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GEOTECHNICAL CONSIDERATIONS IN RESPECT TO THE MUSKEG PORTIONS OF A PROPOSED IRON ORE SLURRY PIPELINE ROUTE

by

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Introduction

Canadian Javelin Limited of Montreal has proposed to utilize a slurry pipeline system to transport a total of twelve million tons of iron ore concentrates annually from its two iron deposits in Labrador and New Quebec to pelletizing and shipping facilities in the vicinity of Sept Iles, Quebec (map 1).

The Julian deposit, situated in the Wabush Lake region of Labrador, and the Star-O'Keefe deposit, located southwest of Mount Wright, Quebec, would produce for shipment approximately nine million and three million tons per year respectively. The company anticipates that the properties will be in production almost simultaneously, therefore, the pipeline system would be designed to accommodate, at start up, the ultimate tonnage from each location.

The system, encompassing 282 miles of line, would be constructed in undeveloped areas of Labrador and Quebec and would traverse the Labrador Plateau, and the Laurentide Massif. In addition, due to the necessity of year-round operation, it would be subjected to harsh climatic conditions involving variable depths of snow cover and low temperature extremes in the range of -50° Farenheit.

Background

The technology of solids pipelining is well established in respect to several mineral and forest product commodities. The most notable recently completed solids pipelines are the 65 mile Savage River iron ore line in Tasmania, and the 165 mile Black Mesa coal line in Arizona.

The technique employed in transporting iron ore in a slurry involves grinding the concentrate (65±% Fe) to the consistency of flour, say 98% -200 mesh, and mixing the finely ground material with water to obtain a fluid mixture containing approximately 65% solids by weight. The iron/water slurry is pumped at 1500± p.s.i. through one or more stations, from input to discharge. The slurry is dewatered at the discharge end and the recovered concentrate is combined with a clay binder, pelletizing and indurated in roasting equipment prior to ultimate shipment to the consumer.

The initial studies conducted by Canadian Javelin indicate that three million tons/year would be carried 50 miles from the Star-O'Keefe deposit to a junction point ('U' -- Map 1) in an 8 inch branch line, whereas the nine million tons/year production from the Julian deposit in Labrador would be transported 80± miles to the junction in a 16 inch line. The trunk line, from the junction point on the Labrador Plateau, 150± miles north of the St. Lawrence, to the terminus, would be 18 inches in diameter.

Scope

The preliminary surveys carried out by Canadian Javelin have indicated that the trunk portion of the line would be more or less confined to the Ste. Marguerite River Valley from the St.

Lawrence to the Labrador Plateau. Construction in the narrow and often deeply dissected river valley would undoubtedly provide challenging engineering, soil mechanics and hydrologic problems, but they are beyond the scope of the current study.

This paper does, however, consider some of the geotechnical problems which are likely to be encountered on the Labrador Plateau portion of the line, north of mile 145 (map 1).

Suggestions will be presented which, hopefully, could be utilized during the design and construction phases, to ameliorate these problems.

General Considerations

Undoubtedly, frost is the major environmental factor to be considered. There is no possibility of freezing the slurry moving at 4 m.p.h. and in a 35^{o} - 40^{o} Farenheit temperature range, provided that the system operates continuously. However, in the event of a prolonged unanticipated stoppage due to a power or equipment failure in mid-winter, the contents of the line could freeze, resulting in an inoperative system for as much as 4 or 5 months. In view of this hazard, frost protection measures are a primary design consideration. Accordingly, the line will be buried and will require some form of insulation, but the insulation type, thickness and application methods have not as yet been determined. For the purpose of this paper, however, it is assumed that the contents are adequately protected from freezing.

Economics, slurry pipeline technology and topography constitute primary route selection criteria. Obviously, the line must follow the most direct path from A to B, but topographic conditions and the grade limitations for slurry lines, e.g., 15°, must be accommodated in the selected route. The preliminary right of way has been chosen based on map and air photo interpretation, ground and airborne reconnaissance and personal knowledge of the region, in accordance with the selection criteria. As a consequence of these technical, topographic and economic conditions, the right of way must be confined to relatively low ground, and on the Labrador Plateau in particular, this means poorly drained areas. Consequently, the most significant geotechnical consideration is muskeg.

Regional Muskeg Conditions

Monaghan (1962), in describing muskeg problems encountered during the construction of the Quebec North Shore and Labrador Railway, reports that string bogs and marshes are the predominant muskeg varieties occurring on the Labrador Plateau.

The string bogs, according to Monaghan average four feet in depth and are commonly underlain by granular or silty soils. Monaghan does not describe the ground surface beneath the marshes, but states that they consist of sedge vegetation and open water and that their surfaces are usually underlain by up to 15 feet of water and semi-fluid material.

Construction Methods

Prior to considering the nature of muskeg in relation to pipeline engineering, it is necessary to review the standard northern regions pipeline construction methods.

In areas of extensive muskeg, most of the work is performed during the winter months in order to take advantage of the improved supporting capacity of the frozen 'ground'. According to Keys (1969), the right of way is cleared in the late fall, after the muskeg has frozen sufficiently to support light weight tracked equipment. A road is plowed adjacent to the center line, and the debris and snow are cast onto the ditch (center) line to inhibit deeper frost penetration. Log corduroy is commonly placed in excessively wet or troublesome areas in the road to improve mobility. Ditching with center line straddling trenching equipment is initiated as soon as the 'ground' will support these wide-track units. The ditch depth is predetermined in order to place the top of the pipe below the normal frost penetration line.

Keys (1969) points out that the pipe is welded, wrapped, insulated and placed in the ditch as rapidly as possible in order to prevent extensive freezing of the back fill peat that had been removed from the ditch. Gravel padding, to reduce 'frost heave', and displace inflow water is often placed beneath and around the pipe just prior to and immediately after pipe emplacement. (Anonymous -- International Pipeline Industry Magazine, August 1970).

Keys (1969) states that almost all pipelines are either weighted, or anchored with hold down clamps to counteract peat/water buoyancy effects.

This precaution might not be required for an iron ore slurry line, once it was in operation, but it would be required for an empty line unless it was filled with water prior to start up.

Planning and Reconnaissance

Surficial geology and physiography maps of this particular area are not available, and detailed ground examination of the proposed right of way has not been undertaken by the company.

Because the choice of the pipeline route depends on a thorough knowledge of the terrain conditions, most of this information must be obtained from aerial photography and ground surveys.

Available stereo air photo coverage provides an excellent source of preliminary information, in respect to the location and extent of muskeg areas, variations in topography and the locations and sizes of possible sources of construction materials.

In reference to muskeg studies, Keeling (1961) suggests that air photos should be utilized in conjunction with concurrent ground examination. In this manner, planners are able to correlate the muskeg patterns exhibited in air photos with actual ground conditions. This practice soon results in the development of considerable interpretative skills. Keeling points out that although the Radforth system of classifying muskeg from air photos is very comprehensive, it is also apt to be too complex. Thus he advises users to develop a simple and meaningful classification system to meet their particular requirements.

Once the route has been identified, surface studies should determine the type of peat bogs present and their physical characteristics.

Although winter construction would probably reduce many of the problems associated with pipe laying in muskeg, the line must operate in this medium for a 30 year (write off) period. In order to assure trouble free operation, it is necessary to know, during the design phase, the depth and physical properties of the peats, depth of frost penetration, and the nature of the underlying soils.

The designers must then integrate the physical, climatic and chemical data in relation to three geotechnical considerations, namely; the physical nature of peat, the effects of frost and the possibility of corrosion.

The Physical Nature of Peat

Radforth (1952) developed a peat classification system based on the physical characteristics of the material. This system recognizes three major groups, e.g., amorphous granular, fine fibrous and coarse fibrous, and seventeen sub-groups. Undoubtedly, the personnel involved in the pipeline route survey would be required to develop a local familiarity with, and the ability to recognize only a portion of the peat varieties in Radforth's system. In all likelihood. most of the engineering examinations would only classify the material within the three major groups.

Following identification of the various varieties, the behaviour of the material must be determined.

Undoubtedly, the strength of peat is of paramount importance. If the pipe ditch is not excavated to the underlying mineral soil, peat will have to bear the weight of the loaded pipe. It will be necessary, therefore, to predict the behaviour of the material in respect to its strength, the settlement to be expected under load, and the rate of settlement (Forest and MacFarlane, 1969).

According to Adams (1969) the most significant engineering characteristic of peat is its compressibility, occurring as: (1) an initial and rapid reduction in volume due to compression under load, (2) settlement due to lateral displacement caused by shear strain, and (3) nearly continuous long-term compression of the solid constituents. Adams states that the degree of compressibility is influenced by the type of peat, with fine and coarse fibrous being the most and least compressible, respectively, and its constituents, e.g., organic solids, gas, water and variable amounts of mineral soil. Furtheremore, the varying mixtures of the constituents influence the porosity and permeability; with porosity accounting largely for the degree of primary consolidation, and permeability accounting for the pore water pressure dissipation rate.

Brawner and Tessier (1969) state that the amount of settlement can be predicted through a simple technique which assumes that the settlement is basically primary consolidation and that Darcy's law applies to the permeability of the material. The test procedure amounts to subjecting undisturbed field samples to loads equal to the expected final load and expressing the amount of observed settlement as a percentage of the unloaded thickness. Thus, it is assumed that actual compression will amount to an approximately equal percentage.

In the case of the loaded but unweighted 18 inch slurry line, this would amount to an applied stress in the order of 200 p.s.f.

Lea and Brawner (1963) state that it is difficult to determine settlement rates in field tests due to changes in permeability and coefficients of compressibility and consolidation. Accordingly, they have proposed an empirical equation which assumes direct proportionality between field and laboratory conditions. The equation, which has been applied to some British Columbia peats, is as follows:

$$\frac{T_f}{T_1} = \frac{(H_f)^{1.5}}{(H_1)^{1.5}}$$

in which, T_f = time in field

T_1 = laboratory time

H = the sample thickness at the beginning of the secondary compression phase

As unpredicted, long-term settlement of the supporting material could develop stresses in the line which might result in rupture, predetermination of the settlement and compression characteristics of peat in the proposed right of way is essential. With this information, the designers could anticipate support problem areas and take precautionary measures such as excavating to the mineral soil, preloading, or installing piers or piles wherever required, to support the loaded pipe.

The settlement characteristics of the mineral soil beneath the peat are as important as those of the peat in respect to supporting the loaded pipe. Monaghan (1962) reports that the

QNSL encountered granular, silty and clayey soils underlying bogs. Thus it may be assumed that these materials will be found along the pipeline route. Adams (1969) points out that the underlying soils can be as dangerous as peat in respect to compressibility. Clays are the most troublesome according to Adams, as they are apt to be in a nearly fluid, or very compressible state due to the lack of overburden pressure from the organic material. In other words, they have been subjected to very little preconsolidation. This may not be as much of a problem in the Labrador Plateau, however, as these glacial clays have probably been well preconsolidated. In any event, the settlement characteristics of the underlying material would have to be determined, even if they were not to be immediately beneath the loaded pipe.

Shear stresses could develop in the ditch walls, due to the weight of the pipe laying equipment, and Hardy (1969) describes settlement due to the lateral extrusion of the material beneath a load (e.g., a footing). This is lateral creep which is the result of a compressible soil being subjected to shear stress.

Peat beneath a slurry line would undoubtedly exhibit this behaviour.

In consideration of these two factors it would be necessary to determine the shear strength of the peat at various depths.

According to Hardy (1969), the shear strength varies qualitatively inversely with the water content and directly with the mineral soil content, with in situ shear strengths varying from 100 to 4,000 p.s.f. Hardy adds that there is a general increase in shear strength with depth, and that all published tests indicate shear strengths increasing with increasing consolidation.

Brawner (1969) points out that unconfined triaxial tests on peat in a laboratory have not been particularly successful due to; the difficulty in obtaining representative samples, the difficulty in preparing the samples, and the high strain to failure characteristics of peat. Accordingly, he recommends in situ vane tests to determine shear strengths.

The vane tester consists of two, four or six blades at the base of a shaft which is inserted to various depths in the peat and rotated with a torque wrench. The shear strength can be calculated from the following equation:

$$\tau_f = \frac{3T}{2\pi r^2 (2r + 3H)}$$

in which T is the torque reading and r and H are the shear vane radius and height, respectively.

Forest and MacFarlane (1969) state that peat can be considered to behave in accordance with the principles of effective stress, thus in vane tests the shear strength (τ_f) can be equated to the normal stress (σ) times tan ϕ_u, the apparent angle of internal friction. Thus, "τ_f = tan ϕ_u." This might be more precisely expressed as $\tau = \bar{\sigma} \tan \phi$, if the authors had considered the effects of pore water pressure.

Due to several limiting factors, the field use of a vane tester is far from the most reliable means of determining shear strengths. Although it is the most easily and universally utilized means of determining shear strength in the field, the user should consider the limiting factors when interpreting the test results.

According to Brawner, (1969), the peat variety, vane size, water content, test procedures, and the inter-relationships between these factors influence the test results.

Brawner states that reasonably consistent results are more often obtained in the amorphous granular and non-woody fibrous than in the woody fibrous varieties.

It is also probably safe to assume that the reliability of the results decreases with increasing fibre content due to the flexible nature of the fibres and the drag which they create on the vanes.

MacFarlane (1960) and Tessier (1967) found in tests with various sized vanes in the same material, that the shear strengths appeared to decrease with increasing vane size. This is probably due to greater drag caused by the fibres acting on increased surface areas.

The combined effects of water content and vane size can also vary the results, but Brawner (1969) states that the relationship is confusing. In one study with a two inch vane, the shear strength increased with increasing water content whereas in another study with a four inch vane the shear strength increased with a decreasing water content.

If vane tests are utilized in the pipeline soil studies, it is recommended that uniform and larger size vanes be employed, and that due consideration be given to the limiting factors when the results are interpreted.

In reference to the lateral extrusion of peat beneath a load, i.e., lateral creep, Hardy (1969) states that it may cause partial or complete failure beneath footings.

The material underlying a loaded pipeline could be extruded similarly, resulting in a comparable loss of support.

Hardy (1969) cites the following formula developed by Jumikis (1962) for determining the approximate magnitude of settlement beneath various foundation shapes:

$$\Delta H = C_4 p \frac{(P)}{(A)}$$

in which ΔH = settlement amount

p = contact pressure

P = the perimeter of loaded area

C_4 = a constant coefficient containing the effect of internal friction in the soil and which must be determined by tests on the soil in question

The above equation could be useful if the peat depth required "floating" support pedestals at various locations along the line.

Bulk density, porosity water content and permeability of peat influence its compressibility, shear strength and buoyant effect. Therefore, these properties must be quantified, preferably by means of field tests.

Bulk density, which can range from 0.4 gm/cc to 1.2 gm/cc depending on variations in organic/inorganic content, may be determined most readily from frozen core samples. Brawner (1969) describes the procedure of pouring a cold liquid into a metal jacket surrounding the core tube inserted in the peat. Time is allowed for the sample to freeze, whereupon the core tube is extracted, and the density determined by weighing the known volume of frozen core.

A gamma ray density meter may also be employed to determine bulk density. The radiation emitted by this unit is relfected to the surface in proportion to the density of the peat. A recorder converts the received radiation to an electric signal, read on an appropriately calibrated scale (Brawner, 1969).

Water content, which may average from 700% to 1,000% can be also determined from frozen samples, or by employing a neutron meter, operating on the same principle as the gamma ray density meter (Brawner, 1969).

The field permeability tests described by Brawner (1969) are essentially practical measurers of water inflow rates. The prescribed method is to excavate pits to various depths, pump out the water and record the time required to refill a measured volume.

As permeability varies with the nature of the material and the degree of compression, the above test would be more useful to indicate ditch filling rates, rather than the permeability of the peat under load conditions comparable to a full pipe.

The Frost Factor

It has been assumed that the pipeline will be sufficiently insulated to protect the contents from freezing in the event of a stoppage and to retard the dissipation of heat into the surrounding soil during tis operation. However, the effects of frost on peat, and more particularly on the underlying mineral soil must be considered, because unpredicted heaving and slumping could develop sufficient stresses on the high pressure line to cause failure.

In order to avoid this problem, the designers must determine the expected depth of frost penetration, the physical properties of the subsoil, and the thermal properties of the various types of peat.

The local annual frost depth is, understandably, the primary consideration. The designers could specify burial to 'x' feet, in order to place the line beneath the maximum known depth of frost in the region. A specification of this nature is apt to be costly, because a burial to a prescribed 'x' depth might not be necessary in many areas due to mitigating air and ground micro-climatic conditions and thermal properties of the soil.

Clearly, more precise information would be required in respect to frost penetration depths along the route. Although an educated guess of frost depth may be derived from the Frost Index of the locality, (i.e., the annual cumulative number of hours multiplied by degrees below $0^{o}C$), this figure applies only to air temperature, and can be misleading, because in actuality the depth of frost depends more on the amount of summer heat in the soil, and the retention of this heat, than on the air temperature. The amount of heat present, and its loss or retention are dependent on the type of soil, moisture content, elevation, vegetative cover (e.g., heat reflecting or absorbing), radiation, precipitation, amount of cloud cover and snow cover.

Although the region is shown to lie between 50 and 125 miles north of the 27.5°F annual isotherm (Climatic Atlas of Canada, 1971) very little detailed climatic information is presently available because of the relatively recent development of the area and the fact that the data reported by stations at Schefferville, Wabush, Gagnon and Lake Eon, only cover a period of approximately ten years.

In order to obtain more definitive frost penetration depths along the proposed route, several sites would have to be monitored for a minimum of three years to determine air temperatures, the amount of radiation received, the snow cover and the ground temperature profile. Undoubtedly, monitoring these factors for a short term would provide rather tenuous penetration depth information. Thus a margin of safety would have to be added. But, this procedure could indicate more realistic depths and result in lower ditch excavation costs.

The possibility of encountering discontinuous permafrost along the route should not be discounted. Monaghan (1962) reports the presence of permafrost in the northern portions of the QNSL, and the writer has abserved this material in the Wabush area. Brown (1969) points out that many maps indicate the position of the southern limit of discontinuous permafrost as being in the mid-Labrador area, but that these limits are based more on speculation than on a knowledge of climate and terrain conditions. Brown cites Ives (1962) as postulating that discontinuous permafrost could exist as far south as the Laurentide scarp. Although the mean annual temperature in the study region is 27.5°F, and mean annual ground temperatures tend to average 6° higher than air temperatures, Brown (1969) states that patches of permafrost could exist in high altitude bogs or on north facing slopes between the 25°F and 30°F isotherms. Brown points out that the cloud cover is normally greater in the area between Hudson's Bay and the Atlantic than it is west of Hudson's Bay, thus radiation is reduced and the possibility of permafrost is increased. Furthermore, he adds that because so little is known in respect to permafrost occurrences in this area, one should not overlook the possibility of its presence.

The methods of preserving or removing lenses of permafrost which might be encountered in the proposed pipeline route are not within the scope of this paper. However, the writer believes that the designers of the line should check for this phenomenon in high altitude areas.

Although peat per se is not as subject to heaving, and if it does heave, it is more uniform (Monaghan, 1962), the mineral soils beneath peat, unquestionably cause the greatest problems associated with frost action. Silts, due to their high capillarity and permeability, which facilitates the upward migration of water to the frost line are the most susceptible to heave and slump. The ice in silts causes heaves which are problems in themselves, but the most serious damage can occur when the ice melts, leaving the loaded pipe in a medium with a very limited bearing capacity (Pearn, 1970).

An additional problem is pointed out by Pearn (1970) and Monaghan (1962) who state that transition zones between silty and granular or clayey soils, (especially common in muskeg areas) are subjected to differential rates of heave and slump, due to differences in soil permeability and moisture content, and that these areas are especially hazardous for pipe or railway lines.

In consideration of these problems, it is commonly necessary to place the pipe below the frost line, or to excavate the troublesome soil, and backfill with sufficient granular material to reduce ice formation in the vicinity of the pipe. In many muskeg areas along the pipeline route, suitable granular fill might not be readily available. Therefore, the pipeline would have to be buried well below a 'prescribed' frost line, or alternatively the depth of penetration would have to be reduced by protection from above.

This protection may be achieved easily in muskeg, due to the so called 'insulating,' but in reality frost retarding property of peat. Monaghan (1962) reports only one to two feet of frost in peat adjacent to ten feet of frost in mineral soil subgrade in plowed sections of QNSL track and DeVries (1969) cites Skaven-Haug (1959) as reporting the extensive use of peat as a frost retardant in Norwegian railway subgrades.

The frost retarding effect of peat is attributed to its high water content and and waters' 80 calories per gram latent heat of fusion. Thus, the higher the peat water content, the greater will be the quantity of heat to be removed in order to convert the water from the liquid to solid phase.

Pipelines are able to take the greatest advantage of this property as construction is basically a matter of clearing, ditching, laying the pipe and back filling. Unlike road and railway operations, there is no requirement for subgrade, surface maintenance and snow removal.

In march areas (similar to those described by Monaghan, 1962), where the material beneath the surface layer consists of a mixture of water and organic material with an average depth of 15 feet, underwater pipe laying techniques would probably be employed. Once the bottom contours had been determined, the pipe could be assembled, and weighted on firm ground, drawn into the marsh and allowed to sink to the bottom, well below the danger of frost.

The relative simplicity of winter pipe laying operations in muskeg could lead to problems in preserving the forst retarding capability however. Pearn (1970) warns of over zealous organic soil stripping during the right of way clearing phase. This could compost and consolidate the peat, or disturb it such that it might aerobically decompose. Either of these conditions would reduce the frost retarding character of the material.

In respect to back filling, Markowsky and McMurtrie (1961) caution against the inadvertent mixing of silty subsoil with backfill peat, which would increase the depth of frost penetration. These writers suggest that the problem may be reduced by segregating the peat and mineral soil portions during both excavating and back filling phases.

The utilization of peat's frost inhibiting property could result in construction cost savings through reduced ditch depth requirements; and insulation costs could be lessened or even eliminated in long muskeg crossings. Furthermore, the iron slurry in an uninsulated pipe could possibly extract some heat from the 'warmer' organic soil.

The use of this material might also be considered as frost retarding backfill in mineral soil portions of the line, that is, placed above the padding or pipe, similar to the Norwegian railway practice, but above rather than supporting the load.

Corrosivity

Corrosion of metal and water concrete may occur in peat because most muskeg tends to be acidic due to the presence of CO_2 and humic acid from the anaerobic decay or organic material. MacFarlane (1969) reports that the pH is usually in the range of 4.0 to 7.0, but that extremes of pH 2.0 to 8.0 have been recorded. MacFarlane also states that some peats, notably in marshes, contain alkaline water, and that this also can cause corrosion.

MacFarlane (1969) states further that metal objects in running water, or in areas with frequent changes in water level are subject to more active corrosion than those in relatively still water. Mainland (1962) points out that metal pipes crossing a mineral/organic soil transition or contact are especially prone to corrosion, with annode pitting occurring in the muskeg portion of the pipe. Mainland also adds that stressed portions of the pipe, such as bends, are prime targets for corrosion.

The most effective and universal method of inhibiting pipeline corrosion is to coat or wrap the pipe with a bituminous based substance and in the case of the proposed slurry line, some form of insulation would also be employed. Mainland, however, warns that the wrapping or coating must be as nearly defect free as possible, especially in areas of changing soil types -- in order to reduce the possibility of concentrates corrosion in very small areas.

The corrosivity of soils can be determined, either through resistivity measurements, with corrosivity being inversely proportional to resistivity, or through the use of 'dissimilar metal' probes which provide an order of magnitude indication of soil corrosivity.

Although corrosion should not be a major problem in respect to a properly wrapped pipeline, the possibility of damage does exist. If the proposed line is to operate for 30 years without trouble, then the problem areas should be identified and precautionary measures, such as annodic protection or insured defect free protective wrapping, should be taken.

Conclusions

Canadian Javelin Limited proposes to utilize a 282 mile slurry pipeline system to transport 12 million tons of iron ore concentrates annually from two ore deposits in Labrador and New Quebec to tidewater. The line would cross the Labrador Plateau and the Laurentide Massif enroute from the properties to pelletizing and shipping facilities on the St. Lawrence River near Sept Iles, Quebec.

As the system would have to operate on a year-round basis, in a region with low temperature extremes of -50^{o}F, it will have to be buried and insulated to protect the contents from freezing. The current study examines and comments upon some of the geotechnical conditions which are likely to be encountered in the construction and operation of the Labrador Plateau portion of the line.

The proposed pipeline would have to follow the low ground in this area, thus muskeg terrain would be predominant. This factor would necessitate winter construction. The designers of the line should develop a usable air photo/ground condition system for classifying the peat varieties most likely to be encountered in the right of way. The air photo study would indicate the size of muskeg areas and the location of possible sources of sand and gravel.

The depths of various bogs may require that peat will have to bear the weight of the loaded pipe. Therefore, field comparison tests will have to be undertaken to determine the behaviour of the material under load. With this information the designers may be able to prescribe appropriate measures such as preconsolidating the peat or installing piles to support the line.

Shear strength tests may also be required, but standard vane tests results should be interpreted in view of significant limiting factors.

Soil moisture, porosity, permeability and density tests should also be undertaken as these properties effect the thermal, strength and buoyancy characteristics of peat.

The nature and compressibility of the underlying mineral soils should be determined because compression or failure of this material would ultimately effect the stability of the line.

In order to avoid more or less arbitrarily prescribing depths of pipe burial based on local maximum known depths of frost penetration, the designers of the line should monitor several selected sites for, say three years, to determine the actual depths of frost penetration which is based on soil type, moisture content, radiation, vegetation and depth of snow cover. Considerable savings may be achieved in construction costs by taking advantage of local mitigating microclimate and soil temperatures and conditions, rather than burying the line to 'x' depth throughout the area.

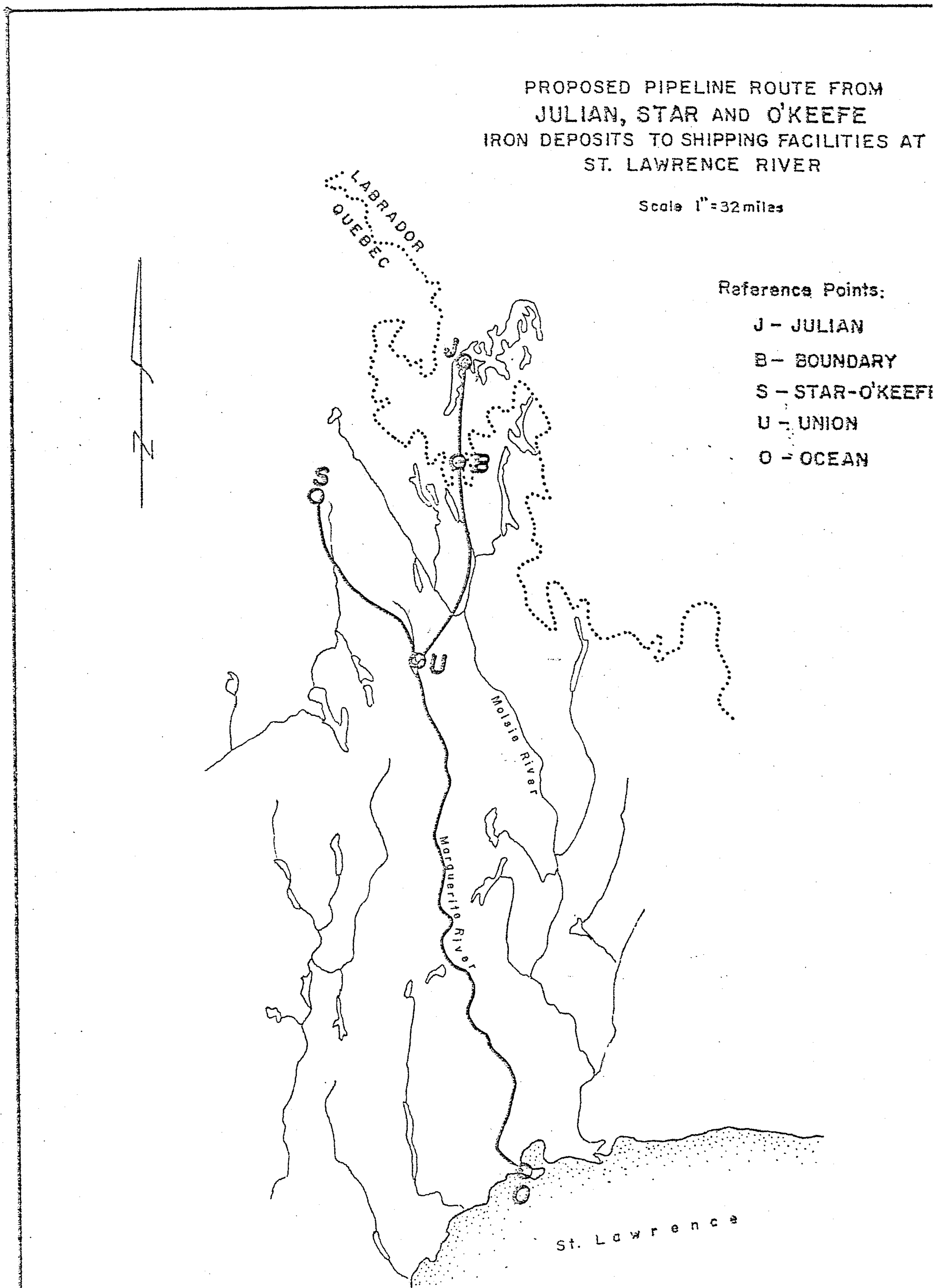
The southern limit of discontinuous permafrost is not precisely known in this region, and it may extend as far south as the Laurentide scarp. Therefore, the designers of the system should be forewarned of the possible occurrence of patches of permafrost at higher elevations and on north facing slopes.

Silty soils are apt to be the most troublesome in respect to heave and slump which could result in excessive stresses on the loaded pipe. Thus these soils should be removed from the pipe trench and replaced or covered with granular soil, or the frost penetration depth should be reduced through protective measures from the surface.

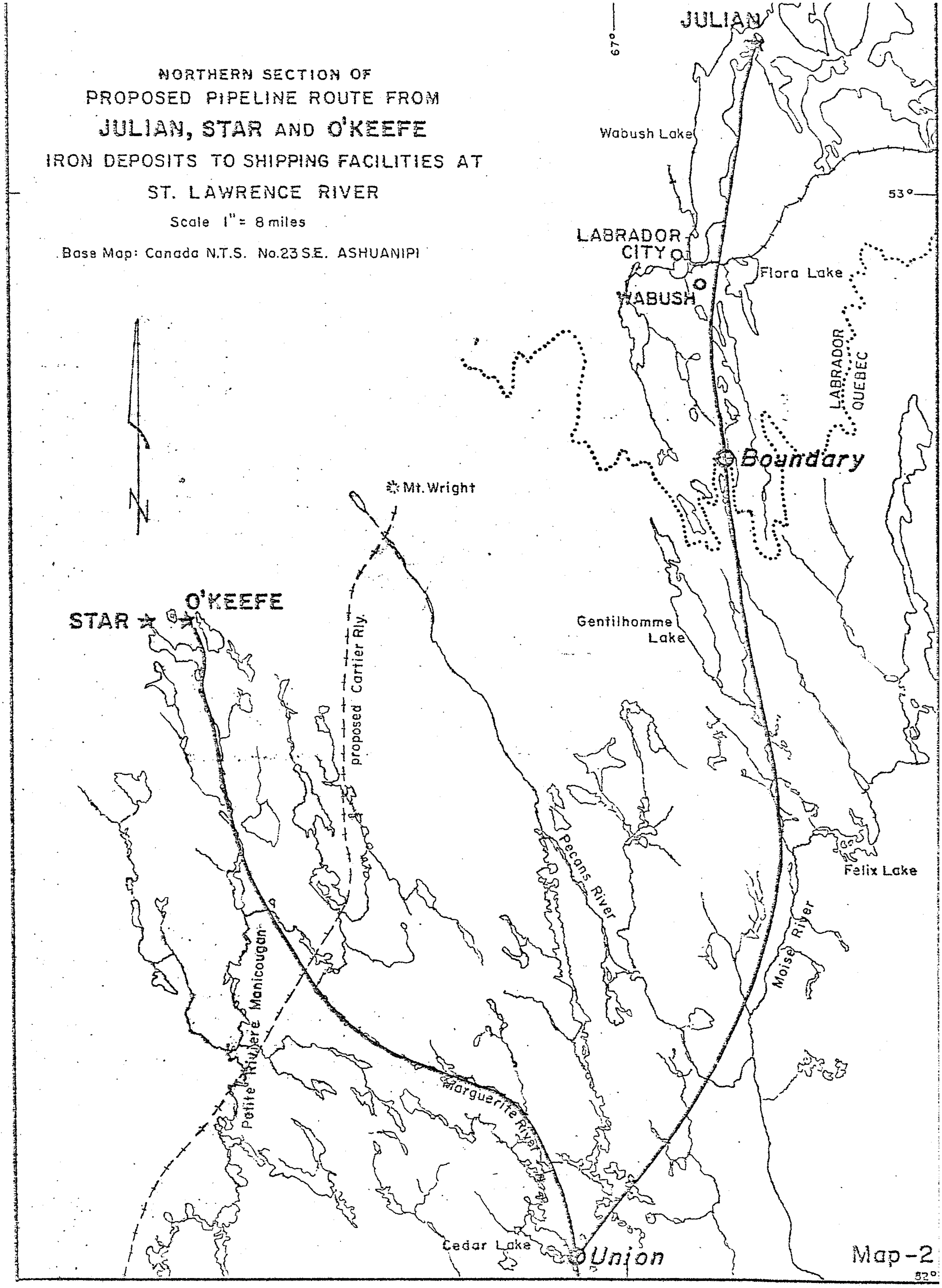
In this respect, the designers should consider the frost retarding effect of peat due to the high water content of the material and the latent heat of fusion of water. This combination greatly inhibits frost penetration in peats as opposed to mineral soils. Consequently construction/excavation costs could be lowered due to reduced ditch depth requirements. It follows that insulation costs could possibly be reduced or eliminated in long muskeg crossings for the same reason. Furthermore, peat could be used as a frost retardant on top of the ditched pipe in mineral soils, similar to the practice followed in Norwegian railway construction. The primary consideration in using this material is to avoid disturbing or mixing peat with mineral soils.

Even though the pipe would be wrapped, and insulated, corrosion is possible in acidic or alkaline bog waters. The designers should identify possible problem areas, and take proper precautionary measures such as insured defect free wrapping or annodic protection.

Consideration of these points should aid in achieving a 30 plus year iron ore slurry pipeline.


PROPOSED PIPELINE ROUTE FROM
JULIAN, STAR AND O'KEEFE
IRON DEPOSITS TO SHIPPING FACILITIES AT
ST. LAWRENCE RIVER
Scale 1" = 32 miles
Reference Points:
J - JULIAN
B - BOUNDARY
S - STAR-O'KEEFI
U - UNION
O - OCEAN
LABRADOR
QUEBEC
N
J
B
S
U
O
Moisie River
Marguerite River
St. Lawrence

Map -



NORTHERN SECTION OF
PROPOSED PIPELINE ROUTE FROM
JULIAN, STAR AND O'KEEFE
IRON DEPOSITS TO SHIPPING FACILITIES AT
ST. LAWRENCE RIVER
Scale 1" = 8 miles
Base Map: Canada N.T.S. No.23 S.E. ASHUANIPI
JULIAN
67°
Wabush Lake
53°
LABRADOR CITY
Flora Lake
WABUSH
LABRADOR
QUEBEC
Boundary
Mt. Wright
N
STAR
O'KEEFE
proposed Cartier Rly.
Gentilhomme Lake
Pecans River
Felix Lake
Moise River
Manicougan
Petite Rivière
Marguerite River
Cedar Lake
Union
52°

Map-2

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