NORMAN WELLS TO ZAMA OIL PIPELINE PERMAFROST AND TERRAIN RESEARCH AND MONITORING PROGRAM:

SITE ESTABLISHMENT REPORT

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1. Executive Summary:

The signing of the Environmental Agreement between the Federal Department of Indian and Northern Affairs Canada (INAC) and Interprovincial Pipelines Ltd. (IPL) in 1982 led to the establishment of a cooperative monitoring program along the Norman Wells to Zama oil pipeline. This pipeline constitutes the first completely buried pipeline in permafrost in North America. A major component of this permafrost and terrain research and monitoring program is the long term collection of thermal and other geophysical data at selected sites along the pipeline right-of-way in collaboration with the Geological Survey of Canada (GSC) of the Department of Energy, Mines and Resources (EMR).

This site establishment report presents the background information for each of the 13 permafrost monitoring sites established along the Norman Wells to Zama pipeline. The report explains the rationale behind each site selection, where the site is located, when and what type of instrumentation has been installed and presents a brief summary of the data collected during the first year of observation. Detailed descriptions of the material types and ice content initially observed at construction time are also provided in Appendix D for each site. This information is necessary for the interpretation of the data that has been, is being and will be collected each month for the next few years at each of these monitoring sites.

Résumé

La signature en 1982 d'une entente sur l'environnement entre le Ministère Fédéral des Affaires Indiennes et du Nord et la compagnie Interprovincial Pipe Lines Ltd. a permis d'établir un programme coopératif de surveillance et d'évaluation sur l'oléoduc allant de Norman Wells à Zama. Cet oléoduc est le premier oléoduc complètement enterré dans du pergélisol en Amérique du Nord. Une composante importante de ce programme de recherches et de surveillance sur le pergélisol et le terrain est la cueillette à longue échéance de données thermiques et géophysiques à une série de sites choisis le long du droit de passage du pipeline en collaboration avec la Commission géologique du Canada (C.G.C.) du Ministère d'Énergie, Mines et Ressources (E.M.R.).

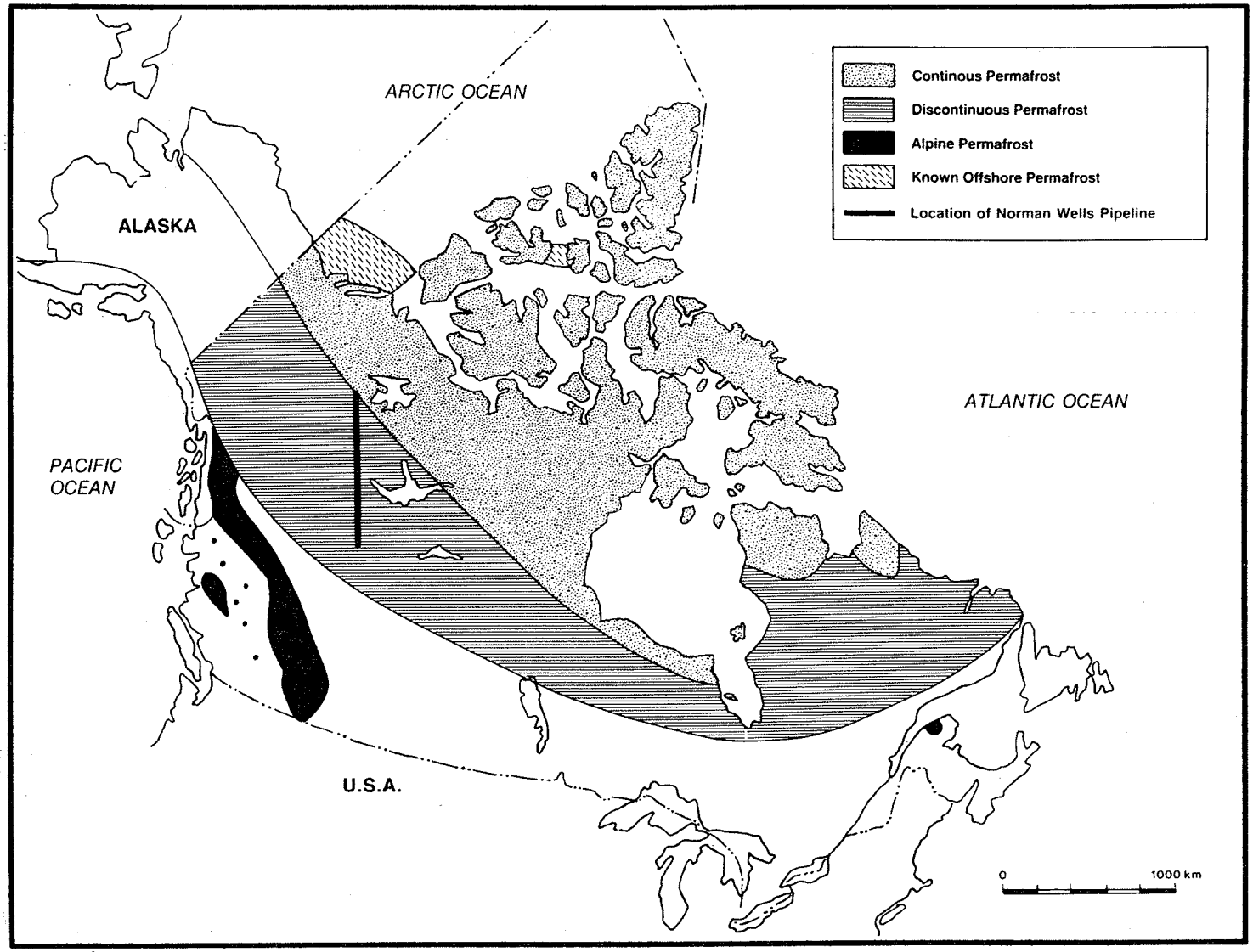
Ce rapport sur l'installation des sites d'étude présente l'information de fond pour chacun des 13 sites de surveillance établis sur l'oléoduc de Norman Wells à Zama. Il explique les raisons du choix de chacun des sites, leur emplacement, quand et quel type d'instrumentation y a été installé et donne un bref sommaire de l'information recueillie à chaque site durant la première année d'observation. Le rapport fourni aussi des détails sur les types de matériaux et le contenu de glace observé initialement lors de la construction. Cette information est nécessaire pour l'interprétation des données qui ont été et seront recueillies au cours des cinq ou dix prochaines années jusqu'à la stabilisation thermique à chacun de ces sites de surveillance.

2. Introduction

The Norman Wells to Zama pipeline, the first and only major hydrocarbon transportation project to be built north of 60° in Canada provides a unique opportunity to examine the effects of the first completely buried oil pipeline in widespread and intermittent discontinuous permafrost (Figure 1). The 869.5 km long, 323 mm diameter pipeline, buried at an average depth of 1 m, is owned by Interprovincial Pipe Line Ltd. (IPL) and carries oil from Esso Canada Resources oilfield at Norman Wells, N.W.T,. south to Zama in northwestern Alberta (Figure 2). The pipeline traverses the discontinuous permafrost zone of northwestern Canada in an almost north-south section varying in elevation from about 50 m A.S.L. near Norman Wells to 670 m A.S.L. in the southern Redknife Hills area (Alberta Plateau). Figure 3 presents the monitoring site locations in relation to their elevation above sea level along the pipeline ROW.

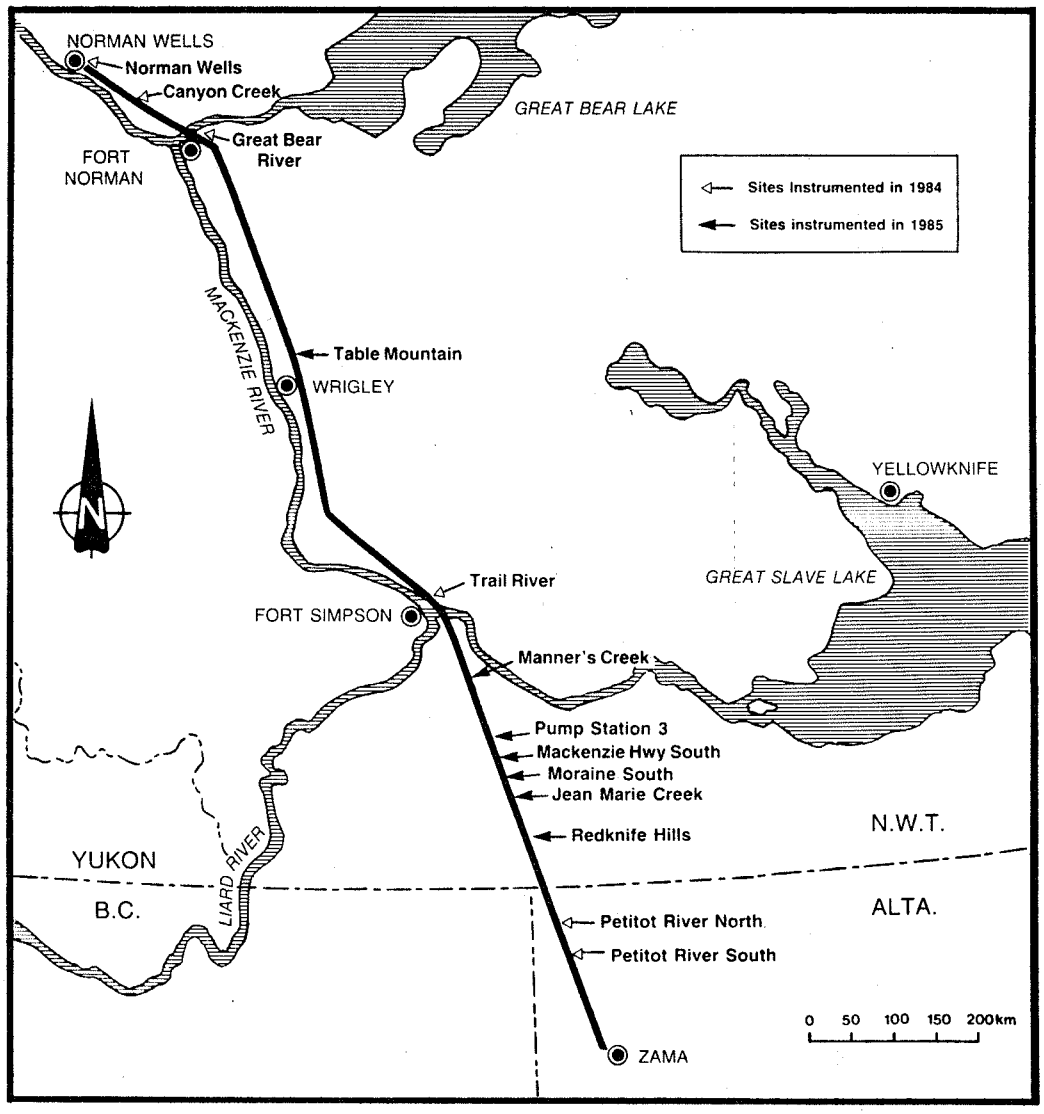
The Norman Wells to Zama pipeline involves new concepts and practices for northern pipeline development including the operation of a small diameter pipeline with initially chilled oil, construction and maintenance primarily using winter access without an associated all-weather road, and the utilization of wood chips for insulating thaw sensitive slopes. The pipeline provides the opportunity to assess the effects of pipeline construction and operation on the ground thermal and moisture regimes, and on the stability of different terrains and related surface conditions. Government has recognized the need to evaluate design approaches which minimize northern terrain disturbances, as well as to obtain information necessary for evaluation and improved design and implementation of northern projects, especially those in permafrost terrain (Hughes et al, 1973; Judge, 1973; FEARO, 1981). The National Research Council has emphasized the importance of the collection of non-proprietary information which would increase the general Canadian capability for engineering work in permafrost areas (Crawford, Gold and Dudgeon, 1982).

The federal government through Indian and Northern Affairs Canada (INAC) signed an Environmental Agreement with Interprovincial Pipelines Ltd. (IPL) in 1982, emphasizing the principle of minimum practicable environmental and land use disturbance, and establishing cooperation in monitoring, evaluating and managing environmental impact.



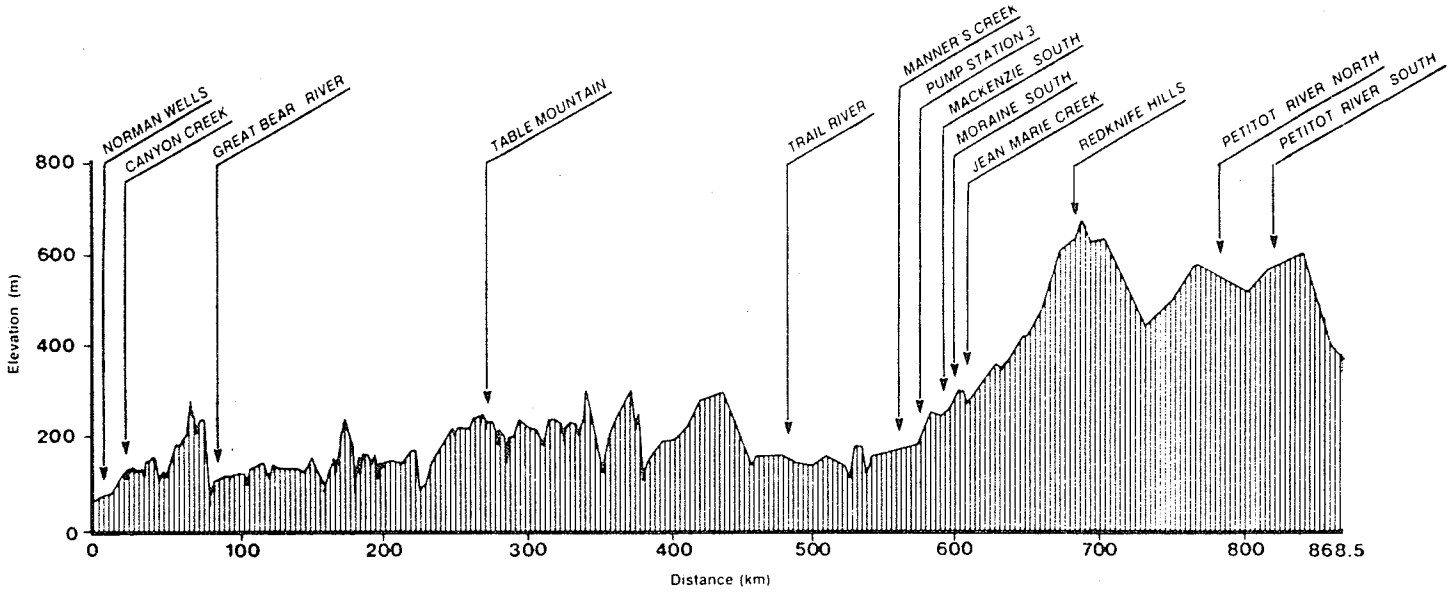
Permafrost map of Canada.

Figure 1



Location of Norman Wells pipeline monitoring sites.

Figure 2



Cross-section of elevation along the pipeline right-of-way(row), indicating the monitoring sites and pump station locations.

Figure 3

Under the agreement INAC has undertaken a program to monitor permafrost conditions and terrain performance on the Norman Wells pipeline in cooperation with the Permafrost Research Section and the Geomorphic Processes and Engineering Geology Section of the Geological Survey of Canada, Department of Energy, Mines and Resources (EMR). A major component of this research and monitoring program is the long term collection of thermal and geophysical data at selected sites along the pipeline right-of-way (ROW), based on a project initiated by staff members of the Permafrost Research Section, formerly in the Earth Physics Branch of Energy, Mines and Resources.

The sites were selected to include areas of sensitive terrain or of strong contrast in earth materials and to provide a representative set of soil, permafrost and ground ice conditions. The temperature data collected under this monitoring project supplement the existing thermal data base available in the area (Judge, 1973 and 1975; Taylor et al., 1982 and the preceding volumes of that collection; Geotech Ltd., 1984). The project also increases the number of permafrost study sites (observatories) for long term research.

This site establishment report describes the location, the rationale, the instrumentation, the geologic materials present and a brief summary of some of the observations obtained during the first year, for each of the thermal fences which make up the thirteen monitoring sites established in 1984 and 1985. It also briefly refers to sampling or additional instrumentation at the sites which are part of other cooperating projects in the "Permafrost and Terrain Research and Monitoring" program.

3. The Norman Wells - Zama Pipeline

The design and construction concepts used to minimize terrain disturbance and to assure pipe integrity under problem conditions such as thaw settlement, frost heave and slope instability are discussed by Nixon and Pick (1986), Pick (1986) and Nixon, Stuchly and Pick (1984). A brief summary follows:

the small 323 mm diameter pipe was selected to limit energy exchange with the environment. It also provides for increased structural strength. Before delivery to IPL the oil entering the line at Norman Wells is cooled to below 0°C but thereafter undergoes no further refrigeration. Over 165 slopes were given special geotechnical examination: wood chips were used to insulate sensitive permafrost slopes (McRoberts et al., 1985).

Right-of-way (ROW) clearance, generally 25 m, and overland pipe laying were undertaken in winter so that no permanent workpad would be required. Whenever practical the pipe was centered in previously cleared alignments, such as seismic lines or the former CN telephone land line. Both conventional and special design wheel ditchers were used for trenching, except in bouldery material where backhoes had to be used. Where wheel ditchers were used trench width was approximately 100 cm. Either local or select backfill was used to fill the trench: backfill was piled above the trench to compensate for settlement that might occur due to snow in the trench or mixed with the backfill. The pipe was buried at approximately 1 metre below ground surface at construction time (excluding roach height). On slopes, clay trench plugs were installed to control water flow in the trench. Sandbags form the major type of diversion berms for erosion and drainage control (Wishart and Fooks, 1985). Sites in mineral soils were fertilized and seeded.

Tree clearance and widening of formerly partially cleared areas commenced in winter 1983. Trenching, starting in January 1984, occurred simultaneously on 3 construction spreads. Great Bear and Mackenzie River water crossings were completed in the summer of 1984. Overland trenching was completed in the January to March construction period in 1985. Oil began to fill the line in March 1985 and the National Energy Board granted leave to open on April 17, 1985. The pipeline is designed to handle flow rates of up to 4,800 cubic metres per day.

4. Permafrost, Terrain and Terrain Stability Monitoring Project

The permafrost and terrain monitoring project, which emphasizes thermal monitoring, along the Norman Wells to Zama pipeline has been set-up to investigate a broad spectrum of permafrost and ground ice conditions and a variety

of terrain or soil type interfaces along the right of way. The project is currently expected to last five to ten years or until conditions stabilize.

The objectives of the project are as follows:

1. to monitor short and long term changes in the active layer, in permafrost conditions and in terrain stability of the alignment area as related to pipeline development and natural climatic change at selected study sites.
2. to assess changes to the thermal and physical conditions of terrain caused by pipeline-related activity, including right-of-way clearance, pipeline installation, operation and maintenance.
3. to compare observed terrain conditions with those predicted during the pipeline design process including thaw depth, thaw settlement and frost heave of the surface.
4. to evaluate the effectiveness of mitigation and restoration procedures, and subsequent surface restabilization at the study sites, including thermal performance of the pipe, wood chip insulation of slopes, drainage control and revegetation.
5. to identify practical improvements which might be made in the planning, construction, operation, monitoring and abandonment of future northern pipelines with special reference to the assessment of environmental impacts including thermal design, route selection, ground surface protection, land stabilization and restoration.

It should be emphasized that this research and monitoring stresses the effects, and investigation of effects, of the pipeline on the environment rather than the effects of the environment on the pipe. Thus, at each site, the monitoring project examines the impact of construction, operation and maintenance of the pipeline and the pipeline right-of-way on the surrounding ground temperatures, soil moisture, ground ice distribution, ground stability and related surface conditions. Results will also be used to assess the adequacy of current knowledge of the regional environmental framework including terrain, climate and climate change, for the design and planning of future northern pipelines.

This project, as indicated earlier, is part of a larger permafrost and terrain research monitoring program which also involves the National Research Council of Canada

and Agriculture Canada. It also includes cooperation with the Atmospheric Environment Service, of Environment Canada, in documenting climate and the response of ground temperature at one of the study sites.

5. Site Selection

Site selection was undertaken in conjunction with the pipeline company and its consultants. The process involved a close examination of the surficial geology, the lithological and ice content description from geotechnical boreholes along the ROW alignment, a review of available ground thermal data from both geotechnical boreholes along the route and other wells along the Mackenzie Valley (Judge, 1973) and the results of geophysical surveys undertaken to map permafrost conditions along the right-of-way (Hardy Associates, 1982, Kay et al., 1983).

Thirteen sites, eleven in the Northwest Territories and two in northwestern Alberta were selected (Figure 2). Twelve of the monitoring sites have from one to three instrumented cross-sections, called "thermal fences", consisting of thermistors around the pipe and several ground temperature cables 5 to 20 m in length: brief site descriptions are given in Table 1 and more specific details are discussed in the last section of this report (Appendix D). There are 23 thermal fences in total and one site has 3 deep cables rather than a thermal fence arrangement. At this site 3 cables are spaced 200 m apart in a line paralleling the pipe to investigate the transition from thin frozen terrain to an unfrozen fen. Where more than one thermal fence is located at a site, fences are designated A, B and C in a north to south sequence.

The sites cover a north-south distance of 819 km and include the following range of conditions:

1. one site with east and west facing slopes, one of which is insulated with wood chips.
2. two joint government-industry sites with instrumented wood chip slopes (north and south facing slopes).
3. four sites with material interfaces (e.g. lacustrine silts and clay, peat, fine and coarse sand) and

TABLE 1

SITE	PIPELINE KILOMETRE POST	YEAR ESTABLISHED	# OF CABLES	DESCRIPTION
Norman Wells 84-1	0.1	1984	5	Ice-rich silty clay material in widespread permafrost.
Canyon Creek				
84-2 A	19.0	1984	1	Level location, frozen till with low ice content in widespread permafrost.
84-2 B	19.3	1984	1	East-facing ice rich slope in widespread permafrost with a 1 m insulating woodchip cover.
84-2 C	19.6	1984	1	West-facing ice-rich slope in widespread permafrost with erosion control berms.
Great Bear				(Joint IPL site)
84-3 A	79.2	1984	4	Stratigraphically complex ice-rick alluvial terrace deposits in widespread permafrost (cliff-base).
84-3 B	79.4	1984	4	Ice-rich, cliff top, lacustrine deposits overlain by veneer of aeolian deposits.
Table Mountain				(Joint IPL site)
85-7 A	270.8	1985	1	Ice rich lacustrine plain (old seismic line).
85-7 B	271.5	1984	1	Helipad clearing on top of north facing slope.
85-7 C	271.8	1984	1	New clearing on level plain.
Trail River				Pipeline previously traversed mostly frozen ground.
84-4 A	477.3	1984	4	Unfrozen saturated sands and silts in sand dune hollow.
84-4 B	79.4	1984	4	Dry sand and silts in dune crest.
Manner's Creek				(Rapidly changing permafrost conditions).
85-8 A	556.9	1985	4	Thin peat with thick (10 m) permafrost.
85-8 B	557.2	1985	4	Thick peat with thin (4 m) permafrost.
85-8 C	557.4	1985	4	Thick peat with thin permafrost (4 m).
Pump Station 3 85-9	582.5	1985	4	Frost free granular soils. Pipe previously traversed long section of frozen ground.
Mackenzie Highway South				
85-10 A	587.5	1985	4	Transition from unfrozen terrain to a very thin permafrost terrain.
85-10 B	587.9	1985	4	
Moraine South 85-11	596.6	1985	4	Thin permafrost (4 m).
Jean Marie Creek				
85-12 A	607.7	1985	4	Thin peat plateau (low-ice).
85-12 B	607.9	1985	4	Thick peat plateau (ice-rich).
Redknife Hills				
85-13 A	681.2	1985	1	Thin frozen terrain surrounding large fen.
85-13 B	681.4	1985	1	Frozen fen (6 m).
85-13 C	681.6	1985	1	Unfrozen terrain surrounding fen.
Petitot River North				
84-5 A	781.9	1984	4	Ice-rich peat; thick (15-18 m) permafrost.
84-5 B	782.2	1984	4	Very thick incy peat (7 m); total 12 m permafrost.
Petitot River South 84-6	818	1984	5	Thick ice-rich peat (5 m)

4. four sites with frozen and unfrozen transitions (three cover frozen to thawed conditions, and one covers unfrozen to frozen condition).

Nine of the sites are totally in permafrost and four sites are in partially or totally unfrozen material. Three sites are in peat plateaux. In addition, to assist in evaluating the thermal performance of the operational pipeline, one site is adjacent to the first pump station and two sites are immediately north and south of the third pump station.

6. Site Construction

The site construction described here involved drilling the boreholes, installing PVC tubing, backfilling the tubing with non freezing silicone fluid and installing the appropriate multi-thermistor cables for ground temperature measurement. For all sites in the Northwest Territories drilling was provided by IPL and supervised by consultants to EMR. The work was done at the time of winter construction after pipe laying and before final restoration.

Six sites were established in 1984 and seven in 1985 as shown on the location map (Fig. 2-3). The 1984 instrumentation was carried out between February 29 and March 22, 1984, using three ground transported drill rigs consisting of two Mobile Auger Super B-61 drill rigs and one Failing 1200 drill rig. The Failing 1200 drill rig was used at site EMR-84-1 only, in order to drill holes T5 and G2 (page 37) to the required depth into bedrock for the deep instrumentation.

The field work was divided into two operations: one was carried out in conjunction with the IPL instrumentation in spreads of 4 and 7; the second was an independent operation in Spread 6. This was necessary because of the time constraints imposed by the timing of winter pipeline construction activities and winter road closure. Where site construction preceded backfilling, both short cables were located on one side of the ROW in contrast with the usual arrangement shown on Fig. 4.

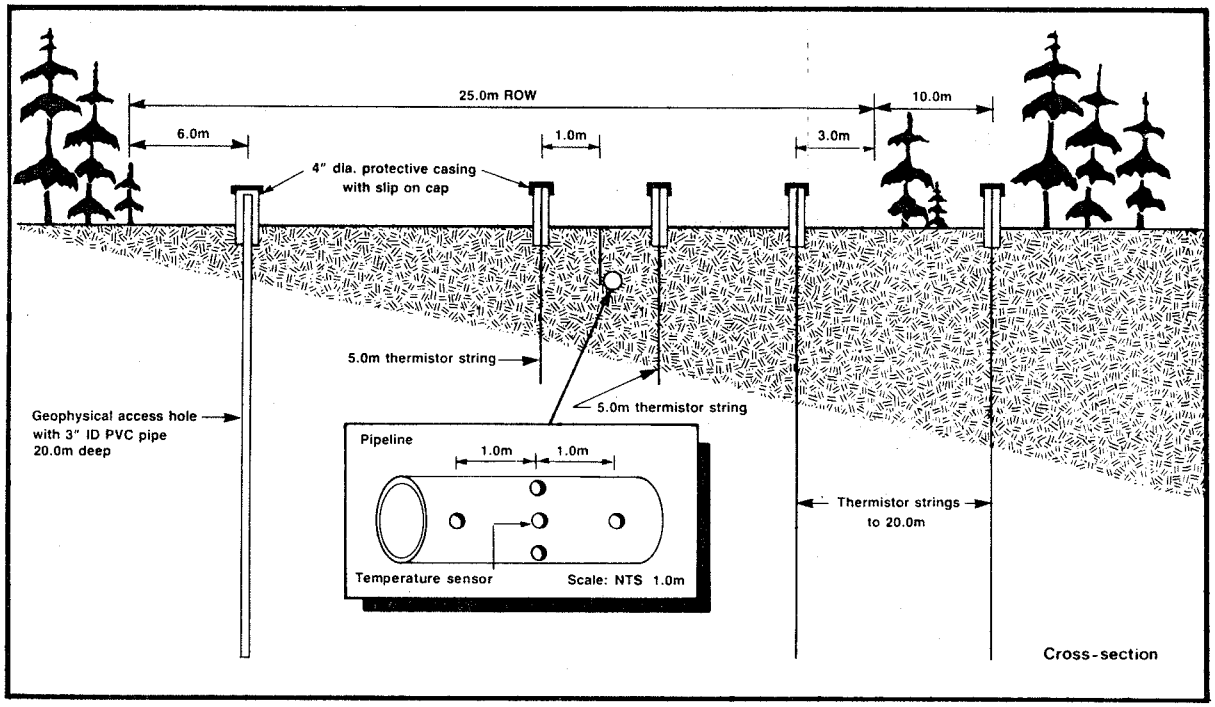
Boreholes for the 1985 instrumentation were drilled between February 16 and March 9, 1985, utilizing a Mobile Auger Super B-61 drill rig and an air-track drill rig. The air-track rig was used to drill all shallow thermistor boreholes (T1 and T2 beside the pipeline) in Spread 5 (sites 85-8, 9, 10, 11, 12) and the deep thermistor boreholes (T3 and T4) where shallow bedrock was encountered (sites 85-9 and 85-10A). The remaining boreholes south of the Mackenzie River and all boreholes at site 85-7A, 7B and 7C were drilled with the Mobile Auger Super B-61 drill rig. The 1985 drilling was divided into two operations in order to complete the work in the time available. One for sites 85-7A, 7B and 7C was carried out in conjunction with the IPL slope instrumentation program, the second was an independent operation for the remainder of the 1985 sites since there was no other IPL instrumentation in this area. The type of drill rig used at the 1985 sites had a direct impact on the sampling program at the various holes, since the air-track rig is incapable of taking core.

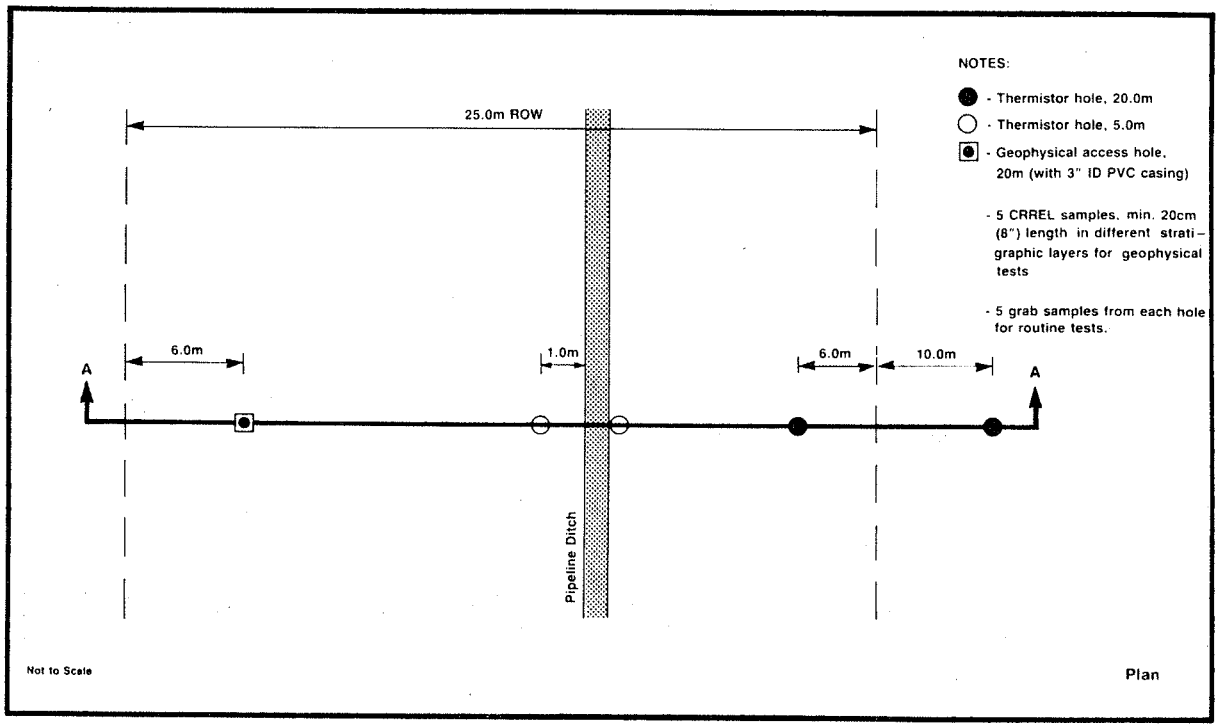
During March 1986, three new reference holes were drilled off the right-of-way at the Table Mountain Site, one each at fences 85-7A, 7B and 7C, with a Longyear 38 wireline diamond drill. The new hole at fence 7A is 94 m deep and will be used to study the current natural climatic change observed in this region of the Mackenzie Valley. The original intention had been to drill a continuously cored 200 m hole but a series of cave-ins between 94 and 125 m limited the useful depth to 94 m.

7. Thermal Fence Layout

At a typical thermal fence, as illustrated in Figure 4, two short 5 m long cables are located close to the pipe, to examine the immediate effect of pipeline trenching, installation and operation on soil temperature. In most cases, the two five metre cables are on each side of the trench. In the 1984 thermal fences, both cables are on one side of the trench (either spoil side or travel side, see site plans). Five temperature sensors, located on the outside of the pipe (installed by IPL prior to trench backfilling) provide an approximate value for the pipe temperature.

Two deeper cables (to 20 m) are located at each fence: one on the ROW and the other off-ROW to investigate the deeper thermal characteristics and enable a comparison of the thermal regime of the ROW and the surrounding terrain. In





Cross-section and plan of a typical thermal fence instrumentation layout at the monitoring sites along the Norman Wells to Zama pipeline.

Figure 4

positioning the off ROW hole, or reference hole, removal of tree cover was necessary in some locations to accommodate the trackmounted drills. Such surface disturbance was kept to a minimum.

At most thermal fences a 20 m deep, 3 inch diameter geophysical access hole was installed usually on the travel side of the ROW to allow future downhole geophysical surveys or additional thermal data collection.

Figure 5 shows the typical depth distribution of sensors at a thermal fence. Modifications to this are shown in the specific site plans in Appendix D. Cable positions are remeasured annually to check thermistor positions in relation to a ground surface undergoing thaw settlement.

In August 1986, adjustable soil temperature probes were installed by the Land Resources Research Center of Agriculture Canada to measure shallow soil temperatures (to 1.5 m) and study the thermal evolution of the active layer at selected monitoring fences. At each location one rigid multi-thermistor probe was installed by hand off the pipeline ROW. In hummocky terrain the off ROW probe was installed on a hummock top. A second multi-thermistor probe was installed on the ROW usually midway between the trench and the edge of the cleared ROW. Locations are shown on the site plans. Further information will be provided in the Agriculture Canada installation report.

To obtain further details of the thermal characteristics of the trench, IPL Ltd. added ditch thermistors in September 1986 at six of the monitoring program thermal fences. Figure 5 also shows a typical ditch thermistor installation cross section.

8. Temperature Instrumentation and Accuracy

Methods of temperature measurement in shallow northern boreholes have been discussed in detail by Judge (1973). For long term monitoring programs the installation of multisensor temperature cables is favoured, in order to ensure a permanent or semi-permanent installation, to simplify site visits (so that it is not necessary to carry a portable downhole logging system), to avoid worry about caving-in or freezing of borehole between logging trips and to ensure readings at

identical spacing. For detailed information on permafrost and active layer characteristics and behavior please refer to Gold and Lachenbruch (1973), Johnston (1981), and Judge (1973).

In contrast to former shallow ground temperature cable installations during the 1970's (for the Mackenzie Valley monitoring of the Environmental-Social Program, Northern Pipelines; Judge, 1973), where the temperature cable was installed immediately after drilling and the borehole backfilled, the Norman Wells pipeline boreholes were lined with PVC casing. The small diameter PVC tubes (25-38 mm) were filled with an environmentally-safe, medium viscosity and non-freezing silicone fluid (Dow Corning 200 centistokes) prior to cable placement. This system allowed for ease in temperature cable installation, even sometime after the drilling operation without worrying about caving or freezeback of an open hole. In addition the possibilities of cable stress and sensor failure due to freezing, thawing or heaving of the surrounding soils were avoided. The possibility of leaky cables, where capacitive effects during sensor measurements present problems for automatic data acquisition systems and lengthen the handheld multimeter measurement time, was also reduced. Furthermore the PVC tubes will facilitate future cable removal, replacement or re-use, and detailed sensor calibration and recalibration.

The shorter cables contain ten thermistor sensors spaced every 50 cm; the longer cables contain eleven, spaced every metre near the surface and then every 2 m or 3 m at depth as shown on Figure 5.

Temperature cables were installed throughout the summer of 1984 at the winter drilled 1984 sites, and at the time of drilling for the 1985 sites. The depth positioning of the cables was relative to the ground surface at the time of cable installation. Thus, although, the sensor spacing along the cable remains constant with time, the absolute depth of the sensors with respect to the surface level at a particular point in time may change as this surface is subjected to heave or settlement. Surveys are conducted annually to record approximate vertical positions of the ground surface to an accuracy of 10 cm over a 20 m x 20 grid at each fence. Cable positions relative to existing ground surface will be remeasured periodically during the monitoring program.

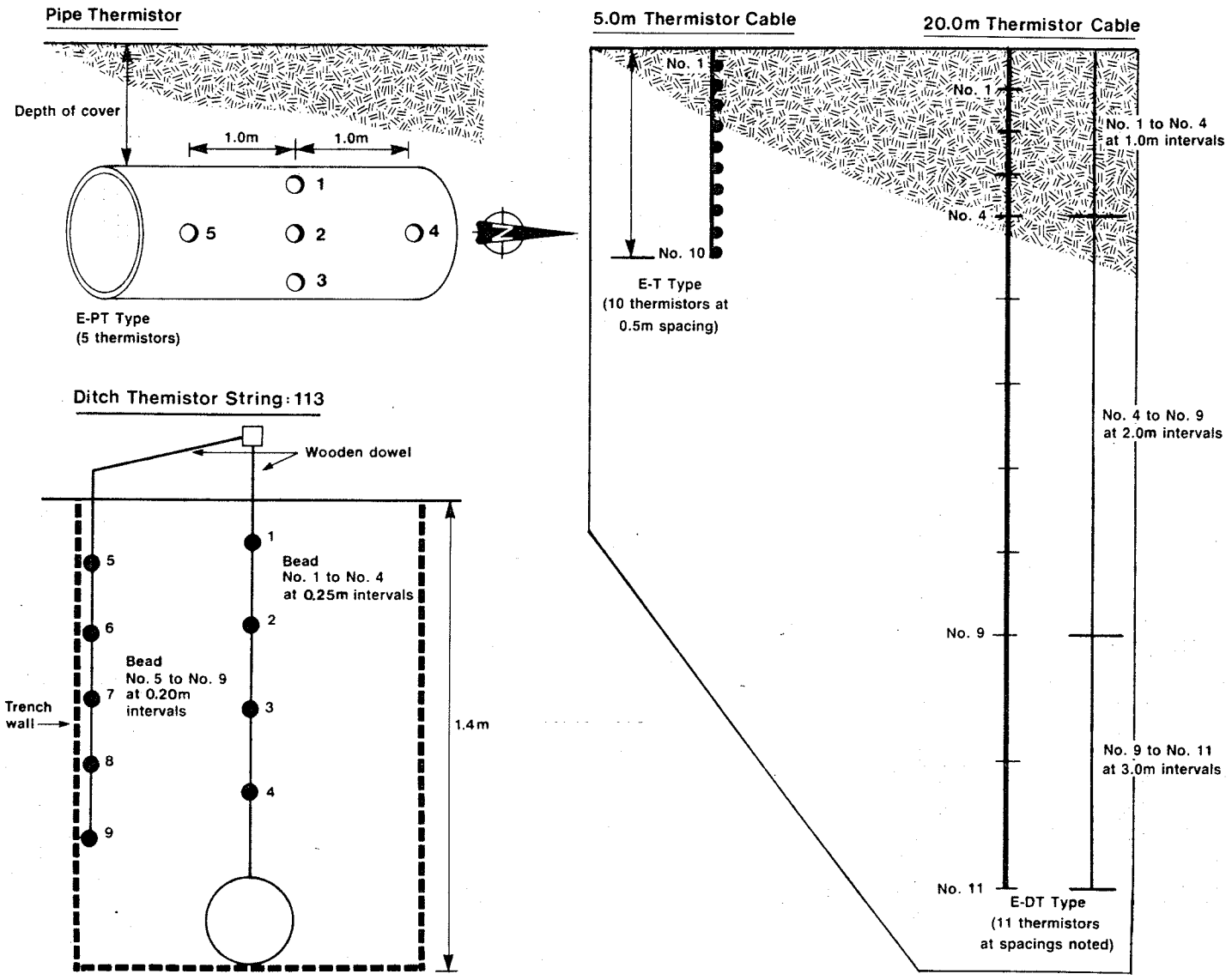


Figure illustrating the typical thermistor configuration and distribution of temperature sensors used at monitoring sites along the Norman to Zama pipeline.

Figure 5

The temperature sensor used in these cables is the thermistor, a semi-conductor device whose electrical resistance varies in an inverse, non-linear relationship with temperature. The thermistor is versatile, reliable, stable and simple to use. The thermistors were calibrated by the manufacturer to an accuracy of 0.1 K. Three types of thermistors were used in the fabrication of the temperature cables for the Norman Wells monitoring program: (1) YSI #44033 sensors, the most frequently used sensors, were placed in all borehole cables in the N.W.T. and all pipe sensors installed in 1985, (2) YSI #44032 sensors were used in all the Alberta boreholes and (3) Atkins #4 sensors were used for all the 1984 pipe sensors and in the 1986 IPL ditch thermistors. YSI #44032 were used in Alberta because a high resistance thermistor was required by the logging system originally intended for these sites. The use of Atkins #4 sensors in the 1984 pipe thermistor arrays was primarily because of an inadequate supply of YSI # 44033 at construction time.

Two field measurement systems are in use, (1) a simple digital, handheld Fluke multimeter system and (2) a portable data acquisition system (DAS) with facilities for data storage on cassette tape and hardcopy printout. The resolution of both of these systems enables relative changes of better than 0.01 K to be determined for a particular sensor. The measurement systems are used interchangeably, depending on the personnel and time of year. A field comparison of the two systems with a standard high precision temperature measurement bridge (described in detail in Judge, 1973) revealed agreement generally to within 0.01 K.

9. Frequency of Data Collection

Manual temperature data collection to date has been on a monthly basis at priority and easily accessible sites. Remote sites distant from either Norman Wells or Fort Simpson, are not read regularly in the winter; these sites are Table Mountain (85-7A,B,C), Redknife Hills (85-13A,B,C), and Petitot River North (84-5) and South (84-6). Winter readings have been primarily undertaken by INAC field staff from Norman Wells and Fort Simpson, while EMR or INAC researchers have been responsible for the May to October visits and data collection in addition to the thermal records. The continuation of this frequency of readings will depend on the level of funding available to the program in future years. The program is designed for five to ten years of data collection, or until conditions stablize.

IPL's geotechnical monitoring program includes reading temperature cables and piezometers on 17 wood chip slopes as well as instrumentation or surveys at several frost heave and thaw settlement sites identified since 1984.

Automatic data loggers will be installed at high priority sites. The frequency of measurement for the data loggers is currently set to three readings per day. In October 1985, fences 85-7A and 85-7B at Table Mountain were equipped with automatic data loggers (Sea-Data model 1250B) to ensure more continuous data gathering. Fences A at Canyon Creek and A at Great Bear were also equipped with Sea-Data loggers, to increase the number of measurements. More frequent measurements were of interest at Canyon Creek A to compliment the automated micrometerorological data collected by the Atmospheric Environment Service of Environment Canada since the winter of 1985 (Granberg, 1985). At Great Bear A, where thaw settlement is leading to the development of hummocky terrain on the ROW, a detailed monitoring of the ground thermal regime in the ice-rich surficial material is desired.

ASSOCIATED DATA

(A) Soil sampling program

At the time of site construction, during winters 1984 and 1985, major soil sampling programs were undertaken with drilling and field logging of the geothermal and geophysical boreholes. At the 1984 sites two to seven undisturbed samples were obtained from each of the various lithological units encountered at each fence. Samples were taken with modified CRREL core barrels in frozen soils and with Shelby Tube in unfrozen soils. At the 1985 sites continuous core was collected from the geophysical hole at each fence. In addition grab samples were collected from the other holes for a basic geotechnical laboratory testing program, including moisture content, Atterberg limit and grain size analyses. The results of these tests are presented in two reports from Hardy and Associates (1978) Ltd. (1984, 1985). The cores are currently stored in a cold-room in Ottawa; detailed descriptions and thermal measurements are being prepared through a contract with Carleton University and electrical property measurements have been undertaken by A-Cubed (1985 c) and (1987).

(B) Geophysical surveys

Geophysical surveys are conducted from time to time to complement the basic thermal information obtained at the fences. To date, two types of geophysical data have been collected fairly extensively at the monitoring sites. These are time domain reflectometry (TDR) and ground probing radar (GPR) surveys. The GPR provides a continuous transect of the active layer, lithology and shallow permafrost characteristics across the ROW to depths of as much as 10 m on the average. These data complement the thermal observations from the multi-thermistor cables and extend them laterally so that a better comprehension of the effects of ROW clearance, pipeline installation and operation is obtained at the study sites. TDR measurements are obtained for the same reasons and provide data on soil moisture conditions and electrical properties to depth of 2 m at three locations along the thermal fence: adjacent to the pipeline in the trench, in the centre of the ROW and off the ROW. These geophysical surveys are described in more detail by Pilon and others (1985 a, b), by A-Cubed Inc. (1984 a, b; 1985 a, b, d) and Lafleche et al. (1987).

From time to time other geophysical methods are also used to test their capability at detecting accurately the permafrost conditions observed at the sites. For example, an EM-31 ground conductivity meter and an EM-39 borehole conductivity meter survey were undertaken in June 1984 and June 1986 respectively.

(C) Active layer profiles

In the falls of 1984 and 1985, at the time of maximum active layer development, active layer transects are carried out at selected monitoring fences to supplement the data from the multi-thermistor cables installed in the drillholes. These profiles were obtained with an "active layer probe" consisting of a 1.7 m long small diameter stainless steel tube with a thermistor embedded in the tip (Pilon and others, 1979) to sense the ambient temperature. The probe was pushed into the ground at 10 cm increments and read until the tip reaches the frost level. In this fashion very detailed temperature profiles are obtained through the active layer. A series of these detailed profiles, on and off the ROW, along the axis of the thermal fences provide additional active layer information at the monitoring sites Subsequently, depth to frost transects have been made at selected thermal fences.

(D) Other data

During the winter season, measurements of snow depth along the thermal fences are taken to maintain a record of snow thickness and distribution at the monitoring sites. Similarly, measurements of water depth in ponds on the ROW or in the trench are also made during the warm season.

Two types of photographic record have been kept of the fences. First, black and white aerial photographs of the ROW were taken yearly at 1:10,000 scale (1983-1987) and larger scale (1:5,000) colour photographs were taken for the areas in the vicinity of the monitoring site along the ROW in selected years. In 1988, black and white photographs were taken of entire ROW at 1:5,000 scale (IPL). Second, a ground photographic record is maintained for the site visits with observations on revegetation, geomorphic processes and ROW maintenance.

Ground Temperature Data Base

The EMR/INAC Norman Wells pipeline thermal data base is currently maintained by the Permafrost Research section, Terrain Science Division, Geological Survey of Canada (GSC), (originally with the former Earth Physics Branch (EPB) of E.M.R). The data base follows the format established by EPB for its Canadian Geothermal Data Collection-Northern Wells (Taylor and others, 1982 for the most recent edition of the collection). A file number has been assigned to each of the 13 monitoring locations (numbers 501 to 513 from North to South).

A complete listing of borehole temperature readings for each cable at each thermal fence site is published from time to time as an open file report (Burgess, 1986 and 1987). The designated site number appears in the table heading opposite the site name. The sensor depths listed in the tables, and kept on permanent record in the file, are those at the time of cable installation.

The data are grouped by monitoring site and presented in site order along the pipeline route (Norman Wells = kilometrepost 0). The data tables include additional information on (1) latitude, longitude, elevation, (2) the distance of the borehole from the pipeline centreline and the location (off ROW, on ROW), (3) the lithology and ice content of the soil, (4) the number and type of thermistors in each cable, and (5) the installation of automatic data loggers.

Measurements of the pipe thermistor sensors are listed separately in Appendix B of the open file reports in order of site occurrence from north to south. Users of these data should note that the depths listed in the data tables were determined from the initial burial depth of the pipe and are not necessarily the current depths, especially in disturbed conditions or in thaw sensitive terrain (such as occurs, for example, at the Norman Wells and Great Bear A sites). The relative position of the sensors on the pipe, however, remains fixed.

Acknowledgements

Many organizations have helped to make the overall thermal monitoring project possible. IPL provided much support and cooperation, and in particular contributed the drilling of the boreholes for most cables in the N.W.T., as well as the staff for installation of the pipe thermistors and logistics support for field programs. The assistance of W. Pearce, A. Pick and J. Smith, all of IPL, requires special mention.

Dr. W. Slusarchuck, Mr. A. Hanna and G. Lem of Hardy Associates (1978) Ltd. provided much assistance with the selection of the best locations for the monitoring fences. Mr. M. Mitchell built the multi-thermistor cables and helped his Hardy colleagues with the construction of the sites in the field. The design of the EMR/INAC ground thermal monitoring program is principally due to the efforts of Kaye MacInnes (Land Resources, INAC, Yellowknife), Alan Judge and Jean Pilon (both with GSC, EMR). The overall establishment of the program was possible thanks to the assistance of several INAC individuals particularly: W. Dunlop, B. Gauthier, J. Wallace and S. Meldrum. The ground temperature data presented in this report was collected with the help of many people. At INAC, Kaye MacInnes and personnel from the District Offices in Norman Wells and Fort Simpson must be thanked; At EMR, David Harry, Vic Allen, Alan Judge, Perry Lanthier, Diana Leblanc-Ross and Jean Pilon contributed to the monitoring program and to Mrs. M. Ford for preparing the multiple manuscripts.

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Additional funding or other assistance has been received from the former Earth Physics Branch (EMR) and from the Geological Survey of Canada (EMR), the Federal Panel on Energy Research and Development and the Office of Environmental Affairs (EMR) and from IPL (N.W.) Ltd.

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APPENDIX A

NOTE ON SITE LOCATIONS

APPENDIX A

NOTE ON SITE LOCATIONS

The chainage used in this report to describe the site locations refer to the monitoring site position according to the 1983 alignment sheet kilometre post (kmp). In addition for each fence there is a construction chainage location which indicates the fence position as the pipeline was laid along the various construction spreads. Finally there is the "as built" construction chainage (1985) which represent the final post-construction true pipeline linear position between Norman Wells and Zama. It accounts for the extra distance caused by the dips and bends along the pipeline and thus is the actual length of pipe laid in the ground.

TABLE A-1 - SUMMARY OF SITE POSITIONS

Site	Alignment Sheet Chainage (km)	Construction Chainage (km)	Continuous "as built" Chainage (km)
84-1	0.0	0.020	0.020
84-2A	18.9	18.972	18.972
84-2B	19.3	19.266	19.266
84-2C	19.5	19.551	19.551
84-3A	78.7	79.180	79.180
84-3B	79.1	79.395	79.395
85-7A	270.8	81.192	271.231
85-7B	271.5	81.947	271.986
85-7C	271.8	82.272	272.311
84-4A	477.3	50.410	477.988
84-4B	477.4	50.282	478.116
85-8A	556.9	28.100	557.828
85-8B	557.2	28.430	558.158
85-8C	557.4	28.605	558.333
85-9	582.5	53.610	583.339
85-10A	587.5	73.960	588.276
85-10B	587.9	73.550	588.686
85-11	596.6	64.840	597.396
85-12A	607.7	53.674	608.562
85-12B	607.9	53.521	608.715
85-13A	681.16	187.250	682.233
85-13B	681.35	187.061	682.422
85-13C	681.56	186.850	682.633
84-5A	781.9	86.520	782.963
84-5B	782.2	86.230	783.253
84-6	818.5	49.975	819.508

APPENDIX B

GLOSSARY OF PERMAFROST TERMINOLOGY

APPENDIX B

GLOSSARY OF PERMAFROST TERMINOLOGY

Active layer: it is the top layer of ground between the surface and the top of the permafrost table which thaws and refreezes during the year.

Depth of thaw: is the distance from the ground surface downward to frozen ground at any time during the thawing season.

Depth of zero annual amplitude: The distance from the ground surface downward to the point beneath which there is virtually no annual fluctuation in ground temperature, a change of no more than 0.1°C through the year is arbitrarily considered as virtually no annual fluctuation.

Frost heave: is the strong lifting action caused by frost in the soil.

Frost table: is the top layer of ground between the surface and the bottom of the seasonally frozen layer.

Ground ice: is the ice in pores, cavities, voids or other opening in soil or rock, including massive ice bodies.

Permafrost: The thermal condition in soil or rock of having temperatures below 0°C persist over at least two consecutive winters and the intervening summer.

R.O.W.: Right of way refers in this report to the band of terrain cleared of trees for the construction and installation of the pipeline.

Seasonal frost: seasonal temperatures causing frost (below 0°C temperature) that affect earth material and keep them frozen only during the cold season.

Talik: A layer or body of unfrozen ground within the permafrost.

Thaw settlement is the process of settling caused by thaw of the subsurface.

Thermal envelope: is the maximum and minimum temperature observed at a given depth during an annual cycle. It defines the range of temperature observed at a point in the ground. Note that the boundaries obtained in this fashion are not observed as such at a given point in time.

Thermal regime: is the summary of the thermal behavior, temperature conditions and thermal properties of surbsurface materials at a location.

Thermokarst: The irregular topography resulting from the process of differential thaw settlement or caving of the ground because of melting of ground ice.

APPENDIX C

NOTE ON ICE CONTENT

GROUND ICE CLASSIFICATIONS

CATEGORY	GROUP SYMBOL	SUBGROUP SYMBOL	DESCRIPTION
		F	UNDIFFERENTIATED
NON-VISIBLE ICE	N	Nf	POORLY BONDED OR FRIABLE FORZEN SOIL
		Nbn	WELL BONDED FROZEN SOIL WITH NO EXCESS ICE
		Nbe	WELL BONDED FROZEN SOIL WITH EXCESS ICE, FREE WATER PRESENT WHEN SAMPLE THAWED
VISIBLE ICE LESS THAN 25MM THICK	V	Vx	INDIVIDUAL ICE CRYSTALS OR INCLUSIONS
		Vc	ICE COATINGS ON PARTICLES
		Vr	RANDOM OR IRREGULARLY ORIENTED ICE FORMATIONS
		Vs	STRATIFIED OR DISTINCTLY ORIENTED ICE FORMATIONS
VISIBLE ICE GREATER THAN 25mm THICK	ICE	ICE + Soil Type	ICE GREATER THAN 25mm THICK WITH SOIL INCLUSIONS
		ICE	ICE GREATER THAN 25mm THICK WITHOUT SOIL INCLUSIONS

NOTE: 1. UF signifies unfrozen ground.
2. F? or UF? Indicates likely thermal condition not obvious during drilling.

ADAPTED FROM NRC 7576

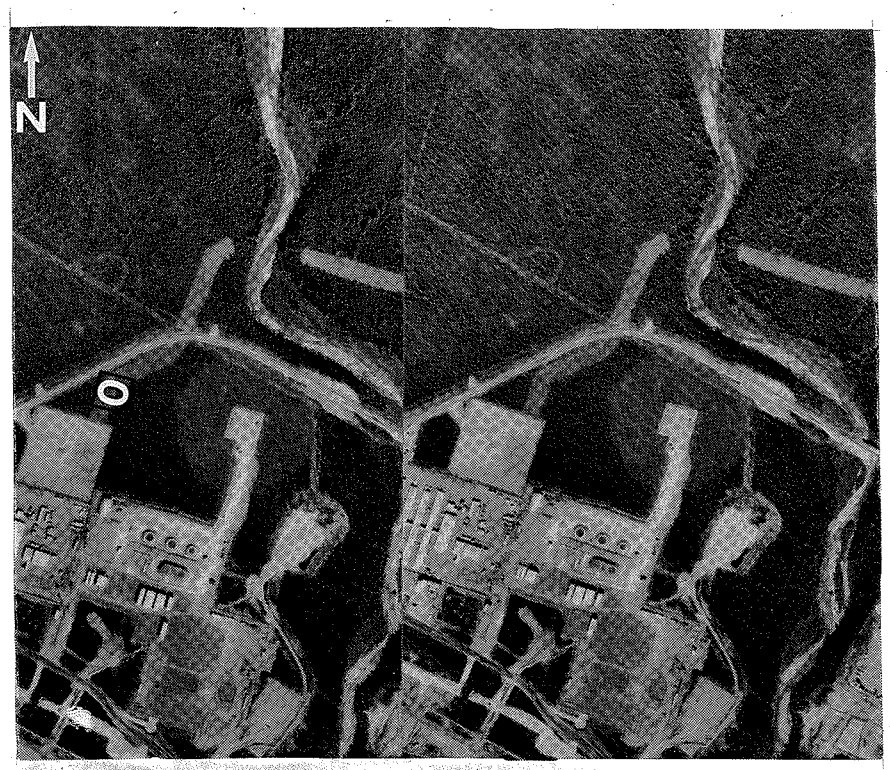
APPENDIX D

SITE DESCRIPTION

THERMAL FENCE

84-1

KP 0.0



Air photos A26353 Nos. 169-170, 3 July 1983

Site number: 84-1

Site name: Pump Station No. 1, Norman Wells

Location: 65°17' 21"N, 126°53'10"W, Kmp 0.06

Elevation: 61 metres A.S.L.

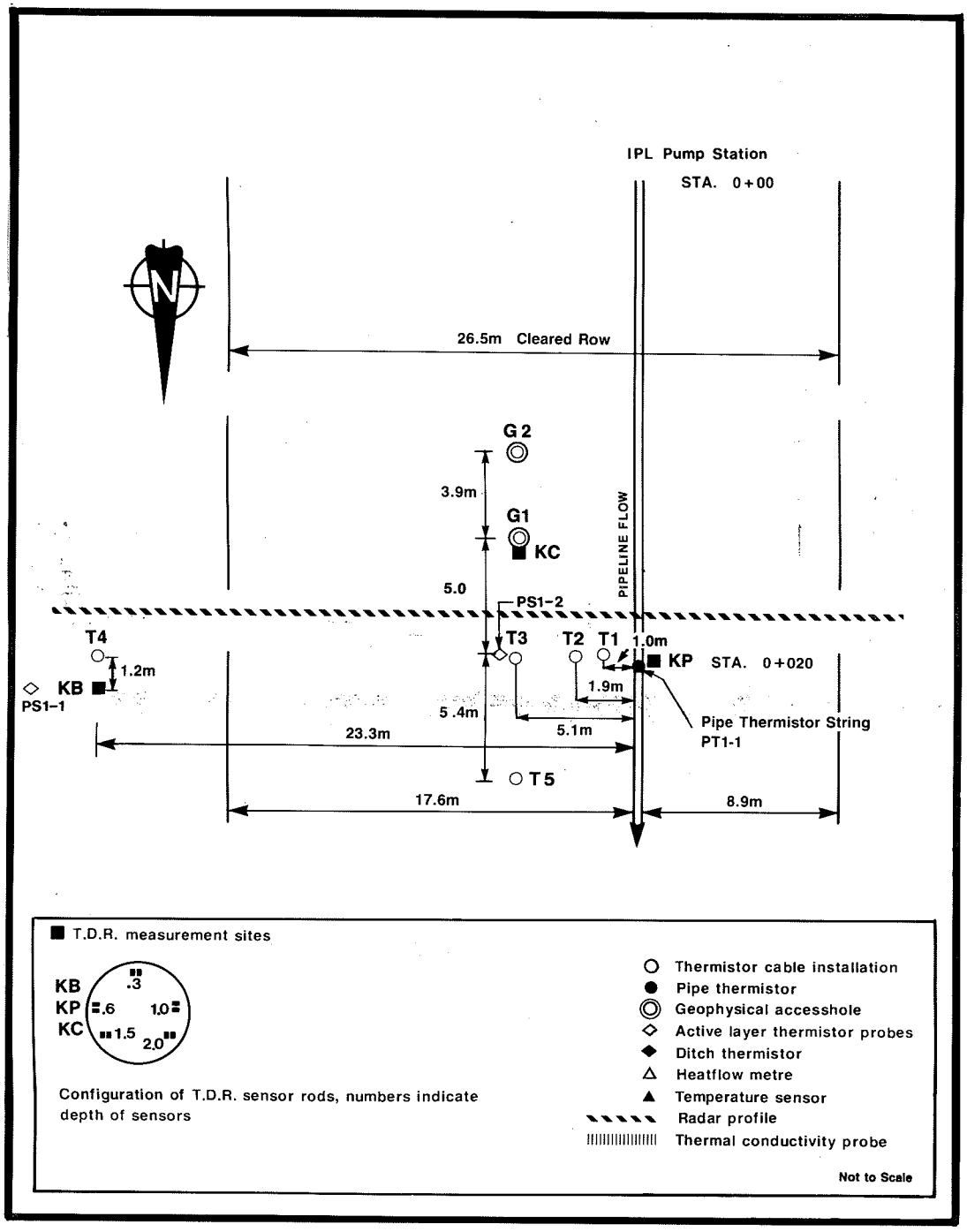
Rationale: This site was established at a level location in a lacustrine plain unit. It has been selected to study the thermal behavior of ice rich silty-clay material located in widespread permafrost. At this location permafrost is expected to be approximately 50 m thick.

Vegetation: Open black spruce-tamarack/ericaceous shrubs, moss, lichen (hummocky) woodland.

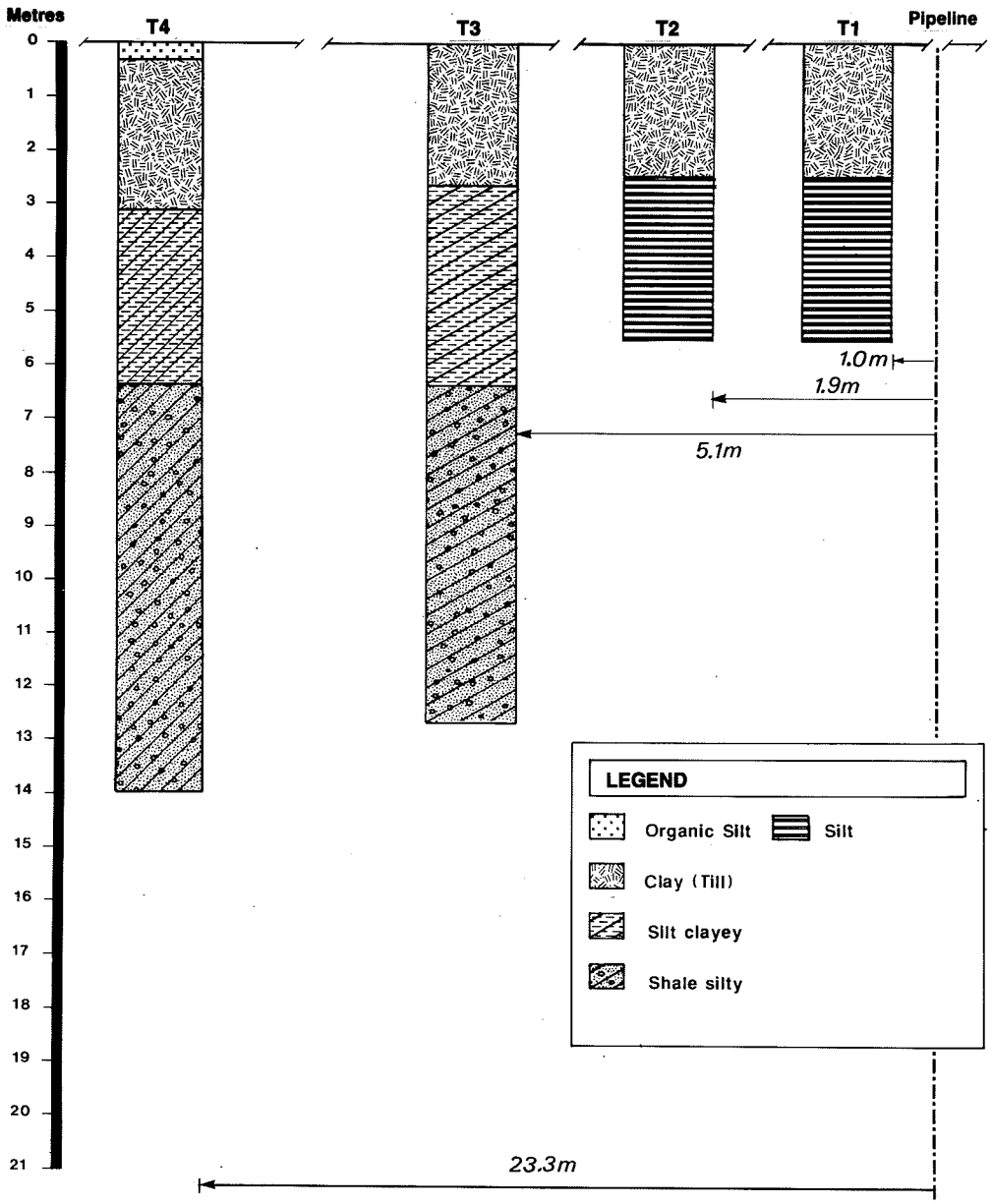
Site history:
- Trees cleared to 26.5 m width in winter 1982-83.
- Trenched in January 1984 with a Bannister 710 Arctic (wheel) Ditcher.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1984.
- Restoration: fertilized and seeded March 1984.
- Bench Marks installed and first surface survey April 1984.

Pipe depth: 0.90 m (excluding Roach) to top of pipe (March 1984).

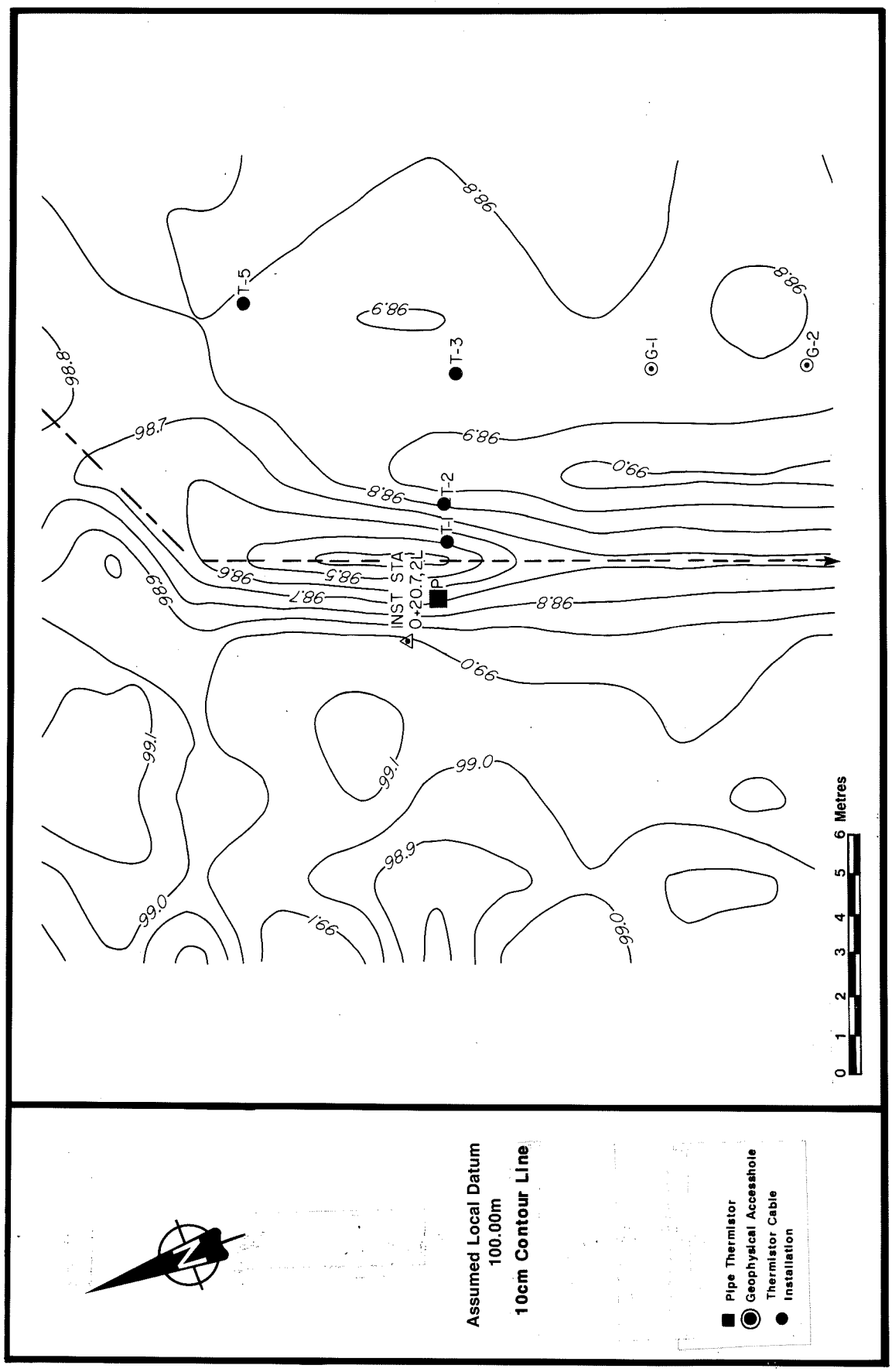
Instrumentation:
5 Multi-thermistor cables
3 Arrays of T.D.R. rods
2 Soil temperature probes
2 Geophysical access holes
1 Pipe thermistor



Site plan of EMR/INAC site 84-1, Norman Wells, Pump Station No. 1



Lithologic cross-section of site 84-1, Norman Wells, pump station no. 1 based on the drill logs from the thermal instrumentation hole.



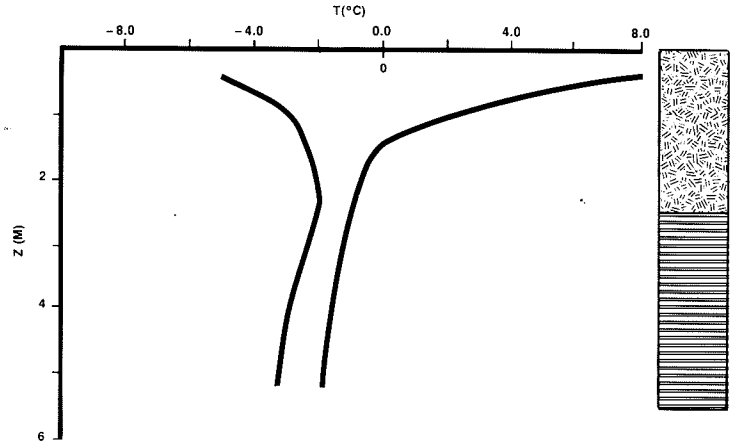
Detailed surface elevation contour map of site 84-1, Norman Wells, Pump Station No. 1, using an assumed local datum of 100 m.

Site 84-1

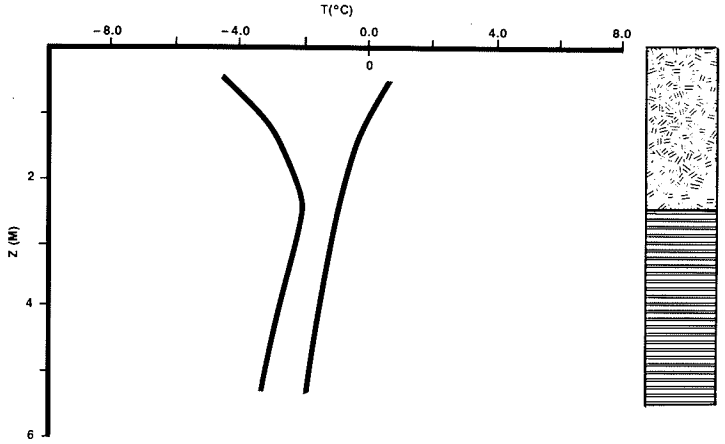
The thermal fence (84-1) at Pump Station no. 1 in Norman Wells shows the following trends in the period under review (summer 84 - summer 85). Active layer development in the R.O.W. based on the thermal cables at the fence seems to be slightly less than a meter and it is about 80 cm at the reference hole off the R.O.W. A first approximation of permafrost thickness at this site on the basis of the temperatures measured in hole T5 indicates a thickness of about 55 meters.

Even though the data base is limited to about a year of data (i.e., one cycle), there are two outstanding features in it. The first is the differential temperature envelopes observed at 5 m on and off the R.O.W. The R.O.W. holes show a change of temperature at that depth of 2.6°C over the period while our reference hole shows only a temperature change of 0.93°C during the same time. This difference can be attributed to the effect of snow removal on the R.O.W. for pipeline construction, which created a larger than normal heat loss over the R.O.W. by removal of the insulting snow cover at the surface. This heat loss being reflected at depth in the first thermal profiles taken last July.

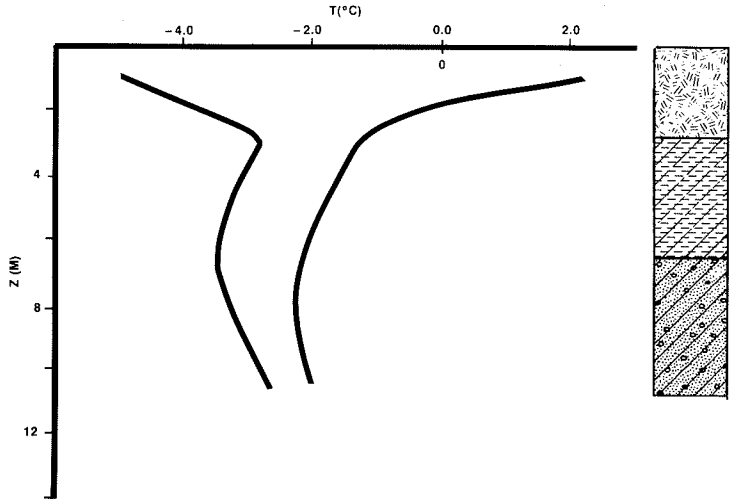
The second noteworthy observation at this site is the marked latent heat effect observed in the R.O.W. holes near the surface (1 m depth) in the fall 84/winter 85 period due to water accumulation at the surface. This has increased the average temperature at -1 m to -0.84°C in the R.O.W. compared to an average of -2.24°C at our reference hole off R.O.W. This contrast is attributable to the change of hydrological conditions created at the surface by the clearing of the R.O.W. and by pipeline construction. Thus, unless major changes occur at the surface, it can be expected that on the long term a marked warming of the ground temperature will occur in the R.O.W. with its consequent effect on the upper zone of permafrost.



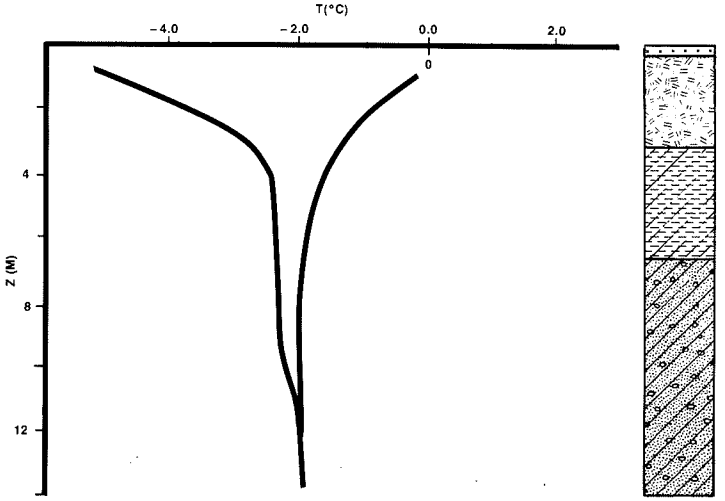
Cable T1 - Sept.84 - Sept.85



Cable T2 - Sept.84 - Sept.85



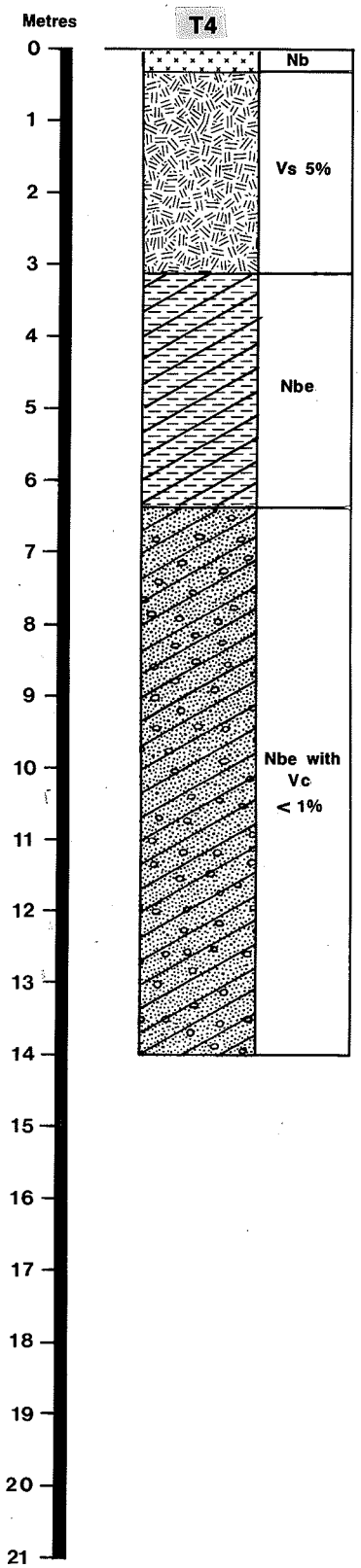
Cable T3 - Sept.84 - Sept.85

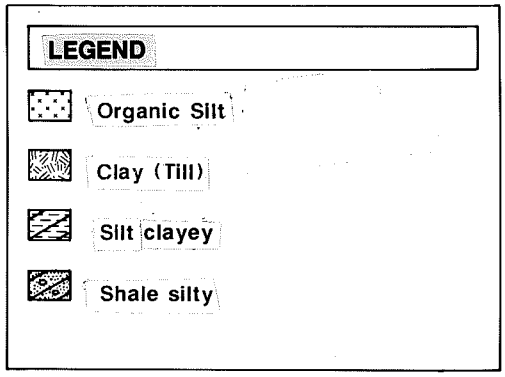


Cable T4 - Sept.84 - Sept.85

LEGEND
Z (M) Nominal depth in metres
T (C°) Temperature in Celcius
Clay (Till)
Silt
Silt clayey
Shale silty
Organic Silt

Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 84-1, Norman Wells Pump Station No. 1.





Ice content distribution observed in hole T4 at EMR/INAC site 84-1, Norman Wells Pump Station No.1

Thermistor depth at site 84-1
depth in meters

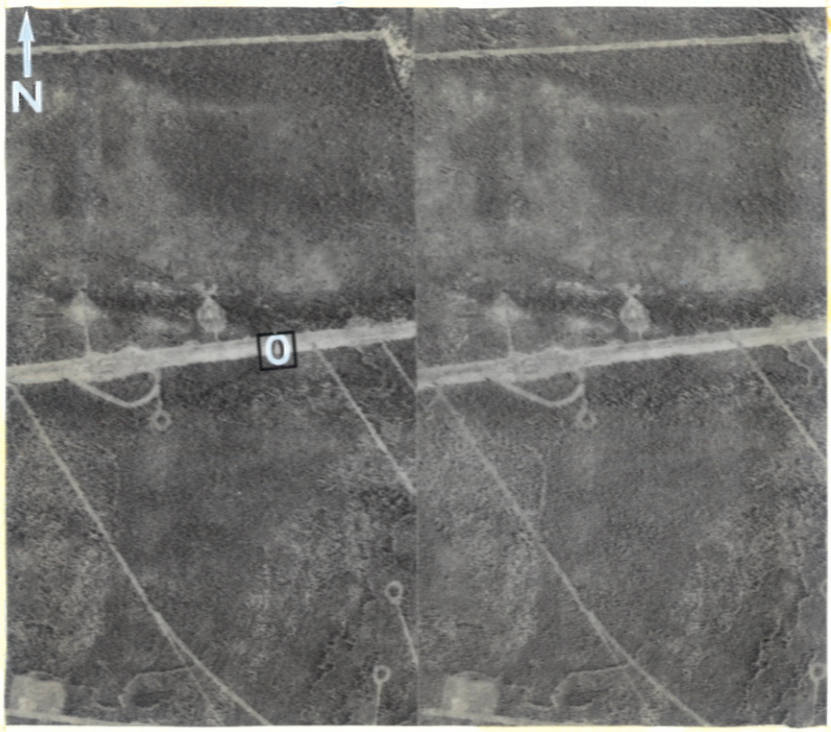
Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4	Cable T-5
1	0.5	0.5	1.0	1.0	1.0
2	1.0	1.0	2.0	2.0	2.0
3	1.5	1.5	3.0	3.0	3.0
4	2.0	2.0	4.0	4.0	4.0
5	2.5	2.5	5.0	5.0	6.0
6	3.0	3.0	6.0	6.0	8.0
7	3.5	3.5	7.0	7.0	10.0
8	4.0	4.0	8.0	8.0	12.0
9	4.5	4.5	9.0	9.0	15.0
10	5.1	5.0	10.4	11.0	18.0
11	-	-	-	13.6	19.6
Diameter of inner PVC tube	25 mm	25mm	38 mm	38 mm	25 mm

Site 84-1 in October 1983, after right-of-way (ROW) clearing.

Site 84-1 in June 1984, after pipeline burial.

Site 84-1 in October 1984, after the first summer's vegetation growth.

THERMAL FENCE
84-2A
KP 18.9



Air photos A26353 Nos. 143-144, 3 July 1983

Site number: 84-2A

Site name: Canyon Creek North

Location: 65°14' 03"N, 126°31'20"W, Kmp 18.97

Elevation: 123 metres A.S.L.

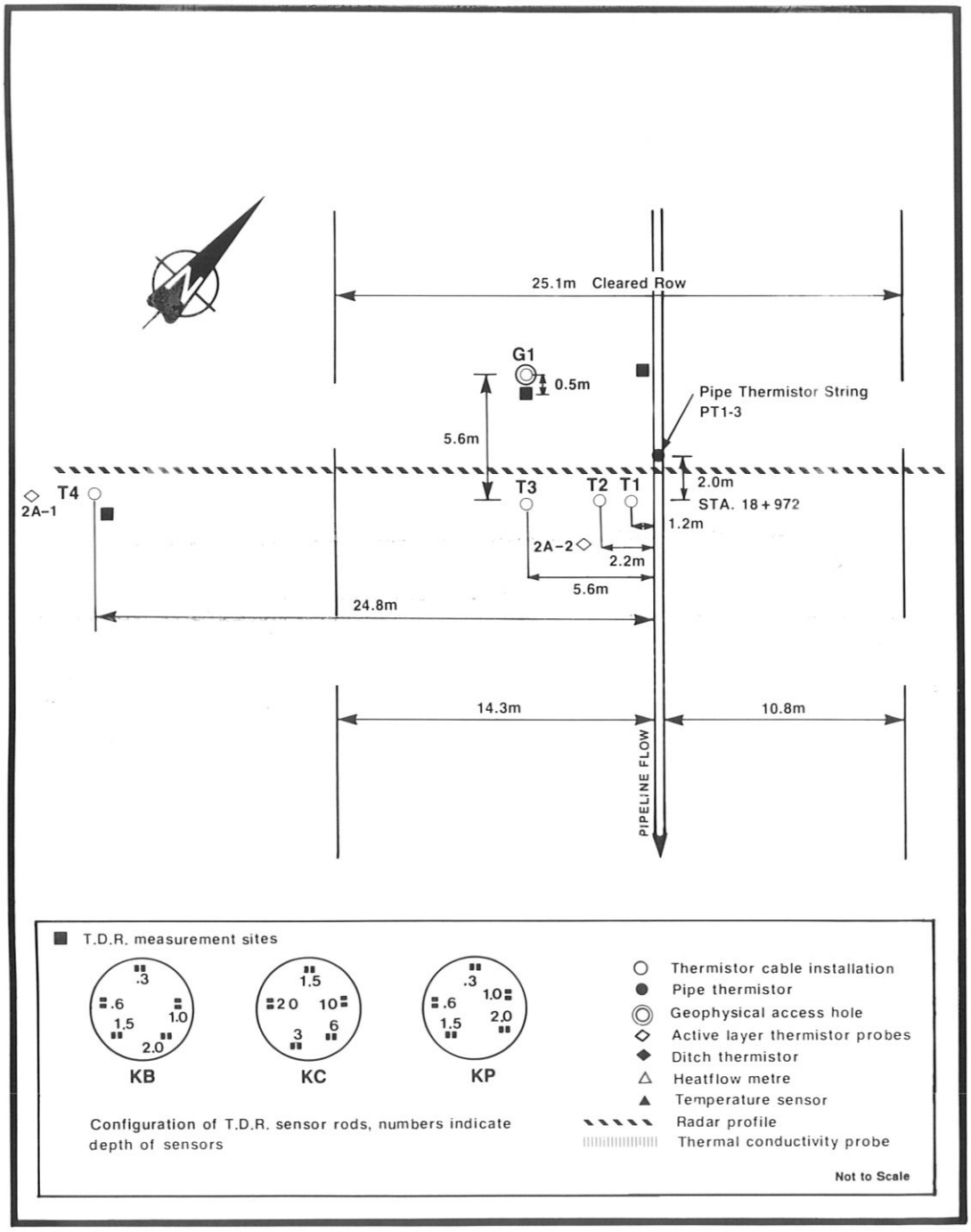
Rationale: This site was established at a level location in a morainic plain unit. It has been selected to study the thermal behavior of frozen till with low ice content in widespread permafrost. At this location permafrost is expected to be approximately 50 m thick.

Vegetation: Black spruce/lichen-moss-woodland.

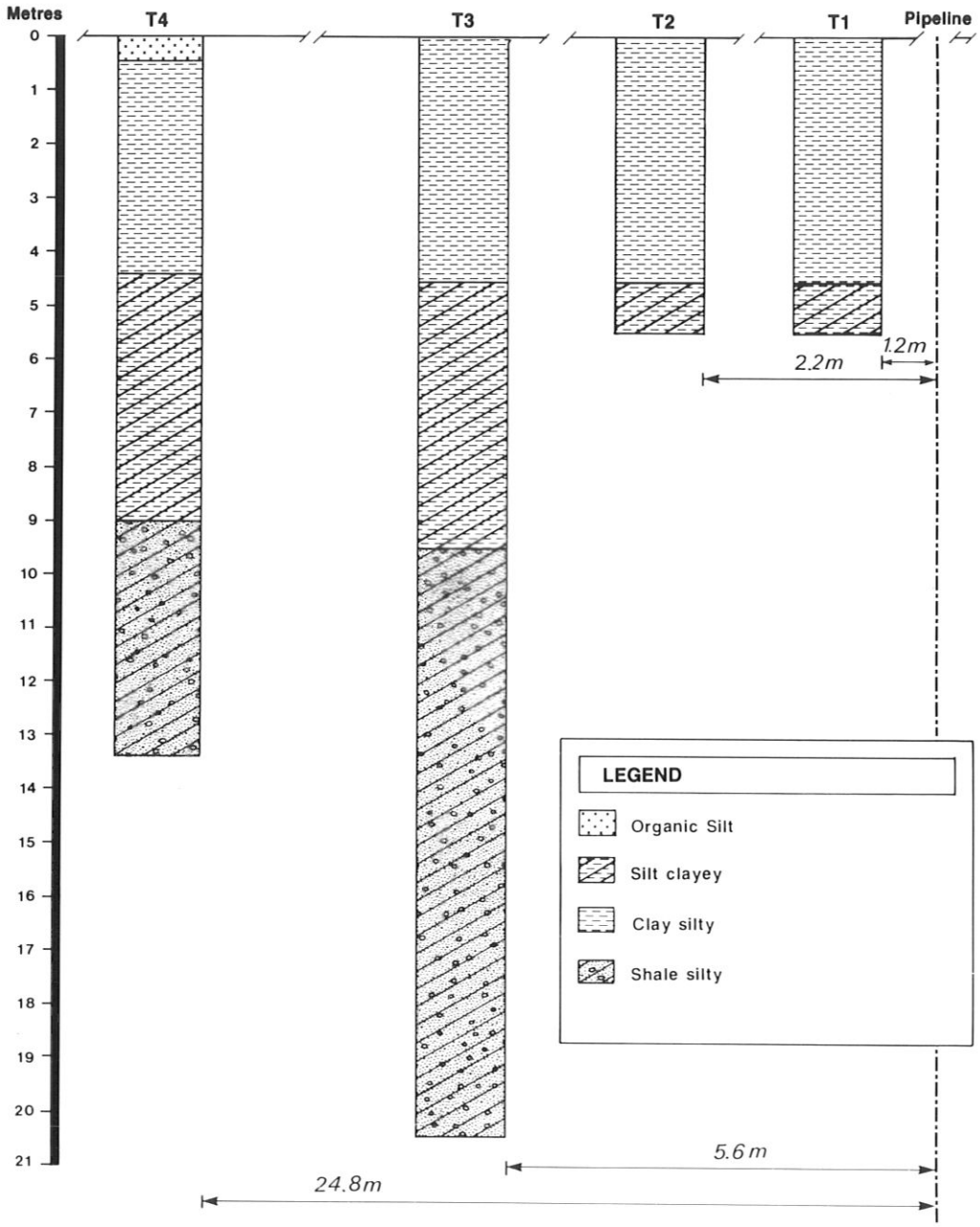
Site history: Part of the pipeline right-of-way (ROW) was cleared in the early 1960's for the Canadian National Telecommunications (CNT) telephone line alignment. Pipe is centered approximately in the center of the old disturbed area.
Trees cleared to 25.1 m width in winter 1982-82.
Trenched with ripper and backhoe.
Instrumentation holes drilled March 1984.
Restoration: fertilized and seeded March 1984.
Bench marks installed and first surface survey August 1984.

Pipe depth: 0.95 m (excluding Roach) to top of pipe.

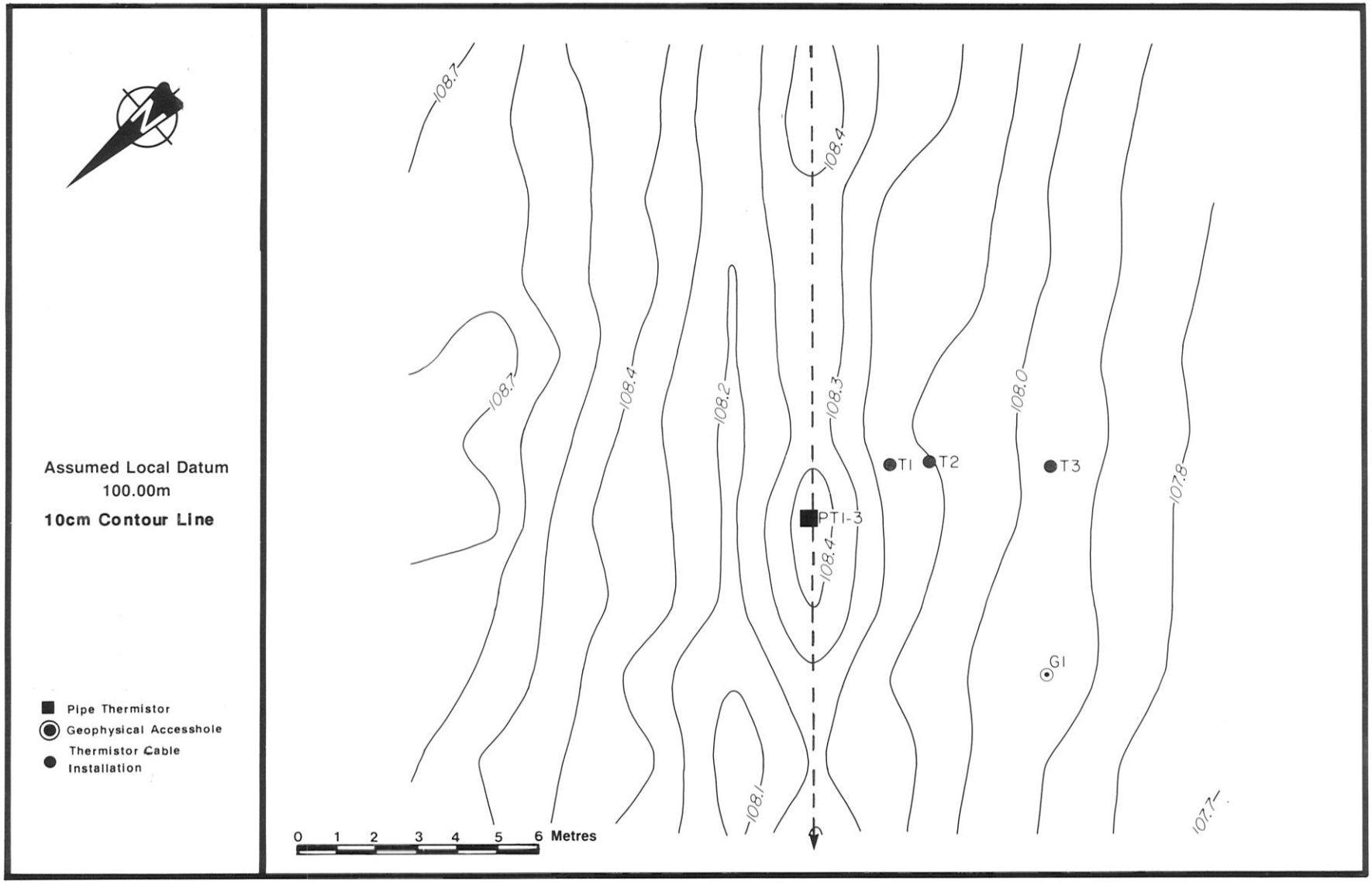
Instrumentation:
4 Multi-thermistor cables
1 Arrays of T.D.R. rods
2 Soil temperature probes
1 Geophysical access holes
1 Pipe thermistor



Site plan of EMR/INAC site 84-2A, Canyon Creek



Lithologic cross-section of site 84-2A, Canyon Creek, based on the drill logs from the thermal instrumentation hole.



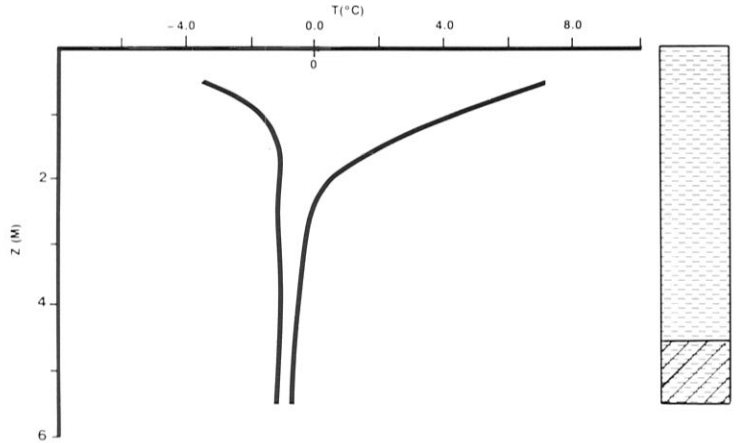
Detailed surface elevation contour map of site 84-2A, Canyon Creek, using an assumed local datum of 100 m.

Site 84-2A

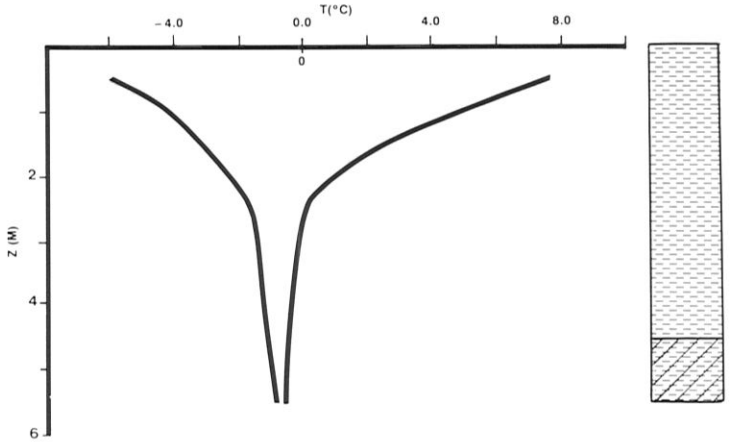
The thermal fence (84-2A) at Canyon Creek in the flat till plain shows the following trends in the period under review (summer 84 - summer 85). Active layer development in the R.O.W. as observed at cables T1 and T2 located in the old C.N.T. R.O.W. is approximately 2.25 m, it is approximately 1.3 m at cable T3 located in new R.O.W. clearing and around 85 cm at cable T4 off the R.O.W. A first approximation of permafrost thickness at this site on the basis of the temperatures measured in hole T3 indicates a thickness of about 33 meters. (See Table 1, p. of present establishment report).

The data collected during the period under review at this fence also show the extra heat loss having occurred in winter 84 because of the snow removal for pipeline construction. This is visible in the amplitude of temperature change at 5 m depth in holes T1 and T2 showing a variation of 1°C as opposed to a 0.3°C change in our reference hole (T4) off the R.O.W.

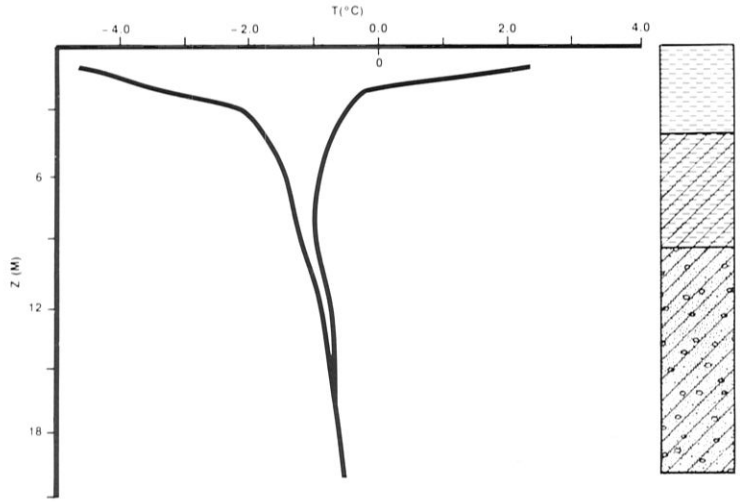
The low water/ice content of the materials at this site is also apparent in the data acquired at this location with the absence of a period caused by latent heat effects in the temperature profiles. Thus even though we can expect that a relatively important permafrost degradation will occur at this site in the new R.O.W. clearing, there should be no serious adverse surface collapse at this site.



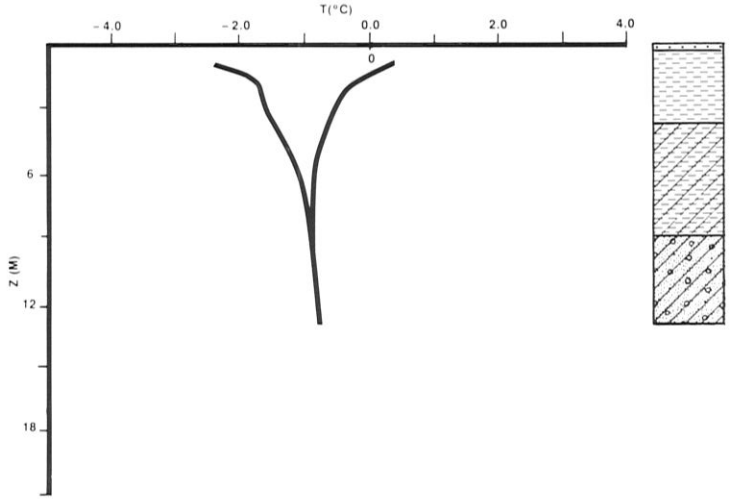
Cable T1 - Aug.84 - Sept.85



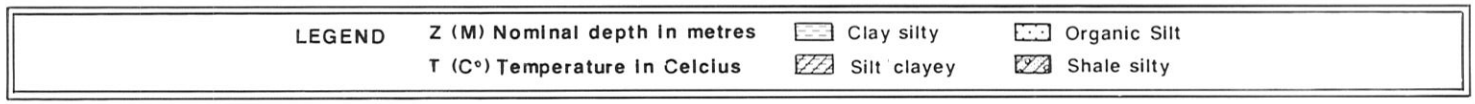
Cable T2 - Aug.84- Sept.85



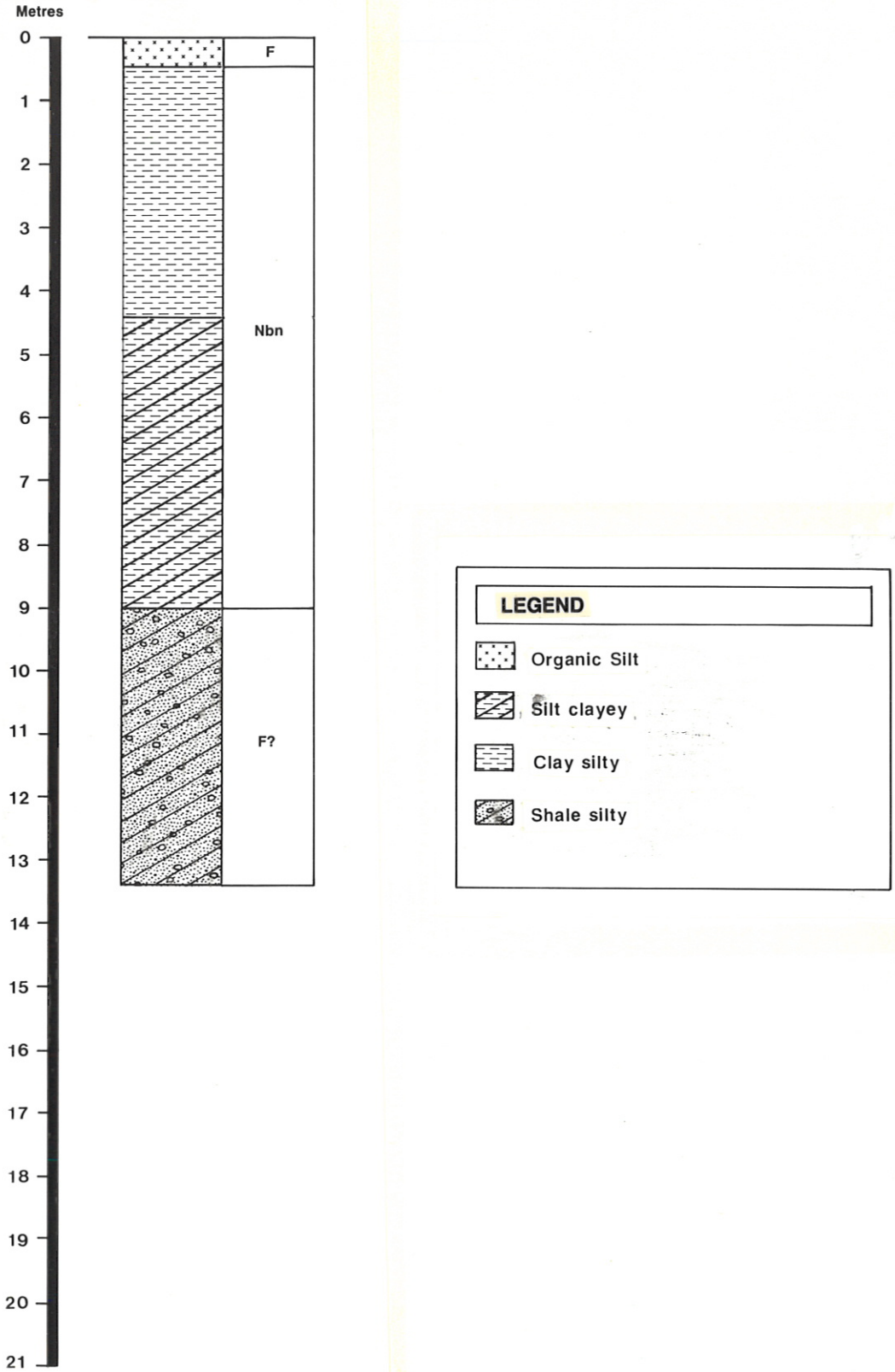
Cable T3 - Aug. 84 - Sept.85



Cable T4 Aug. 84 - Sept.85



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 84-2A, Canyon Creek.



Ice content distribution observed in hole T4 at EMR/INAC site 84-2A, Canyon Creek.

Thermistor depth at site 84-2A
depth in meters

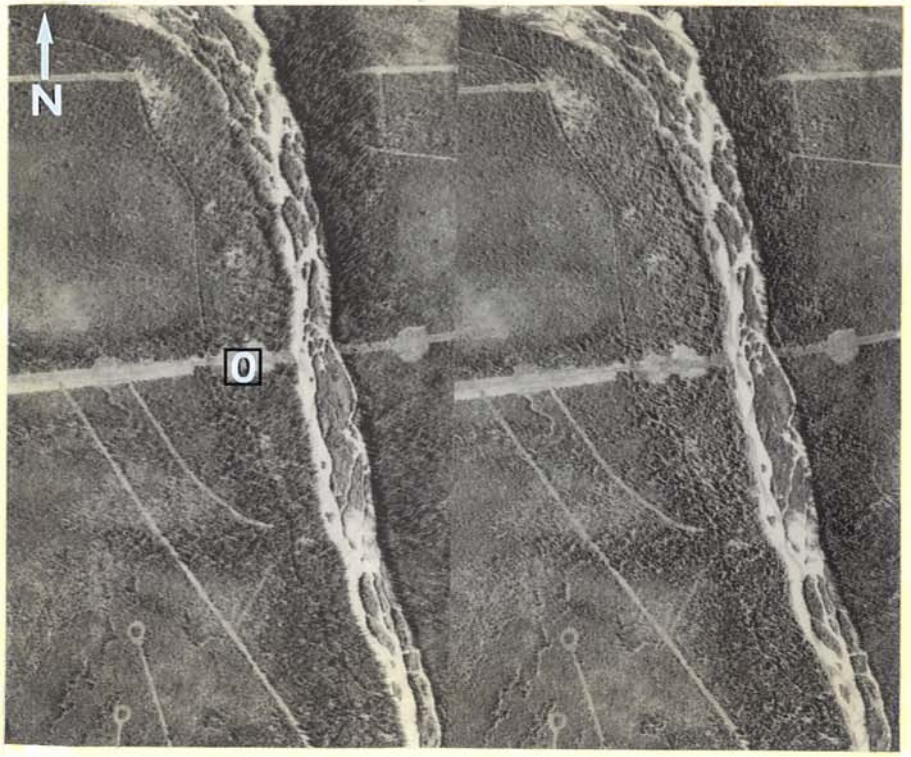
Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	1.0
2	1.0	1.0	2.0	2.0
3	1.5	1.5	3.0	3.0
4	2.0	2.0	4.0	4.0
5	2.5	2.5	6.0	5.0
6	3.0	3.0	8.0	6.0
7	3.5	3.5	10.0	7.0
8	4.0	4.0	12.0	8.0
9	4.5	4.5	15.0	9.0
10	5.3	5.1	18.0	11.0
11	-	-	19.6	13.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	38 mm

Site 84-2A in May 1983, after right-of-way (ROW) clearing.

Aerial view of site 84-2A in June 1984, after pipeline burial and instrumentation installation.

Site 84-2A in October 1984, after the first summer's vegetation growth.

THERMAL FENCE
84-2B
KP 19.3



Air photos A26353 Nos. 143-144, 3 July 1983

Site number: 84-2B

Site name: Canyon Creek Slope North

Location: 65°14' 00"N, 126°31'05"W, Kmp 19.26

Elevation: 110 metres A.S.L.

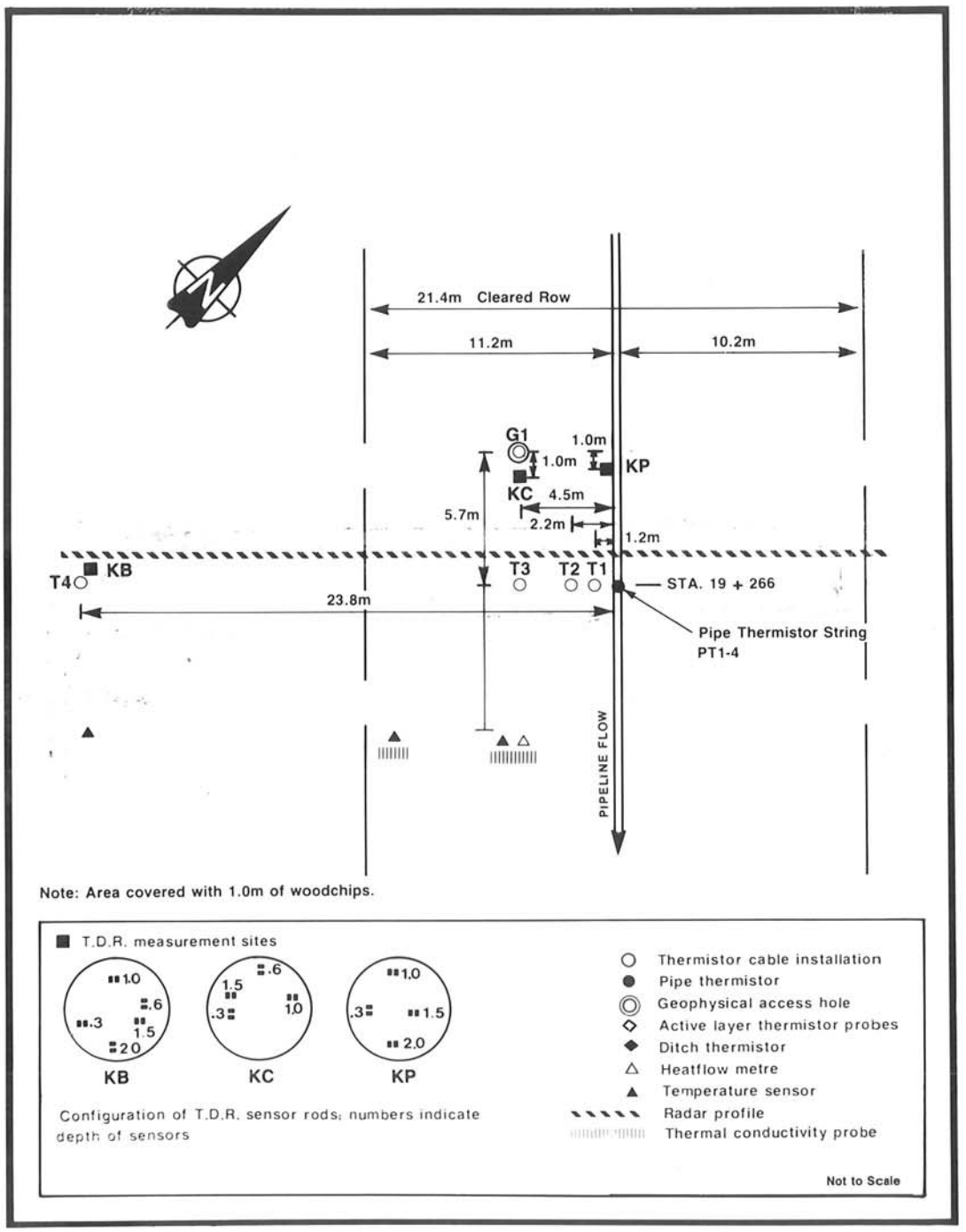
Rationale: This site was established in a steep east facing colluvium slope. It has been selected to study the thermal behavior of east facing ice rich slope in widespread permafrost. It will also be used to evaluate the effect of woodchips on the ground thermal regime and on slope stability. At this location permafrost is expected to be approximately 50 m thick.

Vegetation: White spruce/feathermoss forest (hummocky)

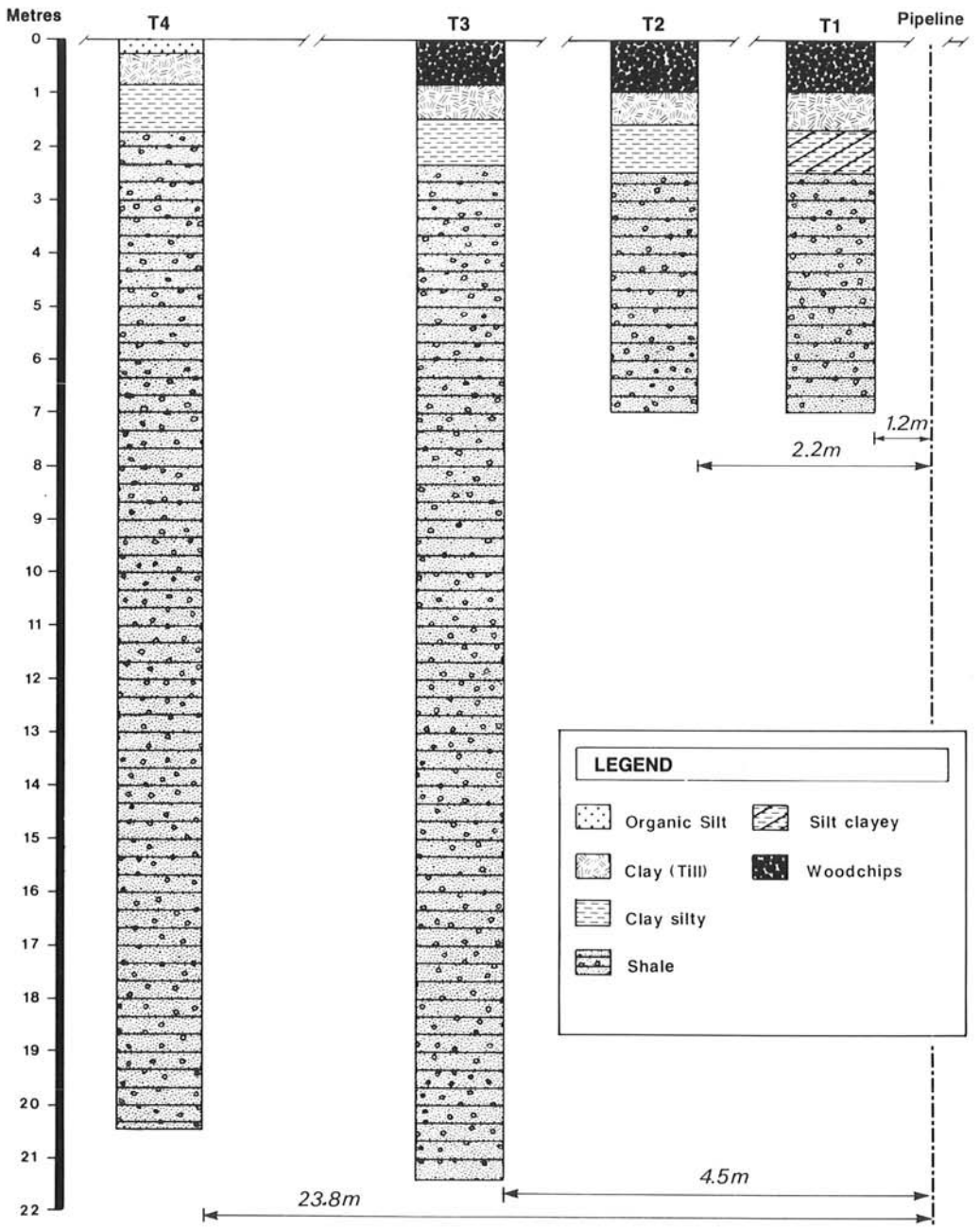
Site history:
- Trees cleared from part of ROW in the early 1960's for the CNT line, subsequently widened for a helipad in 1981.
- Trees cleared to widen ROW to 21.4 meters in winter 1984 prior to trenching.
- Trenched with bannister 710 Arctic (wheel) Ditcher in February 1984.
- Instrumentation holes drilled in March 1984.
- Woodchips placed on slope in March 1984 to a depth of 1 m.
- Bench Marks installed and first surface survey August 1984.

Pipe depth: 1.0 meter (excluding Roach) to top of pipe, and 1 meter of wood chips.

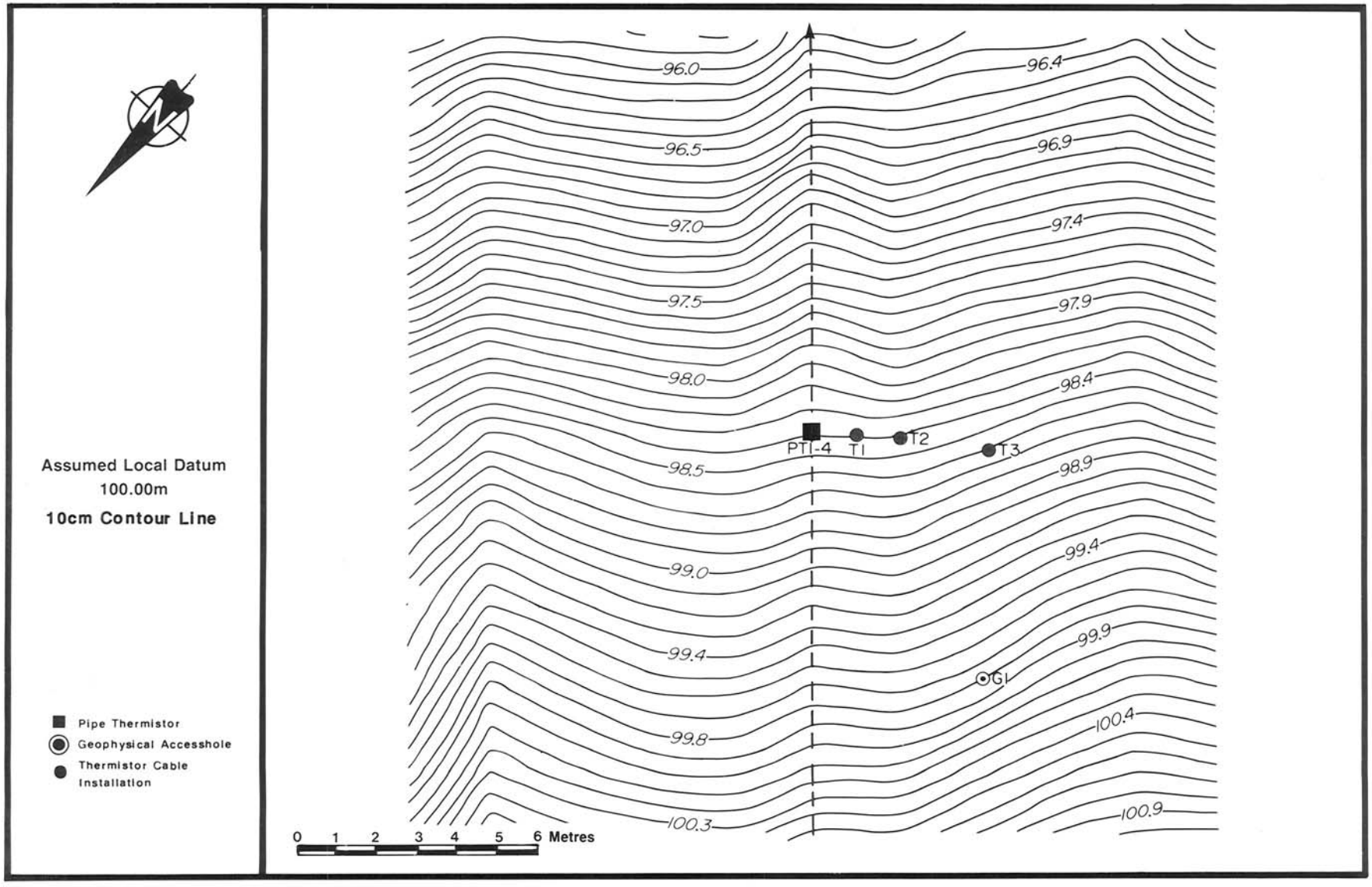
Instrumentation:
8 Multi-thermistor cables
3 Arrays of T.D.R. rods
1 Geophysical access hole
1 Pipe thermistor string
6 Thermal conductivity probes
2 Heat flow meters
1 Stevenson screen



Site plan of EMR/INAC site 84-2B, Canyon Creek



Lithologic cross-section of site 84-2B, Canyon Creek, based on the drill logs from the thermal instrumentation hole.

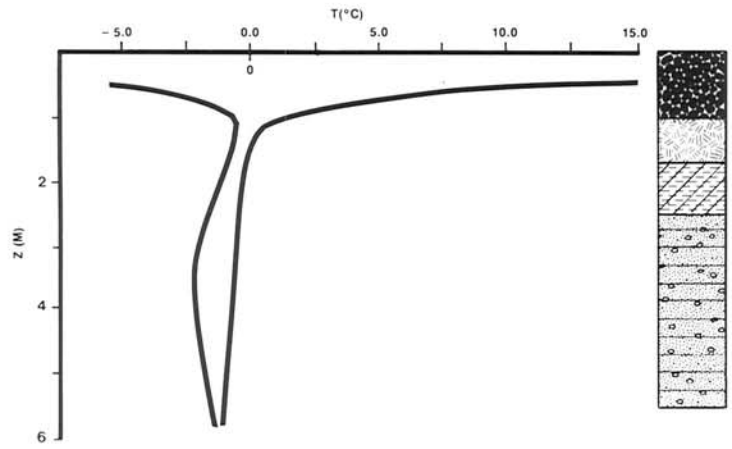


Detailed surface elevation contour map of site 84-2B, Canyon Creek, using an assumed local datum of 100 m.

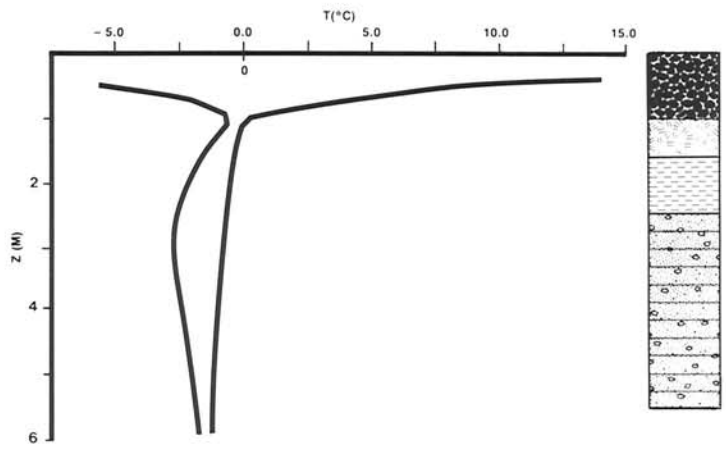
Site 84-2B

The thermal fence (84-2B) at Canyon Creek in a steep east facing slope shows the following trends in the period under review (summer 84 - summer 85). Active layer development in the R.O.W. beneath an insulating surface layer of 1 m of woodchips is approximately 30 cm. It is 1.3 m at our reference hole off the R.O.W. A first approximation of permafrost thickness at this site on the basis of temperatures measured in hole T4 indicates a thickness of about 30 m. (See Table 1, p. of present establishment report).

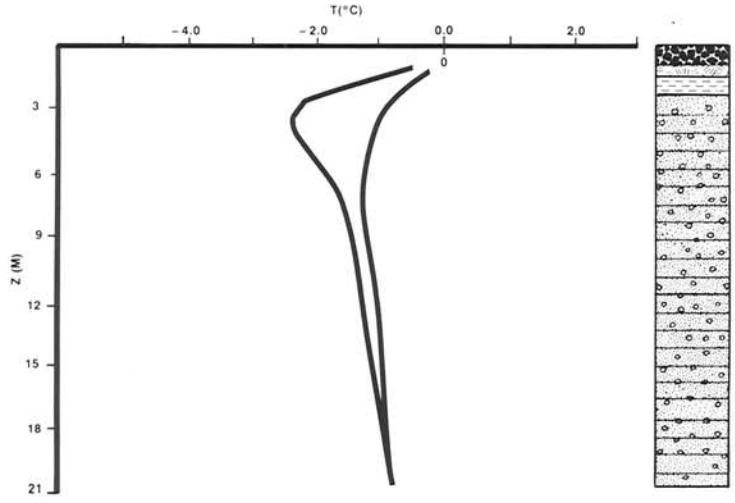
Even with the limited data base available at this site there are a number of interesting features showing up in the data. Again the temperature envelope measured at the holes in the R.O.W. show that a significant heat loss occurred in the right of way during the construction period which resulted in a marked cooling of the profile that propagated with time down to a depth of 15 m during the period. Another interesting feature at this site is the contrast between the deep temperature profiles on and off R.O.W. The entire profile in the R.O.W. (T3) is approximately 0.5°C warmer than the off R.O.W. (T4) one. This temperature difference throughout the profile is attributable to the fact that T3 is located in the old C.N.T. R.O.W. and thus is measuring a distributed temperature profile that had reached equilibrium with time. A last interesting point at this fence is the temperature distribution below the woodchip layer. It is typical of a temperature distribution below an insulating layer. It is interesting to observe that the data collected to date shows that virtually no heat loss is occurring in the ground beneath the woodchip cover during the cold period. If we in addition take into account that biodegradation activity in the woodchip generate heat and that this will occur this summer and the following summers until the biodegrading activity stops, we can forecast that the permafrost initially present beneath the woodchip cover will by that time have disappeared. At the same time a general subsidence of 20 to 25 cm in the surficial material beneath the woodchip cover will have occurred if we take into account the ice volume present in this material.



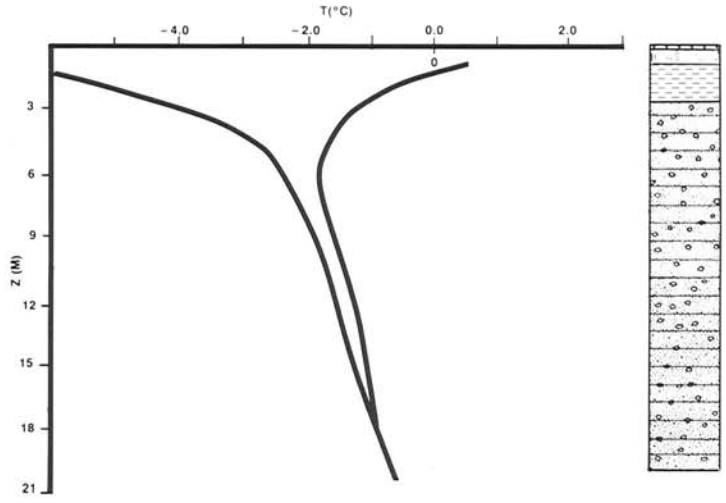
Cable T1 - Aug.84 - Sept.85



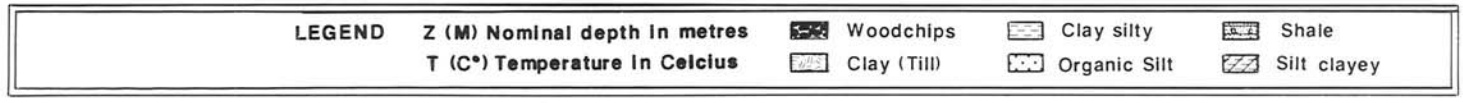
Cable T2 - Aug.84- Sept.85



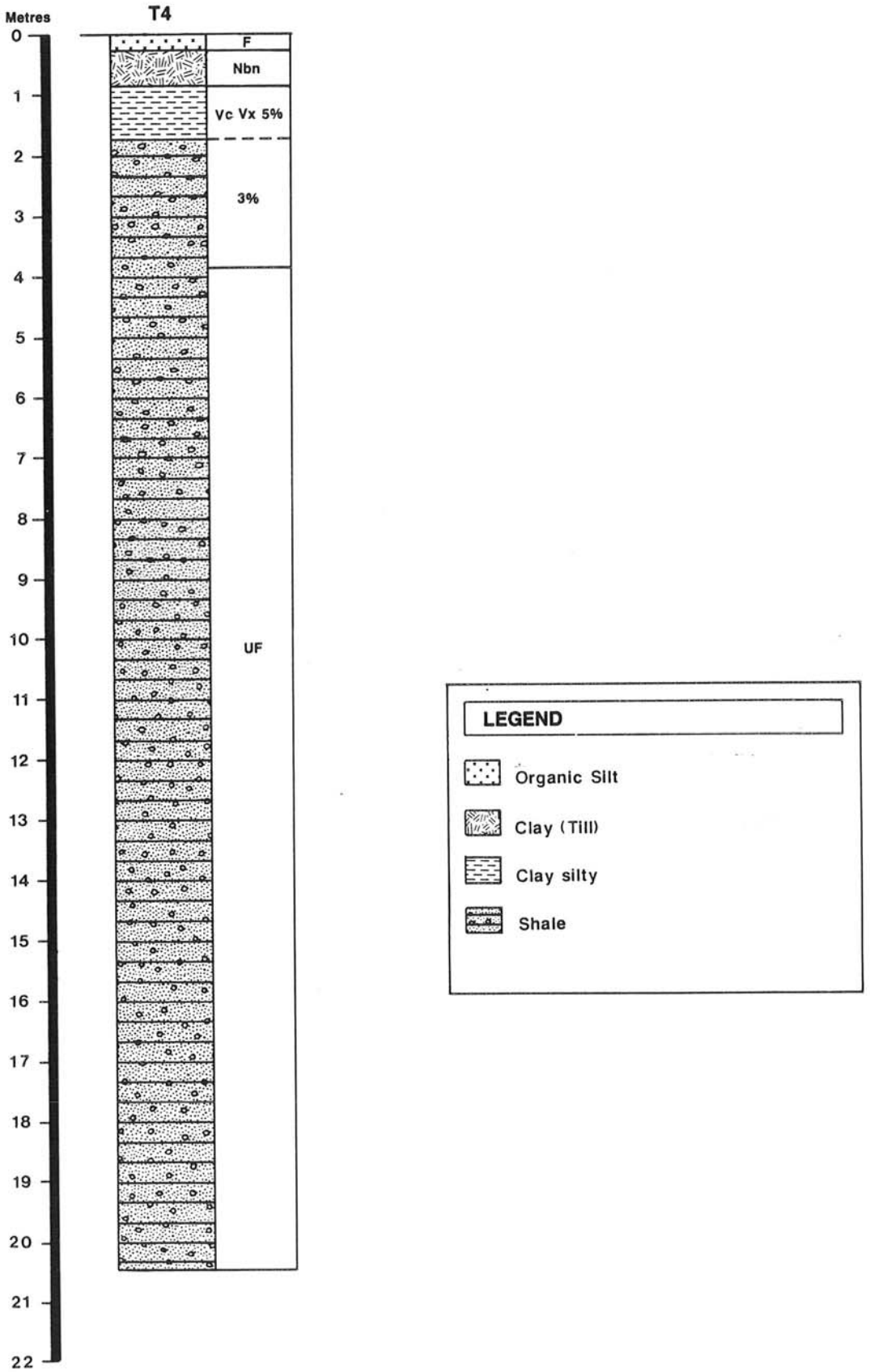
Cable T3 - Aug. 84 - Sept.85



Cable T4 Aug. 84 - Sept.85



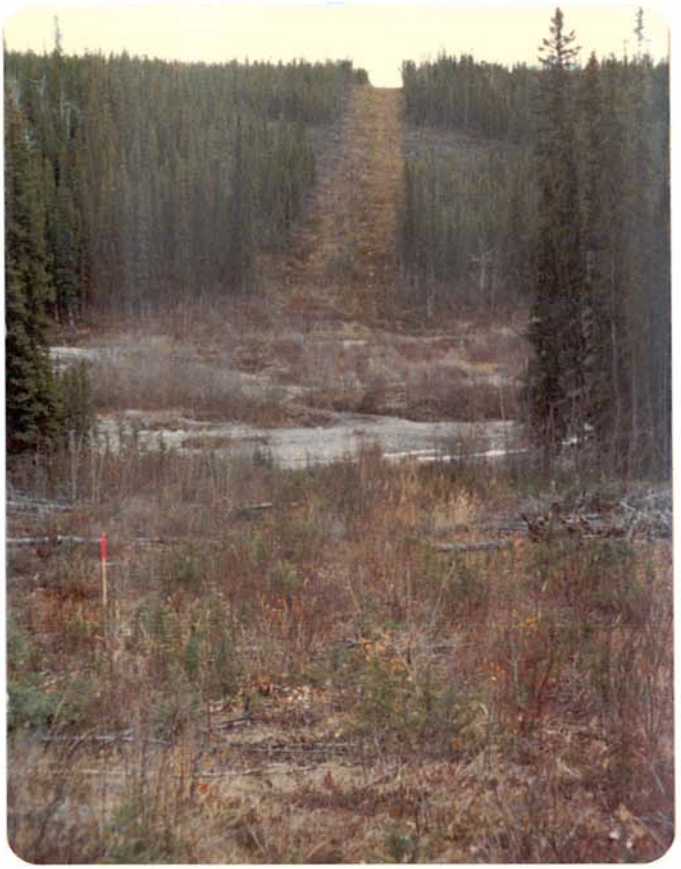
Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 84-2B, Canyon Creek.



Ice content distribution observed in hole T4 at EMR/INAC site 84-2B, Canyon Creek.

Thermistor depth at site 84-2B
depth in meters

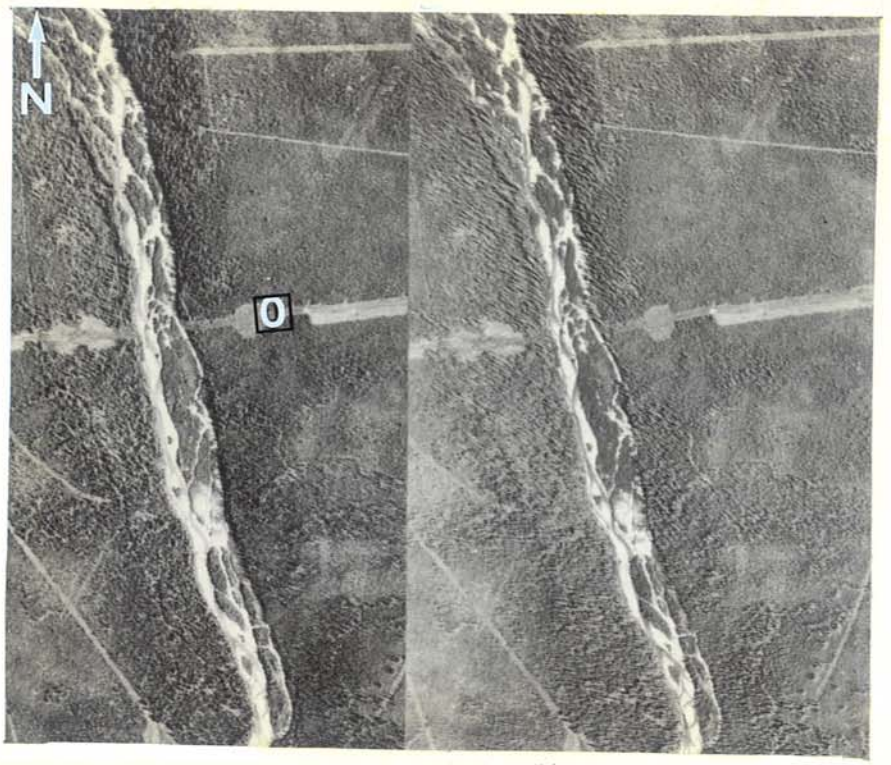
Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	1.0
2	1.0	1.0	2.0	2.0
3	1.5	1.5	3.0	3.0
4	2.0	2.0	4.0	4.0
5	2.5	2.5	6.0	6.0
6	3.0	3.0	8.0	8.0
7	3.5	3.5	10.0	10.0
8	4.0	4.0	12.0	12.0
9	4.5	4.5	15.0	15.0
10	5.8	5.9	18.0	18.0
11	-	-	20.5	20.6
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm



Site 84-2B (foreground) in October 1983, prior to the right-of-way (ROW) land clearing operations.

Site 84-2B (foreground) in June 1984, post-construction with the woodchip cover.

THERMAL FENCE
84-2C
KP 19.5



Air photos A26353 Nos. 142-143, 3 July 1983

Site number: 84-2C

Site name: Canyon Creek Slope South

Location: 65°13' 56"N, 126°30'50"W, Kmp 19.55

Elevation: 119 metres A.S.L.

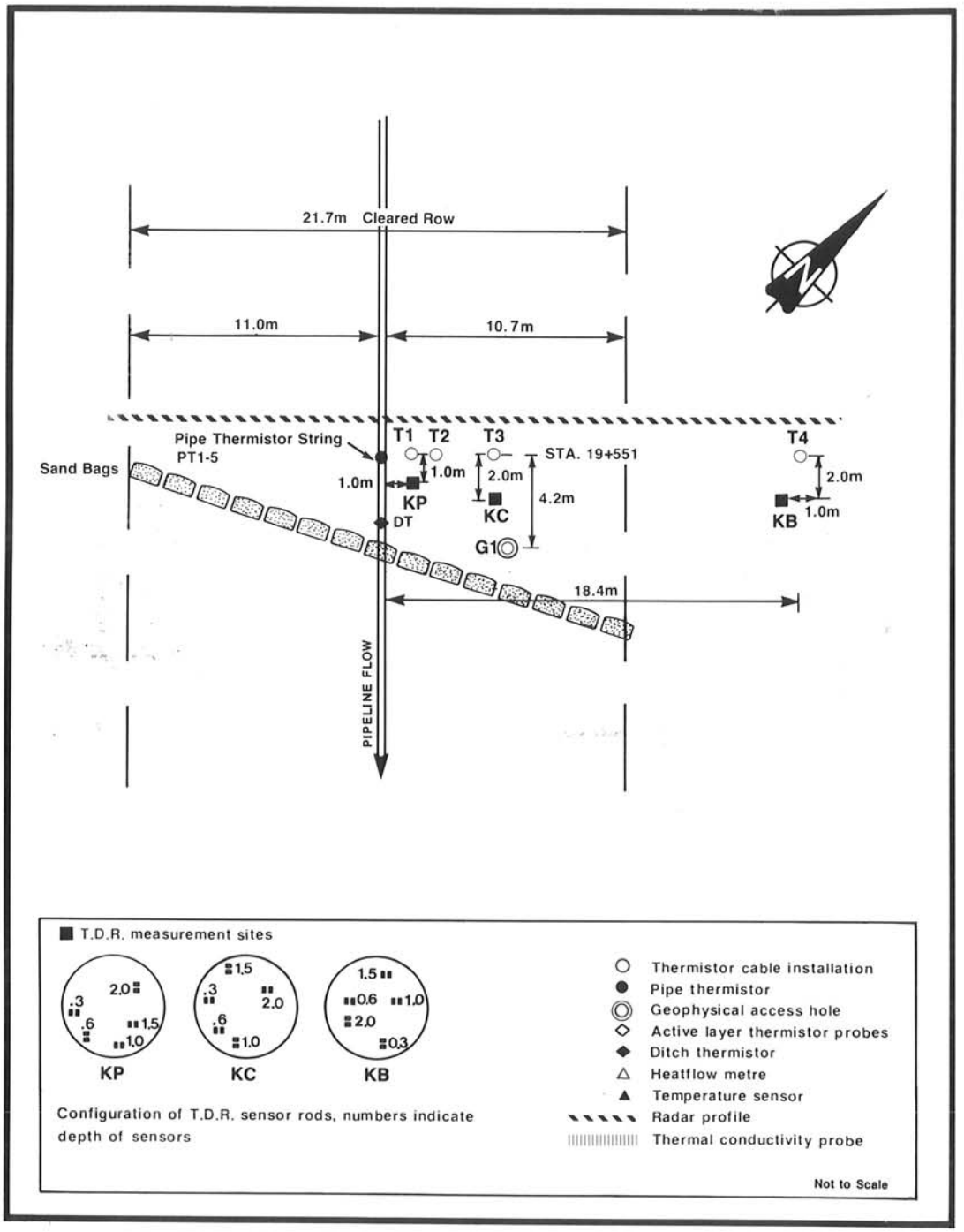
Rationale: This site was established in a steep west facing colluvium slope. It has been selected to study the thermal behavior of west facing ice rich slope in widespread permafrost. It will also be used to assess the effect of an erosion control berm unslope of the thermal fence. At this location permafrost is expected to be approximately 40 m thick.

Vegetation: Black spruce/lichen-moss (hummocky) woodland

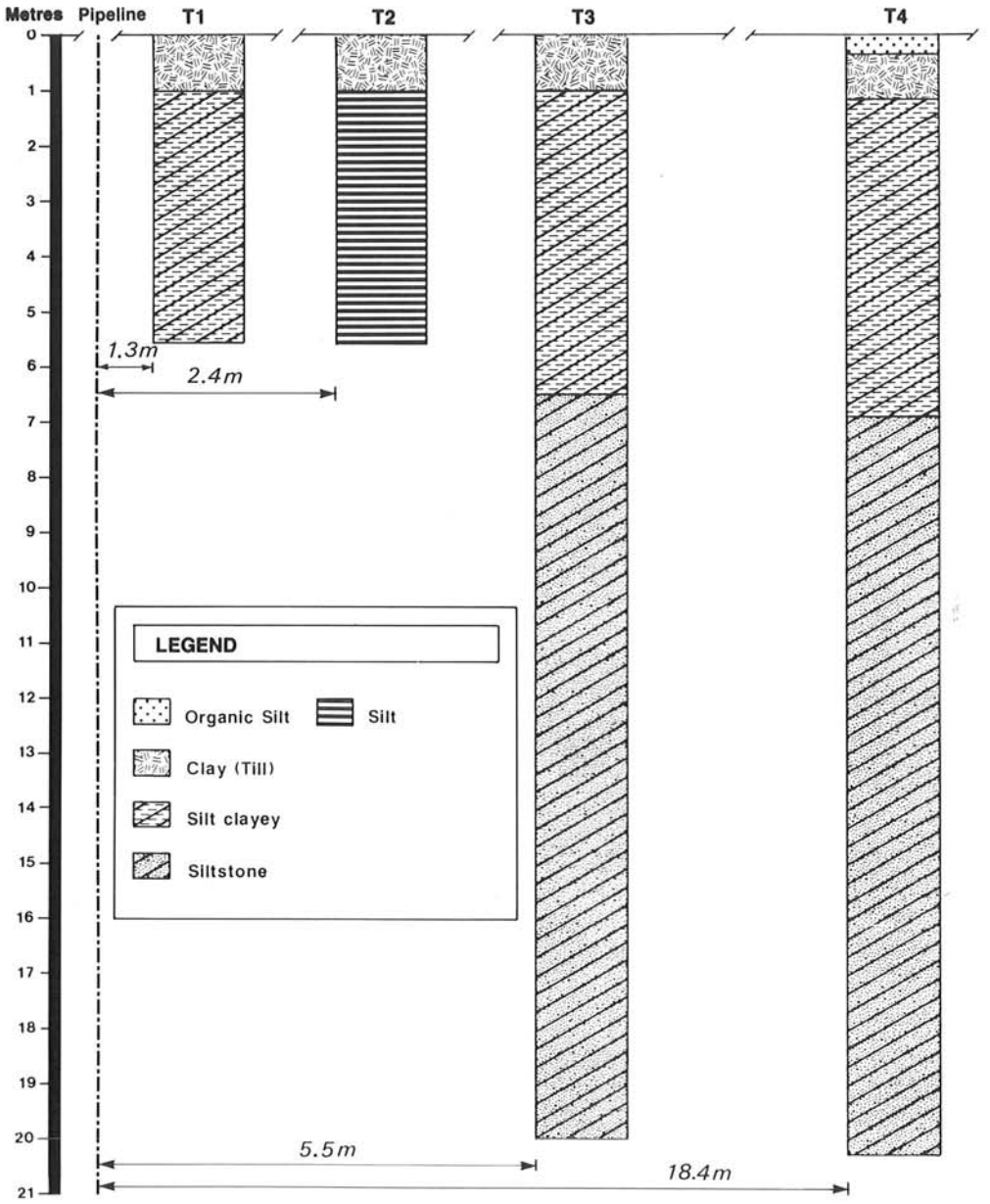
Site history:
- Part of the trees were cleared in the early 1960's along the CNT alignment, and subsequently widened for helipad in 1981, downslope from the thermal fence. Remainder of trees were cleared to 21.7 m width in January 1984.
- Trenched with bannister 710 Arctic (wheel) Ditcher in February 1984.
- Instrumentation holes drilled in March 1984.
- Restoration: erosion control berms, fertilized seeded in March 1984.
- Bench Marks installed and first surface survey August 1984.

Pipe depth: 0.95 m (excluding Roach) to top of pipe.

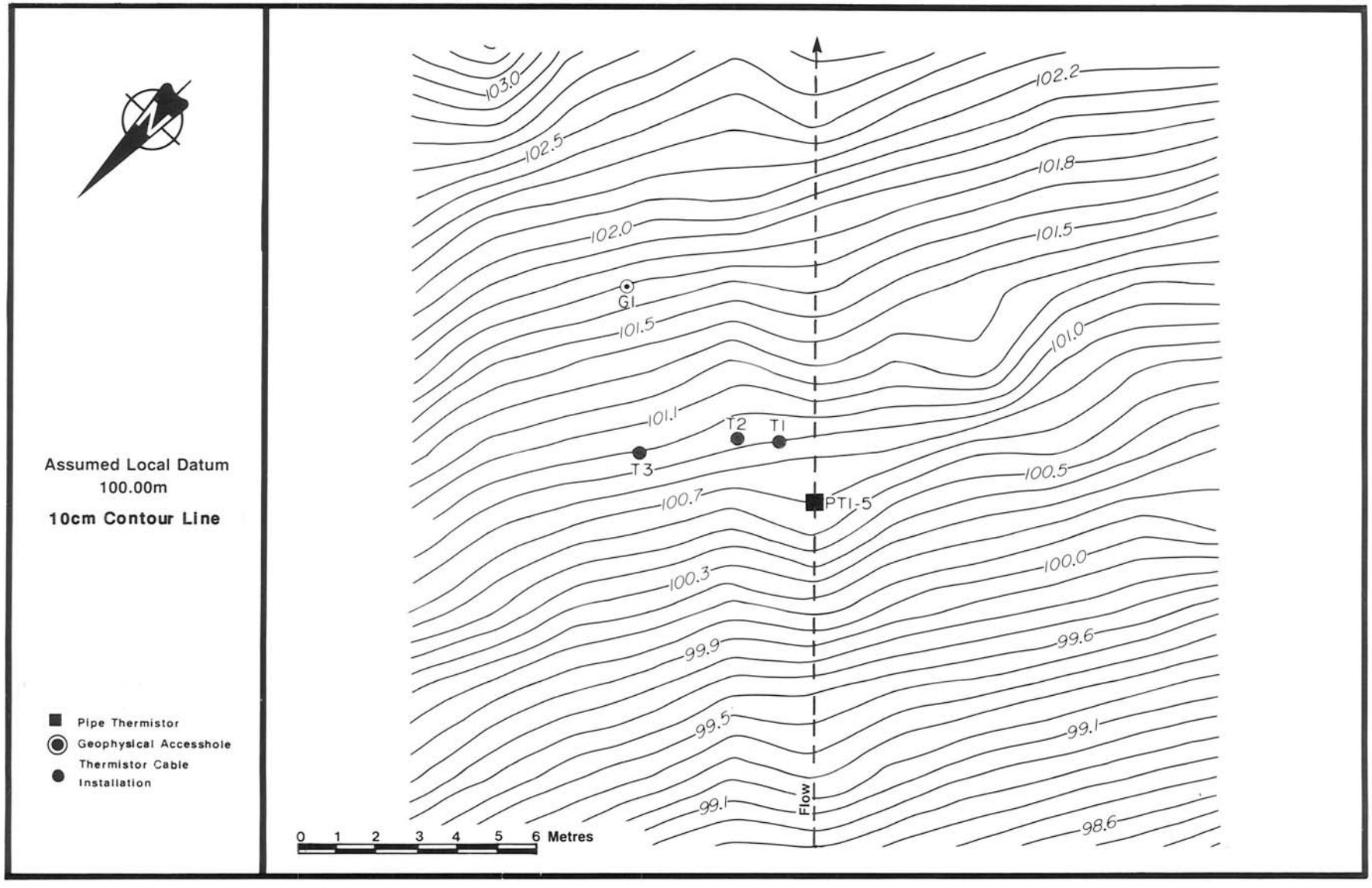
Instrumentation:
4 Multi-thermistor cables
3 Arrays of T.D.R. rods
1 Geophysical access holes
1 Pipe thermistor string
1 Ditch thermistor installation



Site plan of EMR/INAC site 84-2C, Canyon Creek



Lithologic cross-section of site 84-2C, Canyon Creek, based on the drill logs fron the thermal instrumentation hole.

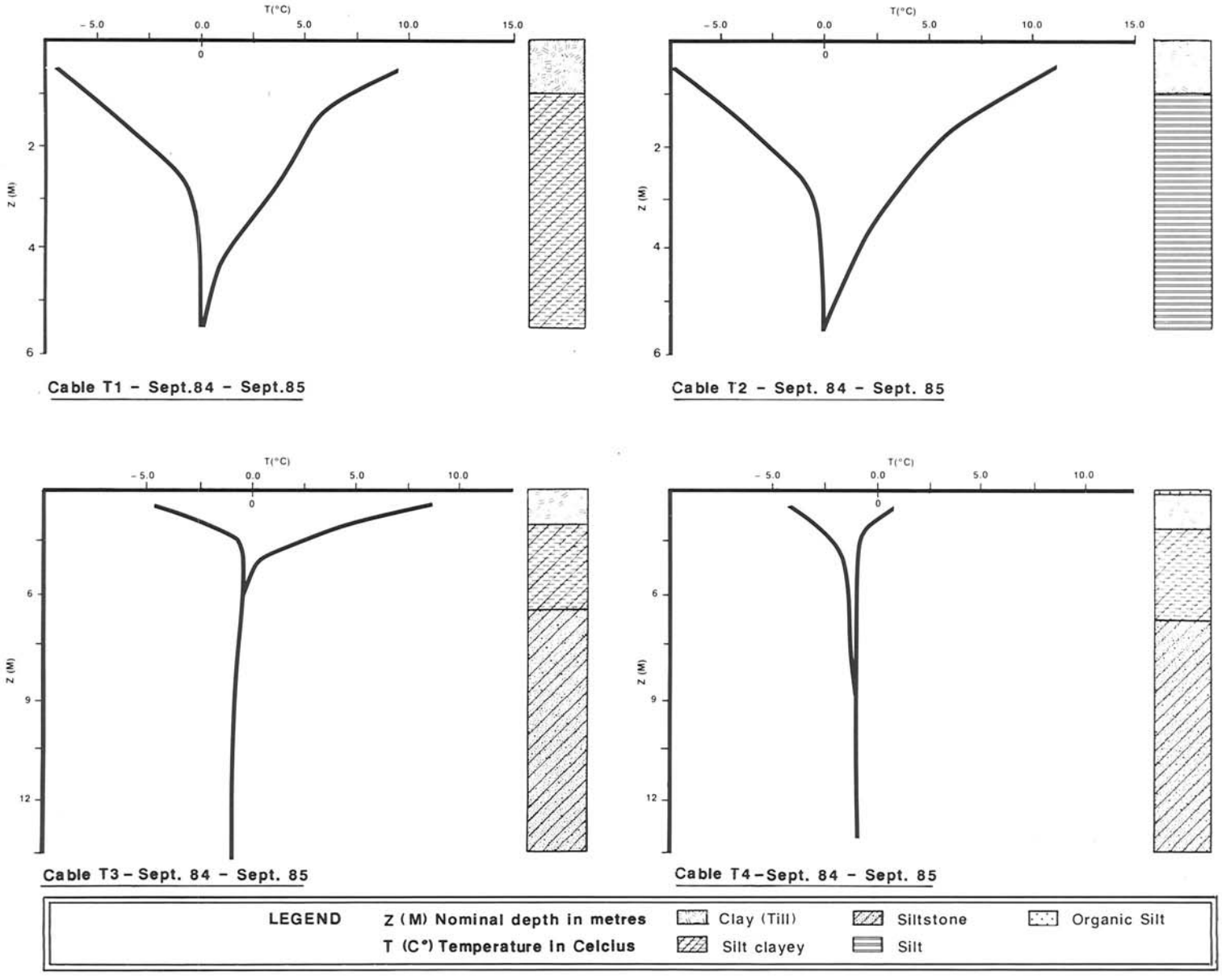


Detailed surface elevation contour map of site 84-2C, Canyon Creek, using an assumed local datum of 100 m.

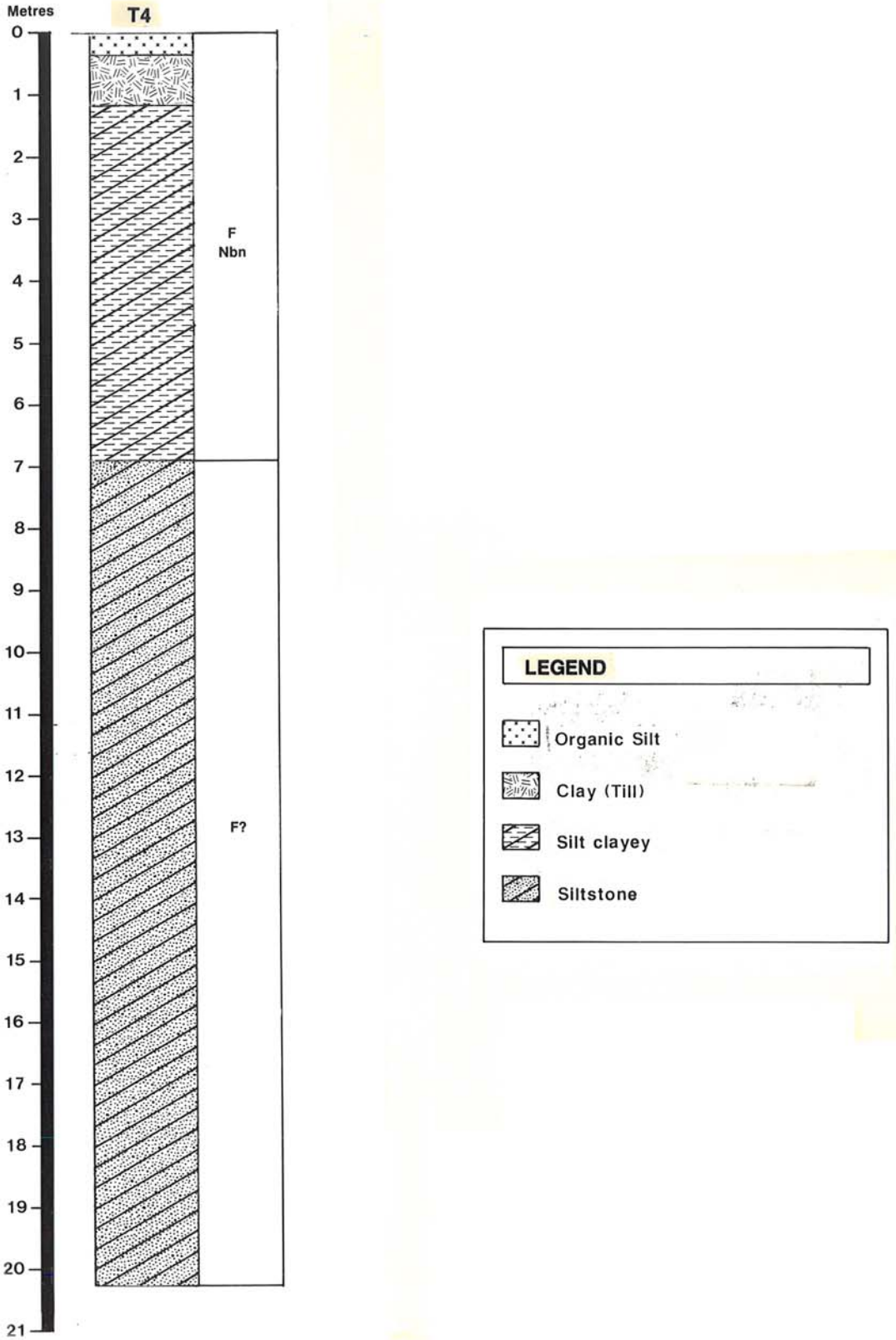
Site 84-2C

Thermal fence 84-2C located in a west facing slope at Canyon Creek shows the following trends in the period under review (summer 84 - summer 85). Active layer development in the R.O.W. as observed at cables T1, T2 and T3 located in the old C.N.T. R.O.W. is approximately 5.5 m. It is around 1.3 m at cable T4 off the R.O.W. A first approximation of permafrost thickness at this site on the basis of temperatures measured in holes T3 and T4 indicates a thickness of approximately 53 meters. (See Table 1, p. of present report).

On the basis of data collected to date at this site the following comments can be made. First, is the marked contrast between the on and off R.O.W. active layer depth, which are approximately five times greater in the R.O.W. specially in the old C.N.T. R.O.W. This leads us to point out that any further permafrost degradation occurring in the R.O.W. should have little deleterious effects in the surficial material on the R.O.W. since the thaw depth observed in the R.O.W. already penetrate through the surficial materials into bedrock. Finally the temperature profiles observed in the R.O.W. show that at this site there are virtually no latent heat effects, the magnitude of the speed of propagation of temperature changes observed at the site leading us to believe that we are almost entirely observing conductive temperature changes in the surficial material.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 84-2C, Canyon Creek.



Ice content distribution observed in hole T4 at EMR/INAC site 84-2C, Canyon Creek.

Thermistor depth at site 84-2C
depth in meters

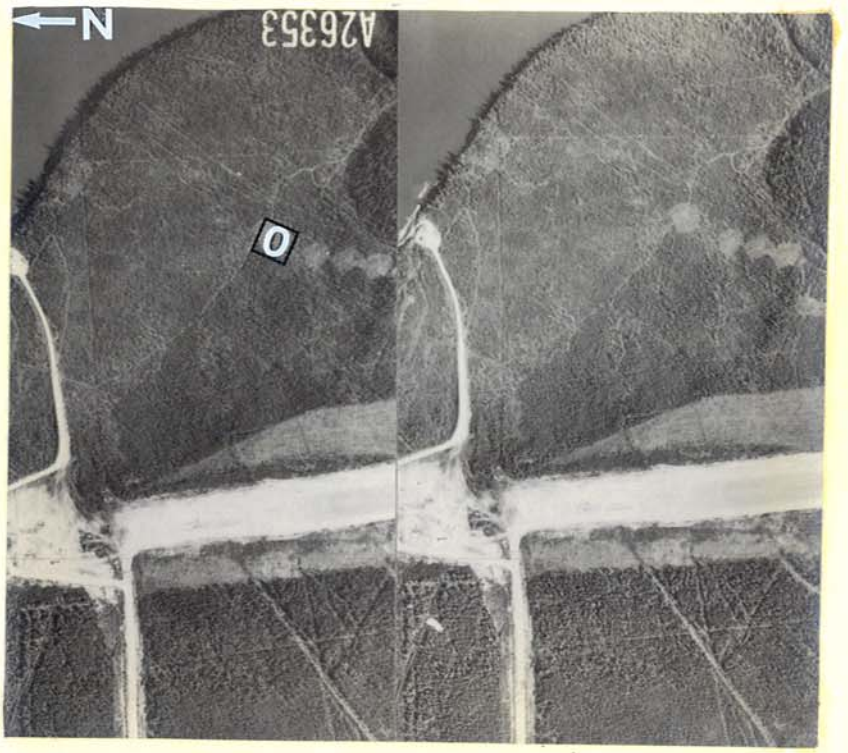
Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	1.0
2	1.0	1.0	2.0	2.0
3	1.5	1.5	3.0	3.0
4	2.0	2.0	4.0	4.0
5	2.5	2.5	6.0	6.0
6	3.0	3.0	8.0	8.0
7	3.5	3.5	10.0	10.0
8	4.0	4.0	12.0	12.0
9	4.5	4.5	15.0	15.0
10	5.8	5.5	18.0	18.0
11	-	-	19.4	20.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm

View of the old C.N.T. right-of-way (ROW) at site 84-2C (background), in May 1983.

Site 84-2C (background), post pipeline construction in June 1984.

Close up of site 84-2C in June 1984.

THERMAL FENCE
84-3A
KP 78.7



Air photos A26353 Nos. 15-16, 3 July 1983

Site number: 84-3A

Site name: Great Bear River Alluvial Terrace

Location: 64°54' 44"N, 125°34'45"W, Kmp 79.18

Elevation: 93 metres A.S.L.

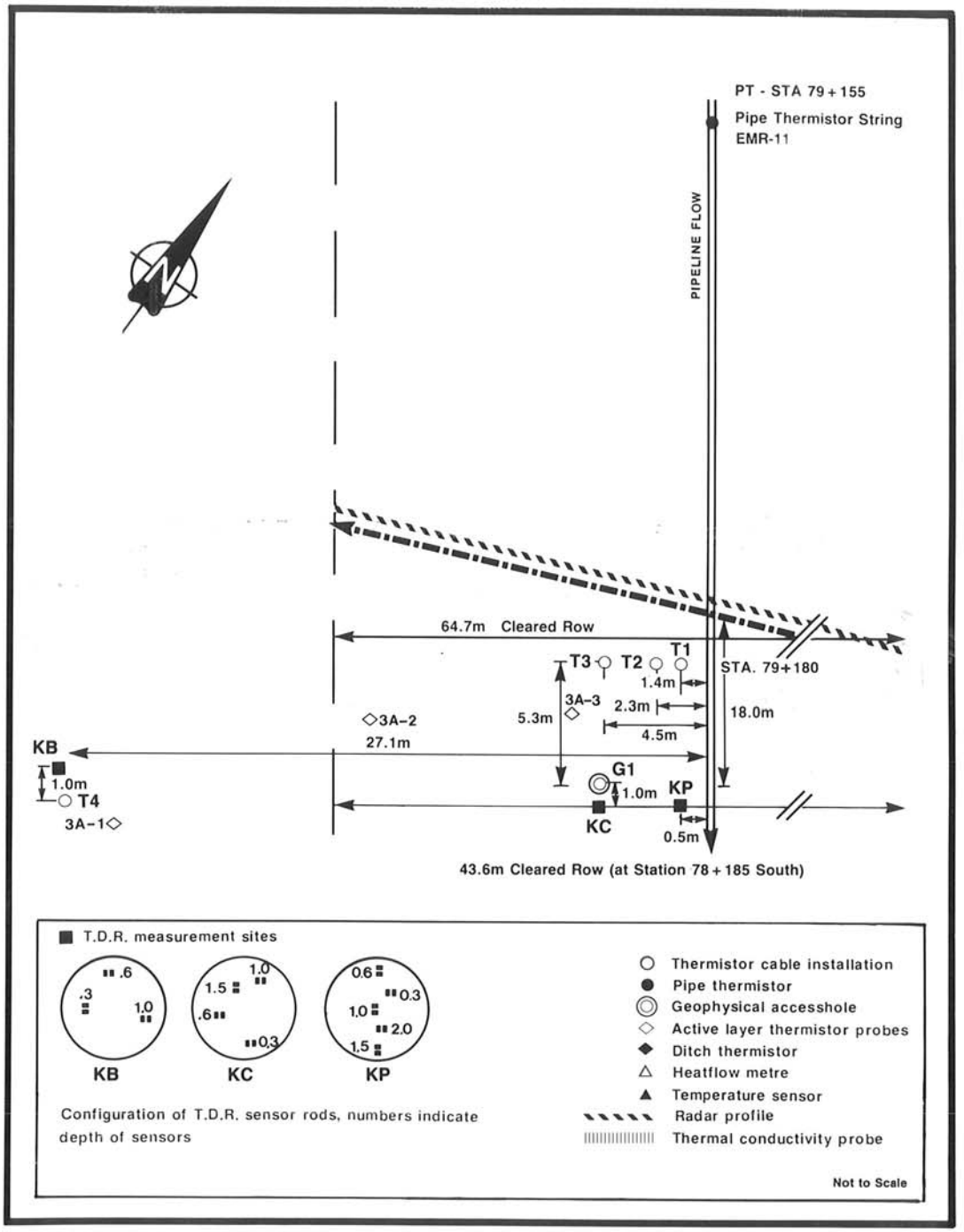
Rationale: This site was established in shallow cliff-top aeolian deposits overlying lacustrine basin deposits. It has been selected to study the thermal behavior of ice rich lacustrine deposits overlain by a veneer of aeolian deposits and forms part of a joint EMR/INAC/IPL study site to investigate the thermal behavior of a major north facing slope in widespread permafrost. At this location permafrost is expected to be approximately 50 m thick.

Vegetation: Black spruce/ericaceous shrubs, lichen-moss (hummocky) woodland.

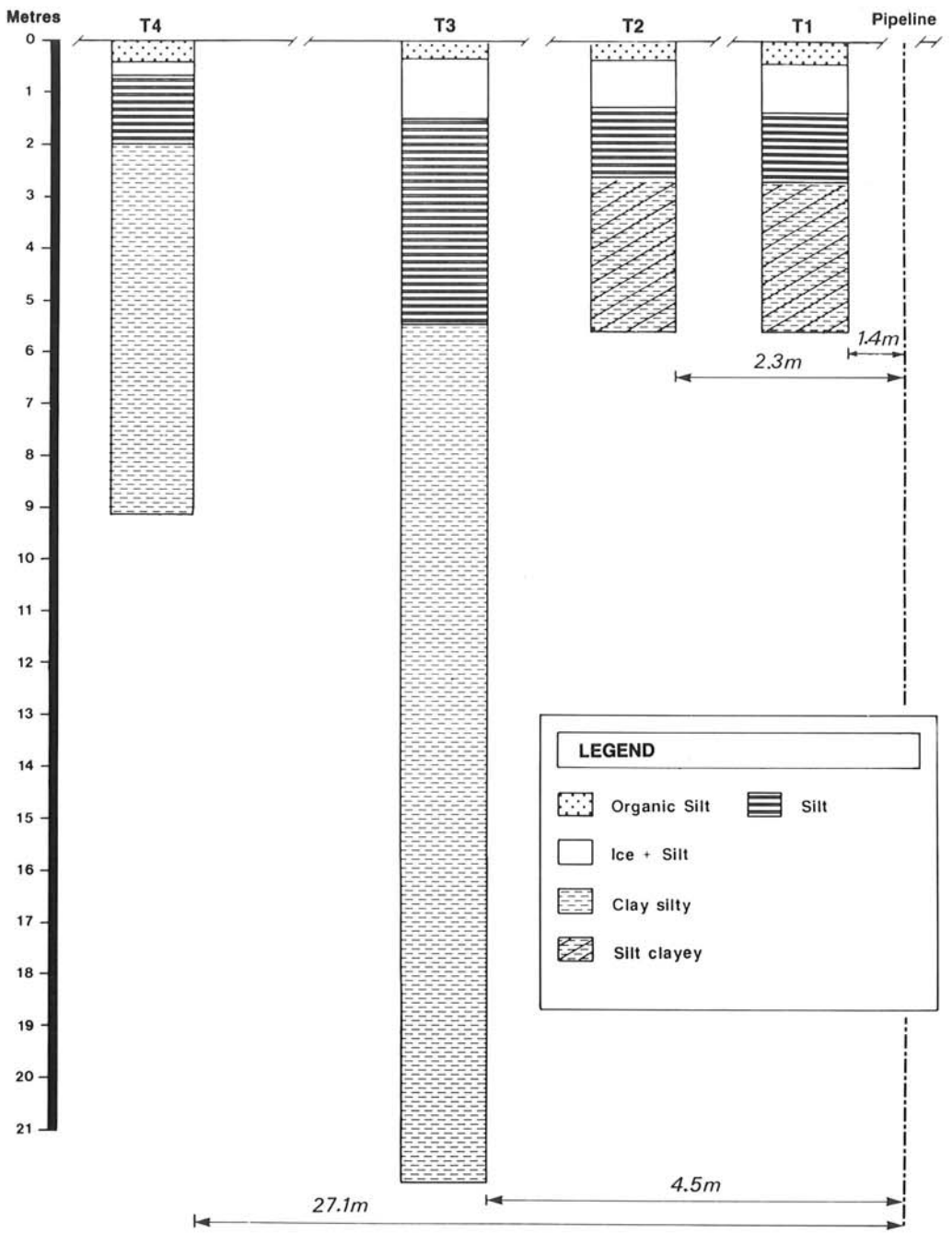
Site history:
- Part of site cleared of trees along a narrow (1-2 m) survey line (date unknown). Trees hand cleared to a width of 16.3 m in January 1984.
- Trenched with a Bannister 710 Arctic (wheel) Ditcher in February 1984.
- Instrumentation holes drilled in March 1984.
- Restoration: Fertilized and seeded in March 1984.
- Bench Marks installed and first surface survey in August 1984.

Pipe depth: 0.85 m (excluding Roach) to top of pipe.

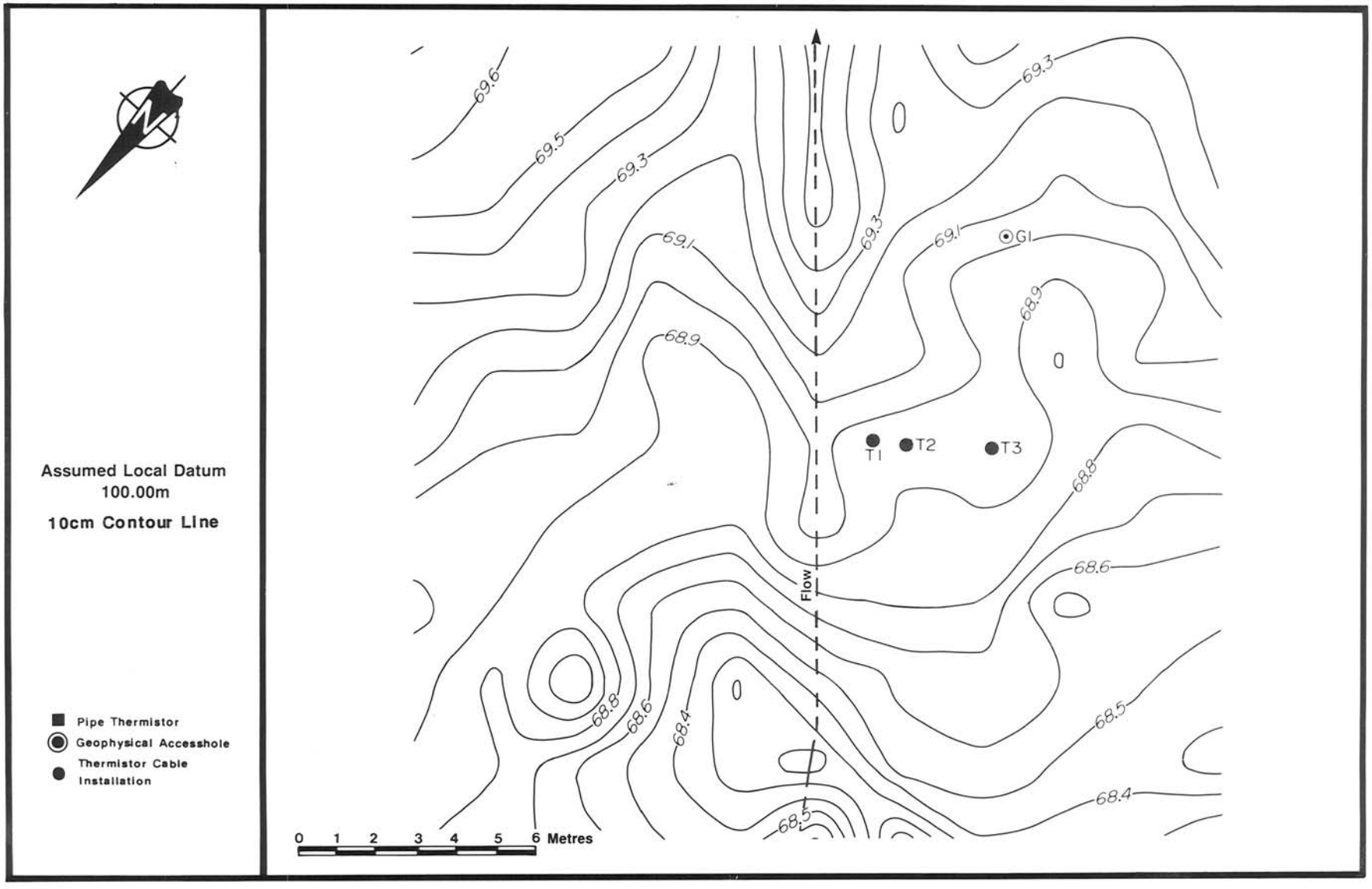
Instrumentation:
4 Multi-thermistor cables
3 Arrays of T.D.R. rods
1 Geophysical access holes
1 Pipe thermistor string (located 13 m north of fence)



Site plan of EMR/INAC site 84-3A, Great Bear River



Lithologic cross-section of site 84-3A, Great Bear River, based on the drill logs from the thermal instrumentation hole.

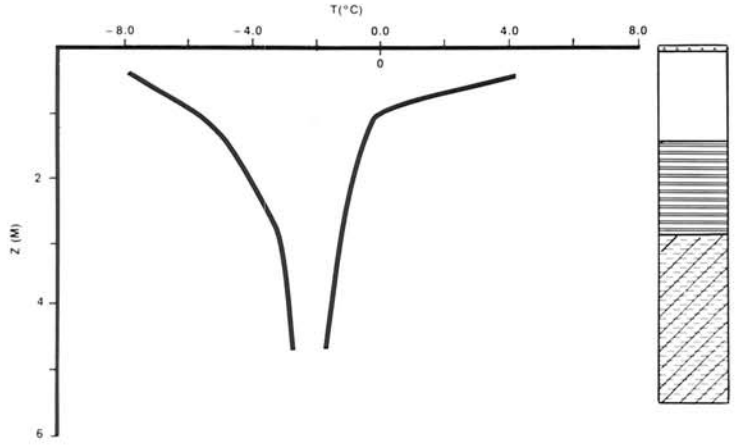


Detailed surface elevation contour map of site 84-3A, Great Bear River, using an assumed local datum of 100 m.

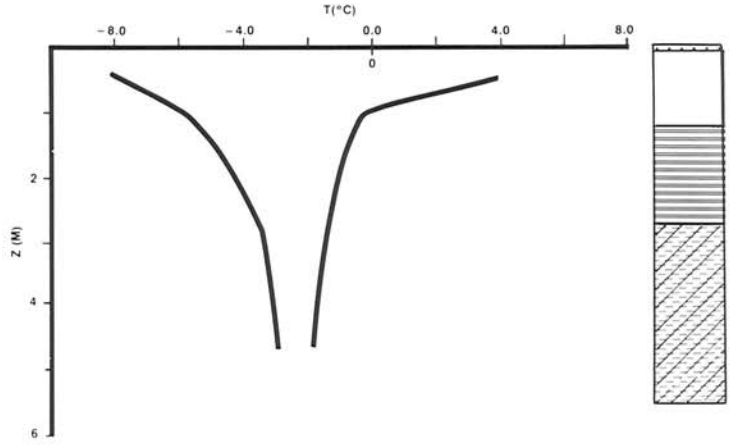
Site 84-3A

Thermal fence 84-3A at the bottom of a north facing slope at Great Bear River shows the following trends in the period under review (summer 84 - summer 85). Active layer development in the newly cleared R.O.W. for the pipeline as observed at cables T1, T2 and T3 is approximately 80 cm whereas it is only about 25 cm at cable T4 off the R.O.W. A first approximation of permafrost thickness at this site on the basis of the temperatures measured in hole T3 indicates a thickness of about 74 meters.

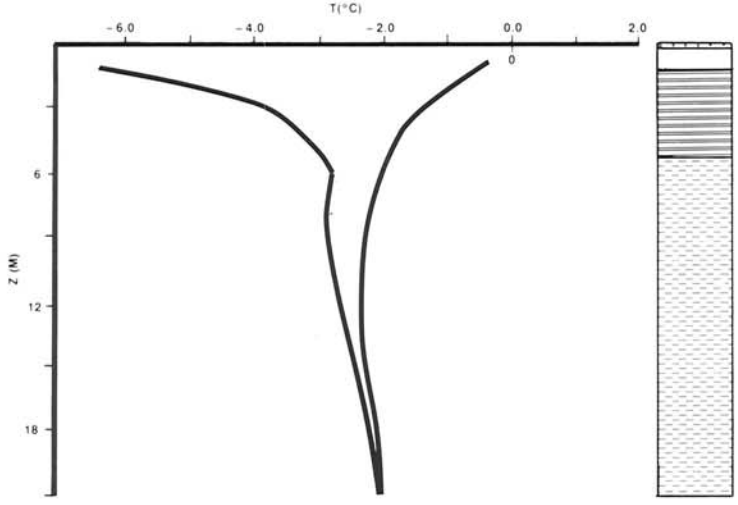
The data collected to date at this site shows that the temperatures observed on the R.O.W. wells indicate that a substantial heat loss occurred in the R.O.W. during winter 84 at construction time. This heat loss can be directly related to the removal of the snow cover. The magnitude of the differential active layer development noted at this site is another interesting feature of this site, specially when we take into account the extremely high ice content of the surficial material at this site already there is evidence of thermokarsting at the surface, which is not surprising since our boreholes indicate that in the first 2.8 m of surficial material there is approximately 1 m of pure ice. Thus this site will prove particularly interesting as the effect of the disturbance at the surface, slowly stabilize with time.



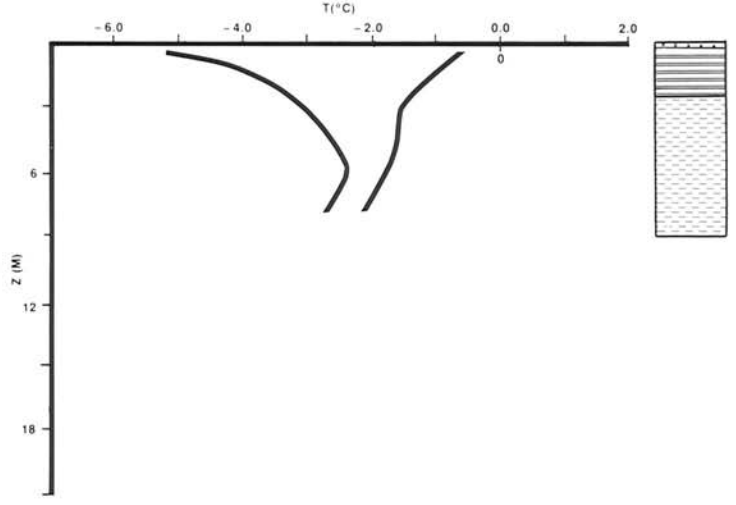
Cable T1 - Sept.84 - Sept.85



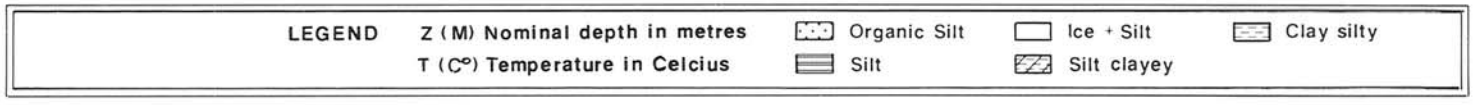
Cable T2 - Sept. 84 - Sept. 85



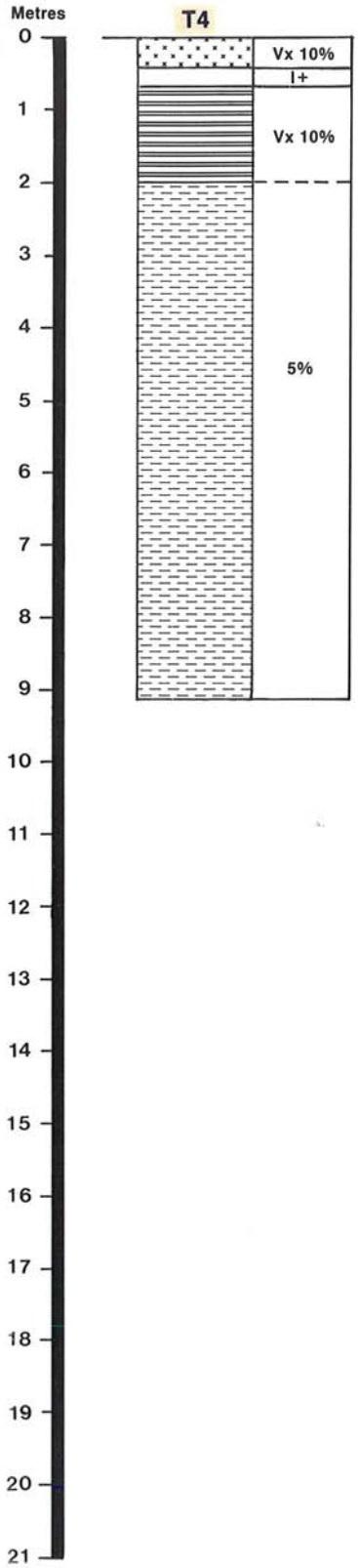
Cable T3 - Sept. 84 - Sept. 85

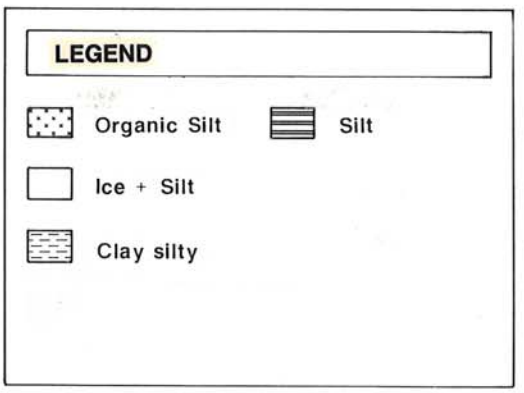


Cable T4 - Sept. 84 - Sept. 85



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 84-3A, Great Bear River.





Ice content distribution observed in hole T4 at EMR/INAC site 84-3A, Great Bear River.

Thermistor depth at site 84-3A
depth in meters

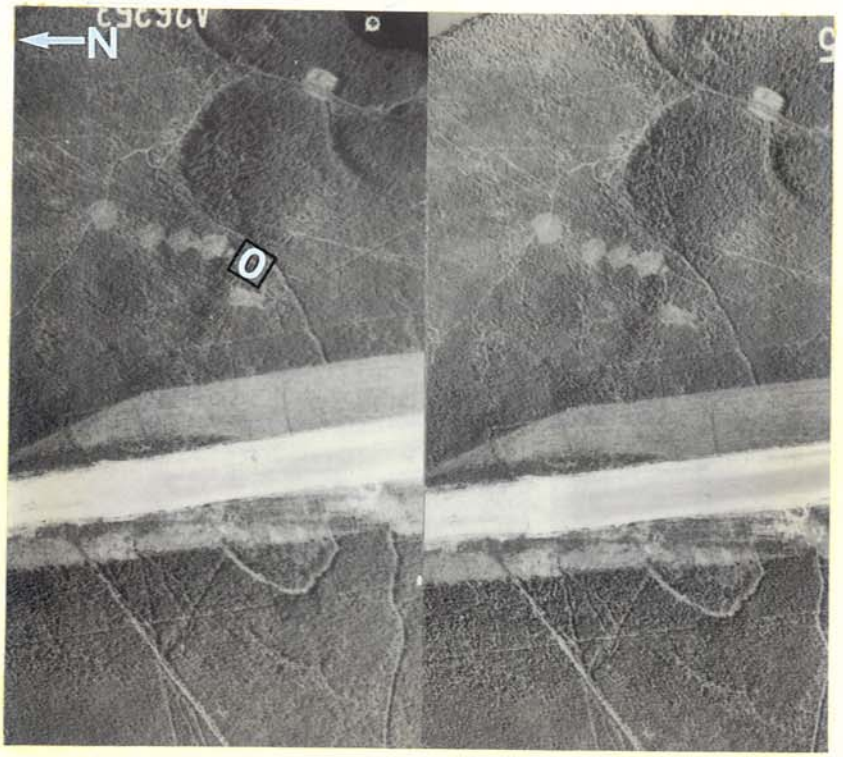
Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	0.5
2	1.0	1.0	2.0	1.0
3	1.5	1.5	3.0	1.5
4	2.0	2.0	4.0	2.0
5	2.5	2.5	6.0	2.5
6	3.0	3.0	8.0	3.0
7	3.5	3.5	10.0	4.0
8	4.0	4.0	12.0	5.0
9	4.7	4.7	15.0	6.0
10	-	-	18.0	7.0
11	-	-	22.1	8.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	38 mm

View of site 84-3A during construction in winter 1984.

Aerial view of site 84-3A in June 1984. (Note the extent of the clearing done for the river crossing operations).

Close up of view of site 84-3A June 1984, post pipeline construction.
(Note the woodchip covered slope in the background).

THERMAL FENCE
84-3B
KP 79.1



Air photos A26353 Nos. 15-16, 3 July 1983

Site number: 84-3B

Site name: Great Bear River Slope Crest

Location: 64°54' 42"N, 125°34'30"W, Kmp 79.39

Elevation: 70 metres A.S.L.

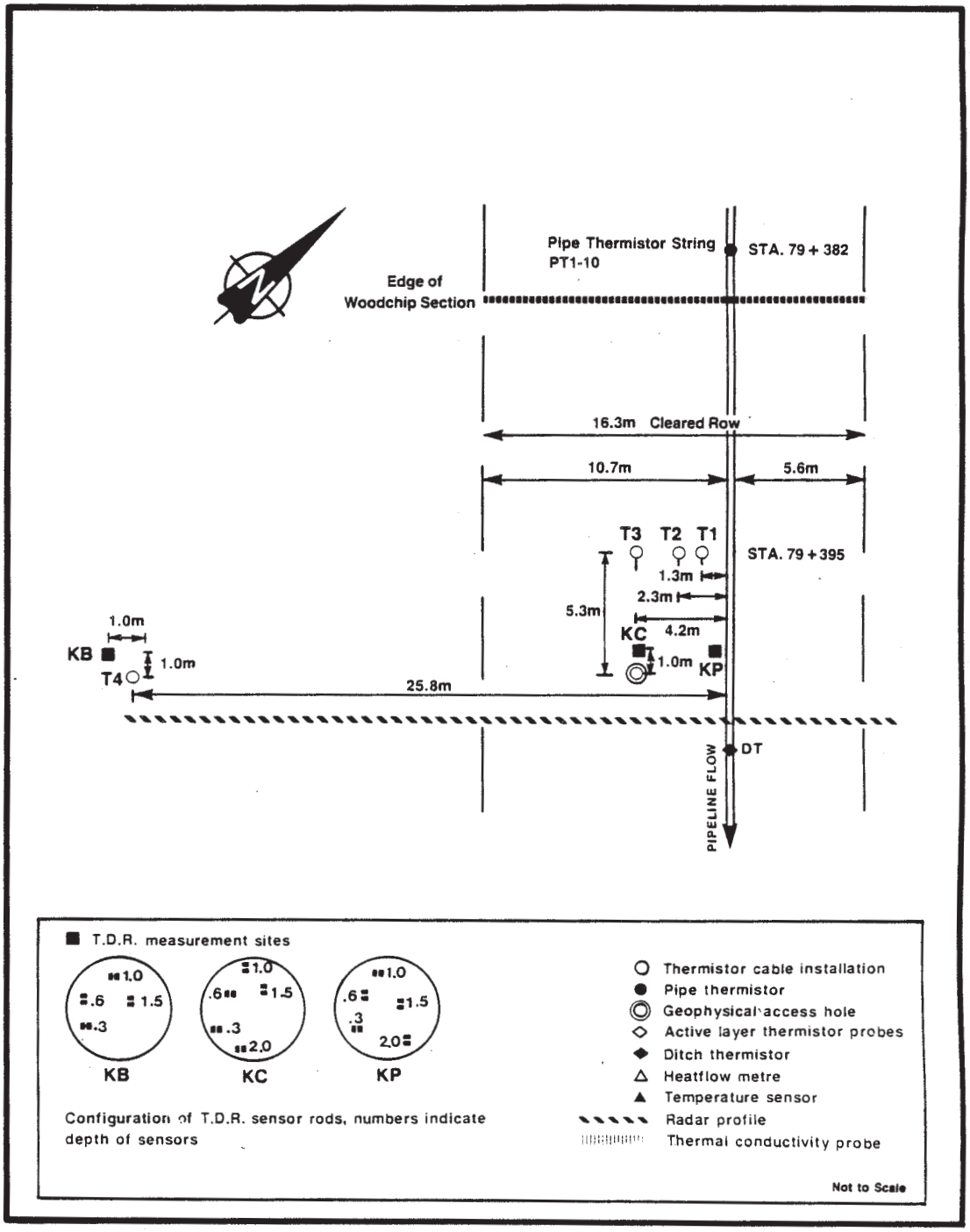
Rationale: This site was established in stratigraphically complex alluvial terrace deposits. It has been selected to study the thermal behavior of ice rich alluvial deposits in widespread permafrost, and forms part of a joint EMR/INAC/IPL study site to investigate the thermal behavior of a major north facing slope in widespread permafrost. At this location permafrost is expected to be approximately 50 m thick.

Vegetation: Black spruce/ericaceous shrubs, lichen-moss (hummocky) woodland.

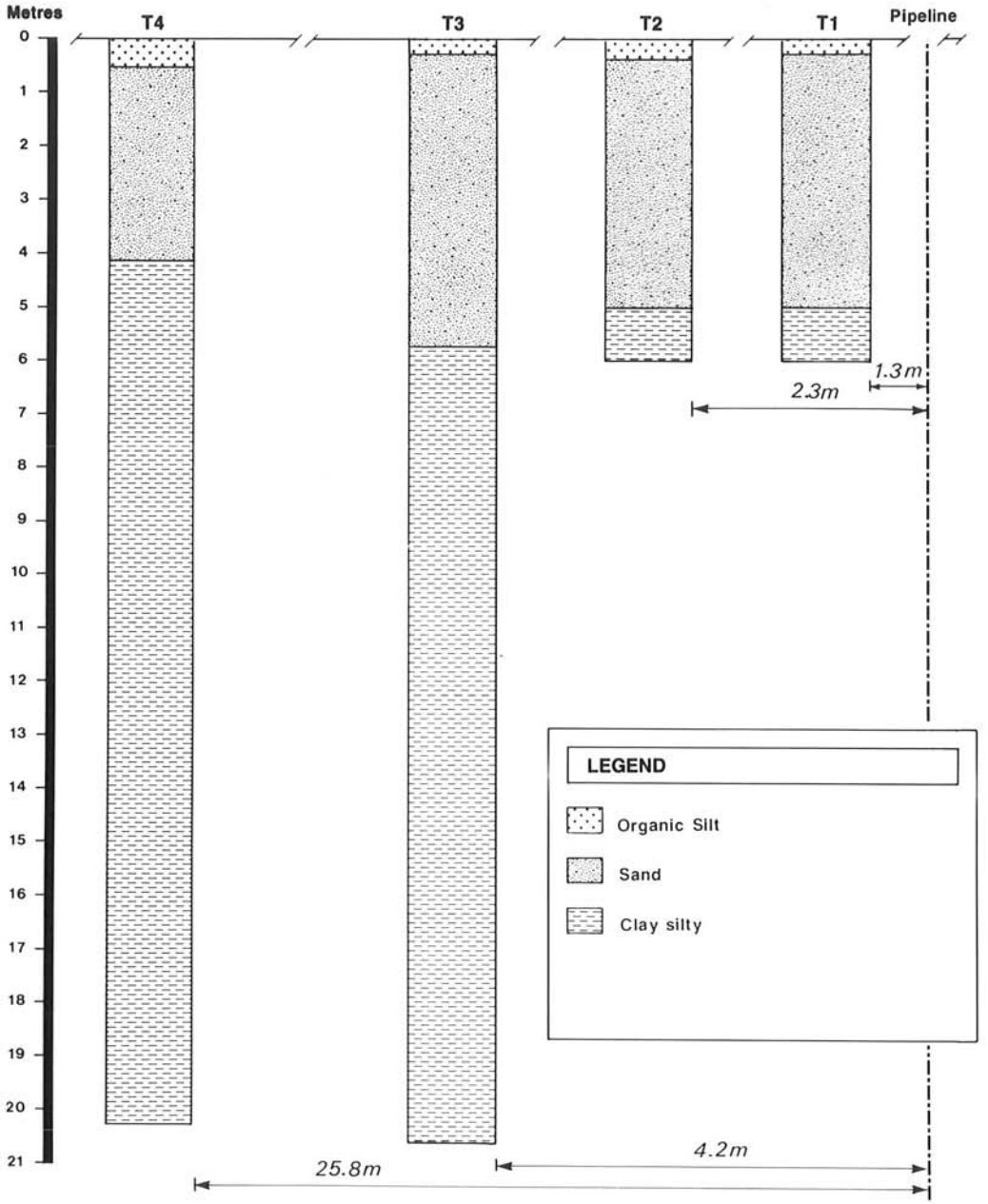
Site history:
- Some trees were cleared for a helipad for geotechnical sampling in 1981. Remainder of trees cleared to a width of 43.6 m in January 1984. Edge of large area cleared for the construction pad of the river crossing.
- Trenched with Bannister 710 Arctic (wheel) Ditcher in February 1984.
- Instrumentation holes drilled in March 1984.
- Restoration: erosion control berms, fertilized and seeded in March 1984.
- Maintenance: drainage ditched and resand-bagged in summer 1984.
- Bench Marks installed and first surface survey August in 1984.

Pipe depth: 0.90 m (excluding Roach) to top of pipe.

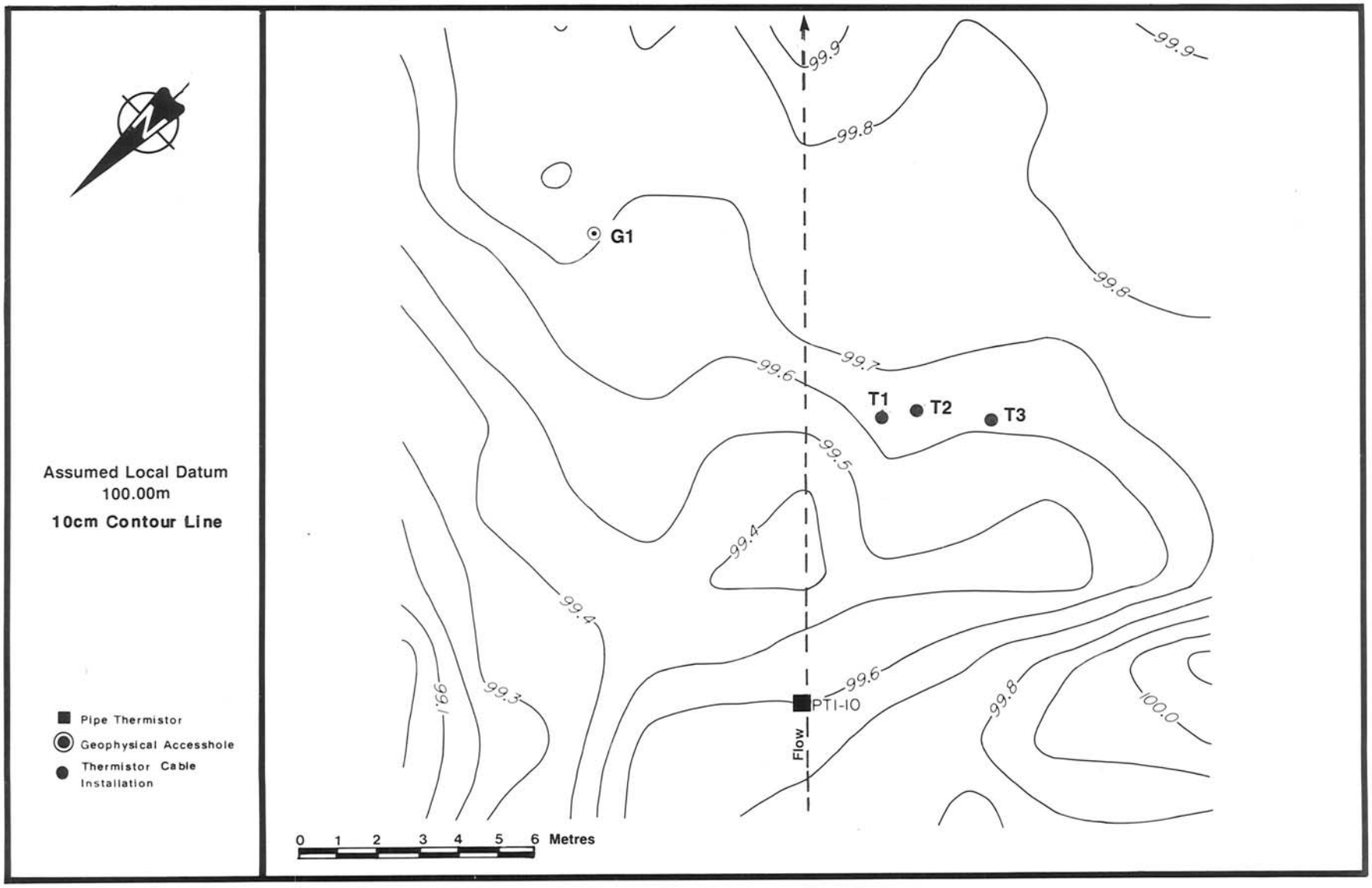
Instrumentation:
4 Multi-thermistor cables
3 Arrays of T.D.R. rods
1 Geophysical access hole
1 Pipe thermistor String (located 35 m north of fence)
3 Soil temperature probes
1 Ditch thermistor installation



Site plan of EMR/INAC site 84-3B, Great Bear River



Lithologic cross-section of site 84-3B, Great Bear River, based on the drill logs from the thermal instrumentation hole.

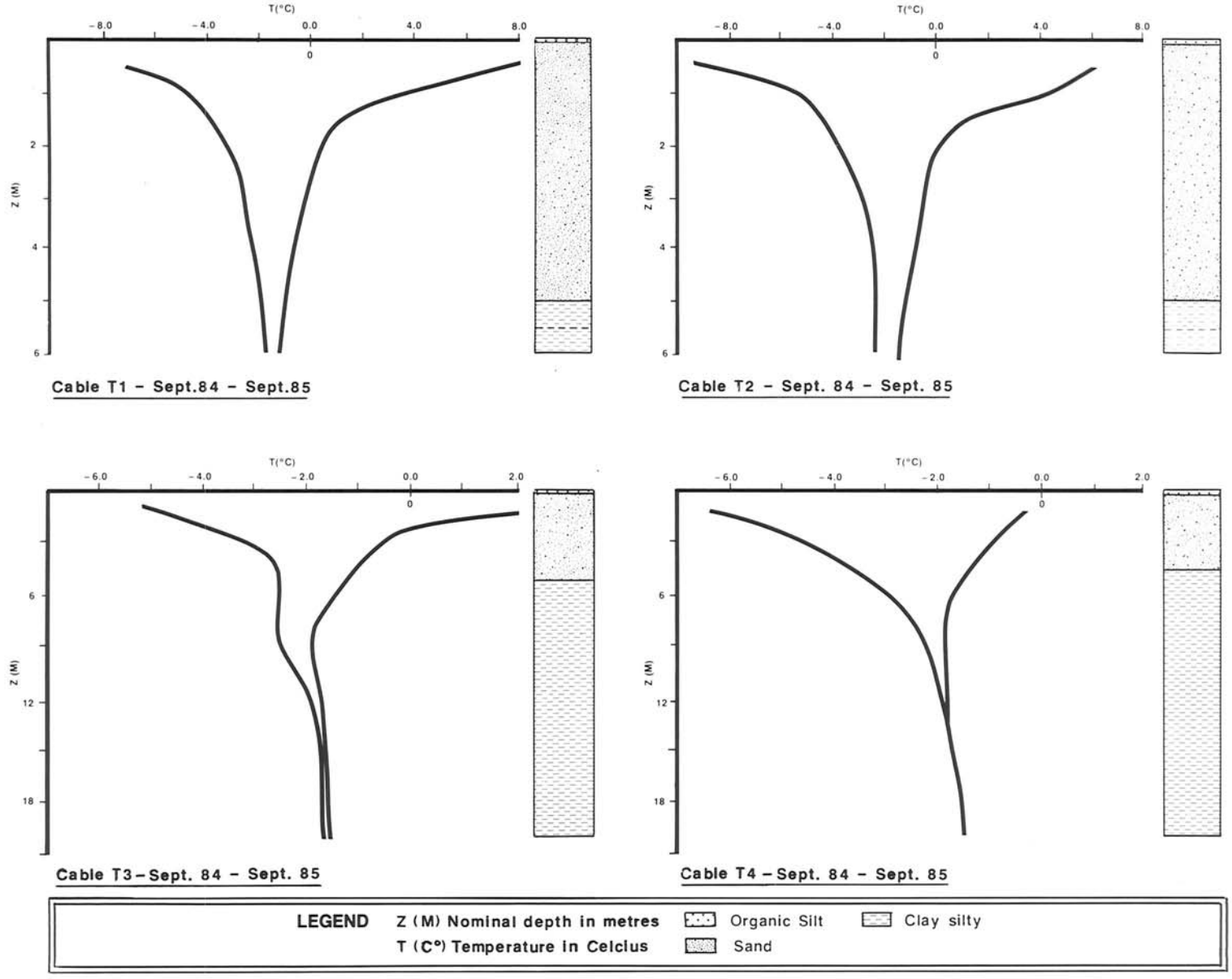


Detailed surface elevation contour map of site 84-3B, Great Bear River, using an assumed local datum of 100 m.

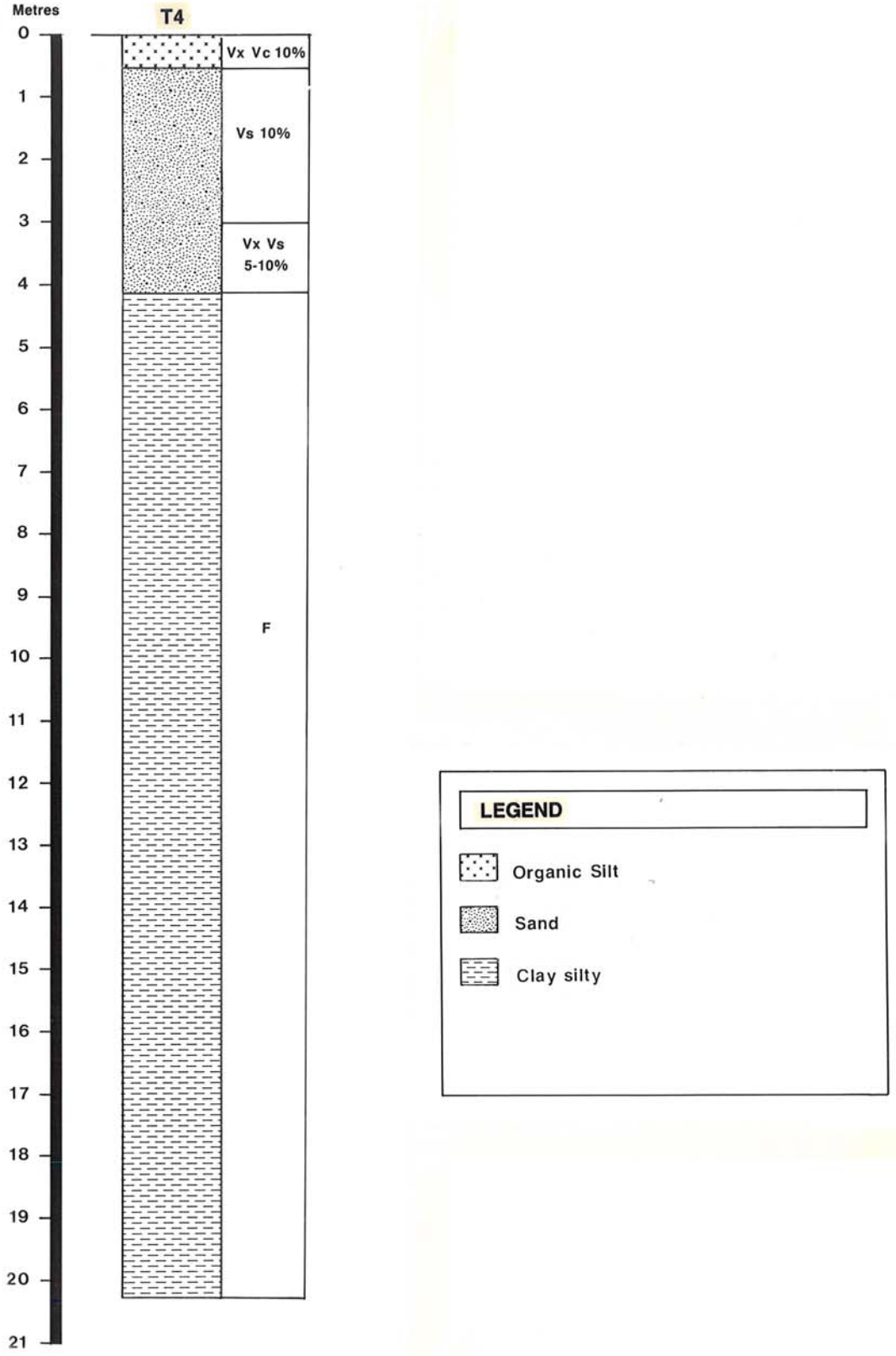
Site 84-3B

Thermal fence 84-3B located at the top of north facing slope at Great Bear River shows the following trends in the period under review (summer 84 - summer 85). Active layer development in the R.O.W. at this newly cleared site as observed at cables T1, T2 and T3, is approximately 1.8 m. It is approximately 60 cm at our reference hole T4, off the R.O.W. A first approximation of thickness at this site on the basis of the temperature profiles measured in holes T3 and T4 indicates a thickness of approximately 57 m (See Table 1, p. present report).

On the basis of the data collected to date at this site the relatively uniform 10% by volume ice content in the first 3 m of surficial material is having a definite 0° curtain effect on the thawing and freeze back of the material at this site although it is less severe than that observed at other sites. Another noteworthy features in the data is that the thickness of the zone of annual temperature variation is some 2 m deeper in the R.O.W. at 12 m compared to the 10 m measured off the R.O.W. and this only 1 year after the R.O.W. clearance. With time we should expect to see a relatively substantial difference between the on and off R.O.W. thermal behavior.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 84-3B, Great Bear River.



Ice content distribution observed in hole T4 at EMR/INAC site 84-3B, Great Bear River.

Thermistor depth at site 84-3B
depth in meters

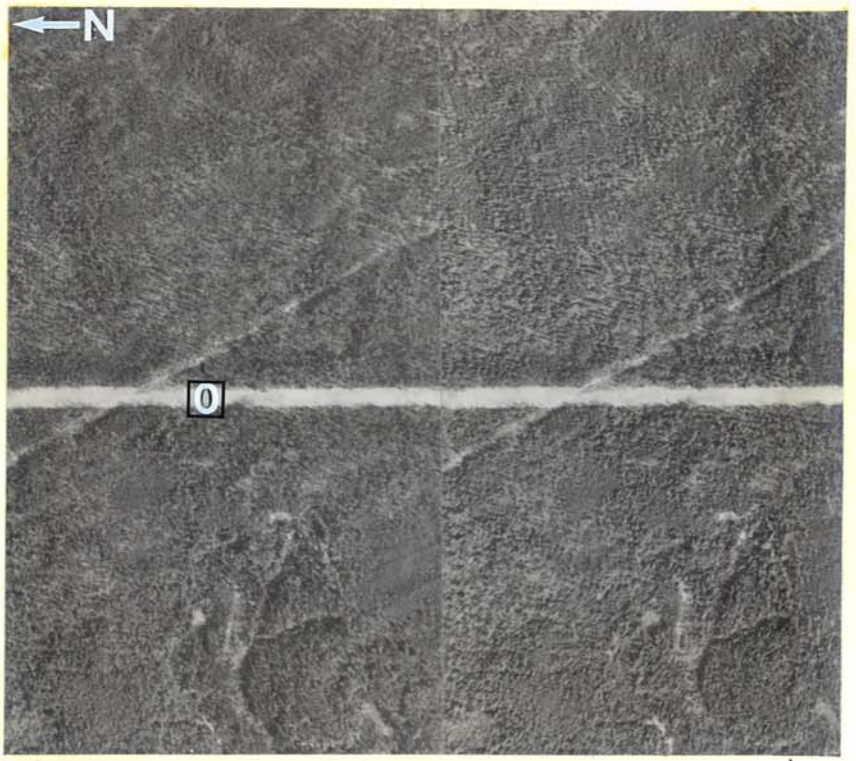
Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	1.0
2	1.0	1.0	2.0	2.0
3	1.5	1.5	3.0	3.0
4	2.0	2.0	4.0	4.0
5	2.5	2.5	6.0	6.0
6	3.0	3.0	8.0	8.0
7	3.5	3.5	10.0	10.0
8	4.0	4.0	12.0	12.0
9	5.0	5.0	15.0	15.0
10	6.3	6.3	18.0	18.0
11	-	-	21.4	20.9
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm

Survey cutline at site 84-3B prior to the right-of-way (ROW) clearing operations.

Aerial view of site 84-3B construction in June 1984 (foreground).

Detailed view of site 84-3B in June 1984, during a geophysical survey.
(Note that the thermal fence is close to the margin of the woodchip cover at the top of the slope).

THERMAL FENCE
84-4A
KP 477.3



Air photos A26351 Nos. 73-74, 2 July 1983

Site number: 84-4A

Site name: Trail River Dune Hollow

Location: 62°05' 12"N, 121°59'33"W, Kmp 477.3

Elevation: 153 metres A.S.L.

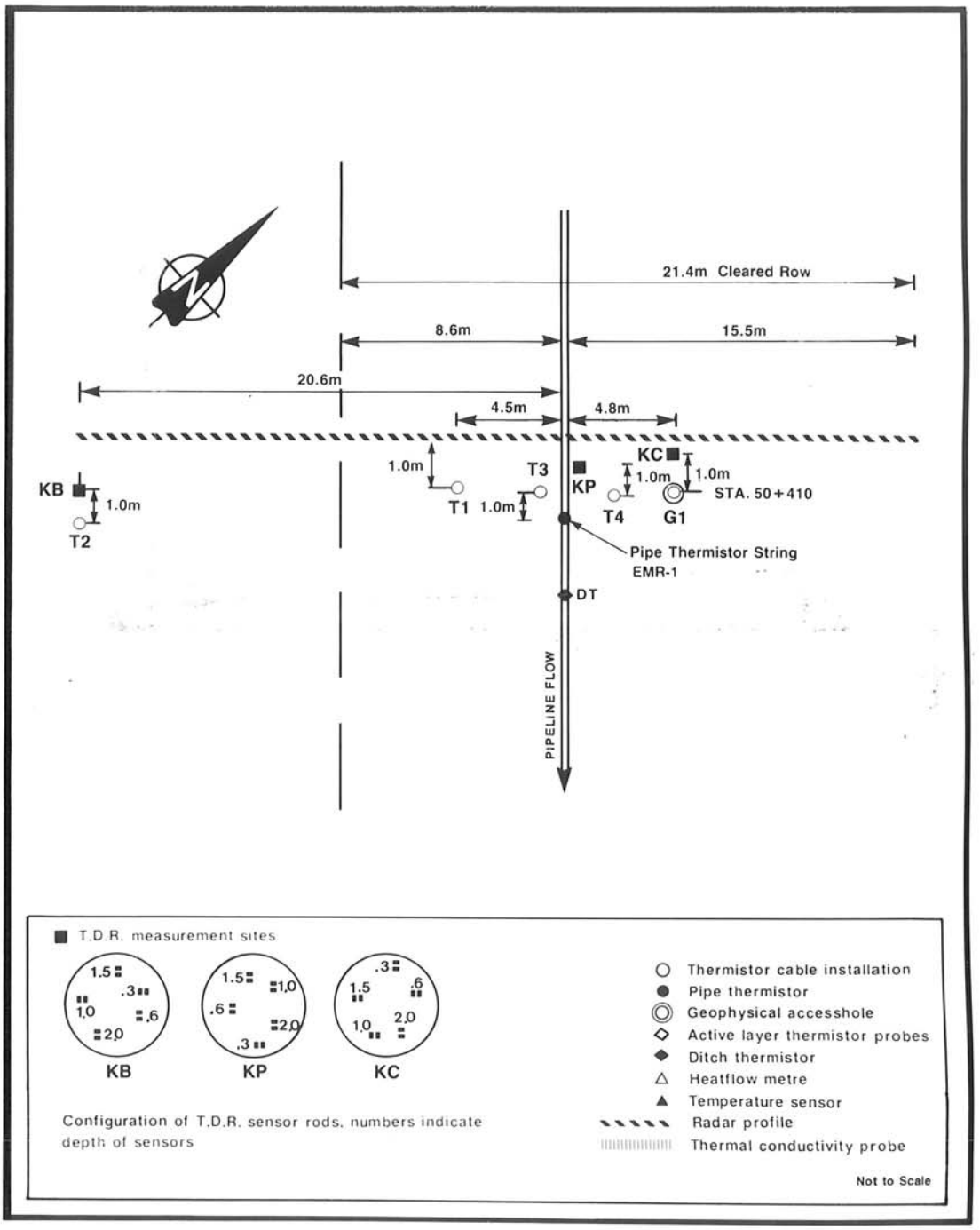
Rationale: This site was established in aeolian deposits with a very high water table. It has been selected to study the thermal behavior of unfrozen, saturated sands and silts as the pipeline enters unfrozen material after a long operating stretch in frozen terrain. Since the pipeline is designed to operate at ambient soil temperature and up to this point it has been almost continously frozen material the oil it contains should still be below 0°C. Thus this site is intended to study the frost bulb growth around the pipeline as it enters unfrozen saturated terrain.

Vegetation: Jack pine-aspen/lichen moss forest.

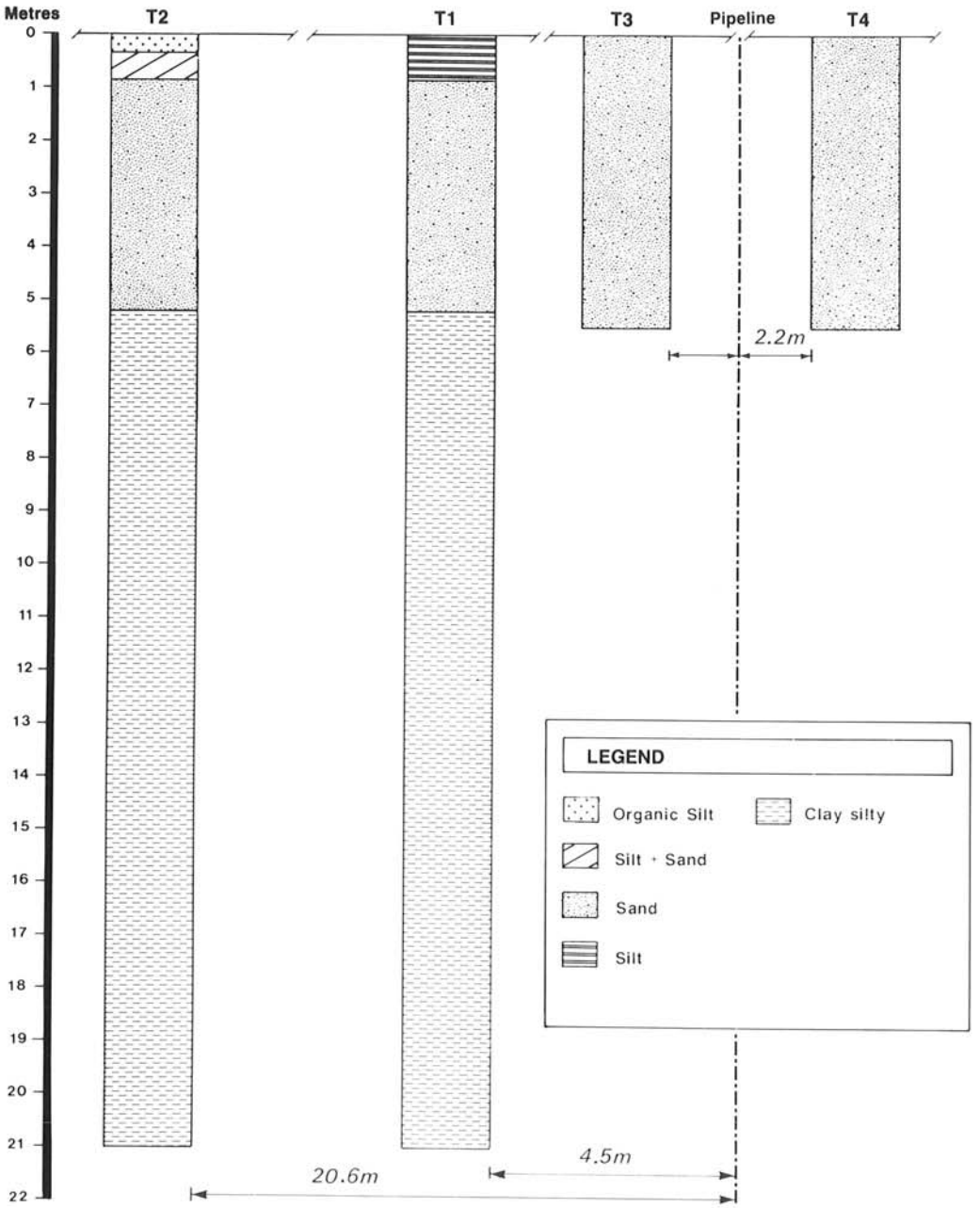
Site history:
- Trees cleared to 24.1 m width during winter 1982-83, ROW bladed and sand filled in hollows.
- Trenched in February 1984 with an Arctic (wheel) Ditcher.
- Instrumentation holes drilled in March 1984.
- Restoration: fertilized and seeded in March 1984.
- Bench marks installed and first surface survey in August 1984.

Pipe depth: 0.90 m (excluding Roach) to top of pipe.

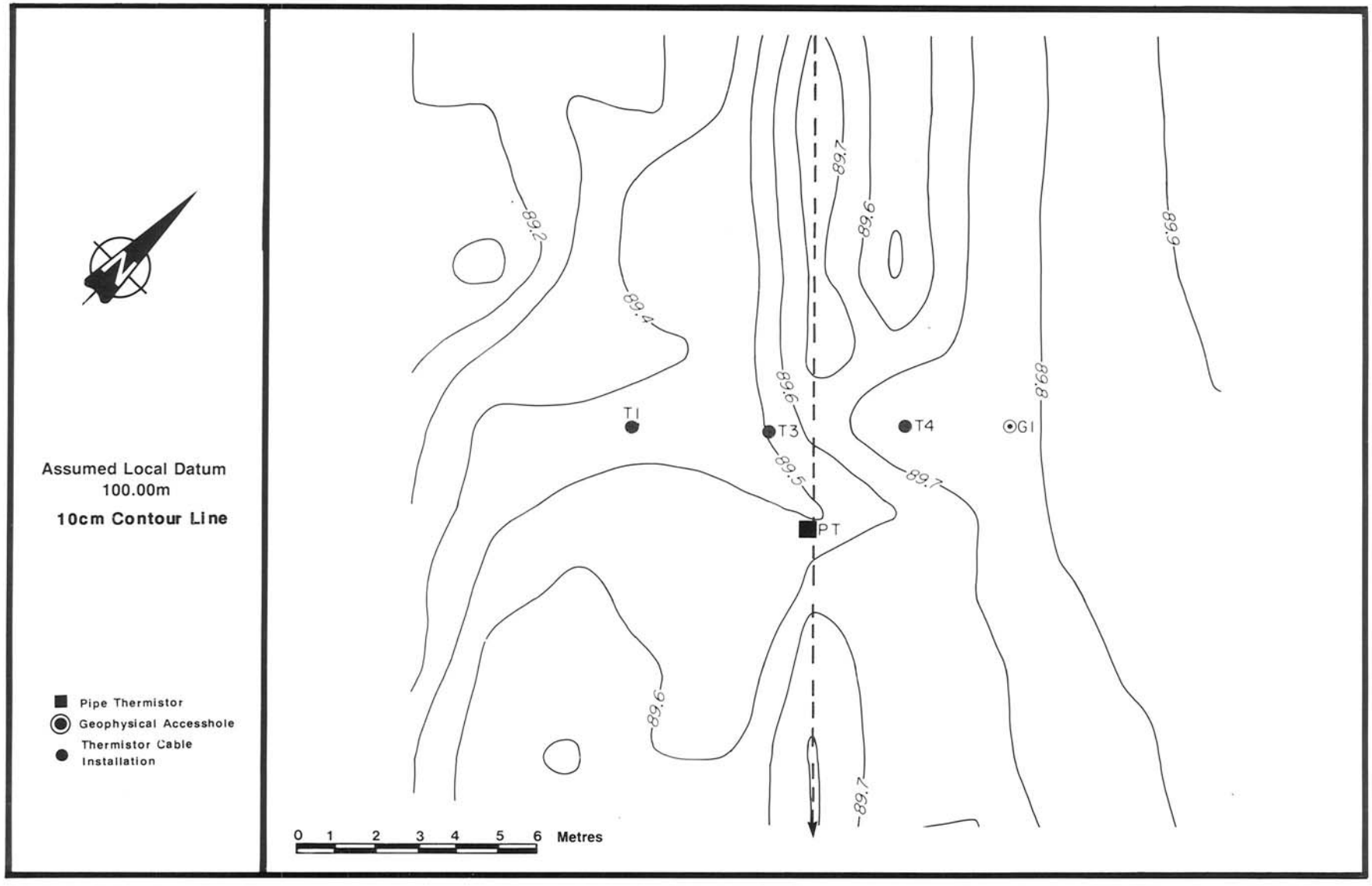
Instrumentation:
4 Multi-thermistor cables
3 Arrays of T.D.R. rods
1 Geophysical access hole
1 Pipe thermistor string
1 Ditch thermistor installation



Site plan of EMR/INAC site 84-4A, Trail River



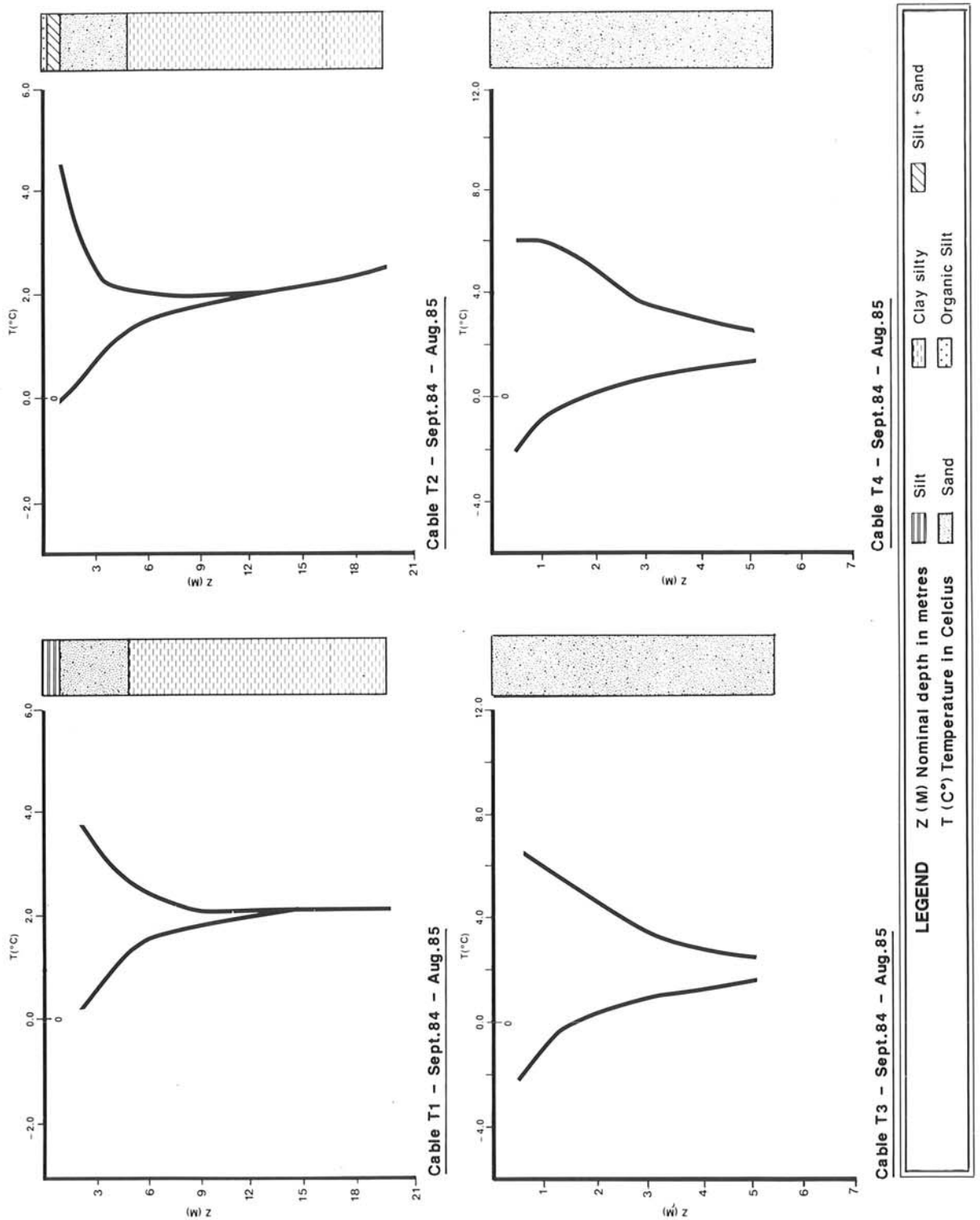
Lithologic cross-section of site 84-4A, Trail River, based on the drill logs from the thermal instrumentation hole.



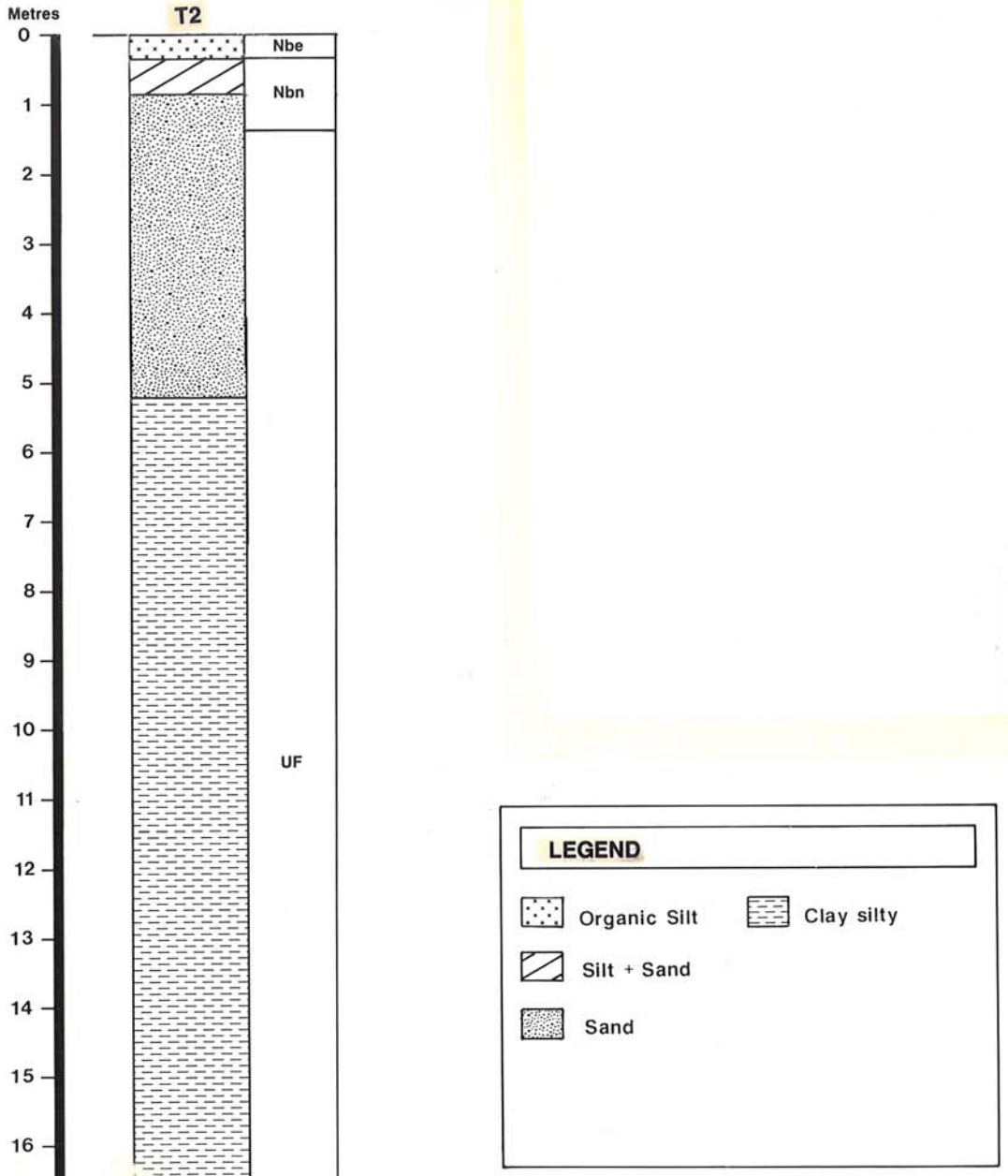
Detailed surface elevation contour map of site 84-4A, Trail River, using an assumed local datum of 100 m.

Site 84-4A

Thermal fence 84-4A is located at the foot of a large aeolian dune. It is a permafrost free site with a relatively high water table which has a relatively marked effect on the penetration of frost during the cold season. At this site the data collected to date show that the frost table penetrates approximately 1.4 m on and off R.O.W. (See Table 4, p. of present report). This site will become interesting after the pipeline has been operating for a while because it is the first substantial non-permafrost area it traverses since its departure in Norman Wells, and it may thus develop a frost bulb if it has in fact been operating at ambient temperature thought the mostly continuous permafrost region traversed prior to entering this dune field.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 84-4A, Trail River.



Ice content distribution observed in hole T2 at EMR/INAC site 84-4A, Trail River.

Thermistor depth at site 84-4A
depth in meters

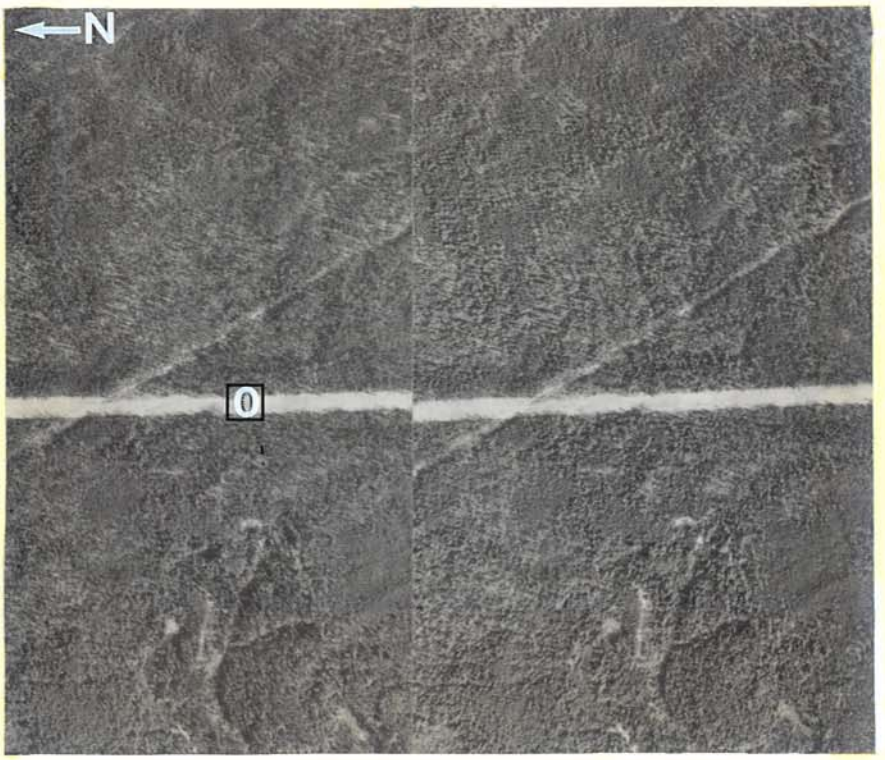
Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	1.0	1.0	0.5	0.5
2	2.0	2.0	1.0	1.0
3	3.0	3.0	1.5	1.5
4	4.0	4.0	2.0	2.0
5	6.0	6.0	2.5	2.5
6	8.0	8.0	3.0	3.0
7	10.0	10.0	3.5	3.5
8	12.0	12.0	4.0	4.0
9	15.0	15.0	4.5	4.5
10	18.0	18.0	5.0	5.0
11	20.0	20.0	-	-
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm

Overall view of site 84-4A (immediately in front of the helicopter) in June 1984, after construction.

Detailed view of site 84-4A in June 1984, post construction.

Overall view of site 84-4A (middle ground in front of helicopter) in October 1984.

THERMAL FENCE
84-4B
KP 477.4



Air photos A26351 Nos. 73-74, 2 July 1983

Site number: 84-4B

Site name: Trail River Dune Crest

Location: 62°05' 17"N, 121°59'25"W, Kmp 477.4

Elevation: 165 metres A.S.L.

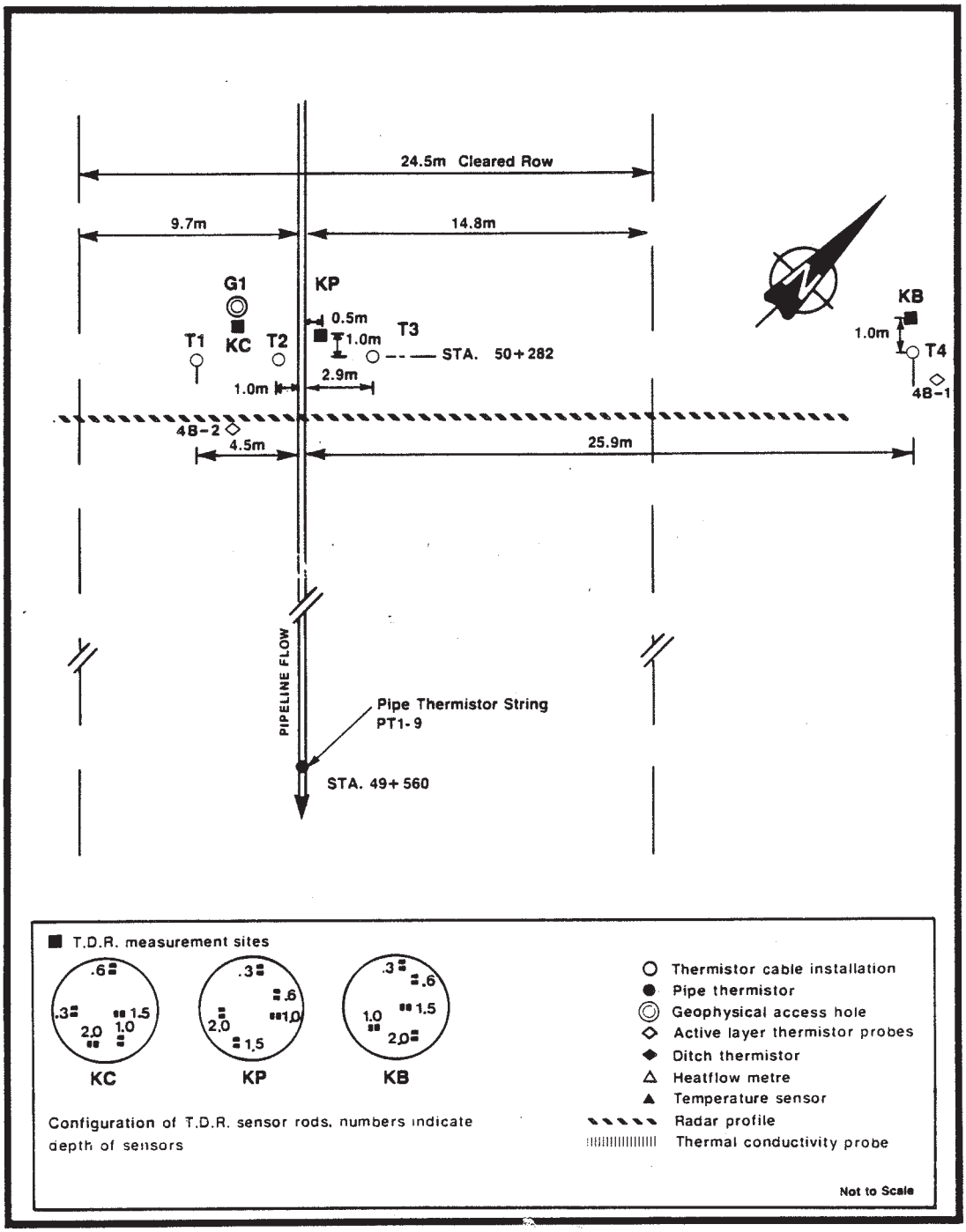
Rationale: This site was established on the crest of an aeolian dune with a low water table. It has been selected to study the thermal behavior of unfrozen, dry sands and silts as the pipeline enters unfrozen material after a long operating stretch in frozen terrain. Since the pipeline is designed to operate at ambient soil temperature and up to this point it has been almost continously in frozen material the oil it contains should still be below 0°C. Thus this site is intended to study the frost bulb growth around the pipeline as it enters unfrozen dry terrain.

Vegetation: Jack pine-birch/lichen - moss forest.

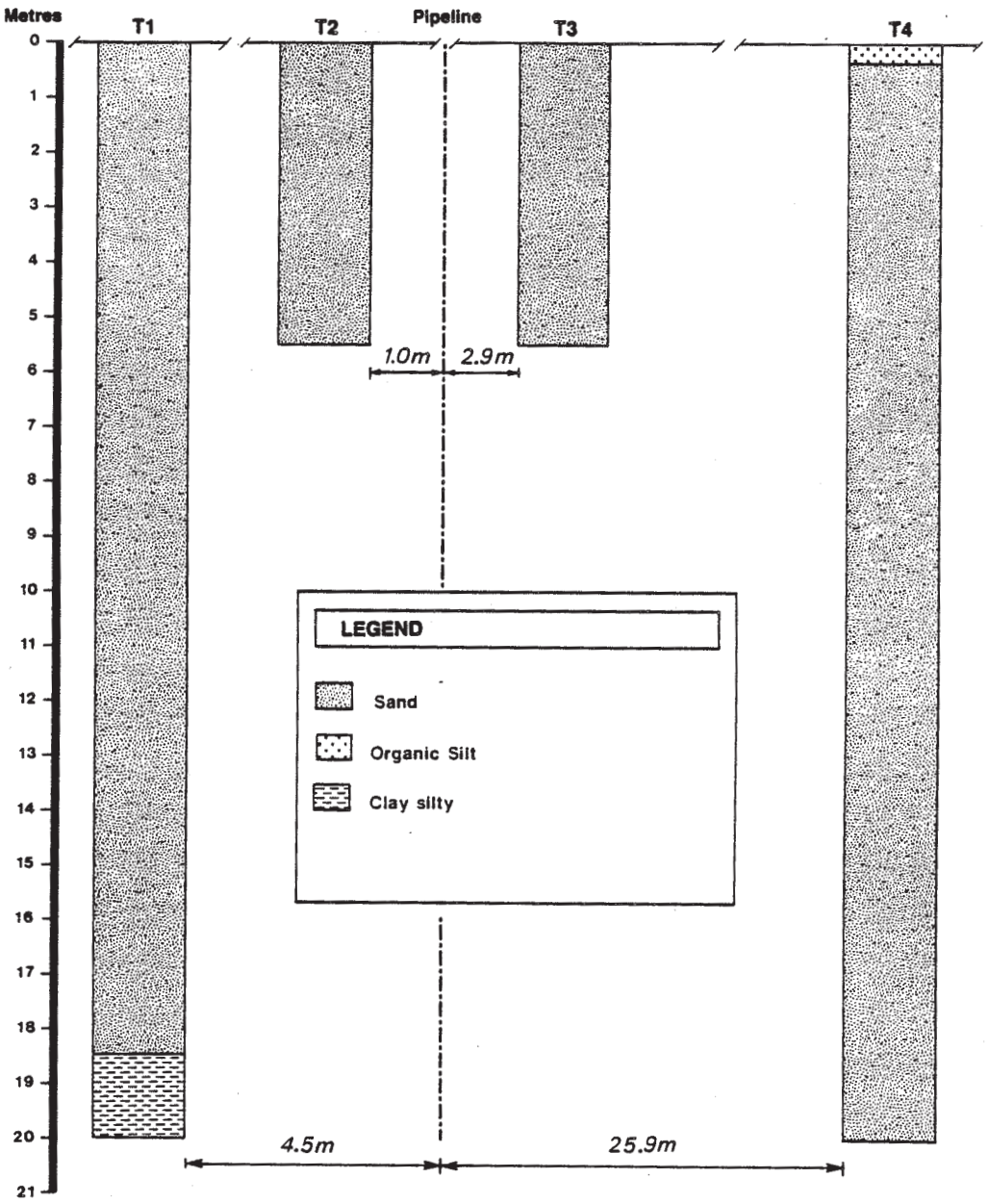
Site history:
- Trees cleared to 24.5 m width during winter 1982-83, ROW bladed and dune crest lowered approximately 1 m.
- Trenched in February 1984 with an Arctic (wheel) Ditcher.
- Instrumentation holes drilled in March 1984.
- Restoration: fertilized and seeded in March 1984.
- Bench marks installed and first surface survey in August 1984.

Pipe depth: 0.90 m (excluding Roach) to top of pipe.

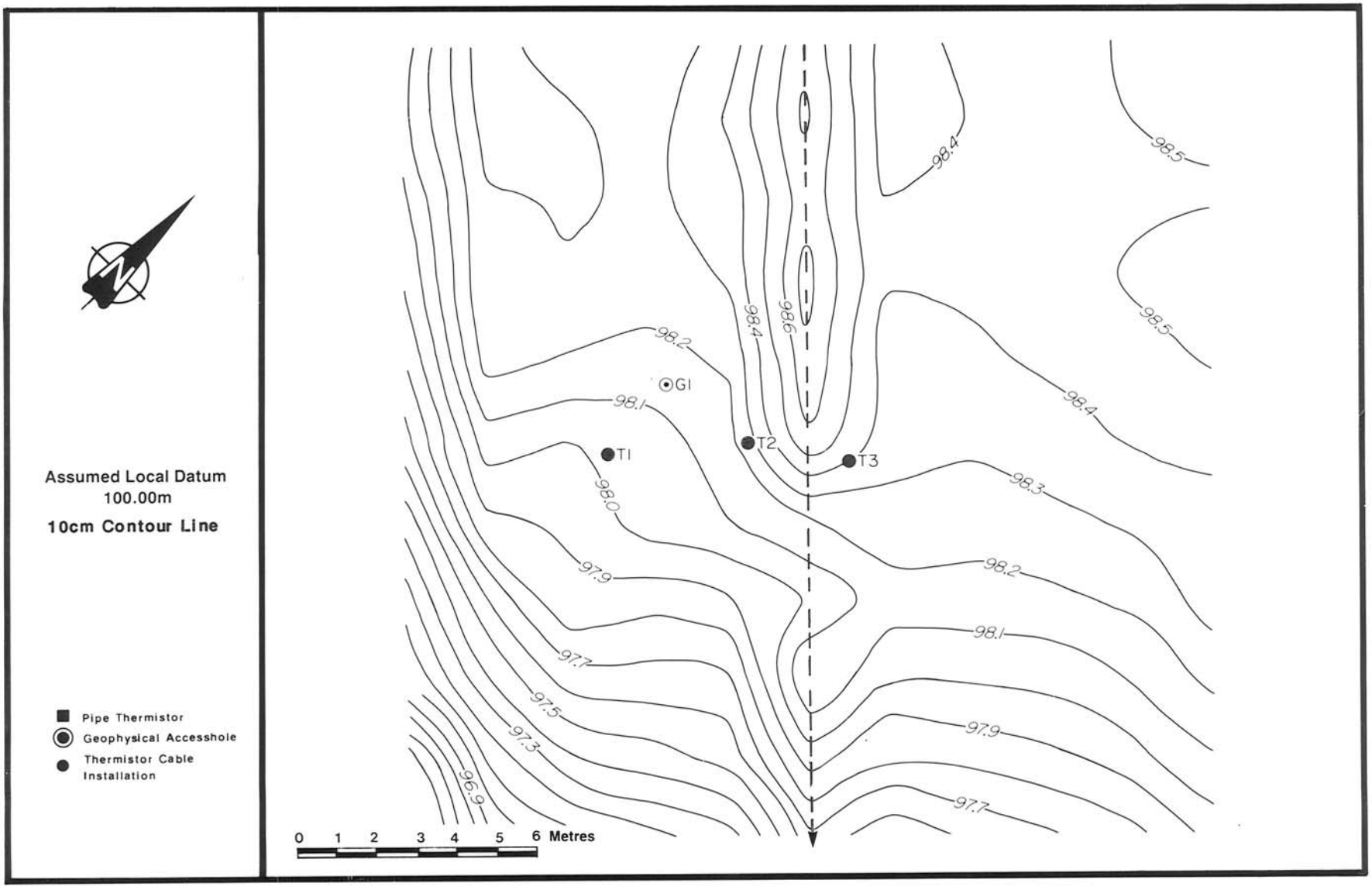
Instrumentation:
4 Multi-thermistor cables
3 Arrays of T.D.R. rods
1 Pipe thermistor string (located 722 m south of fence)
2 Soil temperature probes



Site plan of EMR/INAC site 84-4B, Trail River



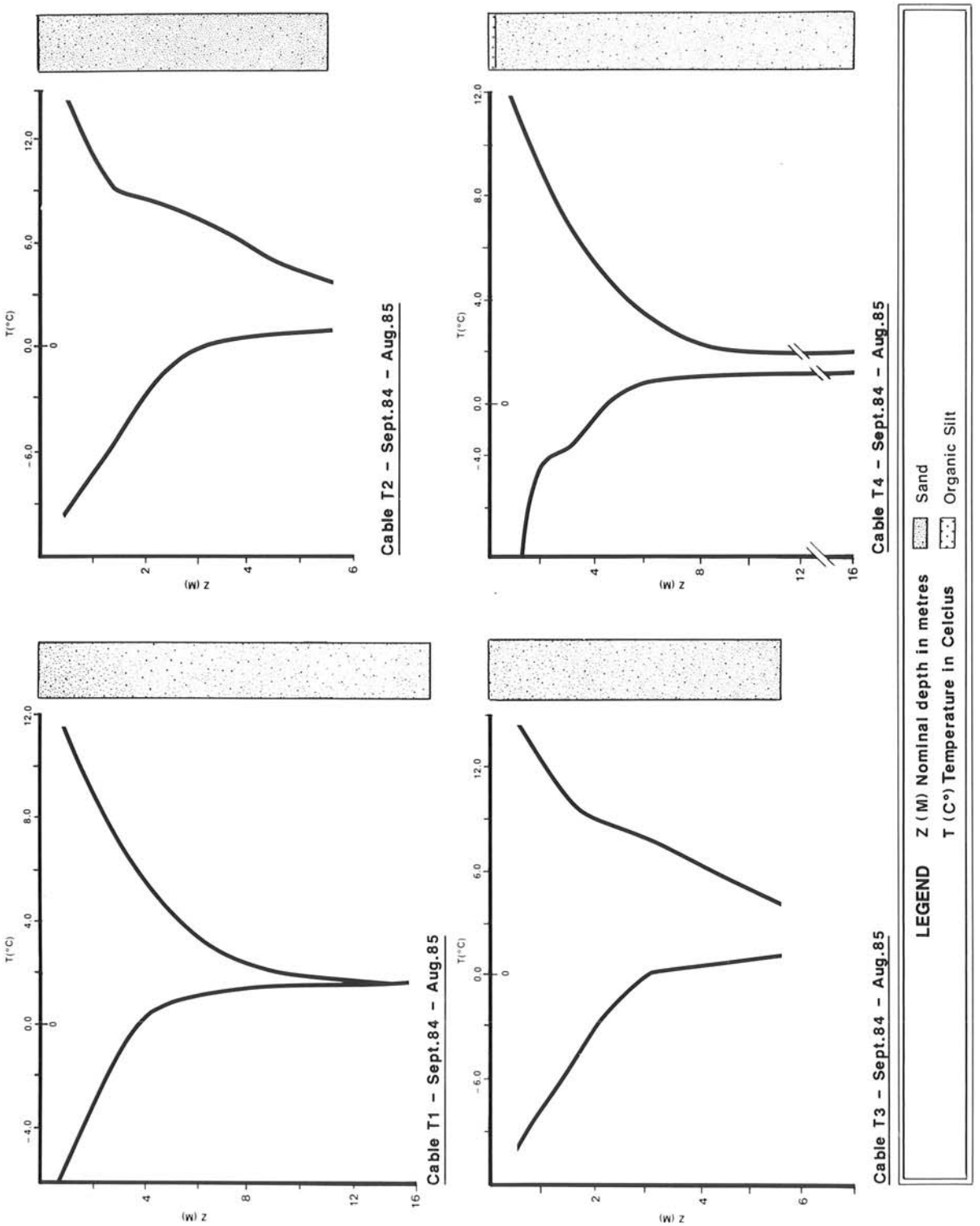
Lithologic cross-section of site 84-4B, Trail River, based on the drill logs from the thermal instrumentation hole.



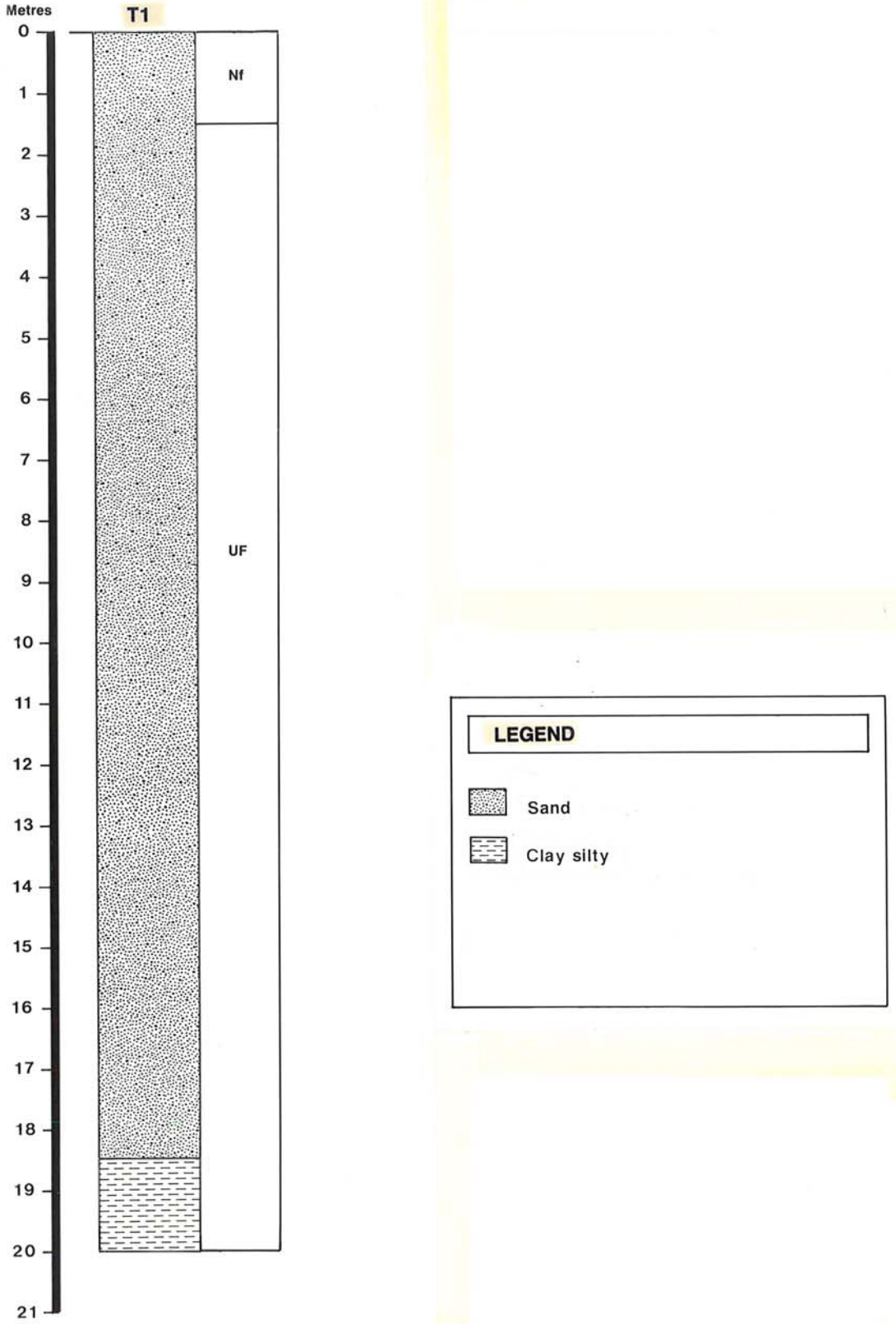
Detailed surface elevation contour map of site 84-4B, Trail River, using an assumed local datum of 100 m.

Site 84-4B

Thermal fence 84-4B is located at the crest of a large aeolian dune. It is a permafrost free site with a very dry surface and a deep water table. As such it has a marked effect on the penetration of the frost table during the cold season. At this site the data collected to date shows that the frost table penetrate approximately 3.0 m on and off the R.O.W. (See Table 4, p. of present report). This is double the depth observed at the bottom of the dune at site 84-4A. It will become an interesting site after the pipeline has been operating for a while if there is a frost bulb accretion around the pipeline.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 84-4B, Trail River.



Ice content distribution observed in hole T1 at EMR/INAC site 84-4B, Trail River

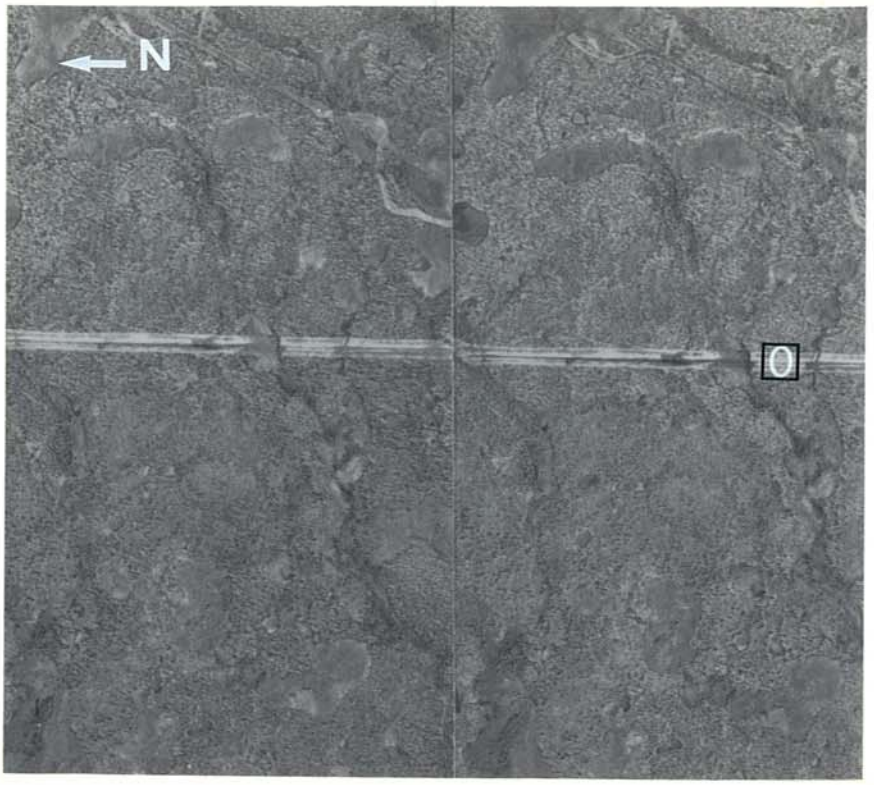
Thermistor depth at site 84-4B
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	1.0	0.5	0.5	1.0
2	4.0	1.0	1.0	2.0
3	7.0	1.5	1.5	3.0
4	9.0	2.0	2.0	4.0
5	-	2.5	2.5	6.0
6	-	3.0	3.0	8.0
7	-	3.5	3.5	10.0
8	-	4.0	4.0	12.0
9	-	4.5	4.5	15.0
10	-	5.5	5.5	18.0
11	-	-	-	20.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm

Aerial view of site 84-4B in June, post pipeline construction.

Detailed view of site 84-4B in October 1984, after the first summer's vegetation growth.

THERMAL FENCE
84-5A
KP 781.9



Air Photos A 26840 Nos 155-156, 7 August 1985

Site number: 84-5A

Site name: Petitot River North

Location: 59° 45.7'N 119° 31.1'W, Kmp 783

Elevation: 552 metres A.S.L.

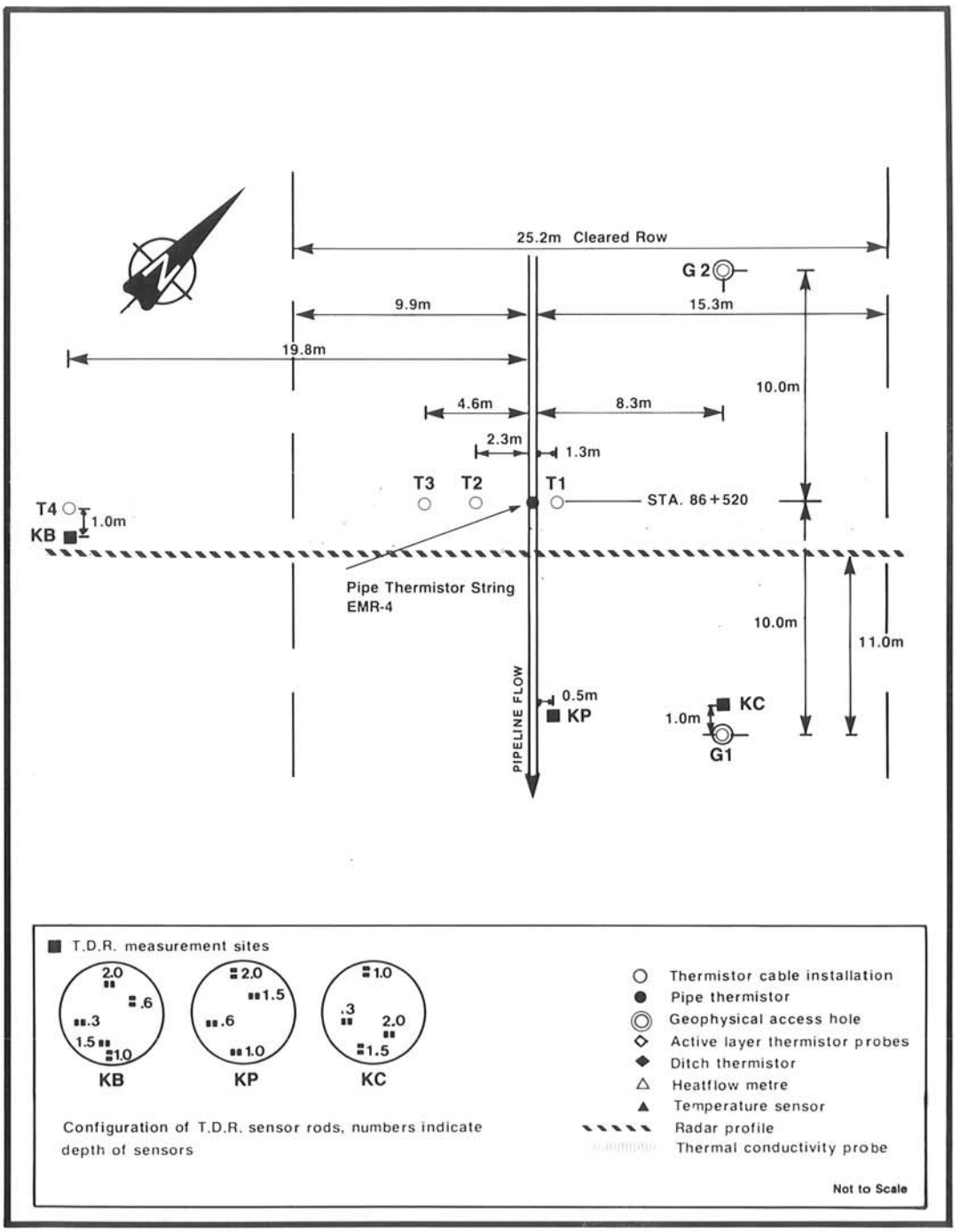
Rationale: This site was established in a thick, ice-rich naturally collapsing peat plateau. It has been selected to study the thermal behaviour of moderately thick ice-rich peat (about 4 m).

Vegetation: Stunted black spruce, ericaceous shrubs, moss woodland

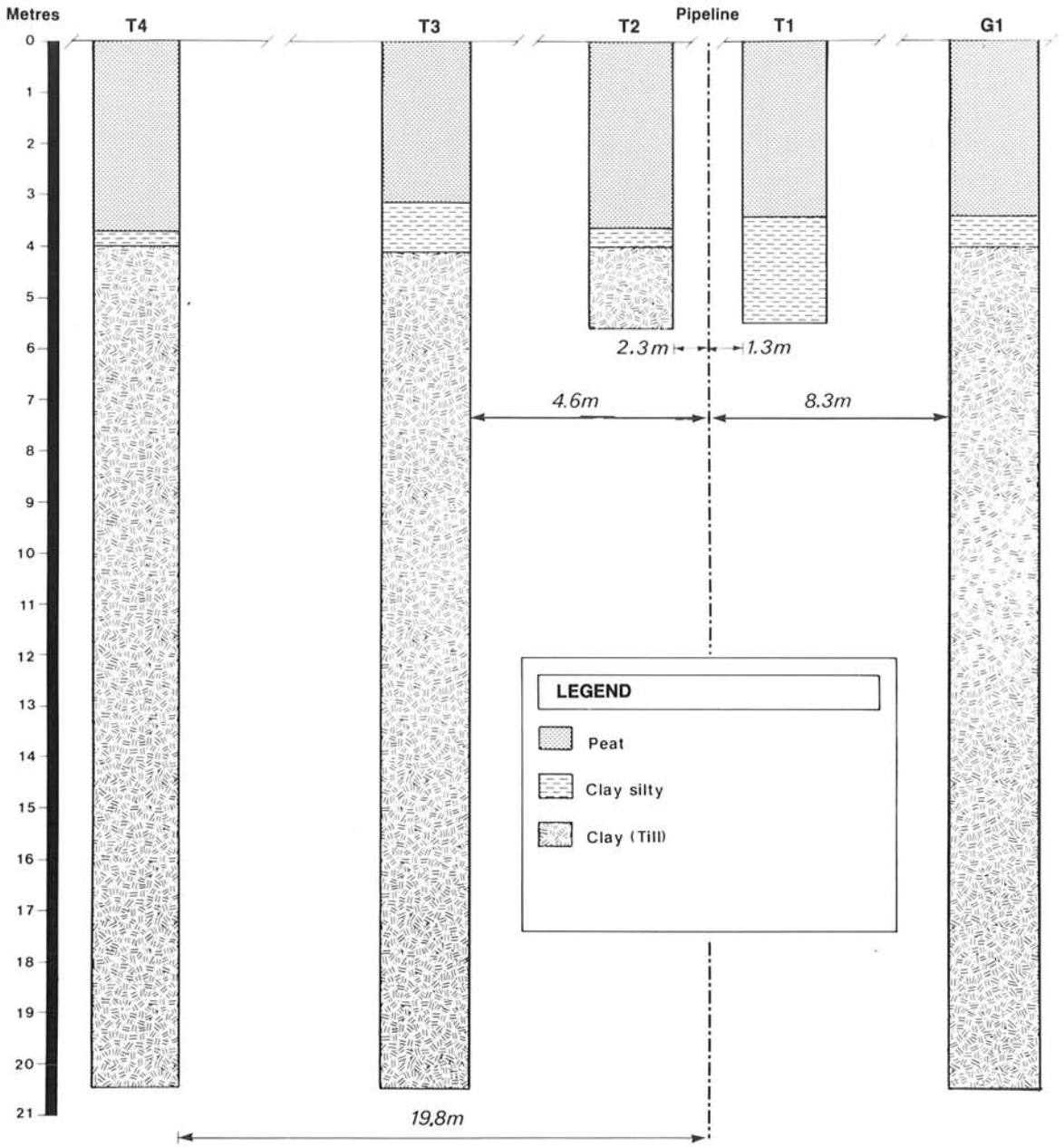
Site history:
- trees cleared to 25.2 m width in winter 1982-83
- trenched in February 1984 with a Barber Green wheel ditcher
- instrumentation holes drilled in March 1984
- no restoration
- bench marks installed and first surface survey in August 1984

Pipe depth: 0.77 m (excluding Roach) to top of pipe

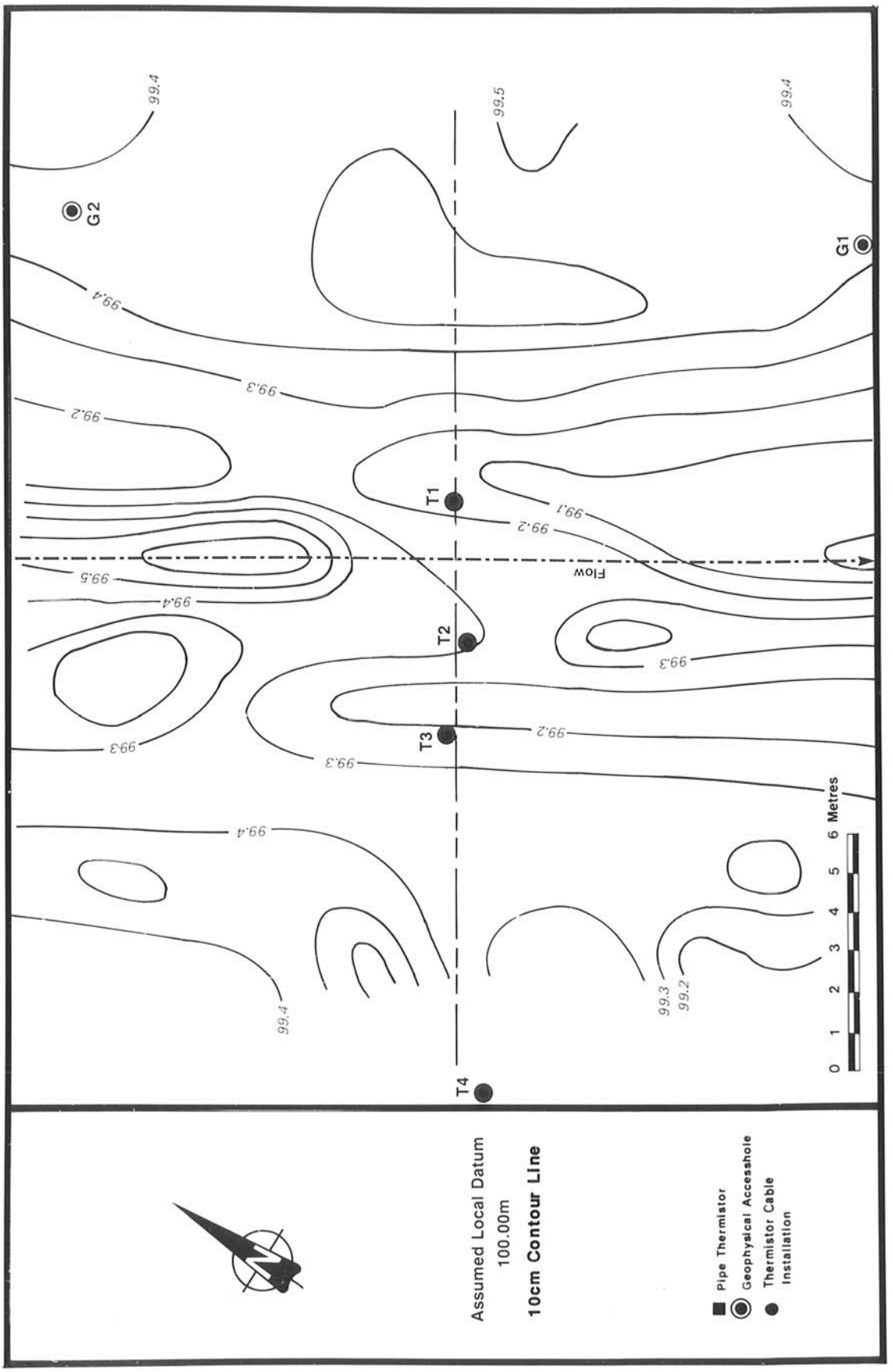
Instrumentation:
4 Multi-thermistor cables
3 Arrays of T.D.R. rods
2 Geophysical access holes
1 Pipe thermistor string



Site plan of EMR/INAC site 84-5A, Petitot River North



Lithologic cross-section of site 84-5A, Petitot River North, based on the drill logs from the thermal instrumentation hole.

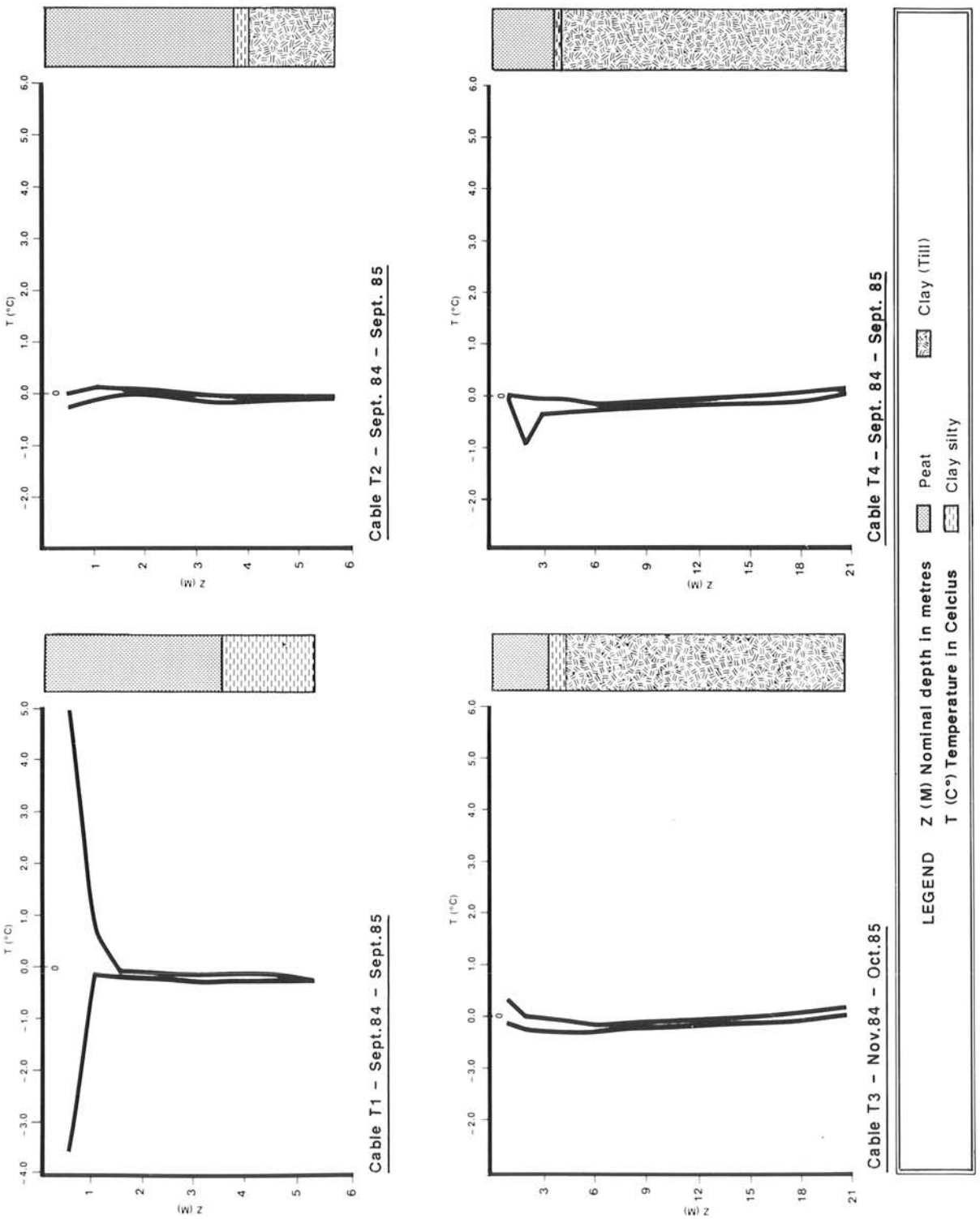


Detailed surface elevation contour map of site 84-5A, Petitot River
North, using an assumed local datum of 100 m.

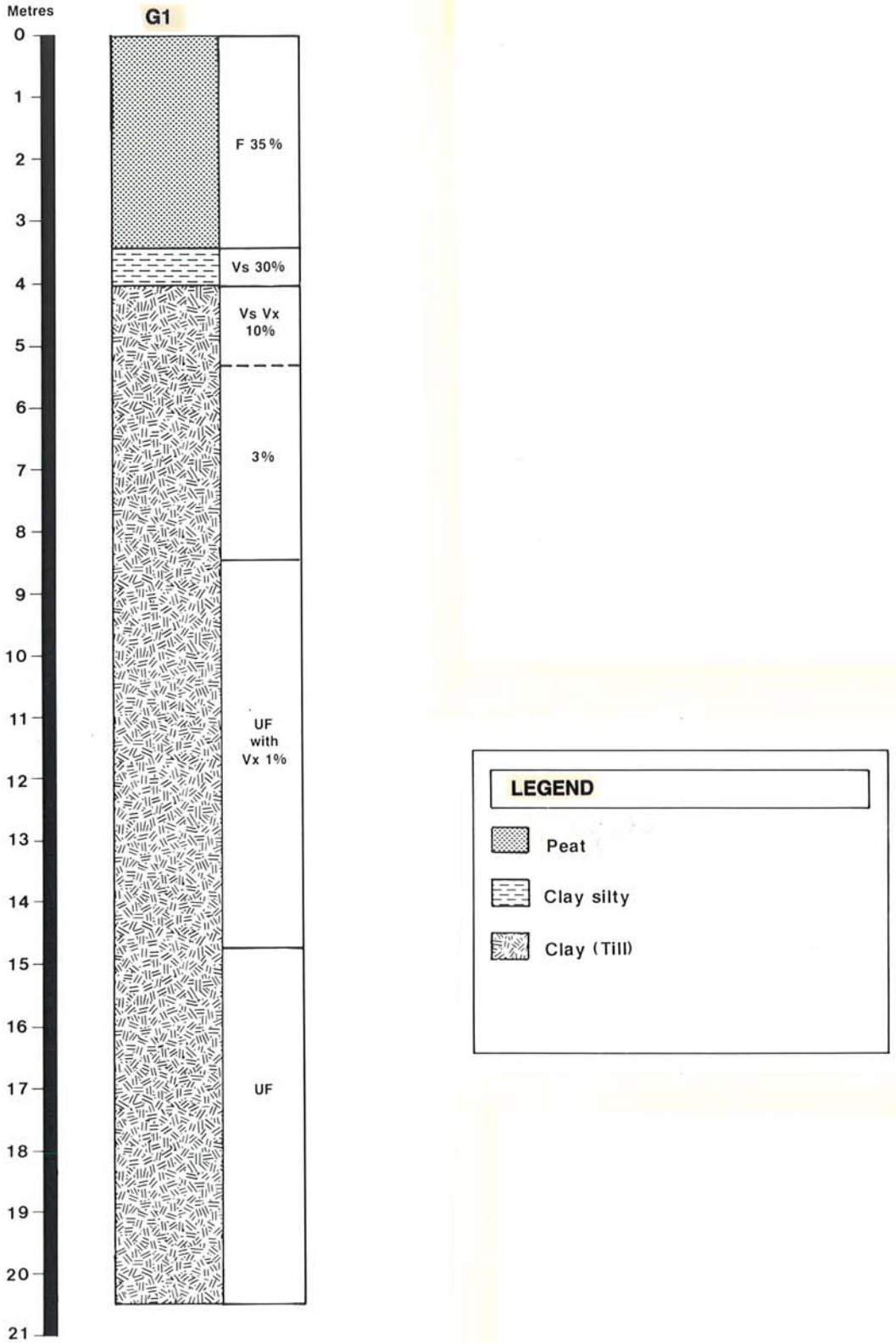
Site 84-5A

Thermal fence 84-5A, at Petitot River North, is located in a moderately thick (3.5 m average) level, ice rich peat plateau. It shows the following trends in the period under review (summer 84 - summer 85). Active layer development in the newly cleared R.O.W. for the pipeline as observed at cables T1, T2 and T3 is approximately 1.2 m whereas it is less than 1 m outside the R.O.W. at cable T4. A first approximation of permafrost thickness at this site on the basis of cables T3 and T4 indicates a thickness of about 17 m.

The data collected to date at this site shows an essentially isothermal temperature profile which is indicative that a climatic change is currently on-going in this high level region (55 cm A.S.L.) of the Alberta Plateau. This is supported by the naturally occurring collapse outside the R.O.W. observed in the vicinity of the site.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 84-5A, Petitot River North.



Ice content distribution observed in hole G1 at EMR/INAC site 84-5A, Petitot River North.

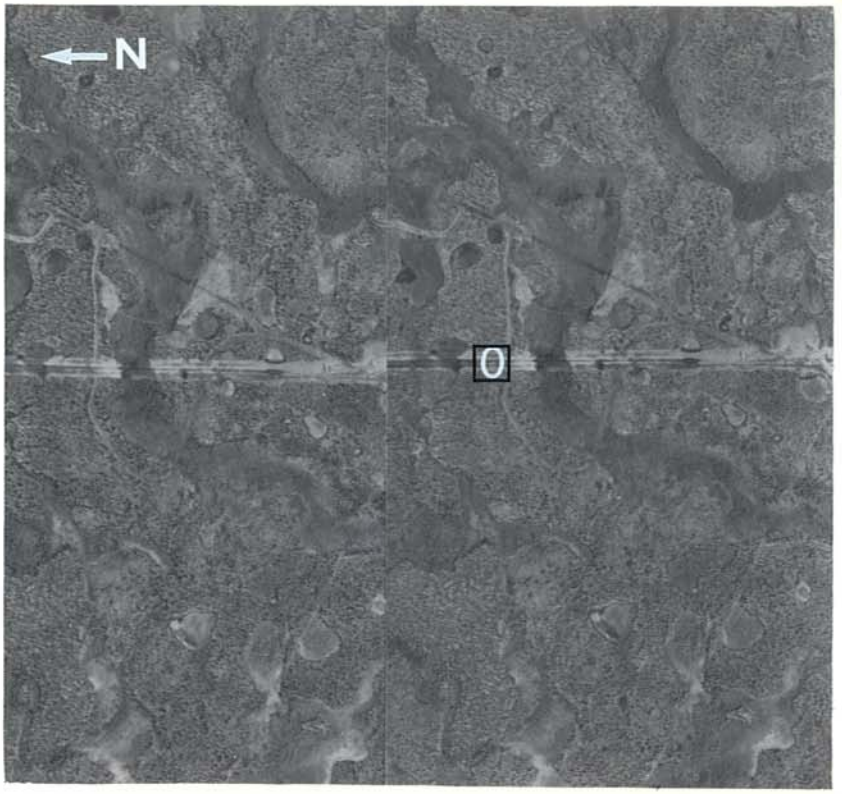
Thermistor depth at site 84-5A
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	1.0
2	1.0	1.0	2.0	2.0
3	1.5	1.5	3.0	3.0
4	2.0	2.0	4.0	4.0
5	2.5	2.5	6.0	6.0
6	3.0	3.0	8.0	8.0
7	3.5	3.5	10.0	10.0
8	4.0	4.0	12.0	12.0
9	4.5	4.5	15.0	15.0
10	5.2	5.6	18.0	18.0
11	-	-	20.6	20.6
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm

Site 84-5A, aerial view in May 1985, note the wet areas on both sides of the trench.

Site 84-5A, ground view in October 1985, after re-roaching for maintenance.

THERMAL FENCE
84-5B
KP 782.2



Air Photos A 26840 Nos 156-157, 7 August 1985

Site number: 84-5B

Site name: Petitot River North

Location: 59° 45.4'N 119° 30.7'W, Kmp 783.3

Elevation: 552 metres A.S.L.

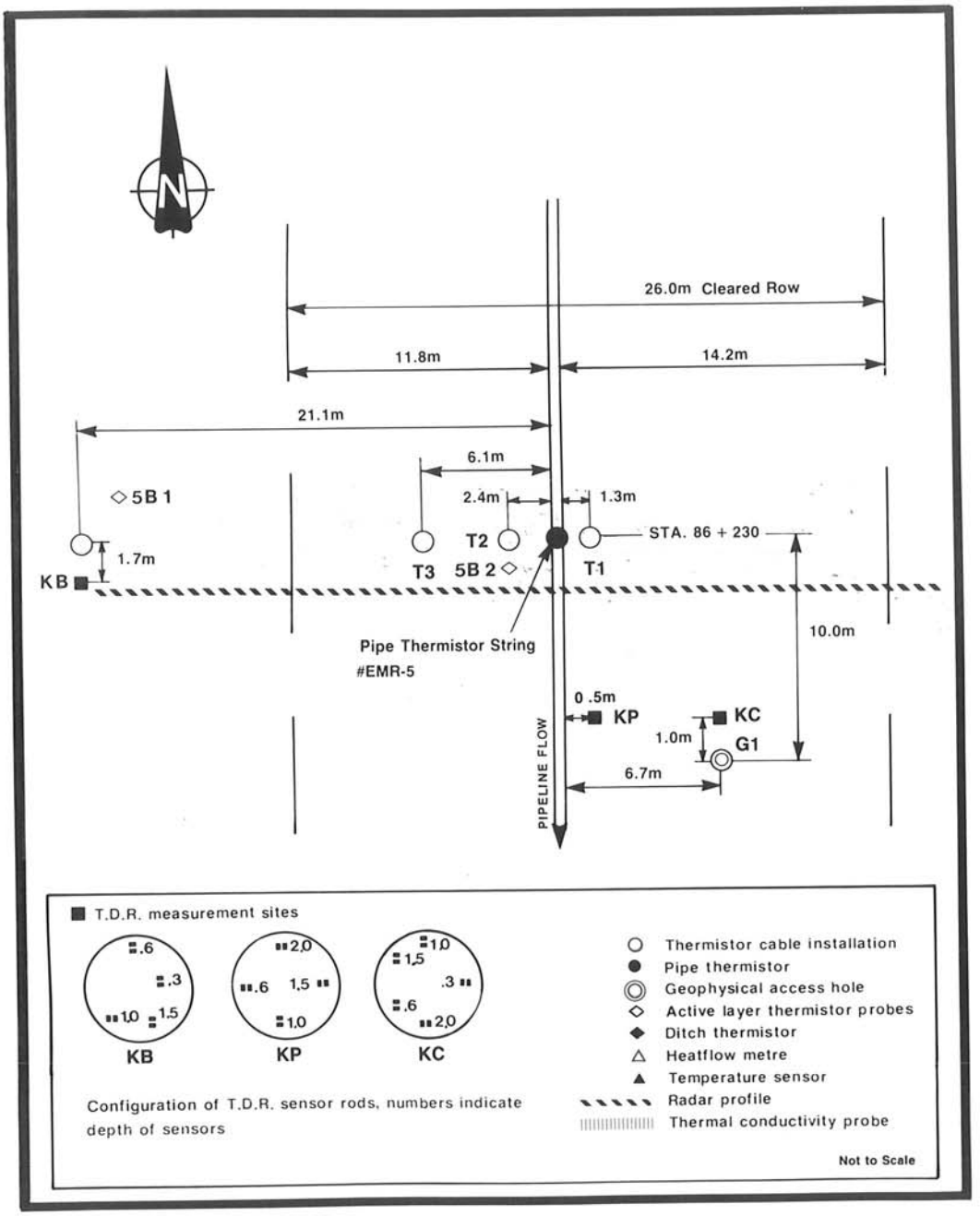
Rationale: This site was established in very thick, ice-rich peat plateau. It has been selected to study the thermal behaviour of very thick ice-rich peat (about 7 m).

Vegetation: Stunted black spruce, ericaceous shrubs, moss woodland

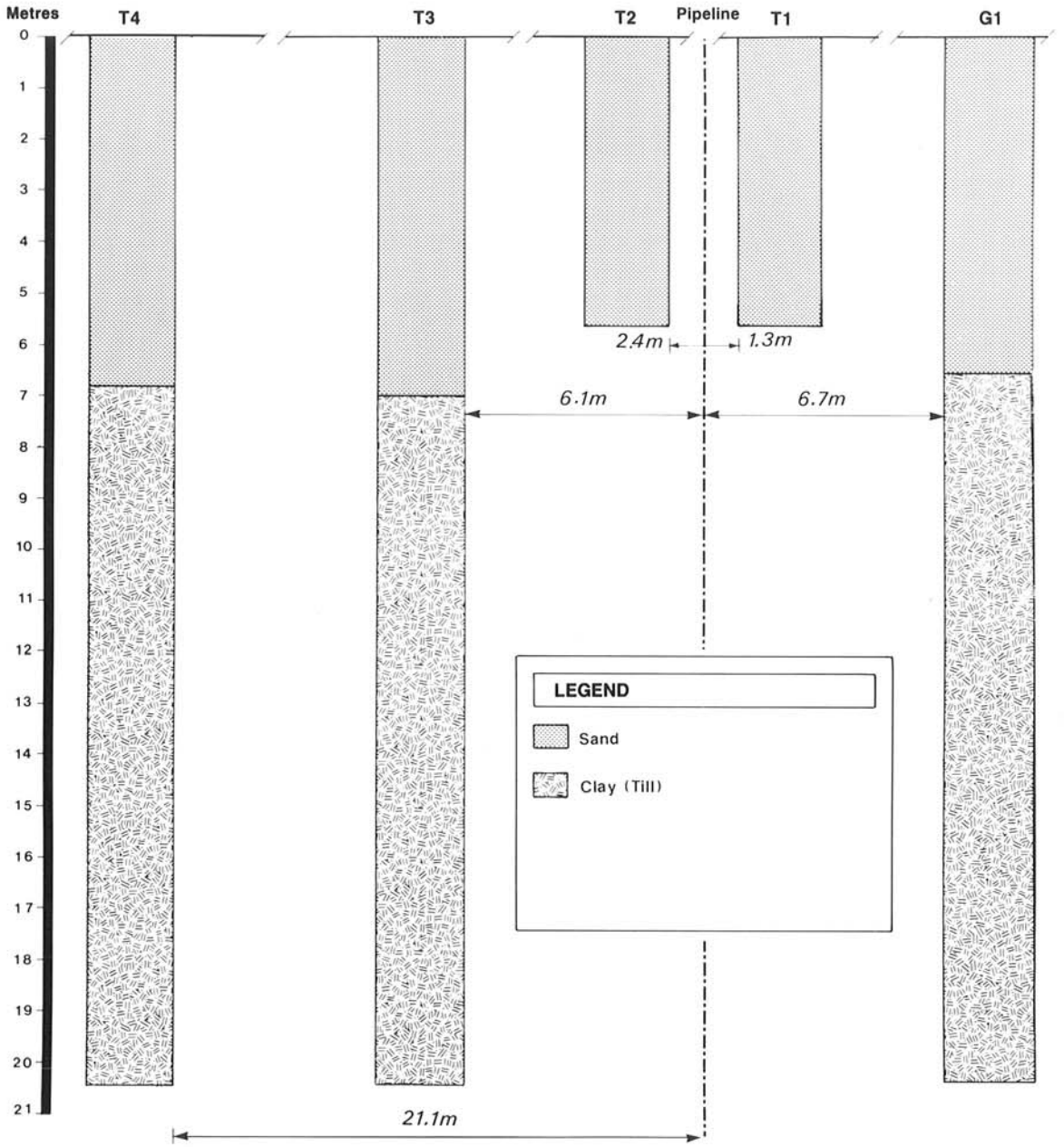
Site history:
- trees cleared to 26 m width during winter 1982-83
- trenched in February 1984 with a Barber Green wheel ditcher
- instrumentation holes drilled in March 1984
- no restoration
- bench marks installed and first surface survey in August 1984

Pipe depth: 0.85 m (excluding Roach) to top of pipe

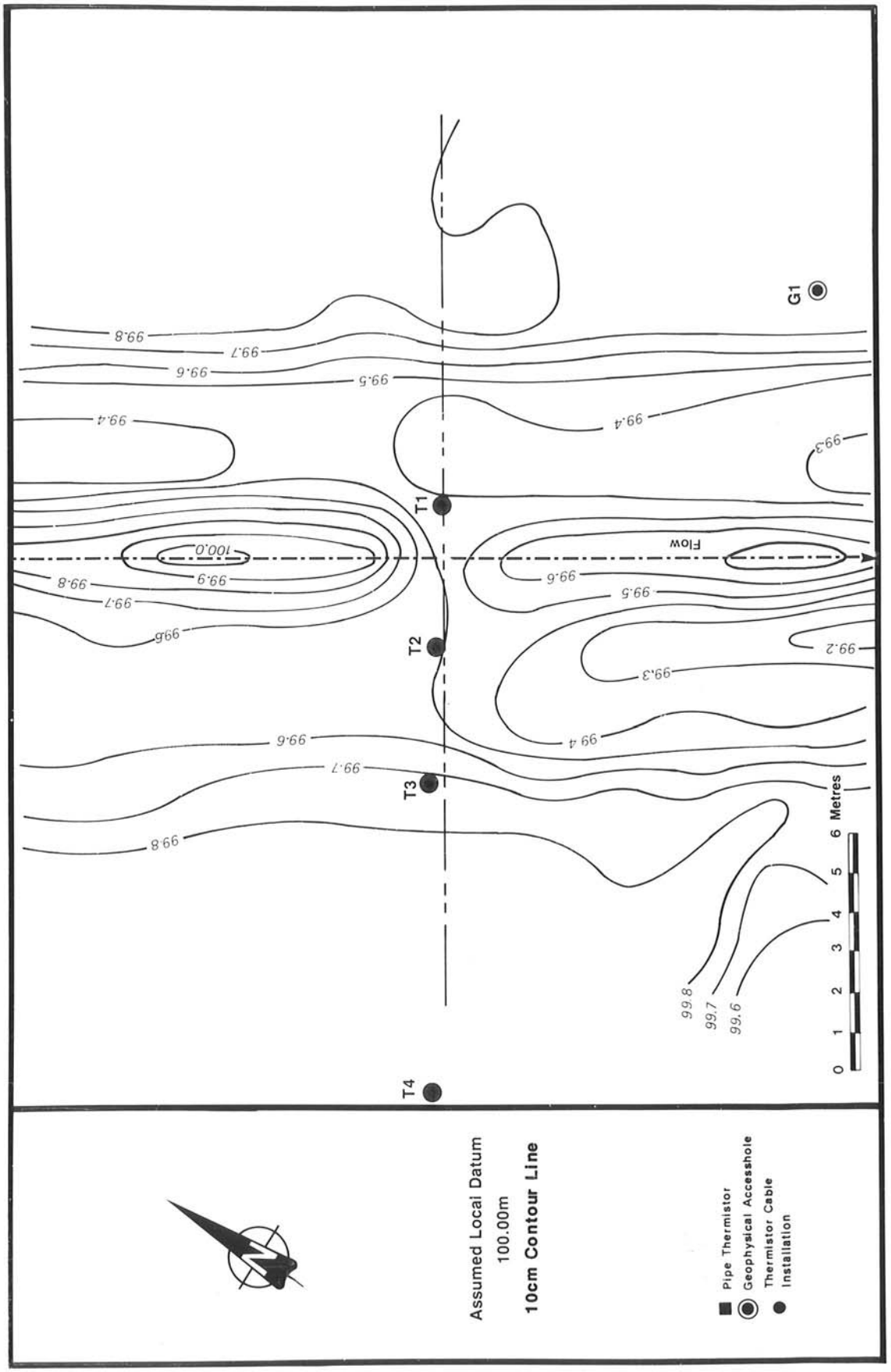
Instrumentation:
4 Multi-thermistor cables
3 Arrays of T.D.R. rods
1 Geophysical access hole
1 Pipe thermistor string
2 Active layer thermistor probes



Site plan of EMR/INAC site 84-5B, Petitot River South



Lithologic cross-section of site 84-5B, Petitot River North, based on the drill logs from the thermal instrumentation hole.

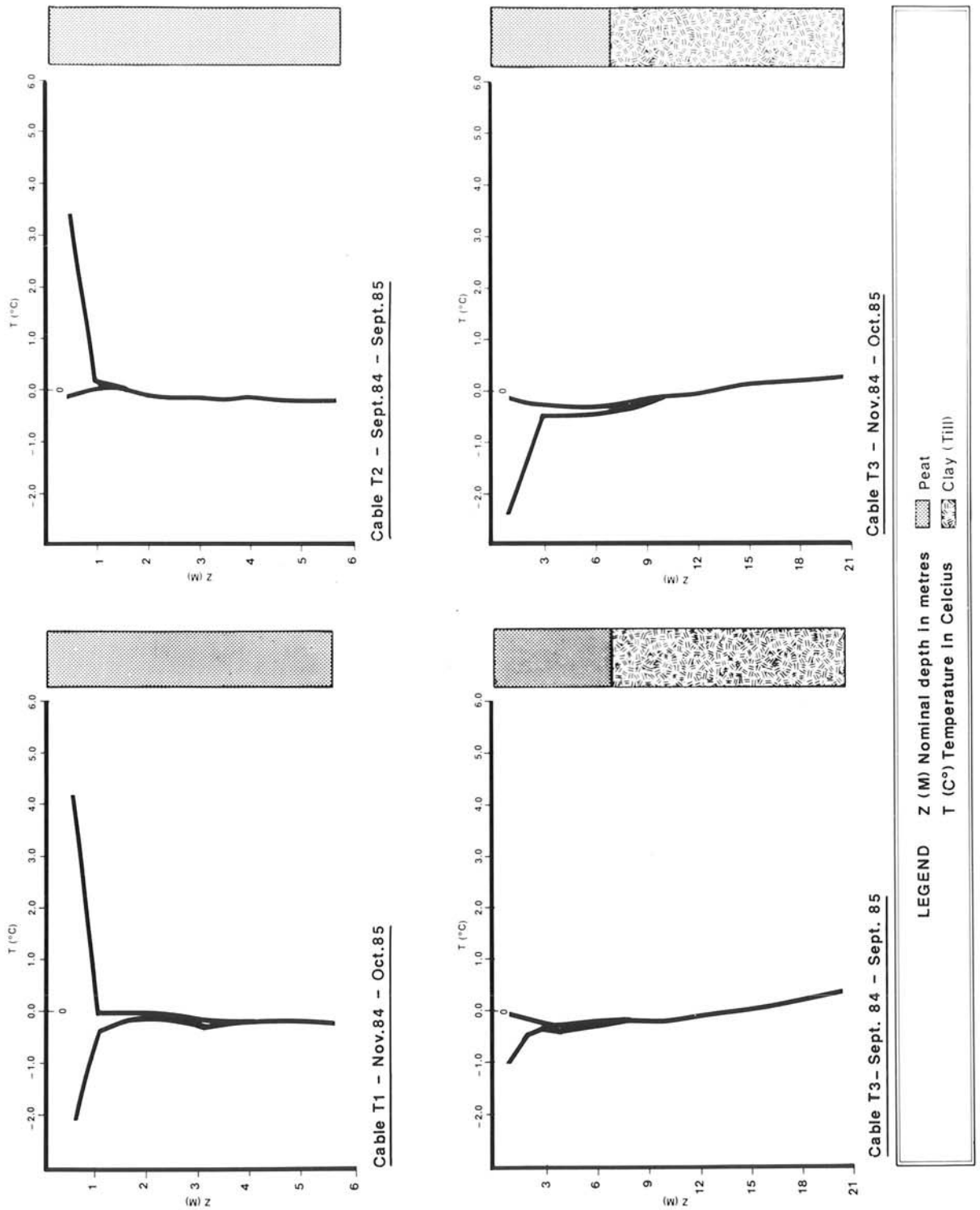


Detailed surface elevation contour map of site 84-5B, Petitot River
North, using an assumed local datum of 100 m.

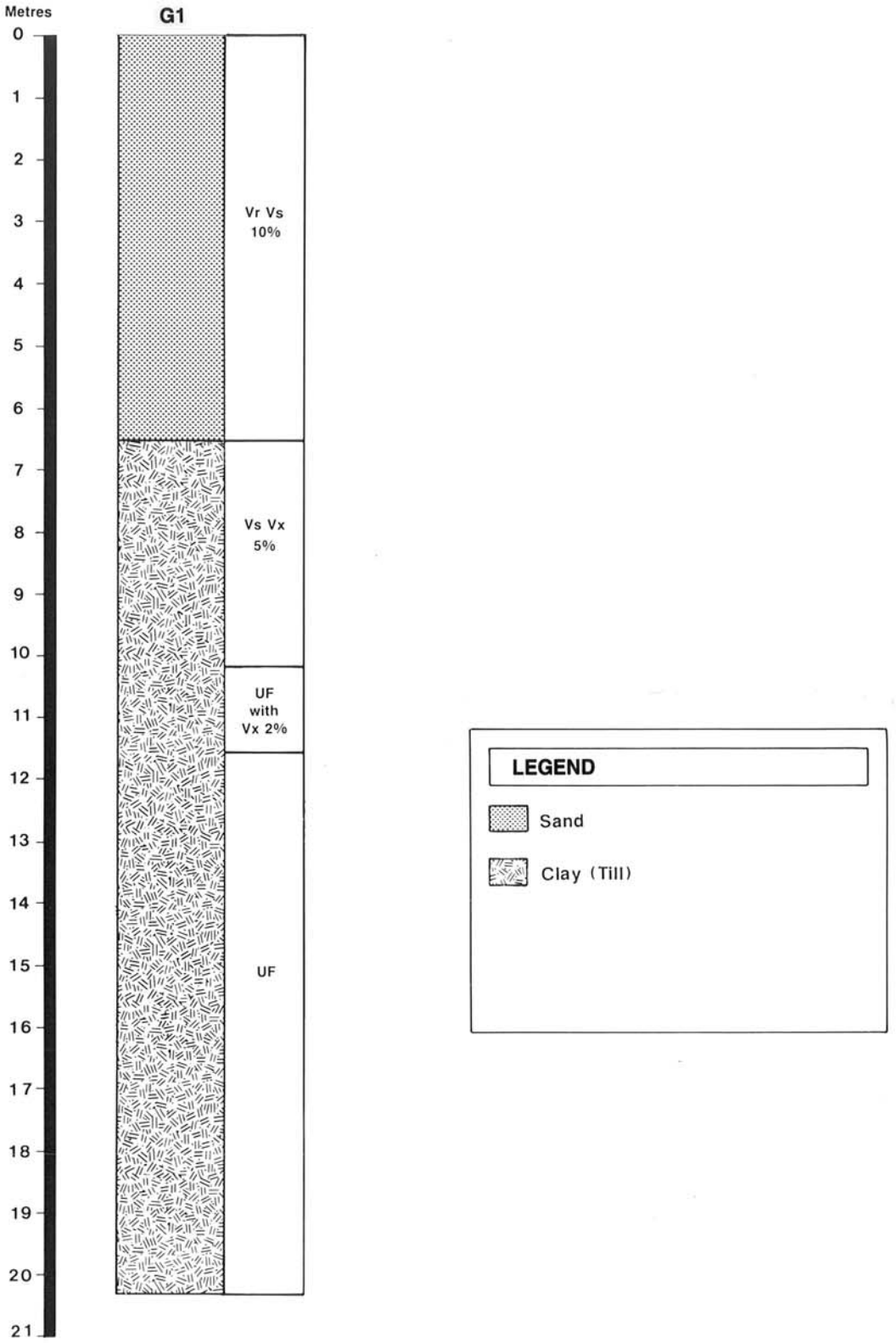
Site 84-5B

Thermal fence 84-5B, at Petitot River North, is located in a very thick (approximately 7 m) level, ice rich peat plateau. In the period under review, (summer 84 - summer 85) it shows the following trends. Active layer development in the newly cleared R.O.W. for the pipeline as observed at cables T1, T2 and T3 and T4 is highly variable, and about 80 m at cable T1, 1.8 m at cable T2 and of less than 1 m at cable T3 and T4 off the R.O.W. A first approximation of permafrost thickness at this site on the basis of cables T3 and T4 indicates a thickness of about 13.5 m. This is a decrease of 3.5 m or 20% from the permafrost thickness observed at fence 84-5A 300 m away.

The data collected during the period at this site also shows a very low temperature gradient which is indicative of an on-going climate change in this region.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 84-5B, Petitot River North.



Ice content distribution observed in hole G1 at EMR/INAC site 84-5B, Petitot River North.

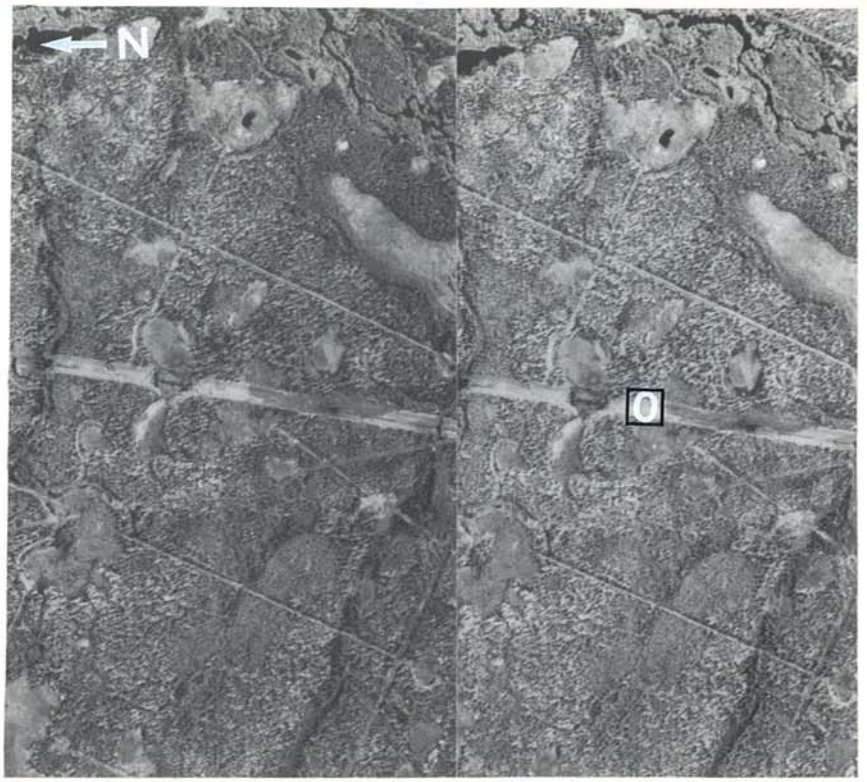
Thermistor depth at site 84-5B
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	1.0
2	1.0	1.0	2.0	2.0
3	1.5	1.5	3.0	3.0
4	2.0	2.0	4.0	4.0
5	2.5	2.5	6.0	6.0
6	3.0	3.0	8.0	8.0
7	3.5	3.5	10.0	10.0
8	4.0	4.0	12.0	12.0
9	4.5	4.5	15.0	15.0
10	5.5	5.7	18.0	18.0
11	-	-	20.5	20.5
Diameter of inner PVC tube	25 mm	25mm	25 mm	38 mm

Site 84-5B, aerial view in May 1985, note the wetter areas on both sides of the trench.

Site 84-5B, ground view in September 1984, note the differential relief in right-of-way (ROW) after one summer.

THERMAL FENCE
84-6
KP 818.5



Air Photos A 26836 Nos 60-61, 7 August 1985

Site number: 84-6

Site name: Petitot River South

Location: 59° 27.8'N 119° 14.7'W, Kmp 819.5

Elevation: 575 metres A.S.L.

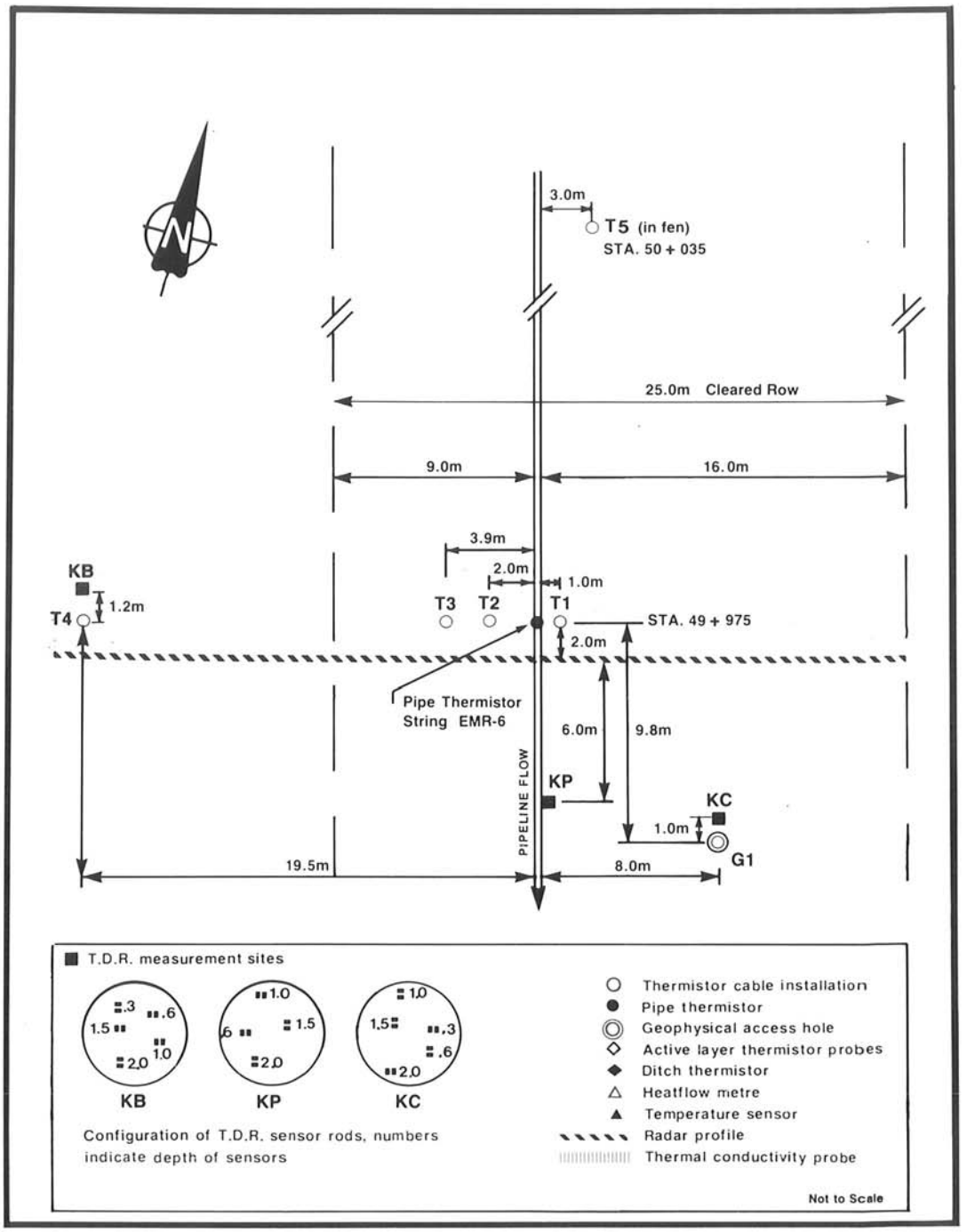
Rationale: This site was established in a thick, ice-rich peat plateau adjacent to a fen depression. It has been selected to study the thermal behaviour of a thick ice-rich peat/fen interface.

Vegetation: Stunted black spruce, ericaceous shrubs, moss woodland

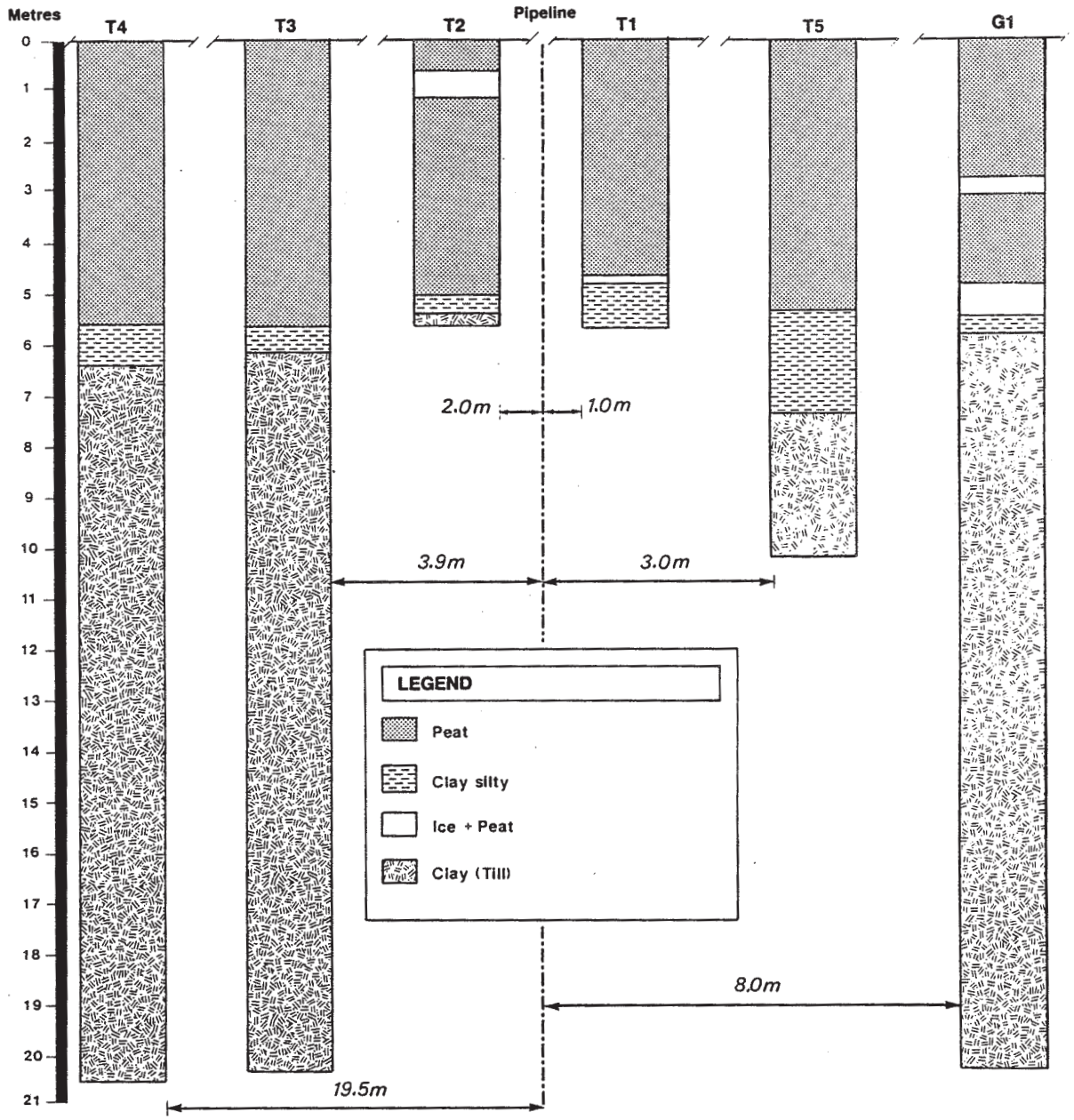
Site history:
- trees cleared to 25 m width in winter 1982-83
- trenched in February 1984 with a Barber Green wheel ditcher
- instrumentation holes drilled in March 1984
- no restoration
- bench marks installed and first surface survey in August 1984

Pipe depth: 0.80 m (excluding Roach) to top of pipe

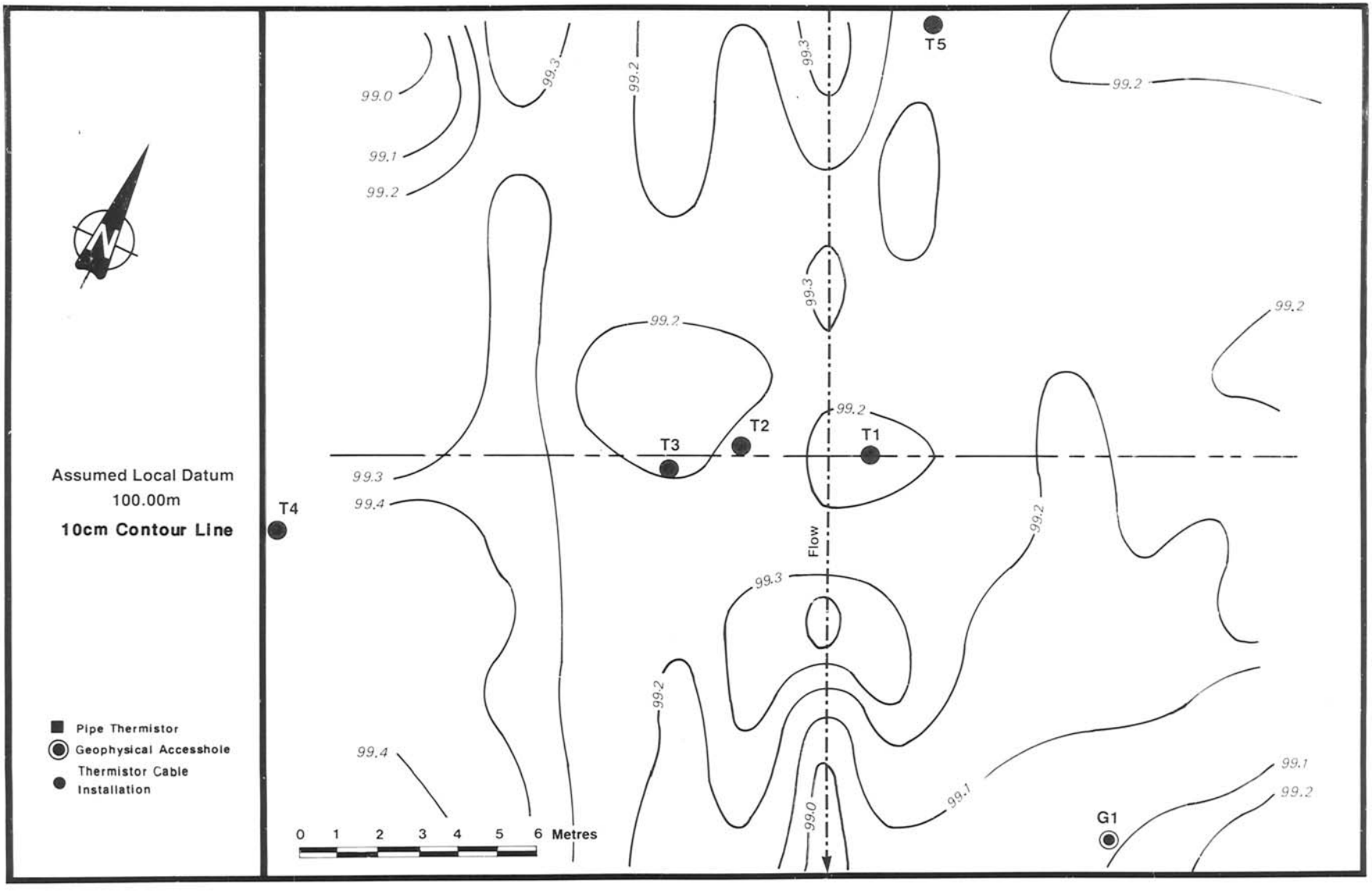
Instrumentation:
5 Multi-thermistor cables
3 Arrays of T.D.R. rods
1 Geophysical access hole
1 Pipe thermistor string



Site plan of EMR/INAC site 84-6, Petitot River South



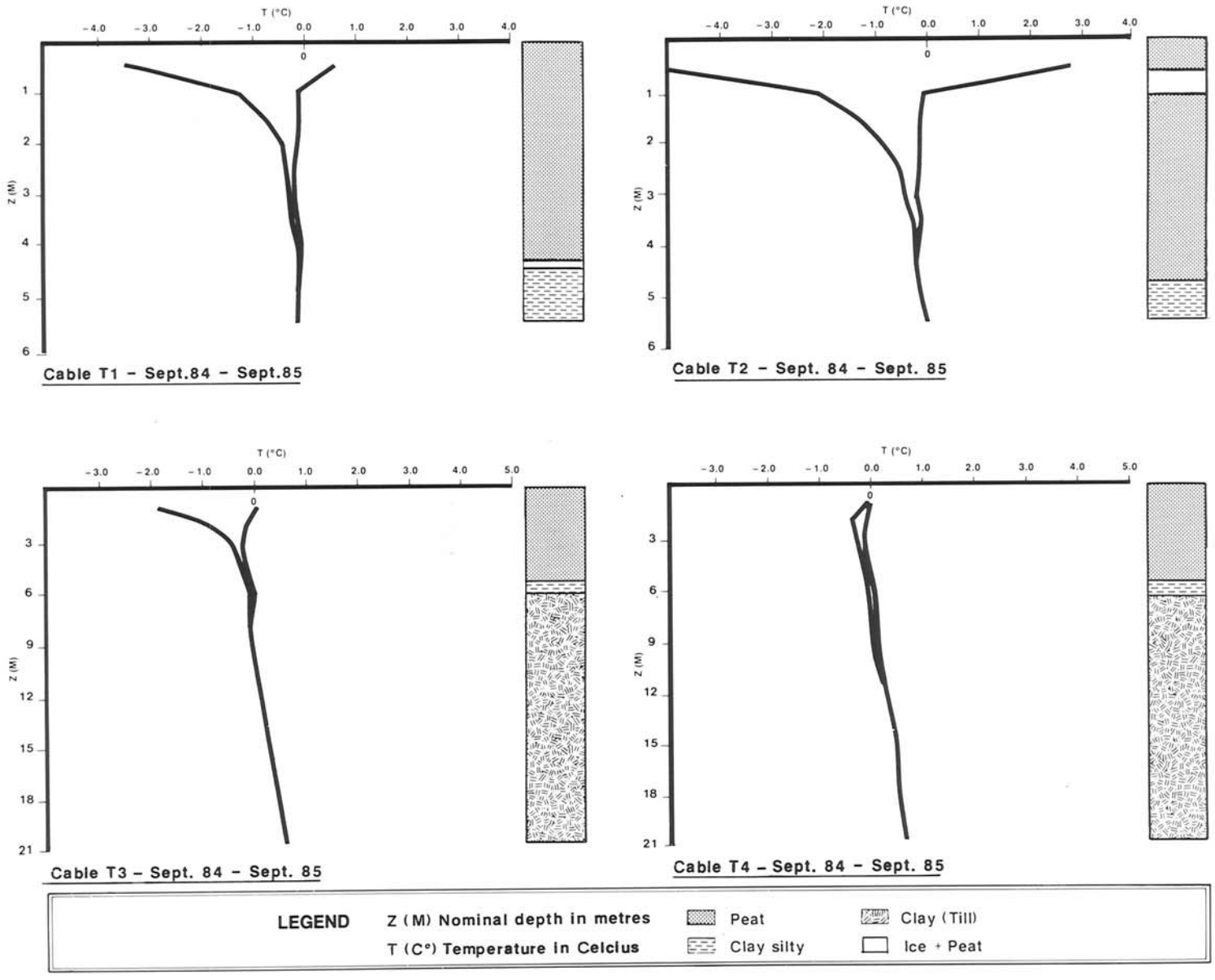
Lithologic cross section of site 84-6, Petitot River North, based on the drill logs from the thermal instrumentation hole.



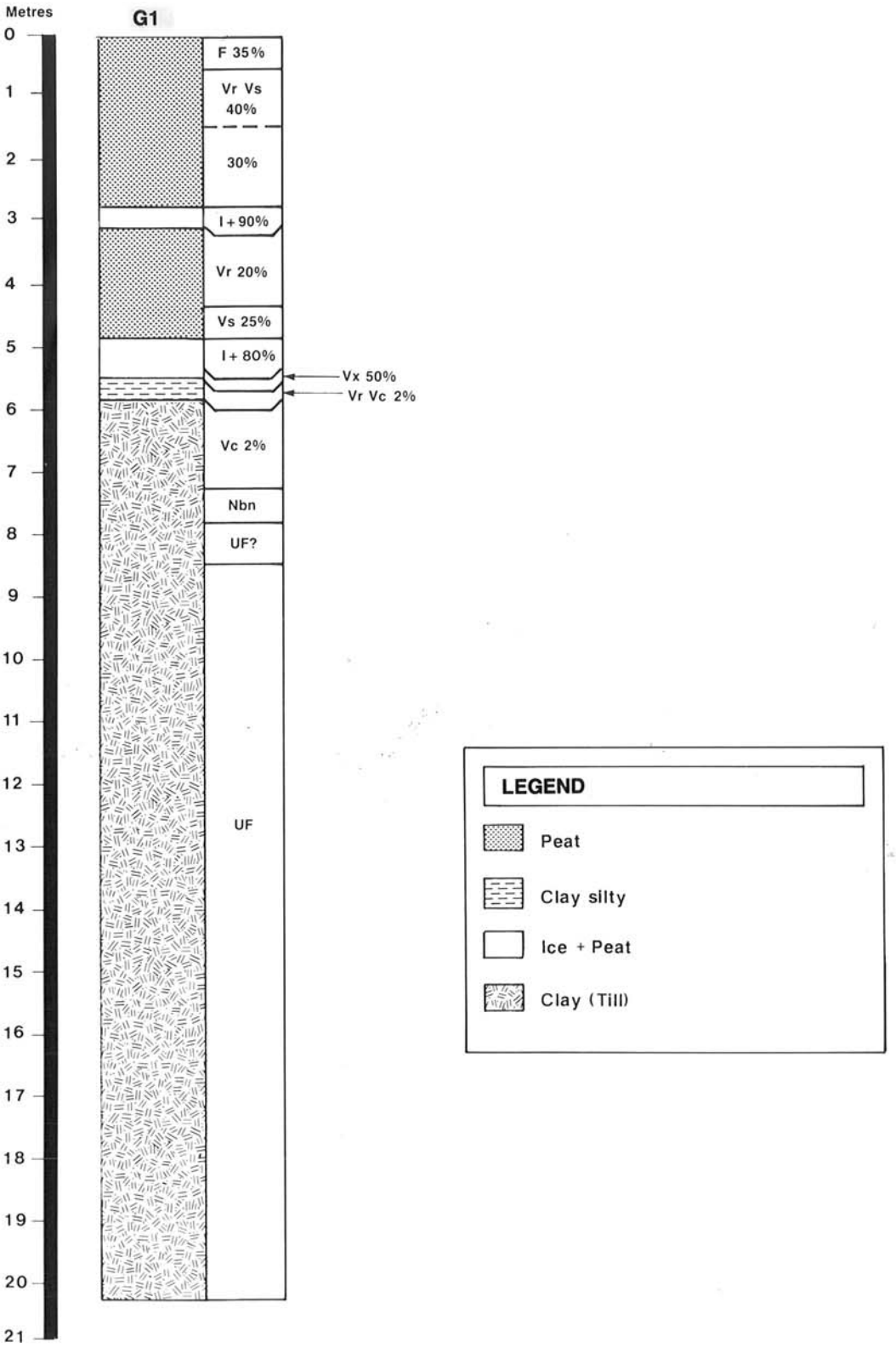
Detailed surface elevation contour map of site 84-6, Petitot River South, using an assumed local datum of 100 m.

Site 84-6

Thermal fence 84-6, at Petitot River South, is located in a thick peat plateau (5.3 m average at the drillholes) with high ice content adjacent to a wet thawed fen depression. It shows the following trend in the period under review (summer 84 - summer 85). Active layer in the newly cleared R.O.W. for the pipeline as observed in cable T1 and T2 is approximately 80 m. Permafrost thickness at this southernmost monitoring site is approximately 9 m at cable T3 and 6 m at cable T4. It is absent in the wet fen depression. The contrast between cable T3 and T4 is likely due to heat loss on the R.O.W. during construction combined with the thick peat layer insulating properties.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 84-6, Petitot River South.



Ice content distribution observed in hole G1 at EMR/INAC site 84-6, Petitot River South.

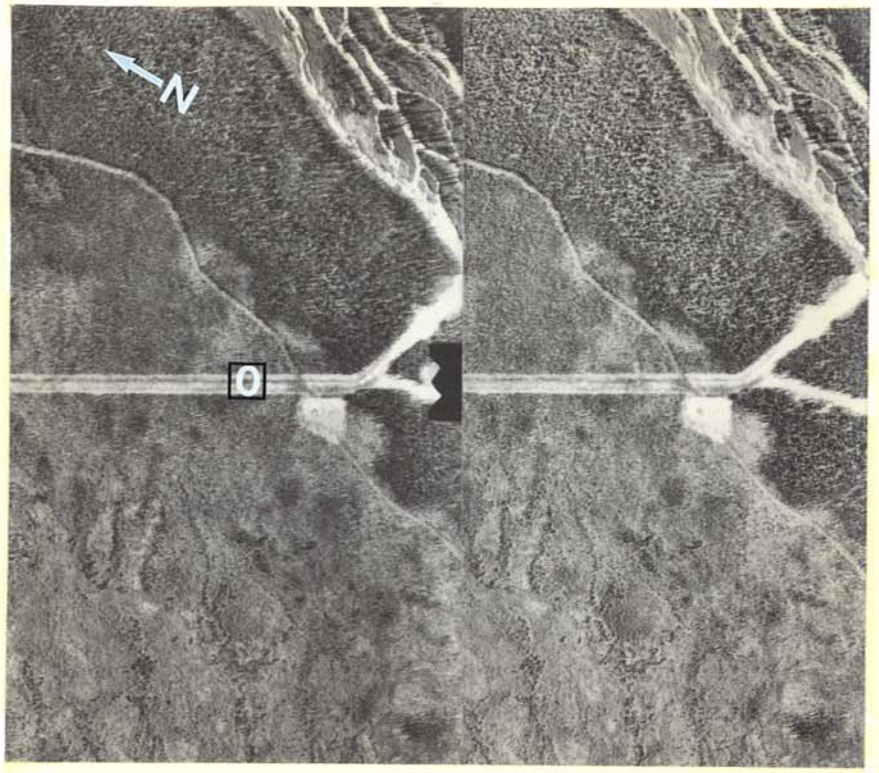
Thermistor depth at site 84-6
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4	Cable T-5
1	0.5	0.5	1.0	1.0	1.0
2	1.0	1.0	2.0	2.0	2.0
3	1.5	1.5	3.0	3.0	3.0
4	2.0	2.0	4.0	4.0	4.0
5	2.5	2.5	6.0	6.0	5.0
6	3.0	3.0	8.0	8.0	6.0
7	3.5	3.5	10.0	10.0	7.0
8	4.0	4.0	12.0	12.0	8.0
9	4.5	4.5	15.0	15.0	9.0
10	5.5	5.4	18.0	18.0	10.1
11	-	-	20.6	20.7	-
Diameter of inner PVC tube	25 mm	25mm	25 mm	38 mm	25 mm

Site 84-6, aerial view in September 1984, after construction.

Ground view of site 84-6 after clearing in October 1983.

THERMAL FENCE
85-7A
KP 270.8



Air photos A26838 Nos. 156-157, 8 August 1985

Site number: 85-7A

Site name: Table Mountain A

Location: 63° 36.91'N, 123° 38.75'W, Kmp 270.8

Elevation: 255 metres A.S.L.

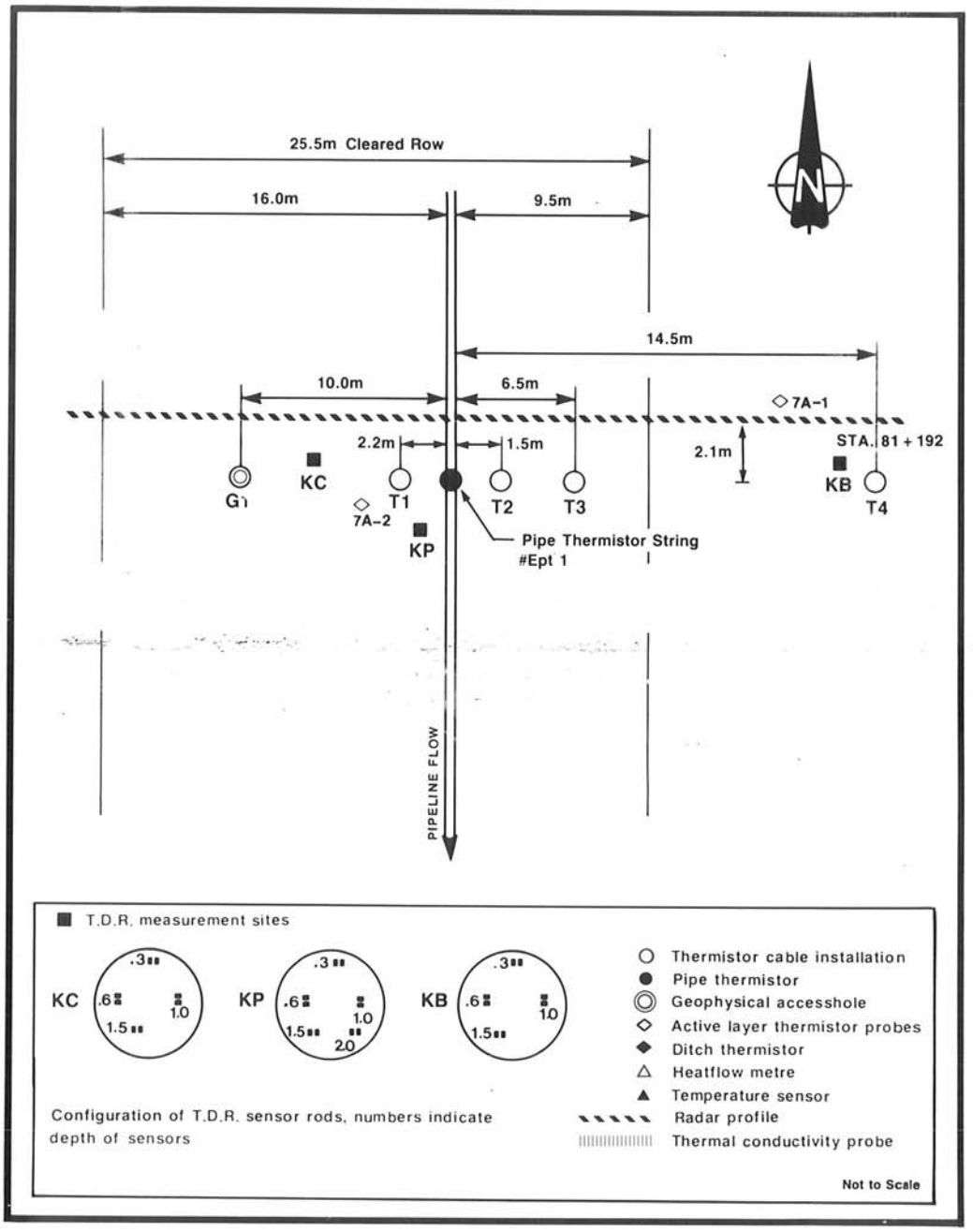
Rationale: This site was established at a level location in ice rich silty clay lacustrine deposits containing massive ice lenses. At this site the R.O.W. is coincident with an old seismic line (about ±20 years old). Permafrost is expected to be approximately 40 m thick.

Vegetation: Open black spruce, alder, ericaceous shrubs, lichen-moss (hummocky)

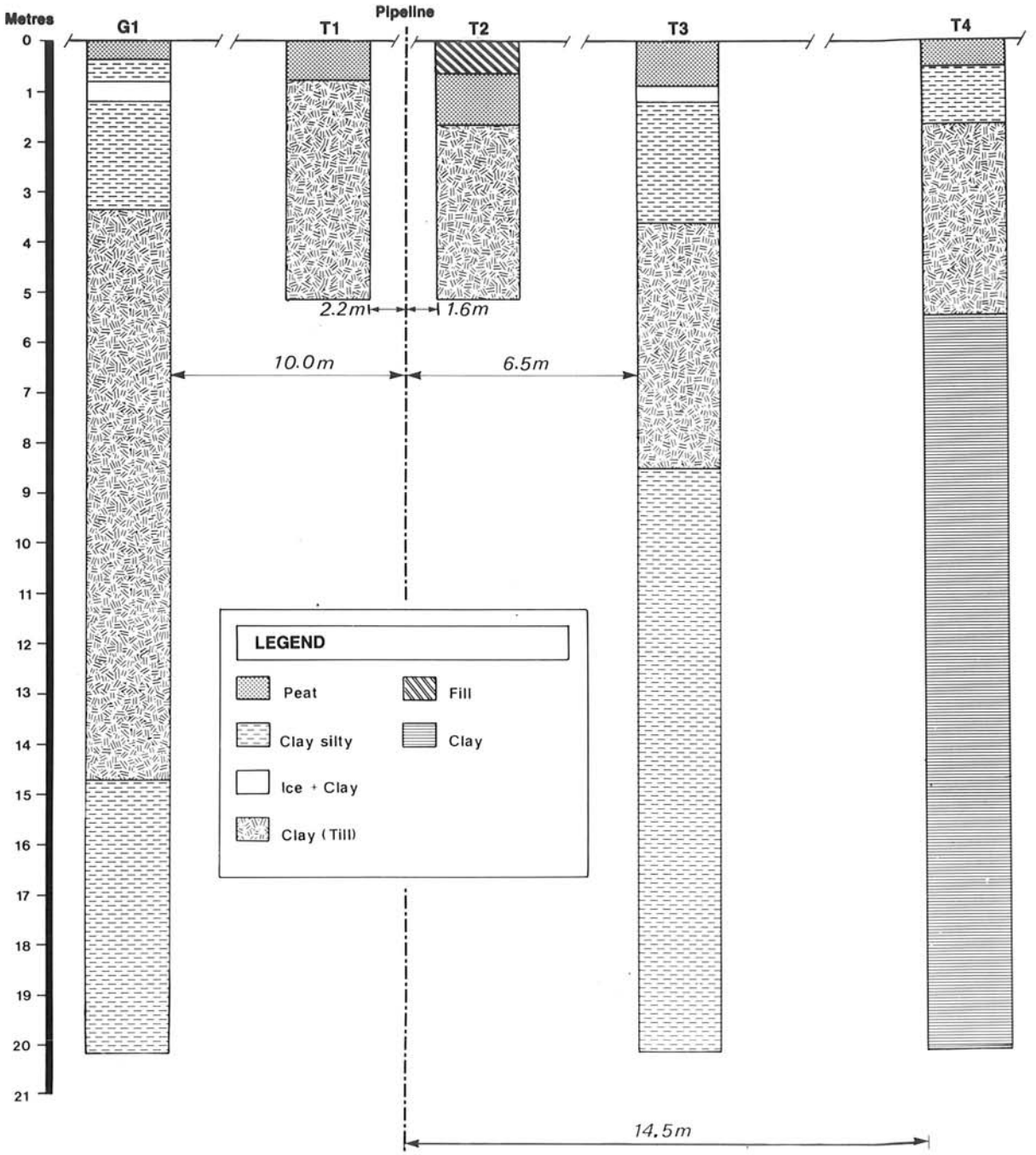
Site history:
- Trees cleared to 25.5 m width in winter 1983-84.
- Trenched in February 1985 with a Bannister 710 Arctic (wheel) Ditcher.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1985.
- Bench Marks installed and first surface survey in May 1985.
- 1 reference Thermistor Cable added in March 1986.

Pipe depth: 0.90 m (excluding Roach) to top of pipe (March 1985)

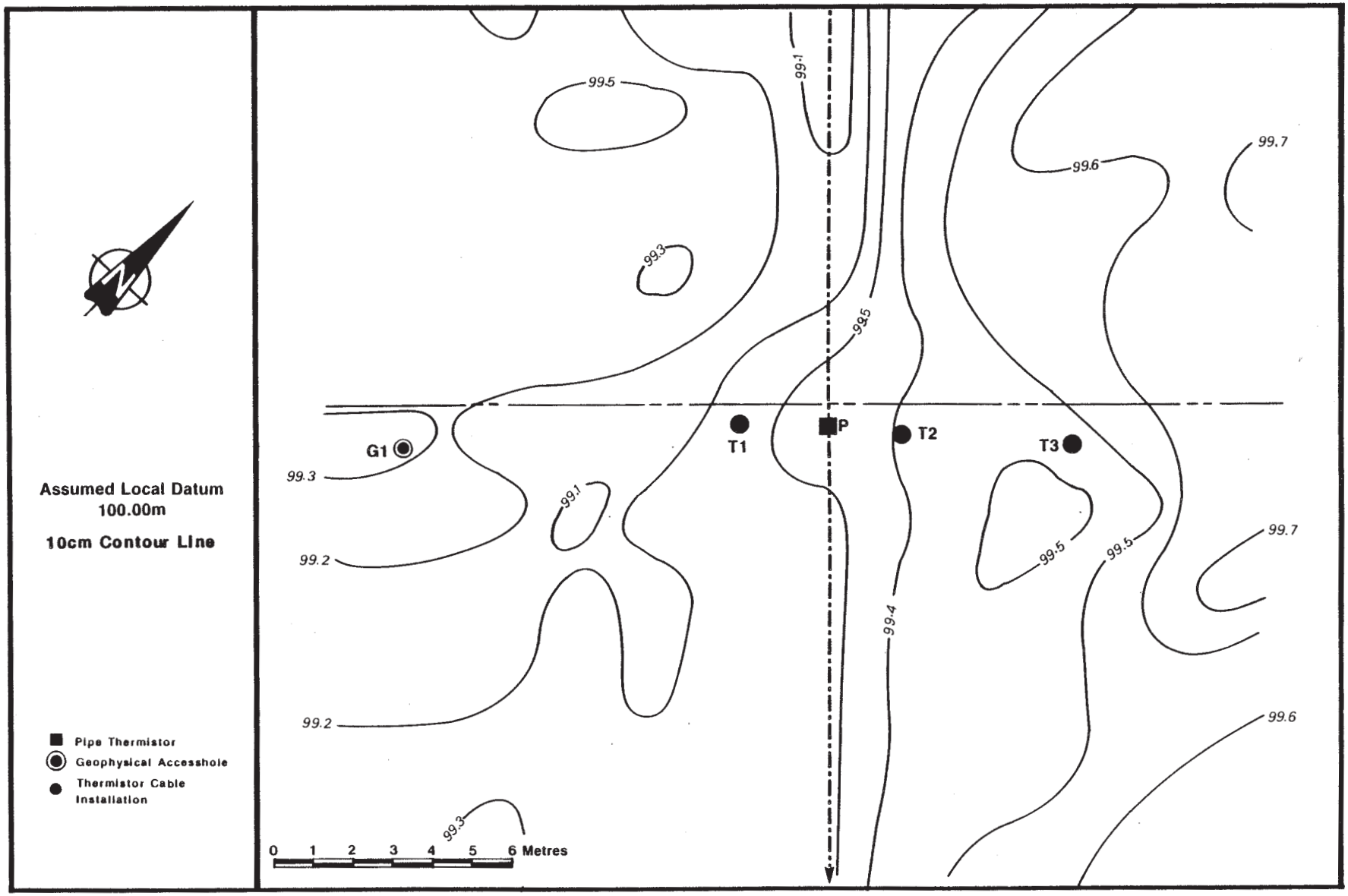
Instrumentation:
5 Multi-thermistor cables
1 Pipe thermistor cable
1 Geophysical access hole
3 Arrays of T.D.R. rods
2 Soil temperature probes



Site plan of EMR/INAC site 85-7A, Table Mountain



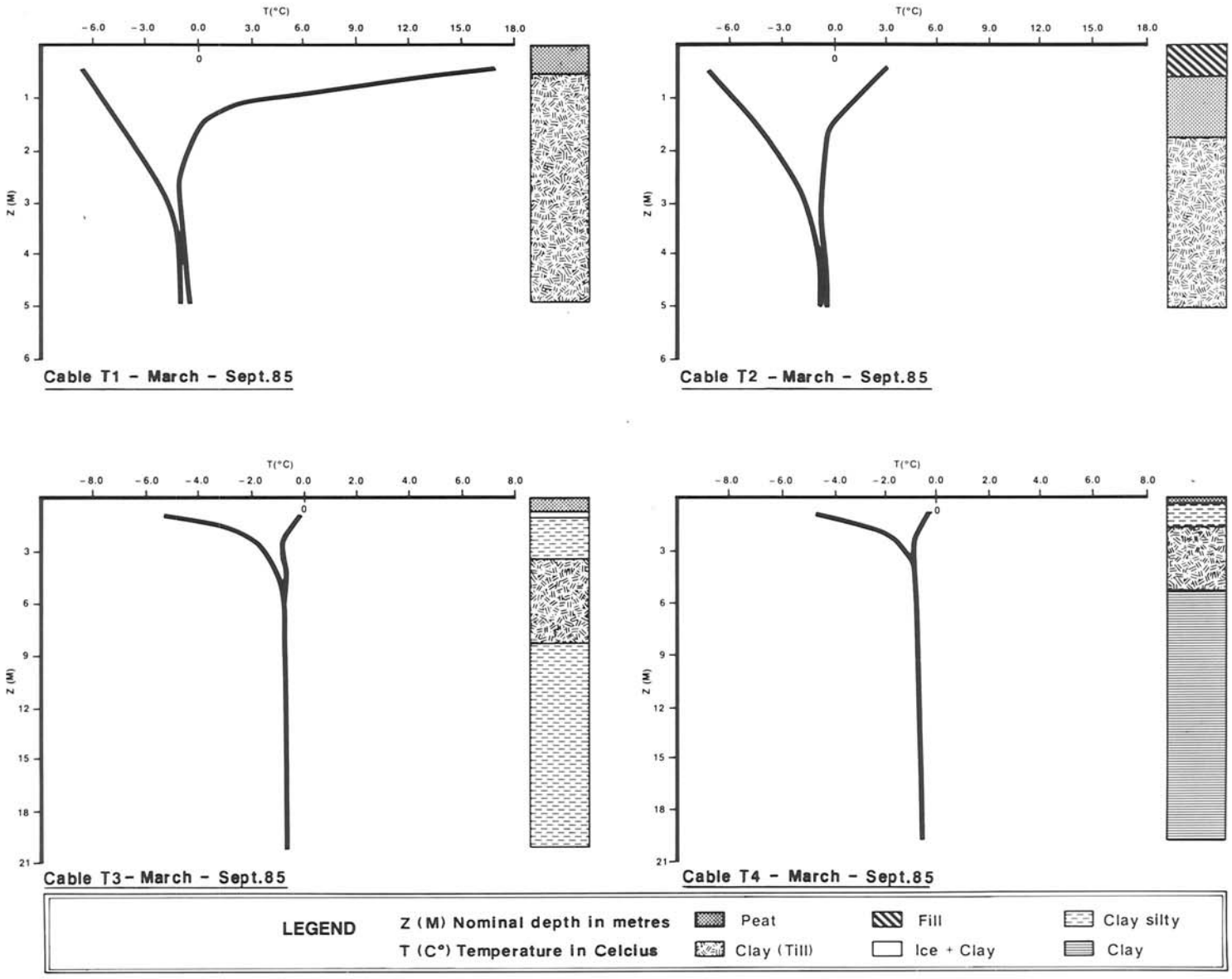
Lithologic cross section of site 85-7A, Table Mountain, based on the drill logs from the thermal instrumentation hole.



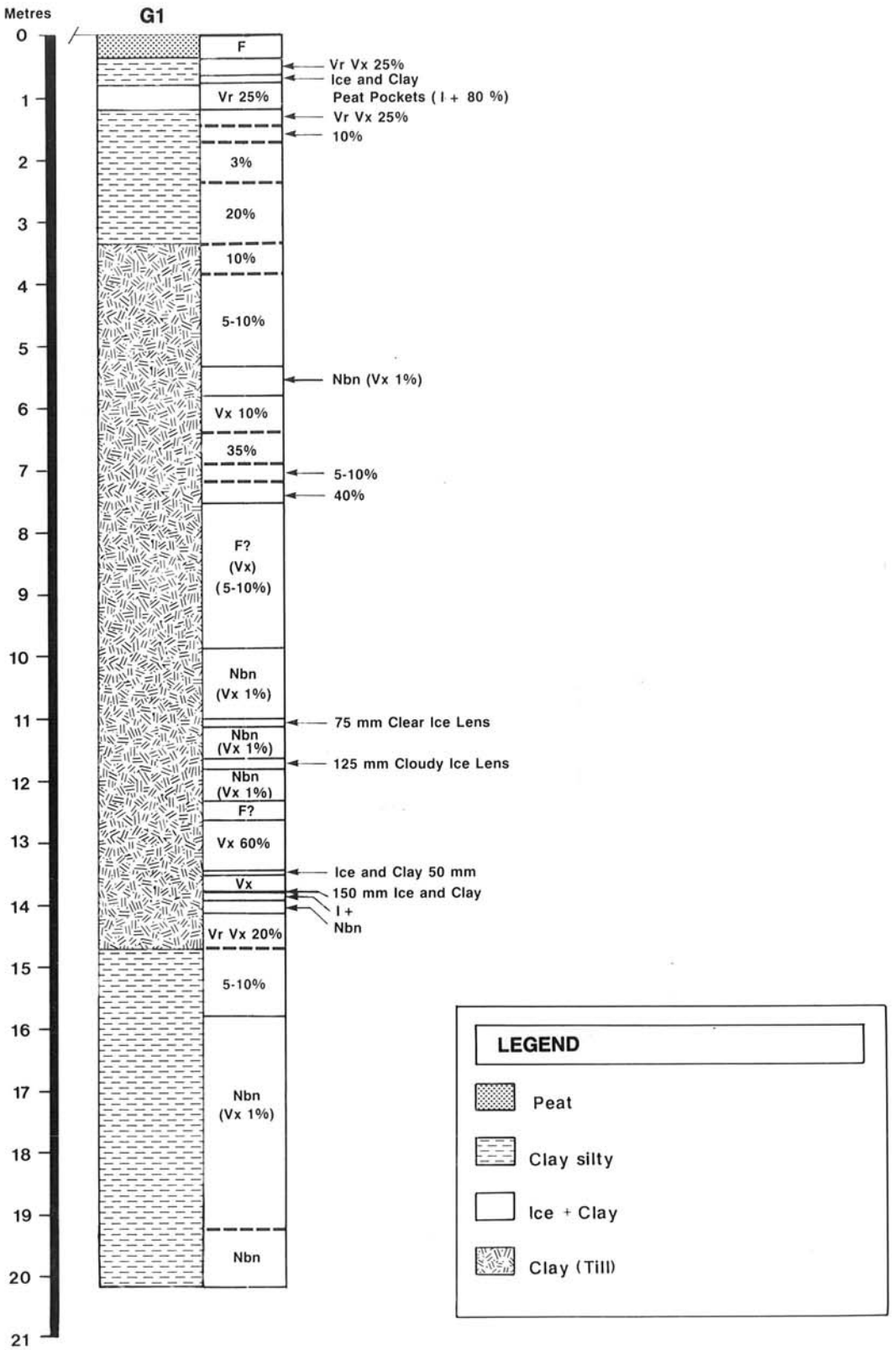
Detailed surface elevation contour map of site 85-7A, Table Mountain, using an assumed local datum of 100 m.

Site 85-7A

Thermal fence 85-7A at the Table Mountain site shows the following trend in its first year of installation. At this fence the R.O.W. is coincident with an old seismic line which is approximately 20 years old. The active layer in the formerly cleared R.O.W. is approximately 1.5 m deep while it is less than 1 m in the newly cleared portion and off the R.O.W. (See Table 1). At this fence the observed permafrost depth is 40 m. It is interesting to note that the very low gradient observed in the lower portion of the deep holes is likely attributable to a climatic change occurring in this portion of the Mackenzie Valley.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 85-7A, Table Mountain.



Ice content distribution observed in hole G1 at EMR/INAC site 85-7A, Table Mountain.

Thermistor depth at site 85-7A
depth in meters

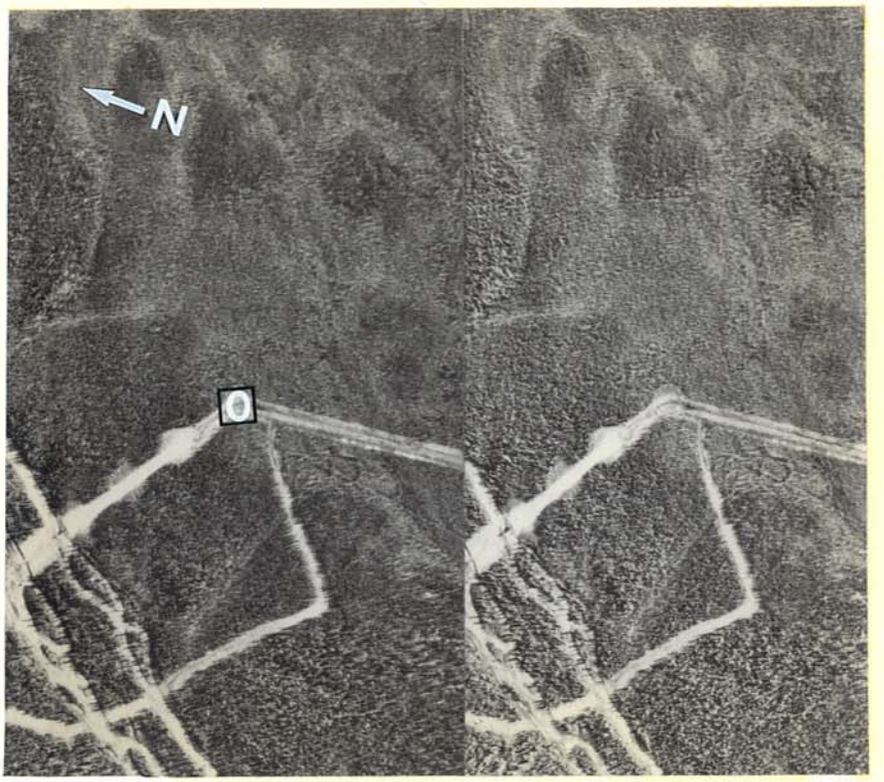
Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4	Cable T-5*	Cable T-6*
1	0.5	0.5	1.0	1.0	1.0	20.0
2	1.0	1.0	2.0	2.0	2.0	28.0
3	1.5	1.5	3.0	3.0	4.0	36.0
4	2.0	2.0	4.0	4.0	6.0	44.0
5	2.5	2.5	6.0	6.0	8.0	52.0
6	3.0	3.0	8.0	8.0	10.0	60.0
7	3.5	3.5	10.0	10.0	12.0	68.0
8	4.0	4.0	12.0	12.0	14.0	76.0
9	4.5	4.5	14.0	14.0	16.0	84.0
10	5.0	5.0	17.0	17.0	18.0	92.0
11	-	-	20.0	20.0	20.0	100.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm	38 mm	38 mm

*Note that cables T-5 and T-6 are installed in the same hole.

Site 85-7A in May 1985, aerial view after winter construction.

Site 85-7A in August 1985, ground view.

THERMAL FENCE
85-7B
KP 271.5



Air photos A26838 Nos. 155-156, 8 August 1985

Site number: 85-7B

Site name: Table Mountain B

Location: 63° 36.59'N 123° 38.06'W, Kmp 270.8

Elevation: 265 metres A.S.L.

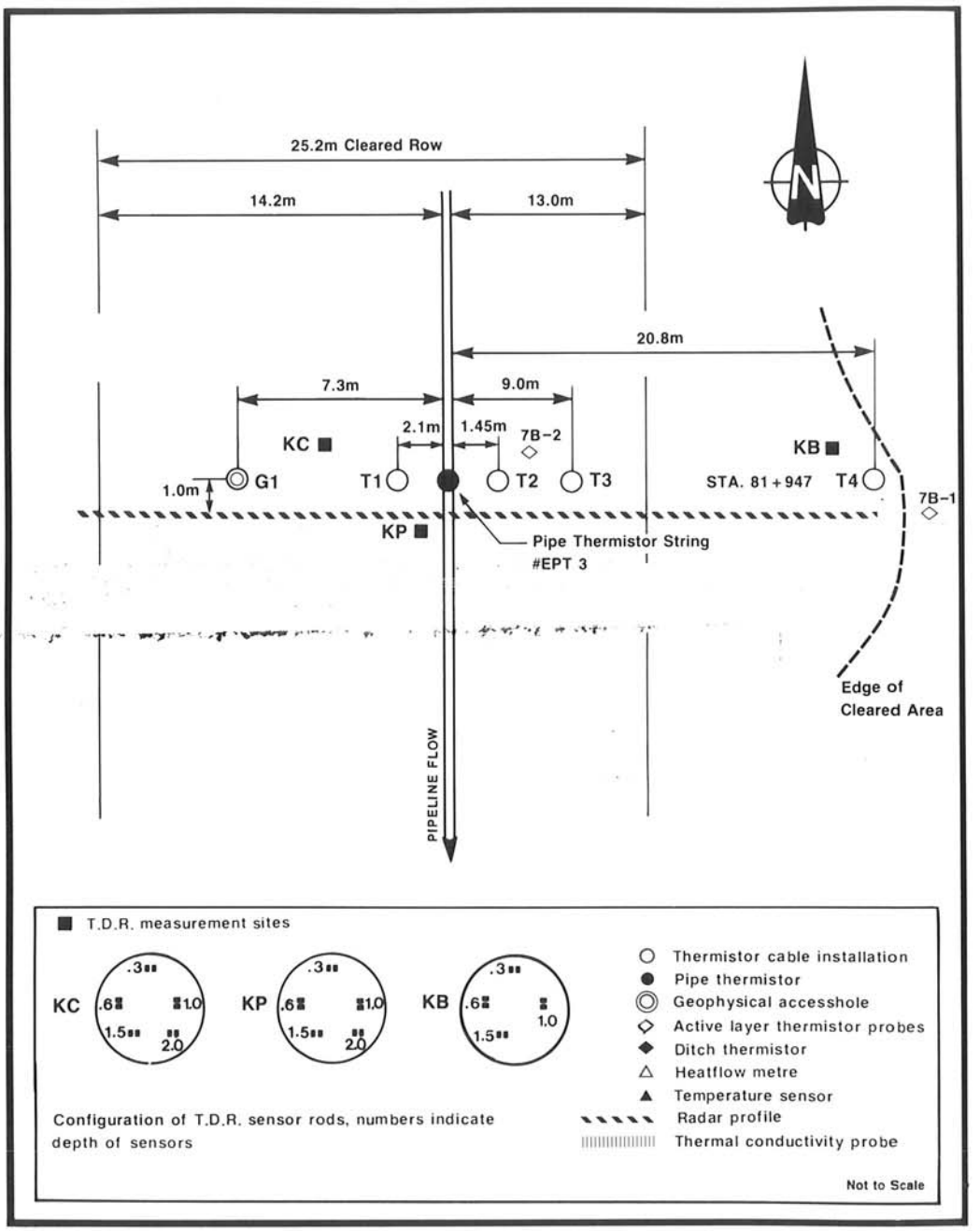
Rationale: This site was established at the top of a north facing slope in ice rich, silty clay lacustrine deposits containing massive ice lenses. At this location the R.O.W. is coincident with an old helidrill pad clearing from the mid seventies. Permafrost is expected to be approximately 70 m thick.

Vegetation: Open black spruce, Alder, ericaceous shrubs, moss, hummocky

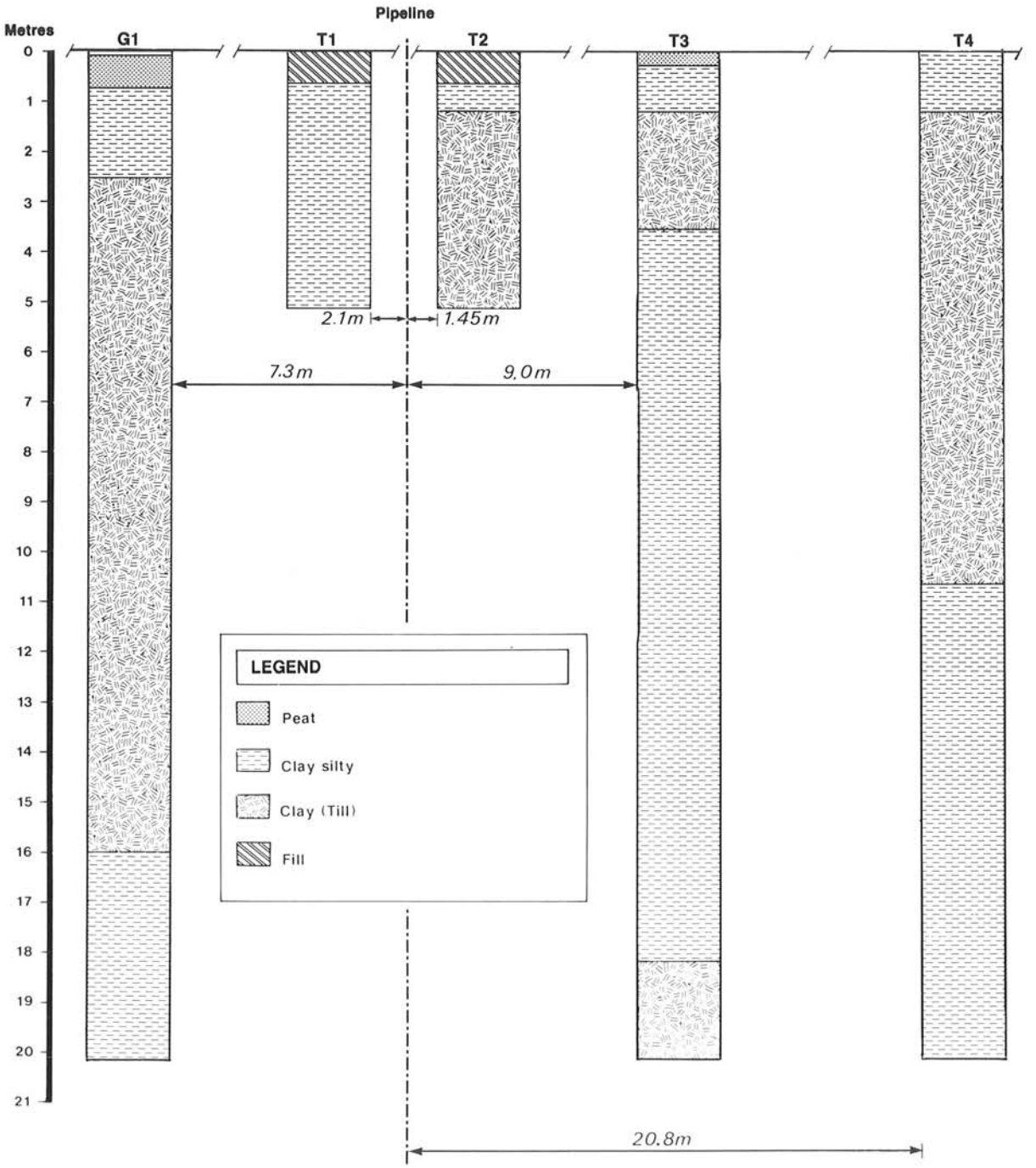
Site history:
- Trees cleared to 30 m diameter helidrill pad in mid seventies.
- Brush cleared in February 1983-84.
- Ditched with Bannister 710 Arctic (wheel) Ditcher in February 1985.
- Holes drilled in February 1985
- Bench Marks installed and first surface survey in May 1985.
- 1 reference thermistor cable added in March 1986

Pipe depth: 0.90 m (excluding Roach) to top of pipe (March 1985).

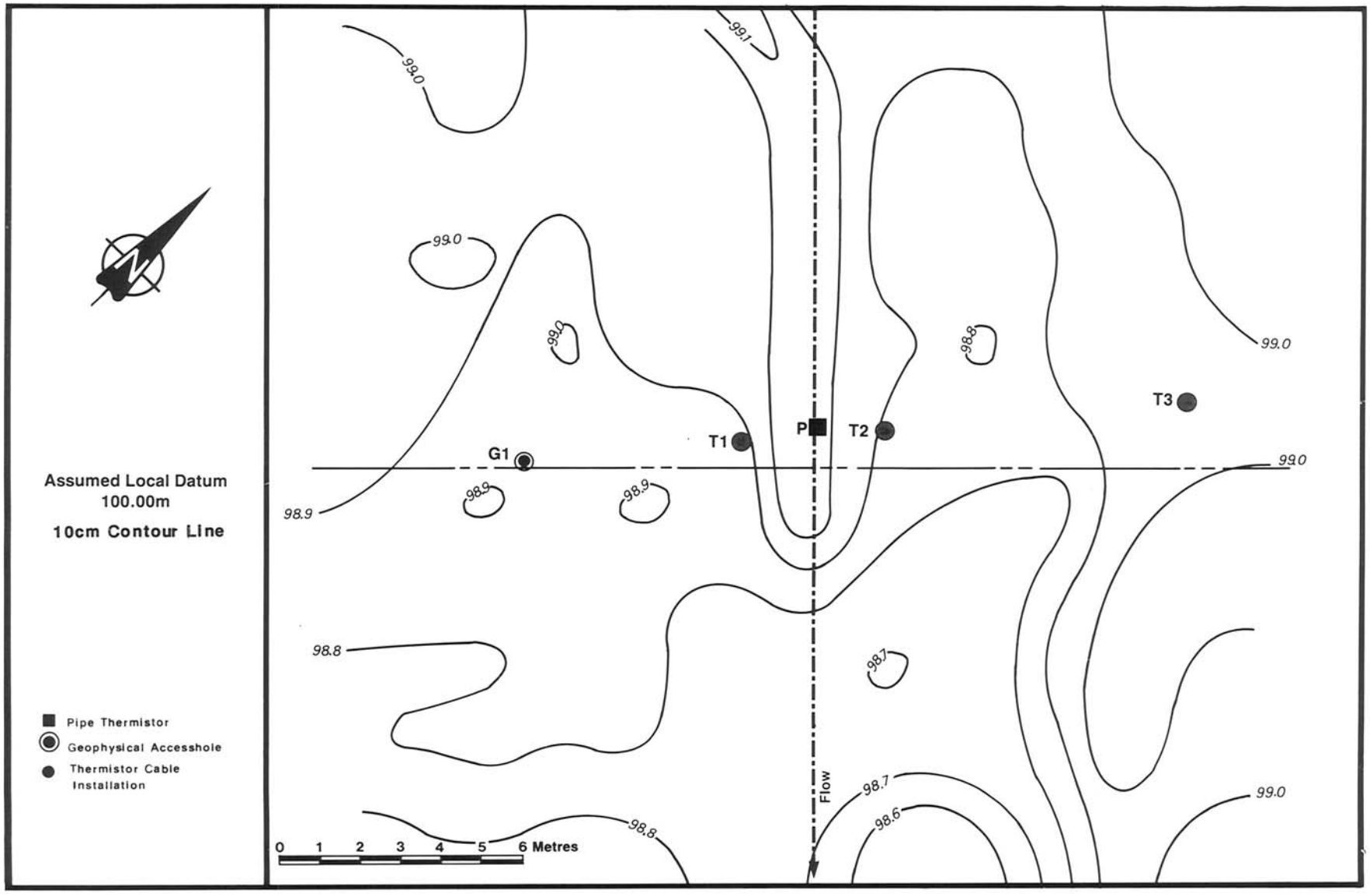
Instrumentation:
5 Multi-thermistor cables
1 Pipe thermistor Cable
1 Geophysical access hole
3 Arrays of T.D.R. rods
2 Soil temperature probes



Site plan of EMR/INAC site 85-7B, Table Mountain



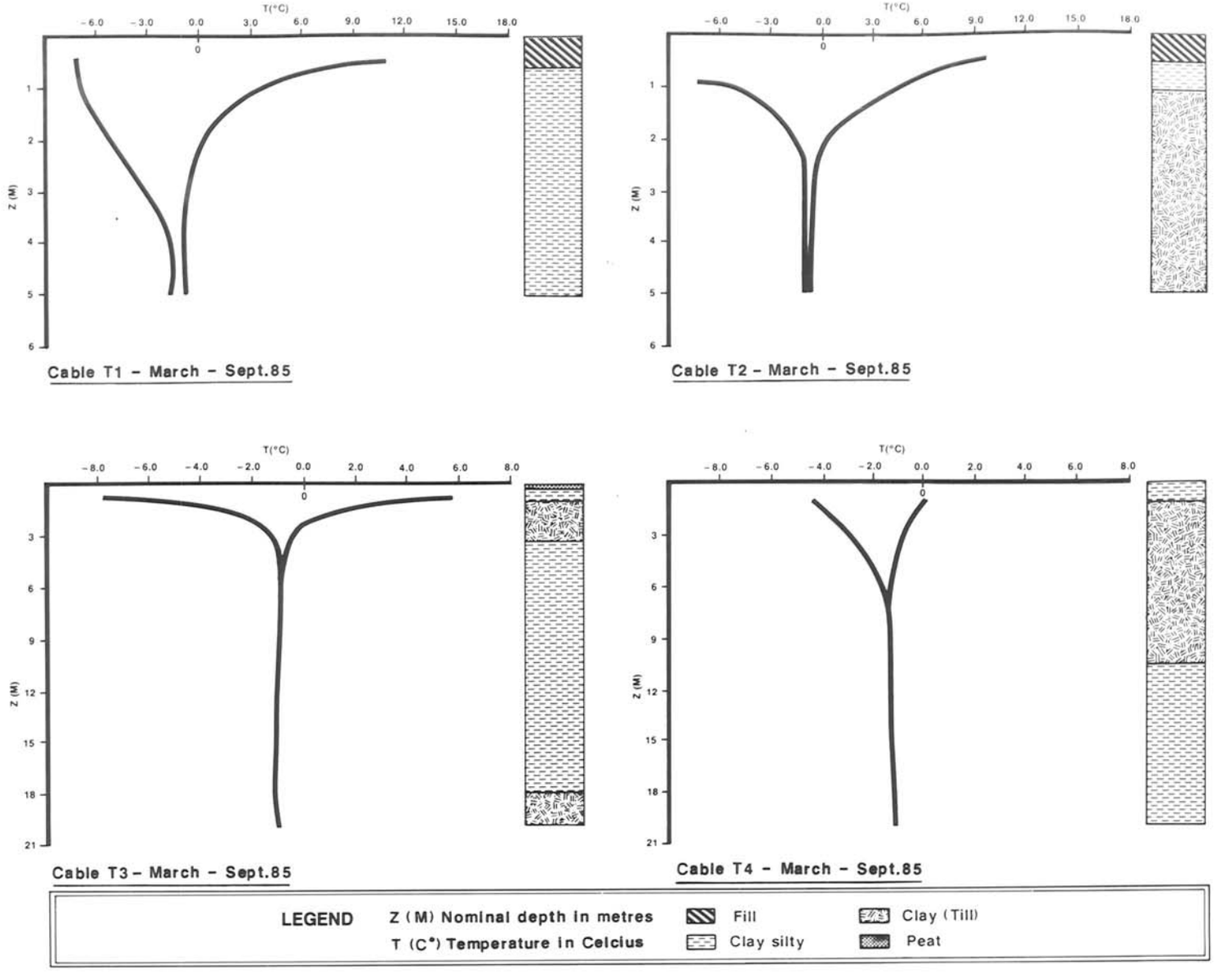
Lithologic cross section of site 85-7B, Table Mountain, based on the drill logs from the thermal instrumentation hole.



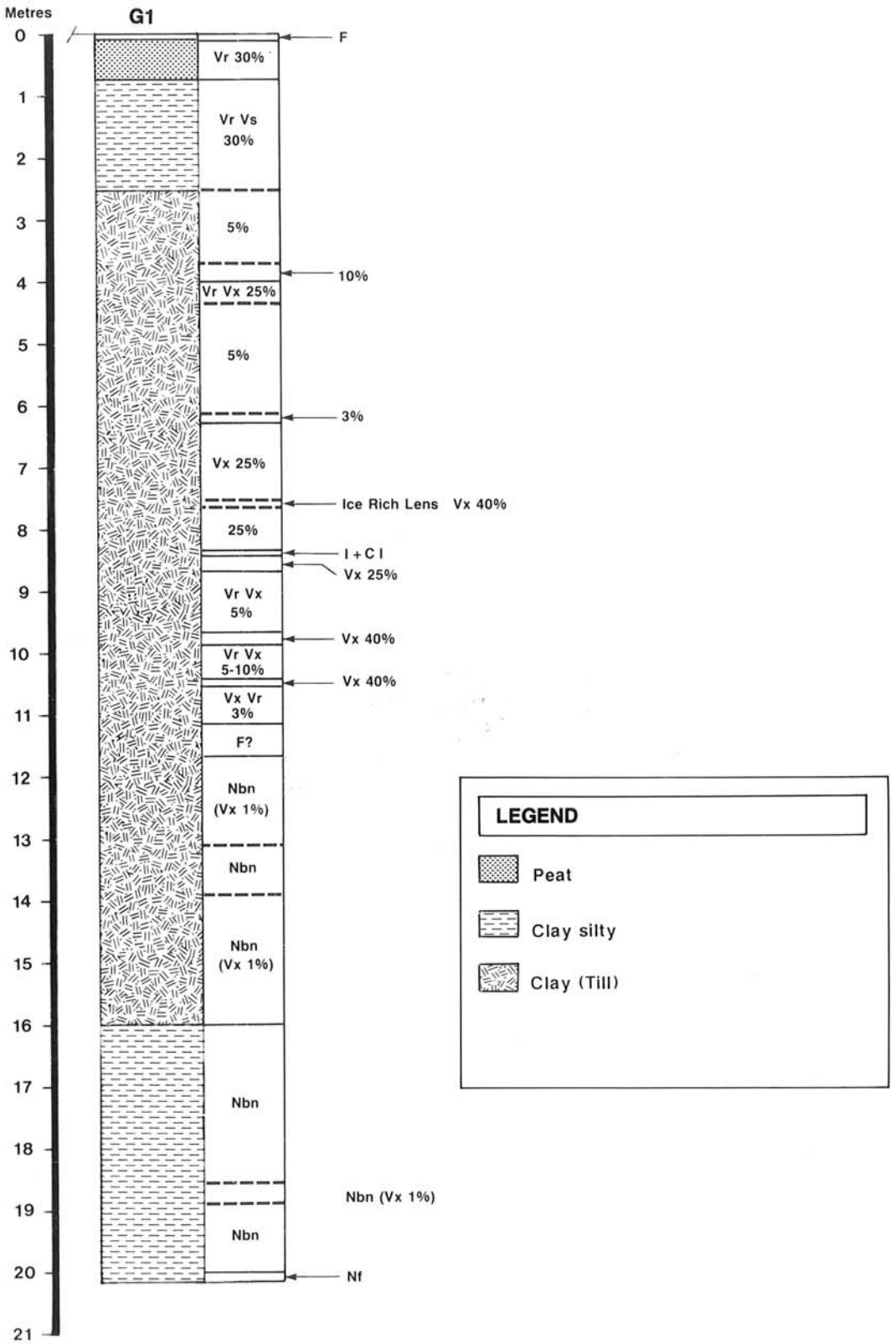
Detailed surface elevation contour map of site 85-7B, Table Mountain, using an assumed local datum of 100 m.

Site 85-7B

Thermal fence 85-7B at the Table Mountain site shows the following trend in its first year of installation. At this fence the R.O.W. is coincident with an old helidrill pad which is about 10 years old. Active layer depth in the previously cleared R.O.W. is approximately 1.7 m deep and about 1 m thick off the R.O.W. It is interesting to note that the temperature at 20 m at this fence is 0.5°C colder than the fence at 85-7A and 0.3°C colder than that observed at fence 85-7C. This colder temperature at this depth is caused by the proximity of this fence to the step north facing slope located immediately to its north which allows extra heat loss from the ground. This coupled to the low gradient also observed at this site yield a calculated permafrost depth of 70 m.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 85-7B, Table Mountain.



Ice content distribution observed in hole G1 at EMR/INAC site 85-7B, Table Mountain.

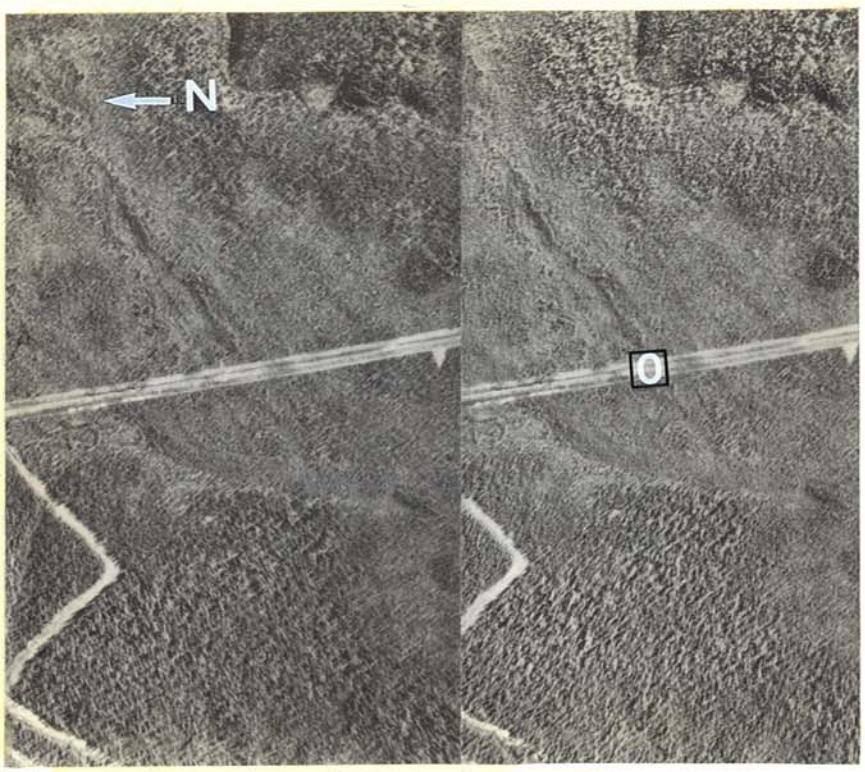
Thermistor depth at site 85-7B
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4	Cable T-5
1	0.5	0.5	1.0	1.0	1.0
2	1.0	1.0	2.0	2.0	2.0
3	1.5	1.5	3.0	3.0	4.0
4	2.0	2.0	4.0	4.0	6.0
5	2.5	2.5	6.0	6.0	8.0
6	3.0	3.0	8.0	8.0	10.0
7	3.5	3.5	10.0	10.0	12.0
8	4.0	4.0	12.0	12.0	14.0
9	4.5	4.5	14.0	14.0	16.0
10	5.0	5.0	17.0	17.0	18.0
11	-	-	20.0	20.0	20.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm	38 mm

Site 85-7B in May 1985, aerial view after winter construction.

Site 85-7B in October 1985, ground view.

THERMAL FENCE
85-7C
KP 271.8



Air photos A26838 Nos. 151-152, 8 August 1985

Site number: 7C

Site name: Table Mountain C

Location: 63° 36.36'N 123° 37.96'W, Kmp 271.8

Elevation: 259 metres A.S.L.

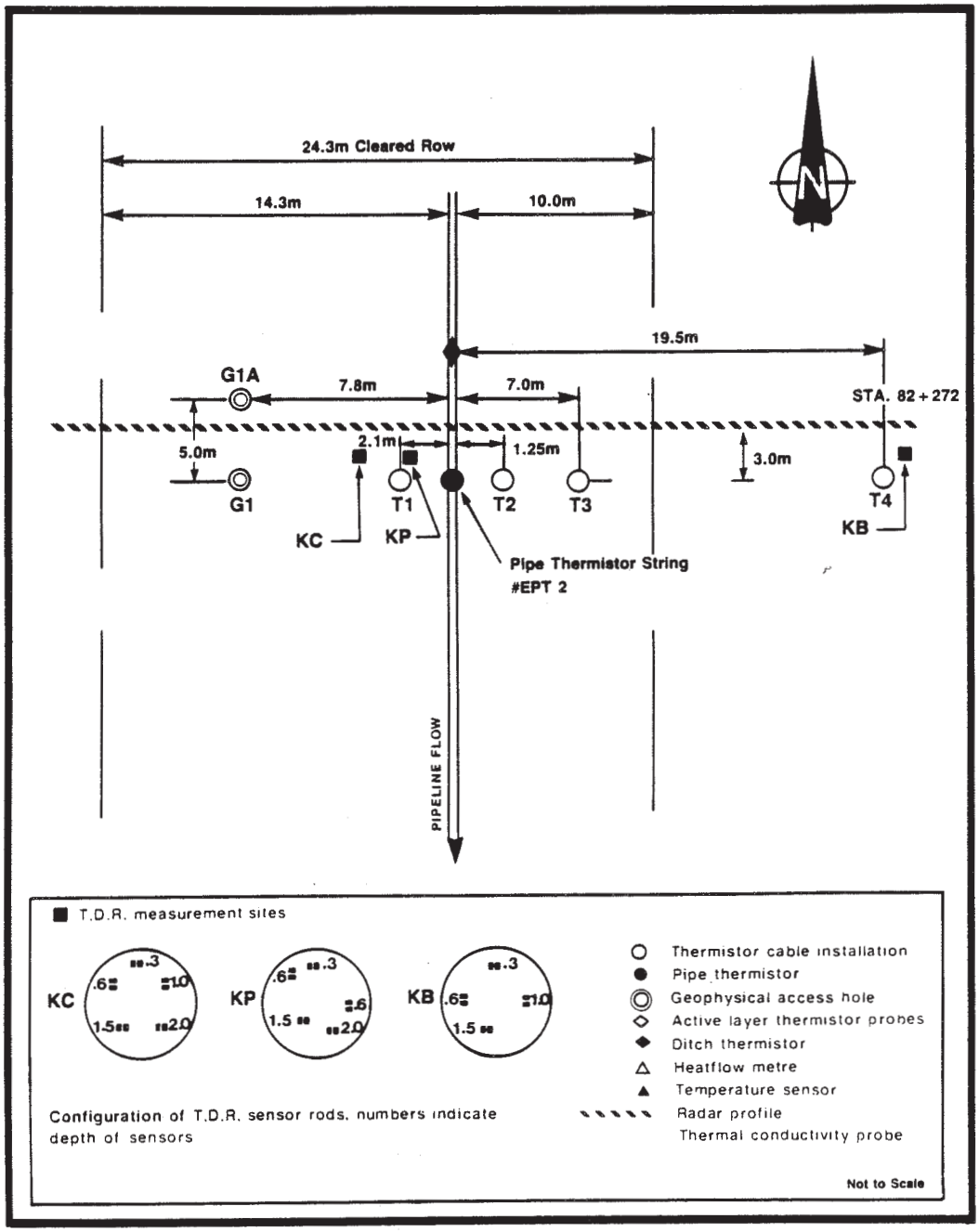
Rationale: This site was established at a level location in ice rich silty clay deposits containing massive ice lenses in a previously undisturbed area. At this location the R.O.W. was cleared in winter 1983-84. Permafrost is expected to be approximately 50 m thick.

Vegetation: Open black spruce, alder, ericaceous shrubs, lichen-moss (hummocky)

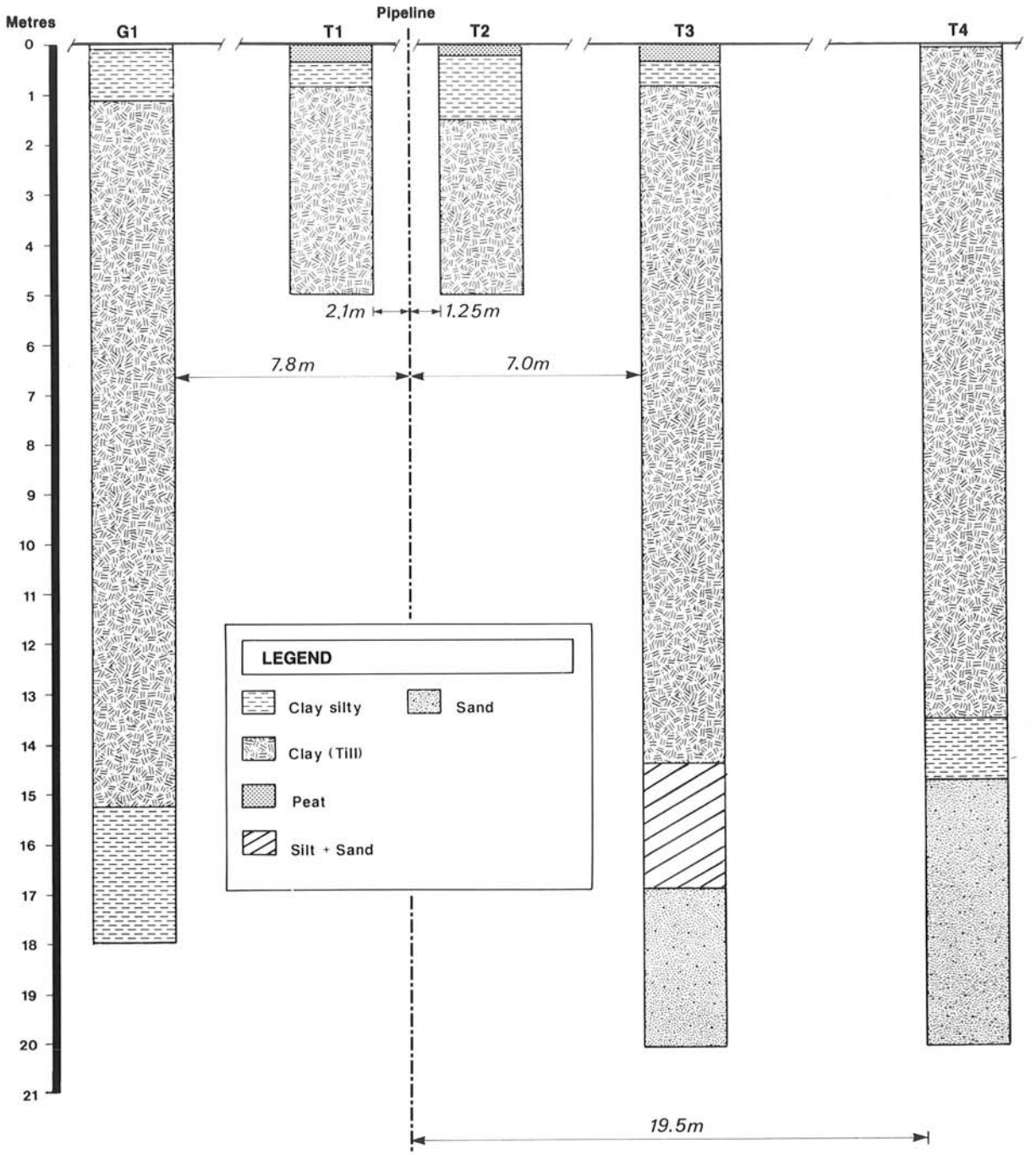
Site history:
- Trees cleared to 24.3 m width in winter 1983-84.
- Trenched in February 1985 with a Bannister 710 Arctic (wheel) Ditcher.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1985.
- Bench Marks installed and first surface survey in May 1985.
- 1 reference thermistor cable added in March 1986.

Pipe depth: 0.90 meters (excluding Roach) to top of pipe (March 1985).

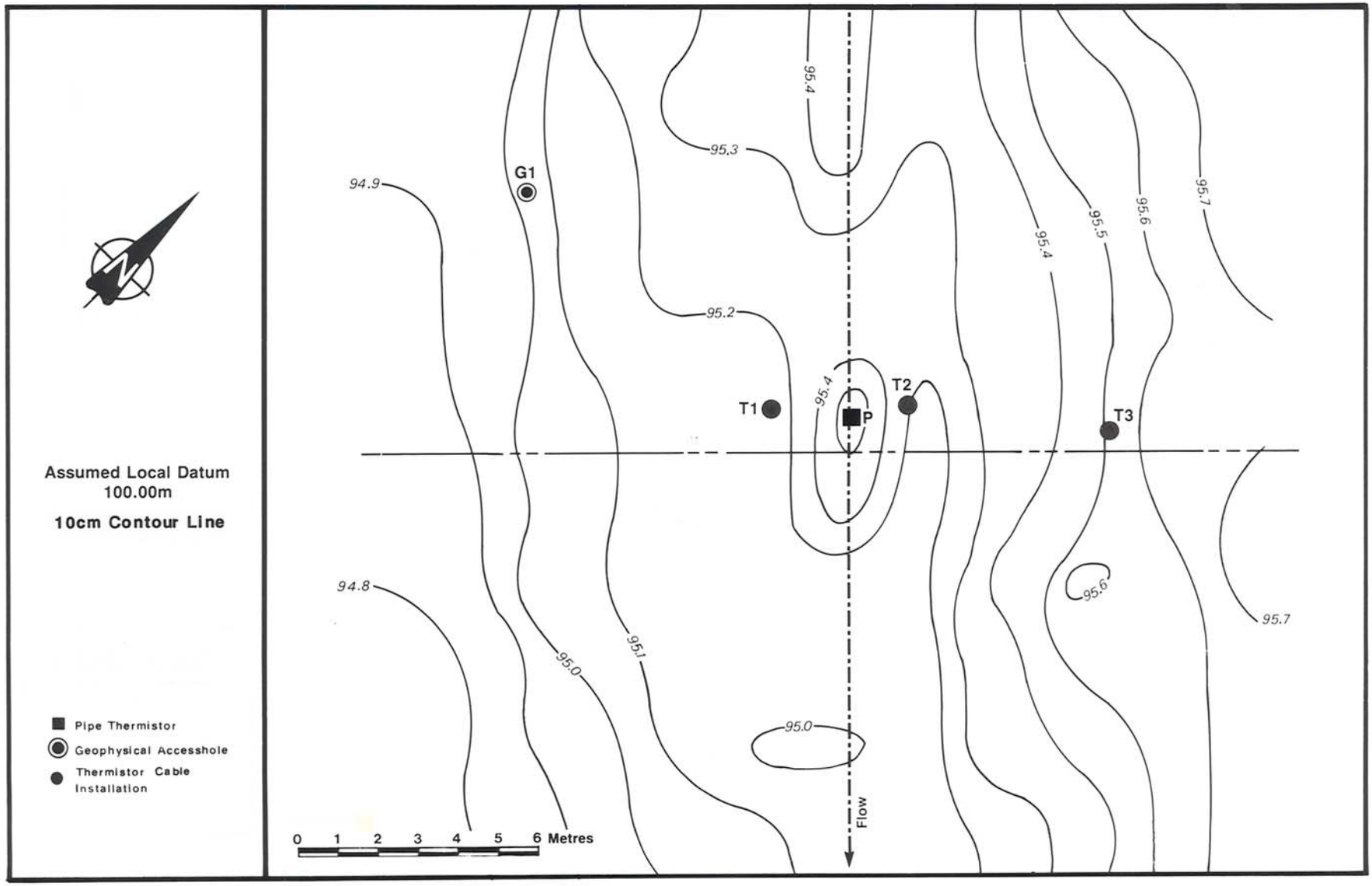
Instrumentation:
5 Multi-thermistor cables
1 Pipe thermistor cable
1 Geophysical access hole
3 Arrays of T.D.R. rods
1 Ditch thermistor installation



Site plan of EMR/INAC site 85-7C, Table Mountain



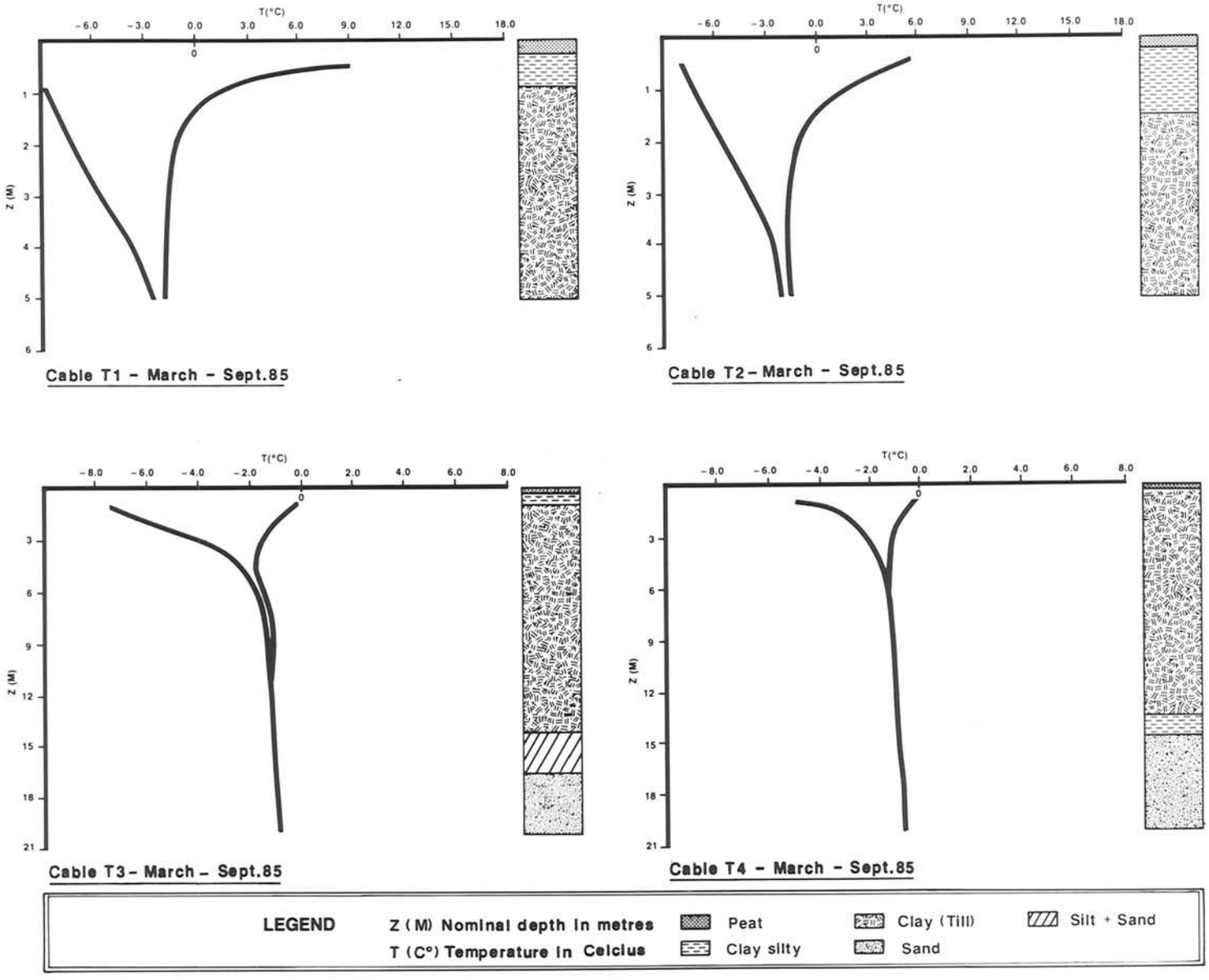
Lithologic cross section of site 85-7C, Table Mountain, based on the drill logs from the thermal instrumentation hole.



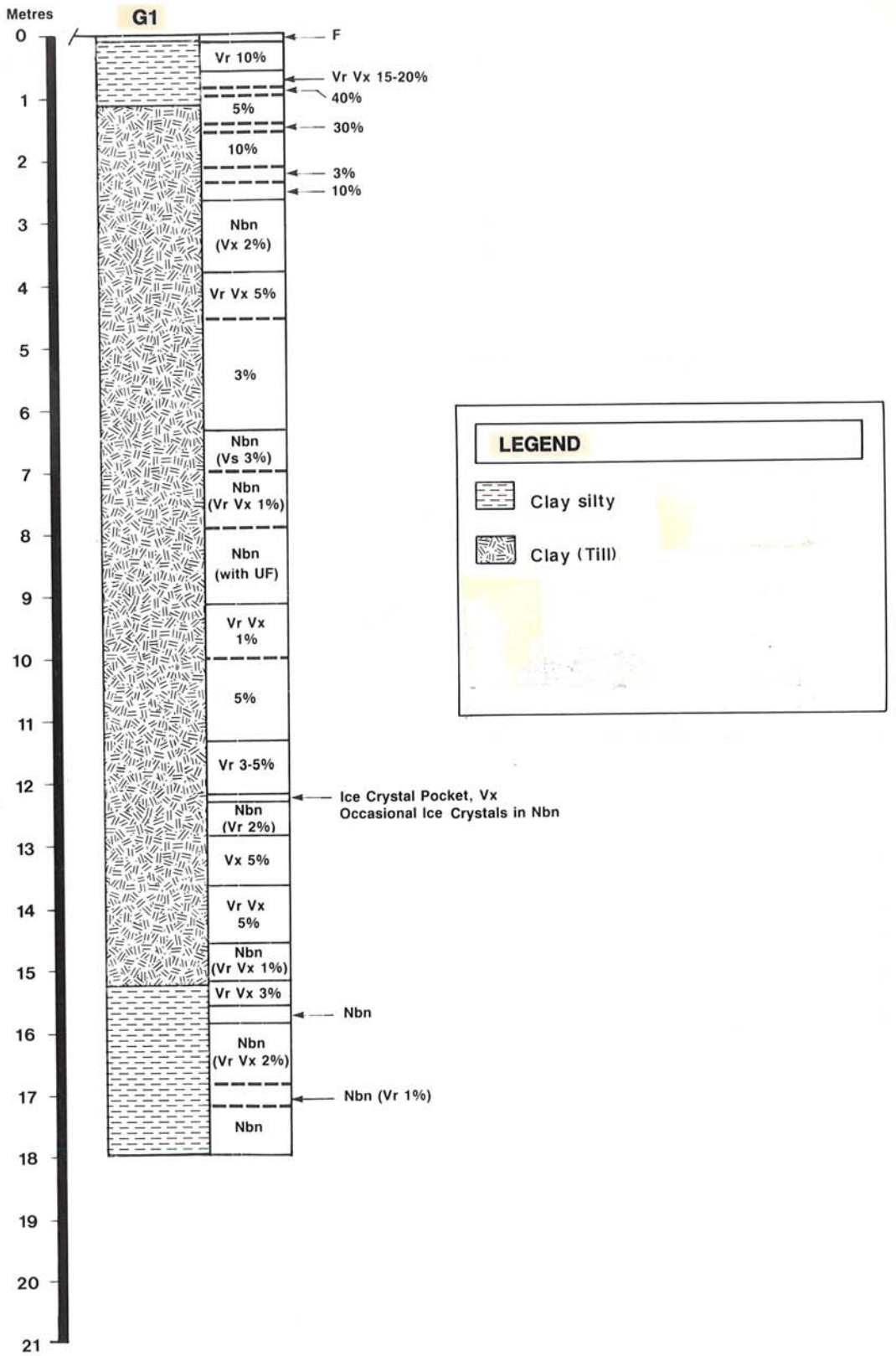
Detailed surface elevation contour map of site 85-7C, Table Mountain, using an assumed local datum of 100 m.

Site 85-7C

Thermal fence 85-7C shows the following trends in its first year of installation. At this fence location the R.O.W. is a new clearing thus the changes observed represent the overall thermal effects of clearing, constructing and operating a small diameter burried oil pipeline on permafrost. The on R.O.W. active layer is approximately 1.3 m thick during the first year of observation, it is less than 1 m at our reference hole off the R.O.W. calculated permafrost depth at the fence is 50 m. This previously undisturbed site also show a very low temperature gradient which indicates that a climatic change is currently on-going in this region of the Mackenzie Valley.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 85-7C, Table Mountain.



Ice content distribution observed in hole G1 at EMR/INAC site 85-7C, Table Mountain.

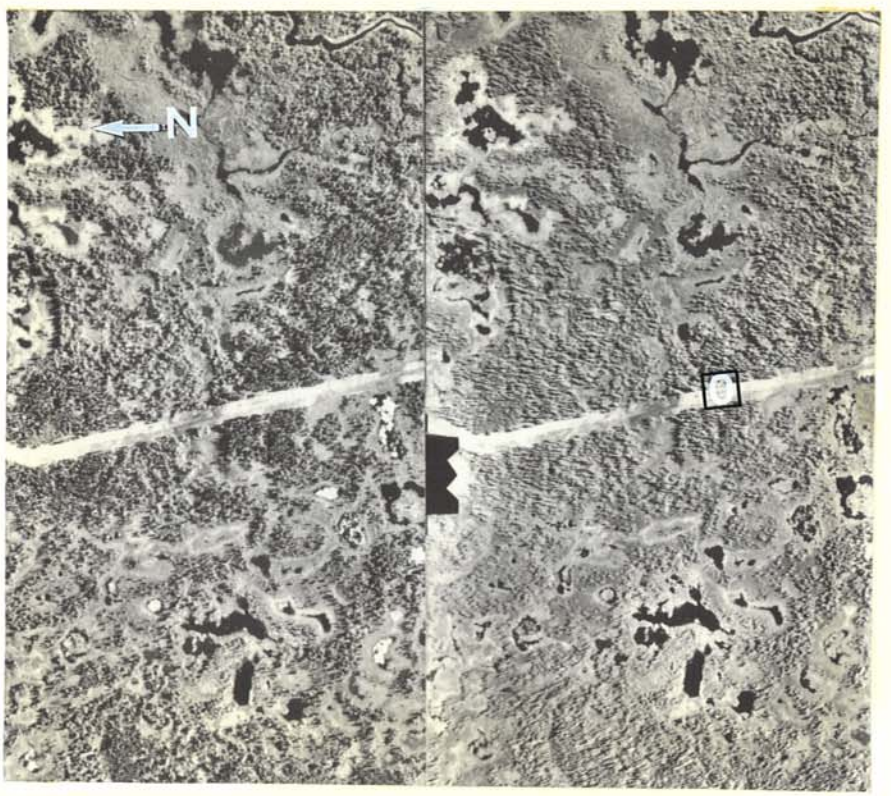
Thermistor depth at site 85-7C
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4	Cable T-5
1	0.5	0.5	1.0	1.0	1.0
2	1.0	1.0	2.0	2.0	2.0
3	1.5	1.5	3.0	3.0	4.0
4	2.0	2.0	4.0	4.0	6.0
5	2.5	2.5	6.0	6.0	8.0
6	3.0	3.0	8.0	8.0	10.0
7	3.5	3.5	10.0	10.0	12.0
8	4.0	4.0	12.0	12.0	14.0
9	4.5	4.5	14.0	14.0	16.0
10	5.0	5.0	17.0	17.0	18.0
11	-	-	20.0	20.0	20.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm	38 mm

Site 85-7C in May 1985, aerial view of roach collapsing.

Site 85-7C in August 1985, ground view.

THERMAL FENCE
85-8A
KP 556.9



Air photos A26837 Nos. 16-17, 7 August 1985

Site number: 85-8A

Site name: Manners Creek A

Location: 61° 36.36'N 121° 05.59'W, Kmp 556.9

Elevation: 190.5 metres A.S.L.

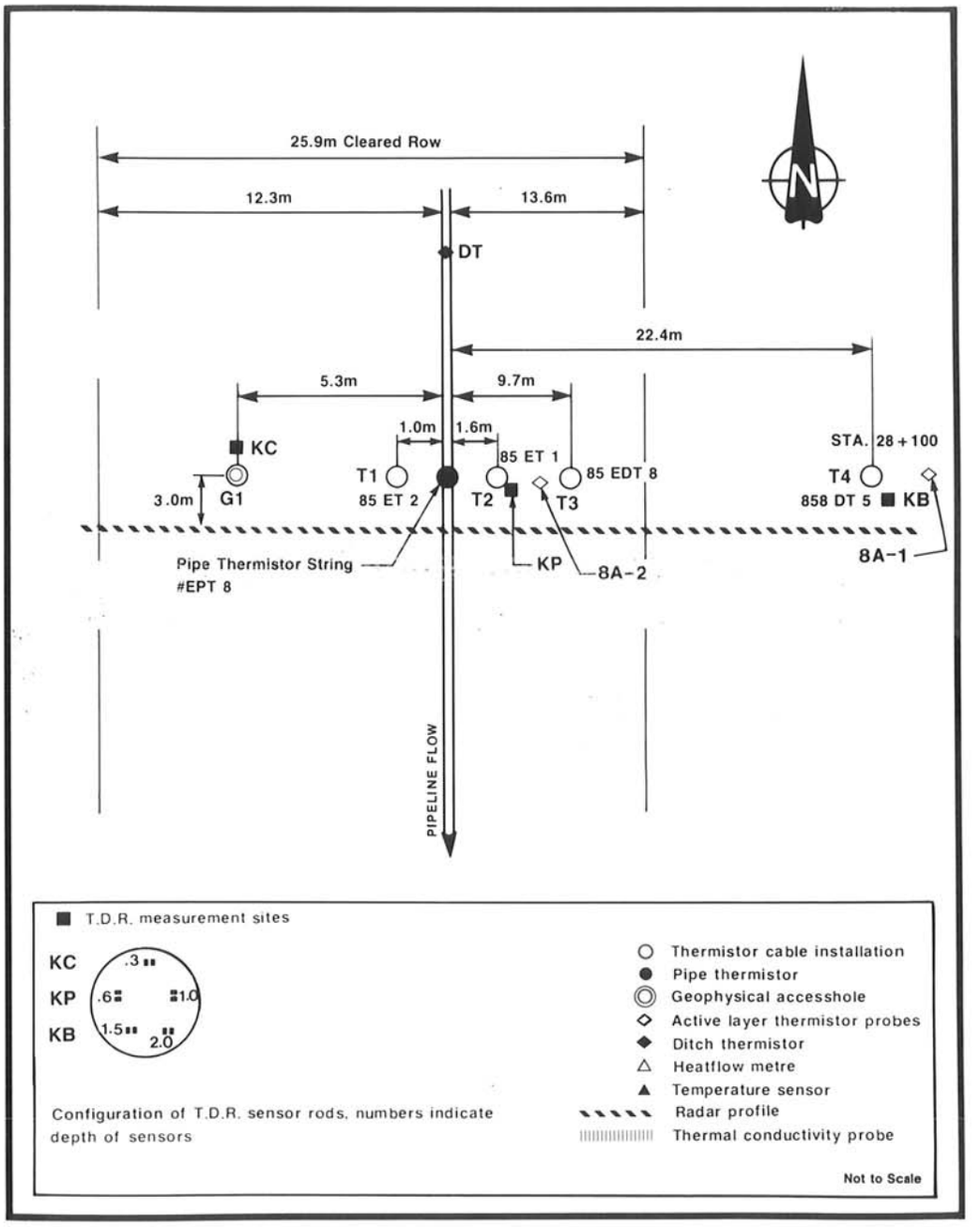
Rationale: This site was established at a level location in shallow rapidly changing permafrost conditions. This fence has a thin peat cover with relatively thick permafrost (10m) containing massive ice lenses.

Vegetation: Closed white & black spruce forest.

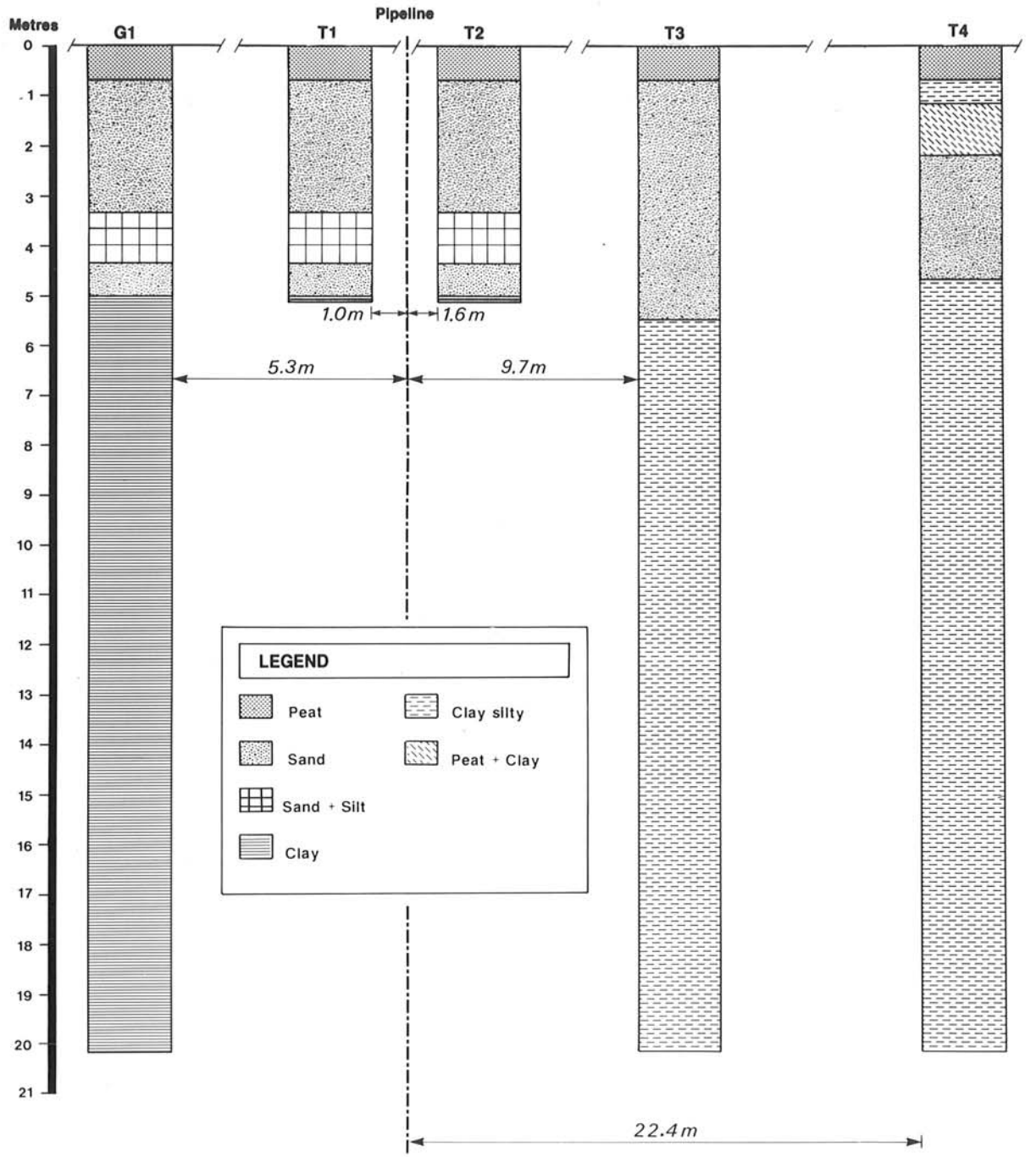
Site history:
- Trees cleared to 25.9 m width in winter 1983-84.
- Trenched in February 1985 with a Barber Green 77 (wheel) Ditcher.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1985.
- Bench Marks installed and first surface survey in May 1985.

Pipe depth: 0.90 m (excluding Roach) to top of pipe (March 1985).

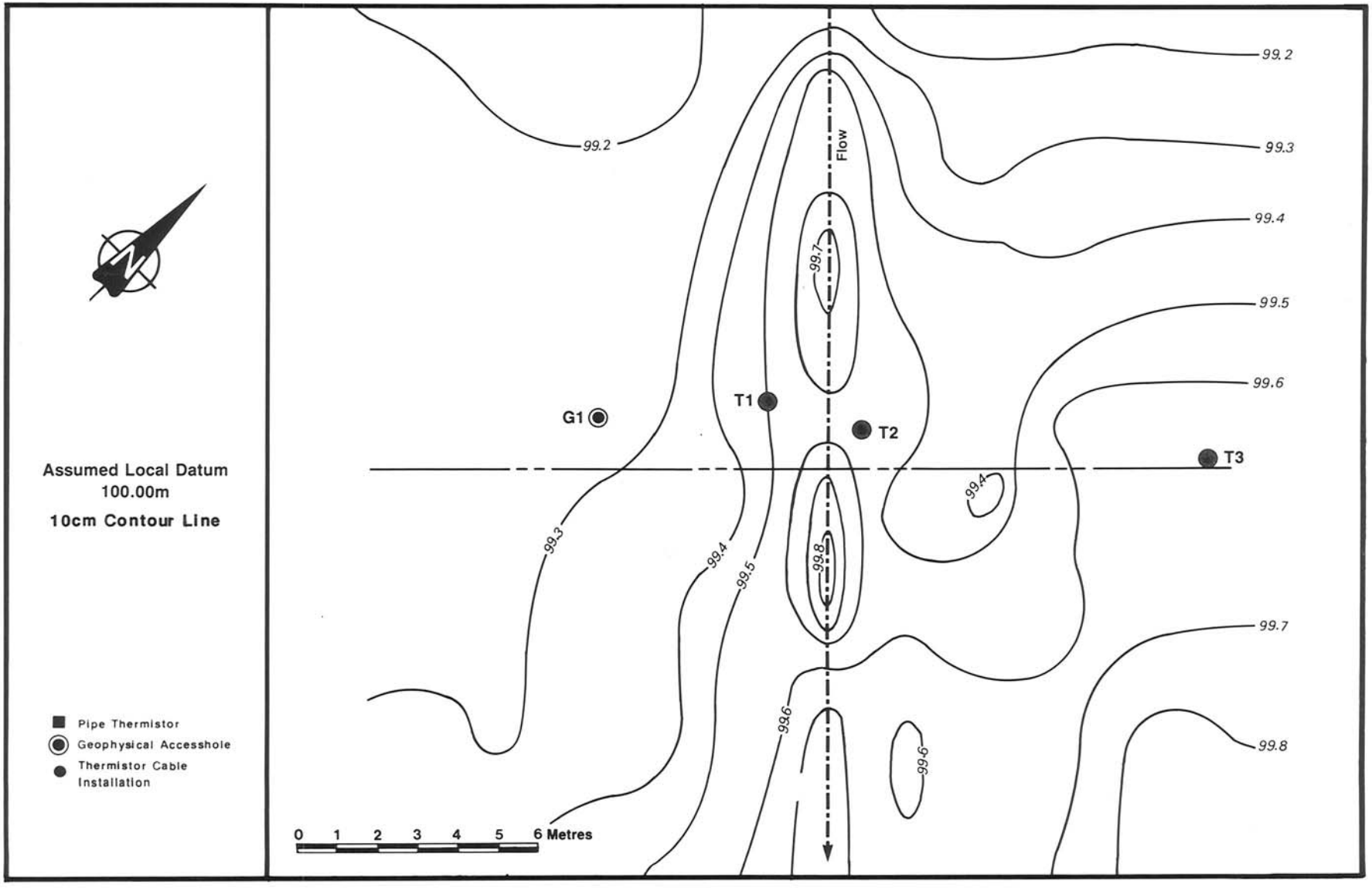
Instrumentation:
4 Multi-thermistor cables
1 Pipe thermistor cable
1 Geophysical access hole
3 Arrays of T.D.R. rods
2 Soil temperature probes
1 Ditch thermistor installation



Site plan of EMR/INAC site 85-8A, Manner's Creek



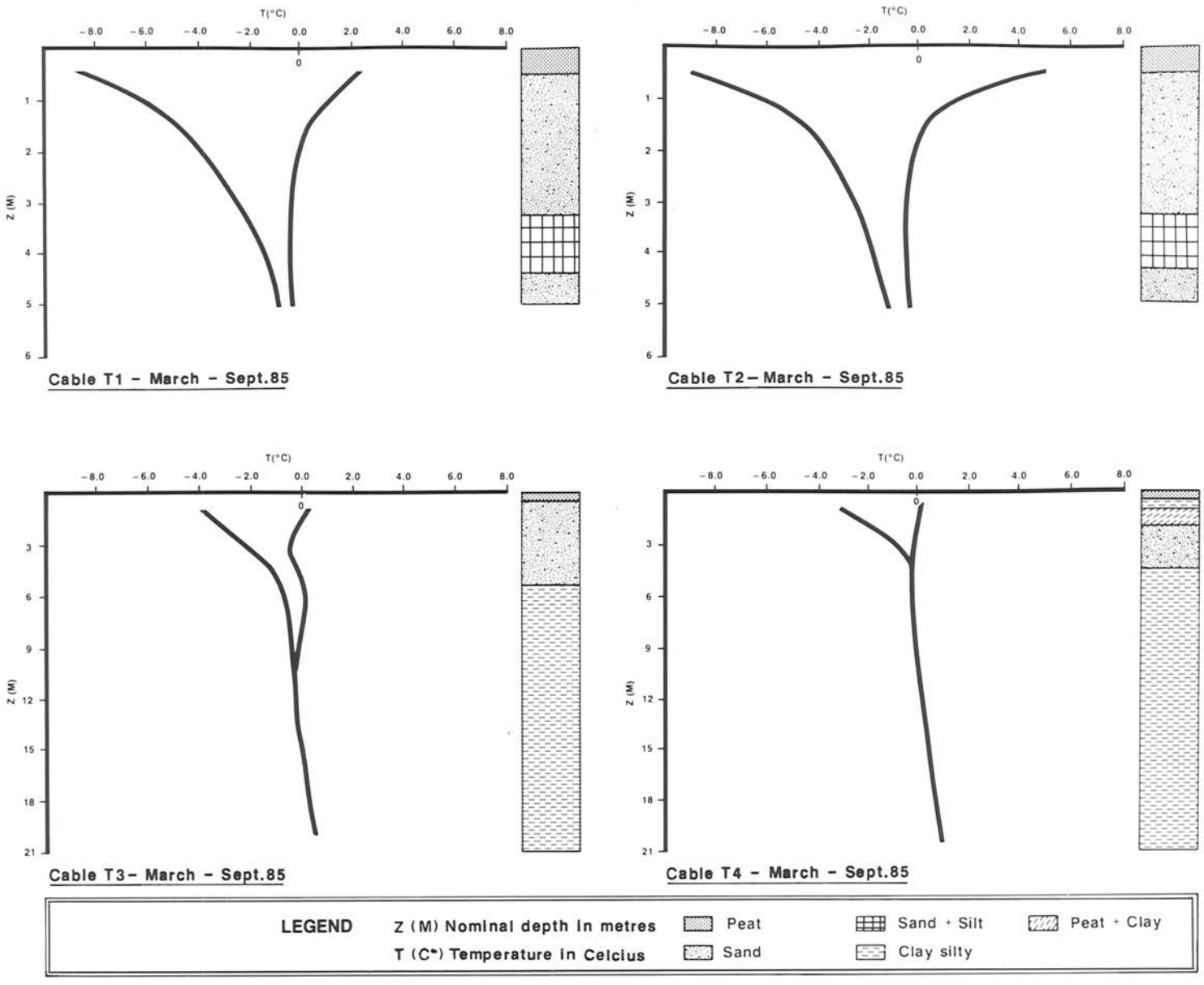
Lithologic cross section of site 85-8A, Manner's Creek, based on the drill logs from the thermal instrumentation hole.



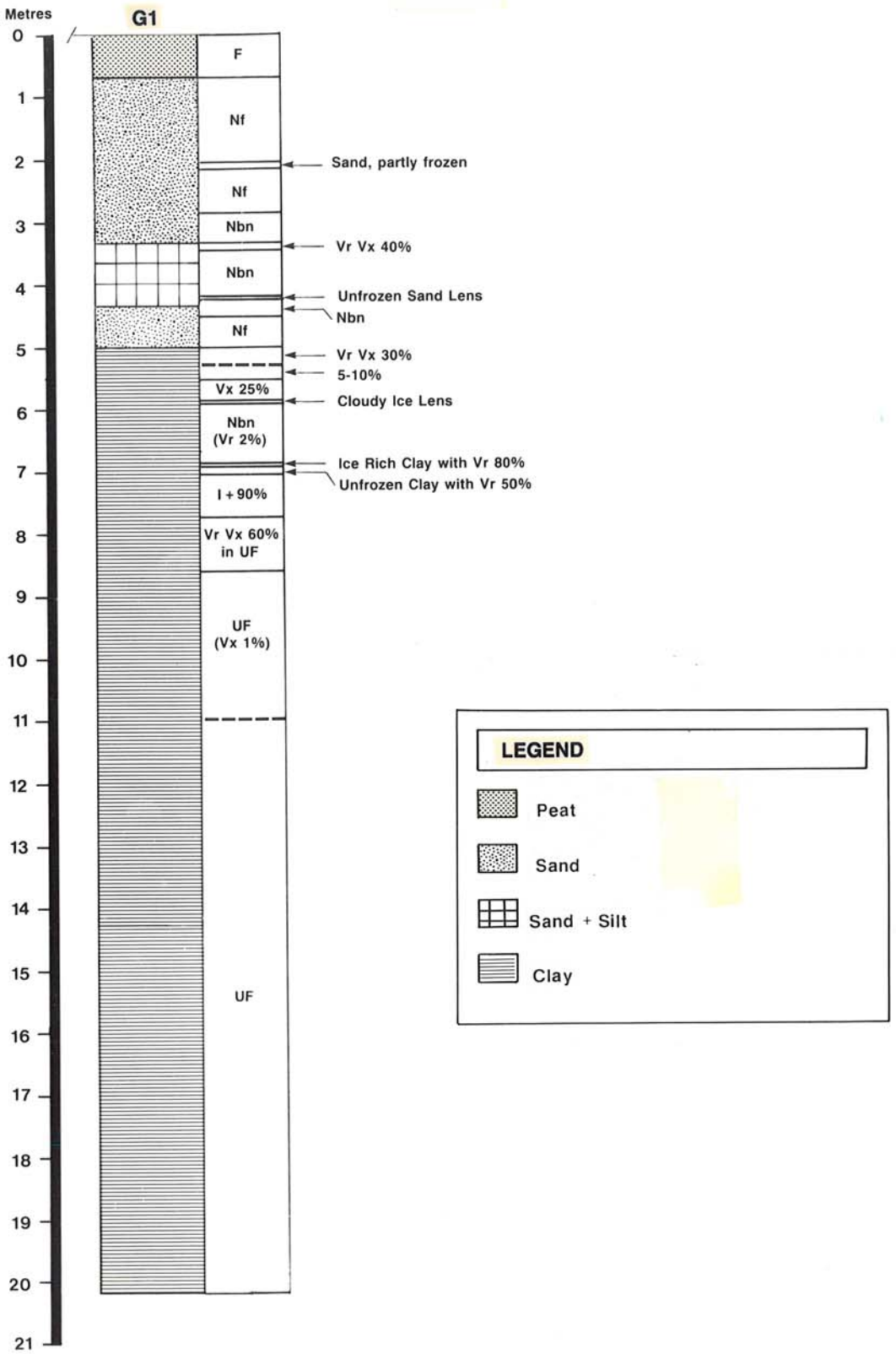
Detailed surface elevation contour map of site 85-8A, Manner's Creek, using an assumed local datum of 100 m.

Site 85-8A

Thermal fence 85-8A shows the following trends in its first year of installation. The closed forest cover was cleared from the R.O.W. in the winter of '83-'84, thus clearing occurred one year before construction in March '85. The on R.O.W. active layer reached up to 2.0 m at cable T2 during the first year of observation, in contrast it is less than 1 m at our off R.O.W. reference site. Permafrost thickness at this fence is approximately 12 m.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 85-8A, Manner's Creek.



Ice content distribution observed in hole G1 at EMR/INAC site 85-8A, Manner's Creek.

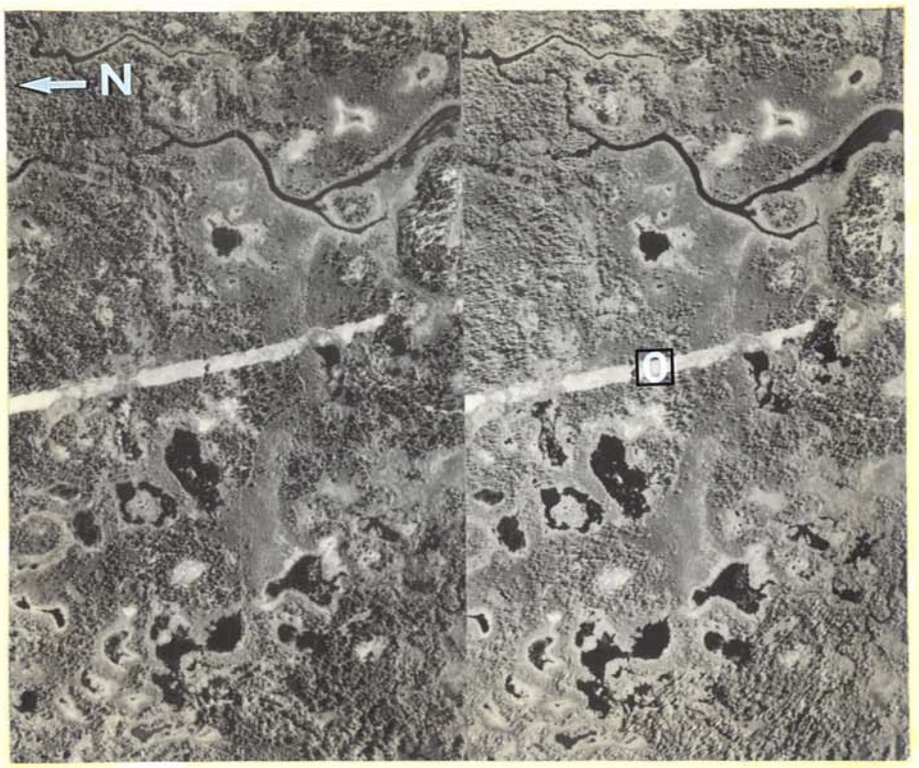
Thermistor depth at site 85-8A
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	1.0
2	1.0	1.0	2.0	2.0
3	1.5	1.5	3.0	3.0
4	2.0	2.0	4.0	4.0
5	2.5	2.5	6.0	6.0
6	3.0	3.0	8.0	8.0
7	3.5	3.5	10.0	10.0
8	4.0	4.0	12.0	12.0
9	4.5	4.5	14.0	14.0
10	5.0	5.0	17.0	17.0
11	-	-	20.0	20.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm

Site 85-8A in May 1985, aerial view of site.

Site 85-8A in October 1985, ground view.

THERMAL FENCE
85-8B
KP 557.2



Air photos A26350 Nos. 220-221, 2 July 1983

Site number: 85-8B

Site name: Manners Creek B

Location: 61° 36.19'N 121° 05.41'W, Kmp 557.2

Elevation: 190 metres A.S.L.

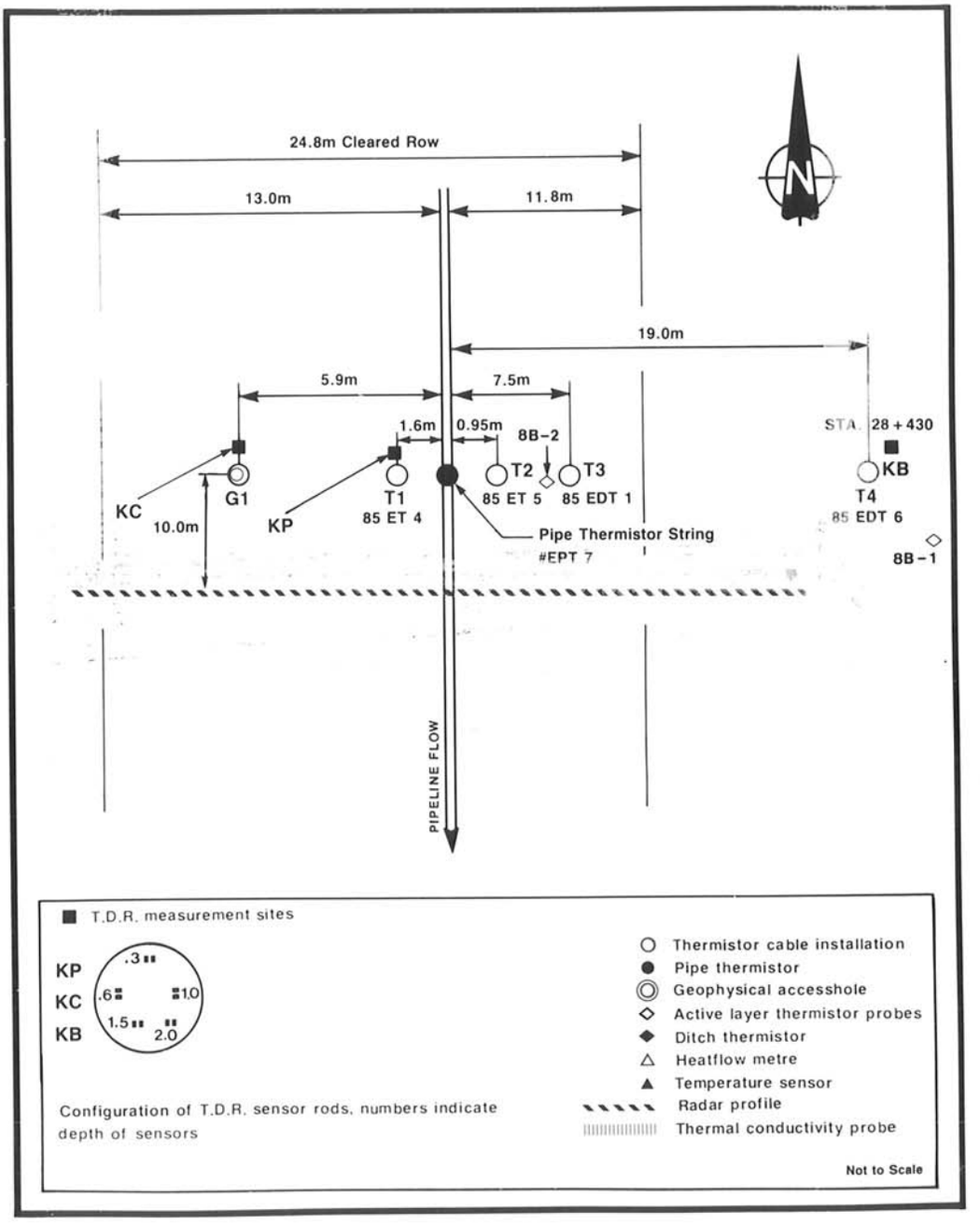
Rationale: This site was established at a level location in shallow rapidly changing permafrost conditions. This thermal fence has a thick peat cover (2.7 m) with thin permafrost (<4 m) and low ice content.

Vegetation: Open birch, willow & alder woodland.

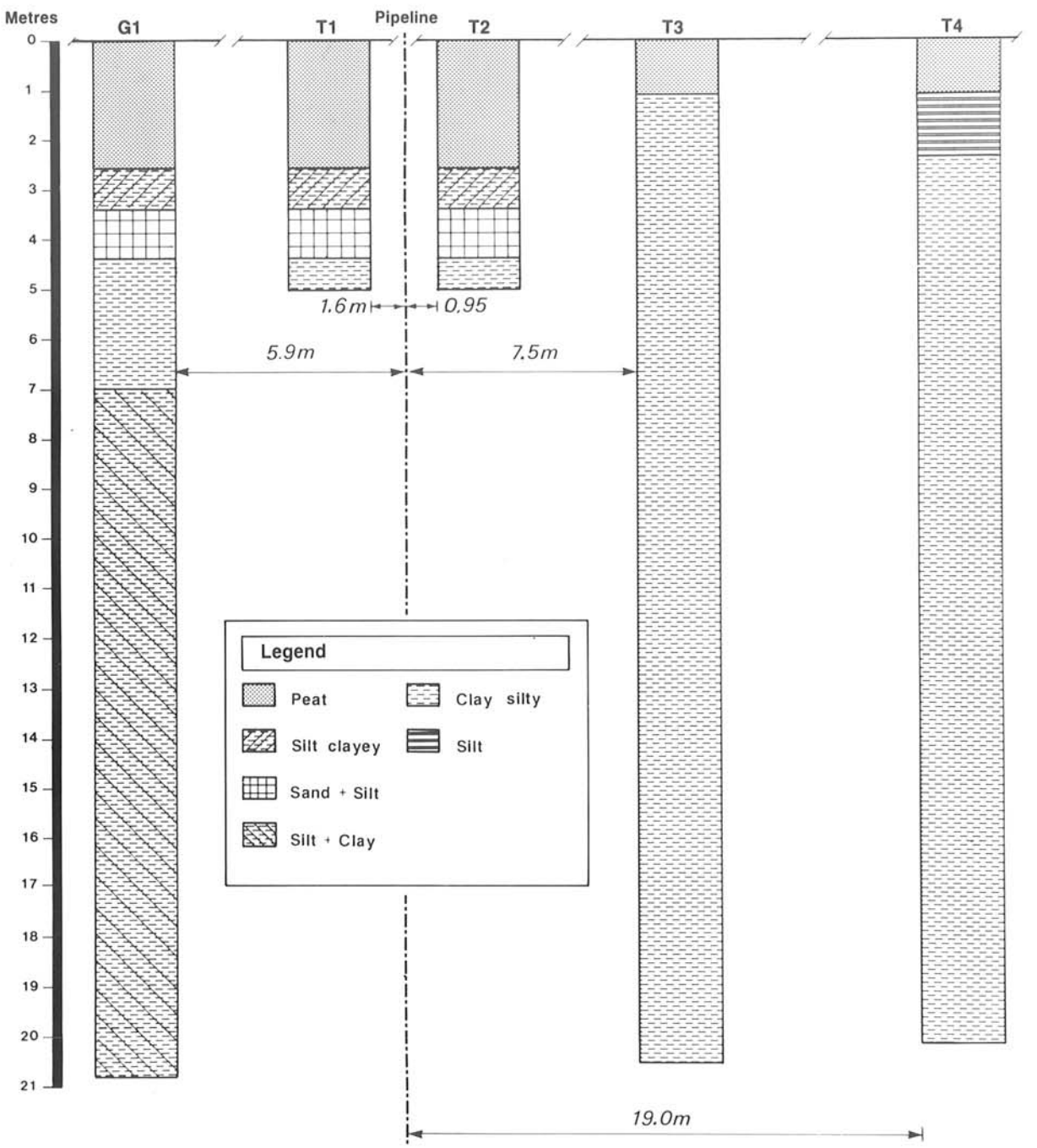
Site history:
- Trees cleared to 24.8 m width in winter 1982-83.
- Trenched in February 1985 with a Barber Green 77 (wheel) Ditcher.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1985.
- Bench Marks installed and first surface survey in May 1985.

Pipe depth: 0.90 m (excluding Roach) to top of pipe (March 1985).

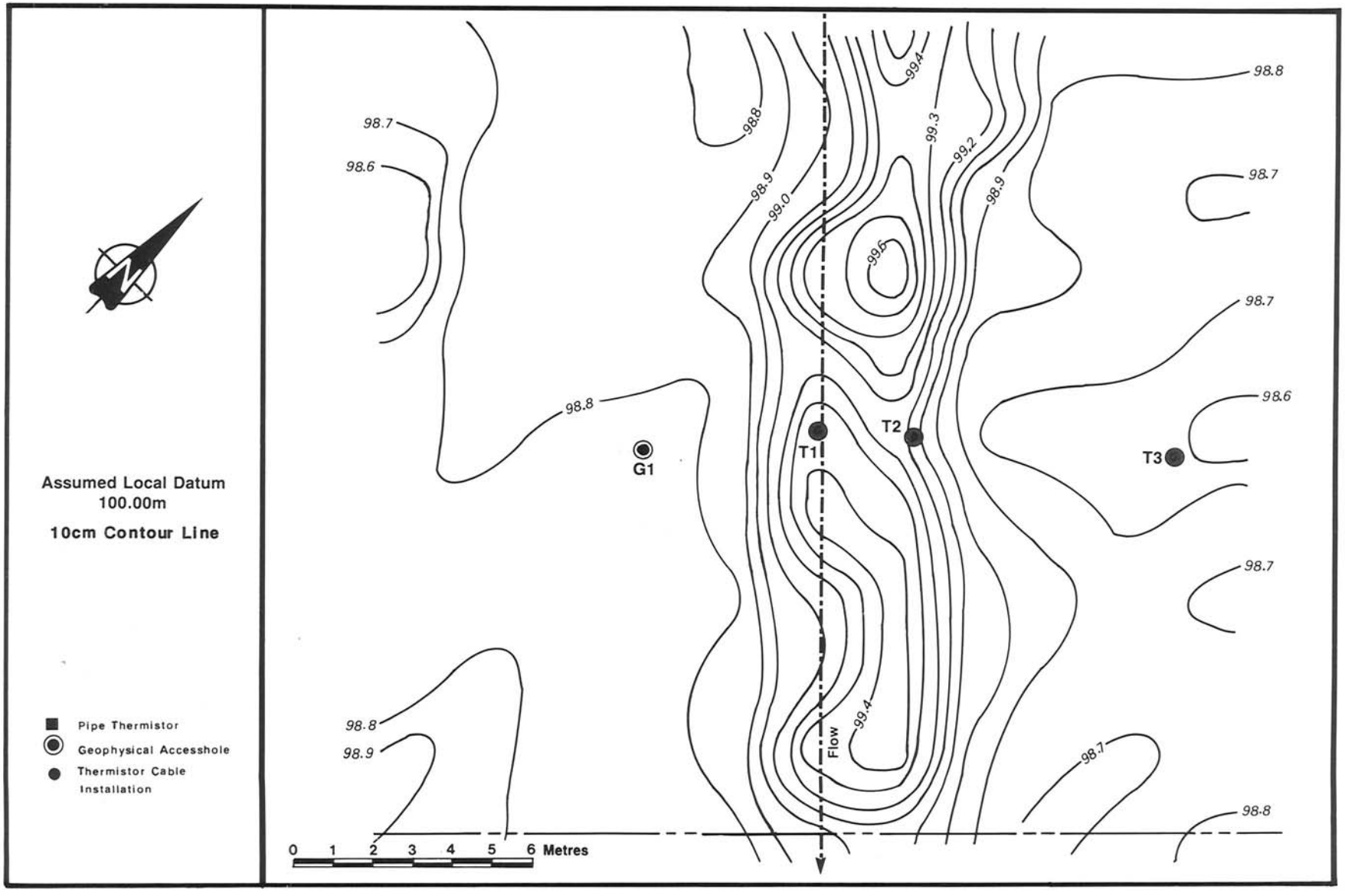
Instrumentation:
4 Multi-thermistor cables
1 Pipe thermistor cable
1 Geophysical access hole
3 Arrays of T.D.R. rods
2 Soil temperature probes



Site plan of EMR/INAC site 85-8B, Manner's Creek



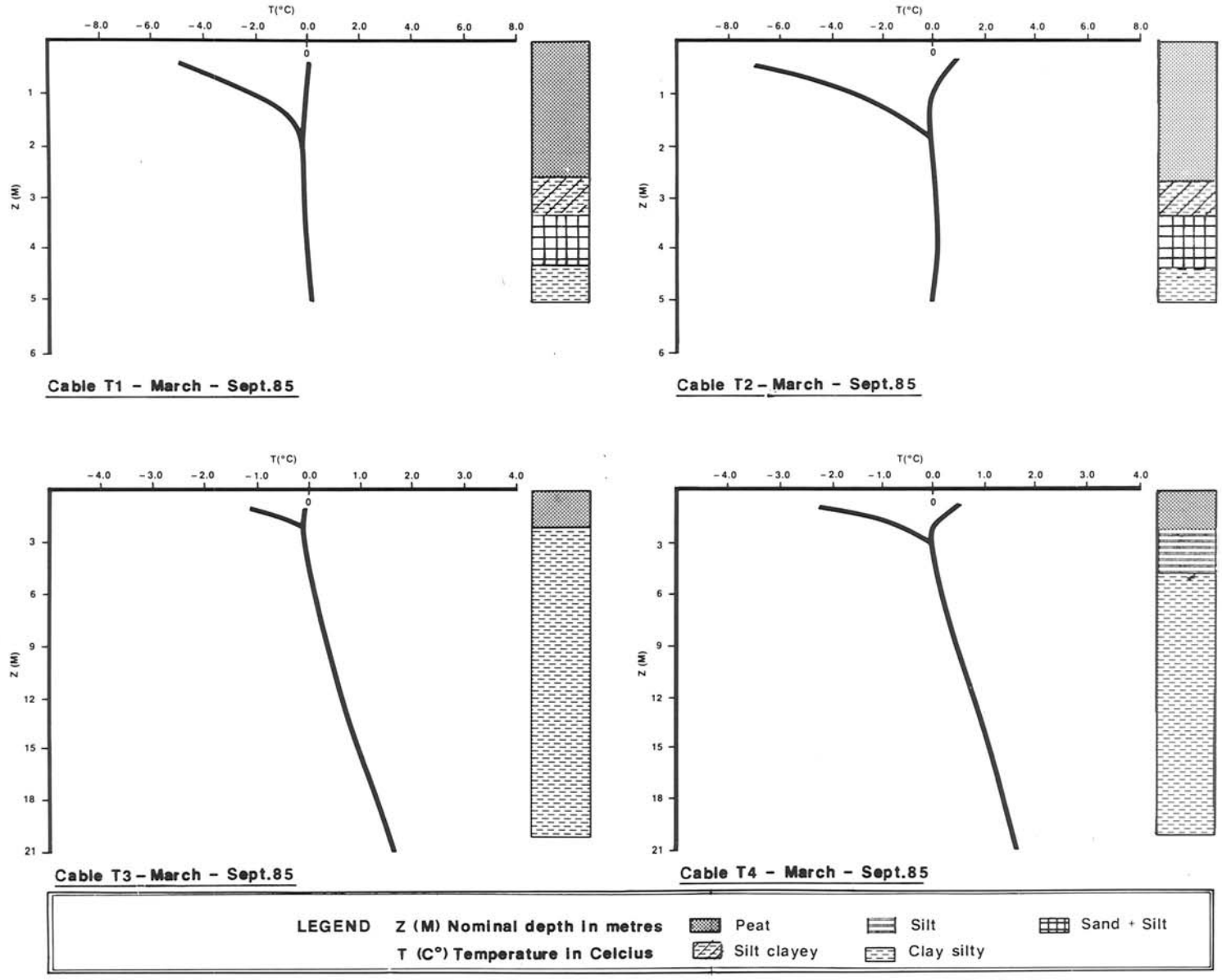
Lithologic cross section of site 85-8B, Manner's Creek, based on the drill logs from the thermal instrumentation hole.



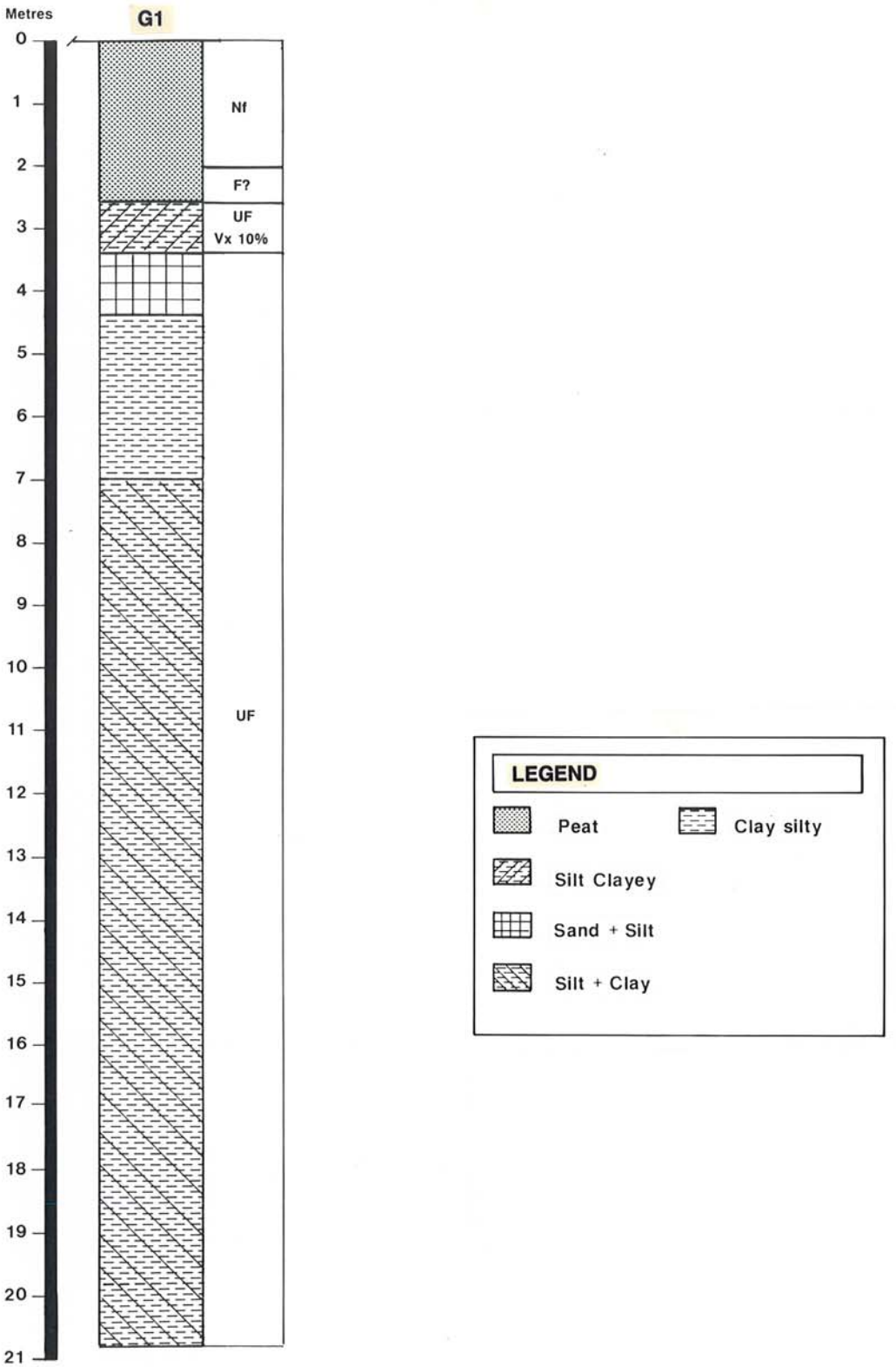
Detailed surface elevation contour map of site 85-8B, Manner's Creek, using an assumed local datum of 100 m.

Site 85-8B

Thermal fence 85-8B shows the following trends in its first year of installation. This thermal fence has a thick peat cover (2.7 m) with thin permafrost varying between 3.5 and 4.5 m at the holes. Active layer in the peat cover of less than 50 m. It is interesting to note that permafrost is almost 1 m thicker on the R.O.W. than off the R.O.W. This is likely the result of snow removed for construction.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 85-8B, Manner's Creek.



Ice content distribution observed in hole G1 at EMR/INAC site 85-8B, Manner's Creek.

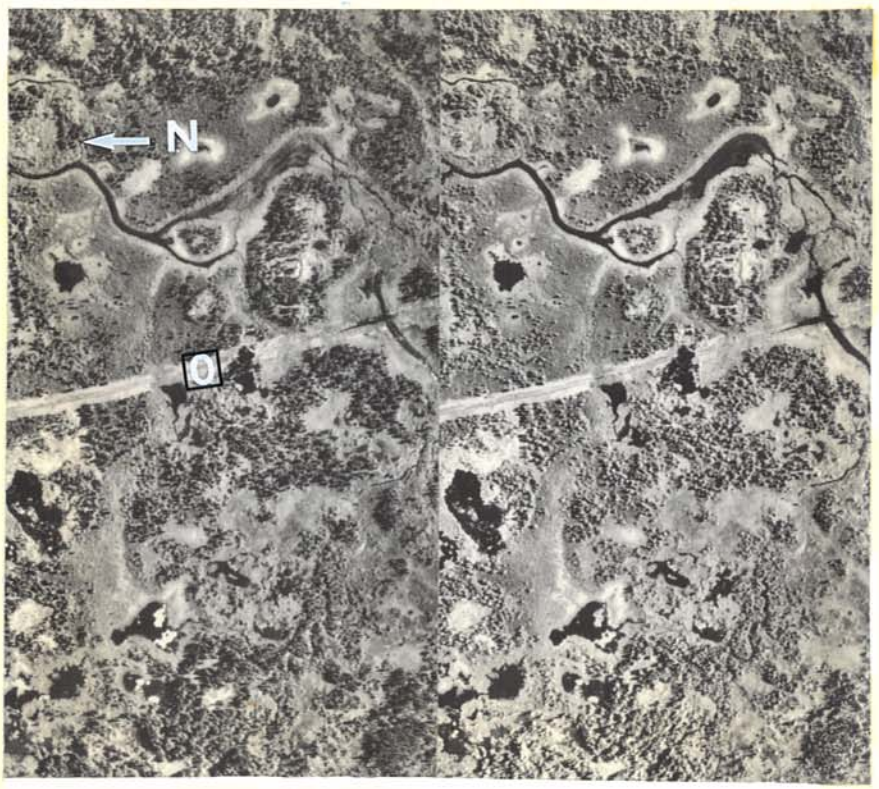
Thermistor depth at site 85-8B
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	1.0
2	1.0	1.0	2.0	2.0
3	1.5	1.5	3.0	3.0
4	2.0	2.0	4.0	4.0
5	2.5	2.5	6.0	6.0
6	3.0	3.0	8.0	8.0
7	3.5	3.5	10.0	10.0
8	4.0	4.0	12.0	12.0
9	4.5	4.5	14.0	14.0
10	5.0	5.0	17.0	17.0
11	-	-	20.0	20.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	38 mm

Site 85-8B in May 1985, note height of roach.

Site 8B in October 1985, backing towards site 8C.

THERMAL FENCE
85-8C
KP 557.4



Air photos A26837 Nos. 16-17, 7 August 1985

Site number: 85-8C

Site name: Manners Creek C

Location: 61° 36.05'N 121° 05.34'W, Kmp 557.4

Elevation: 190 metres A.S.L.

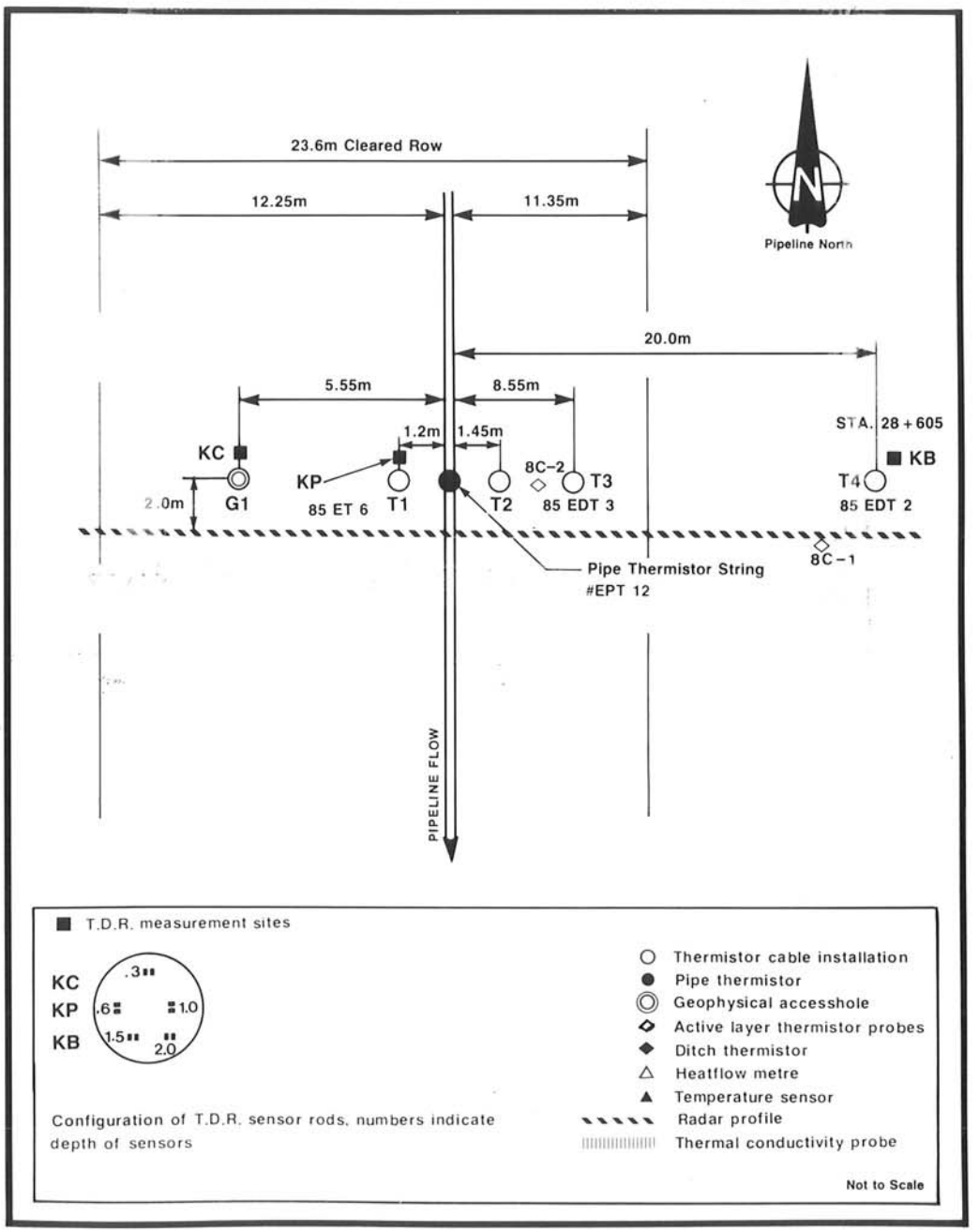
Rationale: This site was established at a level location in shallow rapidly changing permafrost conditions. This thermal fence has a thin peat cover (1 m) with massive ice and thin permafrost (<4 m).

Vegetation: Open birch, willow, alder & moss woodland.

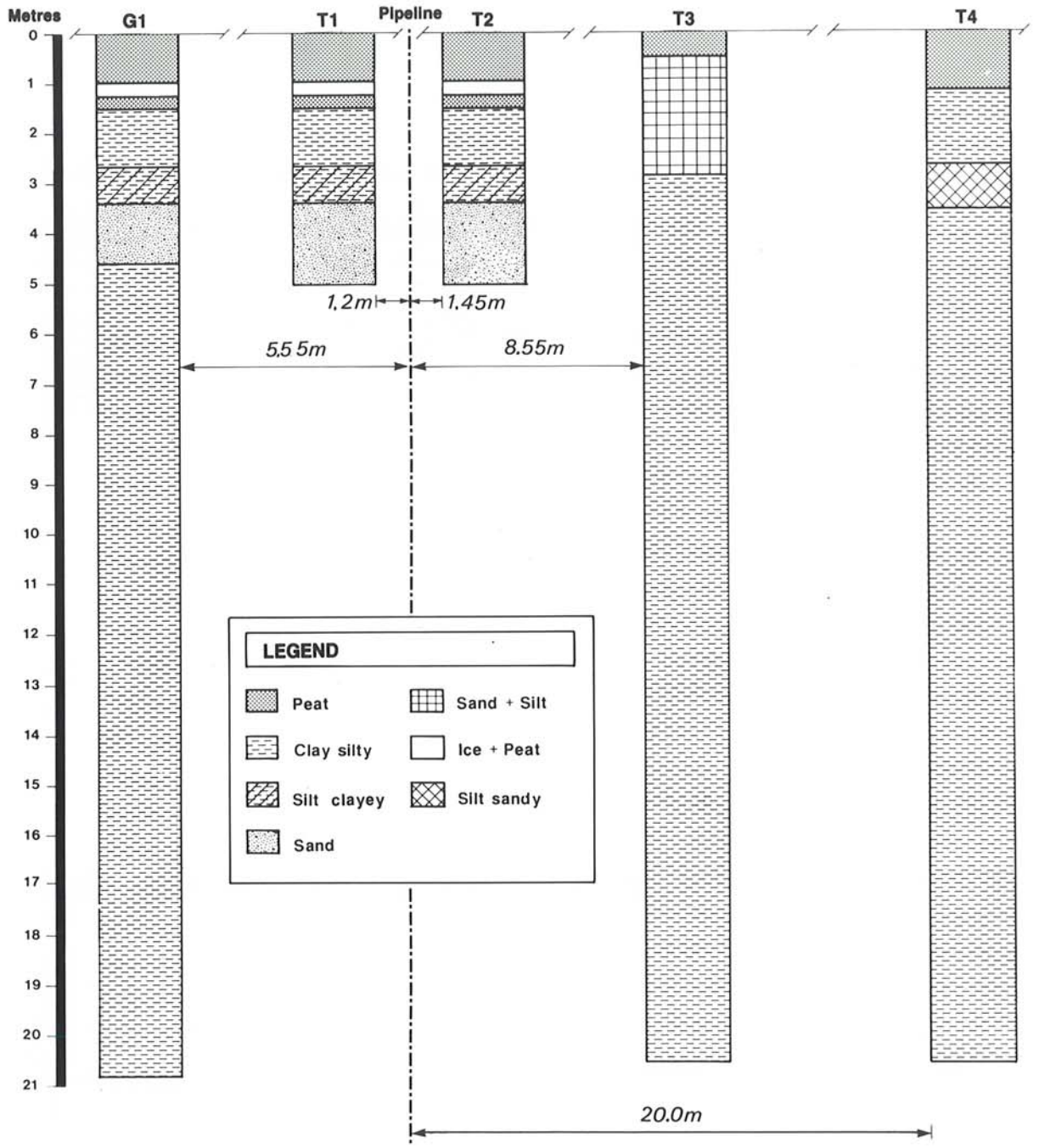
Site history:
- Trees cleared to 23.6 m width in winter 1982-83.
- Trenched in February 1985 with a Barber Green 77 (wheel) Ditcher.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1985.
- Bench Marks installed and first surface survey in May 1985.

Pipe Depth: 0.90 m (excluding Roach) of pipe (March 1985).

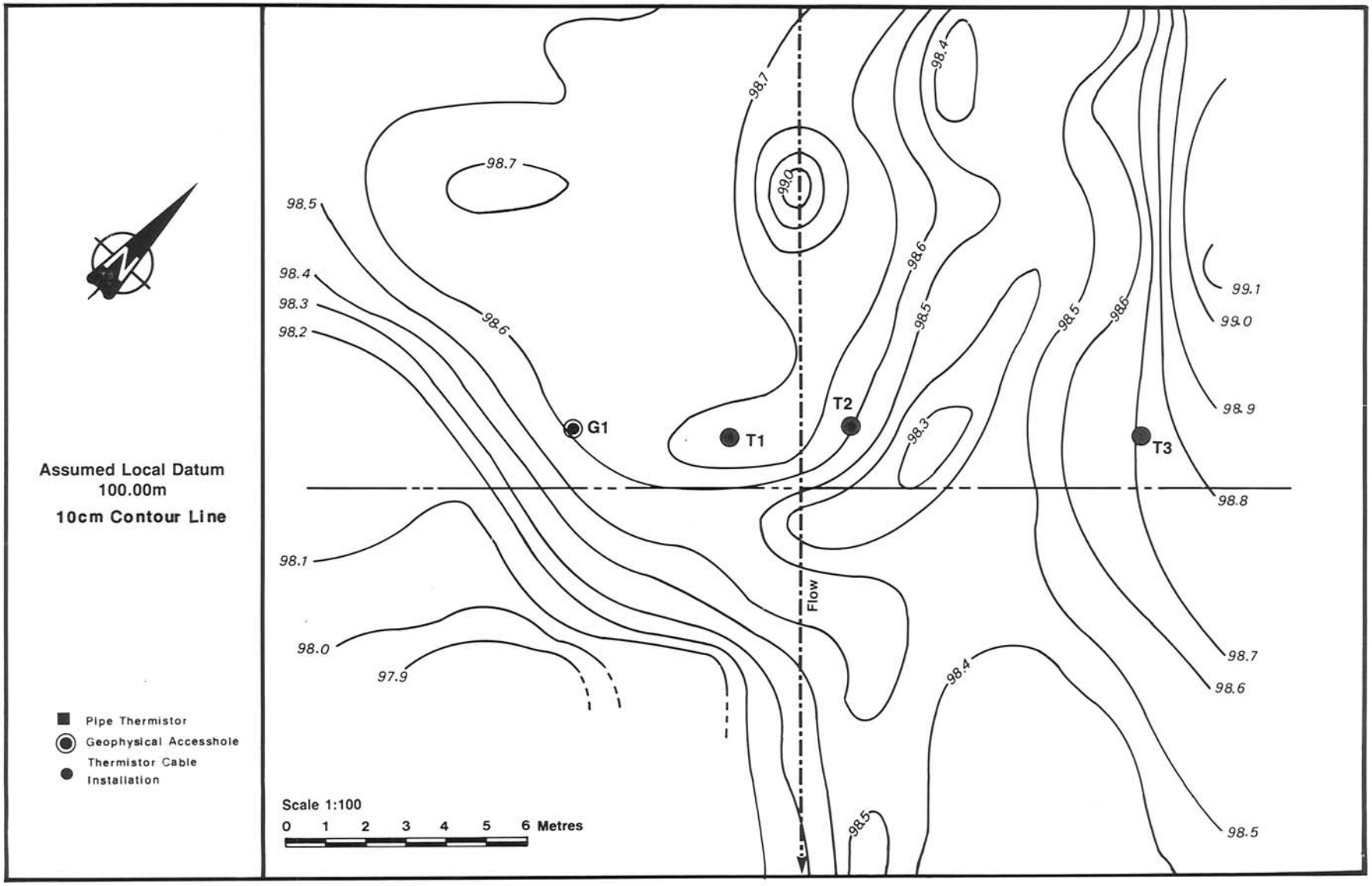
Instrumentation:
4 Multi-thermistor cables
1 Pipe thermistor cable
1 Geophysical access hole
3 Arrays of T.D.R. rods
2 Soil temperature probes



Site plan of EMR/INAC site 85-8C, Manner's Creek



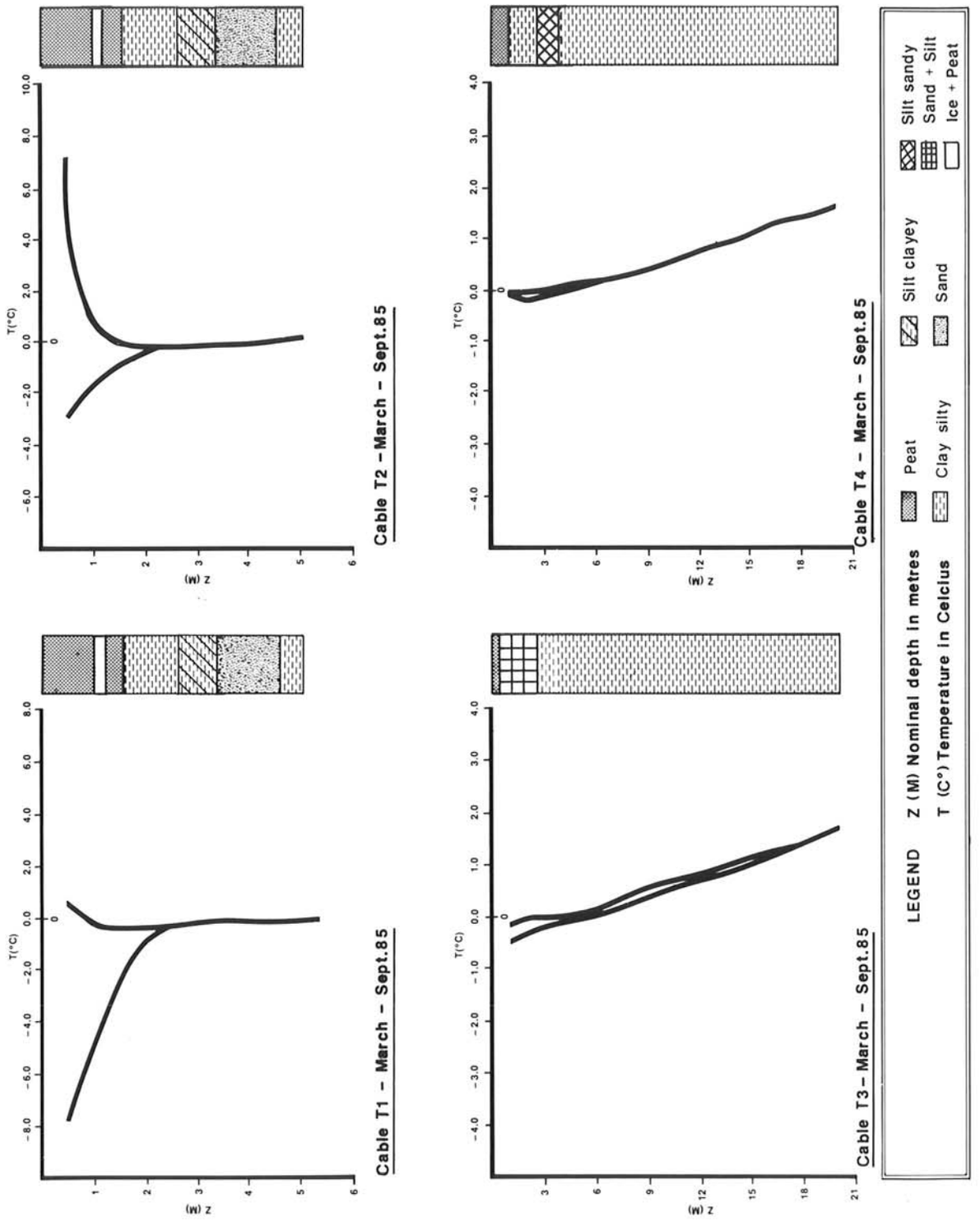
Lithologic cross section of site 85-8C, Manner's Creek, based on the drill logs from the thermal instrumentation hole.



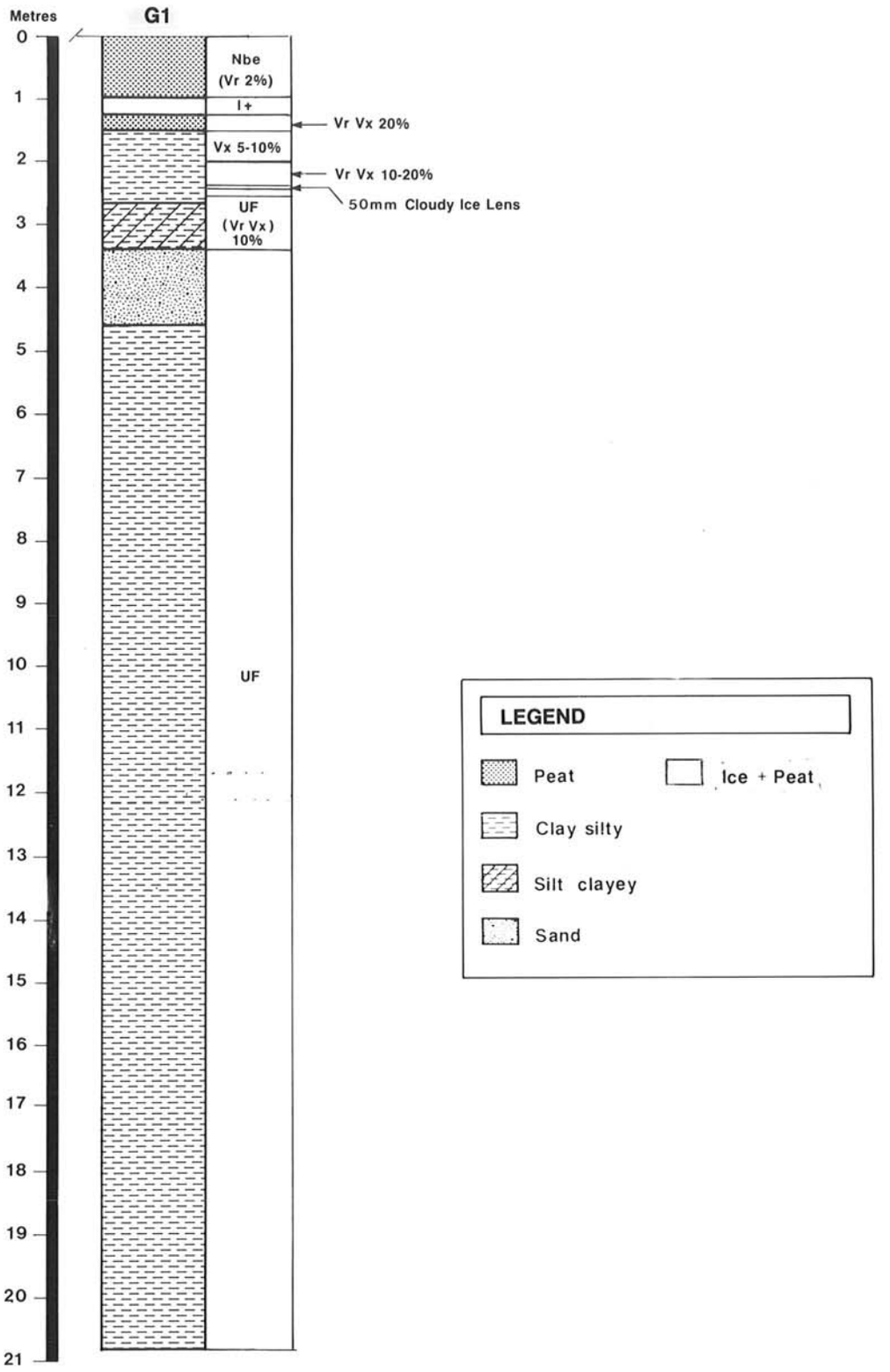
Detailed surface elevation contour map of site 85-8C, Manner's Creek, using an assumed local datum of 100 m.

Site 85-8C

Thermal fence 85-8C shows the following trends in its first year of operation. Active layer on R.O.W. is approximately 1.3 m while it is less than 1 m off R.O.W. Permafrost thickness is about 3.5 m off the R.O.W. and 4.5 m on the R.O.W. This difference is a result of heat loss due to snow removed during construction of the pipeline.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 85-8C, Manner's Creek.



Ice content distribution observed in hole G1 at EMR/INAC site 85-8C, Manner's Creek.

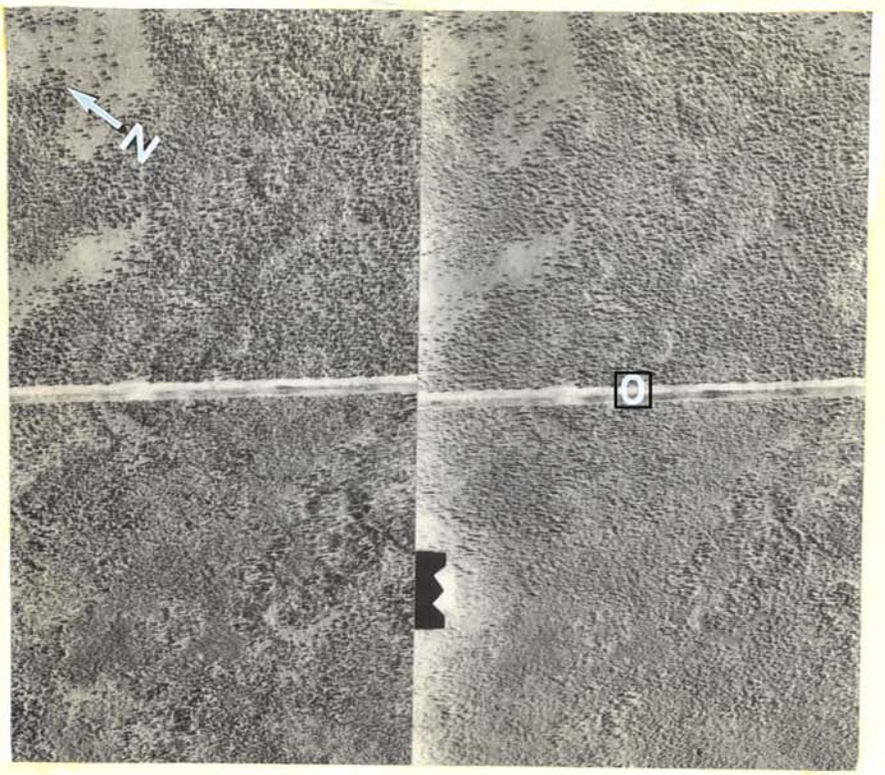
Thermistor depth at site 85-8C
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	1.0
2	1.0	1.0	2.0	2.0
3	1.5	1.5	3.0	3.0
4	2.0	2.0	4.0	4.0
5	2.5	2.5	6.0	6.0
6	3.0	3.0	8.0	8.0
7	3.5	3.5	10.0	10.0
8	4.0	4.0	12.0	12.0
9	4.5	4.5	14.0	14.0
10	5.0	5.0	17.0	17.0
11	-	-	20.0	20.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm

Site 8C in May 1985, ground view showing bog in background.

Site 85-C in October 1985, ground view.

THERMAL FENCE
85-9
KP 582.5



Air photos A26836 Nos. 260-261, 7 August 1985

Site number: 85-9

Site name: Pump Station 3

Location: 61° 23.73'N 120° 53.98'W, Kmp 582.5

Elevation: 222.5 metres A.S.L.

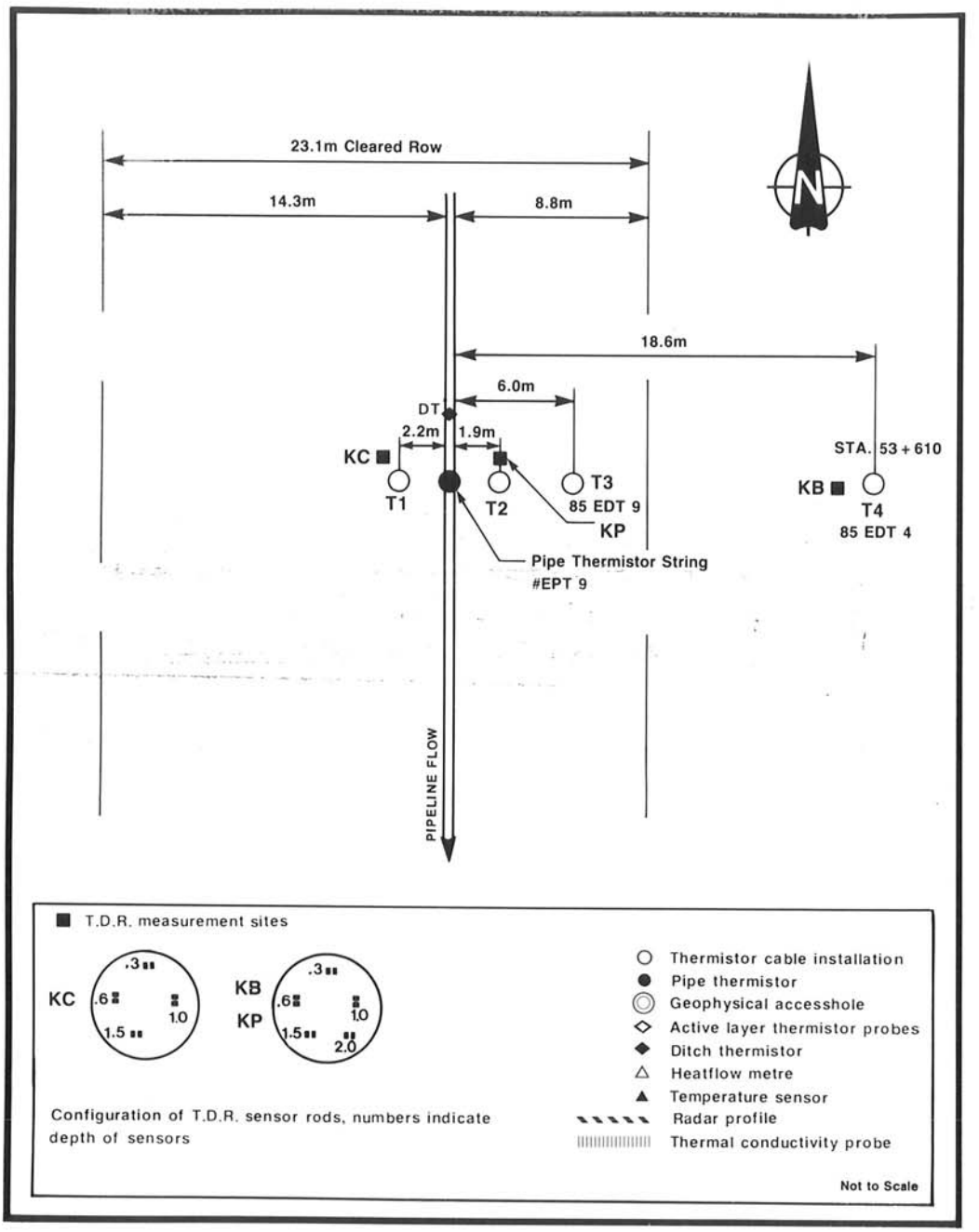
Rationale: This site was established at a level location in permafrost free granular soils. At this location the pipeline enters unfrozen terrain after traversing a long section of frozen ground.

Vegetation: Open black spruce, ericaceous shrubs, moss-lichen woodland.

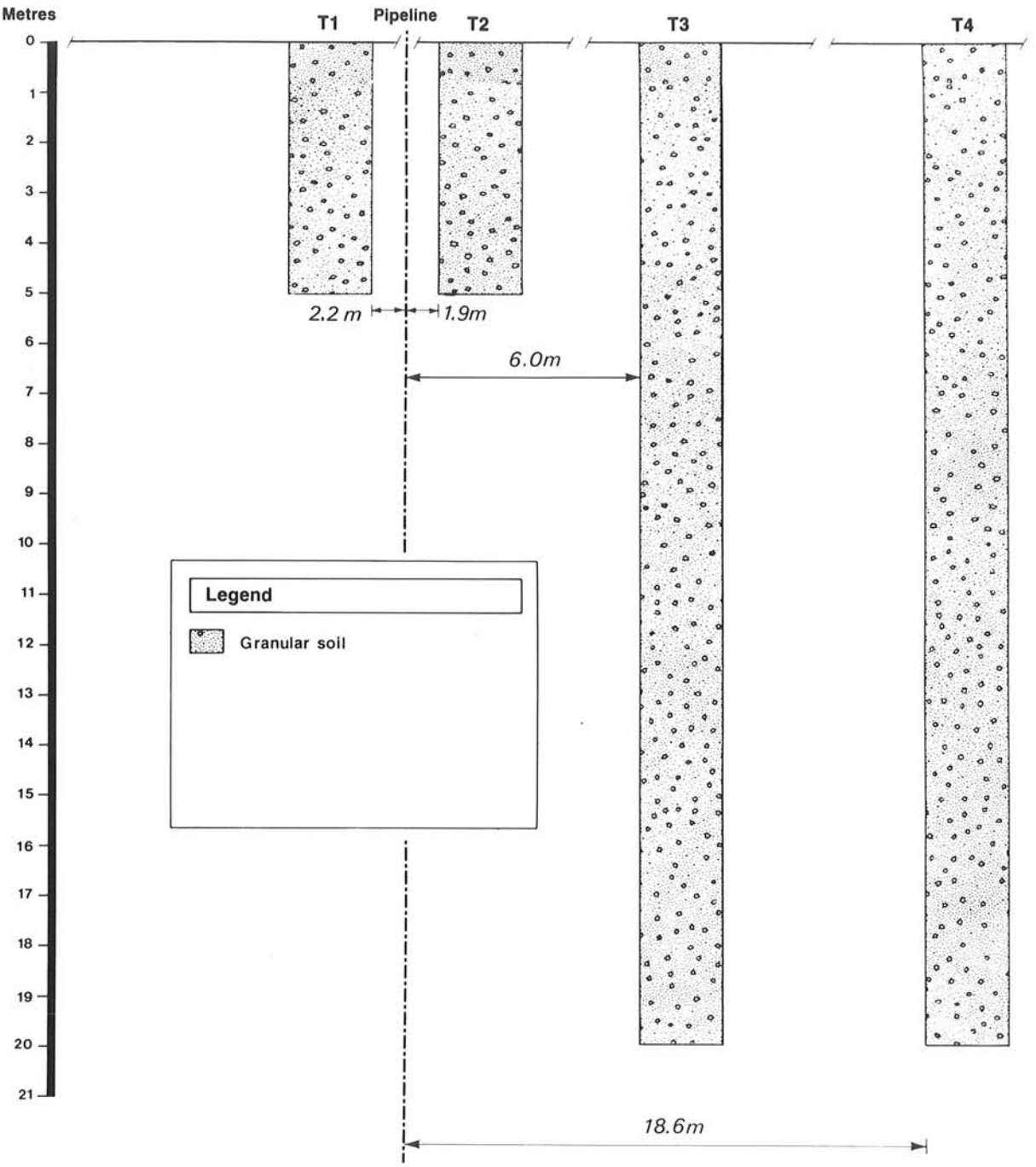
Site history:
- Trees cleared to 23.1 m width in winter 1983-84.
- Trenched in February 1985 with a backhoe.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1985.
- Bench Marks installed and first surface survey in May 1985.

Pipe depth: 0.90 meters (excluding Roach) top of pipe (March 1985).

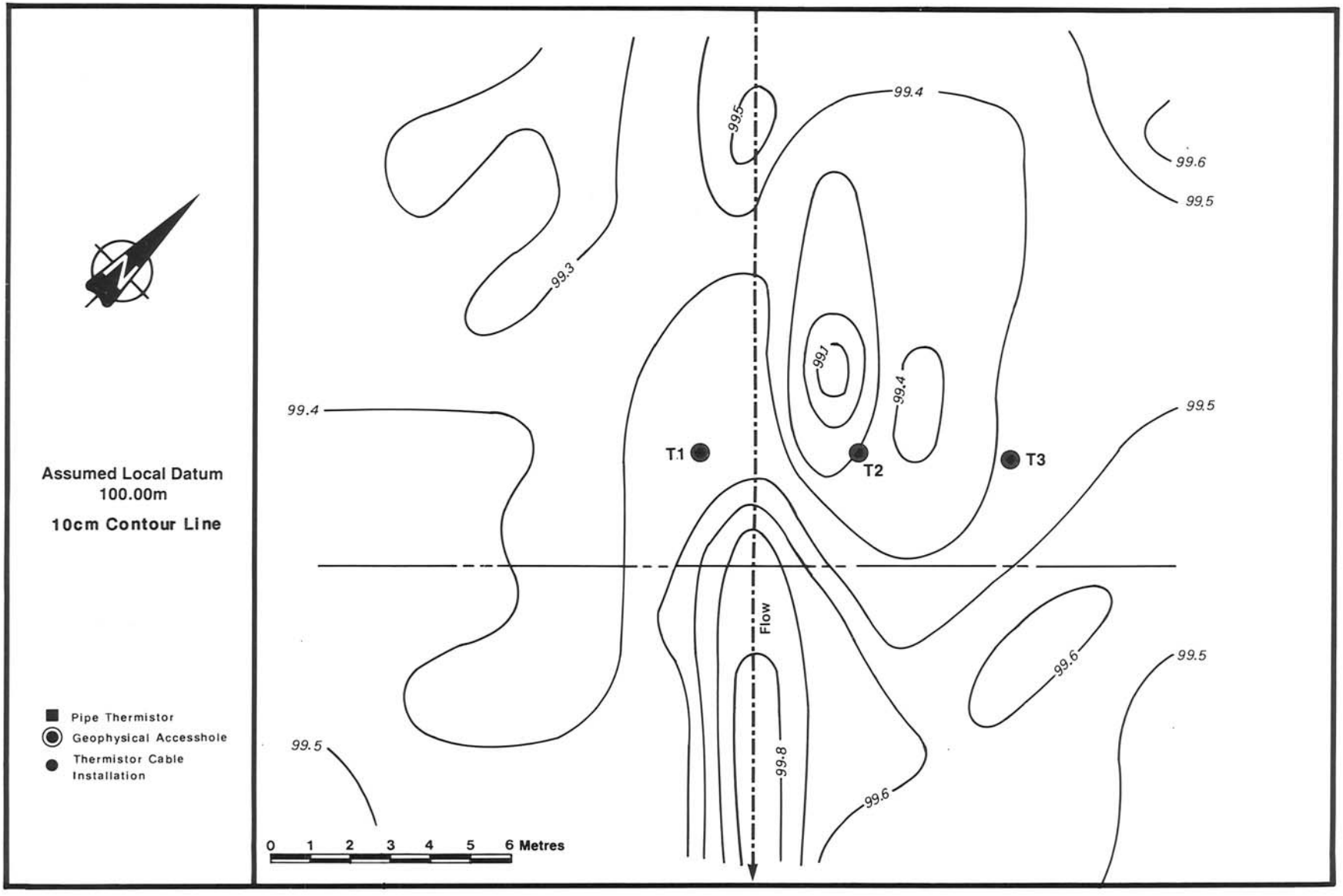
Instrumentation:
4 Multi-thermistor cables
1 Pipe thermistor cable
1 Geophysical access hole
3 Arrays of T.D.R. rods
1 Ditch thermistor installation



Site plan of EMR/INAC site 85-9, Pump Station 3



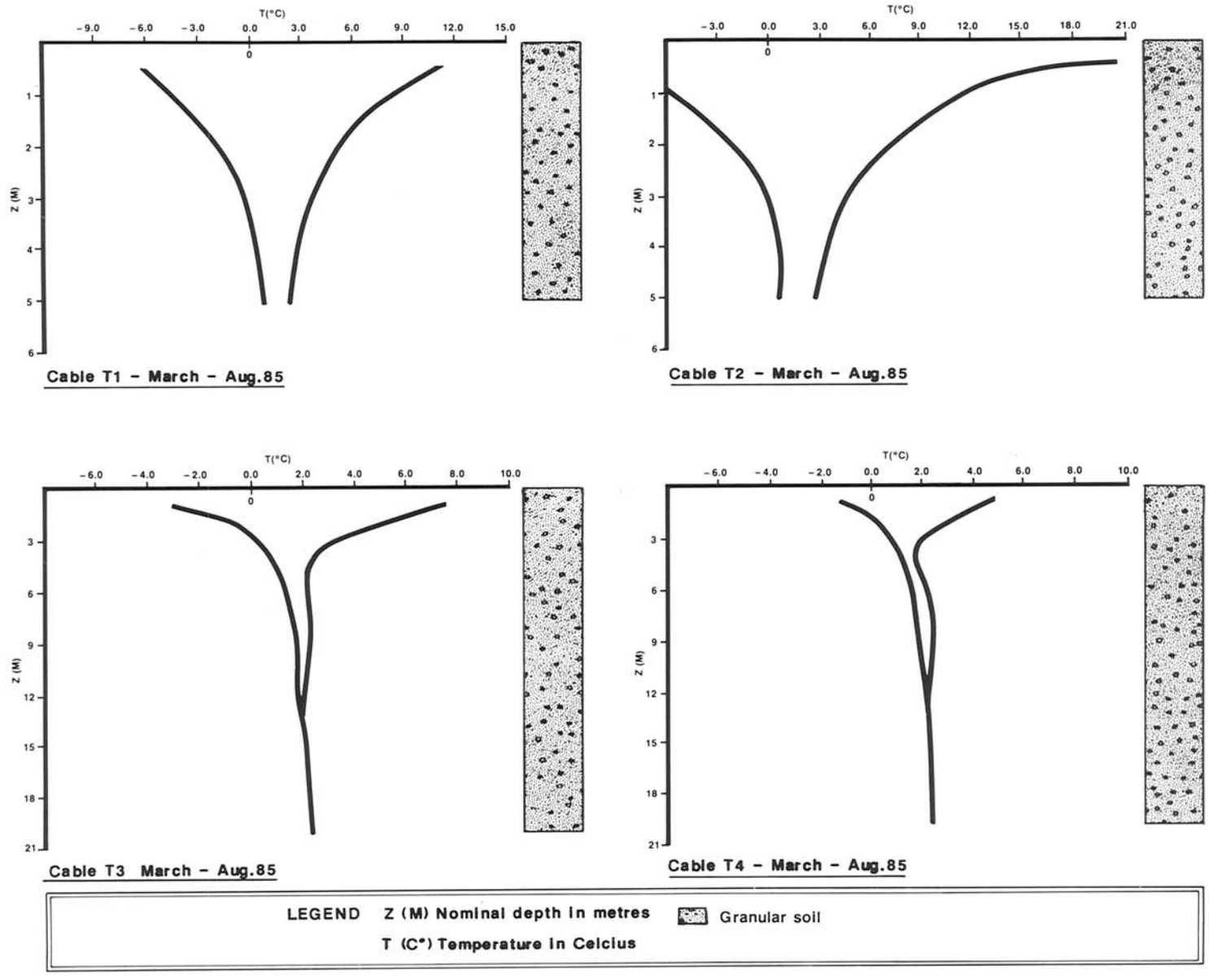
Lithologic cross section of site 85-9, Pump Station 3, based on the drill logs from the thermal instrumentation hole.



Detailed surface elevation contour map of site 85-9, Pump Station No. 3, using an assumed local datum of 100 m.

Site 85-9

Thermal fence 85-9 shows the following characteristics in the first year of observation. The site is free of permafrost and showed a substantial difference in frost penetration on and off the R.O.W. On the R.O.W. frost penetrated more than 3.5 m after pipeline construction whereas the frost table only went down to 1.3 m off the R.O.W. It is interesting to note that because it is well drained this site offered little resistance to a large heat loss in the R.O.W. during the construction period.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 85-9, Pump Station 3.

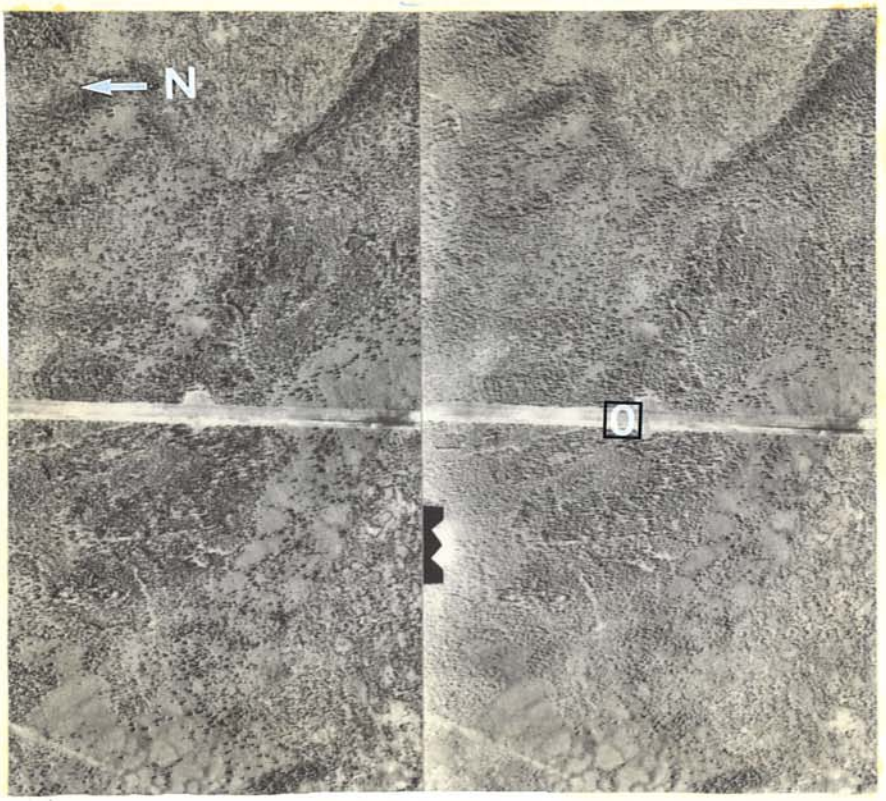
Thermistor depth at site 85-9
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	1.0
2	1.0	1.0	2.0	2.0
3	1.5	1.5	3.0	3.0
4	2.0	2.0	4.0	4.0
5	2.5	2.5	6.0	6.0
6	3.0	3.0	8.0	8.0
7	3.5	3.5	10.0	10.0
8	4.0	4.0	12.0	12.0
9	4.5	4.5	14.0	14.0
10	5.0	5.0	17.0	17.0
11	-	-	20.0	20.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm

Site 85-9 in May 1985, aerial view showing wet state of work side after snow melt.

Site 85-9 in October 1985, ground view illustrating contrast of work side (with grass) and spoil side.

THERMAL FENCE
85-10A
KP 587.5



Air photos A26836 Nos. 255-256, 7 August 1985

Site number: 85-10A

Site name: Mackenzie Highway South A

Location: 61° 21.57'N 120° 52.24'W, Kmp 587.5

Elevation: 244 metres A.S.L.

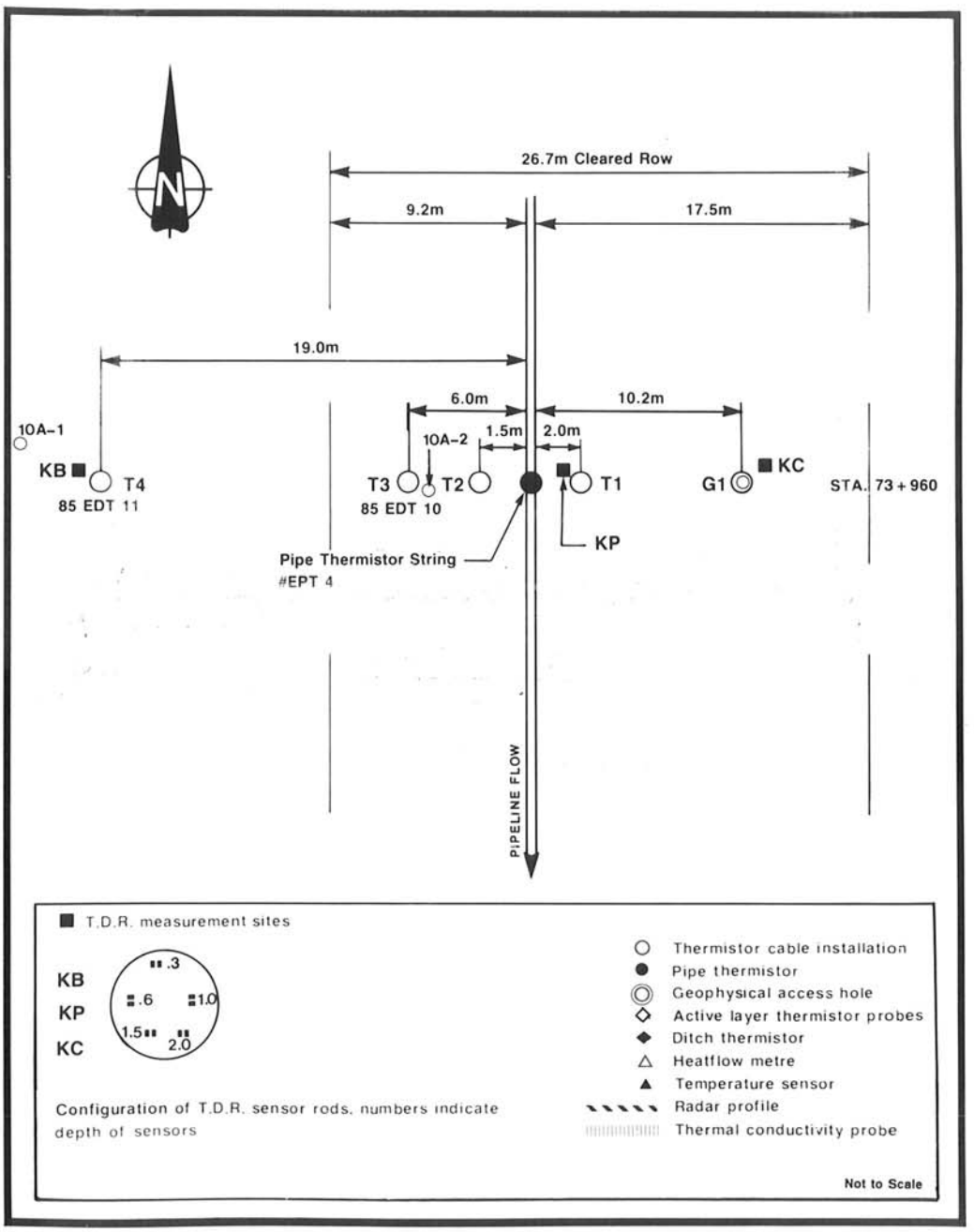
Rationale: This site was established at a level location to study the transition from unfrozen terrain to very shallow permafrost terrain. This thermal fence is in permafrost free terrain.

Vegetation: Open black spruce, jack pine, ericaceous shrubs, lichens woodland.

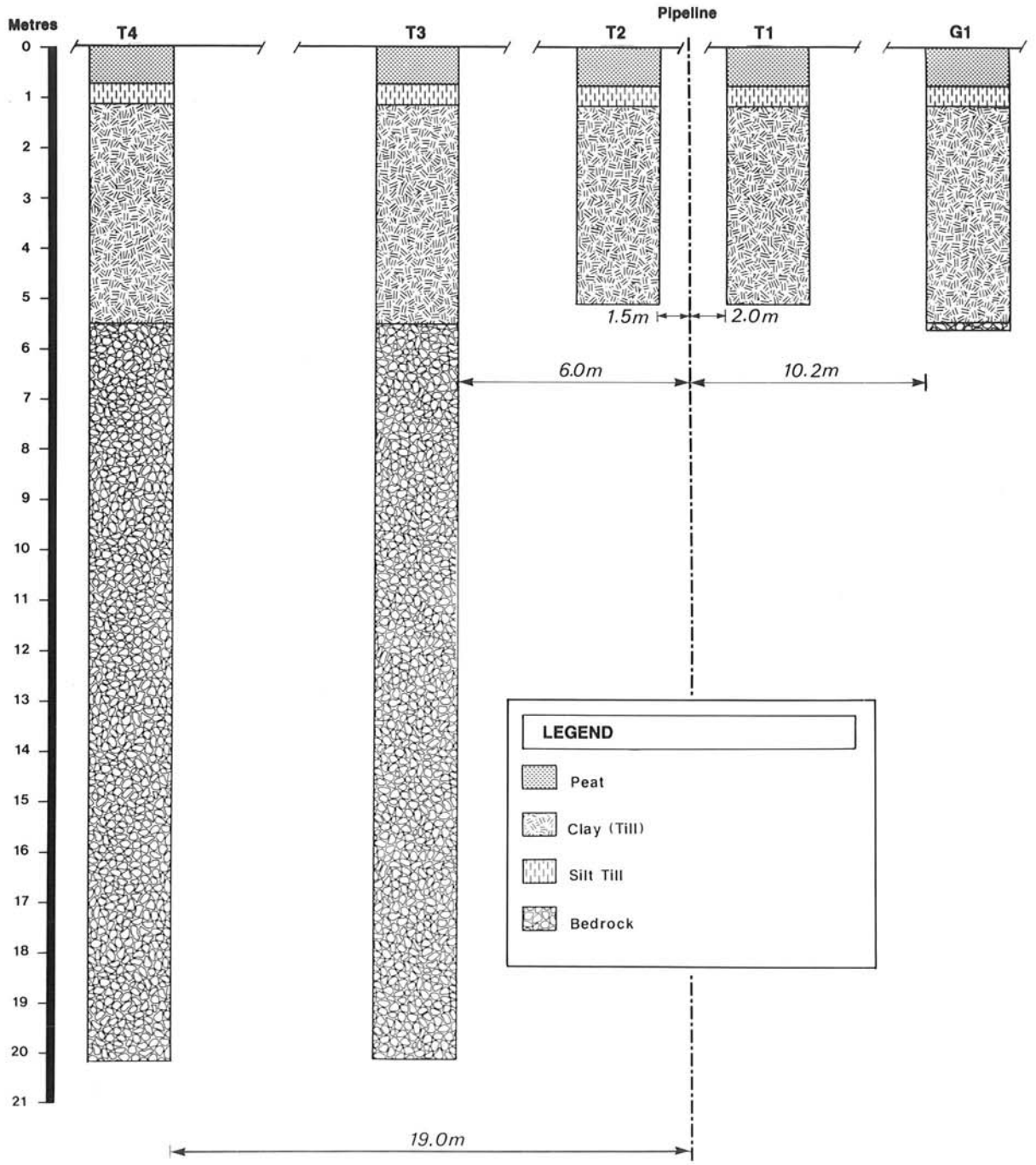
Site history:
- Trees cleared to 26.7 m width in winter 1983-84.
- Trenched by Barber Green 77 (wheel) ditcher in February 1985.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1985.
- Bench Marks installed and first surface survey in May 1985.

Pipe depth: 0.95 meters (excluding Roach) to top of pipe (March 1985).

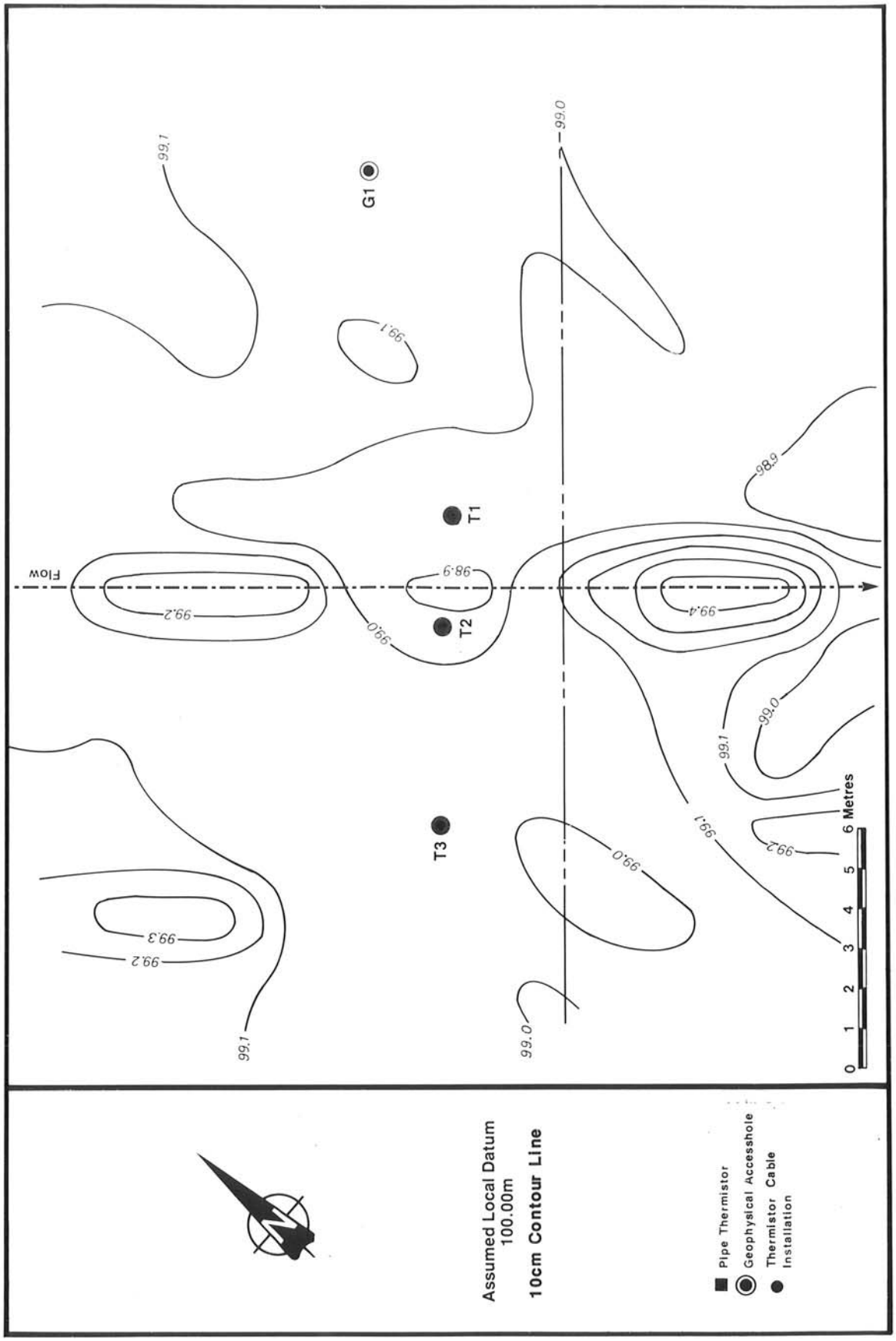
Instrumentation:
4 Multi-thermistor cables
1 Pipe thermistor cable
1 Geophysical access hole
3 Arrays of T.D.R. rods
2 Soil temperature probes



Site plan of EMR/INAC site 85-10A, Mackenzie Highway South



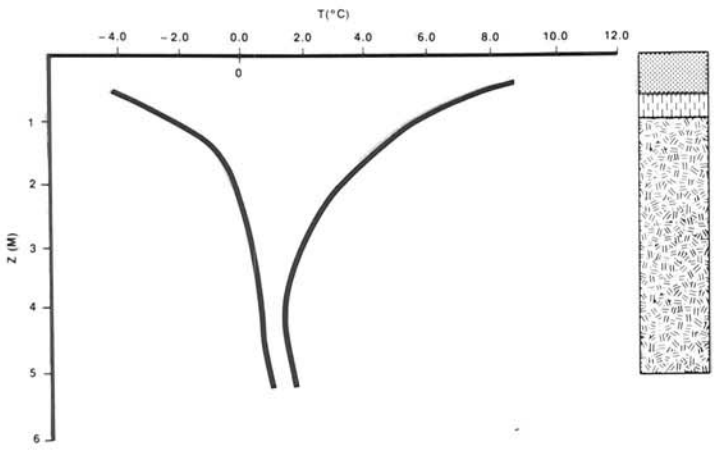
Lithologic cross section of site 85-10A, Mackenzie Highway South, based on the drill logs from the thermal instrumentation hole.



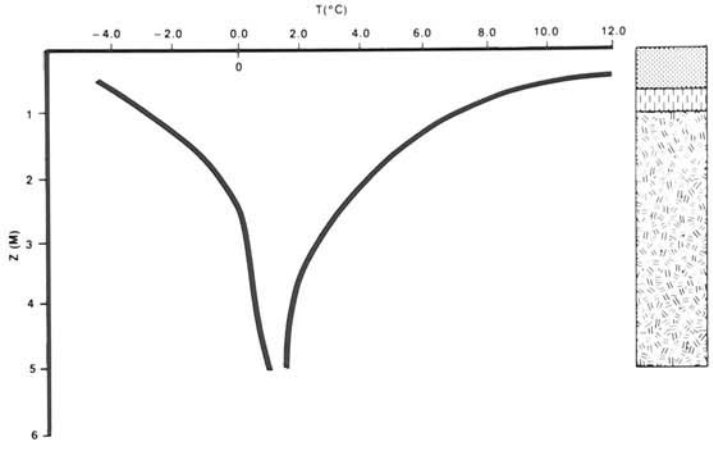
Detailed surface elevation contour map of site 85-10A, Mackenzie Highway South, using an assumed local datum of 100 m.

Site 85-10A

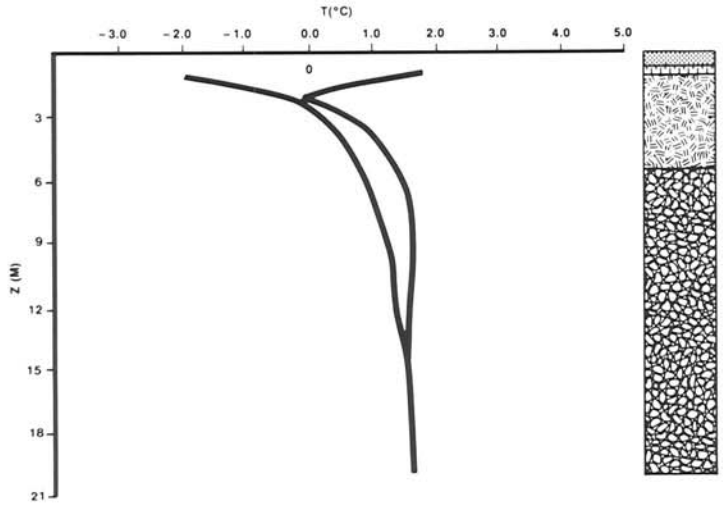
Thermal fence 85-10A is installed at the end of a relatively long stretch of unfrozen terrain just prior to the pipeline R.O.W. reentering a thin permafrost area. It shows the following trends in its first year of operation. It is as expected free of permafrost. The frost table reached 2 m in the R.O.W. and slightly more than 1 m off the R.O.W. It is interesting to note the damaging effect of the moister terrain on seasonal frost penetration which is 1/3 less at this fence than at fence 85-9 with its dryer terrain.



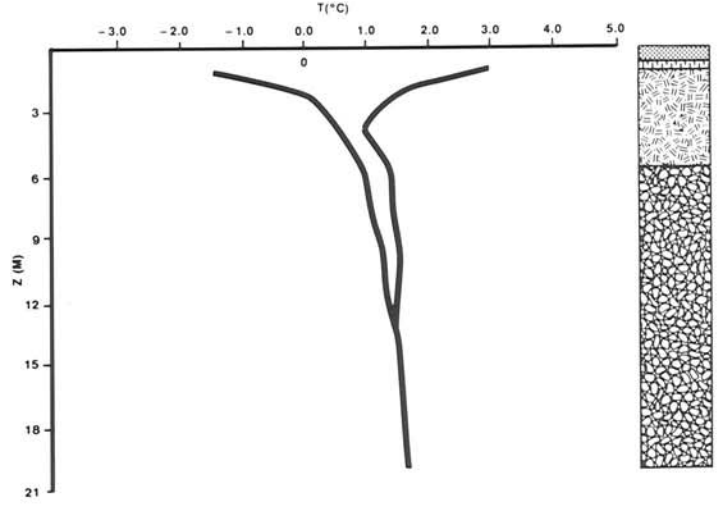
Cable T1 - March - Sept.85



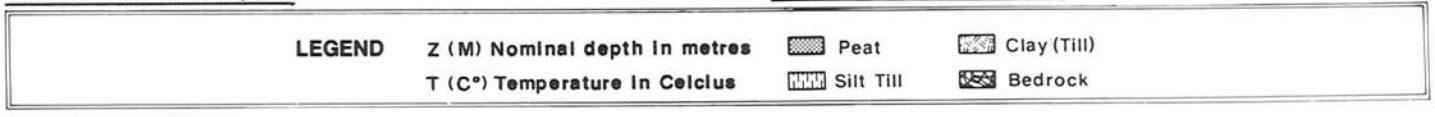
Cable T2 – March - Sept.85



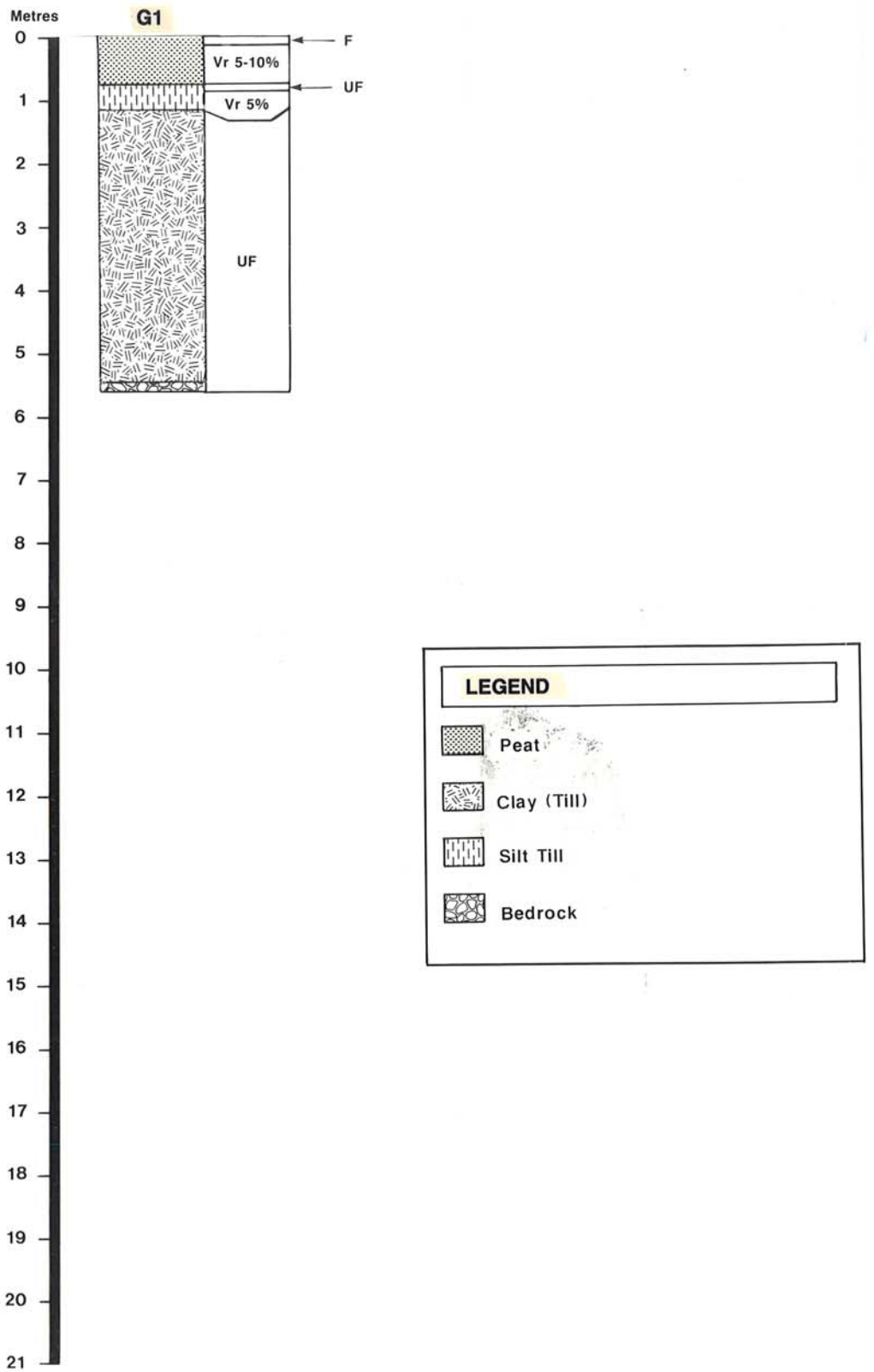
Cable T3 – March - Sept.85



Cable T4 - March - Sept.85



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 85-10A, Mackenzie Highway South.



Ice content distribution observed in hole G1 at EMR/INAC site 85-10A, Mackenzie Highway South.

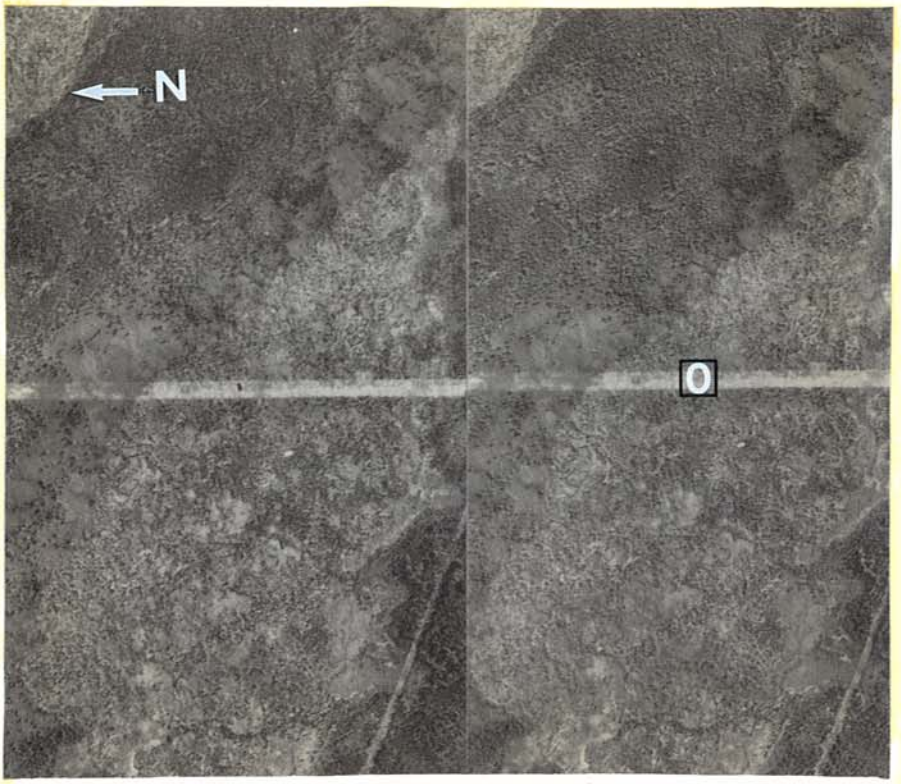
Thermistor depth at site 85-10A
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	1.0
2	1.0	1.0	2.0	2.0
3	1.5	1.5	3.0	3.0
4	2.0	2.0	4.0	4.0
5	2.5	2.5	6.0	6.0
6	3.0	3.0	8.0	8.0
7	3.5	3.5	10.0	10.0
8	4.0	4.0	12.0	12.0
9	4.5	4.5	14.0	14.0
10	5.0	5.0	17.0	17.0
11	-	-	20.0	20.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm

Site 85-10A in May 1985, ground view after construction.

Site 85-10A in October 1985, illustrating successful regrowth of vegetation.

THERMAL FENCE
85-10B
KP 587.9



Air photos A26350 Nos. 188-189, 2 July 1983

Site number: 85-10B

Site name: Mackenzie Highway South B

Location: 61° 21.31'N 120° 52.04'W, Kmp 587.9

Elevation: 244 metres A.S.L.

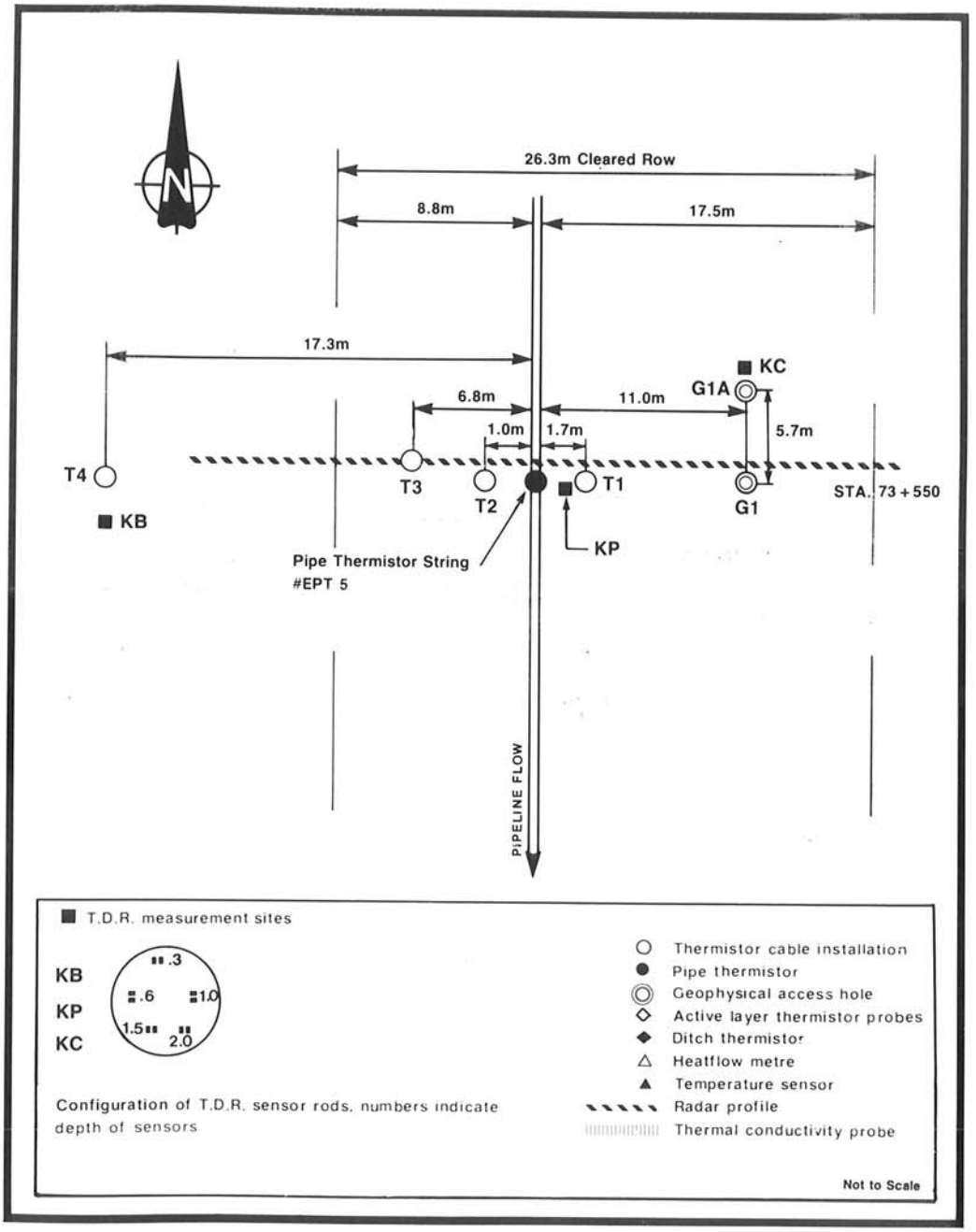
Rationale: This site was established at a level location to study the transition from unfrozen terrain to very shallow permafrost terrain. This thermal fence is in thick peat (2 m) covered till with very thin permafrost (<3 m).

Vegetation: Open black spruce, ericaceous shrubs, moss-lichen woodland.

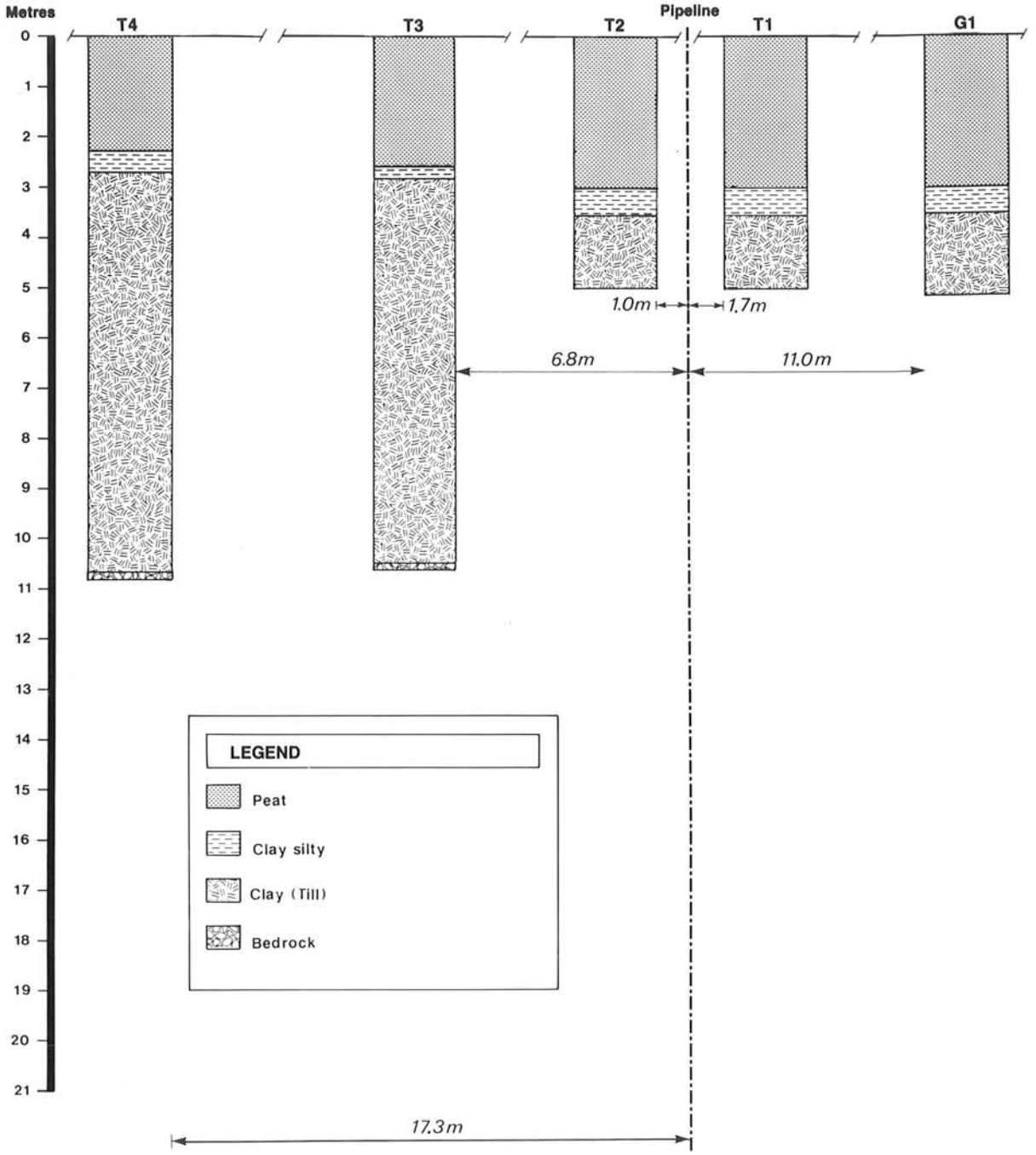
Site history:
- Trees cleared to 25 m in winter 1983-84.
- Trenched by Barber Green 77 (wheel) Ditcher in February 1985.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1985.
- Bench Marks installed and first surface survey in May 1985.

Pipe depth: 0.95 m (excluding Roach) to top of pipe (March 1985).

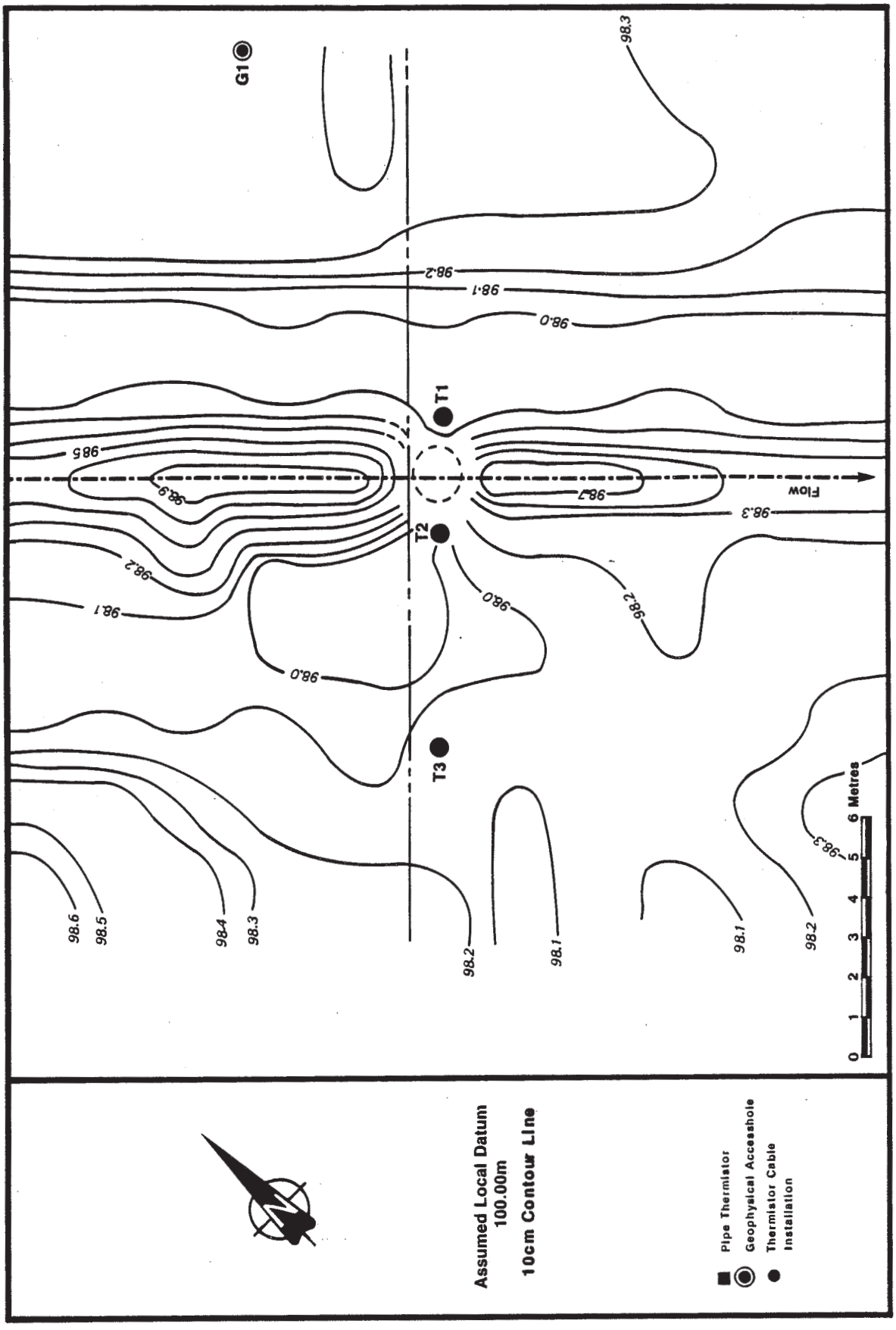
Instrumentation:
4 Multi-thermistor cables
1 Pipe thermistor cable
1 Geophysical access hole
3 Arrays of T.D.R. rods



Site plan of EMR/INAC site 85-10B, Mackenzie Highway South



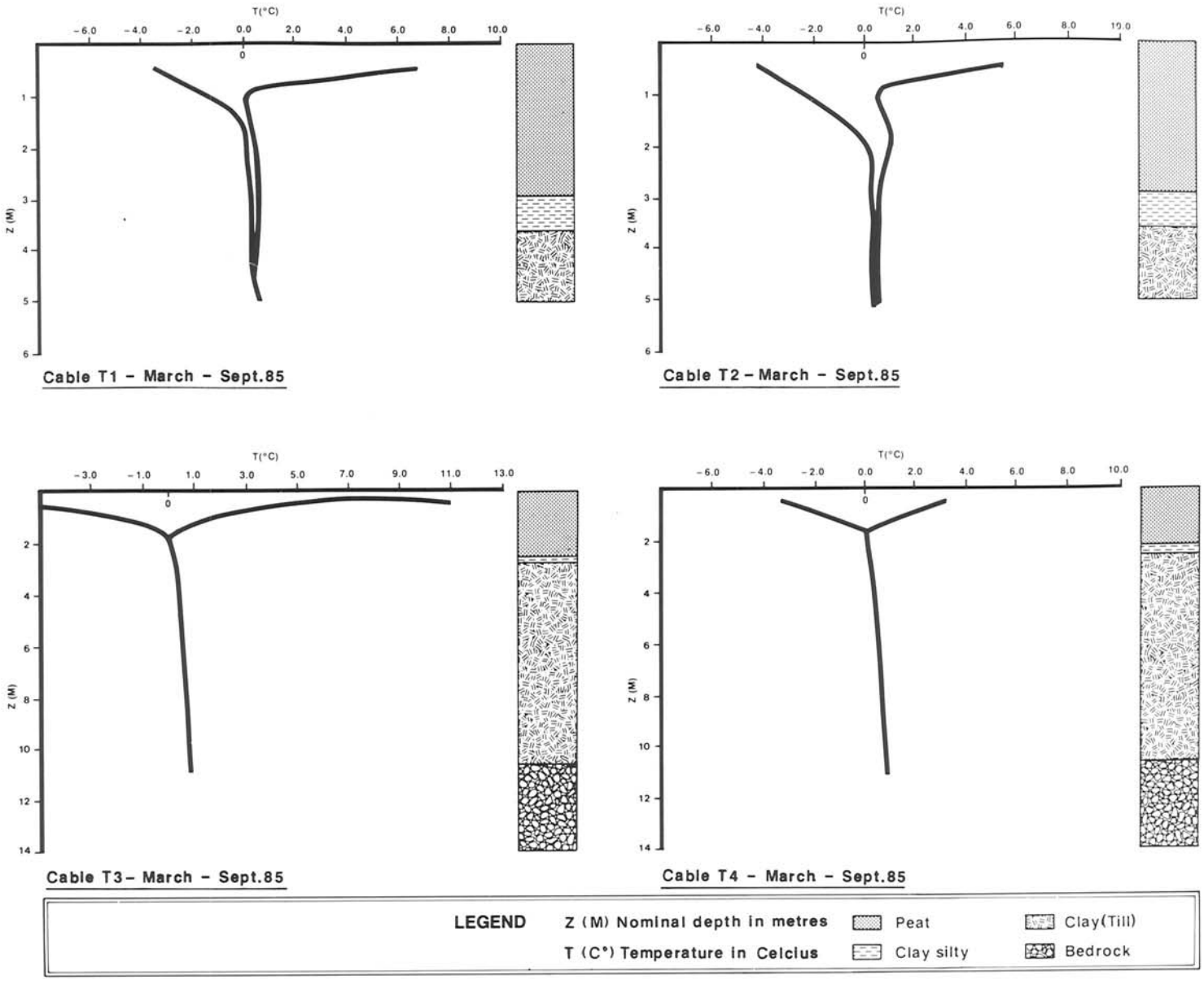
Lithologic cross section of site 85-10B, Mackenzie Highway South, based on the drill logs from the thermal instrumentation hole.



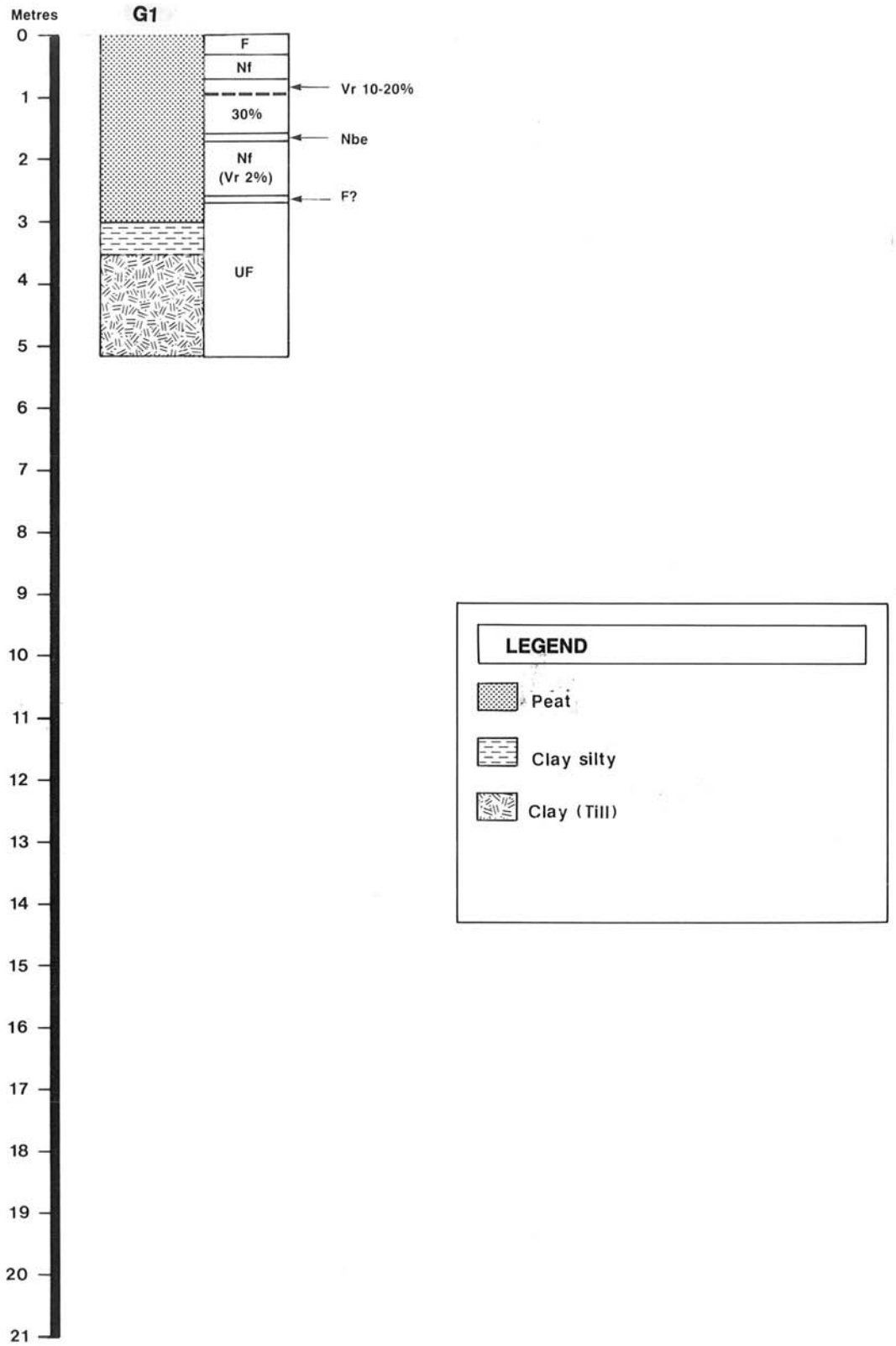
Detailed surface elevation contour map of site 85-10B, Mackenzie Highway South, using an assumed local datum of 100 m.

Site 85-10B

Thermal fence 85-10B shows the following trend in its first year of operation. The off R.O.W. reference shows a permafrost thickness of 2 m with fluctuation down to 2.5 m in the course of the year. The on R.O.W. hole T-1 shows 0.5 m of permafrost while hole T2 and T-3 show complete thawing for a month during the first summer active layer depth on and off the R.O.W. is approximately 1 m. It is expected that with time permafrost will disappear from the R.O.W. at this site.



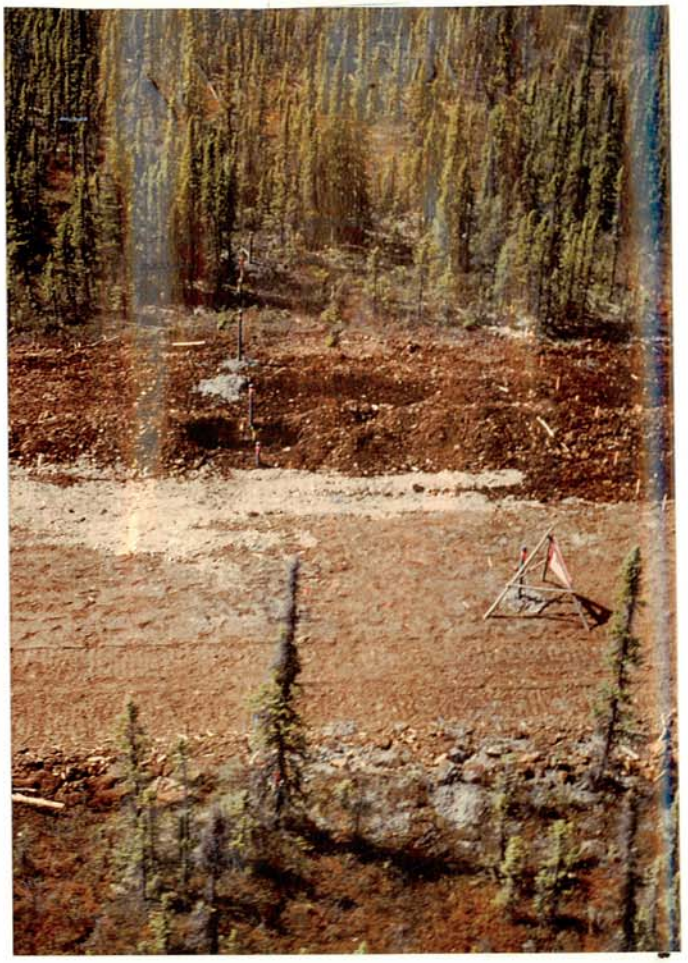
Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 85-10B, Mackenzie Highway South.



Ice content distribution observed in hole G1 at EMR/INAC site 85-10B, Mackenzie Highway South.

Thermistor depth at site 85-10B
depth in meters

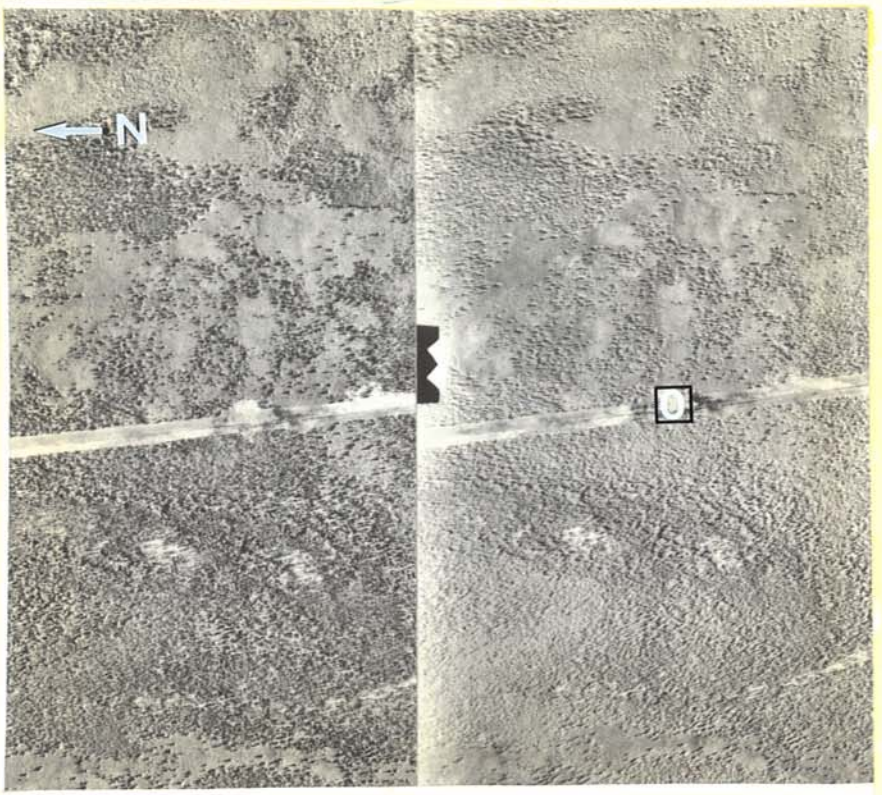
Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	0.5	0.5
2	1.0	1.0	1.0	1.0
3	1.5	1.5	1.5	1.5
4	2.0	2.0	2.0	2.0
5	2.5	2.5	2.5	2.5
6	3.0	3.0	3.5	3.5
7	3.5	3.5	4.5	4.5
8	4.0	4.0	5.5	5.5
9	4.5	4.5	6.5	6.5
10	5.0	5.0	8.5	8.5
11	-	-	10.5	10.5
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm



Site 85-10B in May 1985, aerial view. Note collapsed area along fence.

Site 85-10B in August 1985, ground view of fence. Note lack of vegetation regrowth on peat surface.

THERMAL FENCE
85-11
KP 596.6



Air photos A26836 Nos. 245-246, 7 August 1985

Site number: 85-11

Site name: Moraine South

Location: 61° 16.92'N 120° 48.39'W, Kmp 596.6

Elevation: 251 metres A.S.L.

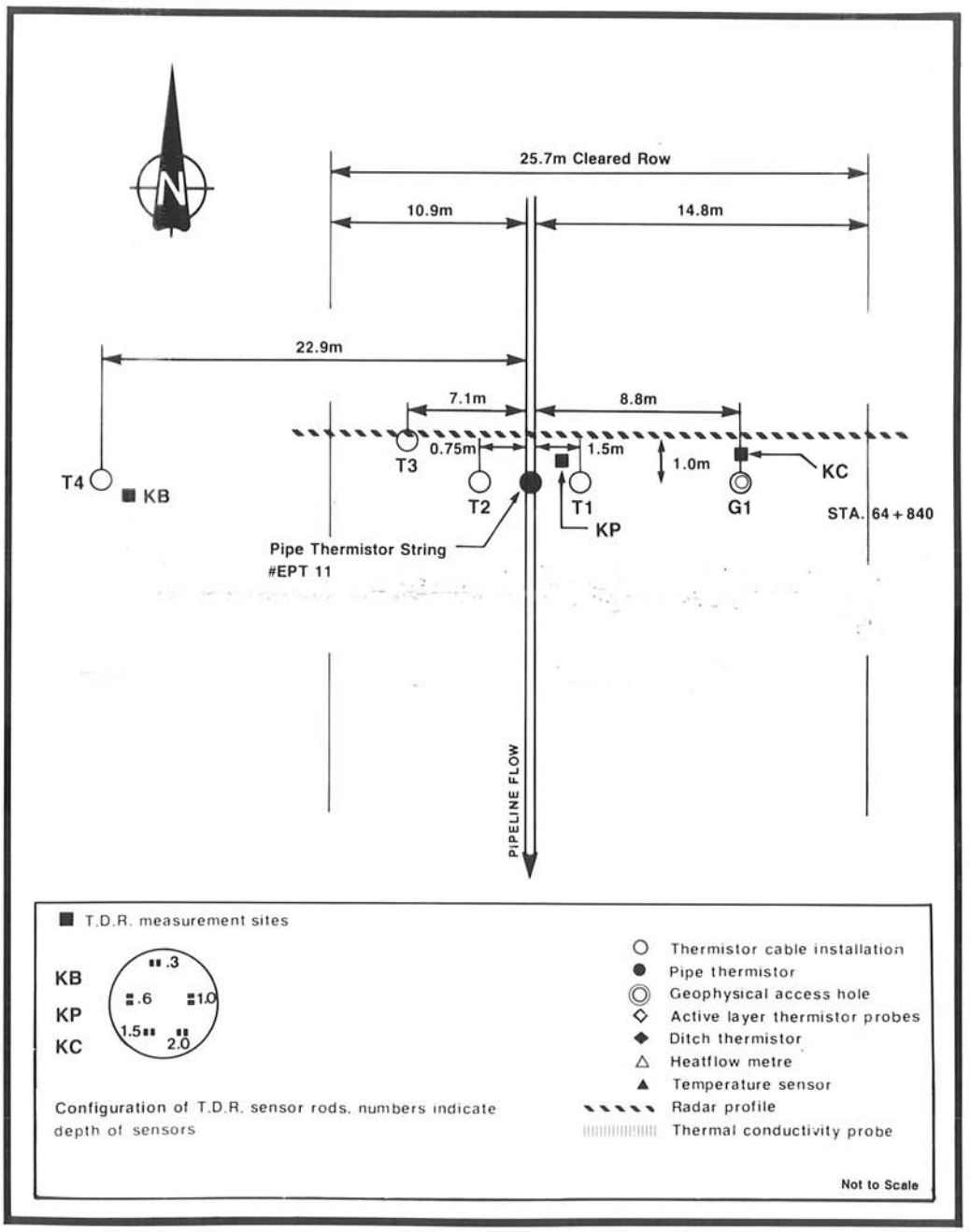
Rationale: This site was established at a level location to study the effect of a pipeline on shallow permafrost (<4 m). It is co-located with a 1981 vintage helidrill pad.

Vegetation: Open black spruce, ericaceous shrubs, moss-lichen woodland.

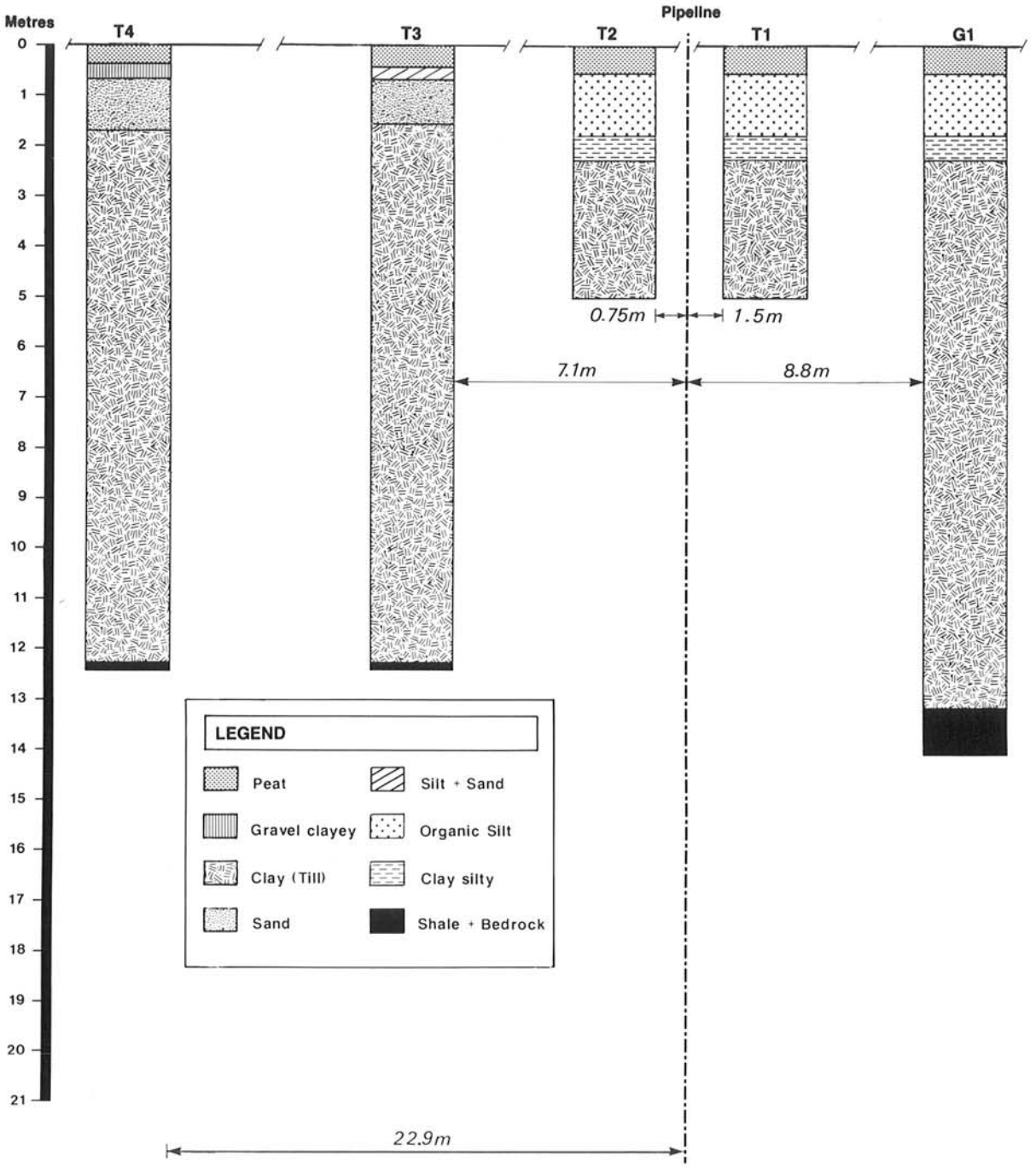
Site history:
- Trees cleared to 25.7 m in winter 1982-83.
- Trenched with a Barber Green 77 (wheel) Ditcher in February 1985.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1985.
- Bench Marks installed and first surface survey in May 1985.

Pipe depth: 0.95 m (excluding Roach) to top of pipe (March 1985).

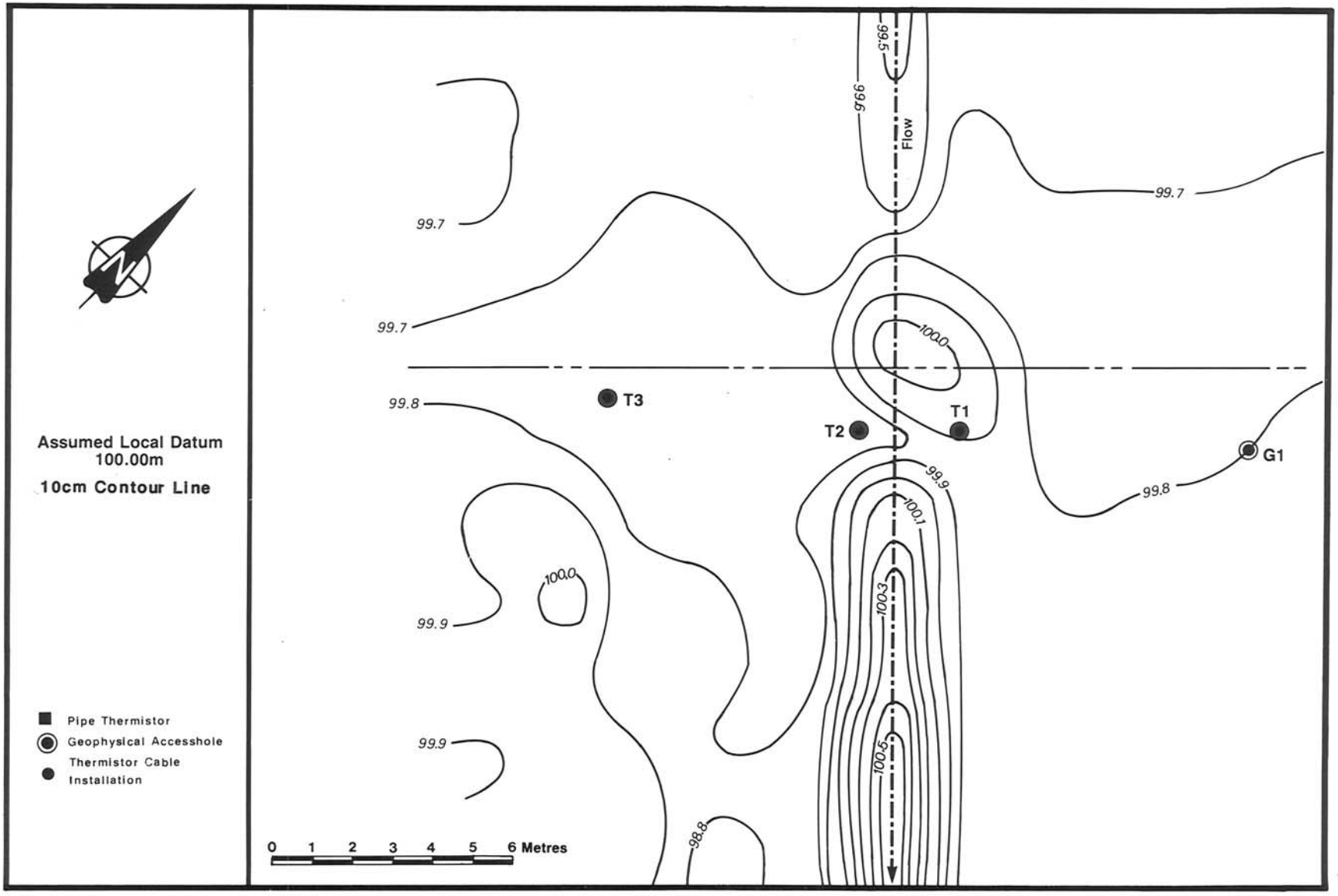
Instrumentation:
4 Multi-thermistor cables
1 Pipe thermistor
1 Geophysical access hole
3 Arrays of T.D.R. rods



Site plan of EMR/INAC site 85-11, Moraine South



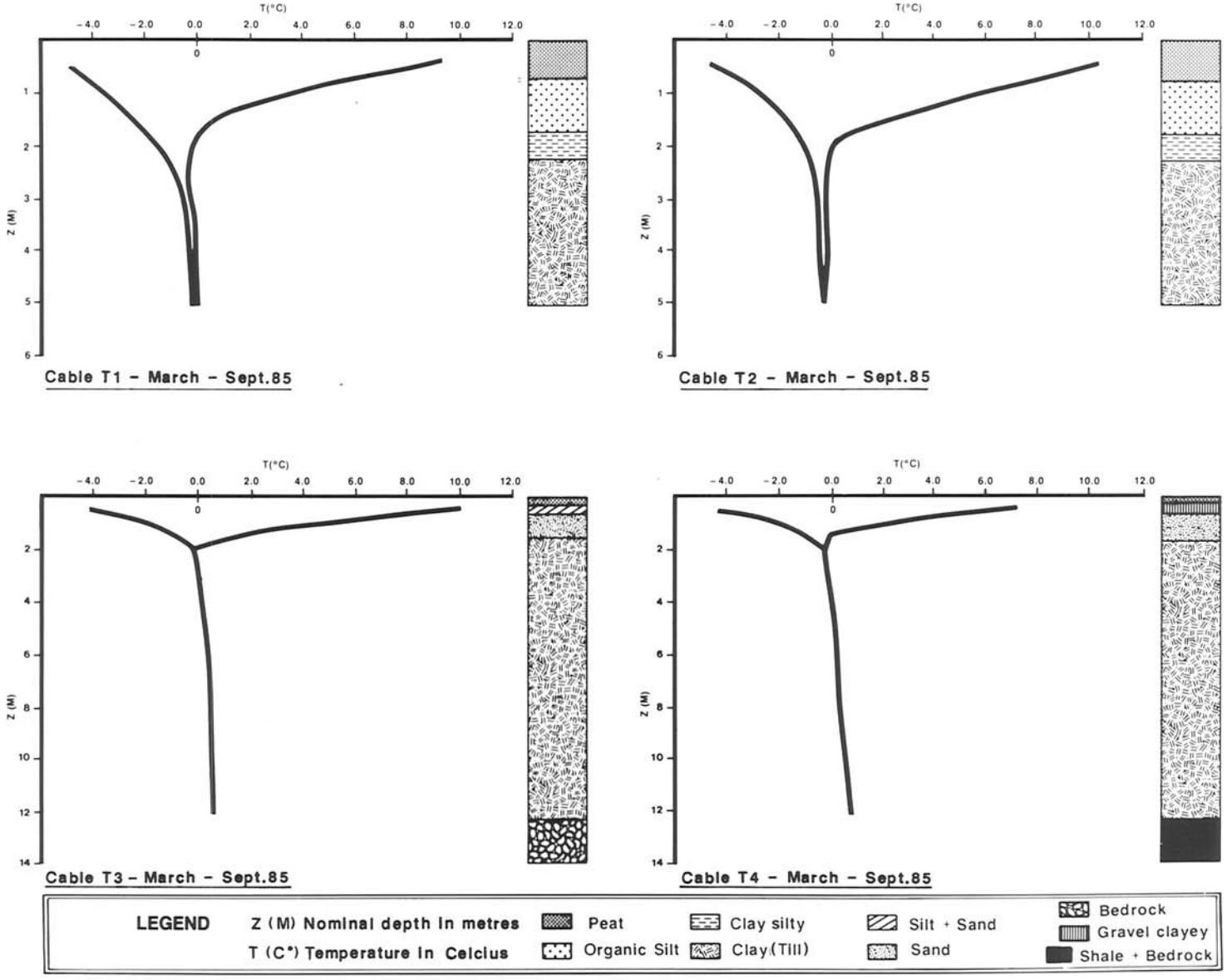
Lithologic cross section of site 85-11, Moraine Highway South, based on the drill logs from the thermal instrumentation hole.



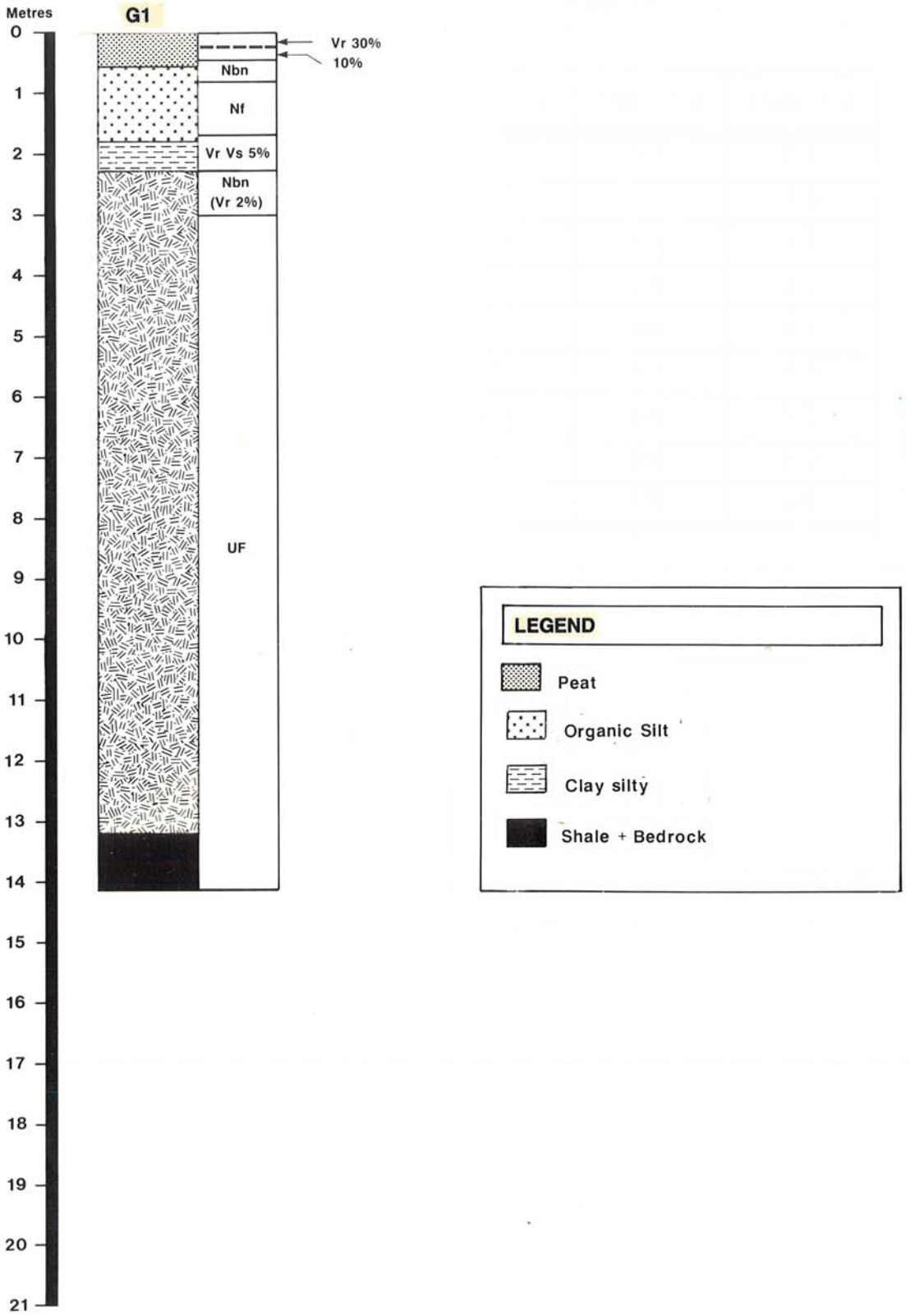
Detailed surface elevation contour map of site 85-11, Moraine South, using an assumed local datum of 100 m.

Site 85-11

The thermal fence at site 85-11 is installed in an old helidrill pad clearing dating back to 1981. It shows the following trend for the first year of observation. Measured permafrost depth off the R.O.W. is 4 m. The on R.O.W. short cables show a permafrost thickness of approximately 5.5 m. The difference is likely caused by the heat loss during construction on the R.O.W. active layer depth was 2.5 m on the R.O.W. during the period while it was 1.5 m off the R.O.W. With time this site should provide very interesting information on thermal stabilization of shallow permafrost after disturbance.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 85-11, Moraine South.

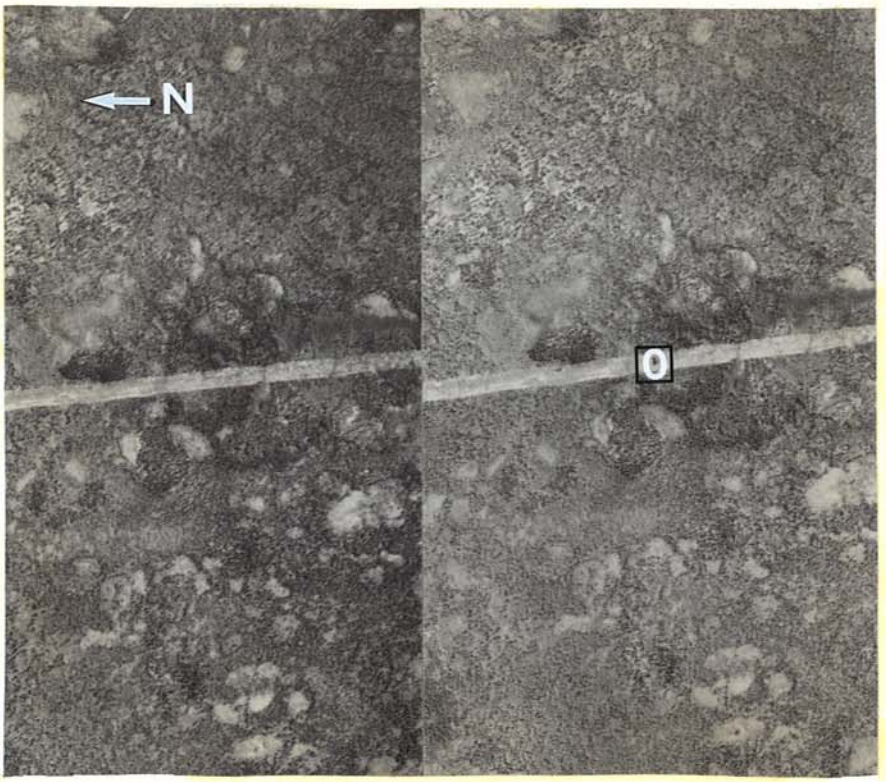


Ice content distribution observed in hole G1 at EMR/INAC site 85-11, Moraine South.

Site 85-11 in May 1985, aerial view. Note water accumulated in trench.

Site 85-11 in October 1985, illustrating vegetation regrowth.

THERMAL FENCE
85-12A
KP 607.7



Air photos A26350 Nos. 166-167, 2 July 1983

Site number: 85-12A

Site name: Jean Marie Creek A

Location: 61° 11.59'N 120° 42.18'W, Kmp 607.7

Elevation: 298 metres A.S.L.

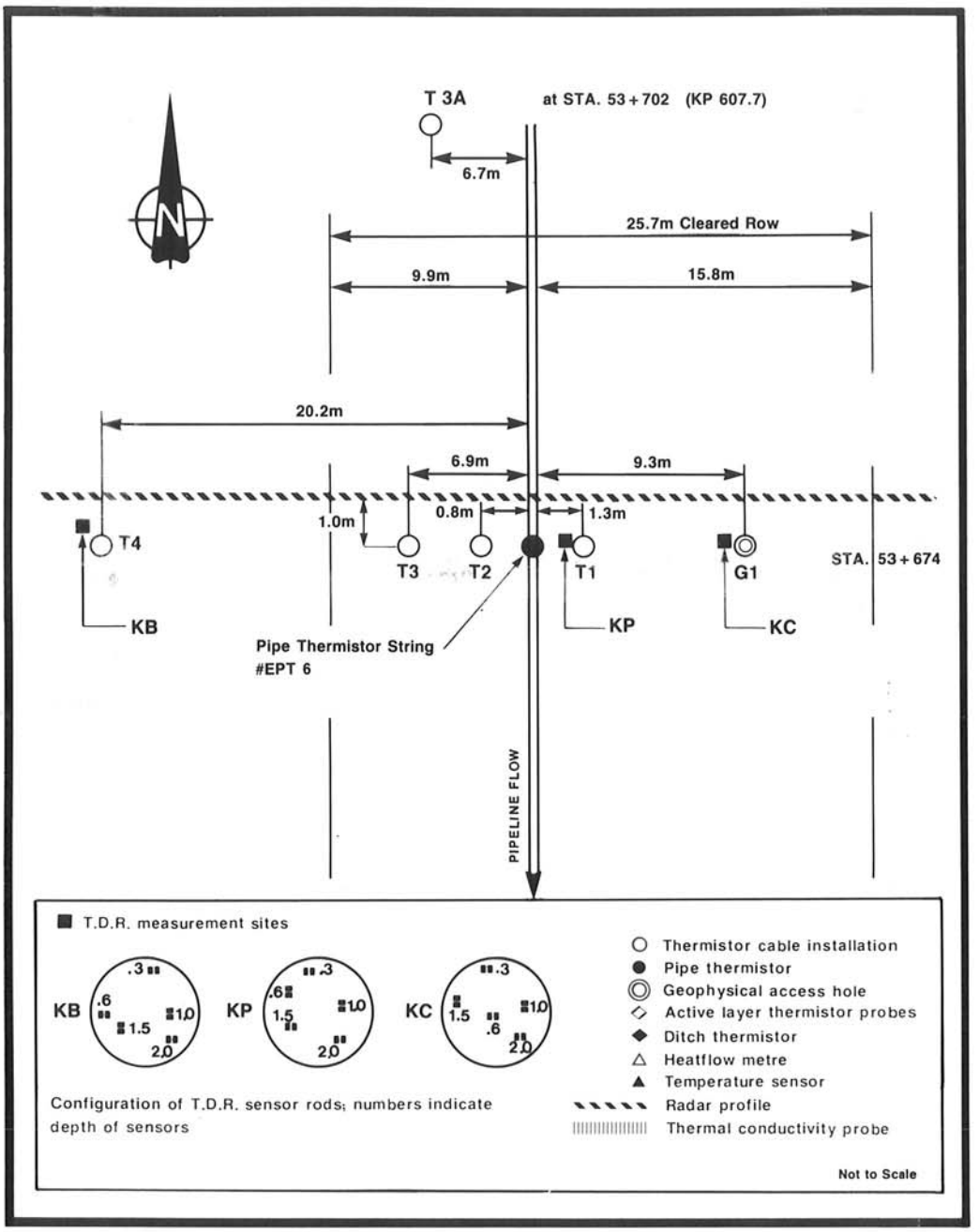
Rationale: This site was established at a level location to study the effects of a pipeline on a sharp interface in a thermokarsted peat plateau. This fence is located in an unfrozen depression and is thus free of permafrost.

Vegetation: Open black spruce, ericaceous shrubs, lichen moss woodland.

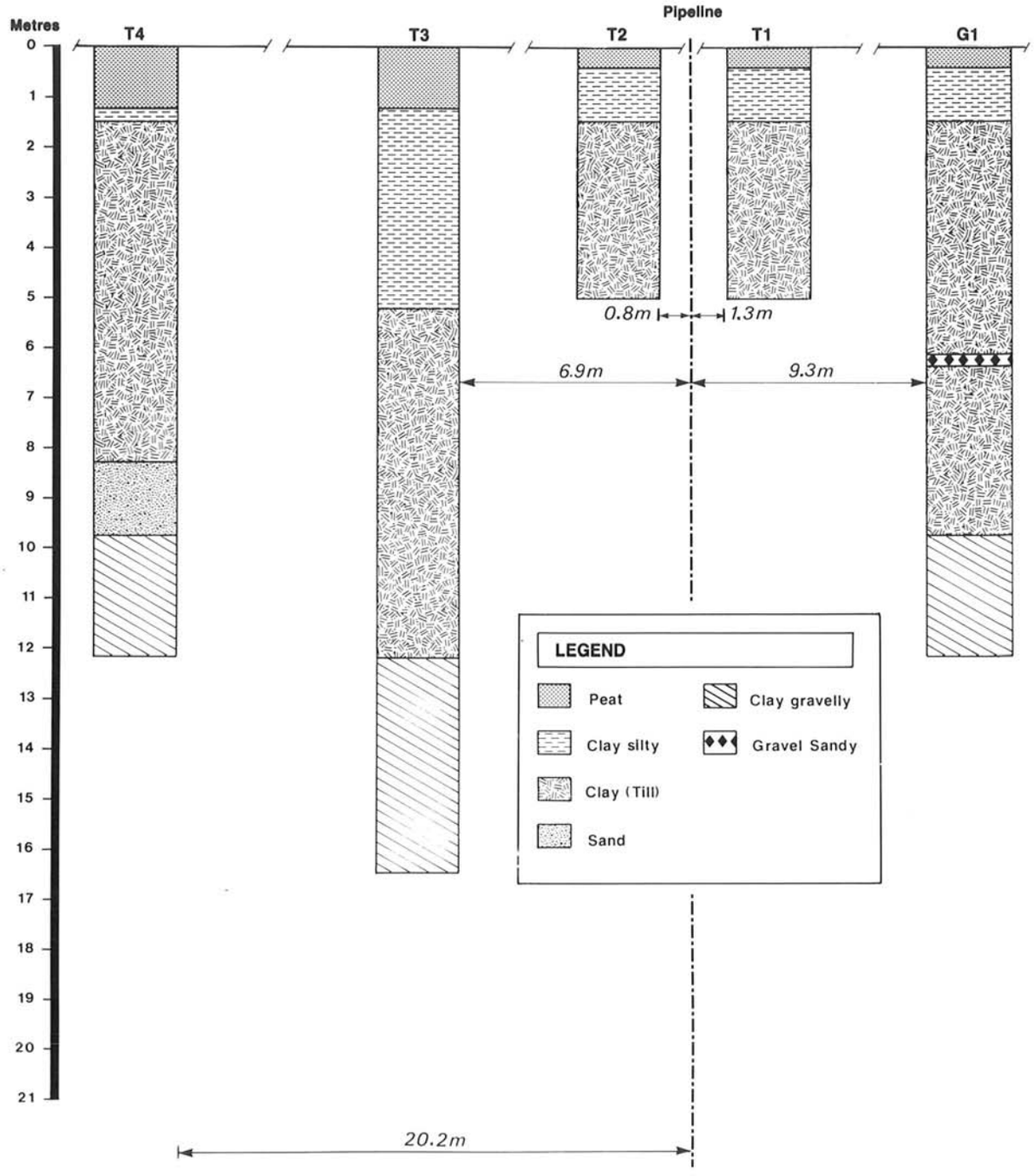
Site history:
- Trees cleared to 25.7 m width in winter 1982-83.
- Trenched in February 1985 with a Barber Green 77 (wheel) Ditcher.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1985.
- Bench Marks installed and first surface survey in May 1985.

Pipe depth: 0.95 m (excluding Roach) to top of pipe (March 1985).

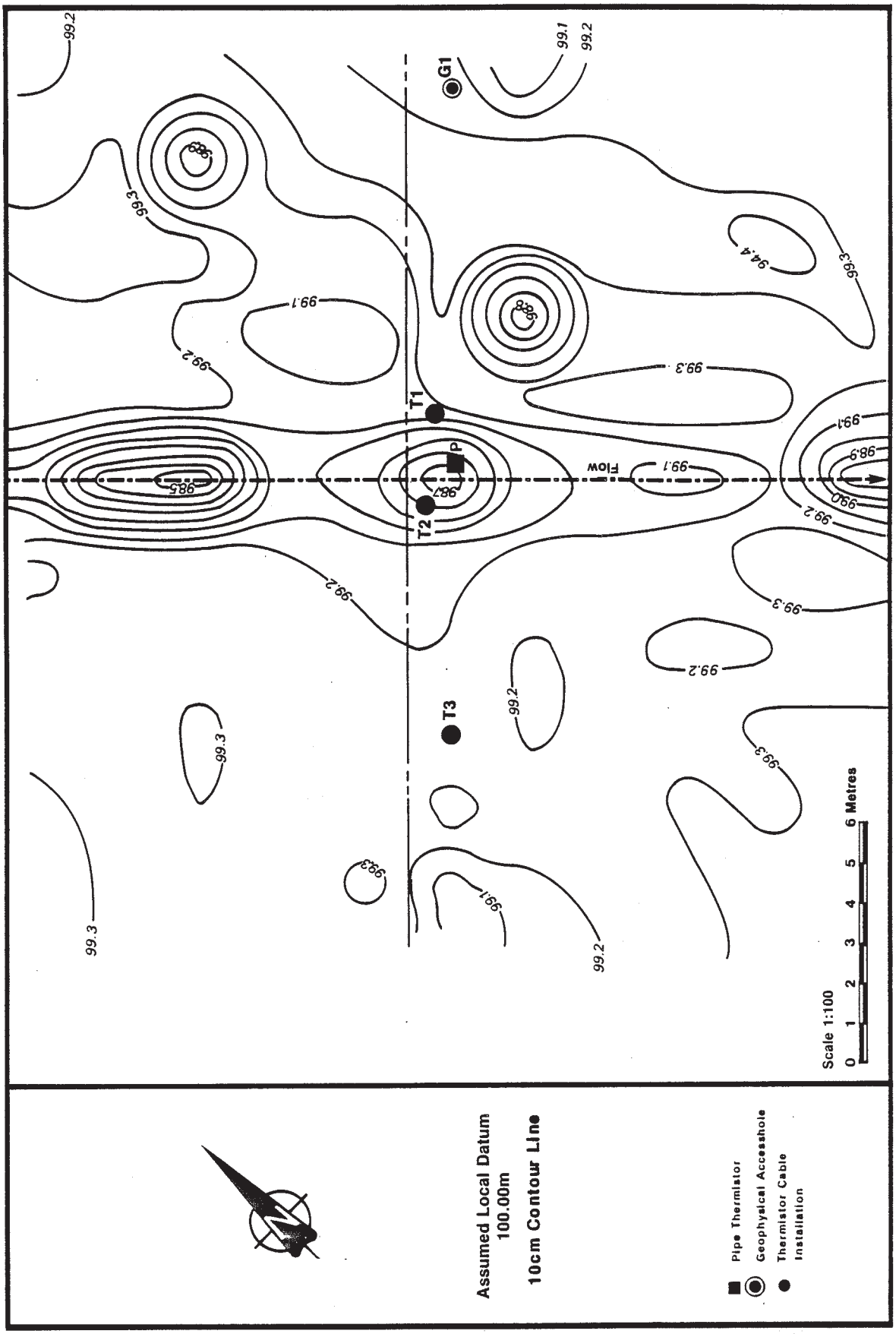
Instrumentation:
4 Multi-thermistor cables
1 Pipe thermistor cable
1 Geophysical access hole
3 Arrays of T.D.R. rods



Site plan of EMR/INAC site 85-12A, Jean Marie Creek



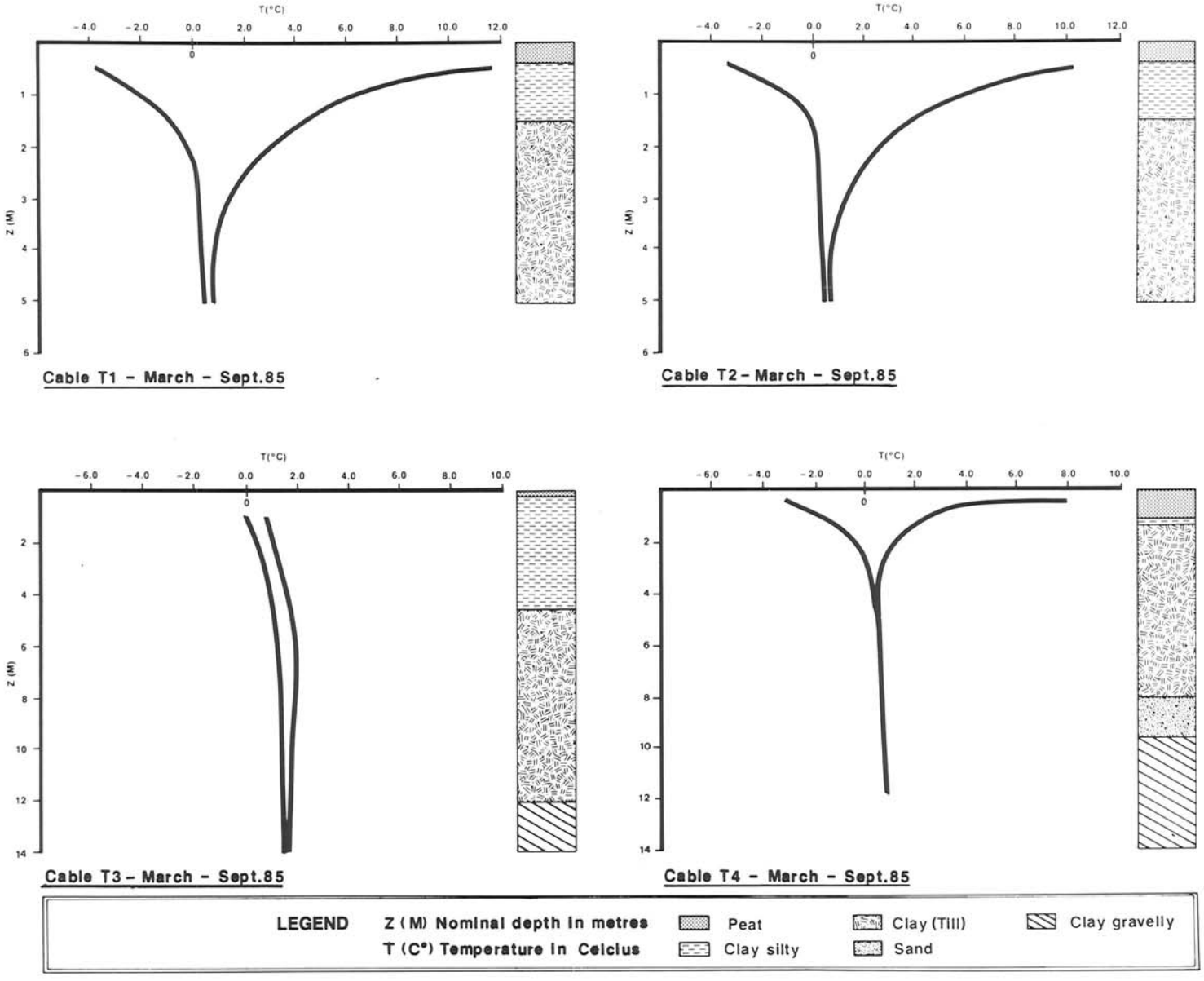
Lithologic cross section of site 85-12A, Jean Marie Creek, based on the drill logs from the thermal instrumentation hole.



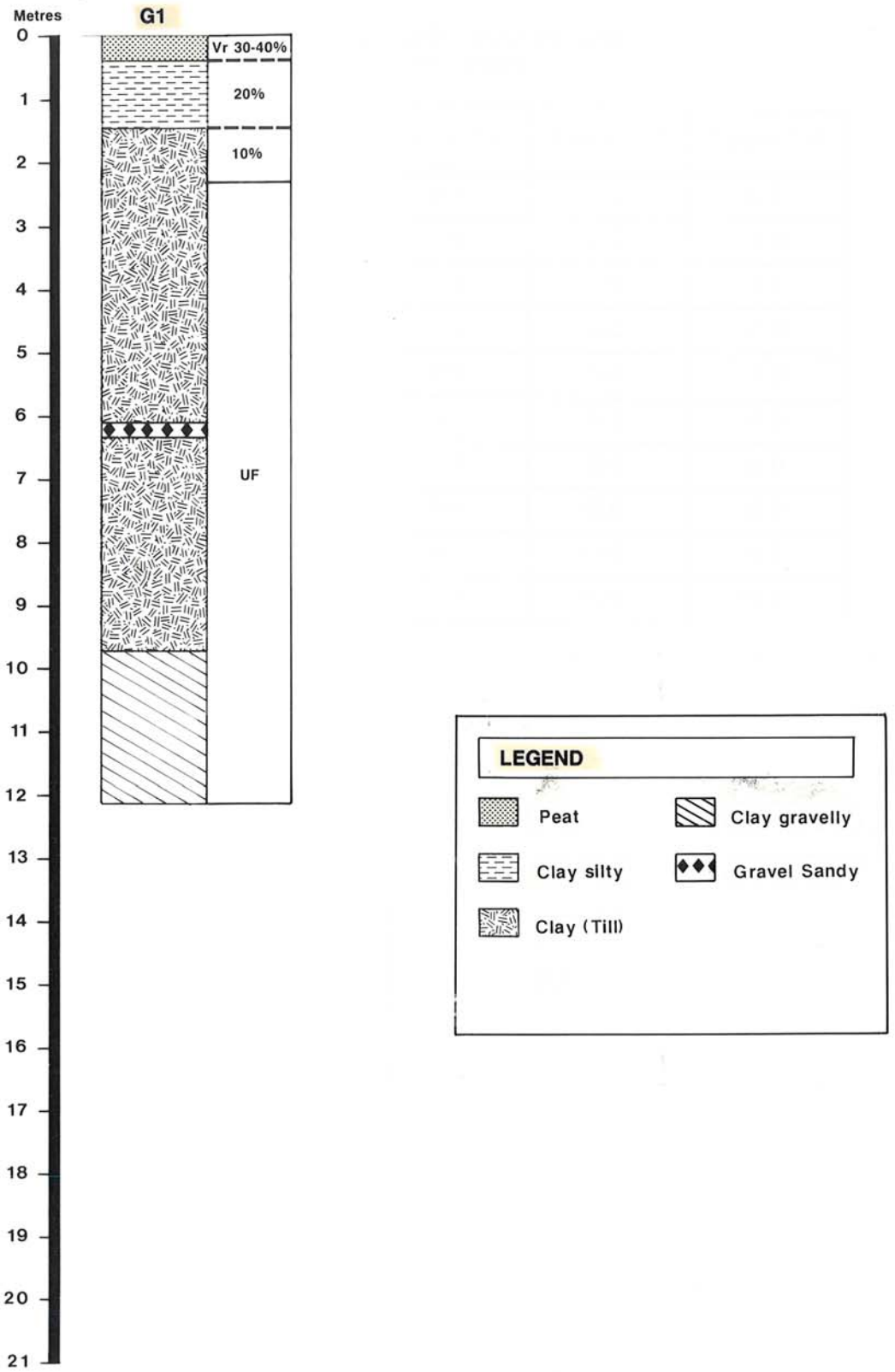
Detailed surface elevation contour map of site 85-12A, Jean Marie Creek, using an assumed local datum of 100 m.

Site 85-12A

Thermal fence 85-12A was installed on the thaw side of a sharp thermokarst interface. As expected it is completely free of permafrost. The frost table shows relatively uniform penetration both on and off the R.O.W. and reaches slightly more than 2 m with a 2 to 3 month frost free period at the end of the warm season.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 85-12A, Jean Marie Creek.



Ice content distribution observed in hole G1 at EMR/INAC site 85-12A, Jean Marie Creek.

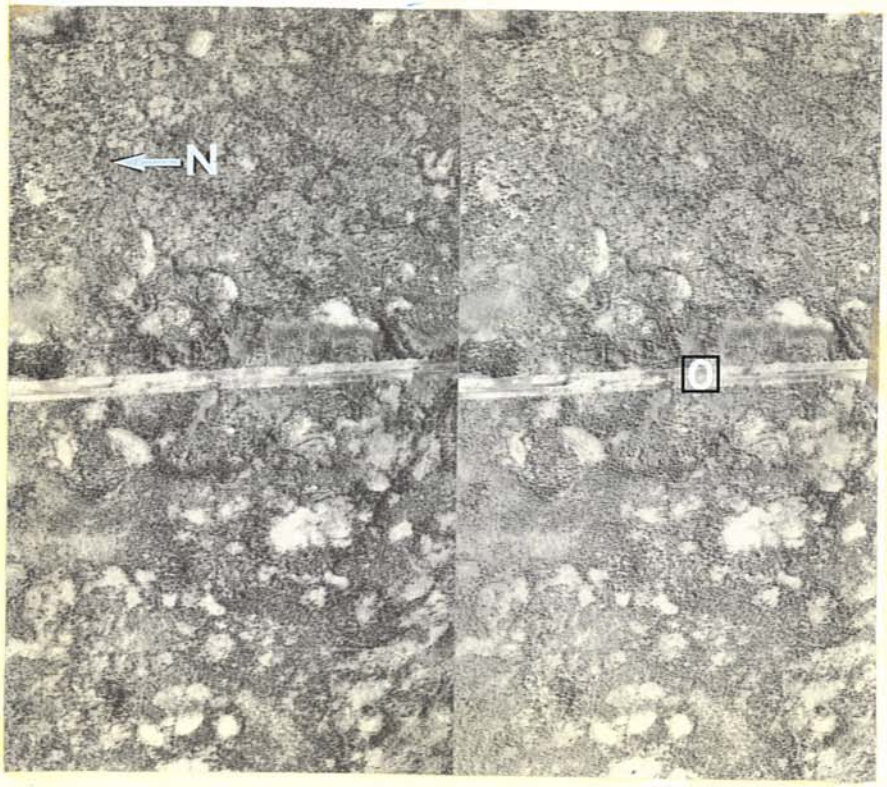
Thermistor depth at site 85-12A
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	1.0	0.5
2	1.0	1.0	2.0	1.0
3	1.5	1.5	3.0	1.5
4	2.0	2.0	4.0	2.0
5	2.5	2.5	5.0	3.0
6	3.0	3.0	6.0	4.0
7	3.5	3.5	8.0	5.0
8	4.0	4.0	10.0	6.0
9	4.5	4.5	12.0	8.0
10	5.0	5.0	14.0	10.0
11	-	-	16.4	12.0
Diameter of inner PVC tube	25 mm	25mm	25 mm	38 mm

Site 85-12A in May 1985, note the use of select backfill in trench.

Site 85-12A in October 1985, showing minimal vegetation regrowth in peat surface.

THERMAL FENCE
85-12B
KP 607.9



Air photos A26836 Nos. 233-234, 7 August 1985

Site number: 85-12B

Site name: Jean Marie Creek B

Location: 61° 11.44'N 120° 42.18'W, Kmp 607.9

Elevation: 300 metres A.S.L.

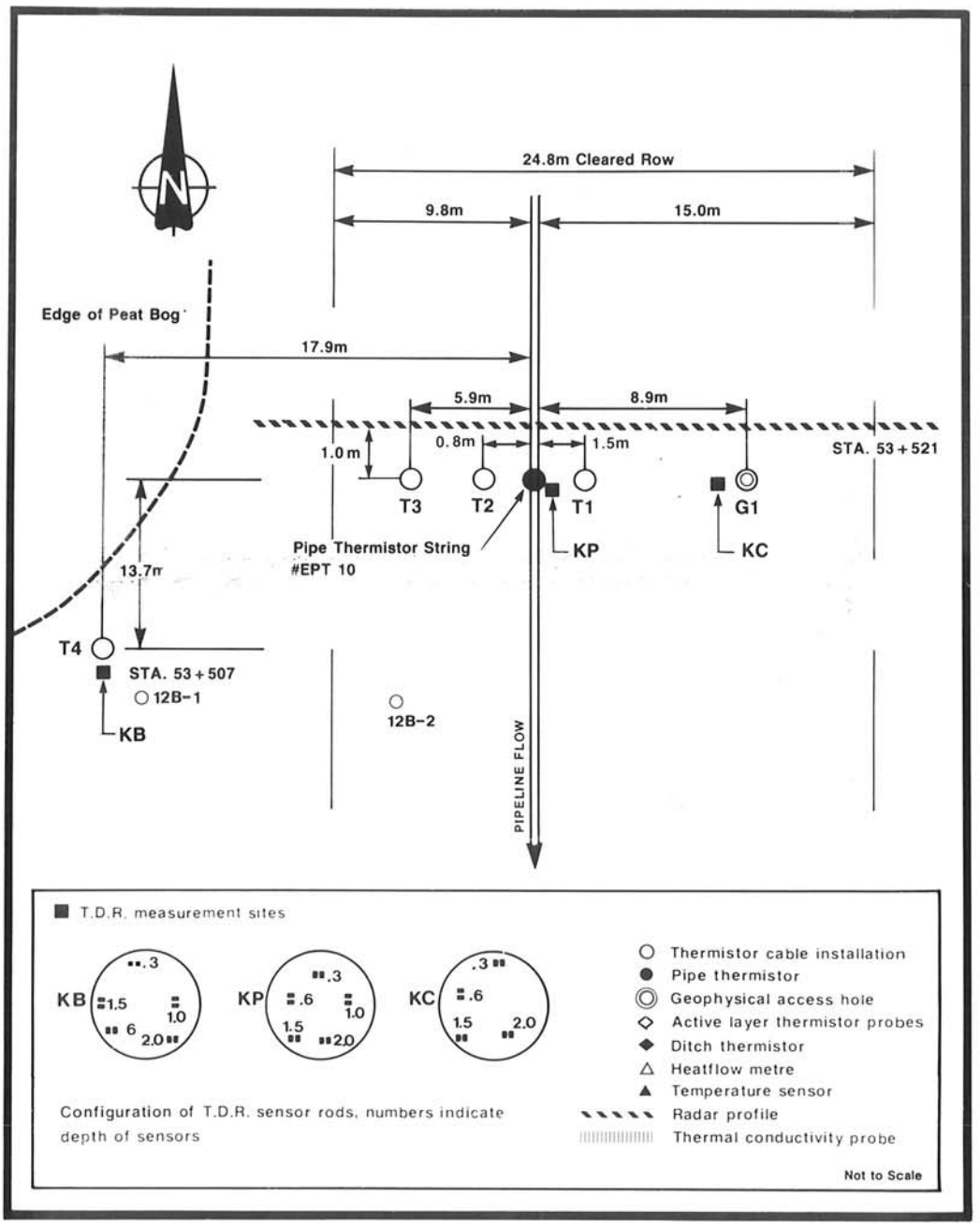
Rationale: This site was established at a level location to study the effects of a pipeline on a sharp interface in a thermokarsted peat plateau. This fence is located in an ice-rich thick peat plateau (3 m).

Vegetation: Open black spruce, ericaceous shrubs, moss-lichen woodland.

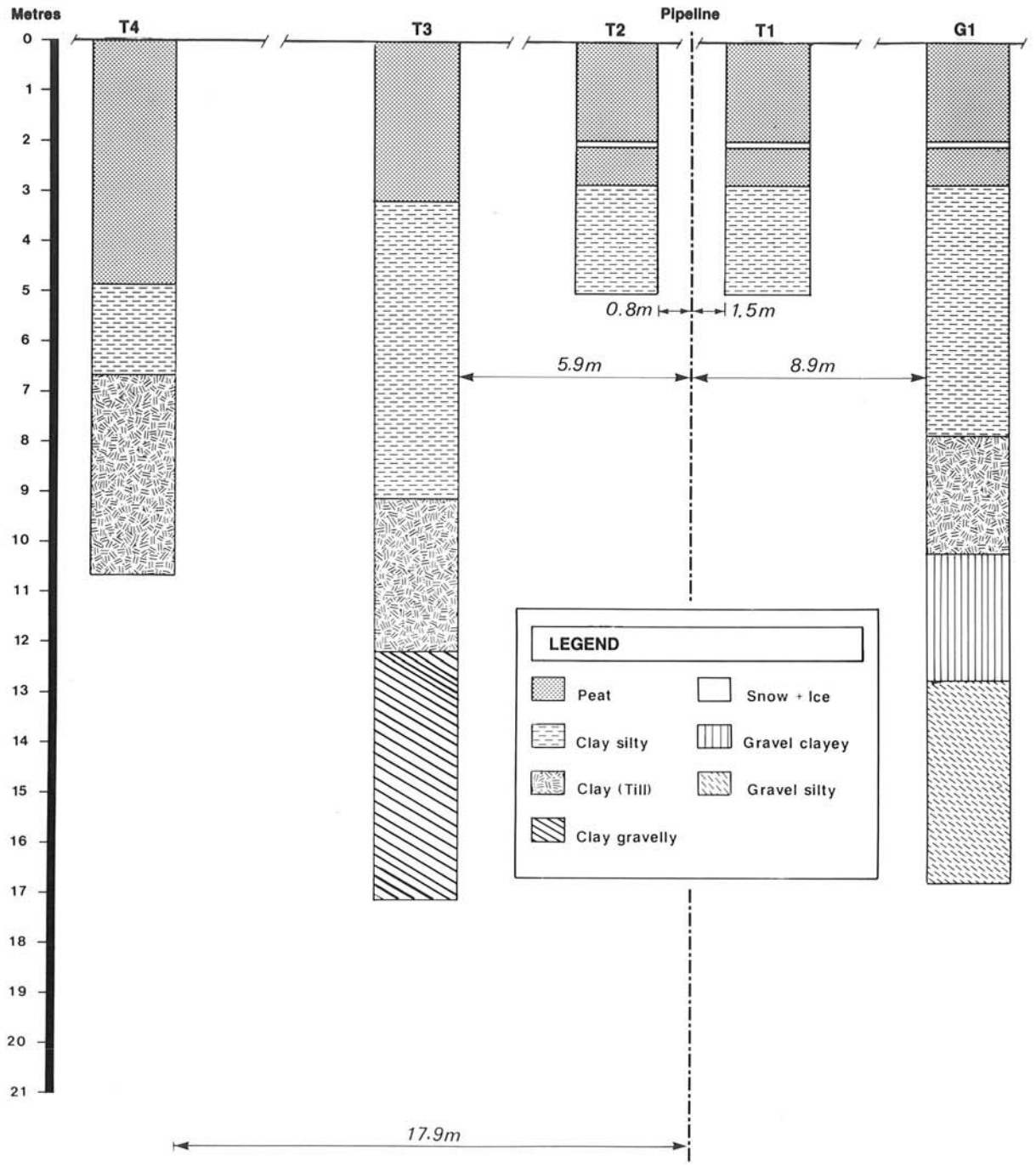
Site history:
- Trees cleared to 24.8 m width in winter 1982-83.
- Trenched in February 1985 with a Barber Green 77 (wheel) Ditcher.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1985.
- Bench Marks installed and first surface survey in May 1985.

Pipe depth: 0.95 meters (excluding Roach) to top of pipe (March 1985).

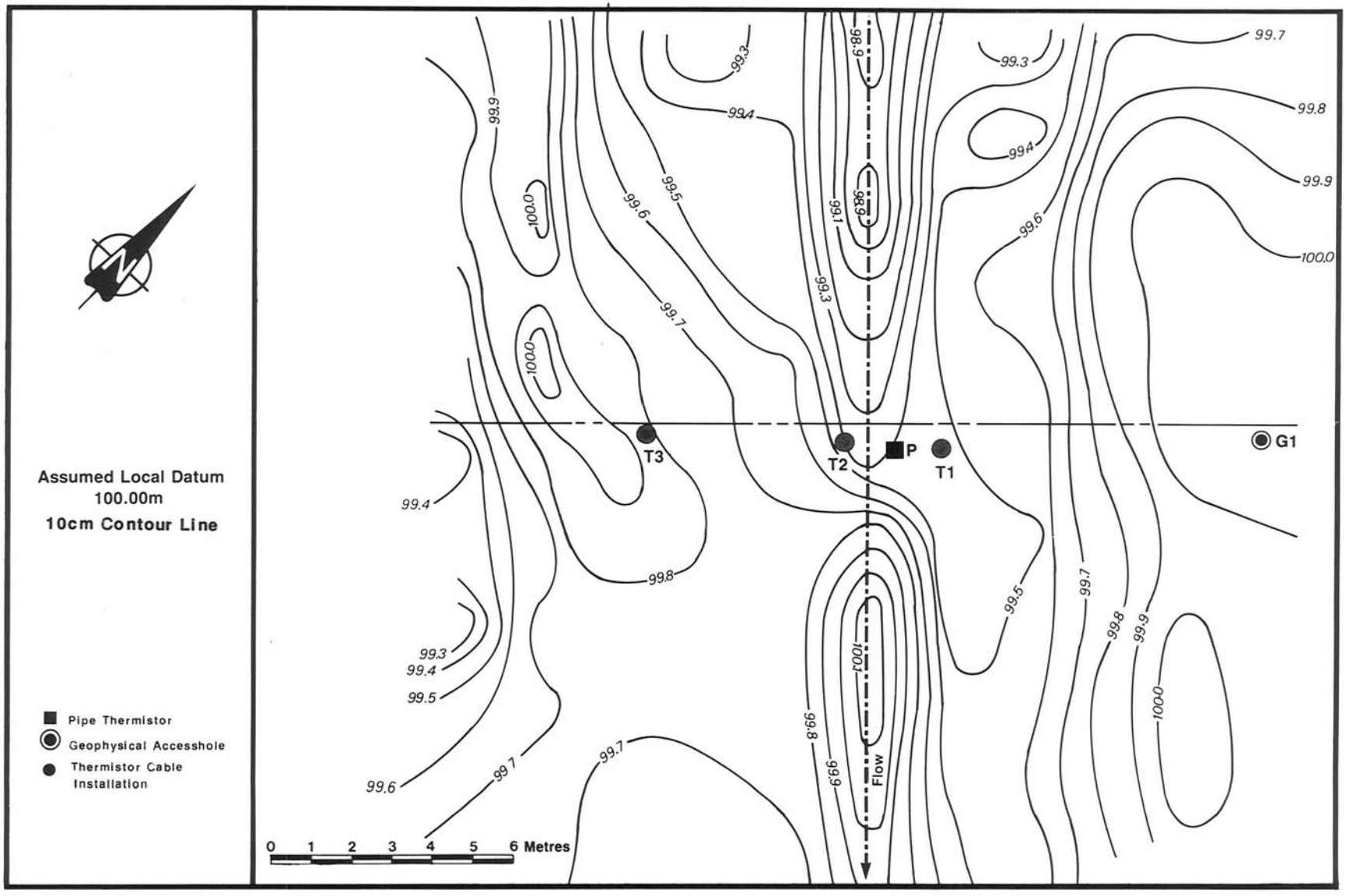
Instrumentation:
4 Multi-thermistor cables
1 Pipe thermistor cable
1 Geophysical access hole
3 Arrays of T.D.R. rods
2 Soil temperature probes



Site plan of EMR/INAC site 85-12B, Jean Marie Creek



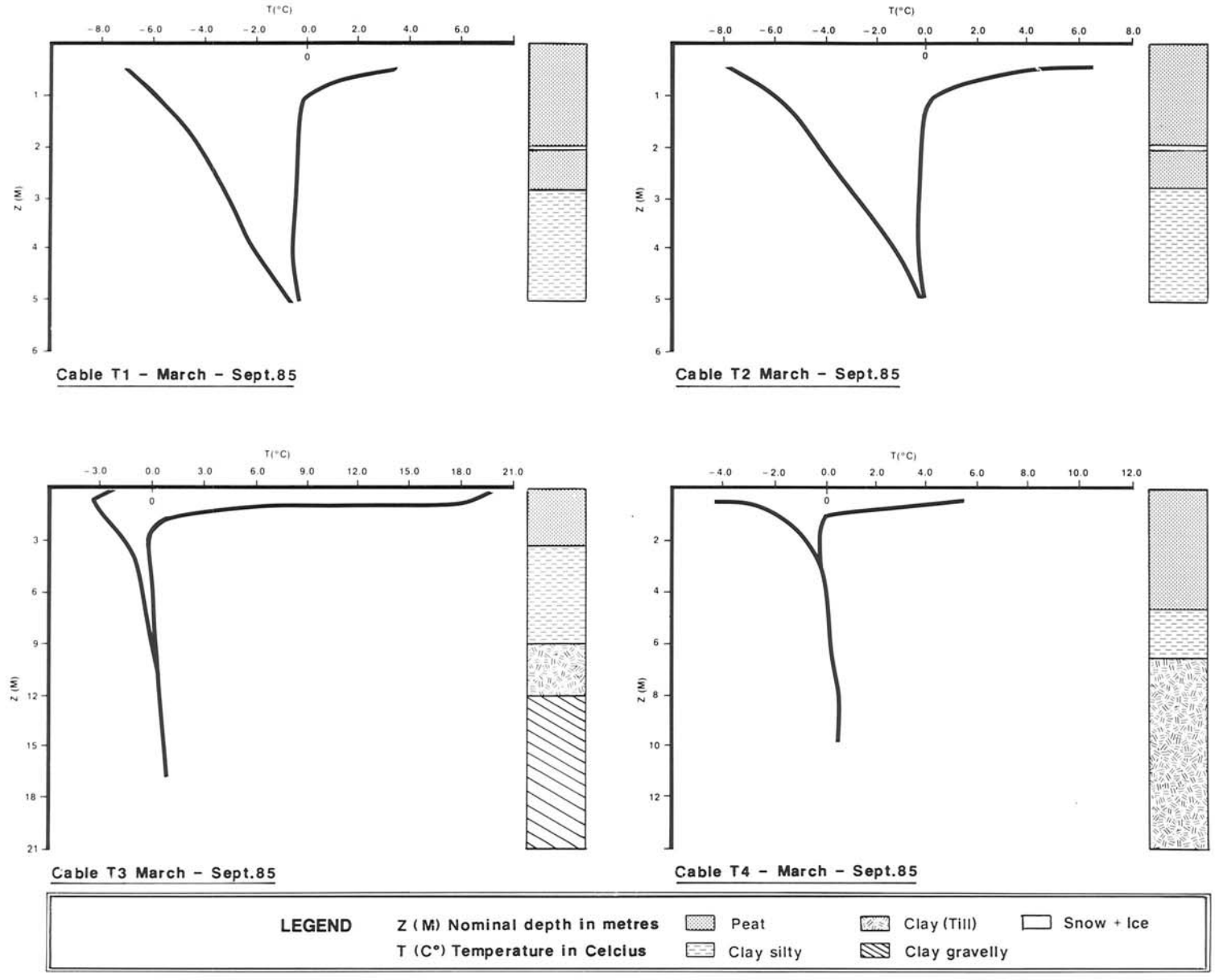
Lithologic cross section of site 85-12B, Jean Marie Creek, based on the drill logs from the thermal instrumentation hole.



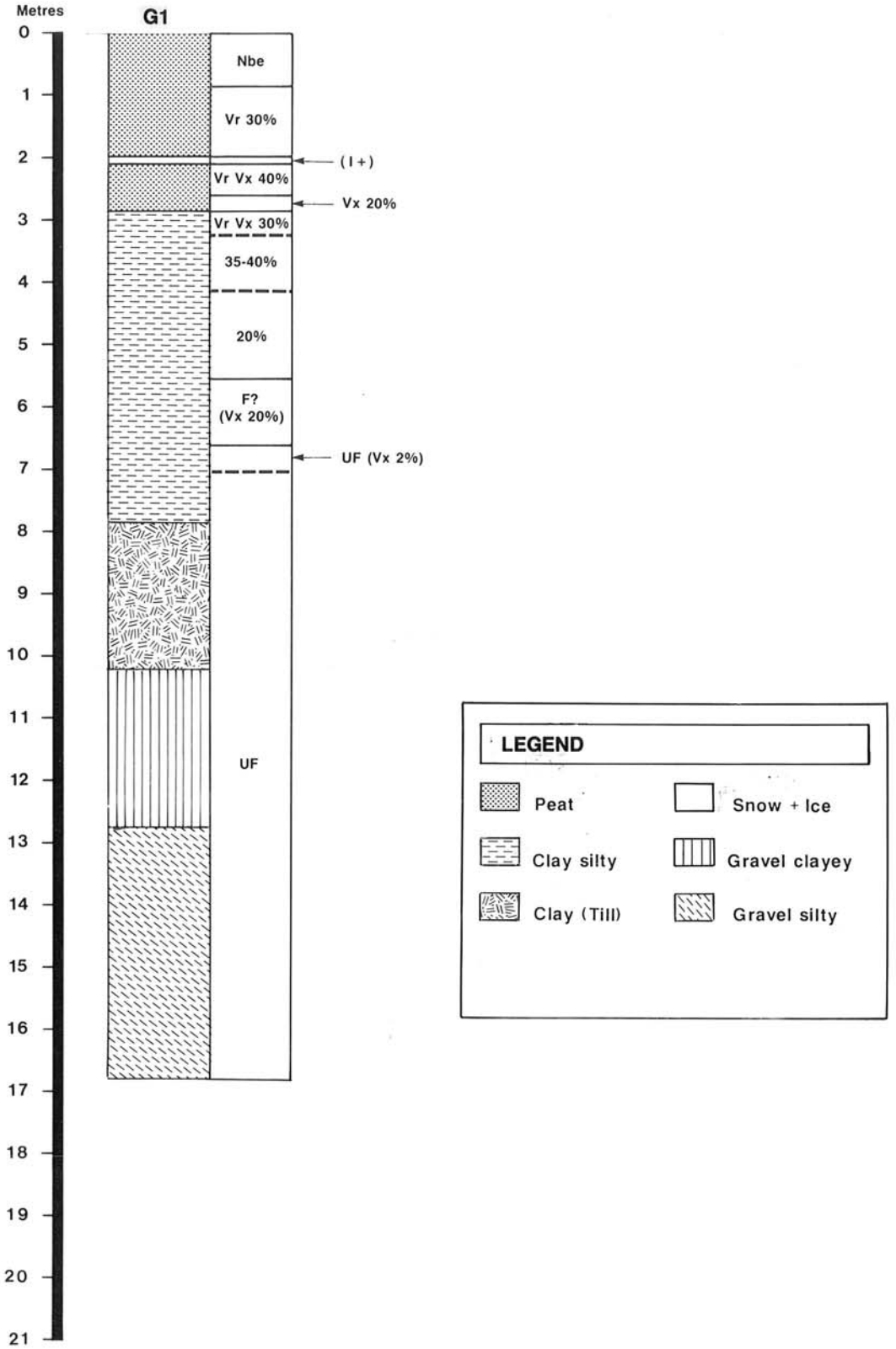
Detailed surface elevation contour map of site 85-12B, Jean Marie Creek, using an assumed local datum of 100 m.

Site 85-12B

Thermal fence 85-12B was installed on the frozen side of a sharp Thermokarst interface in a peat plateau. Measured permafrost thickness during the first year of observations is 4 m off the R.O.W. and 5 m on the R.O.W. at this very ice rich site. Active layer depth reached approximately 0.75 m both on and off the R.O.W. The long term behavior of this site should provide very interesting data of the behavior of ice rich peat interfaces in response to man-induced disturbances.



Thermal envelopes observed at thermistor cables T1 through T4 at EMR/INAC site 85-12B, Jean Marie Creek



Ice content distribution observed in hole G1 at EMR/INAC site 85-12B, Jean Marie Creek.

Thermistor depth at site 85-12B
depth in meters

Position	Cable T-1	Cable T-2	Cable T-3	Cable T-4
1	0.5	0.5	0.0	0.5
2	1.0	1.0	1.0	1.0
3	1.5	1.5	2.0	1.5
4	2.0	2.0	3.0	2.0
5	2.5	2.5	4.0	2.5
6	3.0	3.0	6.0	3.5
7	3.5	3.5	8.0	4.5
8	4.0	4.0	10.0	5.5
9	4.5	4.5	12.5	6.5
10	5.0	5.0	17.2	8.0
11	-	-	-	9.7
Diameter of inner PVC tube	25 mm	25mm	25 mm	25 mm

Site 85-12B in May 1985, with site 12A in background beside helicopter.

Site 85-12B in October 1985, looking south towards fence on top of peat plateau.

SITE
85-13
KP 681

Air photos A26836 Nos. 149-150, 7 August 1985

Site number: 85-13

Site name: Redknife Hills

Location:
Cable A 60° 34.13'N 120° 17.22'W, Kmp 681.2
Cable B 60° 33.99'N 120° 17.12'W, Kmp 681.4
Cable C 60° 33.85'N 120° 17.02'W, Kmp 681.6

Elevation: 634 metres A.S.L.

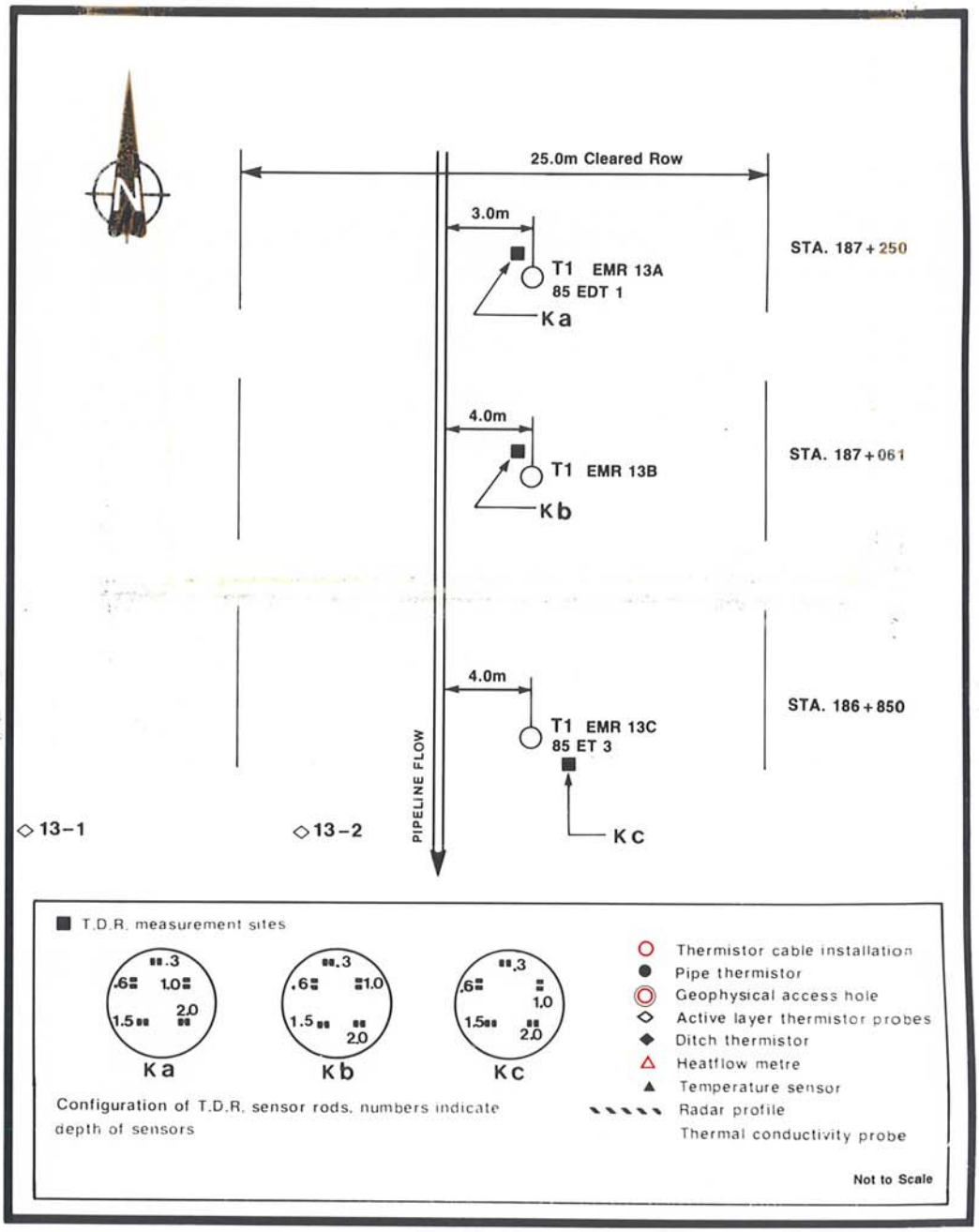
Rationale: This site was established at a level location to study a high-altitude interface from frozen till to a large unfrozen fen bog. This site does not have a complete thermal fence.

Vegetation:
A) Open black spruce, ericaceous shrubs, moss woodland
B) Open black spruce, tamarack woodland
C) Sedge, dwarf birch, moss with stunted black spruce, tamarack, fen

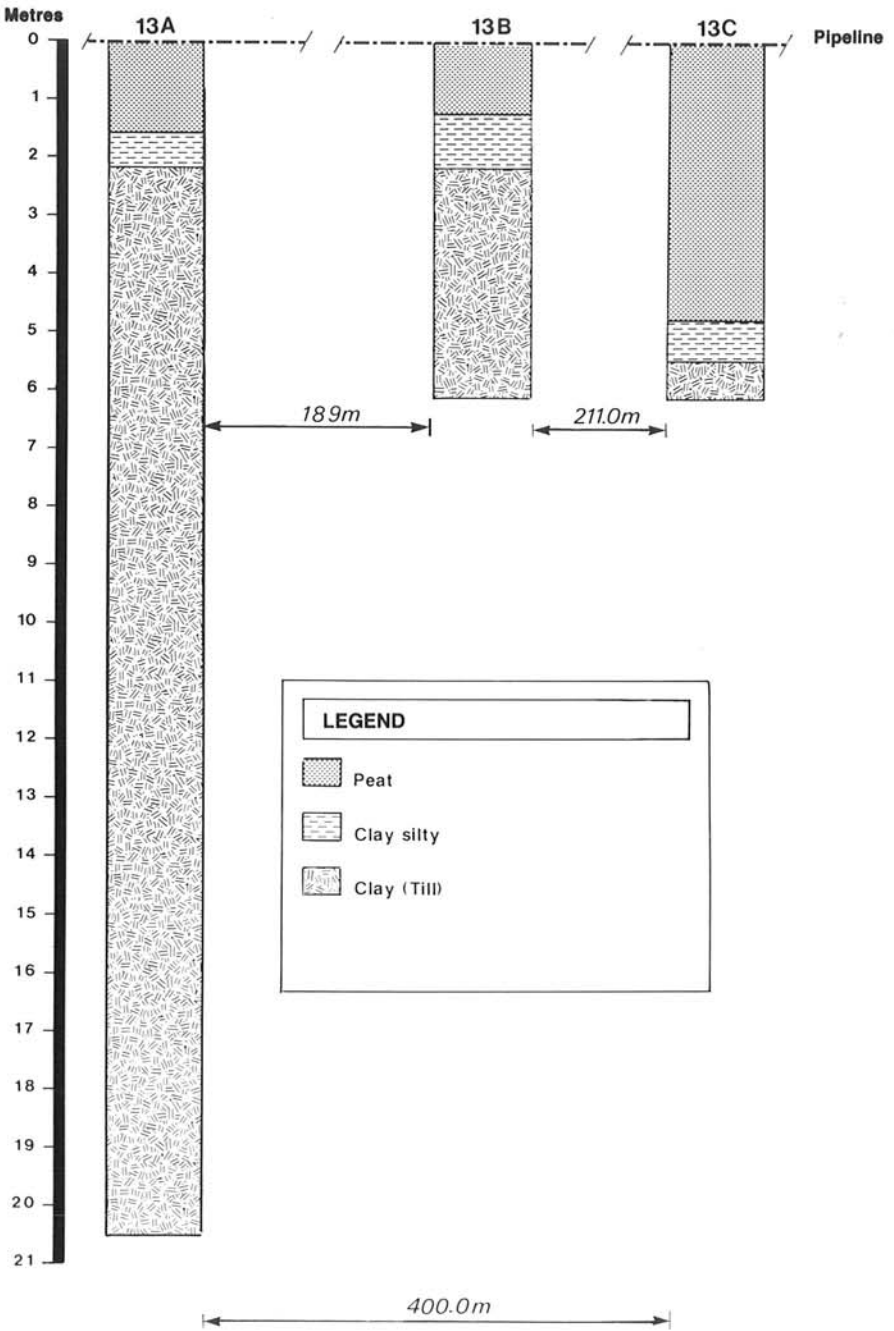
Site history:
- Trees cleared to 25 m width in winter 1982-83.
- Trenched in March 1984 with a Barber Green 77 (wheel) Ditcher.
- Thermal and geophysical instrumentation.
- Holes drilled in March 1985.

Pipe depth: 0.85 m (excluding Roach) to top of pipe.

Instrumentation:
3 Multi-thermistor cables
3 Arrays of T.D.R. rods
2 Soil probes (13C)



Site plan of EMR/INAC site 85-13, Redknife Hills



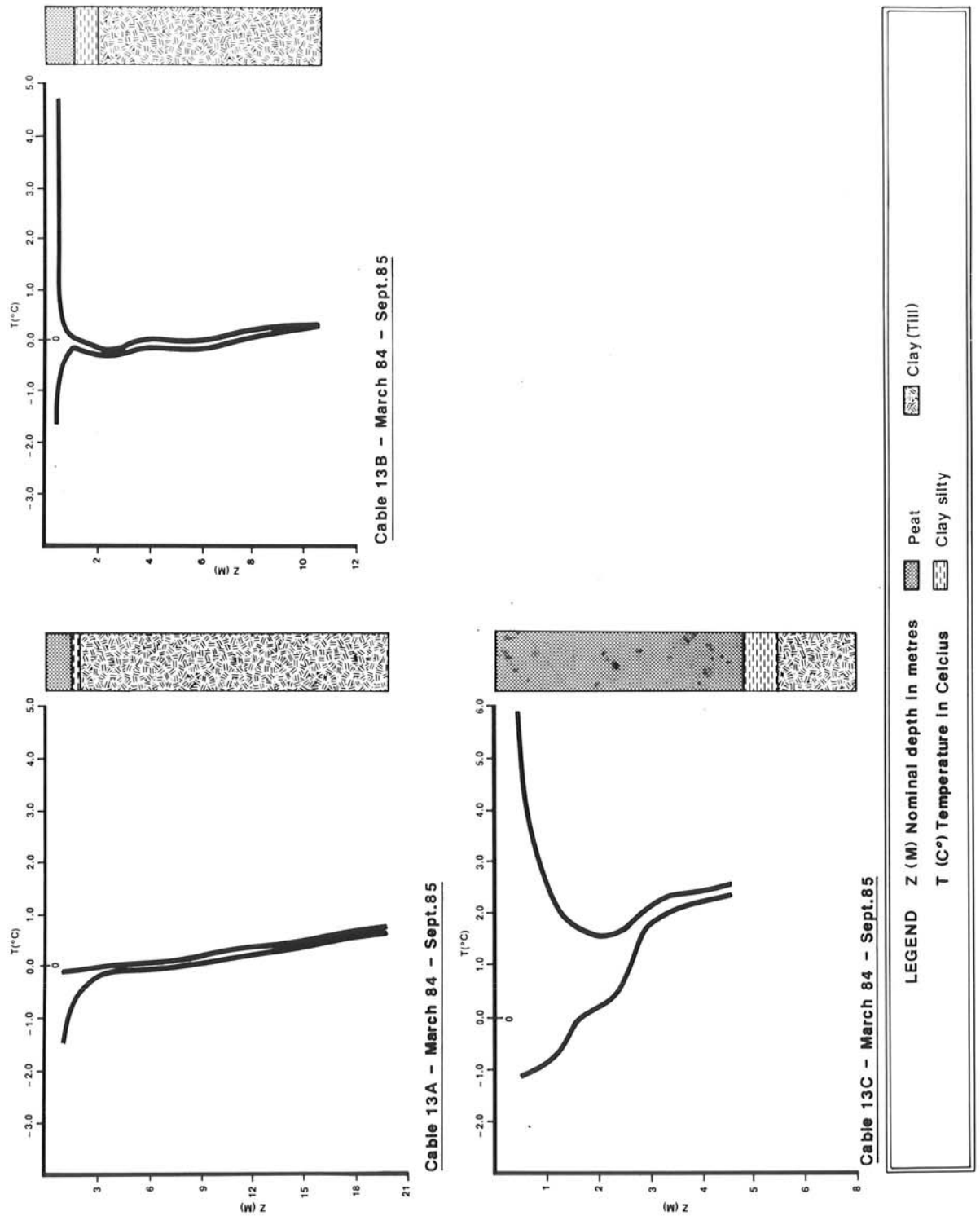
Lithologic cross section of site 85-13, Redknife Hills, based on the drill logs from the thermal instrumentation hole.

Site 85-13A - 13B and 13C

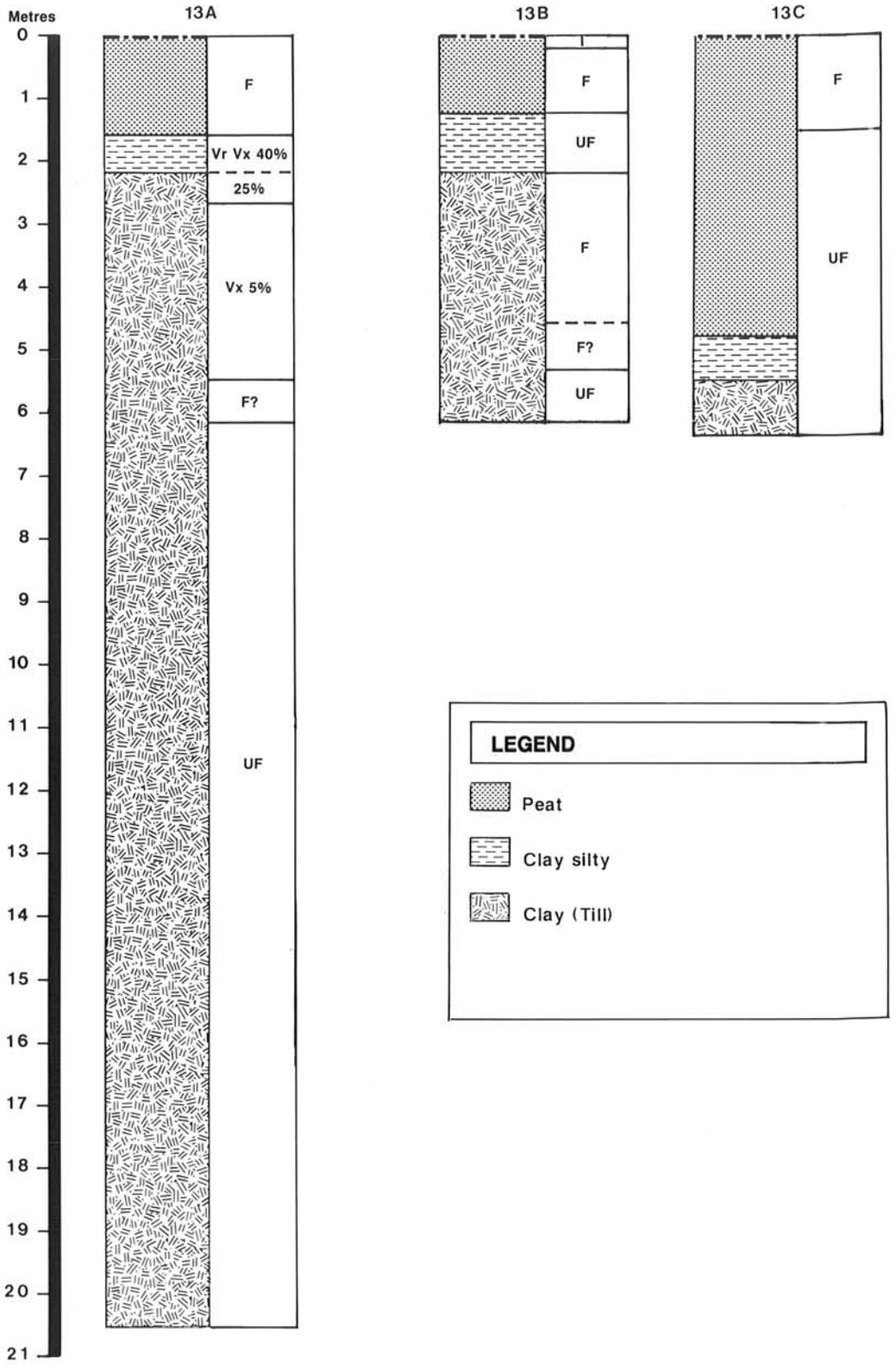
Site 85-13 is particular in that it does not have a complete thermal fence, but consists rather of three cables installed along the R.O.W. to look at the thermal characteristics of a high altitude interface from frozen till to a large unfrozen fen bog. Cable 13-A is installed in thick till and shows that permafrost is approximately 3.5 m thick and the observed active layer is slightly more than 1 m.

Cable 13-B is installed in locustrine clays over till with a 1 m peat cover. Permafrost is measured as 7 m thick with an active layer of less than 1 m.

Cable 13-C is installed in an unfrozen water saturated fen bog. It is free of permafrost and frost table penetration reached 1.5 m during the first year of observation.



Thermal envelopes observed at thermistor cables 13A, 13B, 13C at EMR/INAC site 85-13, Redknife Hills.

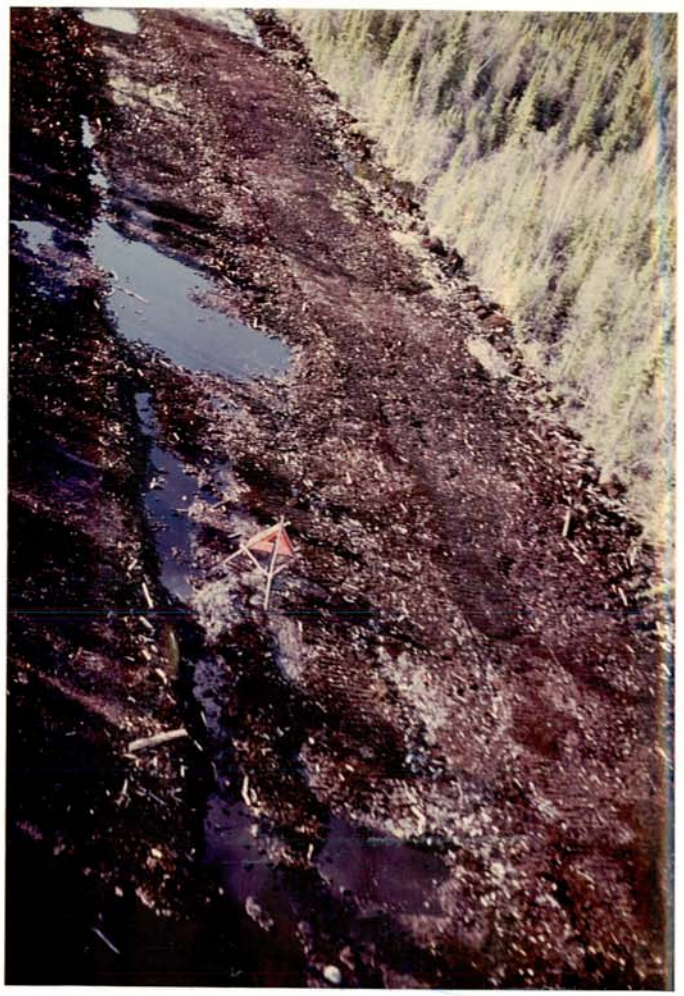


Ice content distribution observed at EMR/INAC site 85-13, Redknife Hills.

Thermistor depth at site 85-13
depth in meters

Position	Cable 13A	Cable 13B	Cable 13C
1	1.0	0.5	0.5
2	2.0	1.0	1.0
3	3.0	1.5	1.5
4	4.0	2.0	2.0
5	6.0	2.5	2.5
6	8.0	3.5	3.0
7	10.0	4.5	3.5
8	12.0	5.5	4.0
9	14.0	6.5	4.5
10	17.0	8.5	-
11	20.0	10.5	-
Diameter of inner PVC tube	25 mm	25mm	38 mm

Site 85-13A in May 1985, in till plateau outside of fence.



Site 85-13B in May 1985, aerial view looking north.

Site 85-13C in October 1985, situated in fen.

Sites 85-13A, B, C, aerial view.