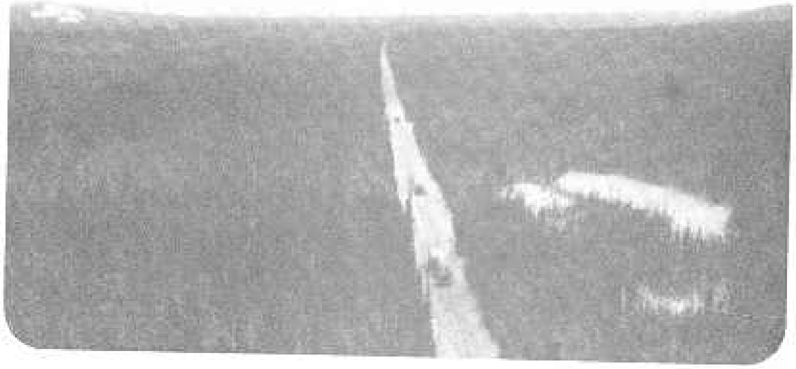

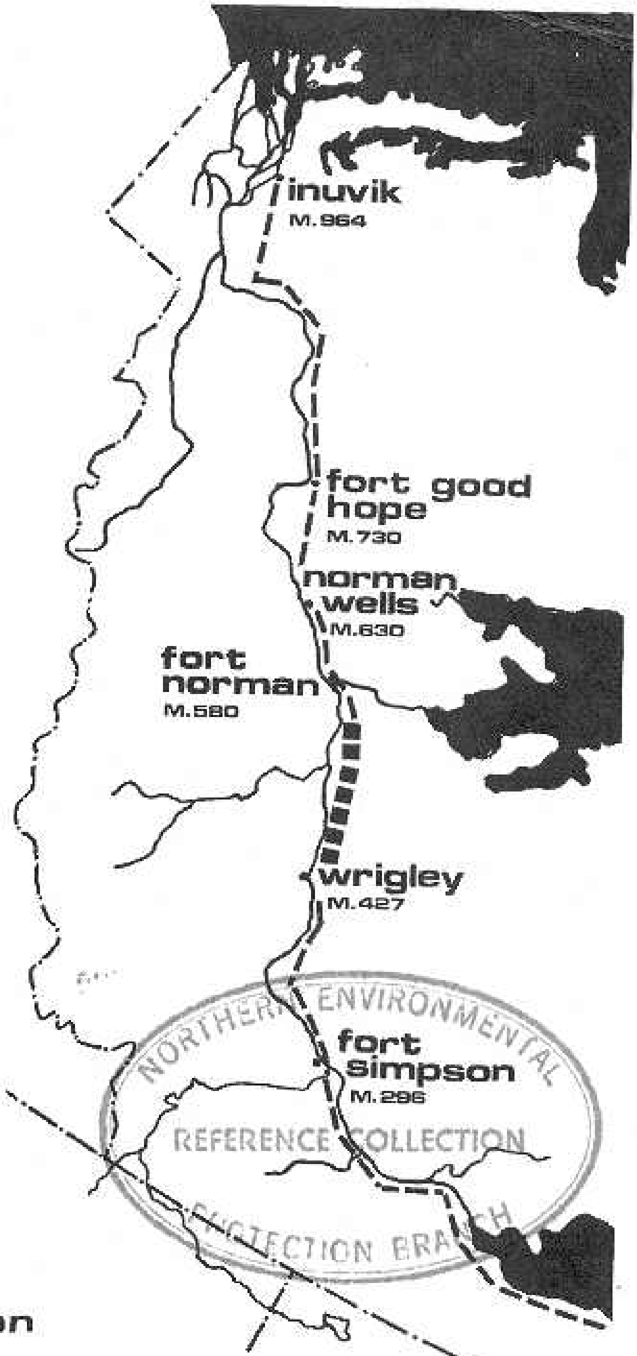

Report on

GEOTECHNICAL INVESTIGATION

for the

PROPOSED MACKENZIE HIGHWAY

MILE 450-545

Prepared for

Government of Canada
Department of Public Works

Underwood McLellan & Associates Limited

Underwood McLellan & Associates Limited

2540 KENSINGTON ROAD N.W. CALGARY ALBERTA T2N 3S3 TELEPHONE 283-4961 TELEX 038-24505

OUR FILE NO 2106-032-45
June 28, 1973

Government of Canada
Department of Public Works
P.O. Box 488
EDMONTON, Alberta T5J 2K1

Attention: Mr. F. E. Kimball
Project Manager-Mackenzie Highway

Dear Sir:

Re: Proposed Mackenzie Highway

Attached please find our report on the geotechnical investigation from Mile 450 to 550 of the proposed Mackenzie Highway.

This report includes detailed recommendations on gradeline revisions, borrow pit selection and problem areas. Test hole logs and test hole location mosaics have been incorporated in separate volumes.

If you have any questions concerning the contents of this report, we would be pleased to discuss them with you, at your convenience.

Yours very truly,

UNDERWOOD McLELLAN & ASSOCIATES LIMITED

Per: D. G. Pennell, Ph.D., P.Eng.,

Per: P. B. Makowichuk, M.Sc., P.Eng.

Enc.
DGP/fm

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I INTRODUCTION

(a) Authorization

Authorization to proceed with the geotechnical investigation of Mile 450 - 550 of the proposed Mackenzie Highway was received by letter dated August, 1972, from Mr. J. A. Brown, the Regional Director, Western Region, Department of Public Works. The investigation was under the direction of Mr. F. E. Kimball, Project Manager, N.W.T. Highways.

(b) Terms of Reference

The consultant was directed to undertake a complete soil survey along the length of the designated section of the proposed Mackenzie Highway, Mile 450 to 550 during the winter (November to April) of 1972/73. The limits of this section are approximately as follows:

> Section - Mile 450 to Mile 550 - Begins just south of the Ochre River to just north of Big Smith Creek.

The geotechnical consultant was to be responsible for three basic areas of investigation -

- to locate and identify potential problem areas, along the proposed route and to recommend solutions in general terms - i.e. embankment stability, embankment settlement, backslope stability in cuts, etc.

- to locate, evaluate and recommend suitable embankment borrow areas along the route within a two mile corridor centered on the route.

- to conduct foundation investigations at preselected bridge sites and to make bridge foundation recommendations; and to investigate preselected approaches to major stream crossings, identify problem areas and to recommend general solutions.

In order to comply with the Territorial Land Use Regulations, all field operations were to be completed during the winter months commencing no earlier than November 1, 1972.

The Department of Public Works was to commence centreline clearing of the route by means of caterpillar tractor on November 1, 1972, and access by tracked vehicles would be possible on centreline after that date. Prior to November 1, 1972, preliminary surveys (alignment and levels) were established on the ground by hand cut lines.

The consultant was responsible for all aspects of the field operation including mobilization of equipment and camps and operational support. It was expected that field drilling crews would have mobile self-sustaining camps and would be supported as required by the most economical means available.

(c) <u>Study Area</u>

As previously outlined the study area was designated as Mile 450 - 550 of the Mackenzie Highway. However, by letter dated January 30, 1973, the study area was revised such that the northern limit was changed to Big Smith Creek at approximately Mile 544. The following list summarizes the river crossings which required foundation investigations and which have been completed by separate report submissions:

1. Mile 455.0 Ochre River
2. Mile 460.0 Whitesand Creek
3. Mile 471.6 Rainbow Creek
4. Mile 491.7 Blackwater River
5. Mile 498.5 No Name Creek
6. Mile 511.5 Steep Creek
7. Mile 520.3 Saline River
8. Mile 533.0 Little Smith Creek
9. Mile 544.0 Big Smith Creek

(d) <u>Study Methodology and Report Preparation</u>

In accordance with the terms of reference provided, the basic study methodology emphasized obtaining maximum relevant field data through test drilling within the time available and the cost constraints. Since the major costs associated with this work are in the collection of field data, maximum utilization of drilling equipment, support equipment, portable camp facilities and transportation facilities were of prime importance.

In order to achieve maximum field efficiency the following preliminary studies were undertaken:

1. Review and compilation of existing data,
2. Interpretation of airphotos and preparation of mosaics,
3. Identification of borrow locations from airphotos and centreline drill sites from plan-profiles,
4. Field reconnaissance and,
5. Review of all existing territorial regulations.

The geotechnical field investigation commenced November 14, 1972 and was completed February 19, 1973.

The field investigation comprised the following major operations:

1. Centreline test hole location from plan-profile and field reconnaissance,
2. Borrow pit test hole location from airphoto mosaics and helicopter and land-vehicle reconnaissance,
3. Bulldozer clearing for borrow pit and centreline test hole access,

4. Drilling borrow pit, centreline and structure test holes with Mayhew 1000 and Heli drills,
5. Sample retrieval primarily from air-drilling and penetrometer sampling,
6. Field laboratory sample testing and identification.

Compilation and analysis of all data collected during field and laboratory operations was performed in Calgary office of Underwood McLellan and Associates Limited. The primary objectives of this report were:

1. Presentation of test hole logs, laboratory data and test hole locations.
2. Detailed description of borrow pit materials and recommended borrow pits for development.
3. Discussion and recommendations on proposed centreline gradeline including details on potential thaw-settlement zones, major cuts and fills and other identified problems.

II ENVIRONMENTAL CONSIDERATIONS

(a) Purpose and Scope

In addition to the engineering and economic problems of constructing the Mackenzie Highway, an essential element for planning and staging of the highway project is a knowledge of the environment. The purpose of this chapter is to present environmental aspects observed during this investigation and relative published data. This discussion is for general information and is not intended to provide conclusions on environmental conditions which are being studied by others.

(b) Climate

Generally, the summers in the area are cool with long cold winters. Temperature conditions of the study area can be considered similar to those at the Wrigley airstrip (Mile 427) where the annual mean temperature is 23°F.*[1] The monthly daily mean temperature averages below 0°F for the months of December, January and February and exceeds 50°F for June, July and August. Wrigley has 73 frost free days which occur from June 6 to August 19. The freezing and thawing index are approximately 6500 and 3100 degree days, respectively (Plate II-1). The average precipitation for Wrigley has been recorded at 13 inches

*[1] *Department of Environment of Canada, Climatology Branch, Calgary, Alberta.*

with 60 percent in the form of rain and 40 percent in the form of snow. Thus, the average amount of snowfall in the area would be approximately 50 inches per year. Average wind directions have been recorded from the north and the west.

Climatic data are included in Plate II-2 for Fort Norman north of the study area and Fort Simpson*[2] south of the area.

(c) Vegetation

The route of the proposed highway is confined within a narrow strip of the Boreal forest which runs adjacent to the Mackenzie River, thus, the vegetation is a mixture of coniferous and deciduous trees which change according to the topography and soil conditions.

The size of trees vary in diameter from approximately 3 inches to 24 inches and from approximately 15 feet to 80 feet in height.

The soils-vegetation relationship along the route was studied to identify any obvious relationship. In low lying poorly drained areas, willow, alder, larch and stunted spruce were prevalent. The soil in these areas was a fine grained material with high ice and moisture content and sporadic permafrost and varying depths of muskeg were recorded. Pure and mixed combinations of poplar, birch and

*[2] *L. M. Lavkulich: Alur 1971-72, Soils, Vegetation and Landforms of the Fort Simpson Area, N.W.T., Indian and Northern Affairs.*

spruce were found in well drained areas containing granular material. The granular material varied in size from a pea gravel to large boulders. The moisture contents were low and permafrost and muskeg were virtually absent. Jackpine stands were encountered in medium drained sites which contained a fine granular soil with a very limited amount of organic cover. Low moisture contents were prevalent with the absence of permafrost.

Low brush and ground vegetation could not be identified with the snow cover that existed during the investigation.

(d) Permafrost and Muskeg

Permafrost, or perennially frozen ground, is defined exclusively on the basis of temperature and refers to the thermal condition of the earth's crust materials. Any material that remains below 32°F for a period of one year or longer, is classified as permafrost.

Canada is divided into two major zones of permafrost. The most northerly part of the nation is the zone of continuous permafrost (Plate II-3). Immediately below this zone, lies the second zone of discontinuous permafrost. The 23°F (-5°C) isotherm of mean annual ground temperature was chosen arbitrarily by the Russians to be the division between the zones of continuous and discontinuous permafrost. This criteria has been adopted and retained in North America.

The section of the proposed Mackenzie Highway, Mile 450 to 545 lies within the discontinuous zone of permafrost. The characteristics of the zone are defined by the occurrence of the permafrost itself. In the southern fringe of the zone, permafrost occurs in scattered islands which vary in size from a few square feet to several acres. Other occurrences are associated with forest cover which increases shading on north slopes, and areas where snow coverage has been reduced. Northward, permafrost becomes increasingly widespread, with the occurrence being directly associated with the type of terrain. Permafrost has been encountered from a few inches in depth at the southern limit of the discontinuous zone to about 200 feet in depth at the southern limit of the continuous zone.

The classification of the permafrost encountered within this section of the proposed Mackenzie Highway, was categorized in accordance with the National Research Council Technical Memorandum 79.*3 A summary of this classification system is included in Appendix C.

Organic material, or more commonly referred to as

*3 *J. A. Pihlainen and G. H. Johnston: Guide to a Field Description of Permafrost for Engineering Purposes. National Research Council Canada, Associate Committee on Soil and Snow Mechanics. Technical Memorandum 79.*

muskeg, was encountered at numerous locations along the investigated section and was found to depths as great as 16 feet although most deposits averaged 2 feet deep.

For the purpose of the field investigation, the muskeg was categorized into the three groupings, granular, fine fibrous and coarse fibrous. This system of classification was used with reference to the N.R.C. technical memorandum 44*[4] which is summarized in Appendix C.

(e) Wildlife

The wildlife that was observed during the field investigation was relatively limited and probably was due to hibernation and migration that takes place prior to freeze up.

Mammals and birds were encountered by all personnel during their respective duties on the project. Mammals consisting of moose, caribou, timberwolves, fox, lynx, snowshoe rabbits, mink, mole and squirrel were observed by various members of the project. Timberwolves and fox were attracted to the campsites for short periods of time and the other animals were noted in their respective environments during various operations of the geotechnical survey.

Birds that were present during the duration of the

*[4] *I. C. MacFarlane: Guide to a Field Description of Muskeg, National Research Council of Canada, Associate Committee on Soil and Snow Mechanics. Technical Memorandum 44, Ottawa. 1958*

project were limited to two species - ravens and whiskey-jacks. Ravens frequented the campsites, while the whiskey-jack was encountered at other locations on the project.

Fish were not encountered at any of the stream crossings during the geotechnical investigation.

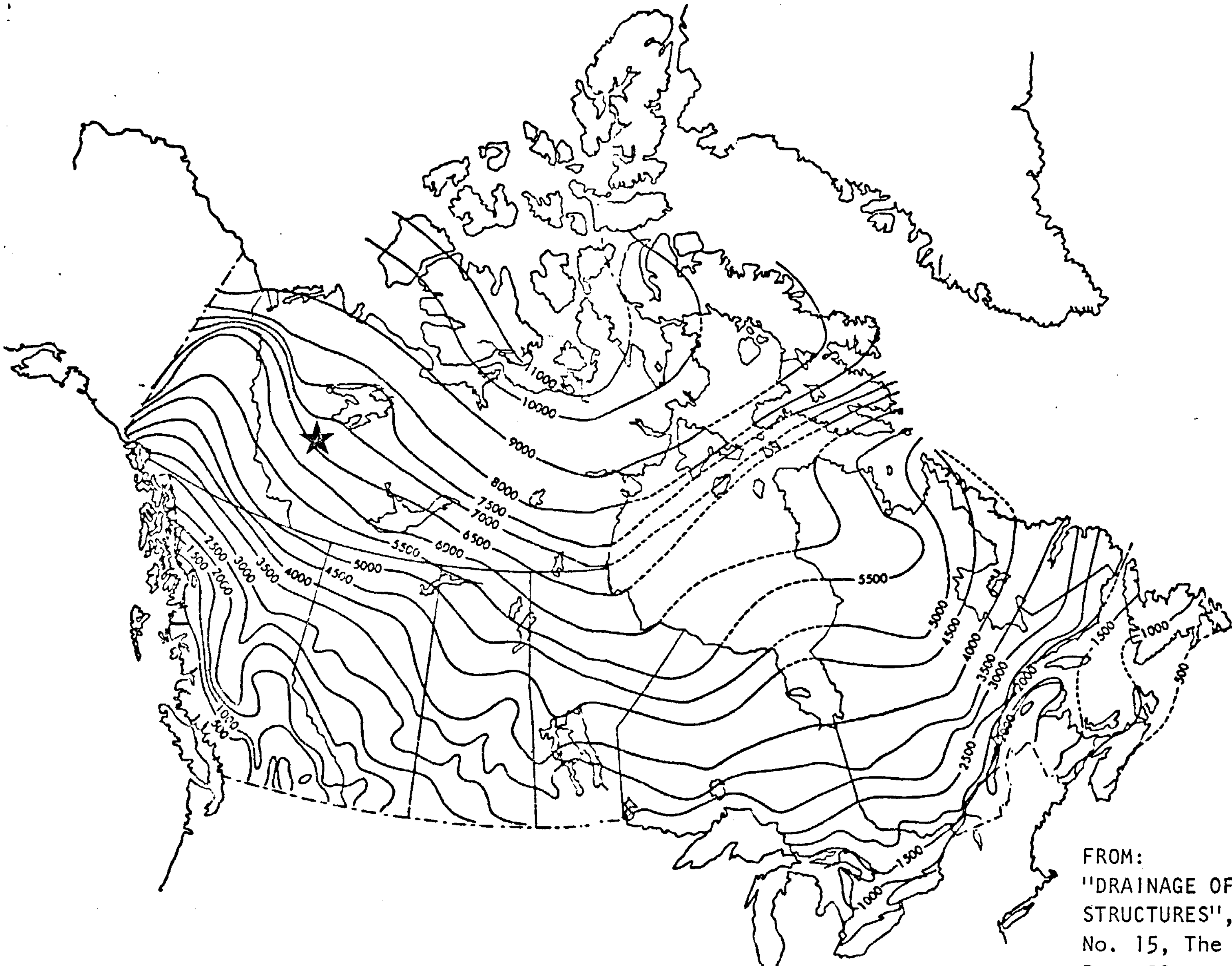
(f) Population

The population of the area from Mile 450 to 545 is virtually nil. The Department of Public Works Engineering Camp at the Blackwater River with a population of 10, and a few trappers in the area, make up the population on a seasonal basis.

The population of settlements in the vicinity of the investigated section include:*5

	Native	Other
Wrigley (Mile 427)	145	30
Fort Norman (Mile 580)	275	25
Fort Simpson (Mile 296)	300	450
Norman Wells (Mile 630)	20	290

*5 *Settlements of the Northwest Territories, Descriptions prepared for the Advisory Commission on the Development of Government in the N.W.T., Ottawa, 1966.*



FROM:
"DRAINAGE OF ASPHALT PAVEMENT STRUCTURES", Manual Series No. 15, The Asphalt Institute Page 93.

DISTRIBUTION OF MEAN FREEZING INDICES

PLATE II-1

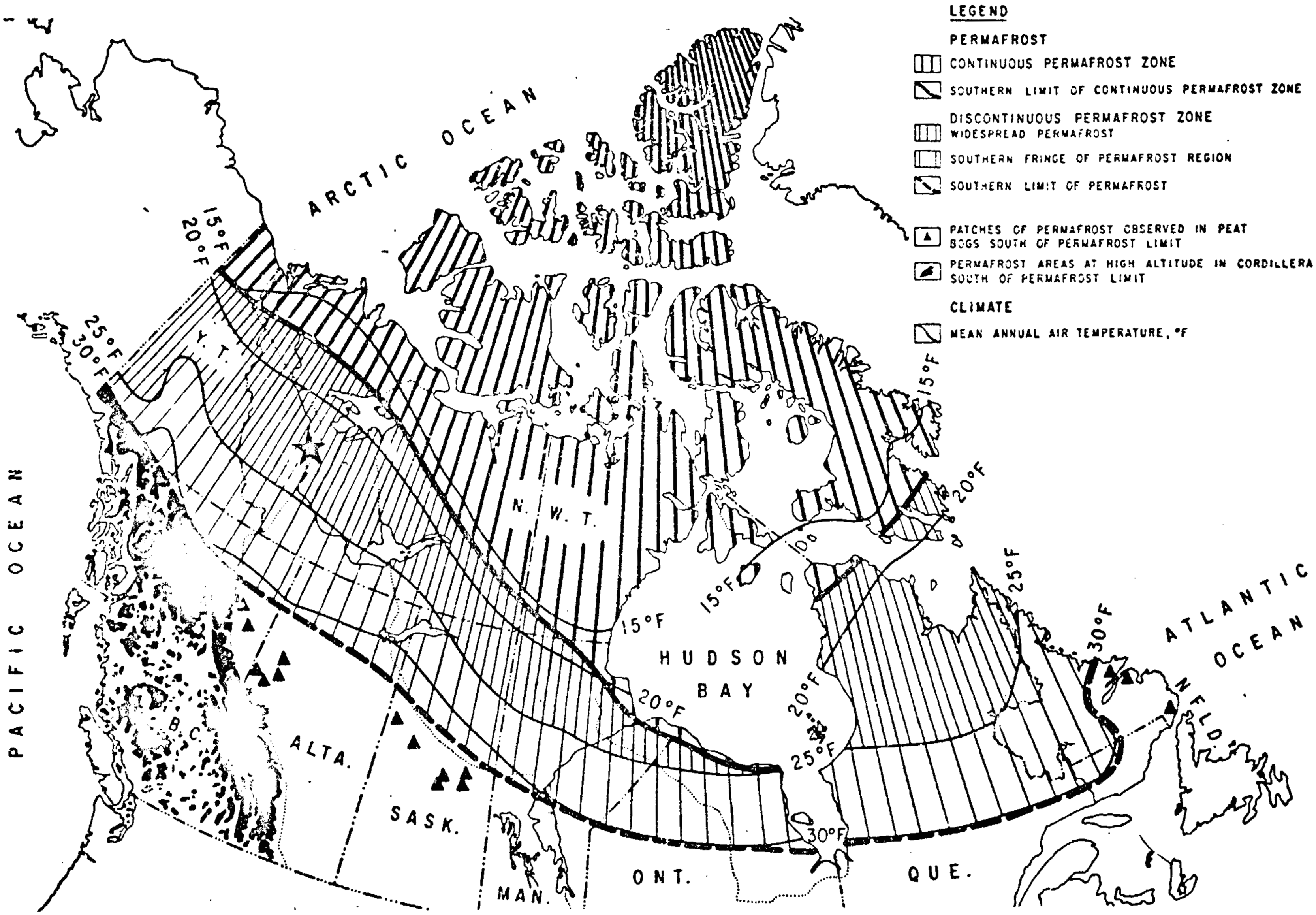
NORMAN WELLS ELEV. 209 FT ASL		J	F	M	A	M	J	J	A	S	O	N	D	ANN
Mean Daily Temperature		–18.7	–15.3	– 1.5	18.3	41.4	56.2	60.7	55.5	42.9	24.8	0.3	–14.8	20.8
Mean Daily Maximum Temperature		–11.2	– 7.1	9.3	29.7	51.5	66.6	71.2	65.1	50.4	30.7	6.5	– 7.8	29.6
Mean Daily Minimum Temperature		–26.1	–23.4	–12.3	6.9	31.2	45.8	50.1	45.9	35.4	18.8	– 5.9	–21.7	12.1
Maximum Temperature		44	41	52	64	83	88	89	89	78	64	47	35	89
Minimum Temperature		–63	–66	–51	–35	1	27	30	21	7	–17	–45	–53	–66
Mean Rainfall	(Inches)	T	.00	.00	.06	.38	1.33	1.94	2.50	1.26	.10	.01	.00	7.58
Mean Snowfall		7.6	6.2	4.7	4.6	2.2	.1	.0	T	2.4	8.4	9.5	8.0	53.7
Mean Total Precipitation		.76	.62	.47	.52	.60	1.34	1.94	2.50	1.50	.94	.96	.80	12.95
No. of Days with Measurable Rain		0	0	0	1	4	10	11	12	10	2	*	0	50
No. of Days with Measurable Snow		13	12	10	7	4	*			3	10	14	13	86
No. of Days with Measurable Precipitation		13	12	10	7	7	10	11	12	12	11	14	13	132
Maximum Precipitation in 24 hrs		.70	.55	.27	.93	.81	1.44	1.78	1.91	1.06	.46	.65	.67	1.91

FORT SIMPSON ELEV. 432 FT ASL		J	F	M	A	M	J	J	A	S	O	N	D	ANN
Mean Daily Temperature		–15.8	–10.0	4.8	25.8	46.3	57.2	62.0	57.9	46.2	29.9	6.3	–10.9	25.0
Mean Daily Maximum Temperature		– 8.0	– 1.1	15.6	36.9	57.3	68.5	73.5	68.9	55.3	36.5	12.2	– 3.7	34.3
Mean Daily Minimum Temperature		–23.6	–18.8	– 6.1	14.7	35.3	45.9	50.5	46.9	37.1	23.3	0.4	–18.0	15.6
Maximum Temperature		53	60	55	71	89	95	97	94	86	75	56	52	97
Minimum Temperature		–66	–69	–52	–39	2	27	33	24	8	–18	–51	–64	–69
Mean Rainfall	(Inches)	.00	.00	T	.19	.93	1.42	2.14	1.88	1.23	.34	T	T	8.13
Mean Snowfall		6.8	4.7	5.7	4.9	2.0	.0	.0	T	.5	4.9	9.6	8.8	47.9
Mean Total Precipitation		.68	.47	.57	.68	1.13	1.42	2.14	1.88	1.28	.83	.96	.88	12.92
No. of Days with Measurable Rain		*	*	*	2	7	9	10	10	9	4	1	*	52
No. of Days with Measurable Snow		10	10	9	6	1				1	7	11	13	68
No. of Days with Measurable Precipitation		10	10	9	7	8	9	10	10	10	10	12	13	118
Maximum Precipitation in 24 hrs		.92	.72	.80	.90	1.60	2.42	3.40	2.33	1.32	1.10	.75	1.00	3.40

CLIMATE

PLATE II–2

FROM: "Arctic Oil Pipeline Feasibility Study". Prepared by Mackenzie Valley Pipeline Research Limited, 1972.



PERMAFROST IN CANADA

PLATE II-3

FROM: R. J. E. Brown
National Research
Council, Canada

III GEOLOGICAL CONSIDERATIONS AND AIRPHOTO INTERPRETATION

(a) Historical Geology

The main elements in the physiography of the study area were probably well developed before Pleistocene time, and the overall effect of glaciation seems to have been to lessen the apparent relief.

Glacial features indicate two directions of glacial movement at approximately S 60° W and N 30° W. The southwesterly oriented features are better preserved suggesting that they were formed later than the northwesterly striking features.

All glacial features and deposits in the area are the result of the Laurentide ice-sheet which crossed the area and penetrated the mountains to the west.

During deglaciation, the ice flowed to the northwest from the east and west highlands depositing material brought from great distances by glacial action and subsequently redeposited it by fluvial action. Later southwesterly oriented ice-movements at the margin of the Laurentide ice-sheet resulted in additional glacial-fluvial deposits over the area.

(b) Topography

In the study area, the Mackenzie river valley parallels the Franklin Mountain Range which has peaks up to 5000 feet above sea level.

The floor of the valley is relatively flat to gently sloping towards the river and is dissected in numerous places by deep, V-shaped drainage courses. Topographic highs on the floor of the Mackenzie river valley are generally bedrock controlled. They are well defined features, bounded in most places by steep scarps.

The banks of the Mackenzie River are generally very steep, and stand as high as 200 feet above river water level.

(c) Surficial Geology

(1) Glacial Deposits

The study area is entirely covered with a continuous and generally thick mantle of Pleistocene glacial till which overlies bedrock. In general, the till is stony and grey-brown, and is silty to clayey in texture. The area has the typical undulating topography of ground moraine. Relief is generally less than 10 feet except where the ground moraine surface is interrupted by other glacial features such as glacial outwash deposits.

Poor drainage has resulted in large areas of swamp and muskeg. The thickness of the organic cover varies between 0 to 18 feet but most deposits are less than 5 feet in depth.

(2) Glacial-Fluvial Deposits

Deposits of glacial-fluvial origin are fairly common in the study area. Sand and gravel, generally bouldery, form the eskers and outwash deposits.

Braided eskers were found at approximately Mile 529, 4 miles east of the proposed highway centreline. They are oriented on an east-west direction and composed of well-washed ice-contact stratified drift, chiefly sand and gravel. They were deposited by subglacial meltwaters flowing in tunnels near the bottom of the glacier ice.

Relatively large outwash deposits are common in the study area. They are bodies of stratified drift that were washed out and deposited by meltwater streams issuing from and discharging beyond active Pleistocene glacier ice. Coarse granulars were deposited closest to the glacier margin and these grade downstream into more extensive areas of sand. Such bodies were identified at the Blackwater River, from Mile 498 to Mile 504, at Mile 509 and finally at

Mile 533. Most of the deposits of this type have been terraced and eroded by postglacial stream actions.

(3) Alluvial Deposits

In small areas along the Mackenzie and other major rivers, deposits of sand and silt are found well above the present flood plain of the rivers and represent alluvial deposits that predate the present regimens of the streams. Elevated silt terraces along the Mackenzie River are a good example.

(4) Lacustrine Deposits

There is no evidence of widespread lacustrine action in the study area. Lacustrine deposits consist mainly of thin lake bottom silts and clays which formed from materials rafted into glacier-margin lakes by icebergs. They resemble the glacial till and are often difficult to differentiate.

(5) Aeolian Deposits

Small and low sand ridges were identified at Mile 526, approximately 5 miles east of the highway centreline and at Mile 541, approximately 1 mile east of the highway centreline. The short ridges are oriented to the northeast and the relief rarely exceeds 10 feet. They are believed to be formed by outwash sand that has been reworked by wind action.

(d) Bedrock Geology

The east side of the Mackenzie River, between Mile 450 and 550 is underlain by middle to Upper Devonian limestones and shales. At the bottom of the valley, flat lying to gently sloping limestone beds were observed. In the mountain range, most of the lithological units are folded and faulted.

On the west side of the Mackenzie River Cretaceous shales outcrop along the Redstone and Dahadinni Rivers where they lie at the southern end of a basin that extends northwestward and beyond Norman Wells.

The bedrock surface is generally weathered and frost-shattered.

(e) Airphoto Interpretation

(1) Methodology

The aerial photo coverage was obtained from the Federal Department of Public Works prior to initiating the field investigations. The photos were then assembled into uncontrolled mosaics at the approximate scale of 1 inch = 3100 feet. These mosaics proved to be a valuable tool in planning the drilling program and assisting in the search for construction materials.

The interpretation was achieved by studying two consecutive photographs, which are called stereopair, using pocketsize stereoscopic glasses and a more sophisticated Carl Zeiss, model N2 stereoscope with a binocular attachment. The pocketsize stereoscope supplied the interpreter with a general appreciation of the ground conditions and the sophisticated unit allowed refinements in the classification of the terrain under study.

Following the identification of different types of materials and ground features, a number (symbols could be used) was attributed to each material type on the mosaics. A legend was then prepared, which consists in the listing of all units (numbers) encountered during the interpretation, accompanied by a detailed description of their nature, structure, relative thickness, mode of deposition and other characteristics such as permafrost conditions, drainage, relief, etc.

(2) Mosaic Legend

The following legend has been utilized to describe airphoto results on mosaics which are included as Appendix E in a separate volume:

Unit No. 1: Moderately to well-drained silts and sandy silts along the Mackenzie River. Deposits of this kind appear as smooth-surfaced, elevated terraces, gently sloping towards the river. The only significant relief is caused by the numerous cross-cutting drainage courses. The thickness of organic cover and the frequency of permafrost increase away from the Mackenzie River.

Unit No. 2: This unit groups all granular deposits, old and recent, of different origins. The unit is subdivided into:

Unit 2A: Flood plains and flood plain terraces associated with the Mackenzie River and its tributaries. These deposits are composed of fine sand to coarse gravel, are relatively permafrost free and the water table reflects existing stream water levels. Drilling has proven thicknesses in excess of 100 feet.

Unit 2B: Thin sandy alluvial fans, generally well-drained and permafrost free.

Unit 2C: Remnants of deltaic, outwash and eskerine deposits which are composed of fine sands to coarse gravels, generally bouldery. Deposits of this kind are generally well-drained and permafrost free. They stand out topographically and their thickness is often in excess of 20 feet.

Unit 2D: Fine to coarse sand over permafrost affected silty clays. Deposits of this kind were identified at the north end of the study area, between Mile 545 and Mile 555. They feature numerous frost meltout potholes ingrown with organic. Permafrost probability is high, particularly in the underlying silty clays.

Unit No. 3: This unit groups the silty to clayey glacial-lacustrine deposits over the glacial till and is subdivided into:

Unit 3A: Stratified silts and clays with a minor sand and gravel content. Shallow organic cover and dense coniferous growth prevail. Drainage is generally moderate throughout the deposits of this kind. This unit erodes into steep sided gullies where the silts and clays are generally well-drained. Gullies formed along escarpments are due to permafrost melting. The thickness is generally in excess of 20 feet over the glacial till and permafrost is prevalent throughout.

Unit 3B: Silts and clays overlain by peat plateaus, heavily permafrost affected. Drainage is moderate to poor and the thickness of the organic cover can be as much as 5 feet. The relief is low and hummocky. The thickness of this unit over the glacial till is often in excess of 10 feet. These deposits feature a moderate coniferous growth and many permafrost collapse scars, some of them ingrown with organic.

Unit 3C: Reworked 3A unit by wave and flood actions, resulting in a sand segregation at the surface of the silts and clays.

Unit 3D: Glacial till and thin silts and clays overlying the till. The organic cover varies from 1 to 3 feet and most of the sub-parallel, closely-spaced drainage courses are infilled with organic. The relief is very low and these deposits generally occupy higher ground at the base of the mountain range.

Unit No. 4: Silts and clays of unit 3 underlying thermokarst ponds and lakes. Relief is generally absent and organic cover prevails. Permafrost is depressed several feet beneath the wet marshes and small thaw lakes and ponds.

Unit No. 5: Limestone and shale outcrops and shallow bedrock covered by colluvial materials and/or glacial deposits. Bedrock is responsible for the major topographic variations in the study area.

(3) Glacial Landforms

The study of aerial photographs has revealed two outstanding glacial landforms namely; crag-and-tail ridges and roches moutonnees.

Crag-and-tail ridges are streamlined ridges resulting from overriding glacial ice and consisting of a knob of resistant bedrock (the crag) with an elongated tapering body (the tail) of softer erodible bedrock or till. These ridges were identified at approximately Mile 525 just east of the proposed highway centreline.

Roches mountonnees with associated streamlined ridges are glacially moulded rock outcrops having a smooth, gently sloping upstream side, (the result of abrasion), and a steep, rough, irregular downstream side, (the result of plucking). Roches mountonnees were identified at approximately Mile 525 and 542, east of the proposed highway centreline. They may be distinguished from crag-and-tail hills by the lack of a tapered streamlined tail composed of lodgement till.

(4) Conclusions of Airphoto Interpretation

Numerous field observations and extensive drilling have proven the office interpretation of aerial photographs to be a valuable tool. Generally, the identification of surficial deposits based on airphoto interpretation was found to be accurate. Minor discrepancies were revealed as drilling proceeded and re-adjustments were made to satisfy localized subsurface conditions.

IV DESCRIPTION OF INVESTIGATION PROCEDURES

This section includes a detailed discussion of field investigation procedures, laboratory testing and field equipment. The information presented and experience gained can be utilized for future planning of other similar investigations.

(a) Mobilization and Equipment

The drilling and support equipment for the project was positioned at Hay River docks prior to September 16, 1972, and then barged down the Mackenzie River and unloaded at the Blackwater River on October 16, 1972. The camp was barged up the river from Inuvik and the fuel was obtained from Norman Wells. The camp was unloaded at the Blackwater River the week of October 5, 1972.

The camp and equipment were assembled and ready for use on November 1, 1972, but due to the Land Use Regulations requiring approximately 2 feet of frost penetration, the actual field drilling did not commence until November 16, 1972. The following summarizes the basic equipment and camp facilities utilized by the Contractor.

Contractor	Equipment
Kenting Big Indian	Mayhew 1000 Drill Track mounted on FN 110 Nodwell. Heli Drill Track mounted on Foremost.

Contractor	Equipment
	3/4 ton 4 x 4 GMC pick-up. FN 60 Nodwell. Hildebrant K balloon tired carrier. 3/4 ton 4 x 4 crew cab pick-up. 3 ton GMC Flatdeck. Miscellaneous support equipment.
Fortier and Associates	1 Diner kitchen unit. 1 Utility washer unit. 4 - 4 man sleepers. 1 - 10 man sleeper. 1 - 20 KW light plant with fuel tank and sloop. All units were sleigh mounted.
Goodzeck Construction Ltd.	1 - D7 Dozer with winch and gin poles. 1 - D6 Dozer wide track with winch. 1 - fuel sloop with 2 - 1000 gal. tanks.
Precambrian Mining Services	1 single side band radio expediting service in Norman Wells.

Since a 24 hour operation was undertaken the technical field staff, supplied by Underwood McLellan and Associates Limited, consisted of 8 personnel included drill inspectors, laboratory technicians, and project supervisors.

Air support for the project was obtained by utilizing fixed wing and helicopter aircraft. In general, camp moves were staged so that existing landing strips or lakes could be utilized for supply of materials and personnel movement. The field investigation work was started at Mile 491, and proceeded south to Mile 450, then returning and working north to termination at Mile 545. This procedure had the advantage of leaving the main fuel supply in a central location and also was scheduled to co-ordinate with the clearing contractor.

The above equipment proved satisfactory with minor exceptions. The camp facilities were slightly inadequate especially when extra personnel arrived in camp (i.e. supervisory, land use inspectors, Public Works inspectors, etc.) which added significantly to the basic field staff of 20 people. The mobility of the camp was acceptable even though an extra trip was required for movement of fuel by the fuel sloop which was towed by a dozer. The two dozers were suitable for the operation as they were utilized for camp moves, hauling camp water, clearing borrow pit areas and dozing snow on centreline and for landing strips. With regard to the drilling equipment, it became apparent that the Mayhew 1000 drill was superior to the Heli drill, as the Mayhew drill obtained extra footage when they were compared under similar conditions. The Mayhew was also more adaptable for subsurface investigation of the stream crossings as well as drilling granular deposits. The performance of the Heli-drill was good when encountering silt and clay subsurface conditions and therefore the field work was adjusted in this regard.

For this type of project, support vehicles require special consideration since it is essential that adequate mobility be maintained on the ground. Since the initial planning was based on a November 1 startup a preference was given to track vehicles and large tired equipment such as the Hildebrant K. However, as the work progressed it was apparent that only one track support vehicle was required (FN 60) and that the remaining support vehicles should consist of 4 x 4, 3/4 ton pick-up cabs or crew cab trucks, and therefore the lease on the Hildebrant K was terminated. Although 4 x 4, 3/4 ton trucks provide good transportation, numerous problems were experienced with transmission, rear-end and front-end failures during the extremely cold weather. Based on the experience encountered, we would recommend that all 4 x 4, 3/4 ton support vehicles be equipped with specially designed heavy duty "drive train" parts to prevent failures during the extremely cold weather period. This recommendation could be expanded to include special modifications for all equipment operating in cold weather.

(b) <u>Field Drilling</u>

During the field drilling program records were maintained on the production rates achieved, and these are summarized below:

Summary of Test Hole
Production Rates

Date	C TH	BP TH	Stream TH Crossings	Total TH	Avg. TH per day
Nov.17/72-Dec.17/72	188	68	7	263	8.2
Jan. 8/73-Jan.31/73	115	236	34	385	16.0
Feb. 1/73-Feb.19/73	202	241	24	467	24.7
Totals (75 days)	505	545	65	1115	14.9

Note: Test holes generally 15' deep except for stream crossings which were variable in depth (20' - 90').

During the field program daily drill footage rates were compiled and emphasis placed on improving overall production rates. The major factors affecting the drilling rate were type of subsurface material, average daily temperature, type of drilling technique, and distance of drill site from camp.

Initially, the subsurface materials encountered were granular, and due to land use regulations, the drilling activity was confined to the existing C.N.T. right-of-way. As a result, the drills were far from the camp and the drilling progress was poor due to the difficult drilling in the granular materials as well as the travel time between drill shifts. During the month of January the work was expanded to include borrow pits and stream crossings which concentrated the drilling activity near the portable camp and the travel time was reduced. This aspect increased the production, however, the cold temperatures in January (-65^{O}F recorded) proved to be a significant factor. During the month of February, the average daily temperatures increased and the main subsurface materials encountered were fine grained materials and as a result improved production was achieved.

The two rotary drills were equipped with air compressors and in addition one mud pump was available to drill with water. Rotary drilling with compressed air as the circulating fluid provided the best method of obtaining footage, however the sample recovery was poor and only broken samples could be obtained. In addition, considerable difficulty was experienced in classifying air returned samples. During air drilling operations permafrost was identified by the presence of ice crystals and/or the hard nature of frozen as compared to unfrozen cohesive soils.

Excellent sample recovery was obtained by use of 2 inch and 3 inch diameter split spoon samplers but this procedure was time consuming. The use of standard Shelby tubes, spiral soil augers and core barrels were tried but did not prove too successful as a result of the high percentage of granular materials. During the field investigation it became important to provide a balance between obtaining an acceptable footage production rate and obtaining sufficient undisturbed samples for laboratory testing in evaluating the engineering properties. This was generally accomplished by utilizing an air rotary drilling technique and obtaining "undisturbed" samples at predetermined depths with the split spoon drive samplers.

For the foundation investigation of the bridge sites, saturated sands and gravels below the stream bed were fairly common and it became necessary to convert to a wet drilling technique utilizing drilling mud and in special circumstances setting casing was necessary to prevent caving. When extremely cold temperatures occurred during this drilling phase, the production was seriously hampered and the driller required considerable experience to prevent the circulating fluid from freezing. In addition to undisturbed sample recovery at the bridge sites standard penetration tests were conducted to determine the relative density of the subsoils. Due to the coarse granular soils encountered at the bridge sites a special 2 inch diameter solid steel penetrometer was fabricated for penetration testing since the standard 2 inch split spoon drive sampler was easily damaged.

(c) Field and Laboratory Testing

A field laboratory was utilized at the investigated site to limit sample volume shipments and eliminate the difficulty of maintaining permafrost samples in a frozen state during shipment to a central laboratory. The testing laboratory in the field was equipped to conduct moisture content, Atterberg Limit, grain size analysis and ice volume tests and in addition, equipment was available to photograph samples. The photographic equipment which consisted of a stand mounted single lense reflex 35 mm. camera with floodlights provided a valuable aid in recording the ice lenses and soil types. The field laboratory technicians performed confirmation of all the field drill inspectors test hole logs and assisted on any difficult classification.

The majority of the testing was performed in the field laboratory except for Atterberg Limit tests and hydrometer analysis which were primarily carried out in the Calgary central laboratory. During the latter stages of the investigation when high production rates were obtained it was necessary to ship the overflow samples to the central laboratory.

During the field drilling it became apparent that due to the sporadic nature of the permafrost (especially in fine grained materials) random test holes did not at times provide an accurate assessment of the ice volume of the subsoil. In some locations test holes spaced close together indicated different results with respect to permafrost occurrence and ice lense classification. Permission to use dozer pits for borrow areas was obtained from the land use inspector provided special controlled procedures were utilized.

Dozer pits excavated in coarse grained materials provided superior granular samples for grain size analysis. Moisture contents and ice classifications determined from test holes in granular materials checked very favorably with similar tests on the dozer pit samples. However, when dozer pits were excavated in fine grained materials, the test results from previous drill holes did not necessarily provide an accurate assessment of the subsoil conditions. Some of the dozer pits revealed islands of permafrost randomly dispersed both horizontally and vertically with very irregular ice concentrations in the permafrost. Under these conditions an individual test hole or a small number of test holes could be misleading. With reference to the above it is recommended that some caution is required in selecting borrow areas in fine grained materials even though a test hole may indicate that the material contains negligible excess ice or unfrozen conditions. During the construction stage a procedure should be adopted to test proposed borrow areas with dozer pits or backhoe pits prior to clearing and total commitment on the particular area.

V PRESENTATION OF SUBSURFACE DATA

This section contains a description of subsurface data presentation including the various appendices where specific information can be located. In addition, test hole location criteria are described.

(a) Centreline Test Hole Data

Centreline test holes were drilled at spacings of approximately 1000 feet wherever terrain conditions were relatively uniform. In addition, test holes were drilled at all proposed cut and culvert sections. Centreline test holes were generally drilled to a 15 foot depth except at cut sections where the holes were drilled to depths below the proposed cut gradeline. Individual test hole results are summarized in Appendix D and include the major soil type encountered in each test hole as well as laboratory results. Appendix F which is a separate volume to this report includes all centreline test hole logs with copies of all sieve and hydrometer analysis performed.

(b) Borrow Pit Test Hole Data

Borrow pit locations were selected with the aid of air photo interpretation studies and field reconnaissance. Approximately 165 locations were investigated for potential borrow material with drilling of 3 test holes to the 15 foot depth at each location to confirm the uniformity of subsoil conditions. Appendix D includes a summary of borrow pit test hole logs similar to the centreline log data indicated in the previous section. Appendix G which is a separate volume to this report includes all borrow pit test hole logs, location sketches and sieve and hydrometer analysis curves.

(c) Bridge Crossing Test Hole Data

Nine proposed bridge crossings were investigated from Mile 450 to 545 and several test holes were drilled to various depths throughout the river valleys to establish the soil profile. Separate reports for each of the nine sites have been prepared. Copies of bridge or structure test holes have been included in Appendix F with centreline test hole logs.

(d) Test Hole Location Mosaics and Air Photo Interpretation Sheets

Appendix E which is a separate volume to this report contains uncontrolled mosaics (1" = 1000') which show locations of all centreline test holes and borrow pits. Only the borrow pit areas have been indicated on the mosaic as the exact test hole locations could not be shown as a result of the mosaic scale and the proximity of the holes to one another. The exact location of test holes at borrow pits are shown on separate sketches which have been included with the test hole logs in Appendix G. Specific zones within recommended borrow areas as shown on the Mosaics have been identified as the best probable area to obtain borrow material. These expansion areas are outside the zone investigated by drill holes and were defined primarily from air photo interpretation. Appendix E also includes all air photo interpretation sheets (1" = 3100') which were used primarily for borrow pit selection and test hole locations.

(e) Photographs

Appendix B of this report includes numerous typical photographs of laboratory samples indicating frozen silty clay, gravel and sand etc. The penetrometer silty clay samples which contained the largest excess ice lenses are included. Photographs are also included of project equipment, terrain and miscellaneous items.

(f) Test Hole Numbering System

Test holes have been designated by mileage, type and number. Examples include 543 B 632 B, 544 C 448 A and 545 S 441 A. The letter symbols and numbers indicate:

543, 544, 545 - highway mileage.

B, C, S - between mileage and test hole number indicate borrow, centreline and structure test holes, respectively.

632, 448, and 441 - test hole numbers.

A, B - after test hole numbers indicate drilling performed by Mayhew 1000 or Heli drill, respectively.

VI ENGINEERING ANALYSIS OF DATA, BORROW PIT SELECTION, GRADELINE DESIGN AND CONSTRUCTION METHODS

This section includes detailed description of soil types and their properties, borrow pit selection and development recommendations, gradeline revisions and construction procedures. It is expected that the content of this section will be of greatest interest to the highway engineer responsible for detailed design. In particular, section (d) containing the gradeline revision recommendations should be utilized in conjunction with the plan-profile sheets containing the proposed gradeline.

(a) Major Soil Types and Engineering Properties

The results of testing carried out on samples to establish soil types and engineering properties are described in this section. A tabulation of the 1115 test holes drilled during the geotechnical investigation from Mile 450 to 550 is included in Appendix D. This tabulation identifies the major soil types encountered in the top five feet below the surface vegetation and includes permafrost classification, wet and dry unit weights, moisture contents and Atterberg Limits. As would be expected, over a 100 mile highway length many different soil types were encountered. In order to simplify design recommendations it was considered necessary to identify and study in detail three of the most commonly occurring soil types found along the route and in the borrow pits. The three general soil groups include silty clay, glacial clay till and gravel-sand mixtures. A summary of the soil properties is included in Table VI-1. The results summarized include both permafrost and non-permafrost areas.

The majority of the silty clay deposits consisted of permafrost although only a few areas exhibited significant excess ice. In most cases the permafrost and unfrozen deposits exhibited similar moisture contents unless excess ice was present in the permafrost.

The average moisture content for the silty clay was found to be 26.5% with liquid and plastic limits of 40% and 23.4%, respectively. The wet unit weight varied from 89.1 pcf to 127.6 pcf with an average of 111 pcf. The dry unit weight varied from 58.9 pcf to 106.2 pcf with an average of 92 pcf. Hydrometer analysis of 12 different clay to clayey silt samples indicated clay contents from 0% to 12% and silt sizes as high as 90%. Although silty clay will be used to describe the general soil group, many deposits consist primarily of silt and would be described as clayey silt or silt. A Standard Proctor compaction test performed on a silty clay with a liquid limit of 50.8% indicated a maximum dry density of 102.0 pcf and optimum moisture content of 20.3%. The average insitu moisture content of 26.5% would be approximately 6% to 8% above the optimum moisture content. In addition, a slurry sample prepared at 61.2% moisture content from the Proctor material resulted in a wet density of 100.1 pcf and dry density of 62.1 pcf. Calculations of the degree of saturation for representative silty clay samples indicated saturated conditions, although seasonal fluctuations can be expected.

The average moisture content for the glacial clay till was 14.0% with liquid and plastic limits of 28.5% and 15.0%, respectively. The wet unit weight varied from 120.0 pcf to 130.7 pcf with an average of 125.0 pcf. The dry unit weight varied from 104.2 pcf to 114.0 pcf with an average of 105.9 pcf. A Standard Proctor compaction test performed on a typical glacial till with a liquid limit of 31.4% resulted in a maximum dry density of 121.0 pcf at an optimum water content of 12.8%. The average insitu moisture content of 14.0% would be approximately 2% above the optimum moisture content. A slurry sample prepared at 42.5% moisture content from the Proctor sample indicated a wet unit weight of 110.6 pcf and a dry unit weight of 77.6 pcf when poured into a graduated cylinder. A small tare load applied to the slurry surface resulted in a final moisture content of 35% and a dry density of 86 pcf. The slurry samples were prepared in order to give some indication of ultimate density subsequent to

TABLE VI-1

TYPICAL SOIL TYPES
AND
ENGINEERING PROPERTIES

	Silty Clay	Glacial Clay Till	Gravel and Sand
No. of Holes	550	115	450
Average Moisture Content	26.5%	14.0%	8.5%
Average Plastic Limit	23.4%	15.0%	
Average Liquid Limit	40%	28.5%	
Average Wet Unit Weight	111 pcf	125.0 pcf	
Maximum Wet Unit Weight	127.6 pcf	130.7 pcf	
Minimum Wet Unit Weight	89.1 pcf	120.0 pcf	
Average Dry Unit Weight	92 pcf	105.9 pcf	
Maximum Dry Unit Weight	106.2 pcf	114.0 pcf	
Minimum Dry Unit Weight	58.9 pcf	104.2 pcf	
Maximum Proctor Dry Density	102.0 pcf	121 pcf	(Sand) 110 pcf
Optimum Proctor Moisture Content	20.3% (Liquid Limit 50.8)	12.8% (Liquid Limit 31.4)	6%

thawing of ice rich zones.

The gravel and sand deposits exhibited an average moisture content of 8.5% with extreme limits of 3% and 25%. The higher moisture contents were obtained where the silt content was highest and the materials were submerged. The gradation limits for gravel and sand deposits are shown on the individual test hole logs. A petrographic analysis and Los Angeles Abrasion Test was performed on a gravel sample obtained from the disposal pit on the airstrip at Mile 533. Photographs 55 and 56 depict the pit run gravel in place during dozer excavation. The petrographic analysis of the 1/2" to 3/4" gravel size indicated the following relative constituents:

Limestone	46.5%
Granitic	39.2%
Volcanic	10.5%
Chert	1.4%
Schist	1.4%
Sibieous Sandstone	1.0%

The Los Angeles abrasion test indicated a weight loss of 21.8% which is relatively low and is probably a result of the rounded particles and the high percentage of hard crystalline limestone. This dozer pit sample consisted of maximum 6" gravel sizes. A sieve analysis conducted on the minus 3 inch indicated 50% sizes larger than the #4 sieve size and 46% fine to coarse sand sizes. The rock characteristics of this gravel deposit are probably typical of the granular materials which have been encountered from Mile 450 to 550. This pit would provide excellent roadway surface crushed gravel or pit run and it may be utilized for concrete aggregate.

The glacial clay till was primarily identified by its heterogeneous nonsorted nature with numerous pebbles. As a general group, the tills are preconsolidated having dry densities averaging 105.9 pcf and moisture contents of 14.0%. The silty clay type soils tend to be stratified and do not contain stones or pebbles but being inter-glacial in origin have been subjected to various degrees of preconsolidation. As a group the silty clays are primary fluvial or lacustrine deposited and exhibit an average dry density of 92 pcf and an average moisture content of 26.5%. In general there is less scatter from the average for properties reported for the glacial till as compared to the silty clay. Rather than indicate the uniformity of the till it is believed that the scatter is based primarily on the number of samples reported. Specifically, few densities were obtained on the glacial till as compared to the silty clay. Although further discussions will relate to the average soil type, it is emphasized that individual deposits must be examined. For example, some silty clay deposits with high density and low moisture contents will have properties similar to the generally denser glacial tills. All glacial clay tills are not necessarily suitable construction materials, therefore, moisture contents and ice conditions of each deposit must be studied.

There were approximately 1115 test holes drilled during the investigation with the occurrence of the silty clay in 550, the glacial clay till in 115 and the gravel-sand mixture in 450. Therefore, 50% contained silty clay, 40% granular material and 10% glacial till, although the spacing of test holes was varied in valleys and uplands the percentages are a good guide to the actual distribution of the materials from Mile 450 to 545.

The soil types which have been discussed above were present in both the unfrozen and permafrost states. In the test holes drilled, 55% exhibited permafrost. The identification and extent of ground ice in the permafrost regions is of importance when evaluating road construction materials and potential centreline and right-of-way problems. In many cases the classification of ice conditions with air recovery procedures is impossible or at the best difficult, therefore, extensive use was made of 2" O.D. and 3" O.D. split spoon penetration tubes. The penetration tubes allowed recovery of approximately 1 foot long samples, allowing excellent visual inspection and description of ground ice. After evaluation of wet and dry unit weights, a large portion of the sample was utilized for moisture content determinations. Several hundred penetrometer samples were recovered throughout the 100 miles investigated and in general very few high ice content zones were located. The locations where ice rich areas were identified will be described in the respective report sections on centreline grades and borrow materials. Although open pits would give better visual inspection of ice extent, it is felt that the average conditions have been recorded by retrieval of penetrometer samples. The ice occurs mainly as hairline thicknesses and is irregularily and randomly distributed.

(b) Permafrost Thaw Settlement Analysis

Two aspects of roadway construction in permafrost that must be considered by the design highway engineer is the depth of potential thaw subsequent to embankment construction and the magnitude of thaw-settlement.

The depth of the active layer at any point is affected principally by air temperatures, but in a complex way is related to time, relief, vegetation, drainage, snow cover and soil type. The most accurate means of determining the active layer thickness is surface probing in the late summer before seasonal frost penetration. During this drilling program which began in late November after significant frost penetration, difficulty was experienced in identifying the unfrozen portion of the active layer below the seasonal frost. Knowledge of the active layer depth below a road embankment aids in the selection of roadway fill depths. Theoretical procedures based upon thermal conductivity have been developed by Sanger*[6] (Plates A-1 and A-2) to evaluate the thaw penetration depths for fine and coarse grained soils. The parameters required include moisture content, dry density and surface thawing index. At Mile 450 to 550 of the Mackenzie Highway, the air-thawing index is 3100 F degree days. The surface thawing index is greater than the air thawing index and is dependent upon the average windspeed and surface materials (Plate A-3). The ratio of the surface thawing index to the air thawing index has been suggested by some investigators at 1.5. Using a 1.5 ratio the surface-thawing index would be 4650 F degree days and application of Sanger's procedure results in potential thaw depths of 7.1 feet in the silty clay, 8.3 feet in the glacial till and 13 feet in gravel. In general, thaw increases with decreasing moisture content, increasing density and increasing thaw index. A recent study*[7] undertaken for the Government of Canada, Department of Public Works on the Dempster

*[6] *Sanger F. J. "Degree-days and Heat Conduction in Soils", Proceedings, First International Permafrost Conference, National Academy of Sciences, 1963.*

Highway with an air thawing index of 2200 F degree days concluded that the thaw depth varied from 4.5 feet for fine-grained soils to 7.5 feet for coarse-grained soils. As mentioned previously, these depths vary, being dependent upon many factors other than just soil type. Drill hole test results during this investigation indicated an average active layer depth in the granular strata of 8.2 feet and 7.2 feet in the cohesive fine-grained soils. Therefore, based upon theoretical methods, field data, experience in other areas and personal judgement, it is recommended that granular fill depths of 9 feet and fine-grained depths of 7 feet should be placed if it is necessary to prevent development of an active layer in the existing insitu subsoils. The thaw depths below the embankments will of course be influenced by the placement moisture contents, compaction of the subgrade and vegetation disturbance. It is further recommended that all surface vegetation and muskeg remain undisturbed before fill placement. Recommendations will be given for subgrade treatment wherever deep muskeg deposits contribute to embankment instability.

Although the fill depth required to prevent thaw in the subgrade has been established, it becomes more important to evaluate the settlement, potential instability and other problems if the subgrade is allowed to thaw. If 7 to 9 feet of fill were

*7 *Highway Design Concept, Construction Practices and Materials, Mackenzie and Dempster Highways*. *Report prepared for Government of Canada, Department of Public Works by Associated Engineering Services Ltd., Consulting Engineers.*

utilized over the permafrost area which comprises 55% of the 100 mile section, excessive costs would result. A specific criteria is necessary outlining the subgrade properties which will allow satisfactory performance of roadway embankments and surfaces when minimum fill depths are utilized that allow thaw penetration into the subgrade. The thaw-settlement which takes place is primarily a function of the excess ice content and is reflected in the bulk unit weight. During the drilling program undertaken in this investigation, several hundred penetrometer samples allowed the evaluation of the frozen bulk density. In order to calculate potential thaw-settlements an estimate must be made of the density subsequent to thawing. The final dry density obtained for the silty clay and glacial till prepared at different slurry moisture contents were indicated in the previous section.

In addition to the above approach a thaw-settlement versus frozen bulk density relationship has been established from field settlement data of pipelines at Inuvik and Norman Wells permafrost test sites (Plate A-4). This empirical data does not consider the final dry density after thaw due to superimposed loads but as a first approximation the pipeline weight may be assumed equal to a minimum 2' foot embankment fill.

An example is included in Appendix A, Plate A-5 which compares the thaw-settlement determined by the above two methods for a clay sample from test hole 458 B 160 B with an excess ice content of 27%. The slurry procedure resulted in thaw-settlement of 3.3 inches/ foot whereas the empirical pipeline approach based on the initial bulk density indicated a potential thaw-settlement of 3.4 inches/foot.

These results compare more favourably than expected and it is recommended that the empirical pipeline curve be utilized for estimates of potential thaw-settlement. In general cohesive soils exhibiting frozen bulk densities greater than 110 pcf will not produce significant settlements and minimum recommended fills of 2.5 feet may be utilized. In individual cases where the bulk density is lower than 110 pcf and the soil contains excess ice, reference will be made to these areas and remedial action suggested.

Frozen soils have very high strengths but when the permafrost melts the subsoil possesses a much lower strength, especially when excess ice exists initially. Whenever ice-rich soils are allowed to thaw, the embankment load is carried by the porewater and the soil is unstable, performing as a fluid. The ability of the thawed subgrade to carry a superimposed load depends upon the permeability of the subsoil and the rate of consolidation. Impermeable frozen ice-rich fine-grained silts and clays upon melting will produce deterioration and failure of the driving surface. Pumping of the subsoil into roadway granular materials often produces failure of the fill.

The primary criteria for construction on permafrost is to maintain the frozen insitu state of the subsoil. As discussed above the thaw-settlement may be prevented by placing a sufficient fill depth to prevent development of an active layer in the permafrost. Another alternative which has been given consideration is the utilization of an insulation material between the embankment and the existing subgrade. Test sections*[8] have been placed in the continuous permafrost area but complete performance results have not been published. A two to three inch layer of polyurethane or equal can be utilized and significant reductions in thaw depths have been noted. Of course, the greatest advantage will be achieved by the insulation where the ice content is the highest and the thawing index is relatively high. Consideration can be given to insulated road sections where excess ice contents are high from Mile 450 to 550 but the occurrence of excess ice is extremely sporadic and is not extensive. The relative economics of insulation and deeper fill depths would require study.

Although fill heights of sufficient thicknesses can

*8 *Knight G. R. and Condo A. C. "Design and Evaluation of Insulated and Uninsulated Roadway Embankments for the Arctic." Proceedings, Symposium on Cold Regions Engineering, University of Alaska, 1971.*

be placed to prevent thawing of the existing subgrade, the designer must be aware of cross-drainage which is intercepted by the roadway fill over long flat slopes. This water flowing against one side of the embankment fill can cause severe thermal erosion and subsequent instability of the roadway.

The design gradeline and alignment should be checked to ensure that cross-drainage does not occur in ice-rich permafrost.

Wherever fills are placed over ice-rich zones, settlement and failure of side-slopes has been found to be common subsequent to thawing. It is recommended that slopes of 4:1 be constructed in excess ice zones if the fill is placed during the winter. When the fills are placed during the summer after thawing of the active layer, settlement occurs during placement of the fill and in these cases slopes of approximately 3:1 can be considered.

(c) General Criteria for Borrow Pit Selection and Centreline Grade Design

The selection of embankment material will depend upon available borrow materials, excavation problems, winter or summer construction, right-of-way conditions, and relative haul distances. The materials which occur along the proposed highway have been discussed, in general terms, previously, in section VI(a) and their properties summarized. The following is a summary of potential embankment materials which are available in order of decreasing preference:

1. Broken shale (limited supply)
2. Well-graded dry coarse sandy gravel
3. Gravelly-sand
4. Unfrozen glacial clay till (W% = 15)
5. Unfrozen silty clay (W% = 25)
6. Frozen glacial clay till (W% = 15 to 20%)
7. Frozen saturated silty clay (W% greater than 25)
8. Unfrozen saturated silts.

A major design consideration which was made in the selection of the initial gradeline was to eliminate cut sections. This design criteria is well justified in permafrost areas where severe slope aggradation may result but consideration can be given to conventional balanced cut-fill sections where permafrost is absent. However, drifting snow tends to cover cut sections, and present maintenance problems. In addition, cut sections should only be considered where drainage is relatively good and water ponding along the roadway will not occur.

Both summer and winter embankment construction have advantages and disadvantages. The primary advantages of winter construction include access to borrow pits, right-of-way clearing and general mobilization and maneuverability of construction equipment. Wherever summer access proves difficult into borrow pits, consideration should be given to construction of haul roads during the winter. The major advantages of summer construction include:

1. Increased density of cohesive embankment materials result from passage of construction equipment over unfrozen materials when the air temperatures remain above 32°F. A high percentage of the construction along the proposed highway will be undertaken by conventional procedures and therefore, compaction techniques can be given consideration.

2. Efficiency of men and equipment is higher in summer as compared to the extremely cold winter period from mid-December through January and February.

The borrow material available along a given section of the highway often dictates the construction schedule.

Although unfrozen till and silty clay borrow pits exist, the development of these pits in the winter is difficult. Excavation of these pits may be undertaken in the summer utilizing conventional scraper and push-cats but the seasonal frost-penetration of 6 to 10 feet would necessitate ripping or blasting and placement of undesirable frozen "chunks" in the roadway embankment. In other words, an excellent borrow pit when worked in the summer can become of inferior quality when developed in sub-zero temperatures. Many areas where frost-penetration depths reach 6 to 10 feet may be economically worked in the late fall before a significant depth of frozen soil has developed. This period with some frost penetration provides good traction for earth-moving equipment.

Gravel and sand deposits can be excavated and placed throughout the year with satisfactory results.

Another particular problem which will be encountered is the excavation of unfrozen material which exhibits moisture contents above the optimum. As a general guide for predicting problem excavation areas, clays with insitu moisture contents less than 5% greater than the optimum may be removed and placed by conventional scraper procedures but moistures 7% and 8% or higher above optimum will prove difficult and in many cases borrow pits would be rejected on the basis of high water contents. In the subsequent section VI-(d) suitable borrow pits have been recommended based upon their unfrozen condition but some soils have been rejected which exhibit saturated or high moisture content conditions.

Generally, within each similar soil type section the borrow pits do not contain significantly different soils. Of course, wherever several borrow pits exist within a short distance the superior materials should be utilized.

An excellent supply of graded gravel and sand is distributed throughout the investigated section although some haul distances would be excessive. Several sand deposits exist which may be readily excavated and placed but the lack of fine fraction (less the #200 sieve) may prevent a stable surface from being established. These sand embankments should be capped by 1/2 to 1 foot of coarse graded gravel.

The primary source of embankment material should be the coarse gravel and sand mixtures. Although broken bedrock would be the most desirable fill its cost will be higher than the granular materials and the bedrock supply is concentrated near the north end of the section near Mile 540.

As a result of the extreme variation in soil conditions and in particular, permafrost and non-permafrost deposits, a detailed description of individual borrow pits, centreline gradelines and problem areas has been undertaken in section VI(d) for each section of the highway from Mile 450 to 550.

(d) Detailed Borrow Pit Selection, Recommended Grade Revisions and Problem Areas

This section consists of detailed recommendations on gradeline revisions, problem areas and borrow pit selection. The gradeline upon which recommendations have been made is that shown on plan-profiles received from the D.P.W. in January, 1973.

The discussion relates to 19 individual sections which have been selected on the basis of lengths of proposed roadway that exhibit continuously similar soil types.

Eighty-eight (88) borrow pits have been recommended suitable for development based primarily upon their unfrozen nature. In general, frozen silty clay and glacial till have been classified as unsuitable for embankment fill. Seventy-seven (77) of the one-hundred and sixty-five (165) borrow pits investigated consisted of frozen cohesive materials.

As indicated above, borrow pits have been selected and classified suitable for embankment construction primarily based upon soil type, unfrozen condition and low moisture content. The utilization of the unsuitable frozen cohesive soils would only be considered when haul distances are to be decreased. From Mile 450 to 492 the sections will involve maximum haul distances of 1.5 miles if only the recommended borrow pits are developed. The section from Mile 492 to 545 will involve two maximum haul distances of 2.3 and 2.5 miles with the remainder below 1.5 miles but numerous hauls will be in the order of 1 mile. In addition, the above approximate haul distances are based on the assumption that sufficient material is available in each borrow area. If granular materials are utilized throughout the section the average haul distances for the south 65 miles will be increased slightly above those noted but the north 30 mile section would have some haul distances of 5 to 6 miles.

From limited experience with cut sections in permafrost cohesive soils, it is recommended that only fill sections be designed. This conservative approach, although justified in many cases, escalates construction and re-alignment costs. Field drilling investigation procedures cannot disclose accurately the ice conditions in a cohesive soil. That is, although moisture contents and bulk densities may indicate no excess ice, the occurrence of ice is sporadic. In any case, the risk of constructing cut sections with major maintenance problems and potential failure should be compared to re-alignment. In this report consideration has been given to cuts in permafrost cohesive soils, although recommendations are only given in zones where field and laboratory data do not disclose excess ice conditions.

The performance of permafrost cohesive cuts has not been well documented and little experience has been gained in Canada. In general, a designer would choose cut backslopes as flat as possible to provide the maximum factor of safety against failure along a weak zone created by melted ice. Slopes should not be constructed steeper than 2½ or 3:1 when considering over-all stability.

Flat cuts undertaken north of Fairbanks, Alaska, reported by Keyes*9, produced greater aggradation and maintenance problems than the steeper slopes. Flat slopes produced greater active erosional debris at the slope base as a result of the greater surface area and in general the healing or thermal equilibrium process takes longer with flatter slopes.

Although excess ice cohesive cuts are not recommended from Mile 450 to 550 consideration may be given at other locations in placing a gravel protective cover over a insulation layer on the exposed frozen face. The gravel slope would be placed at the angle of repose and would be retained at the base by a retaining wall (Plate A-6).

The remainder of this section is devoted to a discussion of the individual roadway section with reference to gradeline design, problem areas and borrow pit selection. Table VI-2 includes a summary of the individual sections.

Table VI-3 located at the end of this section includes a summary of the borrow pits recommended for development with estimated potential volume of each borrow pit.

*9 *Keyes D. E. "Arctic and Sub-Arctic Road Construction Techniques" Proceedings, Symposium on Cold Regions Engineering, University of Alaska, 1971.*

TABLE VI-2

SUMMARY OF HIGHWAY SECTIONS

BASED UPON SOIL CHANGES

MILEAGE	STATION	SOIL TYPE	STREAM CROSSING
449 - 454	369+00 - 585+00	Frozen silty clay	
454 - 456	585+00 - 686+00	Unfrozen gravel & sand	Ochre River
456 - 459	686+00 - 855+00	Frozen silty clay	
459 - 460	855+00 - 925+00	Unfrozen gravel & sand	Whitesand Creek
460 - 464	925+00 - 1395+00	Frozen silty clay	
464 - 465	1395+00 - 1335+00	Sand & gravel	
465 - 468	1135+00 - 1195+00	Frozen silty clay	
468 - 471	1195+00 - 1040+00	Gravel and sand	Rainbow Creek
471 - 482	1040+00 - 485+00	Frozen silty clay	
482 - 492	485+00 - 87+00	Gravel & sand glacial till	Blackwater River
492 - 500	87+00 - 480+00	Frozen silty clay & gravel	Creek Mile 498.5
500 - 504	480+00 - 711+00	Gravel & sand	
504 - 507	711+00 - 875+00	Frozen silty clay	
507 - 512	875+00 - 1137+00	Gravel and sand	Steep Creek
512 - 523	1137+00 - 1086+00	Frozen silty clay & gravel	Saline River
523 - 531	1086+00 - 660+00	Glacial till & gravel	
531 - 536	660+00 - 370+00	Gravel & sand	Little Smith Creek

TABLE VI-2 (cont'd)

MILEAGE	STATION	SOIL TYPE	STREAM CROSSING
536 - 543	370+00 - 10+00	Frozen glacial till & silty clay	
543 - 545	10+00 - 0 - 84+33	Sand & gravel bedrock	Big Smith Creek

1. <u>Mile 449 - 454 - (369+00 - 585+00)</u>

This section consists of frozen silty clay with average moisture of 24% but little excess ice. No significant thaw-settlement expected, utilize minimum fill depths of 3 feet over most of the section.

Mile 451 to 453 - 2 feet of muskeg present, can expect 1 foot of settlement therefore, increase design depth 1 foot so that final fill will be minimum 3 feet above existing grade.

555+00 - 10 foot cut will be in permafrost with moisture content of 22%, slightly above optimum. Recommend re-design to eliminate this cut.

575+00 - 15 foot cut will be in permafrost with low moisture of 10%, utilization of 2½:1 slope is recommended but surface aggradation can be expected. Most conservative design would be design as a fill section as the extent of thawed ice layers is unknown.

<u>Borrow Pits</u>

Mile 450 - 369+00 - frozen clay unsuitable.

378+00 - low moisture content, frozen clay and gravel, develop pit north from hole 91B.

401+00 - frozen clay unsuitable.

Mile 451 - 440+00 - frozen clay unsuitable.

Mile 452 - 497+00 - frozen clay unsuitable.

Mile 453 - 537+00 - unfrozen clay.

548+00 - unfrozen clay.

Mile 454 - 591+00 - (1200' west ℄) - dry unfrozen gravel, stripping up to 4 feet silt.

591+00 - (500' west ℄) - unfrozen silty and sandy gravel.

Recommend development of pit 378+00 for fill near Mile 450. Excellent granular fill may be obtained from 591+00 pits but up-hill haul to uplands would be 300 feet with horizontal distances of up to three miles. Secondary source would be unfrozen clay from 537+00 and 548+00 but utilizing summer construction. Use granular pit 591+00 for south approach fill to Ochre Bridge.

2. Mile 454-456 - (585+00 - 686+00) - Ochre River Valley

This section consists of low moisture content, unfrozen, gravel and sand. Stability of 35' deep approach granular fills at bridge will be stable using 2:1 slopes.

603+00 and 630+00 - cuts at these two sections will be undertaken in unfrozen gravel and sand strata, stability will be adequate with 2:1 slopes.

Borrow Pits

Mile 454 - 630+00 - dry unfrozen gravel on river terrace.

Mile 456 - 691+00 - unfrozen clay, high moisture content of 30%, unsuitable for fill and excavation.

Recommend development of granular pit 630+00 on river terrace for deep approach fills and upland embankments. Several hundred thousand yards of borrow is available along Ochre River.

3. <u>Mile 456-459 - (686+00 - 855+00)</u>

This section consists primarily of frozen silty clay. Certain lengths exhibit high ice content, including 705+00, 725+00, 735+00, 745+00, 765+00, 805+00, 835+00, 845+00 and 855+00. If granular fill is placed when the subgrade is frozen, 7 foot depths should be used over this section. If minimum 3 foot depths are placed, thaw-settlements of 30% or 2 feet are estimated in a thaw depth of approximately 7 feet. Summer construction over the thawed active layer would require fill depths of approximately 5 feet as settlement will occur during construction.

<u>Borrow Pits</u>

Mile 456 - 738+00 - unfrozen clay W = 20%.

Mile 457 - 781+00 - silty gravel and sand W = 13%, unfrozen.

Mile 458 - 817+00 - 8 feet of unfrozen silty clay over sand.

831+00 - frozen silty clay, unsuitable.

Recommend development of pit 781+00, which is in the centre of this section but would be more economical to haul gravel from Whitesand Creek terrace for fill along Mile 458 to 459.

4. Mile 459-460 - (855+00 - 925+00) - Whitesand Creek Valley

Unfrozen gravel and sand are the primary soil types in this section. Utilize minimum fill depths of 3 feet, except where deep embankments are required at the bridge crossing.

872+00 - 35 foot cut will be made in frozen dry sand and gravel with W = 10%, stability should not be a problem with slopes of 2:1.

880+00 - terrace for a 6 foot depth of muskeg which will form the base for a 30 foot fill. Recommend removal of muskeg to ensure stability of the fill.

885+00 - 10 foot cut is proposed near the north abutment in frozen silt and clay, it is recommended that the grade be raised 13 feet to ensure slope stability by elimination of the cut.

Borrow Pits

Mile 45,9 - 871+00 - unfrozen low moisture content gravel south terrace of Whitesand Creek.

891+00 - unfrozen low moisture content gravel north terrace of Whitesand Creek.

Mile 460 - 925+00 - unsuitable, 10 feet of frozen clay - high ice content.

Recommend development of gravel terrace pits at 871+00 and 891+00 to be hauled north and south to the uplands.

5. Mile 460-464 - (925+00 - 1395+00)

This section consists primarily of frozen silty clay with bulk densities as low as 90 pcf. Fill depths should be maintained greater than minimum as noted below to reduce potential thaw-settlement.

965+00 - 10 foot cut will be made in frozen clay with moisture content near optimum and no excess ice. A 2½:1 backslope should not present a slope stability problem but some minor surface aggradation may occur.

989+45 - proposed culvert in 70 foot ravine should be placed on glacial till after removal of 1½ feet of muskeg.

1095+00 - 1110+00 - gravel and sand deposits occur, therefore use minimum 3 feet depth fills.

1110+00 - 1395+00 - high ice content - low bulk density. Increase fill depth from proposed average of 4 feet to 7 feet.

Borrow Pits

Mile 460 - 948+00 - frozen and unfrozen clay, W = 20%.

Mile 461 - 983+00 - (500' W of ℄) frozen clay, unsuitable.

983+00 - (500' E of ℄) frozen low moisture content clay.

993+00 - varying depths of frozen silt and clay over gravel and sand.

1051+00 - (2000' E of ℄) frozen clay, unsuitable.

1051+00 - (2000' E and S of ℄) frozen silt and sand.

1051+00 - (3800' E of ℄) frozen clay, unsuitable.

1051+00 - (900' E of ℄) frozen sand and clay.

1051+00 - (4800' E of ℄) frozen clay.

Mile 463 - 1072+00 - frozen silty clay, unsuitable.

1084+00 - frozen silty clay, unsuitable.

1107+00 - 2 holes of frozen sand and 2 silt and clay. Develop pit west from 117B and 118B.

Mile 464 - 1409+00 - frozen clay with excess ice, unsuitable.

Recommend hauling of granular fill north from Whitesand terrace and develop pit at Mile 463, 1107+00 for fills near Mile 463 and 464. Material may also be hauled from pit at Mile 465, station 1365+00 which is included in the following section.

6. <u>Mile 464-465 - (1395+00 - 1335+00)</u>

This section consists of frozen and unfrozen sand and gravel, therefore, reduce fill heights to minimum 3 feet depth. At 1370+00 lower grade 10 feet to produce a short length of cut and in turn reduce fill heights adjacent to high point. Cut would be in unfrozen sand or gravel.

Borrow Pits

Mile 465 - 1365+00 - frozen sand and gravel, low moisture content.

1363+00 - frozen sand and gravel.

Develop pits 1365+00 or 1363+00 for fill north and south.

7. <u>Mile 465-468 - (1135+00 - 1195+00)</u>

This section contains frozen silty clay, muskeg deposits and excess ice zones.

1235+00 to 1295+00 - maintain fill depth at 4 feet, ice content is low.

1290+00 to 1270+00 - 4 feet of peat, settlement of 2 feet anticipated, increase grade height to 6 feet to allow for settlement.

1270+00 to 1195+00 - maintain proposed grade but at least 5 feet deep along this length, excess ice and 4 foot deep muskeg deposits are present.

Borrow Pits

Mile 466 - 1322+00 West - frozen clay, unsuitable.

1322+00 East - frozen silt, excess ice, unsuitable.

1307+00 - frozen clay, low moisture content, unsuitable.

Mile 467 - 1260+00 - frozen clay, low moisture, unsuitable.

Mile 478 - 1227+00 - silty clay over gravel unfrozen in two test holes, low moisture content, develop north from 210B and 211B.

Recommend development of pit 1227+00 for summer construction. This pit is the only unfrozen potential borrow fill located from Mile 465 to 468. For embankment requirement near 466 utilize frozen granular from pit at 1363+00, Mile 465.

8. Mile 468-471 - (1195+00 - 1040+00)

The primary soil type in this section is gravel and sand, and includes two major drainage courses including Rainbow Creek at Mile 471.6 and a proposed culvert at Mile 469.

1182+00 to 1190+00 - proposed 30 foot cut will be undertaken in sand and gravel, but surface 10 feet at 1183+00 consists of silt and clay of low moisture contents. Recommend backslopes of 2½:1 so that stability will be adequate.

1177+00 - fill depths of 45 feet will be supported on unfrozen gravel underlain by shale. Stability will be adequate and granular excavation from cuts may be utilized.

1174+00 to 1166+00 - cut section on north slope will be made in frozen clay with the surface 15 feet containing excess ice, but below 15 feet clay is gravelly and W% = 10. Severe aggradation can be expected over the 800 foot cut, therefore, either the % grade should be increased or the fill depth in the valley increased.

1160+00 to 1155+00 - excess ice, silty clay W% = 50. Maintain 8 foot fill depths.

1155+00 to 1064+00 - maintain existing grades, or minimum 3 foot depths may be used.

1064+00 to 1058+00 - south approach to Rainbow, increase fill depth to six feet to reduce subgrade thaw.

1058+00 to 1040+00 - maintain minimum 3 foot depths over granular subgrade.

Borrow Pits

Mile 468 - 1184+00 - frozen and unfrozen silty sand and gravel.

Mile 469 - 1162+00 - low moisture content gravel and sandy silt unfrozen.

1140+00 - frozen clay, unsuitable.

Mile 470 - 1104+00 - frozen silty gravel and sand.

Mile 471 - 1056+00 - low moisture content gravel, frozen.

Recommend development of pits at 1184+00, 1162+00, 1104+00 and 1056+00, although 1162+00 and 1056+00 would supply superior material.

9. Mile 471-482 - (1040+00 - 485+00)

This section consists primarily of frozen silty clay with some gravel deposits.

1040+00 to 966+00 - maintain minimum 3 foot depth. There is no significant excess ice.

966+00 - five feet of muskeg is present, therefore increase fill depth to 5 feet to ensure final fill at least 3 feet above existing surface.

970+00 to 947+00 - proposed deep fill will have adequate stability.

947+00 to 936+00 - deep cut section will be in unfrozen stiff clay. Soil conditions are good and do not govern design.

931+00 to 926+00 - shallow cut will be in frozen clay recommend grade change to 4 foot fill.

926+00 to 890+00 - use minimum 3 foot fill depths.

890+00 to 725+00 - low swampy area with large portion exhibiting 2 to 5 feet of muskeg over clay. Place fill depths of 5 to 6 feet so that the final grade will be 3 to 4 feet above existing ground.

725+00 - 635+00 - maintain minimum 3 foot fill depths.

633+00 and 624+00 - cuts are in gravel strata so that stability will be adequate with 2:1 slopes.

620+00 to 530+00 - maintain minimum 3 foot fill depths.

521+00 - proposed 8 foot cut will be in frozen clay with high ice content to depth of 8 feet. Six hundred feet of roadway will consist of degrading frozen clay. Recommend grade change to a 5 foot fill section.

521+00 to 485+00 - maintain minimum 3 foot depths at 500+00 and 490+00, 5 feet of muskeg exists and settlement of 2 feet predicted, therefore place 6 foot fill in order to maintain 4 foot final depth above ground.

<u>Borrow Pits</u>

Mile 471 - 1025+00 - frozen clay, unsuitable.

Mile 472 - 977+00 - frozen clay, unsuitable.

Mile 473 - 923+89 - two holes unfrozen clay, low moisture.

Mile 474 - 892+00 - frozen clay, low moisture, unsuitable.

Mile 475 - 846+00 - two holes unfrozen clay, low moisture content.

822+00 - frozen clay low moisture content, unsuitable.

Mile 476 - 781+00 - frozen clay, unsuitable.

Mile 477 - 731+00 - frozen clay, unsuitable.

Mile 478 - 655+00 - frozen clay, low moisture, unsuitable.

Mile 479 - 605+50 - gravel, excellent fill, unfrozen low moisture.

Mile 480 - 569+50 - frozen and unfrozen gravel.

Mile 480 - 550+00 - unfrozen clay till.

Mile 481 - 505+00 - frozen sandy gravel.

Mile 481 - 493+00 - frozen and unfrozen gravel and till.

Recommend development of pits 923+89 and 846+00 for summer construction. Other pits at 605+00, 569+50, 550+00, 505+00, 493+00 should be developed but 605+50 is the better supply. In addition, develop gravel pits along water course on slopes at 624+00 and 633+00. Near the south portion of this section at Mile 471 to 474 it is recommended that gravel borrow be obtained from the previous section at Mile 471, station 1056+00.

10. <u>Mile 482-492 - (485+00 - 87+00)</u>

This section consists primarily of granular materials, with some glacial till.

480+00 - cut will be performed in dry unfrozen gravel.

470+00 to 450+00 - recommend design this section as cut and use common excavation for fill at Mile 482.

450+00 to 270+00 - granular subgrade, use 3 foot minimum fill depths.

275+00 - cut will be in gravel with good stability.

248+00 - cut will be in frozen clay with high ice content, re-design grade for fill at this section.

240+00 to 0 to 87+00 - granular subgrade use minimum fill depths of 2.5 feet. Blackwater River fills at 53+00 are adequate as designed.

215+00 - 192+00 - section may be designed as cut-fill balance.

30+00 - excess ice occurs in silty clay, increase fill depth to 7 feet near this station.

<u>Borrow Pits</u>

Mile 482 - 465+00 - frozen gravel, low moisture content.

Mile 483 - 427+50 - 2 holes unfrozen gravel, 1 unfrozen clay. Develop towards 166A and 167A.

Mile 484 - 375+00 - unfrozen sand.

334+00 - unfrozen sand.

Mile 485 - 289+00 - unfrozen gravel.

Mile 487 - 221+00 - unfrozen gravel.

190+00 - unfrozen sand.

Mile 488 - 141+00 - dry gravel.

Mile 489 - 114+00 - dry gravel.

78+00 - dry gravel.

Mile 490 - 33+00 - dry gravel.

Mile 491 - 15+00 - dry gravel.

Mile 492 - 66+53 (700' West) - unfrozen high moisture content clay.

66+53 (1700' West) - 8 feet of frozen clay over dry sand.

Recommend development of all granular pits along this section, except those investigated at 66+53. In general, the gravel pits rather than the sand pits should be utilized for fill unless haul distances are to be decreased.

11. <u>Mile 492-500 - (87+00 - 480+00) - Mile 498.5 Creek</u>

This section consists primarily of frozen silty clay, but a major muskeg deposit and some gravel is present.

93+00 - existing ground level is at proposed grade. Subgrade consists of frozen clay, recommend over-excavation to 7 feet, and recompaction of granular fill, or raise gradeline to produce 7 feet fill section above permafrost to prevent thaw-settlement.

107+00 to 123+00 - proposed cuts of 30 feet will be in frozen silty clay with subsequent severe slcpe instability and surface aggradation. Recommend re-alignment to eliminate cut sections or at least decrease maximum depth to less than 10 feet. Consideration may be given to trial permafrost slope insulation techniques.

123+00 to 380+00 - frozen silty clay with isolated high excess ice sections such as indicated by test hole 347B at 338+00. Recommend minimum 5 foot depth over this section, but some thawing of ice-rich zones will result with subsequent maintenance.

380+00 to 390+00 - 3 to 16 feet of muskeg exists at proposed bridge Mile 498.5. Recommend complete organic removal and placement of fill on gravel below muskeg level. See bridge report Mile 498.5 for detailed recommendations.

390+00 to 408+00 - gravel subgrade therefore, use minimum fill depths of 3 feet. Cut at 406+00 is satisfactory in granular material.

408+00 to 480+00 - unfrozen silty clay may use minimum 3 foot fill depths.

Borrow Pits

Mile 493 - 93+00 - (3800' North) - frozen clay, unsuitable.

137+50 - unfrozen clay, 20% moisture content.

Mile 494 - 178+42 - frozen clay, unsuitable.

178+42 - (6000' North) - frozen clay, unsuitable.

Mile 495 - 238+50 - frozen clay, unsuitable.

Mile 496 - 252+00 - frozen clay, unsuitable.

274+50 - frozen and unfrozen clay.

Mile 497 - 300+00 - frozen silty clay and unfrozen silt.

330+50 - (1500' West) - frozen clay, unsuitable.

Mile 497 - 330+50 - (1000' East) - frozen clay, unsuitable.

Mile 498 - 365+00 - frozen clay, unsuitable.

Mile 499 - 412+00 - unfrozen silty clay, low moisture content with 1 to 2 feet of organic overburden.

Mile 499 - 436+75 - unfrozen silt and silty clay, surface material very wet.

Mile 500 - 453+00 - coarse gravel and sand, dry and unfrozen.

Little satisfactory borrow is present along this section from Mile 492 to 499. For the south portion near Mile 492 material can be hauled from the granular pits located along Miles 490 to 491. The only pits that are recommended for development are those adjacent to stations 137+50, 274+50 and 412+00, which consist of unfrozen clay and at the extreme north end of this section pit 453+00 contains excellent granular material which may be hauled south.

12. Mile 500-504 - (480+00 - 711+00)

This section is composed of unfrozen gravel and sands which were deposited in a glacial-fluvial plain.

480+00 to 670+00 - dry granular subgrade, therefore, depths of 2.5 feet and cut sections may be considered where good lateral drainage has been confirmed.

670+00 to 711+00 - consists of 2 to 6 feet of muskeg over gravel. Recommend initial fill depth of 5 feet with ultimate fill height of 3 feet above existing surface after settlement.

Borrow Pits

Mile 500 - 510+00 - unfrozen dry sand, topped with 4 feet of gravel.

Mile 501 - 550+78 - 6 feet of gravel over unfrozen sand.

Mile 502 - 567+00 - dry unfrozen sand and gravel.

596+50 - dry unfrozen gravel and sand.

Mile 503 - 625+00 - dry unfrozen sand and gravel.

665+00 - moist silty sand with water table at 14 feet.

Mile 504 - 698+00 - unfrozen glacial till, low moisture content.

Recommend development of all pits along this section, and in addition, numerous other locations may be utilized if clearing is allowed by land use regulations. The excellent quality of the granular material along this 4 mile section will provide an important source of gravel for roadway surfacing.

13. <u>Mile 504-507 - (711+00 - 875+00)</u>

This two mile section consists primarily of frozen silty clay.

711+00 to 730+00 - 6 feet of muskeg over silty clay exists. Recommend fill depths of 7 feet be utilized so that final depth will be 3 to 4 feet above existing ground level.

730+00 to 840+00 - recommend cut section at 736+00 be re-designed as a fill in this permafrost area and maintain fill depths at 4 feet throughout this section.

840+00 to 875+00 - ice content is high at various locations, recommend fill depths of 7 feet.

Borrow Pits

Mile 505 - 729+00 - frozen clay, unsuitable.

758+00 - unfrozen silty clay, but 10 feet of seasonal frost, recommend summer development or early fall.

Mile 506 - 781+00 - unfrozen glacial till, high moisture content in 10 foot season frost zone.

Mile 506 - 802+00 - frozen silty clay, unsuitable.

826+00 - frozen silty clay, unsuitable.

Mile 507 - 840+00 - frozen silty clay, unsuitable.

856+68 - frozen silty clay, unsuitable.

Recommend development of unfrozen clay and till borrow pits at 758+00 and 781+00 but it would be preferable to haul granular material from glacial-fluvial borrow pits at Mile 504 to the south and from sand borrow pits at Mile 508.

14. Mile 507-512 - (875+00 - 1137+00) - Steep Creek

This section consists primarily of gravels and sands but some clay was encountered along the centreline.

875+00 to 910+00 - 2 to 8 feet of muskeg overlies sand and gravel therefore, construct fill depths so that final depths will be approximately 3 to 4 feet above existing ground. Where the muskeg is 8 feet deep the recommended initial fill should be 8 feet high.

910+00 to 1045+00 - Utilize minimum 3 foot fill depths. Proposed cuts at culvert (976+00) are satisfactory and additional cuts may be considered south from the culvert in the sand subgrade wherever lateral drainage is good.

1030+00 - proposed 30 foot cut will be undertaken in unfrozen sand and gravel and clay till. Back slopes of 2½:1 will ensure stability in this unfrozen deposit.

1045+00 to 1070+00 - high ice content zone, increase fill depths to 7 feet.

1070+00 to 1090+00 - at Steep Creek crossing maintain proposed grades over granular subgrade.

1090+00 to 1102+00 - high muskeg and ice content in clay and silt deposits. Recommend fill depth of 6 feet above existing ground elevations.

1102+00 to 1130+00 - material consists primarily of frozen glacial till but ice content is not high. Suggest that the shallow cuts be eliminated in this section with redesign as minimum fill depths of 3 feet over granular deposits.

Borrow Pits

Mile 508 - 923+00 - unfrozen very dry sand.

Mile 509 - 956+00 - frozen dry sand.

972+00 - (1000' West of ℄) - 10 feet of unfrozen sand over clay.

972+00 - (600' West of ℄) - unfrozen dry sand.

Mile 510 - 1016+00 - (2500' East of ℄) - unfrozen dry sand.

1016+23 - (800' West of ℄) - unfrozen dry sand over glacial till.

Mile 511 - 1050+00 - unfrozen gravel and clay till.

1065+00 - dry unfrozen sandy gravel 2 to 3 feet organic stripping.

Mile 512 - 1098+00 - unfrozen sandy clay - top eight feet has high moisture content and would be unsuitable as embankment fill.

1136+50 - 3 to 4 feet of gravel over unfrozen low moisture content clay.

Recommend development of all pits along this section except 1098+00 which would not allow excavation by standard procedures as a result of high moisture contents. The sand deposits along this section are coarse graded and contain little fine fraction less than the #200 mesh sieve. Without stabilization some difficulty will be experienced in maintaining the roadability of the surface, consequently, a coarse gravel cap of approximately 8 inch thickness should be placed over the roadway surface.

15. <u>Mile 512-523 - (1137+00 - 1086+00) - Saline River</u>

This section consists primarily of frozen silty clay with gravel at the Saline River valley.

> 1137+00 to 1180+00 - unfrozen silty clay. Utilize minimum fill depths of 2.5 feet and cut sections may be considered such as at station 1175+00.
>
> 1180+00 to 1195+00 - this cut section is proposed in frozen and unfrozen silty clay but bulk density and moisture content of permafrost sections indicate low excess ice. Cut sections may be made at 3:1 with subsequent slope aggradation of frozen sections but vertical and horizontal alignment should be given primary consideration to eliminate the cut.
>
> 1203+00 - 35 foot cut, 600 feet long will be performed in frozen silty clay and boulder glacial till. It is recommended that this section be re-designed as fill or re-alignment should be given consideration.
>
> 1213+00 - 60 foot fill will overlie frozen silty clay which will provide suitable

foundation stability. The embankment must be compacted from suitable unfrozen materials to ensure slope stability. The side slopes will depend upon material utilized but 2:1 are recommended for graded granular materials. Slopes of cohesive soils will depend upon their individual strength characteristics.

1218+00 to 1307+00 - maintain minimum 4 foot fills over this section.

1308+00 - 10 foot cut will be performed in unfrozen silty clay and stability will be adequate with 2:1 slopes.

1315+00 to 1333+00 - utilize minimum fill depths of 2.5 feet.

1338+00 to 1341+00 - increase fill depth to 7 feet over this high ice content "knob" hill.

1341+00 to 1390+00 - maintain at least 4 foot depth of fill.

1395+00 - recommend cut at this section be changed to a shallow fill. Frozen moisture contents of 30% in this permafrost will result in surface aggradation.

1395+00 to 1285+00 - (chainage equation) - maintain minimum 3 foot fill depths over this section.

1280+00 and 1265+00 - redesign cuts at these two sections through permafrost as 5 foot deep fills.

1260+00 - large culvert fill will be constructed over silty clay permafrost. It is recommended that compaction of deep fills be undertaken and granular material is preferred.

1257+00 - proposed 10 foot cut will be undertaken in a low moisture content frozen silty gravel.

1255+00 to 1220+00 - high ice content silt therefore, utilize 6 foot fills throughout this area.

1220+00 to 1173+00 - Saline River valley. Maintain proposed design cuts and fills through gravel and glacial till on both north and south slope. (See Saline River bridge subsurface soil report).

1173+00 to 1086+00 - maintain proposed design fill grades.

Borrow Pits

Mile 513 - 1178+00 - unfrozen silty clay, low moisture content.

1188+00 - frozen silty clay, unsuitable.

Mile 514 - 1212+00 - frozen clay, unsuitable.

1212+00 - (3000' West of ℄) - frozen clay, unsuitable.

Mile 515 - 1269+00 - frozen clay, unsuitable.

Mile 516 - 1310+00 - frozen and unfrozen silty clay.

1339+00 - frozen silty clay, unsuitable.

Mile 517 - 1369+00 - frozen silty clay, unsuitable.

1396+00 - unfrozen silty clay.

1408+00 - frozen clay, unsuitable.

Mile 518 - 1447+00 - frozen clay, unsuitable.

Mile 519 - 1292+00 - frozen low moisture content clay till, unsuitable.

1250+00 - frozen silt, unsuitable.

Mile 520 - 1222+00 - frozen silt, unsuitable.

1210+00 - unfrozen gravel and clay.

Mile 521 - 1177+00 - frozen till and silty clay, unsuitable.

Mile 522 - 1135+79 - (3 pits) frozen silty clay, glacial till and silt, unsuitable.

1121+00 - unfrozen and frozen clay.

1100+00 - frozen silty clay.

In general, little suitable borrow material is available along this section. All unfrozen pits should be developed for summer construction including those at 1178+00, 1396+00, 1210+00 and 1121+00. Alternative embankment material must be composed of locally frozen cohesive soils or granular materials may be utilized but with long haul distances. Development of gravel deposits along the Saline River should be given consideration.

16. Mile 523-531 - (1086+00 - 660+00)

This section consists primarily of low moisture content frozen and unfrozen glacial till and granular materials.

1086+00 to 980+00 - utilize fill depths of 2.5 feet and cut sections are recommended in unfrozen till deposits. Cut at 1056+00 will be performed in unfrozen glacial till.

980+00 to 925+00 - area of silty clay overburden with high ice content. Increase fill depth to 6 feet.

925+00 to 820+00 - maintain proposed fill gradeline or minimum 2.5 feet.

820+00 to 790+00 - at this culvert location, the initial gradeline produces a 140 foot deep fill but an alternate grade has been proposed which involves a 80 foot fill and 40 foot deep cuts at the valley slopes. The cut alternative may be considered although the south slope consists of frozen boulder till with a moisture content of 9%. Side slopes of 3:1 should be utilized but the frozen excavated till cannot be placed in the embankment. On the north slope unfrozen glacial till was present and may be placed in the deep embankment if compacted to 95% of Standard Proctor Density. Design shear strength parameters and side slopes for the 90 foot fill should be established whenever the borrow material is selected. The very dense nature of the insitu till as indicated by blow counts from 29 to 104 will provide adequate foundation stability for the proposed embankment. Alternate alignment routes should be studied to reduce the proposed cut sections.

790+00 to 720+00 - maintain existing grades or minimum 2.5 foot depth.

720+00 to 660+00 - subgrade consists of frozen silty clay, and silt with high ice content zones. In addition up to 4 feet of muskeg is present. Recommend fill depth of 5 feet over this terrain.

Borrow Pits

Mile 523 - 1056+00 - frozen and unfrozen glacial till, low moisture content.

Mile 524 - 1013+00 - frozen clay, low moisture content, unsuitable.

Mile 525 - 980+00 - 10 feet of frozen and unfrozen till and gravel over limestone.

934+50 - (1400' East) - frozen clay, unsuitable.

934+00 - (2000 to 4000 ft. East) - 4 to 8 feet of silt over bedrock. (limestone).

Mile 526 - 900+00 - unfrozen glacial till.

Mile 527 - 862+00 - (3000' East) - unfrozen sand.

862+00 - (500' West) - unfrozen dry glacial till.

Mile 528 - 817+00 - dry glacial till.

794+00 - unfrozen gravel and clay.

Mile 529 - 760+00 - frozen gravel and silty clay.

Mile 530 - 694+73 - frozen silty clay, high ice content, unsuitable.

670+50 - (500' East) - frozen clay till, low moisture content, unsuitable.

670+50 - (3500' West) - unfrozen sand and gravel.

670+50 - (3 miles west) - 11 test holes - material varies from unfrozen gravel to frozen clay but haul distance exceeds 3 miles.

Recommend development of borrow pits at 1056+00, 980+00, 900+00, 862+00, 817+00, 794+00, 670+50 (3500' West). Limestone bedrock under 4 to 10 feet of overburden is available at Mile 525, station 934+00 to 980+00.

17. Mile 531-536 - (660+00 - 370+00) - Little Smith Creek

This section comprises gravel and sand deposits extending approximately 3 miles south and 3 miles north of Little Smith Creek. This glacial-fluvial terrace consists primarily of medium grained sands with a little silt but gravel strata are encountered at various depths.

660+00 to 552+00 - low moisture content sandy gravel. Utilize proposed grades or balanced material design with some cut. Fills in flat areas should be minimum 2.5 feet deep.

552+00 to 490+00 - proposed cut at 544+00 will be undertaken in unfrozen silty clay and will perform adequately at 2:1 side slopes. This cut of 10 foot depth may be deepened to approximately 16 feet in order to reduce the approach grades or fill depth but permafrost was encountered at the 22 foot depth.

The 10 foot cut at 515+00 in dry loose gravel may be increased in depth to reduce fill at bridge approach. Cut at 494+00 is suitable in the dry gravel till.

490+00 to 370+00 - utilize proposed grades or use minimum fill depth of 2.5 feet.

Borrow Pits

Mile 531 - 626+00 - dry coarse gravel.

Mile 532 - 600+00 - very dry gravelly sand and gravel.

Mile 532 - 584+17 - dry gravelly sand.

Mile 533 - 548+00 - dry gravelly sand.

531+00 - unfrozen gravelly till.

519+00 - sand and sandy gravel develop pit towards test holes 567B and 569B.

Mile 534 - 505+00 - extreme variation in pit from silty sand, sandy gravel and glacial till.

Mile 535 - 446+00 - (6900' East) dry sand.

446+00 - (2100' North) frozen gravelly sand.

Mile 535 - 427+00 - frozen gravelly sand over silty clay, unsuitable.

Recommended development of all pits along this section except pit 427+00 where shallow depth of gravel overlies frozen silty clay.

18. Mile 536-543 (370+00 - 10+00)

This section of roadway consists primarily of frozen glacial till with an initial length of silty clay deposit.

370+00 to 320+00 - this section consists of frozen silty clay with isolated excess ice pockets. Recommend minimum fill depths of 5 feet.

320+00 to 10+00 - frozen glacial clay till, low moisture content. Utilize minimum fill depth of 3 feet.

Borrow Pits

Mile 538 - 292+00 - (5 miles East) - 4 to 6 feet of frozen silty clay and gravel over shale bedrock.

290+00 - frozen, low moisture content till, unsuitable.

258+00 - unfrozen glacial till.

Mile 539 - 203+50 - (1000' East) - frozen glacial till, unsuitable.

203+50 - (900' East) - frozen glacial till, unsuitable.

Mile 540 - 189+50 - frozen glacial clay till, unsuitable.

187+00 - frozen glacial till, unsuitable.

140+00 - frozen glacial till, unsuitable.

Mile 541 - 98+00 - frozen glacial till, unsuitable.

Mile 542 - 50+00 - frozen glacial till, unsuitable.

Mile 543 - 24+50 - (2000' East) - 2 to 6 feet of silty clay and clay till over shale bedrock.

24+50 - (1500' East) - 2 to 6 feet of glacial till over shale bedrock.

Borrow material along this section is primarily unsuitable frozen cohesive soils. A pit at Mile 538, station 258+00 should be developed for summer construction as it consists of unfrozen glacial till. The majority of the shallow fills which have been proposed for the six miles should be constructed of shale bedrock which was encountered in large volumes adjacent to Mile 543.

19. Mile 543-545 - (10+00 - 0 - 84+33) - Big Smith Creek

This section consists primarily of sand and gravel with bedrock outcrops along the Big Smith Creek.

10+00 to 84+33 - recommend maintaining existing grades with 3 foot minimum deep fills. Proposed cut on north slope of Big Smith Creek was not investigated in detail as a result of clearing regulations, but the nearest test hole indicated that stability will be adequate.

Borrow Pits

Mile 543 - 0+50 - 2 to 4 feet glacial till over shale bedrock.

17+00 - 2 to 3 feet of silt and sand over shale bedrock.

21+75 - (1 mile West) unfrozen sand.

It is recommended that the embankments in this region be constructed with shale bedrock. The Big Smith Creek bridge approach fills should also be constructed with shale or gravel from borrow pits developed on the river terraces.

In conclusion, the granular borrow pits which have been investigated from Mile 450 to 515 will allow construction of all embankments in this 65 mile south section from gravel and sand. The uniformity of granular fill throughout this section will facilitate construction and result in lower maintenance costs then if cohesive sections are utilized.

From Mile 515 to 545 major gravel deposits exist at stream terraces but maximum haul distances will be in the order of 5 to 6 miles. In addition to gravel deposits, bedrock which was found adjacent to Mile

525 and 540 should be developed in lieu of cohesive soils.

After the designer has chosen a final gradeline and determined fill quantities the potential borrow pit volumes in Table VI-3 may be utilized to establish the number of pits to be developed.

(e) Construction and Design Aspects

Recent construction experience attained along the Dempster Highway, Northwest Territories, and on the Mackenzie Highway near Inuvik has indicated that permafrost cohesive soils result in poor quality roadways. In addition, construction methods and scheduling for frozen clay soils varies extensively from the conventional procedures utilized in non-permafrost areas.

This investigation from Mile 450 to 550 is situated in the discontinuous permafrost zone with 55% of the centreline test holes encountering permafrost. But it is emphasized that conventional construction equipment may be employed throughout the majority of this section of highway. This recommendation is based upon the excellent distribution of granular construction materials existing throughout this proposed highway section. Fifty-five (55) of the proposed borrow pits consisted of granular materials which occur along the stream channels flowing into the Mackenzie and in other glacial-fluvial deposits on

TABLE VI-3

RECOMMENDED BORROW PITS FOR DEVELOPMENT

* NOTE: Soils Unfrozen unless indicated otherwise.

MILE	STATION	MATERIAL	ESTIMATED BORROW PIT VOLUME (cu.yd.)
450	378+00	frozen gravel	60,000
453	537+00	clay	10,000
453	548+00	clay	200,000
454	591+00	gravel	600,000
454	630+00	gravel	800,000
456	738+00	clay	150,000
457	781+00	gravel & sand	100,000
459	871+00	gravel	1,500,000
459	891+00	gravel	1,250,000
460	948+00	clay	60,000
463	1107+00	silt & clay	50,000
465	1365+00	frozen sand & gravel	500,000
465	1363+00	frozen sand & gravel	
468	1227+00	silty clay & gravel	60,000
468	1184+00	silty sand & gravel	330,000
469	1162+00	gravel & silt	350,000
470	1104+00	frozen granular	330,000
471	1056+00	frozen gravel	200,000
473	923+89	clay	800,000
475	846+00	clay	100,000
479	605+50	gravel	500,000
480	569+50	gravel	330,000
480	550+00	clay till	300,000
481	505+00	frozen gravel	800,000
481	493+00	frozen gravel	80,000
482	465+00	gravel	1,700,000
483	427+50	gravel	250,000
484	375+00	sand	350,000
484	334+00	sand	350,000

TABLE VI-3 (cont'd)

MILE	STATION	MATERIAL	ESTIMATED BORROW PIT VOLUME (cu.yd.)
485	289+00	gravel	120,000
487	221+00	gravel	200,000
487	190+00	sand	400,000
488	141+00	gravel	3,000,000 (488–489)
489	114+00	gravel	
489	78+00	gravel	1,000,000
490	33+00	gravel	500,000
491	15+00	gravel	1,500,000
493	137+50	clay	80,000
496	274+50	clay	200,000
499	412+00	clay	300,000
500	453+00	gravel	80,000
500	480+00	gravel	300,000
500	510+00	sand	300,000
501	550+78	sand	400,000
502	567+00	sand & gravel	
502	596+50	gravel	3,000,000 (502–503)
503	625+00	gravel & sand	
503	665+00	sand	300,000
504	698+00	glacial clay till	100,000
505	758+00	silty clay	50,000
506	781+00	glacial clay till	80,000
508	923+00	sand	
509	956+00	frozen sand	5,000,000 (508–509)
509	972+00	sand	
509	972+00	sand	
510	1016+00	sand	400,000
510	1016+23	sand	400,000
511	1050+00	gravel & till	200,000
511	1065+00	sandy gravel	600,000
512	1136+50	gravel over clay	100,000
513	1178+00	clay	60,000
517	1396+00	clay	60,000
520	1210+00	gravel & clay	400,000
522	1121+00	clay	50,000
523	1056+00	glacial till	90,000
525	980+00	glacial till	80,000
525	934+00	limestone	Unlimited
526	900+00	glacial till	150,000

TABLE VI-3 (cont'd)

MILE	STATION	MATERIAL	ESTIMATED BORROW PIT VOLUME (cu.yd.)
527	862+00 (3000 ft.E.)	sand	250,000
527	862+00 (500 ft.W.)	glacial till	100,000
528	817+00	glacial till	100,000
528	794+00	gravel & clay	60,000
531	626+00	gravel	1,000,000
532	600+00	sand & gravel	160,000
532	584+17	sand	1,250,000
533	548+00	gravelly sand	
533	531+00	gravelly till	300,000
533	519+00	sand & sandy gravel	80,000
534	505+00	sand, gravel & till	500,000
535	446+00 (6900 ft.E.)	Sand	-
535	446+00 (2100 ft.N.)	frozen gravel sand	100,000
538	292+00	bedrock	Unlimited
538	258+00	glacial till	350,000
543	24+50 (2000 ft.E.)	shale bedrock	
543	24+50 (1500 ft.E.)	shale bedrock	Unlimited
543	0+50	shale bedrock	
543	17+00	shale bedrock	
543	21+75 (1 mile W.)	sand	600,000

the uplands.

Although an economic analysis is not within the scope of this investigation or report, it is felt that the haul distances for suitable materials are not generally excessive such that consideration need be given to the utilization of frozen cohesive embankment soils. As previously noted, a large portion of the highway section may be constructed with granular soils rather than unfrozen cohesive materials. Frozen cohesive soil "chunks" placed in embankments will undergo consolidation with roadway surface disruption for many years and potential failure of deep fill sections. If frozen clay is utilized for various sections, the material should only form a central core with an armour coat of gravel or broken shale. Under no circumstances should frozen clays be utilized in deep fills and particularly not at bridge approaches. Many roadway fills will have minimum depths of 2.5 to 3 feet and an armour cover of 1.5 to 2 feet of gravel or rock would not justify a thin inner clay core. Consequently, it would be reasonable to only employ frozen clay where fills are in the range of 5 to 10 feet deep and where large quantities of granular or bedrock are not available. Although we do not anticipate the utilization of large volumes of frozen clay, it is necessary to employ ripping techniques in the borrow pit wherever frozen soils are encountered. Equipment manufacturers relate ripping characteristics of soils and rocks to their seismic response, but to date, the rippability of frozen soils has not been established. It is recommended that an investigation of frozen soil seismic properties be undertaken and correlated with actual field ripping tests. This correlation would be of value in the continuous permafrost region where soils are predominantly frozen. Where bedrock materials are utilized for fill near Mile 540, standard tractor and ripper techniques will be necessary, although some blasting may be necessary where the strata are hard and durable.

The unfrozen glacial till and clay borrow pits should be developed from July to December, generally avoiding the periods of deep seasonal frost penetration. Wherever borrow pit access is difficult during the summer season, the period from November to December can be a critical period when slight frost penetration allows good vehicle mobility but does not necessitate the excavation and placement of frozen soils.

The numerous granular borrow pits will in many cases allow both summer and winter construction. Wherever borrow pits are located great distances from the centreline, consideration should be given to winter construction in order to eliminate haul road maintenance during the summer.

The present practice of the Department of Public

Works is very limited use of compaction equipment in permafrost regions. This practice is reasonable where frozen cohesive soils are utilized or unfrozen cohesive soils are placed at temperatures well below freezing. In general, compaction techniques have been found to be ineffective in significantly increasing the density of frozen clay and the resulting embankments are of poor quality. Consequently, sections of the roadway constructed with frozen clay would consist of poor quality but others which are constructed of granular material and unfrozen clays would provide good surface roadability and stability.

It is recommended that vibratory or sheepsfoot rollers be employed in fills at culvert and bridge crossings. These areas must be constructed of unfrozen soils compacted to 95% of Standard Proctor density.

Therefore, the better quality materials will provide good embankments as compared to frozen cohesive soils and even much higher quality when compacted according to standard specifications.

It is recommended that fill side slopes of 3:1 be utilized in general wherever fill depths vary from approximately 3 to 10 feet and subgrade instability is not questionalbe. In ice-rich permafrost zones the side slopes should be 4:1 to allow for thaw-settlement below the lower portion of the slope. Slopes of depth fills are to be established after the detailed properties of the materials have been established.

Culverts should be placed when backfill and temperatures are compatible so that 95% of Standard Proctor can be achieved. Compaction is necessary to ensure stability and prevent road subsidence. Wherever stream channels are re-aligned ice-rich permafrost zones, should be avoided.

(f) <u>Bridge Foundation Design and Construction</u>

The proposed Mackenzie Highway from Mile 450 to 550 will necessitate the construction of nine bridges. Separate bridge reports on the subsurface soil conditions have been prepared and recommendations for construction and design of the bridge foundations and approaches were presented.

The soil types at the bridge sites are predominantly stream deposited gravels and sands but bedrock and glacial till were encountered at some locations.

In the gravel strata, driven steel-H or pipe piles have been recommended for the pier foundations primarily based upon their high driving strength, high load capacity and relative ease in splicing. The major construction problem will be the difficulty in attaining pile penetration around large boulders. To advance piles it may be necessary to utilize vibration techniques or large diameter open pipe piles may be employed with churn-drill crushing of large boulders inside the bottom of the pipe. Where-ever pile driving is undertaken in granular deposits, the allowable load capacity should be established from applicable pile-driving formulae. At shallow bedrock locations, conventional pier-footing foundations are recommended.

All bridge approach embankments must be compacted to 95% of Standard Proctor density utilizing high quality unfrozen materials. Granular approach fills are recommended to provide greatest stability during rapid drawdown cases after flood water levels drop. Design fill slopes will depend upon the material type available but well-graded gravel and sand mixtures may be placed at 2:1 slopes. Bridge abutments may be placed on shallow spread footings in the compacted approach fills but wherever the stability or settlement characteristics of a placed fill is in doubt the abutments must be supported on piles driven into the undisturbed subsoil. The lateral pressures subjected to the abutments by compacted fill should be based upon the co-efficient of earth pressure at-rest.

In all cases, approach bridge roadway grades should not be designed to produce cut sections in permafrost cohesive soils.

Soluble sulphate analysis of soils at the various bridge sites indicated sulphate contents near .1%. Therefore, sulphate conditions do not appear to be severe and normal Portland Cement may be used.

VII RECOMMENDATIONS

This section consists of major recommendations relative to the design and construction of the Mackenzie Highway from Mile 450 to 550 and recommendations for future geotechnical work.

(a) At least the initial 65 mile section should be constructed entirely with granular material as this investigation has disclosed a good distribution of granular borrow. Consideration should also be given to granular and bedrock utilization throughout the remainder of the section, although haul distances will be greater than those on the south portion.

(b) All deep approach bridge embankments should be constructed of granular or broken bedrock compacted to 95% of Standard Proctor by vibratory compaction techniques.

(c) Numerous good gravel sources exist along this section from Mile 450 to 550 but accurate grain size analysis are not obtained when diamond bits and air drilling techniques are utilized. The coarse fraction is broken down and the air recovery separates various particle sizes making retrieval of a representative sample difficult. After recommended gravel borrow pits are developed for embankment material, the well graded gravel-sand mixtures should be further subjected to laboratory testing to more accurately define their suitability for crushed roadway gravel and concrete gravel.

(d) Several deep embankment fills are proposed at bridge approaches and culvert locations. The foundation conditions for these fills were determined during this geotechnical investigation but the stability and settlement of the embankment has not been investigated. The design side slopes and potential ultimate settlement will depend upon the borrow pit source chosen for embankment fill. Although coarse graded gravel is recommended for all deep fills, other factors may dictate alternate sources. The stability of each fill material should be determined after obtaining shear strength parameters and pore pressure response characteristics.

(e) Although cuts in ice-rich cohesive permafrost are not recommended consideration may be given to cutting frozen slopes where initial field and laboratory tests do not indicate excess ice conditions. The risk of large cuts has been discussed previously. The decision to utilize some cut sections should be followed by test pits to confirm that excess ice is not present.

In addition some slope protection should be employed to reduce the aggradation debris that will occur when the active layer is established.

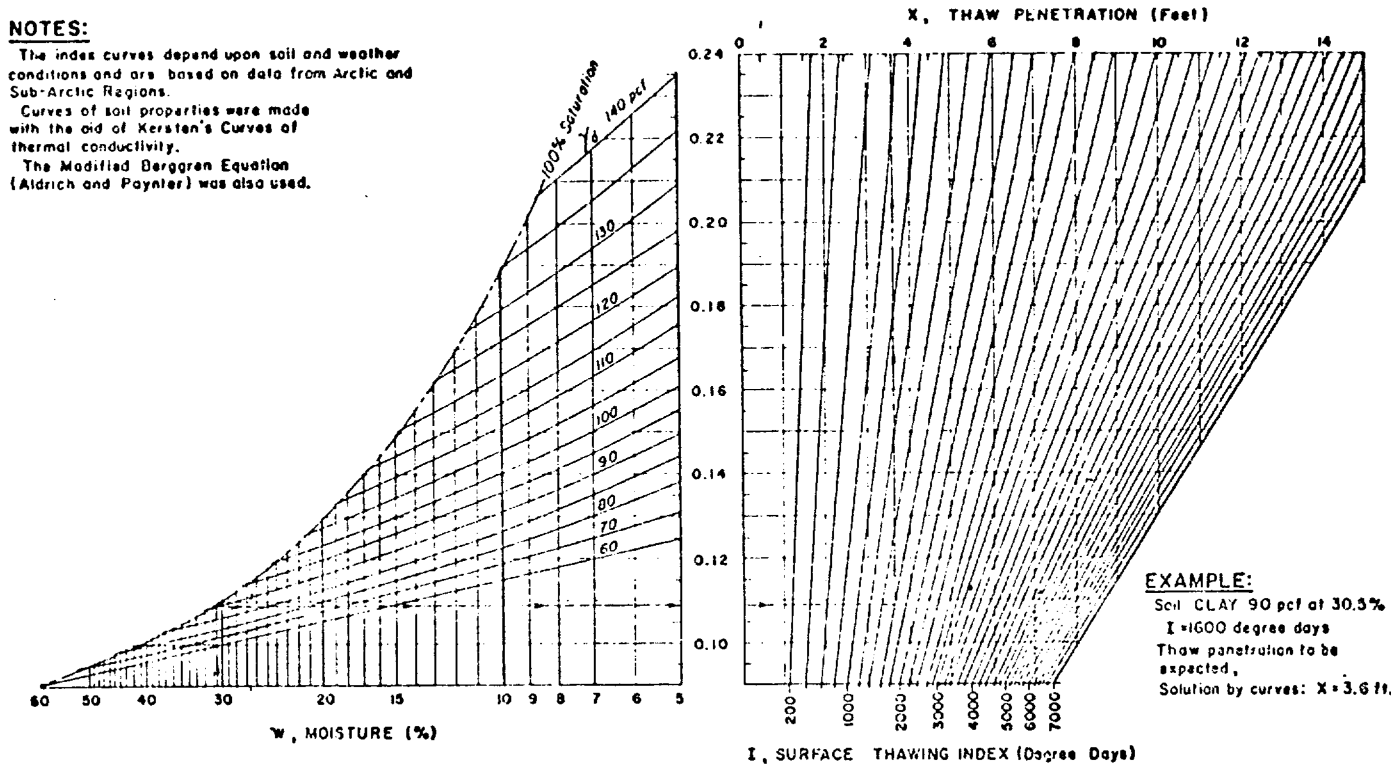
(f) Air-drilling techniques and penetrometer sampling gave a good indication of the soil types encountered but before potentially large borrow pits are cleared, it is recommended that visual inspection of back-hoe test pits be undertaken. In particular, borrow pits have been recommended for development where 2 test holes indicated unfrozen conditions and 1 test hole frozen conditions. The pit suitability and sporadic permafrost occurrence would better be evaluated by test pits before extensive clearing was undertaken.

(g) Condition of haul roads to selected borrow pits is difficult to establish during winter periods when surfaces are frozen and test holes are not drilled. Where good access on high well-drained ground is not available, summer reconnaissance by helicopter and foot would be recommended to establish the extent of haul road construction.

(h) The recommendations and data presented in this report should primarily be utilized to establish a final design gradeline. Subsequently, embankment fill volumes and haul distances may be obtained. At this point it can be established which borrow pits would be most economically developed.

APPENDIX 'A'

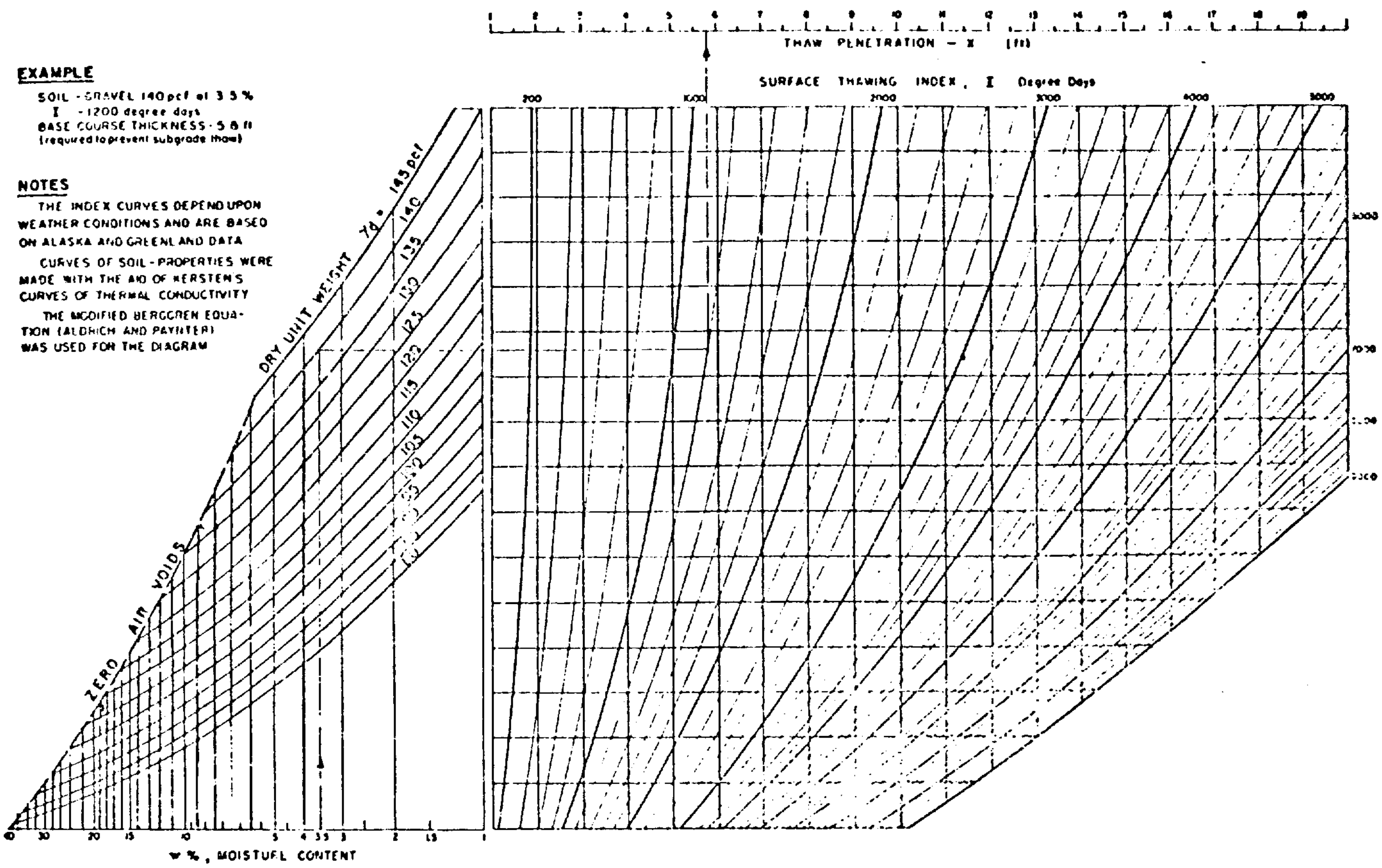
PLATES AND SAMPLE CALCULATIONS



THEORETICAL PENETRATION OF 32°F ISOTHERM

FINE GRAINED SOILS, THAWING

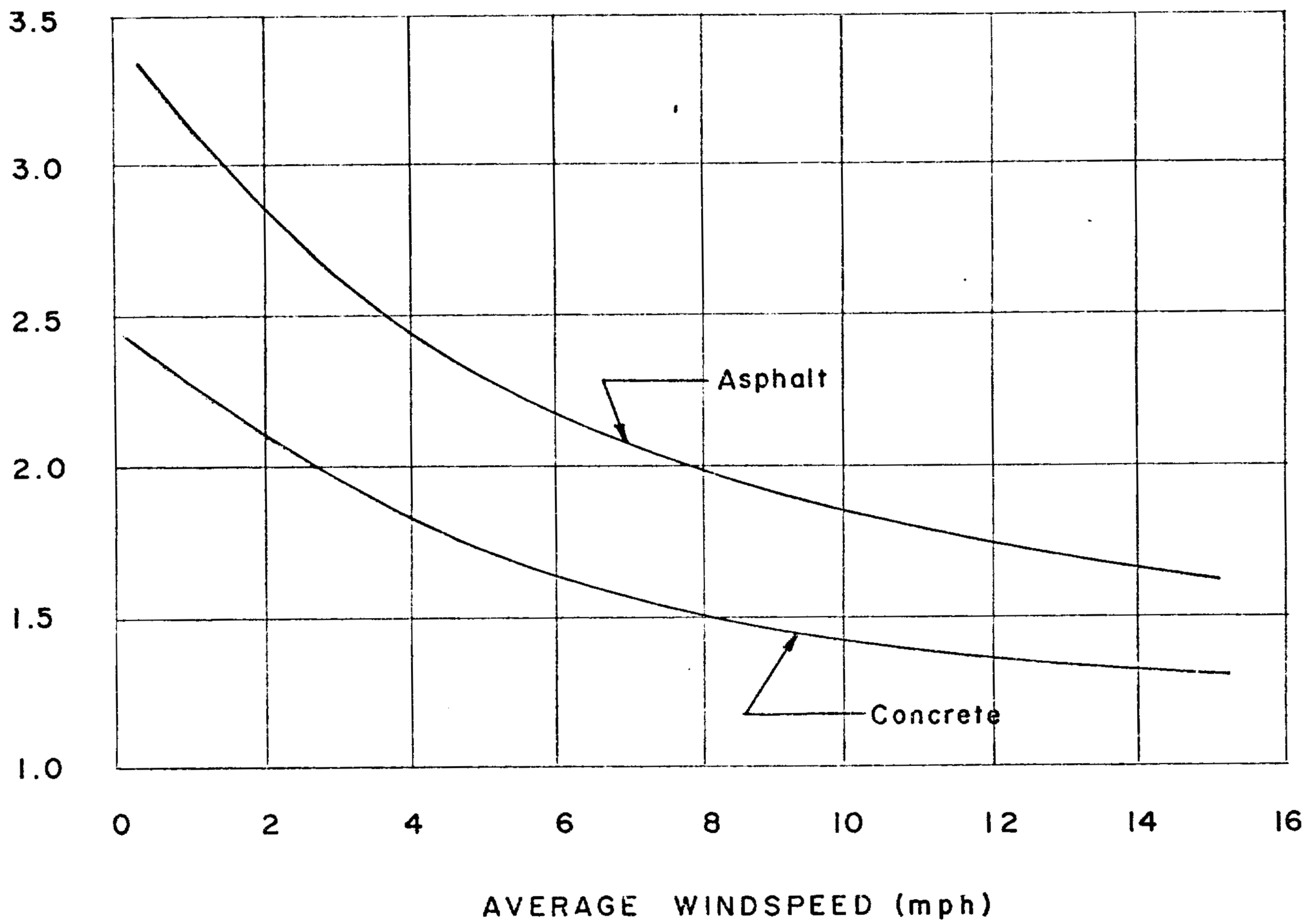
From: "Degree-days and Heat Conduction in Soils" by F. J. Sanger. International Permafrost Conference Proceedings 1963, page 258.



THEORETICAL PENETRATION OF 32°F ISOTHERM

COARSE GRAINED SOILS, THAWING

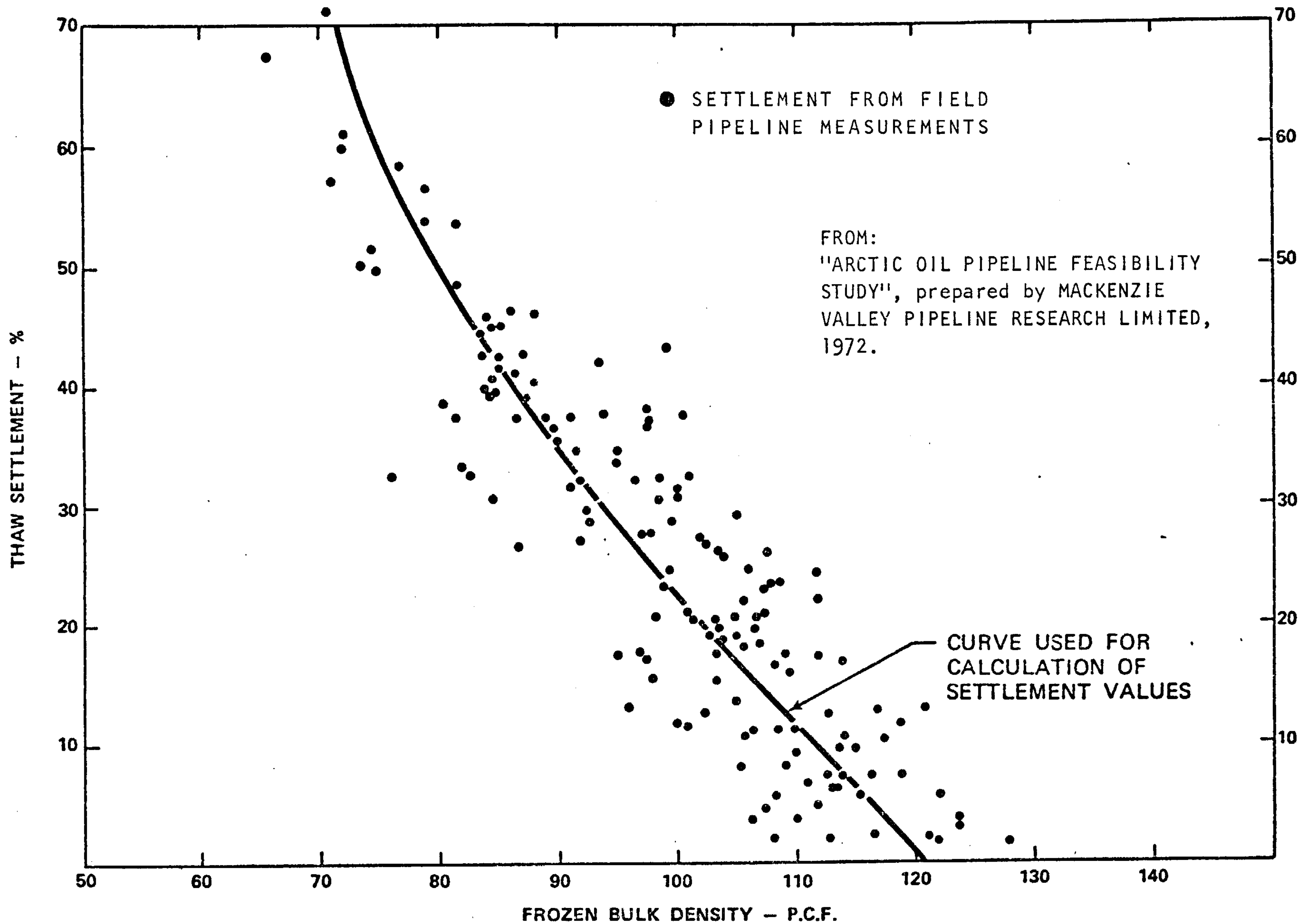
From: "Degree-days and Heat Conduction in Soils" by F. J. Sanger. International Permafrost Conference Proceedings 1963, page 257.



Ratio of surface thawing index (STI) to air thawing index (ATI) for asphalt and concrete pavements for various windspeeds.

From: "Degree-days and Heat Conduction in Soils" by F.J. Sanger. International Permafrost Conference Proceedings 1963, page 261.

PLATE A-3



FROZEN BULK DENSITY vs. THAW SETTLEMENT PLATE A-4

Example of Thaw-Settlement Calculation

Test Hole - 458 B 160 B

Insitu properties -	Bulk wet unit weight	- 95.1 pcf
	Dry unit weight	- 62.9 pcf
	Moisture Content	- 52%
	Liquid Limit	- 36%

A. Thaw-Settlement from Field Initial Density and Final Slurry Density

Slurry sample properties

-	Bulk wet unit weight	= 116 pcf
	Dry unit weight	= 86 pcf
	Moisture content	= 35%
	Liquid Limit	= 31.4%
	Specific gravity	= 2.70

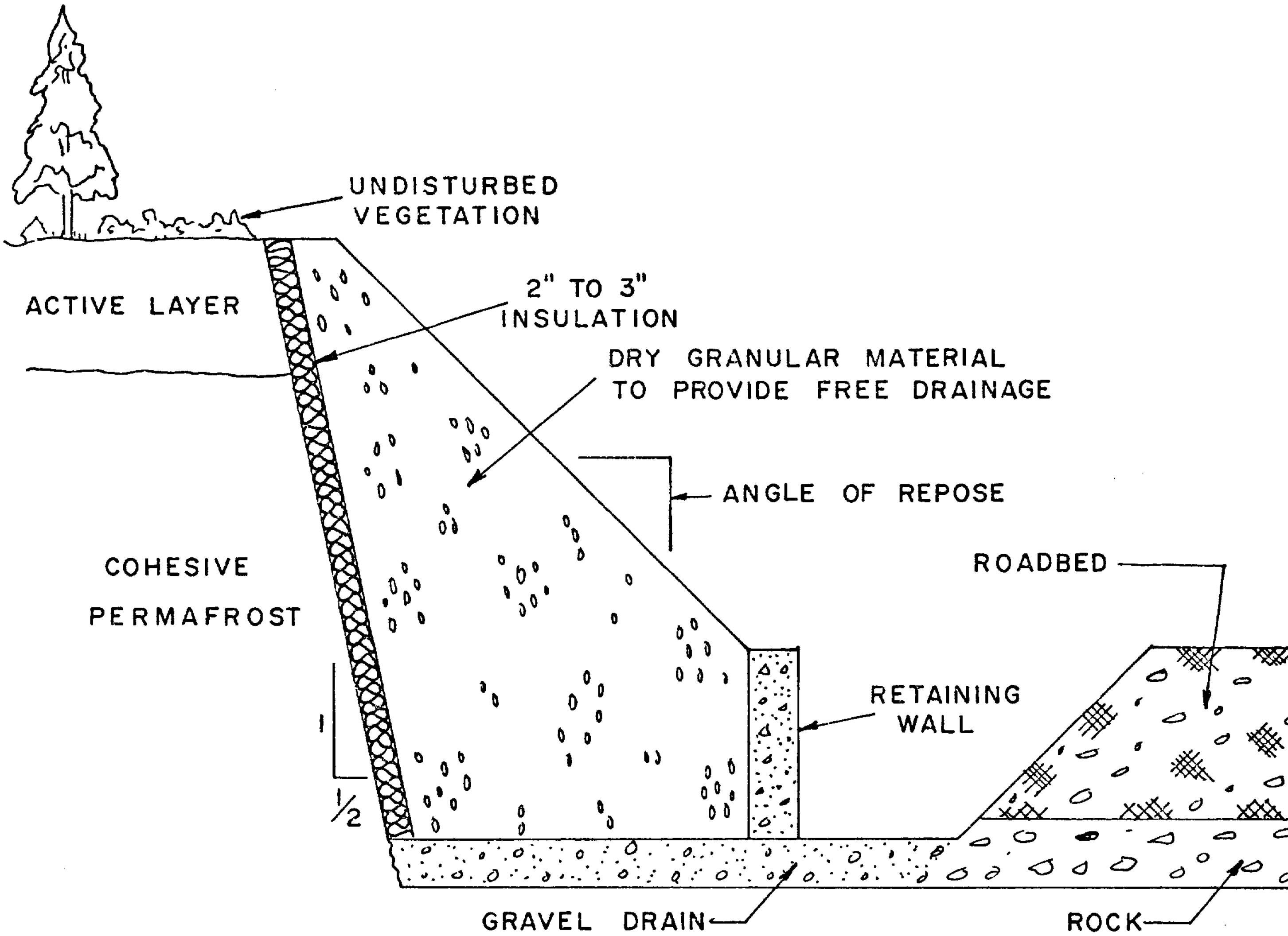
Field void ratio = 1.70
Slurry Sample Void Ratio = .96

$$S = H \frac{e}{1+e_o} = 12 \frac{1.70 - .96}{1 + 1.70} = 12 \frac{(.74)}{(2.70)}$$

Settlement = <u>3.3 inches/foot</u>

B. Thaw-Settlement from Empirical Pipeline Data (Plate A-4)

Insitu bulk density = 95.1 pcf
From curve-settlement = 3.4 inches/foot

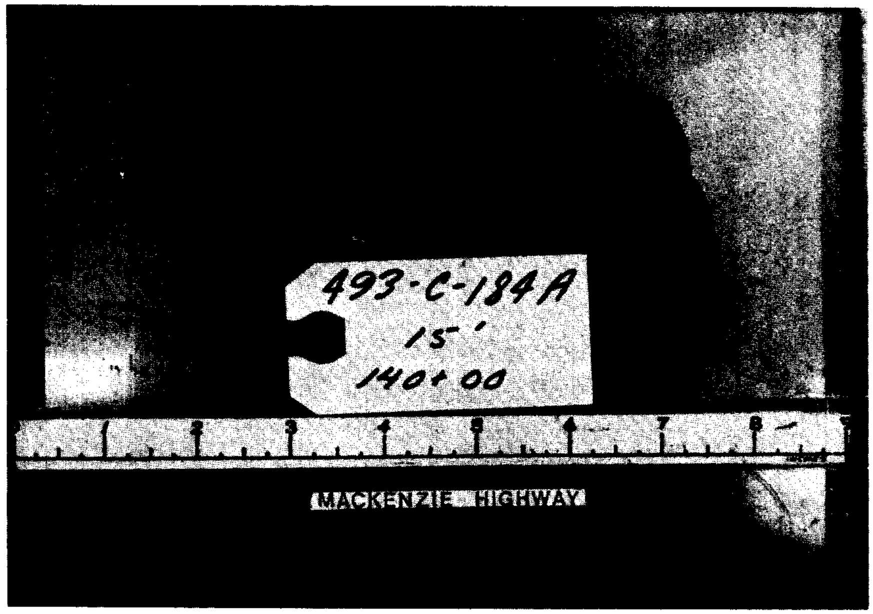


PERMAFROST SLOPE PROTECTION

PLATE A-6

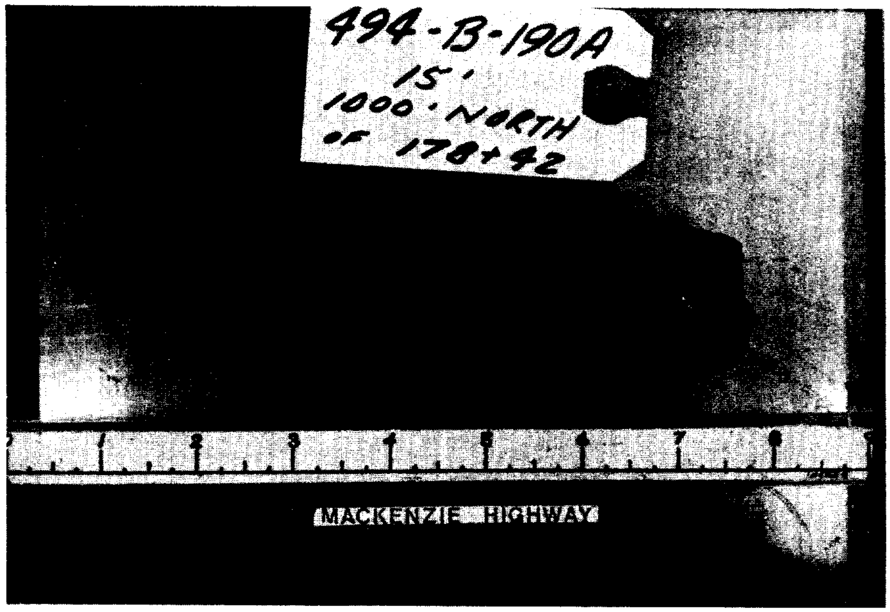
APPENDIX 'B'

PHOTOGRAPHS

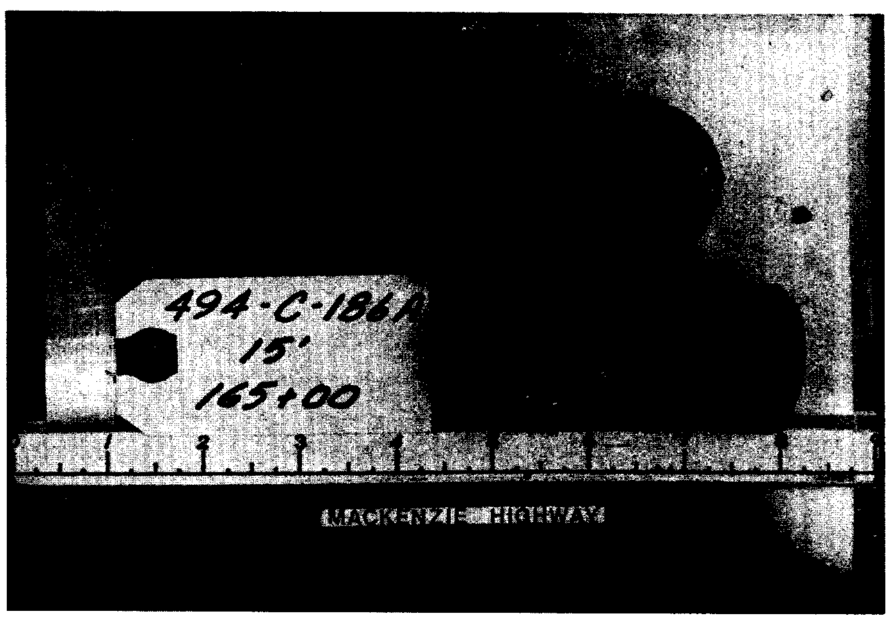


1. *Mile 493, depth 15 feet, silty clay with random ice lenses.*

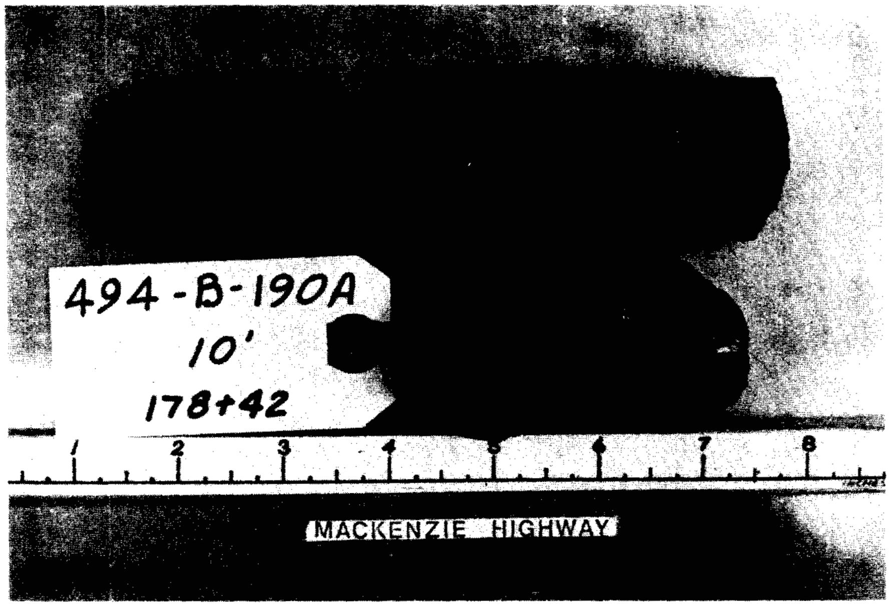
2. *Typical ice lenses (light coloured) in silty clay with fracturing along the lenses.*



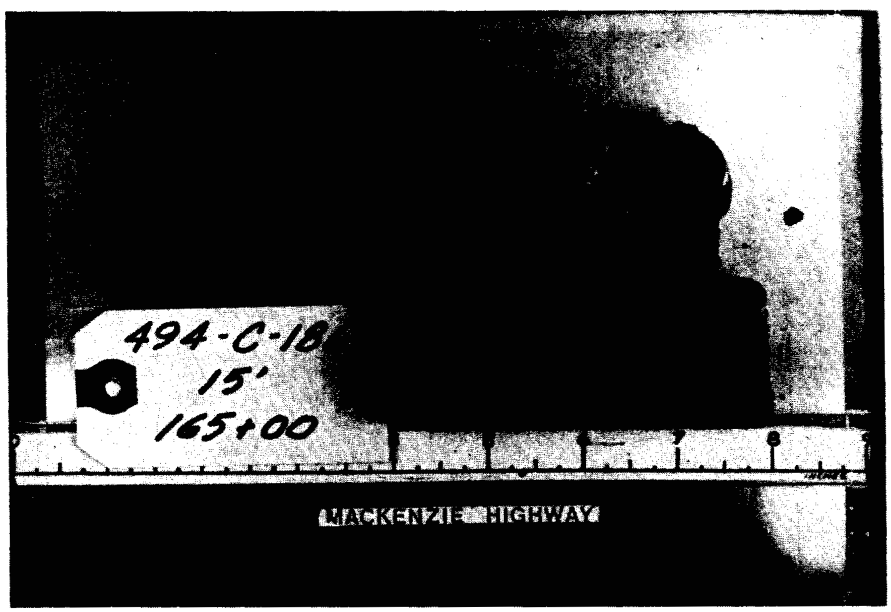
3. *Frozen dark brown clay, moisture content 20.6%, random ice.*



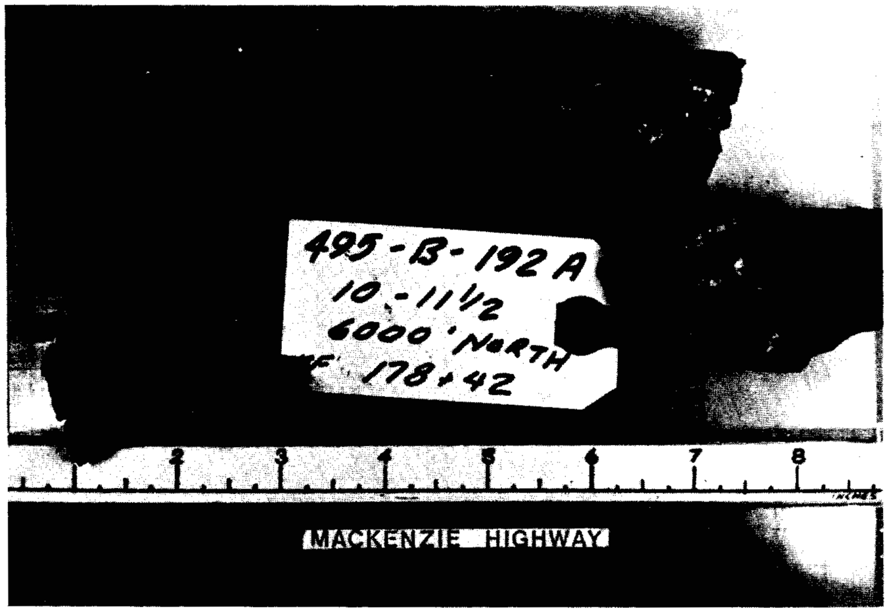
4. *Random ice lenses in silty clay deposit.*



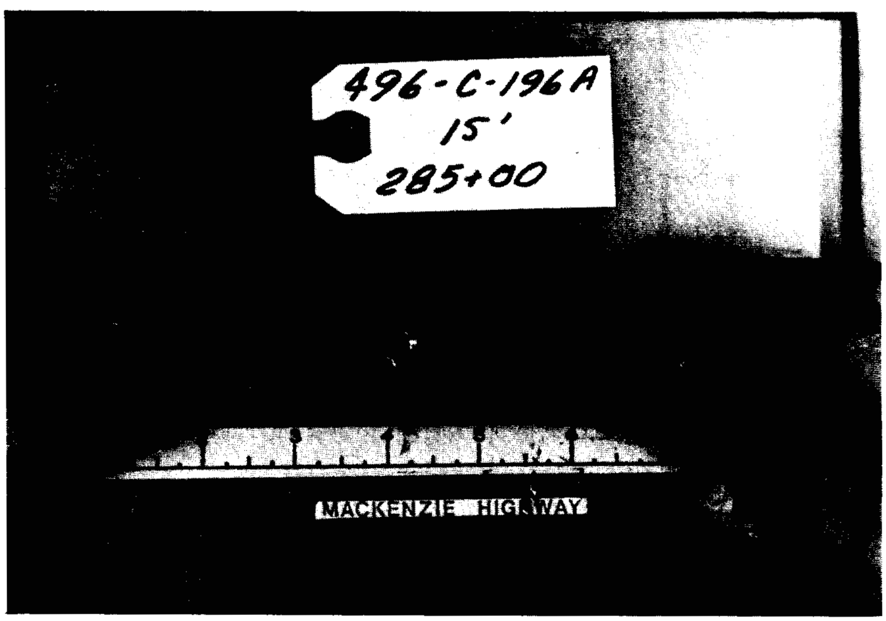
5. *Frozen borrow pit material, stiff silty clay, random ice lenses, moisture content 21%.*



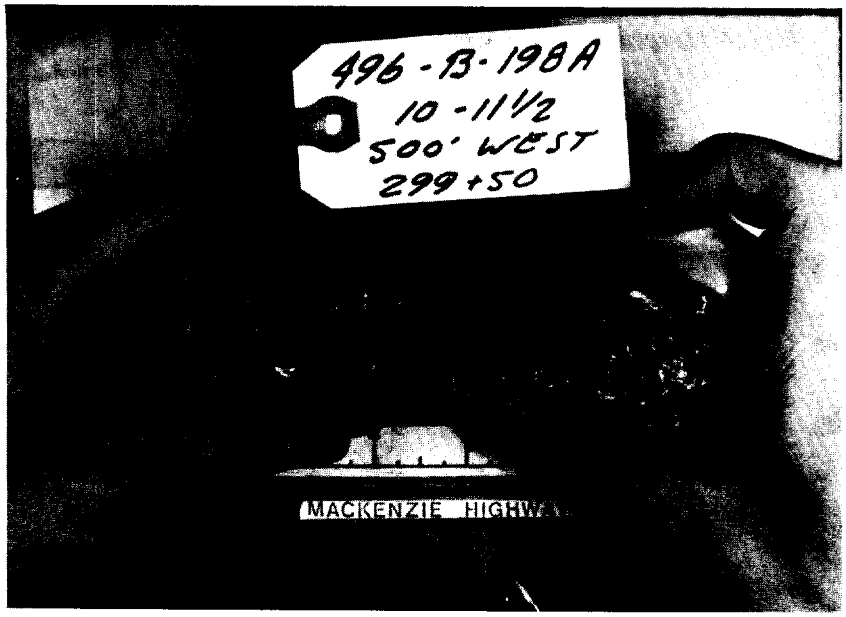
6. *Frozen silty clay, visible random ice lenses, moisture content 22%.*



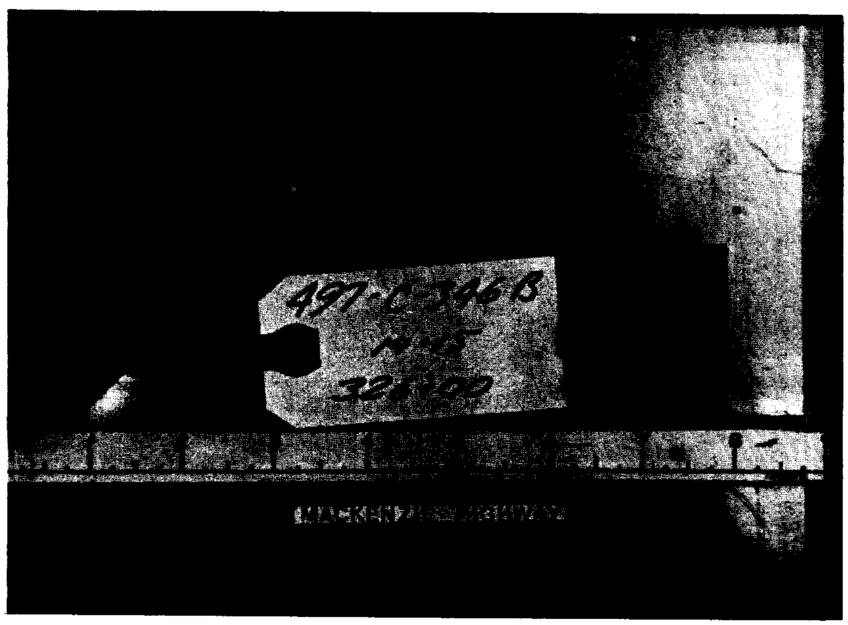
7. *Frozen silty clay, visible random ice, moisture content 23%, bulk density 122 pcf.*



8. *Frozen clay, one-inch ice lenses, average moisture content 50%.*

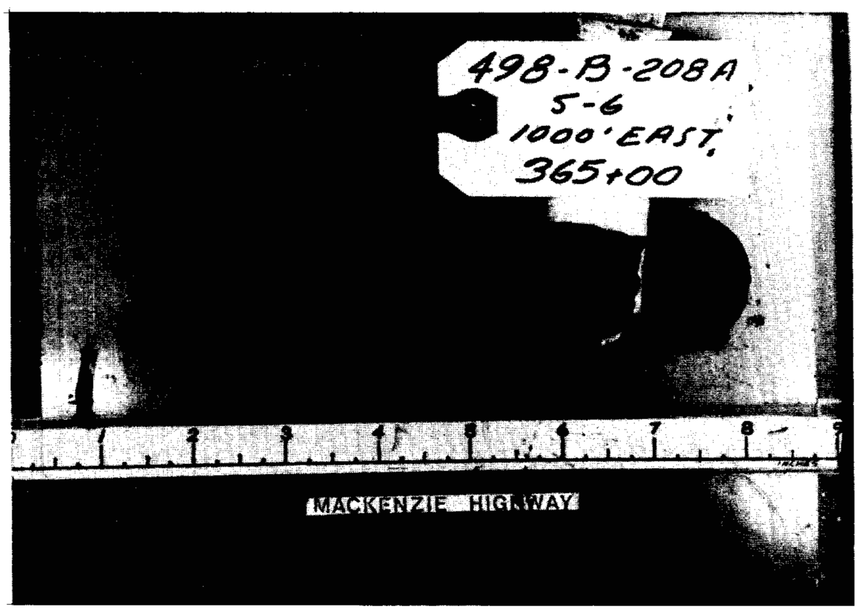


9. *Random ice lenses in silty clay, excess ice less than 5%, moisture content 21%, bulk density 126.4 pcf.*

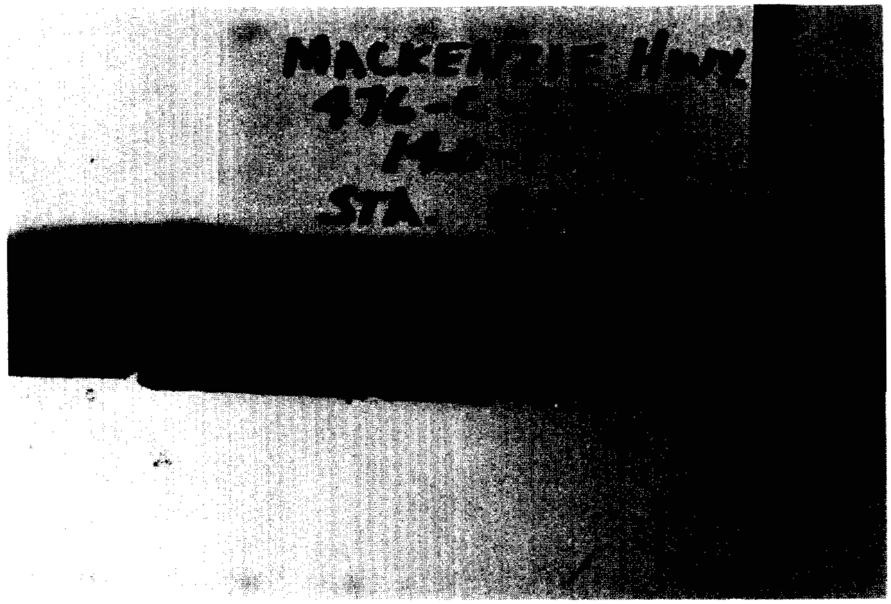


10. *Brown frozen silty clay, low moisture content of 25% does not reflect 1/4-inch ice lenses found in penetrometer sample. Where ice is widely distributed large moisture samples should be taken.*

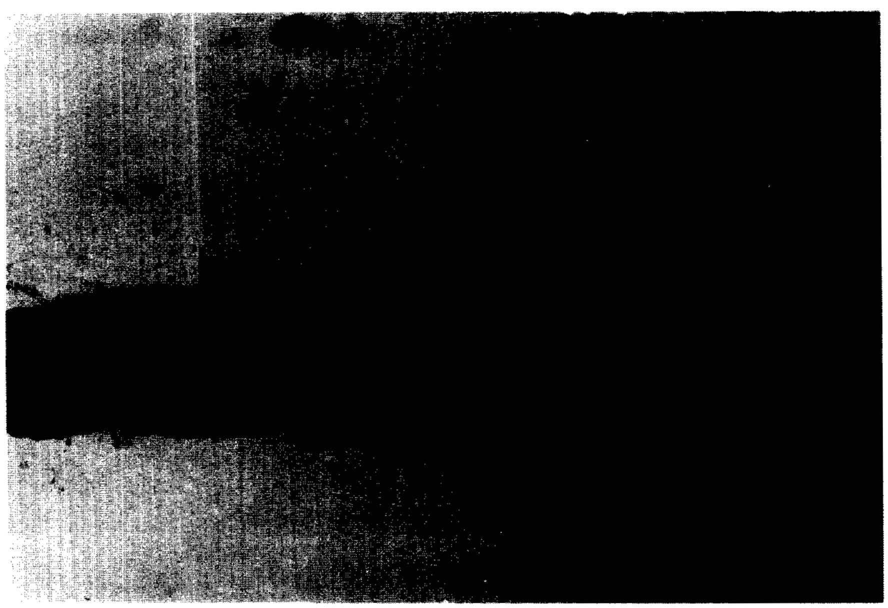
11. *Frozen silty clay, random ice lenses, moisture content 22%, plastic limit 25%, liquid limit 40%, bulk density 123.3 pcf and excess ice negligible.*



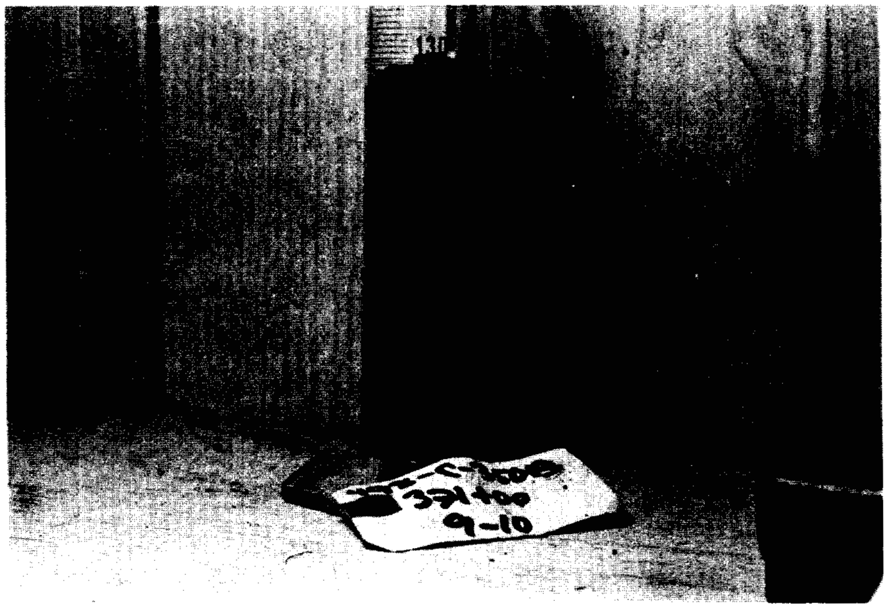
12. *Frozen borrow pit silty clay, visible random ice lenses, moisture content 41%.*



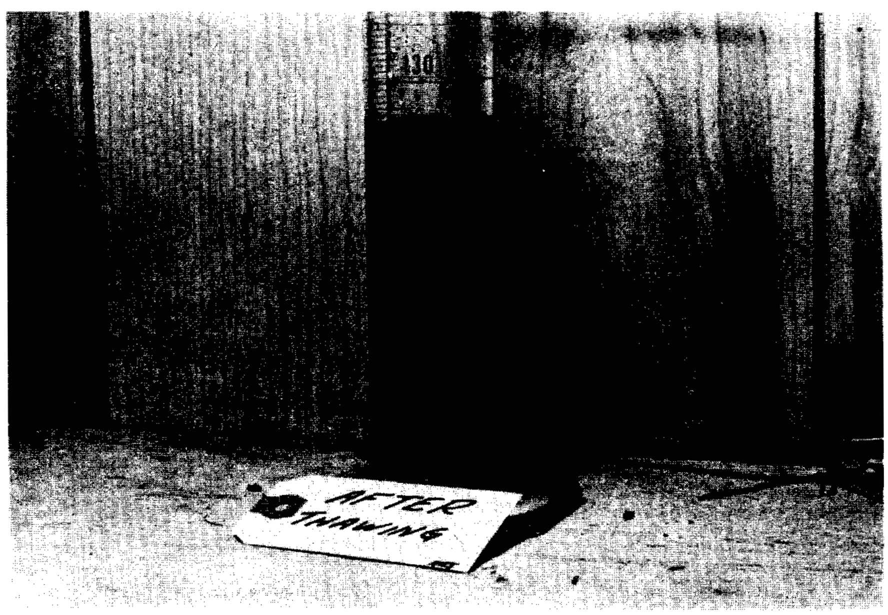
13. *Frozen silty clay, 1/4-inch ice lenses, moisture content 35%, plastic limit 26%, liquid limit 41%.*



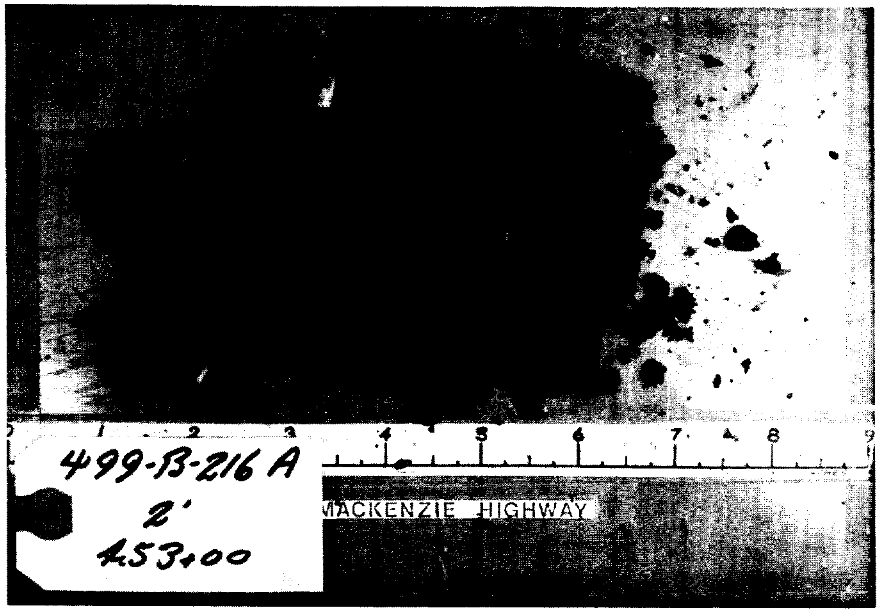
14. *Frozen silty clay, ice lenses widely distributed.*



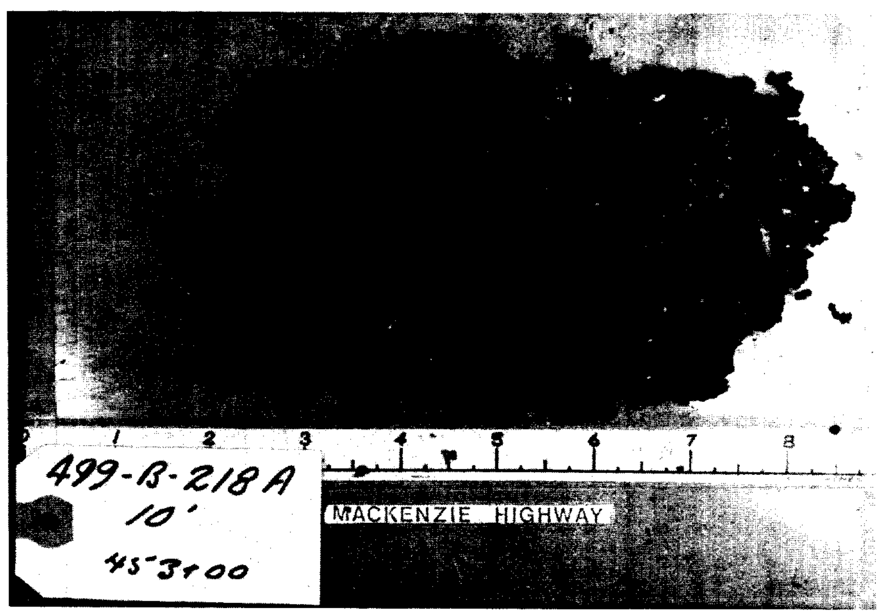
15. *Coarse frozen fibrous muskeg Mile 498. (Thaw settlement experiment.)*



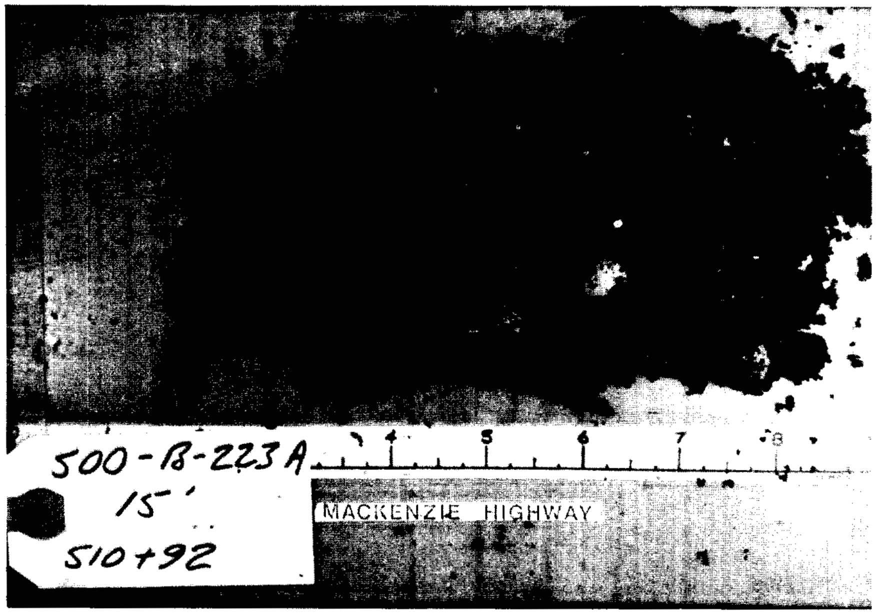
16. *Above muskeg sample unfrozen with thaw settlement of about 15% and moisture content 275%.*



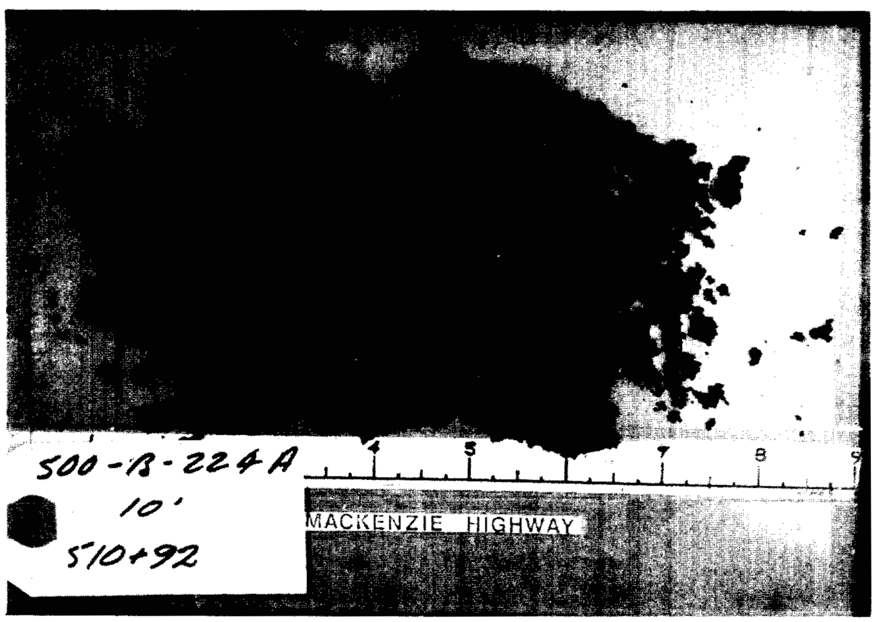
17. *Gravel borrow pit, test hole 216A, unfrozen coarse gravel, moisture content 5.6% at 2-foot depth.*



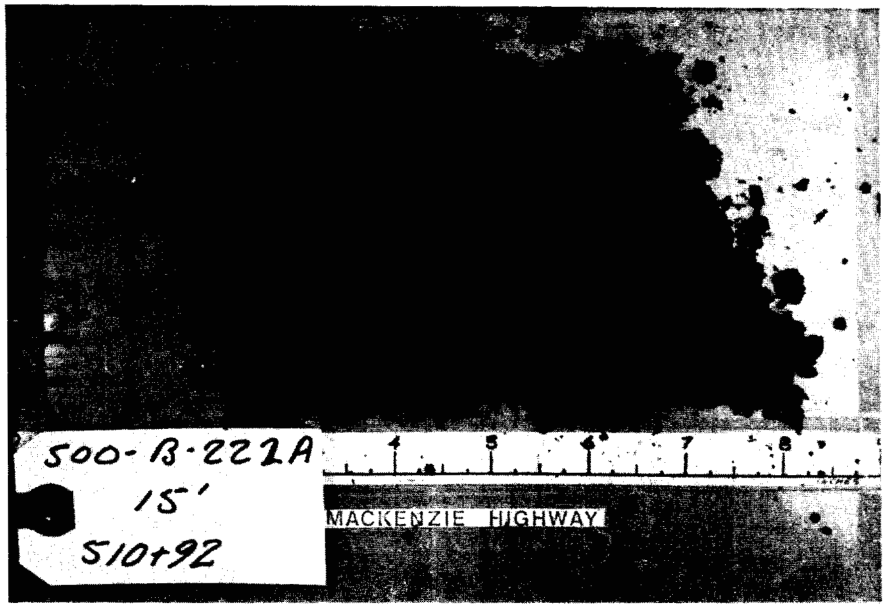
18. *Same borrow pit as above except at 10-foot depth in test hole 218A. Water table encounter at 12-feet results in moisture content of 16.2%.*



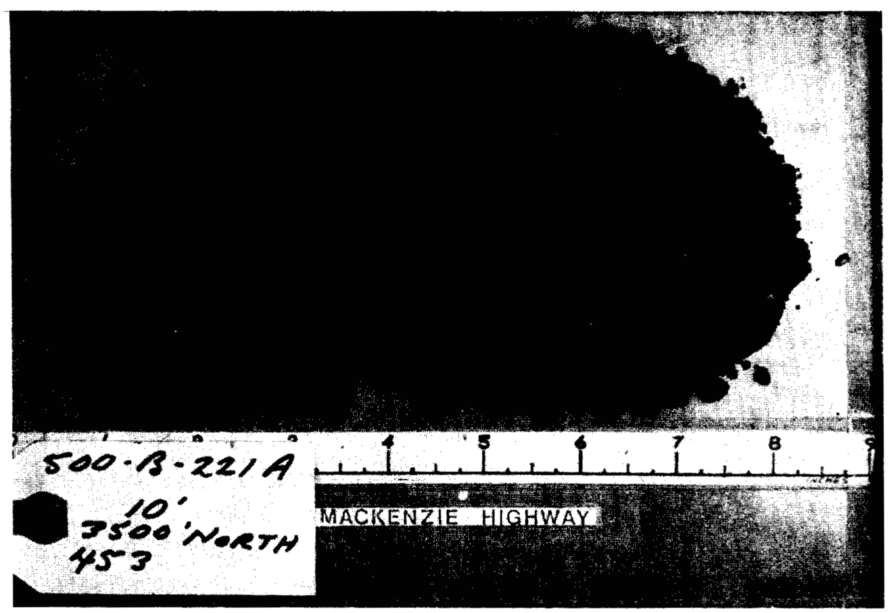
19. *Granular borrow pit at 15-feet, unfrozen coarse sand with pebbles, moisture content 6%.*



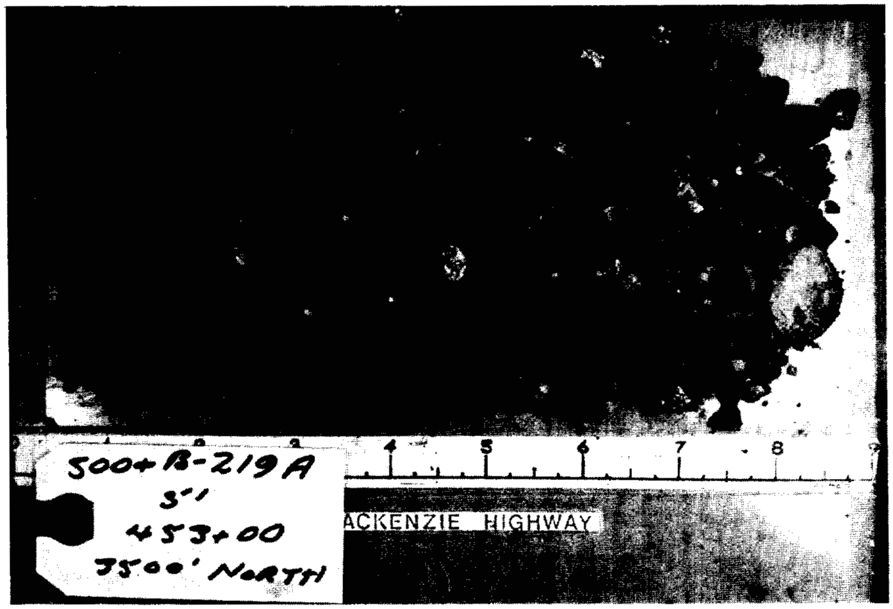
20. *Same borrow pit as above except material contains fewer pebbles and moisture content is 11% at 10-foot depth.*



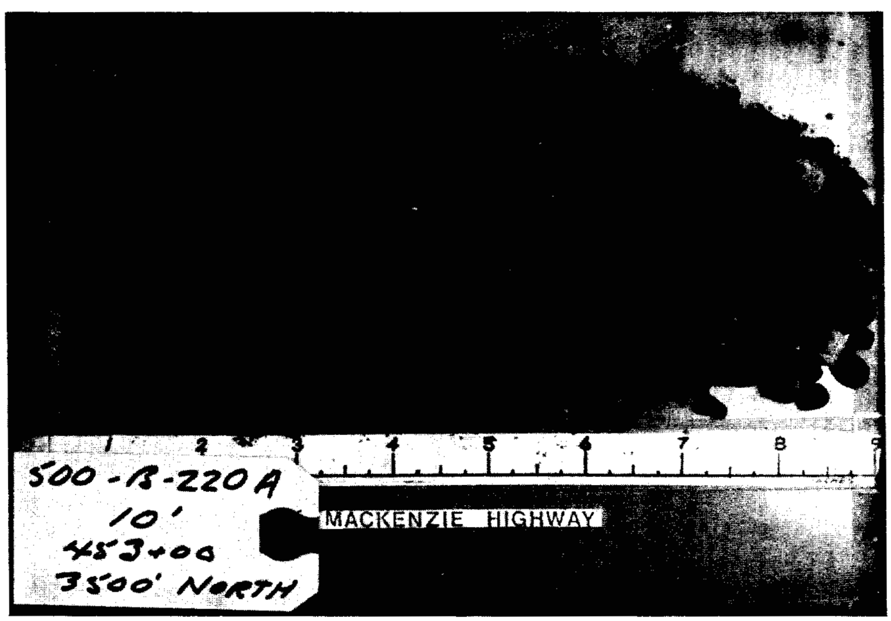
21. *Same borrow pit as photographs 19 and 20 except in test hole 222A at 15-feet frozen sandy clay occurs with moisture content 16%.*



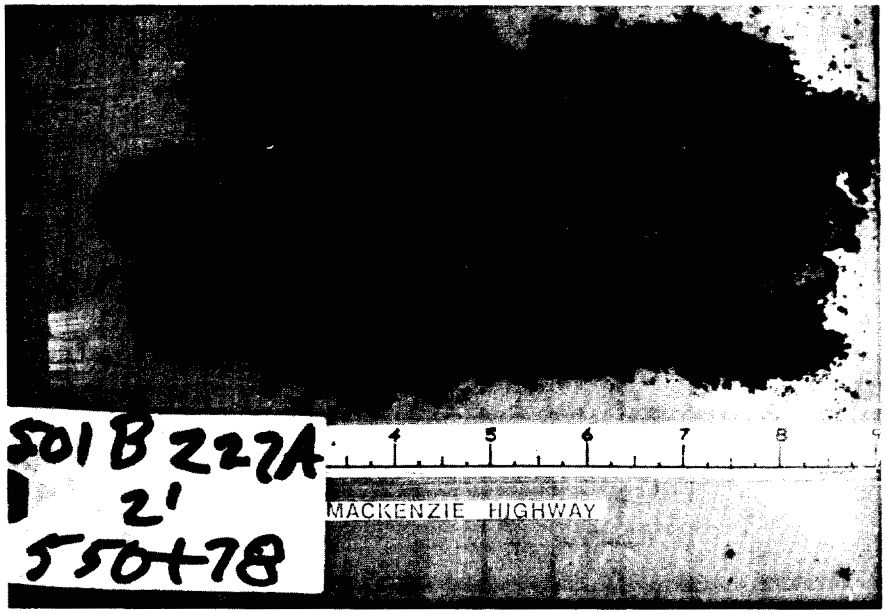
22. *Gravel borrow pit with coarse sand and moisture content 2%.*



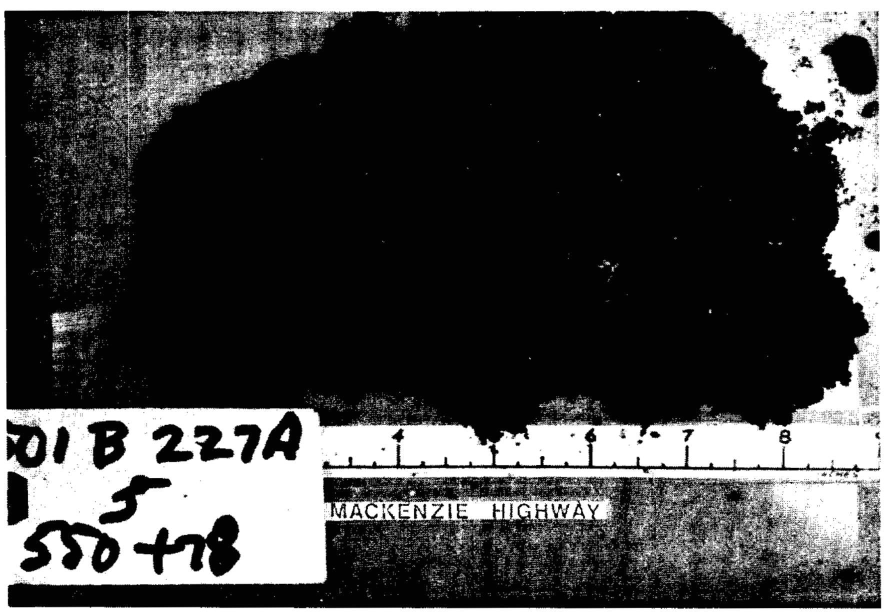
23. *Gravel borrow pit at 5-feet, test hole 219A, unfrozen and dry, moisture content 0.8%.*



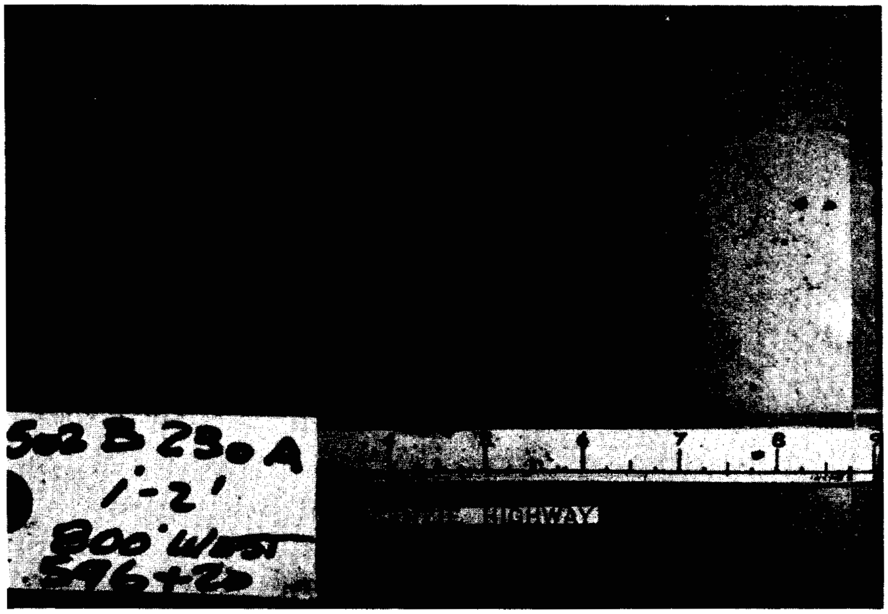
24. *Same borrow pit as above, test hole 220A, except high sand content with pebbles.*



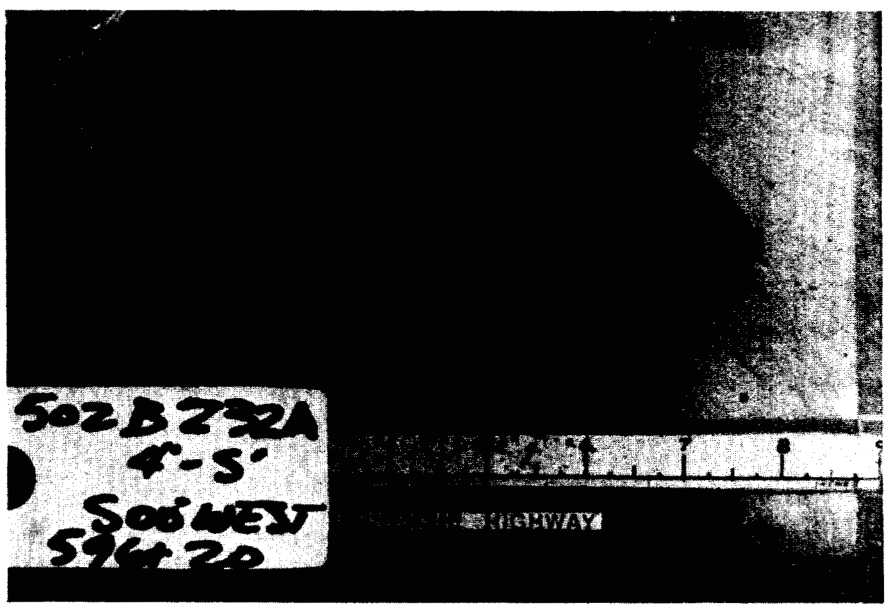
25. *Granular gravel pit, primarily gravel and coarse sand, at 2-foot depth, moisture content 2%.*



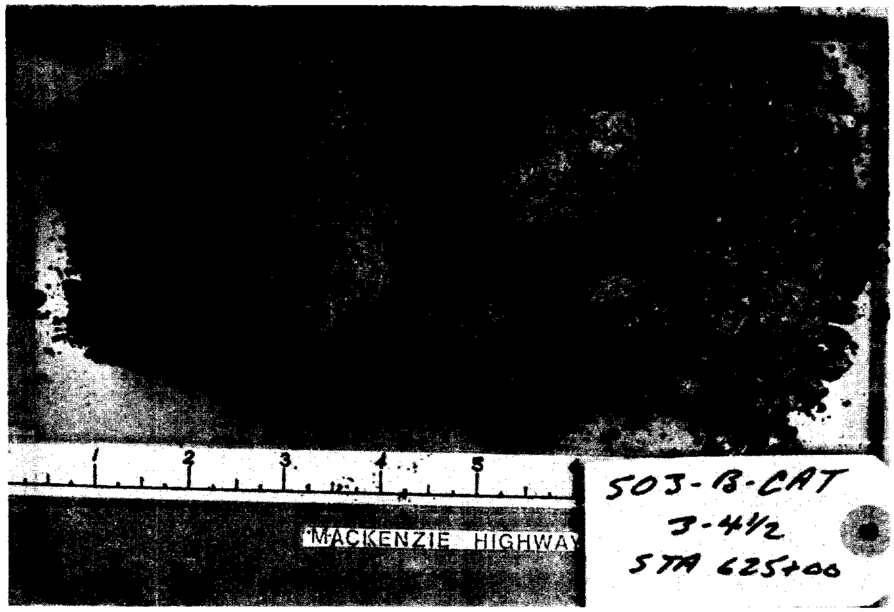
26. *Same test hole as above at 5-foot depth, except coarse sand with fewer pebbles.*



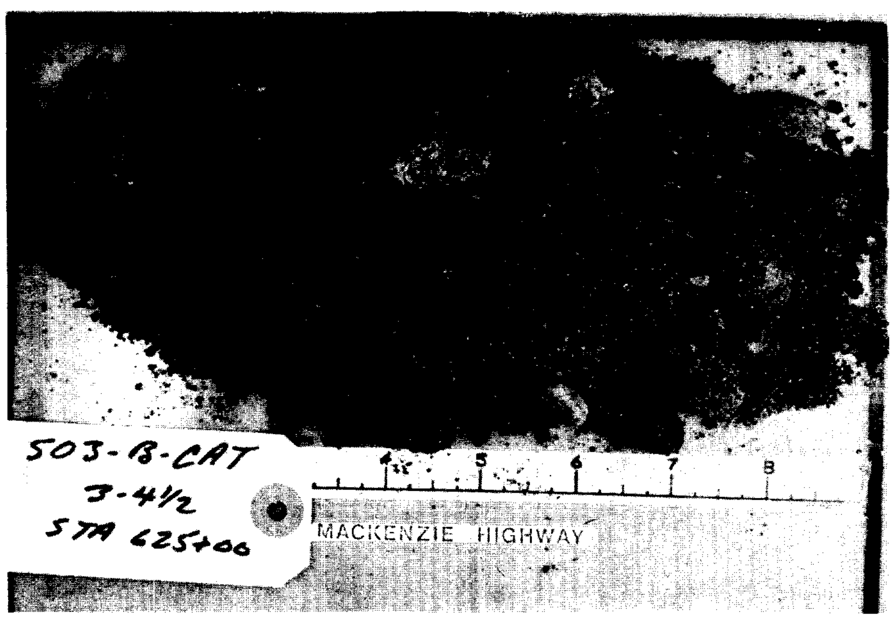
27. *Coarse gravel near the surface of borrow pit with little sand.*



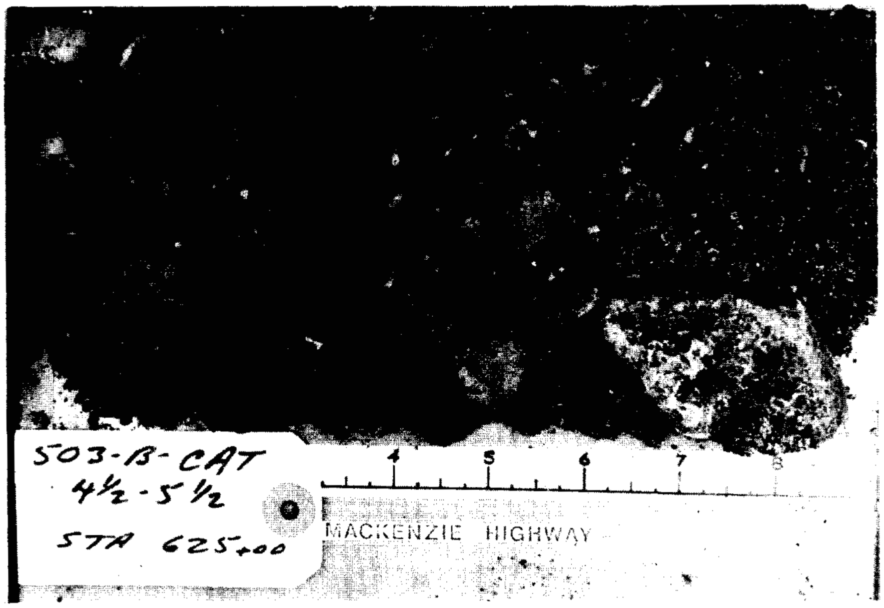
28. *Same borrow pit as above except in adjacent test hole. Material is coarse sand with some pebbles.*



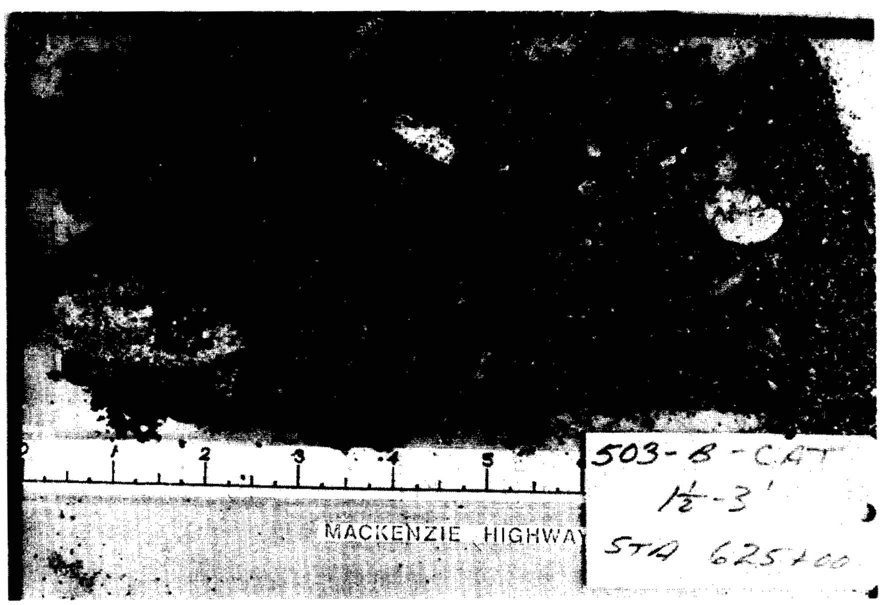
29. *Dozer pit gravel samples from glaciofluvial plain at Mile 503.*



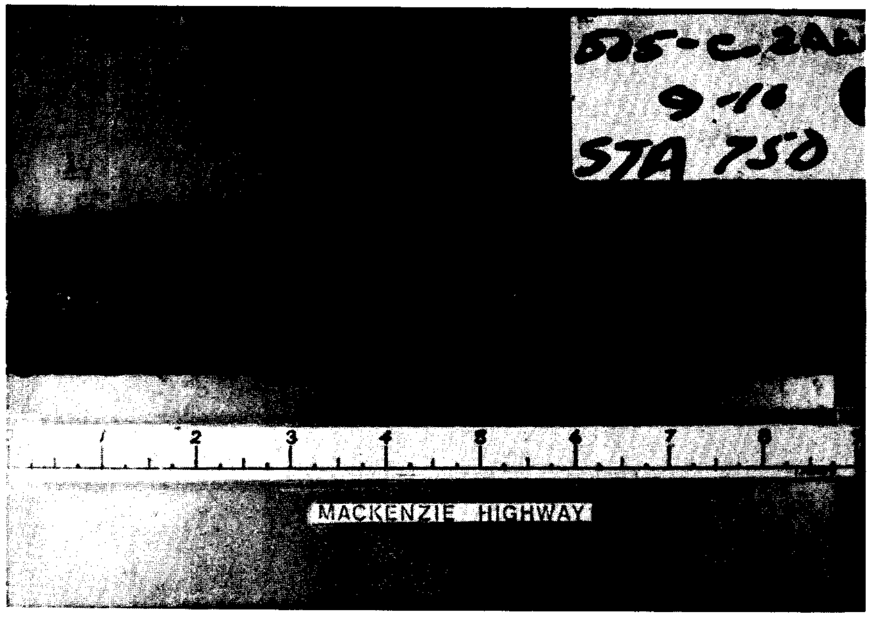
30. *Dozer sample from similar location as above photograph.*



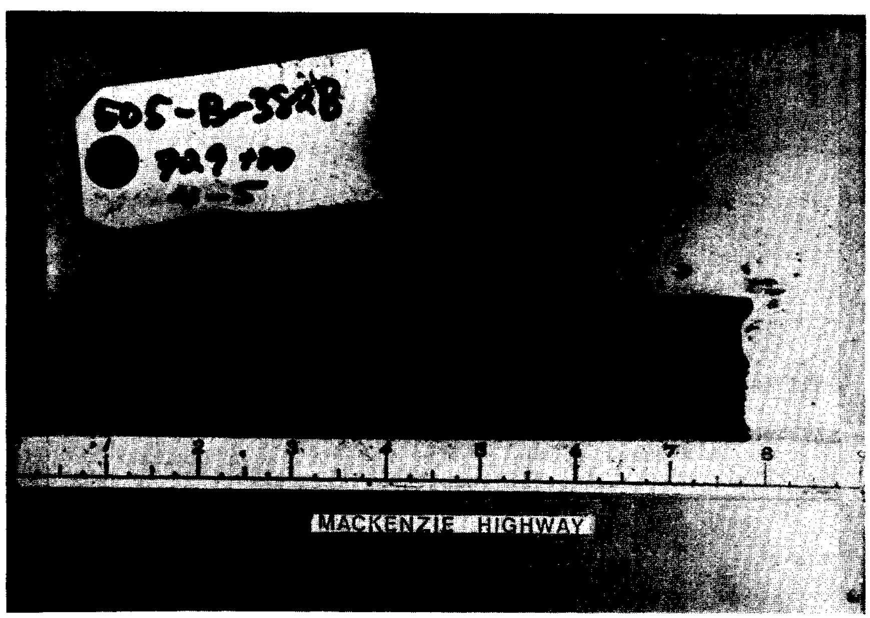
31. *Dozer sample at 4 1/2 to 5 1/2-feet from same pit as photographs 29 and 30.*



32. *Dozer sample at 1 1/2 - 3-feet from same location as 29, 30 and 31 photographs.*

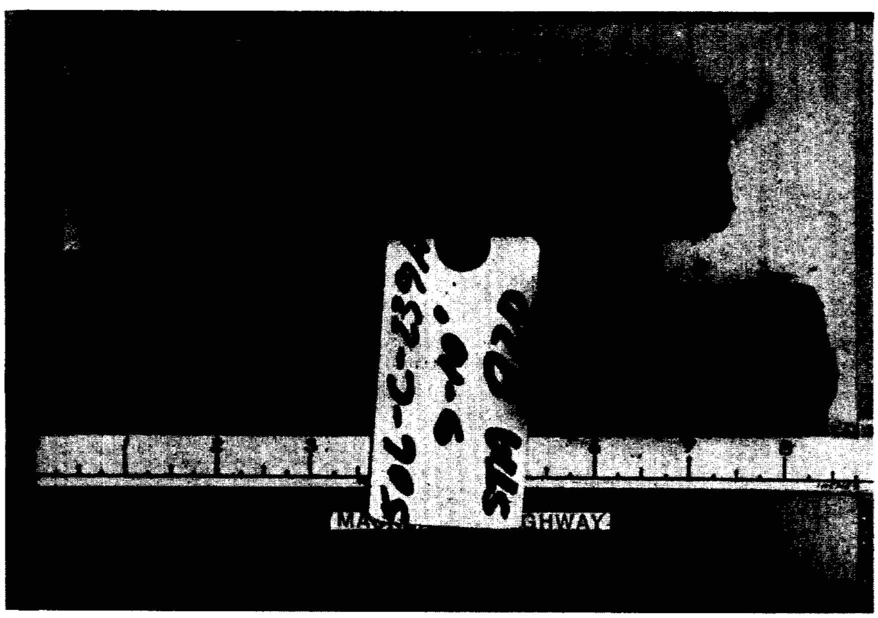


33. *Typical example of frozen silty clay penetrometer sample with visible random lenses but little excess ice. Moisture content 26% is near the plastic limit of 25%. The liquid limit is 47% and the bulk density 121.6 pcf.*

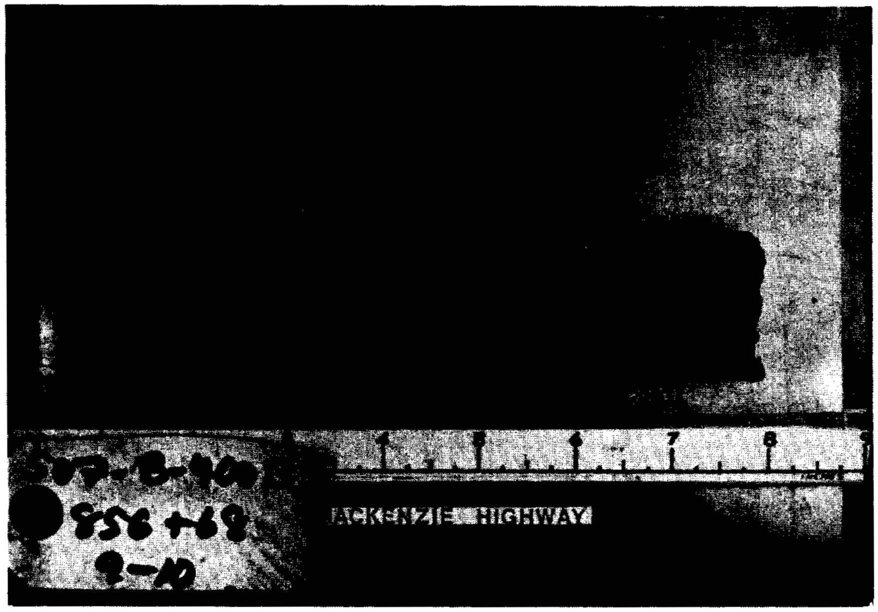


34. *Frozen silty clay borrow pit, random ice, moisture content 25%. Generally unsuitable for embankment fill.*

35. *Frozen silty clay, random ice, moisture content 26%.*

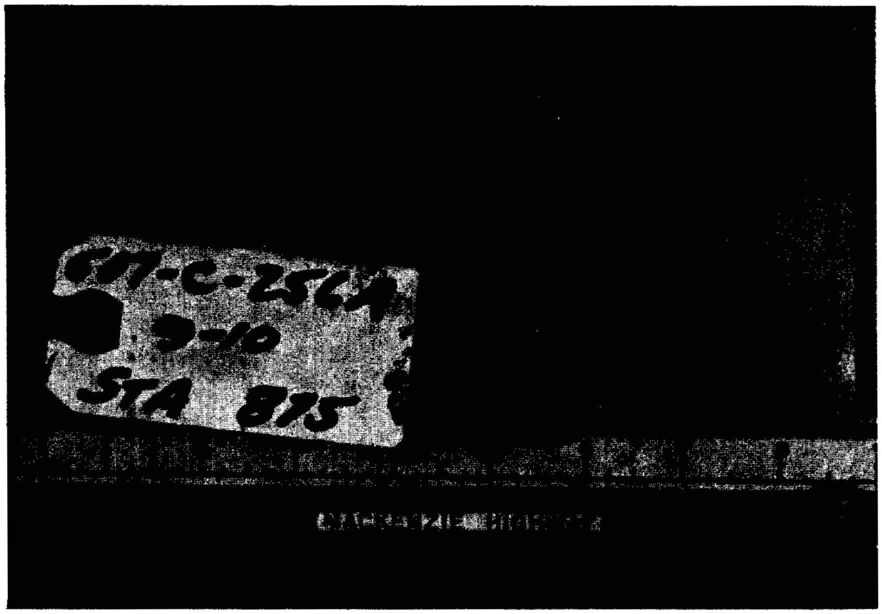


36. *Frozen silty clay, random ice, moisture content 30%, bulk density 120.9 pcf.*

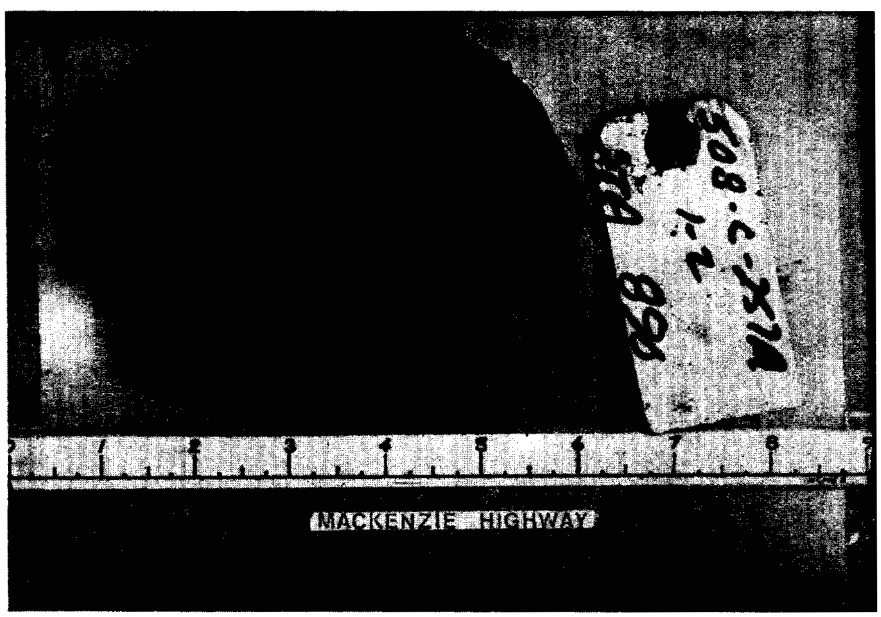


39. *Borrow pit frozen clay, moisture content 27%, random ice. Unsuitable for embankment fill.*

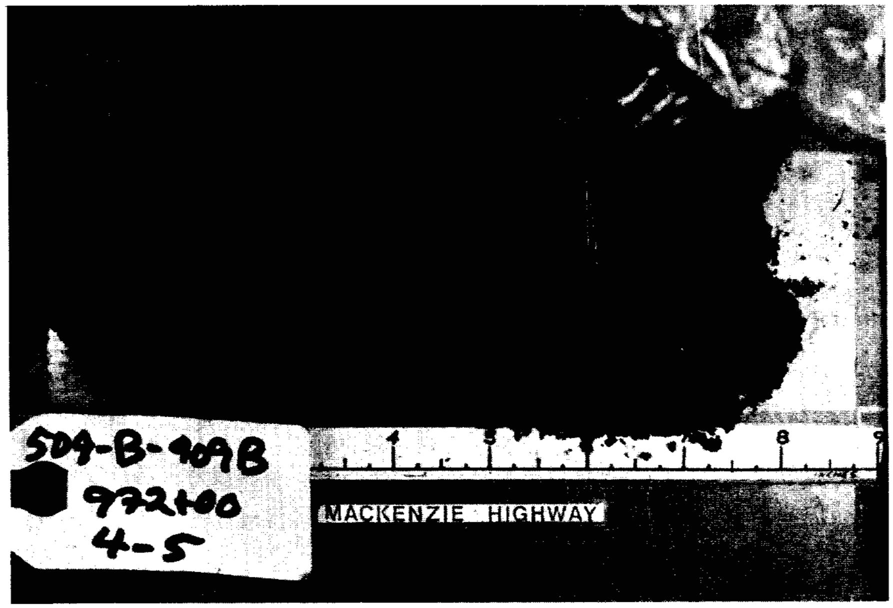
40. *Frozen silty clay, borrow pit, low random ice content, moisture content 25%.*



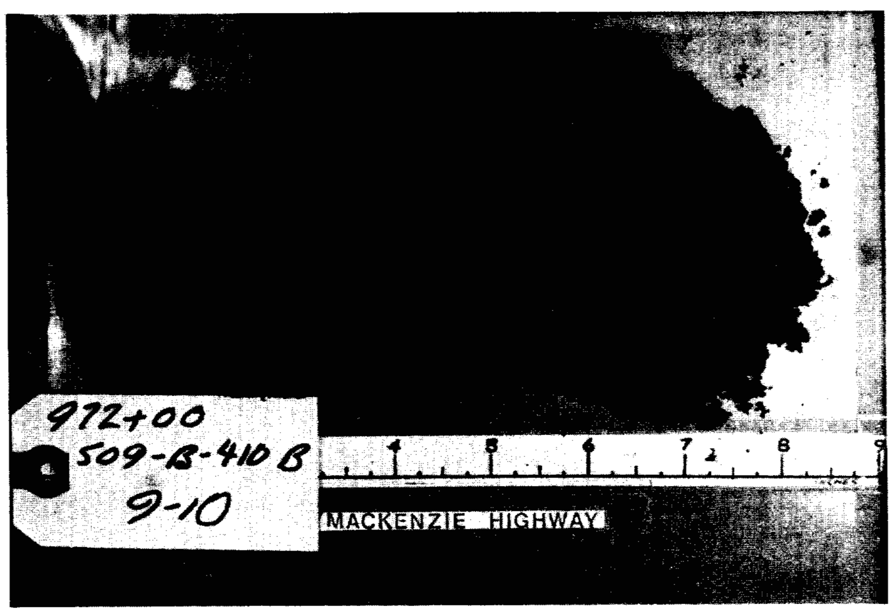
41. *Frozen silty clay, thin random ice lenses, moisture content 33%.*



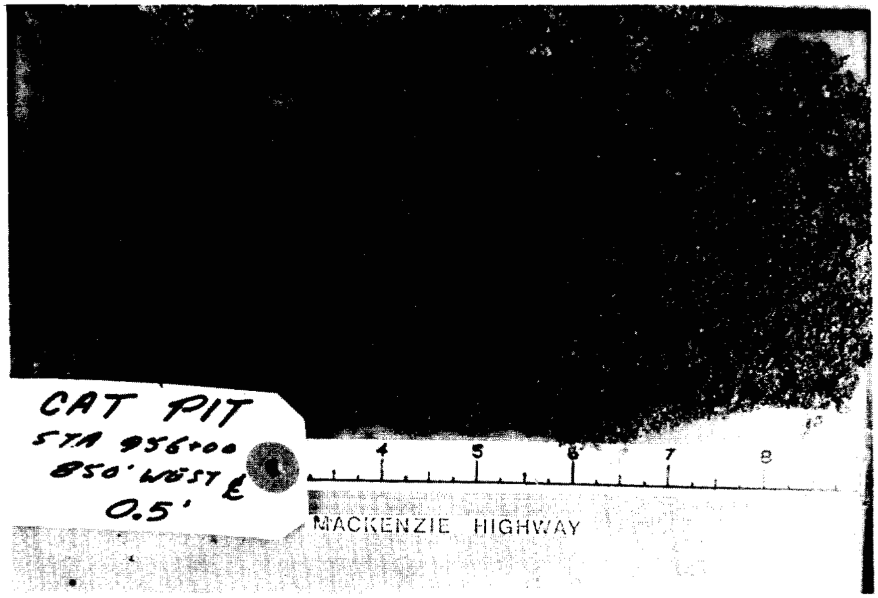
42. *Mile 508 muskeg deposit with moisture content 200%.*



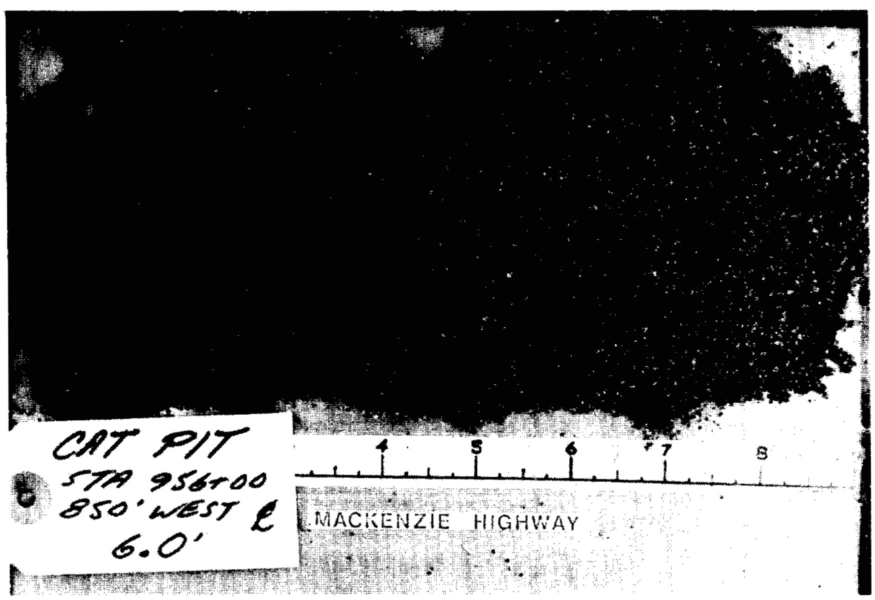
43. *Borrow pit, 4 - 5-feet coarse dry sand, moisture content 2.0%, gap-graded.*



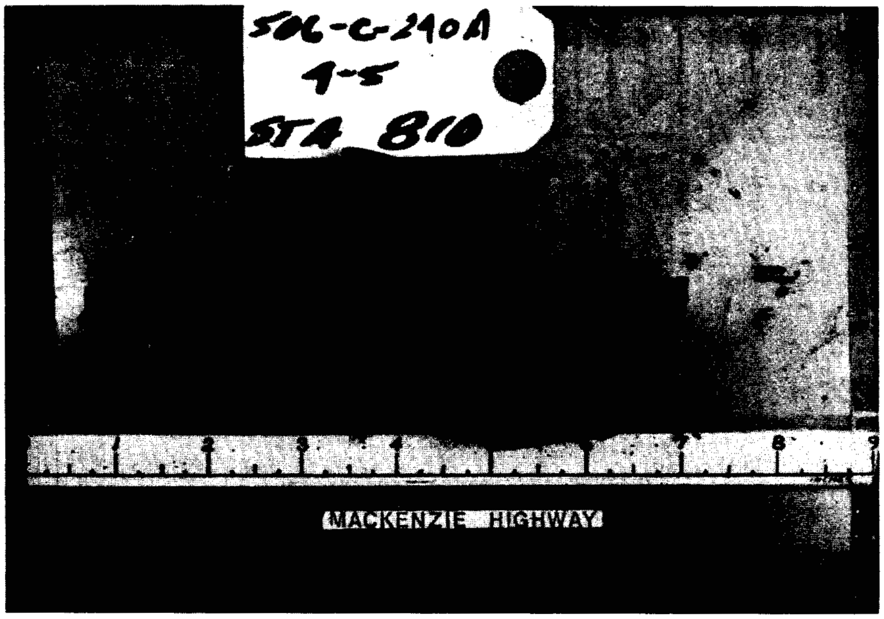
44. *Sand sample from same borrow as above except at 9 - 10-feet.*



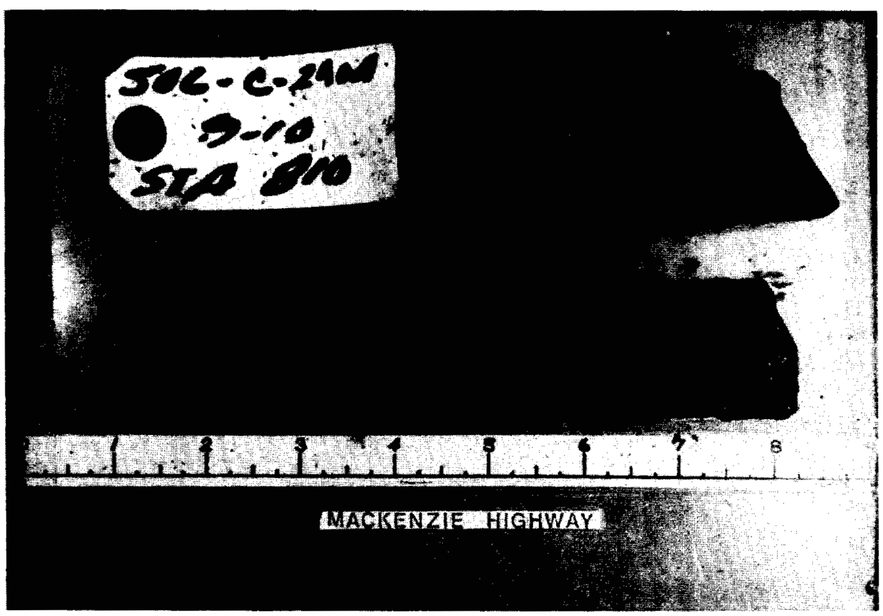
45. *Dozer sample of dry brown coarse sand from 0.5-feet, Mile 509.*



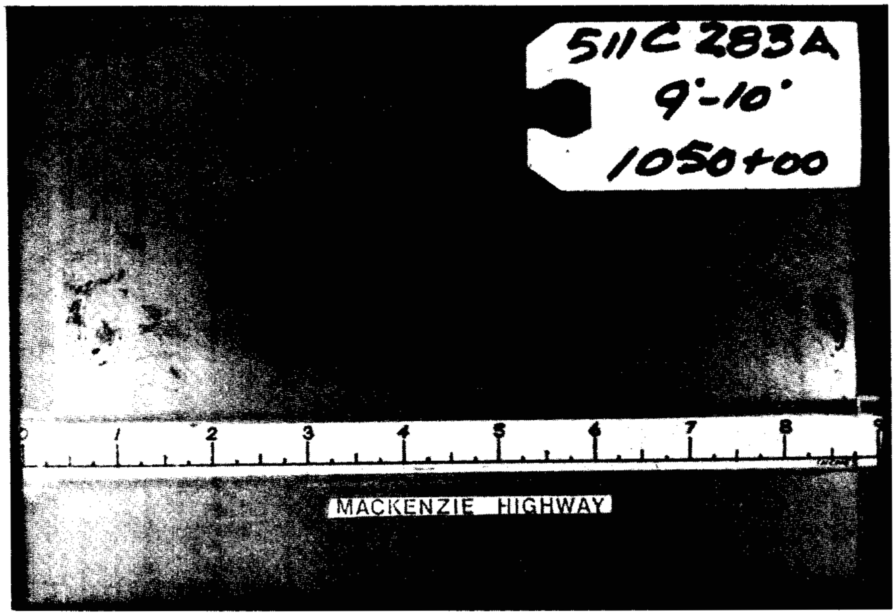
46. *Dozer sample from same pit as above except at 6.0-feet. Coarse sand, gap-graded, very dry.*



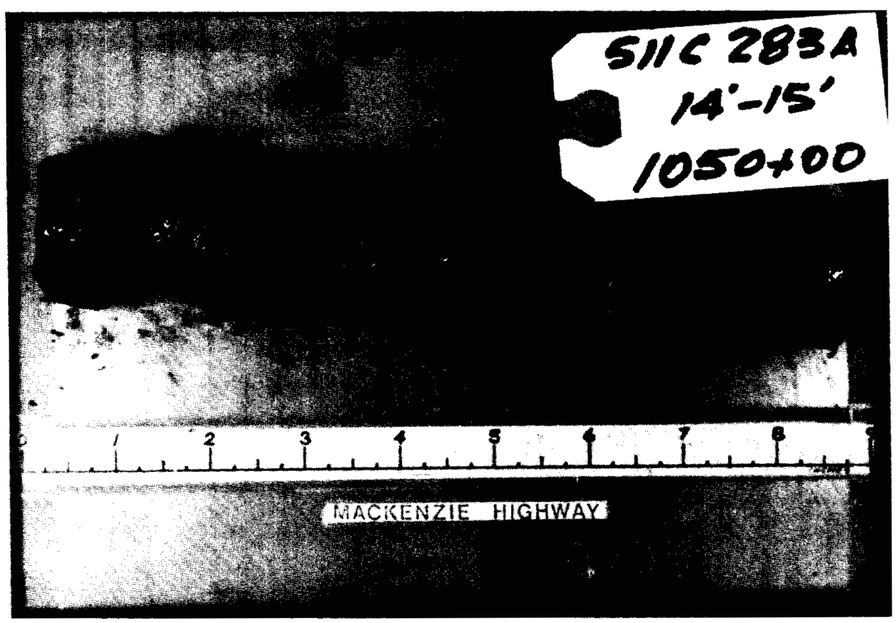
37. *Typical frozen silty clay, random ice, moisture content 28%. Location 4 to 5-feet below surface.*



38. *Same test hole as above except at 9 - 10-feet with moisture content of 23%.*

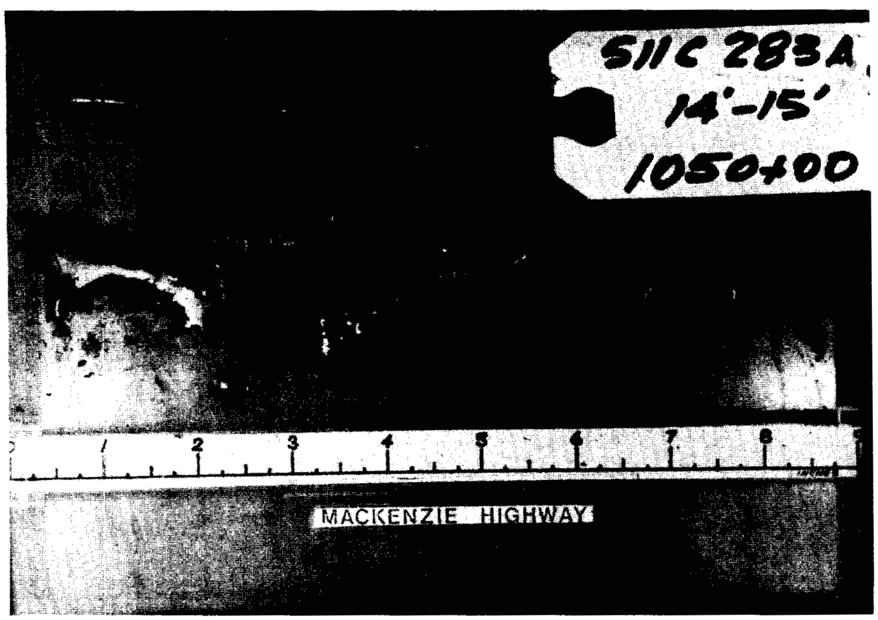


47. *Frozen silty clay, 1/4-inch ice lenses, moisture content 100%.*

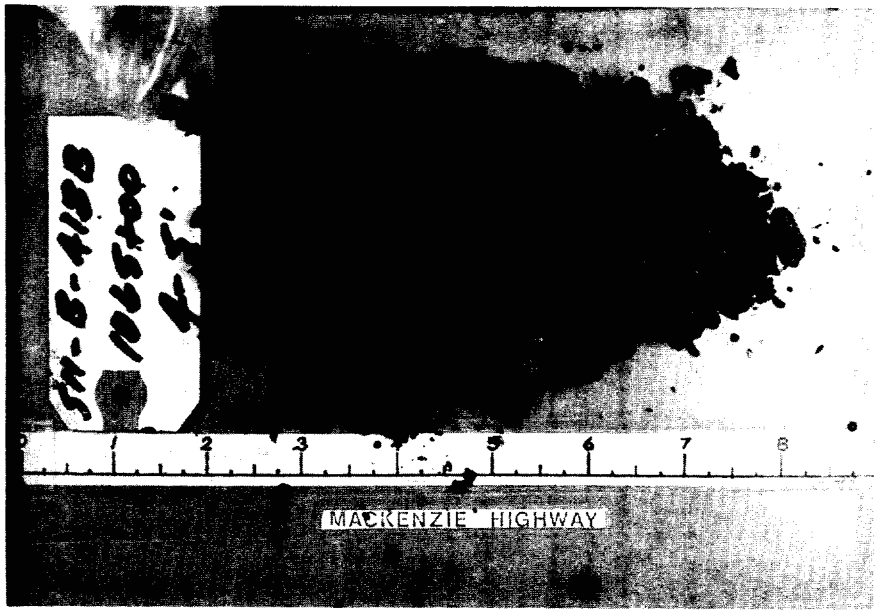


48. *Frozen silty clay, 1/4-inch ice lenses (not well defined in photograph) sample immediately after removal from freezing environment.*

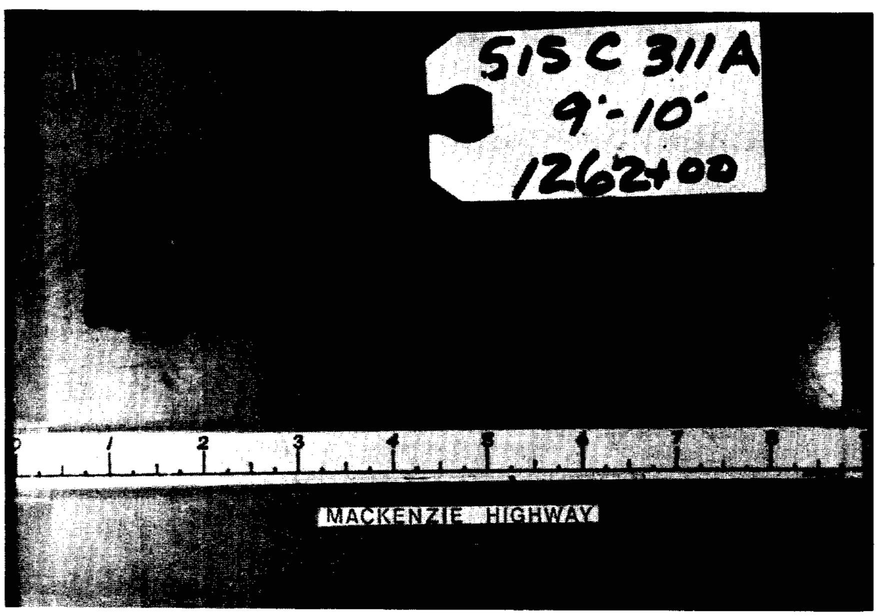
49. *Same sample as photograph 48 but thawing is well advanced.*



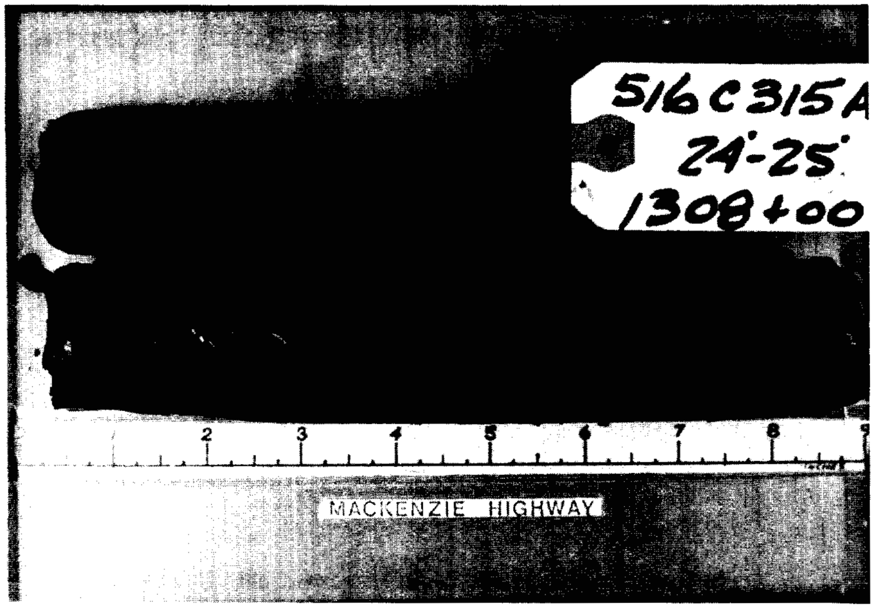
50. *Same sample as photograph 48 and 49 but thawing of permafrost has been completed. Sample in similar condition to that near roadway surface subgrade after thaw.*



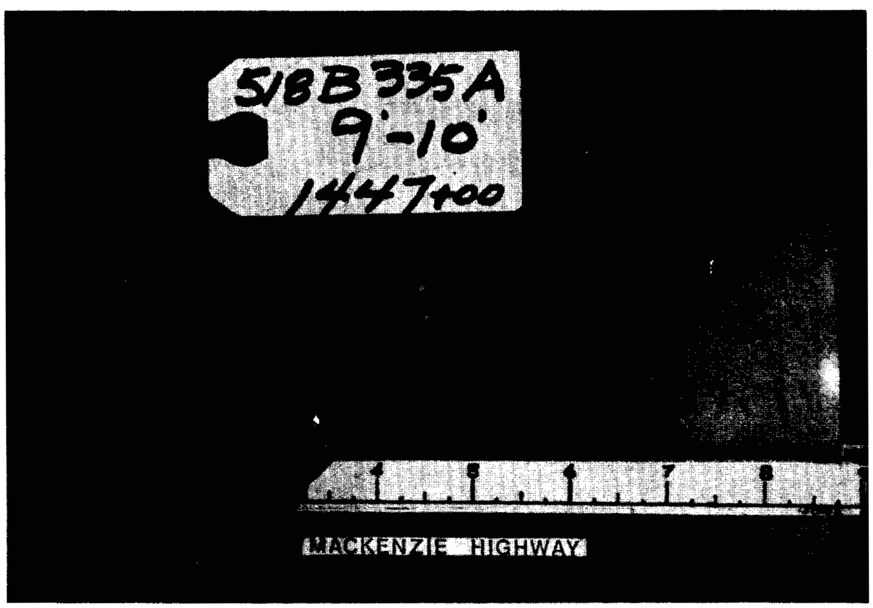
51. *Borrow pit Mile 511, station 1065 + 00 at 4 - 5-feet. Sample consists of frozen sand and gravel with high organic content. Moisture content 65%.*



52. *Frozen silty clay, random ice lenses, moisture content 29%.*



53. *Frozen silty clay, 25-foot depth, moisture content 26%, bulk density 123.6 pcf.*

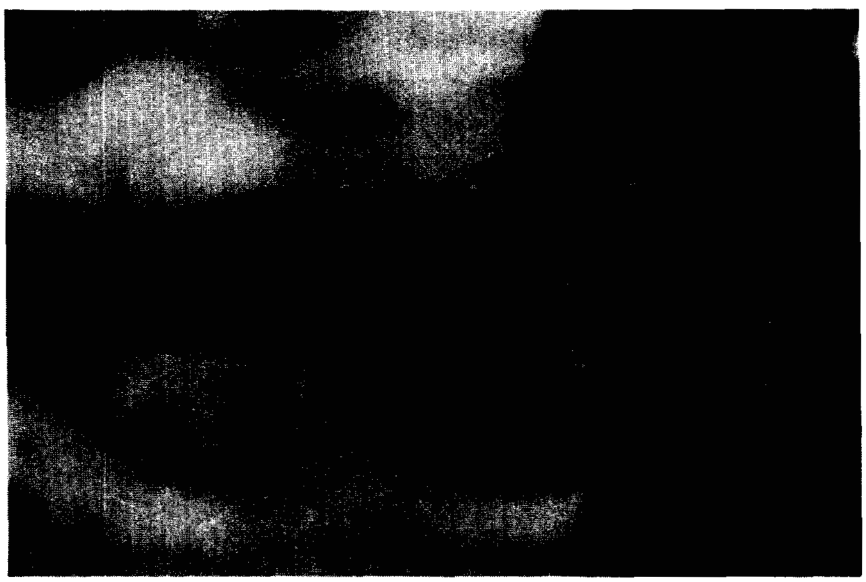


54. *Frozen silty clay, random ice, moisture content 25%, bulk density 125.9 pcf.*

55. *Dozer pit (garbage disposal excavation) at airstrip, Mile 533. Material consists of well-graded gravel and sand with some silt layers.*

56. *Same location as photograph 55.*

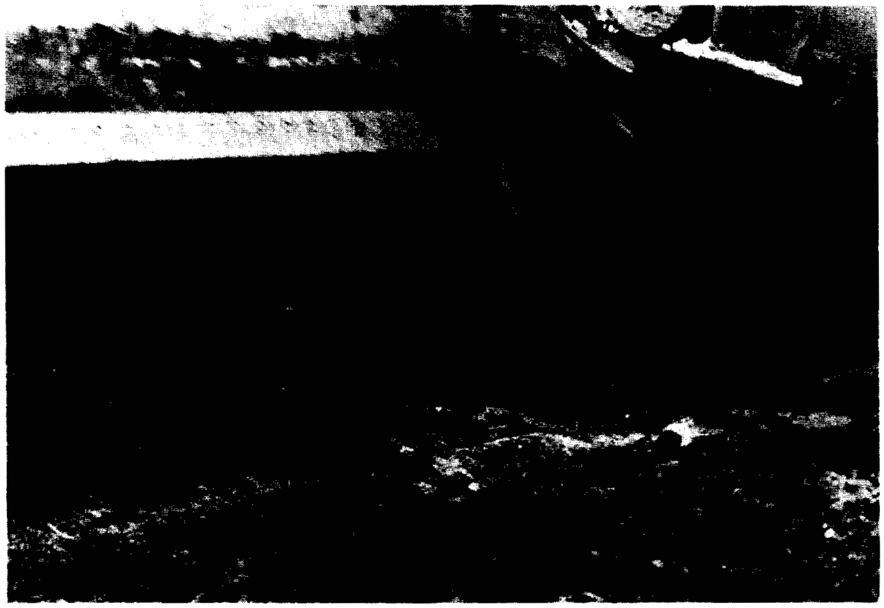
57. *Dozer excavation sample from silty clay borrow pit, Mile 520, 800-feet east on seismic line, station 1250 + 00. Note ice lenses. Moisture content 63.3%.*



58. *Same borrow pit as above except a few feet away. Note lack of ice crystals, and moisture content 17.4%. These two photographs and moisture contents depict extreme variations which exist in permafrost.*

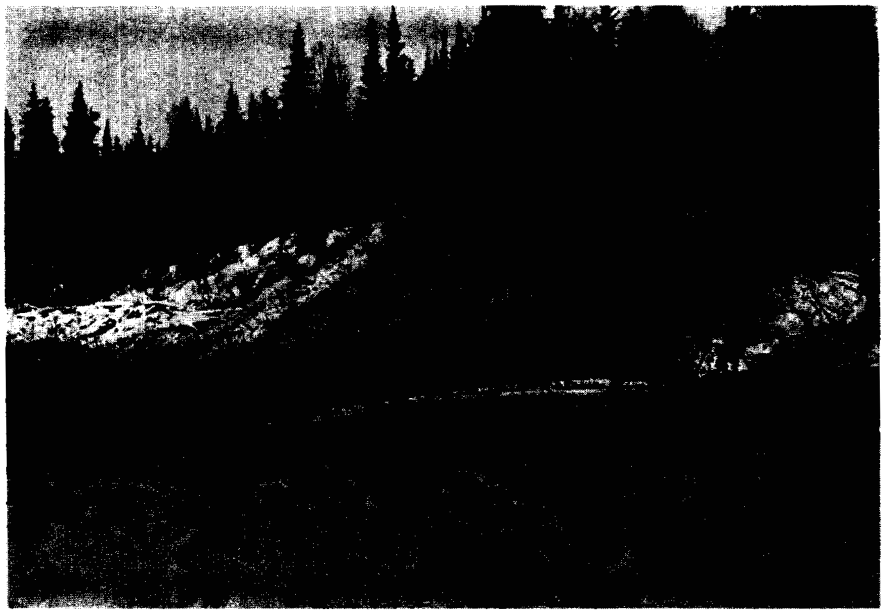
59. Dozer clearing access for drill rig to borrow pit.

60. Snow removal from airstrip at Mile 486.



61. Equipment used for dozer pit investigations showing ripper.

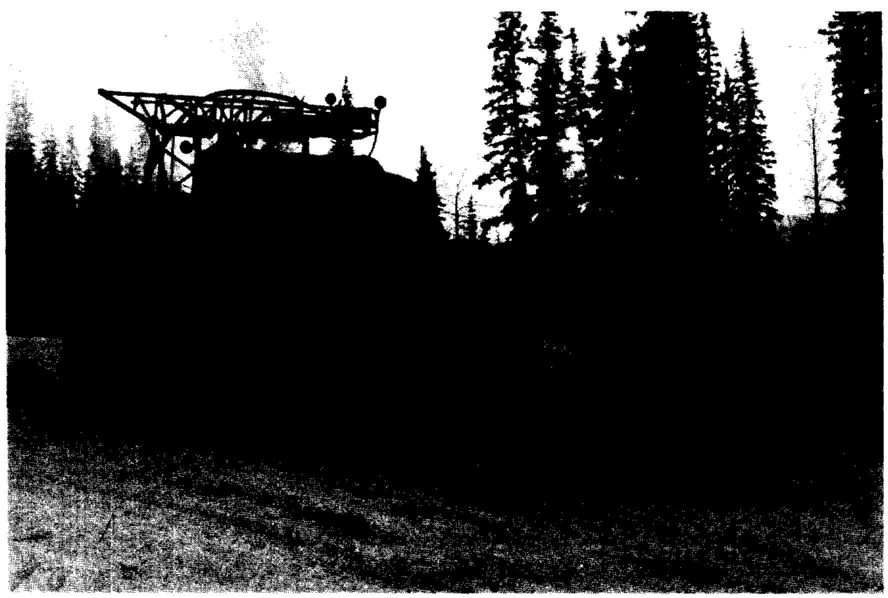
62. Moving skid mounted camp to another location.



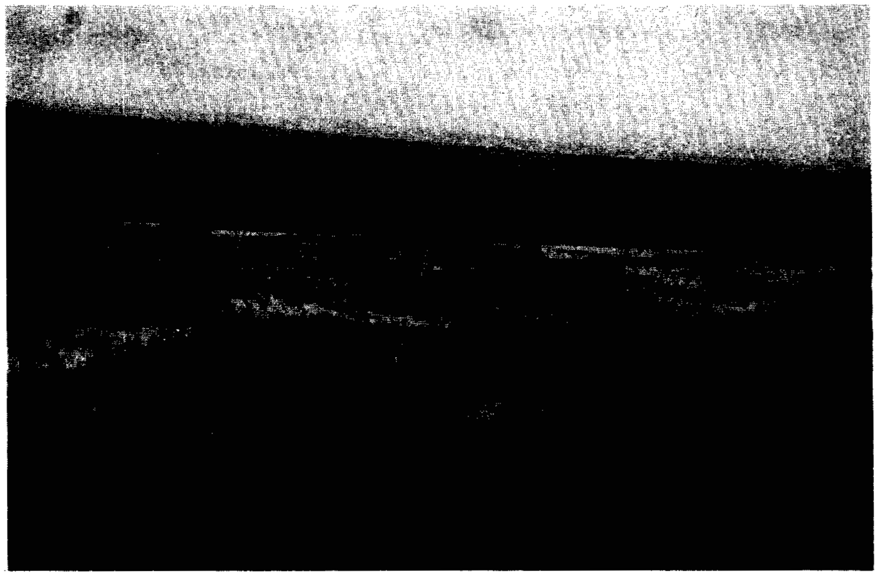
65. Mayhew 1000 drill rig.

66. Campsite Mile 471.6, January 15, 1973, - 65°F.

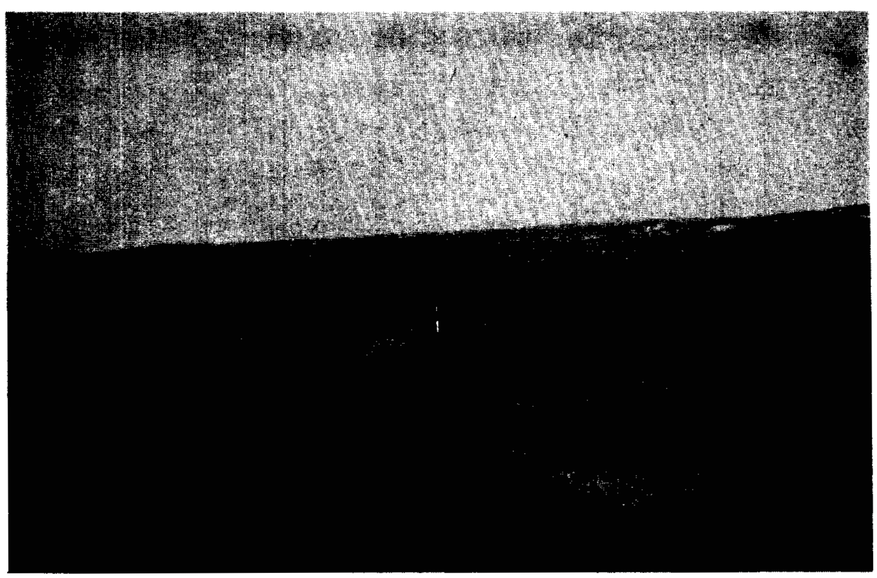
63. *Typical terrain. Mackenzie River to the left, C.N.T. right-of-way and Mile 466 airstrip. Franklin Mountains to the right.*



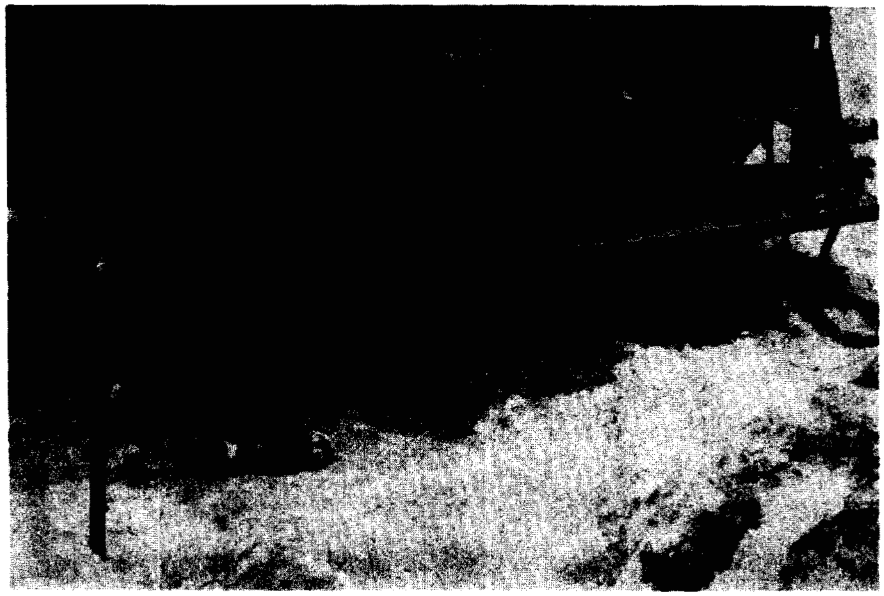
64. *Heli drill rig.*



67. *Typical terrain with C.N.T. right-of-way line.*



68. *Muskeg deposits at Mile 498.*



69. *Air-drilling operations.*

70. *Clearing access to Borrow Pit.*

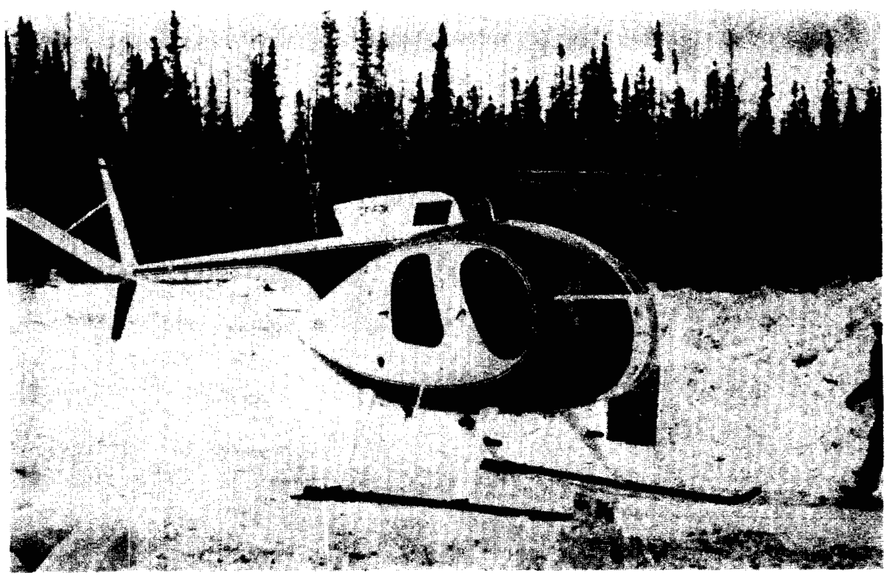
71. *Dozer pit with frozen material being ripped in a cross pattern.*

72. *Dozer clearing 40-foot high spruce from borrow area.*

73. Trapper's log cabin at Steep Creek, Mile 511.

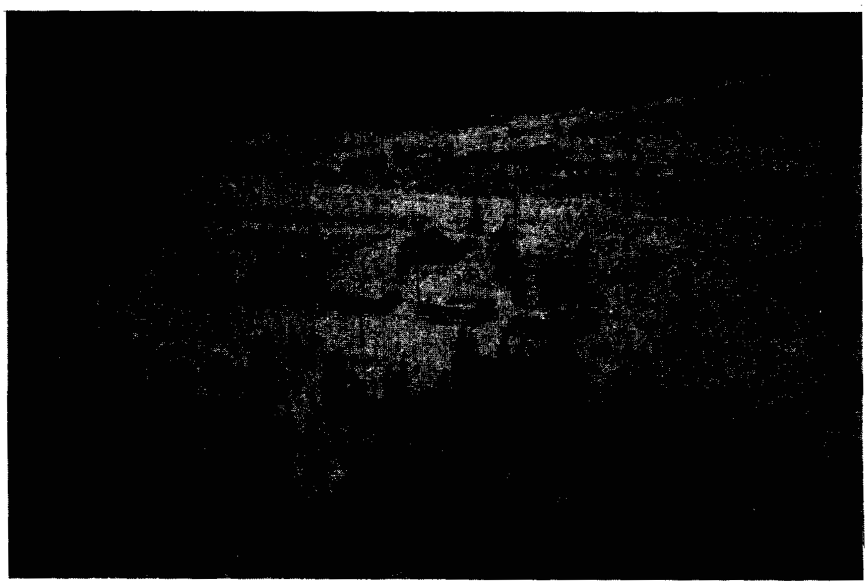
74. Technicians obtaining gravel sample from dozer pit.

75. *Supplies brought to campsite by chartered aircraft.*



76. *The most efficient method of transportation on the project.*

77. Camp move along C.N.T. right-of-way through creek valley.



78. Aerial view of Fort Norman.

79. *Helicopter bringing supplies to campsite that were brought to an airstrip some 10-miles away.*

80. *Drill rig moving on to typical test site.*

APPENDIX 'C'

EXPLANATION OF FIELD AND LABORATORY TEST DATA USED ON TEST HOLE LOG SHEETS

EXPLANATION OF FIELD AND LABORATORY TEST DATA USED ON TEST HOLE LOG SHEETS

These pages present an explanation of the terms and symbols used in summarizing field and laboratory results on the Drill Hole Logs.

DEPTH

This column refers to the depth in feet below the existing ground surface.

SAMPLE TYPE

This column refers to the sample depth interval and the sample condition and type. The following symbols were utilized to define the sample type:

[T]	Shelby tube sample
[P]	Split-spoon penetrometer sample
[C]	Core sample
[⧅]	Disturbed grab sample

PENETRATION RESISTANCE

This test is conducted in the field to determine the insitu relative density of cohesionless soils and the consistency of cohesive soils. The "N" value or blow count is the number of blows from a 140 lb. hammer dropped 30 inches (free fall) which is required to drive a 2" O.D. split-spoon type sampler 12 inches into the undisturbed soil.

UNIFIED SOIL SYMBOL

All soils are classified according to the Unified Soil Classification System which is outlined on Page 5 of this Appendix.

SOIL DESCRIPTION

This column includes a detailed description of soil types and indicates changes in soil strata.

LIMITS OF FROZEN GROUND

The depth intervals over which frozen and unfrozen ground were encountered have been indicated by F and UF respectively.

ICE DESCRIPTION

The ground ice in permafrost was classified according to the National Research Council System. This permafrost classification system is outlined on Page 6 of this Appendix.

The excess ice content was estimated by field laboratory technicians. This estimate is shown in the ice description as a percentage of the total sample.

NATURAL WATER CONTENT

The natural water content is indicated by a circle at various depths. It is expressed as a percentage of the dry soil weight.

ATTERBERG LIMITS

The plastic and liquid limits are shown along with the moisture content by a horizontal bar. The lower moisture content of the bar indicate the plastic limit whereas the upper portion indicates the liquid limit. Atterberg limits are utilized to assist classification of cohesive soils and estimate their insitu consistency.

GRAIN-SIZE ANALYSIS

The proportions of clay, silt, sand and gravel obtained from hydrometer and sieve analysis are summarized. The actual grain size curves have been included with the Test Hole Logs.

WET DENSITY

The wet or bulk density of penetrometer samples is the total weight of the sample divided by the volume and is expressed in lbs. per cubic foot.

DRY DENSITY

The dry density is the dry soil weight divided by the volume and is expressed in lbs. per cubic foot.

TEST HOLE NUMBERING SYSTEM

Test holes have been designated by mileage, type and number. The letter symbols and numbers in the following examples;

543B632B, 544C448A, 545S441A

indicate:

The initial number is the highway mileage. The following letters B, C and S denote a borrow pit, centreline and structure test hole respectively. The next number is the test hole number and the final letters A or B denote drilling performed by Mayhew 1000 or Heli Drill respectively.

MUSKEG CLASSIFICATION

The National Research Council muskeg classification system developed by Radforth has been utilized to partially classify muskeg deposits. Muskegs have only been classified into three basic groups based on their predominant characteristics. A brief summary of the Radforth System is given on Page 7 of this Appendix.

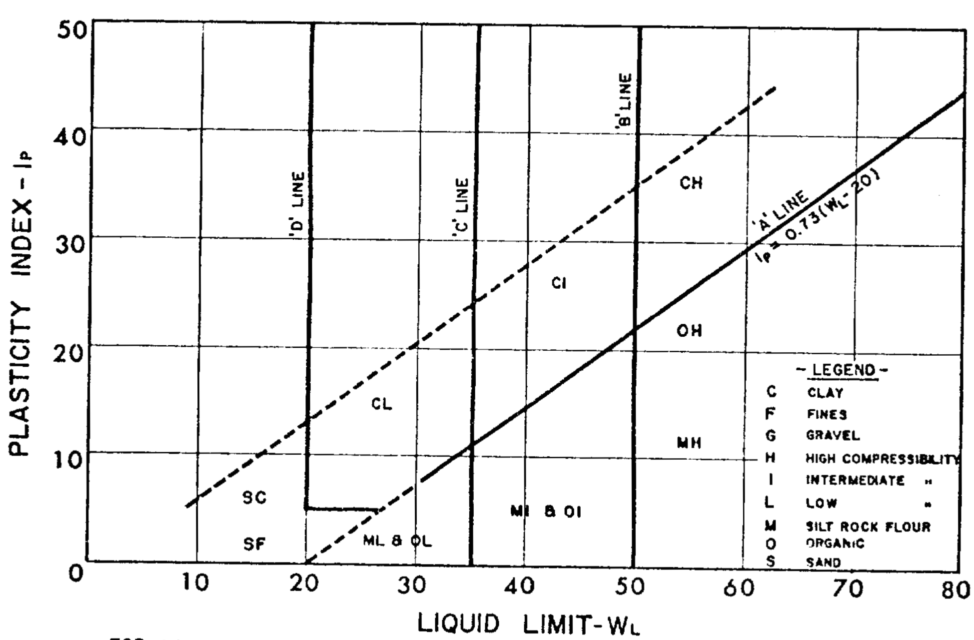
UNIFIED SOIL CLASSIFICATION SYSTEM

MAJOR DIVISIONS			GRAPH SYMBOL	LETTER SYMBOL	TYPICAL DESCRIPTIONS
COARSE GRAINED SOILS MORE THAN 50% OF MATERIAL IS LARGER THAN NO. 200 SIEVE SIZE	GRAVEL AND GRAVELLY SOILS	CLEAN GRAVELS (LITTLE OR NO FINES)		GW	WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
				GP	POORLY-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
	MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)		GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
				GC	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES
	SAND AND SANDY SOILS	CLEAN SAND (LITTLE OR NO FINES)		SW	WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
				SP	POORLY-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
	MORE THAN 50% OF COARSE FRACTION PASSING NO. 4 SIEVE	SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)		SM	SILTY SANDS, SAND-SILT MIXTURES
				SC	CLAYEY SANDS, SAND-CLAY MIXTURES
FINE GRAINED SOILS	SILTS AND CLAYS	LIQUID LIMIT LESS THAN 50		ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
				CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
				OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
MORE THAN 50% OF MATERIAL IS SMALLER THAN NO. 200 SIEVE SIZE	SILTS AND CLAYS	LIQUID LIMIT GREATER THAN 50		MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SAND OR SILTY SOILS
				CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
				OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
HIGHLY ORGANIC SOILS				PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENTS

NOTE: DUAL SYMBOLS ARE USED TO INDICATE BORDERLINE SOIL CLASSIFICATIONS.

SOIL CLASSIFICATION CHART

PLASTICITY CHART



FOR LABORATORY CLASSIFICATION OF FINE-GRAINED SOILS

NATIONAL RESEARCH COUNCIL PERMAFROST CLASSIFICATION SYSTEM

Permafrost ground ice occurs in three basic conditions including non-visible, visible (less than one inch in thickness) and clear ice.

A. Non-visible - N

N_f - poorly bonded or friable frozen soil

N_{bn} - well bonded soil, no excess ice

N_{be} - well bonded soil, excess ice

B. Visible - V (less than 1" thick)

V_x - individual ice crystals or inclusions

V_c - ice coatings on particles

V_r - random or irregularly oriented ice formations

V_s - stratified or oriented ice formations

C. Visible Ice - (greater than 1" thick)

Ice - ice with soil inclusions

Ice + Soil - ice without soil inclusions.

A more complete description of this system is included in NRC publication TM 79.

NATIONAL RESEARCH COUNCIL MUSKEG CLASSIFICATION SYSTEM

PREDOMINANT CHARACTERISTIC	CATEGORY	NAME
Amorphous-granular	1.	Amorphous-granular peat
	2.	Non-woody, fine-fibrous peat
	3.	Amorphous-granular peat containing woody fine fibres
	4.	Amorphous-granular peat containing woody fine fibres
	5.	Peat, predominantly amorphous-granular, containing non-woody fine fibres, held in a woody, fine fibrous framework
	6.	Peat, predominantly amorphous-granular, containing woody fine fibres, held in a woody, coarse-fibrous framework
	7.	Alternate layering of non-woody, fine fibrous peat and amorphous-granular peat containing non-woody fine fibres
Fine-fibrous	8.	Non-woody, fine-fibrous peat containing a mound of coarse fibres
	9.	Wood, fine fibrous peat held in a woody, coarse-fibrous framework
	10.	Woody particles held in a non-woody, fine-fibrous peat
	11.	Woody and non-woody particles held in fine-fibrous peat
Coarse-fibrous	12.	Woody, coarse-fibrous peat
	13.	Coarse fibres criss-crossing fine-fibrous peat
	14.	Non-woody and woody fine-fibrous peat held in a coarse-fibrous framework
	15.	Woody mesh of fibres and particles enclosing amorphous-granular peat containing fine fibres
	16.	Woody, coarse-fibrous peat containing scattered woody chunks

APPENDIX 'D'

SUMMARY OF TEST HOLE LOGS

SUMMARY OF TEST HOLE LOGS

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS W_p%	ATTERBERG LIMITS W_l%	ICE DESCRIPTION
449 C 89B	Silty Clay			20			F, N_f
449 C 88B	Silty Clay			20			F, N_f
450 B 97B	Silty Clay	114.6	90.8	24	23	36	F, V_r
450 B 96B	Silty Clay	117.3	96.3	21	22	39	F, V_r
450 B 95B	Silty Clay	121.4	99.7	22	23	36	F, N_{bn}
450 B 94B	Silty Clay			19			F, N_{bn}
450 C 87B	Silty Clay	118.8	93.7	26	22	35	F, V_r
450 B 90B	Clayey Silt			12			F, V_r
450 B 91B	Silt (Gravel Below)	107.6	94.9	14			F, N_{bn}
450 B 92B	Silty Clay Till (Gravel Below)			9			F, N_{bn}
450 B 93B	Silty Clay Till			6			F, N_{bn}
450 C 86B	Silty Clay			20			F, V_r
450 C 85B	Silty Clay	115.1	87.2	26	21	35	F, V_r
450 C 84B	Clay	112.2	88.0	23			F, V_r
450 C 83B	Silty Clay	118.3	89.4	32			F, V_r
450 B 194B	Dry Silt	110.6	94.2	18			F
450 B 195B	Dry Silt	110.2	94.6	17			F, V_r
450 B 196B	Silty Clay	113.5	92.1	22	19	34	F, V_r
451 C 82B	Silty Clay	117.9	93.6	25	19	31	F, V_r
451 C 92A	Silty Clay			24			UF
451 C 91A2	Clay			21	20	36	F, V_r
451 C 91A	Clay	120.7	99.2	22			F, V_r
451 C 90A	Clay			23			F, V_r
451 C 89A	Clay	110.3	86.1	28			F, V_r
451 B 191B	Clay	111.6	86.2	24			F, V_r
451 B 192B	Clay	113.6	88.6	27			F, V_r
451 B 193B	Clay	120.0	96.2	24			F, V_r
452 C 88A	Silty Clay	115.4	87.2	28	22	35	F, V_r
452 C 87A	Silty Clay	125.7	98.0	24	22	39	F, V_r
452 C 86A	Silty Clay	122.5	95.8	25	22	37	F, V_r
452 C 85A	Silty Clay	123.9	98.9	25	25	41	F, V_r
452 C 84A	Silty Clay	124.1	100.0	22			F, V_r
452 B 188B	Silty Clay	119.0	95.2	25			F, V_r
452 B 189B	Silty Clay	104.1	77.5	34			F, V_r
452 B 190B	Silty Clay	96.4	64.6	50	20	35	F, V_r
453 C 83A	Silty Clay	118.8	97.3	22	21	27	F, V_r
453 C 82A	Clay	125.3	101.7	22	22	42	F, V_r

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS W_p%	W_l%	ICE DESCRIPTION
453 C 97A	Silty Clay	123.1	99.5	25	23	38	F, V_r
453 C 98A	Silty Clay	110.3	90.5	19	21	31	F, V_r
453 C 99A	Clay -Sand & Gravel			10			F, V_r
453 B 182B	Silty Clay	117.7	98.3	20			UF
453 B 183B	Silty Clay			20			UF
453 B 184B	Silty Clay			20			F, V_r
453 B 185B	Silty Clay	119.8	98.1	22	21	32	UF
453 B 186B	Silty Clay			19			UF
453 B 187B	Silty Clay			20			UF
454 C 100A	Clay & Silt			20			F, N_{bn}
454 C 95A	Silt - Sandy			10			UF
454 C 96A	Gravel			4			UF
454 C 94A	Sand - Gravelly			10			UF
454 S 101A	Silt 7' - Sand			10			UF
454 S 102A	Clay over Gravel			20	21	34	F
454 S 93A	Gravel			9			UF
454 C 65B	Silty Clay			35			F
454 C 64B	Sand			10			UF
454 B 176B	Gravel			3			UF
454 B 177B	Gravel			7			UF
454 B 178B	Silt 4' over Gravel			12			UF
454 B 179B	Silt - Sandy			9			UF
454 B 180B	Silty Sand			8			UF
454 B 181B	Gravel			9			UF
454 S 129A	Gravel						F, N_f
454 S 130A	Silty Clay			18	18	23	F, N_{bn}
454 S 131A	Silty Clay Gravel			18	18	27	UF
455 C 80A	Gravel			5			UF
455 C 62B	Sand			9			UF
455 C 61B	Sand			10			UF
455 C 60B	Sand			8			UF
455 C 59B	Sand			12			F, N_f
455 C 79A	Clay - Organic			40			UF

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS W_p%	W_l%	ICE DESCRIPTION
455 B 173B	Gravel			.5			UF
455 B 174B	Gravel			4			UF
455 B 175B	Gravel			4			UF
456 C 78A	Silty Clay Organic			30			UF
456 C 77B	Silty Clay Organic			50			UF
456 C 76B	7' Silty Clay Organic			17			UF
456 C 75B	Silty Clay	104.0	76.6	36			F, V_r
456 C 74B	Silty Clay	92.0	58.9	56			F, V_r
456 B 170B	Silty Clay			32			UF
456 B 171B	Silty Clay	112.2	85.9	30			F, V_r
456 B 172B	Silty Clay			26			UF
457 C 73B	Sandy Clay			35			F, V_s
457 C 72B	Sand			20			F, N_{be}
457 C 71B	Clay - Organic	86.7	59.8	44			F, V_r
457 C 70B	Clay	110.0	82.1	33			F, V_r
457 C 69B	Gravel			8			F, N_f
457 B 128A	Clay	122.8	102.6	19			F, N_{bn}
457 B 168B	Clay - Silty	114.3	101.2	13			UF
457 B 169B	Clay	123.7	103.9	19			UF
457 B 165B	Gravel			11			UF
457 B 166B	Gravel			10			UF
457 B 167B	Sand & Gravel			17			UF
458 C 68B	Clay - Sandy	121.0	98.2	23			F, N_{bn}
458 C 67B	Clay - Sandy			20			F, N_b
458 C 66B	Clay Sandy			24			F, V_r
458 C 77A	Clay			42	31	54	F, N_{be}
458 C 78B	Clay - Organic	101.1	79.2	27	22	33	F, V_x
458 B 162B	Silty Clay			20			UF
458 B 163B	Silty Clay	117.3	93.8	25			F, N_{bn}
458 B 164B	10' Silty Clay - Sand			25			F, N_f
458 B 159B	Silty Clay			42	19	36	F, N_{be}
458 B 160B	Silty Clay	99.5	71.0	40			V_r
458 B 161B	Silty Clay	95.4	69.9	36			F, V_r

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS W_p%	ATTERBERG LIMITS W_l%	ICE DESCRIPTION
459 C 79B	Organic Clay	100.0	71.9	40			F, N_{be}
459 C 80B	Silt	96.8	69.0	40			F, V_r
459 C 81B	Sand & Gravel			10			F, N_{be}
459 C 103A	Sand & Gravel			10			F, N_f
459 C 76A	Gravel			6			UF
459 C 98B	Sand & Gravel			5			F, N_f
459 S 123A	Silt & Clay	113.3	88.7	26			F, V_r
459 S 132A	Sand & Gravel			15			F, N_{bn}
459 S 124A	Sand & Gravel			8			UF
459 B 125A	Gravel			10			UF
459 B 126A	Gravel			8			UF
459 B 127A	Gravel			3			UF
459 B 156B	Gravel			3			UF
459 B 157B	Gravel			3			UF
459 B 158B	Gravel			3			UF
460 C 99B	Sand over Gravel			25			F, N_{bn}
460 C 100B	Silt			16			UF
460 C 75A	Gravel			24			UF
460 C 74A	Silty Clay	104.1	72.8	24	21	39	F, V_r
460 C 73A	Silty Clay	91.9	57.9	63	26	45	F, V_x
460 B 150B	Clay			23			UF
460 B 151B	Clay			25	23	41	UF
460 B 152B	Clay	119.1	101.6	17			F, V_r
460 B 153B	Clay			31	20	32	F
460 B 154B	Clay			33	21	39	F, V_r
460 B 155B	Silty Clay	112.0	86.7	29			F, V_r
461 C 72A	6' Silty Clay - Sand			33			F, V_r
461 C 71A	Silty Clay			23	23	43	F, V_r
461 C 58B	Silty Clay			35			F, V_r
461 C 57B	Clay			35	19	30	F, V_r
461 B 101B	Gravel & Sand			5			F, N_f
461 B 102B	Sandy - Clay	114.5	96.5	18			F, N_{bn}

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS W_p%	ATTERBERG LIMITS W_l%	ICE DESCRIPTION
461 B 103B	Clay over Gravel			23			F, N_{bn}
461 B 104B	8' Silt over Gravel	96.4	73.6	26			F, N_{bn}
461 C 56B	Clay			26	19	29	F, V_r
461 S 121A	Clay			20			UF
461 S 122A	Gravel			9			UF
461 S 133A	Till - Clay			15	15	24	F, V_r
461 B 144B	Silt			26	16	30	F, V_r
461 B 145B	Silt			40			F, V_r
461 B 146B	Clay			25			F, V_r
461 B 147B	Clay			22	22	43	F, N_{bn}
461 B 148B	Clay			21	24	43	F, N_{bn}
461 B 149B	Clay	117.0	95.5	21	25	40	F, V_r
461 S 197B	Clay	113.0	85.9	31	19	26	F
462 B 112A	Clay			30			F, V_r
462 C 55B	Clay			20			F, V_r
462 C 54B	6' Clay over Gravel			30			F, V_r
462 C 53B	Clay			40			F, V_r
462 C 52B	Clay over Silt			25			F, V_r
462 C 51B	Silt		84.2	23			F, V_x
462 B 106B	Clay - (Till)			15	22	43	F, V_r
462 B 107B	Clay (Till)			16			F, N_{bn}
462 B 108B	Clay - Stones (Till)			15	22	43	F, V_r
462 B 109B	Clay (Till)	110.9	95.8	17	26	45	F, V_r
462 B 110B	Clay	103.0	88.1	16	26	44	F, V_r
462 B 111B	Clay	110.1	85.5	27	23	42	F, V_r
462 B 112B	Silty Clay	114.0	99.6	14			F, V_r
462 B 113A	Sand			20			F, N_f
462 B 113B	Silt	122.0	102.5	19	21	41	F, V_r
462 B 114A	Sand			24			F, V_r
462 B 115A	Silty Clay	116.9	93.5	25			F, V_r
462 B 114B	Silty Clay	123.2	99.2	24	24	48	F, N_{bn}
462 B 115B	Silty Clay	119.6	97.2	23	21	35	F, V_r

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS W_p%	ATTERBERG LIMITS W_l%	ICE DESCRIPTION
462 B 116A	Sand	113.9	90.7	8			F, N_f
462 B 117A	Sand	112.4	90.1	14			F, N_{bn}
462 B 118A	Silt - Clayey	121.2	98.2	24	19	27	F, N_{bn}
462 B 119A	Silt	127.6	106.2	25	22	38	F, V_r
462 B 120A	Silty - Clay	118.3	93.5	26	21	28	F, V_r
462 B 105B	Silty Clay			28			F, V_r
463 B 107A	Clay			15	21	36	F, N_{bn}
463 B 106A	Clay	125.0	100.0	24	21	38	F, V_r
463 C 70A	Clay	101.5	64.1	35	50	71	F, V_r
463 C 69A	Clay	117.0	89.1	26	17	23	F, V_r
463 B 105A	Clay	128.1	105.6	15	22	29	F, V_r
463 B 104A	Clay	126.9	105.3	21	18	25	F, V_r
463 C 68A	Silt						F, V_r
463 B 109A	Silty Clay Silt	118.7	91.5	30	23	36	F, V_r
463 B 108A	Silty Clay	118.3	87.3	40	26	47	F
463 B 110A	Clayey Silt	122.7	102.0	21	22	34	F, V_r
463 B 111A	Silty Clay			30			F, V_r
463 C 50B	Clay	117.0	94.0	24	28	49	F, V_x
463 C 49B	Sand & Gravel			13			UF
463 C 48B	Sand & Gravel			13			F, N_{bn}
463 B 118B	Sand			10			F, N_f
463 B 119B	Sandy Silt	108.1	82.0	33	17	25	F, N_{bn}
463 B 117B	Sand			12			F, N_{bn}
463 B 116B	Sandy Silt			15			F, N_{bn}
464 C 67A	Silty Clay			35			F
464 C 66A	Clay	89.1	52.5	90	49	72	F, V_r
464 C 65A	5' Silt over Gravel	125.0	101.8	23	19	34	F, V_r
464 C 64A	Clay	97.0	57.1	72			F, V_r
464 C 63A	Clay			40			F, V_r
464 B 120B	Clay			26			F, N_{bn}
464 B 121B	Clay	91.2	67.3	35			F, V_r
464 B 122B	Clay			35			F, V_r

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS W_p %	ATTERBERG LIMITS W_l%	ICE DESCRIPTION
464 B 123B	Clay			23	21	35	F, V_r
465 C 62A	5' Silt over Gravel			48			F, N_f
465 C 61A	Sand			11			UF
465 B 127B	Sand			12			N_f
465 B 126B	Gravel			13			F, N_f
465 B 125B	Sand			11			F, N_f
465 B 124B	5' Clay over Gravel			19			F, V_r
465 C 60A	Clay over Gravel			25			-
465 B 128B	Sand			17			F, N_{bn}
465 B 129B	Sand			16			F, N_f
465 B 130B	Sand			12			UF
465 B 131B	Sand			15			UF
465 B 132B	Sand			15			F, N_f
465 B 133B	Gravel			15			F, N_{bn}
465 B 134B	6' Clay - Sand			23			F, N_{bn}
465 B 135B	Gravel & Sand			10			F, N_f
465 C 59A	Silt			43			F, N_{be}
465 C 58A	Clay			55			F, V_x
465 C 57A	Sand & Gravel			7			UF

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS Wp%	W1 %	ICE DESCRIPTION
466 B 136B	Silty Clay			26			F-Vr
466 B 137B	Silty Clay			30	19	33	F-Vr
466 B 138B	Silty Clay			36	26	45	F-Vr
466 B 139B	Silty Clay			29	23	36	F-Vr
466 B 140B	Silty Clay			50			F-Vr
466 B 141B	Silty Clay			91	62	86	F-Vr
466 B 142B	Silty Clay			46	26	38	F-Vr
466 B 143B	Silty Clay			73	41	59	F-Vr
466 C 56A	Silty Clay			40			F-Vx
466 C 55A	Silty Clay			40			UF
466 B 205B	Silty Clay			28			F-Nb
466 B 204B	Silty Clay			20			F
466 B 203B	Silty Clay			25			F-Nf
466 B 201B	Silty Clay			24			F-Vr
466 B 202B	Silty Clay			40			UF
466 B 198B	Clay			22			F.Vr
466 B 199B	Clay			21	24	49	F-Vr
466 B 200B	Clay			30			F-Vr
466 C 54A	Clay			34	19	32	F-Vr
466 C 47B	Clay	112.5	86.4	30	23	34	F-Nb
466 C 46B	Clay			47	22	42	F-Nbe
467 C 45B	Silty Clay			60			F-Nb
467 C 44B	Silty Clay			30			F-Vx
467 B 206B	Clay			24			F-Nb
467 B 207B	Clay			23			F-Nb
467 B 208B	Silty Clay			30			F-Nbe
467 C 43B	Silty Clay			35			F-
467 C 42B	Clay			25			F-Vr
467 C 41B	5'Clay Grvl			40			UF
468 C 36B	Sand			27			UF
468 C 37B	Silty Clay			28			F-Vr
468 C 38B	Silty Clay			25			F-Vr
468 C 39B	Silty Clay			45			F-Nbn
468 C 40B	Silty Clay			33			F-Vr
468 B 209B	Silty Clay	113.6	90.5	25			F-Nb
468 B 210B	Silty Clay			22			UF
468 B 211B	Silty Clay	104.5	84.5	24			UF
469 C 29B	9' Silt Gr.			26			UF
469 C 30B	Silty Clay			40	17	31	F-Nf

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS $W_{p\%}$	$W_{l\%}$	ICE DESCRIPTION
469 C 31B	Silty Clay	103.8	74.9	37	21	31	F-Vr
469 S 134A	Silt			23	15	25	UF
469 S 135A	9'Grvl & Shl			3			UF
469 B 212B	Silty Clay	103.6	77.7	33			$F-N_f$
469 B 213B	Silt	110.2	88.2	25			$F-N_f$
469 B 214B	Silt & Sand			10			UF
469 B 215B	5'Snd & Grvl			5			UF
469 B 216B	Silt			12			UF
469 B 217B	Silty Sand			10			UF
469 B 218B	Silty Clay			20			$F-N_b$
469 B 219B	Silty Clay			40			$F-V_r$
469 B 220B	Silty Clay	105.8	85.6	24			F-Vr
469 B 221B	Till			10			F
470 C 26B	Snd & Grav.			7			$F-N_f$
470 C 27B	Gravel			11			UF
470 C 28B	Silty Clay			22			UF
470 C 52A	Gravel			6			$F-N_f$
470 B 222B	Grvl & Snd			8			F
470 B 223B	Grvl & Snd			6			F
470 B 224B	Grvl & Snd			6			F
470 C 225B	7' Slt Snd			30			F
471 S 32B	Gravel			5			$F-N_f$
471 S 33B	12'Grvl Shl						UF
471 S 34B	12'Grvl Shl						UF
471 S 35B	8' Grvl Shl						UF
471 C 50A	Sand			6			UF
471 C 51A	8' Cly & Gr.			13			$F-N_{bn}$
471 C 53A	Gravel			5			UF
471 S 137A	Sand			5			UF
471 S 138A	Gravel			7			UF
471 S 140A	4'Grvl Shl			Shale = 5'	18	25	UF
471 B 226B	Silty Sand & Gravel			6			F
471 B 227B	Silty Sand & Gravel			5			F
471 B 228B	Silty Sand & Gravel			4			F
471 S 229B	Sand & Grvl			15			UF
471 C 236B	Clay			30			$F-V_r$
472 C 44A	Silty-Clay	110.1	84.1	31			$F-N_{bn}$
472 C 45A	Sand	110.1	81.9	34			$F-N_{bn}$

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet	UNIT WEIGHT Dry	W%	ATTERBERG LIMITS W_e	ATTERBERG LIMITS W_p	ICE DESCRIPTION
472 C 46A	Silty-Sand	114.7	88.6	29			$F-N_{bn}$
472 C 47A	Silty-Sand			25			$F-N_{bn}$
472 C 49A	Clay & Sand			26			$F-N_{be}$
471 B 230B	Silty-Clay	114.4	83.8	37			$F-V_r$
471 B 231B	Silty-Clay	109.9	81.3	35	35	57	$F-V_r$
471 B 232B	Silty-Clay	97.0	83.6	16			$F-V_r$
471 B 233B	Silty-Clay			18			UF
472 B 234B	9' Muskeg			Clay			$F-V_r$
	Clay			25			
472 B 235B	Sandy-Clay	102.8	75.0	37			$F-V_r$
473 B 40A	Clay	111.3	89.9	24	25	48	$F-V_r$
473 B 41A	Clay			34			$F-V_r$
473 C 42A	Gravel			4			UF
473 C 43A	5'Peat Clay			33			UF
473 C 139A	Clay	119.0	98.7	21	25	46	UF
473 B 141A	Clay			17			$F-V_r$
473 B 142A	Clay	121.1	99.4	22			UF
473 B 143A	Clay			16			UF
473 C 237B	Clay			22			$F-V_r$
474 C 34A	Clay			25			UF
474 C 35A	Clay			45			UF
474 C 39A	Clay	126.0	101.0	25	24	35	UF
474 C 38A	Clay			20			UF
474 B 238B	Clay	110.8	88.4	25			$F-V_r$
474 B 239B	Clay	108.4	85.3	27			$F-V_r$
474 B 240B	Clay	113.3	91.8	23	29	46	$F-V_r$
474 C 37A	Clay	121.7	99.6	22	25	53	$F-V_x$
474 C 36A	Clay			34			UF
475 C 33A	Clay	126.0	95.3	32			$F-V_x$
475 B 144A	Silty-Clay			25			$F-V_r$
475 B 145A	Silty-Clay	111.9	87.0	29	31	45	UF
475 B 146A	Silty-Clay			27			UF
475 C 32A	Clay	123.1	97.4	26	21	46	$F-N_{bn}$
475 C 31A	Silty-Clay			25			UF
475 B 147A	Silty-Clay			24			$F-V_r$
475 B 148A	Silty-Clay	116.9	97.8	16	27	55	$F-V_r$

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS W_p%	ATTERBERG LIMITS W_1%	ICE DESCRIPTION
475 B 149A	Silty-Clay			25			UF
475 C 25B	Silty-Clay			24	22	45	F-Vr
475 C 24B	Silty-Clay			18			F-Vs
476 C 23B	Silty-Clay			24	26	41	F-V_r
476 C 22B	Silty-Clay			20	25	46	F-V_r
476 B 241B	Clay			22	29	53	F-V_r
476 B 242B	Clay	113.8	88.7	28			F-V_r
476 B 243B	Clay			32			F-V_r
476 C 21B	Silty-Clay			13	26	55	F-V_r
476 C 20B	Silty-Clay			25	23	62	F-V_r
476 C 19B	Silty-Clay			24	22	37	F-V_x
477 C 30A	Clay	120.1	96.0	25	26	44	F-V_x
477 C 29A	Clay	125.0	100.1	25	22	58	F-V_x
477 B 244B	Clay			27			F-Vr
477 B 245B	Clay			26			F-V_r
477 B 246B	Clay			34			F-V_r
477 C 247B	Clay			30			F-V_r
477 C 48A	Clay			25	18	32	F-N_{bn}
478 C 28A	5' Peat & 5' Clay			30			F-N_{bn}
478 C 251A	Clay			35			F-N_{bn}
478 C 18B	Gravel			8			F-N_{bn}
478 B 248B	Clay			20			F-V_r
478 B 249B	Clay			23			F-Vr
478 B 250B	Clay	111.7	89.1	29			F-V_r
478 C 17B	7'Clay Grvl			27			F-N_{bn}
478 C 16B	Clay Organ-			93	24	51	UF
479 C 15B	Gravel			8			UF
479 S 150A	5' Grvl Cly			12			UF
479 C 14B	Gravel			6			UF
479 S 152A	Sand			8			UF
479 S 151A	Gravel			5			F N_{bn}
479 C 26A	Gravel			4			UF
479 C 25A	6' Peat			8			UF
	Gravel						UF
479 C 24A	9' Muskeg &			11			UF
	Gravel						UF
479 B 153A	Gravel			4			UF
479 B 154A	Gravel			4			UF
479 B 155A	Gravel			4			UF
479 C 23A	5'Peat clay	116.9	96.1	22			UF

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS W_p%	W_1%	ICE DESCRIPTION
480 C 22A	Gravel			5			UF
480 C 21A	Gravel			9			UF
480 C 20A	5'Peat till	112.1	88.5	25	25	51	UF
480 B 156A	Gravel			5			UF
480 B 157A	Gravel			10			F-N_{bn}
480 B 158A	Gravel			9			F-N_f
480 C 13B	Silty-Clay			35	23	42	UF
480 B 252B	Clay			14			UF
480 B 253B	Clay			15			UF
480 B 254B	5' Clay Gravel			26			UF
480 C 12B	Till			25	17	32	UF
481 B 159A	Gravel			8			F-N_{bn}
481 B 160A	Gravel			5			F-N_{bn}
481 B 161A	Gravel			5			F-N_{bn}
481 C 7B	7'Peat Clay			32	24	46	UF
481 C 11B	Till			15	14	35	F-N_f
481 C 10B	Till			13	6	27	F-V_r
481 C 9B	Silty Clay (Organic)			100+			F-V_x
481 C 8B	Clay Fibrous			55			F-V_r
481 B 162A	Silty Clay			8			UF
481 B 163A	Gravel			4			F
481 B 164A	Gravel			3			F
482 C 169A	Gravel			12			UF
482 C 255B	Sandy Grvl			5			F
482 C 261B	Gravel			10			F-N_{bn}
482 C 6B	Clay			35			F-N_{be}
482 C 168A	Gravel			3			UF
482 C 170A	Gravel			5			F-N_{bn}
482 B 259B	Gravel			4			F-N_{bn}
482 B 260B	Gravel			8			F-N_{bn}
483 C 262B	Silty Clay			38			F-V_r
483 B 165A	Silty Clay			24			UF
483 B 166A	Gravel Till			8			UF
483 B 167A	Gravel Till			8			F
483 C 263B	Gravel			3			UF
483 C 264B	Gravel			5			UF
483 C 19A	Gravel			7			UF
483 C 18A	Sand			13			UF
483 C 17A	Sand			9			UF

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS $W_{p\%}$	$W_{1\%}$	ICE DESCRIPTION
484 C 16A	Gravel			.4			UF
484 B 265B	Sand			4			UF
484 B 266B	Sand			4			UF
484 B 267B	Sand			9			UF
484 C 15A	Gravel			5			UF
484 C 14A	Gravel			20			UF
484 C 13A	Gravel			14			UF
484 C 12A	Gravel			5			UF
484 B 252B	Silty Sand			6			UF
484 B 256B	Silty Grvl			5			UF
484 B 258B	Silty Sand			5			UF
485 C 11A	Gravel			5			UF
485 C 10A	Gravel			5			UF
485 C 9A	Gravel			5			UF
485 C 271B	Gravel			5			UF
485 B 268 B	Gravel			12			UF
485 B 269B	Gravel			10			UF
485 B 270B	Clay Till			14			UF
486 C 5B	6' Silt Gravel			27			UF
486 C 4B	7' Muskeg Till			24	12	36	UF
486 C 171A	Silty Clay	114.4	86.0	33			$F-V_r$
486 C 274B	Clay Till			9			$F-N_{bn}$
487 B 275B	Sand			8			UF
487 B 276B	Sand			5			UF
487 B 277B	Sand			15			UF
487 B 172A	Clay			5			$F-V_r$
487 B 173A	Gravel			4			$F-N_{bn}$
487 B 174A	Gravel			3			$F-N_{bn}$
487 C 6A	Gravel			5			UF
487 C 3B	Clay Till			13	8	25	UF
487 C 8A	5' Sandy Silt Gravel			4			UF
487 C 7A	Gravel			5			UF
487 C 273B	Clay Till			12			UF
488 C 283B	Gravel			4			UF
488 C 280B	Gravel			4			UF
488 C 281B	Gravel			4			UF
488 C 282B	Gravel			4			UF
488 C 5A	Gravel			5			UF

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS $W_{p\%}$	$W_{1\%}$	ICE DESCRIPTION
488 C 278B	Gravel			5			UF
488 C 279B	Gravel			10			UF
489 B 284B	Gravel			3			UF
489 B 285B	Gravel			3			UF
489 B 287B	Gravel			3			UF
489 B 288B	Gravel			5			UF
489 C 289B	Clay Till			5			UF
489 B 286B	Gravel			6			UF
489 B 290B	Gravel			4			UF
489 B 291B	Gravel			8			UF
489 C 292B	Gravel			4			UF
490 C 1B	Sand			11			UF
490 C 2B	Grvl & Sand			8			UF
490 C 4A	Grvl & Sand			26			UF
490 B 295B	Grvl & Sand			6			UF
490 B 296B	Grvl & Sand			3			UF
490 B 297B	Gravel			7			UF
490 C 3A	Sandy Grvl			18			UF
491 E 304B	6' Clay Silt Gravel			8			UF
491 E 303B	Sandy Silt			16			UF
491 E 302B	Sandy Silt			20			$F-V_r$
491 E 301B	Gravel			10			$F-N_{bn}$
491 C 298B	Grvl & Snd			10			F
491 C 299B	Silty Clay						F
491 C 300B	Silty Sand	112.3	84.5	33			$F-V_x$
491 B 292B	Sand			4			UF
491 B 293B	Gravel			4			UF
491 B 294B	Grvl & Snd			5			UF
491 C 2A	Grvl & Snd			4			UF
491 C 1A	Silty Clay			22			UF
491 C 305B	9' Silt Gravel			15			F
491 S 180A	Gravel			10			$F-N_{bn}$
491 S 175A	Gravel						UF
491 S 178A	Gravel						UF
491 S 181A	Gravel						UF
491 S 179A	Gravel						UF
491 S 182A	Gravel						UF

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS Wp %	ATTERBERG LIMITS Wl%	ICE DESCRIPTION
492 S 176A	Gravel						UF
492 S 177A	Gravel						UF
492 S 183A	Gravel						F Nbn
492 C 319B	8' Silty - Gravel			6			F N_{bn}
492 C 318B	Gravel			10			F N_{bn}
492 C 317B	5' Silty - Sand			28			F N_{bn}
492 C 316B	Sand			29			F N_{bn}
492 B 311B	Clay			26			UF
492 B 310B	Clay			45			F V_r
492 B 309B	Clay			55			F V_r
492 B 314B	Clay			43			UF
492 B 313B	Clay			36			F V_r
492 B 312B	Clay			40			UF
492 C 315B	Silty Clay			35			F V_r
492 C 320B	Silty Clay			25			F V_r
493 C 321B	Silty Clay			31			F V_r
493 B 326B	Clay			25			F V_r
493 B 325B	Clay			24			F V_r
493 B 324B	Clay			24			F V_r
493 C 322B	Silty Clay			23			F V_r
493 C 323B	Clay			17			F V_r
493 C 327B	Clay			23			UF
493 B 330B	Clay	122.6	101.2	21			UF
493 B 329B	Clay			20			UF
493 B 328B	Clay			20			UF
493 C 184A	Clay	119.5	97.8	22			F V_r
494 C 185A	Clay	112.7	92.6	22			F V_r
494 C 186A	Clay	118.8	98.1	21			F V_r
494 C 187A	Silty Clay	121.5	99.8	22			F V_r
494 B 190A	Sandy Clay	117.9	95.4	24			F V_r
494 B 189A	Sandy Clay	122.2	98.0	25			F V_r
494 B 188A	Clay	127.0	104.7	21			F V_r
494 B 191A	Clay	125.9	101.9	24			F V_r
494 B 192A	Clay	122.2	99.1	23			F V_r
494 B 193A	Clay	123.1	101.6	21			F V_r
494 C 194A	Clay			27			F V_r
495 C 331B	Clay			20			UF
495 C 332B	Silty Clay	106.4	83.3	27			F V_r
495 C 333B	Clay	121.4	99.4	22			F V_r
495 B 336B	Clay			27			F V_r

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS W_p%	ATTERBERG LIMITS W_l%	ICE DESCRIPTION
495 B 337B	Silty Clay			27			F V_r
495 B 338B	Silty Clay			25			F V_r
495 C 334B	Clay			24			F V_r
496 B 339B	Silty Clay			24			F V_r
496 B 340B	Silty Clay			33			F V_r
496 B 341B	Silty Clay			20			F V_r
496 C 335B	6' Silty - Clay			25			F V_r
496 B 342B	Silty Clay			27			F V_r
496 B 343B	Silty Clay			20			F V_r
496 B 344B	Silty Clay			25			F V_r
496 C 195A	Silty Clay	126.8	100.6	26			F V_r
496 C 196A	Clay			46			F V_r
496 C 197A	Clay	119.0	97.5	22			F V_r
497 B 200A	Clay	118.2	95.9	23			F V_r
497 B 199A	Clay	120.4	98.4	22	25	45	F V_r
497 B 198A	Silty Clay	112.1	89.4	25	23	39	F V_r
497 C 345B	Clay						F V_r
497 C 346B	Clay			22			F V_r
497 B 201A	Clay	117.3	95.2	24	23	36	F V_r
497 B 202A	Silty Clay			20			F V_r
497 B 203A	Silty Clay	117.9	96.5	22			F V_r
497 B 204A	Silty Clay	122.5	97.0	26	25	40	F V_r
497 B 205A	Silty Clay	124.6	101.3	23			F V_r
497 B 206A	Silty Clay	120.2	98.5	22			F V_r
497 C 347B	Clay			25			F V_r
497 C 348B	5' Sand Clay			25			F V_r
498 C 349B	Clay			27			F V_r
498 B 207A	Silty Clay	114.9	91.9	25			F V_r
498 B 208A	Silty Clay			40			F V_r
498 B 209A	Silty Clay			27			F V_r
498 C 350B	Clay with Organic			56			F V_r
498 C 351B	Clay			45			F V_r
498 C 265A	17'Organic Clay			21			UF
498 C 352B	17'Organic Clay						UF
498 C 266A	16'Organic Gravel						UF
498 C 267A	15'Organic Gravel						UF
498 C 353B	8' Organic Gravel			20			UF

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS W_p%	W_l%	ICE DESCRIPTION
498 C 354B	Gravel			20			UF
498 C 355B	Gravel			6			F
499 C 210A	Gravel			3			UF
499 B 211A	Sandy Silty Clay			21			UF
499 B 212A	Sandy Silty Clay			25	22	28	UF
499 B 213A	Sandy Silty Clay			20			UF
499 C 214A	Sandy Clay			25			F V_r
499 C 215A	Silty Clay			20	20	25	UF
499 B 356B	Clay			25			UF
499 B 357B	Silty Clay			22			UF
499 B 358B	Silty Clay			22			UF
499 C 359B	Clay			22			UF
499 B 216A	Gravel			4			UF
499 B 217A	Gravel			4			UF
499 B 218A	Gravel			5			UF
500 C 360B	Silty Clay			21			UF
500 C 361B	Clay			20			UF
500 B 219A	Gravel			3			UF
500 B 220A	Gravel			2			UF
500 B 221A	Gravel			6			UF
500 C 362B	Gravel			3			UF
500 C 263B	Gravel			3			UF
500 B 222A	Sand			4			F V_r
500 B 223A	Sand			7			UF
500 B 224A	Sand			10			UF
501 C 364B	Gravel			3			UF
501 C 365B	Sand			4			UF
501 C 366B	Sand			2			UF
501 C 367B	Sand			2			UF
501 C 368B	Sand			3			UF
501 B 225A	3' Gravel Sand			4			UF
501 B 226A	6' Gravel Sand			2			UF
501 B 227A	5' Gravel Sand			2			UF
501 C 369A	Sand &Gravel			3			UF
502 B 227A(2)	Gravel			2			UF

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS W_p%	W_l%	ICE DESCRIPTION
502 B 228A	4' Gravel Sand			3			UF
502 B 229A	4' Gravel Sand			3			UF
502 C 370B	Silty Sandy Gravel			3			UF
502 C 371B	Sandy Gravel			3			UF
502 C 372B	Sandy Gravel			3			UF
502 B 230A	4' Gravel Sand			3			UF
502 B 231A	Gravel			12			UF
502 B 232A	Sand			5			UF
502 C 373B	Sandy Gravel			2			UF
502 C 374B	Sandy Gravel			3			UF
503 C 375B	Sandy Gravel			12			UF
503 B CAT	Sandy Gravel						F
503 B 233A	Sandy Gravel			3			UF
503 B 234A	Sandy Gravel			3			UF
503 B 235A	Sandy Gravel			2			UF
503 C 376B	Sandy Gravel			6			UF
503 C 377B	Sandy Gravel			3			UF
503 C 378B	Gravel			2			UF
503 B 249A	Silty Sand			5			UF
503 B 250A	Silty Sand			5			UF
503 B 251A	Sandy Gravel			6			UF
504 C 379B	Silty Sand			16			UF
504 C 380B	Sandy Gravel			18			UF
504 C 381B	Silty Sand			80			F
504 B 236A	Silty Clay			33	21	34	UF
504 B 237A	Silty Clay			20			UF
504 B 238A	Clay Till	138.7	124.9	11	18	25	UF
504 C 249A	Sandy Gravel			15			F N_{bn}
505 C 248A	Granular Peat			100+			F V_r
505 B 386B	Clay			10			F V_r
505 C 247A	Clay	121.9	97.5	24	29	51	F V_r
505 C 246A	Clay	121.6	95.9	27	25	47	F V_r
505 B 382B	Silty Clay			28			F V_r
505 B 389B	Clay			22			F V_r
505 B 390B	Clay			24			F V_r
505 B 388B	Clay			25			F V_r
505 B 387B	Silty Clay			15			F

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS W_p%	W_1%	ICE DESCRIPTION
505 C 245A	Clay	119.1	97.5	22	25	35	F V_r
505 C 244A	Clay	123.7	100.7	23	19	41	F N_{bn}
506 C 243A	Clay	127.0	100.7	26	21	39	F V_r
506 B 385B	Silty Clay			35			F
506 B 384B	Silty Clay			25			F
506 B 383B	Silty Clay			25			F
506 C 242A	Clay	108.7	86.3	26			F V_r
506 C 241A	Clay	117.2	93.5	25	23	41	F V_r
506 B 391B	Silty Clay			30			F V_r
506 B 392B	Silty Clay			32	23	35	F V_r
506 B 393B	Silty Clay			25			F V_r
506 C 240A	Clay	121.6	94.6	28			F V_r
506 C 239A	Clay	120.9	92.9	30			F V_r
506 B 394B	Clay			28			F V_r
506 B 395B	Clay			27			F V_r
506 B 396B	Clay			22	22	43	UF
507 B 397B	Silty Clay			33			F V_r
507 B 398B	Clay			27			F V_r
507 B 399B	Silty Clay			33	22	42	F V_r
507 C 252A	Silty Clay	123.2	99.0	24	23	36	F V_r
507 C 253A	Silty Clay	123.3	97.6	26	25	61	F V_r
507 C 254A	Clay	154.8	119.5	30			F V_r
507 B 400B	Clay			27			F V_r
507 B 401B	Clay			27			F V_r
507 B 402B	Clay			37			F V_r
507 C 255A	Silty Clay	127.8	104.9	23	20	35	F V_r
507 C 256A	Clay			30			F V_r
508 C 257A	6' Muskeg Gravel			10			F N_{bn}
508 C 258A	8' Muskeg Sand			15			F N_{bn}
508 C 259A	Gravel			5			F V_r
508 C 260A	Sand & Gravel			12			F N_{bn}
508 B 403B	Sand			5			UF
508 B 404B	Sand			3			UF
508 B 405B	Sand			3			UF
508 C 261A	Sand			4			UF
509 C 262A	Sand			3			UF
509 C 263A	Sand			3			UF
509 B 412B	Sand			3			UF
509 B 413B	Sand			7			UF

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS W_p%	W_l%	ICE DESCRIPTION
509 B 414B	Sand			9			UF
509 B 409B	Sand			3			UF
509 B 410B	Silty Sand			5			UF
509 B 411B	Sand			4			UF
509 B 406B	Sand			3			UF
509 B 407B	Sand			3			UF
509 B 408B	Sand			3			UF
509 C 264A	Sand			3			UF
509 C 268A	Sand			10			UF
509 C 269A	Sandy Clay			27			F
509 C 270A	Sandy Silty			4			UF
510 S 275A	Silty Clay Gravel			15			F
510 C 276A	Silty Sand			5			UF
510 C 277A	Silty Clay			20			UF
510 B 280A	Gravel			8			UF
510 B 279A	Sand			7			UF
510 B 278A	Sand & Gravel			7			UF
510 B 272A	Sand			3			UF
510 B 273A	Sand			4			UF
510 B 274A	Sand			4			UF
510 C 281A	Sand & Gravel			3			UF
510 C 271A	Sand			11			UF
511 C 282A	Clay			31	22	32	UF
511 C 283A	Sandy Silty			100			F V_s
511 B 415B	Silty Gra-vel & Clay			35			UF
511 B 416B	Gravel Till			15			F
511 B 417B	Gravel Sand & Clay			30			F
511 C 284A	Silty Clay			35			F V_r
511 B 420B	Sand			0			UF
511 B 419B	Gravel			4			UF
511 B 418B	Gravel & Clay			37			UF
511 C 285A	Gravel			37			UF
511 C 286A	Gravel & Sand			10			UF
511 C 287A	Silty Sand			45			UF
511 S 288A	Gravel			5			UF

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT		W%	ATTERBERG LIMITS		ICE DESCRIPTION
		Wet pcf	Dry pcf		W_p%	W_l%	
511 S 291A	Gravel			5			UF
511 S 290A	Gravel			3			UF
511 S 289A	Gravel & Sand			10			UF
511 S 289A(2)	Gravel & Sand			10			UF
512 C 421B	Clay & Sand			32			UF
512 B 292A	Sandy Clay			8			UF
512 B 293A	Sandy Clay			20			UF
512 B 294A	Sandy Clay			45			UF
512 C 422B	Clay & Mus-keg Lenses			68			UF
512 C 423B	Gravel			6			UF
512 C 436B	Clay & Sand			25			UF
512 C 424B	Till			15			F V_r
512 C 425B	Till			16			F
512 C 426B	Gravel			4			UF
512 C 435B	Sand & Gravel			5			UF
512 B 437B	Sand & Gravel			3			UF
512 B 438B	Clay			15			F
512 B 439B	Clay			20			F
513 C 427B	Clay & Gravel			15	22	48	F
513 C 428B	Clay & Gravel			20	22	38	F
513 C 429B	Clay			28	25	42	F
513 B 295A	Clay	123.3	101.5	21			UF
513 B 296A	Clay & Silt	113.6	93.3	22	23	38	UF
513 B 297A	Clay & Silt			22			UF
513 C 430B	Clay			22	18	36	F V_r
513 C 301A	Clay	119.3	97.6	22	25	36	F V_r
513 B 302A	Sandy Silt			15			F V_r
513 B 303A	Clay			20	18	25	UF
513 B 304A	Silty Clay			18			F V_r
513 C 431B	Silty Clay			20			F
513 C 305A	Silty Clay			18	25	36	F
514 C 306A	Clay			15			F V_r
514 C 432B	Silty Clay			20			F V_x
514 B 299A	Silty Clay			23			F V
514 B 300A	Silty Clay			24			F V
514 B 298A	Silty Clay			18			F V

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS W_p%	ATTERBERG LIMITS W_1%	ICE DESCRIPTION
514 C 307A	Silty Clay	115.9	95.4	21	24	35	F V_r
514 B 440B	Clay			25	22	42	F V_r
514 B 441B	Clay			22			F V_r
514 B 442B	Clay			25	22	35	F V_r
514 C 433B	Clay			55	33	48	F V_r
514 C 434B	Clay			32	22	38	F V_r
514 C 308A	Silty Clay			32	26	41	F V_r
514 C 309A	Silty Clay	112.2	87.0	29	22	42	F V_r
515 C 310A	Clay	116.6	94.7	23	21	35	F V_r
515 C 311A	Clay	117.0	90.7	29	23	44	F V_r
515 B 443B	Silty Clay			26			F V_r
515 B 444B	Silty Clay			28			F V_x
515 B 445B	Silty Clay			28			F V_r
515 C 314A	Silty Clay	122.9	96.8	27	23	38	F V_r
515 C 313A	Clay	116.5	92.1	26	22	41	F V_r
515 C 312A	Silty Clay	125.3	99.8	26			F V_r
516 C 315A	Silty Clay	127.3	103.4	23	23	41	UF
516 B 446B	Silty Clay			23			F V_r
516 B 447B	Sandy Clay			25	21	37	UF
516 B 448B	Silty Clay			22			F V_r
516 C 449B	Sandy Clay			23			UF
516 C 450B	Silty Clay			18	22	31	UF
516 B 452B	Silty Clay			28			F V_r
516 B 453B	Clay			27	25	47	F V_r
516 B 454B	Clay			28			F V_r
516 C 451B	Clay			25	1		F V_r
516 C 316A	Silty Clay & Roots			75			F V_r
516 C 317A	Clay	121.1	93.2	28	22	42	F V_r
517 C 318A	Clay	118.9	92.4	27	25	45	F V_r
517 B 462B	Clay			20			F V_r
517 B 463B	Silty Clay			25			F V_r
517 B 464B	Silty Clay			29	17	33	F Vr
517 C 319A	Silty Clay	120.6	95.2	25	27	55	F V_r
517 C 455B	Clay			40			F V_r
517 C 320A	Clay			24	25	44	UF
517 C 321A	Clay	123.2	97.1	27	21	34	F V_r
517 B 456B	Clay			18	22	27	UF
517 B 457B	Silty Clay			21			UF
517 B 458B	Clay			25			UF
517 C 322A	Silty Clay	125.3	100.3	25	18	35	F V_r
517 C 323A	Clay	123.6	97.0	27	21	43	F V_r

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS W_p%	W_l%	ICE DESCRIPTION
518 B 459B	Silty Clay			31	22	42	F V_r
518 B 460B	Clay			30	26	45	F V_r
518 B 461B	Silty Clay	113.0	92.2	25	22	31	F V_r
518 C 324A	Silty Clay	122.8	98.5	25	23	40	F V_r
518 C 325A	Clay			22	22	47	F V_r
518 B 335A	Clay	113.7	88.5	28			F V_r
518 B 336A	Clay	125.3	101.5	25			F V_r
518 B 337A	Clay			30			F V_r
518 C 326A	Till			16			UF
519 C 327A	Till			12	18	31	F V_r
519 B 332A	Clay Till			5			UF
519 B 333A	Clay Till			10			F
519 B 334A	Clay Till			15			F
519 C 328A	Till			13			UF
519 C 329A	Till	127.5	104.2	20	22	38	F V_r
519 C 330A	Clay Till	128.1	104.7	22			F V_r
519 C 331A	Clay	121.9	95.6	27	23	55	F V_r
519 C 348A	Gravel			10			F N_{bn}
519 B 345A	Silty Clay			6			F V_r
519 B 346A	Clay			21			F V_r
519 B 347A	Silty Sand			15			F N_{bn}
519 C 349A	Sandy Gravel			3			F
520 C 338A	Silty Sand & Gravel			38			F V_r
520 C 339A	Silty Sand & Gravel			68			F V_r
520 B 342A	Silty Sand			38			F
520 B 343A	Silty Sand			25			F
520 B 344A	Silty Sand			30			F
520 C 340A	Gravel			3			UF
520 C 341A	Clay Till	126.0	106.3	20			F V_r
520 C 350A	Silt & Gravel			12			F V_r
521 S 351A	Gravel			5			UF
521 S 352A	Gravel			6			UF
521 S 355A	Gravel			5			UF
521 S 353A	Gravel			6			UF
521 S 354A	Gravel			14			UF
521 S 356A	Gravel			4			F V
521 C 357A	Gravel			15			UF
521 B 364A	Gravel			15			F
521 B 365A	Gravel			20			F
521 B 366A	Clay			18	22	42	F

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS W_p%	W_l%	ICE DESCRIPTION
521 C 469B	Clay			10			UF
521 C 468B	Clay			20			UF
521 C 467B	Clay			20			F
522 C 466B	Clay			24			F
522 B 375A	Silty Sand & Gravel			15			F
522 B 376A	Sandy Clay			23			F
522 B 377A	Clay			16			F V_r
522 B 360A	Clay			23			F V
522 B 359A	Clay Till			19			F V
522 B 358A	Silty Clay			16			F
522 B 363A	Clay			26	22	42	F V
522 B 362A	Clay			22			F V
522 B 361A	Clay			27			F V
522 C 465B	Clay			25	29	49	F V_r
522 C 470B	Silty Clay			24			UF
522 C 471B	Clay Till			12			UF
522 C 472B	Silty Sand			16			UF
522 C 473B	Clay Till			22			UF
523 C 505B	Silty Clay & Organic			80			UF
523 C 474B	Till			10	15	28	UF
523 C 506B	Till			15			F
523 C 475B	Silty Sand			15			F
523 C 476B	Clay Till			6			UF
523 B 508B	Till			20	14	25	F
523 B 509B	Till			20			F
523 B 507B	Till			15	21	35	UF
523 C 477B	Till			13			UF
523 C 478B	Silty Sand			15			F

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS W_p %	ATTERBERG LIMITS W_l %	ICE DESCRIPTION
520 B 499B	5' Gravel - Clay			5			UF
520 B 500B	Clay			27			F
520 B 501B	5' Gravel - Clay			5			UF
522 B 502B	Silty Clay			27			F, V_r
522 B 503B	Silty Clay			20	22	38	F, V_r
522 B 504B	Silty Clay			27			F, V_r
522 B 367A	Silty Clay			26	23	38	F, V_r
522 B 368A	Silty Clay			24			F, V_r
522 B 369A	Clay			18			F
523 C 370A	Clay			15			F, V_r
524 C 479B	Gravel & Sand			20			F
524 C 480B	Gravel & Sand			20			F
524 B 371A	Clay & Gravel			10			F
524 B 372A	Silty Clay			15			F
524 B 373A	Clay			15			F
524 C 481B	Sandy Silt			19			F, V_r
524 C 482B	Gravel			17			F
524 C 483B	Gravel			17			UF
525 C 484B	Silty Sand			13			F
525 B 374A	Till			10			F
525 B 378A	7' Clay - Rock			4			UF
525 B 379A	Clay			15	14	25	F
525 C 485B	Sandy Clay			26			F
525 C 486B	Gravel			10			F
525 C 487B	Clay			25			F
525 C 488B	Gravel Till			10			F
525 B 380A	Clay			29			F
525 B 381A	Clay			15			F
525 B 510B	Clay			15	25	35	F
525 B 454A	Clay			15	16	27	F
525 B 455A	4' Silt - Limestone			4			F
525 B 456A	9' Silt & Clay - Limestone			5			F
525 C 489B	Clay			12			F

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS W_p%	ATTERBERG LIMITS W_l%	ICE DESCRIPTION
526 C 490B	Till			13			F
526 C 491B	Till			12			F
526 C 492B	Gravel			10			F
526 B 511B	Till			16			F, V_r
526 B 512B	Till			16			F
526 B 513B	Till			15	16	26	F
526 C 493B	Gravel			10			F
526 C 494B	Sandy Clay			15			F
527 C 495B	Gravel			10			F
527 B 514B	Sand			10			UF
527 B 515B	Till			10	13	24	UF
527 B 516B	Till			13			UF
527 B 517B	Gravel			7			F
527 C 496B	Silty Gravel			13			UF
527 C 497B	Gravel			15			F, V_r
527 C 498B	Gravel			11			F
527 C 518B	Silty Sand			10			F
528 B 519B	Clay			15			F
528 B 520B	5' Sand - Gravel			10			UF
528 B 521B	Gravel			9			UF
528 S 382A	Gravel			10			FV
528 S 384A	Gravel			8			F
528 S 383A	Gravel			8			F
528 B 522B	Gravel			10			F
528 B 523B	5' Organic - Clay			13			F
528 B 524B	Gravel			10			F
528 C 525B	Gravel			10			F
528 C 526B	Gravel			7			F
529 C 527B	Gravel			10			F
529 C 531B	6' Silt - Clay			10			F
529 B CAT	Silt						F
529 B 528B	Gravel & Sandy			12			F
529 B 529B	Gravel			13			F
529 B 530B	5' Clay - Gravel			20			F
529 C 532B	Till			15			F

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS W_p %	W_l %	ICE DESCRIPTION
529 C 533B	Till			14	15	26	F
529 C 534B	Till			12	16	27	F
529 C 535B	Silt			15			F
530 C 536B	Silt			23			F, V_r
530 C 537B	Silt			53			F
530 B 388A	Clay			30			F, V_r
530 B 389A	Clay			42			F, V_r
530 B 390A	Clay			30			F, V_r
530 B 391A	Clay			16			F, V_r
530 C 538B	5' Silt - Clay			30			F
530 C 539B	5' Organic - Clay			20			F, V_r
530 C 543B	4' Organic - Clay			20			F, V_c
530 B 385A	Till			13	15	29	F, V
530 B 386A	Clay Till			5	14	27	F, V
530 B 387A	Clay Till			15	15	27	F, V_r
530 B 540B	5' Sand - Gravel			14			F
530 B 541B	7' Sand - Gravel			20			F
530 B 542B	5' Sand - Gravel			20			F
530 B 641B	Clay			30			F, V_s
530 B 642B	Sand			5			F
530 B 643B	Sand			10			F, V_s
530 B 644B	Sand			10			F, V_s
530 B 645B	Gravel			10			F
530 B 646B	Gravel			10			F
530 B 647B	Till			15			F, V_c
530 B 648B	6' Sand - Gravel	114.1	90.1	22	25	46	F, V_s
530 B 649B	Gravel			5			F
531 C 544B	4' Muskeg - Till			30			F
531 C 543B	Gravel			5			F
531 C 545B	Gravel			5			F
531 C 546B	Gravel			5			UF
531 C 547B	Gravel			10			F
531 B 548B	Gravel			6			UF
531 B 549B	Gravel			10			UF

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS W_p%	W_l%	ICE DESCRIPTION
531 B 550B	Gravel			5			UF
531 C 551B	Gravel			5			F
531 C 552B	Gravel			5			UF
531 C 553B	Gravel			5			F
532 C 554B	Gravel			4			F
532 B 555B	Sand			5			F
532 B 556B	Sand			5			F
532 B 557B	Sand			5			F
532 C 392A	Gravel			5			F, V_r
532 C 393A	Gravel			5			F, V_r
532 B 558B	Sand			5			F
532 B 559B	Sand			5			F
532 B 560B	Sand			5			F
532 C 394A	Sand & Gravel			5			F
532 C 395A	Gravel			5			F
532 C 396A	Gravel			5			F
532 C 397A	Sand & Gravel			5			F
533 B 561B	Sand			10			UF
533 B 562B	Sand			5			F
533 B 563B	Sand			6			F
533 C 398A	Silty Clay			20			F
533 B 564B	Till			10			F
533 B 565B	Till			20	17	31	UF
533 B 566B	Gravel			10			UF
533 C 399A	Gravel			5			F
533 S 400A	Clay Till			6			F
533 S 401A	Gravel			15			UF
533 S 403A	Gravel			15			UF
533 S 402A	Gravel			5			UF
533 B 567B	Sand			5			F
533 B 568B	Clay			23			F
533 B 569B	Gravel			5			UF
533 S 404A	Gravel			5			UF
533 C 405A	Gravel			5			UF
534 C 406A	Gravel			6			F
534 B 570B	Gravel			6			UF
534 B 571B	Clay Till			20			F
534 B 572B	Gravel			6			F, V_c

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS W_p%	ATTERBERG LIMITS W_l%	ICE DESCRIPTION
534 C 407A	Gravel			6			F
534 C 408A	Clay Till			5			F, V_r
534 C 409A	Gravel			5			F
534 C 410A	Sand			5			F
535 C 411A	Sand			5			F
535 B 591B	Gravel			5			F
535 B 592B	Sand			5			UF
535 B 593B	Gravel			5			F
535 B 573B	Gravel			15			F, V_c
535 B 574B	Gravel			10			F, V_r
535 B 575B	Gravel			15			F, V_r
535 C 412A	Gravel			7			F
535 C 413A	Sandy Gravel			6			F
535 B 576B	Sandy Gravel			15			F, V_c
535 B 577B	Gravel			20			F
535 B 578B	Gravel			12			F, V_r
535 C 414A	Till			10			UF
535 C 415A	Sand			9			F
536 C 416A	5' Silt - Gravel			5			F
536 C 417A	3' Silt - Gravel			4			F
536 C 418A	Sand			5			F
536 C 419A	Sand			5			F
536 C 579B	Sand & Clay			25			F
536 C 580B	Clay			26			F, V_r
537 C 581B	Clay			28			F
537 C 420A	4' Organic - Clay			15			F, V_r
537 C 421A	Silty Clay			27			F
537 C 422A	Silty Clay			30			F
537 C 582B	Silty Clay			15			F
537 C 583B	Clay			15			F
538 B 457A	6' Clay - Shale			5			F
538 B 458A	5' Clay - Shale			5			F
538 B 459A	8' Clay - Shale			5			F

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS W_p%	W_l%	ICE DESCRIPTION
538 C 584B	Clay			12			F
538 B 585B	Clay			12			F
538 B 586B	Clay			12			F
538 B 587B	Clay			13	14	27	F
538 C 423A	Clay			13			F
538 C 424A	Clay			10	15	27	F
538 C 425A	Clay Till			13			F
538 B 588B	Clay Till			20			F, V_r
538 B 589B	Clay			20			UF
538 B 590B	Clay			20	22	34	UF
538 C 426A	Clay Till			12	15	32	F
539 C 427A	Clay Till			10	13	29	F, V_r
539 C 428A	Clay Till			10			F
539 C 429A	Clay Till			15			F
539 C 430A	Clay			20			F, V_r
539 C 431A	Clay			18	16	31	F
539 B 451A	Clay			20	17	33	F
539 B 452A	Clay			15	17	33	F
539 B 453A	Clay			20			F
539 B 594B	Clay Till			20			F
539 B 595B	Clay Till			20	17	32	F, V_c
539 B 596B	Clay Till			21	25	32	F, V_c
540 C 432A	Clay Till			22	18	32	F, V_r
540 B 597B	Clay Silty			20			F
540 B 598B	Clay Silty			20			F, V_r
540 B 599B	Clay Silty			20			F
540 B 600B	Clay Silty			20	17	32	F, V_r
540 B 601B	Clay Silty			17			F
540 B 602B	Clay Silty			15			F, V_r
540 C 433A	Clay			17	18	33	F
540 C 434A	Clay			15	15	32	F, V_r
540 C 435A	Clay			17	18	32	F
540 C 436A	Clay			18	15	27	F
540 C 437A	Clay Silty			10	16	35	F
540 B 603B	Clay Silty			20			F, N_{bn}
540 B 604B	Clay Silty			19	21	32	F, N_{bn}
540 B 605B	Clay Silty			18	19	32	F
541 C 438A	Clay			16	16	29	F
541 C 439A	Clay Till			21	18	42	F
541 C 440A	Clay Till			16	16	32	F
541 C 606B	Clay Till			20			F
541 B 607B	Clay Silty			14	18	32	F, V_r

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	Dry pcf	W%	ATTERBERG LIMITS $W_p\%$	$W_l\%$	ICE DESCRIPTION
541 B 608B	Clay Silty			14			F, V_r
541 B 609B	Clay Silty			15			F, V_r
541 B 639B	Clay Silty			20	19	36	F, V_r
541 C 610B	Clay Silty			10			F
542 C 611B	Clay Till			15			F
542 C 612B	Clay Till			15	16	34	F, V_c
542 C 613B	Clay Till			15	18	33	F, V_r
542 B 615B	Clay Till			26	21	27	F, V_s
542 B 616B	Clay Till			25	22	33	F, V_s
542 B 617B	Clay Silty			15	17	30	F, V_s
542 C 614B	Clay Silty			15	19	46	F
542 C 618B	Clay Silty			15			
543 C 619B	Till			22	17	28	F, V_c
543 C 620B	5' Till - Shale			10			F
543 B 621B	6' Till - Shale			10	15	30	UF
543 B 622B	4' Till - Shale			5			UF
543 B 636B	3' Till - Shale			10			F
543 B 637B	4' Silty Clay - Shale			20			F
543 B 638B	6' Till - Shale			10			F
543 C 623B	Silty Clay			10			UF
543 C 624B	9' Gravel - Shale			6			UF
543 C 625B	Gravel			7	12	19	F
543 B 626B	4' Gravel - Shale			5			F
543 B 627B	3' Gravel - Shale			5			F
543 B 628B	2' Gravel - Shale			5			F
543 C 629B	10' Sand - Shale			10			F
543 B 630B	3' Gravel - Shale			5			F
543 B 631B	2' Sand - Shale			5			F

TEST HOLE NO.	SOIL TYPE	UNIT WEIGHT Wet pcf	UNIT WEIGHT Dry pcf	W%	ATTERBERG LIMITS Wp%	ATTERBERG LIMITS Wl%	ICE DESCRIPTION
543 B 632B	2' Sand -			5			F
	Shale			17	16	24	F, V_c
543 C 633B	Clay Till			5			UF
544 B 460A	Sand			5			UF
544 B 461A	Sand			5			UF
544 B 462A	Sand			20	18	37	F, V_c
544 C 634B	Clay Till			10			F
544 C 635B	Gravel						
544 C 449A	12' Sand			20			F
	- Shale			20			F
544 C 448A	Clay Sandy						
544 C 450A	Gravel -						
	Sandy			12	15	31	F
544 C 441A	Sand			10			UF
544 S 442A	Gravel			5			F
544 S 443A	Sand			20			UF
544 S 44A	Sand			10			F
544 S 445A	Gravel Till						
544 S 446A	4' Gravel			-			F
	- Shale			-			-
544 S 447A	Bedrock						