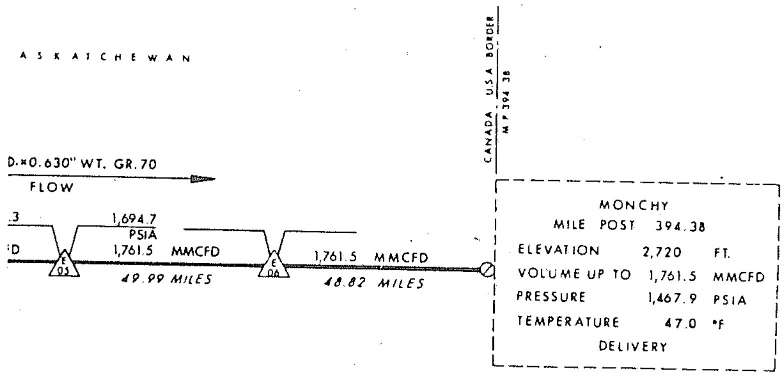
Fold over.

NOTES:

- * HEATER LOAD GIVEN IN MMBTU/HR.
- ** HEATER CAPACITY GIVEN IN MMBTU/HR.

DESIGNED BY: A.K.	NORTHERN ENGINEERING SERVICES COMPANY LIMITED CALGARY ALBERTA		
DRAWN BY: J.S.	ENGINEERS FOR		
CHECKED BY:	CANADIAN ARCTIC GAS PIPELINE LIMITED		SCALE: NTS
ENGINEERS APP.:	FLOW DIAGRAM		DATE: JANUARY, 1977
	MAXIMUM CAPACITY		PROJECT No. 18111
PROJECT MANAGER: J. King	AVERAGE SUMMER CONDITIONS - OPERATING YEAR 4		DRAWING No. 4-0229-6007-2 -C

A S K A T C H E W A N



:-01	E - 02	E - 03	E - 04	E - 05	E - 06	TOTALS
98.39	147.25	191.23	236.03	295.57	345.56	
),010	2,360	2,410	2,390	2,520	3,150	
1		1		1		3
,000		38,000		38,000		
,000		38,000		38,000		114,000
),444		29,654		14,857		74,955
,237.4		3 230.6		1765.8		
6.8		6.7		4.3		17.8
),230.6		3,223.9		1,761.5		
,358.3		1,366.4		1,384.9		
,699.2		1,699.2		1,695.6		
1.25		1.24		1.23		
40.6		41.8		40.3		
72.1		72.4		68.5		
62.0		62.0		68.5		
,263		4,386		0		8649
0		0		0		0
0		0		0		
0		0		0		0
0		0		0		0

LEGEND

PIPELINE

STATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION & CENTRIFUGAL - GAS TURBINE PROPANE COMPRESSION FOR GAS CHILLING.

STATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION & CENTRIFUGAL - GAS TURBINE PROPANE COMPRESSION FOR GAS COOLING.

STATION WITH CENTRIFUGAL-GAS TURBINE GAS COMPRESSION & GAS TO AIR DIRECT HEAT EXCHANGE FOR GAS COOLING

STATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION

GAS MEASUREMENT STATION

PIPELINE PRESSURE

GAS FLOWING VOLUME (14.73 PSIA & 60°F)

SIDE VALVE FOR FUTURE DELIVERIES

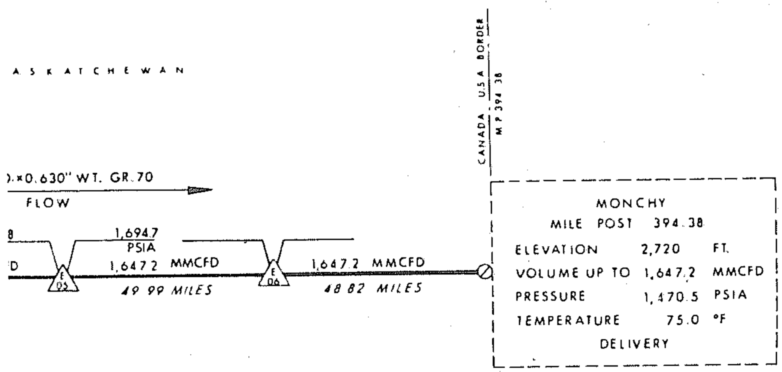
PRESSURE REGULATING FACILITY.

Fold out

NOTES:

- * HEATER LOAD GIVEN IN MMBTU/HR
- ** HEATER CAPACITY GIVEN IN MMBTU/HR.

DESIGNED BY: A.K. DRAWN BY: F.B. CHECKED BY: J.H. ENGINEERS APP: A. [illegible] PROJECT MANAGER: [illegible] King	NORTHERN ENGINEERING SERVICES COMPANY LIMITED CALGARY ALBERTA ENGINEERS FOR CANADIAN ARCTIC GAS PIPELINE LIMITED	SCALE N.T.S.
	FLOW DIAGRAM MAXIMUM CAPACITY AVERAGE WINTER CONDITIONS - OPERATING YEAR 4	DATE: JANUARY, 1977 PROJECT No 18111 DRAWING No 4-0229-6008-2 REV -C



-01	E - 02	E - 03	E - 04	E - 05	E - 06	TOTALS
98.39	147.25	191.23	236.03	295.57	345.56	
,010	2,360	2,410	2,390	2,520	3,150	
1		1		1		3
,000		38,000		38,000		
,000		38,000		38,000		114,000
,016		35,220		32,279		102,515
,484.3		3,476.8		1,654.1		
7.5		7.6		6.9		22.0
,476.8		3,469.2		1,647.2		
,286.3		1,192.7		1,108.1		
,628.7		1,506.7		1,695.6		
1.27		1.26		1.53		
40.5		40.7		44.2		
74.1		74.4		106.8		
61.7		63.4		106.8		
,527		4,701		0		10,228
0		0		0		0
0		0		0		
0		0		0		0
0		0		0		0

LEGEND

PIPELINE

STATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION & CENTRIFUGAL - GAS TURBINE PROPANE COMPRESSION FOR GAS CHILLING.

STATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION & CENTRIFUGAL - GAS TURBINE PROPANE COMPRESSION FOR GAS COOLING.

STATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION & GAS TO AIR DIRECT HEAT EXCHANGE FOR GAS COOLING

STATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION

GAS MEASUREMENT STATION

PIPELINE PRESSURE

GAS FLOWING VOLUME (14.73 PSIA & 60°F)

SIDE VALVE FOR FUTURE DELIVERIES

PRESSURE REGULATING FACILITY.

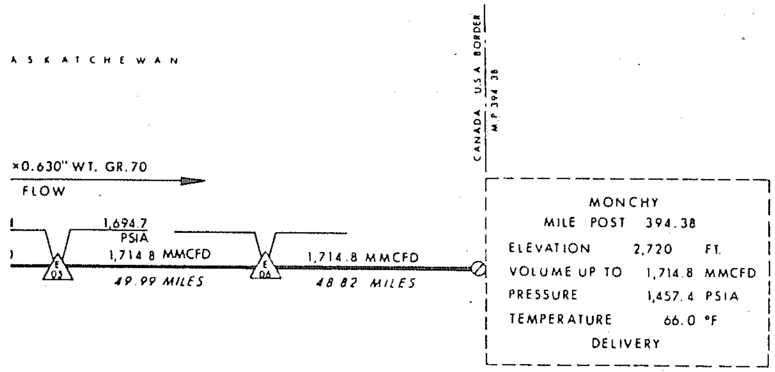
Fold out

NOTES:

- * HEATER LOAD GIVEN IN MMBTU/HR
- ** HEATER CAPACITY GIVEN IN MMBTU/HR.

DESIGNED BY: AC	NORTHERN ENGINEERING SERVICES COMPANY LIMITED CALGARY ALBERTA	
DRAWN BY: D.C	ENGINEERS FOR	
CHECKED BY: JH	CANADIAN ARCTIC GAS PIPELINE LIMITED	SCALE N.T.S
ENGINEERS APP.: A. [signature]	FLOW DIAGRAM	DATE: JANUARY, 1977
	MAXIMUM CAPACITY	PROJECT No 18111
PROJECT MANAGER: [signature]	AVERAGE SUMMER CONDITIONS - OPERATING YEAR 5	DRAWING No. 4-0229-6009-2-C REV

Northern Engineering Services Company Limited



-01	E-02	E-03	E-04	E-05	E-06	TOTALS
98.39	147.25	191.23	236.03	295.57	345.56	
010	2,360	2,410	2,390	2,520	3,150	
1		1		1		3
000		38,000		38,000		
000		38,000		38,000		114,000
817		41,864		36,346		119,027
629.3		3,620.9		1,722.3		
8.4		8.6		7.5		24.5
620.9		3,612.3		1,714.8		
242.1		1,139.9		1,057.6		
621.9		1,493.9		1,695.7		
1.31		1.31		1.60		
35.4		33.8		33.5		
73.2		72.6		102.3		
62.0		62.0		102.3		
,172		4,711		0		9,883
0		0		0		0
0		0		0		
0		0		0		0
0		0		0		0

LEGEND

IPELINE

TATION WITH CENTRIFUGAL - GAS TURBINE GAS OMPRESSION & CENTRIFUGAL - GAS TURBINE ROPANE COMPRESSION FOR GAS CHILLING.

TATION WITH CENTRIFUGAL - GAS TURBINE GAS OMPRESSION & CENTRIFUGAL - GAS TURBINE ROPANE COMPRESSION FOR GAS COOLING.

TATION WITH CENTRIFUGAL - GAS TURBINE GAS OMPRESSION & GAS TO AIR DIRECT HEAT XCHANGE FOR GAS COOLING

TATION WITH CENTRIFUGAL - GAS TURBINE GAS COMPRESSION

GAS MEASUREMENT STATION

IPELINE PRESSURE

GAS FLOWING VOLUME (14.73 PSIA & 60°F)

IDE VALVE FOR FUTURE DELIVERIES

RESSURE REGULATING FACILITY.

Fold out

NOTES:

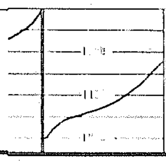
- * HEATER LOAD GIVEN IN MMBTU/HR
- ** HEATER CAPACITY GIVEN IN MMBTU/HR.

DESIGNED BY:	NORTHERN ENGINEERING SERVICES COMPANY LIMITED, CALGARY ALBERTA, ENGINEERS FOR	
DRAWN BY:		
CHECKED BY:	CANADIAN ARCTIC GAS PIPELINE LIMITED	SCALE: NTS
ENGINEERS APP:	FLOW DIAGRAM	DATE: JANUARY, 1977
	MAXIMUM CAPACITY	PROJECT No. 18111
PROJECT MANAGER	AVERAGE WINTER CONDITIONS - OPERATING YEAR 5	DRAWING No. 4-0229-6010-2 -C · REV.

OWNERSHIP

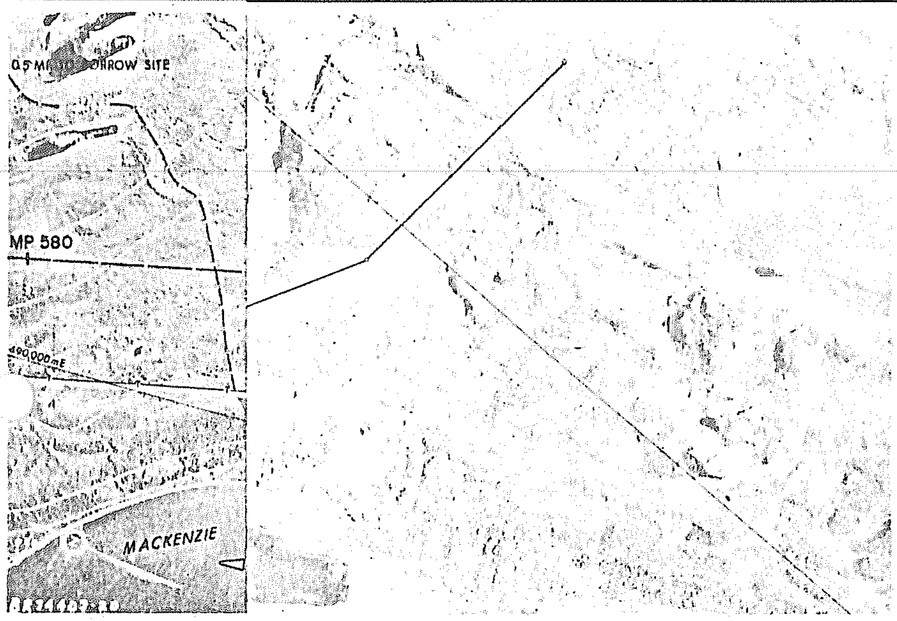
DRILL HOLE DATA

PROFILE



DRILL HOLE DATA LEGEND

TERRAIN TYPING LEGEND



FOOTAGE THIS SHEET

REFERENCE DRAWINGS & NOTES

MATCH LINE 591.52

CHAINAGE (miles)

9.05

DESIGN DATA

SEGMENT

SEGMENT No.

SEGMENT LENGTH

EROSION CONTROL

BUOY.

REVEG.

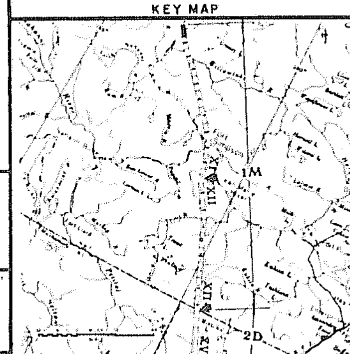
U.T.M. GRID ZONE 10

0 0.5 1.0

SCALE (miles)

Foldout

KEY MAP



PIPELINE

Symbol		Symbol	
	CARRIER PIPE (cover shown)		POINT OF INTER...
	CARRIER PIPE (berm cover)		DRILL HOLE LO...
	BERM BREAK		WARNING SIGN
	SWAMP WEIGHT		MILEPOST SIGN
	RIVER WEIGHT		CHAINAGE EQUA...
	FROST ANCHOR		COMPRESSOR ST...
	SCREW ANCHOR		AIR STRIP
	HEAVY WALL PIPE		STORAGE OR S...
	CASING PIPE		CAMP SITE
	ANCHOR BLOCK (concrete)		STAGING AREA
	BLOCK VALVE		BORROW SITE
	TEST LEAD & DIRECTION OF WIRES		WHARF

REVISION	APPRD BY	APPRD BY
...P ADD AIRSTRIP AND COMM. TOWER		

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA

Northern Engineering Services Company Limited

ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

NORTHWEST TERRITORIES (DIST OF MACKENZIE) & YUKON TERRITORY

UPSTREAM M.P. 587 DOWNSTREAM M.P. 592

DRN BY	DATE		
CHKD BY		SCALE 1" = 2000'	1M - 0200 - 1001
APPRD BY		SHEET 1 OF 19	

TERRAIN MAPPING BY:

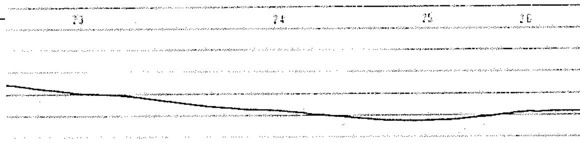
J.D. MOLLARD & ASSOCIATES LIMITED

REGINA, SASK. DATE:

OWNERSHIP

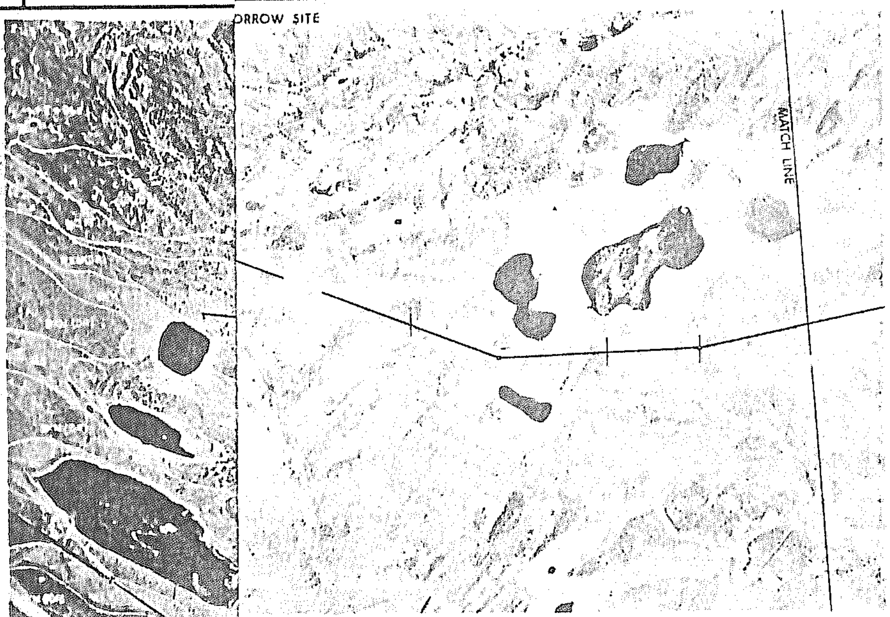
DRILL HOLE DATA

PROFILE



DRILL HOLE DATA LEGEND

TERRAIN TYPING LEGEND



Fold out

FOOTAGE THIS SHEET

CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES: MATCH LINE 603.06

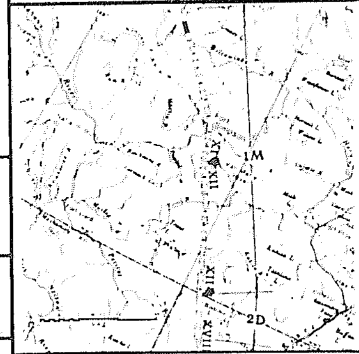
CHAINAGE (miles)	9.43	10.67	11.07	11.54
SEGMENT No.	23	24	25	26
SEGMENT LENGTH	1.09	0.86	0.40	0.47
EROSION CONTROL	EC-1D	EC-1C	EC-1C	EC-1D
BUOY	B-0	B-0	B-2	B-0
REVEG	II-V-2			

U T M. GRID ZONE 10

0 0.5 1.0

SCALE (miles)

KEY MAP



TERRAIN MAPPING BY J.D. MOLLARD & ASSOCIATES LIMITED REGINA, SASK. DATE

PIPELINE

Symbol		Symbol	
	CARRIER PIPE (cover shown)		POINT OF INT
	CARRIER PIPE (berm cover)		DRILL HOLE
	BERM BREAK		WARNING SIGN
	SWAMP WEIGHT		MILEPOST SIGN
	RIVER WEIGHT		CHAINAGE EQ
	FROST ANCHOR		COMPRESSOR
	SCREW ANCHOR		AIR STRIP
	HEAVY WALL PIPE		STORAGE OR
	CASING PIPE		CAMP SITE
	ANCHOR BLOCK (concrete)		STAGING ARE
	BLOCK VALVE		BORROW SIT
	TEST LEAD & DIRECTION OF WIRES		WHARF

REVISION	APPRD BY	APPRD BY
LV AT M.P. 602.7		

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA

NORTHERN Engineering Services Company Limited

ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

NORTHWEST TERRITORIES (DIST OF MACKENZIE) & YUKON TERRITORY

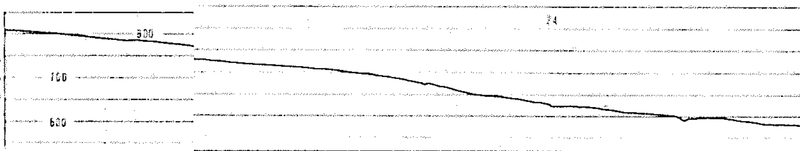
UPSTREAM M.P. 592 DOWNSTREAM M.P. 603

DRN BY	DATE		
CHKD BY		SCALE 1" = 2000'	1M-0200-1002
APPRD	Feb 14/75	SHEET 2 OF 19	

OWNERSHIP

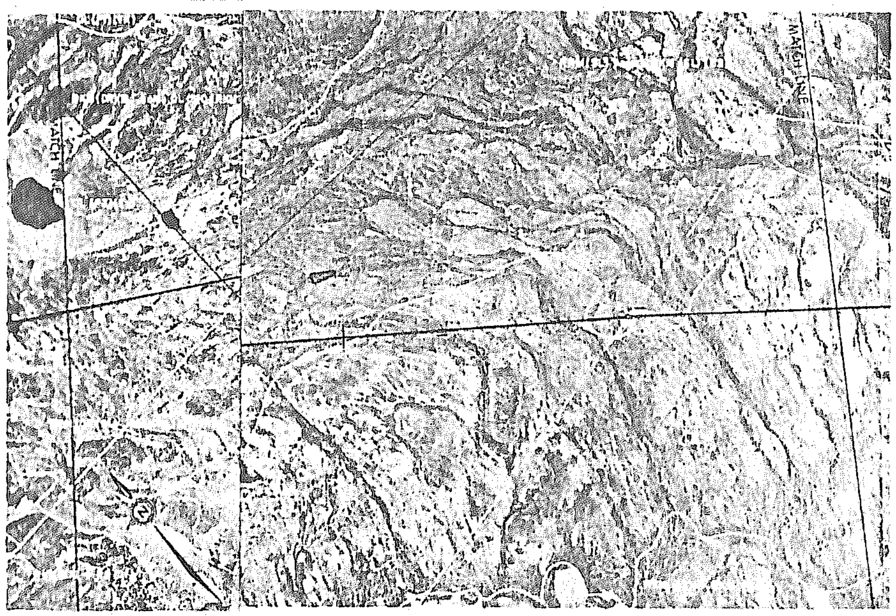
DRILL HOLE DATA

PROFILE



DRILL HOLE DATA LEGEND

TERRAIN TYPING LEGEND



Fold'out

CONSTRUCTION DATA			
REFERENCE DRAWINGS & NOTES	MATCH LINE 602 00		MATCH LINE 616 47
CHAINAGE (miles)	00 00	12 30	13 36
DESIGN DATA			
SEGMENT Nº	1	24	
SEGMENT LENGTH	1 70	2 00	
EROSION CONTROL	EC 1D	EC 1C	
BUOY	B 0	B 0	
REVEG	II V 2		

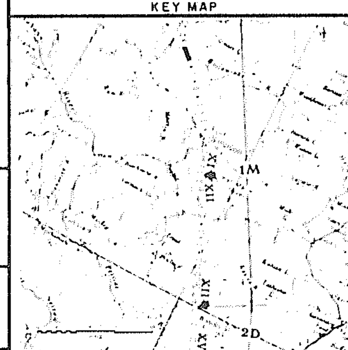
FOOTAGE THIS SHEET

U T M GRID ZONE 10

0 0.5 1.0

SCALE (miles)

KEY MAP



PIPELINE

CARRIER PIPE (SHOW MAIN)	POINT OF INTER
CARRIER PIPE (SHOW LOOP)	DRILL HOLE LO
BERM BREAK	WARNING SIGN
SWAMP WEIGHT	MILEPOST SIGN
RIVER WEIGHT	CHAINAGE EQUA
FROST ANCHOR	COMPRESSOR ST
SCREW ANCHOR	AIR STRIP
HEAVY WALL PIPE	STORAGE OR S
CASING PIPE	CAMP SITE
ANCHOR BLOCK (CONCRETE)	STAGING AREA
BLOCK VALVE	BORROW SITE
TEST LEAD & DIRECTION OF WIRES	WHARF

REVISION	APPD BY	APPD BY
AT M.P. 604.2		

NORTHERN Engineering Services Company Limited

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA

ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

NORTHWEST TERRITORIES : DIST OF MACKENZIE : & YUKON TERRITORY

UPSTREAM M.P. 603 DOWNSTREAM M.P. 616

DRN BY	DATE	
CHKD BY		
APPROVED	Feb 18/75	SCALE 1" = 2000'
		SHEET 3 OF 19

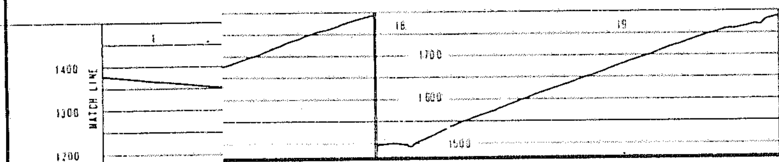
1M-0200-1003

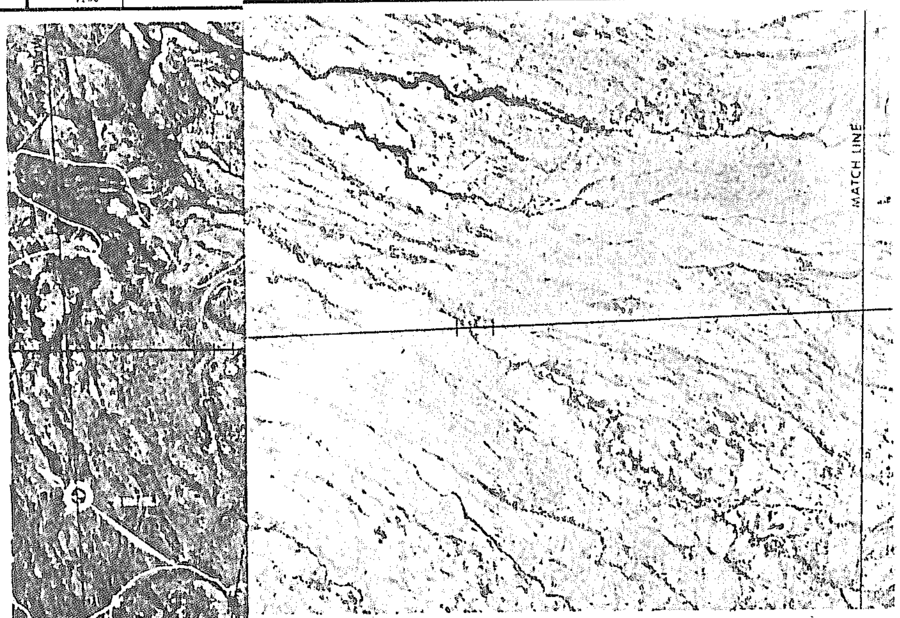
TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

OWNERSHIP

DRILL HOLE DA

PROFILE





TERRAIN TYPING LEGEND

Fold over

FOOTAGE THIS SHEET

CONSTRUCTION DATA

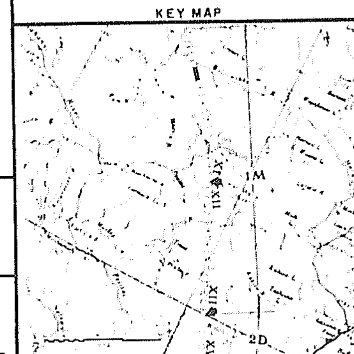
REFERENCE DRAWINGS & NOTES	MATCH LINE 616 42			4-0210-1099		MATCH LINE 629 22
CHAINAGE (miles)	00 00	0 53 0 62 0 71		11 12 11 27		12 80
DESIGN DATA						
SEGMENT Nº	1	2		18	19	
SEGMENT LENGTH	0 53	0 09		0 15	1 53	
EROSION CONTROL	EC 1C	EC 7		N A	EC 1C	
BUOY	B 0	B 0		N A	B 0	
REVEG	II V 2	II V 6		II V 6	II V 2	

U T M GRID ZONE 10

0 0.5 1.0

SCALE (miles)

KEY MAP



PIPELINE

CARRIER PIPE (conc. down)		POINT OF INTERSECTION	
CARRIER PIPE (perm. down)		DRILL HOLE	
BERM BREAK		WARNING SIGN	
SWAMP WEIGHT		MILEPOST SIGN	
RIVER WEIGHT		CHAINAGE EQ.	
FROST ANCHOR		COMPRESSOR	
SCREW ANCHOR		AIR STRIP	
HEAVY WALL PIPE		STORAGE OR	
CASING PIPE		CAMP SITE	
ANCHOR BLOCK (concrete)		STAGING AREA	
BLOCK VALVE		BORROW SITE	
TEST LEAD & DIRECTION OF WIRES		WHARF	

REVISION	APPRD BY	APPRD BY
C. STA. MF-14 AND ... ES FROM M.P. 621.8 ... 625.3	ee	

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA
NORTHWEST TERRITORIES : DIST OF MACKENZIE : & YUKON TERRITORY

UPSTREAM M.P. 616 DOWNSTREAM M.P. 629

DWN BY | DATE
CHKD BY | Jul '75
APPRD BY | Feb 10/75

SCALE 1" = 2000'
SHEET 4 OF 19

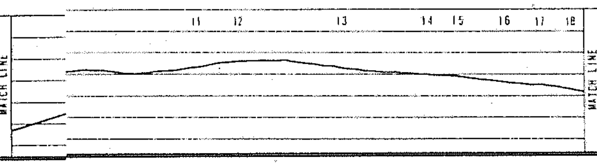
1M - 0200 - 1004

TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

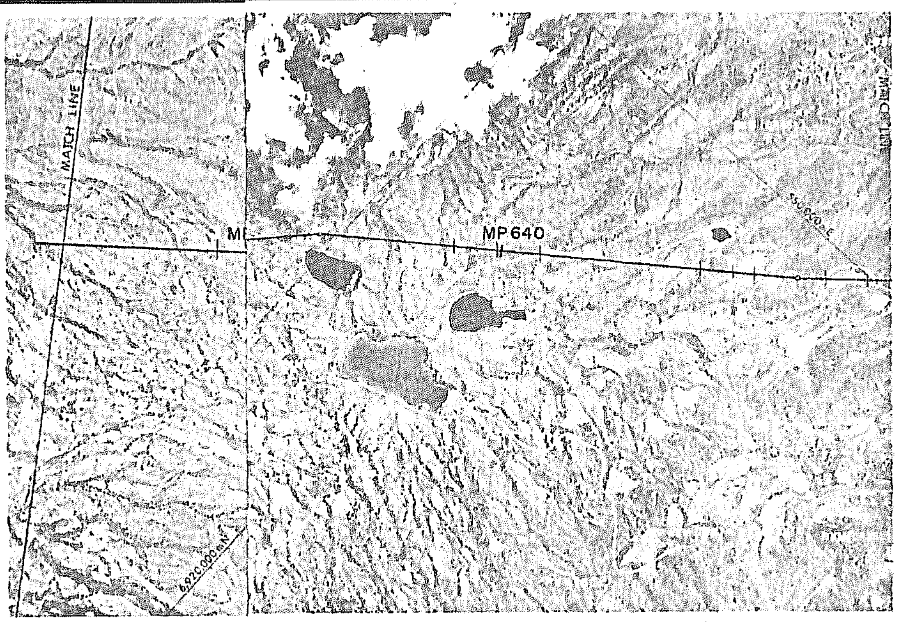
OWNERSHIP

DRILL HOLE DATA

PROFILE



TERRAIN TYPING LEGEND



FOOTAGE THIS SHEET

CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES: MATCH LINE 629.72 — MATCH LINE 641.55

CHAINAGE (miles): 00.00, 0.63, 10.56, 10.76, 10.92, 11.55, 11.65, 11.77, 12.04, 12.21, 12.33

DESIGN DATA

SEGMENT No.	1	10	11	12	13	14	15	16	17	18
SEGMENT LENGTH	0.63	77	0.18	0.16	0.63	0.13	0.09	0.27	0.17	0.12
EROSION CONTROL	EC-1C	-1D	EC-2D	EC-1D	EC-1C	EC-2D	EC-1C	EC-1D	EC-10	EC-6, EC-2D
BUOY	B-0	-0	B-0	B-0	B-7	B-0	B-1	B-0	B-1	B-0
REVEG			II-Y-6		II-Y-2	II-Y-6		II-Y-2		II-Y-6

U T M GRID ZONE 10

0 0.5 1.0
SCALE (miles)

PIPELIN

- CARRIER PIPE (cover shown)
- CARRIER PIPE (berm cover)
- BERM BREAK
- SWAMP WEIGHT
- RIVER WEIGHT
- FROST ANCHOR
- SCREW ANCHOR
- HEAVY WALL PIPE
- CASING PIPE
- ANCHOR BLOCK (concrete)
- BLOCK VALVE
- TEST LEAD & DIRECTION OF WIRES
- POINT OF INTER
- DRILL HOLE LC
- WARNING SIGN
- MILEPOST SIGN
- CHAINAGE EQU
- COMPRESSOR S
- AIR STRIP
- STORAGE OR S
- CAMP SITE
- STAGING AREA
- BORROW SITE
- WHARF

REVISION	APPRD BY	APPRD BY

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

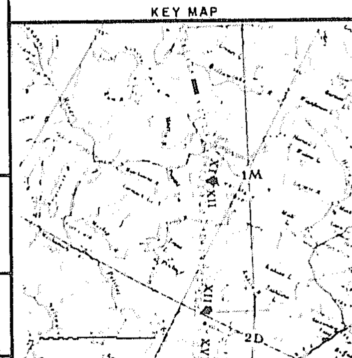
GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA
NORTHWEST TERRITORIES : DIST OF MACKENZIE : & YUKON TERRITORY

UPSTREAM M.P. 629 DOWNSTREAM M.P. 642

DRN BY	DATE		
CHKD BY M.F.L.	Feb 7/75	SCALE 1 : 2000	1M-0200-1005
APPRD BY	Feb	SHEET 5 OF 19	

Fold over

KEY MAP

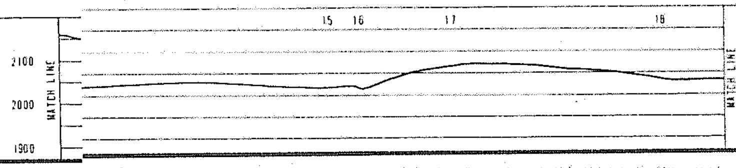


TERRAIN MAPPING BY
J D MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

OWNERSHIP

DRILL HOLE DATA

PROFILE



DRILL HOLE DATA LEGEND

TERRAIN TYPING LEGEND

Fold' ___

CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES: MATCH LINE 641.55 | 4-0210-1099 | MATCH LINE 654.28

FOOTAGE THIS SHEET

CHAINAGE (miles): 00.00 | 0.48 | 0.53 | 10.66 | 11.02 | 11.07 | 12.07 | 12.73

DESIGN DATA

SEGMENT Nº	1	2	15	16	17	18
SEGMENT LENGTH	0.48	0.05	0.16	0.05	1.00	0.66
EROSION CONTROL	EC-2D, EC 6	EC 7	EC 1D	N A	EC 1D	EC 1C
BUOY.	B-0	B-0	B 0	N A	B 0	B 2
REVEG.	II-V-6		II-V-2	II-V-6		II-V-2

0 0.5 1.0
SCALE (miles)

U T M GRID ZONE 10

PIPELINE ...

CARRIER PIPE (... shown) · CARRIER PIPE (... cover) · BERM BREAK · SWAMP WEIGHT · RIVER WEIGHT · FROST ANCHOR · SCREW ANCHOR · HEAVY WALL PIPE · CASING PIPE · ANCHOR BLOCK (concrete) · BLOCK VALVE · TEST LEAD & DIRECTION OF WIRES

POINT OF INTE... · DRILL HOLE L... · WARNING SIGN · MILEPOST SIGN · CHAINAGE EQ... · COMPRESSOR · AIR STRIP · STORAGE GR... · CAMP SITE · STAGING ARE... · BORROW SITE · WHARF

REVISION	APPD BY	APPD BY
E B V AT M.P. 648.4		
643.0		

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

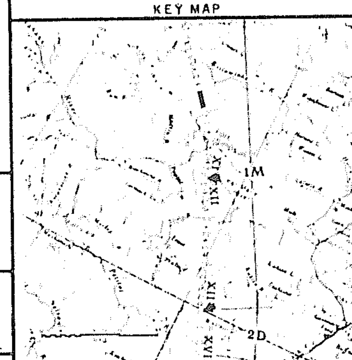
GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

NORTHWEST TERRITORIES (DIST OF MACKENZIE) & YUKON TERRITORY

UPSTREAM M.P. 642 DOWNSTREAM M.P. 654

DRN BY	DATE		
CHKD BY M.J.L.	Feb 7/75	SCALE 1 : 3000'	
APPD BY [signature]	Feb 13/75	SHEET 6 OF 19	1M - 0200 - 1006

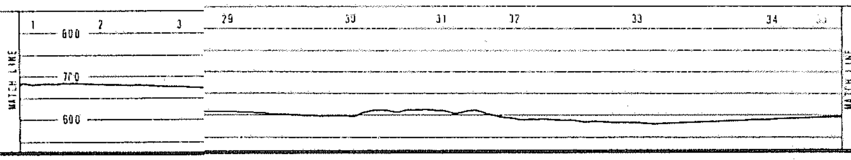
KEY MAP

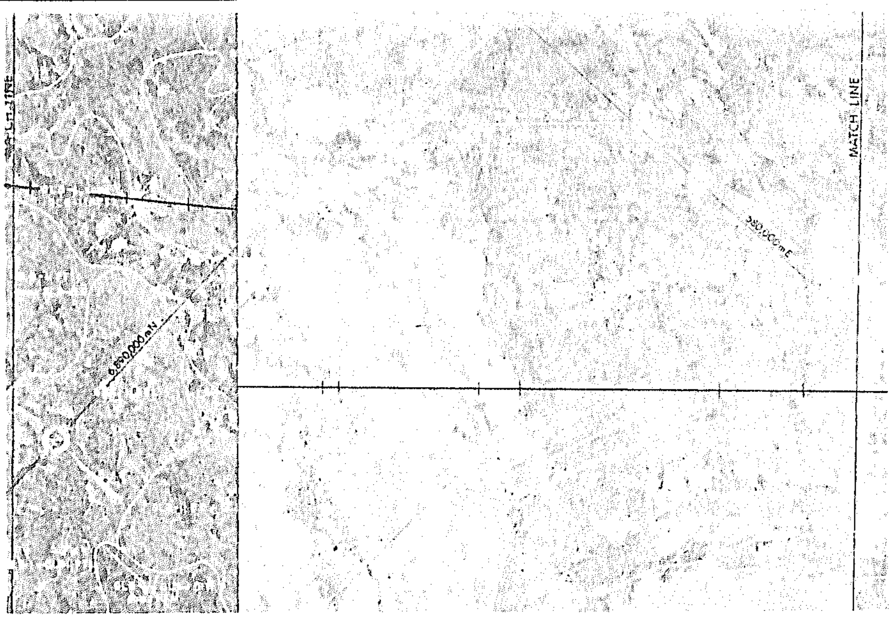


TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK DATE ___

OWNERSHIP	
DRILL HOLE DATA	

PROFILE

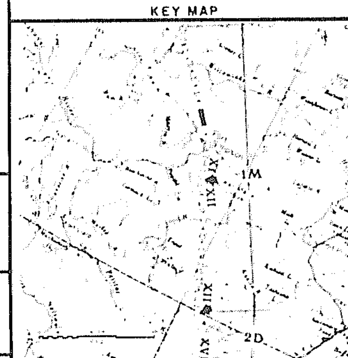




TERRAIN TYPING LEGEND

Fold out

KEY MAP



TERRAIN MAPPING BY

J.D. MOLLARD & ASSOCIATES LIMITED

REGINA, SASK. DATE

CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES: MATCH LINE 654.26 — 4-0210-1069 — MATCH LINE 667.72

FOOTAGE THIS SHEET

CHAINAGE (miles): 00.00, 0.07, 0.50, 0.77, 11.12, 11.18, 11.78, 11.97, 12.81, 13.20, 13.44

DESIGN DATA

SEGMENT Nº	1	2	3	4	30	31	32	33	34	35
SEGMENT LENGTH	0.07	0.43	0.27	0	0.06	0.60	0.19	0.84	0.39	0.24
EROSION CONTROL	EC-1C	EC-1D	EC-1C, EC-6	EC-	N.A.	EC-1C	EC-1C	EC-1C	EC-1C, EC-6	EC-1C
BUOY.	B-2	B-0	B-1	B-	N.A.	B-0	B-1	B-0	B-1	B-0
REVEG.	II-V-2		II-V-2, V-4	II-	II-V-6	II-V-2			II-V-2, V-4	II-V-2

U T M GRID ZONE 10

SCALE (miles) 0 0.5 1.0

PIPELIN…

CARRIER PIPE (some above)	POINT OF INTE…
CARRIER PIPE (berm cover)	DRILL HOLE L…
BERM BREAK	WARNING SIGN…
SWAMP WEIGHT	MILEPOST SIG…
RIVER WEIGHT	CHAINAGE CO…
FROST ANCHOR	COMPRESSOR
SCREW ANCHOR	AIR STRIP
HEAVY WALL PIPE	STORAGE OR…
CASING PIPE	CAMP SITE
ANCHOR BLOCK (concrete)	STAGING ARE…
BLOCK VALVE	BORROW SITE
TEST LEAD & DIRECTION OF WIRES	WHARF

REVISION	APPR'D BY	APPR'D BY
TA M.F.-15 AND		
S AT M.P. 660.8	RK	RB

NORTHERN ENGINEERING SERVICES COMPANY LIMITED

CALGARY ALBERTA

ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

NORTHWEST TERRITORIES · DIST OF MACKENZIE · & YUKON TERRITORY

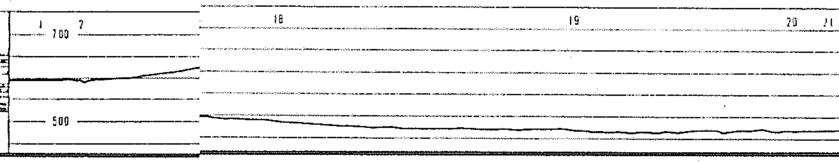
UPSTREAM M.P. 654 DOWNSTREAM M.P. 668

DRN. BY	DATE		
CHKD BY ME	Feb 7/75	SCALE 1" = 2000'	1M-0200-1007
APPRD BY RB	Feb 7/75	SHEET 7 OF 19	

OWNERSHIP

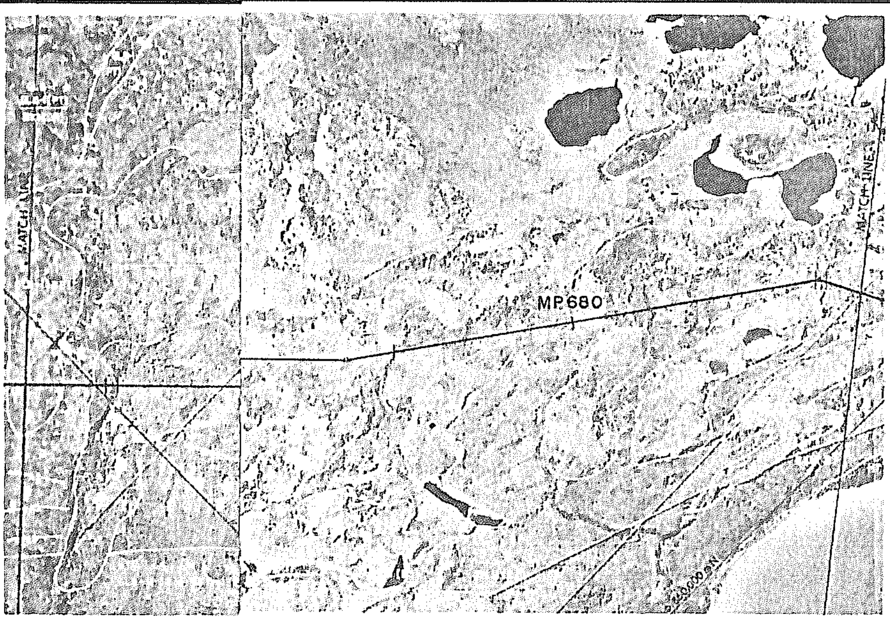
DRILL HOLE DATA

PROFILE



DRILL HOLE DATA LEGEND

TERRAIN TYPING LEGEND



CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES	MATCH LINE 667.72	4-0210-1099			4-0210-1099	MATCH LINE 681.25	
CHAINAGE (miles)	00.00	0.36 0.41		11.52	13.36 13.40	13.53	
DESIGN DATA							
SEGMENT No	1	2	18	19	20	21	
SEGMENT LENGTH	0.36	0.05	0.84	1.84	0.04	0.13	
EROSION CONTROL	EC IC	N A	EC ID	EC ID	N A	EC ID	
BUOY	B 0	N A	B 7	B 0	N A	B 0	
REVEG	II-V-2	II-V-6	II-V-2		II-V-6	II-V-2	

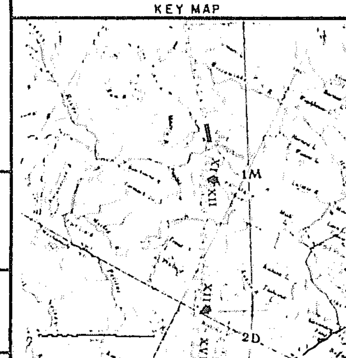
FOOTAGE THIS SHEET

U T M GRID ZONE 10

0 0.5 1.0
SCALE (miles)

Fold out

KEY MAP



TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

PIPELINE

CARRIER PIPE
CARRIER PIPE
BERM BREAK
SWAMP WEIGHT
RIVER WEIGHT
FROST ANCHOR
SCREW ANCHOR
HEAVY WALL PIPE
CASING PIPE
ANCHOR BLOCK (concrete)
BLOCK VALVE
TEST LEAD & DIRECTION OF WIRES
POINT OF INTE...
DRILL HOLE L...
WARNING SIGN
MILEPOST SIGN
CHAINAGE EQU...
COMPRESSOR S...
AIR STRIP
STORAGE OR ...
CAMP SITE
STAGING AREA
BORROW SITE
WHARF

REVISION	APPD BY	APPD BY
STA ME-15 AT ...		

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA
NORTHWEST TERRITORIES - DIST OF MACKENZIE - & YUKON TERRITORY

UPSTREAM M.P. 668 DOWNSTREAM M.P. 681

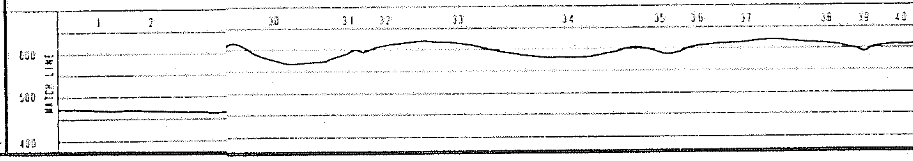
DRN BY	DATE
CHKD BY	Feb 7/75
APPRD BY	Feb 14/75

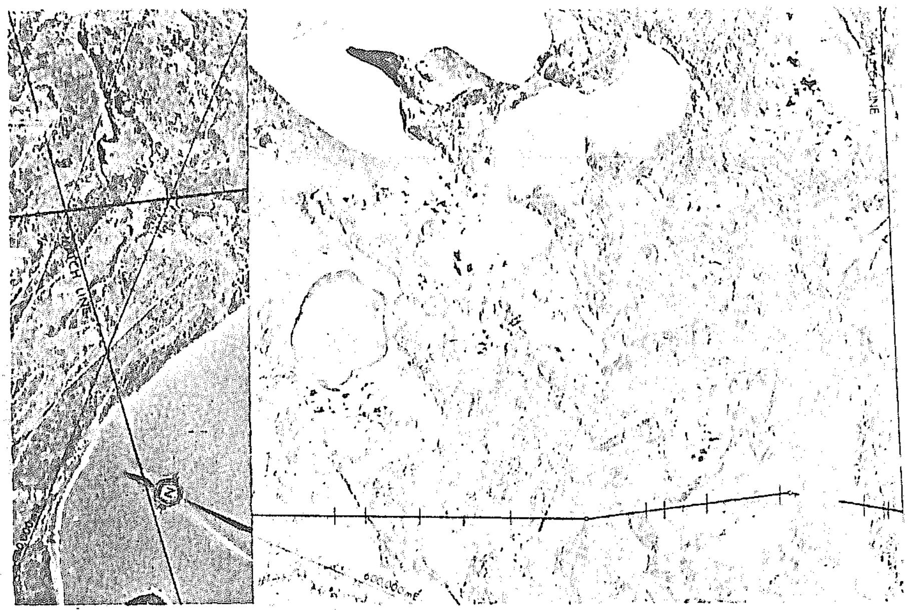
SCALE 1" = 2000'
SHEET 8 OF 19
1M-0200-1008

OWNERSHIP

DRILL HOLE DATA

PROFILE

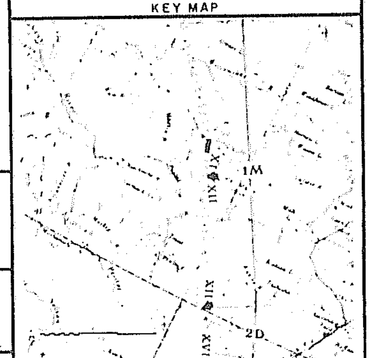




TERRAIN TYPING LEGEND

Fold'out

KEY MAP



TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES: MATCH LINE 681.26 | 4-0210-1099 | 4-0210-1059 | MATCH LINE 694.82

FOOTAGE THIS SHEET

CHAINAGE (miles): 00 00 | 8 45 | 0 49 | 11 20 | 11 33 | 11 55 | 11 93 | 12 52 | 12 59 | 12 77 | 13 07 | 13 42 | 13 52 | 13 57

DESIGN DATA

SEGMENT Nº	1	2	30	31	32	33	34	35	36	37	38	39	40
SEGMENT LENGTH	0 45	0 04	0 40	0 13	0 22	0 38	0 59	0 07	0 18	0 30	0 35	0 10	0 05
EROSION CONTROL	EC 1D	N A	EC 1D	EC 1D	EC 1D	EC 1C	EC 1D	EC 1D	EC 2D	EC 1D	EC 1C	N A	EC 1C
BUOY	B 0	N A	B 0	B 1	B 0	B 2	B 0	B 1	B 0	B 2	B 0	N A	B 0
REVEG.	II V 2	II V 6		II V 2					II V 6	II V 2		II V 6	II V 2

0 0.5 1.0
SCALE (miles)

U T M GRID ZONE 10

PIPELINE

REVISION	APPR'D BY	APPR'D BY
TO SHOW BOAT CROSSING		
...ie River and		
...rom from Bottom pe		

CARRIER PIPE (Conv. Weight)
CARRIER PIPE (Therm. Conc.)
BERM BREAK
SWAMP WEIGHT
RIVER WEIGHT
FRUST ANCHOR
SCREW ANCHOR
HEAVY WALL PIPE
CASING PIPE
ANCHOR BLOCK (concrete)
BLOCK VALVE
TEST LEAD & DIRECTION OF WIRES
POINT OF INTERS.
DRILL HOLE LOC.
WARNING SIGN
MILEPOST SIGN
CHAINAGE EQUA.
COMPRESSOR ST.
AIR STRIP
STORAGE OR ST.
CAMP SITE
STAGING AREA
BORROW SITE
WHARF

NORTHERN Engineering Services Company Limited

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

NORTHWEST TERRITORIES - DIST. OF MACKENZIE - & YUKON TERRITORY

UPSTREAM M.P. 681 DOWNSTREAM M.P. 695

DRN. BY	DATE
CHKD. BY M.L.	Feb 7/75
APPRD. BY JC	Feb 10/75

SCALE 1" = 2000'
SHEET 9 OF 19

1M-0200-1009

OWNERSHIP	
DRILL HOLE DATA	

PROFILE

MATCH LINE	1 SEGMENT	35	36	37	38	39	40	MATCH LINE

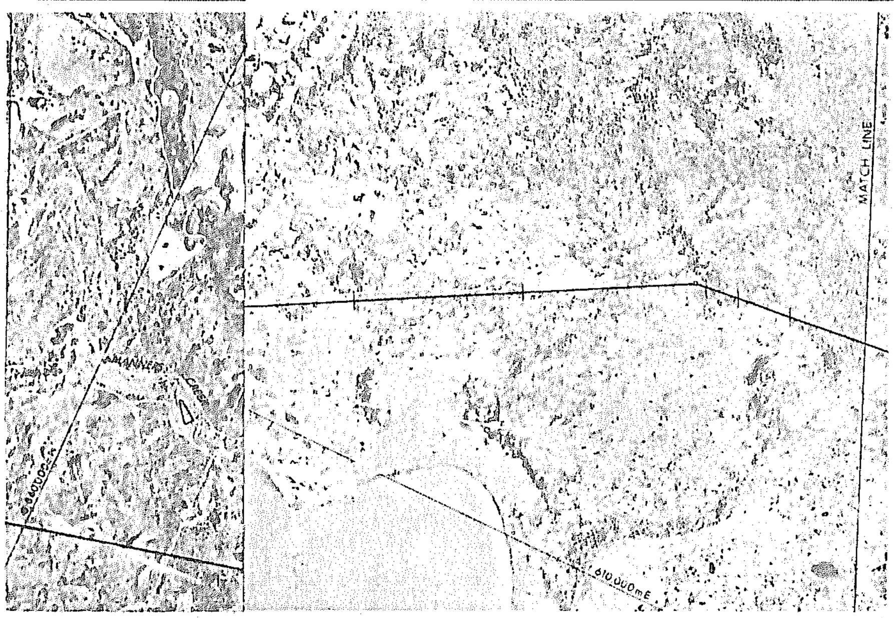
700

600

500

DRILL HOLE DATA LEGEND

TERRAIN TYPING LEGEND



CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES: MATCH LINE 694 87 … MATCH LINE 708 48

FOOTAGE THIS SHEET

CHAINAGE (miles)	10 83	11 46	12 17	12 95	13 08	13 33	13 66

DESIGN DATA							
SEGMENT Nº	1	35	36	37	38	39	40
SEGMENT LENGTH	1 11	0 79	0 71	0 76	0 13	0 25	0 33
EROSION CONTROL	EC-10, EC-20	EC-10	EC-10	EC-10	EC-10	EC-10	EC-10
BUOY	B 0	B-1	B-2	B-1	B 0	B 1	B-0
REVEG	II-V-2, V-6						

U T M GRID ZONE 10

0 0 5 1 0

SCALE (miles)

PIPELINE

CARRIER PIPE (above ground)
CARRIER PIPE (below ground)
BERM BREAK
SWAMP WEIGHT
RIVER WEIGHT
FROST ANCHOR
SCREW ANCHOR
HEAVY WALL PIPE
CASING PIPE
ANCHOR BLOCK (concrete)
BLOCK VALVE
TEST LEAD & DIRECTION OF WIRES
POINT OF INTER…
DRILL HOLE (O…
WARNING SIGN
MILEPOST SIGN
CHAINAGE EQU…
COMPRESSOR S…
AIR STRIP
STORAGE OR S…
CAMP SITE
STAGING AREA
BORROW SITE
WHARF

REVISION	APPR'D BY	APPR'D BY
… AT MP 697 I AND ADD …ISA, AND FACILITIES 699.9	CK	[illegible]

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA

NORTHERN Engineering Services Company Limited

ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

NORTHWEST TERRITORIES - DIST OF MACKENZIE - & YUKON TERRITORY

UPSTREAM M.P. 695 DOWNSTREAM M.P. 708

DRN BY	DATE	
CHKD BY	[illegible]	Feb 7/[illegible]
APPRD BY	JC	Feb [illegible]

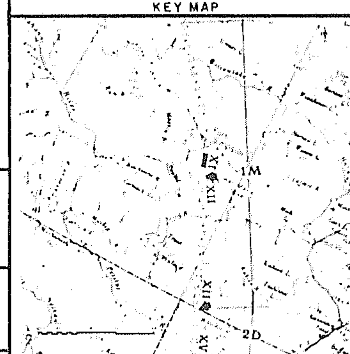
SCALE 1" = 2000'

SHEET 10 OF 19

1M-0200-1010

Fold out

KEY MAP

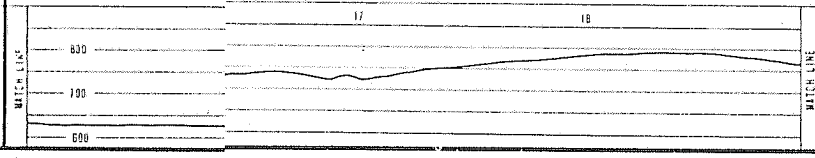


TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

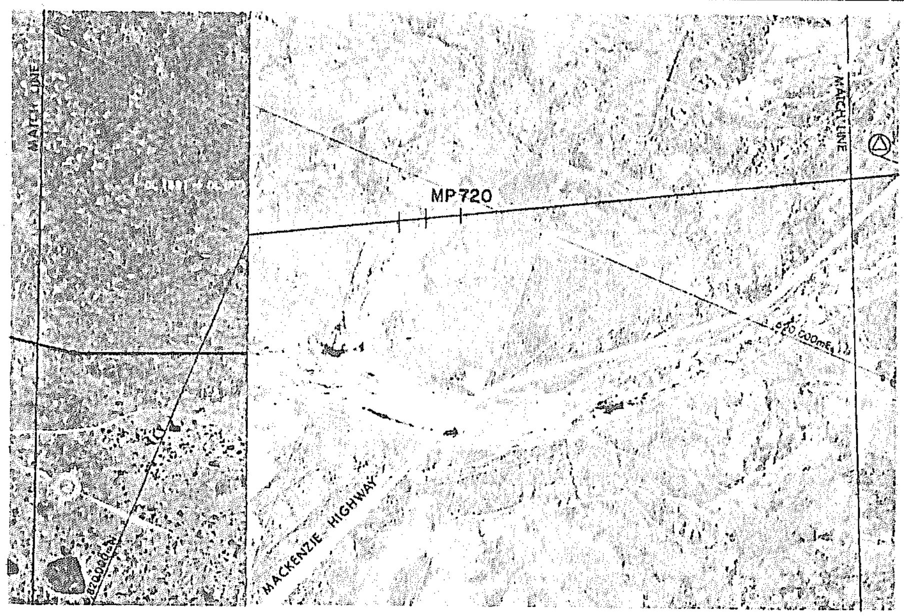
OWNERSHIP

DRILL HOLE DATA

PROFILE



DRILL HOLE DATA LEGEND



TERRAIN TYPING LEGEND

NOTE
DLC - See Physiographic Division XIII

Fold over

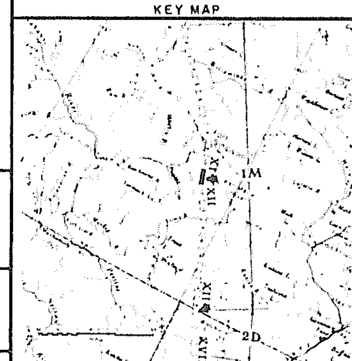
CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES	MATCH LINE 708.48	0300-6020			MATCH LINE 721.66	FOOTAGE THIS SHEET
CHAINAGE (miles)	00.00		11.25	11.37	13.20	
DESIGN DATA						
SEGMENT Nº			17	18		
SEGMENT LENGTH			0.17	1.83		
EROSION CONTROL			EC-18	EC-10		
BUOY			B-1	B-0		
REVEG						

U T M GRID ZONE 10

0 0.5 1.0
SCALE (miles)

KEY MAP



TERRAIN MAPPING BY:
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

PIPELINE

CARRIER PIPE (conv. mount)	POINT OF INTERSECTION
CARRIER PIPE (berm cover)	DRILL HOLE LOCATION
BERM BREAK	WARNING SIGN
SWAMP WEIGHT	MILEPOST SIGN
RIVER WEIGHT	CHAINAGE EQUATION
FROST ANCHOR	COMPRESSOR STATION
SCREW ANCHOR	AIR STRIP
HEAVY WALL PIPE	STORAGE OR S
CASING PIPE	CAMP SITE
ANCHOR BLOCK (concrete)	STAGING AREA
BLOCK VALVE	BORROW SITE
TEST LEAD & DIRECTION OF WIRES	WHARF

REVISION	APPRD BY	APPRD BY
AT MP 717.5 AND STA ME-16 AT	JKC	

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA
NORTHWEST TERRITORIES - DIST OF MACKENZIE - & YUKON TERRITORY

UPSTREAM M.P. 708 DOWNSTREAM M.P. 722

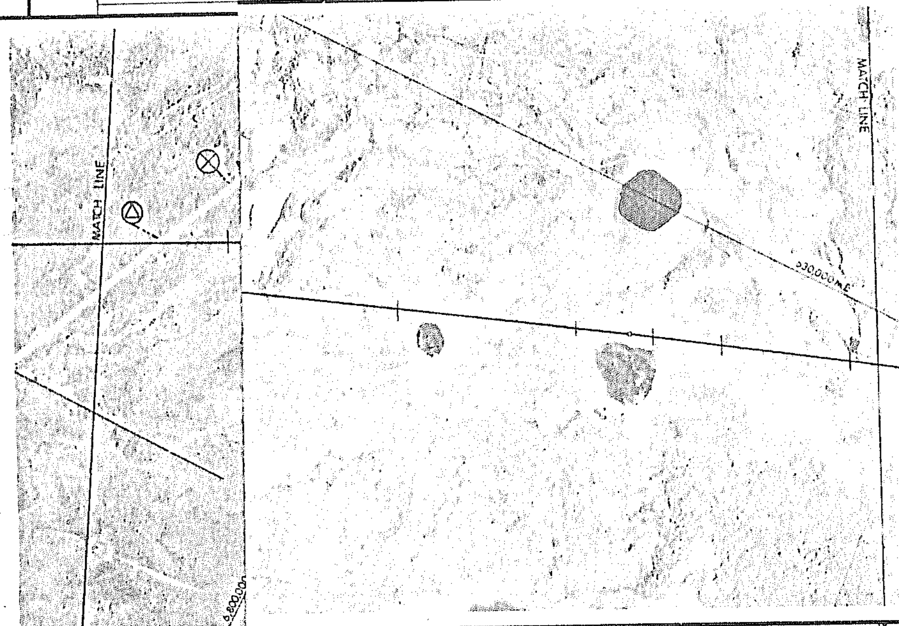
DRN BY	DATE		
CHKD BY MFL	Feb 7/75	SCALE 1" = 2000'	1M-0200-1011
APPRD BY JC	Feb 10/75	SHEET 11 OF 19	

OWNERSHIP

DRILL HOLE DATA

PROFILE

1000 | 900 | 800 — MATCH LINE — 1 | 2 | 27 | 28 | 29 | 30 | 31 — MATCH LINE



TERRAIN TYPING LEGEND

FOOTAGE THIS SHEET

CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES	MATCH LINE 721.68	4-0100-0003						4-0210-1099 MATCH LINE 734.33
CHAINAGE (miles)	00.00	0.52	10.63	11.38	11.71	11.99		12.52 12.65
DESIGN DATA	ROAD							
			26	27	28	29	30	31
SEGMENT Nº	1		0.85	0.75	0.33	0.28	0.53	0.13
SEGMENT LENGTH	0.57		EC-IC	EC-IC, EC-B	EC-1D	EC-IC EC-B	EC-IC	N.A.
EROSION CONTROL	EC-1D		B-1	B-1	B-1	B-1	B-2	N.A.
BUOY.	B-0			II-V-2, V-4	II-V-2	II-V-4	II-V-2	II-V-C
REVEG.	II-V-2							

U T M GRID ZONE 10

0 0.5 1.0
SCALE (miles)

PIPEL

CARRIER PIPE (conv. mode)	POINT OF IN		
CARRIER PIPE (term. conv.)	DRILL HOLE		
BERM BREAK	WARNING SI		
SWAMP WEIGHT	MILEPOST SI		
RIVER WEIGHT	CHAINAGE E		
FROST ANCHOR	COMPRESSOR		
SCREW ANCHOR	AIR STRIP		
HEAVY WALL PIPE	STORAGE D		
CASING PIPE	CAMP SITE		
ANCHOR BLOCK (concrete)	STAGING AF		
BLOCK VALVE	BORROW SI		
TEST LEAD & DIRECTION OF WIRES	WHARF		

REVISION	APPRD BY	APPRD BY
AGING AREA AT		
9	CK	AB

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA

ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

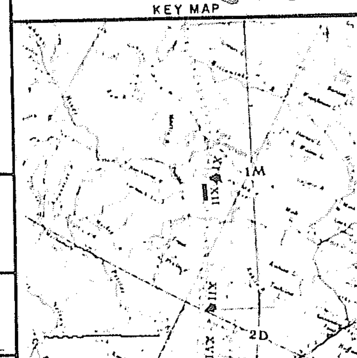
GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

NORTHWEST TERRITORIES - DIST OF MACKENZIE - & YUKON TERRITORY

UPSTREAM M.P. 722 DOWNSTREAM M.P. 734

DRN BY	DATE		
CHKD BY MJL	Jul 7/75		
APPRD JQ	Feb '4/75	SCALE 1" = 2000' SHEET 12 OF 19	1M-0200-1012

KEY MAP

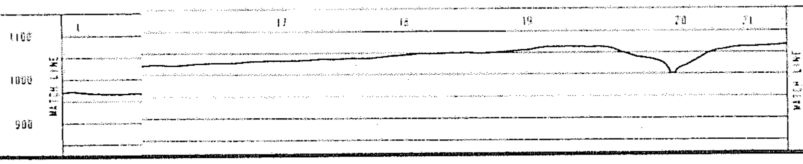


TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

OWNERSHIP

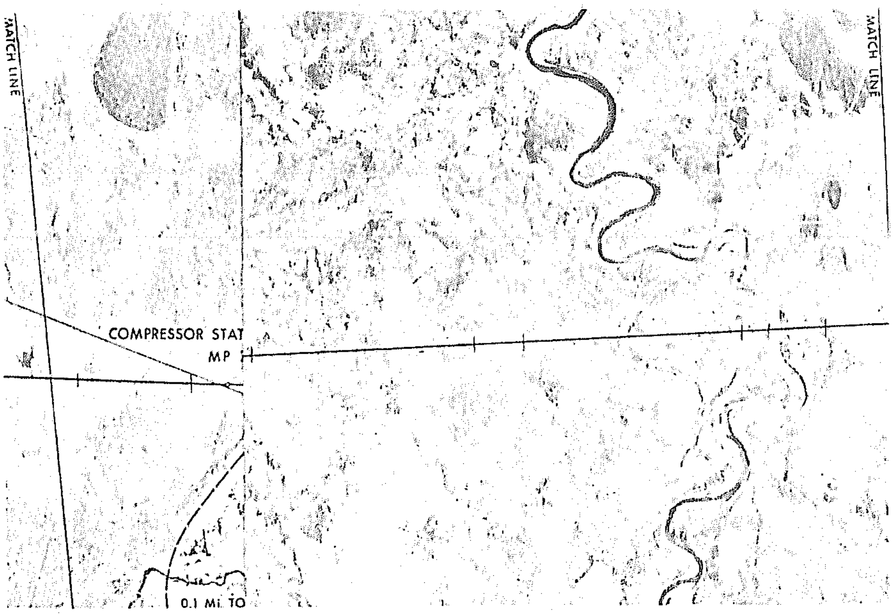
DRILL HOLE DATA

PROFILE



DRILL HOLE DATA LEGEND

TERRAIN TYPING LEGEND



FOOTAGE THIS SHEET

CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES: MATCH LINE 734.33 — 4-0210-1099 — MATCH LINE 747.33

CHAINAGE (miles): 00 00, 00 12, 0 60, 10 33, 11 25, 11 46, 12 37, 12 72, 12 90

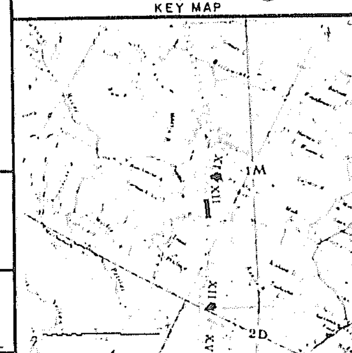
DESIGN DATA

SEGMENT Nº	1	2	3	17	18	19	20	21
SEGMENT LENGTH	0 12	0 48	0 30	0 92	0 21	0 91	0 35	0 28
EROSION CONTROL	EC 8	EC 10	EC 8	EC 10	EC 10	EC 10	N A	EC 10
BUOY	B 1	B 0	B 1	B 0	B 1	B 0	N A	B 1
REVEG	II Y 4	II Y 2	II Y 4	II Y 2			II Y 6	II Y 2

U T M GRID ZONE 10

0 — 0.5 — 1.0 SCALE (miles)

KEY MAP



PIPELINE

REVISION	APPD BY	APPD BY
MF-16, FACILITIES		
735.4, DELETE B.V.		
737.4.	CL	

CARRIER PIPE (lower shown) — POINT OF INTER
CARRIER PIPE (berm cover) — DRILL HOLE LOC
BERM BREAK — WARNING SIGN
SWAMP WEIGHT — MILEPOST SIGN
RIVER WEIGHT — CHAINAGE EQUA
FROST ANCHOR — COMPRESSOR ST
SCREW ANCHOR — AIR STRIP
HEAVY WALL PIPE — STORAGE OR S
CASING PIPE — CAMP SITE
ANCHOR BLOCK (concrete) — STAGING AREA
BLOCK VALVE — BORROW SITE
TEST LEAD & DIRECTION OF WIRES — WHARF

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

NORTHWEST TERRITORIES · DIST OF MACKENZIE · & YUKON TERRITORY

UPSTREAM M.P. 734 DOWNSTREAM M.P. 747

DRN BY	DATE
CHKD BY	Feb 7/75
APPD BY	Feb 4/75

SCALE 1 : 2000 SHEET 13 OF 19

1M-0200-1013

Fold

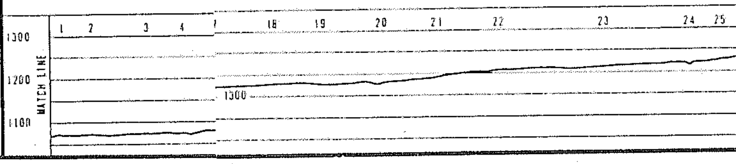
TERRAIN MAPPING BY
J D MOLLARD & ASSOCIATES LIMITED
REGINA, SASK DATE

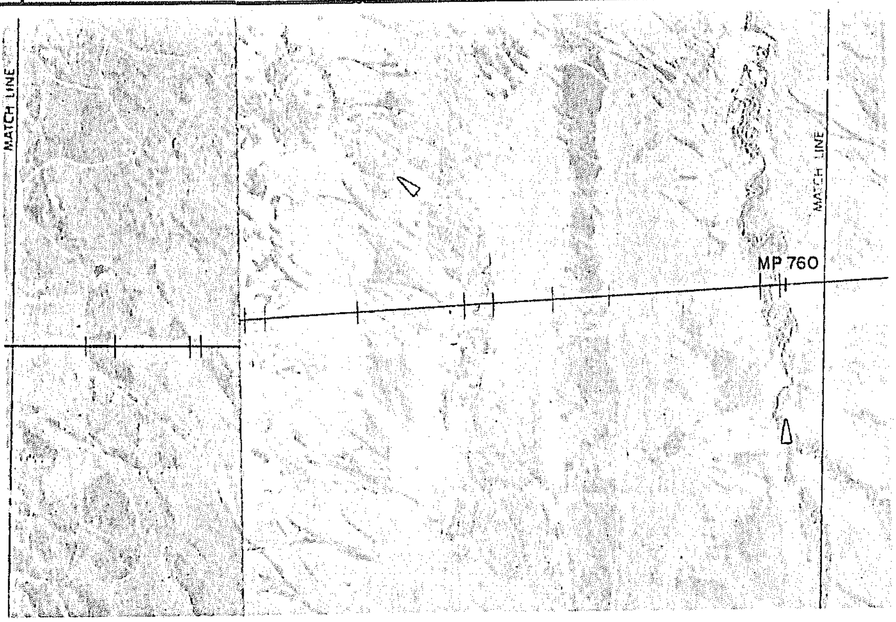
OWNERSHIP

DRILL HOLE DATA

DRILL HOLE DATA LEGEND

PROFILE





TERRAIN TYPING LEGEND

TERRAIN TYPES

[illegible]

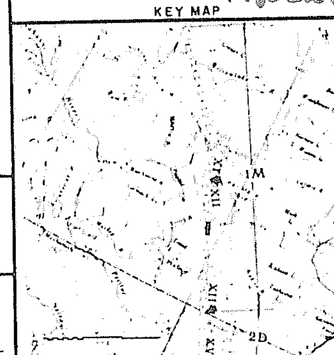
FEATURES AND PHASES

[illegible]

COMPLEXES

[illegible]

KEY MAP



CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES	MATCH LINE 747.33	4-0210-1099	4-0210-1099	4-0210-1099	MATCH LINE 760.20

CHAINAGE (miles): 00.00, 0.31, 0.43, 0.74, 0.79, 10.45, 10.53, 10.87, 11.37, 11.49, 11.73, 11.96, 12.60, 12.68, 12.87

DESIGN DATA

SEGMENT Nº	1	2	3	4	17	18	19	20	21	22	23	24	25
SEGMENT LENGTH	0.31	0.12	0.31	0.05	0.08	0.39	0.45	0.12	0.24	0.23	0.64	0.08	0.19
EROSION CONTROL	EC-1D	EC-1D	EC-1D	N A	FC-1D	EC-1D	EC-1C	N A	EC-1D	EC-1D	EC-1C	N A	EC-1D
BUOY.	B-1	B-0	B-7	N A	B 0	B-1	B-0	N A	B 1	B-0	B-1	N A	B-0
REVEG	II-V-2			II-V-6	II-V-2			II-V-6	II-V-2			II-V-6	II-V-2

FOOTAGE THIS SHEET

U T M GRID ZONE 10

0 0.5 1.0
SCALE (miles)

Symbol		Symbol	
	CARRIER PIPE (conc. weight)		POINT OF INTERSECTION
	CARRIER PIPE (conc. coat.)		DRILL HOLE
	BERM BREAK		WARNING SIGN
	SWAMP WEIGHT		MILEPOST SIGN
	RIVER WEIGHT		CHAINAGE EQU.
	FROST ANCHOR		COMPRESSOR S.
	SCREW ANCHOR		AIR STRIP
	HEAVY WALL PIPE		STORAGE OR
	CASING PIPE		CAMP SITE
	ANCHOR BLOCK (concrete)		STAGING AREA
	BLOCK VALVE		BORROW SITE
	TEST LEAD & DIRECTION OF WIRES		WHARF

PIPELINE REVISION — APPRD BY — APPRD BY
AT M.P. 752.2
C. STA. ME-17 AT
3. — RC — [illegible]

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA
NORTHWEST TERRITORIES : DIST OF MACKENZIE : & YUKON TERRITORY
UPSTREAM M.P. 747 DOWNSTREAM M.P. 760

DRN BY — DATE
CHKD BY [signature] — Jul 7/75
APPRD BY [signature] — Feb 6/75
SCALE 1" = 2000'
SHEET 14 OF 19
1M-0200-1014

TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

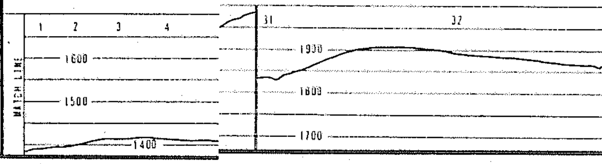
Foldout

OWNERSHIP

DRILL HOLE DATA

DRILL HOLE DATA LEGEND

PROFILE

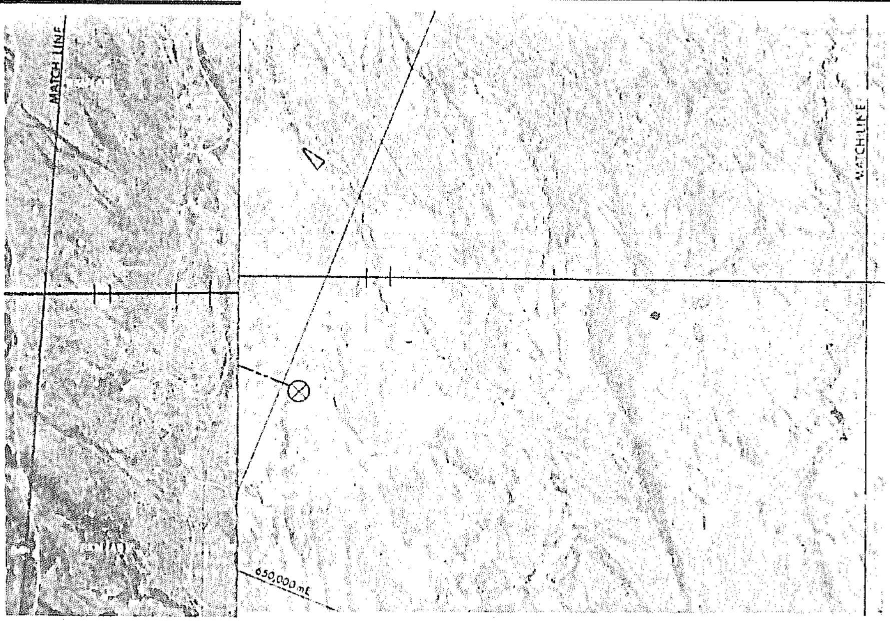


TERRAIN TYPING LEGEND

TERRAIN TYPES

TERRAIN AND PHASES

COMPLEXES



FOOTAGE THIS SHEET

MATCH LINE 760.00

4-0210-1099

MATCH LINE 772.60

1	2	3	4	30	31	32
0.22	0.05	0.27	0.14	95	0.10	1.88
EC-1D	EC-1D	EC-1D	EC-1C	EC-1C	N-A	EC-1C
B-0	B-1	B-0	B-1	B-0	N-A	B-0
II-Y-2					II-V-6	II-Y-2

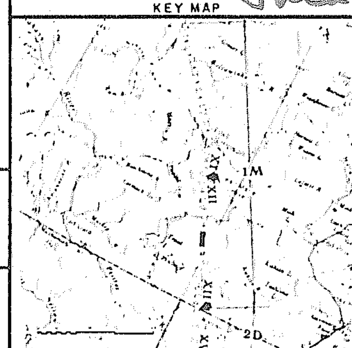
U T M GRID ZONE 10

0 0.5 1.0

SCALE (miles)

KEY MAP

Foldout



PIPELINE

POINT OF INTER. 768.8

DRILL HOLE

WARNING SIGN

MILEPOST SIGN

CHAINAGE EQU.

COMPRESSOR

AIR STRIP

STORAGE OR

CAMP SITE

STAGING AREA

BORROW SITE

WHARF

REVISION	APPR'D BY	APPR'D BY
TA. MF-17, FACILITIES		

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

NORTHWEST TERRITORIES / DIST OF MACKENZIE / & YUKON TERRITORY

UPSTREAM M.P. 760 DOWNSTREAM M.P. 773

DRN BY | DATE
CHKD BY M.L. | Feb 7/75
APPD BY | Feb 20/75

SCALE 1" = 2000'
SHEET 15 OF 19

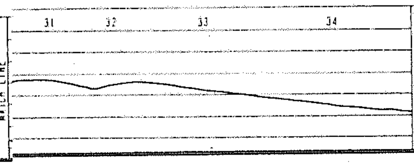
1M-0200-1015

TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

OWNERSHIP

DRILL HOLE DATA

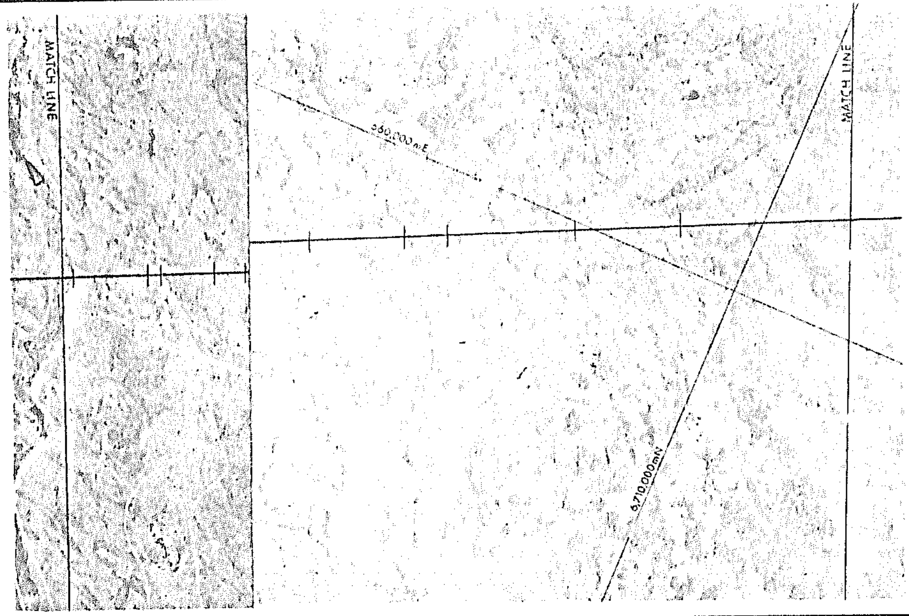
PROFILE

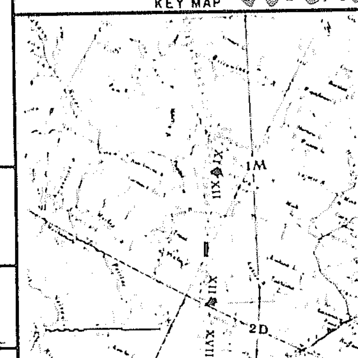


DRILL HOLE DATA LEGEND

TERRAIN TYPING LEGEND

KEY MAP





CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES: MATCH LINE 772 60 — 4-0210-1099 — MATCH LINE 784 20

FOOTAGE THIS SHEET

CHAINAGE (miles): 00 00, 0 04, 0 34, 0 39, 0 61, 0 72, 9 58, 9 93, 10 08, 10 55, 10 97, 11 60

DESIGN DATA

SEGMENT Nº	1	2	3	4		30	31	32	33	34
SEGMENT LENGTH	0.04	0.30	0.05	0.22	0	0.35	0.15	0.47	0.42	0.63
EROSION CONTROL	NA	EC-1C	EC-8	EC-1C	E	EC 10, EC-8	EC-20	EC-10, EC-8	EC 1C	EC-10
BUOY	NA	B-0	B-1	B-0		B-2	B-0	B-2	B-1	B-0
REVEG	II Y 6	II Y 2	II Y 4		II	II Y 2, Y 4	II Y 6	II Y 2, Y 4	II Y 2	

0 0.5 1.0
SCALE (miles)

U T M GRID ZONE 10

PIPELINE LEGEND

- CARRIER PIPE (cover shown)
- CARRIER PIPE (berm cover)
- BERM BREAK
- SWAMP WEIGHT
- RIVER WEIGHT
- FROST ANCHOR
- SCREW ANCHOR
- HEAVY WALL PIPE
- CASING PIPE
- ANCHOR BLOCK (concrete)
- BLOCK VALVE
- TEST LEAD & DIRECTION OF WIRES
- POINT OF INTER...
- DRILL HOLE LC...
- WARNING SIGN
- MILEPOST SIGN
- CHAINAGE EQU...
- COMPRESSOR S...
- AIR STRIP
- STORAGE OR ...
- CAMP SITE
- STAGING AREA
- BORROW SITE
- WHARF

REVISION	APPR'D BY	APPR'D BY
...V. AT M.P. 782.5		

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA
NORTHWEST TERRITORIES (DIST OF MACKENZIE) & YUKON TERRITORY

UPSTREAM M.P. 772 DOWNSTREAM M.P. 784

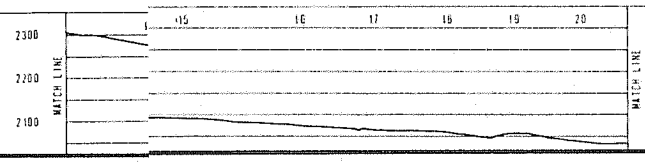
DRN BY — DATE
CHKD BY — Feb 7/75
APPRD BY — Feb 10/75
SCALE 1" = 2000'
SHEET 16 OF 19
1M-0200-1016

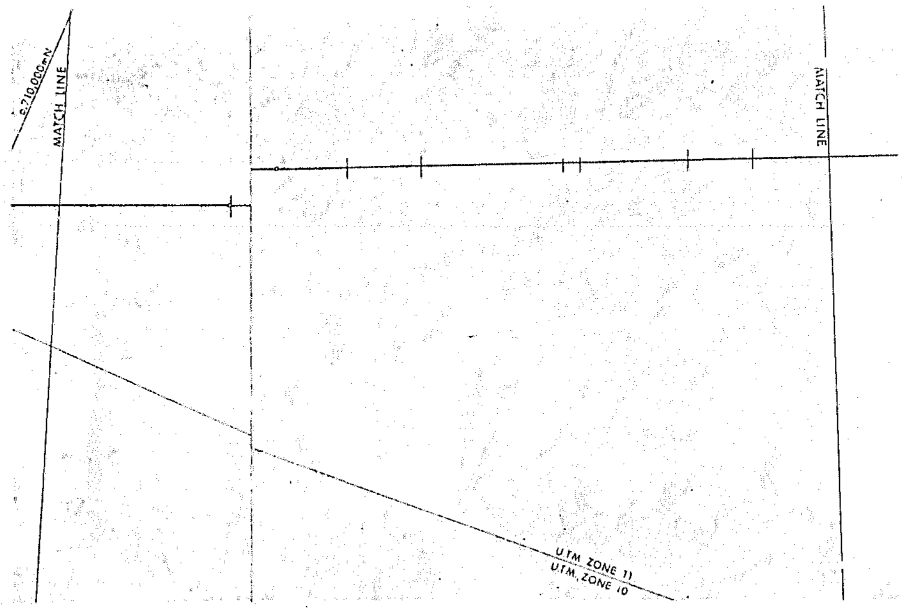
TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

OWNERSHIP

DRILL HOLE DATA

PROFILE





CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES	MATCH LINE 784.20				4-0210-1099				MATCH LINE 796.52
CHAINAGE (miles)	00.00	0.70	10.40	10.70	11.26 / 11.32	11.77	12.02		12.32
DESIGN DATA									
SEGMENT Nº	1	14	15	16	17	18	19	20	
SEGMENT LENGTH	0.7C	0.42	0.30	0.56	0.06	0.45	0.25	0.30	
EROSION CONTROL	EC-1D	EC-1D	EC-1D	EC-1D	N A	EC-1C	EC-1D	EC-1C	
BUOY.	B-0	B-2	B-1	B-2	N A	B-2	B-1	B-2	
REVEG.					II V 6	II V 2			

FOOTAGE THIS SHEET

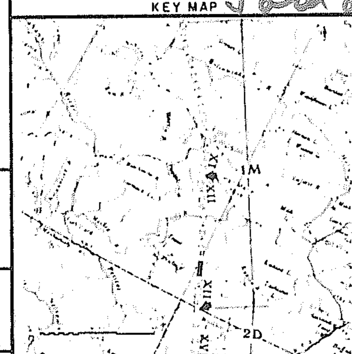
0 0.5 1.0
SCALE (miles)

U T M GRID ZONE 10 & 11

DRILL HOLE DATA LEGEND

TERRAIN TYPING LEGEND

KEY MAP Foldout



TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK DATE

PIPELINE

Symbol		Symbol	
	CARRIER PIPE (cove shown)		POINT OF INTER
	CARRIER PIPE (berm cover)		DRILL HOLE LO
	BERM BREAK		WARNING SIGN
	SWAMP WEIGHT		MILEPOST SIGN
	RIVER WEIGHT		CHAINAGE EQU
	FROST ANCHOR		COMPRESSOR ST
	SCREW ANCHOR		AIR STRIP
	HEAVY WALL PIPE		STORAGE OR S
	CASING PIPE		CAMP SITE
	ANCHOR BLOCK (concrete)		STAGING AREA
	BLOCK VALVE		BORROW SITE
	TEST LEAD & DIRECTION OF WIRES		WHARF

REVISION	APPR'D BY	APPR'D BY
AT M P 789.3		

NORTHERN Engineering Services Company Limited

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA

ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

NORTHWEST TERRITORIES - DIST OF MACKENZIE & YUKON TERRITORY

UPSTREAM M.P. 784 DOWNSTREAM M.P. 791

DRN. BY	DATE
CHKD. BY	Feb 7/75
APPR'D BY	Feb 14/75

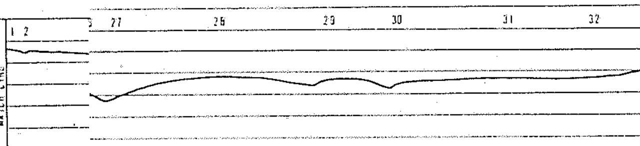
SCALE 1 : 2000
SHEET 17 OF 19

1M - 0200 - 1017

OWNERSHIP

DRILL HOLE DATA

PROFILE

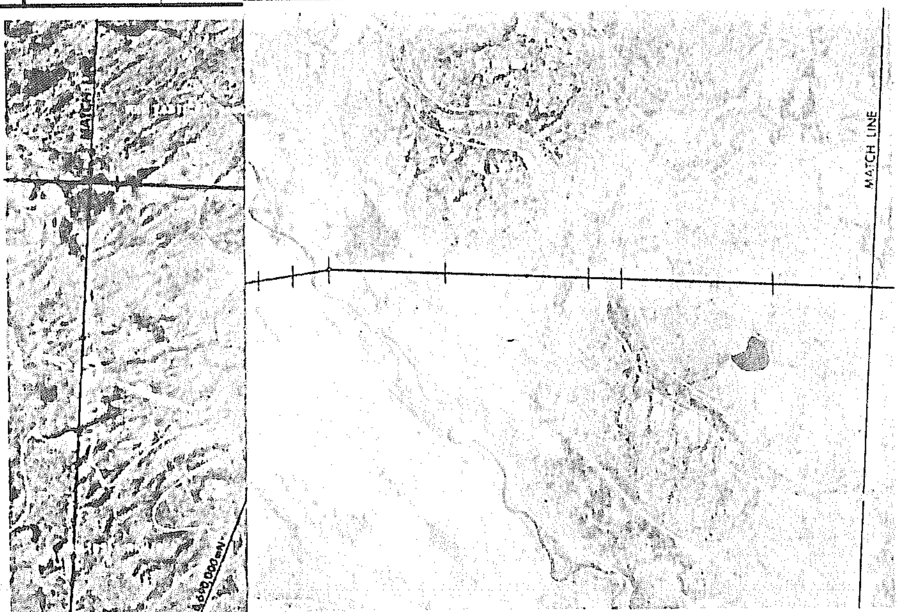


DRILL HOLE DATA LEGEND

TERRAIN TYPING LEGEND

TERRAIN TYPES

FEATURES AND SHAPES



FOOTAGE THIS SHEET

CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES	MATCH LINE 796.52 4-0210-1099			4-0210-1099				4-0210-1099		MATCH LINE 809.17
CHAINAGE (miles)	00.00 0.10 0.17			10.10 10.24 10.40		10.88		11.47 11.60	12.23	12.65
SEGMENT No	1	2	3	26	27	28	29	30	31	32
SEGMENT LENGTH	0.10	0.07	0.7	0.14	0.16	0.48	0.59	0.13	0.63	0.42
EROSION CONTROL	EC-1C	N A	EC-1	EC-1D	N A	EC-1D	EC-1C	N A	EC-1D	EC-1D, EC-8
BUOY	B-2	N A	B-C	B-1	N A	B-0	B-1	N A	B-1	B-1
REVEG	II-Y-2	II-Y-6		II-Y-2	II-Y-6	II-Y-2		II-Y-6	II-Y-2	II-Y-2, Y-4

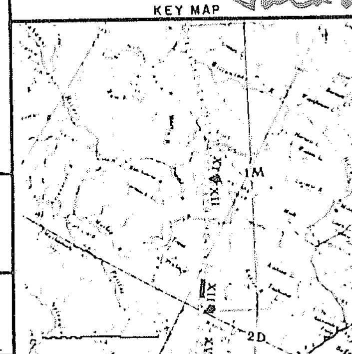
DESIGN DATA

U T M GRID ZONE 11

SCALE (miles) 0 0.5 1.0

KEY MAP

Foldout



PIPELINE LEGEND

CARRIER PIPE (above ground)	POINT OF INTE...
CARRIER PIPE (earth cover)	DRILL HOLE ...
BERM BREAK	WARNING SIGN
SWAMP WEIGHT	MILEPOST SIGN
RIVER WEIGHT	CHAINAGE EQU...
FROST ANCHOR	COMPRESSOR S...
SCREW ANCHOR	AIR STRIP
HEAVY WALL PIPE	STORAGE OR ...
CASING PIPE	CAMP SITE
ANCHOR BLOCK (concrete)	STAGING AREA
BLOCK VALVE	BORROW SITE
TEST LEAD & DIRECTION OF WIRES	WHARF

REVISION | APPD BY | APPD BY

NORTHERN Engineering Services Company Limited

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA

ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

NORTHWEST TERRITORIES - DIST OF MACKENZIE - & YUKON TERRITORY

UPSTREAM M.P. 797 DOWNSTREAM M.P. 809

DRN BY | DATE

CHKD BY | 7.6.7/75

APPD BY | Feb 14/75

SCALE 1" = 2000'

SHEET 18 OF 19

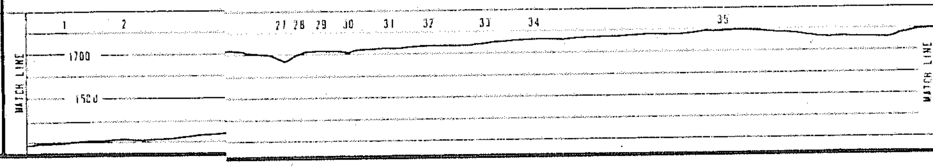
1M - 0200 - 1018

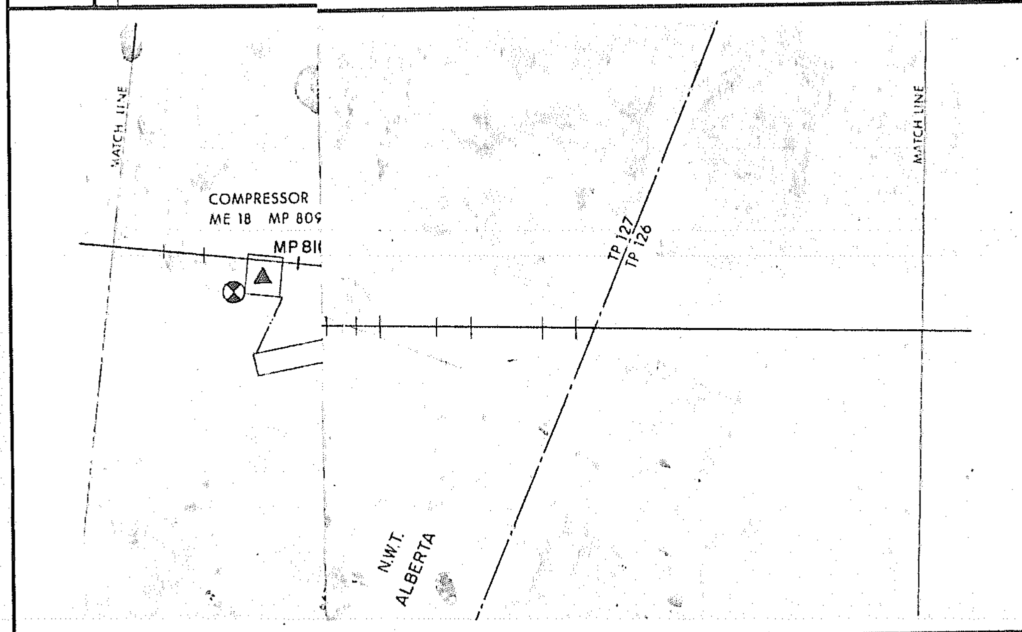
TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

OWNERSHIP

DRILL HOLE DATA

PROFILE





TERRAIN TYPING LEGEND

CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES	MATCH LINE 809.17		0200-1000 0404-1005							MATCH LINE 823.02	
CHAINAGE (miles)	00.00	0.22	0.40	11.23	11.36	11.47	11.73	11.88	12.20	12.35	13.85
DESIGN DATA			M C								
SEGMENT Nº	1	2	3	29	30	31	32	33	34	35	
SEGMENT LENGTH	0.22	0.18	0.79	0.13	0.11	0.26	0.15	0.32	0.15	1.50	
EROSION CONTROL	EC-1D EC-8	EC-1D	EC-1D	EC-1D	EC-8	EC-1D	EC-8	EC-1D	EC-8	EC-1D, EC-8	
BUOY	B-1	B-0	B-1	B-0	B-1	B-2	B-1	B-1	B-1	B-1	
REVEG.	II-V-2, V-4	II-V-2		II-V-2	II-V-4	II-V-2			III-V-4	III-V-2, V-4	

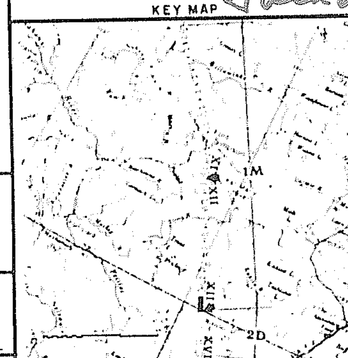
FOOTAGE THIS SHEET

0 0.5 1.0

U T M GRID ZONE 11

SCALE (miles)

KEY MAP



Follows

PIPELINE

CARRIER PIPE
CARRIER PIPE
BERM BREAK
SWAMP WEIGHT
RIVER WEIGHT
FROST ANCHOR
SCREW ANCHOR
HEAVY WALL PIPE
CASING PIPE
ANCHOR BLOCK (concrete)
BLOCK VALVE
TEST LEAD & DIRECTION OF WIRES

POINT OF INTERS
DRILL HOLE LOC
WARNING SIGN
MILEPOST SIGN
CHAINAGE EQUAT
COMPRESSOR STA
AIR STRIP
STORAGE OR STI
CAMP SITE
STAGING AREA
BORROW SITE
WHARF

REVISION	APPD BY	APPD BY
MEASUREMENT STATION		
G STATION RELOCATED		

NORTHERN Engineering Services Company Limited

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA
NORTHWEST TERRITORIES - DIST OF MACKENZIE - & YUKON TERRITORY

UPSTREAM M.P. 809
DOWNSTREAM M.P. 823

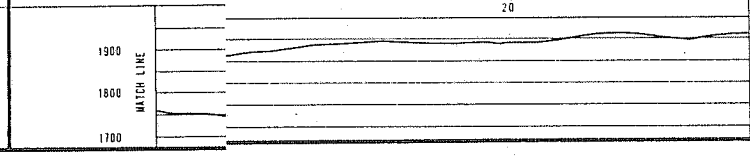
DRN BY	DATE		
CHKD BY			
APPD BY		SCALE 1 = 2000'	1M-0200-1019
		SHEET 19 OF 19	

TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE:

OWNERSHIP

DRILL HOLE DATA

PROFILE



DRILL HOLE DATA LEGEND

TERRAIN TYPING LEGEND

XVIII — BELT PARALLEL TO CHINCHAGA RIVER, NORTHERN ALBERTA PHYSIOGRAPHIC DIVISION

TERRAIN TYPES

AMP Alluvial meander plain: organic silt and fine sand over thin, discontinuous coarse sand and/or gravel over till

GLb Glacial-lake basin: nearly level clay and silty clay plains

K Kames: complexly sorted and stratified mounds of sand and/or gravel with minor silt, till, and boulders

OP Outwash plain: channelled sand and/or gravel deposits

RFM Ridge and swell moraine: undulating to uniformly sloping ground moraine composed of lodgement till

FEATURES AND PHASES

Topographic features

CF Crevasse fillings: narrow sublinear ridges of silt, sand, gravel, and ablation till

EVB Eroded valley banks

OSF Old slide features along river banks

Hydrographic features

MC Meltwater channels

OX Oxbow channels

SL Slopewash features: fine subparallel drainage courses, often with associated surficial organic silt and sand slopewash deposits up to 4 ft thick over till

Shallow phases

AB 2 to 5 ft of loose gravelly-sand-silt ablation till over lodgement till

SO 5 to 15 ft (but generally less than 10 ft) surficial veneer. Note associated paired terrain types to determine stratigraphy, as [illegible]

Permafrost-affected peatland phases*

(Note: Peatland phases are shown along with the underlying mineral-soil terrain types.)

BS Speckled bog pattern: elevated peat bogs, mainly peat plateaus with some palsas. White speckles are small interjacent thaw depressions (collapse scars, wet sedge meadows) resulting from local permafrost degradation, usually pre-conditioned by forest fires. Permafrost is usually absent in the white speckles. In GLB(BS) areas the peat is up to 6 ft but is usually less than 3 ft deep; in RFM(BS) areas the peat is 3 to 20 ft deep but commonly 5 to 15 ft in depressions and is usually less than 6 ft on slopes

FT Generally an even gray peatland appearance, with some waterflow patterns. Locally, transitional to reticulated and ribbed fens. Expect peat 3 to 20 ft deep

FT-S Spotty pattern of peat areas, with peat up to 15 ft deep in small areas that are 1 to 10 acres in size and cover 25 to 50% of the land surface

SB Reticulated and ribbed fens. Water table at or above ground surface in hollows, with sparse trees on ridges (strings). Expect peat depths up to 12 ft

TK Small thermokarst basins containing standing stagnant water. Occurs on peatlands where sporadic permafrost has degraded and shallow water fills small thaw basins

COMPLEXES

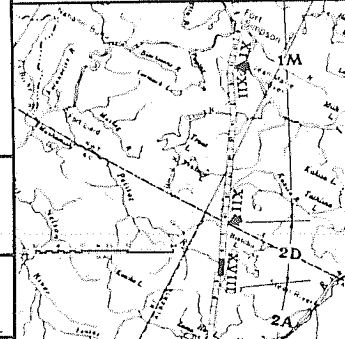
Complexes are shown where two terrain types are either too small or too complexly intermingled to separate at the scale of aerial photography. Examples of percentages in combined terrain units follow:

RFM(BS)+RFM(SB) indicates over 50% BS and 25 to 50% SB
RFM(BS),some RFM(SB) indicates over 75% BS and less than 25% SB
RFM+RFM(BS)(FT) indicates that peat areas in the latter unit, RFM(BS)(FT), comprise more than 50% bog peat (BS) and 25 to 50% uniform-toned fen peat (FT)

*In the southern fringe of the discontinuous permafrost zone, permafrost occurs in scattered islands a few square feet to several acres in size and is confined to certain types of organic terrain, mainly elevated peat plateaus and occasional palsas (BS areas). The permafrost is generally not present in fen land (SB and FT areas). Other isolated occurrences of permafrost are associated with steeper north-facing slopes and areas of dense black spruce, where increased shading from summer thawing and reduced snow-cover enhance permafrost formation and preservation (after Roger J.E. Brown, Permafrost Section, National Research Council of Canada, Ottawa)

Fieldours

KEY MAP



CONSTRUCTION DATA

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SEGMENT LENGTH	1.84			
EROSION CONTROL	EC-1C			
BUOY	B-2			
REVEG.		III-V-2		

0 0.5 1.0
SCALE (miles)

PIPELINE

Symbol		Symbol	
	CARRIER PIPE (cover shown)		POINT OF INTERSECTION
	CARRIER PIPE (berm cover)		DRILL HOLE
	BERM BREAK		WARNING SIGN
	SWAMP WEIGHT		MILEPOST SIGN
	RIVER WEIGHT		CHAINAGE EQ
	FROST ANCHOR		COMPRESSOR
	SCREW ANCHOR		AIR STRIP
	HEAVY WALL PIPE		STORAGE OR
	CASING PIPE		CAMP SITE
	ANCHOR BLOCK (concrete)		STAGING AREA
	BLOCK VALVE		BORROW SITE
	TEST LEAD & DIRECTION OF WIRES		WHARF

REVISION	APPRD BY	APPRD BY
BORROW SITE AND ROAD AIR-STRIP	JK	[illegible]

NORTHERN Engineering Services Company Limited

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CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA
ALBERTA

UPSTREAM M.P. 849 DOWNSTREAM M.P. 861

DRN BY	DATE	
CHKD BY M.J.L.	Feb 7/75	SCALE 1" = 2000'
APPRD BY JK	Feb 12/75	SHEET 3 OF 4

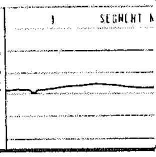
2D-0200-1003

TERRAIN MAPPING BY:
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK. DATE

OWNERSHIP

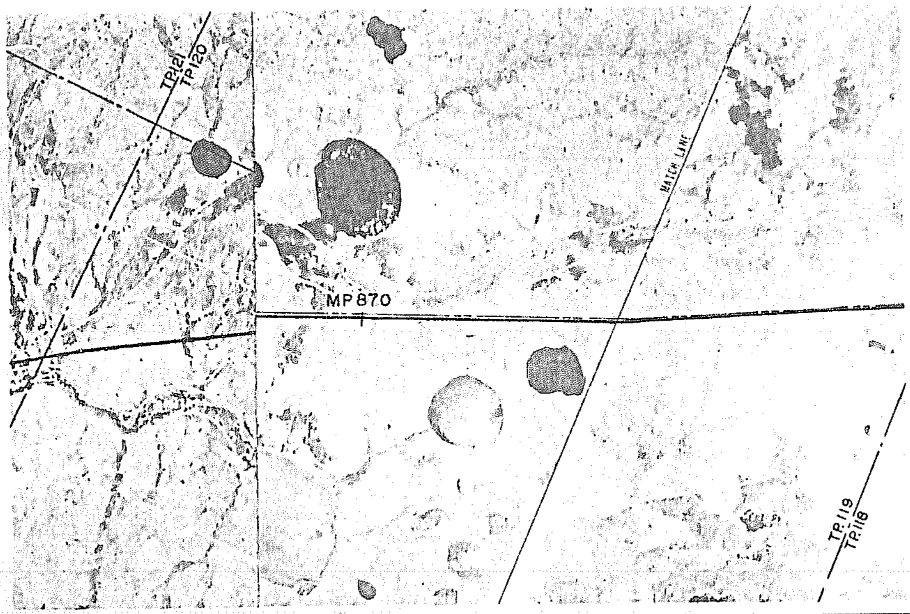
DRILL HOLE DATA

PROFILE



DRILL HOLE DATA LEGEND

TERRAIN TYPING LEGEND



CONSTRUCTION DATA

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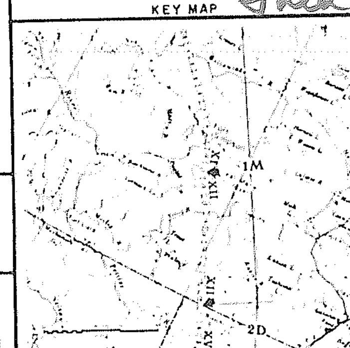
REFERENCE DRAWINGS & NOTES	MATCH LINE 661 02			
CHAINAGE (miles)	00 00	0 46		
DESIGN DATA				
SEGMENT Nº	1			
SEGMENT LENGTH	0 46			
EROSION CONTROL	EC-1C			
BUOY	B-2			
REVEG				

0 0.5 1.0

SCALE (miles)

KEY MAP fold here



PIPELINE

REVISION	APPD BY	APPD BY
ROW SITE AND ROAD		

CARRIER PIPE (Lower Weight)	POINT OF INTERS	
CARRIER PIPE (Concrete Coated)	DRILL HOLE LOC	
BERM BREAK	WARNING SIGN	
SWAMP WEIGHT	MILEPOST SIGN	
RIVER WEIGHT	CHAINAGE EQUAT	
FROST ANCHOR	COMPRESSOR STA	
SCREW ANCHOR	AIR STRIP	
HEAVY WALL PIPE	STORAGE OR ST	
CASING PIPE	CAMP SITE	
ANCHOR BLOCK (Concrete)	STAGING AREA	
BLOCK VALVE	BORROW SITE	
TEST LEAD & DIRECTION OF WIRES	WHARF	

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA

ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

ALBERTA

UPSTREAM M.P. 861 DOWNSTREAM M.P. 864.6

DWN BY	DATE	
CHKD BY		
APPD BY		

SCALE 1" = 2000'

SHEET 4 OF 4

2D-0200-1004

TERRAIN MAPPING BY

J.D. MOLLARD & ASSOCIATES LIMITED

REGINA, SASK. DATE

5

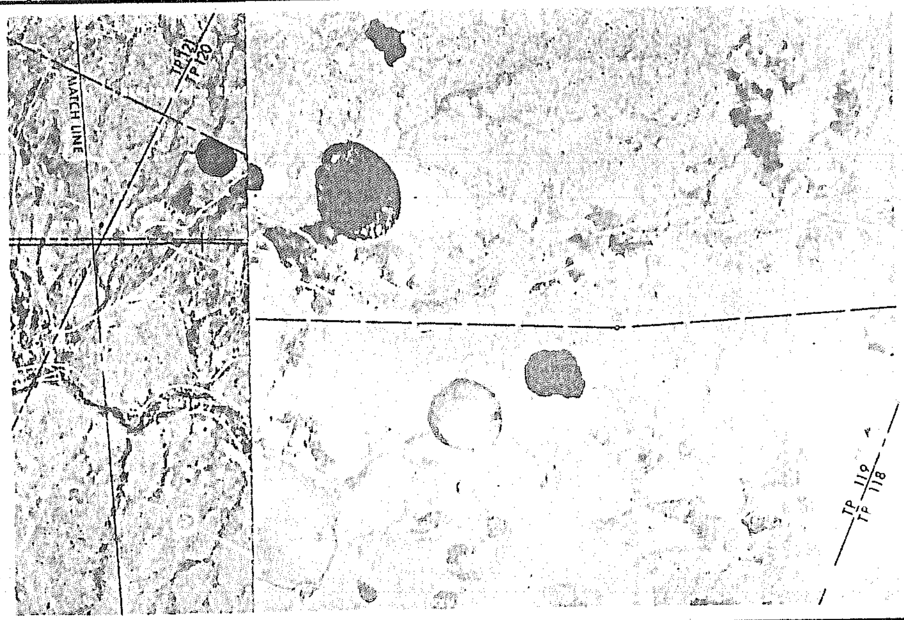
OWNERSHIP

DRILL HOLE DATA

PROFILE

8

MATCH LINE



TERRAIN TYPING LEGEND

XVIII — BUSH PARALLEL TO CHINCHAGA RIVER, NORTHERN ALBERTA PHYSIOGRAPHIC DIVISION

TERRAIN TYPES

AMP Alluvial meander plain: organic silt and fine sand over thin, discontinuous coarse sand and/or gravel over till

GLB Glacial lake basin: nearly level clay and silty clay plains

K Kames: complexly sorted and stratified mounds of sand and/or gravel with minor silt, till, and boulders

OW Outwash plain: channelled sand and/or gravel deposits

RBM Ridge and knoll moraine: undulating to uniformly sloping ground moraine composed of lodgement till

FEATURES AND PHASES

Topographic features

CT Crevasse fillings: narrow sublinear ridges of silt, sand, gravel, and ablation till

EVB Eroded valley banks

Old slide features along river banks

Hydrographic features

Meltwater channels

Oxbow channels

Slopewash features: fine subparallel drainage courses, often with associated surficial organic silt and sand slopewash deposits up to 4 ft thick over till

Shallow phases

[illegible]

Permafrost-affected peatland phases*

[illegible]

COMPLEXES

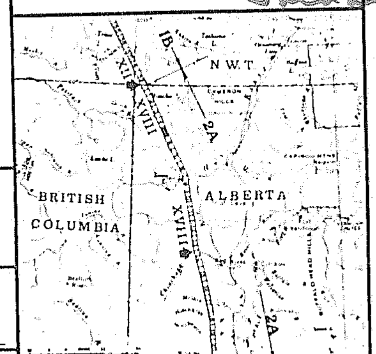
[illegible]

*In the southern fringe of the discontinuous permafrost zone, permafrost occurs in scattered islands a few square feet to several acres in size and is confined to certain types of organic terrain, [illegible] Permafrost Section, National Research Council of Canada, Ottawa)

FOOTAGE THIS SHEET

CONSTRUCTION DATA		
REFERENCE DRAWINGS & NOTES		MATCH LINE 871.00
CHAINAGE (miles)		10.42
DESIGN DATA		
SEGMENT Nº	8	
SEGMENT LENGTH	1.72	
EROSION CONTROL	EC-10	
BUOY	B-1	
REVEG	III-V-2	

0 0.5 1.0
SCALE (miles)



CARRIER PIPE (conc. coated)	POINT OF INTERSECTION	PIPELINE REVISION	APPRO. BY
CARRIER PIPE (conc. coat)	DRILL HOLE	BORROW SITE AND ROAD	
BERM BREAK	WARNING SIGN		
SWAMP WEIGHT	MILEPOST SIGN		
RIVER WEIGHT	CHAINAGE EQU.		
FROST ANCHOR	COMPRESSOR S.		
SCREW ANCHOR	AIR STRIP		
HEAVY WALL PIPE	STORAGE OR S.		
CASING PIPE	CAMP SITE		
ANCHOR BLOCK (concrete)	STAGING AREA		
BLOCK VALVE	BORROW SITE		
TEST LEAD & DIRECTION OF WIRES	WHARF		

NORTHERN Engineering Services Company Limited

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CALGARY ALBERTA
ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA
ALBERTA

UPSTREAM M.P. 861 DOWNSTREAM M.P. 871

DRN. BY | DATE
CHKD. BY | Jan 18/74
APPRD. BY | Jan 23/74

SCALE 1" = 2000' SHEET 5 of 50

2A-0200-1005

TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK.

foldout

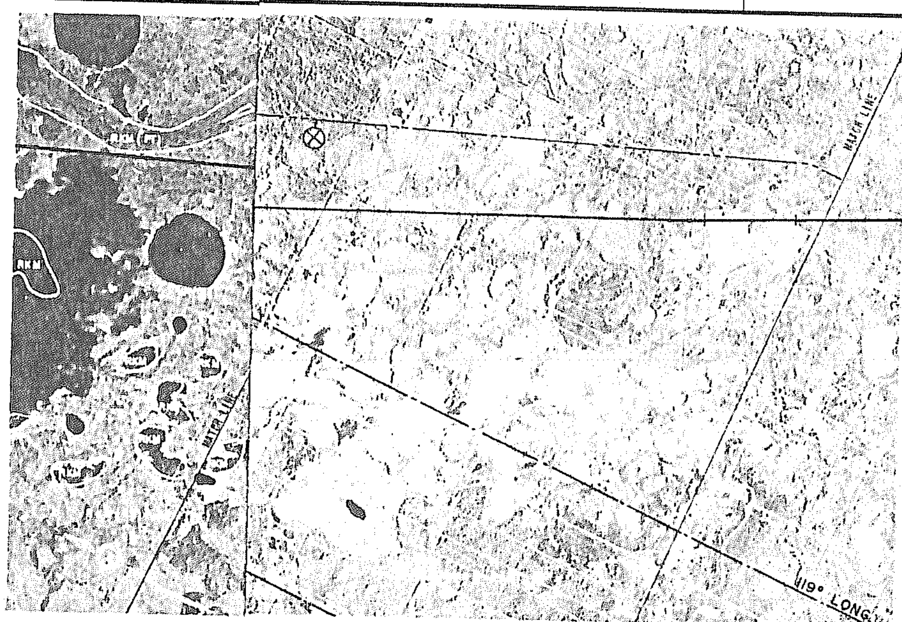
OWNERSHIP	
DRILL HOLE DATA	

PROFILE

2000
1900
1800

5 6 7

MATCH LINE



TERRAIN TYPING LEGEND

XVIII -- 60TH PARALLEL TO CHINCHAGA RIVER,
NORTHERN ALBERTA PHYSIOGRAPHIC DIVISION

TERRAIN TYPES

- AMP — Alluvial meander plain: organic silt and fine sand over thin, discontinuous coarse sand and/or gravel over till
- GLB — Glacial lake basin: nearly level clay and silty clay plains
- K — Kames: completely sorted and stratified mounds of sand and/or gravel with minor silt, till, and boulders
- Ow — Outwash plains: channelled sand and/or gravel deposits
- RKM — Ridge and knoll moraine: undulating to uniformly sloping ground moraine composed of lodgement till

FEATURES AND PHASES

Topographic features

- CF — Crevasse fillings: narrow rectilinear ridges of silt, sand, gravel, and ablation till
- EVB — Eroded valley banks
- OSF — Old slide features along river banks

Hydrographic features

- MC — Meltwater channels
- OC — Oxbow channels
- SL — Slopewash features: fine subparallel drainage courses, often with associated surficial organic silt and sand slopewash deposits up to 4 ft thick over till

Shallow phases

- AB — 2 to 5 ft of loose gravelly-sandy-silt ablation till over lodgement till
- SH — 5 to 15 ft (but generally less than 10 ft) surficial veneer. Note associated parent terrain types to determine stratigraphy, as [illegible]

Permafrost-affected peatland phases*

(Note: Peatland phases are shown along with the underlying mineral-soil terrain type.)

- BS — Speckled bog pattern: elevated peat bogs, mainly peat plateaus with some palsas. White speckles are small intervening thaw depressions (collapse scars, wet sedge meadows) resulting from local permafrost degradation, usually pre-conditioned by forest fires. Permafrost is usually absent in the white speckles. In GLB(BS) areas the peat is up to 8 ft but is usually less than 5 ft deep; in RKM(BS) areas the peat is 3 to 20 ft deep but commonly 5 to 15 ft in depressions and is usually less than 8 ft on slopes
- FT — Generally an even gray peatland appearance, with some waterflow patterns. Locally, transitional to reticulated and ribbed fens. Expect peat 3 to 20 ft deep
- PT-S — Spotty pattern of peat areas, with peat up to 15 ft deep in small areas that are 5 to 10 acres in size and cover 25 to 50% of the land surface
- SB — Reticulated and ribbed fens. Water table at or above ground surface in hollows, with sparse lines or ridges (strings). Expect peat depths up to 12 ft
- TD — Small thermokarst basins containing standing stagnant water. Occurs on peatlands where sporadic permafrost has degraded and shallow water fills small thaw basins

COMPLEXES

Complexes are shown where two terrain types are either too small or too completely intermingled to separate at the scale of aerial photographs. Examples of percentages in combined terrain units follow:

RKM(BS)+RKM(SB) indicates over 50% BS and 25 to 50% SB
RKM(BS),some RKM(SB) indicates over 75% BS and less than 25% SB
RKM+RKM(BS)(FT) indicates that peat areas in the latter unit, RKM(BS)(FT), comprise more than 50% bog peat (BS) and 25 to 50% uniform-toned fen peat (FT)

*In the southern fringe of the discontinuous permafrost zone, permafrost occurs in scattered islands a few square feet to several acres in size and is confined to certain types of organic terrain, mainly elevated peat plateaus and occasional palsas (BS areas). The permafrost is generally not present in fen land (SB and FT areas). Other isolated occurrences of permafrost are associated with steeper north-facing slopes and areas of dense black spruce, where increased shading from summer thawing and reduced snow cover enhance permafrost formation and preservation (after Roger J.E. Brown, Permafrost Section, National Research Council of Canada, Ottawa)

Foldaine

CONSTRUCTION DATA

					FOOTAGE THIS SHEET
REFERENCE DRAWINGS & NOTES				MATCH LINE SHT 05	
CHAINAGE (miles)		11.22	11.61	11.72	
DESIGN DATA					
SEGMENT No.	5	6	7		
SEGMENT LENGTH	3.62	0.39	0.11		
EROSION CONTROL	EC-10	EC-10	EC-10		
BUOY	B-0				
REVEG		0-1	B-0		

0 0.5 1.0
SCALE (miles)

PIPELINE

- CARRIER PIPE (over view)
- CARRIER PIPE (bern view)
- BERM BREAK
- SWAMP WEIGHT
- RIVER WEIGHT
- FROST ANCHOR
- SCREW ANCHOR
- HEAVY WALL PIPE
- CASING PIPE
- ANCHOR BLOCK (concrete)
- BLOCK VALVE
- TEST LEAD & DIRECTION OF WIRES
- POINT OF INTE[…]
- DRILL HOLE (…
- WARNING SIGN
- MILEPOST SIGN
- CHAINAGE EQU[…]
- COMPRESSOR S[…]
- AIR STRIP
- STORAGE OR S[…]
- CAMP SITE
- STAGING AREA
- BORROW SITE
- WHARF

REVISION	APPD BY	APPD BY
ROW SITES & ROAD	[illegible]	[illegible]

NORTHERN Engineering Services Company Limited

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA

ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

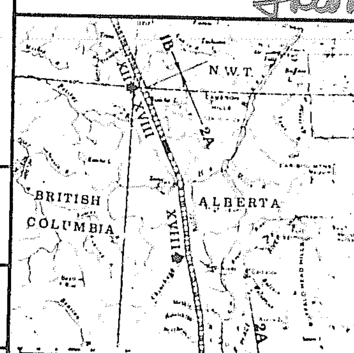
GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

ALBERTA

UPSTREAM M.P. 871 DOWNSTREAM M.P. 883

DRN BY	DATE		
CHKD BY	[signature]	JAN 18/[…]	
APPRD BY	[signature]	Jan 23/[…]	SCALE 1" = 2000'
			SHEET 6 OF 50

2A-0200-1006

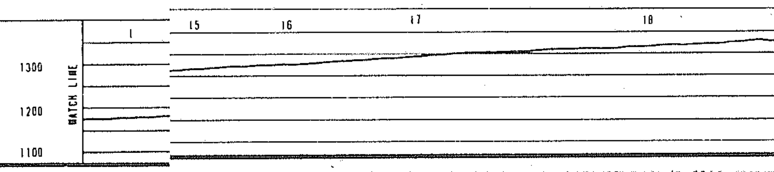


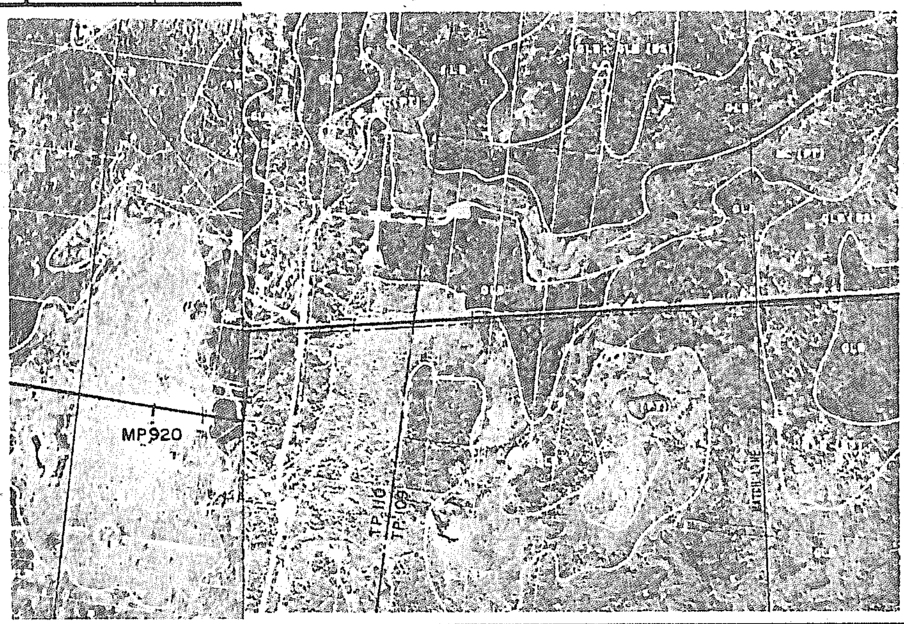
TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK.

OWNERSHIP

DRILL HOLE DATA

PROFILE





TERRAIN TYPING LEGEND

XVIII -- 60TH PARALLEL TO CHINCHAGA RIVER,
NORTHERN ALBERTA PHYSIOGRAPHIC DIVISION

TERRAIN TYPES

- AMP Alluvial meander plain: organic silt and fine sand over thin, discontinuous coarse sand and/or gravel over till
- GLB Glacial lake basin: nearly level clay and silty clay plains
- K Kames: complexly sorted and stratified mounds of sand and/or gravel with minor silt, till, and boulders
- OW Outwash plain: channelled sand and/or gravel deposits
- RKM Ridge and knoll moraine: undulating to uniformly-sloping ground moraine composed of lodgement till

FEATURES AND PHASES

Topographic features

- CF Crevasse fillings: narrow sublinear ridges of silt, sand, gravel, and ablation till
- EVB Eroded valley banks
- OSF Old slide features along river banks

Hydrographic features

- MC Meltwater channels
- OX Oxbow channels
- SL Slopewash features: fine subparallel drainage courses, often with associated surficial organic silt and sand slopewash deposits up to 4 ft thick over till

Shallow phases

- AB 2 to 5 ft of loose gravelly-sand-silt ablation till over lodgement till
- SH 5 to 15 ft (but generally less than 10 ft) surficial veneer. Note associated parent terrain types to determine stratigraphy, as GL(SH)/RKM(DB)

Permafrost-affected peatland phases*

(Note: Peatland phases are shown along with the underlying mineral-soil terrain type.)

- BS Speckled bog pattern: elevated peat bogs, mainly peat plateaus with some palsas. White speckles are small interjacent thaw depressions (collapse scars, wet sedge meadows) resulting from local permafrost degradation, usually pre-conditioned by forest fires. Permafrost is usually absent in the white speckles. In GLB(BS) areas the peat is up to 4 ft but is usually less than 3 ft deep, in RKM(BS) areas the peat is 3 to 20 ft deep but commonly 5 to 15 ft in depressions and is usually less than 6 ft on slopes
- FT Generally an even gray peatland appearance, with some waterflow patterns. Locally, transitional to reticulated and ribbed fens. Expect peat 3 to 20 ft deep
- FT-S Spotty pattern of peat areas, with peat up to 11 ft deep in small areas that are 1 to 10 acres in size and cover 25 to 50% of the land surface
- SB Reticulated and ribbed fens. Water table at or above ground surface in hollows, with sparse trees on ridges (strings). Expect peat depths up to 12 ft
- TK Small thermokarst basins containing standing stagnant water. Occurs on peatlands where sporadic permafrost has degraded and shallow water fills small thaw basins

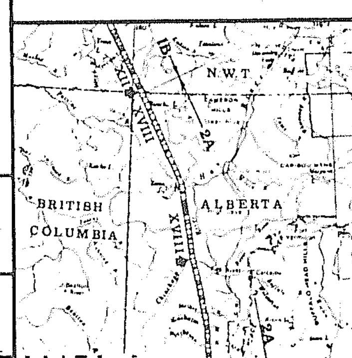
COMPLEXES

Complexes are shown where two terrain types are either too small or too complexly intermingled to separate at the scale of aerial photography. Examples of percentages in combined terrain units follow:

RKM(BS)+RKM(SB) indicates over 50% BS and 25 to 50% SB
RKM(BS),some RKM(SB) indicates over 75% BS and less than 25% SB
RKM+RKM(BS)(FT) indicates that peat areas in the latter unit, RKM(BS)(FT), comprise more than 50% bog peat (BS) and 25 to 50% uniform-toned fen peat (FT)

Follow

*In the southern fringe of the discontinuous permafrost zone, permafrost occurs in scattered islands a few square feet to several acres in size and is confined to certain types of organic terrain, mainly elevated peat plateaus and occasional palsas (BS areas). The permafrost is generally not present in fen land (SB and FT areas). Other isolated occurrences of permafrost are associated with steeper north-facing slopes and areas of dense black spruce, where increased shading from summer thawing and reduced snow cover enhance permafrost formation and preservation (after Roger J.E. Brown, Permafrost Section, National Research Council of Canada, Ottawa)



TERRAIN MAPPING BY
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK.

CONSTRUCTION DATA

						FOOTAGE THIS SHEET
REFERENCE DRAWINGS & NOTES	MATCH LINE 919.67				MATCH LINE 932.55	
CHAINAGE (miles)	0.0	0.55	11.13	11.64	12.88	
DESIGN DATA						
SEGMENT Nº	1	16	17	18		
SEGMENT LENGTH	0.55	0.73	0.51	1.24		
EROSION CONTROL	EC-10	EC-10	EC-8	EC-10		
BUOY.	B-1	B-0	B-1	B-0		
REVEG		III-Y-2	III-Y-4	III-Y-2		

0 0.5 1.0
SCALE (miles)

PIPELI[NE]

- CARRIER PIPE (cover shown)
- CARRIER PIPE (berm cover)
- BERM BREAK
- SWAMP WEIGHT
- RIVER WEIGHT
- FROST ANCHOR
- SCREW ANCHOR
- HEAVY WALL PIPE
- CASING PIPE
- ANCHOR BLOCK (concrete)
- BLOCK VALVE
- TEST LEAD & DIRECTION OF WIRES
- POINT OF INT[ERSECTION]
- DRILL HOLE
- WARNING SIG[N]
- MILEPOST SIG[N]
- CHAINAGE EQ[UATION]
- COMPRESSOR
- AIR STRIP
- STORAGE OR
- CAMP SITE
- STAGING ARE[A]
- BORROW SIT[E]
- WHARF

REVISION	APPR'D BY	APPR'D BY
[B]ORROW SITE AND ROAD	[signature]	[signature]

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CALGARY ALBERTA

ENGINEERS FOR

NORTHERN Engineering Services Company Limited

CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA

ALBERTA

UPSTREAM M.P. 920 DOWNSTREAM M.P. 933

DRN BY	DATE	
CHKD BY [signature]	Jan 18/7[?]	SCALE 1 : 3000
APPRD BY [signature]	Jan 22/7[?]	SHEET 10 OF 80

2A-0200-1010

OWNERSHIP

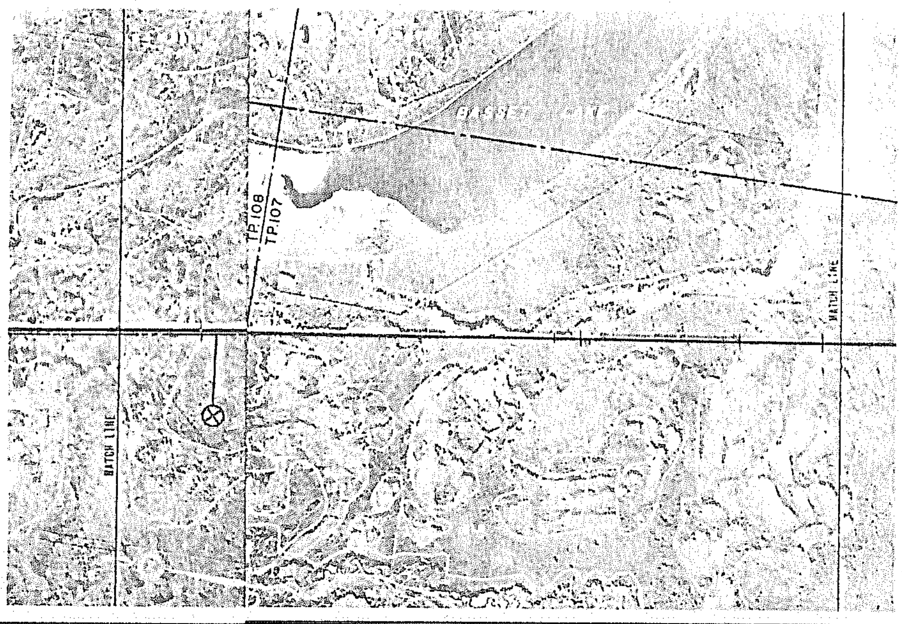
DRILL HOLE DATA

PROFILE

	1	21	22	23	24	25	26
1500							
1400							
1300							

MATCH LINE

MATCH LINE



TERRAIN TYPING LEGEND

XVIII -- 60TH PARALLEL TO CHINCHAGA RIVER,
NORTHERN ALBERTA PHYSIOGRAPHIC DIVISION

TERRAIN TYPES

AMP Alluvial meander plain: organic silt and fine sand over thin, discontinuous coarse sand and/or gravel over till

GLB Glacial lake basin: nearly level clay and silty clay plains

K Kames: complexly sorted and stratified mounds of sand and/or gravel with minor silt, till, and boulders

OW Outwash plain: channelled sand and/or gravel deposits

RKM Ridge and knoll moraine: undulating to uniformly sloping ground moraine composed of lodgement till

FEATURES AND PHASES

Topographic features

CF Crevasse fillings: narrow sublinear ridges of silt, sand, gravel, and ablation till

EVB Eroded valley banks

OSF Old slide features along river banks

Hydrographic features

MC Meltwater channels

OX Oxbow channels

SL Slopewash features: fine subparallel drainage courses, often with associated surficial organic silt and sand slopewash deposits up to 4 ft thick over till

Shallow phases

AB 2 to 5 ft of loose gravelly-sand-silt ablation till over lodgement till

SH 5 to 15 ft (but generally less than 10 ft) surficial veneer. Note associated parent terrain types to determine stratigraphy, as GL(SH)/RKM(GL)

Permafrost-affected peatland phases*

(Note: Peatland phases are shown along with the underlying mineral-soil terrain type.)

BS Speckled bog pattern: elevated peat bogs, mainly peat plateaus with some palsas. White speckles are small interjacent thaw depressions (collapse scars, wet sedge meadows) resulting from local permafrost degradation, usually pre-conditioned by forest fires. Permafrost is usually absent in the white speckles. In GLB(BS) areas the peat is up to 6 ft but is usually less than 3 ft deep; in RKM(BS) areas the peat is 3 to 20 ft deep but commonly 5 to 15 ft in depressions and is usually less than 6 ft on slopes

PT Generally an even gray peatland appearance, with some waterflow patterns. Locally, transitional to reticulated and ribbed fens. Expect peat 3 to 20 ft deep

PT-S Spotty pattern of peat areas, with peat up to 15 ft deep in small areas that are 1 to 10 acres in size and cover 25 to 50% of the land surface

SB Reticulated and ribbed fens. Water table at or above ground surface in hollows, with sparse trees on ridges (strings). Expect peat depths up to 12 ft

TK Small thermokarst basins containing standing stagnant water. Occurs on peatlands where sporadic permafrost has degraded and shallow water fills small thaw basins

COMPLEXES

Complexes are shown where two terrain types are either too small or too complexly intermingled to separate at the scale of aerial photography. Examples of percentages in combined terrain units follow.

RKM(BS)+RKM(SB) indicates over 50% BS and 25 to 50% SB
RKM(BS),some RKM(SB) indicates over 75% BS and less than 25% SB
RKM+RKM(BS)(PT) indicates that peat areas in the latter unit, RKM(BS)(PT), comprise more than 50% bog peat (BS) and 25 to 50% uniform-toned fen peat (PT)

fold in

*In the southern fringe of the discontinuous permafrost zone, permafrost occurs in scattered islands a few square feet to several acres in size and is confined to certain types of organic terrain, mainly elevated peat plateaus and occasional palsas (BS areas). The permafrost is generally not present in fen land (SB and PT areas). Other isolated occurrences of permafrost are associated with steeper north-facing slopes and areas of dense black spruce, where increased shading from summer thawing and reduced snow cover enhance permafrost formation and preservation (after Roger J.E. Brown, Permafrost Section, National Research Council of Canada, Ottawa)

CONSTRUCTION DATA

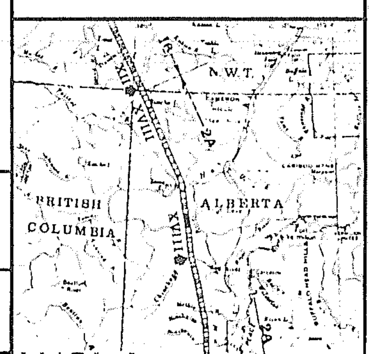
REFERENCE DRAWINGS & NOTES: MATCH LINE 932.55 — MATCH LINE 945.57

FOOTAGE THIS SHEET

CHAINAGE (miles): 0.0 | 0.35 | 11.80 | 11.91 | 12.60 | 12.96 | 12.02

SEGMENT Nº	1	22	23	24	25	26
SEGMENT LENGTH	0.36	1.60	0.11	0.69	0.36	0.06
EROSION CONTROL	EC-10	EC-10	EC-10	EC-10	EC-10	EC-10
BUOY.	B-1	B-0	B-1	B-0	B-2	B-0
REVEG.	III-V-2					

0 0.5 1.0
SCALE (miles)



TERRAIN MAPPING BY:
J.D. MOLLARD & ASSOCIATES LIMITED
REGINA, SASK.

PIPELINE

CARRIER PIPE (Lower Shown)
CARRIER PIPE (Berm Cover)
BERM BREAK
SWAMP WEIGHT
RIVER WEIGHT
FROST ANCHOR
SCREW ANCHOR
HEAVY WALL PIPE
CASING PIPE
ANCHOR BLOCK (concrete)
BLOCK VALVE
TEST LEAD & DIRECTION OF WIRES
POINT OF INTE...
DRILL HOLE L...
WARNING SIGN
MILEPOST SIGN
CHAINAGE EQU...
COMPRESSOR S...
AIR STRIP
STORAGE OR ...
CAMP SITE
STAGING AREA
BORROW SITE
WHARF

REVISION	APPD BY	APPD BY
BORROW SITES, ROADS		
...TE AIR-STRIP		

NORTHERN Engineering Services Company Limited

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ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT AND TERRAIN DATA
ALBERTA

UPSTREAM M.P. 933 DOWNSTREAM M.P. 946

DRN BY	DATE		
CHKD BY	JAN 18/74		
APPRD BY	Jan 23/74	SCALE: 1" = 2000' SHEET 11 OF 60	2A-0200-1011

OWNERSHIP

DRILL HOLE DATA

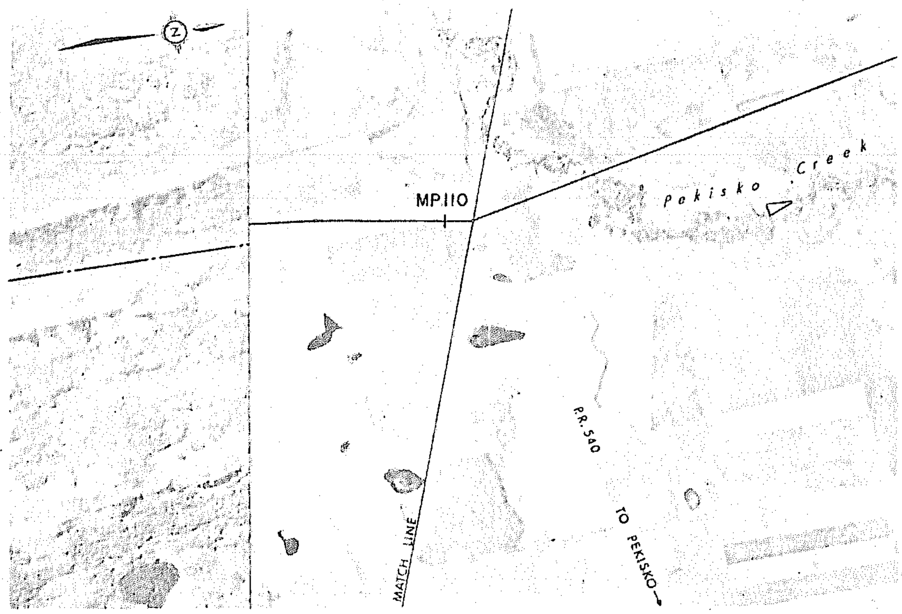
PROFILE

MATCH LINE

4300

4200

4100



CONSTRUCTION DATA

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DESIGN DATA			
SEGMENT No.			
SEGMENT LENGTH			
BUOY			

0 0.5 1.0

SCALE (miles)

PIPELINE | REVISION | APPRD BY | APPRD BY

CARRIER PIPE (... shown) — POINT OF INTER...
CARRIER PIPE (berm cover) — DRILL HOLE LO...
BERM BREAK — WARNING SIGN
SWAMP WEIGHT — MILEPOST SIGN
RIVER WEIGHT — CHAINAGE EQUA...
FROST ANCHOR — COMPRESSOR ST...
SCREW ANCHOR — AIR STRIP
HEAVY WALL PIPE — STORAGE OR S...
CASING PIPE — CAMP SITE
ANCHOR BLOCK (concrete) — STAGING AREA
BLOCK VALVE — BORROW SITE
TEST LEAD & DIRECTION OF WIRES. — WHARF

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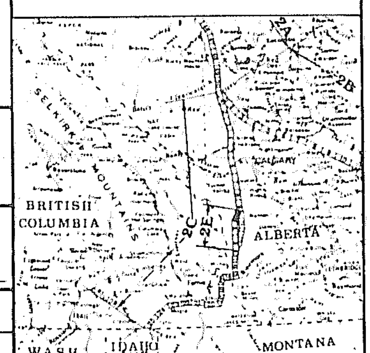
CANADIAN ARCTIC GAS PIPELINE LIMITED
GAS PIPELINE ROUTE ALIGNMENT DATA
ALBERTA

UPSTREAM M.P. 110 DOWNSTREAM M.P. 120

DRN BY	DATE		
CHKD BY RK	Jan 28/77	SCALE 1" = 2000'	2E-0200-1001
APPRD BY	Jan 28/77	SHEET 1 OF 3	

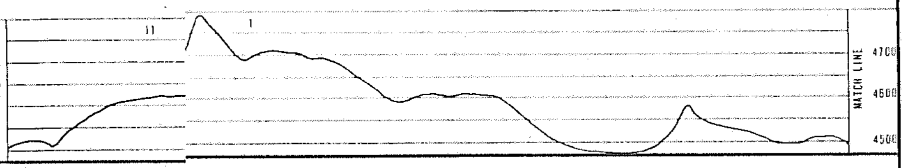


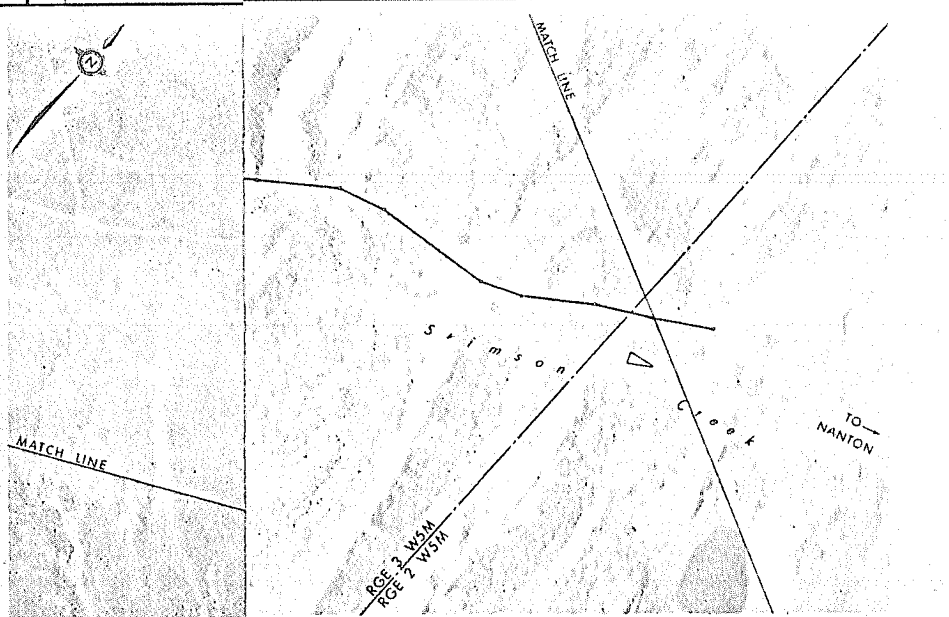
Fold line

OWNERSHIP

DRILL HOLE DATA

PROFILE





CONSTRUCTION DATA

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CHAINAGE (miles)	00.00	
DESIGN DATA		
SEGMENT No		
SEGMENT LENGTH		
BUOY		

0 0.5 1.0
SCALE (miles)

PIPELIN[E LEGEND]

CARRIER PIPE (... ...)	POINT OF INTE[RSECTION]
CARRIER PIPE (berm cover)	DRILL HOLE L[OCATION]
BERM BREAK	WARNING SIGN
SWAMP WEIGHT	MILEPOST SIGN
RIVER WEIGHT	CHAINAGE EQ[UATION]
FROST ANCHOR	COMPRESSOR S[TATION]
SCREW ANCHOR	AIR STRIP
HEAVY WALL PIPE	STORAGE OR
CASING PIPE	CAMP SITE
ANCHOR BLOCK (concrete)	STAGING AREA
BLOCK VALVE	BORROW SITE
TEST LEAD & DIRECTION OF WIRES	WHARF

REVISION	APPRO BY	APPRO BY

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
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ENGINEERS FOR

CANADIAN ARCTIC GAS PIPELINE LIMITED

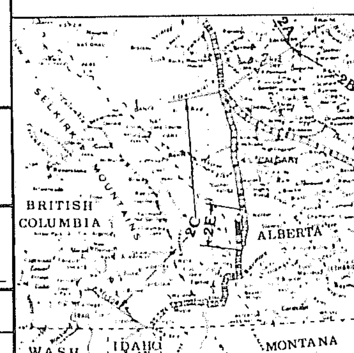
GAS PIPELINE ROUTE ALIGNMENT DATA

ALBERTA

UPSTREAM M.P. 120 DOWNSTREAM M.P. 134

DRN BY	DATE	
CHKD BY AK	Jun 26/75	SCALE 1" = 2000'
APPRD BY [signature]	Jan 28/77	SHEET 2 OF 3

2E-0200-1002



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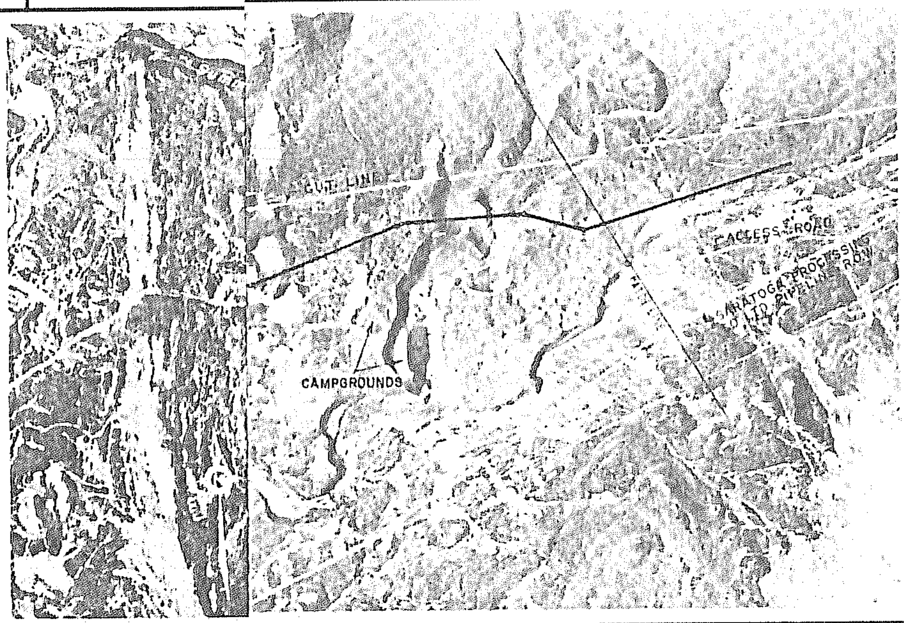
OWNERSHIP

DRILL HOLE DATA

PROFILE



CONSTRUCTION DATA

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DESIGN DATA				
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SEGMENT LENGTH	1.52	0.05	0.48	
BOUY	0.0	0.1	0.0	

0 0.5 1.0
SCALE (miles)

PIPELI...

CARRIER PIPE (cone weight)
CARRIER PIPE (...)
BERM BREAK
SWAMP WEIGHT
RIVER WEIGHT
FROST ANCHOR
SCREW ANCHOR
HEAVY WALL PIPE
CASING PIPE
ANCHOR BLOCK (concrete)
BLOCK VALVE
TEST LEAD & DIRECTION OF WIRES
POINT OF INT...
DRILL HOLE
WARNING SIG...
MILEPOST SIG...
CHAINAGE TO...
COMPRESSOR
AIR STRIP
STORAGE OR
CAMP SITE
STAGING ARE...
BORROW SITE
WHARF

REVISION	APPRD BY	APPRD BY
...UTH OF CAROLINE		
...C STA. K-02 AT		
F4.0		

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CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT DATA

ALBERTA

UPSTREAM M.P. 171 DOWNSTREAM M.P. 176

DRN BY | DATE
CHKD BY | Jan 22/74
APPRD BY |

SCALE 1" = 3000'
SHEET 16 OF 25

2C-0200-1016

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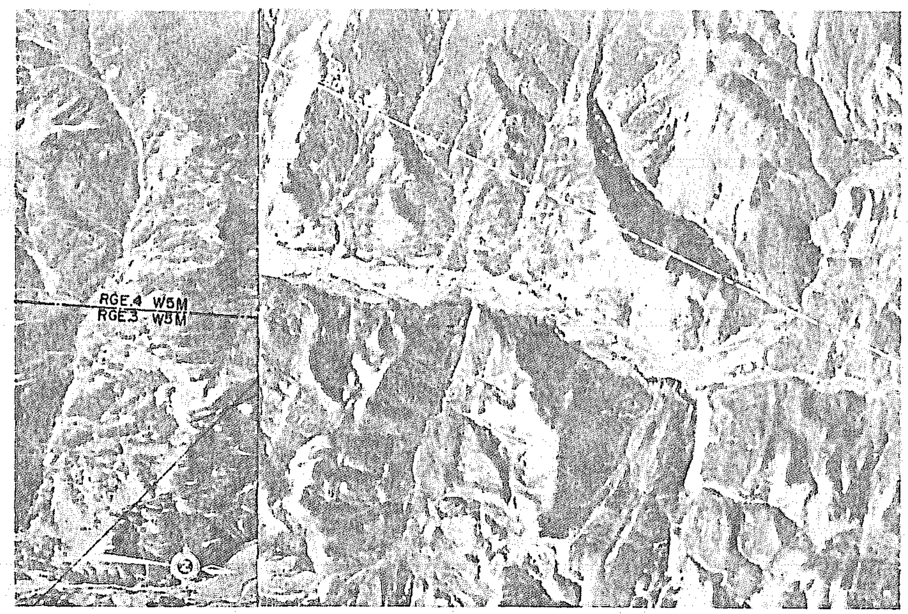
OWNERSHIP	
DRILL HOLE DATA	
PROFILE	



CONSTRUCTION DATA		FOOTAGE THIS SHEET
REFERENCE DRAWINGS & NOTES		
CHAINAGE (miles)		
DESIGN DATA		
SEGMENT Nº		
SEGMENT LENGTH		
BUOY.		

0 0.5 1.0
SCALE (miles)

PIPELIN[E]

CARRIER PIPE (cover shown)	POINT OF INTER[SECTION]		
CARRIER PIPE (bare cover)	DRILL HOLE LO[CATION]		
BERM BREAK	WARNING SIGN		
SWAMP WEIGHT	MILEPOST SIGN		
RIVER WEIGHT	CHAINAGE EQU[ATION]		
FROST ANCHOR	COMPRESSOR S[TATION]		
SCREW ANCHOR	AIR STRIP		
HEAVY WALL PIPE	STORAGE OR S[…]		
CASING PIPE	CAMP SITE		
ANCHOR BLOCK (concrete)	STAGING AREA		
BLOCK VALVE	BORROW SITE		
TEST LEAD & DIRECTION OF WIRES	WHARF		

REVISION	APPR'D BY	APPR'D BY
[SO]UTH OF CAROLINE		
[MOUNT]AIN LAKES RE-ROUTE		

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CALGARY ALBERTA

Northern Engineering Services Company Limited

ENGINEERS FOR
CANADIAN ARCTIC GAS PIPELINE LIMITED

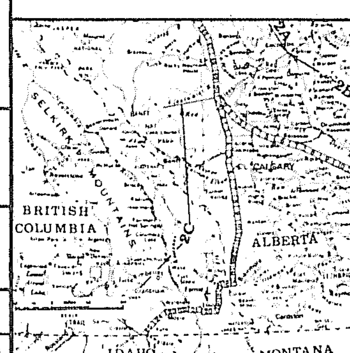
GAS PIPELINE ROUTE ALIGNMENT DATA

ALBERTA

UPSTREAM M.P. 147 DOWNSTREAM M.P. 151

DRN. BY	DATE	
CHKD. BY	Jan 23/75	
APPR'D BY	Jan 11/7[?]	SCALE 1" = 2000'
		SHEET 13 OF 25

2C-0200-1013(R)

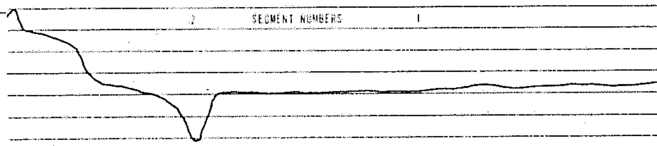


Foldout

OWNERSHIP

DRILL HOLE DATA

PROFILE



CONSTRUCTION DATA

REFERENCE DRAWINGS & NOTES	4-0210-1099	4-0100-0003	MATCH LINE 98.00	FOOTAGE THIS SHEET
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DESIGN DATA		ROAD		
SEGMENT Nº	2	1		
SEGMENT LENGTH	0.07	2.00		
BUOY.	N.A.	8.0		

0 0.5 1.0
SCALE (miles)

PIPELINE

CARRIER PIPE (Low cover)	POINT OF INTER...
CARRIER PIPE (Low cover)	DRILL HOLE LO...
BERM BREAK	WARNING SIGN
SWAMP WEIGHT	MILEPOST SIGN
RIVER WEIGHT	CHAINAGE EQU...
FROST ANCHOR	COMPRESSOR ST...
SCREW ANCHOR	AIR STRIP
HEAVY WALL PIPE	STORAGE OR B...
CASING PIPE	CAMP SITE
ANCHOR BLOCK (concrete)	STAGING AREA
BLOCK VALVE	BORROW SITE
TEST LEAD & DIRECTION OF WIRES	WHARF

REVISION	APPR'D BY	APPR'D BY
...TH OF CAROLINE		
...IN LAKES RE-ROUTE		

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CANADIAN ARCTIC GAS PIPELINE LIMITED

GAS PIPELINE ROUTE ALIGNMENT DATA

ALBERTA

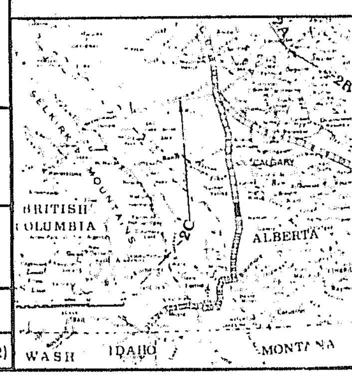
UPSTREAM M.P. 98 DOWNSTREAM M.P. 110

DRN. BY | DATE
CHKD. BY | Jan 22/74
APP'D BY

SCALE 1" = 2000'
SHEET 9 OF 25

2C-0200-1009(R)

Fold out



APPENDIX 16

ADDENDUM TO SECTION 8.b.2

FORMULAE AND BASIC ASSUMPTIONS

The following additional formulae and basic assumptions were used in performing hydraulic flow calculations to determine system capacity and fuel consumption. The subsection numbering system that was used in the original filing of Exhibit 8.b.2 has been retained.

1. Formulae

1.3 Gas Flowing Temperature

For those portions of the pipeline where insulation and heat tracing are required to prevent frost heave, the flowing temperature of the gas is determined using the following formulae:

$$T_2 = T_a + (T_1 - T_a)\, e^{-A} \qquad 1.3.1$$

$$T_a = T_i - \frac{(P_1 - P_2)\, J_{12}}{A} - \frac{\Delta h}{j\, AC_{P12}} \qquad 1.3.9$$

$$A = 5280\, \frac{s\, K_i\, L}{m\, C_{P12}} \qquad 1.3.10$$

$$s = \frac{2\pi}{\ln(D_i/D)} \qquad 1.3.11$$

1.5 Chilling, Cooling, and Gas Heating Stations

Propane compression horsepower, cooling load, and gas pressures and temperatures at stations with mechanical propane coolers are determined using formulae 1.5.1 to 1.5.9.

At stations with aerial cooling, the air temperature rise through the aerial cooler is calculated from the formula:

$$\Delta T = d_a W \qquad 1.5.12\text{-a}$$

2. Basic Assumptions

2.2 Pipe

The details of the line pipe to be installed are summarized as follows:

Segment	Outside Diameter (inches)	Wall Thickness (inches)	Minimum Yield Strength (psi)	Maximum Allowable Operating Pressure (psig)
Alaska-Yukon border to Tununuk Junction	48	0.720	70,000	1,680
Niglintgak to Taglu	24	0.360	70,000	1,680
Taglu to Tununuk Junction	48	0.720	70,000	1,680
Parsons Lake to Parsons Lake Junction	30	0.450	70,000	1,680
Tununuk Junction to Caroline	48	0.720	70,000	1,680
Caroline to Coleman	36	0.464	70,000	1,440
Caroline to Empress	48	0.720	70,000	1,680
Empress to Monchy	42	0.630	70,000	1,680

Detailed Specifications for the line pipe and the other major system components appear in Section 8.b.6, Material Specificiations.

For purposes of the flow calculations, the effective pipe roughness (k) has been assumed as 0.0003 inches, and the drag factor (F_1) as 0.975 for all segments of the system.

2.3 Flowing Gas Temperatures

Prudhoe Bay to Station M-15

Design station discharge temperature	T_o = 12°F
Design station suction temperature	T_s = 0°F
Highest allowable temperature	32°F
Lowest allowable temperature	-13°F

Station M-15 to Station M-20

Design station discharge temperature	T_o = 50°F
Design station suction temperature	T_s = 34°F
Highest allowable temperature	65°F
Lowest allowable temperature (for short periods)	25°F

South of Station M-20

Design station discharge temperature	not less than 58°F
Highest allowable temperature (north of Caroline)	110°F
Lowest allowable temperature (for short periods)	25°F

2.7 Ditch Configuration

The following table lists average values for the burial depth to the top of the pipe and the pipe diameter for each section of the route, as used in the heat-transfer calculations.

Section		Pipe	
From	To	Burial (inches)	Diameter (inches)
Prudhoe Bay	Shallow Bay	48	48
Shallow Bay	Tununuk Junction	48	36*
Niglintgak	Taglu	48	24
Taglu	Tununuk Junction	48	48
Parsons Lake	Parsons Lake Junction	48	30
Tununuk Junction	MF-15	48	48
MF-15	M-20	30	48
M-20	Caroline	36	48
Caroline	Coleman	36	36
Caroline	Empress	36	48
Empress	Monchy	36	42

* Dual pipeline

2.8 Turbine Performance Data

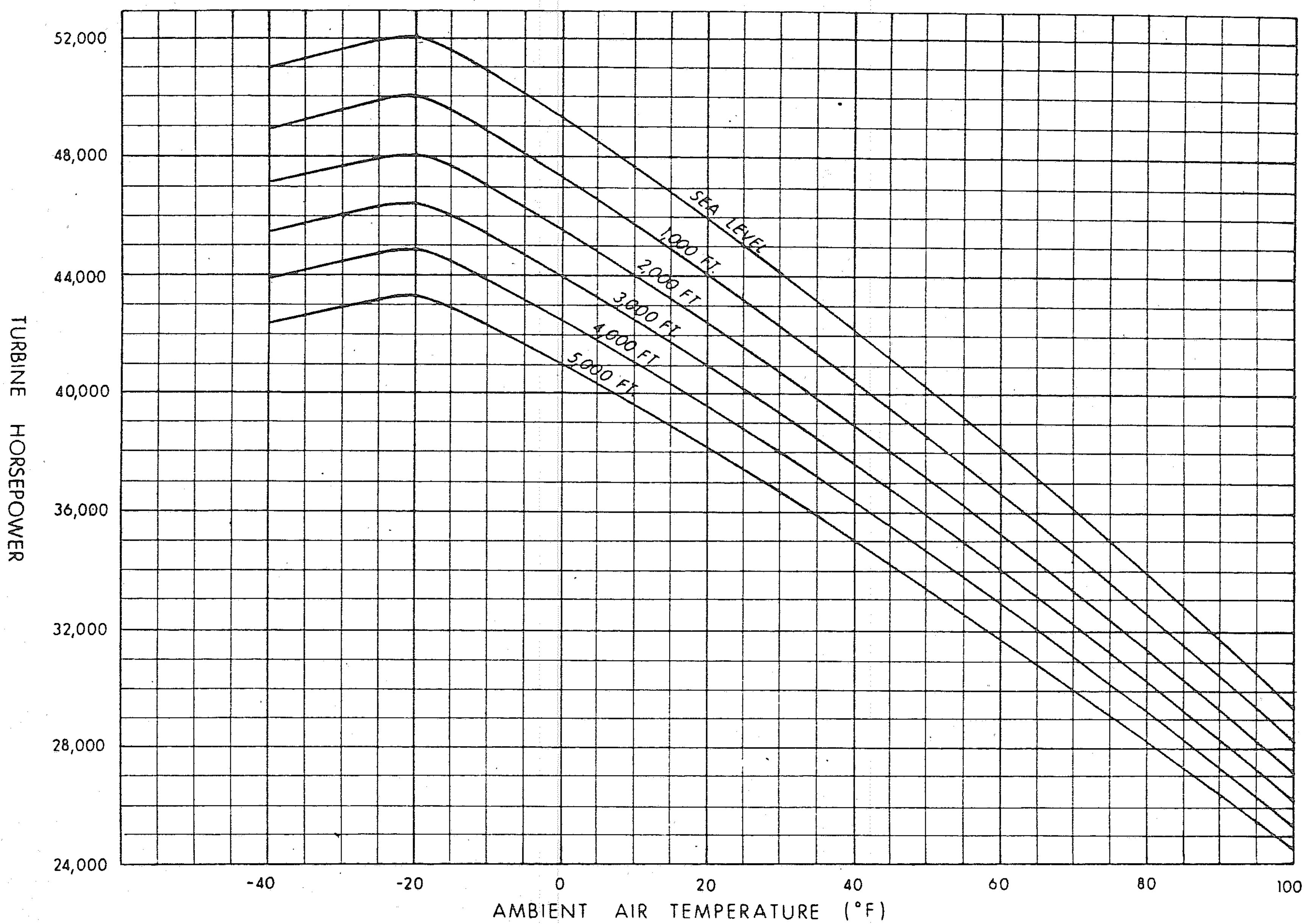
Two sizes of turbine are used for the main gas compression, 30,000 and 38,000 HP (ISO). The horsepower available from these units at each station is interpolated from the performance curves following. The air intake and exhaust losses have been included in the performance curves.

The following values were used for these units in the flow calculations.

	30,000 HP (ISO)	38,000 HP (ISO)
Mainline gas compressor efficiency (E)	80%	80%
Fuel constant (a_1) (BTU/day)	1.733×10^9	1.8770×10^9
Fuel constant (b_1) (BTU/HP-day)	0.0001249×10^9	0.0001545×10^9

	48 inches	42 inches
Equivalent length of station suction piping (Ls) (miles)	0.5826	0.5826
Equivalent length of discharge piping (Ld) (miles)	0.2214	0.1759

TURBINE PERFORMANCE CURVES (ISO RATING = 38,000 H.P.)
8. b. 2



2.9 Chilling/Cooling/Heating Performance Data

The propane refrigeration performance data were based on a 17,000 HP (ISO) turbine driving the propane compressor. The propane refrigeration performance data for the cooled portion of the line were based on a 6,400 HP (ISO) turbine driving the propane compressor. Physical parameters that define the chilling and cooling systems for the flow calculations are given below. The four tables which follow show the maximum capabilities and the horsepower requirements of the two types of propane refrigeration systems, as used in the flow calculations, fuel consumption calculations, and the annual capability analysis.

Propane Chiller Data

Heat transfer factor of propane evaporators (U_1)	5.4×10^6 BTU/hr-°R
Horsepower requirements of propane air circulating fans (d_2)	0.16 HP/ton
Propane turbine fuel constant (a_2)	0.947×10^9 BTU/day
Propane turbine fuel constant (b_2)	0.0001206×10^9 BTU/HP-day
Electrical turbine generator fuel constant (c_2)	0.000288×10^9 BTU/HP-day
Equivalent length of piping through chiller and associated piping (L_c)	0.5489 miles
Equivalent length of piping for station discharge (L_o)	0.2114 miles

Propane Cooler Data

Heat transfer factor of propane evaporators (U_1)	5.4×10^6 BTU/hr-°R
Horsepower requirements of propane air circulating fans (d_2)	0.16 HP/ton
Propane turbine fuel constant (a_2)	0.4200×10^9 BTU/day
Propane turbine fuel constant (b_2)	0.0001375×10^9 BTU/HP-day
Electrical turbine generator fuel constant (c_2)	0.000288×10^9 BTU/HP-day
Equivalent length of piping through cooler and associated piping (L_c)	0.5489 miles
Equivalent length of piping for station discharge (L_o)	0.2114 miles

Aerial Cooler Data

Heat transfer factor of aerial coolers (U_2)	7.2×10^6 BTU/hr-°R
Aerial cooler air temperature rise factor (d_a)	0.0012 °R/ton
Horsepower requirements of aerial coolers air circulating fans (d_3)	0.10 HP/ton
Equivalent length of piping through cooler and associated piping (L_c)	0.8352 miles
Equivalent length of piping for station discharge (L_o)	0.2332 miles

Gas Heater Data

Heater capacity	22.5×10^6 BTU/hr
Overall heater thermal efficiency based on lower heating value of gas (E_H)	75.0%

MAXIMUM CAPACITY OF PROPANE COOLER

W_{max} in tons

(1 ton = 12,000 BTU/hr)

Elevation = 0 feet

Propane Evaporator Temp. °F	Ambient Air Temperature in °F									
	-15	-5	5	15	25	35	45	55	65	75
35	9,972	9,972	9,972	9,972	9,973	9,925	9,757	9,538	8,289	6,900
40	10,248	10,248	10,248	10,248	10,248	10,200	10,032	9,814	8,977	7,427
45	10,605	10,602	10,602	10,602	10,602	10,551	10,363	10,124	9,803	8,041
50	10,839	10,839	10,839	10,839	10,839	10,788	10,607	10,372	10,137	8,662

Elevation = 500 feet

Propane Evaporator Temp. °F	Ambient Air Temperature in °F									
	-15	-5	5	15	25	35	45	55	65	75
35	9,876	9,876	9,876	9,876	9,876	9,828	9,661	9,443	8,159	6,784
40	10,153	10,150	10,150	10,150	10,150	10,104	9,936	9,719	8,843	7,306
45	10,497	10,497	10,497	10,497	10,497	10,442	10,255	10,026	9,659	7,913
50	10,735	10,735	10,735	10,735	10,735	10,683	10,504	10,270	10,031	8,527

evation = 1,000 feet

Propane Evaporator Temp. °F	Ambient Air Temperature in °F									
	-15	-5	5	15	25	35	45	55	65	75
35	9,777	9,777	9,777	9,777	9,777	9,730	9,563	9,345	8,029	6,668
40	10,055	10,052	10,052	10,052	10,052	10,005	9,839	9,622	8,707	7,183
45	10,387	10,387	10,387	10,387	10,387	10,331	10,150	9,927	9,504	7,784
50	10,629	10,629	10,629	10,629	10,629	10,578	10,399	10,164	9,924	8,390

Elevation = 1,500 feet

Propane Evaporator Temp. °F	Ambient Air Temperature in °F									
	-15	-5	5	15	25	35	45	55	65	75
35	9,688	9,686	9,686	9,686	9,686	9,639	9,472	9,255	7,899	6,561
40	9,961	9,961	9,961	9,961	9,961	9,915	9,749	9,533	8,582	7,071
45	10,283	10,289	10,289	10,289	10,289	10,229	10,057	9,835	9,374	7,664
50	10,531	10,531	10,531	10,531	10,531	10,480	10,302	10,063	9,830	8,264

Elevation = 2,000 feet

Propane Evaporator Temp. °F	Ambient Air Temperature in °F									
	-15	-5	5	15	25	35	45	55	65	75
35	9,593	9,593	9,593	9,593	9,593	9,546	9,379	9,169	7,778	6,454
40	9,869	9,869	9,869	9,869	9,869	9,822	9,657	9,442	8,455	6,968
45	10,186	10,186	10,186	10,186	10,186	10,132	9,962	9,741	9,243	7,545
50	10,432	10,432	10,432	10,432	10,432	10,381	10,202	9,961	9,719	8,136

HORSEPOWER REQUIREMENTS OF PROPANE COOLER

HP_2 (in Horsepower)

Cooler Heat Transfer = 4000 Tons

Propane Evaporator Temp. °F	Ambient Air Temperature in °F 15	25	35	45	55	65	75
35	1252	1252	1252	1340	1920	2975	4404
40	1252	1252	1252	1247	1589	2433	3788
45	1263	1263	1263	1263	1263	1912	3172
50	1274	1274	1274	1274	1270	1537	2614

Cooler Heat Transfer = 5000 Tons

Propane Evaporator Temp. °F	Ambient Air Temperature in °F 15	25	35	45	55	65	75
35	1638	1638	1638	1797	2535	3312	4769
40	1565	1565	1565	1565	2131	2881	4119
45	1577	1577	1577	1577	1709	2439	3475
50	1593	1593	1593	1593	1593	2061	2891

Cooler Heat Transfer = 6000 Tons

Propane Evaporator Temp. °F	Ambient Air Temperature in °F 15	25	35	45	55	65	75
35	2370	2370	2370	2371	3222	4152	5145
40	2219	2219	2219	2219	2709	3628	4578
45	2033	2033	2033	2033	2195	3087	4001
50	1914	1914	1914	1914	1914	2626	3528

Cooler Heat Transfer = 7000 Tons

Propane Evaporator Temp. °F	Ambient Air Temperature in °F 15	25	35	45	55	65	75
35	3335	3335	3335	3333	3967	5065	99999*
40	3100	3100	3100	3100	3366	4446	5570
45	2807	2807	2807	2807	2805	3796	4881
50	2677	2677	2677	2677	2677	3261	4322

Cooler Heat Transfer = 8000 Tons

Propane Evaporator Temp. °F	Ambient Air Temperature in °F 15	25	35	45	55	65	75
35	4470	4470	4470	4471	4782	6058	99999*
40	4149	4149	4149	4149	4144	5338	99999*
45	3783	3783	3783	3783	3782	4577	99999*
50	3566	3566	3566	3566	3567	3951	5188

Cooler Heat Transfer = 9000 Tons

Propane Evaporator Temp. °F	Ambient Air Temperature in °F 15	25	35	45	55	65	75
35	5823	5824	5824	5824	5824	99999*	99999*
40	5418	5418	5418	5418	5416	99999*	99999*
45	4911	4911	4911	4911	4906	5429	99999*
50	4635	4635	4635	4635	4635	4710	99999*

* Indicates maximum capability of system has been reached.

2.10 Insulation and Heat Tracing Data

The insulation and heat tracing requirements used in flow calculations and fuel consumption calculations are given below:

Location From	Location To	Extent of Insulation and Heat Tracing (miles)
CD-07	Tununuk Junction	8.9*
Niglintak	Taglu	0.8+
Taglu	Tununuk Junction	0.3
Tununuk Junction	MD-01	0.6*
M-06	M-07	15.0
M-07	M-08	8.7
M-08	M-09	9.3
M-09	M-10	7.7
M-10	M-11	9.8
M-11	M-12	15.0
M-12	MF-13	26.5
MF-13	MF-14	26.3
MF-14	MF-15	24.1

* Dual line, 36" O.D. pipe
+ 24" O.D. pipe

Thickness of insulation	3.0 inches
Thermal conductivity of insulation (K_i)	0.012 BTU/ft-°R-hr
Mean effective temperature of outer surface of insulation (T_i)	35°F

The electrical power requirements associated with mitigating frost heave used for fuel consumption calculations are given below:

Location	Power Required (KW) (Kilowatts)
CD-08	1,195
M-06	666
M-07	1,184
M-08	1,097
M-09	1,228
M-10	1,410
M-11	1,765
M-12	2,389
MF-13	2,677
MF-14	2,438
MF-15	1,446

Overall thermal efficiency of electrical power generation and transmission (E_E)	90%
Electrical turbine generator fuel constant (c_4)	0.000288×10^9 BTU/HP-day

LEGEND

STATION NUMBER (MILE POST) COMPRESSOR STATION DESIGNATION.

THE NUMBER DESIGNATES THE OPERATING YEAR FOR WHICH THE COMPRESSOR STA. OR MEASURING STA. IS REQUIRED.

FUTURE COMPRESSOR STATION NOT REQUIRED UNTIL AFTER THE 5th. OPERATING YEAR.

MECHANICAL REFRIGERATION REQ'D AT COMPRESSOR STNS.

MECHANICAL COOLING REQ'D AT COMPRESSOR STATIONS.

AERIAL COOLING REQ'D AT COMPRESSOR STATIONS.

GAS HEATING REQ'D AT COMPRESSOR STATIONS.

NO REFRIGERATION, COOLING, OR HEATING REQ'D AT COMPRESSOR STATION.

PROPOSED DEMPSTER & MACKENZIE HIGHWAYS.

STOCKPILE SITES WITH WHARVES.

STOCKPILE SITES.

OPERATING AND MAINTENANCE DIVISION AND DISTRICT HEADQUARTERS.

OPERATING AND MAINTENANCE DISTRICT HEADQUARTERS.

PROPOSED NATURAL GAS PIPELINE.

TE: MILEAGES SHOWN FROM COMPRESSOR STATION M-04 TO COMP. STN. MF-19 SHOULD BE DECREASED BY 2 MILES TO OBTAIN THE TRUE MILEAGE FROM RICHARDS ISLAND ORIGIN. MILEAGES SHOWN FROM COMP. STN. M-20 TO CAROLINE JCT. SHOULD BE DECREASED BY 1 MILE TO OBTAIN THE TRUE MILEAGE FROM RICHARDS ISLAND ORIGIN.

Fold out

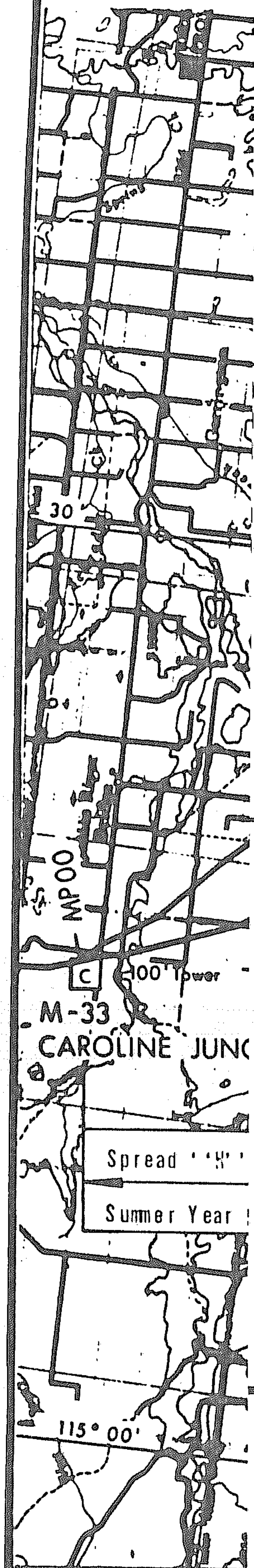
145
150°
155°
160°
Wainwright

ARCTIC GAS
SYSTEM ROUTE MAP
CROSS DELTA AMENDMENT

THIS MAP HAS BEEN
PRINTED BASE MAPS P
THE DEPARTMENT OF
WHICH THE APPLICAN
THOSE INSTALLATIONS
TO THIS APPLICATION

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS STUDY LIMITED

REVISED:	JAN. 27, 1977
DATE:	NOVEMBER 1975
PROJ. NO.:	
DWG. NO.:	4-0254-1004



FACILITY DESCRIPTION	LAND USE	
	AREA ACRES	BORROW CU.YD.
BLOCK VALVE	0.31	
BLOCK VALVE	0.31	
K-00 COMPRESSOR STATION PAD (FUT.)	18.37	
BLOCK VALVE	0.31	
BLOCK VALVE	0.31	
K-01 COMPRESSOR STATION PAD (FUT.)		
METER STATION	18.37	12,000
PIPELINE RIGHT OF WAY	1,890.90	
SUB-TOTAL SPREAD "H"	1,928.88	12,000

CHAINAGE EQUATION

NORTH	SOUTH
147.85	147.20

Fold out

PROPOSED PIPELINE ROUTE MAP
MP-00 TO MP-130
CAROLINE TO ALTA.-B.C. BORDER
CROSS DELTA AMENDMENT

THIS MAP HAS BEEN
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WHICH THE APPLICAN
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TO THIS APPLICATIO

NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS STUDY LIMITED

REVISED: JANUARY, 1977
DATE: NOVEMBER, 1975
PROJ. NO.:
DWG. NO.: 2C-0251-1001

FACILITY DESCRIPTION	LAND USE	
	AREA ACRES	BORROW CU. YD
SUB-TOTAL SPREAD ''H''	1,920.00	12,000
BLOCK VALVE	2.30	
BLOCK VALVE	2.30	
PIPELINE RIGHT OF WAY	875.20	
TOTAL SPREAD ''H''	2,800.00	12,000
TOTAL CAROLINE TO ALBERTA-B.C. BORDER - 36''	2,800.00	12,000

CHAINAGE EQUATION

NORTH	SOUTH
147.85	147.20

Fold our

PROPOSED PIPELINE ROUTE MAP
MP-130 TO MP-175.77
CAROLINE TO ALTA.-B.C. BORDER
CROSS DELTA AMENDMENT

THIS MAP HAS BEEN TA
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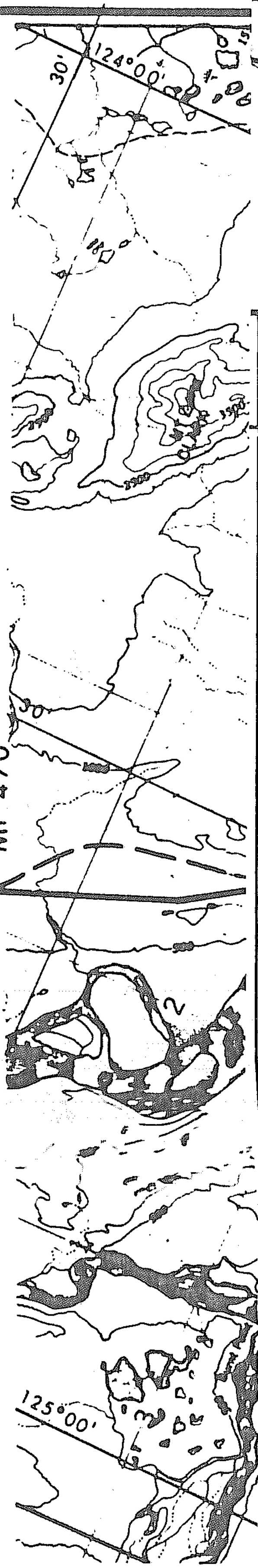
NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS STUDY LIMITED

REVISED: JANUARY, 1977
DATE: NOVEMBER, 1975
PROJ. NO:
DWG. NO: 2C-0251-1002



FACILITY DESCRIPTION	LAND USE	
	AREA ACRES	BORROW CU. YD.
SUB-TOTAL SPREAD ''D''	898.83	1,148,000
RMP 435	15.00	145,000
M-11 COMPRESSOR STATION	41.32	360,000
AIRSTRIP	175.00	180,000
ROAD	72.78	250,000
BLOCK VALVE	2.30	2,000
PIPELINE RIGHT OF WAY	843.84	
SUB-TOTAL SPREAD ''D''	1,846.85	2,086,000
M-12 COMPRESSOR STATION	41.32	320,000
ROAD	81.84	213,000
AIRSTRIP	175.00	180,000
RMP 384	15.00	145,000
REMOTE TOWER	0.52	
BLOCK VALVE	2.30	2,000
RMP 334	15.00	145,000
MF-13 COMPRESSOR STATION	27.55	187,000
ROAD	38.37	125,000
AIRSTRIP	175.00	180,000
BLOCK VALVE	2.30	2,000
PIPELINE RIGHT OF WAY	1,178.18	
SUB-TOTAL SPREAD ''D''	[illegible]	[illegible]
TOTAL SPREAD ''D''	3,577.23	3,585,000

Fold out

PROPOSED PIPELINE ROUTE MAP
MP 470 TO MP 609
THUNDER RIVER TO 60th PARALLEL
CROSS DELTA AMENDMENT

THIS MAP HAS BEEN TA
PRINTED BASE MAPS PRE
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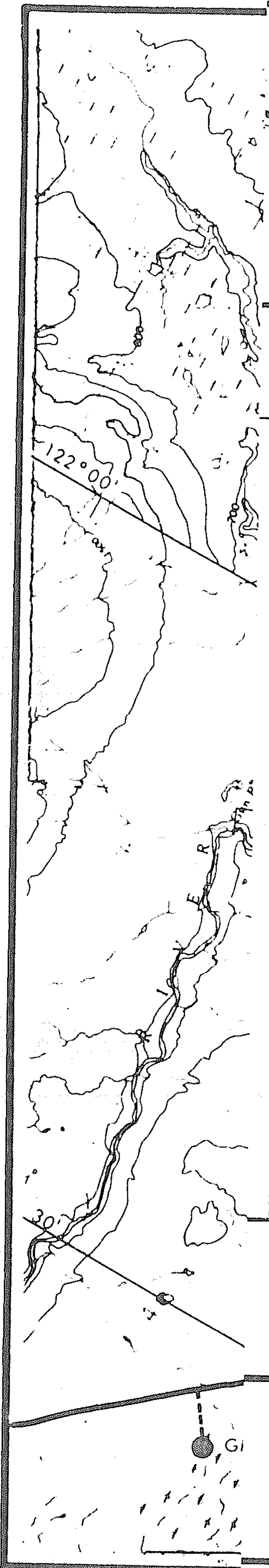
NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS STUDY LIMITED

REVISED:	JANUARY 1977
DATE:	NOV. 1975
PROJ NO.:	18111
DWG NO.:	1B-0251-1008



FACILITY DESCRIPTION	LAND USE	
	AREA ACRES	BORROW CU. YD.
MF-14 COMPRESSOR STATION	27.55	245,000
AIRSTRIP	175.00	330,000
ROAD	262.00	915,000
BLOCK VALVE	2.30	2,000
RMP 255	25.00	193,000
MF-15 COMPRESSOR STATION	29.44	265,000
ROAD	116.36	400,000
RMP 226	25.00	193,000
FORT SIMPSON O & M	8.04	78,000
PIPELINE RIGHT OF WAY	1,076.36	
SUB-TOTAL SPREAD ''E''	1,747.05	2,621,000
MF-15A COMPRESSOR STATION	39.60	302,000
ROAD	138.18	475,000
BLOCK VALVE	2.30	2,000
MACKENZIE HIGHWAY STOCKPILE - PLMP 722	25.00	122,000
ROAD	3.64	12,000
MF-16 COMPRESSOR STATION	43.94	348,000
ROAD	101.82	350,000
PIPELINE RIGHT OF WAY	974.55	
SUB-TOTAL SPREAD ''E''	1,329.03	1,611,000
TOTAL SPREAD ''E''	3,076.08	4,232,000

Fold out

PROPOSED PIPELINE ROUTE MAP
MP 609 TO MP 750
EAST FORT SIMPSON ROUTE REALIGNMENT
CROSS DELTA AMENDMENT

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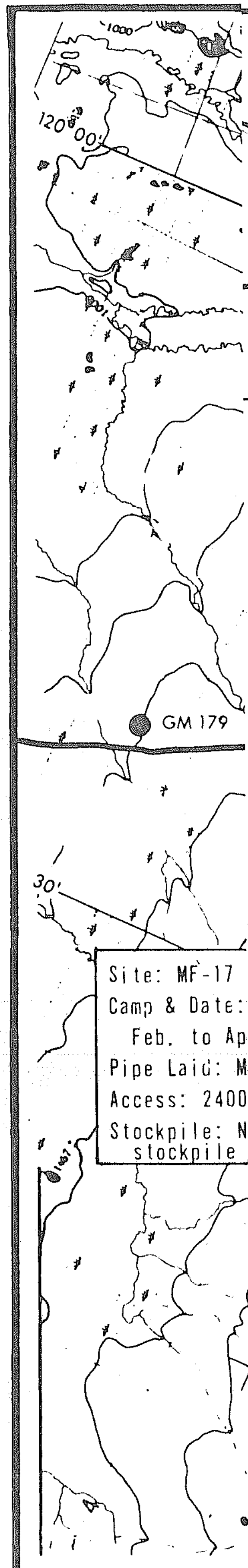
NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS STUDY LIMITED

REVISED:	JANUARY, 1977
DATE:	NOVEMBER, 1975
JOB NO.:	
DWG NO.:	1M-0251-1001



FACILITY DESCRIPTION	LAND USE	
	AREA ACRES	BORROW CU. YD.
BLOCK VALVE	2.30	2,000
MF-17 COMPRESSOR STATION	39.60	397,000
AIRSTRIP	175.00	215,000
ROAD	11.64	40,000
REMOTE TOWER	0.52	
BLOCK VALVE	2.30	2,000
METER STATION	11.00	24,900
MF-18 COMPRESSOR STATION	39.60	416,000
AIRSTRIP	300.00	1,400,000
ROAD	52.40	180,000
PIPELINE RIGHT OF WAY	1,018.18	
SUB-TOTAL SPREAD ''F''	1,652.54	2,676,000
BLOCK VALVE	2.30	2,000
MF-19 COMPRESSOR STATION	39.60	284,000
WORK PAD	15.00	50,000
ROAD	436.37	600,000
BLOCK VALVE	2.30	2,000
PIPELINE RIGHT OF WAY	1,018.18	
SUB-TOTAL SPREAD ''F''	1,513.75	938,000
TOTAL SPREAD ''F''	3,166.29	3,614,000

Fold out.

PROPOSED PIPELINE ROUTE MAP
MP 750 TO MP 890
EAST FORT SIMPSON ROUTE REALIGNMENT
CROSS DELTA AMENDMENT

THIS MAP HAS BEEN
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THE DEPARTMENT OF
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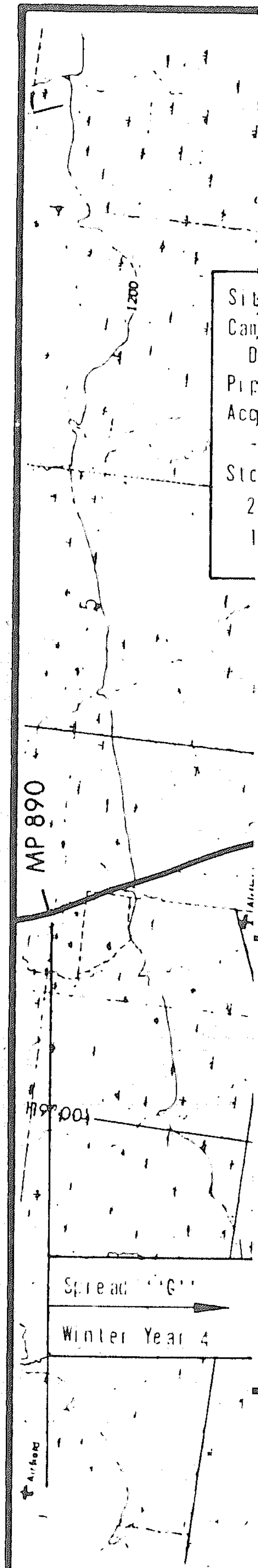
NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS STUDY LIMITED

REVISED: JANUARY, 1977
DATE: NOVEMBER, 1975
PROJ. NO.:
DWG. NO.: 1M-0251-1002



FACILITY DESCRIPTION	LAND USE	
	AREA ACRES	BORROW CU. YD.
M-20 COMPRESSOR STATION	32.83	104,000
HIGH LEVEL O & M	8.04	12,000
BLOCK VALVE	2.30	2,000
M-21 COMPRESSOR STATION	32.83	193,000
ROAD	189.55	140,000
BLOCK VALVE	2.30	1,000
M-22 COMPRESSOR STATION	32.83	104,000
ROAD		84,000
BLOCK VALVE	2.30	1,000
M-23 COMPRESSOR STATION	32.83	104,000
ROAD		140,000
PIPELINE RIGHT OF WAY	2,036.36	
SUB-TOTAL SPREAD ''G''	2,372.17	885,000

Fold over

PROPOSED PIPELINE ROUTE MAP
MP 890 TO MP 1030
60th PARALLEL TO CAROLINE
CROSS DELTA AMENDMENT

THIS MAP HAS BEEN PRINTED BASE MAPS P
THE DEPARTMENT OF
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NORTHERN ENGINEERING SERVICES COMPANY LIMITED
CALGARY ALBERTA
ENGINEERS FOR
CANADIAN ARCTIC GAS STUDY LIMITED

REVISED: JANUARY, 1977
DATE: NOVEMBER, 1975
PROJ NO.:
DWG NO.: 2D-0251-1001

CANADIAN ARCTIC GAS PIPELINE LIMITED
SECTION 10 COST OF FACILITIES
SUMMARY OF CONSTRUCTION COSTS
TOTAL FACILITIES

FINANCIAL FORMAT
CALENDAR YEARS
BASE CASE
ESCALATED DATA

BASE COST MARCH 31, 1976

ITEM NO	DESCRIPTION	COSTS BY CALENDAR YEAR ($ 000)								TOTAL	IN SERVICE
		YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9		
1.	LAND	393	1,959							2,352	Year 5
	Land	79	395							474	Year 6
	Sub-total	472	2,354							2,826	
2.	PIPELINE	756,418	1,270,369	1,492,391	524,370					4,043,548	Year 5
	Pipeline	53,141	99,339	195,176	578,687	222,910				1,149,253	Year 6
	Pipeline				697	5,907	12,102			18,706	Year 7
	Pipeline					749	4,557	4,089		9,395	Year 8
	Pipeline							1,721	8,605	10,326	Year 9
	Sub-total	809,559	1,369,708	1,687,567	1,103,754	229,566	16,659	5,810	8,605	5,231,228	
3.	COMPRESSOR STATIONS		32,521	196,020	167,109					395,650	Year 5
	Compressor Stations		710	33,980	196,299	220,577				451,566	Year 6
	Compressor Stations				21,459	151,279	219,925			392,663	Year 7
	Compressor Stations					30,257	195,720	222,187		448,164	Year 8
	Sub-total		33,231	230,000	384,867	402,113	415,645	222,187		1,688,043	
4.	BUILDINGS AND IMPROVEMENTS		6,946	40,958	31,175					79,079	Year 5
	Buildings and Improvements		866	7,500	20,253	21,995				50,614	Year 6
	Buildings and Improvements				1,501	11,229	18,632			31,362	Year 7
	Buildings and Improvements					2,257	15,082	19,011		36,350	Year 8
	Sub-total		7,812	48,458	52,929	35,481	33,714	19,011		197,405	
5.	MEASURING EQUIPMENT		938	7,029	11,696					19,663	Year 5
	Measuring Equipment			452	4,093	9,172				13,717	Year 6
	Sub-total		938	7,481	15,789	9,172				33,380	
6.	TRANSPORTATION EQUIPMENT			1,701	8,496					10,197	Year 5
	Transportation Equipment			551	2,889	690				4,130	Year 6
	Sub-total			2,252	11,385	690				14,327	
7.	COMMUNICATION EQUIPMENT	3,949	11,197	14,456	13,752					43,354	Year 5
	Communication Equipment	181	521	1,173	3,178	5,422				10,475	Year 6
	Communication Equipment					254	1,268			1,522	Year 7
	Communication Equipment					54	772	2,512		3,338	Year 8
	Communication Equipment							119	596	715	Year 9
	Sub-total	4,130	11,718	15,629	16,930	5,730	2,040	2,631	596	59,404	
8.	TOOLS AND WORK EQUIPMENT			6,876	34,378					41,254	Year 5
	Tools and Work Equipment			514	3,998	7,119				11,631	Year 6
	Sub-total			7,390	38,376	7,119				52,885	
9.	OFFICE EQUIPMENT		12	133	361					506	Year 5
	Office Equipment		7	40	47	36				130	Year 6
	Sub-total		19	173	408	36				636	
10.	PRE-PERMIT COSTS	216,000								216,000	Year 5
	SUB-TOTAL ITEMS 1-10	1,030,161	1,425,780	1,998,950	1,624,438	689,907	468,058	249,639	9,201	7,496,134	
11.	ALLOWANCE FOR FUNDS USED DURING CONSTRUCTION	88,863	248,308	503,751	440,431	114,152	54,167	43,187	750	1,493,609	
	TOTAL CONSTRUCTION COST	1,119,024	1,674,088	2,502,701	2,064,869	804,059	522,225	292,826	9,951	8,989,743	
	SUMMARY BY IN SERVICE DATE:										
	Year 5	1,061,447	1,556,927	2,225,544	1,110,842					5,954,760	
	Year 6	57,577	117,161	277,157	929,108	587,439				1,968,442	
	Year 7				24,919	181,932	286,847			493,698	
	Year 8					34,688	235,378	290,957		561,023	
	Year 9							1,869	9,951	11,820	
	TOTAL CONSTRUCTION COST	1,119,024	1,674,088	2,502,701	2,064,869	804,059	522,225	292,826	9,951	8,989,743	

CANADIAN ARCTIC GAS PIPELINE LIMITED
SECTION 10 COST OF FACILITIES
SUMMARY OF CONSTRUCTION COSTS
TOTAL FACILITIES

ENGINEERING FORMAT
CALENDAR YEARS
BASE CASE
ESCALATED DATA

COST BASE MARCH 31, 1976

ITEM NO.	DESCRIPTION	COSTS BY CALENDAR YEAR ($ 000)								TOTAL	IN SERVICE
		YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9		
1.	LAND	359	1,794							2,153	Year 5
	Land	73	362							435	Year 6
	Sub-total	432	2,156							2,588	
2.	PIPELINE	512,183	945,624	1,236,849	457,457					3,152,113	Year 5
	Pipeline	11,914	69,134	128,005	438,696	188,520				836,269	Year 6
	Pipeline				638	4,311	5,592			10,541	Year 7
	Pipeline							1,009	5,047	6,056	Year 9
	Sub-total	524,097	1,014,758	1,364,854	896,791	192,831	5,592	1,009	5,047	4,004,979	
3.	COMPRESSOR STATIONS		32,002	193,280	166,357					391,639	Year 5
	Compressor Stations		649	33,067	193,152	220,184				447,052	Year 6
	Compressor Stations				21,016	148,750	218,359			388,125	Year 7
	Compressor Stations					29,760	192,954	220,776		443,490	Year 8
	Sub-total		32,651	226,347	380,525	398,694	411,313	220,776		1,670,306	
4.	ANCILLARY FACILITIES	159,895	195,447	105,865	9,342					470,549	Year 5
	Ancillary Facilities	31,123	15,926	44,125	85,277	7,424				183,875	Year 6
	Ancillary Facilities					616	3,082			3,698	Year 7
	Ancillary Facilities					141	702			843	Year 8
	Sub-total	191,018	211,373	149,990	94,619	8,181	3,784			658,965	
5.	MEASURING STATIONS		1,043	7,584	11,856					20,483	Year 5
	Measuring Stations			493	4,351	9,421				14,265	Year 6
	Sub-total		1,043	8,077	16,207	9,421				34,748	
6.	OPERATIONS AND MAINTENANCE FACILITIES	-	3,949	30,455	53,561					87,965	Year 5
	Operations and Maintenance Facilities		799	5,833	10,807	8,006				25,445	Year 6
	Sub-total		4,748	36,288	64,368	8,006				113,410	
7.	COMMUNICATION FACILITIES	3,616	10,246	13,234	12,587					39,683	Year 5
	Communication Facilities	166	477	1,074	2,910	4,963				9,590	Year 6
	Communication Facilities					232	1,161			1,393	Year 7
	Communication Facilities					49	706	2,299		3,054	Year 8
	Communication Facilities							109	545	654	Year 9
	Sub-total	3,782	10,723	14,308	15,497	5,244	1,867	2,408	545	54,374	
	SUB-TOTAL DIRECT COSTS	719,329	1,277,452	1,799,864	1,468,007	622,377	422,556	224,193	5,592	6,539,370	
8.	PRE-PERMIT COSTS	216,000								216,000	Year 5
9.	OPERATIONS PRIOR TO SERVICE	22,173	23,747	25,477	14,392					85,789	Year 5
	Operations Prior to Service	6,123	6,413	7,120	6,247	8,840				34,743	Year 6
	Operations Prior to Service					525	2,625			3,150	Year 7
	Operations Prior to Service					595	3,791	4,088		8,474	Year 8
	Operations Prior to Service							618	3,092	3,710	Year 9
	Sub-total	28,296	30,160	32,597	20,639	9,960	6,416	4,706	3,092	135,866	
10.	ENGINEERING	40,563	71,407	95,233	42,671					249,874	Year 5
	Engineering	2,597	5,238	12,757	44,112	26,311				91,015	Year 6
	Engineering				1,299	9,234	13,692			24,225	Year 7
	Engineering					1,797	11,663	13,384		26,844	Year 8
	Engineering							67	335	402	Year 9
	Sub-total	43,160	76,645	107,990	88,082	37,342	25,355	13,451	335	392,360	
11.	CONTINGENCIES	21,971	38,683	51,587	23,114					135,355	Year 5
	Contingencies	1,405	2,840	6,912	23,892	14,252				49,301	Year 6
	Contingencies				704	5,001	7,416			13,121	Year 7
	Contingencies					975	6,315	7,252		14,542	Year 8
	Contingencies							37	182	219	Year 9
	Sub-total	23,376	41,523	58,499	47,710	20,228	13,731	7,289	182	212,538	
	TOTAL COST (1)	1,030,161	1,425,780	1,998,950	1,624,438	689,907	468,058	249,639	9,201	7,496,134	
	SUMMARY BY IN SERVICE DATE:										
	Year 5	976,760	1,323,942	1,759,564	791,337					4,851,603	
	Year 6	53,401	101,838	239,386	809,444	487,921				1,691,990	
	Year 7				23,657	168,669	251,927			444,253	
	Year 8					33,317	216,131	247,799		497,247	
	Year 9							1,840	9,201	11,041	
	TOTAL COST (1)	1,030,161	1,425,780	1,998,950	1,624,438	689,907	468,058	249,639	9,201	7,496,134	
	(1) EXCLUDES ALLOWANCE FOR FUNDS USED DURING CONSTRUCTION										

CANADIAN ARCTIC GAS PIPELINE LIMITED
SECTION 10 COST OF FACILITIES
SUMMARY OF CONSTRUCTION COSTS
TOTAL FACILITIES

ENGINEERING FORMAT
CONSTRUCTION YEARS
BASE CASE
ESCALATED DATA

COST BASE MARCH 31, 1976

ITEM NO	DESCRIPTION	COSTS BY CALENDAR YEAR ($ 000)								TOTAL	IN SERVICE
		YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9		
1.	LAND		2,153							2,153	Year 5
	Land		435							435	Year 6
	Sub-total		2,588							2,588	
2.	PIPELINE	368,872	859,863	1,374,429	548,949					3,152,113	Year 5
	Pipeline		71,486	57,369	481,190	226,224				836,269	Year 6
	Pipeline					3,830	6,711			10,541	Year 7
	Pipeline								6,056	6,056	Year 9
	Sub-total	368,872	931,349	1,431,798	1,030,139	230,054	6,711		6,056	4,004,979	
3.	COMPRESSOR STATIONS			192,010	199,629					391,639	Year 5
	Compressor Stations			3,893	178,938	264,221				447,052	Year 6
	Compressor Stations					126,094	262,031			388,125	Year 7
	Compressor Stations						178,559	264,931		443,490	Year 8
	Sub-total			195,903	378,567	390,315	440,590	264,931		1,670,306	
4.	ANCILLARY FACILITIES	124,965	209,578	124,796	11,210					470,549	Year 5
	Ancillary Facilities	29,033	12,542	32,841	100,550	8,909				183,875	Year 6
	Ancillary Facilities						3,698			3,698	Year 7
	Ancillary Facilities						843			843	Year 8
	Sub-total	153,998	222,120	157,637	111,760	8,909	4,541			658,965	
5.	MEASURING STATIONS			6,256	14,227					20,483	Year 5
	Measuring Stations				2,960	11,305				14,265	Year 6
	Sub-total			6,256	17,187	11,305				34,748	
6.	OPERATIONS AND MAINTENANCE FACILITIES			23,692	64,273					87,965	Year 5
	Operations and Maintenance Facilities			4,791	11,047	9,607				25,445	Year 6
	Sub-total			28,483	75,320	9,607				113,410	
7.	COMMUNICATION FACILITIES	1,995	9,724	12,859	15,105					39,683	Year 5
	Communication Facilities	98	407	829	2,300	5,956				9,590	Year 6
	Communication Facilities						1,393			1,393	Year 7
	Communication Facilities						295	2,759		3,054	Year 8
	Communication Facilities								654	654	Year 9
	Sub-total	2,093	10,131	13,688	17,405	5,956	1,688	2,759	654	54,374	
	SUB-TOTAL DIRECT COSTS	524,963	1,166,188	1,833,765	1,630,378	656,146	453,530	267,690	6,710	6,539,370	
8.	PRE-PERMIT COSTS	216,000								216,000	Year 5
9.	OPERATIONS PRIOR TO SERVICE	18,327	23,073	27,118	17,271					85,789	Year 5
	Operations Prior to Service	5,089	6,202	7,469	5,375	10,608				34,743	Year 6
	Operations Prior to Service						3,150			3,150	Year 7
	Operations Prior to Service						3,568	4,906		8,474	Year 8
	Operations Prior to Service								3,710	3,710	Year 9
	Sub-total	23,416	29,275	34,587	22,646	10,608	6,718	4,906	3,710	135,866	
10.	ENGINEERING	29,749	64,881	104,039	51,205					249,874	Year 5
	Engineering	1,749	5,089	5,984	46,620	31,573				91,015	Year 6
	Engineering					7,795	16,430			24,225	Year 7
	Engineering						10,783	16,061		26,844	Year 8
	Engineering								402	402	Year 9
	Sub-total	31,498	69,970	110,023	97,825	39,368	27,213	16,061	402	392,360	
11.	CONTINGENCIES	16,114	35,144	56,357	27,740					135,355	Year 5
	Contingencies	945	2,759	3,241	25,253	17,103				49,301	Year 6
	Contingencies					4,222	8,899			13,121	Year 7
	Contingencies						5,840	8,702		14,542	Year 8
	Contingencies								219	219	Year 9
	Sub-total	17,059	37,903	59,598	52,993	21,325	14,739	8,702	219	212,538	
	TOTAL COST (1)	812,936	1,303,336	2,037,973	1,803,842	727,447	502,200	297,359	11,041	7,496,134	
	SUMMARY BY IN SERVICE DATE:										
	Year 5	776,022	1,204,416	1,921,556	949,609					4,851,603	
	Year 6	36,914	98,920	116,417	854,233	585,506				1,691,990	
	Year 7					141,941	302,312			444,253	
	Year 8						199,888	297,359		497,247	
	Year 9								11,041	11,041	
	TOTAL COST (1)	812,936	1,303,336	2,037,973	1,803,842	727,447	502,200	297,359	11,041	7,496,134	
	(1) EXCLUDES ALLOWANCE FOR FUNDS USED DURING CONSTRUCTION										

CANADIAN ARCTIC GAS PIPELINE LIMITED

SECTION 10 COST OF FACILITIES

SUMMARY OF CONSTRUCTION COSTS

TOTAL FACILITIES

FINANCIAL FORMAT
CALENDAR YEARS
BASE CASE
UNESCALATED DATA

COST BASE MARCH 31, 1976

ITEM NO	DESCRIPTION	COSTS BY CALENDAR YEAR ($ 000) YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	TOTAL	IN SERVICE
1.	LAND	329	1,637							1,966	Year 5
	Land	67	332							399	Year 6
	Sub-total	396	1,969							2,365	
2.	PIPELINE	652,751	1,042,029	1,119,143	353,494					3,167,417	Year 5
	Pipeline	45,831	82,870	153,370	438,598	136,871				857,540	Year 6
	Pipeline				518	4,020	7,150			11,688	Year 7
	Pipeline					523	3,178	2,807		6,508	Year 8
	Pipeline							975	4,879	5,854	Year 9
	Sub-total	698,582	1,124,899	1,272,513	792,610	141,414	10,328	3,782	4,879	4,049,007	
3.	COMPRESSOR STATIONS		26,152	152,919	110,790					289,861	Year 5
	Compressor Stations		567	26,354	144,965	136,806				308,692	Year 6
	Compressor Stations				15,928	105,883	131,222			253,033	Year 7
	Compressor Stations					21,533	131,722	120,282		273,537	Year 8
	Sub-total		26,719	179,273	271,683	264,222	262,944	120,282		1,125,123	
4.	BUILDINGS AND IMPROVEMENTS		5,258	30,285	19,961					55,504	Year 5
	Buildings and Improvements		654	5,587	14,276	13,423				33,940	Year 6
	Buildings and Improvements				1,075	7,538	10,821			19,434	Year 7
	Buildings and Improvements					1,539	9,704	10,046		21,289	Year 8
	Sub-total		5,912	35,872	35,312	22,500	20,525	10,046		130,167	
5.	MEASURING EQUIPMENT		769	5,314	7,362					13,445	Year 5
	Measuring Equipment			356	2,904	5,622				8,882	Year 6
	Sub-total		769	5,670	10,266	5,622				22,327	
6.	TRANSPORTATION EQUIPMENT			1,328	6,636					7,964	Year 5
	Transportation Equipment			427	2,238	525				3,190	Year 6
	Sub-total			1,755	8,874	525				11,154	
7.	COMMUNICATION EQUIPMENT	3,261	9,082	11,194	10,094					33,631	Year 5
	Communication Equipment	153	421	880	2,252	3,778				7,484	Year 6
	Communication Equipment					171	853			1,024	Year 7
	Communication Equipment					39	505	1,567		2,111	Year 8
	Communication Equipment							70	348	418	Year 9
	Sub-total	3,414	9,503	12,074	12,346	3,988	1,358	1,637	348	44,668	
8.	TOOLS AND WORK EQUIPMENT			5,426	27,123					32,549	Year 5
	Tools and Work Equipment			406	3,116	5,428				8,950	Year 6
	Sub-total			5,832	30,239	5,428				41,499	
9.	OFFICE EQUIPMENT		9	102	272					383	Year 5
	Office Equipment		6	30	34	25				95	Year 6
	Sub-total		15	132	306	25				478	
10.	PRE-PERMIT COSTS	216,000								216,000	Year 5
	SUB-TOTAL ITEMS 1-10	918,392	1,169,786	1,513,121	1,161,636	443,724	295,155	135,747	5,227	5,642,788	

CANADIAN ARCTIC GAS PIPELINE LIMITED
SECTION 10 COST OF FACILITIES
SUMMARY OF CONSTRUCTION COSTS
TOTAL FACILITIES

ENGINEERING FORMAT
CALENDAR YEARS
BASE CASE
UNESCALATED DATA

COST BASE MARCH 31, 1976

ITEM NO.	DESCRIPTION	COSTS BY CALENDAR YEAR ($ 000) YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	TOTAL	IN SERVICE
1.	LAND	300	1,499							1,799	Year 5
	Land	61	303							364	Year 6
	Sub-total	361	1,802							2,163	
2.	PIPELINE	442,545	776,924	923,385	305,935					2,448,789	Year 5
	Pipeline	10,062	58,131	101,484	334,761	114,070				618,508	Year 6
	Pipeline				474	2,938	2,836			6,248	Year 7
	Pipeline							519	2,597	3,116	Year 9
	Sub-total	452,607	835,055	1,024,869	641,170	117,008	2,836	519	2,597	3,076,661	
3.	COMPRESSOR STATIONS		25,594	149,993	110,122					285,709	Year 5
	Compressor Stations		519	25,599	142,315	136,418				304,851	Year 6
	Compressor Stations				15,563	103,818	130,017			249,398	Year 7
	Compressor Stations					21,119	129,452	119,294		269,865	Year 8
	Sub-total		26,113	175,592	268,000	261,355	259,469	119,294		1,109,823	
4.	ANCILLARY FACILITIES	137,417	158,848	82,347	7,453					386,065	Year 5
	Ancillary Facilities	27,047	12,853	33,690	62,333	5,202				141,125	Year 6
	Ancillary Facilities					399	1,992			2,391	Year 7
	Ancillary Facilities					90	450			540	Year 8
	Sub-total	164,464	171,701	116,037	69,786	5,691	2,442			530,121	
5.	MEASURING STATIONS		849	5,739	7,473					14,061	Year 5
	Measuring Stations			386	3,087	5,787				9,260	Year 6
	Sub-total		849	6,125	10,560	5,787				23,321	
6.	OPERATIONS AND MAINTENANCE FACILITIES		3,021	23,099	39,979					66,099	Year 5
	Operations and Maintenance Facilities		603	4,367	7,949	5,925				18,844	Year 6
	Sub-total		3,624	27,466	47,928	5,925				84,943	
7.	COMMUNICATION FACILITIES	2,985	8,314	10,245	9,243					30,787	Year 5
	Communication Facilities	140	386	806	2,063	3,458				6,853	Year 6
	Communication Facilities					156	781			937	Year 7
	Communication Facilities					35	463	1,434		1,932	Year 8
	Communication Facilities							64	319	383	Year 9
	Sub-total	3,125	8,700	11,051	11,306	3,649	1,244	1,498	319	40,892	
	SUB-TOTAL DIRECT COSTS	620,557	1,047,844	1,361,140	1,048,750	399,415	265,991	121,311	2,916	4,867,924	
8.	PRE-PERMIT COSTS	216,000								216,000	Year 5
9.	OPERATIONS PRIOR TO SERVICE	19,141	19,698	20,381	11,117					70,337	Year 5
	Operations Prior to Service	5,287	5,319	5,692	4,773	6,567				27,638	Year 6
	Operations Prior to Service					375	1,875			2,250	Year 7
	Operations Prior to Service					425	2,686	2,807		5,918	Year 8
	Operations Prior to Service							408	2,042	2,450	Year 9
	Sub-total	24,428	25,017	26,073	15,890	7,367	4,561	3,215	2,042	108,593	
10.	ENGINEERING	3,4992	58,500	71,685	28,809					193,986	Year 5
	Engineering	2,241	4,368	9,978	33,146	16,251				65,984	Year 6
	Engineering				962	6,438	8,137			15,537	Year 7
	Engineering					1,275	7,821	7,242		16,338	Year 8
	Engineering							35	175	210	Year 9
	Sub-total	37,233	62,868	81,663	62,917	23,964	15,958	7,277	175	292,055	
11.	CONTINGENCIES	18,961	31,689	38,837	15,601					105,088	Year 5
	Contingencies	1,213	2,368	5,408	17,956	8,800				35,745	Year 6
	Contingencies				522	3,488	4,408			8,418	Year 7
	Contingencies					690	4,237	3,925		8,852	Year 8
	Contingencies							19	94	113	Year 9
	Sub-total	20,174	34,057	44,245	34,079	12,978	8,645	3,944	94	158,216	
	TOTAL COST (1)	918,392	1,169,786	1,513,121	1,161,636	443,724	295,155	135,747	5,227	5,642,788	
	SUMMARY BY IN SERVICE DATE:										
	Year 5	872,341	1,084,936	1,325,711	535,732					3,818,720	
	Year 6	46,051	84,850	187,410	608,383	302,478				1,229,172	
	Year 7				17,521	117,612	150,046			285,179	
	Year 8					23,634	145,109	134,702		303,445	
	Year 9							1,045	5,227	6,272	
	TOTAL COST (1)	918,392	1,169,786	1,513,121	1,161,636	443,724	295,155	135,747	5,227	5,642,788	
	(1) Excludes Allowance for Funds Used During Construction										

CANADIAN ARCTIC GAS PIPELINE LIMITED

SECTION 10 COST OF FACILITIES
SUMMARY OF CONSTRUCTION COSTS
TOTAL FACILITIES

ENGINEERING FORMAT
CONSTRUCTION YEARS
BASE CASE
UNESCALATED DATA

COST BASE MARCH 31, 1976

ITEM NO	DESCRIPTION	COSTS BY CALENDAR YEAR ($ 000) YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	TOTAL	IN SERVICE
1.	LAND		1,799							1,799	Year 5
	Land		364							364	Year 6
	Sub-total		2,163							2,163	
2.	PIPELINE	321,648	725,381	1,034,638	367,122					2,448,789	Year 5
	Pipeline		60,374	46,914	374,336	136,884				618,508	Year 6
	Pipeline					2,845	3,403			6,248	Year 7
	Pipeline								3,116	3,116	Year 9
	Sub-total	321,648	785,755	1,081,552	741,458	139,729	3,403		3,116	3,076,661	
3.	COMPRESSOR STATIONS			153,562	132,147					285,709	Year 5
	Compressor Stations			3,112	138,037	163,702				304,851	Year 6
	Compressor Stations					93,378	156,020			249,398	Year 7
	Compressor Stations						126,712	143,153		269,865	Year 8
	Sub-total			156,674	270,184	257,080	282,732	143,153		1,109,823	
4.	ANCILLARY FACILITIES	108,881	171,213	97,027	8,944					386,065	Year 5
	Ancillary Facilities	25,334	10,280	25,718	73,550	6,243				141,125	Year 6
	Ancillary Facilities						2,391			2,391	Year 7
	Ancillary Facilities						540			540	Year 8
	Sub-Total	134,215	181,493	122,745	82,494	6,243	2,931			530,121	
5.	MEASURING STATIONS			5,093	8,968					14,061	Year 5
	Measuring Stations				2,315	6,945				9,260	Year 6
	Sub-total			5,093	11,283	6,945				23,321	
6.	OPERATIONS AND MAINTENANCE FACILITIES	-		18,124	47,975					66,099	Year 5
	Operations and Maintenance Facilities			3,617	8,117	7,110				18,844	Year 6
	Sub-total			21,741	56,092	7,110				84,943	
7.	COMMUNICATION FACILITIES	1,658	7,962	10,075	11,092					30,787	Year 5
	Communication Facilities	84	335	639	1,645	4,150				6,853	Year 6
	Communication Facilities						937			937	Year 7
	Communication Facilities						211	1,721		1,932	Year 8
	Communication Facilities								383	383	Year 9
	Sub-total	1,742	8,297	10,714	12,737	4,150	1,148	1,721	383	40,892	
	SUB-TOTAL DIRECT COSTS	457,605	977,708	1,398,519	1,174,248	421,257	290,214	144,874	3,499	4,867,924	
8.	PRE-PERMIT COSTS	216,000								216,000	Year 5
9.	OPERATIONS PRIOR TO SERVICE	15,928	19,279	21,789	13,341					70,337	Year 5
	Operations Prior to Service	4,423	5,183	6,000	4,152	7,880				27,638	Year 6
	Operations Prior to Service						2,250			2,250	Year 7
	Operations Prior to Service						2,549	3,369		5,918	Year 8
	Operations Prior to Service								2,450	2,450	Year 9
	Sub-total	20,351	24,462	27,789	17,493	7,880	4,799	3,369	2,450	108,593	
10.	ENGINEERING	25,929	54,378	79,108	34,571					193,986	Year 5
	Engineering	1,527	4,282	4,799	35,875	19,501				65,984	Year 6
	Engineering					5,773	9,764			15,537	Year 7
	Engineering						7,647	8,691		16,338	Year 8
	Engineering								210	210	Year 9
	Sub-total	27,456	58,660	83,907	70,446	25,274	17,411	8,691	210	292,055	
11.	CONTINGENCIES	14,048	29,460	42,853	18,727					105,088	Year 5
	Contingencies	825	2,320	2,601	19,434	10,565				35,745	Year 6
	Contingencies					3,127	5,291			8,418	Year 7
	Contingencies						4,142	4,710		8,852	Year 8
	Contingencies								113	113	Year 9
	Sub-total	14,873	31,780	45,454	38,161	13,692	9,433	4,710	113	158,216	
	TOTAL COST (1)	736,285	1,092,610	1,555,669	1,300,348	468,103	321,857	161,644	6,272	5,642,788	
	SUMMARY BY IN SERVICE DATE:										
	Year 5	704,092	1,009,472	1,462,269	642,887					3,818,720	
	Year 6	32,193	83,138	93,400	657,461	362,980				1,229,172	
	Year 7					105,123	180,056			285,179	
	Year 8						141,801	161,644		303,445	
	Year 9								6,272	6,272	
	TOTAL COST (1)	736,285	1,092,610	1,555,669	1,300,348	468,103	321,857	161,644	6,272	5,642,788	
	(1) Excludes Allowance for Funds Used During Construction										

CANADIAN ARCTIC GAS PIPELINE LIMITED

SECTION 10 COST OF FACILITIES

SUMMARY OF CONSTRUCTION COSTS

TOTAL FACILITIES

FINANCIAL FORMAT
CALENDAR YEARS
NO EXPANSION CASE
ESCALATED DATA

BASE COST MARCH 31, 1976

ITEM NO.	DESCRIPTION	COSTS BY CALENDAR YEAR ($ 000)								TOTAL	IN SERVICE
		YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9		
1.	LAND	393	1,959							2,352	Year 5
	Land	79	395							474	Year 6
	Sub-total	472	2,354							2,826	
2.	PIPELINE	756,418	1,270,369	1,492,391	524,370					4,043,548	Year 5
	Pipeline	53,141	99,339	195,176	578,687	222,910				1,149,253	Year 6
	Sub-total	809,559	1,369,708	1,687,567	1,103,057	222,910				5,192,801	
3.	COMPRESSOR STATIONS		32,521	196,020	167,109					395,650	Year 5
	Compressor Stations		710	33,980	196,299	220,577				451,566	Year 6
	Sub-total		33,231	230,000	363,408	220,577				847,216	
4.	BUILDINGS AND IMPROVEMENTS		6,946	40,958	31,175					79,079	Year 5
	Buildings and Improvements		866	7,500	20,253	21,995				50,614	Year 6
	Sub-total		7,812	48,458	51,428	21,995				129,693	
5.	MEASURING EQUIPMENT		938	7,029	11,696					19,663	Year 5
	Measuring Equipment			452	4,093	9,172				13,717	Year 6
	Sub-total		938	7,481	15,789	9,172				33,380	
6.	TRANSPORTATION EQUIPMENT			1,701	8,496					10,197	Year 5
	Transportation Equipment			551	2,889	690				4,130	Year 6
	Sub-total			2,252	11,385	690				14,327	
7.	COMMUNICATION EQUIPMENT	3,949	11,197	14,456	13,752					43,354	Year 5
	Communication Equipment	181	521	1,173	3,178	5,422				10,475	Year 6
	Sub-total	4,130	11,718	15,629	16,930	5,422				53,829	
8.	TOOLS AND WORK EQUIPMENT			6,876	34,378					41,254	Year 5
	Tools and Work Equipment			514	3,998	7,119				11,631	Year 6
	Sub-total			7,390	38,376	7,119				52,885	
9.	OFFICE EQUIPMENT		12	133	361					506	Year 5
	Office Equipment		7	40	47	36				130	Year 6
	Sub-total		19	173	408	36				636	
10.	PRE-PERMIT COSTS	216,000								216,000	Year 5
	SUB-TOTAL ITEMS 1-10	1,030,161	1,425,780	1,998,950	1,600,781	487,921				6,543,593	
11.	ALLOWANCE FOR FUNDS USED DURING CONSTRUCTION	88,863	248,308	503,751	440,074	100,845				1,381,841	
	TOTAL CONSTRUCTION COST	1,119,024	1,674,088	2,502,701	2,040,855	588,766				7,925,434	
	SUMMARY BY IN SERVICE DATE:										
	Year 5	1,061,447	1,556,927	2,225,544	1,110,844					5,954,762	
	Year 6	57,577	117,161	277,157	930,011	588,766				1,970,672	
	TOTAL CONSTRUCTION COST	1,119,024	1,674,088	2,502,701	2,040,855	588,766				7,925,434	

CANADIAN ARCTIC GAS PIPELINE LIMITED

SECTION 10 COST OF FACILITIES

SUMMARY OF CONSTRUCTION COSTS

TOTAL FACILITIES

ENGINEERING FORMAT
CALENDAR YEARS
NO EXPANSION CASE
ESCALATED DATA

COST BASE MARCH 31, 1976

ITEM NO.	DESCRIPTION	COSTS BY CALENDAR YEAR ($ 000)								TOTAL	IN SERVICE
		YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9		
1.	LAND										
	Land	359	1,794							2,153	Year 5
		73	362							435	Year 6
	Sub-total	432	2,156							2,588	
2.	PIPELINE										
	Pipeline	512,183	945,624	1,236,849	457,457					3,152,113	Year 5
		11,914	69,134	128,005	438,696	188,520				836,269	Year 6
	Sub-total	524,097	1,014,758	1,364,854	896,153	188,520				3,988,382	
3.	COMPRESSOR STATIONS										
	Compressor Stations		32,002	193,280	166,357					391,639	Year 5
			649	33,067	193,152	220,184				447,052	Year 6
	Sub-total		32,651	226,347	359,509	220,184				838,691	
4.	ANCILLARY FACILITIES										
	Ancillary Facilities	159,895	195,447	105,865	9,342					470,549	Year 5
		31,123	15,926	44,125	85,277	7,424				183,875	Year 6
	Sub-total	191,018	211,373	149,990	94,619	7,424				654,424	
5.	MEASURING STATIONS										
	Measuring Stations		1,043	7,584	11,856					20,483	Year 5
				493	4,351	9,421				14,265	Year 6
	Sub-total		1,043	8,077	16,207	9,421				34,748	
6.	OPERATIONS AND MAINTENANCE FACILITIES										
	Operations and Maintenance Facilities		3,949	30,455	53,561					87,965	Year 5
			799	5,833	10,807	8,006				25,445	Year 6
	Sub-total		4,748	36,288	64,368	8,006				113,410	
7.	COMMUNICATION FACILITIES										
	Communication Facilities	3,616	10,246	13,234	12,587					39,683	Year 5
		166	477	1,074	2,910	4,963				9,590	Year 6
	Sub-total	3,782	10,723	14,308	15,497	4,963				49,273	
	SUB-TOTAL DIRECT COSTS	719,329	1,277,452	1,799,864	1,446,353	438,518				5,681,516	
8.	PRE-PERMIT COSTS	216,000								216,000	Year 5
9.	OPERATIONS PRIOR TO SERVICE										
	Operations Prior to Service	22,173	23,747	25,477	14,392					85,789	Year 5
		6,123	6,413	7,120	6,247	8,840				34,743	Year 6
	Sub-total	28,296	30,160	32,597	20,639	8,840				120,532	
10.	ENGINEERING										
	Engineering	40,563	71,407	95,233	42,671					249,874	Year 5
		2,597	5,238	12,757	44,112	26,311				91,015	Year 6
	Sub-total	43,160	76,645	107,990	86,783	26,311				340,889	
11.	CONTINGENCIES										
	Contingencies	21,971	38,683	51,587	23,114					135,355	Year 5
		1,405	2,840	6,912	23,892	14,252				49,301	Year 6
	Sub-total	23,376	41,523	58,499	47,006	14,252				184,656	
	TOTAL COST (1)	1,031,161	1,425,780	1,998,950	1,600,781	487,921				6,543,593	
	SUMMARY BY IN SERVICE DATE:										
	Year 5	976,760	1,323,942	1,759,564	791,337					4,851,603	
	Year 6	53,401	101,838	239,386	809,444	487,921				1,691,990	
	TOTAL COST (1)	1,030,161	1,425,780	1,998,950	1,600,781	487,921				6,543,593	
	(1) EXCLUDES ALLOWANCE FOR FUNDS USED DURING CONSTRUCTION										

CANADIAN ARCTIC GAS PIPELINE LIMITED

SECTION 10 COST OF FACILITIES

SUMMARY OF CONSTRUCTION COSTS

TOTAL FACILITIES

ENGINEERING FORMAT
CONSTRUCTION YEARS
NO EXPANSION CASE
ESCALATED DATA

COST BASE MARCH 31, 1976

ITEM NO.	DESCRIPTION	COSTS BY CALENDAR YEAR ($ 000)								TOTAL	IN SERVICE
		YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9		
1.	LAND		2,153							2,153	Year 5
	Land		435							435	Year 6
	Sub-total		2,588							2,588	
2.	PIPELINE	368,872	859,863	1,374,429	548,949					3,152,113	Year 5
	Pipeline		71,486	57,369	481,190	226,224				836,269	Year 6
	Sub-total	368,872	931,349	1,431,798	1,030,139	226,224				3,988,382	
3.	COMPRESSOR STATIONS			192,010	199,629					391,639	Year 5
	Compressor Stations			3,893	178,938	264,221				447,052	Year 6
	Sub-total			195,903	378,567	264,221				838,691	
4.	ANCILLARY FACILITIES	124,965	209,578	124,796	11,210					470,549	Year 5
	Ancillary Facilities	29,033	12,542	32,841	100,550	8,909				183,875	Year 6
	Sub-total	153,998	222,120	157,637	111,760	8,909				654,424	
5.	MEASURING STATIONS			6,256	14,227					20,483	Year 5
	Measuring Stations				2,960	11,305				14,265	Year 6
	Sub-total			6,256	17,187	11,305				34,748	
6.	OPERATIONS AND MAINTENANCE FACILITIES			23,692	64,273					87,965	Year 5
	Operations and Maintenance Facilities			4,791	11,047	9,607				25,445	Year 6
	Sub-total			28,483	75,320	9,607				113,410	
7.	COMMUNICATION FACILITIES	1,995	9,724	12,859	15,105					39,683	Year 5
	Communication Facilities	98	407	829	2,300	5,956				9,590	Year 6
	Sub-total	2,093	10,131	13,688	17,405	5,956				49,273	
	SUB-TOTAL DIRECT COSTS	524,963	1,166,188	1,833,765	1,630,378	526,222				5,681,516	
8.	PRE-PERMIT COSTS	216,000								216,000	Year 5
9.	OPERATIONS PRIOR TO SERVICE	18,327	23,073	27,118	17,271					85,789	Year 5
	Operations Prior to Service	5,089	6,202	7,469	5,375	10,608				34,743	Year 6
	Sub-total	23,416	29,275	34,587	22,646	10,608				120,532	
10.	ENGINEERING	29,749	64,881	104,039	51,205					249,874	Year 5
	Engineering	1,749	5,089	5,984	46,620	31,573				91,015	Year 6
	Sub-total	31,498	69,970	110,023	97,825	31,573				340,889	
11.	CONTINGENCIES	16,114	35,144	56,357	27,740					135,355	Year 5
	Contingencies	945	2,759	3,241	25,253	17,103				49,301	Year 6
	Sub-total	17,059	37,903	59,598	52,993	17,103				184,656	
	TOTAL COST (1)	812,936	1,303,336	2,037,973	1,803,842	585,506				6,543,593	
	SUMMARY BY IN SERVICE DATE:										
	Year 5	776,022	1,204,416	1,921,556	949,609					4,851,603	
	Year 6	36,914	98,920	116,417	854,233	585,506				1,691,990	
	TOTAL COST (1)	812,936	1,303,336	2,037,973	1,803,842	585,506				6,543,593	

(1) EXCLUDES ALLOWANCE FOR FUNDS USED DURING CONSTRUCTION

CANADIAN ARCTIC GAS PIPELINE LIMITED
SECTION 10 COST OF FACILITIES
SUMMARY OF CONSTRUCTION COSTS
TOTAL FACILITIES

FINANCIAL FORMAT
CALENDAR YEARS
NO EXPANSION CASE
UNESCALATED DATA

COST BASE MARCH 31, 1976

ITEM NO.	DESCRIPTION	COSTS BY CALENDAR YEAR ($ 000)								TOTAL	IN SERVICE
		YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9		
1.	LAND	329	1,637							1,966	Year 5
	Land	67	332							399	Year 6
	Sub-total	396	1,969							2,365	
2.	PIPELINE	652,751	1,042,029	1,119,143	353,494					3,167,417	Year 5
	Pipeline	45,831	82,870	153,370	438,598	136,871				857,540	Year 6
	Sub-total	698,582	1,124,899	1,272,513	792,092	136,871				4,024,957	
3.	COMPRESSOR STATIONS		26,152	152,919	110,790					289,861	Year 5
	Compressor Stations		567	26,354	144,965	136,806				308,692	Year 6
	Sub-total		26,719	179,273	255,755	136,806				598,553	
4.	BUILDINGS AND IMPROVEMENTS		5,258	30,285	19,961					55,504	Year 5
	Buildings and Improvements		654	5,587	14,276	13,423				33,940	Year 6
	Sub-total		5,912	35,872	34,237	13,423				89,444	
5.	MEASURING EQUIPMENT		769	5,314	7,362					13,445	Year 5
	Measuring Equipment			356	2,904	5,622				8,882	Year 6
	Sub-total		769	5,670	10,266	5,622				22,327	
6.	TRANSPORTATION EQUIPMENT			1,328	6,636					7,964	Year 5
	Transportation Equipment			427	2,238	525				3,190	Year 6
	Sub-total			1,755	8,874	525				11,154	
7.	COMMUNICATION EQUIPMENT	3,261	9,082	11,194	10,094					33,631	Year 5
	Communication Equipment	153	421	880	2,252	3,778				7,484	Year 6
	Sub-total	3,414	9,503	12,074	12,346	3,778				41,115	
8.	TOOLS AND WORK EQUIPMENT			5,426	27,123					32,549	Year 5
	Tools and Work Equipment			406	3,116	5,428				8,950	Year 6
	Sub-total			5,832	30,239	5,428				41,499	
9.	OFFICE EQUIPMENT		9	102	272					383	Year 5
	Office Equipment		6	30	34	25				95	Year 6
	Sub-total		15	132	306	25				478	
10.	PRE-PERMIT COSTS	216,000								216,000	Year 5
	SUB-TOTAL ITEMS 1-10	918,392	1,169,786	1,513,121	1,144,115	302,478				5,047,892	

CANADIAN ARCTIC GAS PIPELINE LIMITED
SECTION 10 COST OF FACILITIES
SUMMARY OF CONSTRUCTION COSTS
TOTAL FACILITIES

ENGINEERING FORMAT
CALENDAR YEARS
NO EXPANSION CASE
UNESCALATED DATA

COST BASE MARCH 31, 1976

ITEM NO.	DESCRIPTION	COSTS BY CALENDAR YEAR ($ 000)								TOTAL	IN SERVICE
		YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9		
1.	LAND	300	1,499							1,799	Year 5
	Land	61	303							364	Year 6
	Sub-total	361	1,802							2,163	
2.	PIPELINE	442,545	776,924	923,385	305,935					2,448,789	Year 5
	Pipeline	10,062	58,131	101,484	334,761	114,070				618,508	Year 6
	Sub-total	452,607	835,055	1,024,869	640,696	114,070				3,067,297	
3.	COMPRESSOR STATIONS		25,594	149,993	110,122					285,709	Year 5
	Compressor Stations		519	25,599	142,315	136,418				304,851	Year 6
	Sub-total		26,113	175,592	252,437	136,418				590,560	
4.	ANCILLARY FACILITIES	137,417	158,848	82,347	7,453					386,065	Year 5
	Ancillary Facilities	27,047	12,853	33,690	62,333	5,202				141,125	Year 6
	Sub-total	164,464	171,701	116,037	69,786	5,202				527,190	
5.	MEASURING STATIONS		849	5,739	7,473					14,061	Year 5
	Measuring Stations			386	3,087	5,787				9,260	Year 6
	Sub-total		849	6,125	10,560	5,787				23,321	
6.	OPERATIONS AND MAINTENANCE FACILITIES		3,021	23,099	39,979					66,099	Year 5
	Operations and Maintenance Facilities		603	4,367	7,949	5,925				18,844	Year 6
	Sub-total		3,624	27,466	47,928	5,925				84,943	
7.	COMMUNICATION FACILITIES	2,985	8,314	10,245	9,243					30,787	Year 5
	Communication Facilities	140	386	806	2,063	3,458				6,853	Year 6
	Sub-total	3,125	8,700	11,051	11,306	3,458				37,640	
	SUB-TOTAL DIRECT COSTS	620,557	1,047,844	1,361,140	1,032,713	270,860				4,333,114	
8.	PRE-PERMIT COSTS	216,000								216,000	Year 5
9.	OPERATIONS PRIOR TO SERVICE	19,141	19,698	20,381	11,117					70,337	Year 5
	Operations Prior to Service	5,287	5,319	5,692	4,773	6,567				27,638	Year 6
	Sub-total	24,428	25,017	26,073	15,890	6,567				97,975	
10.	ENGINEERING	34,992	58,500	71,685	28,809					193,986	Year 5
	Engineering	2,241	4,368	9,978	33,146	16,251				65,984	Year 6
	Sub-total	37,233	62,868	81,663	61,955	16,251				259,970	
11.	CONTINGENCIES	18,961	31,689	38,837	15,601					105,088	Year 5
	Contingencies	1,213	2,368	5,408	17,956	8,800				35,745	Year 6
	Sub-total	20,174	34,057	44,245	33,557	8,800				140,833	
	TOTAL COST (1)	918,392	1,169,786	1,513,121	1,144,115	302,478				5,047,892	
	SUMMARY BY IN SERVICE DATE:										
	Year 5	872,341	1,084,936	1,325,711	535,732					3,818,720	
	Year 6	46,051	84,850	187,410	608,383	302,478				1,229,172	
	TOTAL COST (1)	918,392	1,169,786	1,513,121	1,144,115	302,478				5,047,892	
	(1) EXLUDES ALLOWANCE FOR FUNDS USED DURING CONSTRUCTION										

CANADIAN ARCTIC GAS PIPELINE LIMITED

SECTION 10 COST OF FACILITIES
SUMMARY OF CONSTRUCTION COSTS
TOTAL FACILITIES

ENGINEERING FORMAT
CONSTRUCTION YEARS
NO EXPANSION CASE
UNESCALATED DATA

COST BASE MARCH 31, 1976

ITEM NO	DESCRIPTION	COSTS BY CALENDAR YEAR ($ 000)								TOTAL	IN SERVICE
		YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9		
1.	LAND		1,799							1,799	Year 5
	Land		364							364	Year 6
	Sub-total		2,163							2,163	
2.	PIPELINE	321,648	725,381	1,034,638	367,122					2,448,789	Year 5
	Pipeline		60,374	46,914	374,336	136,884				618,508	Year 6
	Sub-total	321,648	785,755	1,081,552	741,458	136,884				3,067,297	
3.	COMPRESSOR STATIONS			153,562	132,147					285,709	Year 5
	Compressor Stations			3,112	138,037	163,702				304,851	Year 6
	Sub-total			156,674	270,184	163,702				590,560	
4.	ANCILLARY FACILITIES	108,881	171,213	97,027	8,944					386,065	Year 5
	Ancillary Facilities	25,334	10,280	25,718	73,550	6,243				141,125	Year 6
	Sub-total	134,215	181,493	122,745	82,494	6,243				527,190	
5.	MEASURING STATIONS			5,093	8,968					14,061	Year 5
	Measuring Stations				2,315	6,945				9,260	Year 6
	Sub-total			5,093	11,283	6,945				23,321	
6.	OPERATIONS AND MAINTENANCE FACILITIES			18,124	47,975					66,099	Year 5
	Operations and Maintenance Facilities			3,617	8,117	7,110				18,844	Year 6
	Sub-total			21,741	56,092	7,110				84,943	
7.	COMMUNICATION FACILITIES	1,658	7,962	10,075	11,092					30,787	Year 5
	Communication Facilities	84	335	639	1,645	4,150				6,853	Year 6
	Sub-total	1,742	8,297	10,714	12,737	4,150				37,640	
	SUB-TOTAL DIRECT COSTS	457,605	977,708	1,398,519	1,174,248	325,034				4,333,114	
8.	PRE-PERMIT COSTS	216,000								216,000	Year 5
9.	OPERATIONS PRIOR TO SERVICE	15,928	19,279	21,789	13,341					70,337	Year 5
	Operations Prior to Service	4,423	5,183	6,000	4,152	7,880				27,638	Year 6
	Sub-total	20,351	24,462	27,789	17,493	7,880				97,975	
10.	ENGINEERING	25,929	54,378	79,108	34,571					193,986	Year 5
	Engineering	1,527	4,282	4,799	35,875	19,501				65,984	Year 6
	Sub-total	27,456	58,660	83,907	70,446	19,501				259,970	
11.	CONTINGENCIES	14,048	29,460	42,853	18,727					105,088	Year 5
	Contingencies	825	2,320	2,601	19,434	10,565				35,745	Year 6
	Sub-total	14,873	31,780	45,454	38,161	10,565				140,833	
	TOTAL COST (1)	736,285	1,092,610	1,555,669	1,300,348	362,980				5,047,892	
	SUMMARY BY IN SERVICE DATE:										
	Year 5	704,092	1,009,472	1,462,269	642,887					3,818,720	
	Year 6	32,193	83,138	93,400	657,461	362,980				1,229,172	
	TOTAL COST (1)	736,285	1,092,610	1,555,669	1,300,348	362,980				5,047,892	
	(1) EXCLUDES ALLOWANCE FOR FUNDS USED DURING CONSTRUCTION										

THERMOCASE INSULATED GAS LINE

PRODUCT SPECIFICATION

FOR

CANADIAN ARCTIC GAS

REVISION A

GENERAL ELECTRIC COMPANY

THERMAL SYSTEMS PROGRAMS

January 10, 1977

1.0 GENERAL

This specification covers the manufacture and installation of the General Electric ThermoCase insulation system for transporting gas through the Canadian Arctic.

The insulation system consists of two distinct ThermoCase concepts: One for frost-susceptible below ground areas and another for frost-susceptible river crossings. The below ground areas are further broken down into regions requiring high density insulation and those requiring low density insulation.

Each concept consists basically of a double jointed inner transport pipe encased in closed cell rigid polyurethane foam insulation, which is protected by an outer steel jacket providing protection from mechanical damage, moisture, and chemicals (see Figure 1).

The factory insulated casing is transported to the field and welded end-to-end using conventional hand or automatic welding equipment. The exposed joints are covered in the field with pre-molded urethane halves and the outer jacket closed-out by a welded coupling.

The rugged nature of ThermoCase minimizes the precautions usually necessary in stringing, storing, and handling of the completed system. All exposed foam is factory sealed to prevent degradation of the insulation prior to field installation.

Calculated thermal performance for the insulated system is shown below for two cases:

Condition No. 1 - No Heater
15°F Gas Temperature
32°F Jacket Surface Temperature
Heat Loss = 11 Btu/HR/FT

1.0 GENERAL (continued)

Condition No. 2 - With Heaters (Estimated Heat Leak)

15°F Gas Temperature

50°F Average Jacket Surface Temperature

Heat Loss = 28 Btu/HR/FT

2.0 PRODUCT DESCRIPTION

2.1 Below Ground

The below ground system consists of the inner pipe encased in rigid closed-cell polyurethane foam and covered by a protective steel jacket. The foam density will be 2.5 PCF or greater. The jacket thickness may vary from 3/8 to 3/4 inch, depending on field requirements.

Pre-insulated pipe is butt welded at the factory to form double joints. The joining weld is inspected and insulated using pre-molded urethane halves, then closed out with an outer jacket coupling. This same process is used in the field to weld each double joint into the line. Figure 2 shows a completed joint.

The pipe insulation consists of rigid closed cell urethane foam produced in the factory under rigid quality controls. The urethane is foamed-in-place between the carrier pipe and the protective outer jacket (which also functions as a vapor barrier). The foam establishes a natural bond between the carrier pipe and the concentric mounted outer jacket forming an integral structure which minimizes handling problems and mechanical damage.

In addition to the outer jacket which serves as a vapor barrier, all exposed foam at the joint ends is factory sealed using a butyl coating. The coating is sufficiently elastic to withstand anticipated contraction, expansion and distortion under normal field conditions without loss of seal integrity. This seal prevents

2.1 Below Ground (continued)

degradation of the insulation due to exposure to moisture or adverse chemical agents prior to installation and application of the insulation.

The insulated pipe is delivered to the field site with a nominal cut-back for joint welding. Ordinary equipment and procedures are generally acceptable for laying the pre-insulated pipe. Back-filling is handled with the same care provided to any coated line.

The pre-molded urethane halves are made of 2.5 PCF foam and factory sealed with a butyl coating. The halves are taped in the cut-back area after butt welding the inner pipe to provide a continuous insulation giving the joint the same insulating properties as the pre-insulated pipe. This field joining process is fast, efficient, can be accomplished under almost any climatic conditions and requires no special personnel training.

2.2 Below Ground Transitions

Transitioning from insulated below ground pipe to uninsulated pipe is accomplished by a closeout end cap welded to the outer jacket and sealed in the factory to the inner casing, using an elastic (silicone) sealant (see Figure 3).

2.3 River Crossings

River crossing insulated system is the same as the below ground system except for the addition of internal heat traces on the outer jacket as shown in Figure 4. The formed aluminum conduits are installed at the factory prior to the foaming operation. Conduit is placed inside the jacket and sealed to prevent foam separation of the conduit from the jacket. Injected foam forces the conduit into intimate contact with the jacket during the normal foaming process. Retainer rings are used to assure proper alignment and spacing of the conduit.

2.3 River Crossings (continued)

The pre-molded halves for the cut-back area of river crossing insulation fill the cavity to the outer pipe. The cavity above the conduit is left open to allow normal heating of the outer jacket via natural convection.

2.4 River Crossing Transitions

2.4.1 River Crossing to Below Ground

Transitioning from insulated river crossings to normal below ground insulation is accomplished as shown in Figure 5 Heat traces are brought out through the insulated cut-back at the butt joint, a special slotted coupling welded over the cut-back and the cavity where the heat trace exists completely potted to provide a positive seal.

2.4.2 River Crossing to Uninsulated Pipe

Transitioning from river crossing insulation to uninsulated pipe is accomplished as shown in Figure 6. Heat traces are brought out through a factory bonded FRP end cap, potted in place to provide a positive seal.

2.5 Materials

2.5.1 Vapor Barrier

Two-part butyl coating to seal polyurethane foam.

General Physical Properties	Values
Average Solids % by Volume	46%
Dry Time, Touch, Hours	4-8
Minimum Recoat Interval Hours @ 77°F, 50% R.H.	4-8
Maximum Dry Film	15
Thickness per Coat-Mils Theoretical Coverage 50 ft/gal. @ 1 mil	736
Pot LIfe - Hours 77°F	2
100°F	1
125°F	.75
Weight/gal. lbs. 77°F	8.5
K Factor Btu-in/hr Ft^2°F	$\leq$ .64

2.5.1 Vapor Barrier

Dry Film Properties	Values
Tensile Strength PSI	325
Elongation %	475
Water Vapor Transmission Perms @ 20 mil DFT	0.02
Service Temperature °F	-30 to 200
Flame spread, UL 723	

2.5.2 Mylar Tape

Polyester backed tape used to seal heat tracing while foaming. Width 2" - 3":

Properties	Values
Adhesion to Steel	35 oz/in. width
Tensile Strength	
Longitudinal	22 lb/in. width
Transverse	28 lb/in. width
Total Thickness	0.0023 inches
Strength at Break	70%
Water Vapor Transition Rate	Less than 3 gr. H_2O/100 sq.in./24 hrs

2.5.3 Aluminum Retainer Ring (Figure 10)

6063-T6 Material

Ft_u = 35,000 PSI

Ft_y = 31,000 PSI

% Elong. In 2"

1/16" Thickness = 12%

1/2" Thickness = 18%

Fs_u = 22,000 PSI

2.5.4 Aluminum Conduit (Figure 9)

3003 = H14

Ft_u = 22,000 PSI

Ft_y = 21,000 PSI

% Elong = 8% for 1/16" thickness

In 2" =16% for 1/2" thickness

Fs_u = 14,000 PSI

E = 10.0×10^6 PSI

Conforms to QQ-A-250/2 (Standard Aluminum Specification)

2.5.5 Molded Ceramic Fiber - Used for Heat Shields (Figure 8)

Cera-Form by Johns-Manville

Properties	Values
Temperature Limit °F	2100°
Density lb/ft^3	13
Transverse Strength	50 PSI
Lineal Shrink after 2100° Soak %:	
1000°	0.25
1500°	0.3
2000°	2.4
2300°	3.2
Compressive Resistance, PSI	
Pressure Required to Compress:	
5%	1.75
10%	3.25
Conductivity, Btu-ft/hr ft^2 °F, @	
600°F	.49
1000°F	.71
1200°	.84
1400°	.98
1600°	1.13
1800°	1.29
2000°	1.49
Major Constituents	Alumina and Silica

2.5.6 Potting Compound

Two-Part Silicone RTV 619

Uncured Properties	Values
Color	Black
Consistency	Easily Pourable
Viscosity, Poises	90
Shelf Life (months)	6

Cured Properties	Values
Specific Gravity	1.22
Hardness, Shore A	45
Tensile Strength, PSI	925
Elongation, %	125
Tear Resistance, Die B, Lb/in.	25
Brittle Point, degrees F	Below -75
Linear Shrinkage, %	< .2

2.5.6 Potting Compound (continued)

Thermal Properties	Values
Thermal Conductivity Btu-in/hr Ft^2 °F	1.92
@200°F	.16
Coefficient of Thermal Expansion in/in °F (0-350F)	$5x10^{-5}$

Electric Properties	
Dielectric Strength, volts/mil .075"thick	500
Dielectric Constant @ 60 H2	3.0
Dissipation Factor @ 60 H2	.001
Volume Resistivity, OHM-CM	$1x10^{15}$

2.5.7 Urethane Foam Insulation

Insulation used for this ThermoCase system is a rigid closed cell polyurethane foam that can be supplied in any density from 2PCF to 25 PCF. For this application 2.5PCF and 12PCF nominal density foam will be used.

The foam is stable, will not corrode, sustain fungus nor attract rodents or insects. It has a fairly high resistence to most chemicals and solvents, except for some of the chlorinated solvents.

The following minimum physical properties are exhibited by the foam:

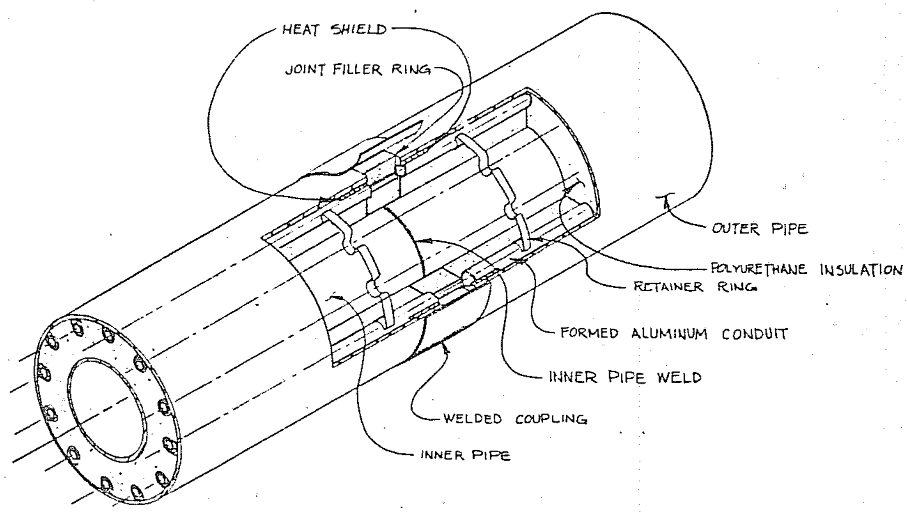
	Type I	Type II
Appearance	Light Tan	Light Tan
Density (min. core) ASTM 1622	2.5 PCF	12.0 PCF
Compressive Strength ASTM 1621 min. parallel to rise	33 PSI	350 PSI
Water Absorption ASTM E96	1.2 PCF	2.2 PCF
Thermal Conductivity (initial ASTM C518 maximum as manufactured (Btu-in/ft^2-hr-°F)	.138	.26
Closed Cell Content ASTM 2856	90%	90%
Dimensional @ -20°F ASTM 2126	1.2%	1.2%
Creep	(see figure 7)	
Shear	28PSI	130PSI
Useful temperature °F	-320° to +225°	-320° to +225°

2.5.8 Elastic Sealant

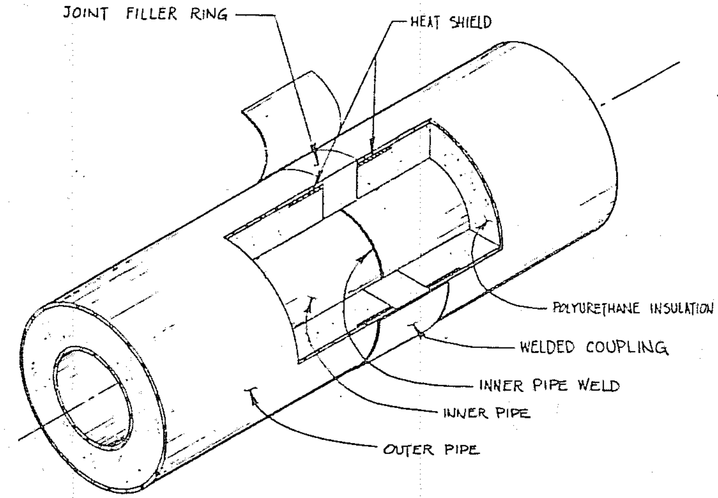
G.E. Selant - 1200

Typical Properties

Property	Value	Test Method
Hardness (Shore A Scale)	35	ASTM D-676-59T
Ultimate tensile strength (at maximum elongation)	400 PSI	ASTM D-412-66T
Peel strength	20 lb/in.	MIL-S-8802C
Staining	None	TT-S-00230 (COM-NBS)
Weathering (after 10,000 hours in Atlas Weatherometer)	No change in hardness or color	
Ozone resistance	Excellent	
Compression set (1/2" thick rod, 1" diameter, under 50% compression for 1 year)	2.6%	
Tear strength (Die B, after 1 year exposure)	35 lb/in.	ASTM D-624-54
Tack-free time	1 hour	
Curing Time	7 to 14 days at 75°F, 1/4" section	
Sag; slump	None	



RIVER CROSSING JOINT



BELOW GROUND JOINT

FIG. 1

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES— TOLERANCES ON
2 PLACE DECIMALS ±
3 PLACE DECIMALS ±
ANGLES ±
FRACTIONS ±
ALL SURF. ✓
MATERIAL—

SIGNATURES
Hutchinson 21 12 76

GENERAL ELECTRIC
GROUND SYSTEMS DEPT LOC TACOMA

THERMOCASE INSULATED GAS LINE

SIZE D | CODE IDENT NO. 16331
SCALE | SHEET

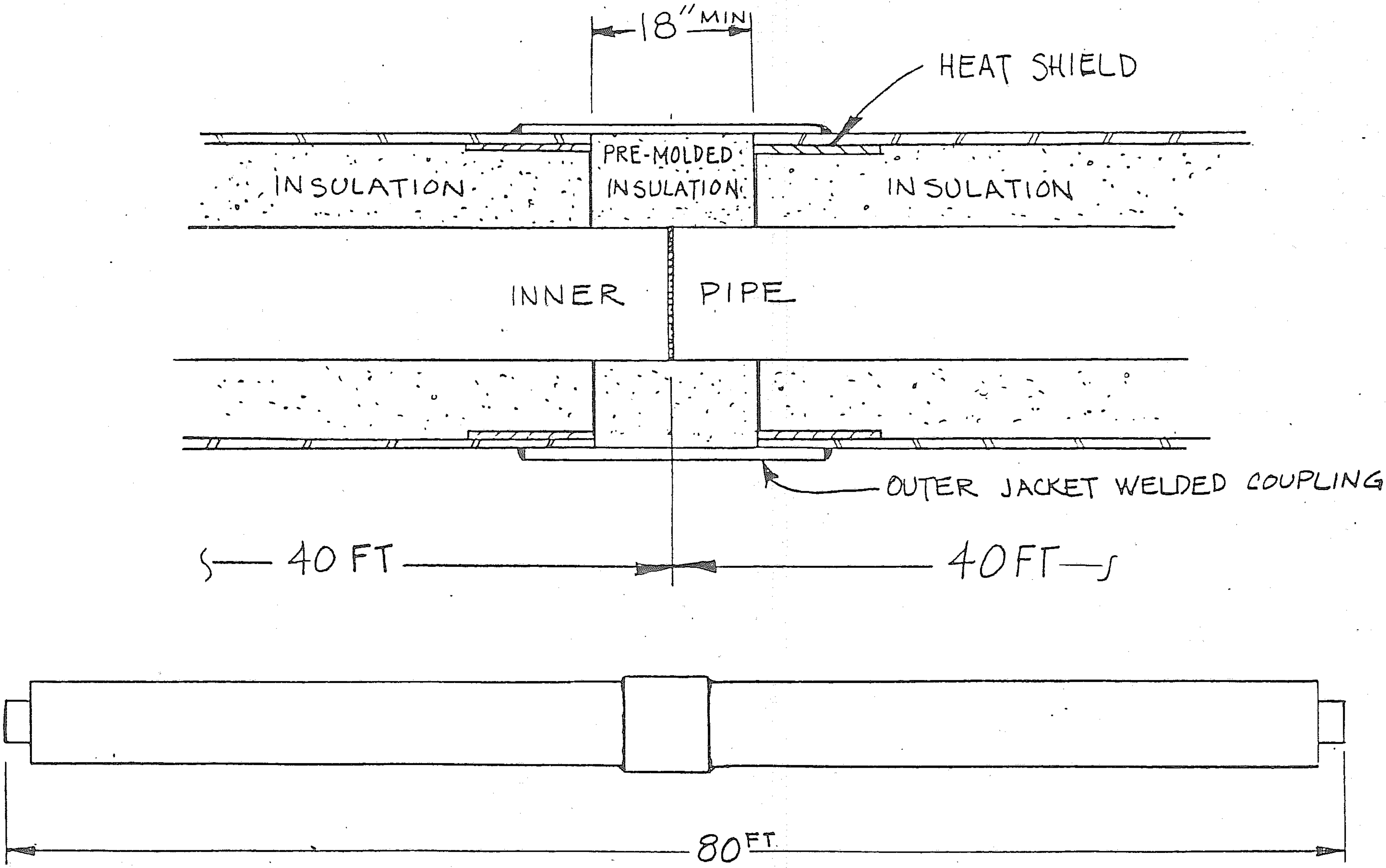


FIG. 2 BELOW GROUND COMPLETED JOINT

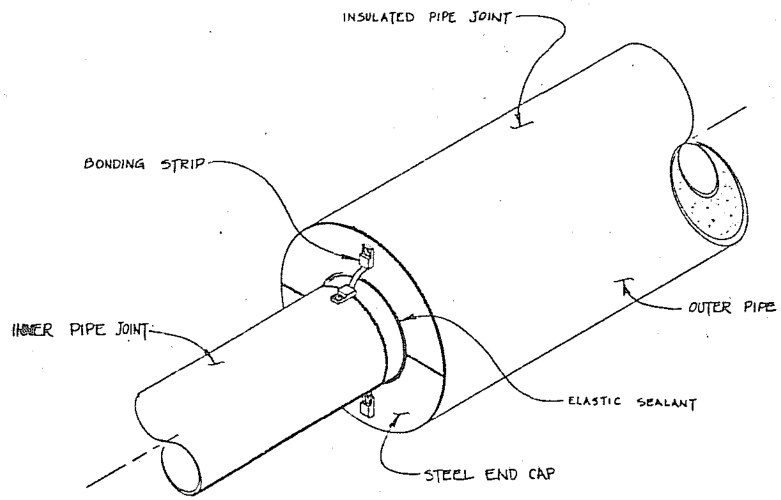


FIG. 3 TRANSITION - INSULATED TO UNINSULATED PIPE
BELOW GROUND JOINT

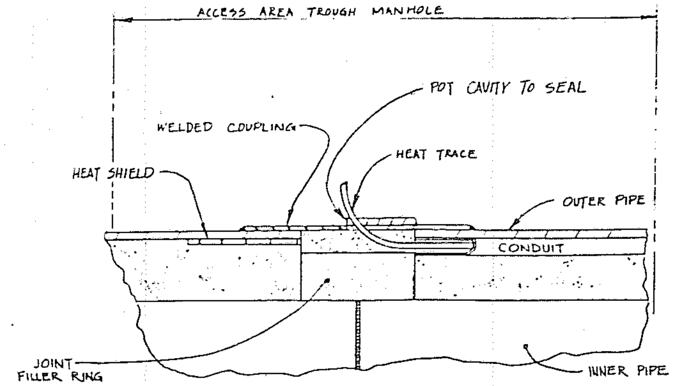


FIG. 5 TRANSITION - RIVER CROSSING TO BELOWGROUND

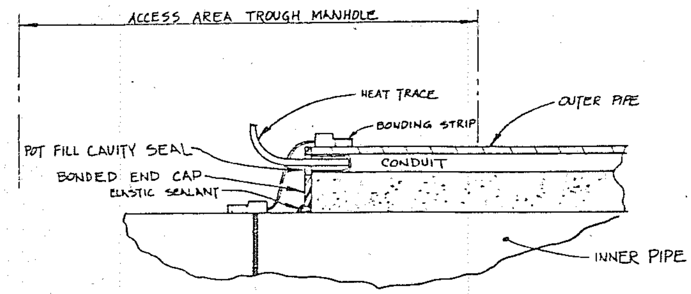


FIG. 6 TRANSITION - RIVER CROSSING TO UNINSULATED PIPE

NOTE:
(TRANSITIONS INCLUDE FACTORY DOUBLE JOINTED PIPE WITH SINGLE JOINT INSULATED TO ALLOW FOR FIELD FITTING TO BARE PIPE.)

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES—
TOLERANCES ON
2 PLACE DECIMALS ±
3 PLACE DECIMALS ±
ANGLES ±
FRACTIONS ±
ALL SURF. ✓
MATERIAL—

SIGNATURES — DRAWN HUTCHINSON 20 12 76

GENERAL ELECTRIC
TACOMA

THERMOCASE
INSULATED GAS LINE

SIZE D | CODE IDENT NO. 16331
SCALE | SHEET

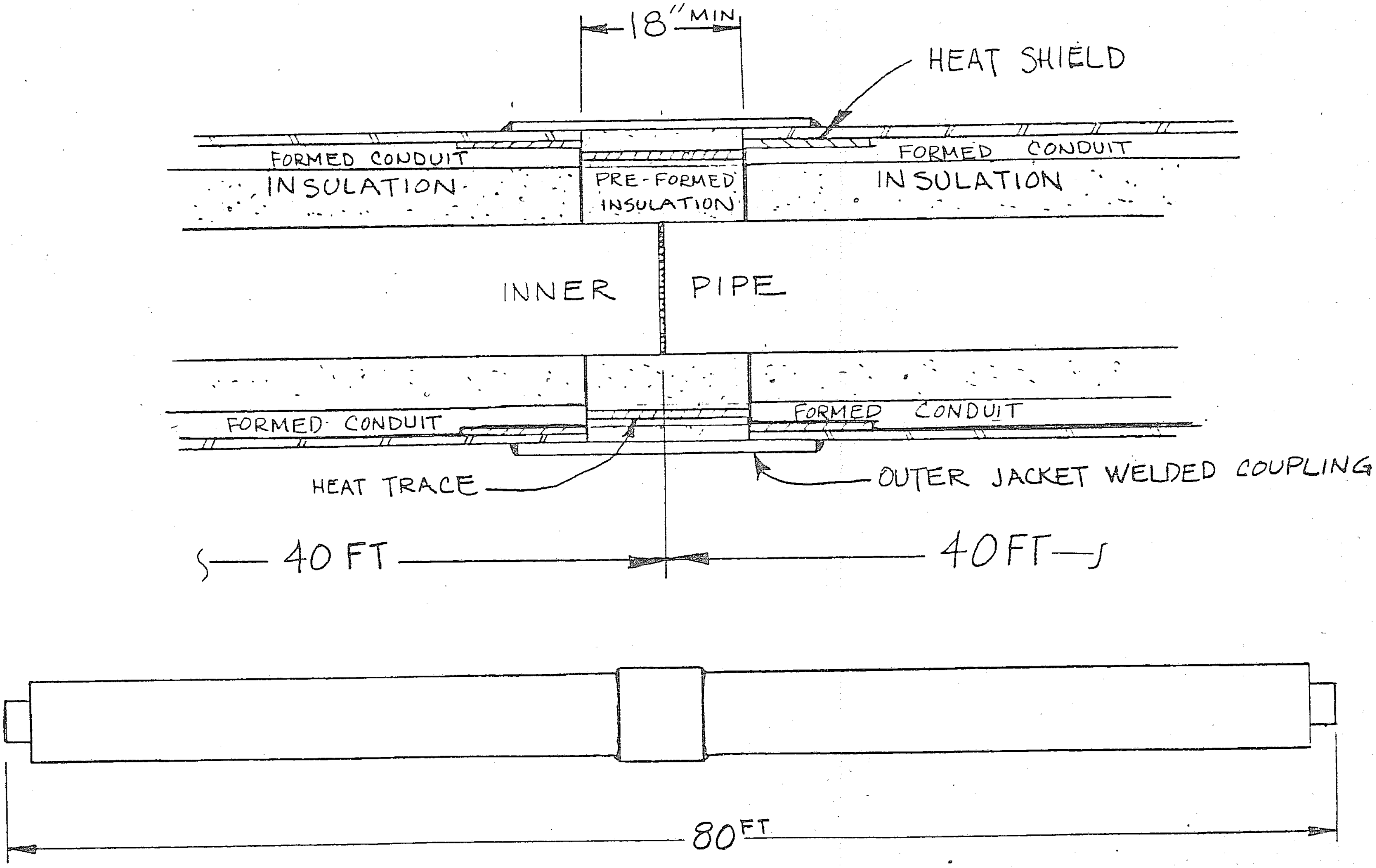
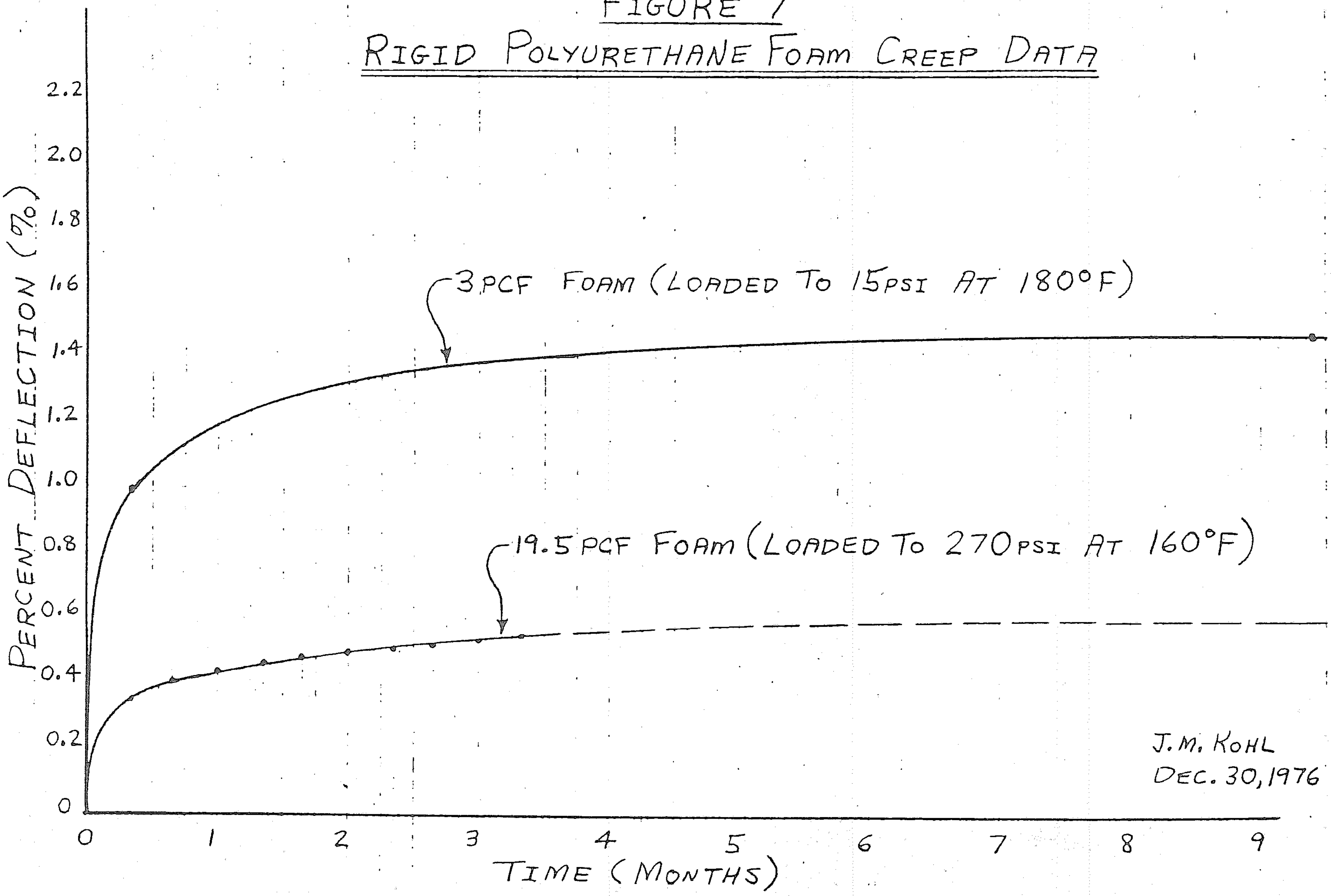


FIG. 4 RIVER CROSSING COMPLETED JOINT

FIGURE 7

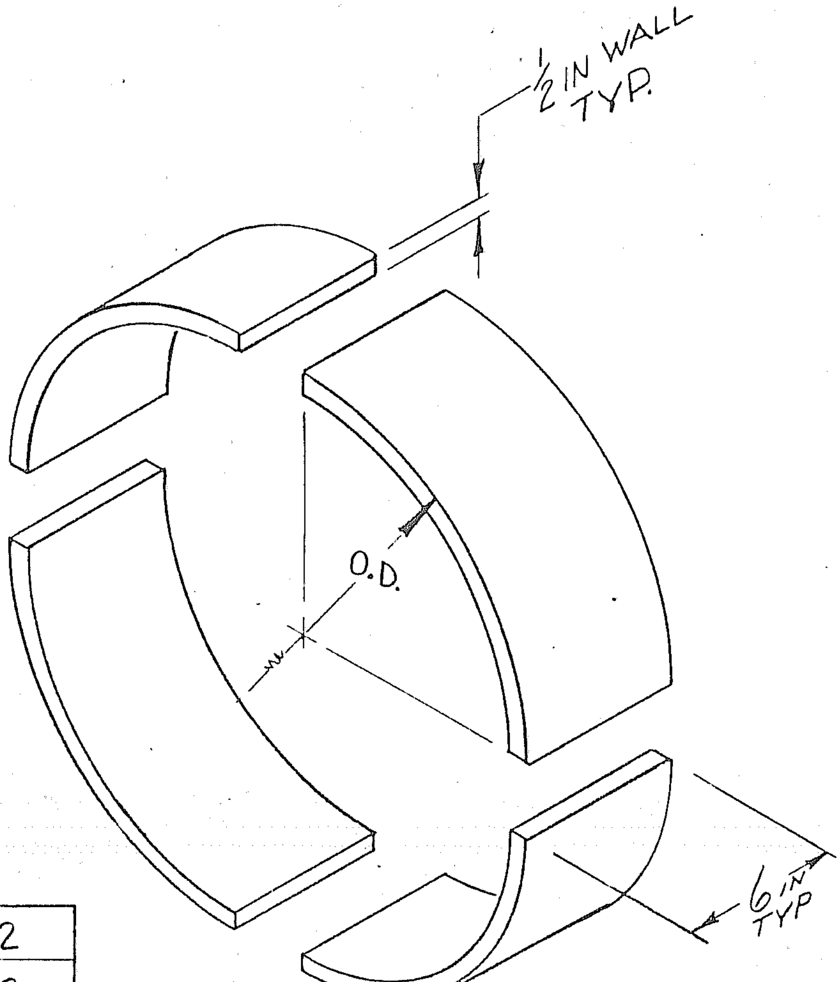
RIGID POLYURETHANE FOAM CREEP DATA



SIZE		SHEET	REV
A			

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED



PART NO.	O.D.	NO. OF SEGMENTS
P4	54 IN.	12
P3	42 IN.	12
P2	54 IN	4
P1	42 IN	4

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON:
FRACTIONS ± DECIMALS ± ANGLES ±

ALL SURFACES ✓

MATL.

SIGNATURES	DAY	MO	YR
DRAWN HUTCHINSON	22	12	76
CHECKED			
ISSUED			
ENGRG			
MFG			
MATLS			

GENERAL ELECTRIC

GROUND SYSTEMS DEPT LOC TACOMA

HEAT SHIELDS

SIZE	CODE IDENT NO.	
A	16331	FIG. 8
SCALE		SHEET

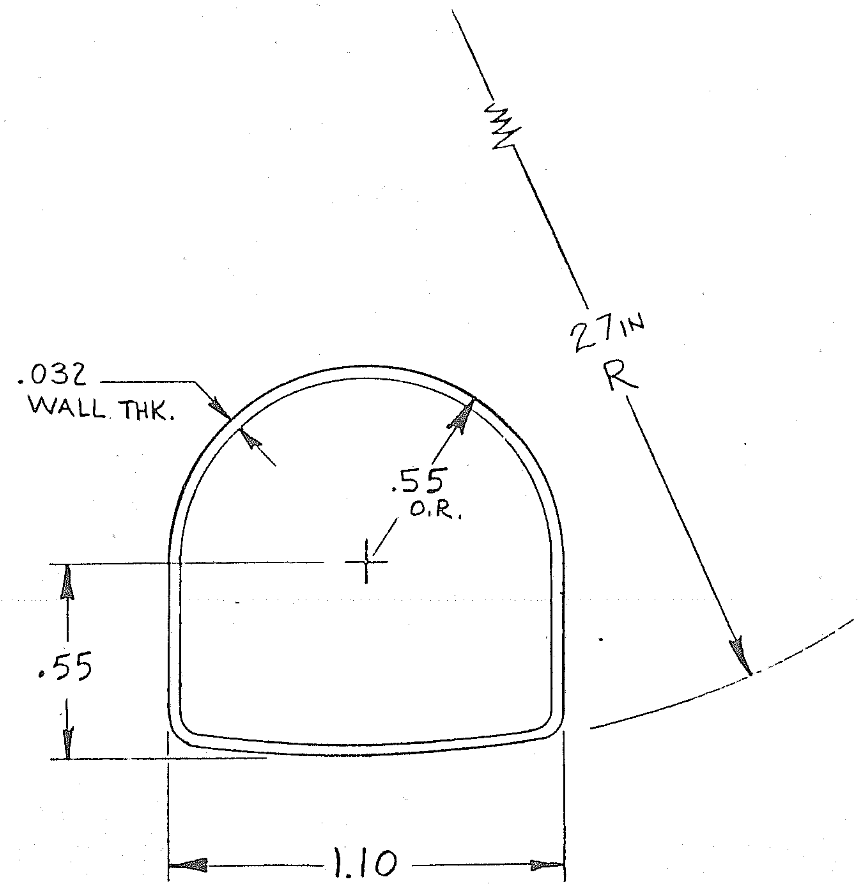
DIST TO

FN 901P (11-74) PRINTED IN U.S.A.

SIZE		SHEET	RLV
A			

REVISIONS

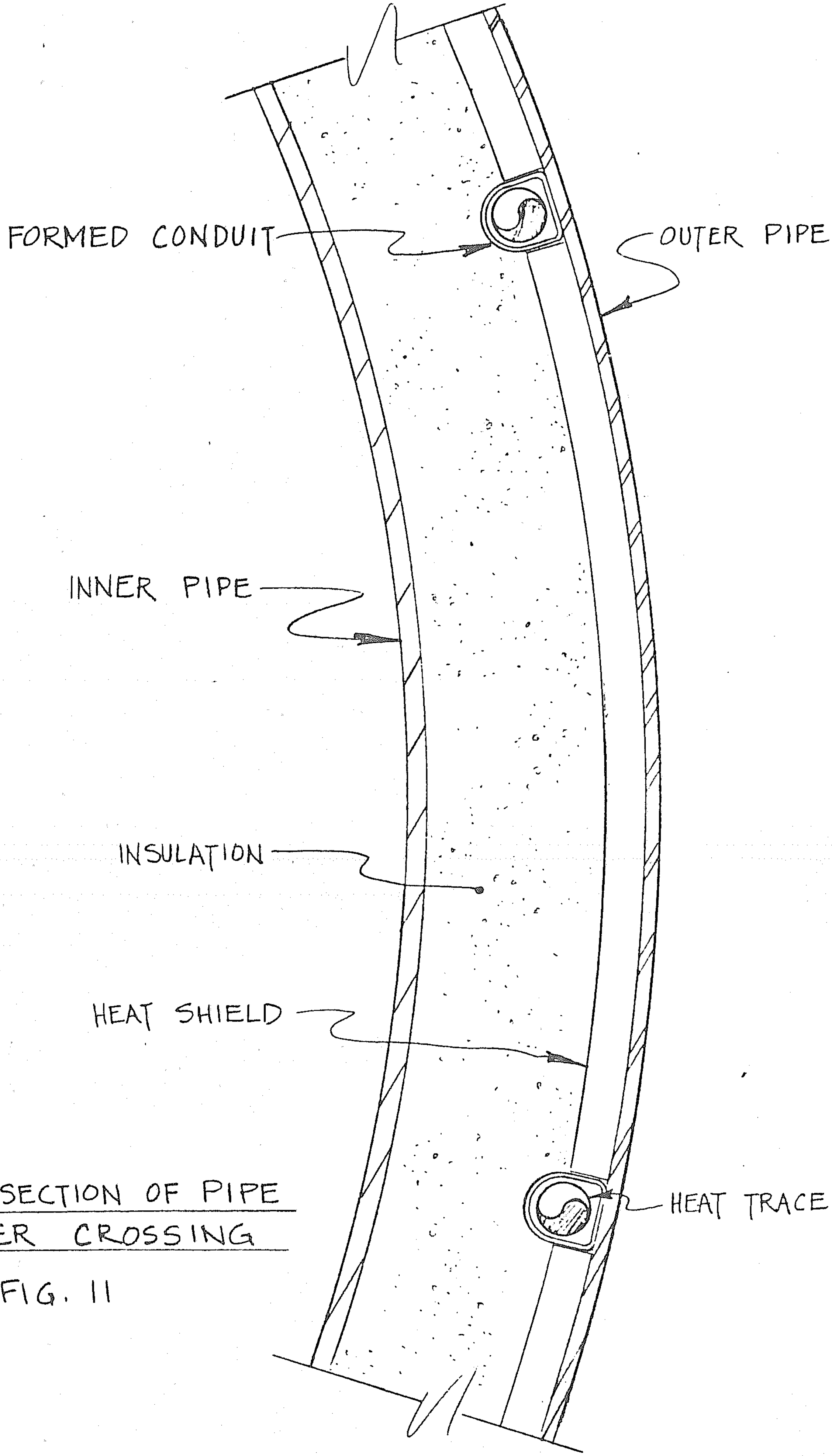
LTR	DESCRIPTION	DATE	APPROVED



FORMED ALUMINUM CONDUIT .032 WALL THICKNESS
IN 20 FT. LENGTHS.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON:	SIGNATURES	DAY	MO	YR	GENERAL ELECTRIC
FRACTIONS ± DECIMALS ± ANGLES ±	DRAWN HUTCHINSON	22	12	76	GROUND SYSTEMS DEPT LOC TACOMA
	CHECKED				FORMED ALUMINUM CONDUIT
	ISSUED				
	ENGRG				
ALL SURFACES ✓	MFG				
MATL.	MATLS				

SIZE	CODE IDENT NO.		
A	16331	FIG. 9	DIST TO
SCALE 2-1		SHEET	

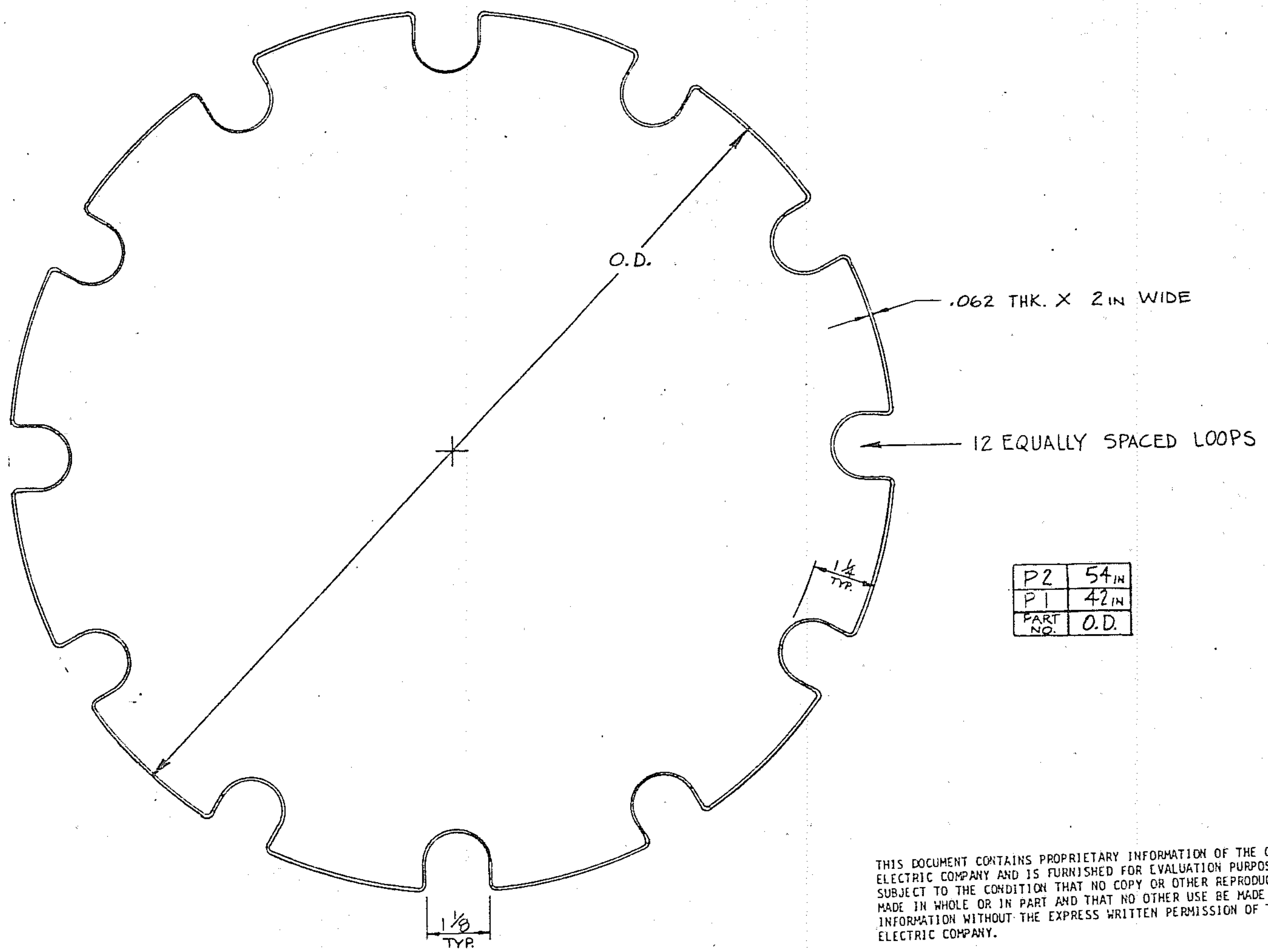


PARTIAL SECTION OF PIPE AT RIVER CROSSING

FIG. 11

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED



PART NO.	O.D.
P1	42 IN
P2	54 IN

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES—
TOLERANCES ON:
2-PLACE DECIMALS ±
3-PLACE DECIMALS ±
ANGLES ±
FRACTIONS ±
ALL SURF. ✓

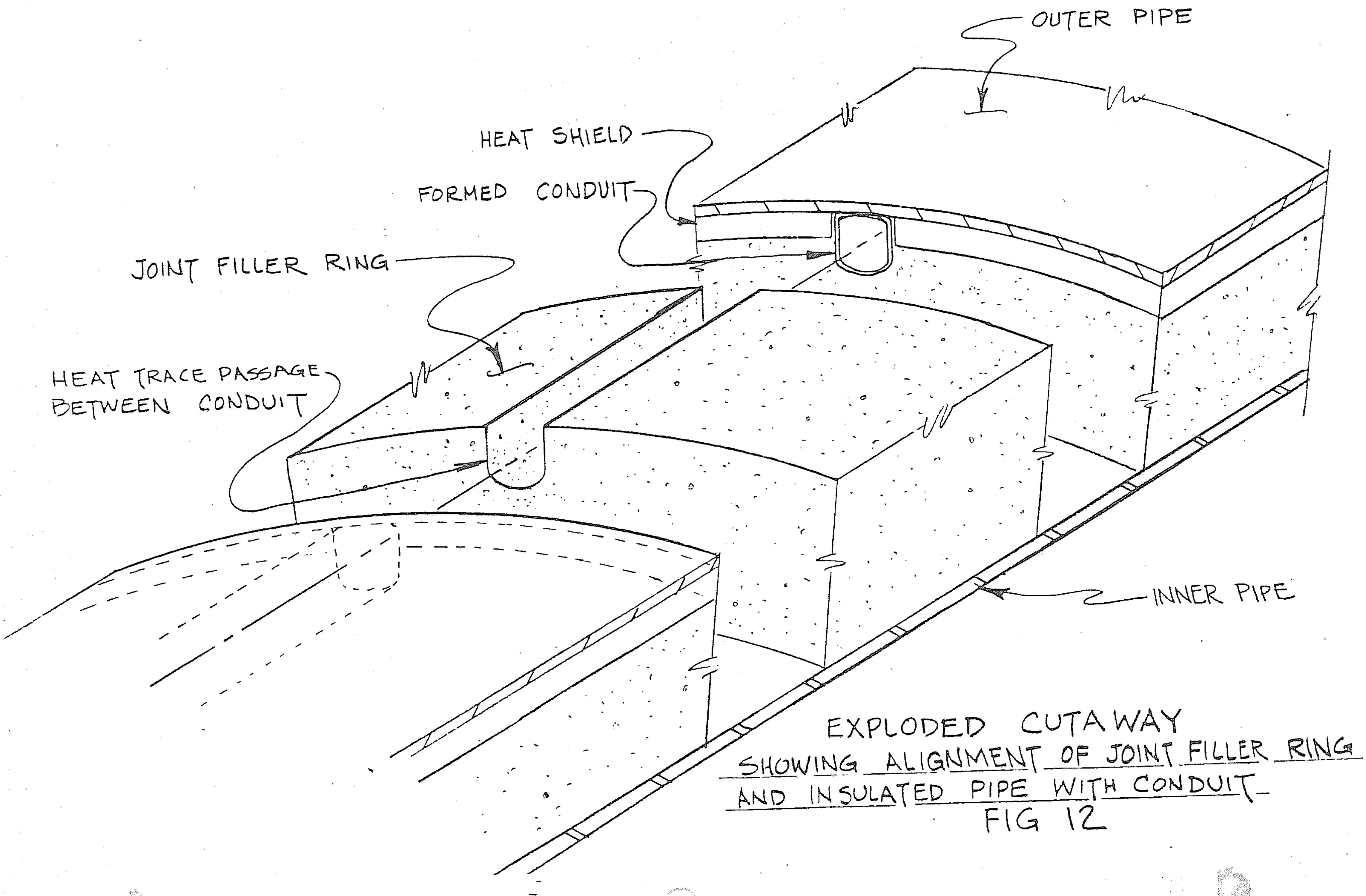
MATERIAL—
6063-T6 OR EQUIVALENT

SIGNATURES	DAY	MO	YR
DRAWN HUTCHINSON	27	12	76
CHECKED			
ISSUED			
ENGRG			
MFG			
MATLS			

GENERAL ELECTRIC
GROUND SYSTEMS DEPT. LOC TACOMA

RETAINING RINGS

SIZE C | CODE IDENT NO. 16331 | FIG. 10
SCALE | SHEET



EXPLODED CUTAWAY
SHOWING ALIGNMENT OF JOINT FILLER RING AND INSULATED PIPE WITH CONDUIT
FIG 12