476

LOCAL VARIABILITY OF GROUND ICE OCCURRENCE AT SELECTED SITES IN THE MACKENZIE VALLEY

by

J.A. Heginbottom

and

P.J. Kurfurst

Terrain Sciences Division

Geological Survey of Canada

Department of Energy, Mines and Resources

Final Report - November 1975

CONTENTS

List of illustrations

List of tables

ABSTRACT

Relatively undisturbed soil and ice samples collected from nine sites between Fort Simpson and Inuvik, N.W.T. formed the basis of this report on investigation of the local variability of frozen ground and ground ice at shallow depths along the Mackenzie Valley Transportation Corridor. The sites were chosen to cover a range of environmental conditions such as slope, aspect, surficial geology, drainage and a range of conditions resulting from the activities of man, such as forest fires, bulldozing, land clearing and highway construction.

Frozen ground was found to be essentially continuous in the north becoming discontinuous to the south. The amount of visible ground ice varied similarly, with many large discrete ice lenses in the north and practically none in the south. The greatest changes occur in the area between Inuvik and Fort Good Hope.

Five factors were found to be particularly significant in affecting the distribution and amount of permafrost and ground ice. The factors, and a summary of their effects, are as follows:

- Latitude: frozen ground is more extensive, occurs at shallower depths and includes more visible ice in the north compared to the south.
- soil texture: fine textured soils contain more moisture and ice than coarse textured soils; there is a clear, positive relationship between the silt content and the natural water content;
- slope aspect: south facing slopes are drier with less ground ice and north facing slopes wetter with more ground ice than flat areas;
- surface drainage: significant differences in ice content were seen under poorly and well drained areas, however the cause of the difference was not consistent;

- surface disturbance: removal of surface vegetation leads to thawing of permafrost and a thicker active layer, the degree of change is a function of time and the extent of vegetation removed.

The relative importance of these factors varies from site to site.

1. INTRODUCTION

An understanding of all aspects of permafrost is of vital importance in almost all phases of programs for development in the Canadian Arctic and Subarctic regions. Adequate knowledge concerning the presence or absence and extent of ground ice, and behaviour of frozen ground must exist during the planning stages of all construction activities in the North to provide sufficient and reliable information necessary for their successful completion.

This study is an investigation of the occurrence and spatial variability of ground ice and frozen ground in the near-surface soils and of the behaviour and properties of various representative soil and rock types along the proposed Mackenzie Highway north of Fort Simpson. Representative sites were chosen near Fort Simpson, Norman Wells and Inuvik.

The study was carried out for the Environmental Working Group - Mackenzie Highway program and as part of the Geological Survey's continuing program of acquiring geological and geomorphological information on northern terrain.

The main objectives were to investigate, record and explain: a) local variation in ground ice content, active layer thickness, and the extent of frozen ground at selected sites involving recent disturbance by road construction, clearings and forest fires, and b) the distribution of ground ice and frozen ground in relation to local variation in surficial geology, slope and aspect, surface and ground waters, and vegetation at selected sites, typical of various terrain types.

This information will help relate the performance of terrain to the activities of man, particularly those involved in the highway construction and operation.

2. STUDY AREA

The study area lies along the Mackenzie Valley Transportation corridor, between latitude 62° N (Fort Simpson), and latitude 68° N (Inuvik), and is shown in Figure 1. Details of the location of each site are shown in Figure 2.

The topography within the study area is varied with considerable contrasts in the regional and local relief. Sites in the Fort Simpson area are characterized by undulating terrain with some hilly areas. The predominant surficial deposits are glacio-lacustrine sands, silts and clays in the southern part and till in the northern part. Devonian shales and carbonates and Cretaceous shales constitute the underlying bedrock.

At the Norman Wells site, surficial deposits consist of till, glacio-lacustrine sands, silts and clays, and glaciofluvial sands and gravels with local aeolian deposits. The underlying bedrock consists predominantly of shales and sandstones of Devonian age. The sites near Fort Good Hope are on flat till plains and glacio-lacustrine sediments with large number of small lakes. The rock units are flat-lying to gently dipping Devonian limestones and shales and Cretaceous sandstones and shales.

At Inuvik one site is in an area of thin clay-silt till overlying Palaeozoic dolomites or Cretaceous shales. The other site is located on low angle clay-silt fans overlying Pleistocene kame terrace gravels. The surficial geology of all the study sites is summarized in Table 1.

The sites investigated are representative of the area which is approximately 1100 km long and extends from the discontinuous to the continuous permafrost zone (Permafrost Map of Canada, 1967); the amount, form and distribution of ground ice therefore varied considerably with location, relief, soil type, vegetation and ground temperature.

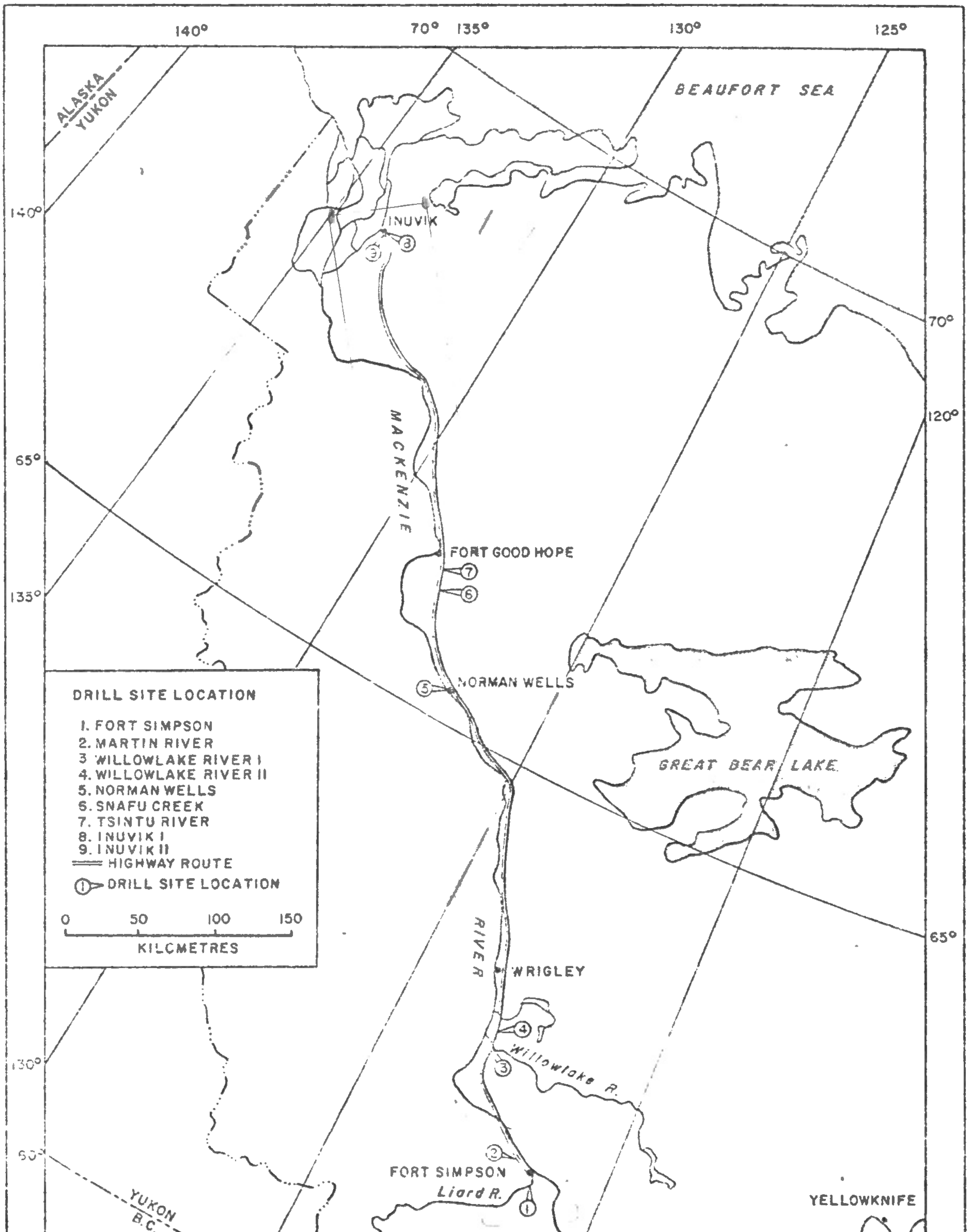


Figure 1. Drill site locations

The climate of the Mackenzie Valley is characterized by long, very cold winters and short, cool summers with some warmer periods (Burns, 1973). Precipitation is generally low, increases southward from 10 inches at Inuvik to nearly 14 inches at Fort Simpson, and is unevenly distributed due to the influence of topography. Temperatures are likewise lowest in the north, with a mean annual temperature of 14.5^{o}F at Inuvik, rising southward until it reaches 25^{o}F at Fort Simpson. Pertinent climatic data are presented in Table II.

TABLE I

Summary of Surficial Geology of Study Sites

Site	Genetic Class	Surficial Geology	Remarks
Fort Simpson	Alluvial	Stratified sands with layers of silt and clay with some surface peat	Some holes drilled through ground along road.
Martin River	Alluvial	Stratified sand, silt and clay with surface peat	Thick organic clays at depth in one hole.
Willowlake River I	Alluvial	Stratified sand, silt and organic clay with some surface peat	Gravel in bottom of hole farthe st from river.
Willowlake River II	Morainal	Plastic, stoney till with surface peat	Some organic material in the till.
Norman Wells A	Morainal	Sandy till with some surface peat	These localities are about 20 m apart.
Norman Wells B	Alluvial	Stratified sand, gravel and silt with some surface peat	
Snafu Creek	Morainal-Alluvial	Silty till with surface layers of alluvial organic silts and clays and some surface peat	
Tsintu River	Morainal-Alluvial	Silty till with surface layers of alluvial sands, gravels and organic silts and some surface peat	
Inuvik I	Morainal	Silty till with a very low stone content, and some surface peat	Layers of peat found at depth also
Inuvik II A	Alluvial	Clayey silts and organic silts over gravel and sand at depth	
Inuvik II B	Alluvial-Morainal	Silty alluvium over silty till	These localities are about 1800 m apart.

TABLE II

Selected Climatic Data

Drill Sites	Ft. Simpson Martin River	Willowlake River	Norman Wells	Snafu Creek Tsintu River	Inuvik
Nearest Station	Ft. Simpson	Wrigley A	Norman Wells A	Ft. Good Hope (1)	Inuvik A
Period of Record	1927+	1943+	1943+	1944+	1955+
Climatic Elements					
Mean annual temp. (degree F)	25.1	22.8	20.6	18.2	14.5
Mean annual max. temp.	34.3	32.1	29.5	27.7	23.8
Mean annual min. temp.	15.9	13.4	11.8	8.8	5.1
Mean annual temp. range	18.4	18.7	17.7	18.9	18.7
No. of days with frost	226	235	239	251	269
Mean rainfall (inches)	8.34	7.66	7.69	6.29	3.99
Mean snowfall	52.6	50.6	56.4	48.8	68.5
Mean total preciptation	13.60	12.73	13.17	11.17	10.25

(Source: Burns, 1973, Appendix A)

3. METHODS AND RESULTS

The study was carried out in three phases. The first comprised site selection and surface investigation, the second shallow drilling, core description and sample collection and the third laboratory testing of samples, data compilation and report writing.

Site selection was by air photo examination and ground reconnaissance. Initially a number of possible sites were chosen on the basis of prior knowledge of the area. These were studied on aerial photographs and a shorter list of potential sites chosen for field examination. The sites finally selected were described in some detail prior to commencement of drilling operations. The actual locations of each site is shown in Figure 2.

During the drilling operations, nearly continuous cores were recovered from the holes. The cores were described immediately so that an accurate description of the soil and ice content could be made. Mineral soil material was described in terms of colour, texture, lithology of pebbles, and was classified according to the Unified Soil Classification System. The condition of the core, whether frozen or unfrozen, was noted and in the case of frozen cores the percentage of ice visible in the core surface was estimated and its distribution described and recorded using the NRC permafrost classification scheme (Pihlainen and Johnston, 1963). Organic constituents of the cores were described in terms of colour, structure (fibrous to amorphous) and origin, if discernable.

In co-operation with Resource Geophysics Division, G.S.C. various geophysical measurements (DC resistivity, seismic refraction and electromagnetic techniques) were carried out at the time of drilling at some sites to determine if these methods could detect permafrost

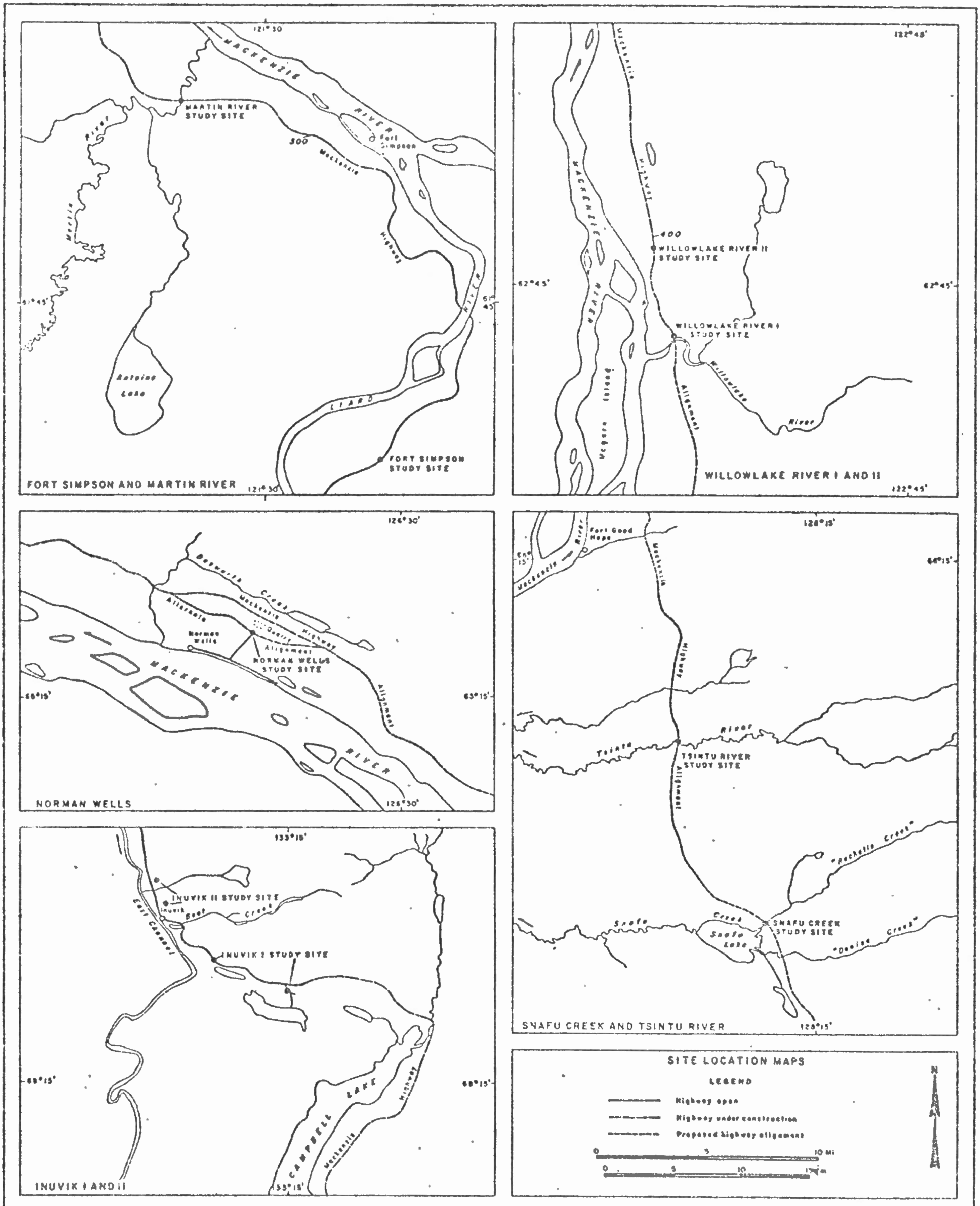


Figure 2: Site location maps

conditions and ground ice content. This work is reported on separately (Scott and Hunter, 1974).

The third stage involved laboratory testing of various soil and rock samples representing different geological and geomorphological units from all sites to determine their physical properties (natural water content, Atterberg limits, grain size). This was followed by compilation and evaluation of results.

3.1 Field site investigation

The main part of the preliminary site investigation included measurements of thaw depth with probe and hand auger, examination of adjacent undisturbed and present conditions of the terrain, detailed study of the local morphology and vegetation cover, types and intensity of any inflicted disturbance, the surficial geological units, and of the local drainage regime.

Following these preliminary observations, the locations of the drill holes at each site were selected.

3.2 Drilling operations

A total of 96 holes, ranging from 1.10 to 5.50 metres in depth, were drilled during the period from May to August 1973 at nine different sites using lightweight split-barrel sampling equipment advanced with a drop hammer. In addition to the drill holes, number of small pits were dug at several sites. 680 soil samples were collected, logged and retained for laboratory testing. Some of the test sites were surveyed to obtain details of microrelief. Most of the drill holes were situated either on and beside the cleared highway right-of-way, or in previously disturbed areas in the vicinity of the highway route.

3.2.1 Fort Simpson site

The Fort Simpson drill site is situated in discontinuous permafrost on the Mackenzie Highway about 20 km south from Fort Simpson. The twenty holes, ranging from 2.40 to 5.30 m in depth, were drilled along two lines at right angles to the highway. These profiles were 150 and 340 m long and had 11 and 9 holes respectively. 150 representative soil samples were collected and logged.

The boreholes were drilled in flat terrain with very little morphological variation and were situated in both undisturbed and previously cleared areas. All clearing was done prior to 1969 when construction of this section of the Mackenzie Highway was completed.

Location and spacing of the drill holes, the depth of thaw and ground ice occurrence are shown in Figure A2. Glacio-lacustrine sands and silts overlain with a thin cover of peat were encountered in every drill hole.

Ground ice, generally in form of ice lenses in peat and the upper parts of sand and silty sand deposits, and in the form of ice coatings on particles in the lower parts of sand and silty sand deposits, was present in all holes drilled in undisturbed areas. The depth of thaw ranged from 10 to 60 cm depending on type and thickness of the vegetation cover. However the thaw depth increased several metres and ground ice was either totally absent or its amount greatly decreased in the holes in the previously cleared areas (see Figure A3).

3.2.2 Martin River site

The drill site at the Martin River crossing, about 15 km north of Fort Simpson, is located along the recently built section of the Mackenzie Highway at mile 306. Of the four holes drilled, two were located on flat ground and the other two on a steep slope. The holes were drilled in pairs with one hole in a disturbed area cleared in 1972 and the other in an adjacent, undisturbed area. The depths ranged from 1.90 to 4.20 m and thirty soil samples were collected. Profiles of the thaw depth and ground ice occurrence are shown in Figure A4. The two drill holes on the slope encountered a thin cover of peat, underlain by 50 cm of silty sand and medium plastic clay with a high ice content. The other two drill holes, situated on flat ground, showed a mixture of sand and sandy silt. The samples from the undisturbed areas contained large amounts of ice while the samples from the hole in the recently cleared area showed, except for the seasonal frost between 1.80 and 3.17 m, total absence of ice.

3.2.3 Willowlake River site I

The Willowlake River site I is situated at about mile 395 of the proposed Mackenzie Highway on the gently rolling terrain on the highway right-of-way. Four holes were drilled along the cleared highway route with drill holes about 30 m apart. Two of the holes were on a gentle slope ($<3^{o}$) with the third and fourth holes on a steeper slope (about 5^{o}) and on a flat surface respectively. The holes, ranging in depth from 2.30 to 3.60 m, encountered sands and silts covered with a thin layer of peat. Ground ice content varied from very low (5%) in the highly disturbed area on the river bank to very high (50-70%) in depressions in the terrain. Thirty-six soil samples were collected and retained for further testing.

The general profile showing thaw depth and ground ice conditions is presented in Figure A6.

3.2.4 Willowlake River site II

The Willowlake River site II is located in a wooded area on gently sloping terrain at mile 399 of the proposed Mackenzie Highway. Three holes, from 2.20 to 3.00 m deep, were drilled along the cleared highway route with two additional drill holes situated on the CNT(Canadian National Telecommunications) line and in an adjacent undisturbed zone. A generalized profile of depth of thaw and ground ice occurrence is shown in figure A8.

A thick cover of peat with a high ice content is generally underlain by till with a moderate ground ice content in the form of thin ice lenses. The shale bedrock was encountered in three drill holes at depths of around 2.50 m. About 40 representative soil samples from all holes were collected and logged.

3.2.5 Norman Wells site

The Norman Wells site is in continuous permafrost at mile 629 of the proposed Mackenzie Highway. Three holes were experimentally drilled with a "SIPRE" drill, which proved to be incapable of drilling through the stony till encountered here. Four additional holes were then drilled with the split-barrel sample to depths ranging from 1.40 to 3.30 m. Three holes were drilled along the cleared highway route with an additional hole situated in the adjacent undisturbed area. The general profile of thaw depth and ground ice occurrence is presented in Figure A10.

Stony till and a mixture of silty sands and sandy silts with a moderate ice content were found, overlain with about 40 cm of peat. A total of 19 soil samples were collected, logged and retained for further testing.

The depth of thaw varied from 28 cm in the undisturbed area to 168 cm in the cleared area on the highway right-of-way in the vicinity of the access road to Kee Scarp.

3.2.6 Snafu Creek site

The Snafu Creek site, about 100 km north of Norman Wells, is in continuous permafrost at mile 702 of the proposed Mackenzie Highway. A total of seven holes from 2.40 to 3.40 m deep were drilled in a gently sloping area. Six holes were drilled along the cleared highway right-of-way and the CNT line with three holes at each location. An additional hole was drilled in an adjacent undisturbed area. The depth of thaw varied significantly from the CNT line, cleared in the early sixties (138-184 cm) to the highway right-of-way cleared in 1972-73 (83-114 cm); the thaw depth in the vegatation-covered undisturbed area was 78 cm. Consideration of thaw depth in relation to the elapsed time suggests that the depth of thaw increases rapidly in the first two years after removal of vegetation, but slows down considerably with additional elapsed time.

Unfrozen peat and organic silt overlie till with moderate to high ice content. There is a noticeably lower ground ice content in the holes located on the CNT line than in those situated on the recently cleared highway route, where there was not enough time for the ground ice to melt.

3.2.7 Tsintu River site

The Tsintu River site is situated in continuous permafrost at mile 711 of the proposed Mackenzie Highway, about 18 km from Fort Good Hope. This site is located on a flat till plain with little or no vegetation cover where various forms of disturbance are evident. These include the CNT and highway clearings done in the early sixties and 1972-73 respectively , an old seismic trail of unknown age and a 1969 forest fire. A total of 13 holes was drilled at this site, but because of difficult drilling in the stony till, several holes had to be abandoned.

Eight holes located on the highway route and CNT line showed an average depth of thaw of 180 cm. Similar thaw depths were observed in the holes situated on the old seismic line. Two holes in the area burnt by the more recent forest fire showed thaw depths of approximately 130 cm, as did the remaining hole in a nearby thinly vegetated undisturbed area. The 34 soil samples collected generally possessed very low ice contents. The generalized profile is shown in Figure A13.

A thin layer of peat (20-30 cm) covers the stony till which has a very low ice content; several holes encountered a mixture of coarse sand and gravel overlain by peat.

3.2.8 Inuvik I

The Inuvik site comprises four subsites, at localities MS-1, MS-2, MS-3 and "B"; all are in the area of lineated terrain between the townsite and the airport. Geology of the sites is similar: clay-silt till over dolomitic and shale bedrock. All four localities are distinguished from the surrounding area by a regular microrelief of mineral soil hummocks separated by shallow, moss filled trenches. The hummocks are composed, near the surface, of a dense, grey-brown clay-silt, showing little or no soil profile development. The mineral soil is generally covered by a thin layer (less than 5 cm) of humus, mosses and lichens. The hummocks are roughly equidimensional on level sites, and generally one to two metres across. On the steeper slopes they are elongated downslope. The trenches between the hummocks are between 30 and 80 cm wide and about 35 cm deep. The trenches are moss-filled, commonly with bog-moss (Sphagnum), and underlain by tapering masses or stringers of peat that extend well below the base of the natural active layer.

Three holes were drilled at each of the localities MS-1, MS-2 and MS-3. Detailed studies of the effects of surface disturbance on the permafrost active layer are being carried out at each of these locations (Heginbottom, 1973a; Lissey, 1975). These three localities are described as follows:

Locality	Slope	Aspect	Vegetation
MS-1	3^o	South	Open spruce, lichen
MS-2	3^o	North	Open spruce, lichen
MS-3	6^o	Northwest	Spruce, willow, lichen

The holes at these localities were drilled in the latter part of May, when the ground was still frozen. The holes were located within the areas under detailed investigation. Ice conditions found in each of these nine holes are presented diagramatically in Figure A15. About 140 samples were retained from these nine holes.

At locality B, a line of seven holes was drilled across a moss-peat trench between two mineral soil hummocks, the total length of this transect being 2.8 m. Ice conditions for each hole are presented in detail inFigure A17. Locality B is a level area of open spruce lichen vegetation. The holes were drilled during the first week in June, when the depth of thaw was between 15 and 45 cm in mineral soil and between 6 and 23 cm in organic soil. On average, ten samples per hole were retained from this locality.

3.2.9 Inuvik site II

Inuvik site II comprises three subsites, at localities "N", "P" and "Q". All are in an area of low angled, clay-silt alluvial fans, overlying kame terrace gravels, north of the Inuvik townsite. At localities N and Q three holes each were drilled along lines crossing the boundary of the forest fire of August 1968, while at locality P, five holes were drilled along a line crossing a back-up fire guard and an old seismic trail. Thus this group of eleven holes were sited so as to examine the effects of surface disturbance on ground ice content and distribution.

Prior to disturbance, this was an area of hummocky microrelief, similar to that at Inuvik site I, but with mineral soil exposed at the ground surface. The vegetation was a spruce - alder - sedge community. Ice conditions found in these holes are presented in Figure A19. Thirty-one samples were retained for further examination.

3.3 Laboratory methods

During the drilling, about 680 representative soil samples of various surficial materials were collected, carefully logged and retained for further engineering classification tests. In the soil testing laboratory, the samples and field logs were examined and the soil type and ice type diagrams were compiled according to Unified Soil Classification System and NRC Permafrost Classification (Pihlainen and Johnston, 1963) respectively. The Atterberg limits, natural moisture content, and grain size distribution were determined. The testing was done in part by the GSC soil testing laboratory and in part at outside engineering laboratory. All laboratory results are summarized in Appendix B.

4. DETAILED DISCUSSION OF RESULTS

As a result of the work described above, some information is available on the occurrence of frozen ground and on the occurrence of excess or visible ice in that frozen ground, in relation to soil properties, site conditions and terrain disturbance from nine discrete locations along or adjacent to the Mackenzie Highway route.

This discussion will consider the effects of the following variables on the distribution of frozen ground and excess ice:

- soil properties: lithology, texture, Atterberg limits, water content
- site conditions: geologic unit, slope angle and aspect, vegetation, surface drainage
- terrain disturbance: burning, clearing, no disturbance

The number of holes drilled and their distribution are such that valid conclusions about variations in frozen ground and excess ice are difficult to substantiate. There is a general impression of frozen ground being more extensive, occurring at shallower depths and with many more large (greater than 1 cm) ice lenses as one goes from south to north; a plot of ice lense percentage in core versus latitude is shown in Figure 3.

As stated earlier, the details of this variation with latitude or location are affected by the much greater variation within sites and within individual drill holes, and by the time of the season at which the various sites were visited. Investigations at Inuvik began at the end of May, when there was still about 50 cm of snow-pack and

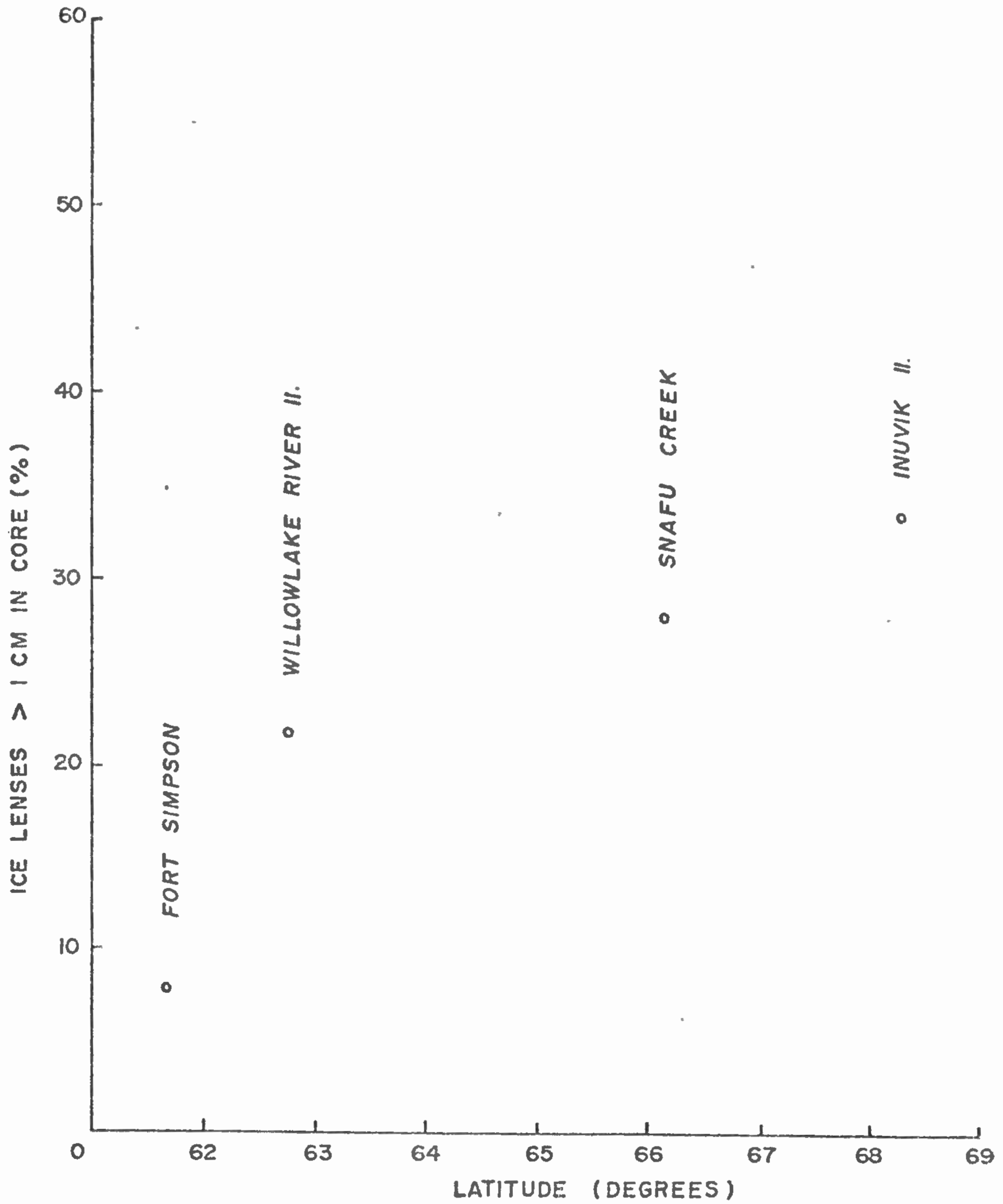


FIGURE 3
ICE LENSE OCCURRENCE (> I CM) vs. LATITUDE IN UNDISTURBED AREAS

the active layer was frozen. The other sites were then visited, from south to north during July and early August. Thus there was no surface snow and a considerable depth of thawed ground at many localities.

A better practice undoubtedly would have been to start at the southern sites in May and move northwards with the onset of warm weather at each site, so that all the sites were visited when they were at approximately similar stages of snow melt or ground thaw.

4.1 Distribution of Frozen Ground

The Inuvik study sites are within the zone of continuous permafrost (Brown 1967), while the sites near Norman Wells and at Willowlake River are in the zone of widespread but discontinuous permafrost. The two sites nearest Fort Simpson, however, lie either side of the Brown's boundary between widespread and sporadic discontinuous permafrost. As this boundary is, in reality, a broad zone of gradual change, no significant difference in permafrost conditions should be expected.

All this is borne out by the drilling done during this study. At the Fort Simpson site, holes in undisturbed areas encountered frozen ground at depths between 10 and 55 cm below the surface, whereas holes in heavily disturbed areas (eg. the highway shoulder or ditch) generally did not encounter frozen ground at depths of less than 300 cm and in two cases no frozen ground was found in holes over 500 cm deep. The four holes at Martin River all encountered permafrost, even though two of them were drilled in a disturbed area. In this case the disturbance took the form of clearing of the trees, but the ground vegetation mat was not damaged.

The only other holes which failed to encounter frozen ground were a number of shallow holes in disturbed ground at the Tsintu River and Norman Wells sites. These were drilled to depths of less than 225 cm in the clearing for the C.N. Telecommunications line. Deeper holes immediately adjacent to these holes encountered frozen ground at depths between about 150 and 300 cm.

4.2 Distribution of Visible Ice

Variations in the distribution of visible ice occur between sites, between drill holes within each site and within each drill hole.

The distribution between sites is the most difficult to describe succinctly. There is a gross increase in the amount of visible ice from south to north. For much of the core from the Fort Simpson site, the ice condition is described as Nbn (no visible ice, soil well bonded, no excess ice), whereas such a designation is very rare for core from the Inuvik sites. Finer detail in the between-site variability is quite masked by the within-site and within-hole variability.

There is, however, one aspect of the distribution of visible ice which can be described in semi-quantitative terms. This is the occurrence of discrete lenses of ice, greater than one centimeter in thickness and containing less than 50% inclusions of soil particles (volume estimate). The data are summarized in Table III. Columns 6 and 7 of this table are a measure of the ice lens frequency of the sites. The northernmost locations (Inuvik I and II) contain by far the most ice lenses, with an average of one ice lens per 1.4 m of hole drilled, or of 1 m of lens-ice per 5.1 m of hole.

At the Inuvik sites, numerous large ice lenses were encountered, often two or three per drill hole. Only two holes did not encounter distinct ice lenses. The actual thickness of the lenses varied from less than 1 mm to nearly 1 m. Those between 1 mm and 1 cm in thickness were so numerous that individual treatment is impractical. Of the 58 discrete lenses thicker

TABLE III

Occurrence of Discrete Ice Lenses

Site (1	No. of holes drilled (2	No. of ice lenses encountered (3	Cumulative depth of hole (m) (4	Cumulative thickness of ice lenses (m) (5	m. of hole per ice lens (6	m. of hole per m. of ice (7
Fort Simpson	20	5	67.3	0.97	13.5	69.4
Martin River	4	5	14.8	1.32	3.0	11.2
Willowlake River I	4	2	13.3	1.12	6.6	11.9
Willowlake River II	5	4	11.6	1.17	2.9	9.9
Norman Wells	7	3	13.7	1.64	4.6	15.3
Snafu Creek	7	1	20.5	0.58	20.5	35.3
Tsintu River	13	0	32.4	0	---	---
Inuvik I and II	29	58	80.4	15.75	1.4	5.1

Note: For this analysis a discrete lense of ice is one that is greater than one centimeter in thickness and contains less than 50% inclusions of soil particles (volume estimate). It should be noted that about 14 of the 78 lenses included in the analysis are actually 'compound', that is they are formed of three or more distinct layers, distinguished by the content of soil inclusions, or the colour or hardness of the ice for the purpose of this analysis.

than 1 cm, the average thickness was 27 cm. Ten of the 58 lenses were "compound", that is they were composed of three or more distinct layers, distinguished on the basis of the amount and type of soil inclusions, or the colour and hardness of the ice. Lenses containing two layers have been regarded as phases of the "simple" (ie. non-compound) lenses, as in many cases the boundary between the layers was broad and merging. In general, the compound lenses tend to be thicker than the simple lenses. However there is considerable overlap between the two.

There was considerable variation in the amount of material included in the ice lenses. The estimates made in the field range from 0 to 50%. (if the visible inclusion exceeds 50% it is classed as a mineral soil with such and so a content of ice, rather than as an ice lens). The average value for inclusions is about 20%. The most common material included in the ice lenses is "fines"; either clay-silt or silt-clay. About seven lenses contained organic inclusions, both alone and with fine soil. Two lenses contained some rock fragments (broken shale) and one some erratic pebbles, all about pea size.

The three sites investigated in the central part of the Mackenzie Valley (Tsintu River, Snafu Creek and Norman Wells) did not contain many discrete ice lenses. Of the 27 holes drilled, only four encountered ice lenses, and only one lens in each of these holes. One of the four was compound, and they all contained a large proportion of fine soil as inclusions (30 to 50%).

The holes drilled at the four sites in the southern part of the region showed somewhat more in the way of ice lenses, including four holes which penetrated two lenses each. The lenses found ranged in thickness from 5 to 94 cm with an average of 29 cm. Three of the lenses were compound.

Again most of these ice lenses have a fairly high content of soil material (20-50%). The inclusions appear to contain slightly coarser material than was found in ice lenses at the Inuvik sites. A number of lenses have inclusions of fine sand or sandy silt, rather than the clayey silt typical of the Inuvik area. Several lenses contained peat inclusions, both with and without soil inclusions.

4.3 Variations in Site Conditions

The site conditions to be considered in the following discussion comprise:

- surficial geology,
- slope angle and aspect,
- drainage, and
- vegetation.

The surficial geology of each site is summarized in Table I. Throughout the Mackenzie Valley the tills are generally similar, being derived largely from the Mesozoic shales and limestones of the Interior Plains. Difference in frozen ground and excess ice in morainal soils can thus be examined between Willowlake River, Snafu Creek, Tsintu River and Inuvik. Alluvial sites can be compared from Fort Simpson to Inuvik. The alluvial sites are fairly similar in that they are generally fine grained as they are derived largely from the silty tills. Mixed morainal-alluvial sites were examined near Fort Good Hope and at Inuvik only. Finally at Willowlake River, Norman Wells and Inuvik the differences between alluvial and morainal sites can be examined. The distribution of drill holes and samples analyzed in terms of surficial geologic units are summarized in Table IV.

4.3.1 Surficial Geology

The representation of the geologic units in terms of numbers of drill holes and numbers of samples analyzed is rather uneven.

TABLE IV

Site	No. of holes in till areas	No. of samples analyzed	No. of holes in alluvial (b areas	No. of samples analyzed	No. of holes in mixed (a areas	No. of till samples analyzed	No. of alluvial samples analyzed
Inuvik I	16	310	-	-	-	-	-
Inuvik II	1	4	4	14	6	19	19
Tsintu Creek	5	26	2	3	2	6	2
Snafu Creek	6	26	-	-	1	3	1
Norman Wells	4	0	2	0	1	0	0
Willowlake River I	-	-	4	36	-	-	-
Willowlake River II	1	5	-	-	4	19	10
Martin River	-	-	4	27	-	-	-
Fort Simpson	-	-	20	0	-	-	-

Distribution of drill holes and samples analyzed to date in terms of surficial geology.

Notes: a) "mixed areas" refers to areas of alluvial deposits overlying tills

b) "alluvial areas" : the materials encountered included gravel, sand, silt, clay and mixtures thereof, plus occaisional surface organic material.

The till of the Inuvik area is frozen, and contains significant quantities of visible, excess ice, including numerous large ice lenses. Considering only the frozen soil, and not the ice lenses, the natural moisture content ranged from 13% to about 200%, with an average estimated at about 60%. The till samples from the Inuvik II site were generally drier than those from the Inuvik I site.

The tills investigated at Tsintu River, Snafu Creek and Willowlake River II were all much drier and contained much less excess ice. In many holes no excess ice was found. The natural water content for the samples were as follows:

- Tsintu River and Snafu Creek

  Range: 10 - 26%, Mean: 14.4.%

- Willowlake River II

  Range: 8 - 36%, Mean: 14.6%

The tills at these sites apparently were all frozen as were those from Norman Wells. Some of the drill holes at Tsintu River penetrated material that was so dry that it was quite difficult to determine if it was frozen.

The alluvial deposits fall into two main groups: glaciofluvial deposits at Inuvik II and Willowlake River I and glaciolacustrine deposits at Martin River and Fort Simpson. The glaciofluvial deposits from the Willowlake River valley may well have been modified by subsequent fluvial action. The alluvial soils from Inuvik II were found to be frozen, and to contain a considerable amount of visible excess ice in the form of lenses and veins. The natural moisture content ranged from 4% to 154% with a mean of 53%. The alluvial soils from the other sites were generally drier and contained much less, and frequently no visible or excess ice. Some drill holes encountered only unfrozen material, but this appears to be generally related to factors such as surface disturbance. The natural moisture content for all the sites (other than Inuvik II) ranged from 4% to 50% with a mean of 27%.

A comparison of till and alluvium at each site again emphasizes the difference between Inuvik and all the areas investigated. At Inuvik the till, as a general rule, contains much more moisture, in the form of excess ice, than does the alluvium. However, at all the other sites for which both till and alluvial deposits were studied, the moisture contents of tills, and alluvia were quite similar.

4.3.2 Slope and Drainage

The locations of the drill holes do not provide much information on the effects of surface slope or drainage on permafrost conditions. The only site for which a range of slope angles with differences in aspect is available is Inuvik I (see page 15). Most other sites have surface slopes less than two or three degrees with similar aspect for all the holes at any site. At such low slope angles, the effects of different aspects are minimal.

At the Inuvik I site the differences in slope aspect appear to have some effect on permafrost conditions. This is noticeable in generally higher natural moisture contents for samples from north facing sites and generally lower natural moisture contents for samples from south facing sites compared to samples from level sites. Average values for samples (excluding peat samples) suggest moisture contents on level sites of about 100%, rising to perhaps 150% on north facing slopes and falling to around 50% on south facing slopes. These values were estimated from the data in Appendix B, no allowance had been made for differences in sample sizes. It should be noted that the level site used in this comparison was on a broad area with both higher and lower ground in the vicinity.

Slope appears to have little effect on permafrost conditions. All the holes drilled at the Inuvik I site encountered permafrost. Ice was visible in all the cores in a variety of forms: random veins, lenses, crystals and coatings on particles. Often more than one form was visible in the same piece of core.

The majority of the study locations were on well drained to fairly well drained sites. Only the Fort Simpson site exhibited a range of drainage conditions, from poor to good. Conditions at this site are complicated by the disturbance due to Mackenzie Highway Construction. Nonetheless, of 20 holes drilled, only four did not encounter permafrost. All four were in sites described as poorly drained. Two (#37 and 38) of the four were in disturbed sites adjacent to the highway. Here no permafrost was found in holes more than 500 cm deep. The other two (#41 and 47) were in relatively undisturbed conditions well away from the road. Permafrost was not found in holes 400 and 300 cm deep respectively. Hole #40, near hole #41 is also in a poorly drained site and encountered frozen ground only between 54 and 100 cm. Below this depth the ground was unfrozen to at least 350 cm. Two other, nearby holes, #42 and 48, both penetrated permafrost with a considerable visible ice content. These holes are in an area classed as fairly well drained.

There is therefore an indication that for undisturbed areas, poorly drained sites are less likely to be frozen than better drained sites in the Fort Simpson area. A different relationship was observed at Willowlake River I, where materials in an undrained depression beneath a thick organic mat had a higher ground ice content than materials on adjacent, better drained areas.

The effect of the position of the site or drill hole on the slope is not well understood. At Martin River there is a significant increase in the ground ice content in the lower slopes of the river valley. This increase is apparently due to draining of the sands and silts in the upper parts of the slopes and accumulation of the excess water in the form of ground ice in the clay deposits of the lower parts of the slopes. However, at Snafu Creek the opposite is observed, with much more ground ice in the upper part of the slope than near the base. At the Inuvik I site, slope does not appear to have any effect on ground ice content. The aspect, slope angle and lithology of the three sites is as follows:

Site	Lithology	Aspect	Angle
Martin River	sand & silt over clay	west	5-10°
Snafu Creek	till	southeast	1-12°
Inuvik I	till	north & south	3° and 6°

The differences between these sites can perhaps be attributed to lithology for Martin River, and slope angle and aspect for Snafu Creek and Inuvik I.

4.3.3 Vegetation

Differences in permafrost due to differences in natural vegetation cannot be easily established from the data available from this study. Half the holes drilled are in areas of recent disturbance, and such disturbance generally overwhelms all differences due to vegetation. The vegetated sites themselves are all dominated by spruce, with minor amounts of alder and a ground flora of mosses, lichens, forbs and grasses.

4.4 Variations in Soil Properties

The soil properties investigated during this study were grain size distribution and texture, plastic and liquid limits, index of

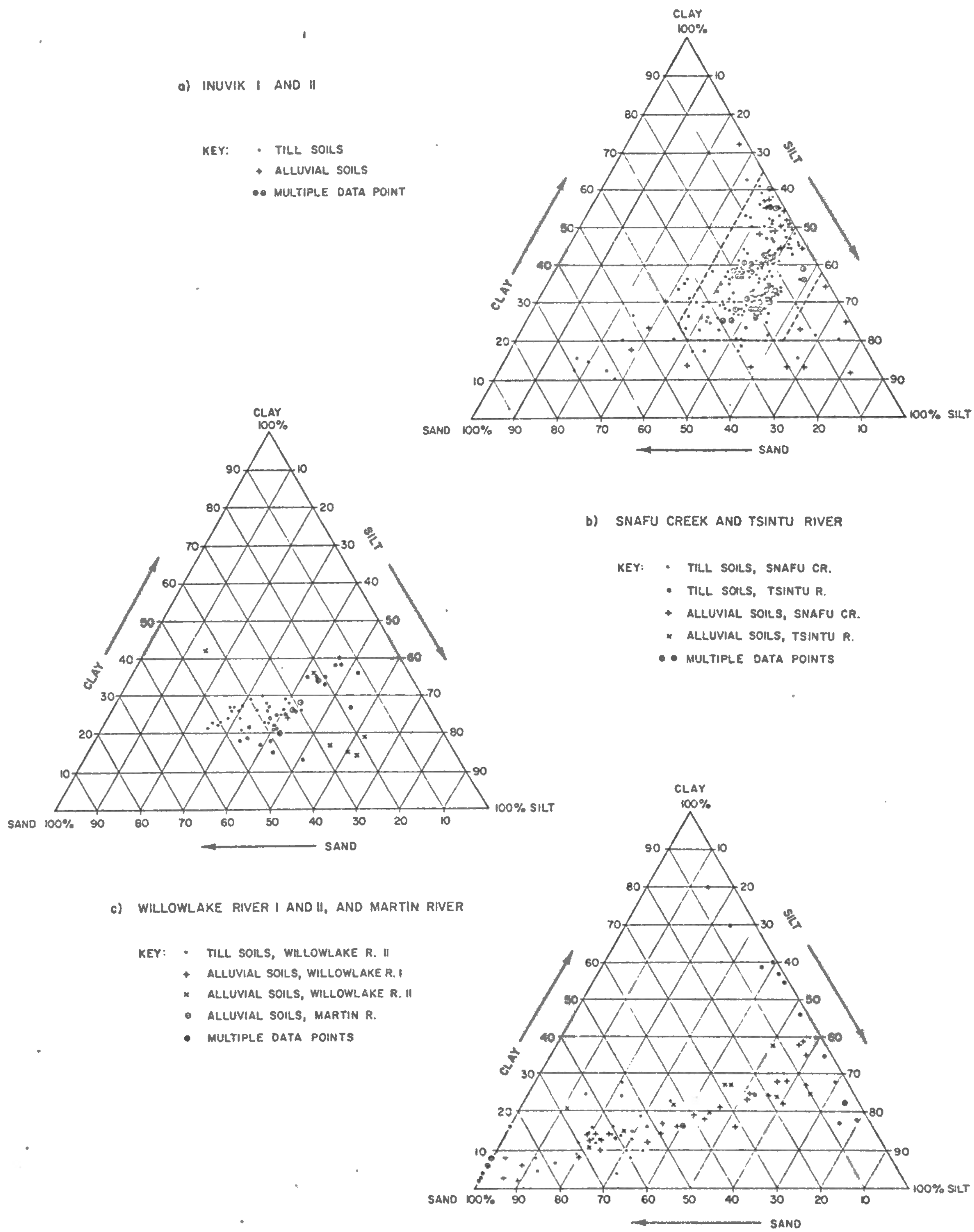


FIGURE 4: SOIL TEXTURE DISTRIBUTION

plasticity and natural moisture content. The results of the laboratory analysis available are presented in Appendix B. Comparisons were made between various pairs or groups of these properties, as well as examination of the individual data sets. Some comparisons produced useful or interesting results, while for others there was no indication of any meaningful relationships.

4.4.1. Grain size distribution and texture

The sand-silt-clay values were plotted on ternary diagrams for each site (see Table IV). The results were quite different for each site (Figure 4).

For the two Inuvik sites, the data pointswere strongly clustered, such that over 85% of the samples were within the textural grouping bounded by 0-40% sand, 36-62% silt (Figure 4a). Soils in such a group may be defined as silty-clays to clayey silts. The alluvial soils were less clustered than the till soils; about half plotted as clay-silts with less than 10% sand while the remainder plotted as silt to sand, with a low clay content.

Tsintu River and Snafu Creek may be considered together, as the data pointsfor both sites were clustered in the clay loam area, with 30-50% sand, 30-50% silt and around 20% clay (Figure 4b). The clustering was less marked than that of the Inuvik data. At Willowlake River the soils varied from a fairly pure silty clay, through well graded loam to almost pure sand. The tills were generally quite sandy (Figure 4c). The data from Martin River showed two points of clustering with most of the samples composed of a silt to clay mixture with less than 8% sand and the remainder composed of over 80% sand with no silt and a little clay (Figure 4c).

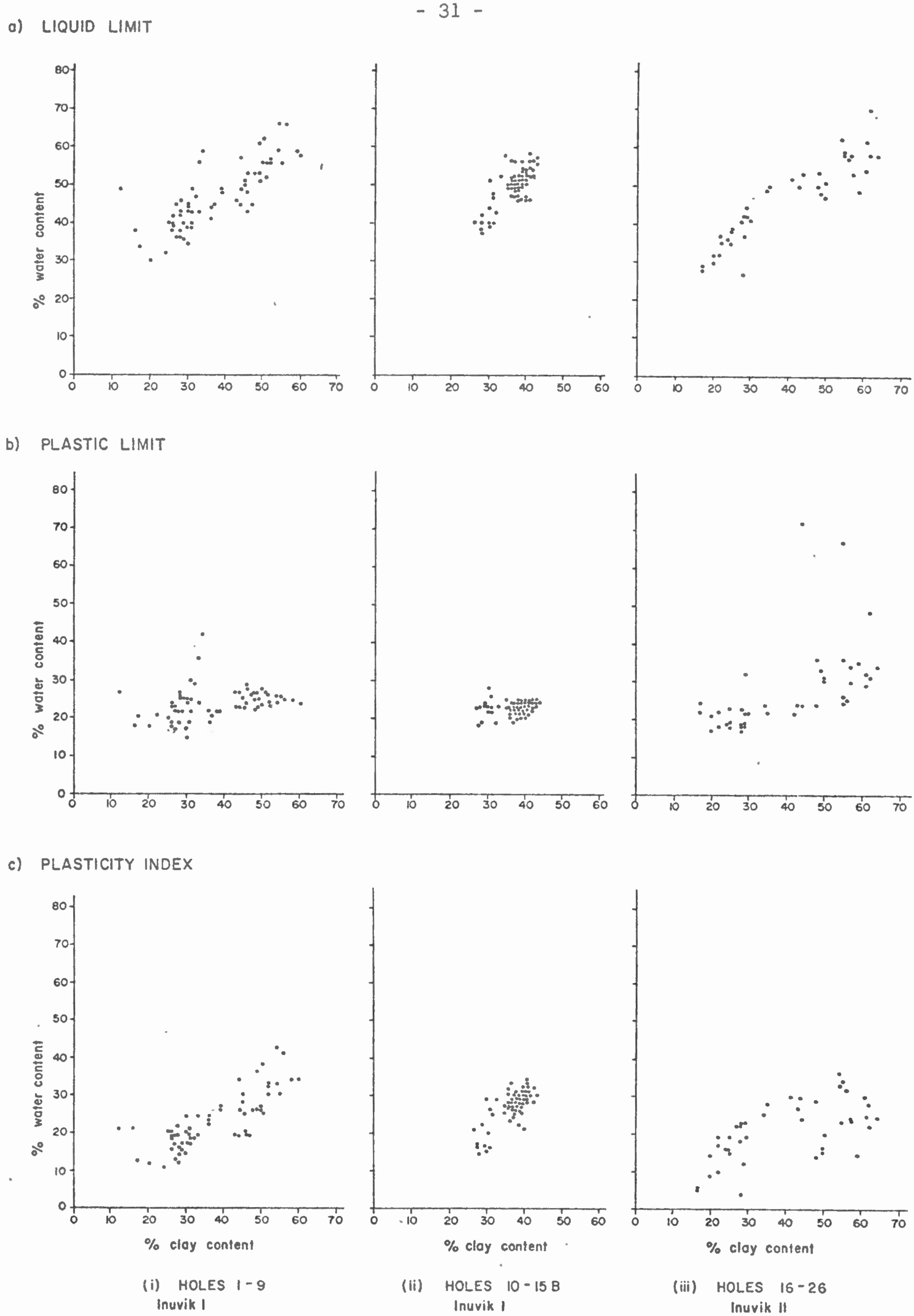


FIGURE 5: SCATTER DIAGRAMS OF ATTERBERG LIMITS PLOTTED AGAINST CLAY CONTENT, FOR TILL AND ALLUVIAL SOILS AT INUVIK SITES I AND II

4.4.2 Texture and Atterberg limits

Using the data for soils from the Inuvik sites, a study was made of the variation in liquid limit, plastic limit and plasticity index with changes in soil texture. This was done by plotting the value for either liquid limit, plastic limit or plasticity index at the appropriate location on a texture triangle. An attempt was then made to plot isolines through these data. The Inuvik data were divided into three groups for this study, namely:

(i) Inuvik site I, localities MS-1, MS-2, MS-3

(ii) Inuvik site I, locality B

(iii) Inuvik site II.

Plotting of the isolines showed two things: first, there was no simple relationship between texture and Atterberg limits and, second, the one textural component which had the strongest relationship with the Atterberg limits was the clay content. Accordingly plots of clay content and Atterberg limits were made for the three groups noted above; these graphs are presented in Figure 5.

Examination of these plots enables the following conclusions to be drawn:

Group (i) (Holes 1-9):

a) liquid limit: a steep rise with increasing clay content (10-60%); values range from 30 to 60%.

b) plastic limit: a slight rise with increasing clay content (10-60%); range of values is 15-30%.

c) plasticity index: rises with increasing clay content (10-60%); range of values is 11-42%.

Group (ii) (Holes 10 - 15B)

a) Liquid limit: rises with increasing clay content (25-45%), a weak relationship with strongly clustered data points: range of values is 37 - 58%. The data points are clustered strongly on the textural triangle plot.

b) Plastic limit: no apparent relationship, with strongly clustered data points;range of values is 18 - 28%.

c) Plasticity index: rises with increasing clay content (25-45%), a weak relationship with strongly clustered data points; from range values 14 to 34%.

Group (iii) (Holes 16 - 26)

a) Liquid limit: steep rise with increasing clay content (15-65%); range of values is 27 - 70%.

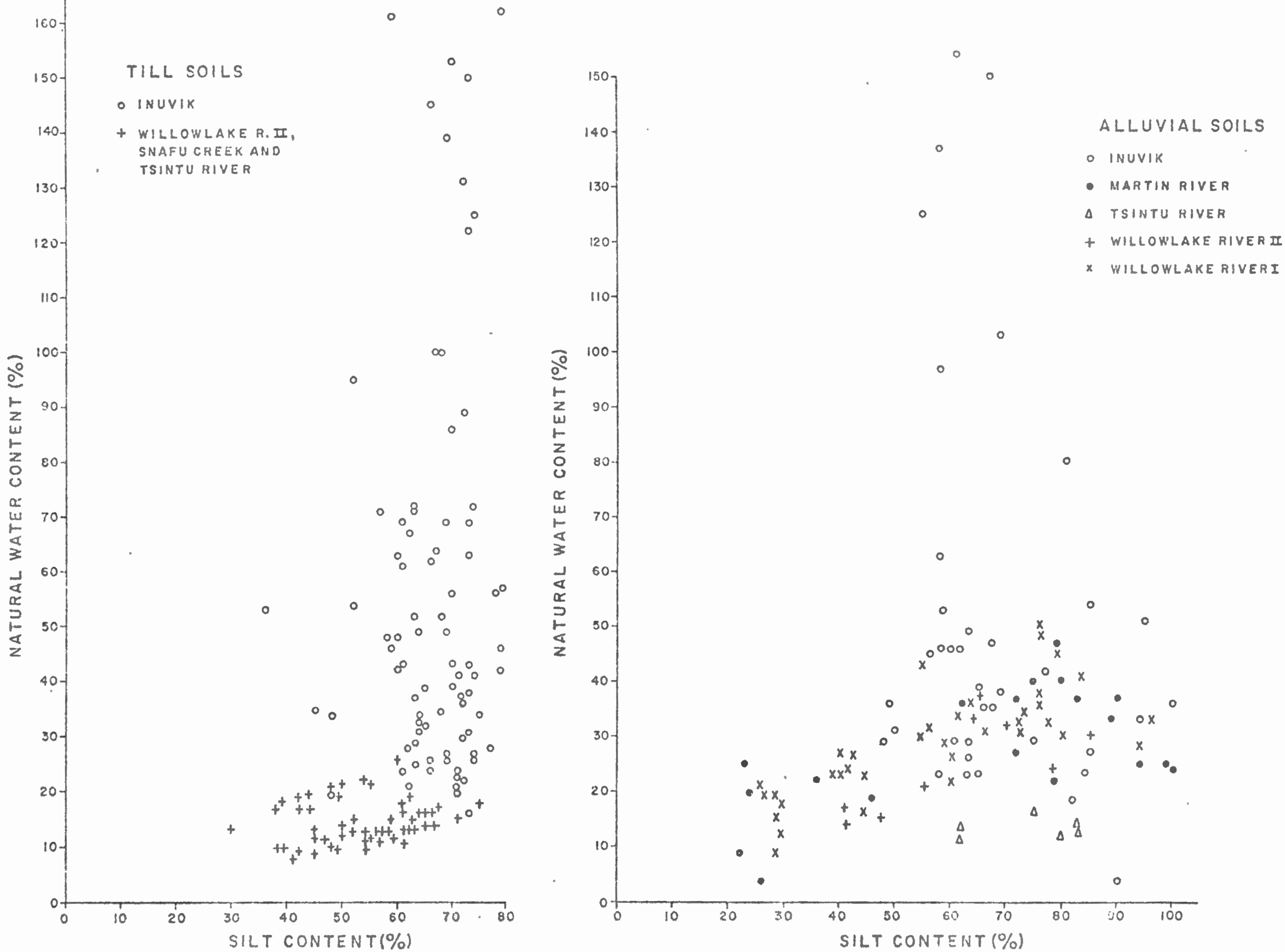
b) Plastic Limit: a slight rise with increasing clay content (15 - 65%); range of values is 17 - 48%.

c)Plasticity index: weakly clustered data points indicating a slight rise with increasing clay content (15-65%), a weak relationship; values range from 4 - 36%.

(Note that data for Group (iii) include samples from both till and alluvial soils).

The weak relationship and strong clustering of the data points in group (ii) are due to the close similarity of the texture for all the samples. They were all collected from a group of holes very close together

Figure 6. Silt content and natural water content for selected samples.



(see section 3.2.8 and Figure A17). The other diagrams in Figure 5, taken together, indicate a good relationship between clay content and liquid limit, and a weak relationship between clay content and plastic limit. The relationship with the plasticity index can best be described as variable.

4.4.3 Texture and Natural Moisture Content

An attempt was made to plot the natural moisture content values on the textural triangle. In many instances very different moisture values occurred at the same location on the triangle, and so the plot was discarded. However, plots of natural moisture content against percentage silt content were made for till soils and for alluvial soils and are more amenable to analysis.

For till soils, the data from Inuvik I, Willowlake River II and Tsintu River plus Snafu Creek were used (Figure 6). The data points for the Willowlake River II, Tsintu River and Snafu Creek sites showed a definite positive relationship between natural water content and silt content. However, the results for the Inuvik I site showed no relationship at all, with the natural moisture content ranging from 20% to over 200% while the silt content was generally between 40 and 60%.

A similar difference was found for alluvial soils between Inuvik I and the other sites (Figure 6). The data points for Willowlake River I and II, Tsintu River, Snafu Creek and Martin River, taken all together or site by site, indicated a definite positive relationship between natural moisture content and silt content. Large range of moisture content can be expected if silt content is more than 40% whereas if silt content is less than 40%, the moisture content range is relatively small (10-25%). The data for Inuvik II showed no apparent relationship.

One possible explanation for these differences is that the positive relationship between moisture content and silt content is only valid if there is no, or at least very little excess ice. For the alluvial soils from Inuvik II, if one considers only the samples with natural moisture contents of less than about 60%, the relationship seen for the other sites appears to hold quite well. However, even this fails for the till soils from Inuvik I.

4.4.4 Natural Moisture Content and Visible Ice Content

A very interesting plot, shown in Figure 7, was made of natural moisture content and the percentage of visible, excess ice in the core. It should be noted that Figure 7 is a semilogarithmic plot, due to the extremely high values of some of the moisture contents of the icy soils when expressed as a percentage of the dry weight. The data values of samples of organic soil show no definite relationship, but the range of moisture content is large for a small range of volume of ice. However, the data for mineral soil and icy soil show a definite positive relationship. The scatter of the data is quite wide and any attempt to predict actual moisture content from visible excess ice would be liable to errors.

4.5 Variations in Terrain Conditions

Approximately half the holes drilled during this study were located in disturbed areas, and in most cases holes in disturbed areas are paired with holes in adjacent similar undisturbed terrain. The terrain disturbance investigated and the number of drill holes at each site in the different terrain classes are summarized in Table V.

The Tsintu River and Inuvik II sites offer the widest variation in terrain conditions at a single site. The Snafu Creek site provides some data on the effects of time since disturbance, as three drill holes are in a recently cleared area while three are in an area cleared several years ago. The sites will be discussed in turn, and then conclusions about the various disturbances will be considered.

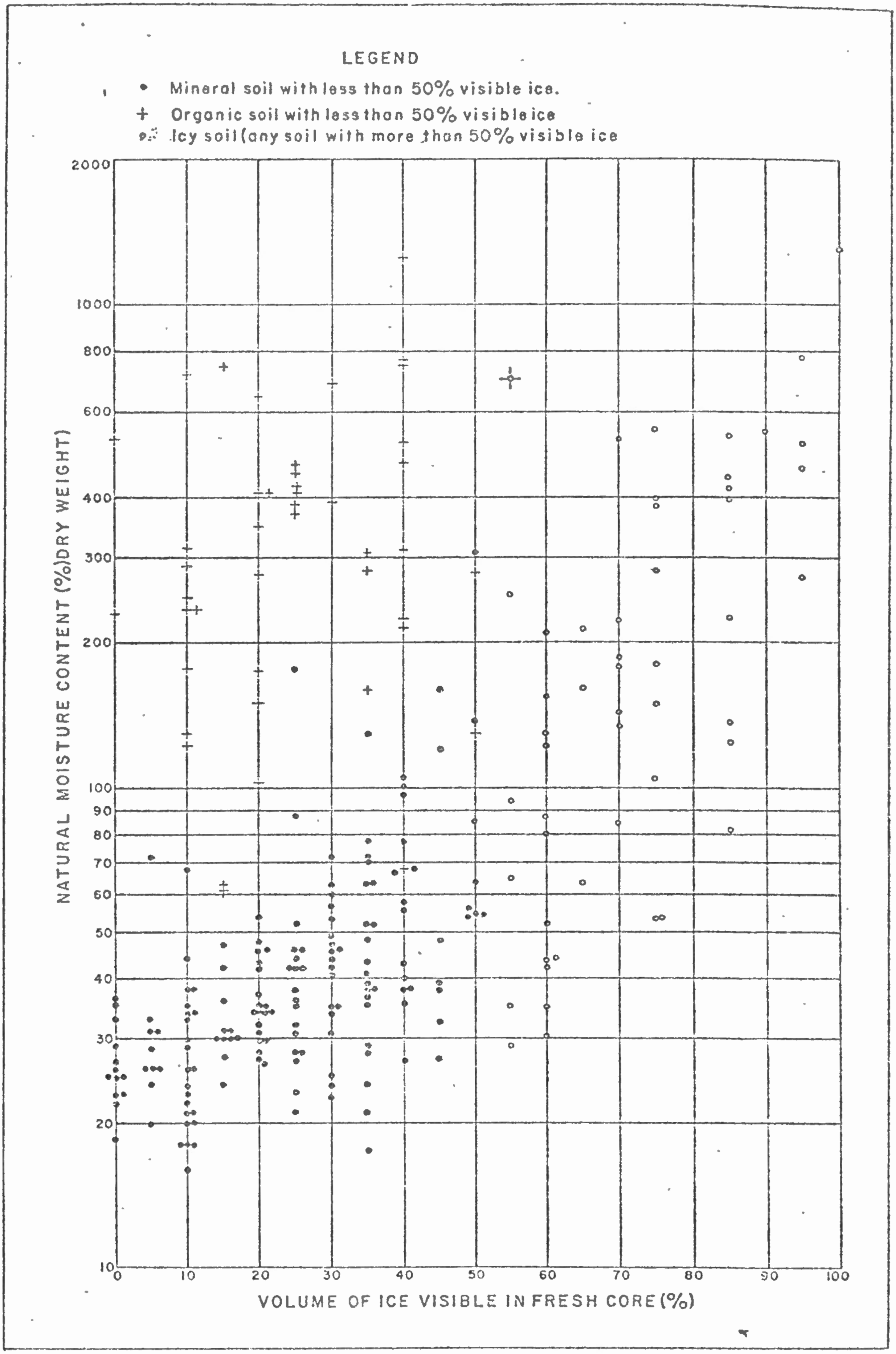


Figure 7. Relationship between visible ice content and natural water content. For explanation see text, Section 4.4.4, p. 36.

TABLE V

Terrain Conditions	Undisturbed	Forest Fire	Bulldozing (fire fighting measures)	Seismic trails	Land clearing: Recent (< 3 yrs.)	Old (> 3 yrs.)	Highway ditch and shoulder
	Number of drill holes						
Inuvik I	16						
Inuvik II	6	1	3	1			
Tsintu River	1	2				6	
Snafu Creek	1				3	3	
Norman Wells	2				4		
Willowlake R. I					4		
Willowlake R. II	1				3	1	
Martin River	2				2		
Fort Simpson	12						8

Terrain disturbances investigated at the various sites.

4.5.1. Inuvik II

This group of eleven holes provides some interesting information concerning the effects of surface disturbance on ground ice content and distribution. Of the eleven holes drilled, six are in relatively undisturbed terrain, while five are in areas that have been quite severely disturbed.

The six holes in undisturbed areas all penetrated layers of massive ice or icy-soil (soil with more than 50 percent visible ice in the core) at depths between 20 and 200 cm and two of the deeper holes encountered similar ice or icy soil at around 300 cm. The layers of massive ice included lenses of ice containing less than 10 percent soil material. Such lenses ranged from 2 to 65 cm in thickness. Layers of icy soil contained 50 to 90 percent ice generally in thin horizontal lenses 1 to 100 mm thick and 1 to 20 mm apart.

Of the five holes in disturbed areas, one area was burned and three subjected to bulldozing in August 1968. The remaining hole was on an old vehicle trail cut before 1964, but which has been used repeatedly since that time. Only one of these five holes penetrated any massive ice or icy soil in the top 1.2 m, and this was in the form of two 10 mm thick lenses at 104 cm and 113 cm. Significant quantities of ice or icy soil were not encountered until depths of 120 to 200 cm were reached.

Thus surface disturbance such as fire or bulldozing appear to lead to the disappearance of excess ice in the upper metre of the ground, and a significant decrease in the quantity of ice in the second metre. In the third metre there is an increase relative to undisturbed areas, while below the three metre mark conditions are probably unaltered. These conclusions are summarized in Figure 8.

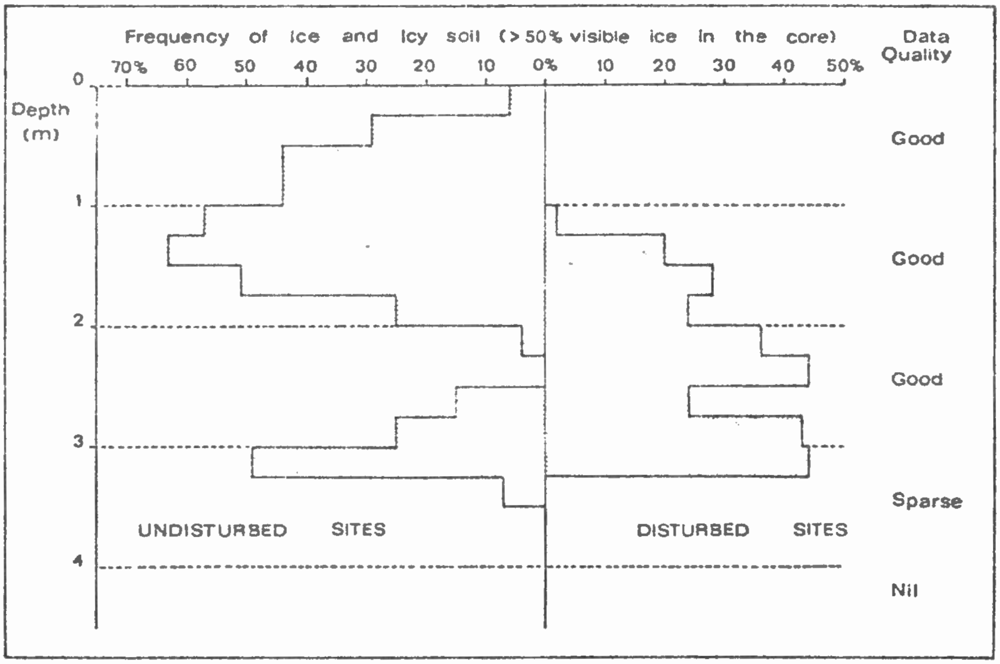


Figure 8. Effects of surface disturbance on ground ice content and distribution of the Inuvik II site.

4.5.2 Tsintu River

Thirteen holes were drilled at this site, however only one was in an undisturbed area. Of the others, two were in a burned area, two were on a seismic trail with date of clearing unknown, and six holes were located along the right-of-way for the C.N.T. land line (cleared in the early nineteen sixties, and used as a winter road since). The remaining two holes were at the intersection of the C.N.T. land line and the old seismic trail.

None of the holes encountered any massive ice or icy soil. Active layer thicknesses ranged from 134 cm in the undisturbed area to greater than 275 cm in one hole in the C.N.T. right-of-way. The depth of thaw in the two holes in the burned area were 135 and 170 cm, while in the seismic trail and C.N.T. right-of-way, it ranged from 157 cm to greater than 275 cm. Below the thawed layer the ground was very dry, and there was generally no ice visible in the cores, except for rare individual crystals. The natural water contents of the samples from this area were all between 10 and 18 percent, with an average of 13.8 percent.

Thus at this site, with holes drilled in the last week of July, the data only permits the simple conclusion that the depth of thaw is thicker in the more severely disturbed areas.

4.5.3 Snafu Creek

At Snafu Creek, three holes were drilled in the C.N.T. right-of-way, cleared in the early nineteen-sixties and used as a winter road since then, three were drilled in the Mackenzie Highway right-of-way, cleared early in 1973, while one hole was drilled in the relatively undisturbed ground between these rights-of-way.

The effects of the longer time period since the surface was disturbed was most marked. The hole in the undisturbed area penetrated only 78 cm of thawed ground and beneath this was approximately 100 cm of icy soil. The holes in the recently cleared highway right-of-way encountered an average of 105 cm of thawed ground over about 65 cm of icy soil, with visible ice contents of 30 to 60 percent. However, the holes in the old C.N.T. right-of-way found an average depth of thaw of 167 cm, and no icy soil at all, just crystals and particle coatings. The amount of visible excess ice was always less than 10 percent.

4.5.4 Fort Simpson

Of the twenty holes drilled at this site, eight were in areas disturbed in greater or lesser extent by highway construction within the last five years, ten were in relatively undisturbed sites, and two were in undisturbed but very wet sites. Only one hole encountered icy soil with a significant proportion of visible ice. This was a hole drilled through the toe of the highway sideslope, in a highly disturbed area. Apart from this hole, none of the holes drilled in disturbed areas encountered very much ice, and two holes penetrated more than 500 cm without encountering frozen ground. The anomalous hole in the toe of the highway sideslope penetrated 50 cm of granular fill underlain by 70 cm of peat. Beneath the peat was frozen sand, silt and peat to 182 cm depth, with visible ice contents of between 40 and 80 percent. It is assumed that the very high organic content of the material beneath the highway fill has enabled this ground ice to survive in such a disturbed area.

The other holes in disturbed areas at this site generally encountered little or no visible ice in the permafrost. The depth of thaw in these holes ranged from 95 to greater than 530 cm. It is possible that the two holes which exceeded 500 cm in depth, without encountering frozen ground may indicate that at these locations permafrost is absent.

The holes in the drier undisturbed areas showed depths of thaw of 10 to 54 cm, with the shallower depths under a thick cover of moss and peat. The frozen ground beneath had generally little or no visible ice. Two of these holes encountered unfrozen ground at depths of 100 and 302 cm. In these holes, the frozen ground may have been only seasonal frost, or the permafrost may actually be very thin here. The two holes in wet, undisturbed areas did not find frozen ground at depths of 400 and 300 cm. These may be locations where permafrost is absent.

4.5.5 Martin River, Norman Wells and Willowlake River I and II

These sites will be discussed more briefly, because only four or five holes were drilled at each site.

At Martin River, the effects of recent highway right-of-way clearing were not really detectable. One hole which encountered frozen ground at 182 cm, passed into unfrozen ground below 317 cm. This may be the base of permafrost at this locality. At Willowlake River I, all four holes were in an area recently cleared for highway construction. The two, northerly holes encountered icy soil, with 50 to 70 percent visible ice, at depths of about 85 cm, and extending down to 105 and 190 cm respectively. Thus the right-of-way clearing has had little effect.

The first hole drilled at Willowlake River II was in the C.N.T. right-of-way. This encountered frozen ground with random visible ice at 27 cm. The next hole, in an adjacent undisturbed area, found frozen ground with 60-70 percent visible ice, at 223 cm. Below 95 cm, only small quantities of ice were visible. The remaining holes were drilled in the recently cleared highway alignment. One found 80% visible ice between 15 and 54 cm, and 65 percent visible ice between 84 and 162 cm, with lesser amounts of ice between and beneath these horizons. The next found frozen ground with some visible ice below 11 cm, while the last hole found 72 cm of thawed ground over frozen ground with no visible ice. It would appear that the effects of surface disturbance at this site are negligible.

Finally at Norman Wells three holes, drilled with a SIPRE core barrel, could not penetrate frozen ground. Four other holes, three in the highway clearing and one in an undisturbed area, found frozen ground with generally small quantities of excess ice. The depth-of-thaw was 28 cm in the undisturbed area and 49 to 168 cm in the cleared area.

4.5.6 Summary

In general, the effects on all forms of surface disturbance are similar: the ground thaws more deeply in summer, and there is a decrease in the amount of excess ice in the upper layers of permafrost. In marginally frozen locations the permafrost may become thinner, or even disappear entirely. Such effects take some time to develop, and may not become apparent for one to two years following the disturbance. There are many exceptions to this general sequence of events.

5. CONCLUSIONS

In this section, an attempt will be made to gather together the specific information presented in Section 4, and to consider what general conclusions can be drawn regarding the distribution of frozen ground and ground ice in the Mackenzie Valley, what environmental factors control this distribution, and how stable the distribution is in face of man's proposed development of the region. Consideration will also be given to the possibility of predicting conditions of the ground in untested areas. Finally, the study methodology will be critically reviewed.

The problems of the effects of ground water differences were not covered, and no useful, new information on the effects of differences in vegetation was obtained. The effect of vegetation in general *versus* no vegetation was also considered in some detail.

5.1 Distribution of frozen ground and ground ice

The general impression is that frozen ground is more extensive, occurs at shallower depths and contains more visible, excess ice as one goes from south to north. The greatest change appears to occur in the uninvestigated area between Fort Good Hope and Inuvik. All the sites studied to the south of Fort Good Hope are in the zone of discontinuous permafrost while the Inuvik sites are definitely within the continuous permafrost zone.

5.1.1 Factors controlling this distribution

The significant factors affecting the distribution of frozen ground and ground ice, as determined in this study appear to be:

- location (latitude)
- soil texture
- slope aspect
- surface drainage
- surface disturbance and vegetation

It should be noted that these items are just listed and are not ranked, even qualitatively. The general impression gained while carrying out the study was that the ranking of these factors would vary from site to site.

In keeping with the generally colder winters and cooler summers of the northern part of the Mackenzie Valley, compared to the southern part (see Table II), the location or latitude of the study sites can be expected to be one of the major controls on permafrost conditions. There are some anomalies however, such as the very dry tills at Tsintu River.

The finer textured soils, such as silts, clays and clay-silt tills generally contain more moisture and more ice than coarser, sandy soils. There appears to be a clear, positive relationship between natural water content and silt content, up to water contents of about 60%. This relationship breaks down for soils with significant quantities of excess ice. Organic soils and peats can have extremely high natural water contents, and considerable quantities of excess ice - up to 1000% by weight. Values as large as this are really meaningless. It would probably be more meaningful to present such information in the form of percentage by volume before thawing.

Differences in slope aspect were examined at the Inuvik I site only. Here there was a strong suggestion that south-facing slopes are drier and north-facing slopes wetter than adjacent level ground. The effects of position on the slope were investigated at Martin River, Snafu Creek and Inuvik, with confused results. Lithology, slope angle and slope aspect appeared to overwhelm differences due solely to the position on the slope.

Ground surface drainage was examined only at Fort Simpson, plus a single observation from Willowlake River I. The conclusion at Fort Simpson was that poorly drained sites did not have permafrost near the ground surface, and possibly none at all. However at Willowlake River, the poorly drained site, with a thick surface peat layer, contained more ground ice than adjacent, drier sites. This is possibly due to the presence of the thick surface peat layer.

The effects of vegetation were considered only in terms of its presence or absence, as a result of surface disturbance. In such cases the removal of vegetation was found to be a major contributor to changes in the thickness of the active layer and in ground ice content. Other work in the Mackenzie Valley has also demonstrated this (Heginbottom, 1973b, Kurfurst, 1973).

5.1.2 The Stability of the Distribution

The distribution of frozen ground and ground ice is a physical expression of the heat balance or thermal regime of the ground of northern Canada. The components of the heat balance are:

- net solar radiation (incoming solar radiation - outgoing earth radiation)
- evaporation and convection,
- ground thermal regime, and
- ground heat storage.

The surface heat balance and mean annual ground temperature at any site depend on the relative magnitude of these components. If the mean annual ground temperature at any depth is below the freezing point, permafrost will occur there. The formation and degradation of permafrost thus depends on changes in the long term heat balance, (Williams, 1971). The two most important causes of such change are changes in climate (long term) and changes in surface cover (long or short term). Changes in surface cover effect the components of evaporation and convection, the "contact resistance" between air and ground, and the heat transfer properties of the ground. Long term changes in surface cover are caused by such things as successional changes in vegetation, while short term changes can be the result of natural catastrophic events (landslides, floods or forest fires) or of the activities of man (bulldozing, land clearing, or construction). Man can quite easily cause gross changes in the ground surface cover, and hence changes in the underlying permafrost of northern Canada.

The data of this study confirm the earlier work cited above (Heginbottom, 1973b; Kurfurst, 1973). The effects of all the forms of surface disturbance examined have been similar, and have lead to a greater amount of heat entering the ground from the atmosphere. The result is a thicker active layer, and a decrease in the amount of excess ice in the upper layers of permafrost. Areas of marginally stable permafrost may disappear entirely. These effects take a few years to become apparent. The time before a new heat balance equilibrium becomes established is not known with certainty, but it appears to be of the order of a few decades for the disturbance considered. It is, in any case, partly dependent on the magnitude or severity of the ground surface disturbance, and partly on the innate stability of the disturbed ground.

5.2 Conditions in Untested Areas

Untested or uninvestigated areas exist on three scales in this study. The small scale areas are the sections of drill core that were not submitted to laboratory analysis. Given good, descriptive logs of the fresh cores, this should pose no problems, and the laboratory data can generally be interpolated for such sections.

Medium scale areas comprise the ground between drill holes, and also the deeper layers of soil, rock or ice beneath the drill holes, at any site. The confidence with which predictions can be made about conditions between and beneath drill holes depends on the distance involved, the complexity of the site conditions perceived in the drill holes and conceptual models of the probable stratigraphy of the site.

Most of the drill holes were located in lines or blocks so as to test the differences in permafrost conditions with regard to environmental factors (slope, aspect, drainage, disturbance, etc.) This facilitates prediction to some extent. Thus the four drill holes at Willowlake River I showed a steady change in lithology, texture and ice content with increasing distance away from the river bank. Similarly at Willowlake River II the holes #49, 50 and 51 showed very similar soil and permafrost conditions, so that one could predict the probable condition adjacent to these holes with some degree of confidence.

This is not always the case, and an example is presented by holes #10-15B at Inuvik I. Summary logs of the ice conditions of these drill holes are shown in Figure A17. It should be emphasized that the horizontal and vertical scales of this diagram are the same, the seven holes were drilled at 25 to 50 cm intervals along a transect 2.8 m long. Although there is a general agreement between the drill logs, there is considerable variation in detail. Similar variations were exhibited by the logs for holes #16-26, at Inuvik II. Holes #16, 17 and 18A were on one transect, about 25 m apart, holes #19, 20 and 21 were on a second transect, 34 and 28 m apart, while holes #22 to 26 were on a third line with the holes 15 to 25 m apart. In no cases would one want to make other than very tentative predictions about the stratigraphy or permafrost conditions between the holes.

This inability to make meaningful predictions concerning the areas between the study sites is even more serious. All that can validly be stated about the permafrost conditions of the Mackenzie Valley, as a whole, is that there is a general increase in the amount of frozen ground and ground ice as one moves from south to north. The variation in conditions between adjacent sites is such that, using the information gathered for this study, one cannot make any useful predictions of the detailed soil or ground ice conditions in the areas between the study sites.

5.3 Study methodology

The equipment used in the field was generally satisfactory, in that clean, relatively undisturbed cores were obtained from both frozen and unfrozen sediments. Penetration of the sampler was difficult in very dense, sticky till, and withdrawal was even more difficult in such material. Core retention proved difficult only in very dry, non-cohesive, sandy soils. No penetration could be achieved into boulders of competent rock or into layers of clean gravel or gravel containing many fragments larger than about 3 cm.

The use of a split sampling barrel enabled extraction of the core to be made with a minimum of disturbance. This is essential if the ice distribution is to be determined, particularly when the air temperature is well above the freezing point. Description of the cores in terms of N.R.C. permafrost terms was satisfactory.

5.4 Mackenzie Highway Geotechnical Information

When construction of the Mackenzie Highway began late in 1972, there was little detailed geotechnical information available on which to base the design. The surficial geology of some of the areas through which the highway was to pass had been mapped at a scale of two miles to the inch (1:125,000), by the Geological Survey of Canada. Mapping of the remainder of the Mackenzie Valley Transportation Corridor was underway. However detailed knowledge and understanding of the distribution and nature of frozen ground and ground ice was not readily available to the design teams.

As so little was known about the details of the nature and distribution of the surficial materials, permafrost or ground ice, the initial strategy for locating drill holes was that there should be average of five holes per mile along the centre-line with additional holes where appropriate. These additional holes were generally in areas where changes in surface slope were encountered, where cuts were anticipated, at culvert sites, in areas of muskeg or organic soils and along the ditch line where sidehill cuts were anticipated. Given the level of other information, this was a reasonable approach.

Since that time considerable research effort has been expending to determine and understand the details of the soils and the relationship between permafrost, ground-ice, soils and other environmental factors.

Examination of the highway geotechnical information, the surficial geology and landform maps, and comparison with the detailed studies described in this report suggest that in future a rather different strategy would be more appropriate.

A drill-hole every 1,000 feet is generally not necessary. Instead the drilling should be concentrated in areas where problems are anticipated. In addition selected sites should be drilled and studied in some detail, so as to permit an evaluation of the range in soil (and ground ice) conditions typical of each geologic mapping unit to be determined. In some areas this approach may lead to considerably less drilling being done, with a concomitant saving in money.

In other areas, better value could be achieved for the same expenditure.

Outside the Mackenzie Valley, considerations should be given to requesting reconnaissance geological mapping be done, so that geotechnical studies can be better planned. This would require a rather longer range approach to development than was applied to the Mackenzie Highway.

6. IMPLICATIONS AND RECOMMENDATIONS

6.1 Relating to Highway and other Construction in the Mackenzie Valley

A considerable amount of geotechnical information has been gathered from within the Mackenzie Valley Transportation Corridor under the auspices of various pipeline programs as well as for the Mackenzie Highway. Most of these programs have collected information on the basis of a few holes per mile, along possible transportation routes, or from special areas such as possible borrow pits, bridge sites, wharf and storage areas. The samples retained frequently have been highly disturbed and usually have been limited to two or three samples per hole. Information gathered in such a manner does not adequately characterize the nature of the ground ice occurrence or distribution, fails to indicate the rapid lateral changes in both lithology and ice content which exist, and frequently leads to under estimation of the account of ice in the ground.

The information gathered during this study has been derived from continuously cored closely spaced drill-holes from nine selected sites. It indicates that there is considerable within-hole and between-hole variability in both the amount of ground ice and in the nature of its occurrence. Thus the following recommendations are made:

1. That predictions of the ice content of soils based on disturbed samples be regarded as minimum estimates; the unreliability of such predictions is directly related to the degree of disturbance of the samples.

2. That considerable variations be expected in texture lithology, ice content and ice distribution within short distances.

3. That in areas of fine-grained soils, highway construction using an overlay or fill technique be used wherever possible, and that no unnecessary cuts be used.

4. That no bulldozing, ditching or mechanical damage to the ground surface be permitted in areas of fine-grained soils.

5. That in areas of discontinuous permafrost, highway grade construction be carried out within twelve months of right-of-way clearing.

6.2 Relating to other areas in the Canadian North

Should similar regional geotechnical information be required for other parts of the Canadian north and particularly permafrost areas, the information gathered during this study should be used in planning drilling program. Specifically, we recommend:

6. That every effort be made to obtain undisturbed continuous core from a sufficient proportion of the drill-holes so as to
   a) adequately characterize the nature of ground ice distribution, and
   b) control the evaluation of disturbed samples from other drill-holes.

7. That in planning a drill program, the nature and complexity of the distribution of surficial geological materials be taken into consideration when choosing the location of all drill holes. If necessary, recconnaissance surficial geological mapping should be undertaken prior to planning the geotechnical program.

8. That at selected sites, a number of holes be drilled at close intervals (1-100 m) so as to determine the extent of short range lateral variations in lithology, ground ice content and ground ice distribution.

9. That the sites for such detailed studies be selected so as to cover the range of the factors thought to be significant in controlling ground ice content and distribution, namely: location, soil texture, slope aspect, surface drainage, vegetation and disturbance.

7. REFERENCES

Bostock, M.S.
1970: Physiographic regions of Canada. Canada, Geol. Surv., Map 1245A, 1:5 million.

Brown, R.J.E.
1967: Permafrost map of Canada. Canada, Geol. Surv., Map 1246A, Scale 1:7603,200

Büdel, J.
1969: Der eisrinder-effekt als motor der tiefererosion in der exzessiver talbilchungszone. Wirtzburger Geographische Arbeiten, Heft 25 (in Polar Record, 16 (100): 125, Jan. 1972).

Burns, B.M.
1973: The climate of the Mackenzie Valley - Beaufort Sea. Vol. 1. Canada, Department of the Environment, Atmospheric Environment Service, Climatological Studies No. 24: 227p.

Heginbottom, J.A.
1973a: "The thermal regime of the permafrost active layer at Inuvik N.W.T." in Proceedings of a Seminar on the Thermal Regime and Measurements in Permafrost 2 and 3 May, 1972 (ed: R.J.E. Brown), Canada, NRC/ACGR, Tech. Memo. No 108: 68-75.

1973b: Effects of surface disturbance on permafrost. Canada, Task Force on Northern Oil Development, Environmental - Social Committee, Northern Pipelines. Report No. 73-16: 66 p.

Kurfurst, P.J.
1973: Terrain disturbance susceptibility, Norman Wells area. Canada, Task Force on Northern Oil Development, Environmental - Social Committee, Northern Pipelines. Report No. 73-24: 36 p., maps.

Lissey, A.
1974: "Groundwater flow in the permafrost active layer, Inuvik N.W.T." in Report of Activities, Geol. Surv. Can. Paper 75-1, Pt-B: 185-186.

Pihlainen, J.A. and G.H. Johnston
1963: Guide to a field description of permafrost. Canada, NRC/ACGR, Tech. Memo No. 79: 24 p.

Rampton, V.N.
1974: Terrain evaluation, Mackenzie Transportation Corridor, northern part, lat. 68° N to Coast, Canada, Task Force on northern Oil Development; Environmental - Social Committee, Northern Pipelines, Report No 73 - 47: 44 p. (Comparison Maps: Geological Survey of Canada, Open file Reports, Numbers 96, 117, 119, 120 and 191).

Scott, W.J. and J.A. Hunter
1974: "Seismic and electrical methods in permafrost detection" in Proceedings of a Symposium on Permafrost Geophysics, 27 and 28 February (ed: I.C. Collett and R.J.E. Brown), Canada, NRC/ACGR, Tech. Memo. No. 133: 48-49.

Williams, G.P.
1971: "Subsurface heat exchange and permafrost" in Proceedings of a Seminar on the Permafrost Active Layer, 4 and 5 May, 1971 (ed: R.J.E. Brown), Canada, NRC/ACGR, Tech. Memo No. 103: 8-12.

APPENDIX A

SITE MAPS, (SITE DIAGRAMS) AND BOREHOLE LOGS

Index to Localities

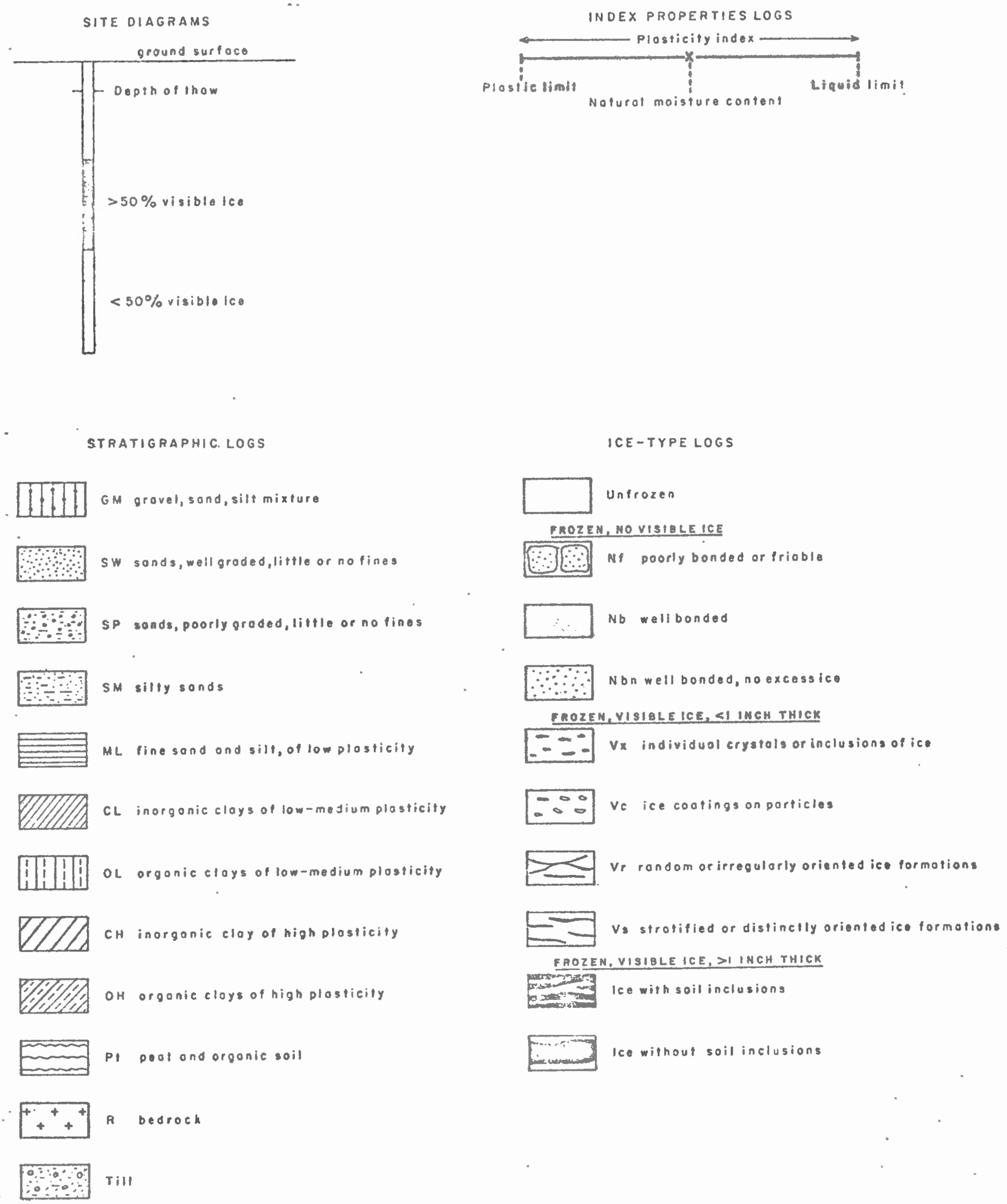
Site name	Holes drilled
Fort Simpson	30 - 48
Martin River	58 - 61
Willowlake River I	54 - 57
Willowlake River II	49 - 53
Norman Wells	62 - 64 and 85 - 88
Snafu Creek	78 - 84
Tsintu River	65 - 77
Inuvik I	1 - 15B
Inuvik II	16 - 26

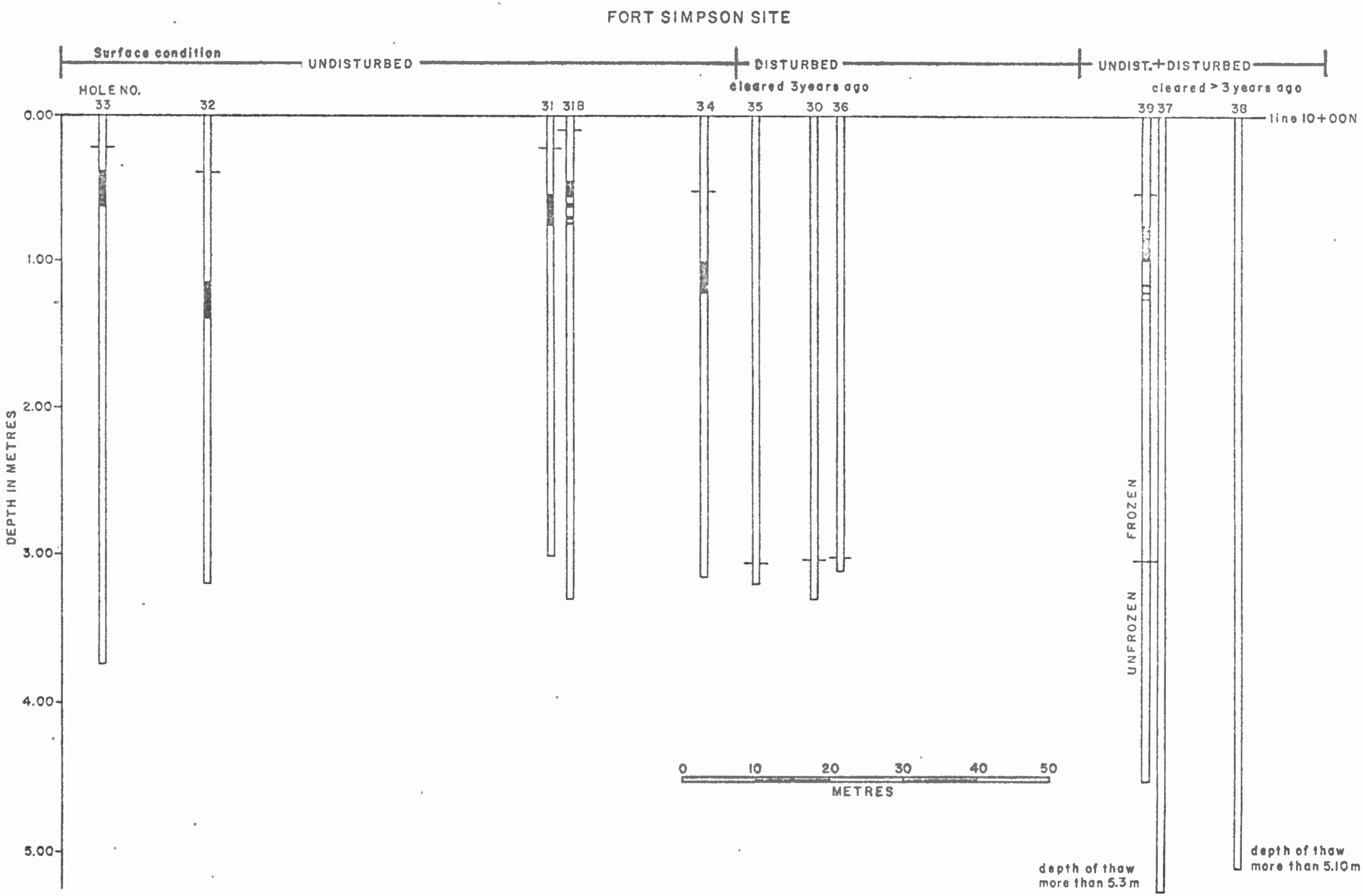
Note: Holes 27 - 29 were not drilled.

List of Figures

FIGURE A1

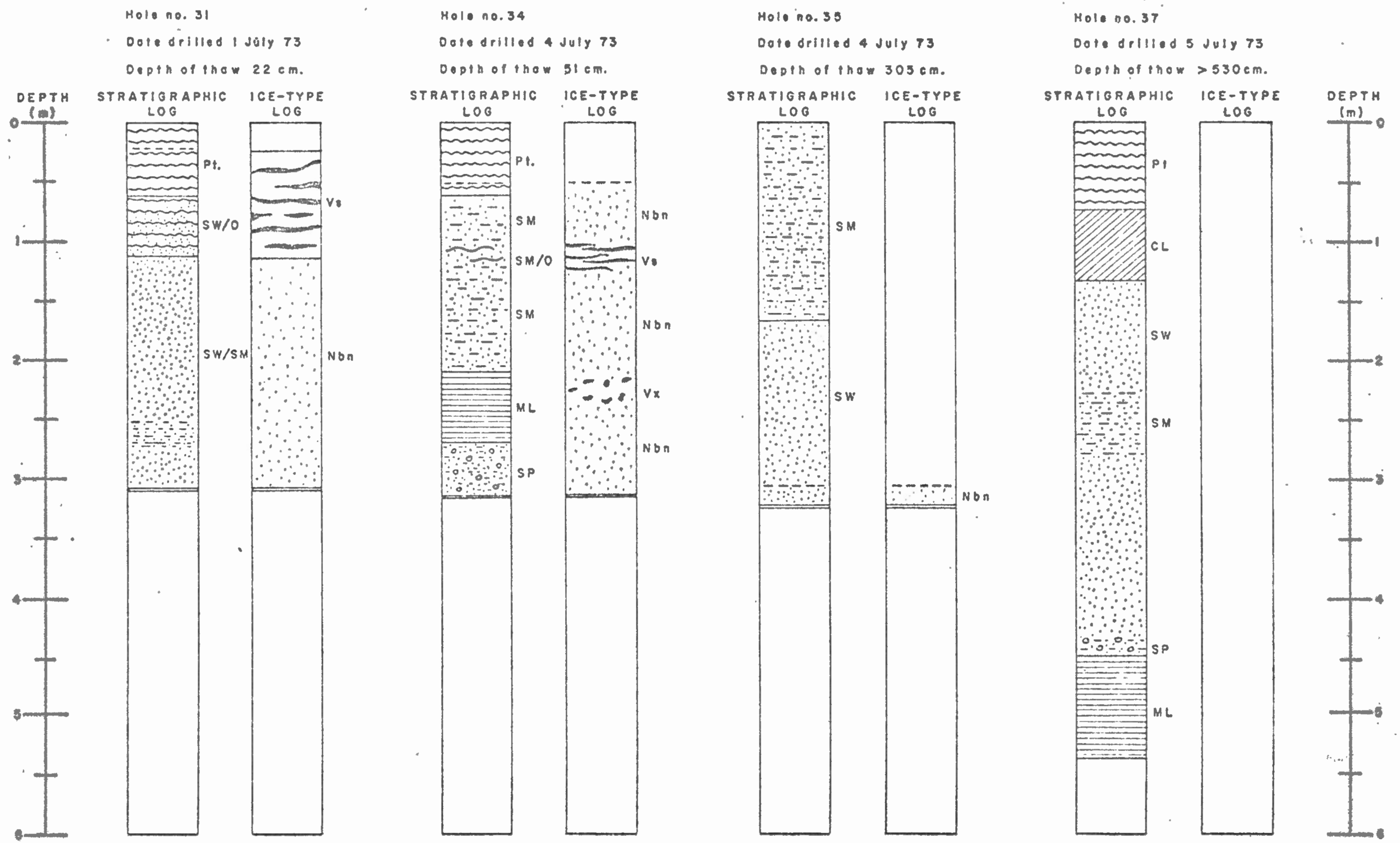
LEGENDS FOR SITE DIAGRAMS AND BOREHOLE LOGS, APPENDIX A





FORT SIMPSON SITE
Surface condition
UNDISTURBED
DISTURBED
cleared 3years ago
UNDIST.+DISTURBED
cleared > 3 years ago
HOLE NO.
33
32
31
31B
34
35
30
36
39
37
38
line 10+00N
0.00
1.00
2.00
3.00
4.00
5.00
DEPTH IN METRES
FROZEN
UNFROZEN
0
10
20
30
40
50
METRES
depth of thaw more than 5.3 m
depth of thaw more than 5.10 m

FIGURE A2



Hole no. 31
Date drilled 1 July 73
Depth of thaw 22 cm.
Hole no. 34
Date drilled 4 July 73
Depth of thaw 51 cm.
Hole no. 35
Date drilled 4 July 73
Depth of thaw 305 cm.
Hole no. 37
Date drilled 5 July 73
Depth of thaw >530cm.
DEPTH (m)
STRATIGRAPHIC LOG
ICE-TYPE LOG
Pt.
SW/O
SW/SM
Vs
Nbn
SM
SM/O
ML
SP
Vx
SW
CL
0
1
2
3
4
5
6

FIGURE A3

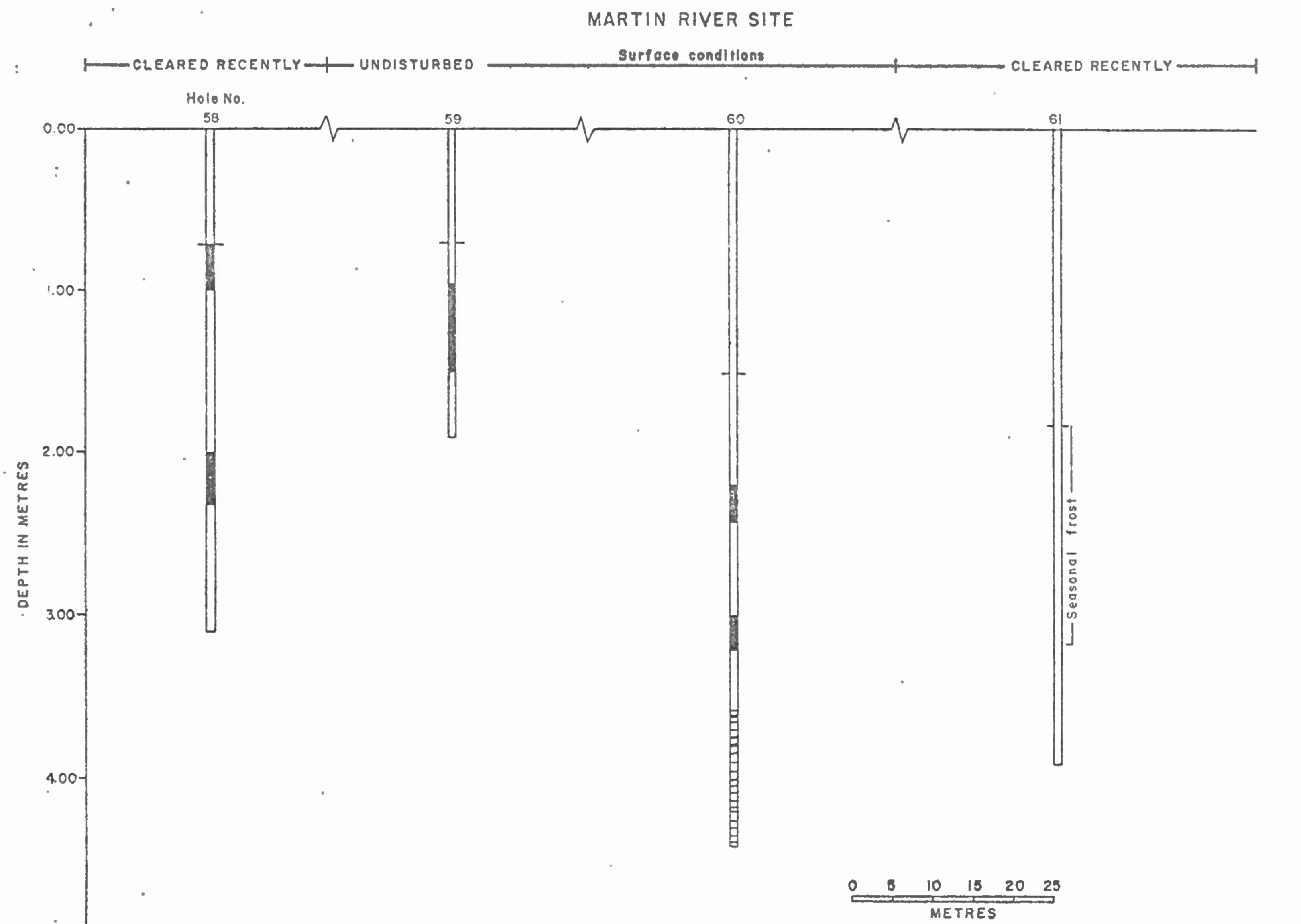

MARTIN RIVER SITE
CLEARED RECENTLY
UNDISTURBED
Surface conditions
CLEARED RECENTLY
Hole No.
58
59
60
61
0.00
1.00
2.00
3.00
4.00
5.00
DEPTH IN METRES
Seasonal frost
0 5 10 15 20 25
METRES

FIGURE A4

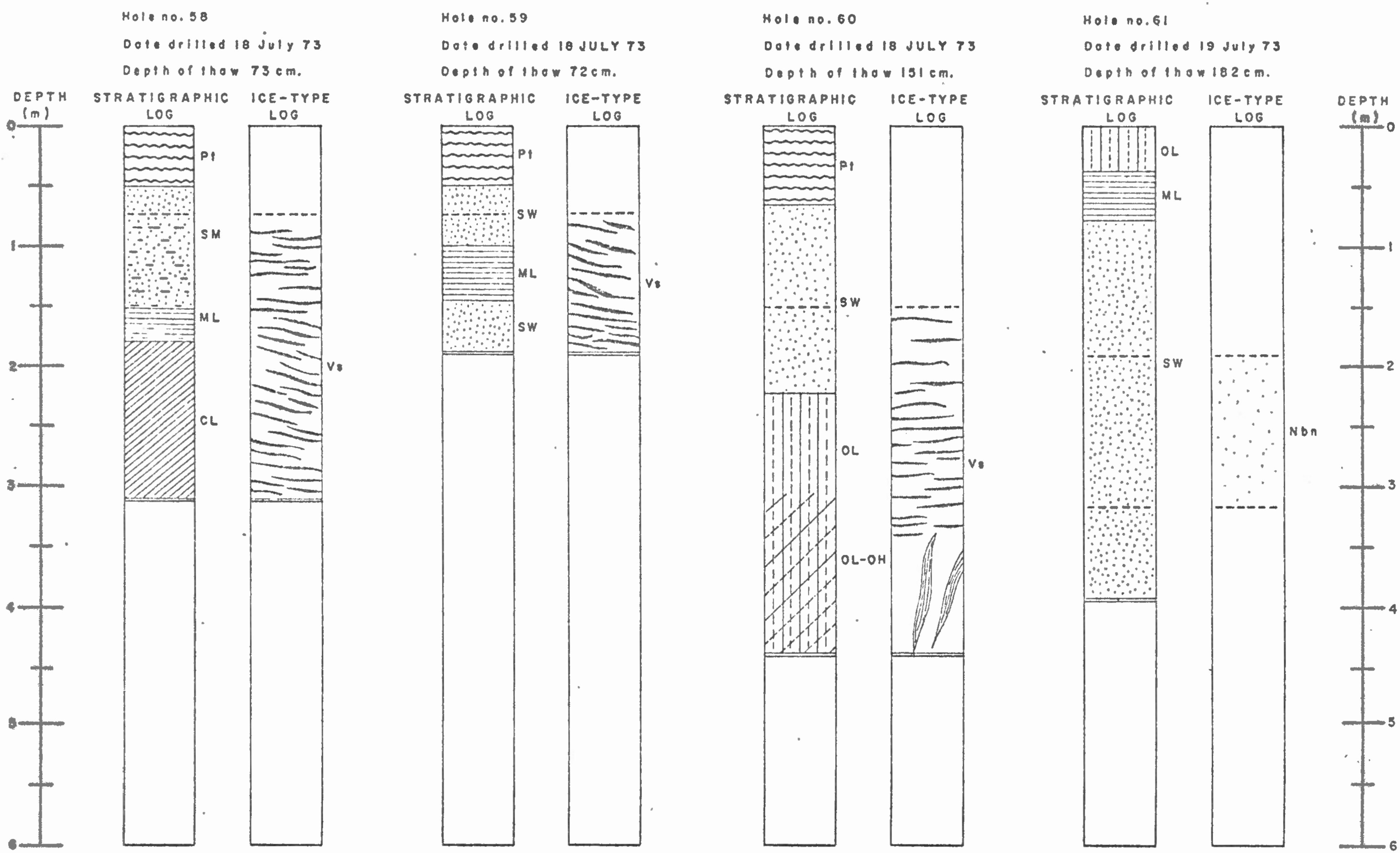
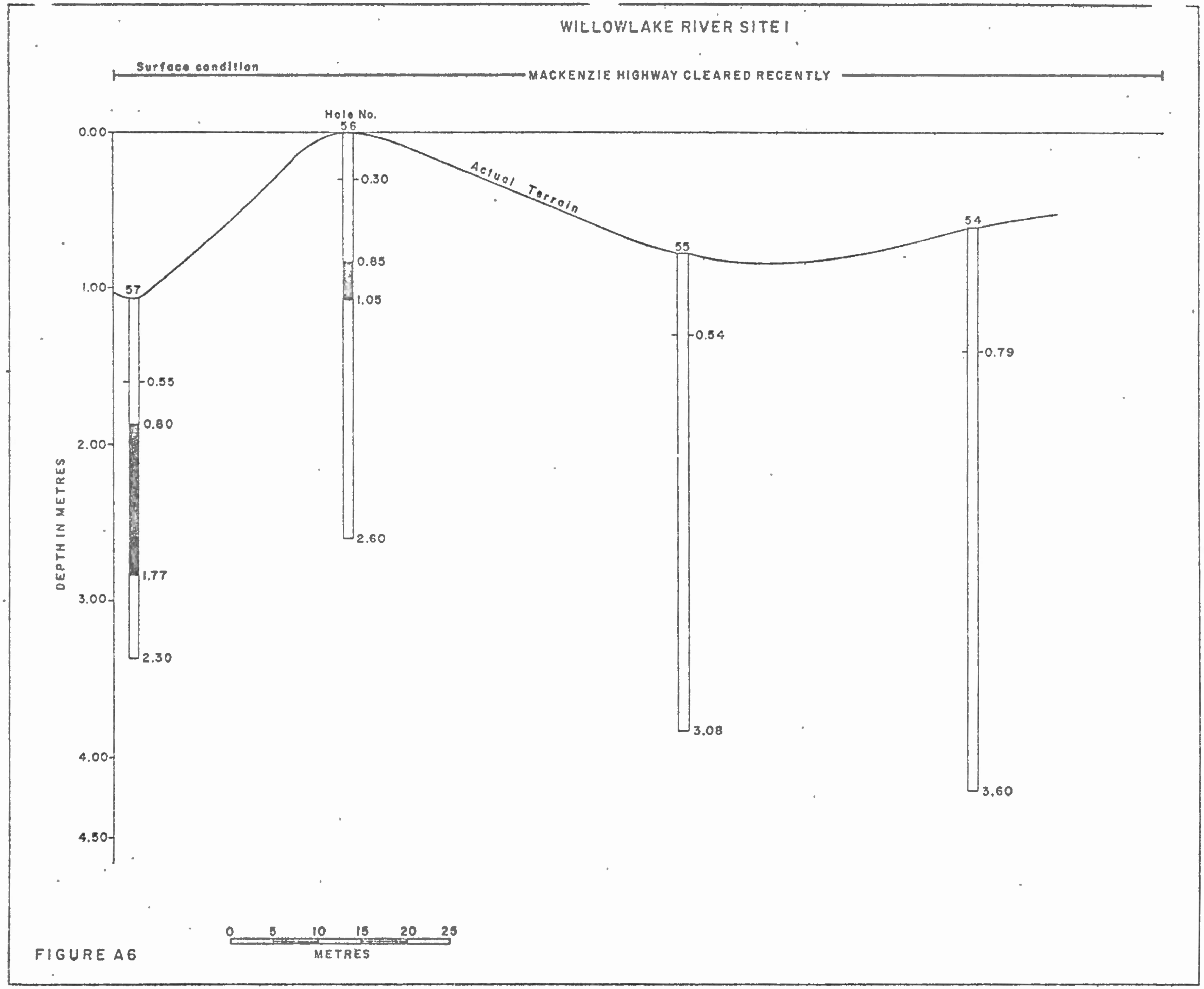

Hole no. 58
Date drilled 18 July 73
Depth of thaw 73 cm.
Hole no. 59
Date drilled 18 JULY 73
Depth of thaw 72 cm.
Hole no. 60
Date drilled 18 JULY 73
Depth of thaw 151 cm.
Hole no. 61
Date drilled 19 July 73
Depth of thaw 182 cm.
DEPTH (m)
STRATIGRAPHIC LOG
ICE-TYPE LOG
Pt
SM
ML
CL
Vs
SW
OL
OL-OH
Nbn
0
1
2
3
4
5
6

FIGURE A5



WILLOWLAKE RIVER SITE I
Surface condition
MACKENZIE HIGHWAY CLEARED RECENTLY
Hole No.
56
57
55
54
Actual Terrain
DEPTH IN METRES
0.00
1.00
2.00
3.00
4.00
4.50
0.30
0.85
1.05
2.60
0.55
0.80
1.77
2.30
0.54
3.08
0.79
3.60
0 5 10 15 20 25
METRES

FIGURE A6

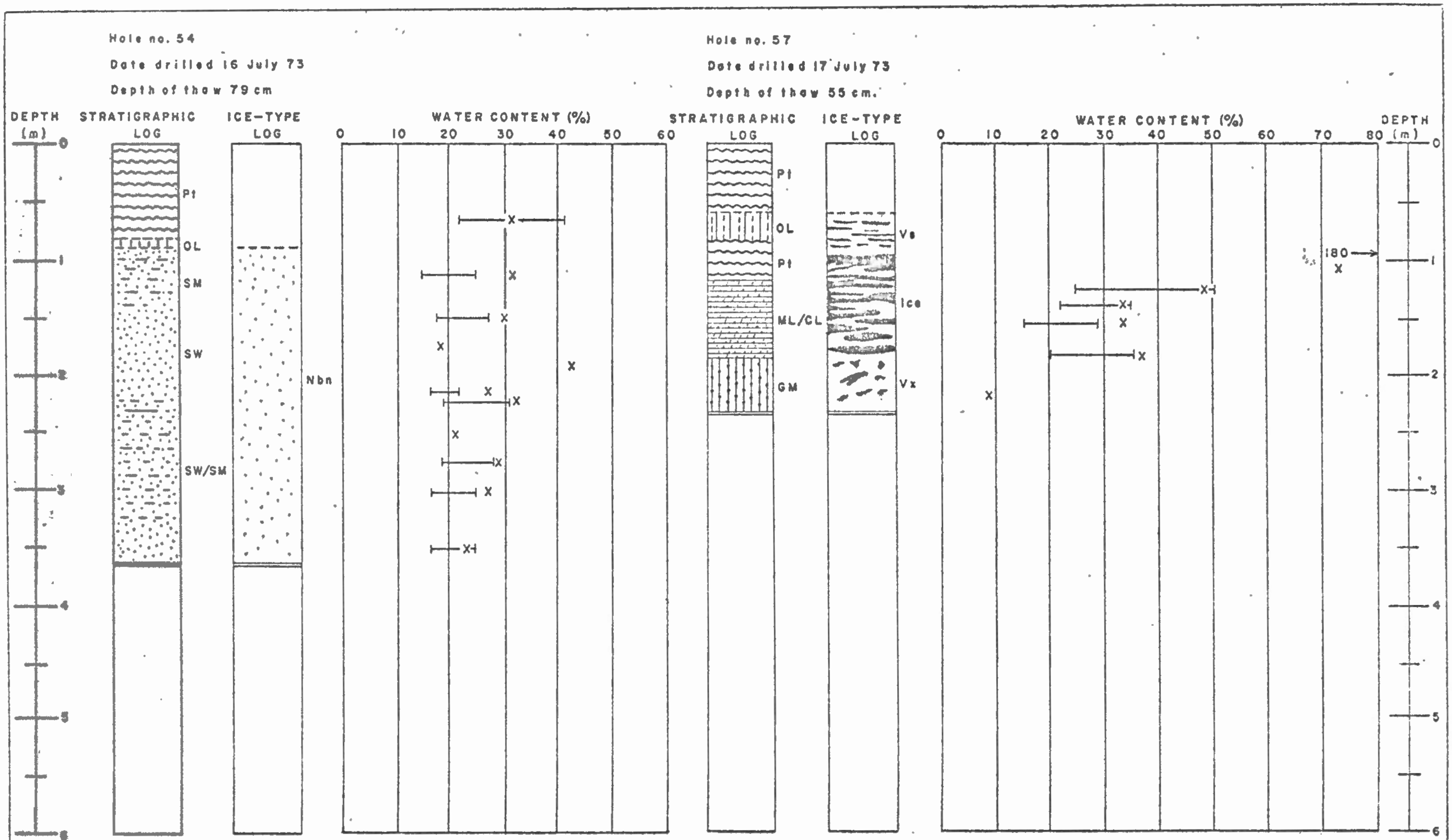

Hole no. 54
Date drilled 16 July 73
Depth of thaw 79 cm
DEPTH (m)
STRATIGRAPHIC LOG
ICE-TYPE LOG
WATER CONTENT (%)
0 10 20 30 40 50 60
Pt
OL
SM
SW
SW/SM
Nbn
0 1 2 3 4 5 6
Hole no. 57
Date drilled 17 July 73
Depth of thaw 55 cm.
STRATIGRAPHIC LOG
ICE-TYPE LOG
WATER CONTENT (%)
0 10 20 30 40 50 60 70 80
DEPTH (m)
Pt
OL
Pt
ML/CL
GM
Vs
Ice
Vx
180

FIGURE A7

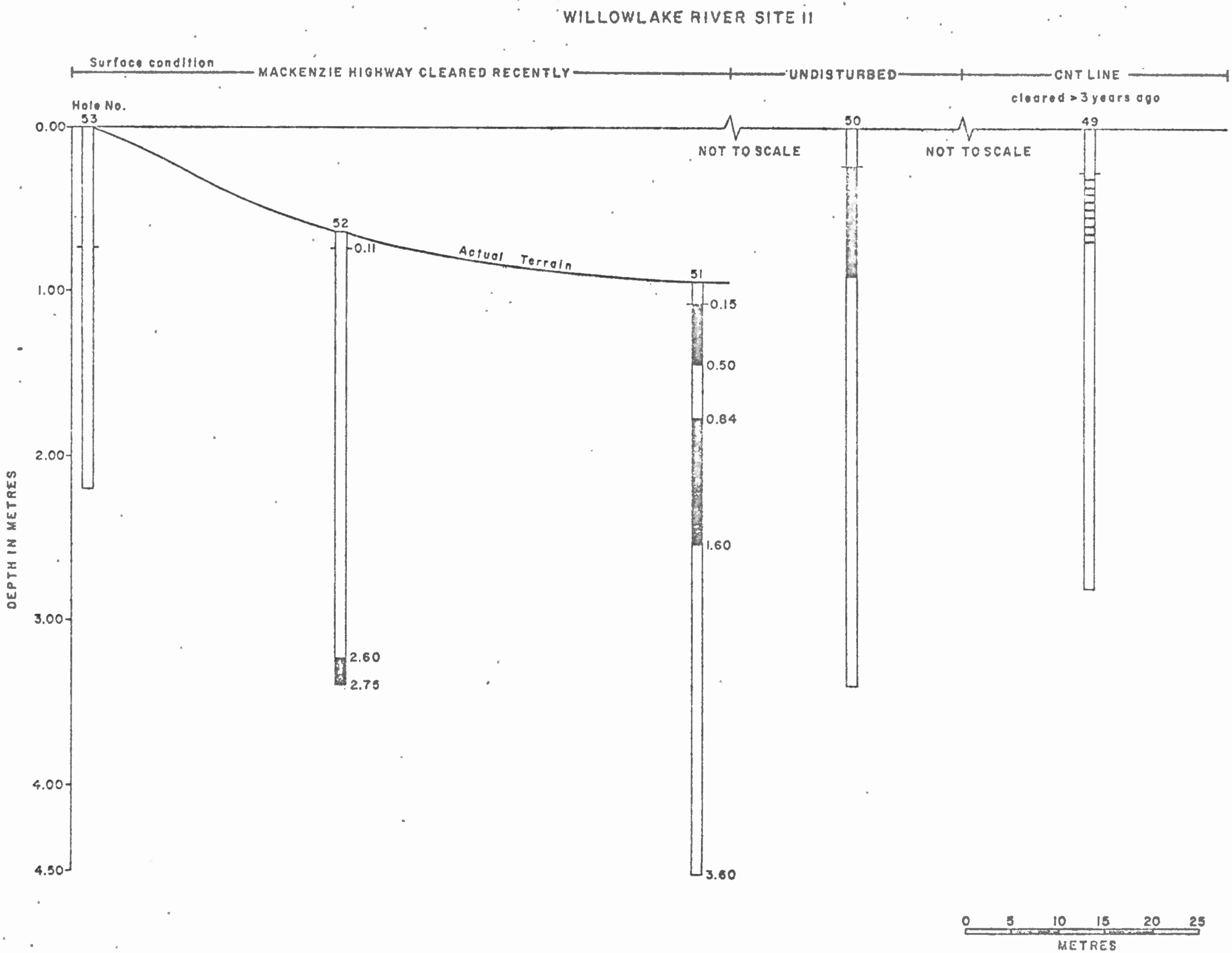
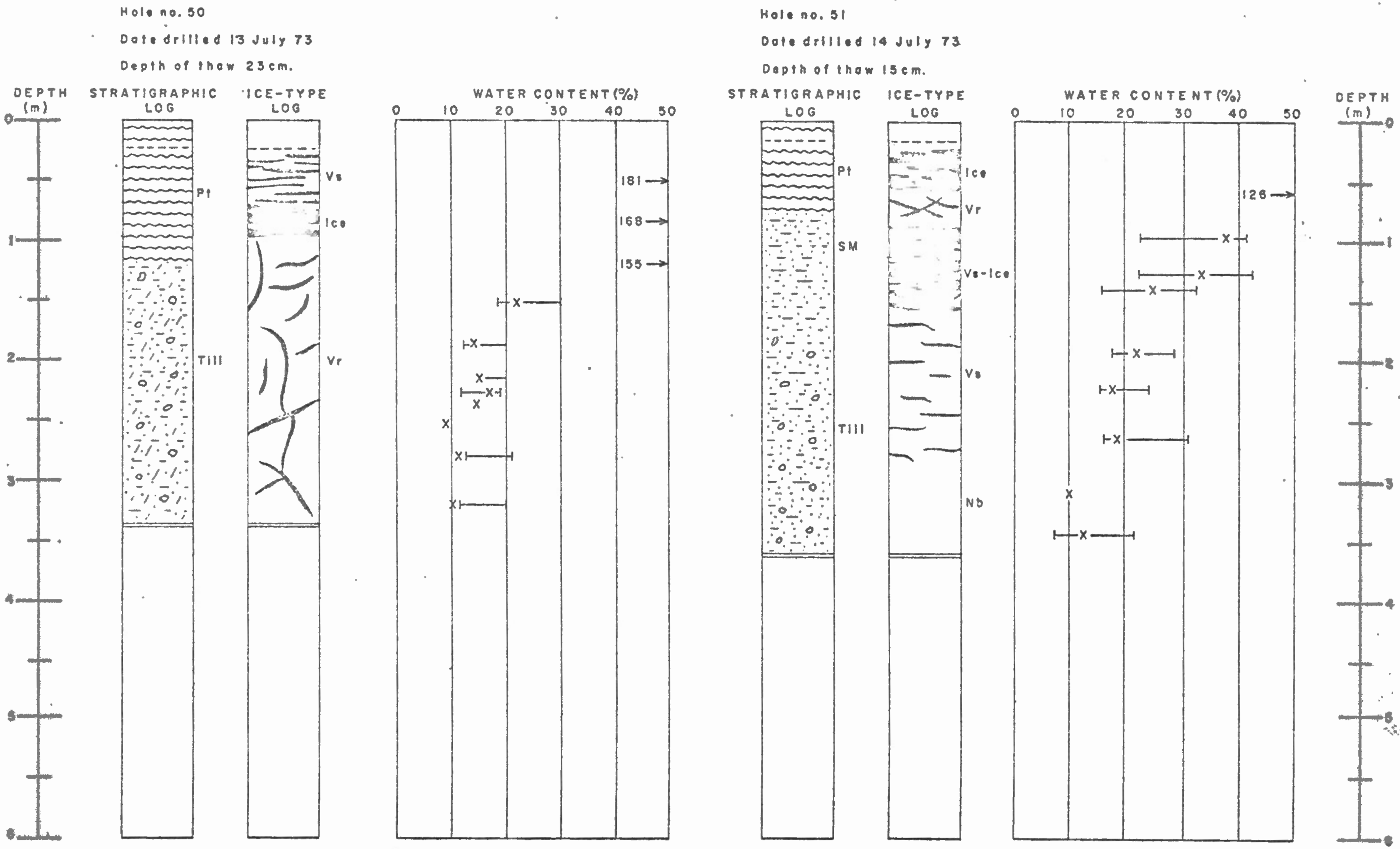

WILLOWLAKE RIVER SITE II
Surface condition
MACKENZIE HIGHWAY CLEARED RECENTLY
UNDISTURBED
CNT LINE
cleared >3 years ago
Hole No.
53
52
51
50
49
NOT TO SCALE
NOT TO SCALE
Actual Terrain
0.11
0.15
0.50
0.84
1.60
3.60
2.60
2.75
DEPTH IN METRES
0.00
1.00
2.00
3.00
4.00
4.50
0 5 10 15 20 25
METRES

FIGURE A8


Hole no. 50
Date drilled 13 July 73
Depth of thaw 23 cm.
DEPTH (m)
STRATIGRAPHIC LOG
ICE-TYPE LOG
WATER CONTENT (%)
0 10 20 30 40 50
0
1
2
3
4
5
6
Pt
Till
Vs
Ice
Vr
181
168
155
Hole no. 51
Date drilled 14 July 73
Depth of thaw 15 cm.
STRATIGRAPHIC LOG
ICE-TYPE LOG
WATER CONTENT (%)
0 10 20 30 40 50
DEPTH (m)
Pt
SM
Till
Ice
Vr
Vs-Ice
Vs
Nb
126
FIGURE A9

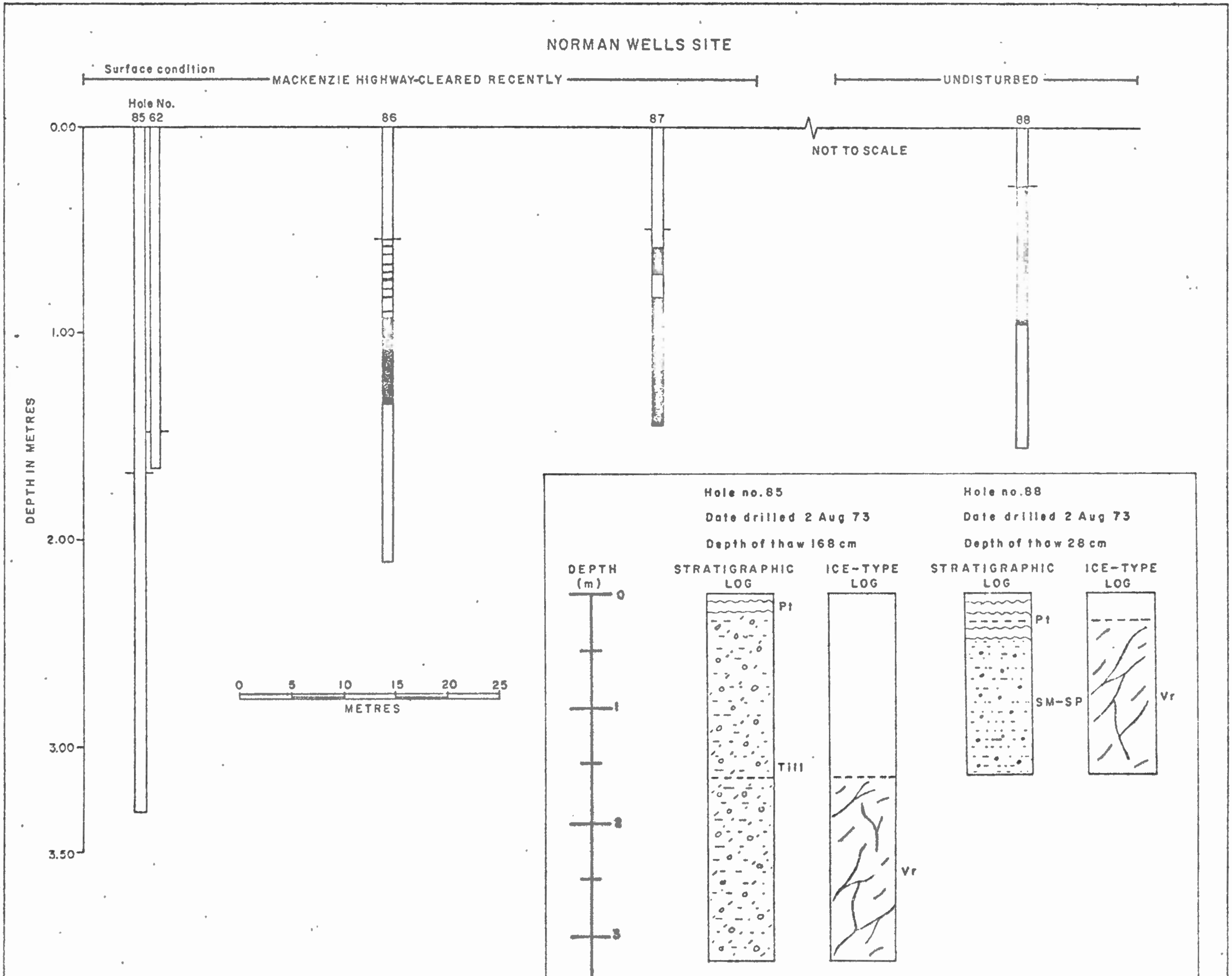

NORMAN WELLS SITE
Surface condition
MACKENZIE HIGHWAY-CLEARED RECENTLY
UNDISTURBED
Hole No.
85 62
86
87
88
NOT TO SCALE
0.00
1.00
2.00
3.00
3.50
DEPTH IN METRES
0 5 10 15 20 25
METRES
Hole no. 85
Date drilled 2 Aug 73
Depth of thaw 168 cm
Hole no. 88
Date drilled 2 Aug 73
Depth of thaw 28 cm
DEPTH (m)
0
1
2
3
STRATIGRAPHIC LOG
ICE-TYPE LOG
Pt
Till
Vr
SM-SP

FIGURE A10

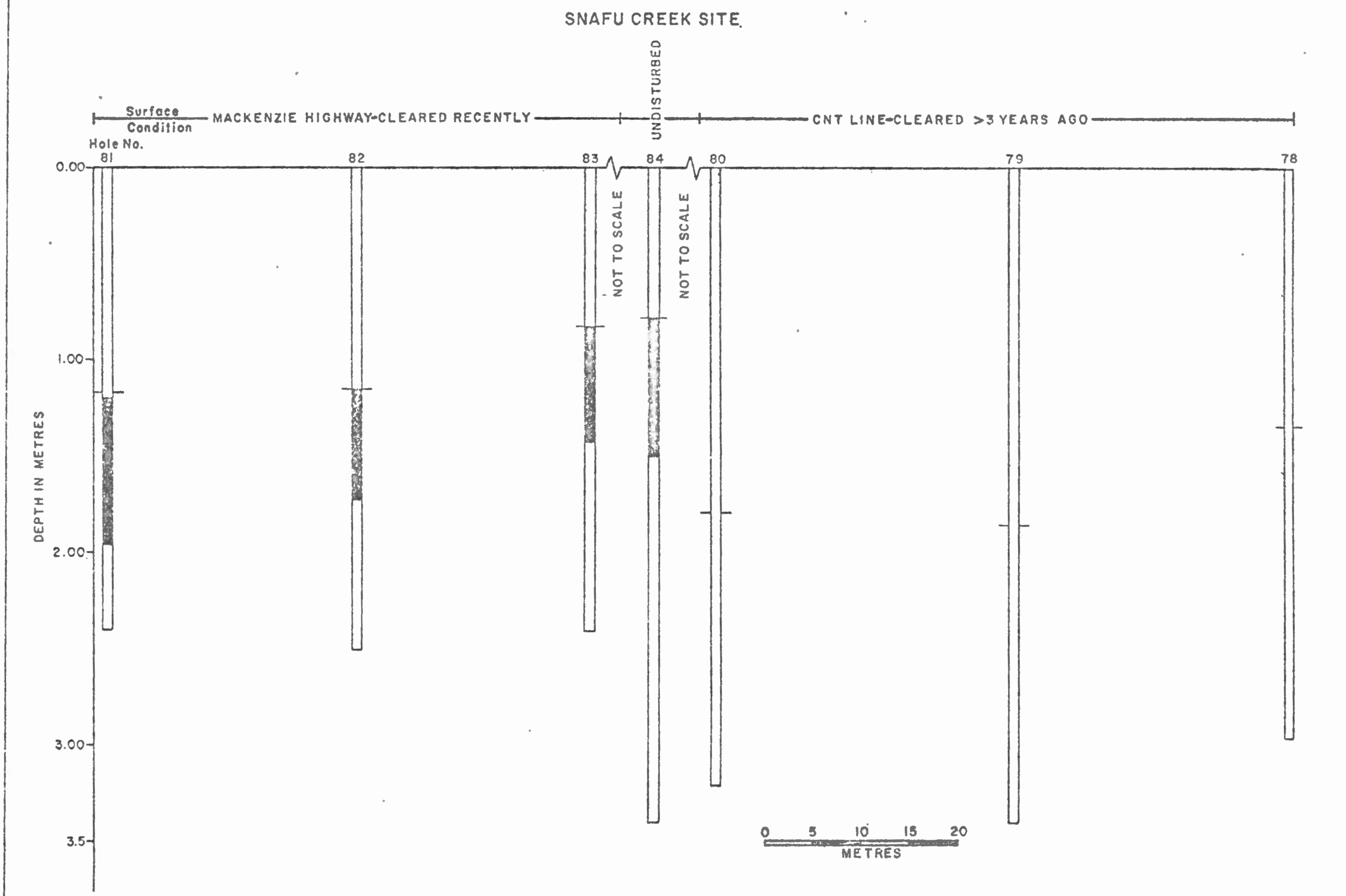

SNAFU CREEK SITE
UNDISTURBED
Surface Condition
MACKENZIE HIGHWAY-CLEARED RECENTLY
CNT LINE-CLEARED >3 YEARS AGO
Hole No.
81
82
83
84
80
79
78
NOT TO SCALE
NOT TO SCALE
0.00
1.00
2.00
3.00
3.5
DEPTH IN METRES
0 5 10 15 20
METRES

FIGURE A11

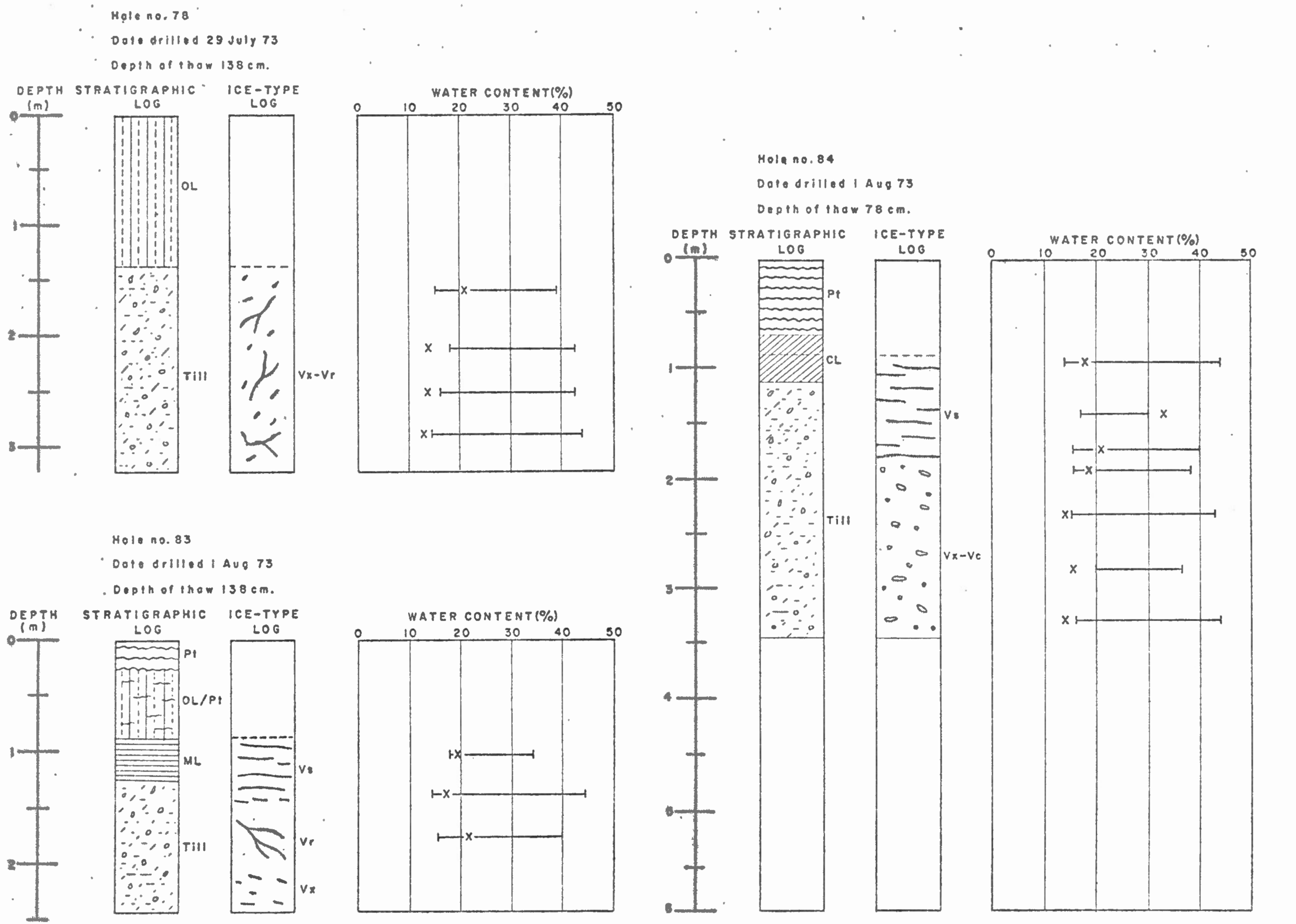
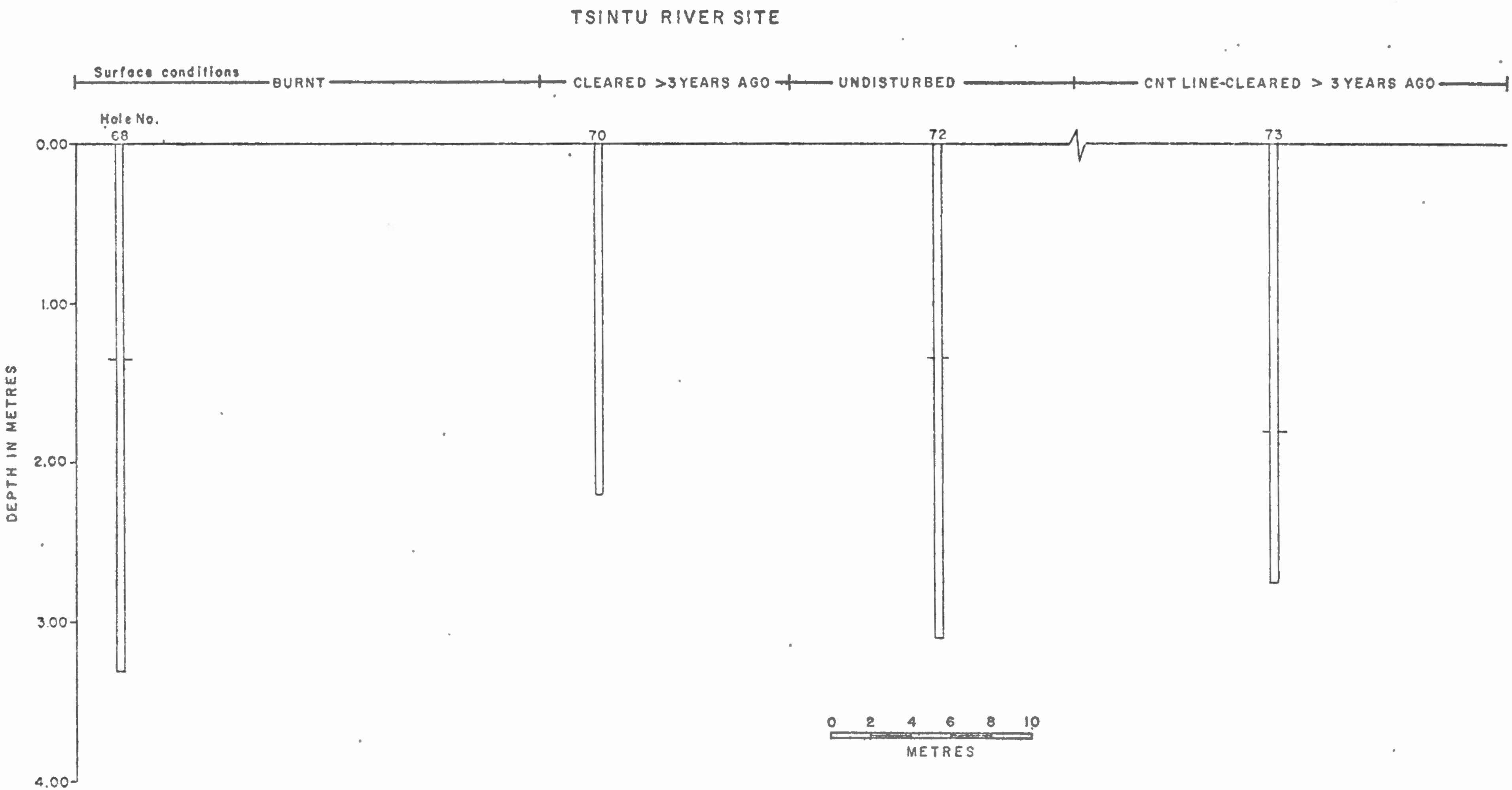

Hole no. 78
Date drilled 29 July 73
Depth of thaw 138 cm.
DEPTH (m)
STRATIGRAPHIC LOG
ICE-TYPE LOG
WATER CONTENT (%)
0
10
20
30
40
50
0
1
2
3
OL
Till
Vx-Vr
Hole no. 83
Date drilled 1 Aug 73
Depth of thaw 138 cm.
DEPTH (m)
STRATIGRAPHIC LOG
ICE-TYPE LOG
WATER CONTENT (%)
0
10
20
30
40
50
0
1
2
Pt
OL/Pt
ML
Till
Vs
Vr
Vx
Hole no. 84
Date drilled 1 Aug 73
Depth of thaw 78 cm.
DEPTH (m)
STRATIGRAPHIC LOG
ICE-TYPE LOG
WATER CONTENT (%)
0
10
20
30
40
50
0
1
2
3
4
5
6
Pt
CL
Till
Vs
Vx-Vc

FIGURE A12



TSINTU RIVER SITE
Surface conditions
BURNT
CLEARED >3 YEARS AGO
UNDISTURBED
CNT LINE-CLEARED > 3 YEARS AGO
Hole No.
68
70
72
73
0.00
1.00
2.00
3.00
4.00
DEPTH IN METRES
0 2 4 6 8 10
METRES

FIGURE A13

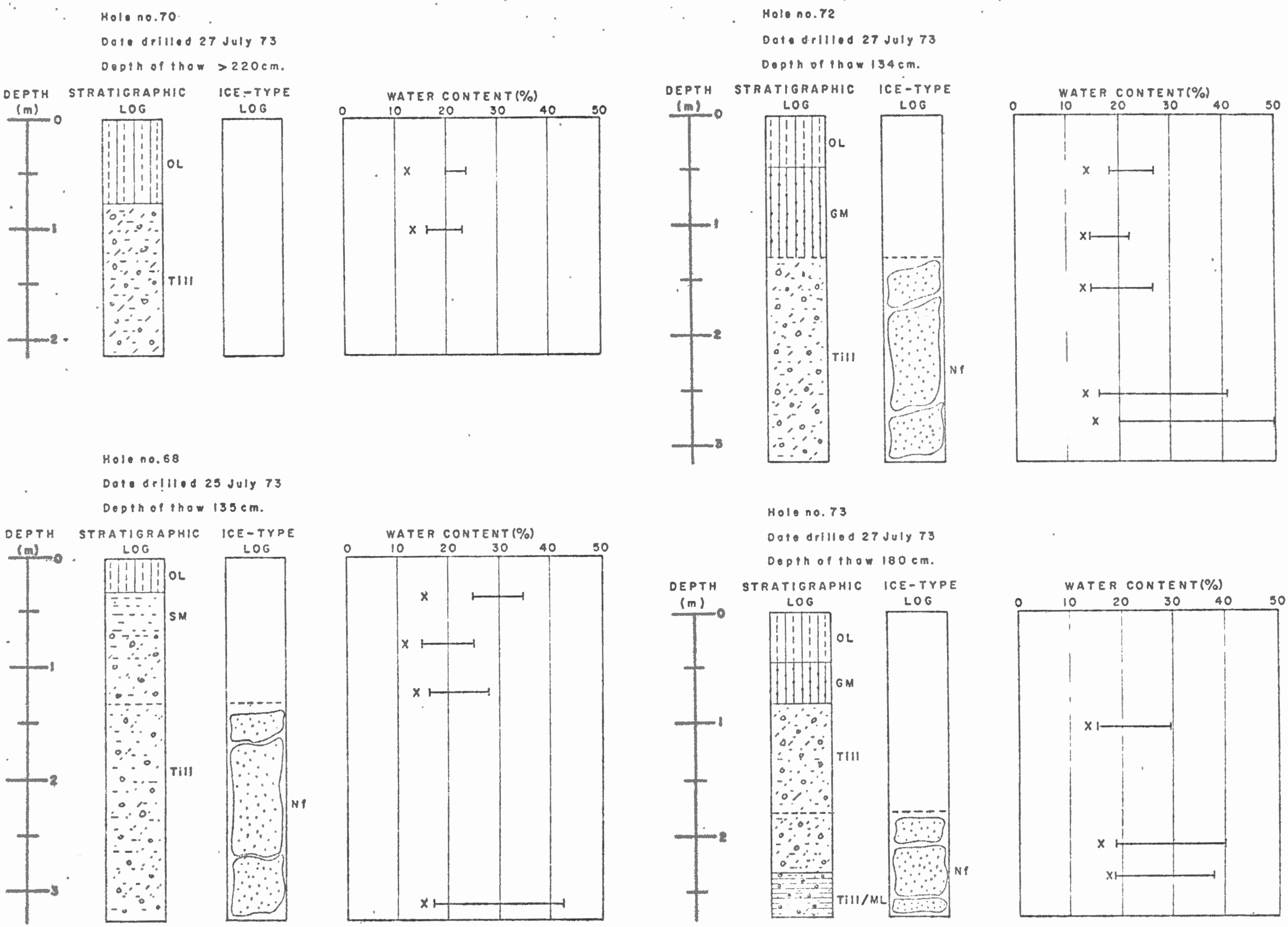
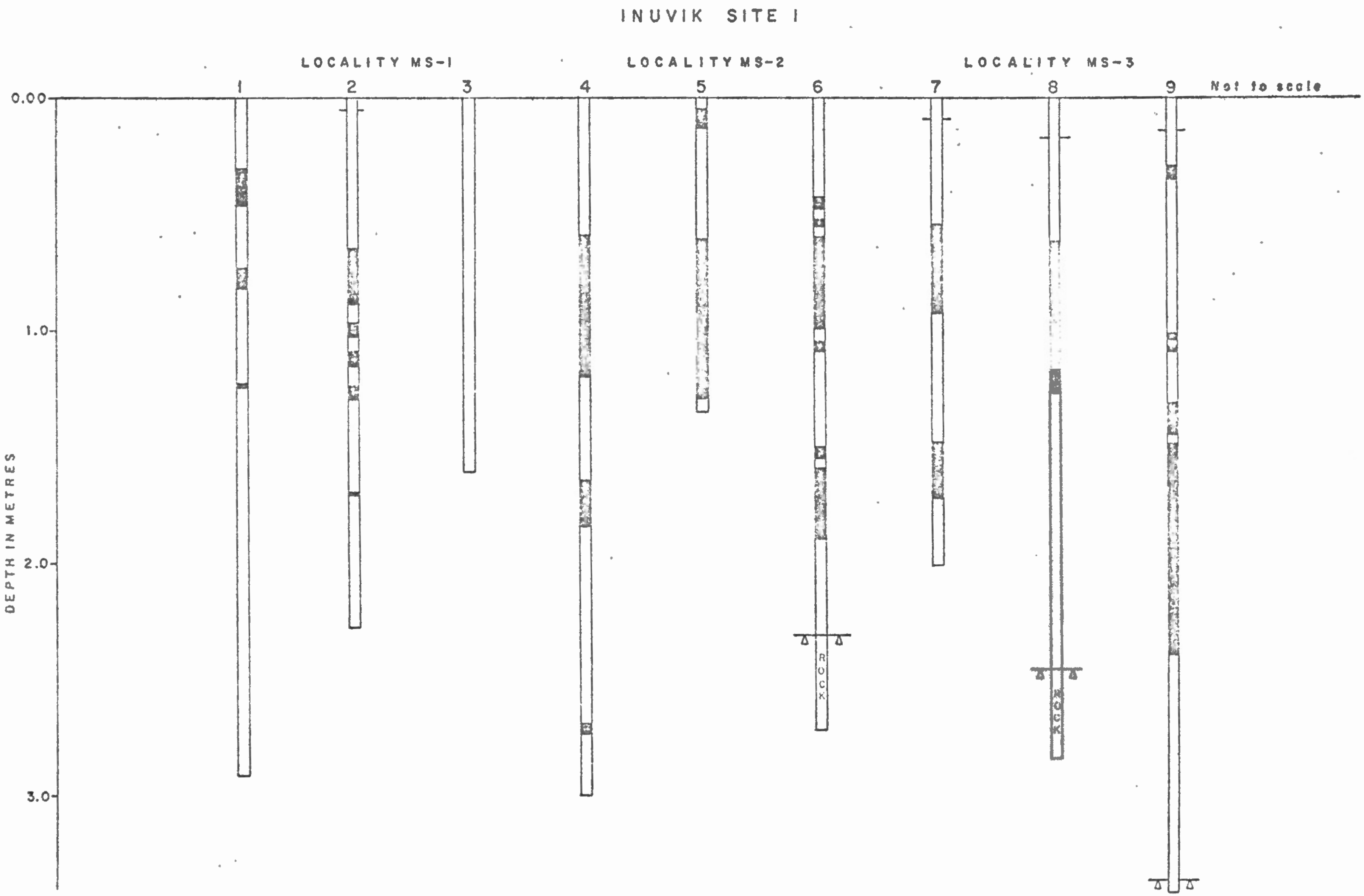

Hole no. 70
Date drilled 27 July 73
Depth of thaw >220 cm.
DEPTH (m)
STRATIGRAPHIC LOG
ICE-TYPE LOG
WATER CONTENT (%)
OL
Till
Hole no. 72
Date drilled 27 July 73
Depth of thaw 134 cm.
GM
Nf
Hole no. 68
Date drilled 25 July 73
Depth of thaw 135 cm.
SM
Hole no. 73
Date drilled 27 July 73
Depth of thaw 180 cm.
Till/ML

FIGURE A14



INUVIK SITE I
LOCALITY MS-1
LOCALITY MS-2
LOCALITY MS-3
1
2
3
4
5
6
7
8
9
Not to scale
0.00
1.0
2.0
3.0
DEPTH IN METRES
ROCK
ROCK

FIGURE A15

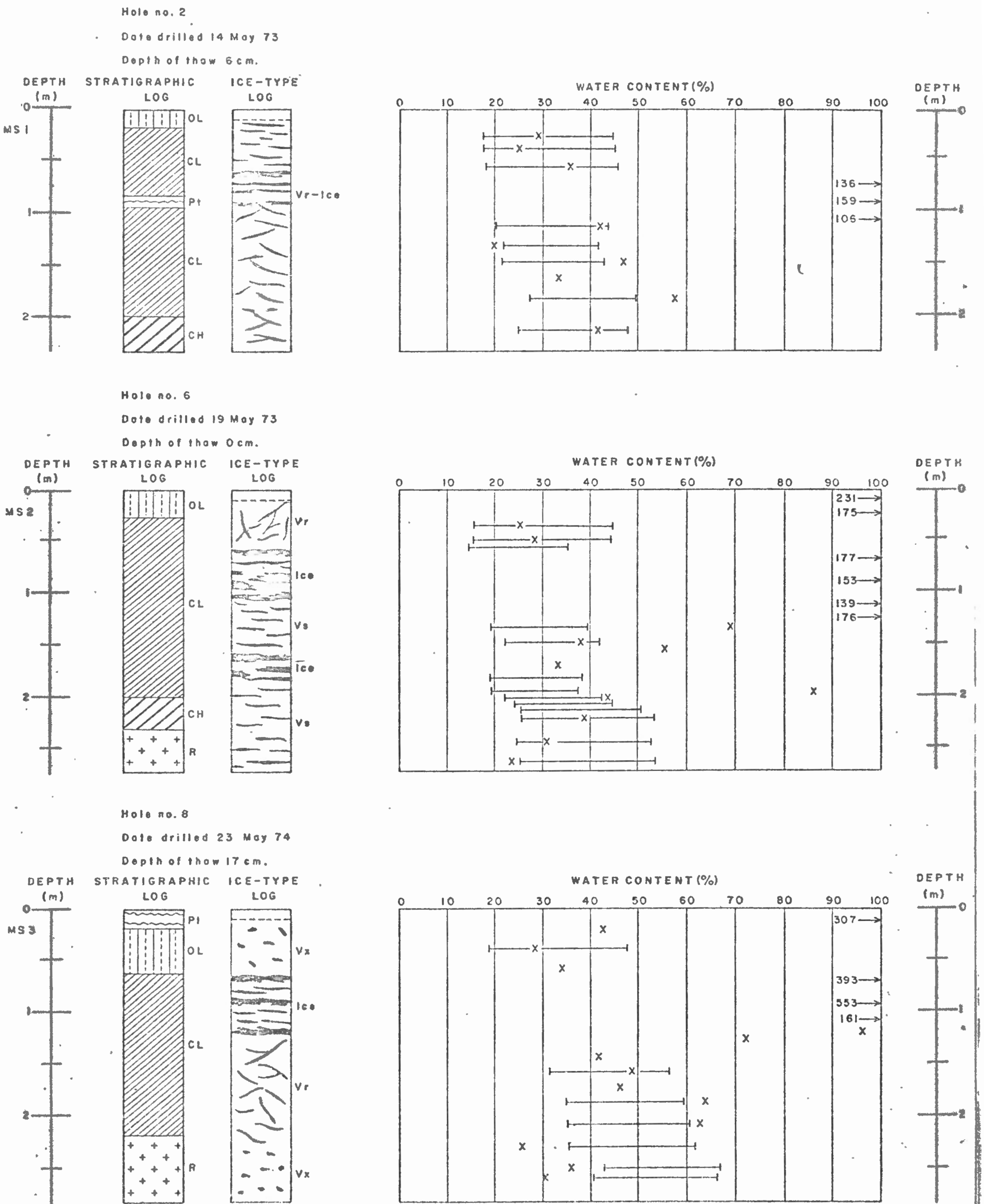
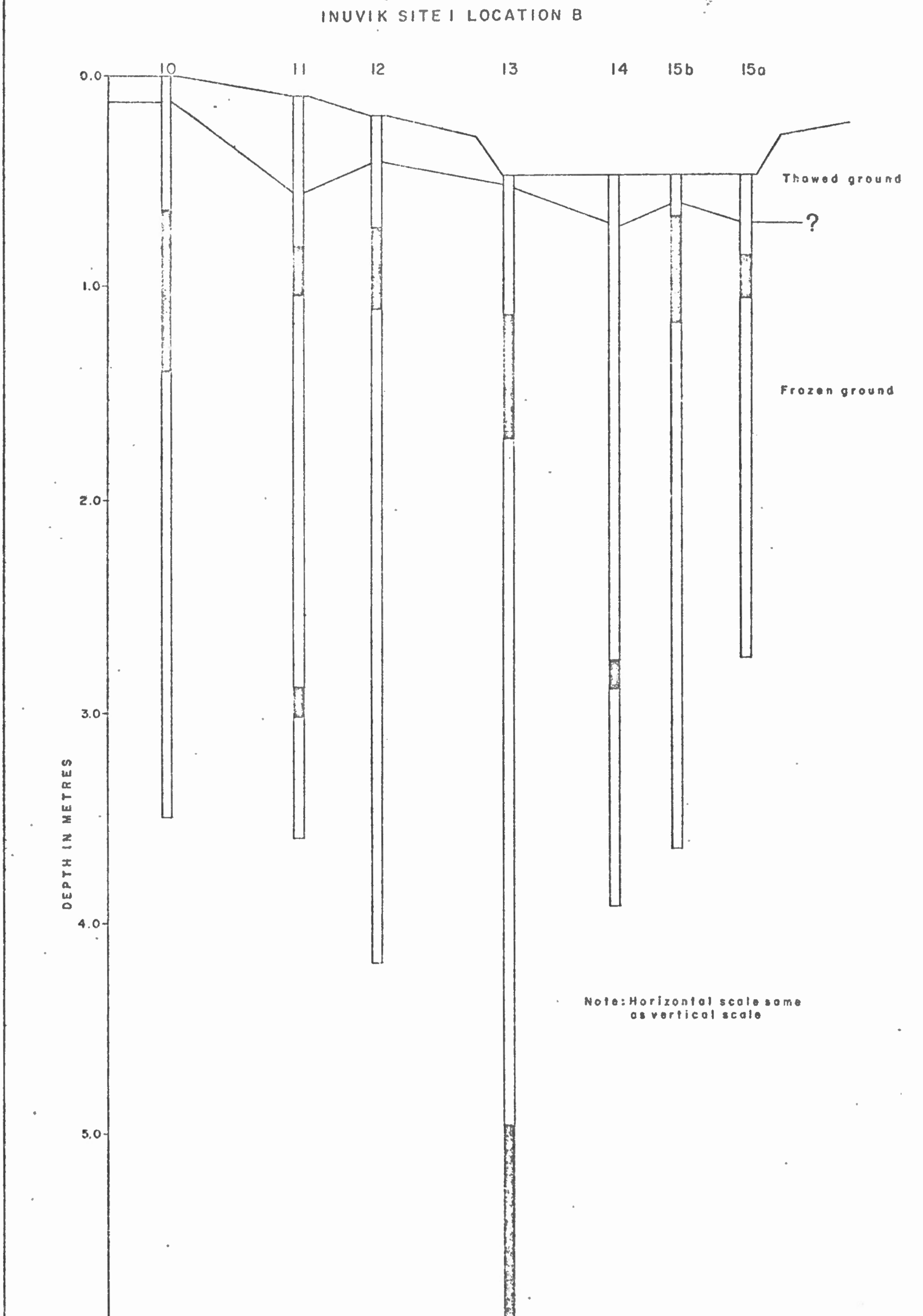

Hole no. 2
Date drilled 14 May 73
Depth of thaw 6 cm.
DEPTH (m)
STRATIGRAPHIC LOG
ICE-TYPE LOG
WATER CONTENT (%)
MS 1
OL
CL
Pt
CL
CH
Vr-Ice
136
159
106
Hole no. 6
Date drilled 19 May 73
Depth of thaw 0 cm.
MS 2
OL
CL
CH
R
Vr
Ice
Vs
Ice
Vs
231
175
177
153
139
176
Hole no. 8
Date drilled 23 May 74
Depth of thaw 17 cm.
MS 3
Pt
OL
CL
R
Vx
Ice
Vr
Vx
307
393
553
161

FIGURE A16



INUVIK SITE I LOCATION B
10
11
12
13
14
15b
15a
0.0
1.0
2.0
3.0
4.0
5.0
6.0
DEPTH IN METRES
Thawed ground
?
Frozen ground
Note: Horizontal scale same as vertical scale

FIGURE A17

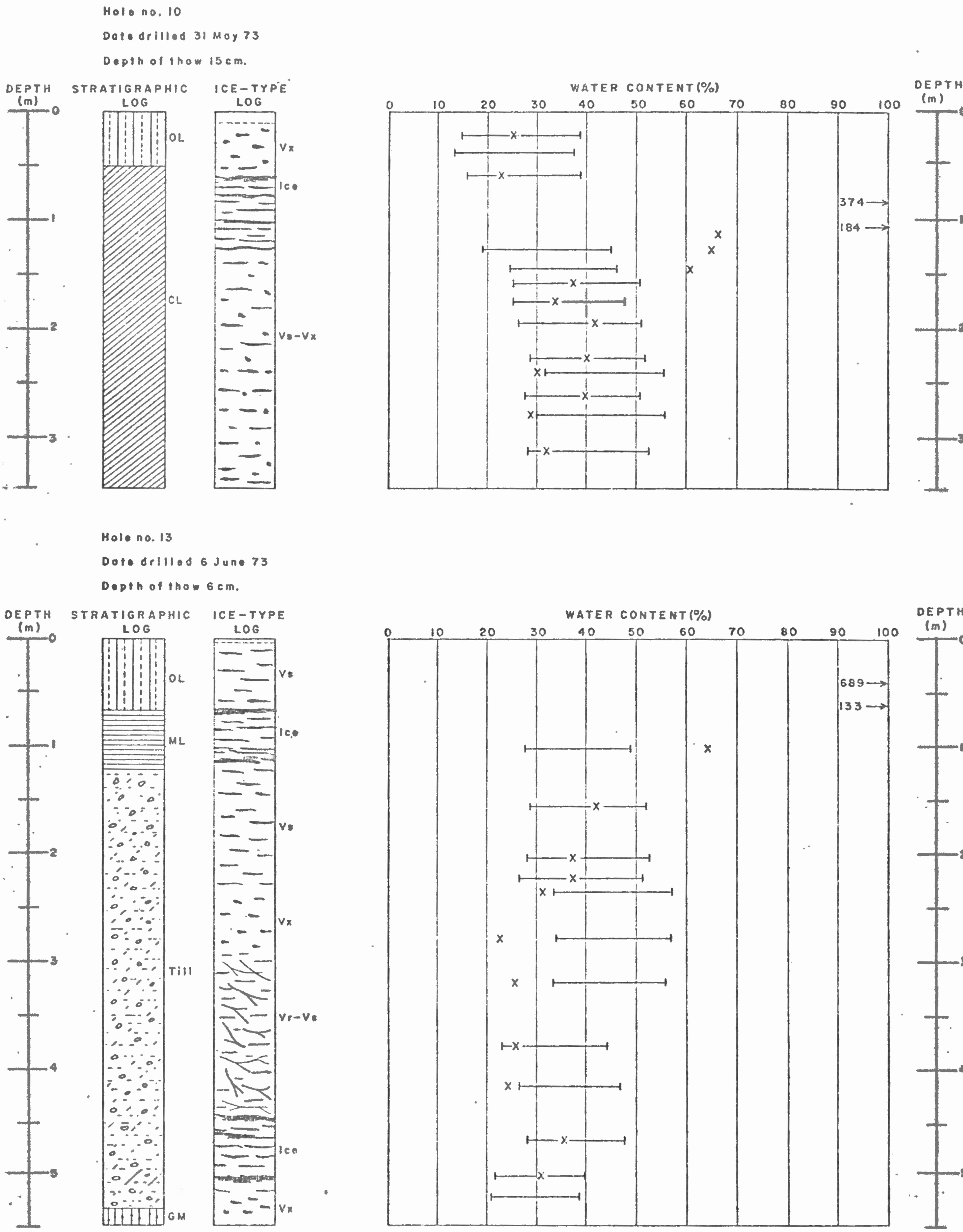
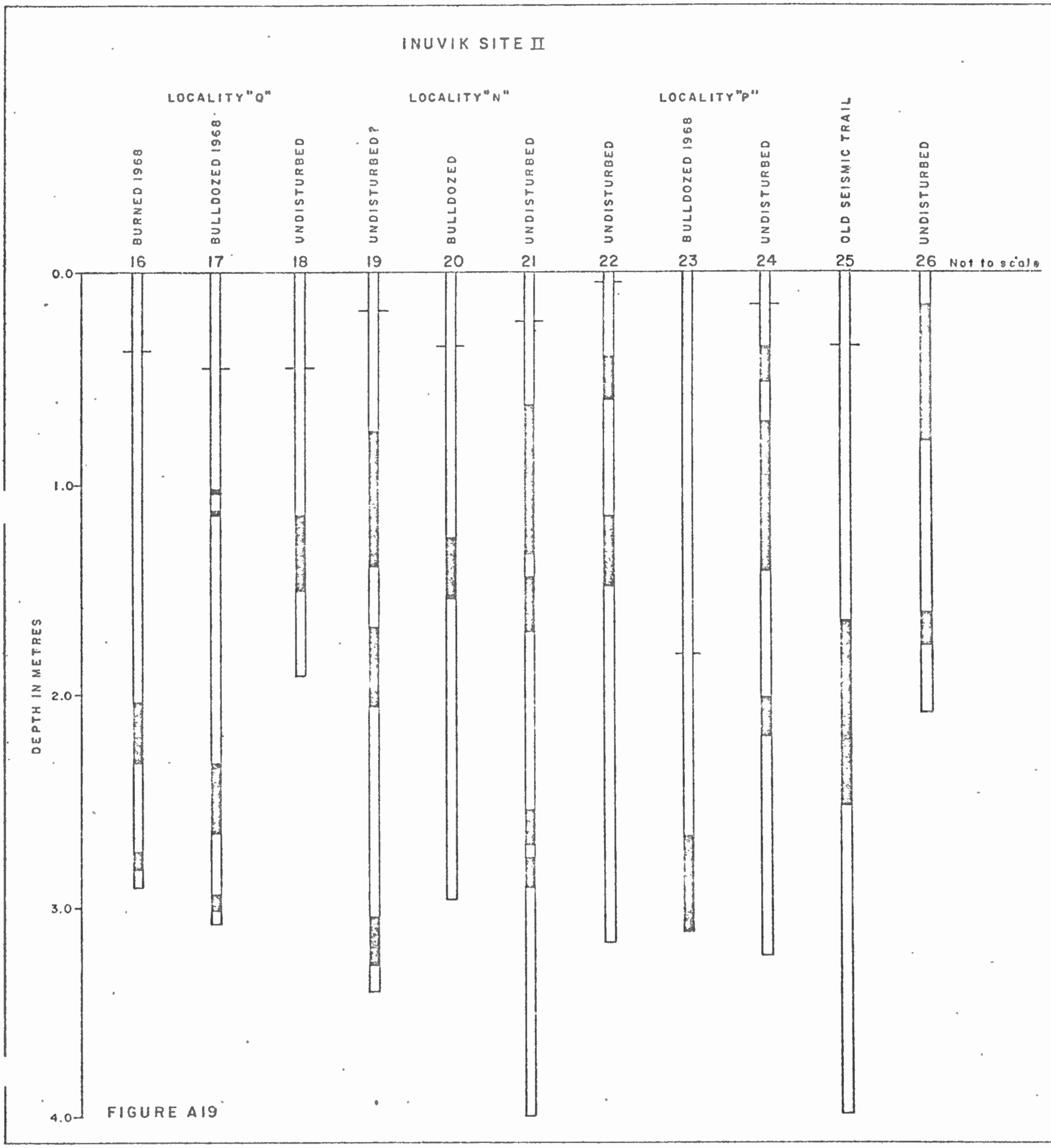

Hole no. 10
Date drilled 31 May 73
Depth of thaw 15 cm.
DEPTH (m)
STRATIGRAPHIC LOG
ICE-TYPE LOG
OL
CL
Vx
Ice
Vs-Vx
WATER CONTENT (%)
0 10 20 30 40 50 60 70 80 90 100
374
184
0 1 2 3
Hole no. 13
Date drilled 6 June 73
Depth of thaw 6 cm.
DEPTH (m)
STRATIGRAPHIC LOG
ICE-TYPE LOG
OL
ML
Till
GM
Vs
Ice
Vs
Vx
Vr-Vs
Ice
Vx
WATER CONTENT (%)
0 10 20 30 40 50 60 70 80 90 100
689
133
0 1 2 3 4 5

FIGURE A18



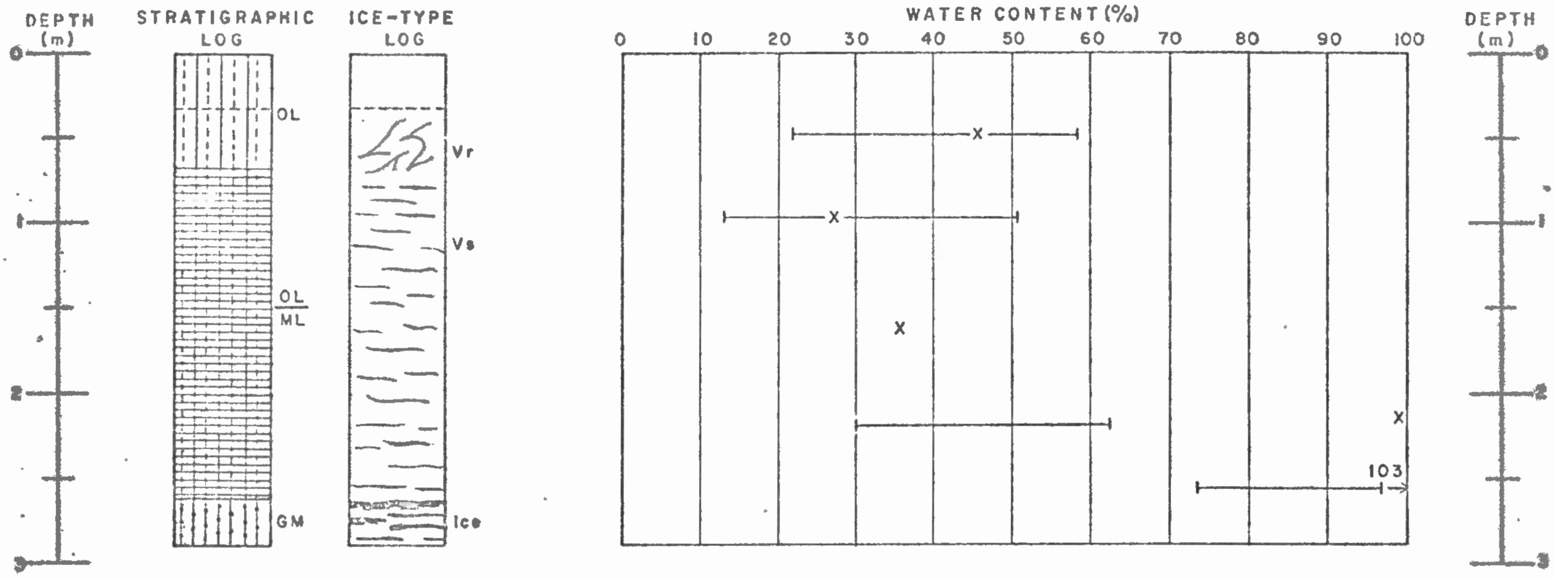
INUVIK SITE II
LOCALITY "Q"
LOCALITY "N"
LOCALITY "P"
BURNED 1968
BULLDOZED 1968
UNDISTURBED
UNDISTURBED?
BULLDOZED
UNDISTURBED
UNDISTURBED
BULLDOZED 1968
UNDISTURBED
OLD SEISMIC TRAIL
UNDISTURBED
16
17
18
19
20
21
22
23
24
25
26
Not to scale
0.0
1.0
2.0
3.0
4.0
DEPTH IN METRES

FIGURE A19

Hole no. 16

Date drilled 9 June 73

Depth of thaw 38 cm.



Hole no. 23

Date drilled 15 June 73

Depth of thaw 181 cm.

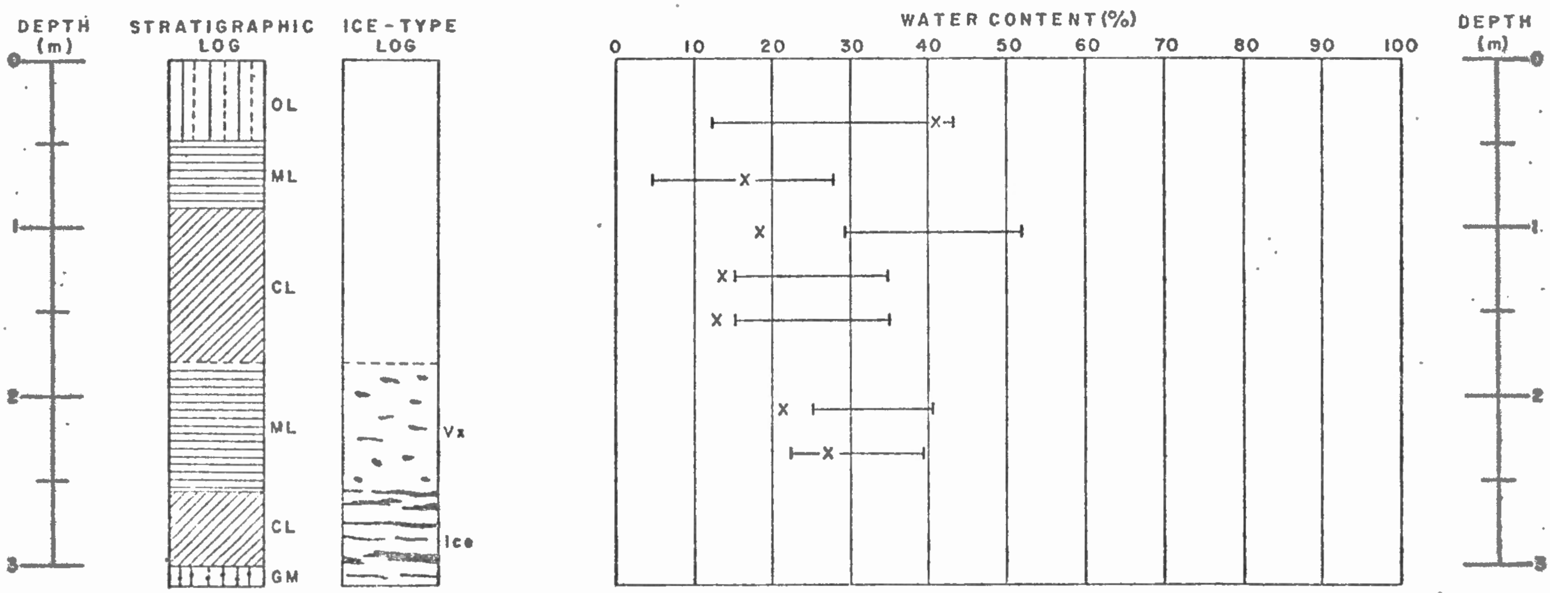
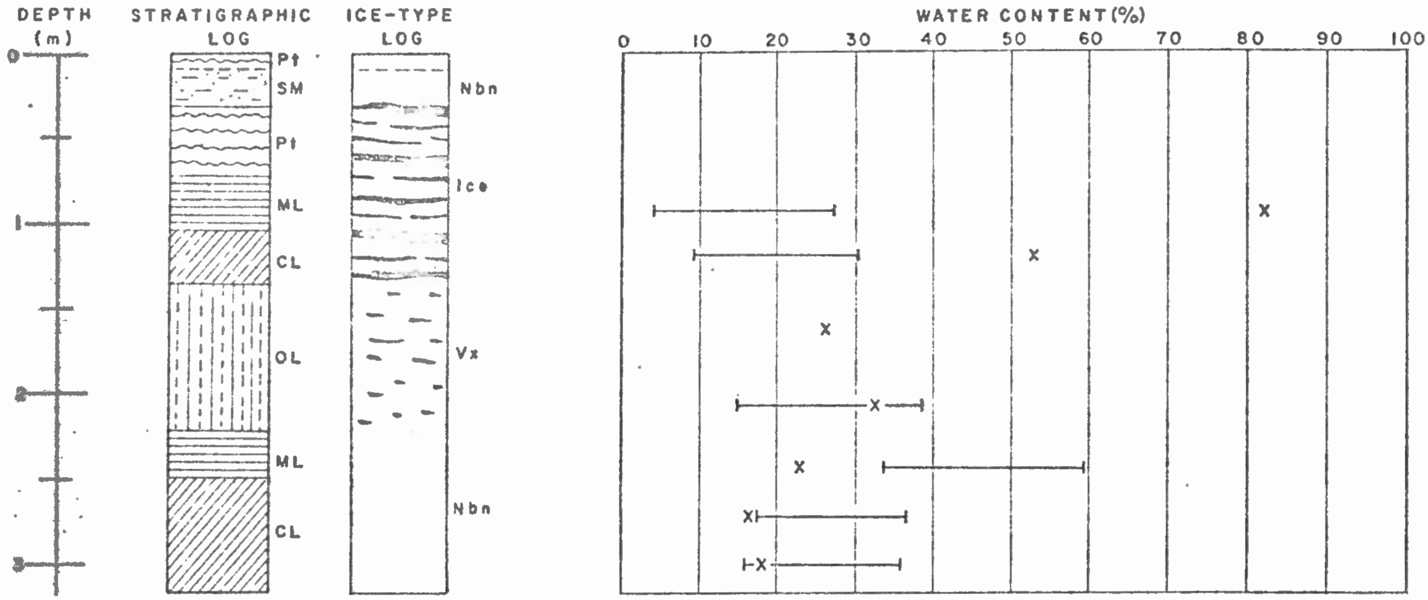


FIGURE A 20

Hole no. 24

Date drilled 18 June 73

Depth of thaw 15 cm.



Hole no. 25

Date drilled 19 June 73

Depth of thaw 35cm

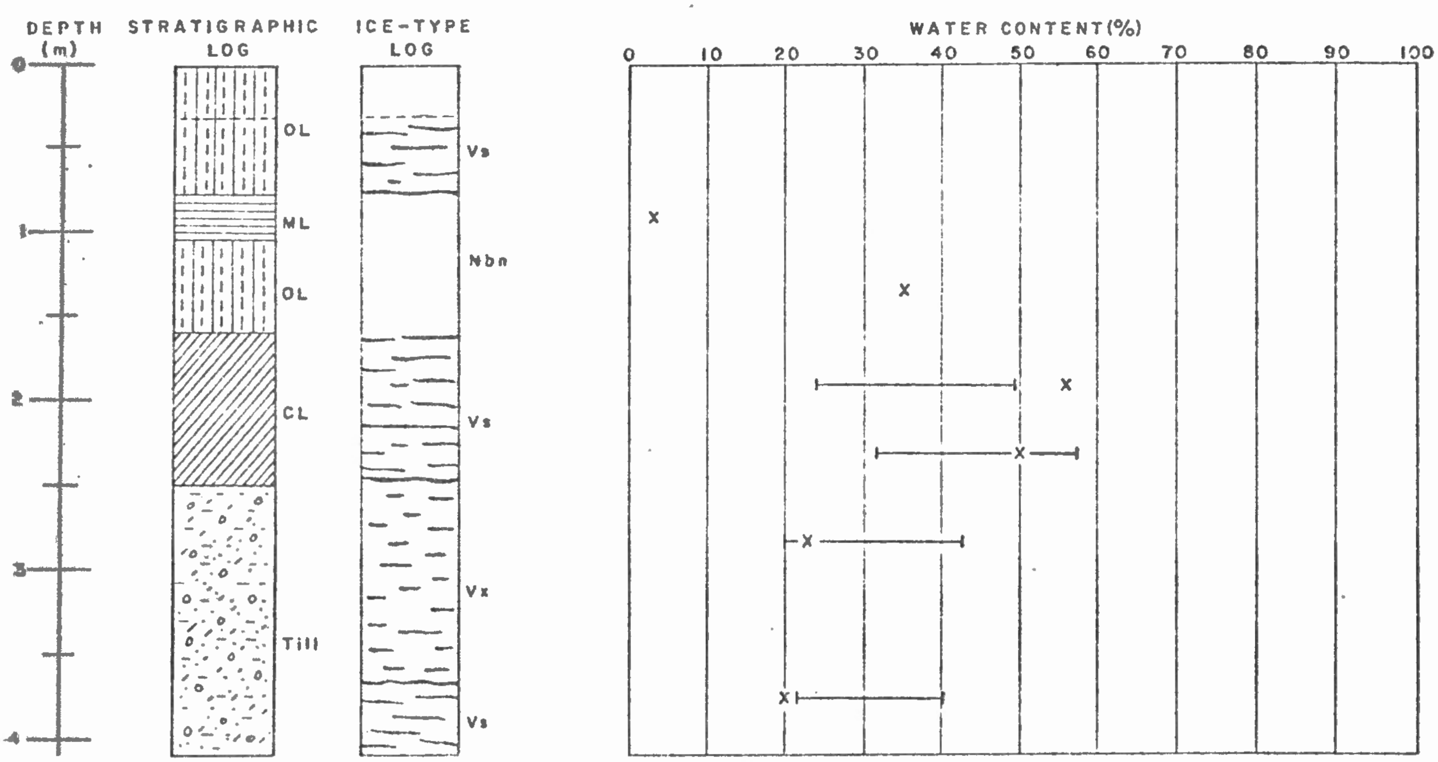


FIGURE A21

APPENDIX B

SUMMARY OF LABORATORY DATA

Index to Localities

Site name	Holes drilled
Inuvik I	1 - 15B
Inuvik II	16 - 26
Fort Simpson	30 - 48
Martin River	58 - 61
Willowlake River I	54 - 57
Willowlake River II	49 - 53
Norman Wells	62 - 64 and 85 - 88
Snafu Creek	78 - 84
Tsintu River	65 - 77

Note: Holes 27 - 29 were not drilled.

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
1	100	24-40	silt gravel	30.9	47.5	26.9	20.6
	101	94-108	clay silt	55.7	44.2	24.7	19.5
	102	112-122	sandy clay silt	99.5	-	-	-
	103	167-174	sandy clay silt	20.3	30.4	17.9	12.5
	104	184-192	silt gravel	34.8	-	-	-
	105	202-212	sandy clay silt	42.9	37.6	17.6	20.0
	106	243-253	clayey silt gravel	34.2	38.3	17.6	20.7
	107	253-265	sandy clay silt	34.8	38.2	18.9	19.3
	108	265-274	clay silt	48.9	39.7	18.9	20.8
2	113	11-21	sandy clay silt	68.5	-	-	-
	114	21-34	clay silt	29.6	45.4	26.6	18.8
	115	34-47	clay silt	25.5	45.2	26.5	18.7
	116	46-66	clay silt	36.6	45.8	26.8	19.0
	117	66-88	clay silt	136.3	-	-	-
	118	88-97	organic clay silt	159.3	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
2	119	97-103	organic clay silt	106.1	-	-	-
	120	103-110	clay silt	42.7	43.6	23.6	20.0
	121	130-137	sandy clay silt	20.8	41.4	18.7	22.7
	122	137-163	clay silt	46.4	43.8	21.6	22.2
	123	163-170	clay silt	33.5	-	-	-
	124	173-201	clay silt	57.0	49.1	21.8	27.3
	125	201-227	clay silt	41.5	47.8	21.9	25.9
3	130	0-13	peat	751.2	-	-	-
	131	13-28	sandy clay silt	33.4	41.6	23.5	18.1
	132	28-40	clay silt	25.0	55.5	25.7	29.8
	133	40-53	clay silt	39.4	51.1	25.0	26.1
	134	53-63	clay silt	61.7	-	-	-
	135	63-87	clay silt	52.2	55.7	25.5	30.2
	136	87-97	clay silt	72.1	58.6	25.8	32.8
	137	97-126	clay silt	41.9	49.4	22.9	26.5
	138	126-152	clay silt	41.4	51.3	23.3	28.0
	139	152-163	sandy clay silt	37.3	44.9	21.0	23.9

Hole No.	Sample No.	Depth cm	Sample Description	Water Content	Liquid Limit	Plastic Limit	Index of Plasticity
4	140	0-6	peat	445.7	-	-	-
	141	6-20	sandy clay silt	130.1	-	-	-
	142	20-28	sandy clay silt	35.8	36.4	23.3	13.1
	143	28-50	sandy clay silt	22.8	36.5	25.0	11.5
	144	50-61	clay silt	31.0	47.2	29.0	18.2
	145	61-76	sandy clay silt	395.5	-	-	-
	146	76-82	clay silt	180.1	-	-	-
	147	82-91	clay silt	458.1	-	-	-
	148	91-102	clay silt	128.8	-	-	-
	149	102-121	clay silt	776.5	-		-
	150	121-140	organic clay silt	224.6	-	-	-
	151	140-154	peat	236.0	-	-	-
	152	154-165	peat	317.7	-	-	-
	153	165-184	peat	211.0	-	-	-
	154	184-192	peat	420.8	-	-	-
	155	192-198	peat	413.6	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
4	156	198-224	peat	386.7	-	-	-
	157	224-237	peat	518.7	-	-	-
	158	237-255	peat	468.4	-	-	-
	159	255-269	clay silt	162.2	-	-	-
	160	269-275	clay silt	525.7	-	-	-
	161	275-295	organic clay silt	307.5	-	-	-
	162	295-299	organic silt clay	216.6	-	-	-
5	163	4-13	sandy clay silt	55.4	-	-	-
	164	13-28	sandy clay silt	16.2	32.5	21.1	11.4
	165	38-60	sandy clay silt	19.8	36.2	21.8	14.4
	166	60-88	sandy clay silt	272.1	-	-	-
	167	88-105	sandy clay silt	85.9	42.8	24.7	18.1
	168	105-132	sandy clay silt	145.3	46.2	27.1	19.1
	169	132-136	peat	130.7	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
6	170	0-26	peat	230.6	-	-	-
	171	26-31	peat	175.4	-	-	-
	172	31-40	sandy clay silt	25.9	44.9	28.1	16.8
	173	40-56	sandy clay silt	28.2	44.5	27.7	16.8
	174	56-60	sandy clay silt	-	35.3	19.9	15.4
	175	60-78	sandy clay silt	177.4	-	-	-
	176	78-96	sandy clay silt	-	-	-	-
	177	96-101	sandy clay silt	152.7	-	-	-
	178	101-105	sandy clay silt	100.4	-	-	-
	179	105-109	sandy clay silt	139.0	-	-	-
	180	109-117	peat	175.7	-	-	-
	181	117-128	gravelly clay silt	-	-	-	-
	182	128-141	sandy clay silt	68.5	39.5	20.3	19.2
	183	141-151	clay silt	37.8	42.9	19.1	23.8

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
6	184	151-156	clay silt	54.7	-	-	-
	185	156-161	clay silt	33.8	-	-	-
	186	161-178	clay silt	84.5	38.9	19.8	19.1
	187	178-189	sandy clay silt	43.2	42.4	20.2	22.2
	188	189-201	clay silt	-	44.7	20.4	24.3
	189	201-214	clay silt	-	49.9	25.0	24.9
	190	214-232	clay silt	38.5	53.3	27.0	26.3
	191	232-260	clay silt	30.9	52.9	28.1	24.8
	192	260-272	clay silt	24.1	53.4	26.9	26.5
7	193	16-23	peat	414.6	-	-	-
	194	23-41	sandy clay silt	21.5	43.0	26.7	16.3
	195	41-56	sandy clay silt	25.8	39.1	24.6	14.5
	196	56-84	sandy clay silt	553.0	-	-	-
	197	84-93	clay silt	223.0	-	-	-
	198	93-112	organic clay silt	150.0	58.6	42.3	16.3
	199	112-126	organic clay silt	413.0	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
7	200	126-139	clay silt	88.6	55.6	36.5	19.1
	201	139-147	clay silt	120.1	-	-	-
	202	147-151	peat	62.8	-	-	-
	203	155-172	clay silt	122.2	38.9	21.6	17.3
	204	172-193	clay silt	70.8	34.7	21.4	13.3
	205	193-202	silty sand gravel	20.0	-	-	-
8	206	17-22	peat	307.3	-	-	-
	207	22-31	clay silt	42.5	-	-	-
	208	31-54	clay silt	26.1	47.7	28.4	19.3
	209	54-64	silt clay	33.6	-	-	-
	210	64-85	silt clay	393.2	-	-	-
	211	85-107	silt clay	553.3	-	-	-
	212	107-120	silt clay	161.0	-	-	-
	213	120-127	gravelly silt clay	94.5	-	-	-
	214	127-135	silt clay	70.5	-	-	-
	215	135-156	silt clay	41.8	-	-	-
	216	156-169	silt clay	47.8	55.8	24.3	31.5
	217	169-178	silt clay	45.8	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
8	218	178-195	silt clay	62.8	58.5	24.4	34.1
	219	195-221	silt clay	61.0	59.0	24.6	34.4
	220	221-247	silt clay	35.8	66.3	23.9	42.4
	221	247-270	silt clay	30.0	65.5	24.6	40.9
	222	270-283	silt clay	25.6	60.9	25.0	35.9
9	223	15-22	organic clay	249.3	-	-	-
	224	22-29	organic clay	291.6	-	-	-
	225	29-34	peat	697.1	-	-	-
	226	34-43	peat	347.7	-	-	-
	227	43-51	peat	474.1	-	-	-
	228	51-69	peat	376.8	-	-	-
	229	69-89	peat	767.2	-	-	-
	230	89-102	peat	746.3	-	-	-
	231	102-119	peat	455.3	-	-	-
	232	119-133	peat	276.9	-	-	-
	233	133-145	silty gravel	52.6	-	-	-
	234	145-151	gravelly silt clay	54.1	-	-	-
	235	241-269	silt clay	42.1	56.7	23.3	33.4

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
9	236	269-285	sandy clay silt	32.4	39.8	20.1	19.7
	237	285-323	silt clay	48.1	61.8	23.8	38.0
	238	323-342	silt clay	28.0	56.7	22.8	33.9
10	239	22-30	clay silt	26.9	39.6	23.4	16.2
	240	30-53	clay silt	71.9	38.6	23.8	14.8
	241	53-61	sandy clay silt	24.2	39.9	23.2	16.7
	242	64-94	clay silt	374.3	-	-	-
	243	94-113	clay silt	184.4	-	-	-
	244	113-126	gravelly clay silt	66.5	-	-	-
	245	126-139	clay silt	64.1	45.6	24.5	21.1
	246	139-157	clay silt	60.2	46.5	21.1	25.4
	247	157-166	sandy clay silt	38.1	50.2	22.6	27.6
	248	166-186	clay silt	34.7	48.3	22.5	25.8
	249	186-224	clay silt	42.7	51.0	23.1	27.9
	250	224-240	clay silt	41.2	52.5	22.9	29.6
	251	240-250	gravelly clay silt	30.8	55.5	22.9	32.6

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
10	252	251-277	clay silt	40.1	50.7	21.8	28.9
	253	277-290	clay silt	29.7	55.5	24.3	31.2
	254	290-340	clay silt	32.5	52.4	23.9	28.5
11	255	45-54	sandy clay silt	34.0	45.9	25.6	20.3
	256	54-66	sandy clay silt	21.3	38.2	22.7	15.5
	257	66-72	sandy clay silt	38.2	-	-	-
	258	72-96	clay silt	214.4	-	-	-
	259	96-124	gravelly clay silt	77.9	49.4	24.8	24.6
	260	146-156	clay silt	31.3	50.1	21.9	28.2
	261	158-187	clay silt	35.2	51.9	21.9	30.0
	262	187-220	clay silt	33.7	52.1	22.5	29.6
	263	220-230	clay silt	27.9	-	-	-
	264	230-255	clay silt	29.5	56.2	23.2	33.0
	265	255-271	clay silt	29.9	51.8	23.4	28.4
	266	271-283	silty gravel	30.8	-	-	-
	267	283-2[illegible]0	clay silt	1[illegible].6	-	-	-
	268	290-333	clay silt	27.5	56.8	24.9	31.9

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
11	269	333-341	clay silt	30.8	55.1	24.7	30.4
12	270	16-23	clay silt	28.5	41.5	24.4	17.1
	271	23-47	clay silt	26.2	43.9	28.1	15.8
	272	47-53	clay silt	25.0	36.9	22.8	14.1
	273	53-64	clay silt	512.5	-	-	-
	274	64-71	clay silt	1298.5	-	-	-
	275	71-91	clay silt	279.2	-	-	-
	276	91-118	gravelly clay silt	57.1	47.1	23.9	23.2
	277	118-139	gravelly clay silt	56.0	46.9	21.4	25.5
	278	139-180	clay silt	47.2	50.3	22.1	28.2
	279	180-197	gravelly clay silt	35.3	50.9	22.1	28.8
	280	197-206	clayey silt gravel	30.0	-	-	-
	281	206-237	clay silt	35.4	50.7	22.5	28.2
	282	237-266	clay silt	30.2	51.3	23.0	28.3
	283	266-286	clay silt	30.0	53.9	23.7	30.2
	284	286-310	clay silt	25.4	54.3	23.5	30.8
	285	335-360	gravelly clay silt	24.2	54.0	23.8	30.2

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
12	286	370-403	clay silt	23.0	49.0	21.7	27.3
13	308	25-49	peat	688.7	-	-	-
	309	49-59	organic clay silt	132.3	-	-	-
	310	79-125	clay silt	62.7	48.7	20.9	27.8
	311	135-175	clay silt	42.9	51.6	22.7	28.9
	312	196-215	gravelly clay silt	38.2	51.9	23.3	28.6
	313	215-231	clay silt	37.8	50.5	23.1	27.4
	314	231-246	clay silt	31.7	57.5	23.7	33.8
	315	266-300	clay silt	22.9	56.2	23.4	32.8
	316	310-340	clay silt	26.9	55.6	23.4	32.2
	317	370-400	clay silt	26.8	43.2	18.7	24.5
	318	415-445	clay silt	25.4	47.3	20.1	27.2
	319	460-485	clay silt	35.4	47.7	19.4	28.3
	320	485-520	sandy clay silt	41.9	40.3	18.2	22.1
	321	520-537	sandy clay silt	82.0	39.6	18.3	21.3
14	[illegible]4	2[illegible]6	p[illegible]t	725.4	-	-	-
	325	46-62	clay silt	122.0	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
14	326	90-125	clay silt	63.6	47.5	21.6	25.9
	327	150-185	clay silt	-	52.5	23.7	28.8
	328	275-305	clay silt	-	54.2	23.3	30.9
15A	289	23-39	peat	650.5	-	-	-
	290	39-48	organic clay silt	420.9	-	-	-
	291	48-56	sandy clay silt	253.8	-	-	-
	292	61-69	clay silt	387.4	-	-	-
	293	74-115	clay silt	77.7	45.8	24.1	21.7
	294	115-137	clay silt	52.0	45.8	21.1	24.7
	295	137-156	gravelly clay silt	17.6	48.3	22.0	26.3
	296	156-165	clay silt	18.3	52.2	22.9	29.3
15B	298	16-21	peat	1273.6	-	-	-
	299	21-41	clay silt	538.5	-	-	-
	300	41-45	clay silt	177.7	-	-	-
	301	45-69	clay silt	443.8	-	-	-
	302	69-117	clay silt	54.2	45.8	22.0	23.8
	303	117-168	clay silt	37.6	49.6	22.5	27.1
	304	168-180	clay silt	39.0	49.9	22.5	27.4

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
15B	305	180-203	clay silt	46.3	54.2	23.2	31.0
	306	203-233	clay silt	44.3	50.6	21.4	29.2
	307	233-276	clay silt	32 6	55.6	23.8	31.8
16	329	38-63	silt clay	45.9	58.8	36.2	22.6
	330	85-107	silt clay	28.5	50.1	35.6	14.5
	331	157-163	silty clay sand	36.4	-	-	-
	332	212-239	silt clay	97.1	61.5	31.5	30.0
	333	245-270	organic clay silt	103.4	95.5	71.9	23.6
17	334	125-145	silt clay	35.4	48.3	33.4	14.9
	335	165-195	silt clay	46.8	50.7	31.2	19.5
	336	265-287	organic silt clay	153.8	100.0	67.2	32.8
18	337	55-95	organic silt clay	28.8	57.6	34.3	23.3
	338	127-140	silt clay	125.4	58.2	34.3	23.9
	339	150-186	peat	275.7	-	-	-
19	341	110-135	silt clay	52.8	58.5	30.8	27.7
	342	138-167	silt clay	46.3	53.4	29.7	23.7
	343	229-245	clayey silt sand	28.6	28.1	21.8	6.3

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
20	344	91-124	silt clay	46.4	54.1	29.2	24.9
	345	180-205	clay silt	29.4	53.2	23.7	29.5
	346	205-265	silt clay	22.5	62.0	25.6	36.4
21	347	22-45	silt clay	44.6	70.3	48.3	22.0
	348	85-110	silt clay	137.3	49.3	35.4	13.9
	349	145-169	organic silt clay	149.5	47.3	30.9	16.4
	350	172-180	peat	234.5	-	-	-
	351	220-235	peat	278.4	-	-	-
	352	240-255	silt clay	63.1	-	-	-
	353	338-369	silty clay sand	30.9	41.0	21.6	19.4
22	354	15-22	clay silt	23.2	31.5	21.6	9.9
	355	76-100	silt sand	25.9	-	-	-
	356	130-148	sandy clay silt	39.3	37.5	18.4	19.1
	357	165-190	clay silt	38.1	53.4	24.5	28.9
	358	190-230	clay silt	34.7	50.3	23.5	26.8
	359	245-289	sandy clay silt	22.6	37.2	18.2	19.0
23	360	26-49	clay silt	41.6	43.8	31.5	12.3

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
23	361	49-88	clayey sand silt	17.6	28.9	23.7	5.2
	362	88-103	sandy clay silt	18.6	51.6	22.1	29.5
	363	103-148	sandy clay silt	14.0	35.0	19.2	15.8
	364	148-167	sandy clay silt	13.0	35.2	18.3	16.9
	365	193-233	sandy clay silt	26.6	40.9	18.5	22.4
	366	233-267	sandy clay silt	28.1	39.5	16.7	22.8
	367	267-290	clayey sand silt	702.6	-	-	-
24	368	90-104	clay silt	80.1	27.1	23.0	4.1
	369	118-130	clay silt	52.2	30.2	21.1	9.1
	370	141-190	clayey sand silt	26.9	-	-	-
	371	205-219	clay silt	32.6	38.4	23.0	15.4
	372	245-253	silt clay	22.9	58.5	24.3	34.2
	373	253-285	clay silt	17.9	37.2	19.0	18.2
	374	285-325	sandy clay silt	17.8	35.7	19.2	16.5

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
25	375	90-100	sand silt	4.3	-	-	-
	376	100-160	silt	35.9	-	-	-
	377	180-200	clay silt	54.3	48.8	23.9	24.9
	378	220-245	silt clay	49.1	57.1	25.4	31.7
	379	265-305	sandy clay silt	20.8	41.8	18.8	23.0
	380	371-396	sandy clay silt	21.1	40.7	18.4	22.3
26	381	39-63	clay silt	225.9	-	-	-
	382	78-108	gravelly silt clay	67.2	49.9	22.4	27.5
	383	135-175	clayey sand silt	35.2	31.6	17.3	14.3
	384	197-205	gravel	18.3	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
30	600	123-43	Sandy silt	17	-	-	-
	601	143-201	silty sand	21	-	-	-
	602	201225	sandy silt	22	-	-	-
	603	240-250	silty sand	20	-	-	-
	604	258-278	sand	23	-	-	-
	605	303-330	sand	22	-	-	-
31	606	60-74	organic silty sand	66	-	-	-
	607	74088	silty sand	25	-	-	-
	608	88-99	organic silty sand	102	-	-	-
	609	114-158	silty sand	19	-	-	-
	610	242-252	silty sand	21	-	-	-
	611	270-306	sand	28	-	-	-
31B	612	45-56	silty sand	42	-	-	-
	613	67-83	sand	21	-	-	-
	614	85-105	sand	31	-	-	-
	615	165-179	sand	23	-	-	-
	616	179-189	sandy silt	19	-	-	-
	617	189-205	silty sand	19	-	-	-
	618	215-245	sand	29	-	-	-
32	619	55-84	peat	203	-	-	-
	620	124-138	silty sand	26	-	-	-
	621	160-180	sand	22	-	-	-
	622	250-261	sandy silt	20	-	-	-
	623	261-285	silty sand	22	-	-	-

Hole No.	Sample No.	Depth cm.	Sample Description	Water content%	Liquid Limit	Plastic Limit	Index of Plasticity
33	624	58-83	silty sand	44	-	-	-
	625	95-123	silty sand	21	-	-	-
	626	165-190	sand	23	-	-	-
	627	270-290	sand	22	-	-	-
	628	318-329	silty sand	30	-	-	-
34	629	84-100	sandy clay	35	-	-	-
	630	100-117	organic silty clay	42	-	-	-
	631	117-132	silty sand	24	-	-	-
	632	136-180	silty sand	21	-	-	-
	633	190-208	sand	24	-	-	-
	634	215-240	sandy silt	24	-	-	-
	635	274-275	sandy silt	15	-	-	-
	636	275-305	sand	15	-	-	-
35	637	70-110	silty sand	16	-	-	-
	638	116-130	sandy silt	24	-	-	-
	639	130-168	sandy silt	21	-	-	-
	640	168-190	silty sand	20	-	-	-
	641	190-218	silty sand	22	-	-	-
	642	218-240	silty sand	22	-	-	-
	643	250-271	silty sand	22	-	-	-
	644	271-290	silty sand	18	-	-	-
	645	305-320	sand	25	-	-	-
36	646	81-100	sandy clay	34	-	-	-
	647	155-195	silty sand	26	-	-	-
	648	195-210	silty sand	26	-	-	-
	649	220-249	sandy clay	23	-	-	-
	650	249-270	sand	23	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index Plasticity
	651	290-301	Silty sand	17	-	-	-
	652	301-305	sand	19	-	-	-
37	653	70-84	organic silty sand	54	-	-	-
	654	100-131	sandy clay	44	-	-	-
	655	131-145	silty sand	22	-	-	-
	656	150-186	silty sand	23	-	-	-
	657	186-210	silty sand	23	-	-	-
	658	220-233	silty sand	18	-	-	-
	659	233-250	silty sand	23	-	-	-
	660	290-325	sand	19	-	-	-
	661	330-350	silty sand	21	-	-	-
	662	420-436	silty sand	21	-	-	-
	663	436-448	sandy clay	21	-	-	-
	664	448-480	sandy clay	11	-	-	-
38	665	60-78	silty sand	64	-	-	-
	666	78-112	silty sand	18	-	-	-
	667	139-158	sandy silt	17	-	-	-
	668	158-165	silty sand	22	-	-	-
	669	180-211	organic silty sand	44	-	-	-
	670	230-250	silty sand	18	-	-	-
	671	250-270	silty sand	13	-	-	-
	672	280-310	silty sand	16	-	-	-
	673	380-390	silty sand	16	-	-	-
	674	430-465	silty sand	17	-	-	-
39	675	52-70	organic silty sand	-	-	-	-
	676	74-96	silty sand	-	-	-	-
	677	96-114	silty sand	28	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
	678	114-125	sandy silt	29	-	-	-
	679	125-138	sandy silt	19	-	-	-
	680	138-152	silty sand	21	-	-	-
	681	177-202	silty sand	19	-	-	-
	682	225-252	silty sand	20	-	-	-
	683	270-302	silty sand	21	-	-	-
	684	302-352	sand	18	-	-	-
	685	352-390	silty sand	4	-	-	-
40	686	65-88	silty sand	14	-	-	-
	687	100-139	silty sand	13	-	-	-
	688	155-169	silty sand	10	-	-	-
	689	280-301	silty sand	16	-	-	-
	690	330-354	silty sand	17	-	-	-
41	691	120-145	silty sand	14	-	-	-
	692	145-184	silty sand	15	-	-	-
	693	184-200	silty sand	17	-	-	-
	694	213-236	silty sand	15	-	-	-
	695	236-245	silty sand	5	-	-	-
	696	335-350	silty sand	13	-	-	-
	697	385-400	silty sand	12	-	-	-
42	698	34-60	peat	435	-	-	-
	699	60-64	peat	174	-	-	-
	700	100-120	silty sand	31	-	-	-
	701	120-131	sandy silt	62	-	-	-
	702	142-163	sandy silt	29	-	-	-
	703	163-180	silty sand	28	-	-	-
	704	180-195	silty sand	36	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
	705	195-210	sandy silt	24	-	-	-
	706	210-235	sand	27	-	-	-
43	707	59-84	peat	450	-	-	-
	708	94-115	silty sand	24	-	-	-
	709	139-145	silty sand	35	-	-	-
	710	155-175	sandy silt	31	-	-	-
	711	189-195	sand	19	-	-	-
	712	209-229	silty sand	35	-	-	-
	713	235-252	silty sand	29	-	-	-
44	714	50-84	peat	296	-	-	-
	715	95-122	peat	447	-	-	-
	716	122-135	sand	26	-	-	-
	717	152-167	silty sand	46	-	-	-
	718	167-181	silty sand	24	-	-	-
	719	181-190	sand	34	-	-	-
	720	200-230	silty sand	24	-	-	-
	721	280-305	sand	24	-	-	-
45	722	51-84	peat	277	-	-	-
	723	135-150	sandy silt	59	-	-	-
	724	150-162	organic sandy silt	244	-	-	-
	725	162-173	sandy silt	37	-	-	-
	726	192-200	silty sand	33	-	-	-
	727	206-220	silty sand	25	-	-	-
	728	220-250	sand	22	-	-	-
46	729	120-136	sandy silt	53	-	-	-
	730	170-190	sandy silt	3	-	-	-
	731	207-240	sand	24	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
47	732	40-62	silty sand	29	-	-	-
	733	62-71	sandy silt	22	-	-	-
	734	84-113	silty sand	74	-	-	-
	735	113-145	silty sand	21	-	-	-
	736	170-198	silty sand	21	-	-	-
	737	212-222	silty sand	20	-	-	-
	738	222-245	silty sand	21	-	-	-
	739	250-260	silty sand	21	-	-	-
	740	270-300	silty sand	26	-	-	-
48	741	30-60	peat	425	-	-	-
	742	70-95	silty sand	41	-	-	-
	743	95-110	silty sand	34	-	-	-
	744	110-120	silty sand	28	-	-	-
	745	144-170	sand	23	-	-	-
	746	175-190	sand	25	-	-	-
	747	200-220	sand	26	-	-	-
	748	220-245	silty sand	26	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
49	749	35-29	organic clay silt	76	-	-	-
	750	59-73	organic silt clay	30	34	20	14
	751	73-80	gravelley silt clay	19	37	19	18
	752	80-105	gravelley clay silt	19	29	17	12
	753	105-130	gravelley clay silt	20	29	17	12
	754	160-180	gravelley sandy clay silt	17	22	14	8
	755	180-220	gravelley sandy clay silt	12	21	13	8
	756	240-260	gravelley sandy clay silt	13	28	18	10
	757	260-280	gravelley sandy clay silt	10	27	17	10
50	758	40-65	peat	181	-	-	-
	759	65-95	peat	168	-	-	-
	760	100-125	peat	155	-	-	-
	761	145-175	gravelley sand	21	30	18	12

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
50	762	175-199	clayey silt	14	20	13	7
	763	199-220	clayey silt	15	20	15	5
	764	220-234	clayey silt	17	18	12	6
	765	234-249	gravelley sandy clay silt	15	-	-	-
	766	249-260	gravelley sandy clay silt	9	-	-	-
	767	260-300	gravelley sandy clay silt	11	22	12	10
	768	310-340	gravelley sandy clay silt	10	20	11	9
51	769	35-65	peat	126	-	-	-
	770	84-105	silty clay	38	41	23	18
	771	105-120	silty clay	33	42	23	19
	772	130-149	silty clay	24	32	16	16
	773	180-200	gravellev sandy clay silt	22	28	18	10
	774	200-240	" "	18	24	16	8
	775	240-280	" "	17	31	19	12
	776	294-320	" "	10	-	-	-
	777	320-360	" "	8	22	12	10

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
52	778	45-70	peat	128	-	-	-
	779	110-130	sandy clay silt	22	-	-	-
	780	160-180	sand	9	-	-	-
	781	180-220	sand	11	25	16	9
	782	220-260	sand	14	-	-	-
	783	262-272	sandy clay silt	21	-	-	-
53	784	72-84	organic clay silt	32	62	36	26
	785	110-135	sandy clay silt	13	36	20	16
	786	160-190	sandy gravelley clay silt	13	25	16	9
	787	200-220	sandy gravelley clay silt	17	26	15	11
54	788	54-75	organic clay silt	32	42	22	20
	789	105-125	sandy clay silt	32	25	15	10
	790	140-162	sandy clay silt	30	27	18	9
	791	162-179	sand	19	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
54	792	190-199	organic sandy clay silt	43	-	-	-
	793	199-211	silty sand	27	22	16	6
	794	211-222	sandy clay silt	33	31	19	12
	795	248-252 260-264	sand	21	-	-	-
	796	268-280	sandy clay silt	29	28	19	9
	797	291-306	silty sand	27	24	16	8
	798	340-356	silty sand	23	24	16	8
55	799	54-75	sandy clay silt	26	29	19	10
	800	90-115	silty sand	16	-	-	-
	801	115-130	sandy clay silt	31	30	18	12
	802	138-180	sandy clay silt	36	30	19	11
	803	208-220	sandy clay silt	31	31	19	12
	804	225-243	sand	15	-	-	-
	805	243-255	silty sand	23	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
55	806	270-290	silty sand	23	-	-	-
56	807	65-85	silty clay	45	43	23	20
	808	85-103	silty clay	50	47	24	23
	809	103-122	silty clay	41	43	22	21
	810	122-140	silty clay	30	36	19	17
	811	156-174	sand	20	-	-	-
	812	174-190	silty clay	36	32	18	14
	813	192-203	sandy clay silt	24	24	16	8
	814	203-217	sand	20	-	-	-
	815	230-245	sandy clay silt	22	26	17	9
	816	240-260	sand and gravel	12	-	-	-
57	817	80-100	peat	180	-	-	-
	818	100-108	organic clay silt	73	-	-	-
	819	108-133	organic clay silt	49	-	-	-
	820	133-150	organic clay silt	34	35	22	13
	821	150-157	organic clay silt	33	29	16	13

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
57	822	179-193	organic clay silt	38	37	20	17
	823	200-230	gravelley sand	9	-	-	-
58	824	73-85	clay silt	28	-	-	-
	825	85-100	clay silt	33	29	23	6
	826	100-123	silty clay	25	34	21	12
	827	127-140	silty clay	33	33	21	12
	828	160-180	silty clay	37	38	19	19
	829	205-230	silty clay	37	44	22	22
	830	248-270	silty clay	33	51	23	28
	831	290-310	silty clay	36	57	24	23
59	832	72-94	sand	22	-	-	-
	833	115-130	clay silt	27	27	15	12
	834	165-190	sandy clay silt	19	-	-	-
60	835	70-105	sand	4	-	-	-
	836	125-151	sand	9	-	-	-
	837	151-175	sand	20	-	-	-
	838	190-210	sand	26	-	-	-

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
60	839	215-240	silty clay	37	31	19	12
	840	210-215	silty clay	27	-	-	-
	841	260-280	silty clay	24	30	20	10
	842	300-320	silty clay	47	38	19	19
	843	332-339	silty clay	22	44	21	23
	844	339-349	clay silt	25	30	18	12
	845	373-400	silty clay	40	42	20	22
	846	415-440	silty clay	40	39	20	19
61	847	85-100	sand	10	-	-	-
	848	122-150	sand	7	-	-	-
	849	182-200	sand	24	-	-	-
	850	214-228	sand	22	-	-	-
	851	228-250	sand	23	-	-	-
	852	270-284	sand	20	-	-	-
	853	300-317	sand	27	-	-	-
	854	385-390	sand	16	-	-	-
62	855	74-84	silty clay	10	22	15	7
	856	104-116	silty clay	12	23	14	9
	857	130-142	silty clay	14	26	16	10
	858	153-165	silty clay	14	26	16	10
65	859	32-59	sandy clay silt	15	25	20	5
	860	110-140	sandy clay silt	13	25	15	10

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
65	861	210-240	sandy silt clay	15	33	16	17
67	862	165-193	sandy silt	13	32	16	16
	863	193-210	sandy silt	13	32	16	16
	864	225-255	gravelley sandy silt clay	10	33	16	17
	865	275-300	silty clay	15	47	21	26
68	866	20-36	silty clay	16	33	24	9
	867	100-135	sandy clay silt	13	27	16	11
	868	56-84	sandy clay silt	11	25	15	10
	869	310-335	clay silt	16	42	18	24
69	870	39-58	gravelley sandy clay silt	10	24	15	9
	871	90-120	gravelley sandy clay silt	12	24	15	9
	872	159-170	gravelley sandy clay silt	12	30	15	15
	873	159-170	gravelley sandy	11	32	16	16
	874	280-300	silty clay	16	44	20	24
70	875	30-60	sandy clay silt	12	23	20	3

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
70	876	90-115	sandy clay silt	13	22	16	6
72	877	38-58	sandy clay silt	13	26	18	8
	878	95-120	sandy clay silt	13	22	14	8
	879	145-170	sandy clay silt	12	27	14	13
	880	230-260	silty clay	14	41	17	24
	881	270-290	silty clay	16	50	20	30
73	882	90-120	sandy clay silt	18	29	15	14
	883	190-220	sandy silt clay	16	40	19	21
	884	230-260	silty clay	18	37	19	18
74	885	35-55	sandy clay silt	12	21	15	6
75	886	46-65	sandy clay silt	11	23	15	8
	887	90-120	sandy silt clay	13	30	16	14
	888	130-160	sandy silt clay	14	30	16	14
	889	205-230	sandy silt clay	17	44	20	24

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
75	890	235-260	sandy silt clay	14	47	19	28
	891	265-290	gravelley silt clay	16	46	19	27
	892	295-320	gravelley silt clay	16	45	20	25
76	893	45-60	clayey silt	14	25	18	7
	894	90-120	sandy gravelley clay silt	13	24	16	8
	895	140-170	sandy gravelley clay silt	13	28	15	13
78	896	145-170	silty clay	21	39	15	24
	897	195-220	silty clay	14	42	18	24
	898	235-260	silty clay	13	42	17	25
	899	265-290	silty clay	12	43	14	29
	900	295-320	silty clay	13	41	15	26
79	901	150-170	silty clay	19	36	16	20
	902	195-220	sandy silt clay	17	41	16	25
	903	255-280	silty clay	14	46	17	29
	904	- - -	silty clay	14	42	18	24

Hole No.	Sample No.	Depth cm	Sample Description	Water Content%	Liquid Limit	Plastic Limit	Index of Plasticity
80	905	73-120	silty clay	16	39	15	24
	906	140-170	silty clay	18	34	15	19
	907	195-220	silty clay	19	36	17	19
	908	265-290	silty clay	15	42	17	25
81	909	119-150	silty clay	21	34	16	18
	910	170-195	silty clay	19	35	15	20
	911	215-240	silty clay	16	39	15	24
82	912	115-140	silty clay	24	32	16	16
	913	145-171	silty clay and gravel	25	36	16	20
	914	171-185	silty clay and gravel	18	37	14	23
	915	225-250	silty clay and gravel	17	43	15	28
83	916	83-110	silty clay and gravel	19	33	18	15
	917	138-150	silty clay	18	43	14	29
	918	155-180	silty clay	21	40	15	25
84	919	78-100	silty clay	21	33	15	18
	920	125-150	silty clay	33	30	17	13

Hole No.	Sample No.	Depth cm	Sample Description	Water Content %	Liquid Limit	Plastic Limit	Index of Plasticity
84	921	155-170	silty clay	26	36	16	20
	922	175-190	silty clay	19	38	16	22
	923	215-240	silty clay	13	42	14	28
	924	265-290	silty clay	15	36	20	16
	925	315-340	silty clay	13	44	17	27
85	926	60-85	silty clay	11	25	16	9
	927	169-200	silty clay	12	31	17	14
	928	225-250	silty clay	13	30	18	12
	929	265-290	silty clay	11	30	18	12
	930	305-330	silty clay	12	31	18	13
86	931	60-85	silty clay	28	22	14	8
	932	110-140	silty clay	20	25	18	7
	933	155-180	silty clay	-	25	16	9
	934	185-210	silty clay	15	28	17	11
87	935	60-85	silty sand	20	-	-	-
	936	105-130	silty sand	37	21	17	4
88	937	64-80	silty sand	13	39	29	10
	938	80-95	silty sand	12	-	-	-
	939	95-119	silty clay	15	27	18	9
	940	132-155	silty clay	23	27	18	9