Report on

GEOTECHNICAL INVESTIGATIONS
MACKENZIE HIGHWAY
MILE 544 to MILE 635

Prepared for

DEPARTMENT OF PUBLIC WORKS OF CANADA

Volume 1

April 20, 1973

R.M.HARDY & ASSOCIATES LTD.
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CONSULTING ENGINEERING & TESTING • GEOTECHNICAL DIVISION

File No.

Mr. F. E. Kimball, P.Eng.,
Manager, Northern Roads Program,
Department of Public Works of Canada,
One Thornton Court,
Edmonton, Alberta.

Re: Geotechnical Investigations
Mackenzie Highway
Mile 544 - Mile 635

Dear Mr. Kimball:

We are pleased to submit a report on our geotechnical investigations along the route of the proposed Mackenzie Highway between miles 544 and 635. This report is in seven volumes of which the first two contain the text of the report and the remaining five contain test hole logs and laboratory test data. In addition, there is a folio of mosaics showing soil mapping and test hole locations.

As you are aware, all the above information has previously been sent to the Department in draft form as field and office work was completed.

We would like to take this opportunity to thank you and your colleagues for your help and cooperation during the course of the work.

Respectfully submitted,

R. M. HARDY & ASSOCIATES LTD.,

THE ASSOCIATION OF PROFESSIONAL ENGINEERS OF ALBERTA
PERMIT NUMBER P 226
R. M. HARDY AND ASSOCIATES LTD.

PROFESSIONAL ENGINEER G. McCORMICK ALBERTA

Per:

G. McCormick, P.Eng.

GM/jc

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GEOTECHNICAL INVESTIGATION

MACKENZIE HIGHWAY

MILE 544 TO MILE 635

E-2510

Prepared for

DEPARTMENT OF PUBLIC WORKS OF CANADA

VOLUME I

R.M.HARDY & ASSOCIATES LTD.

This report is in seven volumes. A Table of Contents is at the front of each volume.

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ILLUSTRATIONS VOLUME II

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ACKNOWLEDGEMENTS

The planning, scheduling, expediting and financial control for this project were under the direction of Mr. R.J. Bednar, P. Eng. of this office. The field work was carried out under the direction of: G. McCormick, P. Eng., B. Constant, P. Eng. B.J. deVos, P. Eng., and H. Barager, P. Eng. G. McCormick prepared the report.

Drilling was sub-contracted to Northern Geophysical Services Ltd. of Calgary. Brock Construction, Edmonton, and Wales Brothers Construction, Grande Prairie, provided bulldozers and operators. The catering contract was let to Crown Caterers.

SUMMARY OF CONCLUSIONS

1. The construction of a gravel surfaced highway in the area of our study is feasible.

2. Great care will be necessary in the selection of borrow material even in those potential borrow areas which were classified as "good".

3. The most expensive areas for construction of a highway are the 12 miles immediately southerly of Fort Norman and the 4 miles immediately north of the Great Bear River.

4. Cut sections are not advised except in the area of sand dunes between mile 550 and 565 and in certain locations north of the Great Bear River. Due to high ice content in near-surface soils, shallow cuts of less than 6 feet should generally be avoided.

5. Most of the sections between mile 544 and 635 could be constructed in either the summer or the winter but, due to ecology considerations, winter construction may be preferable.

6. The treatment of borrow pits after construction is potentially an extremely difficult problem and we can make few recommendations which will be of value to the Department at this time.

7. We strongly recommend the construction of a short test section of embankment to be located approximately

12 miles southerly (at approximately mile 570) from Fort Norman.

8. The effects of embankment position on local drainage should be carefully considered particularly in those sections where the alignment is perpendicular to the drainage.

DEFINITIONS

Active Layer: The layer of soil above the permafrost table (In the area of this study, the active layer usually freezes completely during the winter.)

Continuous Zone: That zone where permafrost occurs everywhere beneath the ground surface including large lakes and rivers.

Discontinuous Zone: That zone where permafrost occurs everywhere beneath the ground surface except beneath large lakes or wide rivers.

Drunken Forest: An area characterized by the appearance of many trees leaning in differing directions without any apparent pattern to the direction of inclination. This phenomenon is caused by differential thawing of ground ice.

Geothermal Gradient: Change in temperature of the earth with depth, either in degrees per unit depth or in units of depth per degree.

Ground Ice: Bodies of more or less clear ice in permanently frozen ground.

Organic Soil: Soil material which contains a significant proportion of organic material. Where the organic nature of the soil is its dominent characteristics, the soil is referred to as a peat.

Permafrost: Permanently frozen ground. (A more complete definition, after Muller, is given in section 19.)

Permafrost Degradation: The lowering of the permafrost table due to thawing.

Permafrost Table: A more or less irregular surface which represents the upper limit of permafrost.

Seasonal Frost: Freezing of the ground during the winter. The term implies that the frost so formed will thaw during the following spring or summer.

Sporadic Zone: That zone where permafrost occurs only in isolated patches (usually beneath peat bogs)

Subgrade: The original ground upon which an embankment is placed.

Surface Degradation: The lowering of the ground surface due to thawing of underlying ground ice.

Thaw Settlement: Settlement of a soil mass due to thawing of ground ice.

Thermal Conductivity: The amount of heat passing through a unit cross-section in unit time under the influence of unit heat gradient.

Thermal Erosion: Erosion due to the melting of ground ice rather than the removal of soil.

Thermal Regime: The temperature conditions in the ground at a given point in time.

Thermokarst: Uneven land subsidence caused by the melting of ground ice. The resulting ground surface resembles the karst topography found in limestone areas.

NOTE: The definitions given above were taken from Permafrost in Canada by R. J. E. Brown and Glossary of Geology and Related Sciences by the American Geological Institute.

1. INTRODUCTION

1.1.1 This report covers work done in the field and in the laboratory by R. M. Hardy & Associates Ltd. for the Department of Public Works of Canada along part of the proposed location of the Mackenzie Highway. Field work was conducted between December 4, 1972 and March 21, 1973. The entire study was carried out by engineers and technicians of the firm with drilling and support facilities being provided on a sub-contract basis.

1.1.2 The text of this report is divided into two volumes. Volume I contains information which will be of specific value to engineers designing this section of highway between Mile 544 and Mile 635. Volume II contains background information on permafrost and the related engineering problems together with a list of references.

1.1.3 Volumes III through VII contain the test hole logs, and laboratory data sheets. The folio of drawings include terrain and soil maps to a scale of 1" to 1000'and a second set of mosaics showing the locations of all test holes drilled in this program. A complete table of contents is included at the beginning of each volume.

1.2 Classification of Soils, Terrain and Ground Ice

1.2.1 Soils were classified according to the Unified

Classification System which is described in Appendix D, Volume I.

1.2.2 The terrain classification system used on the soil maps is based on the system developed by Dr. J. D. Mollard. A legend sheet is included in the folio of maps.

1.2.3 Ground ice was classified according to the National Research Council classification system which is described in Guide to a Field Description of Permafrost published by the National Research Council, Ottawa. A brief description of the NRC system is contained in the explanation sheets in Appendix D, Volume I.

1.2.4 Ice contents, as shown on the test hole log sheets, are expressed as percentages of ice volume to the total volume of a sample. It is the total volume of ice in an undisturbed sample and includes intersticial ice as well as excess ice.

1.3 Bridge Foundations

1.3.1 It is expected that bridges will be required at: Big Smith Creek, Jungle Ridge Creek, Vermilion Creek, Prohibition Creek, Christina Creek, Helava Creek, Francis Creek, Canyon Creek and Bosworth Creek.

1.3.2 After consultation with officers of the Department of the Public Works, it was decided that each of these bridge sites should form the subject of a separate report.

1.4 Drainage

1.4.1 Drainage problems are not within the terms of reference for the study. They have however been mentioned where they have an influence on soil behaviour which may affect the highway.

1.5 Compaction Control

1.5.1 Compaction control was not within the terms of reference of this report.

2. DISCUSSION ON SOIL TYPES

2.1.1 The soil types encountered in this section of the highway can be divided into five groups: rock, gravel, sand, silt and clay. A brief discussion on the problems of: excavation, transportation, placing and construction scheduling for each type follows.

2.2 Rock

2.2.1 Bedrock which would be suitable for embankment use, was found at approximately Mile 590 and also at the existing quarry at Mile 629. The bedrock encountered along Jungle Creek Ridge will be ignored as quarrying of this material would not be permitted.

2.2.2 The bedrock consists mainly of shale and limestone. Excavation would be relatively simple as little drilling and blasting would be required. However, ripping with heavy bull dozers would be required for much of this rock in the summer and for almost all of it in the winter.

2.2.3 The most economical method of transporting broken rock would probably be by means of dump trucks. Experience gained on the Mackenzie Highway in the Inuvik area would be very useful for planning purposes with this material.

2.2.4 Placing of broken rock is relatively simple both in summer and winter. Due to the low water content, there would be no difficulties with the material freezing in the trucks.

2.2.5 Scheduling of construction work using broken rock is also relatively simple with the main problem being maintenance of haul roads into quarries.

2.3 Gravel

2.3.1 Gravel was encountered in the last section covered by this report in the vicinity of Mile 633. Large qantities of excellent material were encountered in eskers.

2.3.2 Excavation of gravel can be carried out by loaders, scrapers or shovels.

2.3.3 Transportation of gravel along the grade can be by means of scrapers or dump trucks. Loading and transportation by means of scrapers is usually the most economical system although, in special circumstances, it may be more economical to use dump trucks.

2.3.4 Placing of gravel presents no problems in either summer or winter due to the low water content. High standards of compaction are easily obtained without the use of special equipment.

2.3.5 As with excavated rock, there will be no difficulties with the scheduling of construction using gravel.

2.4 Sand

2.4.1 Large quantities of sand were found in the section from Mile 544 (Big Smith Creek) to Mile 569. This sand is fine, silty, with water contents varying from 5 to 25 percent with most samples lying within the range of 20 to 25 percent.

2.4.2 Excavation of this sand will be difficult and expensive at any time of the year. The problem is discussed in considerable detail in Section 7.

2.4.3 Transportation of excavated sand would be most economically done by dump trucks as it would be impossible to use scrapers in the pits.

2.4.4 This sand could be placed in a frozen condition with the result that considerable subsidence of the embankment would take place in the summer. Alternatively, the material could be thawed in the borrow pits and placed in an unfrozen condition. Due to slow drainage of excess water, we expect considerable difficulty in compacting this soil in place and we would expect that a continuing maintenance program be required during the first two years following construction.

2.4.5 This material could be excavated and placed at any time of the year with considerable difficulties being experienced in both summer and winter.

2.5 Silt

2.5.1 Large quantities of silt were not encountered isolated from other materials. Silt was encountered associated with clay and sand in the section Mile 570 to Mile 589. Silt is a poor material for highway embankments (although large quantities have been used with success in more southerly locations) due to difficulties associated with compaction. Most of the silt samples tested had high water contents with considerable quantities of excess ice.

2.5.2 Silt is relatively simple to excavate in the winter when it is frozen. However, because of its extremely poor quality as embankment material, we do not recommend the use of silt in the highway. No doubt there will be instances where small quantities of silt are encountered in borrow pits and it will be impossible to exclude this material entirely. But, wherever possible, it should not be used.

2.6 Clay

2.6.1 Clay was encountered along most of the alignment from Mile 569 to Mile 635. Between Mile 569 and 589, most of the clay appears to be water deposited and is of low density with relatively high ice contents. From Mile 589 to 635, most of the clay is till and clay shale.

These materials have high densities and low water contents with the result that they generally form excellent embankment material.

2.6.2 Excavation of till and clay shale can be done by scrapers although ripping would be required for shale and any material that is frozen. Alternatively, loaders and dump trucks could be used although their use would not likely be economical, particularly for frozen soil.

2.6.3 Transportation of this material could be by either scrapers or dump trucks.

2.6.4 Placing of this material in the summer would not pose many difficulties except for the problem of excluding the relatively small quantities of high ice content material. Placing in the winter would entail building the embankment to a considerable height above design grade to allow for subsidence in the following summer. We believe the most economical time of year to place this material is in the summer.

2.6.5 Excavation and placing of this material could probably best be accomplished in the summer although there may be problems with meeting environmental requirements in this season. An alternative method would be to place the material in the embankment in the winter and carry out compaction and dressing of the embankment during the following summer with all the equipment being restricted to travel on the embankment.

3. TERMS OF REFERENCE

3.1.1 The terms of reference were contained in a letter dated September 19, 1972 signed by Mr. N. Huculak, P.Eng., Regional Highways Engineer. A copy of this letter is contained in Appendix C (Volume I). The terms of reference call for the geotechnical consultants to provide data on the soil conditions sufficient for the Department to proceed with design and tender calls for construction. The consultants were also asked to identify and classify the geotechnical conditions along the proposed alignment and to provide terrain classifications. In particular, the consultants were asked to pay attention to probable difficulties which might be encountered in relation to: differential settlements, roadway stability, selection of borrow, backslope stability, slope erosion and seepage. In addition, sufficient information was to be obtained at each proposed bridge site to enable the bridge consultants to formulate their designs.

4. AREA DESCRIPTION

4.1.1 The southern limit of the area investigated by R. M. Hardy & Associates Ltd. is Big Smith Creek at Mile 544, and the northern limit is Bosworth Creek a few miles north of Norman Wells at Mile 635. Mile posts 627, 628 and 629 are duplicated so that Bosworth Creek is shown at Mile 632 on the mosaic sheets.

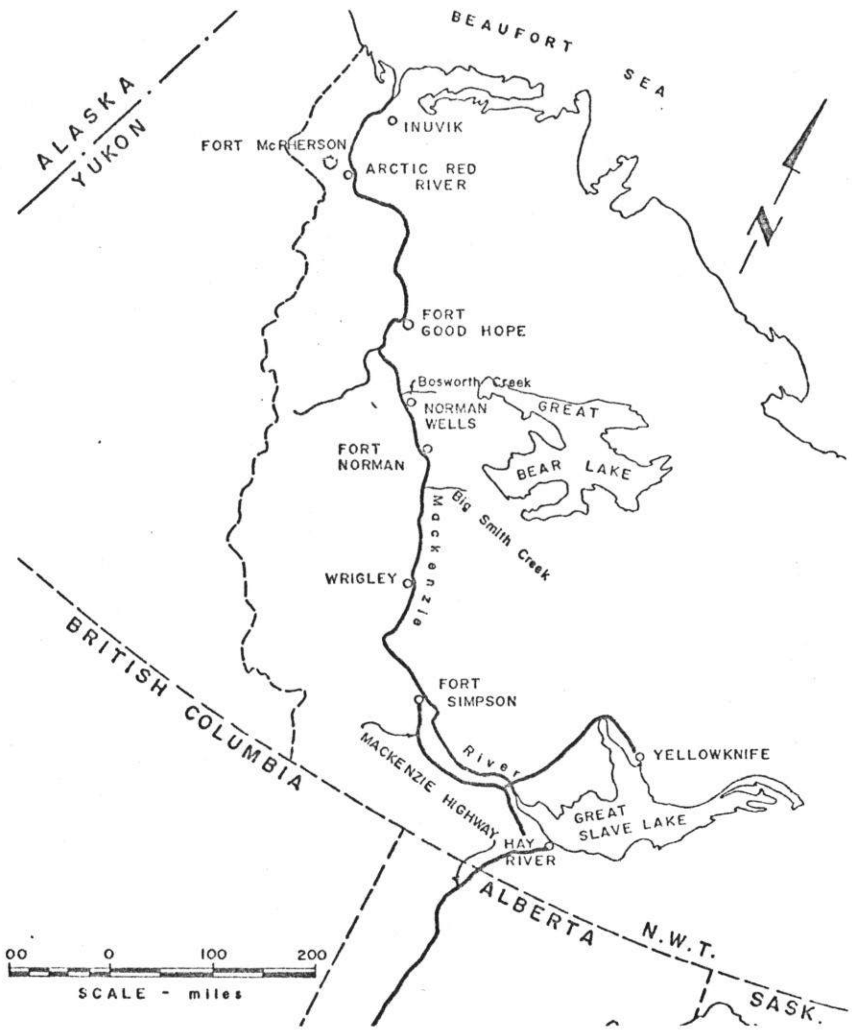


Figure 1

THE MACKENZIE VALLEY

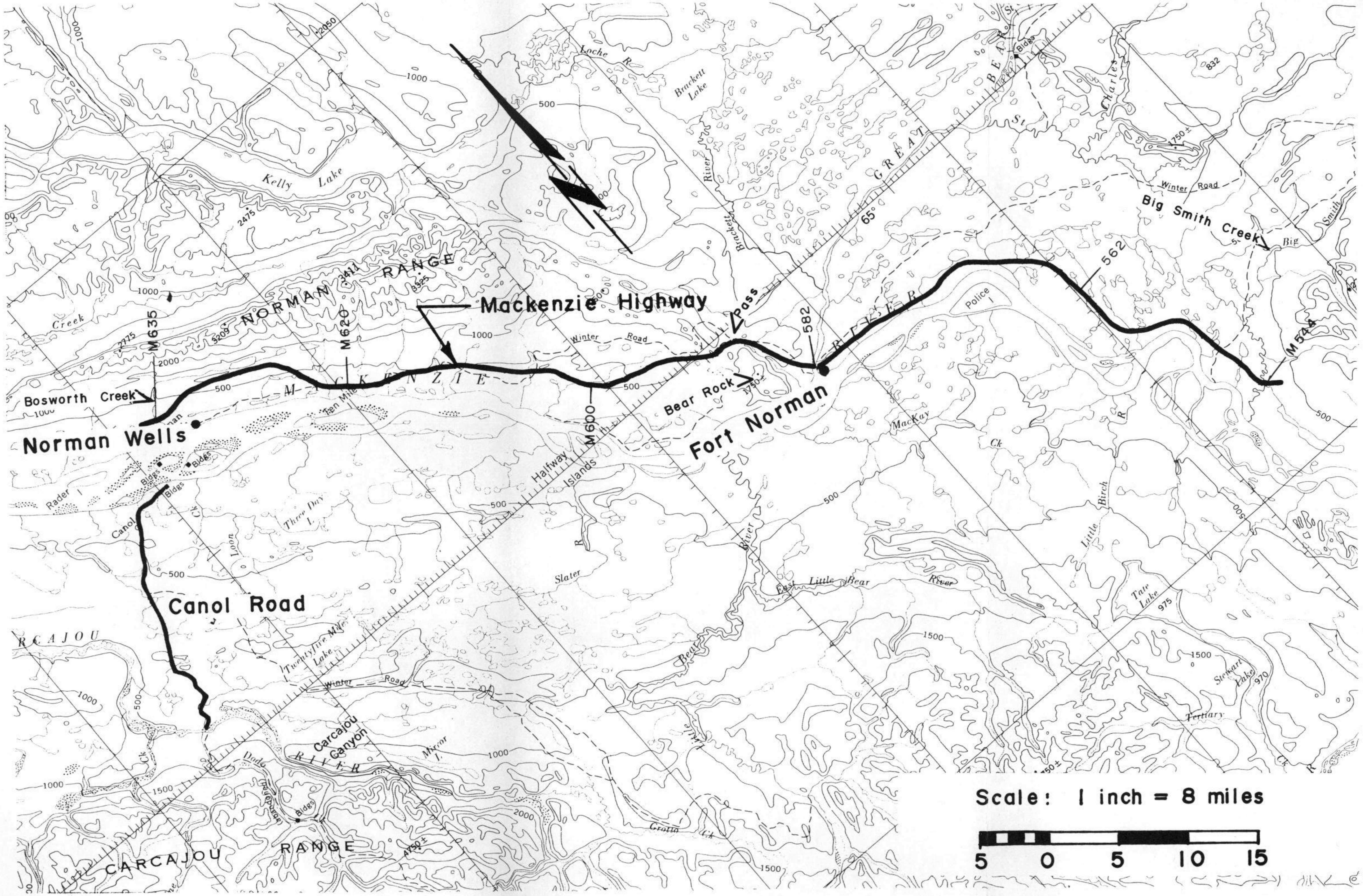
4.1.2 Figure 1 shows the relation of the area investigated to the principle settlements in the Mackenzie Valley. Figure 2 (following page) shows the area investigated in more detail to a scale of 1 inch equals 8 miles. The area lies in map sheets 96C, E and F of the National Topographic Series.

4.2 Published Reports

4.2.1 The geology of the area has been described by Hume (15, 16). Figures in parenthises refer to the list of references at the end of the text in Volume 2. Reference 8 by Brown contains some interesting data from the Norman Wells area. The only other references we have been able to find which specifically deal with the area under investigation are all on the subject of the Canol Road and pipeline. A list of references at the end of the text (Volume 2) contains the titles of works which may be of value in the design of this section of the highway.

4.3 Geology

4.3.1 The bedrock geology of the area has been described by Hume (15, 16). Bedrock exposures can be seen along the lower reaches of the Great Bear River, around Bear Rock, and also along some of the creeks which empty into the Mackenzie, such as Bosworth Creek.



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MACKENZIE HIGHWAY
Mile 544 to Mile 635
E-2510

G.Mc March 22, 1973

FIGURE 2

4.3.2 Near the mouth of the Great Bear River there are exposures of sandstone, shale and conglomerate. This rock was encountered in Test Hole 522.

4.3.3 In the area of the pass to the north of Bear Rock, the bedrock is limestone and shale. Further to the west, in the vicinity of Jungle Ridge, the bedrock is shale and limestone of the Fort Creek Formation. Between Jungle Ridge Creek and Bosworth Creek the bedrock is of the Imperial Formation and consists mainly of sandstone and shale.

4.4 Topography

4.4.1 The topography of the area between Big Smith Creek and Bosworth Creek is relatively level. Steep gradients are only encountered at river and creek crossings except where the alignment passes through the pass to the north of Bear Rock and also where there is a sharp drop in ground level in the vicinity of Mile 554.

4.4.2 The elevation of the ground drops gradually from the vicinity of Big Smith Creek to the Great Bear River. On the north side of Great Bear River the land climbs rapidly to the pass and then descends gradually to Bosworth Creek. In general, the alignment lies across the drainage paths except for the stretch immediately north of Great Bear River and the section which lies on the top of Jungle Ridge.

4.4.3 Photographs 5, 7, 7, 8, 9, 13, 14, 15, 16, 17 and 18 (Appendix A) show typical examples of the topography in the region.

4.5 Climate

4.5.1 The study area lies within the Boreal Zone of the sub-Arctic. The climate is characterized by long cold winters and short, relatively cool, summers. Precipitation is low. Regular weather records have been taken at Norman Wells since 1944. Meterological data from Norman Wells are as follows:

- mean temperature: 20.8^{o}F
- mean annual snow fall: 40 inches
- mean annual rain fall: 7 inches
- mean annual total precipitation: 11 inches
- mean freezing index: 7,200 degree days F
- lowest freezing index recorded: 6,000 degree days F
- highest freezing index recorded: 8,000 degree days F
- mean thawing index: 3,000 degree days F
- lowest thawing index recorded: 2,500 degree days F
- highest thawing index recorded: 3,350 degree days F

4.5.2 Weather records were kept at Fort Norman from the summer of 1940 to the summer of 1949 when the station was closed.

4.5.3 Weather records have been kept at Wrigley from the summer of 1943 to the present. However, many of the records at Wrigley are intermittent with many years showing incomplete record keeping or no record at all. Weather records were kept at Fort Good Hope from at least 1940 to 1971 with only a few years showing incomplete records. Both Wrigley and Fort Good Hope are outside the area covered by this report. Weather data from Fort Good Hope, Norman Wells, Fort Norman and Wrigley are summarized on Plate 1, Appendix E (Volume 2).

4.6 Vegetation

4.6.1 The trees found in the study area consist of: black spruce, birch, willow, alder, tamarack and white poplar (aspen). Black spruce is the dominant tree throughout the area. White poplar (aspen) is found in only a few locations on top of sand ridges where the depth to the permafrost table is considerable.

4.6.2 Labrador tea, alder and berry plants are the principal bushes. Reindeer moss (lichen) is common in the better drained areas and sphagnum in the wetter areas.

4.6.3 Detailed mapping of the vegetation in the area can be found on the series of maps entitled "Vegetation Maps of the Mackenzie Corridor" prepared by the Forest Management Institute of Canadian Forestry Service.

4.6.4 Photographs 8, 11, 12, 15 and 16 show typical views of the vegetation.

4.7 Wildlife

4.7.1 Hunting, trapping and fishing are still important activities for the local population and the area has some potential for recreational purposes. A series of maps "Land Use Information Series" produced by the Department of the Environment for the Department of Indian and Northern Affairs shows wildlife habitats and gives much useful information on breeding and migration patterns of the various forms of wildlife. A study of these maps showed that a winter drilling program would have no appreciable effect on wildlife in this area.

4.8 Logistics

4.8.1 The transportation of heavy equipment into Norman Wells and Fort Norman is usually by barge during the summer months. However, even at this time of year, bad weather may cause difficulties in scheduling. A winter road from Fort Simpson is sometimes open during the winter but this route is usually expensive and, in any case, is seldom available before the middle of January.

4.8.2 Passenger and freight aircraft operate in and out of Norman Wells on regular schedules and the airport is capable of handling the largest aircraft.

The airstrip at Fort Norman can handle aircraft up to the size of a DC-3 and it is possible that larger aircraft could use this strip.

4.8.3 Airstrips capable of handling aircraft up to the size of a Hercules have been constructed on the Mackenzie River in past winters and such strips are normally usable during the period from the beginning of January to the middle of April.

5. PROGRAM DESCRIPTION

5.1.1 The field, laboratory, and office phases of the program consisted of:

- air-photo interpretation
- terrain evaluation
- drilling and sampling (center-line)
- drilling and sampling (borrow areas)
- field laboratory testing
- laboratory testing in Edmonton
- borrow computation
- evaluation of data
- reporting information

The project was under the overall direction of one of the firm's principals who was assisted in the day to day administration of the project by a senior engineer. The field work was under the direction of a senior field engineer who was assisted by a senior technician in charge of the field laboratory.

5.1.2 Junior staff posted to the field included technicians experienced in: sampling techniques, laboratory testing, air photo interpretation and surveying. A sampling technican accompanied the drill-rig on each shift. His duties included visual reporting, correct packaging and labelling of all samples.

5.1.3 A field layout technician was charged with the responsibility of locating test holes and borrow areas under the direction of the field engineer. Two laboratory technicians were employed in the field laboratory and one further technician was employed in computation and drafting logs.

5.1.4 Clearing access into borrow areas and moving camp was done by two bulldozers. The catering contract was let to an experienced catering contractor. Delivery of supplies to the field camp was by means of light aircraft and trucks provided by a local contractor. Photographs 3 and 4 show the mobile camp.

5.1.5 Prior to the commencement of field operations, meetings were held with the Settlement Manager and members of the Settlement Council of Fort Norman, officers of the Forest Service and representatives of the Department of Public Works. During the course of the work, further meetings were held from time to time with representatives of the Settlement Council of Norman Wells, the Forest Service and D.P.W.

5.2 Air-Photo Analysis and Terrain Evaluation

5.2.1 Prior to commencement of field work, aerial photographs were examined and analyzed in order to obtain some idea of the soil types which would be encountered and also to evaluate the terrain. Aerial photographs were also an aid in planning and scheduling the program such as in identifying possible camp sites.

5.2.2 As centerline drilling progressed, air photo analysis was revised in the light of drilling information and the results used in the selection of possible borrow sources.

5.3 Drilling and Sampling

5.3.1 All the test holes in this program were drilled with rotary drill rigs. Between Big Smith Creek and Great Bear River, a Failing 1000 drill rig was used while north of the Great Bear River a Mayhew 1000 drill rig was also used. Both rigs were mounted on Flextrac-Nodwell low ground pressure vehicles equipped with wide tracks. Compressed air was used as the drilling fluid. The Failing 1000 rig is shown on photograph 1, Appendix A.

5.3.2 Three sampling methods were employed. Shelby tubes were used to obtain undisturbed surface samples and also to obtain samples in plastic clays. Core barrels were used to obtain samples of 2.8 inch diameter in frozen material. "Grab" samples were also obtained for soil identification and moisture content analysis. Shelby tube and core samples were obtained in a sufficient number of test holes to obtain data on the in situ density of the material, true ice content and ice type.

The depth of test holes varied to suit circumstances of soil type and grade elevation.

5.4.3 Wherever possible the depth to the permafrost table was noted on the drill hole logs. In many test holes (particularly after the beginning of January) it was found that the seasonal frost had penetrated to the permafrost table so that it was not possible to delineate the permafrost table.

5.5 Field Laboratory Testing

5.5.1 Almost all the samples were tested in a field laboratory which accompanied the camp. Tests carried out were:

- density
- moisture content
- visual soil descriptions
- visual ice descriptions
- grain size analysis (by sieving)

5.5.2 Test hole logs were prepared in the field and all the information from the field laboratory was noted thereon. All necessary calculations were carried out in the field office. Photograph 2 shows the field laboratory.

5.6 Laboratory Testing, Edmonton

5.6.1 A certain number of tests could not be performed in the field laboratory. These included: moisture content of organic samples, hydrometer analysis and Atterberg limits. These tests were carried out in our Edmonton laboratory on selected samples which were shipped from the field.

5.6.2 Sufficient samples have been retained for compaction tests. In addition, samples have been retained for examination by contractors interested in bidding on the project. Representative samples were delievered to the Department of Public Works Office in Norman Wells for storage. Some representative core samples were shipped to Edmonton in insulated boxes and are being stored in cold storage.

6. DRILL HOLE LOCATIONS

6.1.1 The locations of all drill holes are shown on prints of mosaics to a scale of 1 inch equals 1,000 feet which were supplied by the Department. Mile posts are indicated on the mosaics. The chainage at each centerline test hole is shown on the appropriate log. The mile interval is shown on all test hole logs. (Each mile of centerline is referred to by the mile post at the beginning of the mile, e.g. Mile 574 indicates the mile interval 574 to 575.)

7. MILE 544 - MILE 568

7.1.1 This section covers the area from Big Smith Creek northerly for a distance of approximately 24 miles. The topography varies from flat to gently undulating with the only major breaks in the surface being at two creeks and one change in elevation at Mile 554 (in the vicinity of borrow area 38). There are numerous small thermokarst lakes and ponds in the section Mile 544 to 554 but the number of such thermokarst features then rapidly diminishes while the size of them becomes larger.

7.1.2 A creek at Mile 555 (where Test Holes 298 and 334 were drilled) has a valley depth of approximately 40 feet. From this creek the alignment climbs in a series of relatively low steps for approximately one mile. (See mosaic sheet 35A). The alignment then runs along the top of a series of sand ridges and across various small dune formations until the vicinity of borrow area 20 (Near M563 see mosaic sheet 37). At this point the drainage deteriorates and is generally poor to the end of this section at approximately Test Hole 223 at Mile 568.

7.2 Soils

7.2.1 The soils in this section consist mainly of fine sands with the permafrost table near the surface.

Immediately adjacent to Big Smith Creek the near-surface deposits consist of interbedded silts, sands and gravels with shale bedrock within 10 feet of the surface. (The foundation conditions for the bridge at the Big Smith Creek will be the subject of a separate report.)

7.2.2 Test Hole 355 is typical of the soil in this area. It will be observed that the soil profile consists of silty sand to a depth of 27 feet where the material changes to clay-sand. The ice was non-visible and water contents varied generally between 25 and 30 percent.

7.2.3 A creek crosses the alignment at Mile 554.9 (see Mosaic sheet 35A). Test Hole 334 shows clay to a depth of 50 feet with silty sand and more clay beneath it. Water contents in the clay were quite high with estimates of the visible ice being 50 to 60 percent. Another test hole, Test Hole 298 on the northerly side of this same creek, shows the soil profile consisting mainly of silt and sand.

7.2.4 The thickness of organic soil along the centerline is generally only a few inches. At many test holes, the organic surface soils have been stripped completely. The maximum depth of organic material was less than 5 feet in this section.

7.2.5 A total of 171 cores of sand were measured and weighed to determine in situ bulk and dry densities.

The results are summarized in Table I and in the histogram in Figure 3.

TABLE I

In Situ Dry Density (pcf)	No. of Samples	Percentage of Total
less than 80	1	0
80 - 85	3	2
85 - 90	16	9
90 - 95	37	22
95 - 100	62	36
100 - 105	49	29
105 plus	3	2
Total	171	100

7.2.6 Nine samples of sand were tested to determine the dry density after thawing has been completed. These samples were mixed with sufficient water to form a slurry and were then poured into plastic tubes. A porous stone was placed on top of each sample to simulate a load of 300 lbs./sq. ft. Drainage of the samples took place through a porous stone at the bottom of the tubes and also through porous stones at the top. After several days, the samples were measured and weighed and then dried in an oven. The data obtained for each sample included: bulk density, dry

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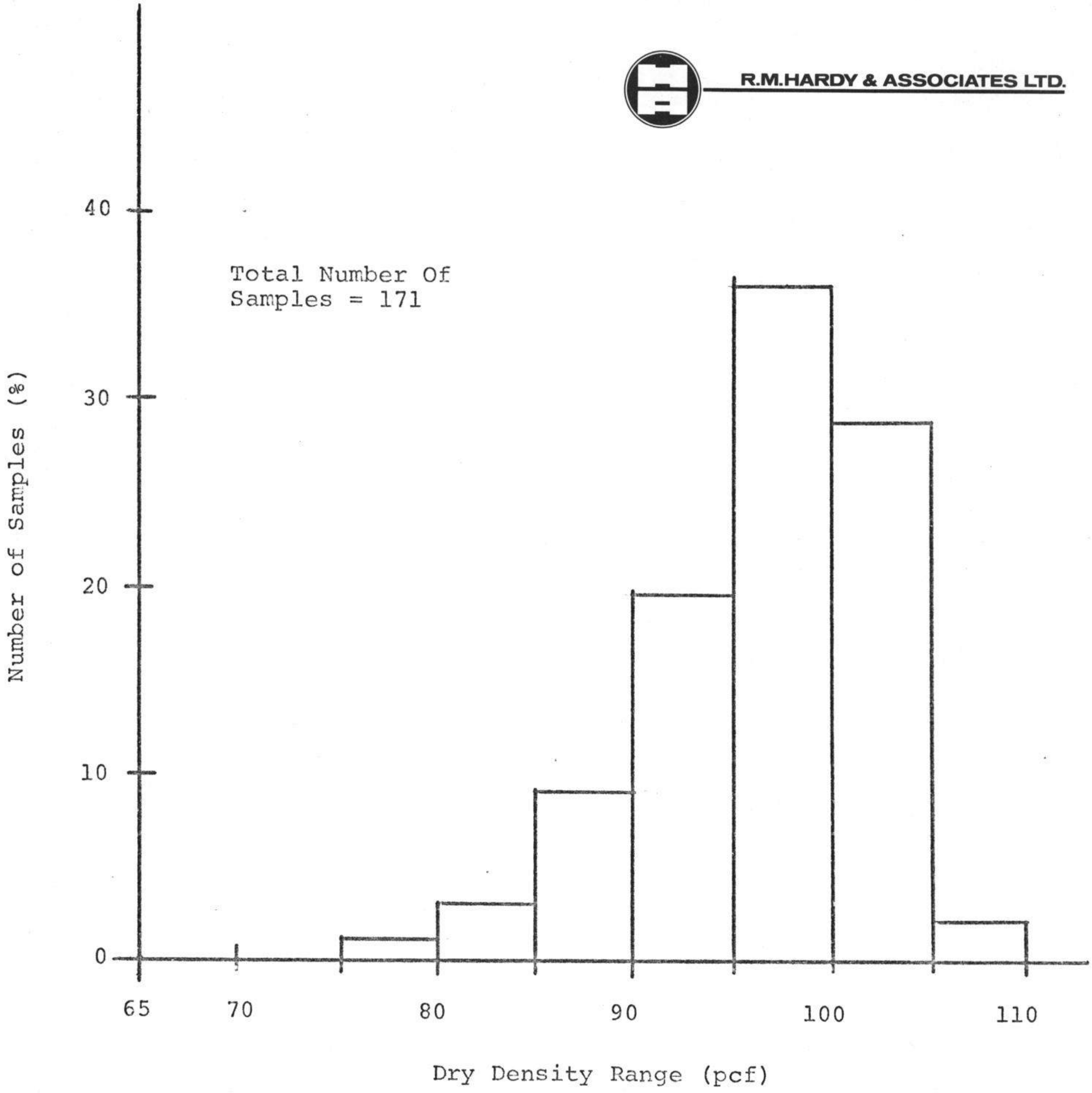


HISTOGRAM OF DRY DENSITIES

SAND

MILE 544 - 572

density and water content. The dry densities ranged from 92 to 115 pcf with a mean of 102 lbs./cu. ft. It will be seen from Table 1, that approximately 30 percent of the samples obtained in the field exceeded a dry density of 100 lbs./cu. ft. Fifty-eight percent of the samples obtained in the field had dry densities ranging from 90 to 100 lbs./cu. ft. and the average for all samples obtained in the field is 96 lbs./cu. ft.

7.2.7 If the terminal dry density cannot be found by laboratory testing, or estimated, some reasonable estimates of probable settlement can still be made. Of more importance from the point of view of maintenance is the question of the rate of settlement which should be expected over a given period of time. The rate at which the thawing isotherm penetrates into soil is approximately proportional to the square root of time. The thawing isotherm will therefore penetrate at a relatively rapid rate during the first few years following construction of a highway and the rate of penetration will then decrease until it becomes, for all practical purposes, imperceptible. Higher excess ice contents are normally found within 10 feet of the ground surface so that the amount of settlement which should be expected will occur mainly during the first few years following construction.

7.2.8 From the above data, and from our experience with other projects, we estimate that settlements of the embankment due to thawing of the sub-grade will be very small and will seldom exceed a few inches. In isolated cases, and for only short stretches of embankment, settlements may exceed one foot but such cases will be rare in this section.

7.3 Borrow Material

7.3.1 Twenty potential borrow areas were examined in this section. Of these 20 areas, one was found to consist mainly of clay with high moisture contents, two were found to consist of layers of sand and silt while the remaining 17 consisted almost entirely of sand with moisture contents ranging from 20 to 30 percent. Data on these borrow areas is summarized in Appendix B, Volume 1.

7.3.2 In general, the 17 borrow areas which contained soil that is considered to be suitable for embankment use, contain sand which is quite fine and very often silty. The ice type was generally classified as Nbn (Non-visible, no excess ice) with moisture contents averaging about 25 percent.

7.3.3 In almost all the test holes in these borrow areas, the entire profile was frozen with the exception of the test holes drilled in the sand ridge at Borrow Area 22 where the permafrost table was found to be at considerable depth.

7.1.4 One noticeable feature in these borrow areas is that the topographic position appears to have little influence on the moisture content of the material. The sand in the sand dunes, or ridges, has just as high a moisture content as sand in the low lying areas.

7.4 <u>Sections of Potential Excessive Settlement</u>

7.4.1 No problems with excessive settlement of the subgrade are expected in this section.

7.5 <u>Stability Problems on Side Hill Locations</u>

7.5.1 The only location in this section where side hill stability may be a problem is in the vicinity of Test Holes 338, 339 and 340 (Mile 554). At this location, the grade of the alignment drops sharply down a steep incline along a side hill. Almost certainly a side hill cut will be required. The soils at this location are sand with relatively low water contents. It is believed that a cut section would be quite feasible at this location. Unfortunately, we have no field data on the inclination of the backslope which can be left in cuts in frozen sand. We would suggest that some simple laboratory testing could be undertaken to ascertain the angle of repose of such sand during and after thawing has been completed. The type of laboratory testing which should be carried out is discussed in a section below entitled "Further Laboratory Testing".

7.6 Stability Problems in Cuts

7.6.1 In this section, there are sixteen locations where the grade designer might wish to cut into the existing ground. The data for each possible cut is summarized in Appendix B. In general, cuts in sand with low water contents are feasible. Where the soils are mixed or consist mainly of clay, cuts are not recommended.

7.6.2 The problem of estimating safe backslopes in excavated sand has been discussed above. In this sand material, the stability of slopes cut on side hills and also through ridges will be similar.

7.7 Liquefaction and Pumping Problems

7.7.1 Due to the silty nature of most of the soil in this section, liquefaction and pumping problems may occur where soil with a moisture content in excess of 25% is included within the embankment. As it may be impossible to exclude soils with water contents in excess of 25 percent from the embankment, it is possible that instances of pumping may occur in a completed embankment within the first year or two after construction.

We suggest that the most economical method of dealing with this problem is to handle sections where pumping occurs as part of a normal maintenance program. We do not expect serious problems with liquefaction and pumping to occur in the subgrade soils where the height of embankment is in excess of 4 feet.

7.8 Erosion

7.8.1 Fine sands, particularly silty sands, are susceptible to erosion by running water and wind. The chart shown as Plate 8, Appendix E shows the relative susceptibility of various soil types to erosion. We believe the most serious problems with erosion in such soils will occur in cuts where the gradient is greater than one percent. Such a gradient is extremely low. The precautions which can be taken include building small dams to act as catchment areas and in seeding. However, as is generally appreciated, it is extremely difficult to obtain a good growth of grass in this area in less than 3 years. The problem of erosion of fine sand will be particularly acute where the alignment crosses a creek or stream. Ditches in such soil materials must not discharge into creeks unless it has been ascertained that no damage to the creek environment can occur.

7.9 Seepage

7.9.1 No problems with seepage of ground water are expected in this section.

7.10 Construction Methods and Scheduling

7.10.1 It is believed that most of the embankment in this section will be constructed out of borrow material and that there will be very little cut-and-fill employed. Most of the embankment material will therefore be borrow and almost all of this will be sand. As discussed in the section "Strength of Frozen Soil" (Volume 2) the strength of frozen soil, and therefore its capability to resist excavation, is a function of the soil type and temperature. As will be seen from Figure 14 (Section 21.2), Volume 2, frozen sand has very high compressive and shear strengths. As far as we are aware, the only cases where frozen sand has been excavated in the winter have been where the sand is in relatively small quantities and the cost of excavation is a small proportion of the total cost of a larger job. In case of highway construction, cost of excavation of borrow can be a significant proportion of the total overall cost.

7.10.2 Excavation of the frozen sand borrow in the winter may well entail drilling and blasting. It is possible that ripping would prove more economical but this is extremely doubtful. If the sand borrow is excavated and placed in the embankment in the winter, there will be considerable loss of volume in the embankment when the material thaws. However, experience near Inuvik has shown that this loss of volume can be allowed for in the original placement with the results that a good embankment results after thawing is complete and the top of the embankment has been dressed by equipment.

7.10.3 Other alternatives would include excavating the sand and placing in the embankment in the summer. We doubt if it would be possible for scrapers, or other moving equipment, to operate in the sand borrow pits in the summer. Almost certainly "quicking" would occur beneath the equipment wheels. However, it is possible that the material could be scraped up as it thaws by bull dozers and drag lines and piled in windrows to allow it to partially dry out. The material could then be loaded into dump trucks and transported to the grade.

7.10.4 We are recommending the construction of a test section of embankment at approximately Mile 580 (see Section 17 "Proposed Test Section") and the most economical method of excavating the various types of borrow could be investigated then. Clearing of the right-of-way and borrow areas could take place during the winter most economically.

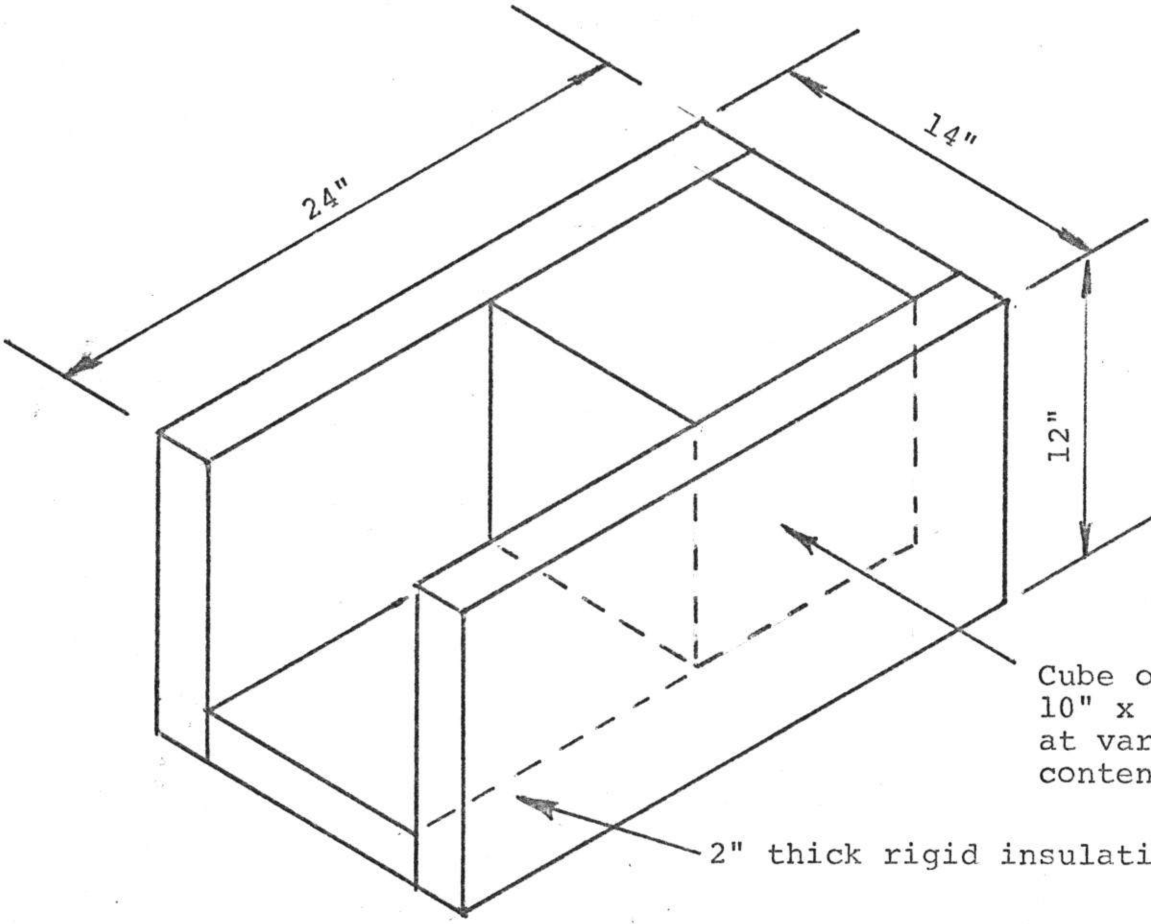
7.11 Further Laboratory Testing

7.11.1 As mentioned above, there is no data available on the behaviour of frozen sands when excavated and allowed to thaw. We therefore suggest that some simple laboratory testing be undertaken in order to ascertain what angles of repose can be anticipated in such material. One simple test we propose is to prepare blocks of frozen sand at a water content corresponding to conditions in the field, and then permit the sand to thaw out on one face. Figure 4, (following page) shows the method of carrying out this test. It should be repeated for various conditions eg. commencing with a vertical cut face, commencing with a face cut to a slope and so on.

7.12 Discussion

7.12.1 The topographic conditions in this section do not pose any particular problems in highway design and location. There is only one stream where a bridge is planned (Big Smith Creek which is really the boundary of this section).

7.12.2 Borrow material is plentiful, but unfortunately, there will be many problems connected with its excavation. We believe that the construction of this section can be carried out most economically during the summer and fall.



SUGGESTED EXPERIMENT TO STUDY ANGLE OF REPOSE OF THAWING SAND

FIGURE 4

However, due to ecological considerations, it will probably be necessary to schedule construction during the winter.

8. MILE 568 - MILE 583

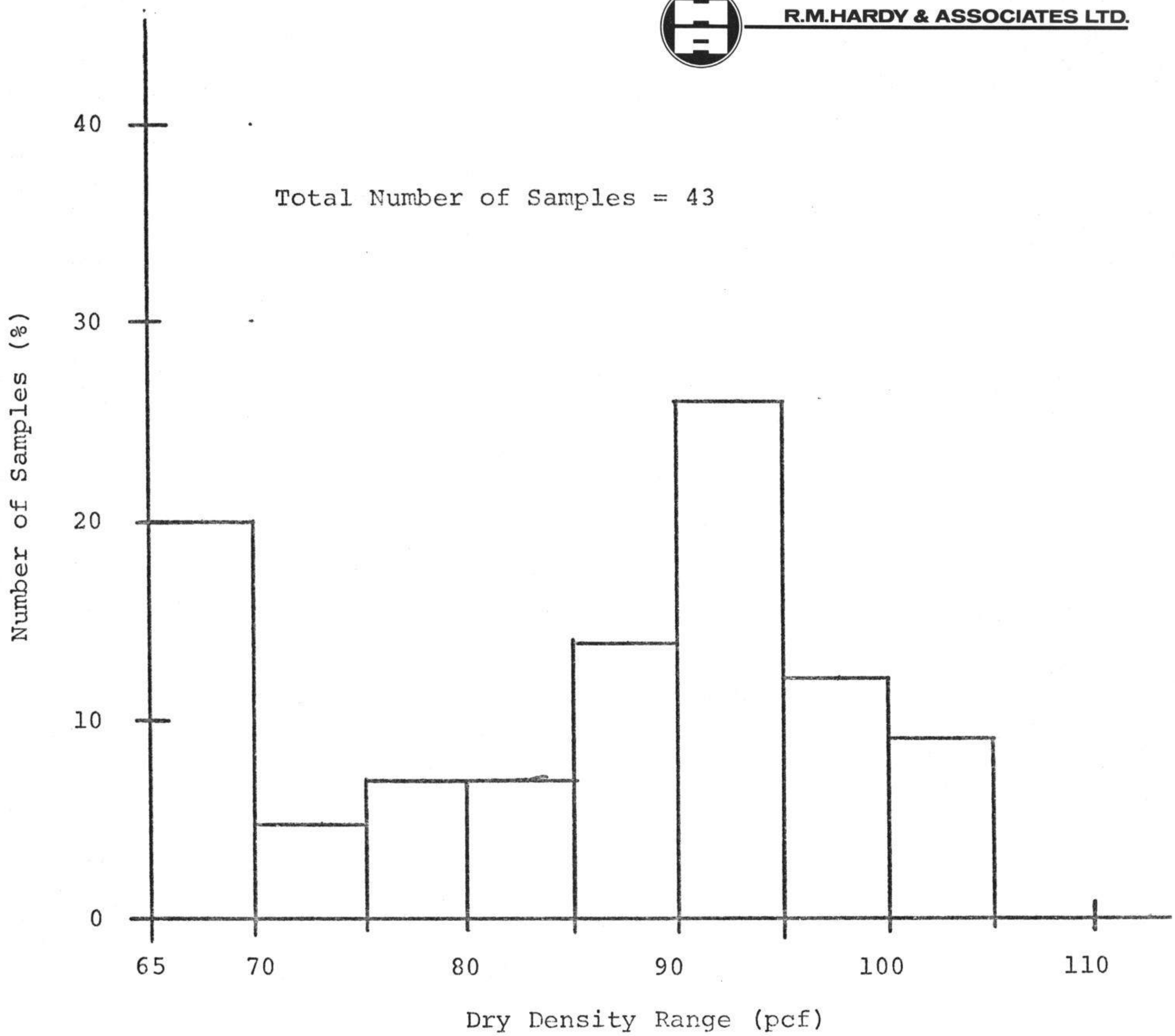
8.1.1 This section comprises the 15 miles of alignment immediately south of the Great Bear River. The topography along the route is fairly level with the only steep gradients being found in the approaches to three creeks and the Great Bear River. Of the three creeks, the only one of significance is at mile 568.1. Drainage is in the direction of the Mackenzie River and is generally poor to fair.

8.2 Soils

8.2.1 The soils in this section of the alignment consist of interbedded clays, silts and sands. There is usually a very thin cover of peat at the surface which is often missing where the C.N.T. right-of-way has been cleared. Moisture contents are extremely variable and are invariably considerably above the optimum for embankment use.

8.2.2 Ground ice is fairly low in volume with estimates of excess ice being much lower than is usually the case with soils so close to the Mackenzie River.

8.2.3 The soils in this section are quite variable in type and density. Figures 5, 6 and 7 show the distribution of dry density versus percentage of occurrence for the three soil types, silt, clay and sand in this section. It will be observed that there is far greater variation

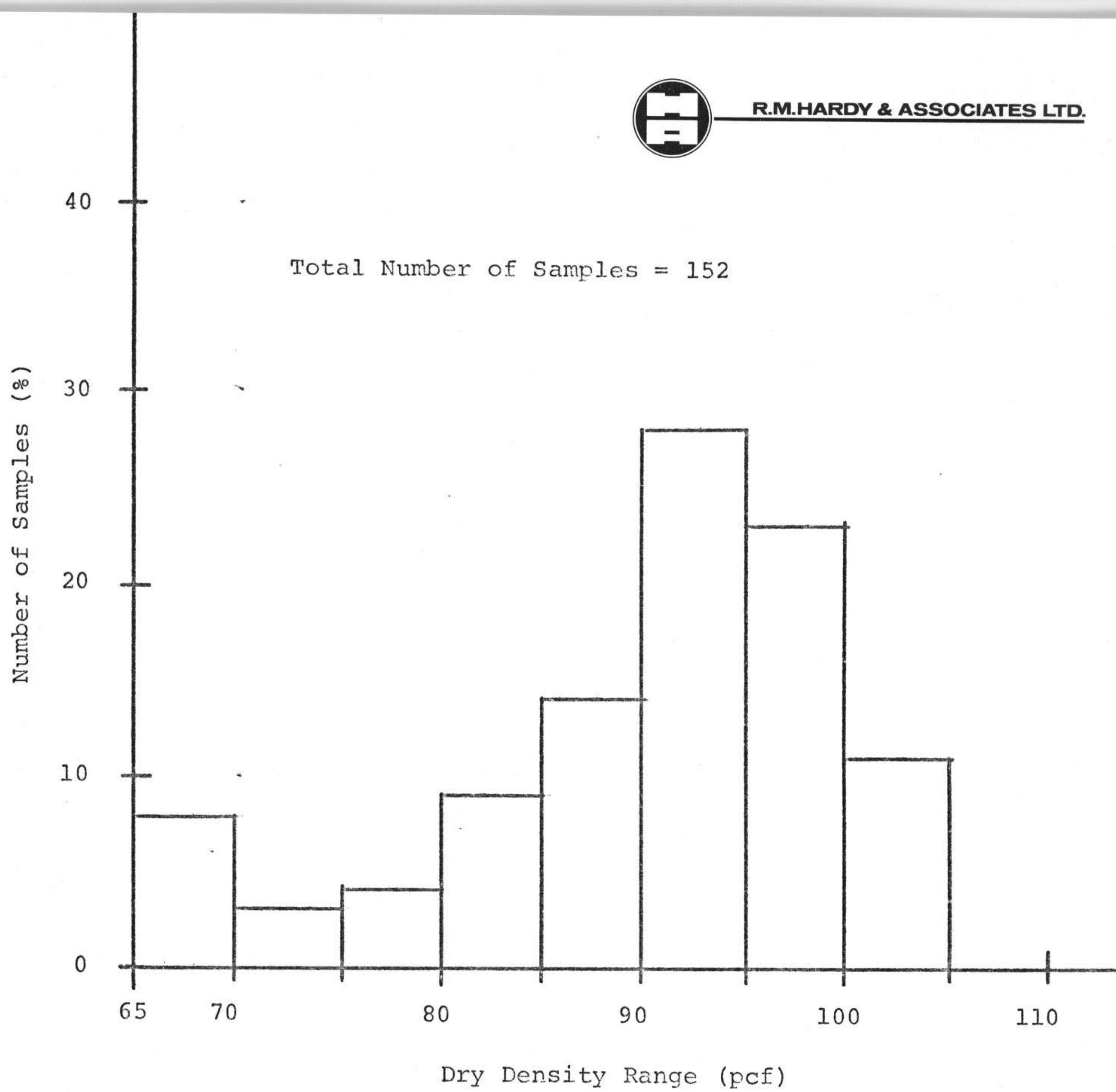


HISTOGRAM OF DRY DENSITIES

SILT

MILE 572 - 584

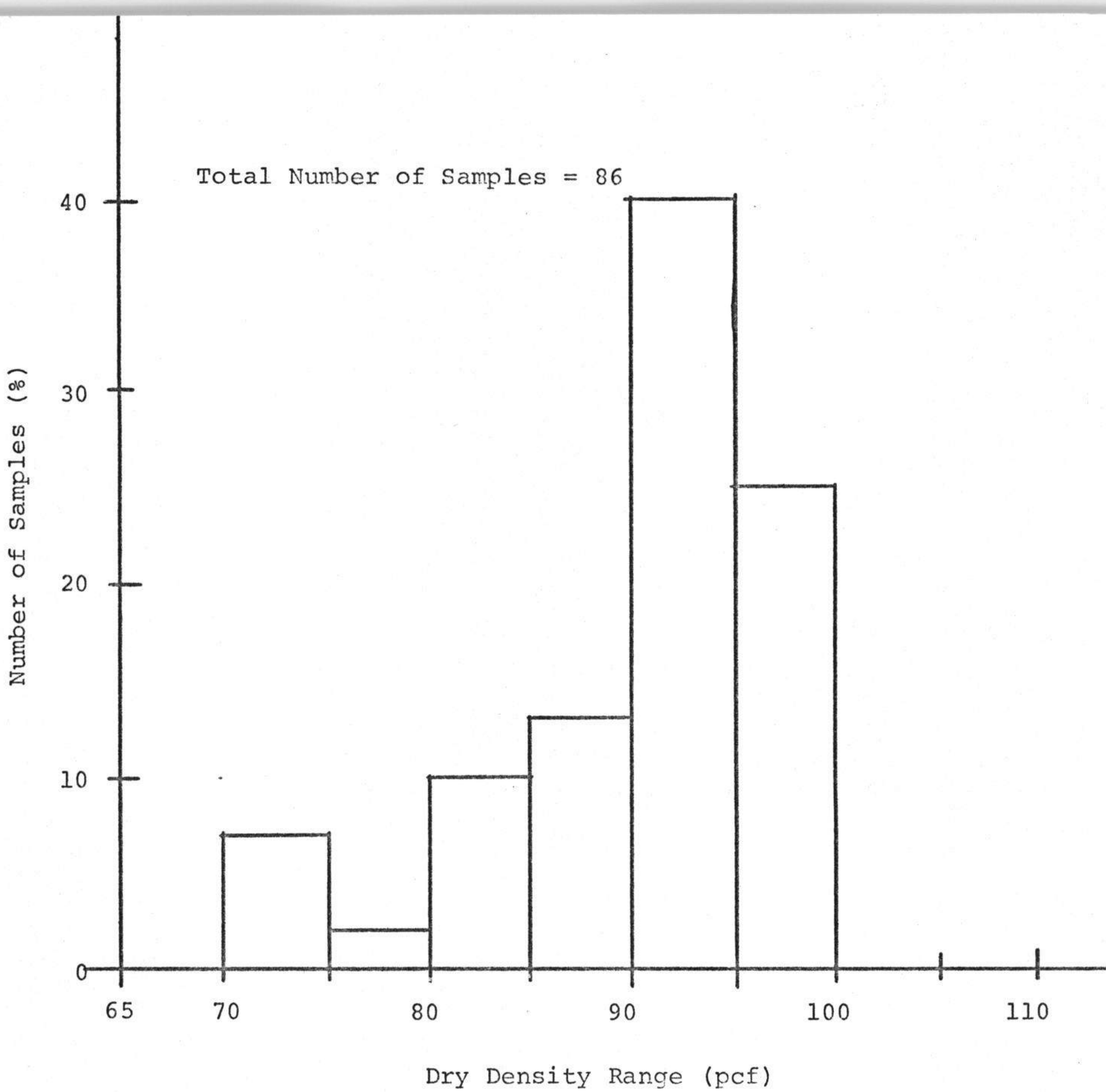
R.M.HARDY & ASSOCIATES LTD.



HISTOGRAM OF DRY DENSITIES

CLAY

MILE 572 - 584



HISTOGRAM OF DRY DENSITIES

SAND

MILE 572 - 584

in the densities of these materials than there is in the sand material in the previous section (see Figure 3). 37 percent of the clay samples tested had dry densities less than 90 pounds per cubic foot. It can be assumed that when the soils do thaw they will consolidate to a density of approximately 90 pounds per cubic foot so that settlements, in some cases fairly considerable, can be anticipated in this section. Of the silt samples tested, 53 percent had dry densities less than 90 pounds per cubic foot. 20 percent of the silt samples had dry densities less than 70 pounds per cubic foot.

8.2.4 We do not anticipate sudden subsidence of any sections of the embankment and the settlements that do occur can almost certainly be taken care of by normal routine maintenance procedures for a gravelled highway. From the above data, we would deduce that settlements of as much as 2 feet can be anticipated in a highway embankment over the course of 20 years. We would also expect that settlements of as much as one foot could occur in the 5 years following construction.

8.3 Borrow Material

8.3.1 Eighteen areas were examined as potential borrow pits in this section of the alignment. The three most southerly areas (designated as borrow areas

17, 39 and 40 at miles 569 and 571) contained sand with low moisture content. The depths of the sand were quite considerable. The next 10 pits, Nos. 6 through 15, all contained clay and silt in different layers with moisture contents varying from 25 to 40 percent and with some considerable ice contents.

8.3.2 The most northerly five areas contained mixtures of sand, clay and silt with moisture contents ranging from 25 to 40 percent. Ice contents were quite high.

8.4 Sections of Potential Excessive Settlement

8.4.1 The problems associated with settlement due to thawing of ground ice has been discussed above.

8.5 Stability Problems on Side Hills

8.5.1 There is only one location in this section where a cut in a side hill may be required. This location is on the south side of the Great Bear River where the alignment drops down to the river crossing. At the time the drilling program was undertaken, the alignment in this section between the Great Bear River and the southerly end of the air strip had not been laid out on the ground. Test Holes 452 and 453 are on either side of the probable location of any cut. Also, the test holes in Borrow Area 1 will give some indication of the probable soil conditions. We believe that a side hill cut in this area would be most unstable and we would advise very strongly against such a design. We believe that the road should be located so as to take advantage of existing routes, such as down an existing creek which has its head at the approximate location of Test Hole 452, or down the existing road to the pump house at the location of Test Hole 453.

8.6 Stability Problems in Cuts

8.6.1 There is only one place where a cut section is a possiblity and that is on the creek crossing at mile 568.1. This crossing is straddled by Test Holes 220 and 221. The south side of the valley of this creek shows evidence of instability due to thawing of ground ice. The log for Test Hole 221 shows 29 feet of sand overlying interbedded clay and till layers which hold fairly high ice contents. Test Hole 222 shows 44 feet of sand overlying clay. Test Hole 219, on the north side of the creek, showed interbedded layers of silt, sand and clay with high ice contents.

8.6.2 We believe that any cuts made in the valley walls of this creek will be unstable and the material so obtained from such cuts will make for a poor embankment. The height of embankment required over the center of the creek will be considerable and will require a large amount of borrow.

8.7 Liquefaction and Pumping Problems

8.7.1 Liquefaction and pumping may occur in sand used in the embankments where the water content of the borrow material exceeds 25%. This problem could also occur where silty soils are used as embankment material. The problem is unlikely to arise where well compacted clay is used as fill although the use of clay in this section is extremely doubtful.

8.7.2 We suggest that the most economical way to handle this problem is as part of a normal maintenance program. That is, to remove problem soils from the embankment and replace them with better material.

8.7.3 We do not expect such problems to arise in the subgrade soils where the height of embankment exceeds 4 feet.

8.8 Erosion

8.8.1 Silts are very susceptible to erosion by water particularly in the spring due to the weakness of thawing soil and the high run-off. Clay is much more resistant to running water. As far as possible, the vegetation (such as grass) in the right-of-way should be preserved and bare patches should be seeded. Run-off from the alignment should not discharge into streams but should be deflected into heavily treed areas. The behaviour of the surface soils along the right-of-way should be closely observed during and after construction. Remedial measures can then be taken as required.

8.9 Seepage

8.9.1 No instances of seepage were found during the field program. We believe it is unlikely that such problems will arise following construction.

8.10 Construction Methods and Scheduling

8.10.1 It is believed that the entire length of embankment in this section will be built from borrow material. As mentioned above in the section entitled "Borrow Material" Section 8.3) most of the material available is of poor quality with high moisture contents. We do not believe it is feasible to excavate most of this material in the summer. We therefore conclude that the only feasible course will be to excavate the sand material in the borrow areas at mile 569 and mile 571 and use the same techniques as described above. (See Section 7)

8.11 Further Laboratory Testing

8.11.1 We do not believe that further testing of the soils in this area is justified.

9. RIVER ISLANDS

9.1.1 Two islands in the Mackenzie River, located opposite the mouth of the Great Bear River, were investigated. Three test holes were drilled on these islands. The holes were number 456, 457 and 458. The soil material in all three test holes was sand, fine to medium grained, fairly well graded. Permafrost was not encountered.

9.1.2 Water contents in the sand ranged from 5 to 25 percent with the average moisture content being 18 percent.

9.1.3 These islands were investigated as possible sources of borrow material for the embankment. It was concluded that, while the material would be suitable for embankment construction, exploiting these deposits would require further study of the effects of removal on ecology and river navigation.

10. MILE 583 TO MILE 590

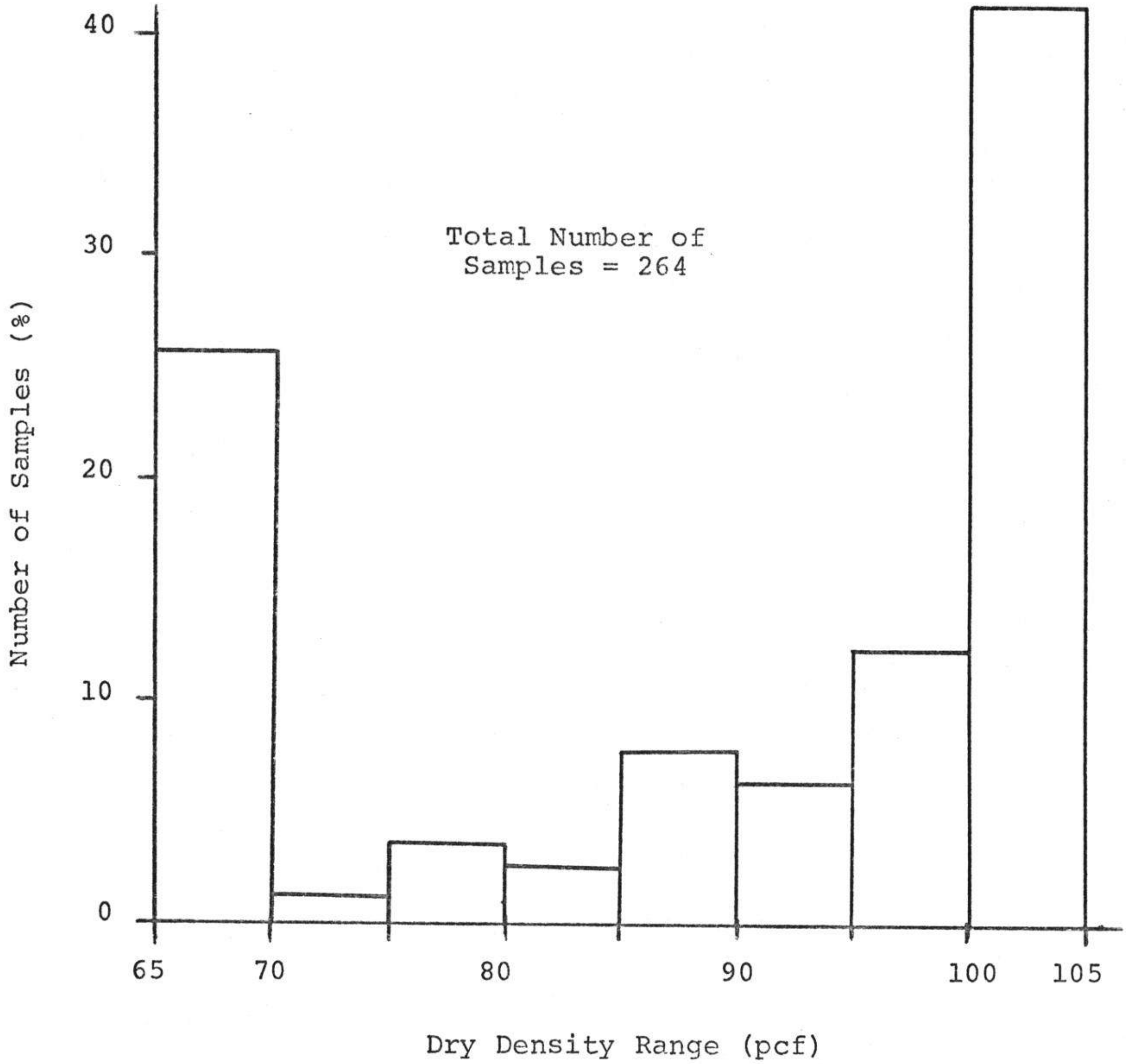
10.1.1 This section covers the area immediately north of the Great Bear River, to the foot of the pass located on the north side of Bear Rock, in which the alignment climbs approximately 500 feet. Drainage is good with the general direction being to the Great Bear River.

10.2 Soils

10.2.1 The soils in this section are glacially deposited tills consisting of layers of clay, silt and sand. Moisture contents are highly variable with values ranging from 10 to 40 percent and higher. Test Hole 470 is typical of this section. Ice and water contents are fairly high in the lower-lying ground near the Great Bear River but become much lower as higher ground is reached. Shale was found in some test holes. Dry densities vary considerably as shown on Figure 8 (following page).

10.3 Borrow Material

10.3.1 The borrow pits contain similar material to that found on centerline. In general, the borrow material in the lower-lying areas is very poor but does improve markedly as higher ground is reached. The borrow pits in this section are numbered 51 through 67. The material in these pits is summarized on the borrow summary sheets in Appendix B. As will be seen from the summary, most of these pits could be used for borrow although, in



HISTOGRAM OF DRY DENSITIES

MILE 583-590

almost every case, it will be necessary to select material and, particularly in the case of the upper material, to waste considerable quantities. As the soil material generally improves with depth in any pit, it may well be economical to limit the number of pits and to use longer hauls. Photographs 19, 20 and 22 show typical soil samples from this section.

10.4 Sections of Potential Excessive Settlement

10.4.1 Settlement can be anticipated in any area where there are large amounts of excess ice in the subgrade. In this particular section, such areas are found in the lower lying ground in the vicinity of the Great Bear River. As higher elevations are reached towards the pass, the amount of excess ground ice is considerably reduced and, therefore, so is the potential for excessive settlements.

10.4.2 As mentioned above, settlement due to thawing of ice in the subgrade will take place at a rate which is approximately proportional to the square root of time. It would be impossible to give actual values for each section without an exhaustive study of the test hole data. However, as a guide for design purposes, we would suggest that settlements of as much as one foot in the subgrade should be expected within the first 5 years following construction and that a further one foot of settlement could be expected in the following

15 years. However, such settlements should only be expected in relatively small sections. On the average, settlements of the subgrade will be much less than these figures.

10.5 Stability Problems on Side Hill Locations

10.5.1 The alignment climbs from the Great Bear River up a ravine. The seriousness of any problems in this section will be dependent on the exact alignment of the centerline. Slopes in the ravine appear stable (no evidence of recent movement was observed). However, the slopes are as steep as 2:1 and any additional loading on top of such a slope, or additional steepening by cutting, will probably cause a problem. As far as possible, the alignment should follow the existing ravine with side hill cuts being avoided. Such an alignment may entail a poor geometric alignment of the road but we believe that this will be preferable to inviting problems with slope failures. Views of this ravine are shown on Photographs 7 and 8, Appendix A.

10.6 Stability Problems in Cuts

10.6.1 A cut section will probably be required between the locations of Test Holes 461 and 521 (Mile 583.6). This cut will be required where the alignment climbs out of the ravine onto higher ground. Test Holes 461 and 521 show that the soil conditions are layers of silt, sand, clay and gravel. Water contents vary from 10 to 28 percent (except in the upper 3 feet where higher water contents were found) and the ice type is generally Nbn.

10.6.2 Due to the low ice contents in the soils, we would expect that cut slopes would be relatively stable. However, it is possible that higher ice contents may be found in isolated sections. Therefore, if a cut section is constructed in this area it may be necessary to overexcavate and face the slopes with more stable material in certain portions. Another alternative is to accept the necessity for remedial work on the slopes from time to time.

10.6.3 Data on possible cut sections is summarized in Appendix B.

10.7 Liquefaction and Pumping Problems

10.7.1 Liquefaction and pumping problems are not anticipated in this section except where silt may be included in the embankment. As it will generally be impossible, for practical purposes, to exclude pockets of silt entirely from the embankment we would suggest that pumping problems can be dealt with as part of routine maintenance.

10.8 Erosion

10.8.1 Problems with erosion can be anticipated where the subgrade soils are silts and sands and particularly where the alignment is on a gradient exceeding 1 percent. As it will be impossible to avoid gradients of such low slope, and as it will also be impossible to avoid placing the alignment in areas of sand and silt, problems with erosion can only be handled by taking precautions as far as possible and also by instituting a program of maintenance. Problems of erosion and suggested solutions are described more fully in Section 22, Volume 2.

10.9 Seepage

10.9.1 No problems with seepage are expected in this section.

10.10 Construction Methods and Scheduling

10.10.1 We do not consider it feasible to excavate and place any of the soil in this area during the summer. This soil material could be excavated and placed in the winter, however experience of winter placement of similar soils has been discouraging. We suggest that winter placement would be feasible provided that care is taken to exclude any of the surface soils which are ice rich and any soils which contain a high proportion of silt. Loss of height in the embankment during the summer following construction must be allowed for in the design. Experience gained in the construction of the test section at Mile 570 could be used as a guide as to whether to use the borrow in this section or excavate bedrock from the next section.

10.11 Further Testing

10.11.1 Further testing of soil materials in this section is not considered to be justified.

10.12 Miscellaneous

10.12.1 We understand it is proposed to provide a ferry service between Fort Norman and the north bank of the Great Bear River which will actually operate on the Mackenzie and will go around the Great Bear. It will therefore be necessary to construct a short section of road from the Mackenzie to meet with the proposed alignment. The location of this section of road has not yet been determined and no test drilling was done. From an examination of aerial photographs, we believe that the soil conditions, and consequent construction practices, will be as already described in this section.

10.12.2 It is probable that the most economical method of obtaining embankment material for this section will be to bring it from north of Mile 590. This will entail long hauls (similar to the conditions on the south side of the Great Bear River) but will probably be the most economical alternative in the long run.

11. MILE 590 TO MILE 601

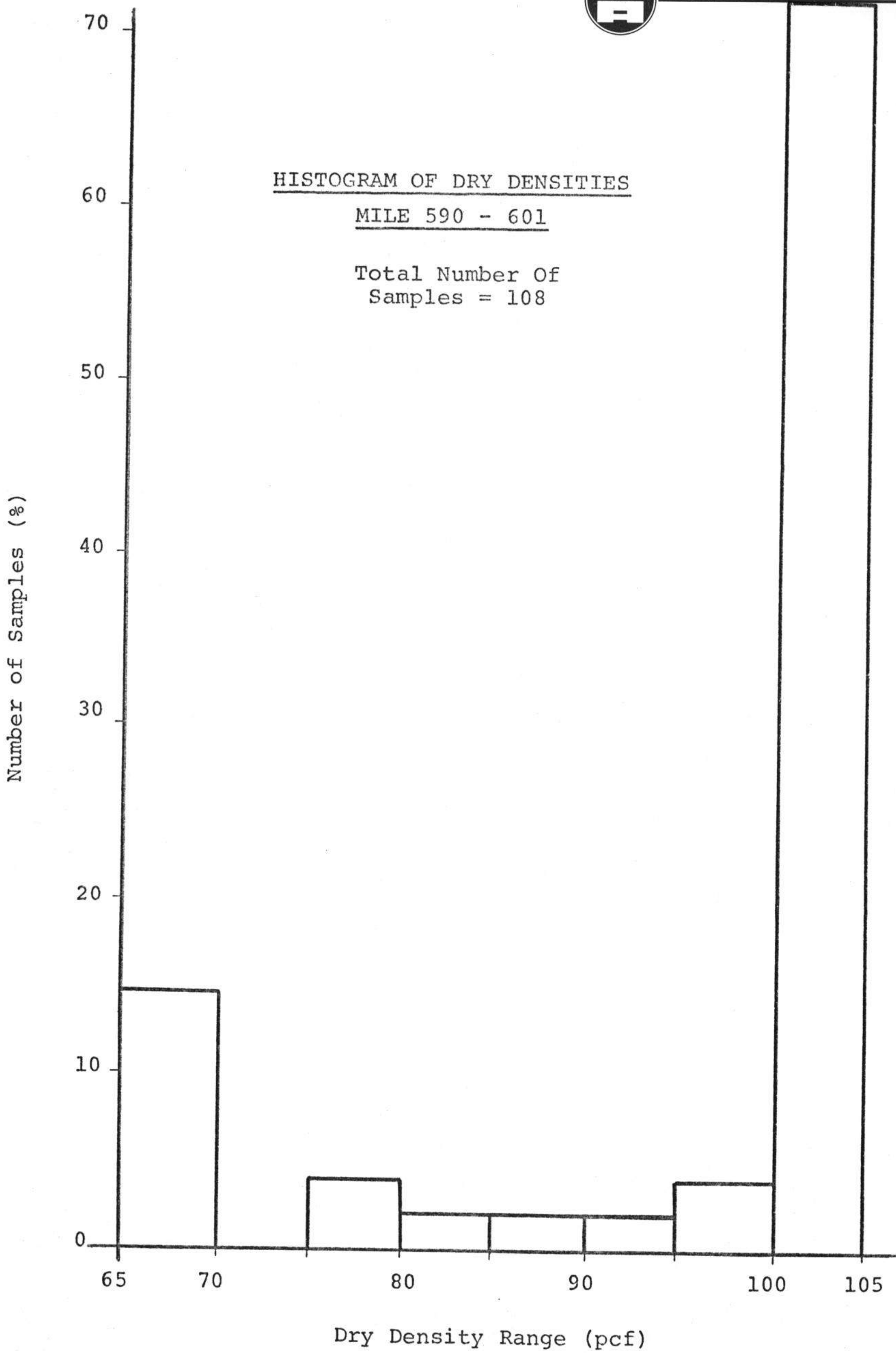
11.1.1 The first two miles of this section runs through the pass to the north of Bear Rock. (See Photograph 9) Drainage is generally to the west with the main drainage channel being Jungle Ridge Creek. There is a fairly steep climb up to the pass and down on the northerly side but from thereon gradients are gentle and the topography is generally undulating. Part of this section runs along the top of Jungle Ridge. (See Photograph 14)

11.2 Soils

11.2.1 The soils in this section consist mainly of clay till with some sand. Moisture contents range from 5 to 20 percent and are generally below 15 percent (except for the surface soils). Bedrock was encountered at shallow depths (4 to 14 feet) in several test holes and is also exposed on the flank of Bear Rock (Photograph 10). Ice contents are also low with very little visible ice being reported. Dry densities are generally high as illustrated on Figure 9 (following page).

11.3 Borrow Material

11.3.1 The borrow pits in this section are numbered from 68 through 88. The borrow material in this section is till, mainly clay, with some sand reported. As the moisture contents are low we believe it would be feasible


HISTOGRAM OF DRY DENSITIES
MILE 590 - 601
Total Number Of Samples = 108
Number of Samples (%)
70
60
50
40
30
20
10
0
65
70
80
90
100
105
Dry Density Range (pcf)

to excavate this material in the summer. As the borrow material in the preceeding section is not so suitable for road construction, we would also advise that borrow material for that section be obtained from this section. See Photographs 21 and 23, Appendix A.

11.4 Sections of Potential Excessive Settlement

11.4.1 No areas of excessive settlement of the embankment are expected in this section. As mentioned above in the section "Soils" ice contents in the till are generally low. Any small settlements in the embankment can be remedied as part of the normal maintenance program during the first few years following construction.

11.5 Stability Problems on Side Hills

11.5.1 It is possible that part of the embankment in the pass will be on side hill locations with a fairly low side gradient. We do not anticipate any problems with the stability at the embankment per se in the sections however, some problems with erosion due to drainage may occur.

11.6 Stability Problems in Cuts

11.6.1 Three cuts are possible in this section. See Appendix B for a summary of the relevant data.

11.7 Liquefaction and Pumping Problems

11.7.1 Liquefaction and pumping is not expected to be a problem in this section.

11.8 Erosion

11.8.1 Problems with erosion are not expected to be serious in this section.

11.9 Seepage

11.9.1 Seepage of subsurface water was observed at approximately mile 591.1 in the vicinity of Test Hole 574. (Photograph 11) Seepage could possibly be a problem in areas of side hill location especially on south facing slopes where the active layer is comparatively deep. However, no other examples of seepage were found during the geotechnical investigation.

11.10 Construction Methods and Scheduling

11.10.1 We believe that most of the borrow pits in this section could be excavated in either the summer or the winter. During a summer operation, some difficulties with the operation of heavy equipment in the borrow pits may be experienced while stripping the near-surface soils which have relatively high water contents. It would undoubtedly be easier to excavate the borrow material during the winter. However, once the high water content soils have been stripped from borrow areas, the excavation and placement of the underlying soils with lower water contents would be easier in the summer. An ideal solution would be to strip the waste material from borrow areas in the late winter and then excavate the more desirable material in the summer.

11.11 Further Laboratory Testing

11.11.1 Further laboratory testing of soils in this area is not considered to be justifiable.

12. MILE 601 TO MILE 603

12.1.1 This section is generally level but is quite well drained with most of the drainage being into Jungle Ridge Creek. (See Photograph 13 for a typical view of the terrain.)

12.2 Soils

12.2.1 The soils consist mainly of clay till with some silt and sand. Moisture contents generally range between 10 and 20 percent and ice contents are low except at the surface. (See Photographs 26, 27 and 28, Appendix A)

12.3 Borrow Material

12.3.1 The borrow material in this section consists of clay till with fairly low moisture and ice contents. Because of the low moisture contents we suggest that winter construction of an embankment is feasible.

12.4 Sections of Potential Excessive Settlement

12.4.1 Because of the low ice contents in these soils, we do not expect any problems with settlement due to thawing of ground ice.

12.5 Stability Problems on Side Hills

12.5.1 No side hill locations are in this section.

12.6 Stability Problems in Cuts

12.6.1 No cuts are expected in this section.

12.7 Liquefaction and Pumping Problems

12.7.1 No liquefaction and pumping problems are expected in this section.

12.8 Erosion

12.8.1 No unsual problems with erosion are expected in this section. Clay soils are generally resistance to erosion except on steep slopes which will not occur in this section.

12.9 Seepage

12.9.1 No problems with seepage of ground water are expected in this section.

12.10 Construction Methods and Scheduling

12.10.1 We believe that most of the borrow pits in this section could be excavated in either the summer or the winter. During a summer program, some difficulties with operation of heavy equipment in the borrow pits may be experienced while stripping the near-surface soils which have relatively high water contents. It would undoubtedly be easier to excavate the borrow material during the winter. However, once the high water content soils have been stripped from borrow areas, the excavation and placement at the underlying soils with lower water contents would be easier in the summer. An ideal solution would to strip the waste material from borrow areas in the late winter and then excavate the more desirable material in the summer.

12.11 Further Laboratory Testing

12.11.1 Further testing of the soil materials in this section is not justifiable.

13. MILE 603 TO MILE 617

12.1.1 In this section, the alignment is generally perpendicular to the drainage. The principle creeks are Nota, Vermilion, Prohibition, Christine and Helava Creek. The topography is gently undulating with the only sharp breaks being at the banks of creeks (see Photographs 16 and 17). Drainage is generally good.

13.2 Soils

13.2.1 The soils in this section consist of a layer of clay till (6 to 15 feet in depth) overlying clay shale. The till consists of silty clay, sometimes sandy, with rust stains and coal pieces scattered through it. Pebbles and stones are very common. Water contents are generally within the range of 10 to 20 percent and ice contents are low.

13.2.2 On top of the till there is very often a thick covering of surface soils consisting of peat, organic clay and silty clay. The thickness of the surface soils varies from a few inches to 4 feet with the average thickness being less than 2 feet. Water and ice contents are generally high in the surface soils although they tend to dry out very rapidly in the summer.

13.2.3 The bedrock, which was encountered at shallow depths, consists of clay shale of high plasticity. Water contents are low, generally less than 10 percent, and the ice was usually non-visible. (See Photographs 24, 25, 29, 30 and 31, Appendix A.)

13.3 Borrow Material

13.3.1 Borrow material also consists of clay overlying clay shale with fairly low moisture contents. Because the clay shale has characteristics which are very similar to the till, we suggest that the material could be treated in the same way.

13.4 Sections of Potential Excessive Settlement

13.4.1 Due to the low ice contents in the subgrade soils, problems with excessive settlement will not occur in this section.

13.5 Stability Problems on Side Hills

13.5.1 No problems on side hill locations will occur in this section.

13.6 Stability Problems in Cuts

13.6.1 Cuts are expected at the approaches to Nota Creek, Vermilion Creek, (on both banks) and also on the southerly approach to Prohibition Creek. We understand that it is intended to provide bridge crossings of these creeks. As each bridge site will form the subject of a separate report, we propose to deal with the problem of cutting into the river banks in those reports and not deal with these problems here except to summarize the data in Appendix B.

13.7 Liquefaction and Pumping Problems

13.7.1 No problems with liquefaction and pumping are expected in this section.

13.8 Erosion

13.81 Erosion problems are not expected to be serious in this section except at creek crossings. Due to the intensity of run off during the short spring, precautions should be taken where any embankment is constructed in the flood plain of any creek. As suitable riprap is unobtainable in this area, resort may have to be taken to using sand bags. Such protection will be necessary at the toes of embankments where a bridge is provided.

13.8.2 Where culverts are installed, it will be necessary to pay particular attention to compaction of the embankment material around the culvert.

13.9 Seepage

13.9.1 No problems with seepage of ground water are expected in this section.

13.10 Construction Methods and Scheduling

13.10.1 We believe the soils in this area can be excavated and placed in either the summer or the winter with summer construction being preferred for economic reasons.

13.11 Further Laboratory Testing

13.11.1 Further laboratory testing of soils in this section is not believed to be justified.

14. MILE 617 TO MILE 622

14.1.1 This section covers the area from ½ mile north from Helava Creek to the vicinity of borrow area 121 on the north side of Canyon Creek. In this section the alignment crosses Francis Creek and Canyon Creek. Drainage is generally good and is perpendicular to the alignment except for the last mile of this section when the drainage is generally parallel with the alignment.

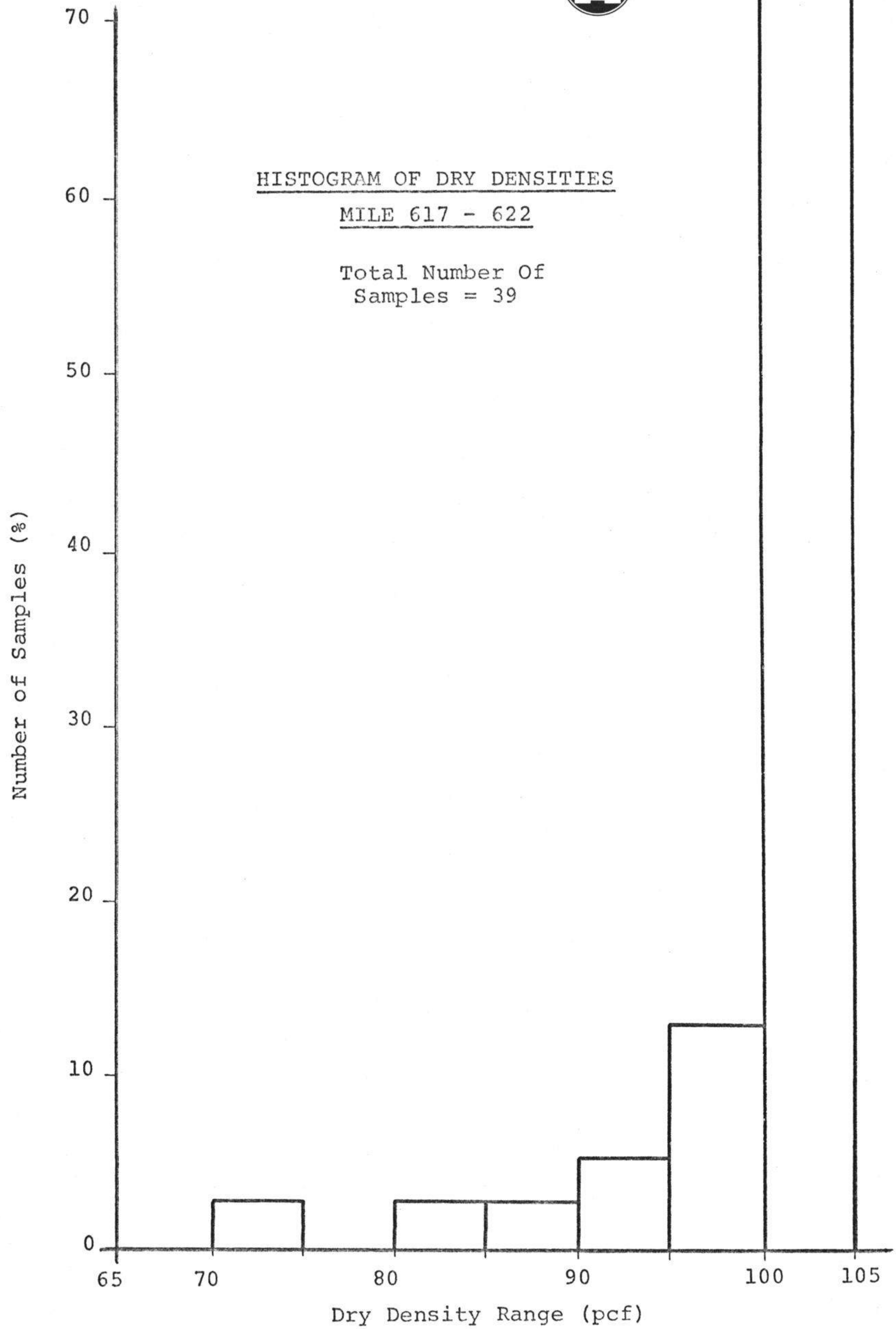
14.2 Soils

14.2.1 The soils in this section consist of clay, silt, sand and gravel which are interbedded. Gravel and sand predominate near creeks. Water contents are highly variable with very high water contents found in the soils near the surface.

14.2.2 Figure 10 (following page) is a histogram showing the distribution of dry density versus the number of samples for 39 core samples taken in this section. It will be observed that over 70 percent of the samples had dry densities in excess of 100 lbs./cu. ft. Most of this high density material was obtained in borrow pits 119 and 120 and can not be considered typical of the soils in this section.

14.3 Borrow Material

14.3.1 The borrow areas in this section are numbered


HISTOGRAM OF DRY DENSITIES
MILE 617 - 622
Total Number Of Samples = 39
Number of Samples (%)
70
60
50
40
30
20
10
0
65
70
80
90
100
105
Dry Density Range (pcf)

110 through 120. Of these eleven borrow areas, numbers 112 through 118 are unsuitable mainly due to the high water contents.

14.3.2 Borrow areas 110 and 111 (mile 617) will provide sufficient material for several miles but the upper material in each case would have to be wasted. Borrow areas 119 and 120 (mile 621) are both good sources of borrow with very little waste being necessary.

14.4 Sections of Potential Excessive Settlement

14.4.1 Water contents in the soils in this section are highly variable. Generally, very high water contents are only encountered in the top 5 feet of the subgrade. We expect excessive settlement of the subgrade soil to occur in small isolated sections so that settlement of the embankment due to thawing of the subgrade soils will be highly irregular. Settlements due to thawing ground ice are not expected to exceed one foot during the first five years following construction and the maximum of another foot in the following 15 years after that.

14.4.2 Because of the extreme variability in the ice content of the soils, it will be impossible to lay out the embankment profile to allow for possible settlement. The only feasible procedure would be to bring the embankment up to grade wherever necessary during routine embankment maintenance.

14.5 Stability Problems on Side Hills

14.5.1 No side hill locations are found in this section.

14.6 Stability Problems in Cuts

14.6.1 No cuts are expected at Francis Creek due to low banks. A cut is not recommended at Canyon Creek (see Appendix B).

14.7 Liquefaction and Pumping Problems

14.7.1 Some liquefaction and pumping problems may occur in this section where silt is found in the top 3 feet of the subgrade. As it will be relatively difficult to forecast accurately the precise locations of any such problems, we believe the best method of handling this problem is through routine maintenance programs.

14.8 Erosion

14.8.1 Erosion is quite possible in this section where the toe of the embankment is in silt. Precautions will have to be taken at the approaches to the creeks to ensure that eroded material is not carried into the stream.

14.9 Seepage

14.9.1 No problems with seepage of ground water are expected in this section.

14.10 Construction Methods and Scheduling

14.10.1 The work in this section could be carried out in either the summer or the winter. In the borrow areas there are high water contents in soils found on the surface. Difficulties may be experienced with heavy equipment attempting to clear waste material from these areas. Such material could be cleared most easily in the winter when it is frozen.

14.11 Further Laboratory Testing

14.11.1 Further laboratory testing of soils is not considered to be necessary for this section.

15. MILE 622 TO MILE 628

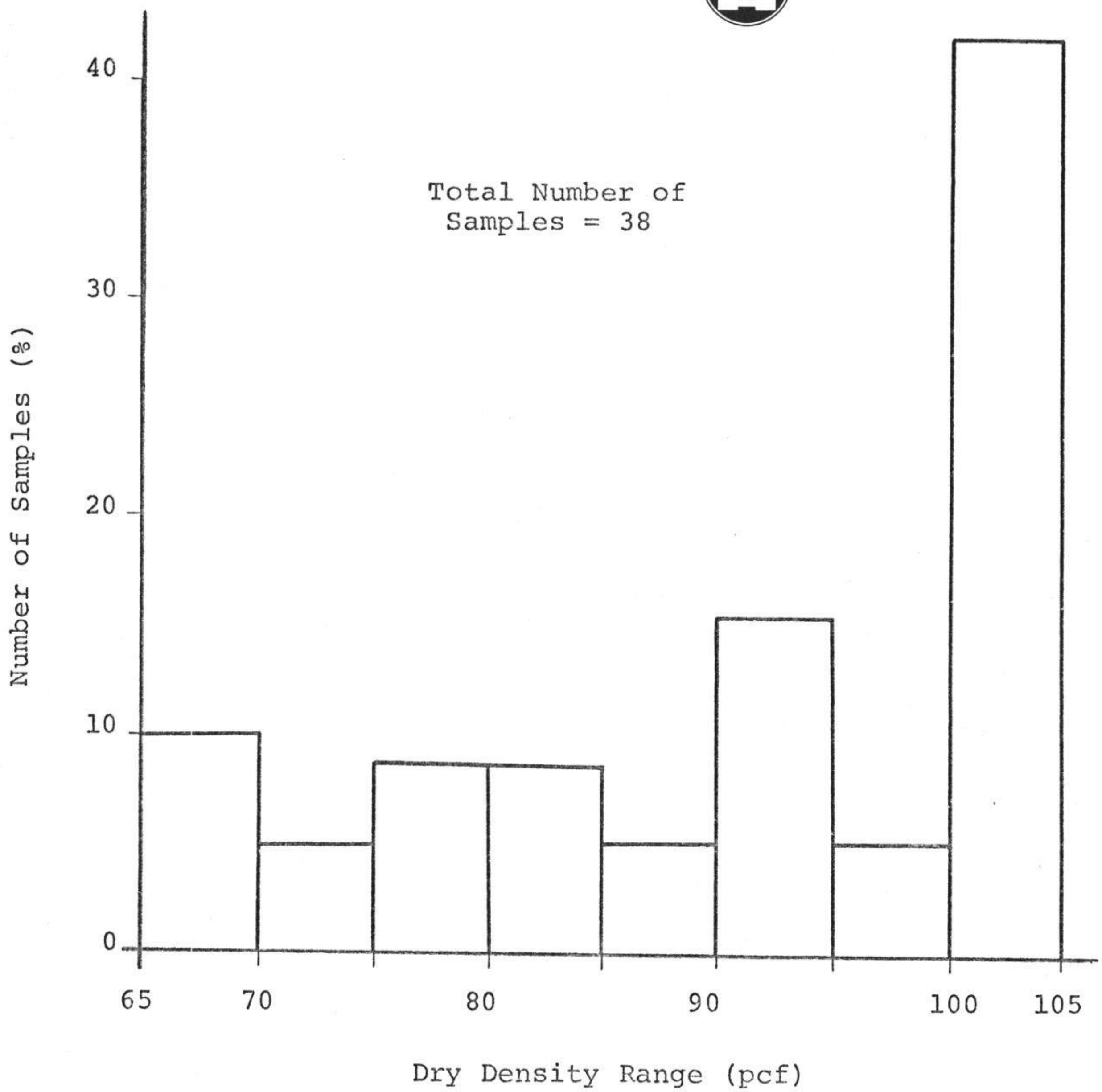
15.1.1 This section runs from the vicinity of borrow area 121 to the vicinity of borrow area 133. In this section the alignment climbs slightly to Hodgson Lake and then drops as Norman Wells is approached. Drainage is generally perpendicular to the alignment and is good.

15.2 Soils

15.2.1 The soils in this section consist of clay till over shale with some deposits of sand and gravel being found. Water contents are fairly high in the surface soils but decrease rapidly with depth.

15.2.2 At Test Hole 1019 (Mile 626.4), seven feet of massive ground ice was encountered in the 13 to 20 foot interval. This test hole was drilled in a small basin, of approximately 100 feet diameter, on an esker or fan deposit. Two other test holes (969 and 970) were drilled close by but did not encounter massive ice. This massive ice deposit appears to be an isolated phenomenon. It is inevitable that this ice will thaw after the embankment has been in place for several years.

15.2.3 Figure 11, following page, is a histogram showing the distribution of dry density versus the number of core samples in this section. It will be observed that the distribution of dry density is fairly even within the range of 65 to 100 lbs./cu. ft. Forty percent



HISTOGRAM OF DRY DENSITIES

MILE 622-628

of the samples had dry densities in excess of 100 lbs./cu. ft. This histogram demonstrates the variablity of dry density, and consequently ice content, within the soils in this section. (See Photographs 32, 35 and 36, Appendix A).

15.3 Borrow Material

15.3.1 The borrow areas in this section are numbered 121 through 133. The material varies with most of the pits containing clay till and some pits containing sand and gravel. Borrow area 125 provides an excellent source of borrow in the form of sand and gravel with maximum water contents of about 15 percent. The estimated available quantity from this area is 200,000 yards. Other good sources are borrow areas 124 and 132. Borrow area 129 provides a good source of borrow and bedrock. The quantity available in this last pit exceeds 300,000 cu. yds. From the other borrow areas, some stripping and wastage of surface material will be necessary before the better material can be obtained.

15.3.2 Some eskers which lie a short distance to the northwest of borrow area 124 were not investigated because they were considered to be too far from the centerline for economical haul. However, it is certain that these eskers do contain large quantities of good borrow and their existance should be taken into account for future requirements.

15.4 Sections of Potential Excessive Settlement

15.4.1 Settlement of the embankment can be anticipated where there are silt soils in the top of the subgrade. It is not expected that eventual settlement in such areas would exceed 2 feet as a maximum in 20 years.

15.4.2 As mentioned above, massive ground ice was encountered in Test Hole 1019 at Mile 526.4. It is probable that there will be a cut through this series of ridges with the result that the final grade may be only 2 or 3 feet above the top of the massive ground ice. In such case, it will be imperative that the ground ice should be excavated and removed and the resulting void backfilled with suitable material.

15.4.3 In the event that a cut is not used at Mile 526.4, it will be permissable to leave the massive ground ice in place and to allow it to thaw. The thawing of this ground ice will take many years and the settlement problems associated with the thawing can be taken care of by routine maintenance.

15.5 Stability Problems on Side Hills

15.5.1 No stability problems on side hill locations are expected in this section.

15.6 Stability Problems in Cuts

15.6.1 The only location for a possible cut in this section is at Mile 526.4. The existance of massive ground ice at this location has been mentioned above. If a cut is made through this ridge, it will be necessary to excavate the massive ground ice and backfill the void as mentioned above.

15.6.2 No problems with the stability of the back-slopes in a cut at this location are anticipated. The ice contents in the soil are quite low and the depth of cut would be relatively small (no more than 15 feet).

15.7 Liquefaction and Pumping Problems

15.7.1 Pumping problems may be encountered where there are deep deposits of silts with high water contents in the subgrade. We do not think it would be economical to remove such soils prior to placement of the embankment. We would suggest leaving them in place and handling any pumping problems as they occur through routine maintenance as the number of places where such problems may occur is quite limited.

15.8 Erosion

15.8.1 Erosion will occur where there are silt or fine sand soils in the subgrade and where the surface vegetation has been removed. The comments in previous sections on erosion will apply here.

15.9 Seepage

15.9.1 No problems with seepage are expected in this section.

15.10 Construction Methods and Scheduling

15.10.1 The work in this section could be carried out in either the summer or the winter. Surface soils with high water contents could best be cleared from the borrow pits in the winter. Excavation and placing of selected borrow could be done in either the summer or the winter with a summer operation probably being more economical.

15.11 Further Laboratory Testing

15.11.1 Further laboratory testing of soils in this section is not considered necessary.

16. MILE 628 TO MILE 635

16.1.1 NOTE - There is a chainage equation in this section. Mile 629.12 Back = Mile 626.47 Ahead. There is, therefore, duplication of mile post numbers 627, 628 and 629.

16.1.2 This section covers the alignment between the vicinity of borrow area 134 and Bosworth Creek. The topography in this area is gently sloping at right angles to the alignment. Drainage is southerly towards the Mackenzie River. The country is fairly level in the direction of the alignment with no major gradient changes.

16.2 Soils

16.2.1 The soils in this section are mixed and consist of sand, clay, gravel and silt interbedded. Siltstone was occasionally encountered in the deeper holes. Water contents are occasionally high in the surface holes but decrease markedly with depth. Ice contents are generally low.

16.3 Borrow Material

16.3.1 The borrow areas in this section are numbered 134 through 146. Most of the borrow areas investigated are useable and the amount of borrow available is more than sufficient for embankment requirements. (Borrow area 134 contains excellent sand and gravel. Access in the summer may not be possible due to muskeg.) The rock exhibits poor resistance to freeze-thaw action.

16.3.2 The soils in the borrow areas consist of sand, shale, clay and some silt with small amounts of gravel occasionally found. Some wastage of surface soils would be necessary from some of the borrow areas but there are other potential borrow areas which have very little waste material and it may not be necessary to use the less desirable pits.

16.3.3 There is an existing rock quarry at Mile 629 adjacent to borrow area 135. This existing quarry is marked on mosaic sheet 52 as Camp 4. The quarry has been used for some years and will yield large quantites of rock suitable for embankment and embankment capping but not for riprap.

16.4 Sections of Potential Excessive Settlement

16.4.1 No severe problems with excessive settlement due to thawing of ground ice are expected in this section.

16.5 Stability Problems on Side Hills

16.5.1 No problems with side hill cuts are expected in this section.

16.6 Stability Problems in Cuts

16.6.1 No cuts are recommended in this section.

16.7 Liquefaction and Pumping Problems

16.7.1 Some problems with liquefaction and pumping may be encountered where there are silt soils in the top of the subgrade. As in previous sections, we do not recommend attempting to remove such soils prior to placement of the embankment but rather to take care of such problems as part of routine maintenance.

16.8 Erosion

16.8.1 No serious problems with erosion of soils are anticipated in this section. Care should be taken where silt and sand soils will be found in the top of the subgrade.

16.9 Seepage

16.9.1 No problems with seepage of ground water are expected in this section.

16.10 Construction Methods and Scheduling

16.10.1 Construction in this section could take place in either the summer or winter. Stripping of waste materials from borrow areas would best be done during the winter. Also, at this time of the year, rock could be quarried and used for embankment material and could be placed in the winter. An alternative would be to place soil borrow in the winter and cap this material with broken rock.

16.11 Further Laboratory Testing

16.11.1 Further laboratory testing of soils in this section is not considered to be necessary.

17. PROPOSED TEST SECTION

17.1.1 Difficulties have been encountered in constructing highway embankments in permafrost conditions at other locations in the Northwest Territories. Also, the number of contractors who have had experience at such work is limited. We suggest that there would be great benefits to be derived from the construction of a short test section of embankment using as many different materials as possible in a location which is as close as possible to being representative of the conditions to be encountered in this area. The test section would serve to gain experience in various construction techniques and methods and of the behaviour of various types of soils when thawing. Preferably, the construction of a test section of embankment should meet the following conditions:

1. It should use as many different soil types as possible.
2. Construction should take place under both summer and winter conditions.
3. The location should be so chosen that the test section will form part of the permanent highway.
4. The location should be sufficiently close to either Norman Wells or Fort Norman to facilitiate mobilization and demobilization of men and equipment.

5. Conditions during construction should simulate, as far as possible, conditions which would actually be encountered on a normal construction project.

17.1.2 One suitable location would be approximately 12 miles southerly from Fort Norman at Mile 571 where clay, silt and sand borrow is available. Access could be along the line of the CNT pole line which would therefore avoid the necessitity for construction of access trails.

17.1.3 We do not believe there is any necessity to construct test sections over muskeg as it has been our experience that such areas do not constitute a problem which is peculiar to permafrost areas. Furthermore, the Department's own forces have had considerable experience in construction over muskeg.

17.1.4 In summary, we would recommend that the test section be constructed at the site mentioned above approximately 12 miles southerly from Fort Norman (Mile 571). Construction should commence in September and can be completed by Christmas. We believe that the section of embankment should be at least half a mile in length and preferably more than one mile in length. Available borrow and the construction techniques which could be used in this area are discussed in other sections of this report.

APPENDIX A

Photographs

Photograph 1: Failing 1000 drill rig mounted on a Flextrac-Nodwell tractor. Note the covered "sloop" which was towed behind the drill rig. This sloop contained a work bench, writing table, extruder, propane heater and a small electric generator. An open deck at the back of the sloop was used for transporting samples and spare fuel.

Photograph 2: The field laboratory. On the right can be seen an electronic Mettler scale. Three electric ovens were kept beneath the benches in order to conserve space. The paper cups and aluminum bread pans contain samples which are ready for drying in the oven.

Photograph 3: Moving camp. The units in this photograph are the generator house (which cannot be clearly seen), the laboratory and utility trailer and the dining trailer at the rear. These units were carried on specially designed wide ski sledges.

Photograph 4: Camp at mile 622. Bunkhouses are at the right. The utility trailer, at the left has been removed from its runners.

Photograph 5: Typical terrain between Norman Wells and the Great Bear River. Notice the sparse growth of spruce at the bottom of the photograph. This is quite typical of many areas in the region.

Photograph 6: Looking south across the Great Bear River from Test Hole 552.

Photograph 7: Looking northerly to Test Hole 459 on the north side of the Great Bear River.

Photograph 8: Looking southerly towards Test Hole 460 at approximately mile 583.

Photograph 9: A view showing the height of land at the top of the pass to the north of Bear Rock.

Photograph 10: Rock exposure on the flank of Bear Rock at approximately mile 587. The field book gives the scale.

Photograph 11: Approximate location mile 591 (near Test Hole 574). Note the seepage which is causing icing on the trail. Note the stunted spruce and the swamp birch in the background. This vegetation is quite typical of the area.

Photograph 12: Near Test Hole 737 at approximately mile 596. The vegetation here is black spruce which is quite typical of large sections of the alignment between Big Smith Creek and Norman Wells.

Photograph 13: Looking southerly from Test Hole 677 at approximately mile 601. The actual centerline of the road is approximately 50 feet to the right of the CNT pole line. The CNT land line was placed on large tripods in this area because of permafrost.

Photograph 14: View from Jungle Ridge looking easterly at approximately mile 602. Observe the flat terrain which, combined with permafrost, causes poor drainage.

Photograph 15: Creek crossing at Jungle Ridge Creek at approximately mile 604 looking southerly.

Photograph 16: From the center of Nota Creek looking northerly towards Test Hole 723. Mileage is approximately 605.

Photograph 17: From the center of Vermilion Creek looking southerly. Approximate mileage is 607.

Photograph 18: At Test Hole 803 looking northerly. Approximate mileage is 609.

Photograph 19: Cores from Test Hole 503. At the bottom of the photograph can be seen organic clay with high ice content. The center sample (marked D3, D4) is clay till with quite low water content. The top sample (marked D6, D7) is frozen sand.

Photograph 20: Cores taken in Test Hole 507. On the left is a sample of organic clay with high ice content and on the right is a sample of clay till. In this case the clay till has a very high ice content.

Photograph 21: Core samples from Test Hole 569. The material in the top half of the photograph is limestone.

Photograph 22: Clay till cores from Test Hole 612. Observe the ice banding in the lower sample in this photograph.

Photograph 23: A sample of clay till, sandy, from Test Hole 616 at a depth of 11 feet. The water content is about 12 percent. Note that there is no visible ice in this sample.

Photograph 24: A sample of clay till, silty-sandy, water content 9 percent, from Test Hole 834 at a depth of 11 to 14 feet. Note there is no visible ice in this sample.

Photograph 25: A sample of clay-shale from Test Hole 843. Depth interval is 6.5 to 7 feet. This material had silt and sandstone partings. Note there is no visible ice.

Photograph 26: A sample of organic silt from Test Hole 885 at a depth interval of 1.5 to 2.0 feet. Note the organic material.

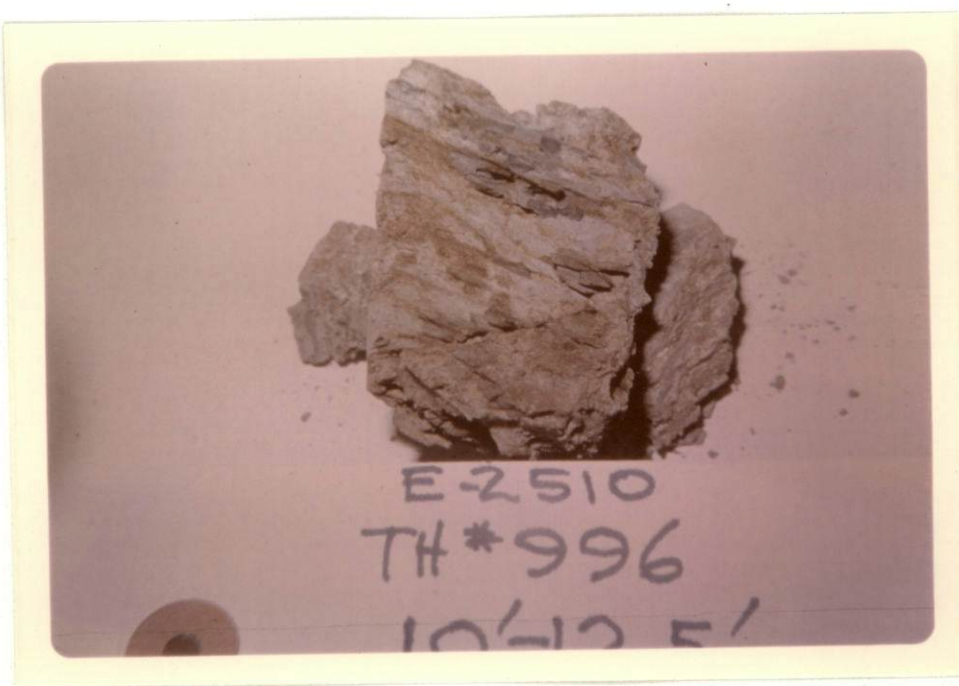
Photograph 27: A sample of clay till from Test Hole 885 at a depth interval of 15 to 15.5 feet. This material contains some pebbles. Water content was 14 percent.

Photograph 28: A sample of varved clay from Test Hole 886. This material was laid down in still water and the light and dark bands are alternating layers of silt and clay. Water content of this material was 28 percent.

Photograph 29: A sample of silty-clay, medium plasticity, from Test Hole 916. Depth interval is 5.2 to 6.0 feet. Water content was 20 percent.

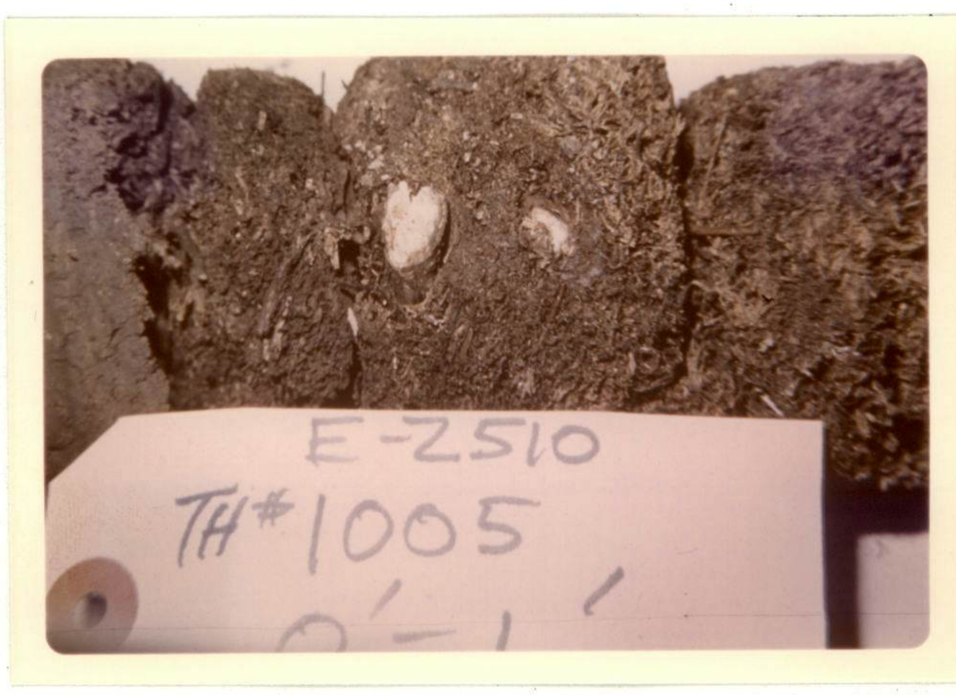
Photograph 30: A sample of silty-clay, medium plasticity, from Test Hole 916. Note the pebbles within this material. Water content was 25 percent.

Photograph 31: A sample of weathered shale from Test Hole 916.



Photograph 32: A sample of clay till, medium plasticity, from Test Hole 996. There was no visible ice in this material and the water content was quite low.

Photograph 33: A sample taken with a Shelby tube from the surface to one foot depth. The surface moss is at the right of the sample and clay is at the left. Between the moss and the clay is peat.



Photograph 34: A close-up of the sample shown in Photograph 33. The peat is category No. 15 using the Radforth system.

Photograph 35: A sample of clay from Test Hole 1022, depth interval 5 to 7 feet. This photograph was taken after the sample had started to thaw in the laboratory. The ice type and content was classified as Vs at 60 percent. The sample is lying on its side and the ice lenses would have been horizontal in the in situ position.

Photograph 36: A close-up of the sample shown in Photograph 35. This photograph is approximately full size. Notice the ice lenses and the pebbles within the material.

APPENDIX B

Data on Borrow Areas and Cuts

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
1	41	Sand, silt, clay	25 +	3,000,000	Water (ice) contents generally too high.	582	900
2	41	Sand, silt, clay	25 +	1,000,000	Water (ice) contents generally too high.	581	500
3	41	Sand, silt, clay	25 +	500,000	Water (ice) contents generally too high.	581	1,800
4	41	Sand, silt, clay	25 +	1,000,000	Water (ice) contents generally too high.	580	500
5	40	Mainly sand	25 +	2,000,000	Sand could be used but careful selection would be necessary.	579	500
6	40	Silt, clay	25 - 40	1,000,000 +	Water (ice) contents too high for borrow.	579	500
7	40	Clay, silt, sand	25 - 40	1,000,000 +	Water (ice) contents too high for borrow.	578	500
8	40	Silt, clay	25 - 40	400,000	Water (ice) contents too high for borrow.	577	500
9	40	Silt, clay	25 - 40	300,000	Water (ice) contents too high for borrow.	577	500
10	40	Silt, clay	25 - 40	1,000,000	Some clay could be used but selection in field would be extremely difficult.	576	500
11	39	Silt, clay	25 - 30	1,000,000 +	Water (ice) contents too high for borrow.	575	1,300
12	39	Clay, silt	25 - 45	1,000,000 +	Water (ice) contents too high for borrow.	574	500

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
13	39	Clay, silt	25 - 45	1,000,000	Water (ice) contents too high for borrow.	573	500
14	38	Clay, silt	25 +	1,000,000	Water (ice) contents too high for borrow.	572	900
15	38	Clay, silt, sand	25 +	1,000,000	Water (ice) contents too high for borrow.	571	1,000
17	38	Sand, fine	20 - 30	1,000,000 +	Some silt. Suitable for borrow.	569	1,700
18	37	Sand, fine	25	400,000	Suitable for borrow.	565	500
19	37	Sand, fine	25	1,000,000	Low-lying area, otherwise suitable for borrow.	564	500
20	37	Sand, fine	25	1,000,000	Suitable for borrow.	563	1,000
22	36A	Sand, fine	10 - 25	1,000,000	Depth to P/frost = 8 - 22 ft. Good source of borrow.	560	4,000
23	35A	Sand, fine	20	1,500,000	Good source of borrow.	557	500
25	35A	Sand, fine	20 - 25	4,000,000	Good source of borrow.	556	800
26	35A	Sand, fine	25	4,000,000	Good source of borrow.	556	500
27	36A	Sand, fine	25	4,000,000	Good source of borrow.	560	2,800
28	35	Sand, fine	5 - 20	600,000	Good source of borrow.	553	500
29	36A	Sand, fine	20 - 25	1,000,000 +	Good source of borrow.	560	1,100
30	37	Sand, fine	20 - 25	600,000	Good source of borrow.	564	500
31	36A	Sand, fine	20 - 25	1,000,000	Good source of borrow.	562	500
32	34	Sand, fine	25	800,000	Good source of borrow.	552	500

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
33	34	Sand, fine	25	500,000	Good source of borrow.	551	500
34	34	Sand, clay, silt			Poor source of borrow.	550	500
35	34	Sand, fine	25	370,000	Some selection of material would be necessary.	549	500
36	34	Sand, fine	15 - 25	500,000	Good source of borrow.	547	500
37	33	Sand, fine, some silt	15 - 25	400,000	Fair source of borrow.	545	500
38	35	Sand, fine	5 - 15	1,000,000	Good source of borrow.	553	500
39	38	Sand, fine	25 - 30	300,000	Fair source of borrow.	570	4,700
40	38	Sand, fine	25 - 30	600,000	Fair source of borrow.	570	2,100

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
51	41A	Sand, silt, clay	10 - 25	400, 000	Suitable for borrow, some selection and wastage will be necessary.	583	500
52	41A	Clay, clay-shale, till, shale	10 - 20+	400,000	Suitable for borrow, some selection and wastage will be necessary.	584	500
53	41A	Clay	10 - 30	400,000	Poor borrow material.	584	1,000
54	41A	Silt, sand, clay	10 - 20+	400,000	Suitable for borrow, some selection necessary.	585	500
55	41A	Clay, silt, sand	10 - 25+	300,000	Suitable for borrow, some selection necessary.	585	500
56	41A	Silt, gravel, sand clay	10 - 30	350,000	Suitable for borrow, some selection will be necessary.	585	500
57	41A	Sand, clay	10 - 40	300,000	Suitable for borrow, some selection will be necessary.	585	3,200
58	42	Clay, sand	15 - 20+	300,000	Upper material has high water content. Lower material suitable for borrow.	586	500
59	42	Clay, sand	10 - 25	400,000	Suitable for borrow, some selection will be necessary.	586	500
60	42	Clay	10 - 60	250,000	Upper material contains high ice volumes. Generally unsuitable for borrow.	586	500

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
61	42	Clay	10 - 30	250,000	Upper material unsuitable. Lower material is suitable for borrow.	587	500
62	42	Clay	10 - 30	500,000	Generally suitable for borrow. Some selection may be necessary.	587	500
63	42	Clay, sand	5 - 20	250,000	Generally suitable for borrow. Some selection may be necessary.	587	500
64	42	Clay (some gravel)	10 - 30	400,000	Mainly suitable for borrow. Some selection will be necessary.	587	500
65	43	Clay	10 - 25	400,000	Mainly suitable for borrow. Some selection will be necessary.	588	600
66	43	Clay		500,000	Mainly suitable for borrow. Some selection will be necessary.	588	2,000
67	43	Clay	10 - 40	250,000	Mainly suitable for borrow. Some selection will be necessary.	589	500
68	43	Clay	10 - 20	400,000	Suitable for borrow.	589	500
69	43	Clay, limestone	2 - 30	min.400,000	Good source of bedrock.	590	500
70	43	Clay, limestone	5 - 15	600,000 min.	Good source of bedrock. Overlying till also suitable for borrow.	591	500

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
71	43	Sand, clay	5 - 25	400,000	Good source of borrow.	591	500
72	43	Clay, gravel, sand	5 - 20	600,000	Good source of borrow.	591	500
73	44	Clay	10 - 20	400,000	Good source of borrow. Some selection will be necessary.	592	500
74	44	Clay	10 - 20	400,000	Good source of borrow.	593	1,600
75	44	Clay		400,000	Good source of borrow. Some selection may be necessary.	593	500
76	44	Clay	10 - 25	500,000	Generally good borrow material. Some selection will be necessary.	594	500
77	44	Clay	5 - 25	400,000	Generally good borrow material. Some selection will be necessary.	594	500
78	44	Clay	10 - 40	400,000	Generally good borrow material. Some selection will be necessary.	594	500
79	44	Clay	10 - 30	500,000	Generally good borrow material. Some selection will be necessary.	595	500
80	44	Clay	5 - 30	500,000	Generally good borrow material. Some selection will be necessary.	595	500
81	44	Clay (some sand)	5 - 35	500,000	Generally good borrow material. Some selection will be necessary.	596	500

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
82	44	Clay	10 - 40	400,000	Generally suitable for borrow. Some selection and waste will be necessary.	596	500
83	44	Clay, limestone (some shale)	5 - 40	1,000,000	Good source of rock. Some over-burden could also be used as borrow.	596	900
84	45	Clay, shale	3 - 45	1,000,000	Good source of borrow. Some wastage of surface material will be necessary.	597	500
85	45	Clay	5 - 40	350,000	Good source of borrow. Some wastage of surface material will be necessary.	597	500
86		Clay	7 - 45	400,000	Good source of borrow. Some wastage of surface material will be necessary.	599	500
87	45	Clay	10 - 60	400,000	Good source of borrow. Some wastage of surface material will be necessary.	600	500
88	45	Clay	10 - 40	350,000	Good source of borrow. Some wastage of surface material will be necessary.	600	500
147	45	Clay, shale	5 - 60	400,000	Good source of borrow. Some wastage of surface material will be necessary.	600	500

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
89	46	Clay, shale	10 - 40	500,000	Not suitable for borrow. Water contents too high.	602	500
90	46	Clay	15 - 60	500,000	Poor material for borrow. Selection would be too difficult.	601	500
91	47	Clay, shale	5 - 40	300,000	Suitable for borrow but considerable quantities would be wasted and selection would be difficult.	603	500
92	47	Clay, shale	5 - 40	250,000	Suitable for borrow but considerable quantities would be wasted and selection would be difficult.	604	500
93	47	Clay, shale	5 - 20	500,000	Good source of borrow. Very little waste will be required.	604	1,200
94	47	Clay, shale	5 - 80	250,000	Unsuitable for borrow. Too much waste would be required.	604	500
95	47	Clay	5 - 50	400,000	Unsuitable for borrow. Too much waste.	605	500
96	47	Clay, shale	5 - 25	600,000	Generally good source of borrow. Some selection and waste will be necessary.	606	500
97	48	Clay, shale	2 - 50	350,000	Generally good borrow material. Some wastage of surface material would be necessary.	607	500

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
98	48	Clay, shale	10 - 40	300,000	Generally good borrow material. Some wastage of surface material would be necessary.	608	500
99	48	Clay, shale	5 - 40	600,000	Generally good borrow material. Some wastage of surface material would be necessary.	609	900
100	48	Clay, shale	10 - 30	500,000	Generally good borrow material. Some wastage of surface material would be necessary.	610	1,100
101	48	Clay, shale	5 - 40	500,000	Generally good borrow material. Some wastage of surface material would be necessary.	611	800
102	49	Clay, sand, gravel	5 - 35	300,000	Generally good borrow material. Some wastage of surface material would be necessary.	612	500
103	49	Clay, shale	10 - 25	400,000	Generally good borrow material. Some wastage of surface material would be necessary.	612	500
104	49	Clay, shale	10 - 30	300,000	Generally good borrow material. Some wastage of surface material would be necessary.	614	1,000
105	49	Clay, shale	10 - 30	350,000	Generally good borrow material. Some wastage of surface material would be necessary.	614	500

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
106	49	Clay	5 - 20	250,000	Generally good borrow material. Some wastage of surface material would be necessary.	615	500
107	49	Silt, clay	10 - 50		Not suitable for borrow. Water contents too high.	615	500
108	49	Sand, clay	10 - 30+		Not suitable for borrow. Water contents too high.	615	500
109	49	Clay, sand	5 - 15	250,000	Good source of borrow.	616	500
110	49	Silt, clay, sand	5 - 30+	300,000	Upper material would be wasted due to high water content. Lower material good source of borrow.	617	500
111	49	Sand, silt, gravel, clay	5 - 45	350,000	Upper material would be wasted. Lower material good source of borrow.	617	500
112	50	Sand, gravel, silt	10 - 40		Not suitable for borrow. Water contents too high.	617	800
113	50	Clay, mixed	8 - 55		Some material would be suitable but selection of good material would not be practical.	618	500
114	50	Clay, silt, shale sand	10 - 60		Waste material would form too high a ratio to suitable borrow. This pit not suitable.	618	500

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
115	50	Clay, silt, gravel	10 - 40+		Waste material would form too high a ratio to suitable borrow. This pit not suitable.	619	500
116	50	Clay, silt, sand	10 - 40		Waste material would form too high a ratio to suitable borrow. This pit not suitable.	619	500
117	50	Clay, sand	5 - 40		Waste material would form too high a ratio to suitable borrow. This pit not suitable.	620	500
118	51	Clay, silt, gravel	5 - 40		Waste material would form too high a proportion of this pit. Not suitable.	620	500
119	51	Gravel, silt, clay sand	5 - 25	250,000	Good source of borrow.	621	500
120	51	Clay, silt, gravel	8 - 35	100,000	Good source of borrow. Some waste will be necessary.	621	500
121	51	Sand	5 - 25	150,000	Good source of borrow. Some waste will be necessary.	621	700
122	51	Clay	10 - 25	150,000	Good source of borrow. Some waste will be necessary.	621	500
123	51	Clay	5 - 25	100,000	Good source of borrow.	622	500

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
124	51	Sand	5 - 8	20,000	Good source of borrow.	622	500
125	51	Sand, gravel	5 - 15	200,000	Excellent source of borrow.	622	500
126	51A	Clay, shale, sand	8 - 40	150,000	Good source of borrow. Some waste will be necessary.	623	500
127	51A	Clay, shale	10 - 60		Water content too high. This pit unsuitable.	624	500
128	51A	Clay, shale	5 - 30	160,000	Lower material is good borrow. Upper material would be wasted.	624	500
129	51A	Gravel, sandstone, shale, clay	5 - 30	300,000+	Good source of borrow and rock. Some till overburden would be wasted.	625	500
130	51A	Clay	5 - 45	200,000	Some wastage would be necessary otherwise a good borrow source.	625	500
131	51A	Clay	5 - 25	300,000	Some wastage would be necessary otherwise a good borrow source.	626	500
132	52	Mixed	5 - 20	200,000	Good source of borrow.	627	500
133	52	Silt, clay	5 - 30	200,000	Fairly good source of borrow but selection may be difficult due to high water contents.	627	500

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
134	52	Sand, shale	5 - 15	200,000	Good source of borrow.	627	1,500
135	52	Sand, clay	10 - 20	300,000	Good source of borrow. Some waste will be necessary.	628	500
136	52	Clay, sand	5 - 18	300,000	Good source of borrow. Some wastage of surface soil will be necessary.	626	500
137	52	Clay	5 - 20	200,000	Good source of borrow. Some wastage of surface soil will be necessary.	626	500
138	52	Silt, clay	8 - 45		Too much waste in proportion to useable borrow. This pit unsuitable.	627	500
139	52	Sand, gravel	5 - 15	100,000	Good source of borrow.	627	500
140	52	Gravel, sand, clay silt	5 - 40	400,000 min.	Good source of borrow. Some selection will be necessary.	627	500
141	52	Clay, gravel, silt sand	5 - 40		Too much waste in proportion to useable borrow. This pit unsuitable.	628	500
142	52	Clay, gravel, sand	5 - 15+	400,000	Good source of borrow. Some wastage will be necessary.	628	500

BORROW SUMMARY

PIT NUMBER	MOSAIC SHEET NUMBER	SOIL MATERIAL	WATER CONTENT RANGE (%)	ESTIMATED AVAILABLE QUANTITY (cu. yd.)	REMARKS	MILE-POST	DISTANCE TO CENTER-LINE (feet)
143	52	Clay, silt	10 - 30		Too much waste in relation to useable borrow. This pit unsuitable.	629	500
144	52	Sand, clay	5 - 15	200,000	Good source of borrow.	629	500
145	53	Silt, clay	10 - 20+	400,000	Fairly good source of borrow but selection will be necessary.	630	900
146	53	Clay, sand, silt-stone	5 - 30+		Proportion of waste to useable borrow is too high. This pit unsuitable.	631	500

POSSIBLE CUT SECTIONS

SUMMARY OF DATA

ILE	STATION	TEST HOLE	DEPTH OF CUT (FT)	SOIL TYPES	ICE CONTENT	WATER CONTENT (%)	REMARKS
44.1	2000	383	10	Mixed	High	30 +	Cut not recommended
48.3	1778	385	6	Clay	High	40	Cut not recommended
59.9	1696	371	7	Silt Sand	Low	10	Cut feasible
51.1	1633	359	8	Mixed	Low to High	25-70	Cut not recommended
53.0	1534	346 347	5	Sand	Low	25	Cut feasible
53.2	1520	346	15	Sand	Low	25	Cut feasible
53.5	1508	345 344	35	Sand	Low	25	Cut feasible
54.0	1480	340 341	50	Sand	Low	20	Cut feasible
54.9	1430	334 298	10 10	Clay Silt	High High	40 + 30 +	Cut not recommended

POSSIBLE CUT SECTIONS

SUMMARY OF DATA

ILE	STATION	TEST HOLE	DEPTH OF CUT (FT)	SOIL TYPES	ICE CONTENT	WATER CONTENT (%)	REMARKS
55.4	1407	296	10	Sand	Low	25	Cut feasible
55.8	1380	293 294	20	Sand	Low	20	Cut feasible
56.7	1337	289 290	15	Sand	Low	5 - 25	Cut feasible
57.0	1322	289	15	Sand	Low	5	Cut feasible
57.8	1276	284	10	Sand	Low	20	Cut feasible
62.5	1028	261	20	Sand	Low	5	Cut feasible
63.1	998	258	15	Sand	Low	20	Cut feasible
68.2	730	219 220 221 222	30 to 40	Mixed	High	- 40	Cut not recommended
74.0	425	156	-	Mixed	High	Very High	Cut not recommended

POSSIBLE CUT SECTIONS

SUMMARY OF DATA

ILE	STATION	TEST HOLE	DEPTH OF CUT (FT)	SOIL TYPES	ICE CONTENT	WATER CONTENT (%)	REMARKS
79.7	119	33 35		Sand Silt Clay	High	High	Cut not recommended
83.0	40						South side of Great Bear River. No soils information
83.6	76 to 100	522 459 460 521 461	-	Mixed	Varies Low to Very High	High	Cut not recommended
85.9	202	480 481	25	Clay Sand	Varies, Mainly Low	15-25	Cut not recommended
86.2	220	483	20	Clay	Low	15-30	Cut feasible
86.5	235	485 486	20	Silt Clay Shale	Varies	15-30	Cut not recommended
87.5	290	492 493 494 495	30	Clay Sand Silt	Mainly Low - Some High	10-40	Cut feasible, Not recommended

POSSIBLE CUT SECTIONS

SUMMARY OF DATA

MILE	STATION	TEST HOLE	DEPTH OF CUT (FT)	SOIL TYPES	ICE CONTENT	WATER CONTENT (%)	REMARKS
590.0	425	566	25	Clay	Low	5-10	Cut feasible
590.4	439	568	25	Clay Limestone	Low	5	Cut feasible
591.0	473 to 496	572 573 574 575	-	Clay Limestone	Low	5-15	Cut feasible
593.4	590	598	22	Clay	Low	15	Cut feasible but not recommended
604.3	1178	722 884 723	5	Clay	High	20-40	Cut not recommended
605.5	1240	751 854 760 882 789 790	-	Clay Shale	Varies	High at Surface Otherwise Low	Bridge site. Cuts not recommended but may be unavoidable.

POSSIBLE CUT SECTIONS

SUMMARY OF DATA

MILE	STATION	TEST HOLE	DEPTH OF CUT (FT)	SOIL TYPES	ICE CONTENT	WATER CONTENT (%)	REMARKS
512.5	1603	772 773 774 853 775 851 852 776 777 778	60 feet assumed	Clay Sand Shale	High in Overburden	5-40	Cut feasible as most of it would be in rock. Problems may arise due to failure of surface soils.
520.5	2030	938 939	20	Clay	High	30	Cut not recommended
526.4	2345	969 1019 970	10	Mixed	High	10-30	Massive ice at 13 ft. depth. In test hole 1019 cut feasible but will require over-excavation and backfilling

POSSIBLE CUT SECTIONS

SUMMARY OF DATA

ILE	STATION	TEST HOLE	DEPTH OF CUT (FT)	SOIL TYPES	ICE CONTENT	WATER CONTENT (%)	REMARKS
							CHAINAGE EQUATION: MILE 629.12 BACK EQUALS MILE 626.47 AHEAD
30.8	4950	973	10	Clay	Low	10-20	Cut not recommended
31.5	4915	1102 1103	20	Clay Sand	High	10-60	Cut not recommended

APPENDIX C

Terms of Reference

B

CANADA

Department of Public Works **Ministère des Travaux publics**
10th Floor, One Thornton Court,
P. O. Box 488,
Edmonton, Alberta.
T5J 2K1.

September 19, 1972.

your file / votre dossier

our file / notre dossier 9305-52-307.

R. M. Hardy & Associates,
Geotechnical Division,
10214 - 112 Street,
Edmonton, Alberta.

RECEIVED
SEP 20 1972
RECEIVED

Dear Sirs:

Geotechnical Investigations -
Mackenzie Highway.

Attached is a draft of the "Project Brief" for geotechnical consultants, which should be of assistance in preparation of final estimates for your work.

Yours truly,

for R.D. Cook
N. Huculak,
Regional Highways Engineer.

Attach.

Mackenzie Highway - Geotechnical Investigations - Mile 346 to Mile 725

1. General

Soil and permafrost conditions vary considerably over the 375 mile reach of the Mackenzie Valley which will be the subject of this investigation. These variations, in combination with other factors such as mobilization, existence of major water course, etc. will result in quite different field programmes for each geotechnical consultant appointed along the route.

The four geotechnical consultants appointed to date and sections of the route designated to each are as follows:

Acres Consulting Services Ltd.	Mile 346 to 450
Underwood-McLellan & Associates Ltd.	Mile 450 to 550
R. M. Hardy & Associates	Mile 550 to 650
E. W. Brooker & Associates Ltd.	Mile 650 to 725

As with any geotechnical project of the magnitude of the proposed Mackenzie Highway investigations, it is not difficult to generalize what the items of concern may be, but it is much more difficult to translate these into an estimate of the numbers and locations of borings, the depths to which these should be drilled, and the sampling and testing requirements. Some guidance in this respect is provided herein.

2. Soil and Permafrost Conditions

To date copies of the Preliminary Engineering Alignment Report outlining the route location from Mile 297 to Mile 544 have been provided to the consultants appointed through this section. A preliminary alignment report for the remainder of the route is currently being prepared and will be available to consultants by September 21.

The route will cross the Mackenzie River at Camsell Bend, run generally northward to the Willow Lake River, and then northward to Norman Wells approximately following the existing C.N. Telegraph line. In the following paragraphs the soil and permafrost conditions expected along the proposed route are summarized.

a) Mackenzie River Crossing to Willow Lake River - Mile 346 to 395.

From the Mackenzie River crossing to the Willow Lake River, the road passes through the broad Interior Plain Region. The surficial deposits in this section are predominantly clay till to within about ten miles of the Willow Lake River, after which interbedded silt, fine sand and sandy clays are anticipated. The thickness of peat will probably average less than 1½ feet but local occurrences up to 15 feet thick are anticipated.

Permafrost will likely be encountered in about one-third of the borings drilled near the Mackenzie crossing, and an increasing frequency to about one-half of the holes drilled near the Willow Lake River. It is unlikely that the frozen soil will contain much excess ice.

Between the Mackenzie and Willow Lake Rivers there are no major watercourses intersecting the proposed route.

b) Willow Lake River to Wrigley - Mile 395 to 435.

From the Willow Lake River to Wrigley the road passes through the Cordilleran Region. To about Mile 425, sands interbedded with silts and silty clays and till-like soil are likely to predominate. Beyond Mile 425, silty clays covered with up to two feet of peat are the predominant soils. Peat up to ten feet thick has been found in bogs along this section. Bedrock may be found close to the surface in places. Obvious material sources will include numerous sand dunes, some eskers and occasionally limestone outcrops.

Permafrost along this section of the route is anticipated in about 50 percent of the borings but the frozen soils will most likely contain little excess ice in the form of pore ice and ice lenses.

Major water courses in this reach of highway are the Willow Lake River (Mile 395) and the River Between Two Mountains (Mile 411), and one stream near Mile 430 which will require a large culvert. Terrain along this section is more undulating than the previous 50 miles.

c) Wrigley to Blackwater River - Mile 435 to 492.

The surficial deposits in this section consist principally of silty clays with some organic clay and till-like soils except at river beds and in fan formations where silty sands and sandy gravels are prevalent. These Pleistocene deposits are underlain by limestones and shales of the Franklin Mountains. The peat thickness to be encountered will likely range up to four feet. Obvious material sources will include large gravel deposits and limestone outcrops in the vicinity of Wrigley.

Permafrost in this section is widespread and frozen soil can be expected in two-thirds of the borings. The frozen soil is likely to contain excessi ice in silts and organic clays but little excess ice in other materials.

This section of the highway will cross Hodgson Creek (Mile 436), the Ochre River (Mile 455) and significant streams at approximately Mile 460 an Mile 471 all of which will require bridges. As well, the route crosses a number of minor watercourses and valleys and large culverts are anticipated at roughly Mile 462, Mile 469 and Mile 479.

d) Blackwater River to Little Smith Creek - Mile 492 to Mile 533.

From the Blackwater River to the Saline River, the surficial soils is predominantly silty clay with silty sand and sandy gravel being common at rivers and in fan formations. Peat up to four feet in thickness has been found to overlie the mineral soils. From the Saline River to Little Smith Creek, silts and silty clays underlain by gravel-sand-clay mixtures are predominant. Occasional rock outcrops will present some obvious material sources through this section.

Permafrost in this section is widespread and is likely to be present in about two-thirds of the borings. Excess ice in quantity is likely to be found in silts and clays from the Saline River to Little Smith Creek.

The terrain in this section is very irregular. Bridge crossings will be necessary at the Blackwater River, for a stream at approximately Mile 511 and for the Saline River (Mile 521). Large culverts will be required for streams near Mile 498, 514, 519 and 528.

e) <u>Little Smith Creek to Ft. Norman - Mile 533 to 584.</u>

From Little Smith Creek to Big Smith Creek, the terrain traversed by the highway is relatively free from lakes. From Big Smith Creek northward to Fort Norman, however, the highway will pass through a region of thermokarst lakes and muskeg. Surficial deposits are largely silty sand. Peat cover up to 15 feet thick has been found in bogs along this section.

Permafrost in this region is widespread and will likely be encountered in 75 percent of the borings. The soils contain considerable ice, ranging from pore ice not visible to the naked eye to ice lenses of a few inches in thickness.

Little Smith Creek and Big Smith Creek are the major streams to be crossed by the highway in this section.

f) <u>Ft. Norman to Norman Wells - Mile 584 to 630.</u>

From Ft. Norman to Norman Wells the route traverses along the base of the Norman Range and crosses numerous drainage channels with headwaters in the adjacent mountains. Surficial soils are predominantly silts and silty clays with some sandy gravels. Bedrock consisting primarily of shales, sandstones and some limestone can be expected at shallow depths in many locations. Organic cover will generally be 1 to 4 feet but thicknesses of peat up to 15 feet have been encountered at some locations through this area.

Permafrost in this section is widespread and will likely be encountered in 75 - 80% of borings. Ice will be excessive in silts and some clays, but not excessive in gravels.

Bridge crossings will be required at the Great Bear River (Mile 585), Jungle River Creek (Mile 601), Vermillion Creek (Mile 605), Prohibition Creek (Mile 612), Christina Creek (Mile 615), Helava Creek (Mile 616), Francis Creek (Mile 618) and Canyon Creek (Mile 620).

Obvious material sources through this stretch will include shale and sandstone outcrops parallel to the highway, large talus slopes, and limestone ridges parallel to the route.

g) <u>Norman Wells to Ft. Good Hope - Mile 630 to 725.</u>

North of Norman Wells the route will continue along the base of the Norman Range to Gibson Ridge, swing east of Gibson Ridge and proceed north near Chick Lake to Ft. Good Hope. Surficial soils are predominantly silts and clays with some silty sands and sandy gravels. Permafrost can be expected in 90 - 100 percent of test holes and excessive ice will be encountered in all fine grained soils. Obvious materials sources will include rock outcrops and ridges, primarily shale, and large talus slopes.

Bridges or large culverts will be required at Bosworth Creek (Mile 632), Oscar Creek (Mile 650), Elliot Creek (Mile 660), Hanna Creek (Mile 670), Donnelly River (Mile 685), Snafu Creek (Mile 695), Tsintu River (Mile 710), Jackfish Creek (Mile 722) and Hare Indian River (Mile 725).

3. Objective of Investigation

a) General

In general terms, the geotechnical consultant in each designated section will be responsible for providing sufficient subsoil data on the route centreline and on selected borrow areas to permit the Department to proceed with final highway design and tender call for construction. In addition, the consultant shall conduct foundation investigations at major stream crossing in collaboration with the bridge consultants appointed by the Department. The following paragraphs will outline specific concern and responsibilities of the consultant.

b) Differential Settlements

In addition to the identification and classification of general soil conditions along the centreline of the proposed highway, it is expected the consultant will provide a terrain classification along the route and will indicate areas of excessive ice, extensive peat zones, etc. which could result in subsidence of the road embankment and a maintenance problem. It is not expected the consultant should conduct thermal analyses and indicate fill height requirements to maintain permafrost in the underlying soil, but that potential areas of extensive embankment subsidence due to thaw be delineated and an estimate of the total subsidence be provided. Centreline boreholes should therefore not be located on a regimented basis but should be located from airphoto analysis of terrain and from field judgement and assessment of preceding boreholes data. A borehole depth of no more than 15' on centreline is considered adequate and the number of holes will depend upon the variation in terrain.

c) Roadway Stability

Overall stability of the roadway may be aproblem in some high fills and cuts on side hills, especially if the latter is of a part cut, part fill nature. The number, location and depth of holes necessary to adequately define a particular situation, however, will depend largely on the grade and alignment of the road. Since grade lines are unlikely to have been established at the time of the geotechnical investigation, the consultants engineering staff must use their experience to judge cut and fill requirements, identify potential problem areas and outline solutions in general terms.

Liquefaction and soil pumping may cause problems with some soils in certain grade situations. An assessment of the potential occurrence of these phenomena should be included.

d) Selection of Borrow

The utilization of borrow areas along a highway route must depend not only upon the location of suitable materials but upon the economics of construction. Consequently it is expected the consultant will take into consideration various items on the construction of embankment sections in his selection of the borrow pits to be tested. These factors will include deadhaul, overburden, clearing, access roads, and the comparison of excavation and haul costs for common material or rock borrow. A pre-established search corridor centered along the right-of-way need not be the range-limit in the search for suitable borrow, but rather on economic limit based upon the factors outlined above should be used. In assessing borrow locations, the suitability of material in obvious cut sections should be considered, but it can be generally assumed the majority of the highway will be embankment (especially so north of Willow Lake River) with minimal cut sections, and embankment requirements will be approximately 60,000 cubic yards per mile.

All potential borrow areas should initially be located from airphoto analysis and route reconnaissance. The areas subsequently investigated in the field should depend upon continued field judgement as acceptable borrow areas are proven. It is estimated an average of four borrow areas per mile will require evaluation to strategically locate suitable borrow sources. The number, depth and location of boreholes in any area should be a field judgement based upon drilling results, the characteristics of the feature being tested, and the estimated borrow requirements.

e) Backslope Stability and Slope Erosion.

Backslope stability in cuts, and slope erosion along cuts and sidehills, ditches and toes of embankment has been a fairly common source of trouble in permafrost affected areas. With the current emphasis on environmental protection and restoration, these aspects are currently more significant than ever. The proposed highway design in cut sections will include only V-ditches hence erosion problems could be significant. It is expected the consultant will identify potential erosion or back-slope stability problem areas and suggest solutions in general terms.

f) Drainage

The Department will conduct drainage surveys, and surface drainage will be outside the scope of these geotechnical investigations. However, subsurface drainage is prevalent in the active layer in many parts of the Mackenzie Valley, and interceptions of such seepage paths with a highway may result in the formation of icings during the winter. The consultants' field staff should be on the lookout for seepage areas and any suspect regions should be noted, described and sampled, wherever possible.

g) Bridge Locations

Permafrost conditions at river crossings are usually quite complex. Many of the banks and beds of the watercourses draining into the Mackenzie River from the east along this reach of the Mackenzie Valley are free from permafrost to a considerable depth. Exposure of the banks, however, is a significant variable and the permafrost conditions will have to be confirmed at the specific locations chosen for bridge crossings.

From a soils point of view, the bridge designer will be interested in the nature and stability of the soils forming the banks, the permafrost profile the strength and density profiles of the soils, the depth of the present and future, (i.e. anticipated post-construction), active layer, the foundation design criteria, and whether approach fills or cuts will endanger the structure. Many of the watercourses intersected by the highway route flow in deeply incised valleys having steep slopes, and there is evidence of valley wall erosion and channel shift in some. They represent areas which will require fairly extensive investigation to establish foundation design criteria, even if they are found to be free from permafrost.

At all stream crossings the geotechnical consultant shall respond to the requirements of the bridge consultants and/or the hydrology consultants appointed by the Department. The firms commissioned to date are summarized below. Bridge consultants beyond Mile 550, and hydrology consultants beyond Mile 500, will be appointed in the near future and the geotechical consultant(s) involved in these sections will be notified accordingly. Bridge site drilling requirements will be provided by the various bridge consultants by at least December 1, 1972.

Bridge Consultants

T. Lamb, McManus & Associates - Willow Lake River

Canada North Engineering Ltd. - Blackwater River

Reid Crowther & Partners Ltd. - Mile 300 - 460

Stanley Associates Engineering Ltd. - Mile 461 - 550.

Hydrology Studies

Bolter, Parish & Trimble - Mile 300 - 500

h) Field Observations, Sampling and Laboratory Testing.

Due to the cost and time limitations imposed on the field operations, movement of drill crews along the route must be relatively rapid - in the order of 1 to 2 miles per day. Hence it will be difficult, if not impossible, to confirm field drill logs at any location with laboratory test results, until drill crews have advanced several miles along the route. The success of the field operations must, therefore, depend largely upon the information and data obtained, and the judgements made, by drill inspectors and field engineers. Pertinent information recorded in the field should include:

(i) Visual identification and classification of the mineral and organic soils in accordance with the Modified Unified Classification System. Where permafrost is found, ice description should be in accordance with the methods set forth in N.R.C. Technical Memorandum No. 79, Guide to the Field Description of Permafrost.

(ii) Depth of the active layer (where apparent).

(iii) Description of the type of vegetation cover, terrain relief, drainage and snow cover. Photographic records should be taken in regions of major interest or at anticipated problem areas.

Soil sampling in centreline borings should be sufficient to reveal the general soil conditions along the route, to provide data on ice (moisture) contents and volumes of ice, and to provide samples from which thaw settlements can be estimated. These samples can be largely disturbed for classification testing, however some semi-continuous cores will be required in ice rich zones for ice volume and thaw settlement evaluations.

Sampling in borrow areas should be sufficient to confirm the drill inspectors logs, and to provide moisture contents and soil classification data which will be included in the tender documents for construction. Since compaction control will not be exercised during construction, moisture density relationships on borrow materials will not be required.

Sampling and testing in anticipated problem areas such as deep cuts, high fills, seepage zones, etc. should be sufficient to accurately define the problem. It is anticipated sampling would be semi-continuous with coring or penetration sampling devices.

Sampling and testing at bridge sites should be consistent with normal engineering practice for foundation investigations. Sampling should be on a semi-continuous basis using coring, Shelby tubes or penetration sampling devices.

4. Field Operations

a) Consultant Responsibility

The consultant will be responsible for all aspects of the field operations including mobilization of equipment and camps, staffing and operational support. Anticipated equipment requirements will include two track mounted drilling rigs, at least one of which must be capable of drilling rock, dozer support for clearing access to borrow pits, ground transport vehicles for crews, camp trailers and fuel sloops. Camps must be mobile and either track mounted or sled mounted for travel on the cleared highway centreline. Field laboratories may be utilized however the benefits of on-site testing and the inherent costs of a field lab and maintaining technicians in the field should be balanced against the cost and disadvantages envisaged in shipping samples 'south' for testing. Support for field crews should be supplied in the most economical means available.

The consultant should endeavour to employ residents of the N.W.T. whenever possible, subject to the availability of the skills required. All employment of local staff must be through the Canada Manpower Centres at Ft. Simpson or Inuvik.

b) Departmental Activities.

The Department will commence centreline clearing of the route by means of dozers and mobile camps on November 1, 1972 and access with tracked vehicles will be possible thereafter. Centreline clearing will begin at 3 locations - the starting mileages, direction of work and clearing contractors are outlined below. The progress rate for clearing is estimated at approximately 2 miles per day and geotechnical consultants can plan field operations accordingly. No dozer assistance will be provided by the Department for the borrow pit clearing.

Contractor	Equipment	Work Schedule
Robert Reason Contracting	2 - D-7 Dozers	Start at Mackenzie River Crossing-Mile 346-and work north to Mile 470.
Dallas Contracting	2 - D-8 Dozers	Start at Ft. Norman-Mile 584-and work south to Mile 470.
Carl Mueller Contracting	1 - D-7 Dozer 1 - D-8 Dozer	Start at Ft. Good Hope-Mile 725-and work south to Ft. Norman-Mile 604.

The Department will establish and maintain camps at Ft. Simpson (Mile 297), Willow Lake River (Mile 395), Blackwater River (Mile 492), Norman Wells (Mile 630), and Ft. Good Hope (Mile 720). With the exception of Ft. Simpson, the camps will be staffed with only a skeleton crew during the winter months, however consultants may utilize the camps as staging areas and may make use of the accommodation facilities available at anytime during their field operations. Food supplies at the camps will be minimal and consultants will be expected to provide their own resources in this regard.

c) Land Use Regulations

All consultant field operations must comply with Territorial Land Use Regulations. The department will obtain a General Land Use Permit for operations on the route right-of-way, however all movement off the right-of-way must be approved by an additional permit or by an extension to the general permit. In order for the Department to obtain a permit for exploration off the right-of-way it will be necessary to indicate the extent of movement into virgin terrain. Therefore the consultant shall pre-select potential borrow sources from air photo study and route reconnaissance and submit a mosaic outlining these tentative exploration areas to the Department prior to the start of field operations. Since any request for a land use permit requires approximately 1 month for approval, these mosaics should be available as quickly as possible to avoid any delay in field operations. Any specific queries regarding Land Use Regulations during field operations should be directed to:

Mr. D. J. Gee, Regional Manager, Water, Forests & Land
Department of Indian Affairs and Northern Development,
Yellowknife, N.W.T.

5. Available Route Information

The Department has assembled existing terrain mapping and borehole data along the general route corridor to roughly Mile 660, and this data is available to consultants. In addition, two sets of airphotos (1000 and 3000 feet to the inch - flown in summer 1972) are available for study in the Regional Office in Edmonton. Copies of the airphotos will be made available to the consultants as soon as possible.

6. Schedules

Narrative reports outlining the progress of the investigations should be submitted to the Department on a bi-weekly basis, and very preliminary technical reports consisting primarily of borehole logs should be provided at the same time. Final reports on the centreline, borrow pit and problem area investigations, including laboratory testing and recommendations, shall be submitted by April 30, 1973. Foundation reporting on bridge sites should be co-ordinated through the bridge consultants, however, it is anticipated a final report on any bridge site should be available within 5 weeks after completion of the field work at the bridge site.

APPENDIX D

Explanation Sheets

EXPLANATION OF TERMS AND SYMBOLS

USED ON TEST HOLE LOG SHEETS

Depth

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

Sample Number

Tube and core samples were numbered consecutively from the surface. Grab samples were not numbered.

Sample Type

This column indicates the depth interval and condition of each sample attempted. Undisturbed samples in this program were obtained with Shelby tubes of 18 inches length and 3 inches diameter, manufactured from 11 gauge steel, or by core drilling. Cores were of 2.85 inch diameter and up to 36 inches long.

Disturbed samples were obtained from the returned cuttings.

T indicates tube sample

C indicates core sample

 indicates large grab sample

Note: Grab samples taken for water content and visual examination are not indicated in this column.

Percent Recovery

This column shows the length of sample recovered as a percentage of the length attempted. 100% recovery is not indicated and may be assumed where no value is shown.

Penetration Resistance

No standard penetration tests were performed during this program.

Soil Symbol

The soil symbols used are explained in full on page 5 of this appendix.

Soil Description

Soils of different engineering classification are grouped generically for ease of reference. The system used is the Modified Unified Classification System for Soils.

Frozen Ground

The depth intervals over which frozen and unfrozen ground were encountered are indicated by F and UF respectively. No attempt was made to differentiate between seasonal frost and permafrost.

Ice Description

The ice content of permafrost soils has been classified according to the National Research Council System for describing permafrost. A brief review of the NRC System is contained on page 9 of this appendix. Where no entry is made, the type was not recorded in the field.

The amount of ice contained in a soil sample was estimated in the field laboratory by inspection. The value arrived at by the laboratory technician has been left unchanged.

Water Content

The natural water content of the soil at the time of drilling is plotted against depth on the chart at the right hand side of the log. The water content, which is indicated by a circle, is expressed as a percentage of the dry weight of the soil. It will be observed that water contents in excess of 100% are indicated in the column at the right of the chart by figures.

Volume of Ice

The total volume of ice in undisturbed samples is indicated on the same chart as water contents. The value is indicated by a triangle. This volume is the total volume of ice in an undisturbed sample and includes intersticial ice, as well as excess ice, and is expressed as a percentage of the total volume of the sample.

Grain Size Analysis

The proportions of clay, silt, sand and gravel in a sample are summarized. Grain size curves for each sample so analyzed are on separate sheets.

Wet Density

The wet in situ density of undisturbed samples is the total weight of the sample in pounds (including ice and water) divided by the volume of the sample in cubic feet.

Dry Density

The dry in situ density of undisturbed samples is the weight of dry soil divided by the volume of the sample in cubic feet.

Atterberg Limits

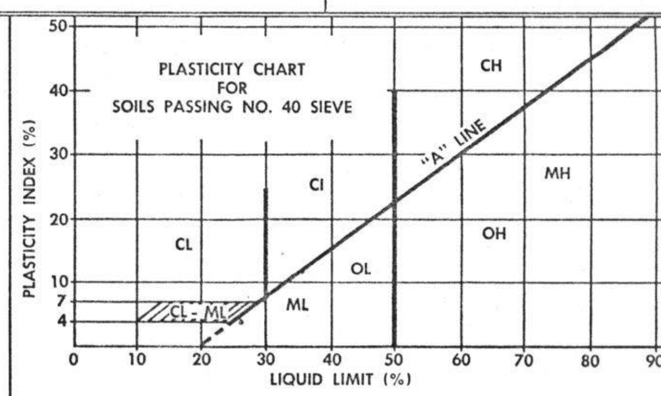
The plastic and liquid limits are shown on the water content chart by a horizontal bar. The Atterberg system is discussed in the following section.

NOTES ON ATTERBERG LIMITS

Soils which possess a significant fraction of clay can exist in liquid, plastic or solid states according to the water content. Where the water content is very high, so that the soil is in the form of a slurry, the soil behaves as a liquid. If the water content is reduced, for example through evaporation, the clay will enter into a plastic state. If the water content is reduced yet further, the clay will become a solid. The transition from one state to another occurs gradually over a range of water content. Atterberg, a Swedish agronomist, developed a method for delineating the boundaries between the three states. If his method is used, the water content which marks the dividing line between the plastic and liquid state is known as the Liquid Limit. These water contents are all expressed as percentages of the dry weight of soil. The range of water content between the plastic

MODIFIED UNIFIED CLASSIFICATION SYSTEM FOR SOILS

MAJOR DIVISION			GROUP SYMBOL	GRAPH SYMBOL	COLOR CODE	TYPICAL DESCRIPTION	LABORATORY CLASSIFICATION CRITERIA	
COARSE-GRAINED SOILS (MORE THAN HALF BY WEIGHT LARGER THAN 200 SIEVE)	GRAVELS MORE THAN HALF COARSE GRAINS LARGER THAN NO. 4 SIEVE	CLEAN GRAVELS (LITTLE OR NO FINES)	GW		RED	WELL GRADED GRAVELS, LITTLE OR NO FINES	$C_U = \frac{D_{60}}{D_{10}} > 6$ $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}} = 1$ to 3	
			GP		RED	POORLY GRADED GRAVELS, AND GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	NOT MEETING ABOVE REQUIREMENTS	
		DIRTY GRAVELS (WITH SOME FINES)	GM		YELLOW	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES	CONTENT OF FINES EXCEEDS 12%	ATTERBERG LIMITS BELOW "A" LINE P.I. LESS THAN 4
			GC		YELLOW	CLAYEY GRAVELS, GRAVEL-SAND-(SILT) CLAY MIXTURES		ATTERBERG LIMITS ABOVE "A" LINE P.I. MORE THAN 7
	SANDS MORE THAN HALF FINE GRAINS SMALLER THAN NO. 4 SIEVE	CLEAN SANDS (LITTLE OR NO FINES)	SW		RED	WELL GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	$C_U = \frac{D_{60}}{D_{10}} > 4$ $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}} = 1$ to 3	
			SP		RED	POORLY GRADED SANDS, LITTLE OR NO FINES	NOT MEETING ABOVE REQUIREMENTS	
		DIRTY SANDS (WITH SOME FINES)	SM		YELLOW	SILTY SANDS, SAND-SILT MIXTURES	CONTENT OF FINES EXCEEDS 12%	ATTERBERG LIMITS BELOW "A" LINE P.I. LESS THAN 4
			SC		YELLOW	CLAYEY SANDS, SAND-(SILT) CLAY MIXTURES		ATTERBERG LIMITS ABOVE "A" LINE P.I. MORE THAN 7
FINE-GRAINED SOILS (MORE THAN HALF BY WEIGHT PASSES 200 SIEVE)	SILTS BELOW "A" LINE NEGLIGIBLE ORGANIC CONTENT	$W_L < 50\%$	ML		GREEN	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY SANDS OF SLIGHT PLASTICITY	CLASSIFICATION IS BASED UPON PLASTICITY CHART (see below)	
		$W_L > 50\%$	MH		BLUE	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS, FINE SANDY OR SILTY SOILS		
	CLAYS ABOVE "A" LINE ON PLASTICITY CHART NEGLIGIBLE ORGANIC CONTENT	$W_L < 30\%$	CL		GREEN	INORGANIC CLAYS OF LOW PLASTICITY, GRAVELLY, SANDY, OR SILTY CLAYS, LEAN CLAYS		
		$30\% < W_L < 50\%$	CI		GREEN-BLUE	INORGANIC CLAYS OF MEDIUM PLASTICITY, SILTY CLAYS		
		$W_L > 50\%$	CH		BLUE	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS		
	ORGANIC SILTS & CLAYS BELOW "A" LINE ON CHART	$W_L < 50\%$	OL		GREEN	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY	WHENEVER THE NATURE OF THE FINE CONTENT HAS NOT BEEN DETERMINED, IT IS DESIGNATED BY THE LETTER "F", E.G. SF IS A MIXTURE OF SAND WITH SILT OR CLAY	
		$W_L > 50\%$	OH		BLUE	ORGANIC CLAYS OF HIGH PLASTICITY		
HIGHLY ORGANIC SOILS			Pt		ORANGE	PEAT AND OTHER HIGHLY ORGANIC SOILS	STRONG COLOR OR ODOR, AND OFTEN FIBROUS TEXTURE	



1. ALL SIEVE SIZES MENTIONED ON THIS CHART ARE U.S. STANDARD, A.S.T.M. E.11.
2. BOUNDARY CLASSIFICATIONS POSSESSING CHARACTERISTICS OF TWO GROUPS ARE GIVEN COMBINED GROUP SYMBOLS, E.G. GW-GC IS A WELL GRADED GRAVEL SAND MIXTURE WITH CLAY BINDER BETWEEN 5% AND 12%.

and liquid limit is known as the plastic range and the numerical difference between the liquid and plastic limits is called the Plasticity Index.

It will be appreciated that where the natural water content is in excess of the liquid limit, the soil mass will be most unstable and will readily flow into excavations or trenches. Such considerations will not apply where the soil mass is kept frozen. However, in cases where the frozen soil is allowed to thaw, the relationship between the natural water content and liquid limit becomes critical.

On page 5 there is a chart showing the relationship between the Plasticity Index, the Liquid Limit and the group symbols of the Unified Classification System. The Atterberg Limit system is extremely useful for identifying and classifying soils.

NOTES ON THE RADFORTH SYSTEM FOR CLASSIFYING PEAT

The Radforth classification system for describing muskeg (organic terrain) is a method for classifying the three elements of vegetation, topography and organic surface cover using letter and figure symbols. Height and type of vegetation is described by using capital letters (A through I). Topography is described by using lower case letters (a through p) Organic cover type if described by using figures (1 through 16).

Table I outlines these figure symbols and the peat structure and type represented by them. A complete description of the Radforth system is contained in "Guide to a Field Description of Muskeg" published by National Research Council, Ottawa, from which has been copied Table I.

TABLE I

SUBSURFACE CONSTITUTION

Predominant Characteristic	Category	Name
	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.
	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.
	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.

NOTES ON THE NATIONAL RESEARCH COUNCIL SYSTEM FOR DESCRIBING PERMAFROST

Ground ice occurs in three conditions. Non-visible, visible (but less than one inch in thickness) and clear ice. Non-visible ice is designated N with an added suffix of one or two lower case letters. Visible ice is designated V with an added suffix of one lower case letter. Clear ice is designated ICE with notes on ice type.

TABLE IV

Symbol	Description
Nf	Non-visible ice, frozen soil in friable condition.
Nbn	Non-visible ice, frozen soil well bonded, no excess ice.
Nbe	Non-visible ice, frozen soil well bonded, excess ice revealed on melting sample.
Vx	Visible ice crystals.
Vc	Ice coatings on soil particles.
Vr	Ice formations irregularly orientated.
Vs	Stratified ice lenses.
ICE	Clear ice over one inch in thickness.
ICE + soil	Ice over one inch thick with soil inclusions.

A complete description of this system is contained in "Guide to a Field Description of Permafrost" published by National Research Council, Ottawa.