Permafrost investigations at Aklavik, 1953: drilling and sampling

Pihlainen, J. A.; Johnston, G. H.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20358965
Technical Paper (National Research Council of Canada. Division of Building Research), 1954-01

NATIONAL RESEARCH COUNCIL

CANADA

PERMAFROST INVESTIGATIONS AT AKLAVIK: 1953
(DRILLING AND SAMPLING)

BY

J. A. PIHLAINEN AND G. H. JOHNSTON

JANUARY 1954

TECHNICAL PAPER NO. 16

OF THE

DIVISION OF BUILDING RESEARCH

OTTAWA

NRC NO. 3393

PRICE 50 CENTS

This publication is one of a series being produced by the Division of Building Research of the National Research Council as a contribution towards better building in Canada. It may therefore be reproduced, without amendment provided only that the Division is advised in advance and that full and due acknowledgment of this original publication is always made. No abridgment of this report may be published without the written authority of the Division. Extracts may be published for purposes of review only.

Publications of the Division of Building Research may be obtained by mailing the appropriate remittance, (a Bank, Express, or Post Office Money Order or a cheque made payable at par in Ottawa, to the Receiver General of Canada, credit National Research Council) to the Publications Section, Division of Building Research, National Research Council, Ottawa. Stamps are not acceptable.

A coupon system has been introduced to make payments for publications relatively simple. Coupons are available in denominations of 5, 25, and 50 cents and may be obtained by making a remittance as indicated above. These coupons may be used for the purchase of all National Research Council pub[illegible]cations of the Canad[illegible]ard.

Aklavik, N.W.T. - The Site of the 1953 Permafrost Investigations

(Photograph courtesy of National Film Board)

NATIONAL RESEARCH COUNCIL

CANADA

PERMAFROST INVESTIGATIONS AT AKLAVIK: 1953

(Drilling and Sampling)

by

J.A. Pihlainen and G.H. Johnston

Technical Paper No. 16

of the

Division of Building Research

Ottawa
January 1954

FOREWORD

The authors are both research officers in the N.R.C., Division of Building Research, working in the Permafrost Section of which Mr. Pihlainen is the Head. Both are graduate civil engineers. Although they have made extensive literature surveys as a part of their research, this is not reflected in their paper since so little is known about the exploration of permafrost. Some relevant references appear at the end but these were of little (if any) use for the investigation described which included some operations which may be described as pioneer work. The paper is, in effect, a progress report. It is hoped that it will soon be followed by more detailed statements of further work.

R. F. Legget,
Director.

PREFACE

Soil and site investigations in those areas of Northern Canada underlain by perennially frozen ground (permafrost) have been generally either neglected or disregarded. The omission of this important engineering phase in northern construction has been responsible for many building failures. Although many of the structures in Canada's North are relatively small, the lack of site investigations is due mainly to insufficient knowledge and experience of sampling equipment, techniques, and personnel.

Initiating research on permafrost and its associated problems, the staff of Division of Building Research of the National Research Council spent two summers compiling field information on the performance of existing buildings on permafrost (1). A review of these data suggested the general path for the Division's permafrost research program. One of the main and most pressing responsibility was the development of soil sampling techniques and equipment in permafrost areas.

During the winter of 1952-53, the Division was informed that the Department of Resources and Development (now the Department of Northern Affairs and National Resources) intended to construct a ten-room school and an eight-apartment "teacherage" at Aklavik, N.W.T. Little factual information about the Aklavik soils was available. The construction of these two large structures offered an excellent opportunity to try out existing soil sampling techniques and to initiate the first of the Division's long-term observations on the effects of buildings on permafrost conditions. The Division, therefore, welcomed the opportunity of co-sponsoring a program of permafrost investigations jointly with the Department of Northern Affairs and National Resources.

This report contains a record of the Aklavik permafrost investigations carried out during the summer of 1953. Full details of drilling in permafrost, and drilling difficulties in particular, are included in Part I since the equipment and methods used have not been generally reported in Canada. Most of the soil testing results or summaries of these data are presented in Part II. The effect of the two large buildings on permafrost conditions, as recorded by observations of thermocouple installations under selected points of the structures, will be reported at some future date.

Much of the success of the project was due to the co-operation and interest of the Department of Northern Affairs and National Resources both in Ottawa and Aklavik. The assistance and help of Mr. R. R. Ross, Engineering and Architectural Division of this Department at Aklavik, is especially noted. Finally, it is a pleasure to record also appreciation of the assistance rendered by the personnel of the Department of Public Works in Aklavik and Edmonton. Their help ranged from supplying forgotten

bolts to the loan of their steam generator and was appreciated in a fashion known only to those who work in these isolated, northern regions of Canada.

Appendix 3 is reproduced by kind permission of the Acting Director of the Snow, Ice and Permafrost Establishment of the U.S. Corps of Engineers (SIPRE) at Wilmette, Illinois, with the staff of which the Division is privileged to maintain close and cordial liaison in fields of mutual interest.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

PERMAFROST INVESTIGATIONS AT AKLAVIK: 1953

(DRILLING AND SAMPLING)

by J.A. Pihlainen and G.H. Johnston

INTRODUCTION

1. The Mackenzie River Delta and Aklavik

More than one hundred miles before emptying into the Beaufort Sea, the Mackenzie River begins to divide into a series of channels that flow through its delta. This delta is an area of low and flat topography, interlaced and dissected by numerous lesser channels and spotted with thousands of stagnant lakes.

The town of Aklavik, nearly halfway down the delta and on a western channel, is chiefly a centre for fur-trading, government administration, and missionary activities (see Frontispiece). The mean annual temperature is 15°F. with a July mean of 56°F. The mean annual rainfall is 4 inches and snowfall is approximately 5 feet.

At the beginning of the twentieth century, Fort MacPherson was the main post for the Mackenzie delta and the Arctic coast. Herschel Island was the coastal whaling centre, but did not have a trading post until 1916. In 1912, the Hudson's Bay Company and the Northwest Trading Company established posts on opposite sides of the West Channel, the Northwest Trading Company on the present site of Aklavik and the Hudson's Bay Company on Pokiak Island. In 1919, the Anglican Mission was established, so the Hudson's Bay Company moved across the channel to the present site. It is here that the present town of Aklavik has developed. Probably because of the large missions, (The Roman Catholic mission was established in 1926) coupled with the fact that it is excellent muskrat country, Aklavik has grown into the main centre for the Northwest Territories, Arctic, and coastal areas.

The settlement is built on the inside of a sharp bend in the West Channel. The houses are mainly strung out along the river bank and down the one "main" street which runs inland (Fig. 1). The main groups of buildings are those of the missions, Anglican and Roman Catholic, Hudson's Bay Company, Royal Canadian Mounted Police, Royal Canadian Signals, and governmental administration buildings.

2. Location and Scope of Investigations

The sites of the proposed ten-room school and eight-apartment teacherage are on the northern edge of the settlement (Fig. 1). As is the case for most of the town, the sites are low-lying areas with an organic covering averaging 12 inches. Shoulder-high, alder-willow thicket covers both sites but will be cleared before construction begins.

These two wood-frame structures, the school being 168 by 60 feet and the teacherage 105 by 29 feet, will be constructed with precut members and will be supported by wooden piles (20 feet in ground) with 14-inch minimum butts. Specifications called for a 12-inch moss fill under the buildings with an air-space between the top of the moss and the floor of the building.

Fifteen boreholes were drilled at the proposed sites, three boreholes being exploratory while the remaining twelve holes were for thermocouple installations. At each of the proposed sites, three thermocouple installations were placed under the furnace room location and under the site of a typical floor section. The location, elevation, and other details of these installations are shown in Fig. 2. A photograph of the actual installation is shown as Fig. 3.

PART I - SITE INVESTIGATIONS

3. Introduction

Obtaining soil samples of perennially frozen ground with conventional hand methods is difficult and at times impossible. Because of the rock-like resistance of permafrost, its first contact usually constitutes refusal for hand augers. If some penetration is possible, it is through the auger scraping small flakes of permafrost. Drive samplers, such as heavy-duty pipe with a cutting edge, are at times more effective but the method is slow, laborious, and unsure. The difficulties of obtaining permafrost samples have restricted much data on northern soils to descriptions of soils in the annually thawed layer; soil data on permafrost are virtually non-existent.

The need for portable power drilling equipment has been realized for some time by United States agencies engaged on permafrost research. One of the first developments in this field was made by the Frank L. Howard Engineering Company for the U.S. Corps of Engineers. On the basis of the drilling experience in Alaska of U.S. Corps of Engineers, this Company modified one of its concrete samplers for permafrost drilling. So encouraging were the reports of its first trials in Alaska that the Division purchased one of these drilling units for the use of its Permafrost Research Station.

The principles of drilling and obtaining frozen soil cores are similar to those of diamond drilling. A power-driven rotating core barrel with a bit cuts into the frozen soil, producing a cylindrical core. The soil cuttings are carried away from the advancing edge of the bit by wash water under pressure. This wash water travels down the inside of the drill rods and then up the sides of the hole to the surface with the cuttings. The frozen core is retained inside of the core barrel.

There are, however, many differences in detail and technique between drilling in frozen soil and in rock. The greatest difficulty is that of trying to retain the core in its frozen state. The ice content of frozen soils is above the liquid limit of the soil in almost all cases. Thus, if the core melts, it turns into a soil slurry and is valueless for record purposes. This is but one difficulty of drilling in frozen soil. Others will be reported following the description and operation of the drill rig.

4. Drill Rig Details

Drilling for the Aklavik permafrost investigations was carried out with a special, lightweight drill rig, the Concore Type E5-48, manufactured by the Frank L. Howard Engineering Company (Fig. 4). The heaviest component of the outfit weighs only 126 pounds while the whole rig weighs slightly more than 700 pounds (not including accessories such as drill rod, and core barrel). The lightweight feature is accomplished by the use of aluminum whenever possible and is coupled with the fact that all parts will pass through openings 2 feet square, making the rig easy to transport by light aircraft.

The Drill Head.- The drill head rotates the drill rods and core barrel (Fig. 4). This unit weighs about 75 pounds with the drill chuck attached. It has a gear ratio of 10 to 1, allowing a spindle speed of 280 to 360 r.p.m. with the gasoline engine. The drill head engine is a Briggs and Stratton Model 14, single-cylinder, 4-cycle, L-head, air-cooled type rated at 8 h.p. The gear case and cover of the drill head are made of aluminum alloy and the drive spindle and chuck have an inside diameter sufficient to pass "A" drill rod. The drill is fed into the work with a hand crank through reduction gears in the drill head and travels on the feed rock of the column.

Pump Unit.- The wash water pump is a 3/4-inch herringbone gear pump with a built-in pressure relief valve and chain driven by a 4-h.p. Briggs and Stratton gasoline engine similar to that of the drill head. The pump is rated at 1.033 g.p.m. per 100 revolutions and with the engine in high position, the pump turned at 1200 r.p.m. giving a discharge of approximately 12 g.p.m. The highest pressure developed by the pump was between 35 and 40 p.s.i. at 4 g.p.m. discharge. Wash water pressure and discharge were measured with a pressure gauge (0 - 100 p.s.i. range) and a 3/4-inch water meter.

The wash water reservoir consisted of four 45-gallon oil drums welded two together. The 180-gallon capacity of the supply tanks was found to be sufficient for the average 25-foot hole. A domestic water line was always within 500 feet of the drill rig and an auxiliary pump was not required.

The Core Barrel.- The core barrel used was a Longyear L Series Double Tube Roller Bearing Swivel Type, Size NX. A 5-foot core barrel was used giving a 3-inch diameter hole and a core of 2 1/8-inch diameter in the inner core barrel. The core barrel is constructed with one core tube inside the main core barrel. A roller bearing swivel head allows the outer tube with the bit to rotate, while the inner tube which holds the core remains stationary. Wash water coming through the drill rods passes on the outside of the inner tube, washes away the bit cuttings, and passes up the hole on the outside of the outer barrel. Thus the core is protected from the melting effect of the wash water and is retained in the inner tube by means of core catcher springs. Hard metal or "carballoy" insert bits were used throughout the drilling and a diamond bit was on hand in case a boulder was encountered.

The Drill Rig Shelter.- Anticipating poor weather at Aklavik, a wood-frame shelter, 14 by 11 feet was built on log skids for the drill rig. Apart from the drill rig, the shelter contained work benches, note tables, and all of the accessories needed by the project. The shelter was constructed on a stone-boat framework consisting of two spruce logs, 14 inches in diameter and 16 feet long, spaced 7 feet apart and tied together by four 4- by 8-inch timber beams. The actual building was 11 by 14 feet and 11 1/2 feet high with a peaked roof. Shiplath siding covered 2- by 4-inch studs and a large door (5 1/2 by 6 1/2 feet) was left in the front to allow bulky equipment to be moved in or out easily. Supports at the rear on one side held the water supply tanks on the outside.

A note-keeping table was built in one corner of the shelter and two narrow work benches 10 feet long were erected along one wall, one above the other. The top one was used for core sampling and the lower one for extruding the cores from the core barrel. The drill rig base was bolted to the 2- by 4-inch plank floor in such a way that the rig could be levelled by adjusting bolts rather than by jacking the whole building. Details of the shelter are shown in Fig. 5.

A drill rig shelter accessory which was found most useful was a portable 1,000-watt, 110-volt, 60-cycle generator. Apart from occasional use as a light plant, the generator supplied power for power tools, electric speed flash, and soldering thermocouples.

5. The Drilling Operation

Before a hole was started, the thawed surface material, mostly organic, was cleared from an area about two feet square down to frozen ground. At Aklavik, this thawed depth varied in July from 8 to 24 inches. The drill rig shelter was then centred over the cleared area and the rig levelled. The first few holes were cased with a 3-foot length of 6-inch pipe to prevent "slumping" at the top of the hole. It was difficult, however, to bond the casing to the frozen ground and the casing proved to be more of a nuisance than an aid to drilling. Accordingly, it was not installed for the remaining holes.

Prior to drilling, the wash water tanks were filled and all engines, pumps, and rotary parts were checked for gasoline, oil, and grease. After the core barrel was carefully centred in the drill head chuck, wash water circulation was started and drilling begun. Drilling followed for a full 5-foot increment unless pressure or water gauges showed a stoppage of wash water. Drilling a 5-foot length took from 5 to 45 minutes, the drill was stopped, and wash water was bypassed to the supply tanks. With the drill head swung out of way, the string was pulled by hand with a block and tackle using pipe wrenches as holding tools. The core barrel was then dismantled and the inner tube taken out. Usually, the core came out easily from the inner tube when the core retainer assembly was removed but if some thawing of the core had taken place, the core was extruded with a hand-cranked gear-rack piston. While the core was being described, recorded, and sampled, the core barrel parts were cleaned and re-assembled for the next drilling increment.

The rather detailed sampling and field description requirements limited drilling to about 25 feet for a ten-hour day. Continuous drilling to complete a hole is recommended since time can be lost in re-drilling through ice and slush in a hole left even overnight. By no means should the string be left in a hole for a period of time exceeding six hours. In one instance, the string was left in the hole overnight at the 12-foot depth. It was only by thawing the hole with steam that the string was recovered.

Drilling and sampling were carried out with a three-man crew. For most efficient operation, the crew should number four -- two men on drilling and water supply and the remaining two carrying out sampling and field descriptions.

6. <u>Drilling Comments</u>

In general, the drill rig functioned well except for the pump unit. The lightweight features of the rig are commended even though on these particular investigations shipment was by barge where weight was not a significant cost factor. The use of lightweight alloys did not affect the function of the rig. A minor disadvantage of the drill rig was the short 9-foot mast arrangement which allowed only 5-foot pulls. A mast sufficiently high to allow 10-foot pulls would have speeded drilling operations. At times, a power winch for pulling the string would have been appreciated. Unless this accessory is available as a lightweight unit its use is not necessary for this type of drilling.

The Drill Head.- No real difficulties were experienced with the drill head or its engine and both performed well. Future minor improvements could include a manual clutch for the engine and a self centring chuck for the spindle head.

The Pump Unit.- By far the greatest difficulties arose from the pump unit. The shortcomings of the wash water system were reflected by poor core recovery, damage to core barrel, slow penetration, and, in some cases, jamming of the core barrel in the hole.

Water circulation in any type of drilling is important and for drilling in permafrost, close control of wash water is absolutely essential. Too large a volume of water tends to melt and wash away the core while too small a volume is not sufficient to carry away bit cuttings. Pressure is also important or the cuttings will clog up the sides of the hole and wedge the core barrel so tightly that hand pulling is impossible.

The biggest shortcoming of the herringbone gear pump supplied was its low pressure discharge. The largest discharge pressure that was recorded was approximately 35 to 40 p.s.i. It is now thought that pressures from 100 to 150 p.s.i. are necessary. The pump capacity was sufficient as 4 g.p.m. were generally used and the pump could have supplied 12 g.p.m.

Two instances where wash water was the direct cause of nearly halting operations will illustrate the importance of wash water and its control. In one hole, wash water stopped circulating and silting occurred between the inner and outer tubes. It took two 36-inch pipe wrenches to undo the core barrel, with the result that the lock nut on the roller bearing shaft and the shaft were stripped of their threads. Fortunately, it was possible to re-thread the shaft and continue operations. On another occasion, poor wash water circulation allowed silt to pack up the sides of the hole so tightly that the core barrel acted like a piston. So tight was the core barrel in the hole that a 6- by 10-inch beam and two "track jacks" were required to pry the string from the hole.

For future drilling operations, a domestic water supply line may not be available. A portable supply pump with about 1,000 feet of hose will therefore be needed. The "oil drum" water supply reservoir is relatively heavy and bulky and so the possibility of using heavy canvas (or equivalent) bags of 300-gallon capacity should be explored. The wash water pump for future operations should have a capacity of about 10 g.p.m. and be capable of exerting pressures up to 150 p.s.i. High pressure and positive displacement requirements seem to indicate that a piston-type pump is needed, even though lightweight is not a feature of this type of pump.

The Core Barrel.- Core recovery ranged from 0 to 100 per cent but averaged approximately 60 per cent. Much of the poor core recovery is attributed directly to the unsatisfactory wash water systems. The use of the double tube roller bearing swivel head barrel will be continued until some special core barrel for permafrost can be developed.

Two carballoy bits were used for the entire drilling project, i.e. a total of approximately 500 feet in frozen silt and fine sand. Both were in good condition at the end of the project. The extra heavy core retainer springs did not function very effectively but the difficulty may again be due to the wash water system that was used. Twisted core retainer springs frequently chewed and destroyed much core. "Burning in the core" or drilling the last 3 or 4 inches with no wash water and thereby jamming the lower end of the core barrel proved effective. This method, however, was used only as a last resort in order to retain core since possible damage and freezing-in of the core barrel were great.

The Drill Rig Shelter.- The drill rig shelter was found to be quite satisfactory for these investigations. The potentially hazardous fumes from the gasoline engines can be eliminated with flexible metal hose from the engines to the outside. For an extensive soil exploratory program, this type of drill rig housing is recommended not only as a shelter but as storage for the many accessories. Thus, drilling was never delayed by poor weather and moving to a new drill hole location consumed a minimum of time.

For future large operations, this relatively permanent type of housing will be used. For more isolated investigations, where only manpower is available for a move, a tent can provide the needed shelter. Occasional exploratory holes can be drilled with no shelter. If some drilling is to be done in freezing weather, then some form of heated shelter must be provided for the convenience of the crew and for water storage. In choosing a heating unit, possible toxic and fire hazards should be kept in mind.

7. Frozen Core Observations and Sampling

As mentioned previously, core recovery ranged from 0 to 100 per cent but averaged 60 per cent. Good or "select" cores averaged 2 inches in diameter, average frozen core diameters ranged from 1 1/2 to 2 inches and poor cores were either completely thawed or had frozen portions from 1/2 to 1 inch in diameter.

Select and average cores were removed easily from the inner tube and usually fell out when the core retainer ring was removed. Poor cores, on the other hand, filled in and stuck to the sides of the inner tube. In these cases, the gear-rack piston type extruder was used. Immediately after the core was removed from the barrel the recovered length of core was measured and recorded. The actual core came out in pieces from 3 to 30 inches in length and was cut or separated into one-foot increments. These one-foot frozen core portions were then individually split in half with a knife and hammer with observations of ice segregation and a field description of the soil recorded before the core melted. Representative samples, adequate for the various necessary soil tests, were then taken and recorded.

Much of the soil sampling technique was based on the assumption that the form and extent of ice segregation was related to soil particle size. Accordingly, changes in ice segregation were considered as significant as visibly discernible changes in soil particles. After some field experience, this assumption seemed reasonable since ice segregation seemed to diminish as samples became more "sandy". Thus, after samples from representative types of ice segregation had been taken, only unusual forms or variations of ice segregation were sampled.

Subsequent testing proved that the assumption was not altogether correct, i.e., the form and extent of ice segregation is not solely related to soil particle size. Dr. H. Nakaya, now with the Snow, Ice and Permafrost Research Establishment of the U.S. Corps of Engineers, Wilmette, Illinois, has shown in experiments (the report on which has yet to be published) that the size and form of ice segregation is dependent on both the particle size and the rate of freezing. Thus much of the information collected gave data on ice contents but failed to point out significant differences in the soil constituent of permafrost. Future sampling will therefore be based on discernible changes in soils while the form and extent of ice segregation will be secondary, although still pertinent.

The time in which a frozen split core melts and thus obliterates ice segregation is very short and ranges from three to fifteen minutes. A concise and comprehensive form of "shorthand" is therefore necessary for core description and identification. Several such classification systems exist for soils but only one, as far as known, has been proposed for the ice phase of permafrost.

Soil Description.- The soil constituents of permafrost were described and identified using the Unified Soils Classification (Appendix 3). Although it is beyond the scope of this report to describe the classification system, some comments on its use may be of interest.

By far the greatest difficulties in using the Unified Soils Classification arose in the major soil group designated "organic soils", known more widely in Canada as "organic terrain". The occurrence of these deposits ranged from black, hairline streaks to strata two-feet thick. The composition ranged from minute black specks or flakes to mat-like mixtures of decomposed and undecomposed vegetable matter. Although the behaviour of these various forms of organic terrain are not known, it is thought that some subdivision of this major soil group is necessary to speed field observations. For future investigations, the following subdivisions of organic material will be tried:

1. Streaks -- hairline streaks and traces of organic material usually in the form of black to dark brown particles or flakes;

2. Decomposed -- predominantly decomposed organic material in dark brown particles or flakes with random pieces of twigs and leaves;

3. Undecomposed -- predominantly undecomposed organic material usually fibrous or stringy with branches, twigs, and leaves with random pockets or layers of decomposed material.

It is hoped to try out also in the field the classification system for organic terrain suggested by Dr. N.W. Radforth (2).

Ice Description.- The Frozen Soil Classification system of the U.S. Corps of Engineers was used to describe the ice phase in permafrost samples (Appendix 3). This system divides frozen soils into two broad groups on the basis of ice formation:

(i) Frozen soils in which the ice has not segregated but cements, bonds, or fills the voids between the soil particles; and

(ii) Frozen soils in which ice segregation in the form of lenses, veins, layers, and dikes takes place.

With only one field season of experience in using the classification system and for only a limited number of soils, general comments only will be recorded at this time.

The subdivision of frozen soils on the basis of discernible ice segregation or the lack of it appears satisfactory. Deductions as to soil type using this basis are, however, questioned (see item 7, page 7). Soils that do not generally have ice segregation, such as sandy gravels, and are well bonded are thought of as "suitable" or "preferred" soils. Frequently stringy and predominantly undecomposed organic terrain has no discernible ice segregation and is also well bonded (Appendix 1, picture 781). Furthermore, test results showed two similar soils (silts with some fine sand) with different ice phases -- one with ice segregation, while the other was described as well bonded (Appendix 1, photographs 793 and 788). Thus for future investigations, the classification system will be used to describe and identify ice conditions in a frozen soil but inferences as to soil type, on the basis of ice segregation, will be made and used with caution.

The most frequent form of ice segregation observed during the Aklavik Investigations was the DE type (Appendix 1, pictures 785, 786, 787, 788, 792 and 795). At times, the horizontal ice segregation was so closely spaced that it could have been literally referred to as the DE type (Appendix 1, picture 785). However the DZ type was arbitrarily assigned to individual and random ice dikes (Appendix 1, picture 784). Ice types termed DO, were confined mainly to coatings on twigs and branches and only in rare instances were the DX, or individual crystals, observed. For future investigations the ice phase in soils with ice segregation will be reported in essentially the same form as shown in Appendix 2. The only addition (to speed description) will be to subdivide the DE ice type into fine, medium, and large subsections on a size basis of individual ice layers.

Photographs.- Photographs of split frozen cores are a most useful supplement to field descriptions. Many times on reviewing soil test data and field descriptions, significant information on ice segregation is available long after the core has melted or been discarded. At Aklavik, a camera outfitted to photograph the mouths of patients (the personal property of Dr. T. Hunt, Dental Office, National Health and Welfare Department) was used to photograph some frozen cores in colour (see Fig. 6). The results were so favourable (Appendix 1 contains prints of these photographs) that the Division is now developing this type of photography for future operations.

Soil Samples.- In this preliminary stage of permafrost investigation, only the relatively simple classification tests were carried out. Thus the samples obtained were used to carry out moisture content, unit weight or field density, specific gravity, grain-size distribution, and Atterberg limit determinations. The volume of ice in frozen cores was often more than the volume of soil or mineral constituents (Fig. 7) and hence sample sizes were determined mainly "by eye".

Moisture content samples were taken at right angles to ice segregation, from the centre of the core, and were 1/4 to 1/2 inch square by 1 inch long (15 to 30 grams). The sample was then placed in an aluminum tin, wrapped with aluminum foil, and coated with "petrowax". If some time elapsed before the tin was wrapped and sealed, condensation formed on the tin. Accordingly, the tins were carefully wiped before sealing. It was noted that "petrowax" will crack if applied too hot or in thick layers. Dipping the aluminum wrapped tins in petrowax slightly above the melting point proved most successful.

Field density or unit weight samples were obtained from measured lengths of select (that is, constant diameter) core. The samples were 3- to 4-inch lengths of 2-inch diameter core and weighed approximately 500 grams. The average of at least five measurements of length and diameter were taken as the true dimensions. These samples were placed in glass jars and sealed to prevent the loss of moisture.

Samples for grain size, specific gravity, and Atterberg limit determinations were stored in unsealed glass jars. Frozen bits of core enough to fill a one-quart jar were usually sufficient to carry out these tests.

Field Notes.- The field notebook contained a record of drilling, core, and sampling observations. Drilling data included records of the depths at which drilling started and ended, the length of core recovery, and any significant changes in amounts of wash water or equipment difficulties. Soil and ice descriptions were recorded for recovered lengths of core using the U.S. Corps of Engineers Frozen Soil Classification. The field notes also contained records of where samples or photographs were taken. Typical notes from the field notebook are shown in Fig. 8.

8. Thermocouple Installations

The Aklavik Permafrost investigation offered an excellent opportunity to initiate the first of the Division's long term projects on the effects of buildings on permafrost. Thermocouple installations were accordingly made at the two sites to measure soil temperatures at various depths (Fig. 2). At the site of the eight-apartment teacherage, thermocouples were placed at the 0-, 1-, 2 1/2-, 5, 7 1/2-, 10-, 12 1/2-, 15-, and 20-foot depths while at the ten-room school site, soil temperatures are to be measured at the 0-, 2 1/2-, 5-, 7 1/2-, 10-, 12 1/2-, 15-, 20-, and 25-foot depths.

The thermocouple installations were made in the field. Required lengths of thermocouple wire were cut, taped together, and slipped into fibre tubing. Rubberoid sealing compound was then poured into the tubing and was also used as an outside coating for the tubing. The 3/4-inch and 5/8-inch fibre tubing in 3-foot lengths were then "telescoped" alternately, joints pin-connected with a nail, and taped with electrician's tape. The installations will be completed with compensating junctions and switches when the structures have been completed. At the present time, small wooden boxes protect the leads (Fig. 3).

PART II - SOIL TESTING RESULTS

9. General Summary of Aklavik Soils

The soil at Aklavik to a depth of 35 feet is predominantly a series of stratified fine sands, silts, and organic material. The complete absence of coarser particles was remarkable; not even a pebble was encountered in the 16 drilled holes. Organic material ranged from black, hairline streaks to strata two feet thick and was composed of a heterogeneous mixture of decomposed and partly decomposed organic matter. Plastic soils such as lean clays were scarce and when found were usually associated with organic deposits. Ice segregation in the Aklavik fine-grained soils consisted predominantly of horizontal ice lenses (in thickness from hairline to 3/4-inch) although small and random vertical ice formations were also observed.

Grain-size Distribution.- As would be expected for a delta region, the grain-size distributions for the samples tested (numbering 95) fall between narrow limits and almost all grain sizes are below the No. 60 sieve size. The limits of grain-size distribution, representative samples, and the frequency with which they occurred are shown in Fig. 9. Soils in the silt size occur most frequently and the absence of even medium or coarse sand size particles is notable.

Moisture or "Ice" Contents.- Generally, the form of the ice in the Aklavik soils observed was of two types;

(a) ice which bonded individual particles but was not always discernible to the unaided eye, and

(b) ice which segregated or formed layers, lenses, and dikes in size from hairline to 5/8-inch thick.

Photographs and descriptions of typical cores, to illustrate the many types of ice occurrences, are shown in Appendix 1.

The moisture, or more correctly "ice", contents (per cent of water or ice to dry soil on a weight basis) plotted at sample depths are shown in Fig. 10. These data have been analysed by statistical methods and details are given in Appendix 2.

It has been found that for the first 10 feet at Aklavik, the moisture content varies linearly with depth or,

$$y = 172.11 - 12.35x$$

where y is the moisture content in per cent at x, the depth of the sample from the ground surface, in feet. The correlation ratio, however, for this regression is low and so it should be used only as an approximation. Had more samples been obtained in this interval, no doubt a higher degree polynomial would have given "stronger" correlation.

It is interesting to note that moisture contents at depths greater than 10 feet are "statistically" constant at 54 per cent (Fig. 10). This depth is too low to be the limit of yearly thaw and refreeze but could be the depth at which yearly temperature effects are no longer felt or reflected by ice formations in the soil.

The possibility of correlating moisture contents with depth will be explored further in future years since the ice content is usually of much more significant value than the consolidation characteristics of a frozen soil in settlement studies.

Unit Weights.- The mass and dry weights of some typical Aklavik soils are shown in Table 1. The mass unit weight is the weight per unit volume of a soil sample in its natural state, while the dry unit weight is the "dried" weight per unit of original volume. The samples for these determinations were field measured lengths of select frozen core which were sealed and shipped to Norman Wells for weighing in the "natural" and "oven-dried" states.

The results, averaging 92 lb./ft.^{3} and 52 lb./ft.^{3} for the mass and dry unit weights respectively, are generally low. For example, typical unit weight values for thawed, loose, uniform sand in the natural state is 90 lb./ft.^{3} in the dry state and 118 lb./ft.^{3} in the saturated state. Only one sample (AB15-12, Table 1) even approaches these values.

The low unit weight values are thought to be explained by the expansion due to freezing of water, the high "moisture" or "ice" contents, and the presences of bulky but light-in-weight organic material. Unfortunately, the number of samples is small. Although the effects of ice and organic material are realized, the magnitude of the effect must be left for future investigation.

TABLE 1

Unit Weights of Some Aklavik Soils

Sample	Soil Description	Moisture Content %	Dry Unit Weight lb/ft^3	Mass Unit Weight lb/ft^3
AB15-12	Sandy silt	54	76	116
AB1-7	Silt with trace of fine sand and some clay	63	59	96
AB1-23	Silt with organic material	62	54	88
AB1-22	Silt and stratified organic material	69	53	90
AB6-2	Organic material with silt	43	51	73
AB1-9	Silt with clay and organic material	87	47	88
AB3-3	Silt and stratified organic material	87	47	87
AB6-6	Silt with some fine sand	117	41	88
AB3-8½	Silty sand with organic material	150	39	98
		Average	52	92

Plastic Soils at Aklavik.- Plastic soils were scarce at Aklavik and the ones noted in Table 2 were all that were encountered. Average values for the liquid and plastic limits were 38.0 and 28.4 per cent, while the plasticity index averaged 9.6 per cent. It is interesting to note that all of the natural moisture contents are in excess of the liquid limit, i.e., although the soil has a solid form when frozen, it is transformed into a "liquid" or "slurry" if the contained water melts.

Organic Contents.- Present methods of reporting organic contents in soils are based on a weight basis, i.e., the organic content is defined as a ratio of the weight of combustible material to the weight of incombustible material expressed as a percentage. Since the difference in relative weights of organic material and mineral particles is large, organic contents expressed as percentages are low. Furthermore, significant visual differences in organic contents are not reflected proportionately in the results of organic content tests.

These two points are illustrated well by test results shown in Table 3. The organic contents of the nine test samples average 11.6 per cent and range from 8.4 to 19.1 per cent. An organic content of 8.4 per cent was found in a silt, one foot from the ground surface where organic material was suspected but was not discernible visibly. On the other hand an organic content test on what was thought to be practically "pure" organic material gave a test result of 19.1 per cent or an increase of only 10.7 per cent. Accordingly, extensive sampling for organic content tests was not carried out because of the questionable value of the data in this form.

TABLE 2

Atterberg Limits of Some Aklavik Soils

Sample Number	Natural Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %
AB1-5	62.5	39.8	28.9	10.9
AB3-5	123.1	37.3	26.9	10.4
AB4-23	48.6	37.9	32.0	5.9
AB5-10	45.8	39.0	29.1	9.9
AB6-5	91.4	39.4	26.9	12.5
AB6-7	66.6	38.8	29.2	9.6
AB6-20	55.0	40.4	29.7	10.7
AB12-26	55.8	36.8	27.5	9.3
AB16-21	48.1	33.2	25.6	7.6
		38.0	28.4	9.6

TABLE 3

Organic Contents of Some Aklavik Soils

Sample No.	Organic Content %	Field Description of Organic Material and Parent Material
AB1-12	19.1	Mixture of flakey and stringy dark brown to black organic material well bonded with use but no readily discernible ice segregation. Small pockets or lenses of silt with hairline to 1/16-inch ice segregation.
AB1-15.3	15.7	Hairline to 1/4-inch stratified organic material and silt.
AB1-18	12.4	Hairline stratifications of silt and organic material.
AB2-10a	10.9	Silt with black traces of organic material and some small twigs.
AB1-14.5	9.9	Silt with clay and some hairline strata of black organic material.
AB1-25	9.9	Silt with hairline to 1/8-inch strata of organic material.
AB1-22	9.8	Silt with hairline strata of organic material.
AB1-7	8.6	Silt with hairline strata of organic material.
AB2-1	8.4	Silt, one foot from ground surface, no organic material discernible visibly.

10. Conclusion

This report records the first attempts of the Division of Building Research in the development of site investigation techniques and equipment in permafrost areas. The Division is aware that much of the information is descriptive but early publication was prompted by the present increased interest and work in the North. It is also hoped that soil data for the Aklavik region will contribute to a wider knowledge of northern soils. Comments on the report, especially on drilling and sampling methods, will be welcomed.

11. References

(1) Pihlainen, J. A. (1951). Building foundations on permafrost, Mackenzie Valley, N.W.T. Technical Report No. 8, Division of Building Research, N.R.C., Canada. June 1951, 42p., illus.

12. Bibliography

As may be imagined, there is no real "literature" of drilling in permafrost, so that the work described in this paper was based only upon experience -- that of the authors themselves, of the American authorities who developed the drill-rig, and of a few Canadians with experience in drilling in the North, notably Mr. P.C. Bremner and other officers of the Canadian Longyear Co. Ltd. As a convenient reference, the following list is included with the paper: it contains all references known to the authors in any way relevant to the subject matter of the paper.

Cumming, J. D. (1951). Diamond drill handbook, J. K. Smit and Sons of Canada Ltd., Toronto; xxiii + 501, illus., Toronto 1951.

Pchelincev, A. M. (1951). A new drill for taking samples of frozen ground and soils with the structure undistrubed, Pochvoredeniye, Vol. 1, pp. 57-59 (Translation by E.R. Hope, Defence Research Board, Canada, T 58 R, January 15, 1954).

Hall, P. B. (1952). Surface and blast hole diamond drilling in Canada, Journal of the Chemical, Metallurgical and Mining Society of S. Africa, Vol. 52, pp. 430-449 (esp. p.441), April 1952.

MacCarthy, G. R. (1952). Geothermal investigations on the Arctic slope of Alaska, Trans. Am. Geophys. Union, Vol. 33, pp. 589-593, August 1952.

Thomson, A., and P. C. Bremner (1952). Permafrost drilling and soil-temperature measurements at Resolute, Cornwallis Island, Canada, Nature, Vol. 170, pp. 705-6, 25 October 1952.

Vonder, K. L. (1953). Operating problems in oil exploration in the Arctic, The Petroleum Engineer, Vol. 25, pp. B.12-B.18, February, 1953.

Bremner, P. C. (1954). Diamond drilling in permafrost at Resolute Bay, Northwest Territories, Publication of the Dominion Observatory, Vol. XVI, No. 12, 1954.

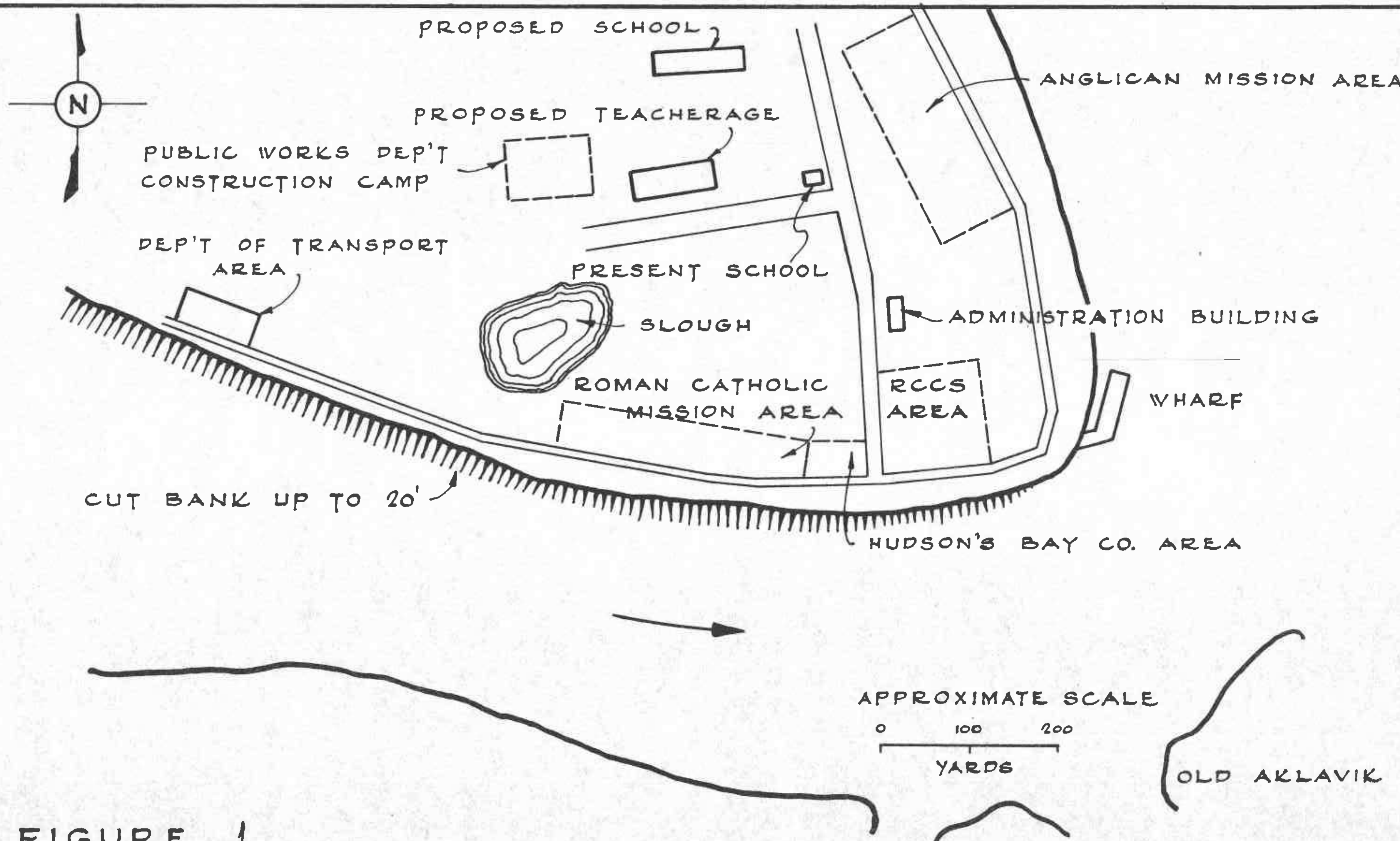


FIGURE 1

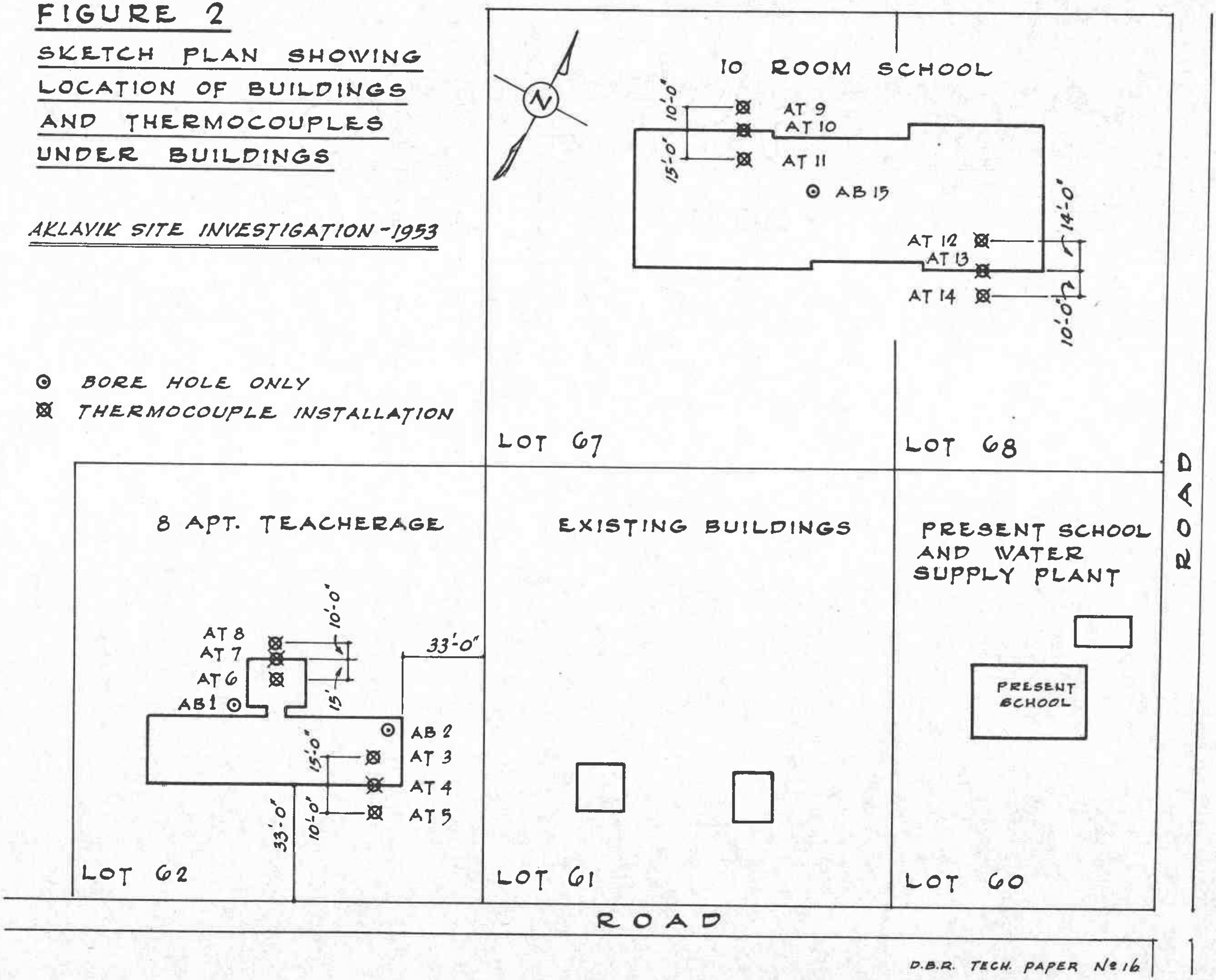
SKETCH PLAN OF AKLAVIK, N.W.T. SHOWING APPROX. LOCATION OF PROPOSED SCHOOL & TEACHERAGE

D.B.R TECH. PAPER No16

FIGURE 2

SKETCH PLAN SHOWING LOCATION OF BUILDINGS AND THERMOCOUPLES UNDER BUILDINGS

AKLAVIK SITE INVESTIGATION - 1953



⊙ BORE HOLE ONLY

⊠ THERMOCOUPLE INSTALLATION

Fig. 3 Thermocouple installations at the proposed teacherage site. The organic cover averages 12 inches and the area has been cleared of shoulder-high alder willow thicket. Thermocouple installations AT3, 4, and 5 are under a typical floor section while AT6, 7, and 8 are located under the furnace room.

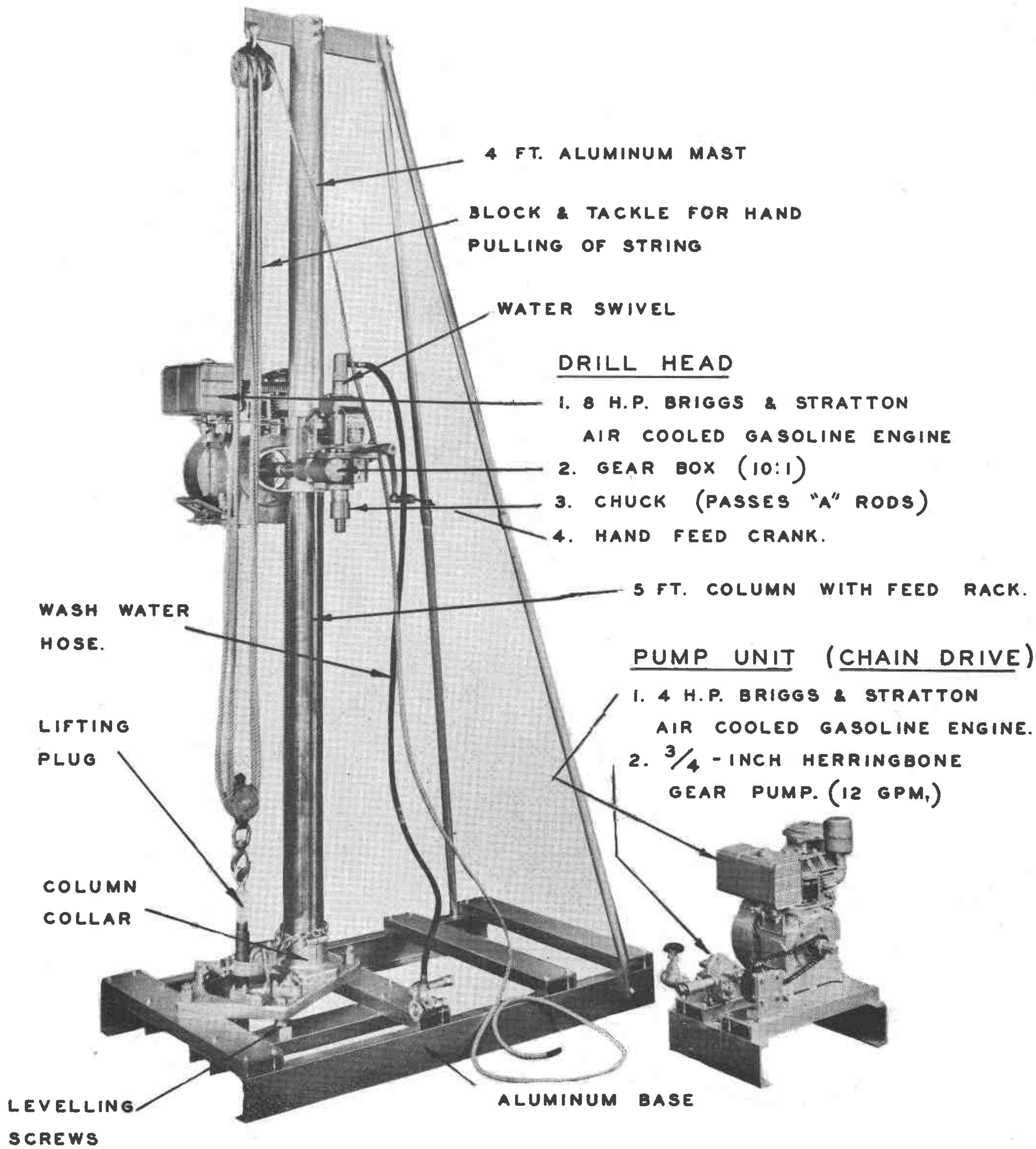
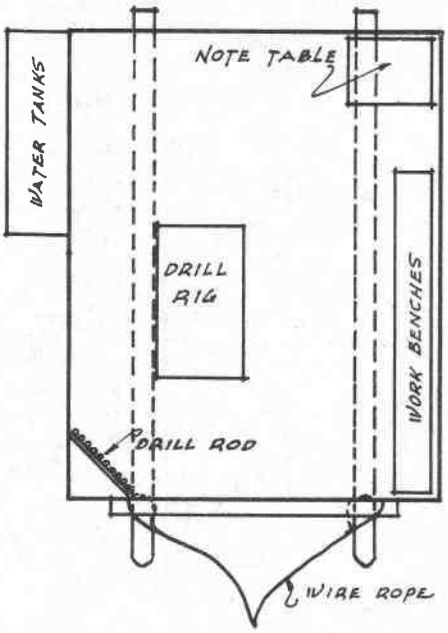


FIGURE 4

CONCORE TYPE E5-48 "SPECIAL"
PORTABLE CORE CUTTING MACHINE

P.D. 11·2·54

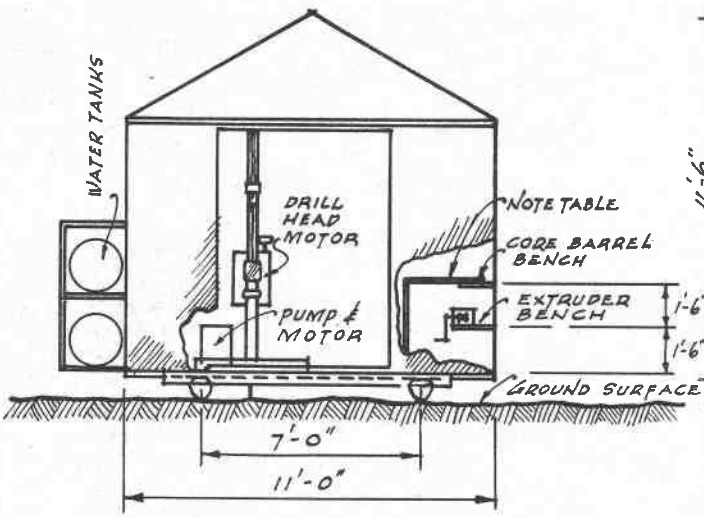
D.B.R. TECH. PAPER No 16
BR. 574



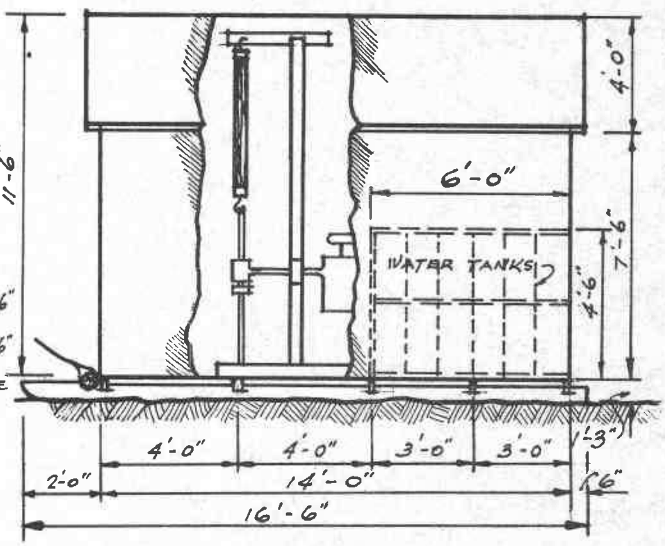
PLAN

DATA

- NOTE TABLE 2'-0" x 2'-6"
- WORK BENCHES 2"x8" PLANKS 9'-9" LONG
- WATER TANKS - EACH HOLDS 90 GALLONS. TOTAL = 180 GALLONS
- FLOOR BEAMS - 4"x6" x 11'-0"
- DOOR SPACE - 64" x 80" (TWO DOORS OPENING OUTWARDS)



FRONT ELEVATION



SIDE

FIGURE 5

DRILL RIG SHELTER

T.N.B. JAN 29/54

D.B.R. TECH. PAPER No 16
D.B.R. DWG. 562

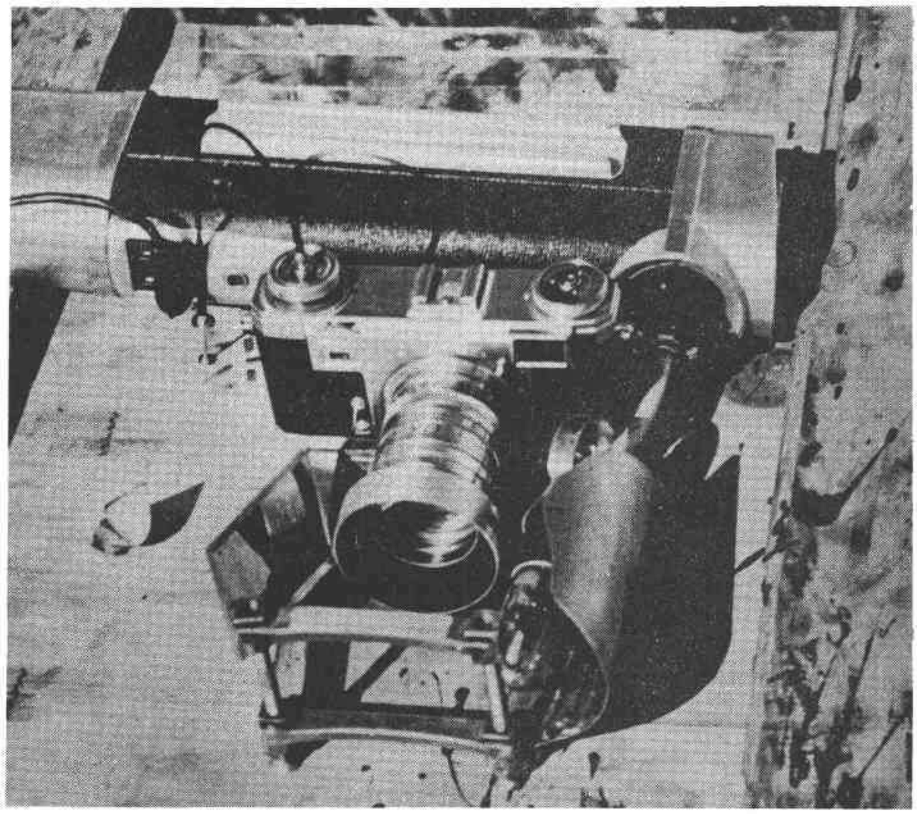


Fig. 6 - The camera assembly that was used to photograph frozen cores. The camera is a Contax with four supplementary lenses equivalent to Portra 10. The mirrored light source is a Powell Repeater Flash with a 1/1500 sec. light duration and the lens opening used was f22. The unit is the personal property of Dr. T. Hunt, National Health and Welfare Department.

Fig. 7 - The various types of soil samples are shown ready for shipment. The sealed tin and jar in front were used for moisture and organic contents. The sealed jar on the left contains a unit weight sample while the unsealed glass jar was used for specific gravity, grain size distribution, and Atterberg limit tests. Note large volume of water in unsealed glass jar.

BOREHOLE AB-6

	1st Core	Hole started 1' - 8" below ground surface -- at top of frozen soil.
		1st Core from 1' - 8" to 6' - 7" 48" core recovery.
1st Foot	Organic material with some silt, twigs, and roots. Ice lenses DZ from hairline to 3/16".	Field Density Sample 5 1/16" x 2" Ø
2nd Foot	0 - 2" - frozen wood, clear ice separating mass into stringy wood fibres and ice.	
	2" - 6" - Silt with much organic material of twigs, etc. Ice segregation DZ from hairline to 3/16". Ice dikes DZ have columna structure 6" - 12" as above but more silt.	moisture content sample
3rd Foot	0 - 6" brown silt with much large DE ice segregation from hairline to 1/4 inch -	
	1/4" average large ice segregation DE	moisture content sample (a) } Specific Gravity Sample
	6" - 12" as above but DE fine ice segregation	moisture content sample (b) } Specific Gravity Sample
4th Foot	0 - 1/2" - clear ice - no structure 1/2" - 12" - light brown silt with DE fine ice segregation.	

Fig. 8 - Typical notes from the field log.

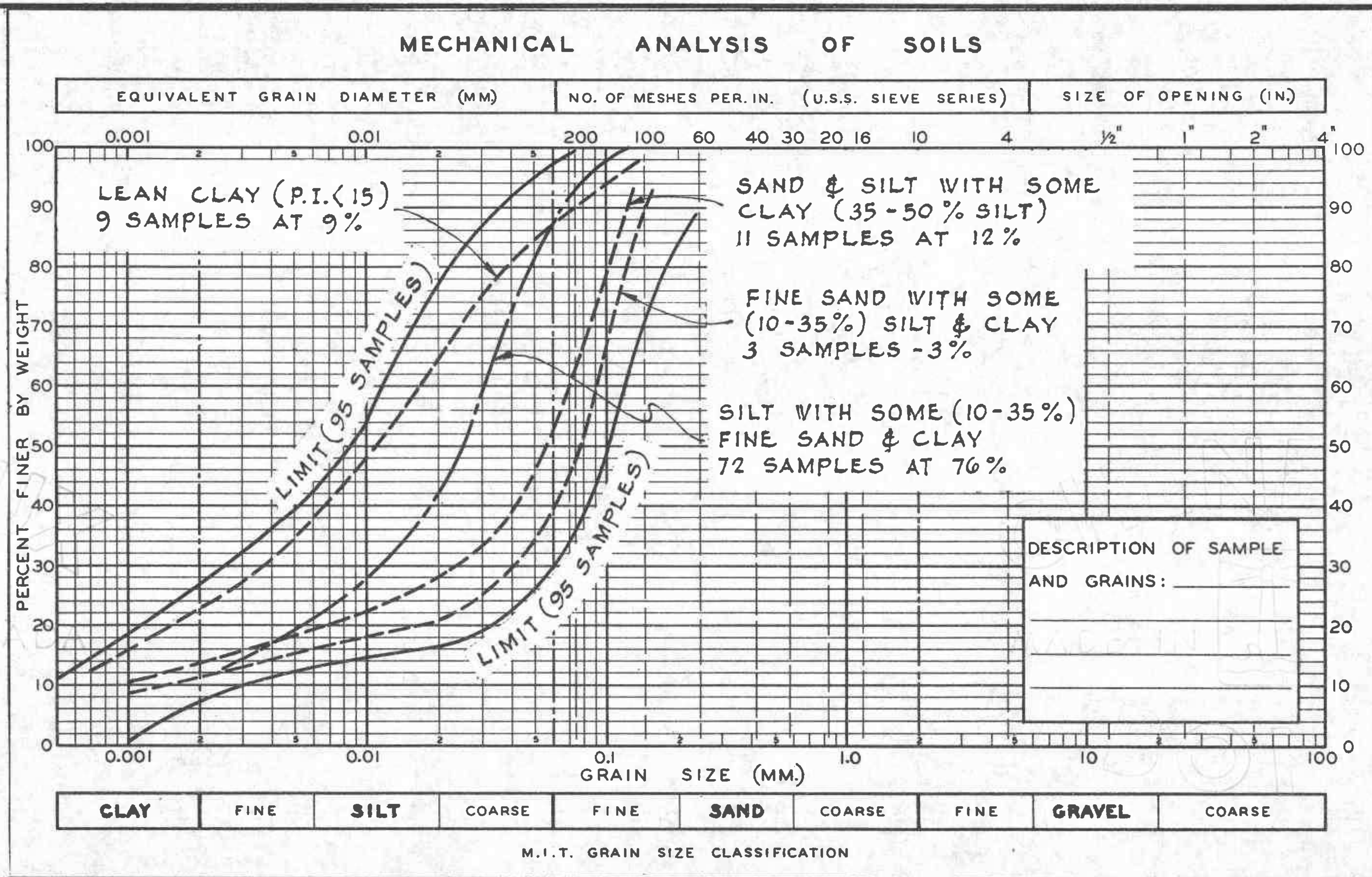


FIGURE 9: AKLAVIK PERMAFROST INVESTIGATIONS (1953)

REPRESENTATIVE GRAIN SIZE DISTRIBUTION CURVES, LIMITS, & FREQUENCY OF OCCURRENCE

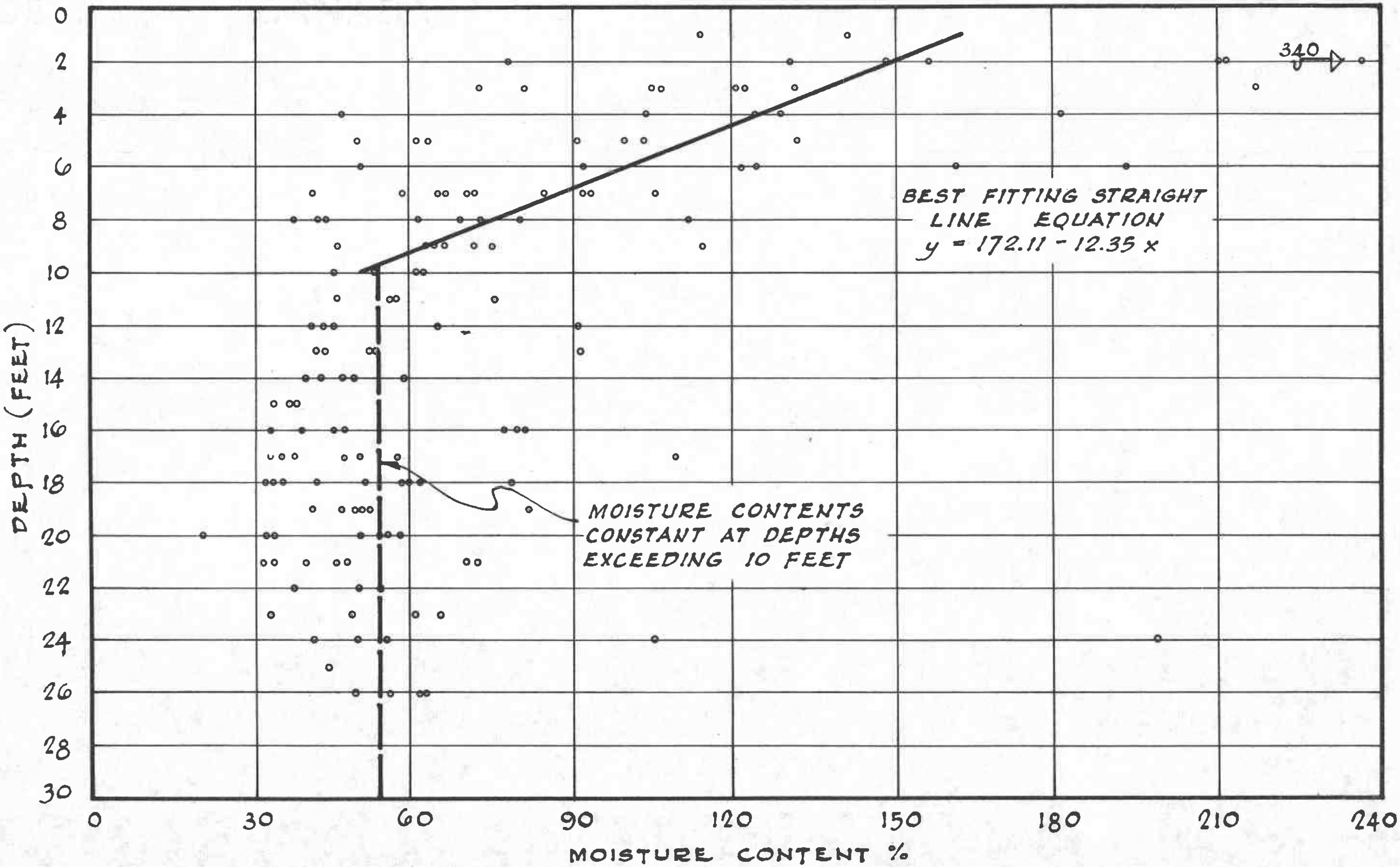


FIGURE 10

AKLAVIK PERMAFROST INVESTIGATION 1953 MOISTURE CONTENT VERSUS DEPTH

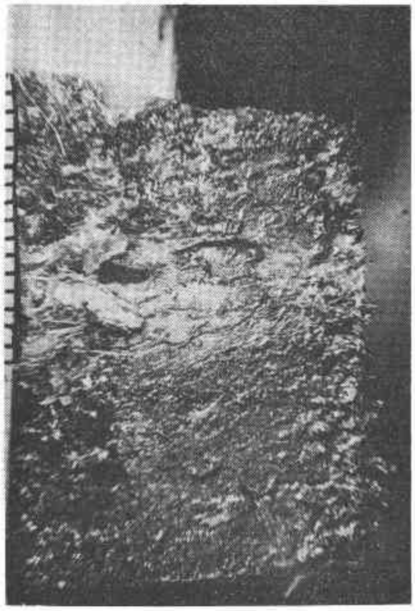
(16 HOLES, 153 SAMPLES)

APPENDIX 1

PHOTOGRAPHS AND DESCRIPTIONS OF TYPICAL FROZEN CORES

Scale

1-inch with
16 Divisions



Sample
Depth
3 feet

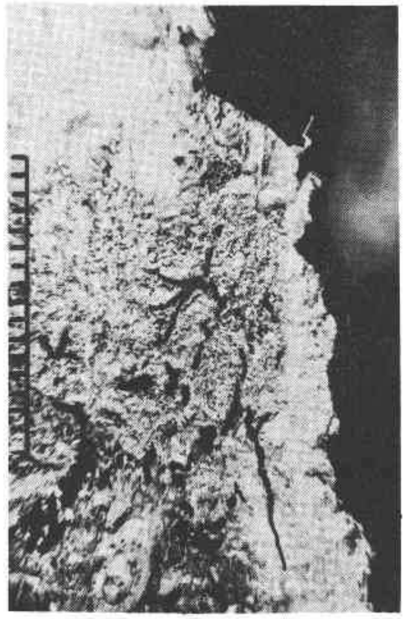
Picture No. 781

Core Description

Organic material, stringy and fibrous with partly decomposed twigs up to 3/8 inch in diameter and pockets of silt. Ice bonds fibrous organic material uniformly although random irregular ice segregation also noted. Moisture content 212%.

Scale

1-inch with
16 Divisions



Sample
Depth
4 feet

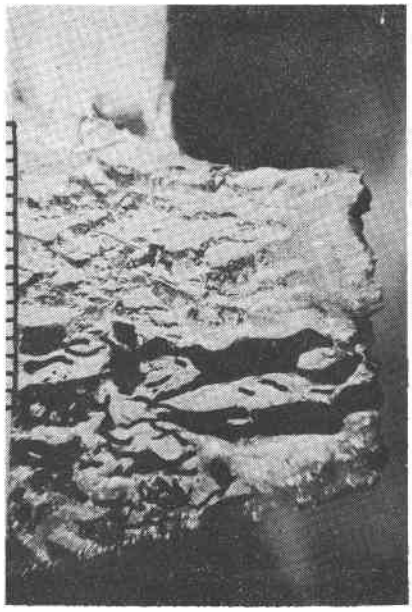
Picture No. 784

Core Description

Greyish brown silt with some clay and fine sand. Random pockets of organic material. (Note twig 1/4-inch diameter at bottom of photograph). Ice segregation irregular with hairline to 3/8-inch. Ice dikes or veins random spaced (some darkened in above photograph).

Scale

1-inch with
16 Divisions



Sample
Depth
4 ft. 6 inches

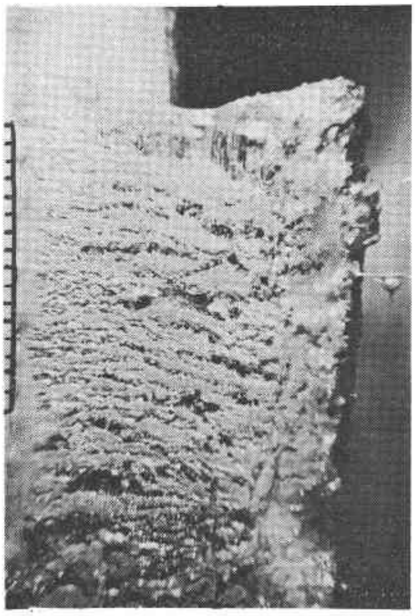
Picture No. 785

Core Description

Grey silt with some fine sand and clay. Ice segregation irregular from hairline to 3/16-inch. Ice segregation in lower half of photograph darkened to show form and extent. Moisture content 104%.

Scale

1-inch with
16 Divisions



Sample
Depth
6 ft. 6 inches

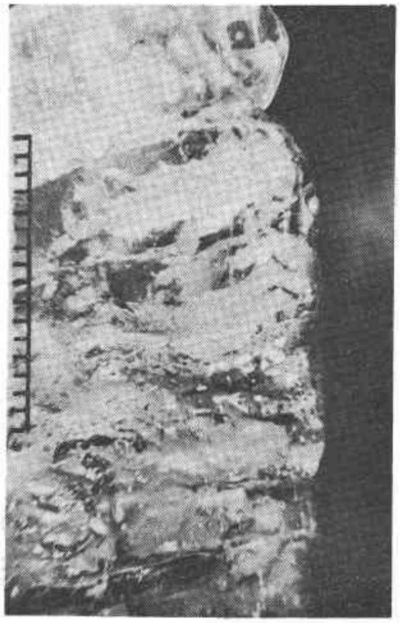
Picture No. 786

Core Description

Light brown silt with fine sand. Ice segregation from hairline to 3/16-inch (top right). Note core melting at both edges. Moisture content 122%.

Scale

1-inch with
16 Divisions



Sample
Depth
7 feet

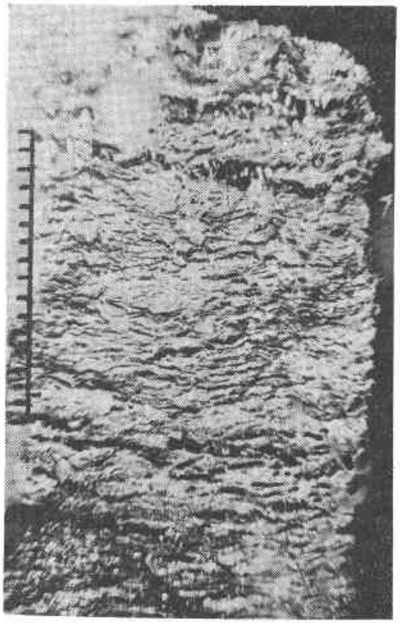
Picture No. 787

Core Description

Ice lenses averaging 1/4-inch but as large as 5/8-inch with their inclusions of silt.

Scale

1-inch with
16 Divisions



Sample
Depth
8 feet

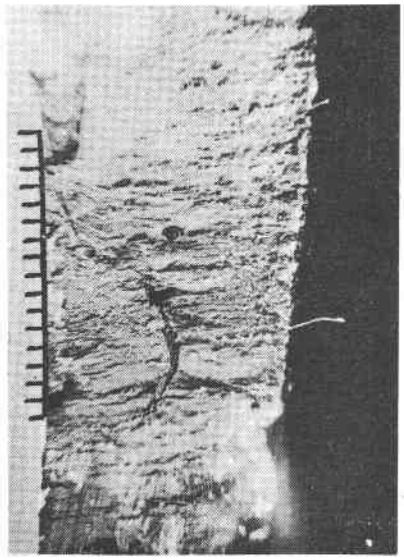
Picture No. 788

Core Description

Light brown silt with fine sand. Ice segregation predominantly horizontal and averaging hairline in size. Top of core photograph with ice segregation averaging 1/16-inch. Moisture content in hairline ice segregation 74%.

Scale

1-inch with
16 Divisions



Sample
Depth
11 feet

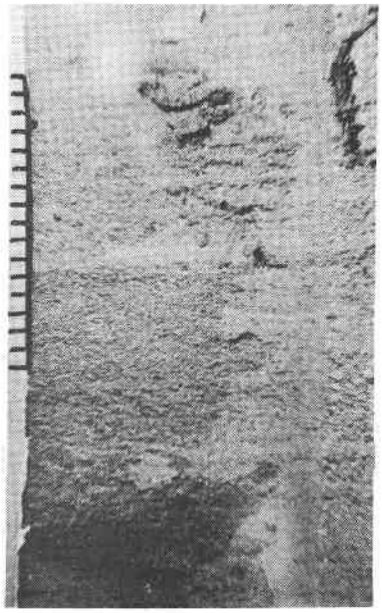
Picture No. 792

Core Description

Light brown silt with fine sand and clay. Hairline ice segregation. Also note ice surrounding small twig in centre of photograph.

Scale

1-inch with
16 Divisions



Sample
Depth
13 feet

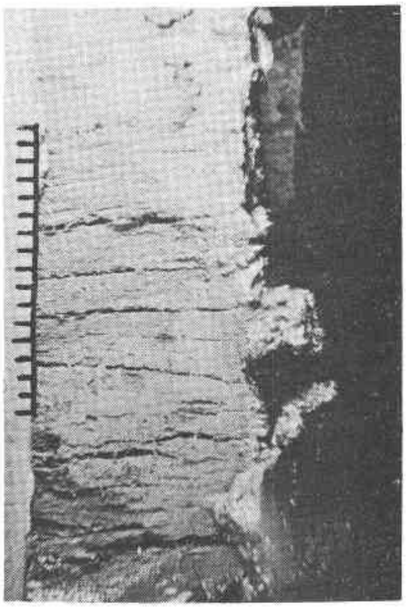
Picture No. 793

Core Description

Light brown silt with some fine sand and clay. Very random hairline ice segregation but predominantly particles well bonded with ice. Moisture content 53%.

Scale

1-inch with
16 Divisions



Sample
Depth
16 ft. 6 inches

Picture No. 795

Core Description

Light brown sandy silt with hairline ice segregation and regularly spaced at approximately 1/8-inch. Moisture content 47%.

APPENDIX 2

A Note on the Statistical Analysis of Aklavik Moisture Contents with Depth

After the Aklavik moisture contents were plotted at their respective depths, visual examination suggested some regression correlation. Using all of the data for depths from zero to 28 feet, successive trials for the best fitting second and third degree polynomials did not show significant correlation for a 5 per cent level of significance (see Table 1 of this Appendix).

Regression correlation for the fourth degree polynomial appeared to be a time-consuming task and so it was decided to subdivide the data arbitrarily on the basis of depth. The large moisture contents and sample variances in approximately the first ten feet and the relatively constant moisture contents in the remaining 18 feet suggested a convenient subdivision and these results were analysed separately. It should be noted that this subdivision was quite arbitrary but it is thought justifiable since many engineering works, such as roads, ditches, sewer and water lines, are mainly in the first 10 feet while ordinarily only foundations extend to the deeper depths.

Using moisture content data from the first 10 feet, the statistical hypothesis that the true regression is a straight line of the equation

$$y = 172.11 - 12.35x$$

where y is the moisture content as a per cent and x is the depth in feet, was accepted for a 5 per cent level of significance (see Table 1 of this Appendix). The low correlation ratio should be noted and hence this equation should be used with caution.

From Table 1, it can be seen that regression correlation for moisture contents at depths from 11 to 28 feet is not significant for a 5 per cent level of significance. Accordingly, the moisture content can be assumed to be 54 per cent for this significance level.

TABLE 1

SUMMARY OF STATISTICAL ANALYSES;
AKLAVIK MOISTURE CONTENTS WITH DEPTH

Source	Degrees of Freedom	Sums of Squares	Mean Squares	Remarks
DATA FROM 0 - 28 FEET				
Straight Line				
Between Columns	27	178,819	6,622	$\rho^2 = 0.36$
Due to Regression	1	75,235	75,235	$\eta^2 = 0.85$
Deviation from Regr.	26	103,582	3,984	
Within Columns	125	31,320	251	
Totals	152	210,139		
Parabola				
Between Columns	27	178,819	6,622	
Due to Regression	2	131,466	65,733	$\rho^2 = 0.62$
Deviation from Regr.	25	47,353	1,894	$\eta^2 = 0.85$
Within Columns	125	31,320	251	
Totals	152	210,139		
DATA FROM 0 - 10 FEET				
Straight Line				
Between Columns	9	91,053	10,117	
Due to Regression	1	69,237	69,237	$\rho^2 = 0.369$*
Deviation from Regr.	8	21,816	2,727	$\eta^2 = 0.486$
Within Columns	56	96,191	1,718	
Totals	65	187,244		
DATA FROM 11 - 28 FEET				
Between Columns	17	9,296	546.8	$\left(\frac{546.8}{508.9}\right.$ not significant for $\alpha = 0.05$
Within Columns	69	35,111	508.9	
Totals	86			

no regression
correlation possible

APPENDIX 3

METHODS OF DESCRIBING AND CLASSIFYING FROZEN SOILS

Proposed by

THE FROST EFFECTS LABORATORY CORPS OF ENGINEERS, U. S. ARMY NEW ENGLAND DIVISION, BOSTON, MASS.

JUNE 1951

INVESTIGATION OF DESCRIPTION CLASSIFICATION, AND STRENGTH PROPERTIES OF FROZEN SOILS FISCAL YEAR 1951

APPENDIX A: METHODS OF DESCRIBING AND CLASSIFYING FROZEN SOILS

LIST OF PLATES

APPENDIX A

METHODS OF DESCRIBING AND CLASSIFYING FROZEN SOILS

Existing types of classification schemes for frozen soils are mainly structural classifications such as those shown on Plate A1. Here the principal strata are identified as "Permafrost", "Frost Zone", "Active Zone", etc. This type of system provides no way of describing the appearance and physical properties upon which depend the engineering behaviour characteristics of the materials in the frozen state and the changes which the materials undergo upon thawing. Also if one wishes to describe and classify a specimen of soil frozen in the laboratory, the terminology shown on Plate A1 is entirely inapplicable. A system is therefore needed which is independent of the geologic history or mode of origin of the material and which can be easily expanded or contracted in order to cover as much or as little detail as desired.

A preliminary classification and description system for frozen soils which attempts to meet these needs is shown on Plate A2. As indicated in Part I on this Plate, it is proposed that the soil phase be identified independently of any characteristics resulting from the frozen condition of the material, using the Department of the Army Uniform Soils Classification System. The basic elements of the latter system are indicated on Plate A3. The soil characteristics resulting from the frozen state of the material may be then added to the soil description in accordance with the organizational system shown in Part II of Plate A2. Major ice strata found in the soil may be described as shown in Part III of Plate A2.

Referring to Column 2, Part II of Plate A2, the simple and elementary adjectives "frozen" and "unfrozen" should be used as applicable in any logs of explorations in frozen soil regions.

As shown in Column 3 of Plate A2, frozen soils may be divided into two major groups -- homogeneous and heterogeneous frozen soils. In homogeneous frozen soils the ice phase is uniformly dispersed through the soil and no appreciable concentrations of ice have been formed in the freezing process which are distinguishable to the eye. Heterogeneous frozen soils, on the other hand, show distinct ice concentrations. At present it is believed it may be sufficient to divide homogeneous frozen soils into only two main types: (a) well-bonded frozen soils in which the ice cements the material into a hard, solid mass, and (b) poorly-bonded to friable materials in which the ice only weakly cements the particles together. The heterogeneous frozen soils have been divided into four principal sub-groups on the basis of the form in which the ice concentrations within the soil mass appear. These four principal ice forms are: (a) stratified ice lenses or layers, (b) irregularly orientated lenses, veins, etc., (c) coatings of ice on individual particles, and (d) individual ice crystals within the soil mass.

In addition to the soil name, with the descriptive adjectives as indicated in Columns 2 and 4 of Plate A2, further descriptive terms may be added where applicable, as indicated in Column 6 of Plate A2, covering such features as thickness, orientation and spacing of ice lenses, etc. When greater detail and more specific information than is obtainable from visual inspection is desired, physical tests and measurements may be performed on the frozen soil as indicated in Column 7 of Plate A2, and the resulting data may be added to the previous descriptive information to give a complete picture of the characteristics of the frozen soil. Plate A4 shows an example of the use of the frozen soil classification system outlined on Plate A2 as applied in preparation of the log of a subsurface exploration. If temperature, density and other measured data were obtained, they would be added after the appropriate descriptions on Plate A4.

The adjective description system shown in Part III on Plate A2 is based on a preliminary ice classification system proposed by the Frost Effects Laboratory in "Final Report on Development of Ice Mechanics Test Kit for Hydrographic Office, U. S. Navy" dated March 1950.

The letter symbols shown in Column 5 of Plate A2 are intended for convenience in preparing graphic logs of explorations or geologic profiles and may be added to the Department of the Army Uniform Soil Classification System symbols in the manner shown at the bottom of Plate A2 or on Plate A4. However the word description system is the fundamental feature of the classification system proposed, and the temptation to regard the letter designations as other than a subsidiary part of the system should be resisted.

It is not expected or intended that all the detail and descriptive material outlined on Plate A2 should always be shown. In much simple engineering work only the most fundamental details need be recorded. In many scientific studies, on the other hand, very detailed records may be necessary.

The proposed classification system will undoubtedly require modifications in the future in order to fit requirements not now foreseen. It is recommended it be tried in classification and description of soils in field explorations in permafrost areas and in seasonal frost areas, and in laboratory studies. The sooner any needed modifications are determined, the better, since frozen soil data are rapidly accumulating and adequate identification of the materials involved is essential in order that the results of different investigations may be correlated with each other.

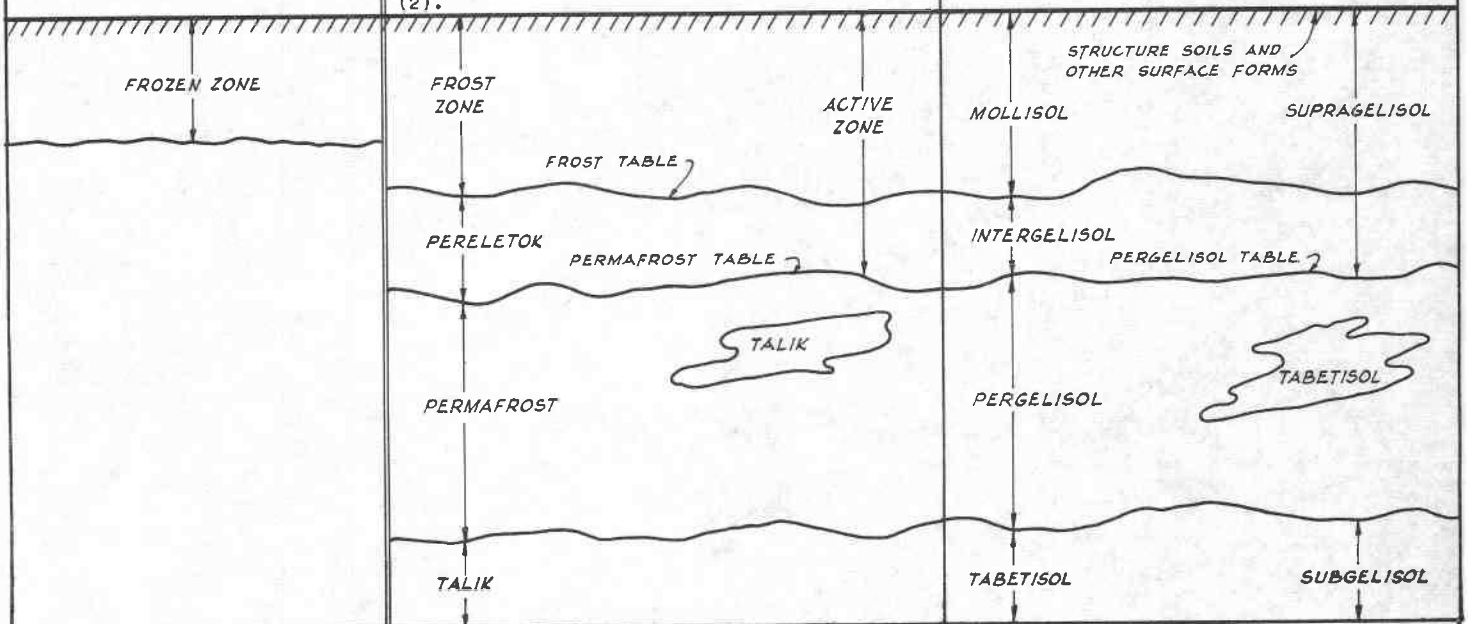
PLATE A1

ILLUSTRATIONS OF TERMINOLOGY USED OR PROPOSED BY OTHERS TO IDENTIFY CHARACTERISTIC STRUCTURAL CLASSIFICATIONS OR DIVISIONS OF SOILS PRODUCED BY FREEZING PHENOMENA

June 1951

Frost Effects Laboratory, New England Division, Corps of Engineers, U.S. Army, Boston, Mass.

Areas of Only Seasonal Frost Action	Areas of Permanently Frozen Ground	
	Terms as Defined by Permafrost Division, St. Paul, Corps of Engineers, U.S. Army (1) or by Muller in Strategic Engineering Study No. 62 (2).	Terms Suggested by Kirk Bryan (3)



DEFINITIONS

Frost Action is a general term used in reference to freezing of moisture in materials and the resultant effects on these materials and structures of which they are a part.

Frozen Zone is the range of depth within which the soil is frozen. The frozen zone may be bounded both top and bottom by unfrozen soil.

Permafrost - Permanently frozen subsurface material not subject to seasonal freezing and thawing.(1)

Active Zone - The entire layer of ground above the upper surface of the permafrost layer, most of which freezes and thaws every year.(1)

Frost Zone - The top layer of ground subject to seasonal freezing and thawing. Where seasonal freezing penetrates to the upper surface of the permafrost layer, the frost zone and active zone are identical.(1)

Frost Table - A more or less irregular surface that represents the penetration of spring and summer thawing of the seasonal frozen ground.(2)

Permafrost Table - A more or less irregular surface which represents the upper limit of permafrost.(2)

Pereletok - A frozen layer at the base of active layer which remains unthawed for one or two summers.(2)

Talik - A Russian term for a layer of unfrozen ground between the seasonal frozen ground and the permafrost. Also applies to an unfrozen layer within the permafrost as well as to the unfrozen ground beneath the permafrost.(2)

Pergelisol - Permanently or perennially frozen ground. Same as "permafrost".(3)

Mollisol - Seasonally thawed ground above the pergelisol.(3)

Intergelisol - A layer of frozen ground between the pergelisol and the mollisol, which may persist for one or several years. Same as "pereletok".(3)

Tabetisol - Unfrozen ground above within or below the pergelisol. Same as "talik".(3)

Pergelisol Table - Top of pergelisol. Same as "permafrost table".(3)

Supragelisol - Zone above the pergelisol.(3)

Subgelisol - Zone of unfrozen ground below permanently frozen ground.(3)

Sources of Terminology and Definitions:

(1) Permafrost Division, St. Paul District, Corps of Engineers, U. S. Army, "Comprehensive Report, Investigation of Military Construction in Arctic and Subarctic regions 1947-48", prepared for Office of the Chief of Engineers, Airfields Branch, Engineering Division, Military Construction, June 1950 (Restricted).

(2) Muller, Siemon Wm. "Permafrost or Permanently Frozen Ground and Related Engineering Problems", U. S. Geological Survey, Special Report, Strategic Engineering Study No. 62, Prepared for Military Intelligence Division, Office, Chief of Engineers, U. S. Army, 1945. Reprint by J. W. Edwards, Inc., Ann Arbor, Michigan, 1947.

(3) Bryan, Kirk, "Cryopedology - The Study of Frozen Ground and Intensive Frost-Action with Suggestions on Nomenclature", American Journal of Science, Vol. 244, 1946, pp. 622-642.

PLATE A2

FROZEN SOILS INVESTIGATION

A PRELIMINARY NON-GENETIC CLASSIFICATION AND DESCRIPTION SYSTEM FOR FROZEN SOILS

Frost Effects Laboratory, New England Division, Corps of Engineers, U. S. Army, Boston, Mass.

June 1951

PART I DESCRIPTION OF SOIL PHASE (Independent of frozen state)	Classify Soil Phase by the Department of the Army Uniform Soil Classification System (See Plate A3).

	Condition of Material (2)	Major Groupings (3)	Key Descriptive Terms Relating to Ice Phase (4)		Letter (5)	Field Identification (6)	Pertinent Properties of Frozen Materials Which May be Measured by Physical Tests to Supplement Field Identification. (7)	Guide Criteria (8)
PART II DESCRIPTION OF FROZEN SOIL	FROZEN or UNFROZEN	Homogeneous frozen soils. Soils in which all the water is frozen within the natural voids existing in the soil, without observable accumulation of ice crystals, ice lenses or frost forms exceeding in volume such natural void spaces. B	NO ICE SEGREGATION	WELL-BONDED W	BW	Identify by visual examination State degree of ice segregation	In-Place Temperature Density and Void Ratio a. In Frozen State b. After Thawing in Place Water Content (total H_2O, including ice) a. Average b. Distribution Strength a. Compressive b. Tensile c. Shear d. Adfreezing Elastic Properties Plastic Properties Thermal Properties Ice Crystal Structure (using optical instruments). a. Orientation of Axes b. Crystal Size c. Crystal Shape d. Pattern of Arrangement	Generally all gravelly and sandy soils which contain less than 3% of grains by weight finer than 0.02 mm. in diameter are not susceptible to significant ice segregation* within the soil mass during freezing. They therefore usually occur as Homogeneous Frozen Soils. In permafrost areas ice wedges or other ice bodies may be found within such soils, but it is considered their mode of origin may be different. Finer-grained soils may also be homogeneously frozen if insufficient moisture is available to permit ice segregation.
				POORLY BONDED to FRIABLE P	BP	Identify by visual examination State degree of ice segregation		
		Heterogeneous frozen soils. Soils in which a part of the water in the soil is frozen in the form of observable ice crystals, ice lenses or other frost forms, occupying space in excess of the original soil voids. D	STRATIFIED ICE LENSES OR LAYERS E		DE	Identify by visual examination For ice formations, record following as applicable: Location Orientation Thickness Length Spacing Hardness, Structure, Color } per Part III, below		Generally all silt and clay soils and gravelly and sandy soils which contain more than 3 per cent of grains finer than 0.02 mm. in diameter by weight are susceptible to occurrence of ice segregation within the soil mass and therefore occur as Heterogeneous Frozen Soils if frozen at normal rates with water readily available. These soils have been classified into the folllowing 4 groups listed in order of increasing susceptibility to ice segregation and degree of weakening during thawing: Group / Description F1 Gravelly soils containing between 3 and 20 per cent finer than 0.02 mm. by weight F2 Sands containing between 3 and 15 per cent finer than 0.02 mm. by weight. F3 (a) Gravelly soils containing more than 20 per cent finer than 0.02 mm. by weight and sands, except fine silty sands, containing more than 15 per cent finer than 0.02 mm. by weight. (b) Clays with plasticity indices of more than 12, except varved clays. F4 (a) All silts including sandy silts. (b) Fine silty sands containing more than 15 per cent finer than 0.02 mm. by weight. (c) Lean clays with plasticity indices of less than 12. (d) Varved clays.
			IRREGULARLY ORIENTED LENSES, VEINS, ETC. Z		DZ			
			COATINGS ON PARTICLES O		DO	Identify by visual examination For ice formations, record following as applicable: Location Type and Size of Particles Thickness		
			CRYSTALS X		DX	Identify by visual examination For ice formations, record following as applicable: Location Size Shape Pattern of Arrangement		
PART III DESCRIPTION OF ICE STRATA IN SOIL		ICE or Ground Ice. Soil phase is negligible or absent.	Designate material as ICE and use descriptive terms as follows, usually one item from each group, as applicable: Hardness: HARD, SOFT (of mass, not individual crystals). Structure: CLEAR, CLOUDY, POROUS, CANDLED, GRANULAR, STRATIFIED Color: COLORLESS, GRAY, BLUE (examples) Admixtures: CONTAINS FEW THIN SILT INCLUSIONS. (example).		ICE	Identify by visual examination	Same as Part II above, so far as applicable, with special emphasis on Ice Crystal Structure.	

NOTES:

The letter symbols shown are to be affixed to the Uniform Soil Classification letter designations, or may be used in conjunction with graphic symbols, in exploration logs or geological profiles. Example - a lean clay with essentially horizontal ice lenses:


or

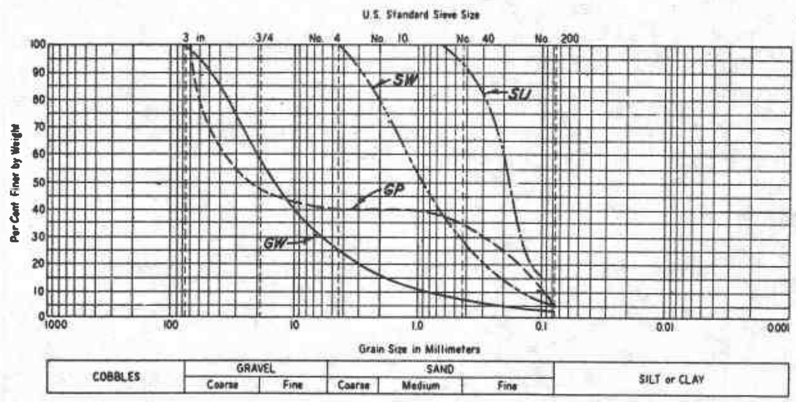

The descriptive name of the frozen soil type and a complete description of the frozen material are the fundamental elements of this classification scheme. Additional descriptive data should be added where necessary. The letter symbols are entirely secondary and are intended only for convenience in preparing graphical presentations. Since it is frequently impractical to describe ice formations in frozen soils by means of words alone, sketches and photographs should be used where appropriate, to supplement descriptions.

*Ice segregation in soils is the growth of bodies of ice during the freezing process, most commonly as ice lenses or layers oriented normal to the direction of heat loss, but also as veins and masses having other patterns.

UNIFORM SOILS CLASSIFICATION SYSTEM								
MAJOR DIVISIONS		LETTER	SYMBOL		NAME	FIELD IDENTIFICATION		LABORATORY CLASSIFICATION TESTS
			Hatching	Color		Dry Strength	Other Pertinent Features	
COARSE-GRAINED SOILS	Gravels and Gravelly Soils	GW		RED	Gravel or Sandy Gravel, well-graded	None	Gradation, grain shape	Sieve Analysis
		GP			Gravel or Sandy Gravel, poorly graded	None	Gradation, grain shape	Sieve Analysis
		GU			Gravel or Sandy Gravel, uniformly graded	None	Gradation, grain shape	Sieve Analysis
		GM		YELLOW	Silty Gravel or Silty Sandy Gravel	None to slight	Gradation, grain shape, examination of fines	Sieve Analysis LL and PL on "Minus 40"
		GC			Clayey Gravel or Clayey Sandy Gravel	Medium to high	Gradation, grain shape, examination of fines	Sieve Analysis LL and PL on "Minus 40"
	Sands and Sandy Soils	SW		RED	Sand or Gravelly Sand, well-graded	None	Gradation, grain shape	Sieve Analysis
		SP			Sand or Gravelly Sand, poorly graded	None	Gradation, grain shape	Sieve Analysis
		SU			Sand or Gravelly Sand, uniformly graded	None	Gradation, grain shape	Sieve Analysis
		SM		YELLOW	Silty Sand or Silty Gravelly Sand	None to slight	Gradation, grain shape, examination of fines	Sieve Analysis LL and PL on "Minus 40"
		SC			Clayey Sand or Clayey Gravelly Sand	Medium to high	Gradation, grain shape, examination of fines	Sieve Analysis LL and PL on "Minus 40"
FINE-GRAINED SOILS	Silt and Clay Soils Low Compressibility Liquid Limit < 50	ML		GREEN	Silts, Sandy Silts, Gravelly Silts, or Diatomaceous Soils	None to slight	Examination wet (shaking test)	Sieve Analysis LL and PL on "Minus 40"
		CL			Lean Clays, Sandy Clays, or Gravelly Clays	Low to medium	Examination in plastic range	Sieve Analysis, if applicable, LL and PL on "Minus 40"
		OL			Organic Silts or Lean Organic Clays	None to slight	Examination in plastic range, color, odor, organic content	LL and PL before and after oven drying
	Silt and Clay Soils High Compressibility Liquid Limit > 50	MH		BLUE	Micaceous Silts, Diatomaceous Soils or Elastic Silts	None to slight	Examination wet (shaking test)	Sieve Analysis LL and PL on "Minus 40"
		CH			Fat Clays	High	Examination in plastic range	Sieve Analysis, if applicable, LL and PL on "Minus 40"
		OH			Fat Organic Clays	Medium to high	Examination in plastic range, color, odor, organic content	LL and PL before and after oven drying
FIBROUS ORGANIC SOILS		Pt		ORANGE	Peat, Humus, and other Organic Swamp Soils	Readily Identified		Consistency, Texture, and Water Content

Plate A3

Department of the Army
Uniform Soil Classification System



TYPICAL WELL GRADED AND POORLY GRADED SOILS

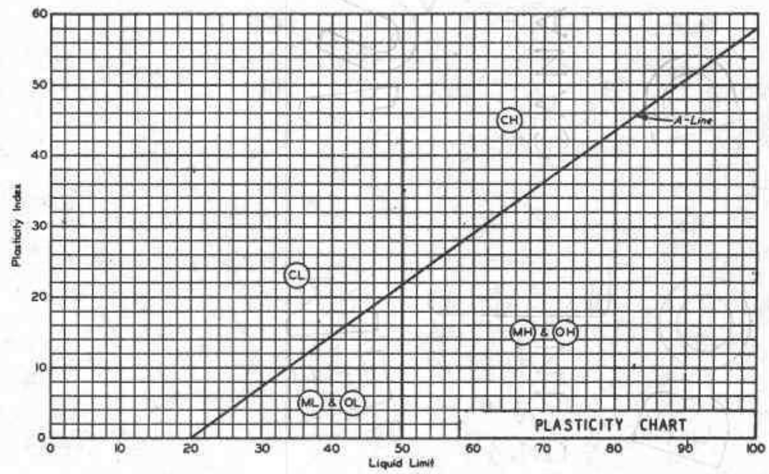


Plate A3

Department of the Army
Uniform Soil Classification System

ILLUSTRATIVE EXAMPLE OF THE USE OF THE FROZEN SOIL CLASSIFICATION SYSTEM IN TYPICAL EXPLORATION LOG

Surface Elevation 963.2 Ft.

0 – 1.3	GW	Brown, well-graded SANDY GRAVEL medium compact, moist, unfrozen.
1.3 – 3.2 (2)	GW-BP	Brown, well-graded SANDY GRAVEL, frozen, no ice segregation, negligible thin ice film on gravel sizes and within larger voids, poorly bonded, low degree of ice saturation.
3.2 – 4.9 (4)	GW-BW	Brown, well-graded SANDY GRAVEL, frozen, no ice segregation, well bonded, high degree of ice saturation.
4.9 – 7.2 (6)	SM-DE	Fine, black, micaceous SILTY SAND, frozen, stratified horizontal ice lenses averaging 4 inches in horizontal extent, hairline to 1/4 inch in thickness, 1/2 to 3/4 inch spacing. Ice = 20±% of total volume. Ice lenses hard, clear, colorless.
7.2 – 8.6 (8)	ICE	ICE, hard, slightly cloudy, colorless, few scattered inclusions of silty sand.
8.6 – 10	PT-BW	Dark brown PEAT, frozen, no ice segregation, well bonded, high degree of ice saturation.
10 – 13.8 (12)	MH-DZ	Light brown SILT, frozen, irregularly oriented ice lenses and layers 1/4 to 3/4 inch thick on random pattern grid approx. 3 to 4 inch spacing. Ice = 10±% of total volume. Ice lenses moderately soft, porous, gray-white.
13.8		Bottom of Exploration