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Johnston, G. H.

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DRILLING IN PERMAFROST AT NORMAN WELLS, N.W.T., 1958

by

G. H. Johnston

Internal Report No. 218

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PREFACE

A knowledge of the thermal regime existing at depth in areas of perennially frozen ground is of particular importance in furthering a better understanding of permafrost. To obtain such information, deep ground temperature installations are required. A number of problems are involved, however, in making these installations particularly with regard to the placing of the equipment to the required depth in the frozen ground.

It was for this reason that when the Division of Building Research, National Research Council, undertook to install two thermocouple cables to depths of 200 ft. at Norman Wells, N.W.T. in the summer of 1958, the recording of information on the actual drilling operation became an important part of the project.

The author, who is a research officer in the Northern Building Section of the Division, has been concerned with the investigation of drilling and sampling techniques in perennially frozen ground over the past few years and also engineering studies of the performance of foundations in permafrost.

Ottawa
February 1961

Robert F. Legget
Director

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DRILLING IN PERMAFROST AT NORMAN WELLS, N.W.T., 1958

by

G. H. Johnston

Deep ground temperature measurement installations in permafrost areas are few in number, being limited to Point Barrow, Alaska (1); Resolute Bay, Cornwallis Island, N.W.T. (2,3,4); and Thule, Greenland. These installations provide information to depths exceeding 650 feet below the ground surface in perennially frozen ground.

As part of the wartime Canol project, a number of exploratory oil wells were drilled in the Norman Wells, N.W.T. area and the occurrence of permafrost was reported to depths of about 180 feet below the ground surface. During the summer of 1958, the Northern Building Section of the Division of Building Research undertook the installation of deep ground temperature measuring instruments at Norman Wells to determine more accurately the depth and the long-term performance of permafrost in that area. The work was carried out during the period 21 July to 12 August 1958. Two holes (NWB 14 and NWB 16) were drilled at two different locations to depths of about 200 feet and two holes (NWB 15 and NWB 17) were drilled to depths of 10 feet. In each of the four holes, thermocouple cables were installed to measure the ground temperatures at various depths. The experience gained in installing this equipment forms the basis of this report.

LOCATION

Norman Wells is located on the northeast bank of the Mackenzie River at 65° 37' north latitude and 127° 20' west longitude. (The river flows to the northwest at this point.) The settlement is strung out along the river bank for a distance of approximately 1¼ miles and extends back from the river for a maximum distance of one half mile. Permafrost conditions have changed considerably in and adjacent to the settlement because of construction activity. To eliminate the effects of the inhabited area, therefore, all holes were drilled outside the settlement boundary in undisturbed terrain. Holes NWB 14 and NWB 15 are located about three quarters of a mile north of the river near Seepage Lake. Holes NWB 16 and NWB 17 are located about 400 feet from the river and approximately 800 feet east of well 17X on the road to the airport (Fig. 1).

PHYSIOGRAPHY AND GEOLOGY (5,6)

The Mackenzie Lowland section of the Canadian Interior Plains lies between the rugged Canadian Cordillera on the west and the desolate Canadian Shield on the east. In the vicinity of Norman Wells, the Mackenzie Lowland occupies a relatively narrow strip of land between the Norman (or Discovery) Range of mountains on the east and the Carcajou Mountains on the west. The Norman Mountains rise about 2,500 feet above the Mackenzie River but the Carcajou Mountains are much higher and more rugged. Except for the mountains, the area is generally level, broken only by terraces on the western side of the river and resistant sandstone and limestone ridges of the tilted Paleozoic rocks on the east.

The Norman Mountains are about five miles to the northeast of the Norman Wells oil field. They are anticlinal in form and represent the western half of a great fold, the axis of which has been eroded leaving a deep valley with abrupt eastward-facing cliffs. Silurian limestones outcrop on the top and east side of this range and the successive higher formations (Devonian) are found on the west flank. On the west slopes of the valley, Devonian limestones again appear at the surface at the eastern edge of the Carcajou Mountains and westward in the mountains, Silurian and Cambrian rocks occur, indicating an eastern dip. Thus the Norman Wells oil field is on a monoclinal structure on the southwest flank of the Norman Range and on the northeast limb of the Carcajou basin.

The whole area was subjected to glacial action, the general movement of ice being in a northwest direction. An obliterating mantle of glacial material and recent sands and silts of variable depth cover the area.

The upper Devonian formations encountered during the drilling program were the Imperial sandstones and the Fort Creek shales. The upper nonbituminous member of the Fort Creek shales consisting of grey shales and thin sandstones was encountered throughout the depth of hole NWB 14. The Imperial formation consisting of green, fine-grained sandstone and shales was encountered throughout the depth of hole NWB 16 (Fig. 2).

SOIL AND PERMAFROST CONDITIONS

Soil samples were obtained for laboratory testing from holes NWB 14 and NWB 16. The soils to bedrock are predominantly stony silt clays with some fine sand. Immediately overlying the bedrock formations, a very dense blue clay occurs for a depth of approximately 2 to 3 feet. Soil moisture (or ice) contents decreased with depth varying from 142.5 per cent to 11.4 per cent with an average value of 48.7 per cent.

Frozen ground was encountered in all holes at a depth of about 1 foot below the ground surface. The maximum depth of thaw which occurs each year at Norman Wells under similar soil and vegetation cover conditions has been observed to be about 24 to 30 inches and occurs during early October. Poor core recovery in hole NWB 14, because of the stony nature of the soil, prevented the determination of the distribution of ice in the soil and the depth of frozen material in this hole. The underlying Fort Creek shales were encountered at a depth of 12 feet 5 inches. Somewhat better core recovery was obtained in hole NWB 16. The ice segregation occurred as horizontal lenses from hairline to ¼ inch thick spaced from 1/16 inch to 1 inch apart. Some irregularly oriented lenses also occurred sporadically through the soil. Frozen material was encountered down to the underlying Imperial sandstone at 35 feet 6 inches. It was not determined to what depth in the bedrock the frozen condition exists.

DRILLING EQUIPMENT

A Longyear Junior Straightline diamond drill (gas engine), fitted with an N-size hydraulic head, was used to bore all holes. The rig was mounted on a pipe sled approximately 12 by 6 feet in size constructed of 6-inch pipe (Fig. 3).

A 5-foot NXL double-tube, swivel-head core barrel (giving 2-inch Ø cores) was used through overburden and rock cores (1¼-inch Ø cores) were obtained using a 5-foot AXL double-tube, swivel-head barrel. Both core barrels were fitted with 6-tooth carboloy insert bits and spring steel core retainer teeth. These were used throughout the overburden and bedrock drilling. NX flush-coupled casing was drilled down and set in bedrock and AX flush-joint casing was then used to prevent cave in bedrock. A-size drill rods were used throughout. A steel tripod with 20-foot legs of 2-inch pipe allowed 10-foot pulls to be made.

Water for drilling was obtained from ponds nearby, the longest supply line being about 500 feet. A chain-driven gear pump was used for supply to the rig. The pressure pump at the rig was a Smart Turner duplex piston pump of 1,000 gpm (U.S.) capacity.

DRILLING OPERATION

The drill crew consisted of a drill runner and helper. A member of the Northern Research Station staff took samples, logged the core and made observations on the drill performance and the general drilling operation. Observations were made on the temperature of the water supply and the return water, water pressure, volume of water, bit pressure, bit penetration, and actual drilling time wherever possible. A typical set of observations for hole NWB 14 are summarized in Table I. The holes were cored for their full depth (Table II) and the core was retained for future examination. Select pieces of the rock core were sent to Dr. A. D. Misener of the University of Western Ontario for determination of conductivity values (Table III).

At hole NWB 14, NX casing was drilled to a depth of 14 feet using a 6-tooth carboloy insert casing shoe. AX casing was set to a depth of 65 feet using a diamond set casing shoe. Much vibration during drilling loosened both sets of casing in the hole. Upon completion of the hole, all AX casing was recovered with little difficulty but 10 feet of the NX casing plus the carboloy set shoe were left in the hole. The wash water eroded the extremely friable shale such that the lower 10 feet of NX casing which had become uncoupled dropped into the enlarged hole and could not be recovered.

At hole NWB 16, NX casing was drilled to a depth of 38 feet using a 6-tooth carboloy insert casing shoe. AX casing was drilled to a depth of 81 feet using a diamond set casing shoe. Vibration again jarred both sets of casing loose so that they turned freely in the hole. All NX casing and the casing shoe were removed from the hole--but with great difficulty. Freezing conditions and silting around the outside of the casing held it securely so that repeated blows of a 350-lb drive hammer were required to jar it loose. The AX casing had become uncoupled so that only 44 feet were recovered. The AX diamond casing shoe and 36 feet of casing were thus left in the hole at an undetermined depth.

The friable nature of both the sandstones and shales encountered in both holes, together with the abrasive nature of the sandstones which ground off the core retainer springs, made core recovery difficult on many runs. On several occasions, the spring steel core retainer teeth had to be replaced after each 5-foot run. To make sure the core was recovered, "dry blocking" was resorted to several times, particularly in the sandstones in hole NWB 16. Attempts were made to recover lost core by fishing with the core barrel with varying degrees of success. The back end of an AXL double-tube barrel broke at the 186-foot depth in hole NWB 16 but on the first fishing attempt, the outer tube and bit, which remained in the hole, were recovered.

Fairly good core recovery was obtained in both of the deeper holes (the two shallow holes, NWB 15 and NWB 17, were not cored). At hole NWB 14, only 13 per cent of the soil cored was recovered (0 feet to 12 feet 5 inches) but 84 per cent recovery was obtained in the rock. About 66 per cent

TABLE I

TYPICAL DRILLING OBSERVATIONS

Hole - NWB 14 Date - 26-7-58 Formation - Fort Creek shale - light grey, platy

Depth		Run	Core		Elapsed	Wash Water				Bit		Remarks
From	To	Interval, in.	Recovery in.	Recovery %	Time, min.	Press., psi	Temp. (°F.) in	Temp. (°F.) out	Return gpm	Press. psi	Pen. in./min.	
												String left down hole overnight
70'- 8"	75'- 6"	58	54	93	55*	70	63.5	60	-	280	-	Difficulty with water circulation - hole cave
75'- 6"	80'-10"	64	62	97	45	-	-	-	-	-	-	
80'-10"	86'- 2"	64	58	91	65*	70	68	61.5	-	300	1.33	Supply pump breakdown
						60	66.5	63.5	-	280	1.50	
86'- 2"	91'- 4"	62	53	85	60	50	69.5	63.5	5.1	280	2.00	
91'- 4"	96'- 4"	60	60	100	50	60	68	65	-	280	0.80	
96'- 4"	101'-10"	66	-	-	55	70	69.5	66	-	280	1.27	Lost core - wash water eroded friable shale
						60	70	66.5	-	280	1.33	Left string down hole

* Drilling difficulties - time noted not indicative of actual drilling time.

TABLE II

RECORD OF DRILL CORE AND CORE BOXES - 1958

Borehole NWB 14

Core Box No.	Core Size	Depth, ft
1	NXL	10 - 30
2	NXL	30 - 45
3	AXL	45 - 70
4	AXL	70 - 95
5	AXL	95 - 120
6	AXL	120 - 145
7	AXL	145 - 170
8	AXL	170 - 195
9	AXL	195 - 208

Borehole NWB 16

Core Box No.	Core Size	Depth, ft
1	NXL	0 - 20
2	NXL	20 - 35
3	AXL	35 - 60
4	AXL	60 - 85
5	AXL	85 - 110
6	AXL	110 - 140
7	AXL	140 - 165
8	AXL	165 - 190
9	AXL	190 - 209

TABLE III

ROCK CORE SAMPLES FROM NORMAN WELLS, N.W.T.
SELECTED FOR CONDUCTIVITY
TESTS

Borehole	Depth	Description
NWB 14	79' 7" to 80' 0"	light grey shale
	111' 8" to 112' 3"	light grey shale with thin sandstone layers
NWB 16	50' 8" to 50' 10"	light grey shale
	66' 1" to 66' 7"	light green sandstone
	91' 7" to 92' 2"	light green sandstone
	141' 1" to 141' 7"	light grey sandstone
	162' 8" to 163' 2"	light green sandstone
	170' 4" to 170' 8"	light green sandstone
	202' 2" to 202' 5"	light grey shale with sandstone layers

frozen soil core was recovered in hole NWB 16 (0 feet to 35 feet 6 inches) and 82 per cent rock core was recovered. Most cores were full size (NXL or AXL), although in some cases, smaller diameter cores resulted from washing action in the sandstone. The low recovery rate in the soil can be attributed to the many stones encountered which jammed in the bit and thus prevented the core from moving up into the barrel and also prevented rapid penetration of the bit due to a great deal of vibration. Poor soil recovery was also caused by the use of relatively large volumes of water to prevent mudding of the bit and silting of the barrel.

The carboloy insert bits performed satisfactorily. The stones encountered in the soil caused considerable damage to the teeth but very little wear occurred when drilling the shales and sandstones. Good penetration rates in the rock were achieved with these bits.

Penetration rates were measured by observing the time taken for the hydraulic head piston to move through a distance of 3, 6 or 18 inches. Most observations were made on a 3-inch movement of the piston. The maximum and minimum rates of penetration in the shale at hole NWB 14 (34 observations) were 3.00 and 0.75 inches, respectively, and the average penetration rate was calculated to be 1.47 inches/minute. For eight observations made during the drilling of hole NWB 16 in sandstone, the maximum and minimum rates were 6.00 and 3.00 inches/minute with an average penetration rate of 4.19 inches/minute. These values vary considerably and because most were obtained by timing relatively short piston movements (3 inches), the results are not indicative of actual penetration rates that might be expected in these rock types.

The driller, of course, controls the rate of penetration by regulating the hydraulic feed control valve. Depending on the water pressure and the volume of wash water used, the rate of penetration is increased or decreased during drilling. Generally, the water pressure was maintained between 60 and 80 psi. Rather crude measurements indicated that, on the average, about 5 gpm (imp) of wash water were circulated through the drill string. Therefore the values obtained for the rate of penetration are applicable only for these conditions of water pressure and water volume. The actual time to drill a 5 foot core in hole NWB 14 was about 48 minutes or a rate of 6.3 feet/hour. In hole NWB 16, the time required was about 21 minutes or a rate of about 14.3 feet/hour. The difference in times can be attributed perhaps to different rock types and the fact that the drillers were more familiar (at the second hole) with the machine and the over all operation.

The temperature of the supply water in the tank and the wash water returning through the casing was measured by means of a dial thermometer. For hole NWB 14, the temperature of the supply water averaged about 69 to 70°F while the temperature of the return water was from 3 to 5° lower. The temperature of the supply water at hole NWB 16 was about 60 to 62°F and the return water was 6 to 10° lower. It is assumed that the supply water would be cooled somewhat when passing down through the drill string which is surrounded by a mass of frozen soil and rock, although between this water and the wall of the hole are the drill rod, the wash water returning to the surface and the steel casing. On passing the rotating bit, heat would be added to the water but then while returning up the hole to the ground surface, cooling would again occur due to the surrounding frozen soil and rock. It is impossible to attempt an evaluation of the cooling and heating effects introduced by the frozen ground mass and the rotating bit. It is believed, however, that the greatest rate of heat extraction would occur when the wash water is returning to the surface from the bit.

No measurements of bit rotational speed were made but the machine was generally run in high gear at from three-quarters to full throttle and thus an average speed of approximately 1,500 rpm would be obtained. The oil pressure in the hydraulic feed system varied between 250 and 300 psi. The total load on the bit is affected by several factors including the size of the bit, the rotational speed, the number and size of cutting edges on the bit, the pressure and volume of wash water, weight of drill rods and core barrel (7). The bits used had six carboloy insert teeth, which carry the bit load. Assuming that a 5-foot AXL double-tube core barrel is being used at the 150-foot depth and the hydraulic pressure is 275 psi, the total load on the six teeth would be in the neighbourhood of 600 lb or 100 lb/tooth, (estimated cross-sectional area of each tooth = 0.03 sq in.; weight of 5-foot AXL core barrel is 26 lb and weight of fifteen 10-foot A rods is 525 lb). This value is only an approximate indication of probable bit load and could be in considerable error, since no calibration of hydraulic pressure with thrust was attempted and the effects of the several factors noted above are difficult to evaluate.

No difficulties that could be attributed to the effect of permafrost were encountered during the drilling of hole NWB 14. The core barrel and string of rods were left down the hole at the 100-foot depth over one weekend (39 hours) and when drilling was resumed, the string turned freely. In hole NWB 16, however, on the first day of drilling the NX casing froze in between the ground surface and the 25-foot depth during the noon hour. Large volumes of water were circulated to thaw and loosen the casing so that more casing could be added and drilled in. At the beginning of the second day of drilling, slush ice which had formed in the hole overnight to the 38-foot depth had to be thawed and removed by circulating water through the AX casing. At the end of the second day's operation, the core barrel and string of rods were left down the hole at the 80-foot depth. The following morning, the string was frozen in solidly and had to be freed by drilling AX casing to the bottom of the core barrel. The morning of the fourth day, frozen material was encountered at the 80-foot depth but the core barrel and string of rods were easily lowered to the bottom (100 feet) by circulating water through the string. Upon completion of drilling on each of the fourth and fifth days, a mixture of about 7 lb of $CaCl_2$ and $\frac{1}{2}$ lb of sodium chromate were added to 20 gallons of water and this was then pumped down the hole to prevent freezing. The sodium chromate acts as an inhibitor to reduce the corrosive effect of the $CaCl_2$ on metal parts and on the drill operator's skin. The mixture used was sufficient to lower the freezing point to about 30°F. In general, however, the existence of permafrost did not create any serious problems in the drilling of these holes.

GROUND TEMPERATURE INSTALLATIONS

Thermocouple cables were fabricated at the Northern Research Station using 16-gauge and 20-gauge copper-constantan thermocouple wire. The depths at which ground temperatures are measured and the size of wire used are summarized in Table IV for each of holes NWB 14, 15, 16 and 17. Holes NWB 15 and 17 were drilled to a depth of 10 feet, approximately 15 feet away from holes NWB 14 and 16. The short thermocouple cables installed in these holes allow the ground temperatures near the ground surface to be measured. The temperatures as measured by the thermocouple cables to depths of 200 feet in holes NWB 14 and 16 will permit an estimate to be made of the depth of permafrost and the temperature gradient existing at Norman Wells.

The thermocouple cables were enclosed in non-toxic black 3/4-inch diameter polyethylene pipe (Canadian Government Specifications Board specification 41-GP-5A) to reduce the possibility of the effect of moisture on the thermocouples. The bottom of the tubing was stoppered using a lucite plug and the tubing was then filled with No.10 SAE automobile engine oil to reduce the effect of convection currents on the thermocouple points.

The lead wires (10 feet long) from each of the long and short thermocouple cables at each location have been brought to a common switch box to facilitate observations. Temperature observations were begun in the early summer of 1959 using a modified portable precision potentiometer. These were discontinued during the winter of 1959-60 but resumed again in the summer of 1960; monthly readings will be continued throughout the winter of 1960-61.

TABLE IV

DETAILS OF GROUND TEMPERATURE INSTALLATIONS

Depth, ft	Copper-constantan Thermocouple Wire Gauge (B and S)			Depth, ft	Copper-constantan Thermocouple Wire Gauge (B and S)	
	NWB 14	NWB 16			NWB 15	NWB 17
10	20	20		1	20	20
20	20	20		2	20	20
30	20	20		3	20	20
40	20	20		4	20	20
50	20	20		5	20	20
75	20	20		6	20	20
100	16	20		7	20	20
125	16	20		8	20	20
150	16	20		9	20	20
175	16	20		10	20	20
200	16	20				
200	20	--				

SUMMARY

1. At each of two widely separated locations in the immediate vicinity of Norman Wells, two boreholes were drilled and thermocouple cables installed to measure the ground temperature at various depths. At location 1 near Seepage Lake, thermocouple cables were installed to depths of 200 feet and 10 feet (boreholes NWB 14 and NWB 15, respectively). At location 2 east of the settlement, thermocouple cables were installed to depths of 202 feet and 10 feet (boreholes NWB 16 and NWB 17, respectively).

2. The depth of permafrost was not determined during the drilling operation.

3. No difficulties were encountered due to permafrost during the drilling of hole NWB 14. Some minor trouble occurred with freezing-in of casing and drill string during the drilling of hole NWB 16.

4. The two deeper holes were cored for their full depth and the rock cores were stored for future examination.

5. All thermocouple circuits were checked and found to be functioning satisfactorily, following installation of the cables in the boreholes.

6. The proposed program was successfully completed with little difficulty.

ACKNOWLEDGEMENTS

The co-operation of Canadian Longyear Ltd., North Bay, Ontario in providing the drill crew and for supplying pieces of equipment on short notice is gratefully acknowledged. The interest and the assistance and co-operation given by Martin Strand, drill runner, and George Perrier, drill helper, enabled the work to be successfully completed, at times under adverse circumstances, and their help was much appreciated. J. Plunkett and D. Kelly of the DBR Northern Research Station staff at Norman Wells, assisted in logging the cores and carried out the testing of the soil samples.

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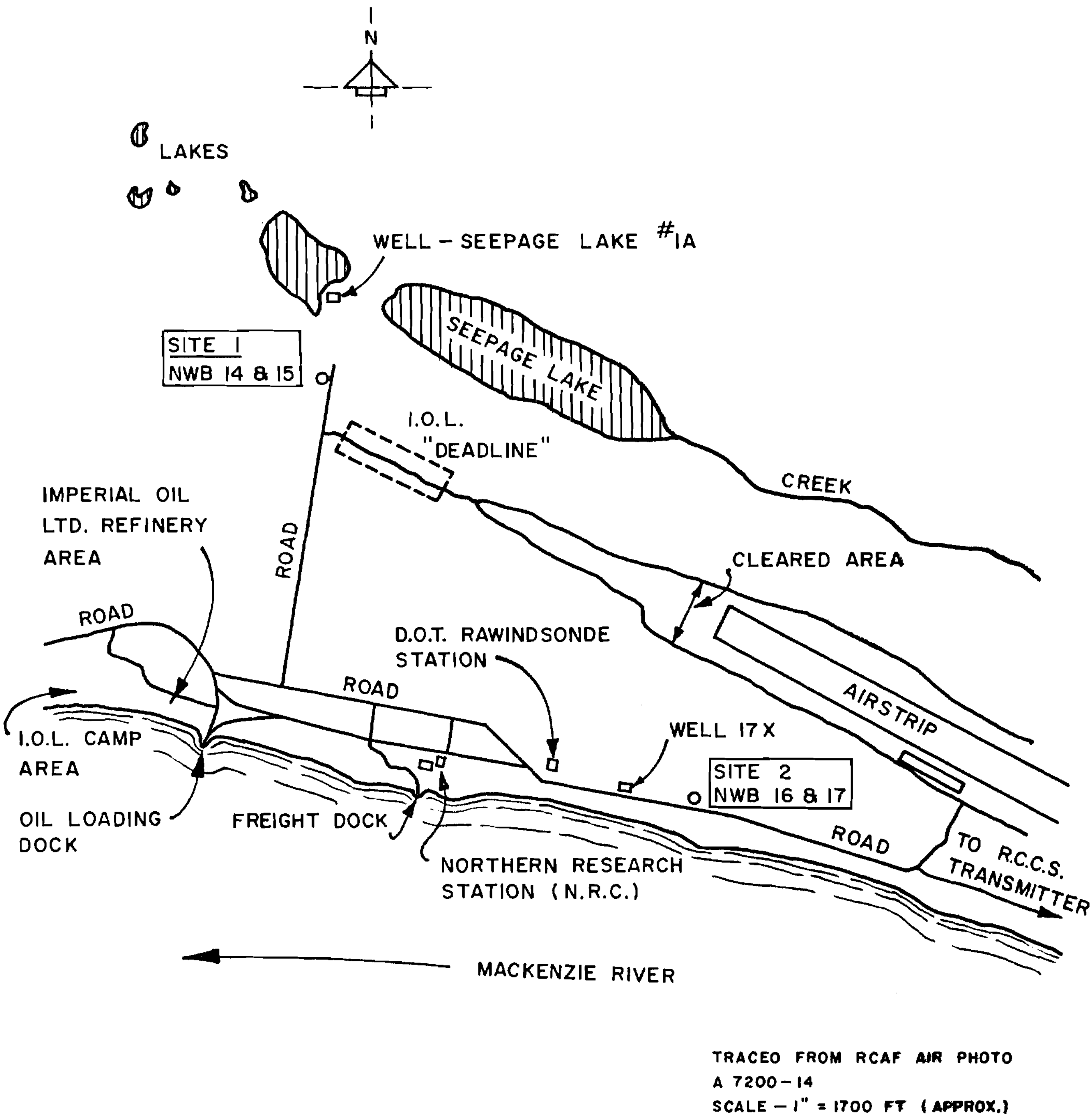

FIGURE 1
LOCATION OF BOREHOLES NWB 14, 15, 16, & 17 – 1958 NORMAN WELLS, N.W.T.

BR 2348-1

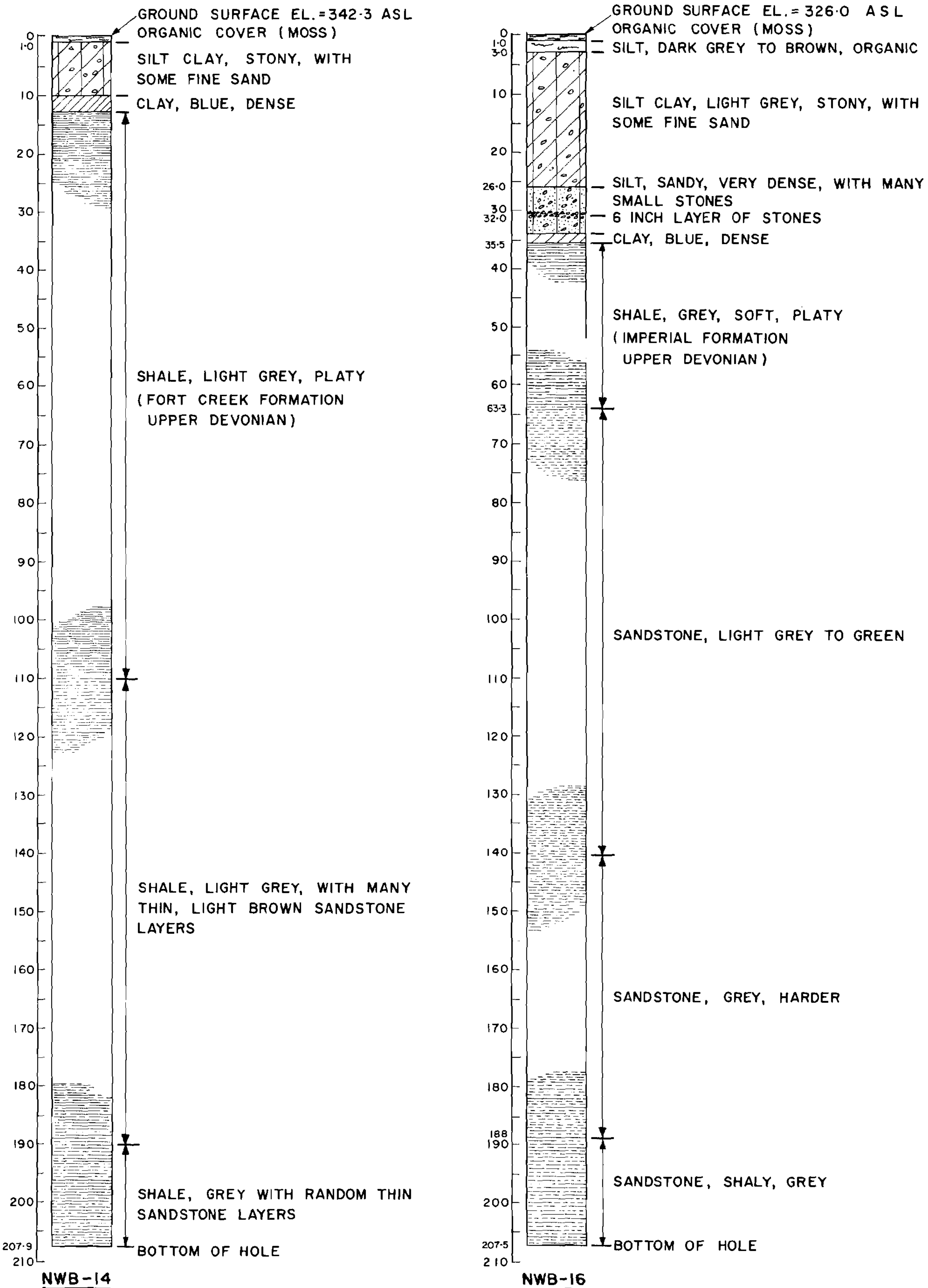

FIGURE 2
BOREHOLE LOGS NORMAN WELLS, N.W.T.

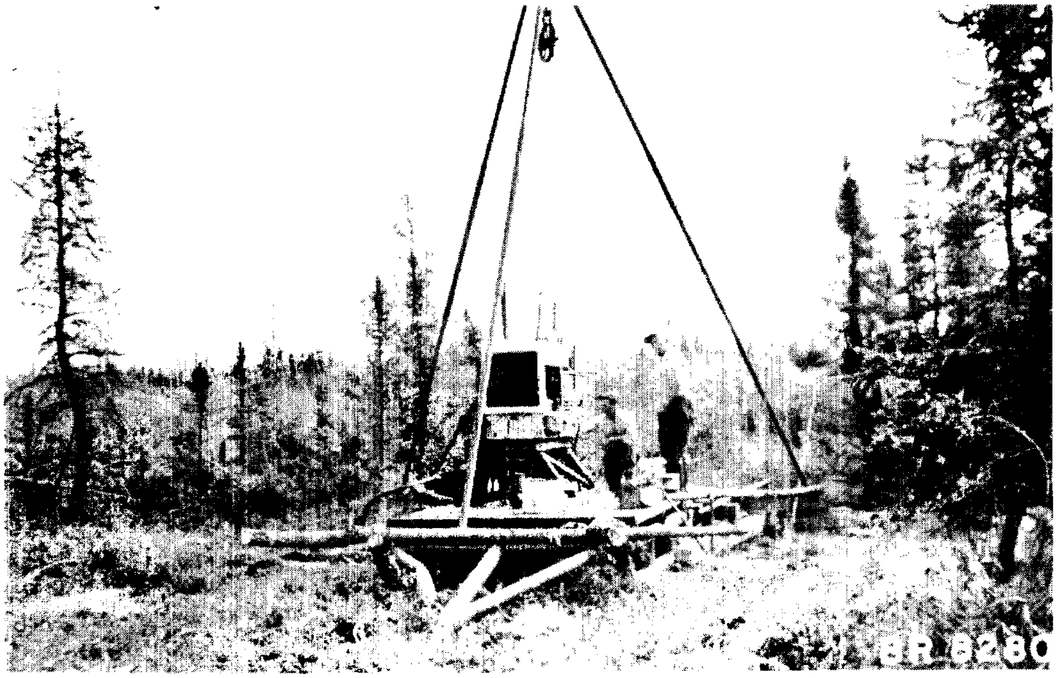

FIGURE 3 Drill set up at borehole NWB 14. Photo taken looking east. Note vegetation cover of small spruce, low brush and moss or organic material. Drill rig is mounted on pipe sled.

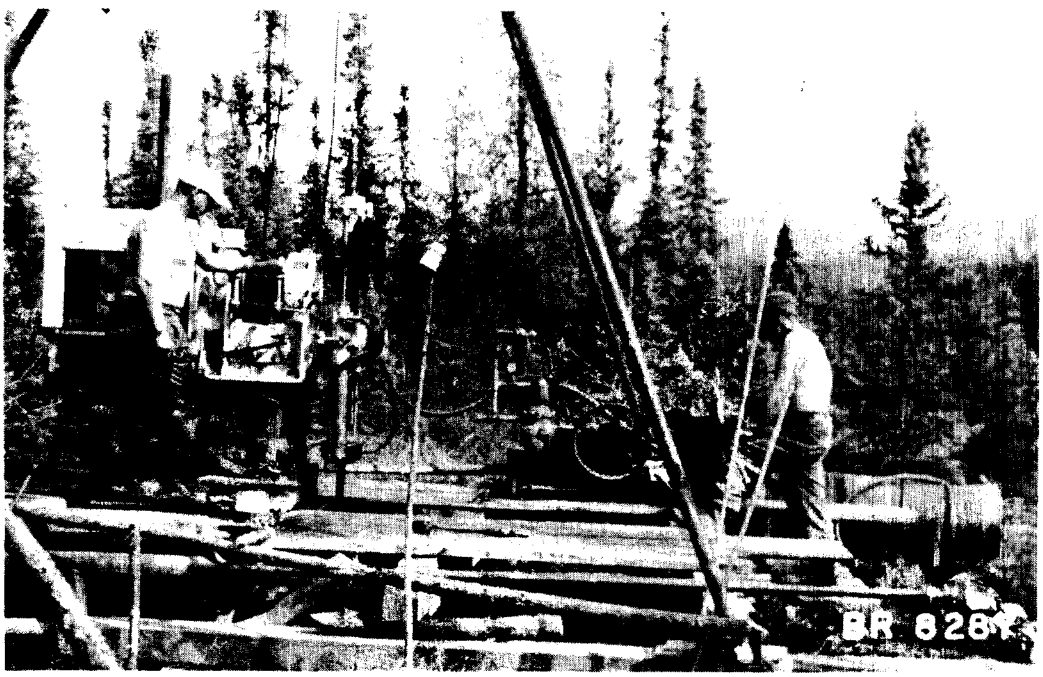

FIGURE 4 Drilling at borehole NWB 14. Photo taken looking north. General layout of drilling equipment - drill, water pump and water supply tank.

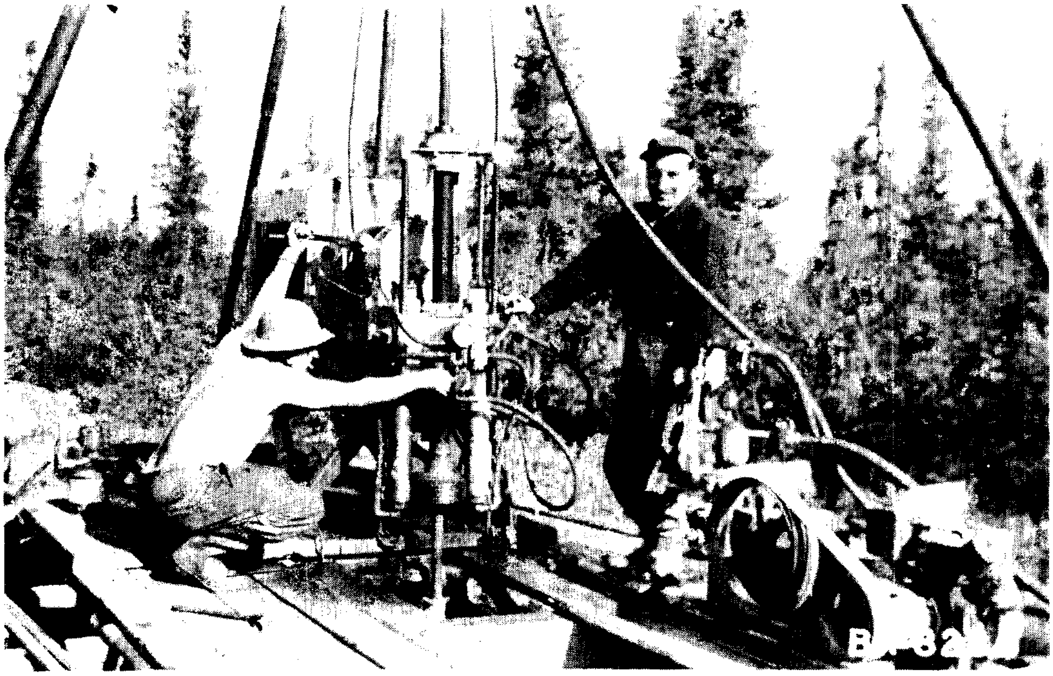

FIGURE 5 Drilling at borehole NWB 14. Note pressure gauges on hydraulic head and on water pump. Drill runner is controlling rate of feed by adjusting hydraulic head oil valve.

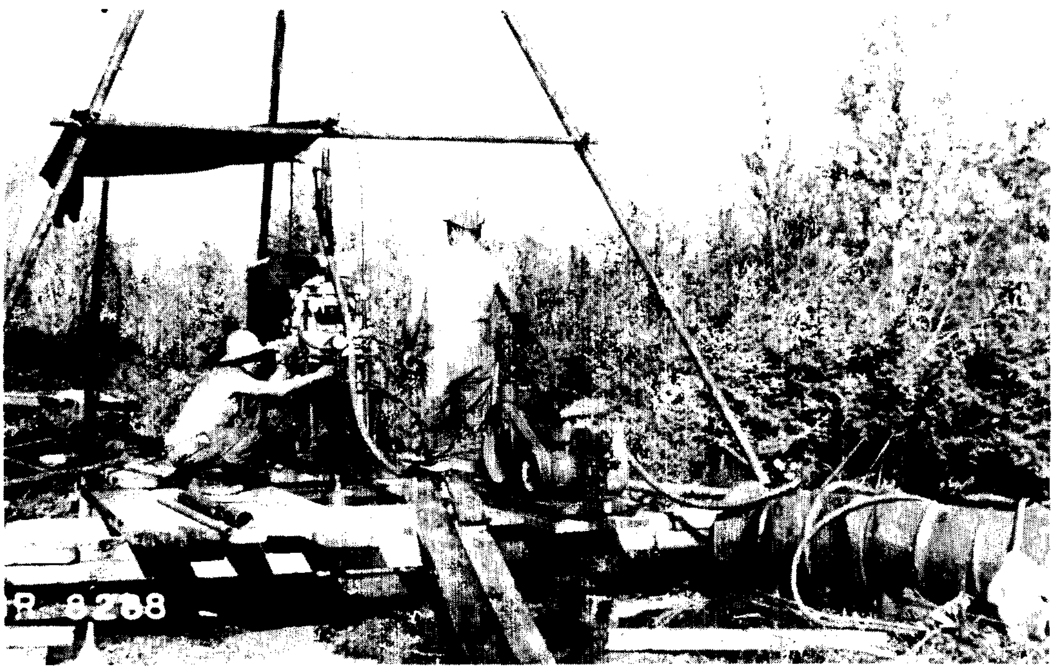

FIGURE 6 Drilling at borehole NWB 16. Photo taken looking north. Norman Range of mountains in background. Note vegetation cover of birch, some small spruce and thick brush. Heavy mat of organic material covers ground surface.